Argo as a Contribution to CLIVAR

Dr. W. John Gould, Scripps Institution of Oceanography, 9500 Gilman Drive, La Jolla, CA 92093-0230, USA, wjg@ucsd.edu
Dr Dean Roemmich, droemmich@ucsd.edu

The international Argo profiling float project will enable, for the first time, continuous observations of the physical state (temperature, salinity, velocity) of the upper ocean globally in near-real time. This new capability will improve our understanding of the ocean's role in the climate system as well as spawning a wide range of other valuable ocean applications.

Data are collected by autonomous floats that spend most of their life at depth (they are stabilised at a constant level by being less compressible than sea water). Every 10 days the floats pump fluid into an external bladder, rise to the surface and measure a profile of temperature and salinity. On surfacing the data are downloaded to satellite. The bladder then deflates and the float sinks to depth to drift until the cycle is repeated. Argo aims to make all observations available within 24 hrs of collection to anyone wanting to use them. Data with corrections for salinity offsets are available with a delay of several months.□

Argo's target of 3000 operating floats (one float every 3° of latitude and longitude) is expected to be reached in 2006 and will provide 100,000 T/S profiles per annum. This array density will not resolve mesoscale ocean variability and for that reason Argo is teamed with Jason-1, the high precision altimeter satellite launched in 2002. Argo and Jason together are primary data sources for one of Argo's sponsors, the Global Ocean Data Assimilation Experiment (GODAE). Argo's other sponsor is CLIVAR. By the end of 2003 over 1000 floats were operating.

Examples will be given of the application of Argo data to the monitoring and understanding of a wide range of CLIVAR-relevant issues - monsoonal changes in the Indian Ocean, ENSO monitoring, winter watermass modification, detection of decadal-scale subsurface changes in temperature and salinity, assessment of global and regional scale heat storage.

Enhancing Global Ocean Observations to Understand Climate

Mr. Michael Johnson, National Oceanic and Atmospheric Administration (NOAA), Office of Global Programs, 1100 Wayne Avenue, Suite 1210, Silver Spring, MD 20910 USA, mike.johnson@noaa.gov
Dr. Sidney Thurston, sidney.thurston@noaa.gov
Dr. Diane M. Stanitski, diane.stanitski@noaa.gov

Observation is key to describing, understanding, and predicting the Earth's climate system. The NOAA Office of Climate Observation (OCO) supports oceanic and marine meteorology projects designed to contribute to the implementation of a global climate observing system. Although the focus of the Office of Climate Observation is to support projects that deploy autonomous in situ platforms, the overall objective is to

foster a "system" approach to effective international organization of complementary in situ, satellite, data, and modeling components of climate observation. The observing system will help satisfy the long-term requirements of operational forecast centers, international research programs, and the major scientific assessments, and effectively plan for and manage responses to climate change. NOAA has worked with both national and international partners to begin building this sustained global ocean system for climate. With the initial system design nearly 45% complete, the Office of Climate Observation's goal includes enhancing the subsystems of tide gauges, Argo profilers, drifting buoys, moored buoys, expendable bathythermographs, ocean reference stations, and ocean carbon measurements. Global ocean coverage is anticipated by 2010. OCO-sponsored projects are predominately U.S. contributions to global networks coordinated through international science and implementation panels, and managed in cooperation with the Joint WMO/IOC Technical Commission for Oceanography and Marine Meteorology (JCOMM). The Office of Climate Observation promotes the utilization of platform and data infrastructure for several objectives, including understanding the Earth's climate system, and documenting sea level change and the global carbon and water cycles. This poster provides a view of the status of the global ocean observing system, a system that helps to develop a more robust understanding of sea level, carbon, heat, salinity, and air-sea exchange parameters.

IDC-3

The Dutch Long-Term Ocean Climate Observations (LOCO) Program

Dr. Herman Ridderinkhof, Royal Netherlands Institute for Sea Research, PO Box 59, 1790 AB den Burg, Netherlands, rid@nioz.nl
Prof. Dr. W.P.M. de Ruijter, Utrecht University, PO Box 80005, 3508 TA Utrecht, Netherlands, w.p.m.deruijter@phys.uu.nl
Dr. H. van Aken, Royal Netherlands Institute for Sea Research, PO Box 59, 1790 AB den Burg, Netherlands, aken@nioz.nl

A team of Dutch physical oceanographers from the Royal Netherlands Institute for Sea Research (NIOZ), the Institute for Marine and Atmospheric Research (IMAU) and the Royal Meteorological Institute (KNMI) recently obtained funding from the Netherlands Organisation for Scientific Research for the so-called 'Long-term Ocean Climate Observations (LOCO)' program. The LOCO program intends to obtain long-term (5 years) observations on some aspects of the (time-variability in) the global overturning ocean circulation using sub-surface moorings. The program forms a major component of the Dutch contribution to the CLIVAR programme. In 2003, the moorings have been deployed in the Irminger Sea (North-Atlantic ocean), the Mozambique Channel (Indian ocean) and one of the passages in the Indonesian seas.

The primary goals of the observations, the instrumentation used and the exact location of the sub-surface moorings will be discussed for all projects that fall under the LOCO program. More detailed information will be given on the long-term ocean observations in the Mozambique Channel which is a follow-up of our recent studies based on in-situ observations.

These observations have shown that in this area important branches of the global ocean overturning circulation can be identified and quantified. In the centre of the Mozambique Channel a regular train of anti-cyclonic eddies was identified which contribute to the pole-ward transport of heat in the Indian ocean. A deep north-ward flowing undercurrent composed of North Atlantic Deep Water, as found at the most narrow and shallow section. Estimates on the volume transport through the channel could be done only using several assumptions. These estimates showed that the time variability of the volume transport is large and oscillates remarkably regular with minimum and maximum values varying roughly between 20 Sv northward and 60 Sv southward. No seasonal variability in the volume transport was measured.

The results from these observations motivated us to extend the array of current meter moorings in the Mozambique Channel as part of the LOCO program 1) over a longer period to obtain observations of the currents and transports in the Mozambique Channel at interannual time scales and 2) to optimise the design of the array of moored instruments based on the information that has been obtained from the first array and 3) to install additional sensors and current meters (ADCP's). The present design minimises the under sampling of our previous observations drastically.

IDOC-4

The UK CLIVAR Programme

M. Stephen Hall, Southampton Oceanography Centre, Ocean Circulation and Climate Group, Empress Dock, Southampton SO14 3ZH, United Kingdom, sph@soc.soton.ac.uk

The UK CLIVAR programme is the United Kingdom's contribution to the international CLIVAR programme. Through major contributions from the Met Office, NERC Centres/Surveys and Universities, many of the UK's leading research groups are actively involved in CLIVAR related projects. A particular focus of UK CLIVAR is the North Atlantic Ocean. There are three primary areas of research:

Storms, gyres and the North Atlantic Oscillation – the mechanisms of North Atlantic variability, supported by the NERC COAPEC programme.

Rapid Climate Change – Thermohaline Circulation, addressed primarily by the NERC RAPID programme.

Interactions of the Atlantic with the Global Climate System with an emphasis on El Nino and interactions with the Southern Ocean.

Other components of UK CLIVAR include use of our world class expertise in global coupled modelling and in understanding the seasonal to decadal variability of the tropics. The research is underpinned by the UK Argo programme.

The UK CLIVAR secretariat is currently hosted by the Ocean Circulation and Climate group at Southampton Oceanography Centre (SOC) where the work is part of our portfolio of science management tasks, serving the UK and international marine science community.

CLIVAR/Marin-2, a German Contribution to the Climate Variability and Predictability Project

Dr. Eberhard Fahrbach, Alfred Wegener Institute for Polar and Marine Research, Columbusstrasse, 27568 Bremerhaven, Germany, efahrbach@awi-bremerhaven.de

On the background of ongoing global warming and its potential impact on the structure and the intensity of the oceanic global thermohaline overturning circulation, a German contribution to CLIVAR was established. It is focussed on the quantification and improved understanding of the variations of the thermohaline circulation by measurements and modelling. CLIVAR/marin is funded by the German Federal Ministry of Education and Research (BMBF) and started in 1999. Its second phase, CLIVAR/ marin-2, comprises 11 projects from 9 German institutions which provide essential contributions to 8 Principal Research Areas. CLIVAR/marin-2 addresses climate variability in the Atlantic, Indian and Southern oceans. A central project is the explanation of the dynamics of fluctuations of the thermohaline circulation by assimilation of data from the North Atlantic in a large scale model.

Field programmes comprise observations and analysis of low-frequency interactions of the subpolar gyre and the North Atlantic Current and their implications for the thermohaline circulation, in particular for the meridional transport of heat. Arrays with moored instruments are deployed in the subtropical Atlantic to measure the fluctuations of the southward transport of North Atlantic Deep Water, the inflow into the Caribbean south of Guadeloupe, the tropical-subtropical exchanges in a shallow circulation cell in the tropical western Atlantic and the northward flow of Antarctic Bottom Water through the Vema Channel in the subtropical South Atlantic.

The fieldwork is accompanied by high resolution modelling studies of the structure and the variability of the current system and the relation to atmospheric forcing. Studies with coupled global ocean-sea ice-atmosphere models will help to identify the processes and feedbacks responsible for the low period variability and stability of the Atlantic thermohaline circulation under the conditions of global warming. Particular attention is given to the effect of variable fresh water transport from the Pacific into the Atlantic and the influence of stochastic forcing. The interannual variability of the tropical Indian Ocean sea surface temperature which strongly affects the rainfall of several regions adjacent to the Indian Ocean is investigated by modelling and data analysis. The long-term variability of the ice-ocean system in the Southern Ocean is studied with a combined effort of fieldwork and modelling. Particular emphasis is given to open ocean processes in the eastern Weddell Sea and the influence of shelf ice regions on the freshwater budget of the Weddell Sea.

Development of the Profiling Observational Network and Monitoring the Ocean Climate Variability

Dr. Alexander A. Zelenko, Hydrometeorological Research Center of Russia (Hydrometcenter of Russia), 11-13 Bolshoi, Predtechensky Per., Moscow, 123242 Russia, zelenko@mecom.ru
Dr. Yurii D. Resnyansky, Hydrometcenter of Russia, 11-13 Bolshoi Predtechensky Per., Moscow, 123242 Russia, resn@mecom.ru

Monitoring the ocean state variables has a significant place in climate studies, since the ocean is a very important constituent of the climate system. The modern observational networks and ocean modeling tools provided the basis on which the global monitoring systems of the ocean principal parameters could be created. In many respects oceanologists are oriented to achievements in meteorology, where the monitoring (data assimilation) and prognostic (model based forecasts) systems proved to be quite successive.

For monitoring climate variability, along with seasonal, interannual and lower frequency variations of oceanographic fields, it is necessary to take account of relatively short-term components. Among them of special interest is variability associated with synoptic eddies of the open ocean (analogues of atmospheric cyclones and anticyclones). The major part of the ocean kinetic energy falls to the share of these eddies. In this connection it is hardly possible to simulate the climate variability properly without a correct description of these components. The main mechanism of generating the ocean synoptic motions is a baroclinic instability of large scale ocean currents. A theoretical estimate of the synoptic eddies characteristic scale – internal radius of deformation (Rossby scale) – agrees closely with data of field experiments.

The estimates have been obtained of the data densities required and available with present day networks of near real-time observations for monitoring synoptic variability in the ocean. The regions are designated, for which the first-priority development of observational network is needed. Whereas the remote means of measuring the ocean surface level forms the plausible basis for monitoring the barotropic component of ocean currents, then the vertical structure of synoptic motions, which are baroclinic in their nature, are not adequately resolved by existing in situ observations. The estimates indicate that the realization of the ARGO observational program severely ameliorated the situation. However if the problem is posed (by analogy with atmosphere) to implement a regular diagnosis of synoptic variations, then rather larger volumes of information may be required. Although the direct practical importance of diagnosis and forecast of synoptic variations in the ocean is not so obvious, as in meteorology, it is clear that they are highly important for determining a number of climatically significant parameters (meridional heat transport, building-up the ocean general circulation etc.), and therefore for monitoring the climate as a whole.

OC-7

South Atlantic Ocean Observing System for Climate

Dr. Silvia L. Garzoli, NOAA/AOML, 4301 Rickenbacker Causeway, Miami FL, 33149, Silvia.Garzoli@noaa.gov
Mr. Mike Johnson, 1100 Wayne Ave., Silver Spring MD 20910-5603, Mike.Johnson@noaa.gov
Mr. Alberto Pioal, Servicio de Hidrogarfia Naval, Avenida Montes de Oca,

Buenos Aires, Argentina, apiola@hidro.gov.ar
Dr. Christine Provost, Laboratoire d'Oceanographie Dynamique et de Climatologie, UMR 7617 CNRS/IRD/UPMC/MNHN, Université Pierre et Marie Curie, Tour 45-55, 5ème étage, case 100, 4 place Jussieu, 75252 PARIS Cedex 05, FRANCE, cp@lodyc.jussieu.fr
Gustavo Goni, NOAA/AOML, 4301 Rickenbacker Causeway, Miami FL 33149

The South Atlantic Ocean connects the three major ocean basins: The Pacific Ocean, the Atlantic Ocean and the Indian Ocean. The meridional gaps between the continents of the Southern Hemisphere and Antarctica allow for a free exchange of water among the basins. Despite its small size, the Atlantic Ocean is responsible for over half of the heat transport carried by the global ocean. Meridional heat flux in the ocean is a key element of the climate system because of the role that the ocean plays in determining the Earth's climate through its interaction with the atmosphere. Another topic of relevance to CLIVAR is the distribution of sea surface temperature (SST). The knowledge of the distribution of SST anomalies in the South Atlantic is important at the global scale for modeling and prediction. The South Atlantic has been historically one of the less sampled basins. The spatial and temporal gaps in the observations result in poor climate forecasts. This poster presents a review of the role of the South Atlantic in climate and the currently existing components of the international effort towards a South Atlantic Observing System. This includes sustained and long-term planned observations.

DC-8

The CLIVAR and Carbon Hydrographic Data Office at UCSD/SIO

Dr. James H. Swift, Mr. Stephen C. Diggs, Mr. Jerry A. Kappa, Ms. Danielle B. Kinkade, UCSD Scripps Institution of Oceanography, 9500 Gilman Dr., Mail Code 0214, La Jolla, CA 92093-0214 USA, whpo@ucsd.edu

At the CLIVAR and Carbon Hydrographic Data Office (CCHDO) at the UCSD Scripps Institution of Oceanography, formerly and concurrently known as the WOCE Hydrographic Program Office (WHPO), the CTD, hydrographic, and tracer data used in large scale ocean circulation studies are brought together, verified, corrected for content and format errors, assembled with relevant documentation, and carefully prepared for dissemination and archive. In addition the CCHDO/WHPO works to promote appropriate methodology, applicable community standards, communications, and data compatibility.

The WHPO at UCSD/SIO supported these functions for WOCE Hydrographic Program data from 1997-present. The office, with the new name CCHDO, has been invited to continue these functions for CLIVAR hydrography, global ocean carbon hydrography, and similar programs which make use of high quality ocean profile data.

Data of the type dealt with by the CCHDO/WHPO are created by >100 data originators worldwide, sometimes 5 or more contributing to one file. All data users must cope with the temporal-, content-, and format-related file diversity these different originators engender. It is the enormous advantage of bringing data sets together to a common content and readability standard that remains the strongest rationale for the

CCHDO/WHPO, with the principal additional advantage that the documentation associated with the data are collected, reorganized to a common standard (where possible), and preserved with the data.

The CCHDO/WHPO disseminates data via the internet and on CD-ROMs and data DVDs. It also provides its total public holdings, including documentation, to NODC/WDC-A for archive and further distribution.

IODC-9

The Global Sea Level Observing System (GLOSS)

Dr. Christian Le Provost, LEGOS, Toulouse, France
Dr. Philip Woodworth, Proudman Oceanographic Laboratory, Joseph Proudman Building, 6 Brownlow Street, Liverpool L3 5BX, U.K. plw@pol.ac.uk
Dr. Thorkild Aarup, Intergovernmental Oceanographic Commission Dr. Mark Merrifield University of Hawaii Sea Level Center
Dr. Gary Mitchum, University of South Florida

The Global Sea Level Observing System (GLOSS) is a programme of the Joint Technical Commission for Oceanography and Marine Meteorology (JCOMM) of the Intergovernmental Oceanographic Commission (IOC) and the World Meteorological Organisation (WMO). It aims at the establishment of global and regional networks of tide gauges for application to climate, oceanographic and coastal sea level research. GLOSS can be considered a component of the Global Ocean Observing System (GOOS), and particularly as a major contributor to its Climate and Coastal Modules. During 2003, GLOSS progress was extensively re-assessed by the GLOSS Group of Experts in what is called the GLOSS Adequacy Report. That reviewed the status of the GLOSS Core Network (GCN) of 290 gauges distributed worldwide, designed to provide an approximately evenly-distributed sampling of global coastal sea level variations; the GLOSS Long-term Trends (LTT) gauges sites for monitoring long-term trends and accelerations in global sea level; the GLOSS altimeter calibration (ALT) set, to provide an ongoing facility for mission intercalibrations; and the GLOSS ocean circulation (OC) set, including in particular gauge pairs at straits and in polar area, complementing altimetric coverage of the open deep ocean. GLOSS data streams, including the relatively new 'fast' stream were also reviewed. GLOSS activities include a range of international training courses and materials with several courses planned for 2004. This presentation will provide further information on these developments.

IODC-10

Automated Weather System Observations from Research Vessels for Climate Applications

Mr. Shawn R. Smith, Center for Ocean-Atmospheric Prediction Studies, The Florida State University, Tallahassee, FL 32306-2840 USA, smith@coaps.fsu.edu
Dr. Mark A. Bourassa, bourassa@coaps.fsu.edu

Climate applications of surface meteorological observations collected by automated weather systems (AWS) on research vessels (R/V) will be discussed. Many climate studies utilize surface fields produced from remotely-sensed (e.g., satellite) observations or derived by model assimilation systems (e.g., national weather center reanalyses). Surface winds and air-sea fluxes are of principle interest over the oceans. R/V-AWS observations will be shown to be an ideal resource to benchmark the surface fields used for climate research.

Since 1994, R/V-AWS data have been collected, quality processed, and compared to model and satellite-derived products by the data assembly center (DAC) at the Florida State University. Data collected during the World Ocean Circulation Experiment were used to identify severe underestimation of the sensible and latent heat fluxes in the first National Center for Environmental Prediction reanalysis products. R/V-AWS data have also been used to validate three satellite scatterometers (NSCAT, SeaWinds on QuikScat and Midori-2). The R/V observations have revealed the great accuracy of the winds observed by these instruments. Ongoing comparisons and future plans to use AWS data collected on CLIVAR repeat hydrography lines in combination with non-CLIVAR data to benchmark satellite and model fields will be presented. All R/V data collected and processed at the DAC are freely available. Access information will be provided to the CLIVAR community.

OC-11

Sea Surface Temperature and Primary Productivity Products from MODIS and their Possible Application to Climate Research

Dr. Dongliang Yuan, Code 902, DAAC, NASA Goddard Space Flight Center, Greenbelt, MD 20771, USA, dyuan@daac.gsfc.nasa.gov
Dr. Andrey K. Savtchenko, asavtche@g0mos16.gsfcmo.ecs.nasa.gov;
Dr. William Teng, teng@daacmail.gsfc.nasa.gov;
Dr. Gregory Leptoukh, leptoukh@eosdata.gsfc.nasa.gov

The Goddard Earth Science (GES) Distributed Active Archive Center (DAAC) distributes sea surface temperature (SST) and the primary productivity products observed by the Moderate Resolution Imaging spectroradiometer (MODIS) instruments onboard of Terra and Aqua satellites. The data can be accessed via the URL http://www.daac.gsfc.nasa.gov/MODIS. The MODIS SST observations have been archived into daytime and nighttime products at 11 micrometer and 4 micrometer wavelengths. The 11 micrometer sensor is a heritage of the traditional Advanced Very High Resolution Radiometer (AVHRR) with improved spatial resolution and accuracy. The 4 micrometer SST is insensitive to water vapor in the atmosphere and is of better accuracies than the AVHRR measurements. The MODIS primary productivity product is released recently by the MODIS science team and is the first such product from remote sensing for public use. At the time of submission of this abstract, the 11 micrometer daytime and nighttime SST and the 4 micrometer nighttime SST are validated products. The primary productivity product has just been reprocessed and is subject to validation. An example of the application of the products to climate studies is the apparent strong cooling of the Gulf Stream Extension area during the year of 2002 and the associated large variability of the primary productivity at the peak of the 2002/2003 El Nino. The

Gulf Stream, which is the western boundary current of the North Atlantic ocean subtropical gyre, is of great importance to the North Atlantic Climate, because of its role in closing the mass and heat transports of the subtropical gyre and its dissipation of the wind vorticity in the gyre interior. The structures of the variabilities in the products will be discussed and questions with respect to the acquisition and analysis of the data will be answered.

OC-12

Acoustic Remote Sensing of Large-Scale Temperature Variability in the North Pacific Ocean

Dr. Bruce D. Cornuelle, Scripps Institution of Oceanography, University of California at San Diego, La Jolla, CA 92093-0230, USA, bcornuelle@ucsd.edu
Dr. Brian D. Dushaw, Applied Physics Laboratory, University of Washington, 1013 Northeast 40th Street, Seattle, WA 98105, USA, dushaw@apl.washington.edu
Dr. Matthew A. Dzieciuch, Scripps Institution of Oceanography, University of California at San Diego, La Jolla, CA 92093-0225, USA, mdzieciuch@ucsd.edu
Dr. Bruce M. Howe, Applied Physics Laboratory, University of Washington, 1013 Northeast 40th Street, Seattle, WA 98105, USA, howe@apl.washington.edu
Dr. Dimitris Menemenlis, Jet Propulsion Laboratory, California Institute of Technology, 4800 Oak Grove Drive, Pasadena, CA, 91109, menemenlis@jpl.nasa.gov
Dr. James A. Mercer, Applied Physics Laboratory, University of Washington, 1013 Northeast 40th Street, Seattle, WA 98105, USA, mercer@apl.washington.edu
Dr. Walter H. Munk, Scripps Institution of Oceanography, University of California at San Diego, La Jolla, CA 92093-0225, USA
Dr. Robert C. Spindel, Applied Physics Laboratory, University of Washington, 1013 Northeast 40th Street, Seattle, WA 98105, USA, spindel@apl.washington.edu
Dr. Detlef Stammer, Institut fur Meereskunde, Universitat Hamburg, Troplowitzstrasse 7, III. OG., Hamburg, D-22529 GERMANY, stammer@ifm.uni-hamburg.de
Dr. Peter F. Worcester, Scripps Institution of Oceanography, University of California at San Diego, La Jolla, CA 92093-0225, USA, pworcester@ucsd.edu
Mr. Michael Zarnetsky, Applied Physics Laboratory, University of Washington, 1013 Northeast 40th Street, Seattle, WA 98105, USA, mikez@apl.washington.edu

Acoustic measurements of large-scale, depth-averaged temperatures have been made in the North Pacific Ocean over the last eight years. A source located on Pioneer Seamount off central California transmitted (intermittently) to receivers distributed throughout the North Pacific from 1996 through 1998 as part of the Acoustic Thermometry of Ocean Climate (ATOC) project. A second ATOC source located north of

Kauai began transmitting in late 1997. The Kauai transmissions are now continuing as part of the North Pacific Acoustic Laboratory (NPAL) project, providing (intermittent) acoustic time series up to six years long. The Kauai source typically transmits six times per day at four-day intervals. The source and receivers are cabled to shore, providing near-real time data.

Basin-wide acoustic observations give integral measurements of large-scale ocean temperature variations. These observations provide the spatial low-pass filtering needed to detect weak, gyre-scale signals in the presence of a much stronger mesoscale variability. Seasonal signals are apparent in the travel times from the Pioneer Seamount source, but no longer-term trends are evident during the (relatively short) time that the source was transmitting. Long-term trends in large-scale ocean temperature are readily visible in the longer time series from the Kauai source, however. The paths to the east, particularly those paths from Kauai to the California coast, show cooling (longer travel times) relative to the earlier data. A path to the northwest showed modest warming (shorter travel times) until early 2003, when a cold event caused the longest travel times observed during the entire six-year period. Data obtained from ARGO drifters in the vicinity of the acoustic path at the time of the cold event are not inconsistent with the acoustic observations, but the variability in the ARGO data is too great to permit definitive conclusions.

Acoustic travel-time data have been used previously in simple data assimilation experiments, and they can now be compared to assimilation products from state-of-the-art models from the ECCO (Estimating the Circulation and Climate of the Ocean) Consortium. Not surprisingly, comparisons between measured and predicted travel times show significant similarities and differences. Measured acoustic travel times have uncertainties much less than the differences between two model implementations by the ECCO Consortium. The acoustic data ultimately need to be combined with upper-ocean data from ARGO and sea-surface height data from satellite altimeters to detect changes in abyssal ocean temperature and to quantitatively determine the complementarity of the various data types.

IODC-13

Managing and Distributing Operational Oceanography Data at the U.S. National Oceanographic Data Center

Dr. Charles L. Sun, NOAA/NESDIS/NODC, 1315 East-West Highway, Silver Spring, Maryland, USA, Charles.Sun@noaa.gov
Dr. Norman Hall,NOAA/NESDIS/NODC, 8604 La Jolla Shores Drive, La Jolla, California, 92037, USA Norman.Hall@noaa.gov
Mr. Michael Simmons, NOAA/NESDIS/NODC, 1315 East-West Highway, Silver Spring, Maryland, USA, Michael.Simmons@noaa.gov
Ms. Melanie Hamilton, Melanie.Hamilton@noaa.gov
Mr. Robert Van Wie, bob@nodc.noaa.gov
Ms. Shannon Niou, Shannon.Niou@noaa.gov

An end-to-end, state-of-the-art environmental data and information system for managing and distributing operational oceanography data, developed at the U.S. National Oceanographic Data Center (NODC), is presented in this paper. The purposes

of this paper are: (1) to describe the development and implementation of the system and (2) to illustrate the procedures of quality control, loading oceanographic data into the NODC ocean database.

The NODC participates in the Argo project and the Global Temperature-Salinity Profile Program (GTSPP), which are sponsored by the Climate Variability and Predictability (CLIVAR) program of the World Climate Research Programme. The NODC ocean data management system currently focuses on acquiring , processing, and distributing ocean data collected by Argo and GTSPP. The data stream of the two operational ocean observing systems contains upper ocean temperature and salinity data mainly from Expendable Bathythermographs (XBTs) but also from Conductivity-Temperature-Depths (CTDs) and bottles. In addition, there are now a substantial number of profiling floats operating in the oceans also included in the NODC ocean database.

Argo has used resources from 15 or so countries to make unprecedented in-situ observations of the global ocean. All Argo data are publicly available in near real-time via the GTS (Global Telecommunications System) and in scientifically quality-controlled form with a few months delay. The NODC operates the Global Argo Data Repository of Argo data for long-term archiving and serves Argo latest (daily) data in the NODC version of Argo netCDF and tab-delimited spreadsheet text formats to the public through the NODC Web site at http://www.nodc.noaa.gov/argo/.

The GTSPP is a cooperative international program. It maintains a global ocean T-S resource with data that are both up-to-date and of the highest quality possible. Both real-time data transmitted over the (GTS), and delayed-mode data received by contribution countries are acquired and quality controlled by the Marine Environmental Data Service (MEDS, Canada) and are eventually incorporated into a continuously managed database maintained by the NODC. Information and data are made publicly available at http://www.nodc.noaa.gov/GTSPP/

In the future, we will develop Web-based tools that will allow users on the Web to query and subset Argo delayed-mode data by parameter, location, time, and other attributes such as instrument types and quality flags.

IODC-14

Exploring Subpolar Atlantic Climate with Seagliders

Charles Eriksen, Peter B. Rhines, School of Oceanography and Department of Atmospheric Sciences, University of Washington, Seattle, Washington 98195
rhines@ocean.washington.edu

The first major exploration of the deep ocean using autonomous undersea vehicles began offshore of Nuuk Greenland on 2 October 2003, in a program directed at high-latitude ocean climate change. Two Seagliders were launched at the 1000m isobath in the Labrador Sea. During their first 2 + months, at the time of this writing, each has traveled over 1000km while making about 230 dives to 1000m. Observations of temperature, salinity, dissolved oxygen, fluorescence and two-channel particle scattering were made along the saw-tooth paths, with average horizontal resolution of 3 km. The vehicle's known flight characteristics make it possible also to measure vertically averaged horizontal velocity and fine-scale vertical velocity, giving estimates of horizontal circulation and vertical convection/internal waves. Control and data

transmission occurs through the Iridium satellite system, during the three-times daily surfacing of the vehicle, and has been successful in one of the stormiest seas on Earth. Meridional sections have been carried out along 55W and 58W, crossing the central Labrador Sea gyre to the Labrador continental shelf. The shape of the Labrador Sea gyre has been determined along these lines, contrasting the narrow boundary currents and broad, multi-path limb of the gyre in the northwestern Labrador Sea. Interior fronts have been found, in which the mixed-layer changes depth by 50% in 3 km or less. Strong anticylonic eddies have been profiled, some of which carry a 'top-hat' of low-salinity shelf water out to the central Sea. The transport of fresh-water in the surface layer of the Labrador Sea, its communication with the low-salinity shallow circulation on the continental shelves, and its engulfment into deep-waters by deep wintertime convection are objects of interest.

Climate change in the Atlantic involves transports of heat and fresh-water which are impossible to estimate historically. Adequate observations are needed, sustained in time, and with spatial resolution sufficient to deal with relatively small-scale ocean boundary currents and upper ocean layers, as well as the larger water masses. The transition between the 'natural' past and the anthropogenic present and future has been observed only partially, owing to the absence of sustained measurement programs. A combination of new technologies, satellites, moorings, chemical tracers, drifting/profiling floats, and now gliders, is available to close this gap.

IDC-15

Nonlinear Balance Constraints for 3DVAR and Applications to Altimetry Data Assimilation

Prof. Jiang Zhu, Institute of Atmospheric Physics, Chinese Academy of Sciences, Beijing 100029, China, jzhu@mail.iap.ac.cn
Dr. Changxiang Yan, ycxlasg@mail.iap.ac.cn

In many applications of 3DVAR, the balance constraints are considered via proper definition of the background error covariance matrix B (Derber and Bouttier, 1999): firstly define the background error covariance matrix B(u) (a block-diagonal matrix) of unbalanced parts of model variables; secondly define the balance operator K transforming unbalanced parts to model variables, then construct B using B = KB(u)KT. The formulation is only applicable to those linear or linearized balance constraints. We derive some generalizations based on the Derber-Bouttier formulation. Then we applied the nonlinear balance constraint to a problem of assimilating surface dynamic height.

A 3DVAR-based data assimilation scheme is proposed to estimate temperature and salinity profiles from surface dynamic height information. The scheme takes vertical correlations for both temperature and salinity background covariance and nonlinear temperature-salinity relation constraint into consideration. The assimilation scheme works directly in the model state space and does not require EOF transformations. In this study we designed some one-dimensional test cases to examine the separate and combined impacts of the vertical correlations and the nonlinear T-S relation constraint on estimations of temperature and salinity profiles by comparing with a simple 3DVAR scheme that does not consider vertical correlations and T-S relations. Results show that the simple 3DVAR scheme cannot simultaneously improve temperature and salinity profiles from their backgrounds in some cases, and could make the correction non-

smooth at different depths. The consideration of vertical correlations helps to balance the magnitude of the profile correction among all depths and produce smoother results. However consideration of vertical correlations cannot help much in reducing the root-mean-square error of estimation. The consideration of the nonlinear T-S relation constraint can improve both temperature and salinity estimations in all tested cases and significantly reduce the root-mean-square error of estimations. The combined effects of both vertical correlations and nonlinear T-S relation constraint are similar to that of the latter but with vertically smoother results.

IDC-16

The ECCO Consortium - Future Directions for Ocean State Estimation

Patrick Heimbach, MIT, EAPS, Room 54-1518, 77 Massachusetts Avenue, Cambridge, MA 02139, USA, heimbach@mit.edu
Carl Wunsch, MIT, EAPS, room 54-1522, 77 Massachusetts Avenue, Cambridge, MA 02139, USA, cwunsch@mit.edu

Recent results by the ECCO consortium (e.g. Stammer et al. [2002/2003], Lee et al. [2002/2003]; see also http://www.ecco-group.org and http://mitgcm.org) have demonstrated the practicality and power of oceanic state estimation through near-rigorous combinations of the ECCO-MIT GCM and a multitude of global-scale and regional data types. The initial products have been directed, using the adjoint method (Lagrange multipliers), primarily at determining the physical state of the ocean (the general circulation and its properties). As ECCO moves into the CLIVAR era, several extensions of the present estimation capability are planned. These include: (1) coupled ocean -- sea ice with a fully-fledged sea ice model incorporaring multi-category thermodynamics and viscous-plastic dynamics to enable sea ice extent and property estimation; (2) fully coupled ocean -- atmosphere aiming at incorporating atmosphere-ocean feedbacks into the estimated state. A computational issue lies with the very different predictability and stability timescales of the sub-components; (3) coupled ocean -- biogeochemistry with the ultimate goal of estimating the global carbon cycle (and its interaction with further relevant tracers such as oxygen, iron, etc.), as well as addressing paleo-climatic problems (possible in conjunction with simplified versions of the atmospheric component.

All applications take advantage of substantial improvements currently being made to the dynamical kernel and its adjoint component. For example, a conformal expanded spherical cube will be used to (i) extend the quasi-global grid to the pole enabling for coupled sea ice modeling and inclusion of the polar oceans, (ii) enable a global coupled atmosphere-ocean configuration with a hierarchy of atmospheric components (statistical atmosphere, atmosphere of intermediate complexity physics paramererizations, high-end atmosphere).

Higher-order advection schemes have been implemented in conjunction with a multi-tracer advection package along with extensions of the GM/Redi and KPP mixing parameterizations for extended biogeochemical models. Underlying codes have been adapted to adjoint code generation and preliminary biogeochemical sensitivity studies have been performed. Besides the novel data sets accompanying the new coupling

components, new physical data sets, such as those from Jason and GRACE, will be used.

The overarching goal remains to produce ongoing best-estimates of all elements of the time-evolving ocean circulation combining the knowledge implicit in both data and numerical models.

IDC-17

Long-period Changes in the ECCO Global Synthesis

Detlef Stammer, Universität Hamburg, Zentrum für Meeres- und Klimaforschung Institut für Meereskunde, Bundesstr. 53, 20146 Hamburg, Germany, stammer@ifm.uni-hamburg.de
A. Koehl, Physical Oceanography Research Division, Scripps Institution of Oceanography, 9500 Gilman Dr.; MS: 0230, La Jolla, CA 92093-0230, koehl@ucsd.edu.
B. Cornuelle, Physical Oceanography Research Division, Scripps Institution of Oceanography, 9500 Gilman Dr.; MS: 0230, La Jolla, CA 92093-0230, bdc@ucsd.edu.
C. Wunsch, Department of Earth, Atmospheric and Planetary Sciences Massachusetts Institute of Technology, Mass Ave. , Cambridge MA 02139 USA, cwunsch@ocean.mit.edu.

An estimate of the time-varying ocean circulation is obtained for the period 1992 - 2002 by combining most of the WOCE ocean data sets with a global general circulation model on a 1 degree horizontal grid. The estimates are consistent with the model equations and have none of the artificial sources or sinks of momentum, heat and freshwater that are common to most assimilation efforts. To bring the model into agreement with observations, its initial temperature and salinity conditions are permitted to change, as are the time-dependent surface fluxes of momentum, heat and freshwater. The resulting changes of these “control vectors'' are largely consistent with accepted uncertainties in the hydrographic climatology and meteorological analyses. Time-mean horizontal transports, estimated from this fully time-dependent circulation, have converged with time-independent estimates from box inversions over most parts of the world ocean. Underneath the seasonal thermocline, temperature and salinity changes to a large extend are due to heaving effects and dependent on wind forcing. Near steep topography, high-frequency wind changes are important for the evolution of the deep temperature and salt fields due to the interaction of horizontal currents with the topography.

Changes in the model's heat content are smaller than those reported by Levitus and correspond to a global net heat uptake of about 1.1 W/m/m over the model domain. Associated abyssal temperature and salinity changes are complex in their geographical patterns and point toward air-sea interaction in water mass formation regions as the primary cause of changes in the model's deep density fields.

The model drift in sea surface height over the estimation period is consistent with observations from TOPEX/POSEIDON over most of the global ocean. Sea surface height changes in the model are primarily steric but show a clear contribution of mass redistribution in high latitudes. Steric contributions are primarily temperature-based.

However, the North Atlantic and the ACC regions reveal the importance of salt in large-scale sea level variations.

OC-18

The ECCO Global Ocean Synthesis/Reanalysis 1952 - 2002

Dr. Armin G. Köhl, Scripps Institution of Oceanography, 9500 Gilman Dr., La Jolla, CA 92093-0230 USA, akoehl@ucsd.edu
Prof. Detlef B. Stammer,Universität Hamburg, Zentrum für Meeres- und Klimaforschung, Institut für Meereskunde, Bundesstr. 53, 20146 Hamburg Germany; Scripps Institution of Oceanography, 9500 Gilman Dr., La Jolla, CA 92093-0230 USA

The consortium for Estimating the Circulation and Climate of the Ocean (ECCO) has demonstrated the feasibility and skill of global estimates of the full three-dimensional, time-varying oceanic state over the period 1992-2002. However, in order to address climate relevant problems longer time scales have to be taken into consideration.Paralleling the 50 year NCEP/NCAR reanalysis an estimation of the ocean circulation and its changes is attempted over the period 1952-2002. The approach is identical to the 11 year ECCO estimation in which initial temperature and salinity conditions as well as the time-dependent surface fluxes of momentum, heat and freshwater are adjusted by the adjoint method in order to bring a global 1 degree model into agreement with observations. Before 1992 the state is mainly constrained by an extensive data base of subsurface XBT and MBT measurements whereas only after 1992 the same data rich data base is available as for the 11 year estimation. Information about the optimization will be presented and first results will be discussed in terms of decadal variations of SSH and current fluctuations, heat and freshwater content, transport variations as well as model-data residuals.

OC-19

SODA: A Climate Reanalysis for the Oceans

Dr. James A. Carton, Department of Meteorology, Computer and Space Sciences Bldg., University of Maryland, College Park, MD 20742 USA carton@umd.edu
Dr. Benjamin S. Giese, Department of Oceanography, Texas A&M University, College Station, TX 77843-3146, bgiese@ocean.tamu.edu

Here we describe a newly available six-decade long reanalysis of the physical climate of the ocean. This new reanalysis has been created in support of the needs of the climate research and monitoring community to study ocean circulation changes, air-sea interaction topics such as ENSO, as well as to provide physical estimates in support of biological and chemical studies. The domain is the global ocean, including a full arctic, with emphasis on the upper 1000 m. The model we use is based on Parallel Ocean Program physics, while the data assimilation represents an evolution of the Simple Ocean Data Assimilation sequential estimation approach including explicit bias-correction. The error covariances are allowed to evolve as a function of the flow field,

and thus are oriented along major current systems such as the Gulf Stream. The horizontal resolution is eddy-permitting (0.4 x 0.25 degrees at the equator) with 40 vertical levels. Assimilated observations include all available surface and subsurface temperature and salinity data from the National Oceanographic Data Center as well as altimeter sea level and are subject to additional quality control checks. Surface wind forcing is provided by the NCEP/NCAR reanalysis, which has been corrected to match recent scatterometer estimates. The surface freshwater flux is a sum of satellite-based estimates of rainfall, parameterized net evaporation, and climatological river discharge. Heat flux is similarly determined by bulk formula.

The improved eddy-permitting resolution of this reanalysis has a number of advantages over our previous reanalysis (Carton et al., 2000). It allows vastly improved representation of climatically important narrow passages such as the Indonesian throughflow as well as a statistically reasonable midlatitude mesoscale field. We present results from an initial set of three reanalyses, a control reanalysis spanning the full period, a first reanalysis experiment covering the last 14 years, but with no altimetry, and a second reanalysis experiment examining the impact of bias correction. The former will be made available to the community online through the Live Access Server mechanism. This presentation will describe the main features of the control reanalysis, comparison to independent observations, as well as results from examination of the two reanalysis experiments.

IDC-20

Evaluation of the Global Ocean Data Assimilation System at NCEP: The Pacific Ocean

Dr. Yan Xue, Room 605, Climate Prediction Center, 5200 Auth Rd, Camp Springs, MD 20746, USA, yan.xue@noaa.gov
Dr. David Behringer, EMC/NCEP, 5200 Auth Rd, Camp Springs, MD 20746, USA, david.behringer@noaa.gov

The new global ocean data assimilation system (GODAS) at NCEP was developed using the Geophysical Fluid Dynamics Laboratory's Modular Ocean Model version 3 (MOM.v3) and a three-dimensional variational data assimilation scheme. Compared with the operational ODAS developed for the Pacific Ocean (referred as RA6 hereafter), the major changes include 1) an extension from the Pacific basin to the quasi-global domain for 75OS-65ON, 2) a model change from MOM.v1 to MOM.v3 that contains more vertical levels, an explicit free surface, the Gent-McWilliams mixing scheme and an improved vertical mixing scheme (KPP), 3) a forcing change from momentum flux forcing only to momentum flux, heat flux and fresh water flux forcings of the NCEP Reanalysis 2, and most importantly, 4) a data input change from temperature only to temperature and synthetic salinity that is constructed from temperature and a local T-S climatology. The temperature data includes those from XBTs, profiling floats and TAO moorings. The temperature fields from GODAS and RA6 are compared with the TAO mooring data to estimate how well the analyses fit to observations. Then the quality of the analyses is evaluated with independent data sets such as the sea level observations at tide gauges and from the TOPEX/Poseidon and Jason satellite

altimeters, the current data from the TAO moorings and the satellite-derived current analysis.

Preliminary results suggest that the temperature field in GODAS is closer to observations than that in RA6, and the poor salinity field in RA6 is dramatically improved. Although this version of GODAS does not assimilate satellite sea level as RA6 does, GODAS does as well as or better than RA6 in comparisons with TOPEX altimetry and tide gauge sea level records. However, the surface currents in both GODAS and RA6 have large discrepancies (30 cm/s) in the western equatorial Pacific when compared with observed TAO currents and with satellite-derived currents. Preliminary studies suggest that those errors are related to an underestimation of the interannual variability of surface salinity. In fact, the surface currents in a simulation run that assimilates no data but uses the same external forcings as GODAS compare well with observations. We found that surface salinity anomalies have a significant impact on dynamic height anomalies in the western equatorial Pacific around 165OE. Both GODAS and RA6 have positive biases in dynamic height anomalies during the recent three cold events (1999-2001), which results in positive biases in surface currents. By calculating geostrophic and non-geostrophic surface currents, we further analyze the sources of errors in the surface currents.

IODC-21

Dynamical Ocean State during 1996-2002, Estimated from a 4 Dimensional Variational Data Assimilation

Dr. Shuhei Masuda, Frontier Research System for Global Change, 3173-25, Showa-machi, Kanazawa-ku, Yokohama-city Kanagawa, 236-0001, Japan
smasuda@jamstec.go.jp
Prof. Toshiyuki Awaji, Kyoto univ., Department of Geophysics, Graduate School of Science, Kyoto University, Kyoto 606-8502, Japan, awaji@kugi.kyoto-u.ac.jp
Dr. Nozomi Sugiura, FRSGC, 3173-25, Showa-machi, Kanazawa-ku, Yokohama-city Kanagawa, 236-0001, Japan, nsugiura@jamstec.go.jp
Dr. Hiromichi Igarashi, FRSGC, 3173-25, Showa-machi,Kanazawa-ku, Yokohama-city Kanagawa, 236-0001, Japan, higarashi@jamstec.go.jp
Dr. Yoichi Ishikawa, Kyoto univ., Department of Geophysics, Graduate School of Science, Kyoto University, Kyoto 606-8502, Japan, ishikawa@kugi.kyoto-u.ac.jp

Data assimilation approaches have recently focused on the derivation of an optimal synthesis of observational data and model results for better descriptions of the ocean state. By using an ocean general circulation model (OGCM) and the 4-dimensional variational (4D-VAR) adjoint method, we have constructed a global ocean data assimilation system that provides a comprehensive 4-dimensional reanalysis dataset based on available observational data. The resulting state estimate is consistent with the model equations as it has no artificial sources or sinks. In this study, a data assimilation experiment is performed to define a global ocean state during 1996-2002. The assimilated elements in this experiment are water temperature, salinity data from WOD2001 and FNMOC, and sea surface height anomaly data derived from TOPEX/Poseidon altimetry. The ARGO float data, which can provide higher quality subsurface information covering the entire ocean, is also used for recent years. The

OGCM is equipped with several sophisticated parameterization schemes. Its horizontal resolution is 1 degree in both latitude and longitude, with 36 vertical levels. This model is better able to reproduce ocean circulation and is expected to form a platform suitable for the use of the 4D-VAR adjoint model. The obtained reanalysis dataset shows good consistency with previous knowledge of important climate events. For example, the root mean square difference value between the observed time-evolution of Nino3 SST and the assimilated one is 0.69 K during 1996-1998, while for the simulated case the difference is 1.60 K. This much improved reproduction of the evolution of Nino3 SST gives us confidence in the validity of our dataset as representing the climate variability in this region. Further, our dataset exhibits realistic subsurface water mass distribution and enables us to clarify the water mass formation and movement processes. To illustrate this, we show that dichothermal and mesothermal waters dominating in upper subarctic regions in the North Pacific (an important sink for carbon dioxide) are well reproduced. The North Pacific Intermediate Water, which is characterized by a subsurface salinity minimum, is also successfully reproduced. This good correspondence is the result of both realistic subsurface flow patterns and surface processes in our reanalysis data. These results illustrate that the ocean state derived from our data assimilation has greater information content and that the forecast potential for climate variability is greater than that due either to the models or the data alone.

IDC-22

Results from an Eddy Permitting Global Coupled Climate Model

Dr. Malcolm J. Roberts, Met Office, Hadley Centre for Climate Prediction and Research, FitzRoy Road, Exeter EX1 3PB, UK, malcolm.roberts@metoffice.com

A global coupled atmosphere-ocean-sea-ice GCM with an eddy-permitting ocean (HadCEM) has now completed a 150 year control run and an 80 year idealised climate change run at the Hadley Centre. The model is a development of the successful HadCM3 model and uses exactly the same atmospheric and sea-ice components, with the ocean model having a full suite of physics and using a 1/3 degree resolution; parallel low resolution experiments have also been completed.

There are significant improvements in the ocean circulation at the higher resolution, including improved boundary currents, a more active equatorial circulation and Agulhas eddies shed into the South Atlantic. There is also a smaller mean water mass drift away from the initial conditions and improved large-scale flows.

The impact on the mean atmospheric climate is locally significant, with improved SST's giving land temperatures which are several degrees closer to observations than found in HadCM3. However, the large-scale changes to the mean climate and its variability are rather more subtle, with little change seen in the ENSO cycle despite the improved ocean circulation.

The simulated climate response to a quadrupling of CO2 does seem to be sensitive to ocean model resolution. Large-scale mass and heat transports are seen to change less in the high resolution model, leading to enhanced warming particularly in the Northern Hemisphere. At issue is whether these changes are a matter of different adjustment timescales for the different models, or whether ocean model resolution changes the simulated climate sensitivity.

Eddy-Resolving Simulation in the World Ocean; - 50 Years Spin-Up, Subsequent a Half Century Hindcast and Tracer Experiment

Mr. Hideharu Sasaki, Earth Simulator Center, 3173-25 Showamachi, Kanazawa-ku, Yokohama, Kanagawa 236-0001, Japan, sasaki@jamstec.go.jp
Dr. Yoshikazu Sasai, Frontier Research System for Global Change, 3173-25 Showa-machi, Kanazawa-ku, Yokohama, Kanagawa 236-0001, Japan, ysasai@jamstec.go.jp
Dr. Masami Nonaka, nona@jamstec.go.jp
Dr. Takashi Kagimoto, kagimoto@jamstec.go.jp
Dr. Yukio Masumoto, Dept. of Earth and Planetary Science, Graduate School of Science, Univ. of Tokyo, 7-3-1, Hongo, Bunkyo-ku, Tokyo 113-0033, Japan, masumoto@eps.s.u-tokyo.ac.jp
Dr. Akio Ishida, Japan Marine Science and Technology Center, 2-15 Natsushima-cho, Yokosuka, Kanagawa 237-0061, Japan, ishidaa@jamstec.go.jp
Dr. Hirohumi Sakuma, Earth Simulator Center 3173-25 Showamachi, Kanazawa-ku, Yokohama, Kanagawa 236-0001, Japan, sakuma@jamstec.go.jp

Following the successful 50 years eddy-resolving spin-up on the global domain, we started a hindcast covering the period from 1950 to 2002 and a tracer simulation. OFES, the MOM3-based OGCM code optimized for the earth simulator, enables us to execute the series of the eddy-resolving simulations in a relatively short time. The computational domain covers near global region extending from 75S to 75N with the horizontal grid spacing of 0.1 degree and 54 vertical levels. The spin-up starts from an annual mean field without motion and the surface flux is specified from monthly mean value of NCEP/NCAR re-analyses data, while the subsequent hindcast simulation is forced by daily mean NCEP/NCAR re-analyses.

Our 50 years spin-up run reproduces quite realistic features of the world ocean both in the mean fields and meso-scale eddy activities. For instance, the simulated Kuroshio separates at the correct latitude and the sea surface height variability is similar to the observation. In the South Pacific, horizontal distributions of the recently discovered South Pacific Eastern Subtropical Mode Water are simulated well: Low potential vorticity waters associated with it extend northwestward by the subtropical gyre from the eastern South Pacific.

In our hindcast experiment, there has been a noticeable improvement in the meso-scale eddy activities due to the realistic high-frequency forcing. The frequency of eddy shedding at the loop current and at the southern edge of the east Australian current together with subsequent eddy longevity are improved much by the realistic forcing. Unexpected remarkable coincidences of the timing and amplitude of Nino 3 SST and Dipole Mode Index from partial monitoring from 50s to 70s encourage us to compare carefully our simulated dynamical fields with observed big events in the 90s.

After 50 years spin-up run, the chlorofluorocarbons (CFCs) have been incorporated into the ocean circulation model to investigate the processes determining the uptake and accumulation of chemical tracers. The model simulates the observed CFC-11 distribution along the AJAX section in the South Atlantic very well especially in the deep layer where deep western boundary current ventilates the CFC burdened

Antarctic Bottom Water. The CFC-11 distributions capture the realistic pathway of the western boundary deep current in the Western Atlantic. Our realistic results seem to owe much to the employed high-resolution that resolves the bottom topography in a realistic fashion and hence improves the ocean circulation.

IDC-24

A New Approach for Coupled GCM Sensitivity Studies

Dr. Dughong Min, Center for Ocean-Land-Atmosphere Studies, 4041 Powder Mill Road, Suite 302, Calverton, MD 20705-3106, USA, min@cola.iges.org
Dr. Ben P. Kirtman, kirtman@cola.iges.org
Dr. P.S. Schopf, schopf@cola.iges.org
Dr. E. K. Schneider, schneide@cola.iges.org

A new multi-model approach for coupled GCM sensitivity studies is presented. The purpose of the sensitivity experiments is to understand why two different coupled models have such large differences in their respective climate simulations. In the application presented here, the differences between the coupled models using the Center for Ocean-Land-Atmosphere Studies (COLA) and the National Center for Atmospheric Research (NCAR) atmospheric general circulation models (AGCMs) are examined. The procedure is to simultaneously couple the two different atmospheric component models to a single ocean general circulation model (OGCM), in this case the Modular Ocean Model (MOM) developed at the Geophysical Fluid Dynamics Laboratory (GFDL). Each atmospheric component model experiences the same SST produced by the OGCM, but the OGCM is simultaneously coupled to both AGCMs using a cross coupling strategy. In the first experiment, the OGCM is coupled to the heat and fresh water flux from the NCAR AGCM (Community Atmospheric Model; CAM) and the momentum flux from the COLA AGCM. Both AGCMs feel the same SST. In the second experiment, the OGCM is coupled to the heat and fresh water flux from the COLA AGCM and the momentum flux from the CAM AGCM. Again, both atmospheric component models experience the same SST. Based on these sensitivity experiments we conclude that the tropical ocean warm bias in the COLA coupled model is due to errors in the heat flux, and that the erroneous westward shift in the tropical Pacific cold tongue minimum in the NCAR model is due errors in the momentum flux. All the coupled simulations presented here have warm biases along the eastern boundary of the tropical oceans suggesting that the problem is common to both AGCMs. In terms of interannual variability in the tropical Pacific, the CAM momentum flux is responsible for the erroneous westward extension of the sea surface temperature anomalies (SSTA) and errors in the COLA momentum flux cause the erroneous eastward migration of the El Nino-Southern Oscillation (ENSO) events.

IDC-25

The Characterization of Four Separate Decades of Ocean Variability

Dr. Robin T. Tokmakian, OC/tk, Department of Oceanography, Naval Postgraduate School, Bldg. 323, Rm 328, 833 Dyer Rd., Monterey, CA 93943-5122, USA, robint@ucar.edu

A simulation of the global ocean at a resolution of 0.2 degrees will be described. The 40+ year simulation (1957-2000) forced with daily varying fields of winds, heat, and freshwater is used to examine the ocean's physical processes. The model is a primitive equation model as defined by Smith [2000], the Parallel Ocean Program (POP) formulation. It contains 40 levels in the vertical and includes an implicit free surface. A blended bathymetry was created from Smith and Sandwell [1997], International Bathymetric Chart of the Arctic Ocean [IBCAO, Jakobsson et al., 2000], and British Antarctic Survey (BEDMAP) products. The forcing was constructed from National Center for Environmental Prediction (NCEP) fluxes [Doney et al., 2002]. Surface momentum, heat, and salt fluxes were calculated using bulk formulae [Large et al., 1997] and a combination of daily NCEP analyses, monthly Internal Satellite Cloud Climatology Project (ISCCP) radiation data, and monthly Microwave Sounding Unit (MSU) and Xie-Arkin precipitation data. An important component to these simulations is the use of the Large et al. [1994] mixed layer formulation, K-Profile Parameterization (KPP). Each of the four decades covered by the simulation are characterized by their variability in the upper ocean with a concentration on the northern hemisphere. The connection between the mesoscale and basin scale processes are described for each decade. Special emphasis is placed on how representative the last decade (the WOCE decade) is of the other decades over the last forty years. Comparisons to observational time series is also shown along with the relationship of the ocean's variability to various climate indices.

OC-26

On the Mechanisms of Decadal Variability of the Wind-Driven Ocean Circulation

Dr. Andrew McC. Hogg, Southampton Oceanography Centre
Prof. Peter D. Killworth, Southampton Oceanography Centre, Empress Dock, Southampton SO14 3ZH, England, p.killworth@soc.soton.ac.uk
Mr. Jeffrey R. Blundell, Southampton Oceanography Centre, Empress Dock, Southampton SO14 3ZH, England, j.blundell@soc.soton.ac.uk
Prof. William K. Dewar, Dept. of Oceanography, Florida State University, Tallahassee, Florida 32306-3048, USA, bill@ocean.ocean.fsu.edu

Eddy resolving simulations of wind driven circulation in a large ocean basin are presented. A series of numerical experiments are used to demonstrate that the mean state and variability of the circulation is dependent upon the strength of ocean eddies, which in turn are controlled by parameters such as viscosity and bottom drag. In particular, strong modes of low-frequency variability arise in many parameter regimes, and these modes depend upon the presence of ocean eddies in the simulation. The dependence upon eddies may be due to either an eddy--mean flow feedback loop, or else may occur because of oscillations in the mean flow which contains strong nonlinear features due to the cumulative effect of the eddy field. Both of these possibilities are explored. In addition it is shown (using a coupled version of the model) that this intrinsic ocean variability may contribute to midlatitude climate variability.

IDC-27

A Coupled Climate Model Based on an Eddy-Permitting OGCM

Dr. Yongqiang Yu, LASG, Institute of Atmospheric Physics, Chinese Academy of Sciences, P. O. Box 9804, Beijing 100029, P. R. China, yyq@lasg.iap.ac.cn
Dr. Yongqiang YU, LASG, yyq@lasg.iap.ac.cn
Dr. Hailong LIU, LASG, lhl@lasg.iap.ac.cn
Dr. Xuehong Zhang, LASG, zxh@lasg.iap.ac.cn
Dr. Tianjun ZHOU, LASG, zhoutj@lasg.iap.ac.cn
Dr. Wei LI , LASG, liwei@lasg.iap.ac.cn
Dr. Rucong YU,LASG, yrc@lasg.iap.ac.cn

An eddy-permitting OGCM with a homogeneously horizontal resolution-- 0.5 degree, the LASG/IAP Climate Ocean Model (LICOM), was developed in this study. The model LICOM does not can capture the essential characters of the large-scale circulation only, but also well simulates the western boundary currents including Indonesian Through Flow (ITF).

Another experiment has been carried out with LICOM forced by daily ERA wind stresses from 1979 to 1993. The model can simulate the ENSO (El Nino-South Oscilation) signal in the Pacific and IOD (Indian Ocean Dipole) signals in the Indian Ocean very well. EOF analysis of 20C isotherm depth exhibited that the significant signal is interannual variability. The simulated ITF transport is large during El Nino and small during La Niña. The interannual variation of ITF is decided by the difference of sea surface height (SSH) between the western Pacific Ocean and the eastern Indian Ocean.

Based on NCAR Flux Coupler 5, the oceanic component model POP of CCSM2 was replaced with the ocean model LICOM. The coupled model, named as FGCM version 1, has been integrated more than 200 years. There is no serious climate drift in the extended coupled integration, although the coupled model suffers from some very common biases as the other directly coupled model. Meanwhile, the coupled model also simulates significant ENSO-like variability.

IDC-28

Understanding Differences in Regional Climate Sensitivity of GCMs.

Dr. Benjamin A. Cash and Dr. Edwin K. Schneider, Center for Ocean-Land-Atmosphere Studies, 4041 Powder Mill Rd, Suite 302, Calverton, MD, 20705-3106 USA, bcash@cola.iges.org, schneide@cola.iges.org

The object of this study is to clarify the causes of differences between the extratropical sensitivity of different coupled models in the CMIP (Coupled Model Intercomparison Project) to increasing CO2, especially in the North Atlantic. In particular, the question is whether differences in the responses can be attributed either to differences in the tropical SST anomalies or to differences in the atmospheric response to similar tropical SST anomalies, or whether some other explanation is required.

There are two parts to the study. First, the atmospheric responses to the observed SST evolution and to the observed tropical SST trend over the past 50 years are found. We have used two AGCMs, ECHAM4 and CCM3. Each model gives an internally similar response to the observed evolution of the SST and to the tropical trend forcing. However, the northern hemisphere 500mb DJF height responses differ significantly between the models (and observations).

In the second part of the study, we force the models with SST sensitivity anomalies (SST at time of doubling minus control) calculated using the CMIP database. As was the case when forced by the observed trend, we find significant differences in the extratropical response between the models forced with identical SST fields. Likewise, forcing the same model with different tropical SST fields produces significant differences in the extratropical response. The results indicate that both internal differences in the AGCMs and the external forcing from different tropical SSTs (ultimately also due to internal differences in the components of the coupled models) play a role in producing the different model regional responses to climate change scenarios.

IDC-29

Monthly Mapping, Validation and Application by Objective Analysis with Argo Float and TRITON Buoy in the Pacific Ocean

Dr. Shigeki Hosoda, 2-15, Natsushima-cho, Yokosuka, Kanagawa, 237-0061, Japan, hosodas@jamstec.go.jp
Dr. Shinya Minato, Japan Marine Science and Technology Center, 2-15, Natsushima-cho, Yokosuka, Kanagawa, 237-0061, Japan, sminato@jamstec.go.jp

Monthly mapping of temperature and salinity is applied by increasing Argo float data. Generally, the Argo floats with well-controlled quality observe each 10 days down to 2000db routinely in the world ocean. The TRITON buoy and the Argo float data realize the Operational Oceanography, which monitors the climate variability and ocean situations from products of mapped and grid data. The important thing to monitor the subjects is not only to make production but also to check the quality of its accuracy. We have attempted to perform the validation of our products by comparison with CTD data along 137E, which have been observed by Japan Meteorological Agency (JMA) for 30 years. The comparison with the standard deviation indicates that our estimated data have good performance for the basin-wide ocean variability. From these data, we calculate the warm water volume (WWV) for the 2002-2003 El Nino in the western Pacific Ocean. Further, we investigate sea surface height (SSH) calculated from our data and apply the extra high tide phenomena at Naha in Jul. 2001. These two applications are displayed well with the large scale variability in the ocean. To produce these mapping routinely, we think the basin-wide climate change can be monitored well.

IODC-30

SeHyD (Selected Hydrographic Dataset): New Pacific Historical Dataset for the ARGO Delayed-Mode Quality Control and its Performance of Salinity Correction

Dr. Taiyo Kobayashi, Frontier Observational Research System for Global Change, 2-15, Natsushima-cho, Yokosuka, Kanagawa, 237-0061, Japan, taiyok@jamstec.go.jp
Dr. Shinya Minato, Japan Marine Science and Technology Center, 2-15, Natsushima-cho, Yokosuka, Kanagawa, 237-0061, Japan, sminato@jamstec.go.jp

For the standard method of the Argo delayed-mode quality control, JAMSTEC/FORSGC have made a new Pacific historical dataset, named as Selected Hydrographic Dataset (SeHyD). SeHyD covers the whole open Pacific and consists of the quality-controlled historical profiles, which originate from World Ocean Database 2001 except for the regions around Japan and off the coast of North America from severer quality controlled datasets, HydroBase (Macdonald et al. 2001) and our CTD dataset including WOCE-CTD data. This regional classification is based on our preliminary study (Kobayashi and Minato, 2003; submitted to JTECH) on the observation density and the noise/signal ratio of datasets. We will continue to improve SeHyD; its latest version (1.0, as of December 2003) is available from ARGO JAMSTEC web site:

http://www.jamstec.go.jp/ARGO/product/SeHyD_1.zip

We will show our selection roles for making SeHyD and some statistics of it.

The performance of the Argo delayed-mode quality control with SeHyD is very good. In the case that Argo floats measure profiles from the depth of 2000 dbar constantly, except for the Mixed Water Region where the water-mass structure has very large variations, the Argo goal on salinity measurement accuracy (+/-0.01psu) can generally be achieved: Most of the quality-controlled salinities agree with the true values obtained by nearby shipboard CTDs or post-calibrations in laboratory, and their correction errors are smaller than +/-0.01 psu. In the tropical Pacific the delayed-mode quality control system can provide salinity data with sufficient quality even form the float profiles to the depth of 1000 dbar, that is, the Argo goal on salinity measurements can be achieved without new higher performance floats with powerful bladder.

From the viewpoint of delayed-mode quality control we found little reason to adopt a new anomalous observation scheme at least in which floats normally measure shallower profiles to a depth of 1000 dbar and sometimes deeper profiles to 2000 dbar.

IODC-31

On Oxygen Content Inter-Annual Variability in the Upper World Ocean

Hernan E. Garcia, NOAA/NODC Ocean Climate Laboratory, SSMC III E/OC5 Room 4326, 1315 East-West Highway, Silver Spring, MD 20910, USA Hernan.Garcia@noaa.gov

John.Antonov@noaa.gov,
Tim.Boyer@noaa.gov,
Sydney.Levitus@noaa.gov,
Ricardo.Locarnini@noaa.gov

We report on variability in dissolved oxygen based on an analysis of pentadal (5-year running composites) anomalies of oxygen and Apparent Oxygen Utilization (AOU) content for the period 1955-2000 for the upper 100 m of the world ocean. The historical measurements are from the NODC/WDC-World Ocean Database 2001. The water column inventories as a function of time are generally characterized by relatively small linear trends and large decadal variability. The trends are not monotonic but in general, the composite data suggest a small positive linear trend in oxygen and a small negative trend in AOU content anomalies. About half of the oxygen content variability can be explained based on gas solubility variability over the same time period. This suggests the interplay of additional forcing processes such as changes in biological production and upper ocean ocean vertical stratification. Our results contain uncertainty due to data coverage limitations and non-uniform quality of the data, particularly for oxygen data collected prior to the mid 1960s. Estimates of oxygen variability will help to substantiate assumptions of the non-steady state of dissolved oxygen, a parameter central in estimates of oceanic carbon uptake that rely on the Redfield molar ratios.

IODC-32

On Constraining the Biological Component of the Air-Sea Oxygen Flux

Hernan E. Garcia, NOAA-NODC Ocean Climate Laboratory, SSMC-III, E/OC5, Room 4326, 1315 East-West Highway, Silver Spring, MD 20910-3282, USA, Hernan.Garcia@noaa.gov
Cara Wilson, NOAA/NMFS Pacific Fisheries Environmental Laboratory, 1352 Lighthouse Avenue, Pacific Grove, CA 93950-2097, USA, cwilson@pfeg.noaa.gov

The seasonal oceanic biological cycle directly impacts the chemistry of the oceans, resulting in a pronounced annual cycle in the biologically active dissolved gases (e.g., O2 and CO2), dissolved nutrients, and dissolved inorganic carbon, and in the seasonal variations of O2 and CO2 in the atmosphere. Because of strong linkages, seasonal variations of O2, carbon, and nutrients can be used to estimate rates of new production and remineralization in the surface ocean. However, over the past few decades a net decrease has occurred in the amount of atmospheric O2/N2 and oceanic O2. In the ocean, these changes in oxygen concentration are generally larger than can be accounted for by thermal changes alone, suggesting that they are produced by decreases in biologically mediated O2 production (marine production) or changes in vertical thermal stratification. Hence, it is important to quantify the biologically mediated oceanic O2 contributions due to seasonal variability in primary production. Here we use satellite chlorophyll and primary production measurements from SeaWiFS to estimate the non-thermal component of the air-sea O2 flux on a global basis. Additionally, in situ

data from CalCOFI, BATS, and the Wold Ocean Database will be used to examine seasonal to interannual variability.

OC-33

Response of Ocean Ecosystems to Climate Warming

Patrick Schultz, Department of Geosciences, Princeton University, Guyot Hall, Princeton, NJ 08544, USA, pschultz@Princeton.edu
Richard D. Slater, Atmospheric and Oceanic Sciences Program, Princeton University, PO Box CN710, Princeton, NJ 08540, USA, rdslater@splash.Princeton.edu,
Jorge L. Sarmiento, jls@Princeton.edu

Modeling changes in ocean primary productivity in response to global warming is crucial for understanding the role of the oceans in climate. Biological activity and thus uptake of CO2 by phytoplankton is strongly dependent on oceanic temperature, stratification, circulation, convective overturning, and patterns of cloud cover and sea ice extent. Coupled climate models predict dramatic changes in these parameters.

Global remote sensing data on the abundance of algal biomass suggest that the ocean can be divided into biogeographical regions that are defined by the physical forcing. In particular, upwelling regions and regions with strong vertical mixing support higher biological productivity whereas downwelling and highly stratified regions are associated with lower productivity. In our study we use the sign of the vertical velocity at 50 m depth and the maximum wintertime mixed layer depth to define a set of biomes: an equatorially influenced biome, a permanently stratified subtropical biome, a seasonally mixed subtropical biome, a low latitude upwelling biome, a subpolar biome, and a marginal sea ice biome. These biomes are then further separated into biogeographical regions to account for light supply and airborne supply of macro- and micronutrients.

We assess the effect of global warming on the relative extent of these biogeographical regions in two model simulations of century-scale warming. Our data is derived from a coupled ocean-atmosphere model developed at the Geophysical Fluid Dynamics Laboratory (GFDL R30). Both simulations follow a radiative forcing scenario, which uses a 1% increase in atmospheric CO2 per year after 1990 until reaching two times and four times the initial level after 70 and 140 years, respectively. Earlier work suggests significant shifts in the global pattern of high and low productivity regimes as a result of projected changes in ocean circulation. The net effect of ecosystem changes on ocean carbon uptake is quantified in a second step using an empirical model of chlorophyll and primary production.□

OC-34

Autocorrelation of pCO2 Data For World Ocean

Dr. Zhen Li, Science Applications International Corporation, 4600 Powder Mill Road, Beltsville, MD 20705, USA, zhenli@janus.gsfc.nasa.gov
Dr. David Adamec, Ocean and Ice Branch, NASA/Goddard Space Flight Center, Greenbelt, MD 2077, USA, David.Adamec@nasa.gov

Dr. Taro Takahashi, Lamont-Doherty Earth Observatory, Columbia University, Palisades, NY10964, USA, taka@ldeo.columbia.edu

A statistical study is performed on the pCO2 data to understand the spatial and temporal correlation of the partial pressure of CO2 in surface waters of world ocean. The pCO2 data set is grouped into segments based on specific time and space intervals, and then the spatial and temporal correlation functions of the pCO2 data at each segment are calculated. Results on the fine scale calculation show a bimodal behavior in the spatial correlation, either that pCO2 data has a consistent large spatial correlation or the correlation skill drops very quickly in space, less than 20km. The correlation functions are necessary knowledge for use of this data set in "optimal" data assimilation systems that attempt to use this data to simulate the exchange of CO2 between the atmosphere and ocean and the effect of these exchanges on climate. The geographic dependence of both the temporal and spatial correlation functions will be presented.

IDC-35

Seasonal, Interannual and Decadal Variability of the Surface Water pCO2 and Air-Sea CO2 Flux in the Equatorial Pacific: A 3-Dimensional Carbon Cycle Model

Dr. Xiujun Wang, Earth System Science Interdisciplinary Center, 2207 Computer and Space Sciences Building, University of Maryland, College Park, MD 20742 USA, wwang@essic.umd.edu
Dr. Jim R. Christian, Canadian Centre for Climate Modelling and Analysis, University of Victoria, Victoria, BC, V8W 2Y2 Canada, acrnrjc@ec.gc.ca
Dr. Ragu Murtugudde, Earth System Science Interdisciplinary Center, 2207 Computer and Space Sciences Building, University of Maryland, College Park, MD 20742 USA, ragu@essic.umd.edu
Prof. Antonio J. Busalacchi, tonyb@essic.umd.edu

A basin-scale three-dimensional carbon model is applied to simulate the carbon cycle in the upper ocean of the Equatorial Pacific for the past three decades. The model is forced by climatological monthly data of solar radiation, cloudiness, and precipitation. Air temperature, and air humidity are computed by an advective atmospheric mixed layer model coupled to the OGCM-biogeochemical model. The model is forced with 6-day mean surface wind-stresses and wind-speeds such that only wind-forcing and latent/sensible heat fluxes are interannually varying. Biological parameters are selected to capture the surface variability observed in the SeaWiFS derived chlorophyll a concentration. The model produces significant variability in pCO2 and air-sea CO2 flux, on seasonal to interannual time scales in particular in the eastern equatorial Pacific. On seasonal time scales, the pCO2 is relatively high both in fall and in spring but low in the boreal summer in the eastern upwelling region. While the high pCO2 in fall is associated with the upwelling of rich carbon water, the high pCO2 in spring is due to low wind speed and subsequent low out-gassing. On inter-annual time scales, the central and eastern equatorial Pacific is a strong source of CO2 to the atmosphere during non-El Nino periods, but weak to near neutral during strong El Nino years. On decadal time scales,

the entire equatorial Pacific showes significant change in CO2 chemistry due to the Pacific Decadal Oscillation phase shift. While the surface water pCO2 had no increase before the shift, it increased about 20 ≈Ìatm after the shift. This change significantly influenced the flux of CO2 in the equatorial Pacific and altered the carbon source and sink in the global carbon budget.

OC-36

Ocean Heat Transport and Tropical Variability in the CCCma Coupled Climate Model

William J. Merryfield, Canadian Centre for Climate Modelling and Analysis, Meteorological Service of Canada, University of Victoria, P.O. Box 1700 Victoria, B.C. V8W 2Y2, Canada, Bill.Merryfield@ec.gc.ca

The role of ocean heat transport in low-frequency tropical variability is examined in the CCCma global coupled climate model. Both natural variability and the response to anthropogenically forced climate change are considered. Variability in tropical Pacific heat content is found to be due primarily to advection of mean temperature by anomalous currents, as found for example by Stammer et al. (JGR 2003), whereas advection of T anomalies by mean currents contributes only a small fraction of heat content variance. The anomalous advection of heat into the tropical Pacific under positive-phase, El Nino-like conditions is divergent at relatively high frequencies (corresponding to periods shorter than ~8 years) and convergent at low frequencies. Evidence for the former tendency has been observed on ENSO time scales (Sun and Trenberth, GRL 1998), whereas the latter is in accord with modeled Pacific Ocean response under global warming (Yu and Boer, Clim. Dyn. 2002). An explanation for these opposing tendencies is suggested.

OC-37

Wave-Related Modification of Ocean Surface Stresses

Dr. Mark A. Bourassa, Center for Ocean-Atmospheric Prediction Studies Florida State University, Tallahassee, FL 32306-2840, USA, bourassa@coaps.fsu.edu

A new ocean surface stress model is used to examine the extent of wave modification of monthly ocean surface stresses. Due to the non-linearity of the wave-related impacts, much shorter time-scale wind and wave fields are used to determine the monthly mean modifications. Wave-related changes in stress are rarely considered in stress fields for forcing ocean models; consequently, the estimated dependencies reflect systematic biases in ocean forcing. The surface stress model used in this study is ideal in that it has been demonstrated to be relatively accurate over a very wide parameter space in wind speed, atmospheric stability, and wave characteristics. Furthermore, the model considers variability in stress due to differences in wind direction and the direction of wave propagation. Systematic biases in surface stress will result in systematic errors in ocean models (e.g., currents), and consequently in the ocean's horizontal transport of energy and other scalar quantities and their impacts on climate.

OC-38

World Ocean Heat Content, 1955-2000

Sydney Levitus, NODC/NOAA, E/OC5, 1315 East West Highway, Silver Spring, MD, 20910, USA, Sydney.Levitus@noaa.gov
John Antonov, John.Antonov@noaa.gov
Tim Boyer, Tim. Boyer @noaa.gov

We update our earlier estimates (Levitus et al., 2000) of ocean heat content for the world ocean with the additional 1.7 million temperature profiles that have become available as part of "World Ocean Database 2001". The results are quantitatively similar through the early 1990s but the newerestimates are lower for the 1990s due to an error in processing the XBT data for the earlier results. This difference does not affect any previous conclusions regarding the dominance of ocean heat content in the earth's heat balance for this period or possible causes of the heat content variability. Several diagnostic analyses of ocean heat content are presented.

OC-39

The Roles of Vertical Correlations of Background Error and T-S Relations in Estimation of Temperature and Salinity Profiles from Sea Surface Dynamic Height

Ms. Changxiang Yan, Institute of Atmospheric Physics, Chinese Academy of Sciences, Beijing 100029, China,
ycxlasg@mail.iap.ac.cn
Prof. Jiang Zhu, jzhu@mail.iap.ac.cn

Sea level observations reflect with high correlations the subsurface seawater density structure and form a good proxy for the sea surface dynamic height (SDH) (Katz et al. 1995). This fact provides the physical foundation for estimating the ocean temperature and salinity structures from altimetry data. The object of this study is to analyze how to do direct estimations of temperature and salinity from SDH without considering EOF modes. The estimation method uses a newly proposed, 3DVAR-based data assimilation scheme that considers vertical correlations of background error and T-S relations. Some simple observation simulation experiments are designed to test the individual and combined effects of vertical correlations and nonlinear T-S relations on the estimation. Results show that the newly proposed scheme has greatly improved temperature and salinity estimations compared with the old scheme that neither considers vertical correlations nor considers T-S relations. Vertical correlations helps to balance the relative magnitude of the profile correction at all depths. However, in some cases, it can make the estimated results further away from observations than the old scheme. The nonlinear T-S relations can improve both temperature and salinity estimations and significantly reduce the root-mean-square error of estimations. Furthermore, the sensitivity of estimated results to T-S has been implemented. Results

show that an T-S diagram with deviations of about 0.1-0.2psu from true T-S may still produce good estimation.

IODC-40

A Global Mixed Layer Depth Climatology Based on Individual Profiles

Mr. Clement De Boyer Montegut, Laboratoire d'Oceanographie Dynamique et de Climatologie, UMR 7617 CNRS/IRD/UPMC, Institut Pierre Simon Laplace, Tour 45/55 - 4ieme etage, 4, place Jussieu, 75252, Cedex 05, Paris, France
cdblod@lodyc.jussieu.fr
Dr. Albert S. Ficher, asf@lodyc.jussieu.fr
Dr. Alban Lazar, alban.lazar@lodyc.jussieu.fr
Dr. Daniele Iudicone, daiudi@lodyc.jussieu.fr
Dr. Gurvan Madec, gm@lodyc.jussieu.fr

The oceanic mixed layer (ML) mediates the transfer of mass, momentum, and energy to the rest of the ocean. The thickness of the ML determines the heat content and mechanical inertia of the layer that directly interacts with the atmosphere, and is crucial parameter in understanding and modeling the climatic system. A climatology of ML depth is then important for validation of oceanic general circulation models and turbulent mixing and bio-optical parameterizations, as well as for biological studies.

A new global climatology of the ML depth based on individual profiles is presented. Previous global climatologies have been based on density climatologies, potentially losing information contained in individual profiles. The 4,490,571 profiles were obtained from the NODC and WOCE databases, representing all the high vertical resolution data available from 1941 to 2002.

The criterion selected to find the base of the ML is a threshold value of temperature or density from a near-surface value. The median value of the distribution within a geographical box is then calculated. A validation of the criterion on moored timeseries data shows that the method is successful at following the base of the ML. In particular, the first spring restratification is better captured than in previous climatologies, changing the timing of the seasonal cycle of the ML. Globally, the ML depths revealed in this climatology are up to 20% deeper than in the averaged-profile climatologies using the same criterion.

The seasonal cycle of the barrier layer is computed, which finds layers on the order of 20 m in the western equatorial Pacific and Atlantic oceans, and up to 25 m in the Bay of Bengal and eastern equatorial Indian Ocean in winter.

One interesting result is the prevalence in the mid- and high-latitude winter hemispheres of vertically compensated layers, where temperature and salinity changes perfectly compensate to create an isopycnal, but not mixed layer. These appear related to the recently reported prevalence of horizontal compensations within the mixed layer. Some mechanisms are proposed to explain such vertical compensations.

As an independent estimate and validation of the maximum annual ML depth, the 95% oxygen saturation limit is calculated, which extends coverage in the southern hemisphere. http://www.lodyc.jussieu.fr/~cdblod/

OC-41

A New Approach to Improved SST Simulations Using Altimeter Data: Parameterizing Entrainment Temperature from Sea Level

Dr. Rong-Hua Zhang, Earth System Science Interdisciplinary Center (ESSIC), 224 Computer and Space Science Building, University of Maryland, College Park, MD 20742-2425, USA, rzhang@essic.umd.edu
Prof. Antonio J. Busalacchi, tonyb@essic.umd.edu
Dr. Raghuram G. Murtugudde, ragu@vinsanto.essic.umd.edu
Mr. Eric C. Hackert, eric@barolo.essic.umd.edu
Dr. Joaquim Ballabrera, joaquim@essic.umd.edu

Observed Topex/Poseidon/Jason-1 (T/P/J) altimeter sea level (SL) data are used to improve an empirical parameterization of the temperature of subsurface water entrained (Te) into the mixed layer. An inverse modeling method is first adopted to estimate Te from a SST anomaly equation using observed SST and simulated upper ocean currents from an intermediate ocean model (IOM). An empirical relationship between anomalies of Te estimated and SL observed from T/P/J altimeter is then constructed by utilizing a singular value decomposition (SVD) of their covariance. As compared with SST simulations using modeled SL data, the use of T/P/J SL data allows observed information about dynamic ocean adjustments to be built directly into the empirical Te model being used to parameterize the thermodynamic effect on SST. The improved Te model leads to better SST simulations in the tropical Pacific, with the largest coherent area of improvement in the eastern equatorial basin. Cross validation is made to examine the sensitivity of the SST simulations to the period chosen for training the Te model. The proposed approach provides a new way to more effectively use T/P/J altimeter data in climate studies.

OC-42

Impact of Horizontal Heat Advection on the Surface Layer Heat Budget in the Equatorial Oceans

Dr. Fabrice Bonjean, Earth & Space Research, 1910 Fairview Ave. E, Suite 210 Seattle, WA 98102 USA, bonjean@esr.org
Dr. Gary S.E. Lagerloef, lager@esr.org
Dr. Eric S. Johnson, ejohnson@esr.org

This presentation is focused on the analysis of the surface horizontal heat advection by the surface currents compared to the net air-sea heat flux in the tropical Pacific Ocean on seasonal-to-interannual timescale. Preliminary results regarding the tropical Atlantic and Indian Ocean surface heat budget are also presented.

Major interannual climate disturbances occur in the tropics and have a large societal impact on the surrounding lands and subtropical regions, namely El Nino-Southern Oscillation in the Pacific (ENSO), the Indian Ocean Dipole (IOD), and the Tropical Atlantic Variability (TAV). Past studies underlined the important role played by the equatorial surface ocean currents during the onset, development and demise of El

Niño and La Niña. Notably, a revised version of the delayed action oscillator theory of ENSO attributes a fundamental role to zonal motion and heat advection at the ocean surface. We here explore the validity extent of such theory by quantitatively analyzing the terms of a surface layer partial heat budget including the heat storage rate, horizontal heat advection and net air-sea heat flux. For this, we use surface currents derived from satellite altimetry, scattero-meter and sea surface temperature data (SST) from the Ocean Surface Current Analysis Real-time (OSCAR, http://www.oscar.noaa.gov/), together with space-based SST observations and air-sea reanalysis data products. Results indicate that horizontal advection and net air-sea heat transfer explain to a very large extent the SST variations in the central-western equatorial area of the Pacific. The east-west migration of the separation zone between warm-pool and cold tongue is a prominent feature of ENSO evolution. In a non-eulerian analysis, we find that horizontal advection plus net air-sea heat flux largely explain the zonal motion of the 28˚C isotherm that characterizes well the aforementioned separation zone, including when it is shifted far to the east, and as long as this zone stays defined. Zonal heat advection is the most important term of this partial heat budget in the central-western equatorial area as well as in the motion of the warm-pool/cold tongue separation zone. This thus clearly supports the “advective” theory when warm-pool and cold tongue are well differentiated. In the central-eastern area and further east, or in extreme conditions as when warm waters (>28˚C) cover the entire equatorial band (e.g 1997-98 El Nino peak), other processes are important, as shown by the implicit missing residual terms of this analysis, and can be attributed to the vertical heat mixing and advection terms.

OC-43

Role of Advection in Generating Non-Seasonal SST Anomalies

Dr. Rob Scott, The University of Texas Institute for Geophysics, 4412 Spicewood Spgs Rd., Bldg 600, Austin, TX, 78727, USA, rscott@ig.utexas.edu
Prof. Bo Qiu, 1000 Pope Road, Dept of Oceanography, University of Hawaii, Honolulu, HI 96822, USA, bo@soest.hawaii.edu

Satellite altimeter data, observational sea surface temperature (SST) data, and various other data sets are used to quantify the role of horizontal advection in generating SST anomalies. We focus on the non-seasonal anomalies from monthly to interannual timescales. Alongtrack altimeter data from the TOPEX/Poseidon and Jason-1 satellites and mean dynamic topography from the World Ocean Atlas 2001 are used to quantify the advection across the satellite ground tracks within the oceanic mixed layer. This is time integrated, using various observation-based estimates of the damping time, to estimate the timeseries of advection generated SST anomalies within the diamond shaped grid cells outlined by the statellite ground tracks. The results are presented for North Pacific waters with depth greater than 2000m.

OC-44

The Role of the Peruvian Coastal Upwelling in Climate for 1991-2000 Period

Enrique H. Aguirre, Oceanographic Square, 191, University City, São Paulo, Brazil, CEP 05508-900, huaringa@usp.br
Dr Edmo D. Campos, edmo@io.usp.br
Oc. Roberto F. De Almeida, roberto@dealmeida.net

The Peruvian Coastal Current, the drag force of the southwestward trade winds and the subsuperficial current establish the mechanism which maintains the coastal upwelling along the peruvian coast. The variation of depth the thermocline gives the clues to recognize the intensity of these coastal upwelling events. According to it, in this work we aim to estimate the behavior the thermocline under unusual climate events along the peruvian coast during 1991-2000 period. In order to do this, the Princeton Ocean Model (POM) was applied forced by the wind stress climatology of the CERSAT/IFREMER and by the Levitus 94 salinity and temperature climatology. In strong wind events, the thermocline rises and the sea level height is lower. Conversely, when the trade winds are weak the thermocline sinks and the sea level height is higher.

EDC-45

Low Frequency Circulation and Coastal-Trapped Waves Propagation along Central Chile

Claudia A. Valenzuela-Cuevas, Servicio Hidrografico y Oceanografico de la Armada, Errazuriz 232, Playa Ancha, Valparaiso. Chile, cvalenzuela@shoa.cl
MSc. Sergio N. Salinas-Marchant, Pontificia Universidad Catolica de Valparaiso, Av. Altamirano 1480, Playa Ancha, Valparaiso. Chile, ssalinas@ucv.cl

In the Pacific Ocean, eastern boundary circulation is influenced by interanual fluctuations in a direct relationship with remotely originated atmospheric perturbations. Coastal trapped waves, represents an environmental variability for currents over the continental shelf, and also they influence coastal upwelling, heat and salt distribution, among others.

For the chilean coasts, it`s been reported in sea level (Pizarro, 1991; Bilbao, 1991) and currents (Shaffer et al., 1997), low frequency high variability as coastal trapped waves, in analogy to the observed currents in California and Peru coasts. According to a travelling low frequency variability, in chilean coasts has been reported that the observed variability is remotely forced (Bilbao, 1992; Shaffer et al., 1997), so it seems to be the manifestation of poleward propagating free coastal trapped waves.

In this research, sea level coastal trapped waves (CTW) are studied, identifing the most energetic frequencies, and determining its influence over shelf circulation in central Chile. CTW propagated southward with phase velocities of 250 km/d, widely modulating sea level variability.

The study area ranges from 27º S to 36.7º S, where current meter data was available at 30º S (at 170, 400, and 700 m depth) from JGOFS-Chile project (Joint Global Ocean Fluxes Study), and at 34º S (at 170, 480, and 730 m depth) from UCV-DGI 223.757 project (Shelf Circulation on central Chile). Sea level measured in Caldera (27º S), Coquimbo (30º S), Valparaíso (33º S), and Talcahuano (36.7º S) was provided by the Chilean Navy Hydrographic and Oceanographic Service

Currents at 30º S, had poleward average velocities of 13.5 and 2.0 cm/s at 170 and 400 m, respectively, and 1.0 cm/s equatorward at 700 m. At 34º S, currents were

predominately poleward in all depths, with averages of 6.3, 2.2, and 0.7 cm/s, at 170, 480, and 730 m respectively. Alongshore flow was characterized by high energy in the band of 40, 15, and 7 days.

Alongshore flow and coastal sea level, were modulated by poleward propagating coastal trapped waves with phase velocities of 242 and 245 km/d, respectively.

IDC-46

Observational Evidence for Extratropical Ocean-Atmosphere Interaction

Shang-Ping Xie, IPRC/SOEST, University of Hawaii, 2525 Correa Road, Honolulu, HI 96822, USA. xie@hawaii.edu

Lack of understanding how extratropical oceans affect the atmosphere is a stumbling block in recent efforts to study non-El Nino climate variability. Climatic datasets typically have resolutions of several 100 to 1,000 km and of a month to a season, poorly representing ocean fronts near major currents like the Kuroshio and Gulf Stream. It is on these narrow oceanic fronts, however, that ocean dynamics become important and cause large SST variations. Thus, conventional climate datasets may severely under-represent such dynamically induced SST anomalies and their atmospheric effect.

The rapid advance in space-based microwave remote sensing is revolutionizing ocean observations, providing global fields of key ocean-atmospheric variables at unprecedented resolutions in space and time. These new satellite observations reveal a ubiquitous pattern of SST, winds and clouds near major ocean fronts/currents in various parts of the world ocean. This pattern is characterized by a positive SST-wind speed correlation indicative of ocean-to-atmosphere feedback, in contrast to the negative correlation that dominates on the basin scale and is now attributed to atmospheric forcing of the ocean mixed layer. This positive SST-wind speed correlation is consistent with the vertical mixing mechanism the near-surface atmosphere is unstably stratified on the warmer flank of SST fronts, enhancing mixing that accelerates surface winds by bringing faster winds from aloft. The wind curl due to this ocean-to-atmosphere feedback is as large as the basin-scale one that drives ocean currents in the first place.

Ocean fronts affect baroclinicity in the atmospheric boundary layer. Atmospheric model experiments show that this baroclinicity effect affects the growth of storms, resulting in further changes downstream through storms effect on precipitation.

OC-47

Interannual-to-Decadal Variation of Tropical-Subtropical Exchange in the Pacific Ocean: Boundary Versus Interior Pathways

Dr. Tong Lee ,Jet Propulsion Laboratory, California Institute of Technology MS 300-323, 4800 Oak Grove Drive, Pasadena, CA 91109, USA, tlee@pacific.jpl.nasa.gov.

Dr. Ichiro Fukumori, if@pacific.jpl.nasa.gov

Tropical-subtropical exchange of water masses is considered to be important to interannual-to-decadal variability in the tropical Pacific. On average, the exchange is accomplished by a shallow (< 400 m) meridional circulation which connects the equatorial upwelling, poleward Ekman flow near the surface, and equatorward transport of pycnocline waters originating from the subtropics. Pycnocline waters arrive at the tropics via western-boundary and interior pathways. It is well-established that, on time average, the two pathways re-enforces each other. However, less is known about their relative role on interannual-to-decadal time scales and the underlying physical processes. In this study, we address these issues using a global ocean general circulation model and sea level measurements obtained by the TOPEX/Poseidon satellite altimter. Variation of pycnocline transport via the boundary is found to be (1) anti-correlated to and (2) smaller in magnitude than that of the interior. These features are attributed to the combined effect of two different forcing mechanisms: (1) the variation of local wind stress curl changes the strength of horizontal circulation and results in variation of boundary flow that is opposite in direction and comparable in magnitude to that of interior flow; (2) the variation of equatorial zonal wind stress which affects the strength of meridional circulation with net pycnocline flow opposing the surface Ekman flow. Due to the partial compensation by boundary flow, the convergence of pycnocline waters into the tropics is about 50% of that inferred from interior pycnocline flow alone. The net pycnocline transport reflects ENSO forcing on interannual time scales. There is less equatorward intrusion of pycnocline water in 1990s than in 1980s, consistent with recent observation. Interior pycnocline transport in the North Pacific is more important to interannual-to-decadal variability in the tropical Pacific despite a substantially larger boundary transport on average.

OC-48

Decadal–Scale Variability of Upper Ocean Heat Content Anomaly in the Central Equatorial Pacific and Its Relationship with Atmospheric Anomaly Fields

Mr. Takuya Hasegawa, Physical Oceanography Laboratory, Dept. of Geophysics, Tohoku University, Aramaki-Aza-Aoba. Aoba Ward. Sendai. 980-8578 Japan, hasegawa@pol.geophys.tohoku.ac.jp
Prof. Kimio Hanawa, hanawa@pol.geophys.tohoku.ac.jp

Decadal-scale variability of upper ocean heat content (OHC) and atmospheric anomaly fields in the Pacific Ocean are investigated for the period of 45 years from 1955 to 1999. The previous studies show that the amplitudes of the decadal-scale OHC anomalies with periods of 10 – 18 years are large in the central equatorial Pacific (Nino-3.4 region). In this study, it is shown that westerly and easterly wind stress anomalies at the decadal scale are dominant in the western/central and eastern tropical Pacific respectively, when the decadal – scale OHC anomalies in the Nino-3.4 region are positive. Further, the results show that the meridional gradients of sea level pressure (SLP) anomalies of low- to mid- latitudes of central Pacific are negative and positive in the north and south of the Nino-3.4 region respectively, and zonal SLP gradients are

negative and positive in the western and eastern tropical Pacific respectively when the decadal – scale OHC anomalies in the Nino-3.4 region are positive. The present results imply that such a SLP gradient pattern in the tropics and extra-tropics of the North and South Pacific leads westerly wind stress anomaly in the western/central tropical Pacific and easterly wind stress anomaly in the eastern equatorial Pacific, and this wind stress distribution pattern deepens the thermocline depth in the Nino-3.4 region by means of the oceanic advection in the equatorial region, which results in positive OHC anomalies in the Nino-3.4 region.

In addition, relationship between the decadal – scale variations and ENSO – related variations is also investigated. The results show that the decadal – scale positive OHC anomalies are found in the Nino-3.4 region, when La Nina events occur with small negative OHC anomalies in the Nino-3.4 region. On the other hand, the decadal – scale OHC anomalies in the Nino-3.4 region are negative when La Nina events appear with large negative OHC anomalies in the Nino-3.4 region. In contrast, El Nino events do not show such large differences of ENSO – scale OHC anomalies in the Nino-3.4 region. The results suggests that relationship between the asymmetry behavior of ENSO events and the decadal – scale variability in the Nino-3.4 region is important for understanding the climate variability in the tropical Pacific.

IDC-49

How Does Heat Transport Respond to Decadal ENSO-Like Variability?

Dr. Wilco Hazeleger, KNMI, Oceanogr. Res. Dept., PO Box 201, 3730 AE, De Bilt, The Netherlands, Wilco.Hazeleger@knmi.nl
Dr. Richard Seager, Lamont Doherty Earth Observatory, Rt 9W, Palisades, NY 10964, USA, rich@maatkare.ldeo.columbia.edu

Decadal wind and SST variability in the tropical Pacific has a pattern that is comparable to the El Nino pattern. Here, we show the response of the energy transport in the ocean and atmosphere to this decadal ENSO-like variability. It is shown how the circulation rearranges to accomodate changes in energy transport.

We coupled a primitive equation ocean model to an atmospheric mixed layer (LOAM) to study the response of ocean heat transport to ENSO-like wind anomalies. The wind-driven subtropical cells (STCs) weaken in response to reduced zonal winds and transfer less heat poleward than normal, in accordance to observations. However,a spin down of the gyres causes the equatorward heat transport by the horizontal flow to reduce as well. So, the gyres partially compensate the reduced poleward heat transport by the STCs. Also, variations in the strength of the Indonesian Troughflow and variability in the midlatitudes contribute significantly to the heat transport in the tropical Pacific.

To study the atmospheric response, a primitive equation atmosphere model (Speedy) is coupled to a slab mixed layer. Warming due to decadal ENSO is prescribed by a reduced oceanic heat transport represented by an anomalous "Qflux" in the slab mixed layer.The atmosphere responds with an enhancement of the energy transport. This is mainly accomplished by a strengthening of the Hadley Cell. Also, the subtropical jets increase in strength and the jet cores displace equatorward. Consequently, the transient eddy fluxes change and the winds in the midlatitudes decrease. This causes

the SST in the mid- and high-latitudes to warm in response to the reduced evaporative heat loss. In general, the atmospheric and oceanic heat transport compensate. Implications for conceptual models of tropical climate and climate change are discussed.

OC-50

A Delayed Action Oscillator Shared by Biennial, Interannual, and Decadal Signals in the Pacific

Dr. Yves M. Tourre, MEDIAS-France, CNES, 18 Avenue Edouard Belin, BPi 2102, 31401 Toulouse Cedex 4, France, tourre@medias.cnes.fr
Dr. M. Barlow, Atmospheric and Environmental Research, Inc., 131 Hartwell Ave, Lexington, MA USA 02421
Dr. M. Dettinger, United States Geological Survey, San Diego, CA USA

Biennial, interannual, and decadal signals in the Pacific basin are observed to share patterns and evolution in covarying sea surface temperature (SST), 18°C isotherm depth (Z18), zonal surface wind (ZSW), and wind stress curl (WSC) anomalies from 1955 to 1999. Each signal has warm SST anomalies propagating slowly eastward along the equator, generating westerly ZSW anomalies in their wake. These westerly ZSW anomalies produce cyclonic WSC anomalies off the equator which pump baroclinic Rossby waves in the western/central tropical North Pacific Ocean. These Rossby waves propagate westward, taking ~6, ~12, and ~36 months to reach the western boundary near ~7°N, ~12°N, and ~18°N on biennial, interannual, and decadal period scales, respectively. There, they reflect as equatorial coupled waves, propagating slowly eastward in covarying SST, Z18, and ZSW anomalies, taking ~6, ~12, and ~24 months to reach the central/eastern equatorial ocean. These equatorial coupled waves produce a delayed-negative feedback to the warm SST anomalies there. The decrease in Rossby wave phase speed with latitude, the increase in meridional scale of equatorial SST anomalies with period scale, and the associated increase in latitude of Rossby wave forcing are consistent with the delayed action oscillator (DAO) model used to explain El Niño. However, this is not true of the western-boundary reflection of Rossby waves into slow equatorial coupled waves. This requires modification of the extant DAO model. We construct a modified DAO model, demonstrating how the various mechanisms and the size and sources of their delays yield the resulting frequency of each signal.

OC-51

Tropical-Extratropical and Interhemispheric Climate Interaction: Atmospheric Bridge and Oceanic Tunnel

Haijun Yang, Department of Atmospheric Science, School of Physics, Peking University, 209 Chengfu Road, Beijing 100871 China, hjyang@pku.edu.cn
Prof. Zhengyu Liu, Center for Climatic Research, University of WIsconsin-Madison, 1225 West Dayton Street, Madison, WI 53705 USA, zliu3@wisc.edu

Tropical-extratropical climate interaction is studied using a coupled climate model. It is found that the extratropical impact on tropical climate is as strong as the

tropical impact on extratropical climate, with the remote SST response being about half the magnitude of the imposed SST change in the forcing region. The extratropical impact on tropical SST is accomplished by both the atmospheric bridge (70%) and the oceanic tunnel (30%). The equatorial SST increase is first driven by the latent heat flux and the poleward surface Ekman transport, and then enhanced by the change in subtropical cells¡¯ strength and the equatorward subduction of warm anomaly. In contrast, the tropical impact on the extratropical climate is accomplished solely by the atmospheric bridge. The extratropical SST change is initiated by the atmospheric radiation forcing, and then enhanced by the positive sea ice ¨C albedo feedback. Sensitivity experiments also explicitly show the dominant role of the Southern Hemisphere (SH) in global climate change. A warm SST in the SH contributes 30% more than that in the Northern Hemisphere (NH) to the warming of equatorial SST because of stronger southern Hadley circulation change. Moreover, the NH climate response to the SH forcing is faster and stronger than the SH climate response to the NH forcing.

OC-52

Eddy-Driven Interdecadal Variability in a Coupled Ocean-Atmosphere Model of Midlatitude Climate

Dr. Sergey V. Kravtsov, Department of Atmospheric Sciences, University of California, Los Angeles, 405 Hilgard Ave., Los Angeles, CA 90095 USA, sergey@atmos.ucla.edu
Dr. William K. Dewar, Department of Oceanography, Florida State University, Tallahassee, FL 32306-3048 USA, dewar@ocean.fsu.edu
Dr. Pavel S. Berloff, Physical Oceanography Department, Woods Hole Oceanographic Institute, Clark Lab 205A, MS29, Woods Hole, MA 02543 USA, pberloff@whoi.edu;
Dr. James C. McWilliams, Department of Atmospheric Sciences, University of California, Los Angeles, 405 Hilgard Ave., Los Angeles, CA 90095 USA, jcm@atmos.ucla.edu;
Dr. Michael Ghil, ghil@atmos.ucla.edu.

We examine mid-latitude climate variability in a model that consists of oceanic and atmospheric components, each of which captures the turbulent nature of the corresponding fluid. The two components are coupled through an active oceanic mixed layer. It is argued that intrinsic ocean dynamics of the so-called inertial recirculations combined with nonlinear atmospheric sensitivity to sea-surface temperature (SST) anomalies play a dominant role in the variability of the coupled system.

We study the parameter regime in which the atmosphere-only low-frequency variability is characterized by irregular transitions between two zonal-flow states, namely high-latitude and low-latitude states, the former being more persistent.

In a coupled model, the low-latitude state occurrence frequency exhibits a statistically significant broadband signal with a period of 15--30 years. The same signal is found in the time series of the ocean energy. Accompanying uncoupled ocean-only and atmosphere-only integrations are characterized by the decreased power in the interdecadal band relative to the coupled integration, and do not exhibit statistically significant peaks in this range.

The time scale of the coupled interdecadal oscillation is set by nonlinear adjustment of the ocean's inertial recirculations to high-latitude and low-latitude atmospheric forcing regimes. This adjustment involves, in turn, SST changes, which result in long-term ocean--atmosphere heat-flux anomalies that induce the transitions between atmospheric regimes.

OC-53

SST Variability and Changes with Global Warming

Dr. Bin Yu and Dr. George J. Boer, Canadian Centre for Climate Modelling & Analysis, Meteorological Service of Canada, c/o University of Victoria, P.O. Box 1700 STN CSC,Victoria, BC V8W 2Y2, Canada, Bin.Yu@ec.gc.ca George.Boer@ec.gc.ca

Sea surface temperature (SST) mediates the energy exchange at the air-sea interface and the variability of SST on different timescales reflects this. Based on the surface energy budget, the SST variance is written as the product of three factors: the sum of the variances of surface radiative and turbulent heat fluxes and the ocean heat transport, a transfer factor measuring the persistence of surface temperature, and an efficiency factor depending on the covariances among surface heat fluxes and the ocean heat transport.

The large-scale features of SST variability and surface heat flux and ocean transport variability are analyzed based on the NCEP/NCAR reanalyses and the results of the CCCma coupled atmosphere-ocean model. It is found that the heat flux covariances and SST persistence, as well as the total variances of surface heat fluxes all play important roles in maintaining the SST variability.

OC-54

A Nonlinear Paradigm for Tropical Pacific Decadal Variability

Keith B. Rodgers, LODYC, T26, 4E, 4 pl Jussieu - boite 100, 75252 Paris Cedex 05, France, rodgers@lodyc.jussieu.fr
Petra Friederichs, Meteoroligisches Institut, Bonn, Germany, pfried@unit-bonn.de
Mojib Latif, Institut fuer Meereskunde, Kiel, Germany, mlatif@ifm.uni-kiel.de

A 1000-year integration of a coupled ocean/atmosphere model (ECHO-G) has been analyzed to describe decadal to multi-decadal variability in equatorial Pacific sea surface temperature (SST) and thermocline depth (Z20), and their relationship to decadal modulations of ENSO behavior. Although the coupled model is characterized by an unrealistically regular 2-year ENSO period, it exhibits significant modulations of ENSO amplitude on decadal to multi-decadal timescales.

Our main finding is that the structures in SST and Z20 characteristic of Tropical Pacific Decadal Variability (TPDV) in the model are due to an asymmetry between the anomaly patterns associated with the model's El Nino and La Nina states, this asymmetry reflecting a nonlinearity in ENSO variability. As a result, the residual (i.e. the sum) of the composite El Nino and La Nina patterns exhibits a dipole structure across

the equatorial Pacific, with positive perturbation values in the east and negative values in the west for SST and Z20. During periods when ENSO variability is strong, this difference manifests itself as a change in the mean state through a rectifier effect.

For comparison, a similar analysis was applied to a gridded SST dataset spanning the period 1871-1999. The data confirms that the asymmetry between the SST anomaly patterns associated with El Nino and La Nina for the model are realistic. However, ENSO in the observations is weaker and not aas regular as in the model, and tus the changes due to ENSO asymmetries for the observations can only be detected in the NINO12 region.

OC-55

Pacific Interdecadal Climate Variability: Linkages between the Tropics and North Pacific since 1900

Dr. Clara Deser, Mr. Adam S. Phillips, Dr. James W. Hurrell, Climate and Global Dynamics Division, NCAR, PO Box 3000, Boulder CO 80307-3000, USA, cdeser@ucar.edu

This study examines the Tropical linkages to inter-decadal climate fluctuations over the North Pacific during boreal winter through a comprehensive and physically-based analysis of a wide variety of observational data sets spanning the 20th century. Simple difference maps between epochs of high sea level pressure over the North Pacific (1900-1924 and 1947-1976) and epochs of low pressure (1925-1946 and 1977-1997) are presented for numerous climate variables throughout the Tropical Indo-Pacific region, including rainfall, cloudiness, sea surface temperature and sea level pressure. The results support the notion that the Tropics play a key role in North Pacific inter-decadal climate variability. In particular, SST anomalies in the Tropical Indian Ocean and Southeast Pacific Ocean, rainfall and cloudiness anomalies in the vicinity of the South Pacific Convergence Zone, stratus clouds in the eastern Tropical Pacific, and sea level pressure differences between the Tropical Southeast Pacific and Indian Oceans, all exhibit prominent inter-decadal fluctuations that are coherent with those in sea level pressure over the North Pacific. The spatial patterns of the inter-decadal Tropical climate anomalies are compared with those associated with ENSO, a predominantly interannual phenomenon; in general, the two are similar with some differences in relative spatial emphasis. Finally, a published 194-year coral record in the western Tropical Indian Ocean is shown to compare favorably with the 20th century instrumental records, indicating the potential for extending our knowledge of Tropical inter-decadal climate variability to earlier time periods.

OC-56

Dynamical Balance of the Upper Ocean from In Situ and Remote Observations

Dr. Nikolai A. Maximenko, IPRC/SOEST, University of Hawaii, 1680 East West Road, POST #401, Honolulu, HI 96822 USA, nikolai@soest.hawaii.edu
Prof. Pearn P. Niiler, Scripps Institution of oceanography, University of California, San Diego, USA, pniiler@ucsd.edu;

Prof. James C. McWilliams, University of California, Los Angeles, USA, jcm@atmos.ucla.edu;
Dr. Chester J. Koblinsky, koblinsky@gsfc.nasa.gov

Data of surface drifters, satellite altimeters and various remote and reanalysis wind products are used jointly to study the horizontal momentum balance of the upper ocean on the global scale. Products of the developed techniques are at mesoscale spatial resolution and include the mean geostrophic velocities corrected to the bias in distribution of the drifter ensemble and the mean absolute sea level of the global ocean, with the "mean" defined as a Eulerian (temporal) average over the 1992-2003 decade of quasi-continuous altimetry observations. The GRACE, float and historical hydrographic data are used to optimize the parameterization of the Ekman term. The parameterization formula obtained for different wind products are compared and interpreted using a simple model of the Ekman layer. The residual momentum imbalance is evaluated and explained by the neglected higher order terms and by systematic errors in the data.

IDC-57

The North Pacific as a Regulator of Summertime Climate over North America and the Eurasia

William K. M. Lau, Laboratory for Atmospheres, Code 910, NASA/Goddard Space Flight Center, Greenbelt, MD 20771, USA, William.K.Lau@nasa.gov
Hailan Wang, Climate and Radiation Branch (UMBC/GEST), NASA/Goddard Space Flight Center, Code 913, Greenbelt, MD 20771, USA, hwang@climate.gsfc.nasa.gov

The interannual variability of summertime rainfall over the U.S. may be linked to climate anomalies over Pacific and East Asia through teleconnection patterns that may be components of recurring global climate modes in boreal summer (Lau and Weng 2002). In this study, maintenance of the boreal summer teleconnection patterns is investigated. The particular focus is on the potential effects of North Pacific air-sea interaction on climate anomalies over the U.S. Observational data, reanalysis and outputs of a series of NASA NSIPP AGCM and AGCM coupled to NASA GSFC Mixed Layer Ocean (MLO) model experiments are used.

Statistical analysis of observations and NSIPP AMIP type simulations indicates that, the interannual variability of observed warm season precipitation over the U.S. is related to SST variation in both tropical and North Pacific, whereas the NSIPP AMIP simulated summertime U.S. precipitation variation mainly reflects impact of ENSO in tropical Pacific. This implies the potential importance of air-sea interaction in North Pacific in contributing to the interannual variability of observed summer climate over the U.S. The anomalous atmospheric circulation associated with the dominant summertime teleconnection modes in both observations and NSIPP AMIP simulations are further diagnosed, using stationary wave modeling approach. In observations, for the two dominant modes, both anomalous diabatic heating and anomalous transients significantly contribute to the anomalous circulation. The distributions of the anomalous diabatic heating and transient forcing are quadrature configured over North Pacific and North America, so that both forcings act constructively to maintain the teleconnection

patterns. The contrast between observations and NSIPP AMIP simulations from stationary wave modeling diagnosis confirms the previous conclusion based on statistical analysis. To better appreciate the role of extra-tropical air-sea interaction in maintaining the summertime teleconnection pattern, various dynamical and physical fields and their inter-linkage in the series of NSIPP AGCM and AGCM coupled to MLO model experiments are examined in-depth. Based on comparison between different model experiments, we will discuss the physical and dynamical mechanisms through which the air-sea interaction in extratropics, and transient-mean flow interactions over the North Pacific, affect interannual variation of U.S. climate during boreal summer.

IDC-58

Formation Region of North Pacific Subtropical Mode Water in the Late Winter of 2003

Dr. Eitarou Oka, 2-15 Natsushima-cho, Yokosuka, Kanagawa 237-0061, Japan, okae@jamstec.go.jp
Dr. Toshio Suga. Aoba-ku, Sendai 980-8578, Japan, suga@pol.geophys.tohoku.ac.jp

The mixed layer structure and properties in the formation region of the North Pacific Subtropical Mode Water (STMW) east of Japan in the late winter of 2003 were examined using temperature and salinity data primarily from Argo profiling floats. The formation region extends south of the Kuroshio Extension, between 30N and 35N and as far east as 175E. It is characterized by a mixed layer with depths greater than 200db and meridionally uniform temperature between 16.5C and 18.2C, associated with a mixed layer front at its southern edge. The mixed layer in the formation region becomes colder, fresher, and denser toward the east, leading to the formation of warmer, saltier, and lighter STMW in the western part of the region. The spatial variation of the mixed layer depth in the formation region corresponds well with the underlying permanent thermocline depth.

IDC-59

Differential Formation and Circulation of North Pacific Central Mode Water

Dr. Eitarou Oka, 2-15 Natsushima-cho, Yokosuka, Kanagawa 237-0061, Japan, okae@jamstec.go.jp
Dr. Toshio Suga. Aoba-ku, Sendai 980-8578, Japan, suga@pol.geophys.tohoku.ac.jp

Formation and circulation of the North Pacific Central Mode Water (CMW) were examined using synoptic data from the repeat hydrographic section along 165E during 1996-2003 and the WOCE Hydrographic Program one-time sections, instead of climatological data that had been commonly used. The CMW formation region, along the northern edge of the subtropical gyre, extends at least as far west as 165E, much farther than recognized in previous studies as located between 175E and 160W. The frontal structure around the northern gyre boundary is essential for the CMW formation.

CMW is formed in two interfrontal regions: the southern region between the Kuroshio Extension front and the Kuroshio Bifurcation front and the northern one between the Kuroshio Bifurcation front and the subarctic front. The CMW formed in the northern region is significantly colder and denser than that formed in the southern region, reflecting the difference in the winter mixed layer condition between the two regions. The differential formation of CMW across the Kuroshio Bifurcation front affects its basin wide distribution. The denser (lighter) CMW is advected and distributed along an outer (inner) route in the subtropical gyre, which is consistent with the formation locations of these CMWs.

IDC-60

Subsurface Pycnostads Formed in the Subtropical-Subarctic Transition Region in the North Pacific and its Possible Effect on the Decadal Variation of Sea Surface Temperature

Ms. Hiroko Saito, Department of Geophysics, Graduate School of Science, Tohoku University. Aoba-ku. Sendai. 980-8578 Japan, piko@pol.geophys.tohoku.ac.jp
Dr. Toshio Suga, suga@pol.geophys.tohoku.ac.jp
Dr. Kimio Hanawa, suga@pol.geophys.tohoku.ac.jp
Dr. Nobuyuki Shikama. Frontier Observational Research System for Global Change. 2-15 Natsushima-Cho. Yokosuka. 237-0061 Japan, nshikama@jamstec.go.jp

The subtropical-subarctic transition region in the North Pacific is one of the regions that show the largest decadal variability in sea surface temperature (SST) in the open ocean. Available hydrographic climatology exhibits that the deepest winter mixed layer in the North Pacific develops western and central part of transition region, which suggests that vigorous ventilation of the subsurface layer occurs there. However, effects of this deep mixed layer on maintenance and variability of the upper thermohaline structure in the subtropical-subarctic transition region have not been fully clarified.

Recently, a new type of thick pycnostad, or potential vorticity (PV) minimum layer, was found in the western transition region and its winter convective origin was confirmed. Motivated by this finding, we investigate the formation and distribution of possible other pycnostads throughout the transition region using Argo float data. 3193 profiles from 119 floats at 35 degree - 50 degree north, 140 degree east - 140 degree west during January, 2002 to August, 2003 have been analyzed so far. It is found that the winter mixed layer deeper than 200 m develops in the major part of the western transition region, which results in the pycnostads of various density, ranging from 26.2 to 26.6 sigma-theta, and water properties, ranging from 4 degree to 11 degree C and from 33.3 to 34.3 psu. The wide ranges of properties result from large meridional gradients of¡¡temperature and salinity in the surface layer of the transition region. These pycnostads spread widely over the analyzed area. Spatial distribution of the properties of these pycnostads at each typical density layer suggests that they are considerably modified by mixing in the course of their spreading.

The fundamental difference in the subduction process at the transition region from that of the subtropical region is that downward advection due to Ekman pumping is

not so large. Therefore the pycnostads are expected to stay near the surface for a few to several years, being affected by atomospheric forcing. Time series of the surface/subsurface stratification over a couple of years suggest that anomalies are given to the pycnostads in peculiar way in this region, which may foster the decadal variations of the upper thermohaline structure.

IDC-61

Interannual Variability in the Northeast Pacific Ocean

Ms. Elizabeth M. Douglass, Scripps Institution of Oceanography, 9500 Gilman Dr., MC 0230, La Jolla, CA 92093 USA, emdougla@ucsd.edu
Dr. Dean Roemmich, droemmich@ucsd.edu,
Dr. Detlef Stammer, Universität Hamburg, Zentrum für Meeres- und Klimaforschung, Institut für Meereskunde, Bundesstr. 53, 20146 Hamburg, Germany, detlef@fjord.ucsd.edu

Interannual variability in the Northeast Pacific Ocean is explored by comparing output from a constrained, data-assimilating model with remotely sensed and in situ data. Time-varying temperatures and geostrophic velocities from XBT lines with high spatial and temporal resolution, along with remotely sensed sea surface height, are used to determine where and under what circumstances the model output varies from data. The possibility of coherent variability between transport northward through the Alaska Current and southward through the California Current, as a result of changes in the eastward-flowing North Pacific Current, is supported by both model output and data. Possible sources of forcing of long-term variability are considered; Sverdrup transport is calculated from model winds and compared with the geostrophic transport. Differences between these two indicate both how much of the variability is due to regional wind forcing, and how closely the dynamics of this region agree with the simple Sverdrup balance. In the Alaskan Current region, although the bottom torque term has a large impact on the magnitude of the time-varying Sverdrup transport, the shape is similar to that calculated from data or from model output.

IDC-62

Subsurface Water Masses in the Subtropical-Subarctic Transition Zone of the Central North Pacific and Their Decadal Variations

Dr. Toshio Suga, Department of Geophysics, Graduate School of Science, Tohoku University, Aoba-ku, Sendai 980-8578, Japan, suga@pol.geophys.tohoku.ac.jp
Mr. Kazunori Motoki, motoki@pol.geophys.tohoku.ac.jp
Ms. Hiroko Saito, piko@pol.geophys.tohoku.ac.jp
Dr. Kimio Hanawa, hanawa@pol.geophys.tohoku.ac.jp

The subarctic-subtropical transition region of the central North Pacific is one of the regions that show the largest decadal signals of winter sea surface temperature

(SST) in the open ocean. Winter SST anomalies represent anomalies in the winter mixed layer temperature, which can spread into the subsurface layer through advective and diffusive processes. While it has been shown that some of the decadal SST signals in this region are subducted into subtropical thermocline, it is not clear what types of water mass changes occur associated with the winter SST variations. The purposes of the present study are to identify characteristic subsurface water masses in this region and their source areas, and to examine their decadal variations.

A repeat hydrographic section maintained over two decades along the 180 deg. meridian across the subarctic-subtropical transition region was analyzed along with an isopycnally averaged hydrographic climatology, the North Pacific HydroBase. The section is naturally divided into at least three distinct zones. In the Subarctic Zone north of 46 deg. N, the permanent halocline dominates the density stratification, supporting a subsurface temperature minimum (STM). The Subarctic Frontal Zone (SFZ) between 42 deg.-46 deg. N is the region where the subarctic halocline outcrops. To the south is the Subtropical Zone, where the permanent thermocline dominates the density stratification, containing a pycnostad of North Pacific Central Mode Water (CMW). The STM water colder than 4 deg. C in the Subarctic Zone is originated in the winter mixed layer of the Bering Sea. The temporal variation of its core temperature lags 12-16 months behind the variations of both the winter SST and the summer STM temperature in the Bering Sea, suggesting that the thermal anomalies imposed on the STM water by wintertime air-sea interaction in the Bering Sea spread over the western subarctic gyre, reaching the 180 deg. meridian within a year or so. The CMW in this section originates in the winter mixed layer near the northern edge of the Subtropical Zone between 160 deg. E and 180 deg. The CMW properties changed abruptly from 1988 to 1989; its temperature and salinity increased and its potential density decreased. It is argued that these changes were caused by the climate regime shift in 1988/1989 characterized by weakening of the Aleutian Low and the westerlies and increase in the SST in the subarctic-subtropical transition region. The argument is evaluated quantitatively using surface fluxes of NCEP/NCAR reanalysis data.

OC-63

A Simple Model of Ocean/Atmosphere Interactions to Predict the Variability of Sea Surface Salinity

Mr. Sylvain Michel, DRO/LOS, IFREMER, BP 70, 29280 Plouzane, France, smichel@ifremer.fr
Dr. Bertrand Chapron, bchapron@ifremer.fr
Dr. Nicolas Reul, nreuln@ifremer.fr

The Sea Surface Salinity is a parameter of major importance to estimate the influence of oceans over climate. Unlike the temperature, it has an undirect effect on the air/sea exchanges, as it determines the convection or re-emergence of water masses, which are crucial for the seasonal to interannual variability. But measurements of SSS are expensive and very inhomogeneously distributed, so that even its seasonal cycle is still poorly known over much of the world's ocean. A local model of the oceanic mixed layer is used to determine the anomalies of SSS caused by the surface heat fluxes, the evaporation-precipitation budget and the wind stress. It is shown that the variations in the wind-induced transport is the first cause of salinity variability, but that the fresh water

flux can dominate locally. The effect of advection by the superficial current can be neglected over most of the areas.

The model is first tested with high-frequency climatological fluxes from a meteorological model, in terms of time spectrum and spatial distribution of the salinity response. Then the analysis is performed over the recent years, from an optimal combination of space-born observations and model outputs. The results are validated using in situ measurements from buoy arrays in the tropical Pacific and Atlantic. Finally, the interest of this method is examined in view of the future SMOS and Aquarius satellites, both dedicated to the SSS retrieval.

OC-64

Salinity Variability in the Subtropical South Pacific

Keir M. Colbo and Robert A. Weller, Woods Hole Oceanographic Institution, PO Dept., MS #29, Woods Hole, MA, 02543, USA, kcolbo@whoi.edu, rweller@whoi.edu

A possible mechanism by which the southern subtropical Pacific may influence the equatorial Pacific Ocean is investigated. Meridional transects through the equatorial Pacific Ocean show a marked asymmetry between the northern and southern hemispheres. A strong subsurface salinity maxima which penetrates into the core of the equatorial undercurrent is observed in the southern hemisphere. In contrast there is very little vertical variation in salinity to the north of the equator. The water in the southern salinity maxima is formed in subtropical mixed layers, where the annual rate of evaporation greatly exceeds that of precipitation. Variability in the strength of the trade winds can have a strong effect on latent heat fluxes, and hence the formation rate and water properties of the mode water that reaches the equator.

Using historical data from the equatorial Pacific, we examine the variability of the salinity maxima in both space and time. Lagged correlations with large-scale atmospheric indices, such as the Southern Oscillation Index and the strength of the trade winds, are investigated. The variability in data from a moored buoy at 20S, 85W is presented, and used to estimate the potential variability in mode water formation rates and properties.

OC-65

Interannual Variability of Sea Surface Salinity in the Western North Pacific

Dr. Frederick M. Bingham, 5600 Marvin K. Moss Ln., Wilmington, NC 28409, USA, bigkahuna@fredbingham.com

To investigate the interannual variability of sea surface salinity (SSS) in the western North Pacific we have used a dataset derived from the World Ocean Database of 1998. This dataset includes over 1 million observations of SSS going back to the early 20th century.

Interannual variability of SSS in the tropical Pacific is dominated by El Nino - related variations, as previously documented by Delcroix and Henin (1991) and shown in

the current study. There is a strong seasonal signal in the tropical Pacific as well as in mid-latitudes which masks any interannual trends. For this reason, we use fall-spring values of SSS and avoid summer measurements.

In the tropcial Pacific, there is a significant downward trend in fall-spring SSS between the 1930's and 1990's with a decrease of about 0.4 over that period. The decrease is not monotonic, but is interrupted by an upward spike in the mid 1970's. Because of the structure of the seasonal cycle, this amounts to a significant decrease in the amplitude of the seasonal cycle of SSS. At higher latitudes no similar long-term trend exists, but there is still interesting interannual variability, with an amplitude of 0.1-0.2. There is relatively high SSS in the early 1940's, lower in the early 1950's and another dip in the mid-1970's.

To add some definition to thses trends, we used wintertime SSS distributions along 137E, a repeat hydrographic section done by the Japanese government since 1967. Examination of these data confirm the large-scale freshening in the tropics since the 1970's and the major dip in mid-latitude values in the mid-1970's. The importance of ENSO-scale variability is confirmed as well, particularly the 1983 event. Also contributing to the SSS signal is a southward meander of the Kuroshio in the mid-1970's. A linear fit at 15N at the southern edge of the subtropical gyre gives a decrease of 0.01 per year, or nearly 0.3 in the 30 years of observations along 137E.

We speculate on the relationship of observed interannual variations in SSS to changes in gyre structure, migration of the intertropical convergence zone, the hydrologic cycle, and changes in vertical mixing and advection.

IDC-66

Numerical Study on the Interannual Variability of Warm Water Volume in the Tropical Pacific

Dr. Akio Ishida, Ocean Observation and Research Department, Japan Marine Science and Technology Center, 2-15 Natsushima-cho, Yokosuka 237-0061, Japan, ishidaa@jamstec.go.jp
Dr. Akio Ishida, ishidaa@jamstec.go.jp
Dr. Shigeki Hosoda, hosodas@jamstec.go.jp
Dr. Kentaro Ando, andouk@jamstec.go.jp
Dr. Yuji Kashino, kashinoy@jamstec.go.jp
Dr. Yoshifumi Kuroda, kuroday@jamstec.go.jp

The variation of the warm water volume (WWV) in the tropical Pacific has important process for understanding of the dynamical mechanisms responsible for El Nino–Southern Oscillation (ENSO) events. The buildup and decrease of WWV before and after ENSO events and part of this variability was accounted by poleward transport across a wide range of longitudes in the interior region. However, the contribution by the western boundary currents has not been fully understood. In this study, we investigate the interannual variability of the WWV by diagnosing the output from a hindcast experiment covering the period from 1982 to 2002 with a high-resolution ocean global circulation model. The model simulates the results of previous studies showing that the WWV builds up prior to ENSO events and rapidly decreases during the events due to volume flux out of the equator. The model also indicates the buildup of the WWV in the

off-equatorial area between around 8 degrees and 16 degrees latitude after the mature period of the ENSO events. The most significant buildup signal is recognized during 1998 to 2001 off Philippines and this long sustained warm anomaly is released during the 2002/03 ENSO event. The meridional convergence of the WWV from the off-equatorial area is found to contribute to the WWV variation in the equatorial Pacific for the ENSO events.

PDC-67

The Centroid Motion of the Pacific Warm Pool Described by Spherical Coordinates

Mr. Fábio Vieira Machado, Institute of Astronomy, Geophysic and Atmospheric Science - University of São Paulo / IAG-USP, Rua do Matão, 1226, Cidade Universitária, São Paulo - SP – Brazil.Cep: 05508-900, fabiovm@usp.br
Dr. Victor de Amorim d'Ávila, Dept. of Oceanography - Rio de Janeiro States University, Rua São Francisco Xavier, 524/4009E, Maracanã, Rio de Janeiro, RJ – Brazil, Cep: 20550-900 and Dept. of Astronomy and Astrophysic – National Observatory, Rua General José Cristino, 77, São Cristóvão, Rio de Janeiro, RJ – Brazil., Cep: 20921-400
Dra. Jacyra Ramos Soares, Institute of Astronomy, Geophysics, and Atmospheric Science-University of Sao Paulo/IAG-USP, Rua do Matao, 1226, Cidade Universitaria, Sao Paulo-SP-Brazil., CEP: 05508-900

The centroid of the Pacific warm pool estimated in spherical coordinates was investigated by using monthly NCEP sea surface temperature (SST) analyzed fields obtained from NASA Physical Oceanography Distributed Active Archive Center. Here the centroid is defined by a sum of 'n' vectors from the center of the Earth to each grid point with SST equal or superior 29,0ºC. During El Niño years the warm pool moves toward east and during La Niña years the warm pool is retained in the west side of the Pacific Ocean. The meridional component of the centroid is related to the annual solar cycle where the seasonal cycle is the dominant characteristic. Examining the zonal component of the centroid movement is possible to note that the centroid of the warm pool moved across 180º during El Niño years. It indicates that the Pacific warm pool extended eastward in those years. In the case of the two strongest El Niño events (1982-83 and 1997-98) observed in the investigated period our analysis indicated that they both started in the same time of the year and displaced toward east following the same path. The seasonal phase locking for the beginning of the phenomenon and the peak on the eastward propagation of the Pacific warm pool centroid can be observed too. It is presented as evidence that centroid zonal component of the Pacific warm pool in spherical coordinates can be used as an alternative form to monitor and to describe the evolution of El Niño episodes. The only arbitrary parameter required to define the centroid is the value of the minimum sea surface temperature that characterizes the Pacific warm pool.

PDC-68

Closing the Time-Varying Mass and Heat Budgets for Large Ocean Areas: The Tasman Box

Dean Roemmich, Mail Code 0230, Scripps Institution of Oceanography, University of California San Diego, 9500 Gilman Drive, La Jolla CA 92093-0230 USA, droemmich@ucsd.edu
John Gilson, gilson@eori.ucsd.edu,
Josh Willis, jkwillis@ucsd.edu,
Philip Sutton, National Institute of Water and Atmospheric Research, Greta Point, Wellington NZ, p.sutton@niwa.co.nz,
Ken Ridgway, CSIRO Marine Research, Hobart, Tasmania, Australia, ken.ridgway@csiro.au

The role of oceanic advection in seasonal-to-interannual balances of mass, heat, and salt is studied using a 12-year time-series of quarterly eddy-resolving XBT surveys around the perimeter of a region we call the Tasman Box in the southwestern Pacific. The region contains the South Pacific's subtropical western boundary current system and associated strong mesoscale variability. Mean geostrophic transport in the warm upper ocean (> 12-degrees C) is about 3.8 Sv southward into the box across the Brisbane - Fiji northern edge. Net outflows are 3.3 Sv eastward across the Auckland - Fiji edge, and 2.7 southward across Sydney - Wellington. The mass budget is closed by 2.2 Sv of mean Ekman convergence. Net water mass conversions in the upper ocean - inflowing waters of about 26-degrees C and 35.4 psu, balanced by outflow at 18-degrees C and 35.7 psu - reflect the net evaporation and heat loss in the formation of South Pacific Subtropical Mode Water. The mean heat balance shows good agreement between ocean heat flux convergence in the Box (43 W/m**2), heat loss to the atmosphere (39 W/m**2 in ECMWF operational analyses), and heat storage calculated from data in the Box interior (1.3 W/m**2). On interannual time-scales, volume transport through the Box ranges from about 1 to 9 Sv, with heat flux convergence ranging from about 20 to 60 W/m**2. An interannual balance in the heat budget is achieved to within about 10 W/m**2, and will be improved substantially with implementation of Argo and other new observing system elements. Maxima in the advective heat flux convergence occurred in 1993, 1997 and 1999-2000, and corresponded to maxima in air-sea heat loss. On interannual timescales, ocean circulation is central to the heat budget of the air-sea climate system in the western boundary current region.

OC-69

The Contribution of Midlatitude Western Boundary Currents to Decadal Climate Variations

Dr. Kathryn A. Kelly and Ms. Shenfu Dong, Applied Physics Laboratory, Box 355640, University of Washington, Seattle, WA 98195-5640, USA,
kkelly@apl.washington.edu
shenfu@apl.washington.edu

Strong western boundary currents in the northern hemisphere midlatitude oceans transport heat from the warm tropical regions to the cool subpolar regions and are responsible for much of the ocean's share of the mean heat transport. In addition, these

current systems flux much of their heat to the atmosphere, thus increasing the atmosphere's heat transport at about 40N. Recent studies point to the importance of interannual-to-decadal heat transport fluctuations in both oceanic heat storage and in the fluxes of heat to the atmosphere. Analyses of upper ocean heat budgets and of longer records of ocean heat content suggest that much of the variability is in phase between the North Pacific and the North Atlantic, so that the ocean variations may make a hemispheric contribution to climate variations. Measurements of ocean currents by the radar altimeter on the TOPEX/Poseidon satellite have provided an unprecedented 10-year time series of variations in the boundary currents. These observed currents have been used in parallel studies of the upper ocean heat budget for the regions surrounding the Kuroshio Extension in the North Pacific and the Gulf Stream in the North Atlantic. The heat budgets of these regions reveal several unexpected results: 1) these regions store a large amount of heat for periods of several years, 2) heat storage is controlled by the transport of heat into the region by the currents, rather than by air-sea fluxes, 3) that the currents which transport most of the heat are geostrophic, rather than locally forced Ekman currents, and 4) that the surface fluxes in these regions are controlled by the ocean's heat storage, rather than the other way around.

Surprisingly, a comparison of the heat budgets for the Pacific and the Atlantic show that fluctuations in the heat content and heat transport convergence are in phase, and correlated with the Northern Hemisphere Annular Mode (also known as the Arctic Oscillation). The ocean connection is apparently provided by in-phase variations in winds: winds force changes in ocean circulation, which in turn cause changes in advection; accumulation of heat by advection in the western boundary current regions forces anomalous heat fluxes to the atmosphere. These analyses suggest the potential for predicting variations in ocean circulation that may in turn force climate variations.

IDC-70

The Eddy Shedding from the Kuroshio Bend at Luzon Strait

Dr. Yinglai Jia, Physical Oceanography Laboratory & Ocean-Atmosphere Interaction and Climate Laboratory, jiayingl@ouc.edu.cn
Prof. Qinyu Liu, Physical Oceanography Laboratory & Ocean-Atmosphere Interaction and Climate Laboratory, Ocean University of China, 5 Yushan RD. Qingdao, P. R. China, 266003

The TOPEX/ POSEDIENT-ERS satellite altimeter data along with the mean state from Parallel Ocean Climate Model result are used to investigate the variation of Kuroshio intrusion and eddy shedding at Luzon Strait during 1992-2001. The Kuroshio penetrates into the South China Sea and forms a bend. The Kuroshio bend is temporally various and anticyclonic eddies are periodically shed from the Kuroshio bend. Criteria of eddy shedding are identified: 1)When the shedding event occurs, there are usually two centers of high SSH together with negative geostrophic vorticity in the KB area. 2)Between the two centers of high SSH there usually exists positive geostrophic vorticity. Using those criteria, the eddy shedding times and locations are determined. The most frequently occurred eddy shedding intervals are 70, 80 and 90 days. In winter and summer monsoon period, the most frequently occurred locations are both 119.5E and 120E, which means that the seasonal variation of eddy shedding location is unclear.

OC-71

Interannual Variability of Oyashio Transport Estimated from SSH Anomaly Based on TOPEX/POSEIDON Altimetry

Dr. Shin-ichi Ito, Tohoku National Fisheries Research Institute, 3-27-5, Shinhama-cho, Shiogama, Miyagi 985-0001, Japan, goito@affrc.go.jp
Dr. Kazuyuki Uehara, National Research Institute for Far Seas Fisheries, Orito, Shimizu, Shizuoka 424-8633, Japan, kuehara@affrc.go.jp.
Dr. Takashi Miyao, Hakodate Marine Observatory, Mihara, Hakodate, Hokkaido 041-0806, Japan, tmiyao@met.kishou.go.jp.
Dr. Hideo Miyake, Hokkaido University, Minato-cho, Hakodate, Hokkaido 041-8611, Japan, miyake@fish.hokudai.ac.jp.
Dr. Ichiro Yasuda, Department of Earth and Planetary Science, Graduate School of Science, University of Tokyo, Japan, ichiro@eps.s.u-tokyo.ac.jp.
Dr. Tomoo Watanabe, National Research Institute of Fisheries Science, Fukuura, Kanazawa-ku, Yokohama, Kanagawa 236-8648, Japan, wattom@affrc.go.jp.
Dr. Yugo Shimizu, Tohoku National Fisheries Research Institute, 3-27-5, Shinhama-cho, Shiogama, Miyagi 985-0001, Japan, yugo@affrc.go.jp.

An observation line along the TOPEX/POSEIDON (T/P) ground track 060 was set to estimate the Oyashio transport. We named this line the OICE (Oyashio Intensive observation line off-Cape Erimo). Along this line we have been conducting repeated hydrographic observations and maintaining mooring systems. T/P derived sea surface height anomaly (SSHA) was compared with velocity and transport on OICE. Although the decorrelation scale of SSHA was estimated at about 80-110 km in the Oyashio region, the SSHA also contains horizontal, small-scale noise, which was eliminated using a Gaussian filter. In the comparison between the SSHA difference across two selected points and the subsurface velocity measured by a moored Acoustic Doppler Current Profiler (ADCP), the highest correlation (0.92) appeared when the smoothing scale was set at 30 km with the two points as near as possible. For the transport in the Oyashio region, the geostrophic transport between 39º30'N and 42ºN was compared with the SSHA difference across the same two points. In this case the highest correlations (0.79, 0.88 and 0.93) occurred when the smoothing scale was set at 38, 6 and 9 km for reference levels of 1000, 2000 and 3000 db, respectively. The annual mean transport was estimated as 9.46 Sv in the 3000 db reference case. The Oyashio transport time series was derived from the T/P SSHA data, and the transports are smaller than that estimated from the Sverdrup balance in 1994-1996 and larger than that in 1997-2000. This difference is consistent with baroclinic response to wind stress field.

OC-72

Can Luzon Strait Transport Play a Role in Conveying The Impact of ENSO to the South China Sea?

Dr. Tangdong Qu, Yoo Yin Kim, Max Yaremchuk, Tomoki Tozuka, Akio Ishida, and Toshio Yamagata, IPRC/SOEST, University of Hawaii, 2525 Correa Road, Honolulu, HI 96822, USA, tangdong@hawaii.edu

The Luzon Strait Transport (LST) from the Pacific into the South China Sea (SCS) is examined using results from a high-resolution ocean general circulation model. The LST from the model has a mean value of 2.4 Sv, and reaches its seasonal maximum (6.1 Sv, westward) in winter and seasonal minimum (0.9 Sv, eastward) in summer. Both the annual mean and seasonal variation of LST compare favorably with earlier observations. On interannual time scale, LST tends to be higher during El Nino years and lower during La Nina years, with its maximum (minimum) leading the mature phase of El Nino (La Nina) by 1 month. The interannual variation of LST appears to be oppositely phased with the Kuroshio transport east of Luzon, indicating a possible nonlinear hysteresis of the Kuroshio as a driving mechanism of LST. For the annual average, water leaving the SCS in the south is of higher temperature than that with LST, thus producing a cooling advection in the upper 405 m equivalent to a surface heat flux of –19 W m-2. Most of this cooling advection is balanced by the atmospheric heating (17 W m-2). From late spring to early fall, surface heat flux is the primary heating process; only a small part of the heat content change can be explained by heat advection. But, in winter, heat advection seems to be the only important process responsible for the cooling in the upper-layer of the SCS. The interannual variation of the upper-layer heat content has a strong signature of ENSO, cooling in the development of El Nino and warming in the development of La Nina. An oceanic connection is revealed, in which LST seems to be a key process conveying the impact of the Pacific ENSO into the SCS.

OC-73

Variability of the Mindanao Current - Observational and Numerical Studies

Dr. Yuji Kashino, JAMSTEC, 2-15 Natsushima, Yokosuka, Kanagawa, 237-0061, Japan, kashinoy@jamstec.go.jp
Dr.Akio Ishida, ishidaa@jamstec.go.jp,
Dr.Shigeki Hosoda, hosodas@jamstec.go.jp,
Dr.Kentaro Ando, andouk@jamstec.go.jp,
Dr.Yoshifumi Kuroda, Japan, kuroday@jamstec.go.jp

The Mindanao Current (MC), which is the northern low-latitude western boundary current of the Pacific, is thought as one of the paths of the signals such as heat content anomaly in ENSO scale from the northern subtropical Pacific to the equatorial region. Considering this background, we conducted observations of the MC using a mooring deployed near southeast cost of Mindanao Island and R/Vs Mirai and Kaiyo since 1999, in order to understand variability and hydrographic structure of this current. We also analyzed the results from the global ocean circulation model with resolutions of 1/4 degrees in horizontal and of 55 levels in vertical.

Time series of current data indicates that the MC was very stable; standard deviations of daily averaged meridional velocity is O(0.2m/s) in spite of its large average velocity exceeding 1.3m/s around 100m depth, and that the current velocity of the MC is large during boreal summer. The monthly averaged meridional velocity at 100m depth and Southern Oscillation Index highly correlated from 1999 autumn to 2002 summer,

including the 2002 El Nino. After the westerly burst in Dec 2001, current velocity of the MC increased up to 1.8m/s. Similar results are also derived from the numerical experiment although intraseasonal variability of the MC in the model is larger than observation.

IDC-74

Influence of the Halmahera and Mindanao Eddies on Watermass Pathways in the Pacific Ocean

Dr. Roxana C. Wajsowicz, Dept. of Meteorology, 3433 Computer and Space Science Building, University of Maryland, College Park, MD 20742, U.S.A. roxana@atmos.umd.edu

The Halmahera and Mindanao Eddies are thought to be quasi-permanent features centered at the Pacific entrance to the Indonesian seas. However, during eight cruises from Septermber 1987 and June 1990 along 8N, evidence of the Mindanao Eddy was found on only two. A simple dynamical model shows that the location and magnitude of these Eddies may determine the upper thermocline watermass pathways at the western equatorial Pacific crossroads.

Absent of the Eddies, the North Pacific Ocean upper thermocline is essentially isolated (no implied interhemispheric transport) for decades in which the zero Sverdrup streamline lies to the north of the Australian continent. The North Pacific western boundary current contribution to the equatorial thermocline is maximal, and the Indonesian Throughflow is wholly fed from the South Pacific. The presence of the Halmahera Eddy revises the isolation criterion to north of the Halamhera Eddy, which substantially reduces the likelihood of such an occurrence. The North Pacific contribution to the equatorial thermocline is submaximal, and the Throughflow composition mixed. If the Halmahera Eddy is present, then the appearance of the Mindanao Eddy minimizes the North Pacific western boundary current contribution to the equatorial Pacific thermocline, and maximizes that in the Throughflow, so maximizing the implied interhemispheric transport. Absent of the Halmahera Eddy, the presence of the Mindanao Eddy has no significant effect on the watermass pathways.

Experiments with almost-global ocean GCM confirm the differing roles of the Eddies in providing the observed robust North Pacific-fed Indonesian throughflow, and interhemispheric transport this implies, in the presence of large interannual, and longer timescale variability, in the tropical Pacific wind A hindcast with the ocean GCM also shows considerable variability in the undercurrents by the crossroads, specifically absence of the Mindanao Undercurrent, thought to transport Antarctic Intermediate Water northwards, as found in the aforementioned cruises. Causes for the variability and impact on the watermass pathways are described.

OC-75

Indonesian Throughflow International Measurement Program: INSTANT

Arnold L. Gordon, Lamont-Doherty Earth Observatory, 61 Route 9W, Palisades, NY, 10964-8000, USA, agordon@ldeo.columbia.edu

International Nusantara Stratification and Transport (INSTANT), a CLIVAR program involving Indonesia [Indroyono Soesilo], United States [A. Gordon, Janet Sprintall, R. Dwi Susanto, Amy Ffield], Australia [Susan Wijffels], France [Robert Molcard] and the Netherlands [Hendrik van Aken] to measure the velocity, temperature and salinity of the Indonesian throughflow (ITF) through simultaneous mooring deployments in both the inflow and outflow passages the over a three year period.

The Indonesian seas provide a low-latitude pathway for the transfer of warm, low salinity Pacific waters into the Indian Ocean. It is essential that the ITF be properly measured, as it will lead to a much-improved understanding of the regional and large-scale climate system. In the past, measurement programs of the ITF lacked temporal coherence: the data cover different time periods and depths in the different passages of the complex pathways leading to the Indian Ocean. This has lead to ambiguity of the mean and variable nature of the ITF, and the transformation of the thermohaline and transport profiles within the interior seas. INSTANT is designed to provide a time series of ITF transport and property fluxes, and their variability from intraseasonal to annual time scales, along the ITF pathway from the intake of Pacific water at Makassar Strait and Lifamatola Passage, to the Lesser Sunda exit channels into the Indian Ocean. The moorings are set more-or-less simultaneously in Makassar Strait, Lifamatola Passage, Lombok Strait, Ombai Strait and Timor Passage. In addition, shallow pressure gauges that measure sealevel will be deployed in Lombok, Ombai and Timor Passage. The measurement period began in December 2003.

INSTANT objectives:

1. To determine the full depth velocity and property structure of the Throughflow and it's associated heat and freshwater flux.

2. To resolve the annual, seasonal and intraseasonal characteristics of the ITF transport and property flux.

3. To investigate the storage and modification of the ITF waters within the internal Indonesian seas, from their Pacific source characteristics to the Indonesian Throughflow water exported into the Indian Ocean.

4. To contribute to the design of a cost-effective, long-term monitoring strategy for the ITF.

5. The training of Indonesian scientific and technical personnel in the acquisition, processing and analysis of state-of-the-art oceanographic data.

IDOC-76

Direct Determination of the Indonesian Throughflow Using the Tritium Radioactive Clock

Philippe Jean-Baptiste, Laboratoire des Sciences du Climat et de l'Environnement, DSM/LSCE, CEA-Saclay, Gif/Yvette cedex 91191 France
pjb@lsce.saclay.cea.fr
W. J. Jenkins, Woods Hole Oceanographic Institution, Woods Hole, MA 02543 USA
V. Leboucher and M. Fieux, Laboratoire d'Océanographie Dynamique et de Climatologie, CNRS-Université Paris VI, Paris, 75752 France

The Pacific-Indian throughflow across the Indonesian Seas is a major feature of the Indian and Pacific oceans equatorial oceanography and a significant component of the world ocean circulation. Because of the large seasonal and interannual variability of the climatological forcings of the throughflow, the various methods used to estimate its intensity show a fair amount of scatter, with values ranging from a few Sverdrup (1 Sv = 1E+6 m3/s) to 18.6±7 Sv. Here, we focus on the tritium (3H) distribution to derive the intensity of the flow from the comparison of the 3H water column inventory in the western Pacific and in the eastern Indian oceans, i.e. on both sides of the throughflow. On the Pacific side, the data belong to the WOCE P4 zonal transect performed in 1989 by at the WHOI tritium facility. The selected stations belong to the core of the Mindanao current and are representative of the north Pacific waters entering the Indonesian seas. On the Indian side, the tritium samples were obtained in 1989 during the JADE cruise in the straits of Sumba, Savu and Roti located downstream of the Ombai strait, and in the Timor passage, where the Indonesian waters leave the archipelago and enter the equatorial Indian Ocean. Our approach is based on the simple idea that the tritium radioactive decay half-life of 12.32 yr is well adapted to infer the transit time (and hence the mass flow) of the waters through the Indonesian archipelago. We show that the tritium budget of the Indonesian Seas implies a flow of waters from the Pacific Ocean to the Indian Ocean in the range 15.7±3.6 Sv. This value represents a robust estimate since it is averaged over the transit time of the water masses (i.e. over about 6 years), thus removing the seasonal as well as much of the interannual variability. The present estimate supports a throughflow value in the upper range of published figures, and points to its major role in the heat and salt balance of the Pacific-Indian oceans, with potential implications to the global thermohaline circulation and climate system.

OC-77

The Years of El Nino, La Nina and Interactions with the Indian Ocean

Dr. Gary A. Meyers, CSIRO Marine Research, GPO Box 1538, Hobart TAS 7001, Australia, gary.meyers@csiro.au

The Indian Ocean Dipole (IOD) has been a subject of increasing interest and sometimes scientific debate since 1999 when the first papers on it were published in Nature. This paper is concerned with identifying the IOD and its relationship to the El Nino Southern Oscillation phenomenon (ENSO). The physical oceanographic characteristics of IOD are identified by reviewing selected, recently published papers. Upwelling on the Indian Ocean coasts of Java and Sumatra is identified as a key controlling process in IOD, generating the cold eastern pole observed in XBT and altimeter measurements during recent decades. Then, the relationship between IOD and ENSO is characterized by carefully classifying each year of the 20th century as a year of El Nino, La Nina or neither; and positive IOD, negative IOD or neither. The classification is based on the latest version of the GISST data set. The method of classification is critically dependent on recognizing the important role of upwelling in both the Pacific equatorial cold tongue and off the Java/Sumatra coast. The relationship between IOD and ENSO is then described in terms of global SST patterns for cases when particular phases of the two phenomena occur together or independently.

OC-78

The Indian Ocean Climate and Dipole Variability in the Hadley Centre Coupled GCMs

Dr. Hilary Spencer, CGAM, Reading University and The Met Office, UK
Department of Meteorology, University of Reading, Earley Gate, Reading, RG6 6BB, UK
Dr. Rowan Sutton, Department of Meteorology, University of Reading, Earley Gate, Reading, RG6 6BB, UK
Prof. Julia Slingo, Department of Meteorology, University of Reading, Earley Gate, Reading, RG6 6BB, UK
Dr. Malcolm Roberts, Hadley Centre, The Met Office, FitzRoy Road, Exeter, Devon, EX1 3PB. UK

Prediction of Indian Ocean interannual variability may be limited by the systematic biases in coupled GCMs or by a lack of resolution of the processes involved. In particular, little is known about the impact of ocean resolution on simulated climate variability. The simulation of Indian Ocean climate is investigated in Hadley Centre coupled models with different horizontal and vertical ocean resolutions. The simulations of the mean state of the Indian Ocean and the Indian Ocean dipole are investigated.

The mean state of the Indian Ocean is not found to improve when horizontal resolution is increased from 1.25deg to 1/3deg or when vertical resolution is increased from 20 to 40 vertical levels. However, improvements in the simulation of the dipole are found. All versions of the model realistically simulate dipole onset between April and June, peak in September to October and then rapid decay between October and January. The SST anomalies are accompanied by realistic equatorial easterly wind anomalies with thermocline shoaling in the east and deepening in the southwest.

In the model with the 1.25deg ocean and 20 vertical levels, the dipoles do not terminate completely but persist through the Austral summer and then frequently re-invigorate the following year. This unrealistic behaviour is eliminated when the ocean vertical resolution is increased from around 20m in the thermocline to 10m in the whole of the top 135m and when Java is represented (even at 1.25deg resolution). It is hypothesised that the improvement is due to the resolution of the separation between the thermocline and the surface mixed layer.

OC-79

Role of the Indian Ocean Dipole in ENSO Variability

Dr. Swadhin K. Behera, Frontier Research for Global Change, 3173-25 Showa-machi, Kanagawa 236-0001, Japan, behera@jamstec.go.jp
Dr. Jing Jia Luo, luo@jamstec.go.jp
Dr. Sebastien Masson, smasson@jamstec.go.jp
Prof. Toshio Yamagata, Department of Earth and Planetary Science, Graduate School of Science , The University of Tokyo, Tokyo 113-0033, Japan, yamagata@eps.s.u-tokyo.ac.jp

Active world-wide research conducted during the TOGA period clarified physical mechanisms of air-sea interaction in the evolution of the El Niño/Southern Oscillation (ENSO) phenomenon. Besides the role of feedback mechanisms internal to the tropical Pacific, the role of external influences in the ENSO evolution has been discussed.

In a recent study, Behera and Yamagata (2003) showed that the changes in the atmospheric condition, related to a similar ocean-atmosphere coupled phenomenon in the Indian Ocean now known as the Indian Ocean Dipole (IOD), influence the pressure variability at Darwin and therefore the Southern Oscillation. This is further supported by the evidence that three strongest El Niño events of 1972/73, 1982/83 and 1997/98 during the last several decades are followed by positive IOD events in the Indian Ocean. In fact, El Niño events in absence of IOD events in the Indian Ocean are generally weak e.g. the 2002/03 event. A natural question arises here: does the absence of IOD affect the strength of the Pacific phenomenon?

We investigated the nature of IOD influence by checking differences in ocean-atmosphere conditions of Indo-Pacific sector during two of the most recent El Niño events of 1997/98 and 2002/03. In addition to the observational datasets, experiment results from an atmospheric GCM (ECHAM4) are employed in the analysis. It is found that the sea surface temperature (SST) anomalies related to IOD in the Indian Ocean cause anomalous divergent westerly winds over the central Pacific during summer of 1997. These IOD-related wind anomalies are appropriate to strengthen the internal feedback processes linked to El Niño. Therefore, external IOD forcing is an important factor for the amplification of warm SST anomalies in eastern Pacific.

We also examine the decadal nature of the Indian Ocean influence on ENSO using observed data and simulation results from a sophisticated ocean-atmosphere coupled model (SINTEX-F1.0) integrated on the Earth Simulator.

IODC-80

Estimation of Sea Surface Salinity from Outgoing Longwave Radiation

Dr. Bulusu Subrahmanyam, Centre for Ocean-Atmospheric Prediction Studies (COAPS), Florida State University, Tallahassee FL 32306-2840, USA, sub@coaps.fsu.edu
Dr. V.S.N. Murty, Physical Oceanography Division, National Institute of Oceanography, Dona Paula, Goa –403 004, India, vsnmurty@darya.nio.org
Dr. James J. O'Brien, Centre for Ocean-Atmospheric Prediction Studies (COAPS), Florida State University, Tallahassee FL 32306-2840, USA, obrien@coaps.fsu.edu

Salinity is one of the three state variables (along with temperature and pressure) that determine the density of seawater and is missing from direct measurements of space-borne satellites. It is the key parameter that determines the hydrological cycle over the oceans and hence has the climatic implications. This study provides a technique to determine the Sea Surface Salinity (SSS) in the tropical Indian Ocean based on the algorithms developed using the satellite measured Outgoing Longwave Radiation (OLR). The algorithms are the statistical relationships between the OLR and an oceanic parameter, the Effective Oceanic Layer (EOL), and between EOL and

climatological (World Ocean Atlas 1998) Sea Surface Salinity (SSS). The algorithms are applied to the tropical Indian Ocean to estimate the monthly SSS using 22 years (1979-2000) of monthly mean OLR data. These algorithms are also used for the estimation of daily SSS during the period of synoptic weather disturbances. This study boosts the coupled models, ENSO forecast models as well as ocean global circulation models (or regional scale circulation models).

IODC-81

Indian Ocean Mode Water Heat Balance from ARGO Data

Kevin Speer, Oceanography Dept., Florida State University, Tallahassee Florida, 32303, USA, kspeer@ocean.fsu.edu
Nicolas Wienders, wienders@ocean.fsu.edu
Sophie Wacongne, wacongne@ocean.fsu.edu

ARGO data from the southeastern Indian Ocean are used to construct heat balances for the upper 1000m. Profiles are averaged in an area corresponding to subantarctic mode water production for the seasonal cycle. Heat fluxes at the surface from several climatologies are used together with estimates of Ekman and geostrophic lateral advection to determine the dominant balances.

IODC-82

Predictive Relationships between South Pacific and Indian Ocean SST and North-West India Winter Precipitation

Mr. Ramesh Kumar Yadav, Research Scholar, Climatology and Hydrometeorology Division, Indian Institute of Tropical Meteorology, Dr. Homi Bhabha Road, Pashan, Pune, Maharashtra, India. PIN- 411 008, yadav@tropmet.res.in
Dr. Rupa Kumar Kolli, kolli@tropmet.res.in, or rk_kolli@yahoo.com
Dr. M Rajeevan, rajeevanm@hotmail.com, or imdpune@pn2.vsnl.net.in

Northwestern parts of India has mainly two rainy seasons, summer and winter, when it receives considerable amount of precipitation and in between two transition periods. The winter season consist months of December to March and the precipitation during the season is mainly associated with the sequence of mid-latitude synoptic systems known as western disturbances. The precipitation is very important for Rabi crops, particularly for wheat, as it supplements the irrigation/moisture and maintains low temperature for the crops. The precipitation in the form of snow over the hilly regions of north west India helps in maintaining the Glaciers extend which serves as the vast store-house of the water in different seasons for the great rivers which take their birth there. The northwestern parts of India are the main regions for wheat production of the country therefore, the season is critically important for the agrarian economy of the country. The precipitation has considerable inter-annual variability with mean 112mm, standard deviation 38.2mm, and Coefficient of Variation 34%.

Monthly sea surface temperature (SST) data of 54 years (1949-2002) have been analyzed to examine the relationship of SST anomalies in the southern Pacific and

Indian Ocean with North-West India Winter Precipitation (NWIWP) and to derive useful predictors for long-range forecasts of NWIWP. There is a significant positive correlation between NWIWP and SST over the south-west Indian Ocean (SWIO), east of Madagascar and negative correlation over south-east equatorial Indian Ocean (SEEIO), north-west of Australia, and south central Pacific Ocean (SCPO), during the months of July to October in Indian Ocean and September to November in Pacific Ocean. SEEIO signal remains stagnant from the month of May to October, SWIO signal is significant only in the months of July to October while SCPO signal is significant in the months of September to November. Both, SWIO and SEEIO shows maximum correlation in the month of October and the correlation falls sharply to insignificant after the month of October while SCPO shows maximum in the month of November. Such an event (positive anomaly over SWIO and negative anomaly over SEEIO and SCPO) is associated with above normal precipitation over north-west India during winter season (December - March).

Three SST indices SWIO, SEEIO and SCPO have been derived as useful predictors for the long-range forecasts of NWIWP. The correlation coefficient (for the period 1949-2002) of SWIO, SEEIO and SCPO with NWIWP are statistically significant. A regression equation has been developed for predictive purpose by using these predictors.

IODC-83

A Break in the Indo-Pacific Warm Pool over the South China Sea in Boreal Winter: Seasonal Development and Interannual Variability

Prof. Qinyu Liu, Physical Oceanography Laboratory, Ocean University of China,Yushan Road #5, Qingdao 266003, China, liuqy@ouc.edu.cn
Ms. Xia Jiang, jiangxia@mail.ouc.edu.cn
Dr.Shang P. Xie,International Pacific Research Center and Department of Meteorology, University of Hawaii, Honolulu, HI 96822,USA, xie@hawaii.edu
Dr. W. Timothy Liu, Jet Propulsion Laboratory, Pasadena, CA 91109,USA, liu@pacific.jpl.nasa.gov

The Indo-Pacific warm water pool in boreal winter shows a conspicuous gap over the South China Sea (SCS) where sea surface temperature (SST) is considerably lower than over the oceans both to the west and east. The formation mechanisms for the climatology and interannual variability of SCS SST in boreal winter are investigated using a suite of new satellite measurements. The winter SCS is divided into two parts by the axis of the maximum northeasterly monsoonal winds. The positive wind curl in the southeastern half of the ocean drives a cyclonic gyre circulation in the deep basin. As its western boundary current, an intense southward flow is found south of Vietnam on the continental slope separating the Sunda Shelf to the west and the deep SCS basin to the east. This slope flow exceeds 50 cm/s in speed and advects cold water from the north. This cold advection results in a distinct cold tongue in the winter SST climatology. Both the slope current and cold tongue are strongest in November to February. This winter cold tongue displays considerable interannual variability that is highly correlated with eastern equatorial SST. In an El Nino, the winter monsoon weakens, causing the SCS

ocean circulation to spin down. The reduced western boundary current and its thermal advection result in a warming in the SCS winter cold tongue. Both SST variance and its correlation with ENSO peak along the climatological cold tongue, indicating that ocean dynamics are an important player in SCS climate variability.

IODC-84

Indian Ocean Warm Pool Characteristics in Relation with Indian Summer Monsoon

C. P. Neema, P. V. Hareesh Kumar and C. A. Babu
Department of Atmospheric Sciences, Cochin University of Science and Technology, Cochin, 682016, India, babuca@cusat.ac.in

Arabian Sea mini warm pool, which is part of Indian Ocean warm pool, is a region in the southeastern Arabian Sea where SST exceeds 30ºC during the pre-monsoon period. The objective of the study is to explain the variation in the mini warm pool characteristics in relation with Indian summer monsoon. The features of mini warm pool during flood, normal and drought monsoon years were studied. In general, the mini warm pool forms about three weeks prior to onset of monsoon and dissipates about one week ahead of the monsoon onset. The intensity and extent of mini warm pool are identified for different types of monsoon. During the flood year, the mini warm pool was observed with temperature exceeding 30.75º C in the Arabian Sea from 67º E to 75º E and 11º N to 15º N with a core of 31º C. A lateral spread of temperature zone of 30º C across the Arabian Sea was also noticed. During the normal monsoon year, mini warm pool extends from 60º E to 75º E and 9º N to 16º N and core temperature reaches up to 30.5º C. During the drought year, the core temperature exceeds 31º C but the extent of mini warm pool is 69º E to 75º E and 0º to 11º N, which is different from the other two cases. Thus flood year warm pool is the most intense and has maximum area coverage. Studies indicated that salinity plays a significant role in the formation of warm pool. Presence of low saline Bay of Bengal water in the upper layer of eastern Arabian Sea during winter stabilizes the top few meters. This can lead to the formation of a shallow mixed layer, resulting high temperature in this region causing the formation of mini warm pool. The study on distribution of salinity in the surface layers revealed that intrusion of Bay of Bengal water mass is responsible for low salinity during monsoon but with different spatial extent according to the nature of the monsoon. This helps in the formation of warm pool. In the southeastern Arabian Sea, the surface salinity during flood year is lowest (< 34.5 PSU) compared to normal year (34.75 PSU) and drought year (> 35 PSU). Thus by studying the thermohaline features of the warm pool one can judge the forthcoming monsoon.

IODC-85

Temperature and Salinity Variations Observed from TRITON Buoys in the Upper Layer of the Eastern Indian Ocean

Dr. Hideaki Hase, Ocean Observation and Research Department, Japan Marine Science and Technology Center. 2-15, Natsushima-cho, Yokosuka, Kanagawa 237-0061, Japan, haseh@jamstec.go.jp

Dr. Yukio Masumoto. Frontier Observational Research System for Global Change, JAMSTEC. 2-15, Natsushima-cho, Yokosuka, Kanagawa 237-0061, Japan, masumoto@@eps.s.u-tokyo.ac.jp
Dr. Yoshifumi Kuroda. Ocean Observation and Research Department, JAMSTEC. 2-15, Natsushima-cho, Yokosuka, Kanagawa 237-0061, Japan, kuroday@jamstec.go.jp

Temperature and salinity variations in the upper layer of the eastern Indian Ocean are examined based upon the time series data obtained from TRITON buoys at 1.5S-90E and 5S-95E. The TRITON buoys have measured water temperature and salinity from surface (1.5-m depth) to 750-m depth and current at 10-m depth since October 2001 with surface meteorological data.(see TRITON web site http://www.jamstec.go.jp/jamstec/TRITON/index.html)

The striking features from spectrum analysis applied for the TRITON temperature data are the dominant the annual and intra-seasonal variations in the surface layer from 1.5 to 50-m depth and the semi-annual signal in the thermocline layer from 100 to 750-m depth at both buoy sites. The mean, annual and semi-annual signals are removed respectively using the least square fitting method. The amplitude and phase of the semi-annual variation of temperature below 100-m depth indicate that there is upward propagation of signal, which implies a downward propagation of energy in the form of equatorial waves. On the other hand, for salinity, the intra-seasonal variation of the periods between 30 and 90 days is seen from surface to 150-m depth in addition to the semi-annual signal. Those data are invaluable when we consider the formation process of the Indian Ocean warm water pool.

IODC-86

Upper Ocean Thermohaline Structure, Circulation and Their Variability in the Southeast Indian Ocean

Prof. Zhaoqian Dong, Polar Research Institute of China, 451 Jinqiao Road Shanghai 200129, P. R. China, zhaoqian@stn.sh.cn or dongzhaoqian@pric.ac.cn
Mr. Zhigang He, PhD sdtudent, prof.he@tom.com
Dr. Xiaojun Yuan, Lamont-Doherty Earth Observatory of Columbia University 61 Rt. 9W, Palisades, NY 10964, USA, xyuan@ldeo.columbia.edu
Dr. Jianyu Hu, Xiamen University, Xiamen City, 361005, P. R. China, hujy@xmu.edu.cn

XBT/XCTD and shipboard ADCP data obtained from five Chinese cruises of 1998-2003 across the Southeast Indian Ocean between the Prydz Bay, Antarctica and Fremantle, Australia are used to examine the upper ocean thermohaline structure, circulation and their temporal variability in the ocean. Three major fronts, the Subtropical Front (STF), Subantarctic Front (SAF) and Polar Front (PF) are clearly identified and compared with earlier studies. Particularly, a double PF feature appears in the southeast Kerguelen Plateau and a double STF structure is identified by the 2003 data. Dynamic height across the ACC is calculated and reveals more detailed structure of the ACC: two

jets associated with the SAF and primary PF (pPF) are embedded within the broad Antarctic Circumpolar Current (ACC).

A strong temporal variation is found in the upper ocean thermal structure in the southeast of the Kerguelen Plateau. The depths of the mixed layer and Tmin layer deepen with time. The mixed layer temperature decreases while the Tmin temperature increases in the same time. In addition, both the ice-free period and surface wind stirring prior to XBT/XCTD sampling increase from 1998 to 2002, which would cause enhanced turbulent mixing and internal diffusive processes, and result a deeper mixed layer depth and entrainment of more cold water from the Tmin layer to the warmer waters above/below the Tmin layer. The surface forcing apparently dominate in determining the upper ocean thermal structure in this region.

Additionally, ADCP data across ACC are utilized to study front jet currents in the region. Except for the STF, the other two major fronts coincide with the jet currents. The strongest jet currents occur at the SAF and pPF with the highest velocity exceeding to 70cms-1. A Southern ACC Front (SACCF) and jet with velocity less than 30cms-1 is observed in the most part of the ACC, which is often ignored previously because of its weak hydrographic property. The representation had been found for the bottom pressure drag of meridional seamount balancing the momentum flux of westerlies. The speed of the jet currents corresponding to SAF and pPF decreases comparing with their downstream after they cross Kerguelen plateau. The speed of jet currents corresponding to the secondary PF (sPF) and SACCF does not decrease significantly because the sPF probably passes Kerguelen plateau through a col and SACCF flows through the Princess Elizabeth Trough south of Kerguelen plateau with little bottom pressure drag.

IODC-87

The Role of High-Latitude Southern Oceans

Dr. Achim Stoessel, Texas A&M University, Department of Oceanography, 3146 TAMU, College Station, TX 77843, USA, astoessel@ocean.tamu.edu

It seems that low- and mid-latitude climate variability receives much more attention than such of the high-latitudes. The high-latitudes are nevertheless the regions where the largest signal of anthropogenic climate change is expected and where critical impacts on the large-scale circulation emerge. At the same time, these are the regions where the physical processes are least understood due to the complexity of the interaction with the cryosphere and due to small-scale processes that are not resolved by the governing equations of typical climate models. This paper is to illustrate impacts arising from the high-latitude Southern Ocean. It turns out that the global deep-ocean properties and circulation depend sensitively on the way sea ice and convection are treated and resolved in global ocean GCMs. Oceanic plume convection in conjunction with a high-resolution sea-ice model embedded in a coarse-resolution global ocean model seems one way to cope with the problem of representing first-order high-latitude approach is supported by satellite-derived ice concentration for verification and assimilation on a daily time scale and a 30km space scale. This, in turn, is anticipated to provide an appropriate basis for further investigation and improvement of the coupling between the thermodynamically highly heterogeneous atmospheric boundary layer over sea ice and the large-scale atmospheric circulation, a critical issue yet to be satisfactorily solved in global climate models. This poster will be based on the major findings of the

following recent papers: SJKim and Stoessel (2001, JPO); Stoessel, Yang, and SJKim (2002, JPO); Stoessel and SJKim (2001, JGR); Stoessel and Markus (in press, JGR); Loennroth, Haapala, and Stoessel (submitted to JGR); JTKim and Stoessel

OC-88

Decadal Variability of South Pacific Subtropical Mode Water

Mr. Takamasa Tsubouchi, Department of Geophysics, Graduate school of Science, Tohoku University,Aoba-ku, Sendai 980-8587, Japan, t-taka@pol.geophys.tohoku.ac.jp
Dr. Kimio Hanawa, hanawa@pol.geophys.tohoku.ac.jp

High resolution XBT trancects (PX06 Line) data between New Zealand and Fiji from 1986 to 2000 are used to describe spatial and temporal variability of South Pacific Subtropical Mode Water (SPSTMW). One of the outstanding features in its spatial distribution is that the core layer temperature (CLT) of SPSTMW clearly changes by 1.5 degree across the subsurface front at about 29S, while the CLT is meridionally uniform over 300-500km in each side of the front. This front is seen in all seasons and likely an extention of the Tasman Front.

The average inventory of SPSTMW in the northern side was 57.3 km^2 and standard deviation was 16.3 km^2 in this period. The temporal variation of inventory in the northern side was characterized by the maximum in 1986, minimum in 1990, maximum in 1994 and a gradual reduction afterward. The average inventory in the southern side was 78.9 km^2 and standard deviation was 10.2 km^2. The temporal variation of the inventory in the southern side was characterized by the maximum in 1987, minimum in 1991, maximum in 1998 and a sudden reduction afterward. The CLT of each side also has a long-term variability with an amplitude of half degree which has a negative correlation with inventory. These long-term variability is possibly caused by the change of heat transport by East Australian Current and meridional Ekman transport. The further analysis to clarify these aspects are under way.these aspects are under way.

OC-89

The Renewal of Pacific Antarctic Intermediate Water

Daniele Iudicone, Laboratory of Biological Oceanography, Stazione Zoologica "Anton Dohrn", Villa Comunale, 80121 Naples, Italy, iudicone@szn.it
Gurvan Madec, LODYC, IPSL, Tour 26 - 4ème ètage - Boîte 100, 4 place Jussieu, 75252 PARIS CEDEX, FRANCE, gm@lodyc.jussieu.fr
Keith Rodgers, LODYC, IPSL, Tour 26 - 4ème ètage - Boîte 100, 4 place Jussieu, 75252 PARIS CEDEX, FRANCE, rodgers@lodyc.jussieu.fr
Richard Schopp, IFREMER BP70 - 29280 Plouzane, France, Richard.Schopp@ifremer.fr

The southern regions of all three major ocean basins are characterized by the northward spreading of the low-salinity, oxygen-rich Antarctic Intermediate Water (AAIW), an important component of the global thermohaline circulation. Nevertheless the

pathways and mechanisms which determine the injection of AAIW towards lower latitudes have not been previously accounted for.

Here we present the results of an analysis of recent in situ data from the South Pacific, where the freshest AAIW is observed. The analysis shows that AAIW enters the Pacific in the southeast corner of the basin, and that the signature of the equatorward meridional flow near the South American coast isoneutral surfaces.

The analysis of output from a global coupled ocean/ice model reveals a similar pathway for AAIW injection into the Pacific. The model output has been used to describe the seasonal cycle in the circulation feeding controlling the injection. In addition, the model output reveals that this subsurface circulation feature is baroclinic in nature, involving a coupling of the AAIW flow with the southward flowing upper circulation, linked to the West Drift system. A series of ocean model sensitivity experiments (with lower resolution than the control run) reveal the dynamical controls of the circulation feature, whose volume transport is found to be related to the large meridional baroclinic pressure gradient. The circulation of the northward excursion of the AAIW which feeds this circulation feature is dynamically similar to a mechanism for intergyre exchange which has previously been described for the North Atlantic. Finally, we offer speculation on the dynamics of the variability of the AAIW injection towards lower latitudes.

IDC-90

Mechanisms of Mode Water Variability in HadCM3

Dr. Sheila Stark, Hadley Centre, Met Office, FitzRoy Road, Exeter , Devon, EX1 3PB, United Kingdom, sheila.stark@metoffice.com
Dr. R.A. Wood, richard.wood@metoffice.com
Dr. H.T. Banks, helene.banks@metoffice.com

Subantarctic Mode water (SAMW) is a globally important water mass which ventilates the thermoclines of the subtropical gyres and is responsible for the uptake and storage of heat, freshwater and carbon. Both hydrographic and model studies have documented changes in SAMW and Antarctic Intermediate Water (AAIW) in the interior of the Pacific and Indian Oceans which have been related to predictions of warming and/or freshening in the Southern Ocean and hence an intensification of the global hydrological cycle.

In this study SAMW variability has been examined along 32°S in the Indian Ocean in the coupled climate model HadCM3. This hydrographic section has been occupied 5 times between 1936 and 2002 providing a direct comparison with which to validate the model results. HadCM3 shows freshening of the mode waters under greenhouse gas forcing since the 1960s which intensifies in the future up to 2100. However the most recent cruise data shows that in 2002 SAMW conditions along the section had returned to near 1960s conditions while the deeper modes continued to freshen. This apparent discrepancy between the model and the observations is explored by looking at the mechanisms of mode water formation in the model and has important implications for model predictions of future freshwater budget changes.

Traditionally it has been thought that the characteristics of SAMW are set in the subantarctic zone by air-sea exchange of heat and freshwater. However examination of freshwater gain in the formation regions of both the warmer, lighter mode seen on the west of the section and the cooler, denser eastern mode show that this is insufficient to

explain the freshening seen, with a decrease in P-E evident south of Australia. Further examination shows that there is an increase in model freshwater gain south of 55°S which combined with a northerly Ekman flux into the mode water formation regions is likely driving the observed changes, particularly in the eastern mode. Despite the data sparse nature of the Southern Ocean it appears that HadCM3 overestimates annual mean precipitation in this region and is a likely cause of the discrepancy between HadCM3 and recent observations. Other contributing factors include the model mixed layers being too shallow which leads to surface flux changes being amplified and SAMW forming outside of the winter season.

IDC-91

Southern Ocean Meridional Overturning Circulation Response to Surface Forcing in a Global Ocean Model

Dr. Simon Marsland, CSIRO Marine Research and ACE CRC, GPO Box 1538, Hobart, Tasmania 7001, Australia, simon.marsland@csiro.au
Andrew Lenton, ACE CRC and CSIRO Marine Research, GPO Box 1538, Hobart, Tasmania 7001, Australia, andrew.lenton@csiro.au

We explore the effect of different atmospheric surface forcing and boundary layer mixing schemes on the strength and variability of the Southern Ocean component of the meridional overturning circulation using a global ocean model (MOM 3.0). We compared simulations forced by NCEP-NCAR (Reanalysis) R1 and R2 products, ECMWF climatology as used in the CLIVAR/WGOMD Ocean Model Intercomparison Project, and climatology from a coupled ocean/atmosphere model (CSIRO Mk3.0). We also compare the circulation simulated using two different mixing schemes, the Chen et al. and KPP. The responses of the model are explored by comparison with observations collected along the WOCE SR3 line (south of Australia). Finally, we perturb the surface forcing to investigate the question of how the Southern Ocean meridional overturning circulation may be expected to evolve under global warming.

IDC-92

Interannual Variability in the South Indian and Atlantic Oceans

Miss Juliet Hermes, Department of Oceanography, University of Cape Town,, Private Bag, Rondebosch, 7701, South Africa, jhermes@ocean.uct.ac.za
Assoc. Prof C. J. C. Reason, cjr@egs.uct.ac.za
Prof J. R. E. Lutjeharms, johann@ocean.uct.ac.za

A global ocean model forced with 50 years of NCEP re-analysis winds and heat fluxes has been used to investigate interannual variability in sea surface temperatures (SST) in the South Indian and Atlantic Oceans. Previous work has found dipole-like patterns occurring in both basins, these consist of a positive (negative) event whereby there are anomalous warm (cool) features evident in the south west of the ocean basin and cool (warm) features in the northeast. Evidence exists that these anomalous SSTs may influence weather patterns over southern Africa and Australia.

This study investigates the link between the events in the South Atlantic and South Indian Oceans and the possibility of large-scale forcing in the form of a wave 4-type pattern in geopotential height and sea level pressure. A relationship to the Antarctic Oscillation is also apparent, and seems to strengthen after the mid 70's. The results of this study confirm the ability of the model to represent these dipole patterns and indicate that wind-driven changes in evaporation, changes in short wave radiation, Ekman pumping and Ekman heat transport may all contribute in their evolution. Relationships with subtropical Rossby Waves originating from the eastern boundary of each basin are also explored.

OC-93

Temporal Variability of Antarctic Coastal Polynyas and Watermass Formation

Dr. Simon Marsland, CSIRO Marine Research and ACE CRC, GPO Box 1538, Hobart, Tasmania 7001, AUSTRALIA, simon.marsland@csiro.au
Dr. Nathan Bindoff, ACE CRC, University of Tasmania, Private Bag 80, Hobart, Tasmania 7001, AUSTRALIA, n.bindoff@utas.edu.au
Guy Williams, IASOS and ACE CRC, University of Tasmania, Hobart, Tasmania 7001, AUSTRALIA, gdwillia@postoffice.antcrc.utas.edu.au
Paola Petrelli, ENEA, Rome, ITALY, paola.petrelli@casaccia.enea.it

The Max Planck Institute Ocean Model (MPIOM) is used to study coastal polynya processes in the Southern Ocean. The MPIOM bipolar orthogonal curvilinear grid allows for arbitrary placement and sizing of the model poles. This allows for the construction of global ocean models with high horizontal resolution in the region of interest. High horizontal resolution is essential for resolving bathymetric and coastline features. The geometry constrains sea ice flow out of coastal polynyas, impacting on the open water area and the areal sea ice concentration. We consider two model configurations: one with high horizontal resolution over the Mertz Glacier Polynya, East Antarctica; and a second with high resolution over the Terra Nova Bay Polynya, Ross Sea. The coastal polynyas are found to have considerable interannual variability. The variability can largely be attributed to variability in atmospheric forcing (e.g. air temperatures). Corresponding variability in sea ice formation rates drives High Salinity Shelf Water formation via brine rejection. This in turn affects the rate of Antarctic Bottomwater formation, which drives the lower limb of the global meridional overturning circulation.

OC-94

Decadal-Scale Variations of Water Mass Properties in the Deep Weddell Sea

Dr. Eberhard Fahrbach, Alfred Wegener Institute for Polar and Marine Research, Columbusstrasse, 27568 Bremerhaven, Germany, efahrbach@awi-bremerhaven.de
Dr. Olaf Boebel, oboebel@awi-bremerhaven.de
Dr. Mario Hoppema, mhoppema@awi-bremerhaven.de

Dr. Olaf Klatt, oklatt@awi-bremerhaven.de
Mr. Gerd Rohardt, grohardt@awi-bremerhaven.de
Dr. Michael Schröder, mschroeder@awi-bremerhaven.de
Mr. Andreas Wisotzki, awisotzki@awi-bremerhaven.de

The Weddell Sea is known to feed freshly formed deep and bottom waters into the Antarctic circumpolar water belt from where it spreads into the contiguous basins of all three world oceans. Data from cruises between 1989 and 2003 with “FS Polarstern” were used to construct section-wide potential temperature and salinity time series of the main water masses in the Weddell Gyre. Additionally time series from moored instruments and profiling floats obtained between 1989 and 2003 are used. The regional and methodological consistency of the data set allows us to quantify variations which are not visible in less homogeneous data sets. The data reveal significant temperature and salinity variations of the Warm Deep Water and the Weddell Sea Bottom Water on a decadal time scale. The longest time series were obtained at the prime meridian. Here warming is observed in the Warm Deep Water from 1992 to 1998 followed by cooling. In the Weddell Sea proper, measurements of instruments moored in the Weddell Sea Bottom Water layer recorded a temperature increase over 6 years at a rate of 0.01°C yr-1. CTD casts in 1998 point to a weakening of the trend. The warming trend in the bottom water occurs over most of the Weddell Sea as detected in the additional CTD surveys. The variations are close to the detection level in the voluminous Weddell Sea Deep Water. The initial warming trend of the Warm Deep Water is consistent with warming trends reported in literature of subsurface waters of the Antarctic Circumpolar Current. The reversal of the trend in the Weddell Sea seems to be related to variations of the atmospheric conditions which can affect both the intrusion of Circumpolar Deep Water from the north and the circulation of the Weddell Gyre. Because the Warm Deep Water is the major source water for the formation of deep and bottom water in the Weddell Sea, it is suggested that its increase of temperature and salinity is likely to at least partly cause the variations which were observed in the bottom water.

DC-95

Dense Water Drainage from the Weddell and Ross Seas

Arnold L. Gordon, Lamont-Doherty Earth Observatory, 61 Route 9W
Palisades, NY 10964-8000, USA, agordon@ldeo.columbia.edu
Martin Visbeck, visbeck@ldeo.columbia.edu
Gerd Krahmann, krahmann@ldeo.columbia.edu
Bruce Huber, bhuber@ldeo.columbia.edu
Robin Robertson, rroberts@ldeo.columbia.edu
K. Boda, kboda@ldeo.columbia.edu

The export of dense shelf water from Antarctica is investigated with two ongoing CLIVAR relevant programs: ARCHES [NOAA funded; conducted by the authors of this abstract] in the Weddell Sea and AnSlope [a collaborative NSF/OPP funded program] in the Ross Sea. Three ARCHES deep and bottom water focused moorings installed in April 1999 south of the South Orkney Islands provide a time series of the combined

outflow (currents and temperature/salinity) of Antarctic Bottom Water drawn from various sites within the Weddell Sea. The AnSlope program began in April 2003 with CTD/LADCP stations [A. Gordon, M. Visbeck, S. Jacobs, results discussed below; a microstructure sensor added to the CTD frame by L. Padman] and the deployment of a two year array of current meters [the mooring component is lead by Alex Orsi, Tom Whitworth, Dale Pillsbury] over the continental slope of the western Ross Sea.

Analysis of the near bottom potential temperature and salinity records of the ARCHES moorings from April 1999 to November 2001 suggest a seasonal cycle, albeit with some year-to-year variability. These are likely a consequence of changes in the production of dense Weddell Sea bottom water associated with varying amounts or source changes of the shelf water component. In addition, there are cold bottom water events lasting 1 to 2 days, embedded in the 0.1 m/s mean isobath following eastward flow. They can be simulated as bottom intensified advected Rankine vortices, and may represent frequent invasion of shelf water into deeper water.

The AnSlope CTD/LADCP data from the initial cruise in February to April 2003 reveals the export of near freezing point, saline (above 34.8) shelf water from the Drygalski Trough of the western Ross Sea onto the continental slope to form a well defined, 150-250-m thick, benthic layer. The most saline bottom water is matched to high bottom speeds (above 0.6 m/s) with significant (up to 30°) descend angle relative to the isobaths. A distinct benthic layer frequently extends, with significant temporal variability, seaward across the 1500-m isobath, contributing to Antarctic Bottom Water.

IDC-96

Deep Water Mass Variability in Western Weddell Sea and Bransfield Strait

Dr. Mauricio M. Mata, FURG - Departamento de Física, R. Alfredo Huch 475, Rio Grande (RS), 96201-900, BRAZIL, mauricio.mata@furg.br;
Dr. Carlos Alberto Eiras Garcia, dfsgar@furg.br

A significant contribution to the understanding of the Southern Ocean role on oceanic variability and climate has come through the DOVETAIL program (Deep Ocean Ventilation Through Antarctic Intermediate Layers). This international program aims to quantify the amount of of bottom water being exported from the Weddell Sea through the deep passages of the South Scotia Ridge. This water mass is vital to the large scale oceanic thermohaline circulation and thus climate. The multiyear field work phase of DOVETAIL led to valuable information about the region's hydrography, providing the necessary support for the development of models of the Weddell Sea dense water formation and its spread towards lower latitudes. Nevertheless, the good results from DOVETAIL also led to a new set of questions, suggesting that further field efforts should be conducted. For example, using hydrography and direct measurements, DOVETAIL scientists found evidences that properties of the Weddell Sea Deep Water (WSDW) have profoundly changed over the past decade, showing a marked warming trend. In this sense, there is a call for monitoring field programs in this remote an climate relevant region of the world ocean.

The Brazilian Antarctic Program (PROANTAR) gave a significant contribution to DOVETAIL through two fruitfull Brazilian-German cruises in the area. In 2002, PROANTAR decided to further support the pledge of DOVETAIL community for a

monitoring field program in the western Weddell Sea and Bransfield Strait. The main objective of this program is to investigate the interanual variability of hydrography and water masses in the area. The first cruise took place in January/2003 occupying 40 hydrographic stations between 55o-64oW and 61o-64oS, centered in the Bransfield Strait. We found the presence of WSDW (-1.8oC/34.56 psu) huging the bottom of the slope near Joiville Island. Observation of the density field indicates that these waters are entering the eastern Bransfiled basin near the tip of Antarctic Peninsula, following a cyclonic gyre and leaving through the northern end of the Straint near Elephant Island. Further west, the only evidence of this water mass was a modified form of WSDW, having influence of waters from the Bellingshausen sector. In January/2004, the same stations will be covered again, focusing on the understanding of the hydrography and water masses internanual variability in the region. At that time, there is a plan to occupy a high resolution transect between Joinville and Elephant Island to provide detailed distribution pattern of the WSDW entering/leaving eastern Bransfield Strait.

IDC-97

Adelie Land Bottom Water Production: I) Seasonal Formation and Export of Dense Shelf Water from the Adelie Depression, East Antarctica and Ii) Downslope Mixing and Production of Adelie Land Bottom Water from the Adelie Depression, East Antarctica

Dr Guy D. Williams, Antarctic Cooperative Research Centre, IASOS & ACECRC University of Tasmania, Private Bag 80, Hobart, Tasmania, 7001 Australia gdwillia@postoffice.antcrc.utas.edu.au (guy_wil@aurora.aad.gov.au 8/12/03 - 14/2/04)
A. Prof N. Bindoff, TPAC & ACECRC, University of Tasmania Private Bag 80, Hobart Tasmania, 7001 Australia, n.bindoff@utas.edu.au
Mr Stan Jacobs LDEO, P.O. Box 1000 61 Route 9W Palisades, NY 10964-1000 USA sjacobs@ldeo.columbia.edu
Dr Simon Marsland, CSIRO and ACECRC, CSIRO Marine Research GPO Box 1538 HOBART TAS 7001 AUSTRALIA, Simon.Marsland@csiro.au
Dr Steve Rintoul, CSIRO and ACECRC, CSIRO Marine Research GPO Box 1538 HOBART TAS 7001 AUSTRALIA, Steve.Rintoul@csiro.au

Adelie Land Bottom Water is a major component of the abyssal circulation of the Australian-Antarctic Basin and the global thermohaline circulation. The formation of dense shelf waters beneath coastal polynyasfrom enhanced sea-ice production and brine rejection duringwintertime is critical to the production of Adelie Land Bottom Waters found in the Australian-Antarctic Basin. This paper reports on dense shelf water formation within theAdelie Depression between 1998-2001 and describes the production of Adelie Land Bottom Water that escapes and mixes with ambient slope waters down the continental slope to abyssal layer of the Australian-Antarctic basin.

The paper is in the form of two posters i) Seasonal evolution and export of dense shelf waters, and ii) Downslope mixing and final production rate of Ad\'elie Land Bottom Water.

In part i) the general circulation and seasonal evolution of key water masses in the Ad\'elie Depression is describedfrom time series of salinity and temperature from moored hydrographic instruments against the Mertz Glacier Tongue and in the sill region. ADCP measurements in the Adelie Sill are used to quantify the export of dense shelf waters from this location.

In part ii) the downslope mixing of cold, dense shelf watersthat escape the Adelie Depression is described. This is the final process in the evolution of ALBW. Hydrographic time series from mooring locations on the continental slope are used to determine the seasonal variability of water masses against the slope. A simple kinematic streamtube model is introduced to examine the final production rate of Adelie Land Bottom Water after the entrainment of ambient circumpolar deep waters into a downslope gravity current of cold dense shelf water increases the volume of the final water mass.

The overall production of ALBW from the Adelie Depressionis sensitive to small-scale changes to the air/sea/ice to the supply of circumpolar deep waters across the slope front. The combination of factors such as sufficient residence volume, critical sill depth, intense sea-ice production (formation and removal), the blocking effect of the MGT and shelf break bathymetry all make the production of ALBW from the Adelie Depression the largest single source of ALBW to the Australian-Antarctic Basin.

It is likely that there are other sites of episodic dense shelf water formation and export along the remaining Adelie Land coastline (depending on the local sea-ice regime and underlying bathymetry). Many other sites may not produce large amounts of shelf waters dense enough to form true ALBW (>2500m depth) but instead partially mix downslope to intermediate depth levels carrying atmospheric gases and nutrients.

Variability of Mass and Property Fluxes in Drake Passage from XBT and Altimeter Measurements

Janet Sprintall and Angela Adams, Scripps Institution of Oceanography. UCSD, Mail Code 0230, 9500 Gilman Drive, La Jolla, CA 92037-0230, USA, jsprintall@ucsd.edu, aadams@ucsd.edu

Year-round monitoring of the upper-ocean temperature variability in Drake Passage has been undertaken since 1996 through XBT measurements. The bimonthly, closely-spaced XBT transects are combined with altimeter measurements to examine the seasonal to interannual variability in mass and property fluxes associated with the Antarctic Circumpolar Current in Drake Passage. The altimeter provides complementary spatial and temporal context for the high resolution XBT measurements, while the XBT data reveals the subsurface structure of the features observed by the altimeter. We will present results from various techniques employed to determine the most effective and accurate method for estimating the circulation and transport of the ACC in Drake Passage, over time scales from weeks to years. Transport estimates of the ACC are further complicated as the Drake Passage is a region of high eddy variability. There is strong agreement between the location of the eddies from XBT and XCTD data with extrema in concurrent maps of altimetric sea surface height data. We use the synergy between the two data sets to determine the number of eddies formed each year, their subsequent motion and rate of decay, and their associated mass and heat flux.

Advances in Modelling the Mediterranean Basin and its Effects on Climate

Dr. Vincenzo Artale , ENEA Casaccia, Progetto Speciale Clima Globale, Unità di Modellistica Oceanografica (CLIM-MOD); Via Anguillarese, 301; 00060 Santa Maria di Galeria, Rome , Italy,
vincenzo.artale@casaccia.enea.it
Dr. Sandro Calmanti, sandro.calmanti@casaccia.enea.it;
Dr. Giovanna Pisacane, giovanna.pisacane@casaccia.enea.it;
Dr. Volfango Rupolo,volfango.rupolo@casaccia.enea.it;

Marginal seas bordering the world's oceans make important contributions to the global thermohaline ocean circulation through their exchange of water with the major oceanic basins. It is well known that some of the intermediate and of the deep-water masses of the world's oceans are produced as the result of intense air-sea exchange in marginal seas. The Mediterranean Sea in this context can be considered an exceptional basin where a wide range of oceanic processes may occur. OGCM (MOM) was used to represent the Mediterranean Sea circulation, and its sensitivity to the surface boundary conditions (e.g. Eastern Mediterranean Transient). In the control run, temperature and salinity were relaxed to climatological values and the basin circulation was simulated for over several hundred years, after reaching a steady state. Starting from the same stationary state, but switching to mixed boundary conditions, the model reached a different final steady state, in which the convective activity in the Eastern Basin and that in the Gulf of Lion seemed to be connected through a cyclic process of salty water intrusion in the Sicily Channel, over multi-decadal time scales. The Mediterranean Outflow (MOW) depends on the variability of the inner basin circulation that in turns is crucially affected by the change in the surface forcing: the mixed boundary conditions acted to destabilize the main circulation cell in the Eastern Basin, and to stabilize that in the Western Basin. These results underlined the critical role of the Sicily channel in the interaction between the eastern and western part of the Mediterranean Sea and of the Gibraltar Strait as an 'active two way' passage that may influence the circulation in the Mediterranean basin and in the North Atlantic Ocean. The Gibraltar Strait represents a key point for the study of the Mediterranean-North Atlantic interaction. In fact, our simulations based on OGCM's (OPA and POM) suggests that important qualitative changes in the structure of the THC may arise from a poor representation of marginal seas and, in general, of intermediate waters, especially when deep convection processes are involved. This poster is a tentative to insert the Mediterranean processes, and its internal variability and the consequent variability of Mediterranean outflowing, in the context of the global ocean thermohaline circulation and in particular the "climatic" role-played by the Strait of Gibraltar, that is the site from which the MOW (Mediterranean Outflow Water) is originated.

IDC-100

The EMA Project, a Study on Mediterranean Water Outflow and Dispersion in the North-East Atlantic

Virginie Thierry, IFREMER, DRO/DOPS/LPO, BP 70, 29280 Plouzane cedex, France, Virginie.Thierry@ifremer.fr
Xavier Carton, Xavier.Carton@ifremer.fr
Pascale Lherminier, plhermin@ifremer.fr

Mediterranean Water (hereafter MW) enters the North Atlantic through the Straits of Gibraltar and form a large-scale tongue of « source water » at 1000m whose mixing determines the distribution of water masses over a wide range of depths in the whole North Atlantic basin. Though we know that MW noticeably contributes to the thermohaline circulation, interacts with surface currents and with intermediate and deep water masses, we still lack quantitative estimates of these contributions. In particular the impact of MW on climate variability and on the formation of deep waters is still an open question. The long-term variability of the outflow of MW as well as of its mesoscale features (meddies in particular), the quantitative estimate of heat and salt fluxes associated with meddies are other unknowns or still debated values. Finally reproducing MW outflow and evolution in primitive-equation models (even with surface data assimilation) is as yet an unmet challenge.

The EMA project not only aims at a better understanding of the MW processes, but also at improving operational model (data assimilation, model validation). During the first stage of the experiment (2004-2006), existing data will be analyzed and in-situ sensors (multicycle acoustic and profiling floats, gliders, acoustic tomography) will be developed and tested. During the second stage of the experiment (2007-2009), long-term monitoring of exchanges between the Mediterranean Sea and the Atlantic Ocean will be performed, and observational networks allowing correlations between upstream and downstream variability (at Gibraltar, along the Iberian shelf and in the ocean interior) will be installed to quantify this variability and in particular meddy formation.

IDC-101

A Basin-Wide Oscillation of the Mediterranean Sea

Ichiro Fukumori , JPL M/S 300-323, 4800 Oak Grove Dr, Pasadena, CA, 91109, USA, fukumori@jpl.nasa.gov
Benyang Tang, btang@pacific.jpl.nasa.gov
Tong Lee, JPL M/S 300-323, tlee@pacific.jpl.nasa.gov
Dimitris Menemenlis, menemenlis@jpl.nasa.gov

A new prominent mode of oscillation is described in the Mediterranean Sea. More than 50\% of the non-tidal, non-seasonal, sea leve fluctuation of the Mediterranean Sea can be attributed to an oscillation that is nearly uniform in phase across the basin. The oscillation, measured by satellite altimetry, has a period ranging from 20-days to several months and has an amplitude as large as 10 cm. Standard corrections are applied to the altimeter data, including tidal and inverse barometer corrections. Ocean model estimates of the Consortium for "Estimating the Circulation and Climate of the

Ocean" (ECCO; http://www.ecco-group.org) is analyzed to examine the nature of this fluctuation and to elucidate its forcing mechanism. The model is highly coherent with the altimetric observations and suggests that the observed oscillation is a barotropic fluctuation of the entire basin. Model sea level changes are compatible with ocean bottom pressure variability and with expected eustatic changes corresponding to net fluctuations in mass transport through the Strait of Gibraltar. Transport changes through the Strait, and consequently the observed Mediterranean Sea oscillation, is found to be mostly driven by variation of the winds in the vicinity of the Strait.

OC-102

Coupled Modes of Variability in the South Atlantic

Dr. Edmo J. D. Campos, IOUSP/DOF, Pca. do Oceanografico, 191 Cid. Universitaria, 05508-900 Sao Paulo, SP, Brazil, edmo@usp.br
Mr. Roberto A. F. de Almeida, Instituto Oceanográfico, Universidade de São Paulo (IOUSP)
Dr. Reindert J. Haarsma, Royal Netherlands Meteorological Institute (KNMI)
Dr. Rainer Bleck and Dr. Carlos A. D. Lentini, Los Alamos National Laboratory (LANL)

An investigation of the coupled modes of variability in the South Atlantic was carried out with Wei Cheng's output of an ocean-atmosphere model (MICOM+CCM3) run at the Los Alamos National Laboratory. The main objective was to compare the model patterns of variability, from interannual to multidecadal time-scales, with results of similar analyses with the NCEP data set. Analysis of the numerical model output, with the use of Empirical Orthogonal Functions and Maximum Covariance Analysis (MCA) between SST and MSLP with zer lag, produces dipolar modes of SST variability very similar to those reported in the scientific literature in recent years.

Lead-lag MCA indicate the existence of two modes of variability of the atmospheric South Atlantic Convergence Zone (SACZ). This result is similar to the results of previous work. One of these modes is a result of remote forcing while the other is a local response to the oceanic forcing. The differences between the two analyses are due to the different climatological states of the data and the model output: there is an excessive southward displacement of the Austral Summer ITCZ in the model result.

OC-103

The Mesoscale Circulation of the South Atlantic Ocean

Dr. Ricardo P. Matano, College of Oceanic & Atmospheric Sciences, Oregon State University, Corvallis, OR 973331-5506, USA, rmatano@coas.oregonstate.edu
Dr. M. Schouten, University of Utrecht, The Netherlands, m.w.schouten@phys.uu.nl
Dr. E. Palma, Universidad Nacional del Sur, Argentina, uspalma@criba.edu.ar
Dr. Edmo Campos, University of Sao Paulo, Brazil,ecampos@io.usp.br

Since Gordon's (1986) influential article on the workings of the global thermohaline circulation (GTC), numerical and observational studies have attempted to estimate the magnitude of the South Atlantic heat and salt fluxes. Most of these studies, however, did not considered the role of mesoscale processes in the determination of the pathways and variability of the GTC. Neglect of mesoscale process has no scientific justification. Rather it has resulted from the lack of both data and the computing power required to resolve simultaneously the short period, mesoscale processes responsible for the upper portion of the GTC, and the long period, large-scale processes responsible for the deeper branches. This presentation discusses the role of the South Atlantic's mesoscale variability on the upper branch of the GTC. The analysis of recent eddy-permitting numerical simulations and observations indicate that the water mass characteristics of the upper limb of SA branch of the GTC are largely determined at the highly energetic eastern and western boundary regions (the Brazil/Malvinas Confluence and the Agulhas Retroflection Region). Since these regions are also choke points of the GTC, we postulate the need to improve our understanding of the linkages between these regions and the large-scale circulation. In particular, we argue that for predictability purposes it is not sufficient to know the magnitude of the inflows south of Cape Horn and the Cape of Good Hope to determine the export of thermocline waters to the North Atlantic because the characteristics of the northward fluxes depend on time and spatial scales set by the South Atlantic's circulation.

IDC-104

Large Scale Features of the South Atlantic Ocean Subduction Process

Mr. Marlos P. A. Goes, Instituto Oceanografico da Universidade de Sao Paulo, Praca do Oceanografico, 191 - Cidade Universitaria, Sao Paulo/SP, 05508-900
marlos@usp.br
Dr. Ilana E. K. C. Wainer, wainer@usp.br

In this study we focus on the large scale features of the South Atlantic Ocean Subduction process. The region studied goes from 10S-40S and from 70W-30E. In order to do this we used 50 years of a simulation of Community Climate System Model (CCSM) from the National Center for Atmospheric Research (NCAR) and calculated the monthly entrainment (instantaneous subduction) fields. At first we tested Stommel's mixed layer "demon" theory, which states that the subduction into the permanent thermocline is strongly biased by toward the late winter values, in an EOF (Empirical Orthogonal Functions) basis, applying the method on the entrainment field. The first EOF mode represents 65% of the total variance and shows the same signal in the whole basin. Its related time series shows a seasonality with maximum positive values (detrainment) occurring during late winter and early spring (September-October) and negative values (entrainment) occurring, with less intensity, during late fall and early winter (mainly in June). In a second step, the interannual variability of the entrainment field anomalies is studied, and associated with the atmospheric fluxes. The main EOF mode (18%) is dipole-like, and presents a blue spectrum due to atmospheric influences. However, the advective terms of the instantaneous subduction presents a red spectrum with the highest energy with a periodicity in decadal and interannual time scales.

Good-Hope / Southern Ocean : Monitoring the Indo-Atlantic Connections an International Co-Operative Project a Process Study and a Contribution to CLIVAR - Southern Ocean

Dr. Sabrina Speich, Laboratoire de Physique des Oceans, Universite de Bretagne Occidentale, UFR Sciences 6, avenue Le Gorgeu - BP 809, 29285 Brest Cedex, France, sabrina.speich@univ-brest.fr
Dr. Deirdre Byrne Deirdre, School of Marine Science, University of Maine, Orono, Maine, USA, Dbyrne@umeoce.maine.edu
Drs. Olaf Boebel and Eberhard Farbach, Alfred-Wegener Institut, Bremerhaven, Germany, oboebel@awi-bremerhaven.de & Efahrbach@awi-bremerhaven.de
Dr. Isabelle Ansorge, Department of Oceanography, University of Cape Town, Rondebosch 7000, South Africa, Ansorge@ocean.uct.ac.za
Dr. Serguey Gladyshev, Shirshov Institute, Moscow, Russia, Gladyshev@sio.rssi.ru
Drs Silvia Garzoli and Gustavo J. Goni, AOML-NOAA, Miami, USA, Silvia.Garzoli@aoml.noaa.gov & Gustavo.Goni@aoml.noaa.gov
Dr. Michel Arhan, Laboratoire de Physique des Oceans, IFREMER, Plouzane, France, marhan@ifremer.fr
Dr. Alexander Klepikov, Arctic and Antarctic Research Institute, St. Petersburg, Russia, Klep@aari.nw.ru
Dr. Marta Alvarez Rodriguez, Instituto de Investigaciones Mariñas, CCSIC, Vigo, Spain, malvarez@iim.csic.es
Dr. Brian King, James Rennel Division, Southampton Oceanography Center, Southampton, UK, b.king@soc.soton.ac.uk

The Southern Ocean (SO) plays a unique role in coupling the ocean to the atmosphere and cryosphere. Variations in the mechanisms responsible for this coupling are thought to be linked to the global climate variability. The state of observations and modelling of the Southern Ocean is not as well-developed as in other regions of the ocean and atmosphere. While major achievements were made during the WOCE/JGOFS era, we still have only an incomplete glimpse of the mean state and variability of the Southern Ocean, its coupling with the atmosphere and cryosphere, and the zonal and meridional fluxes. SO observations are dramatically sparse in space and time; consequently, further emphasis on exploratory investigations in the Southern Ocean needs to be placed than in better-sampled ocean basins.

While the Southern Ocean dynamics is suspected to have a major role in the global ocean circulation and present day climate, our understanding of its three-dimensional dynamics, variability, and the impact of such variability on the climate system, is rudimentary. The GoodHope project aims to partially fill in this knowledge gap by periodic observations along a line between the African and Antarctic continents. The objectives are fourfold:

* A better understanding of the Indo-Atlantic interocean exchanges (in term of water masses, heat and fresh-water budgets) and their impact on the global thermohaline circulation and present climate;

* A better understanding of the impact of these interocean exchanges on the local climate of the African continent;

* A through characterization of the variability of particular dynamical features (Antarctic Circumpolar Current, frontal systems, …);

* A quantification of the local air-sea exchanges and their role on the global heat budget (with emphasis on the intense exchanges in the Agulhas Retroflection region).

The GoodHope line extents from Cape Town southeast along Jason groundtrack 133. At the northern edge it passes over the US ASTTEX moorings; at the Greenwich meridian it turns south eventually intersecting the German WECCON moorings. Due to the large extent of the section and the need of a long-term commitment, this project is conducted in co-operation with various scientific institutes of different countries. The monitoring is done using a combination of the following observational tools: Altimetry, high density XBTs, XCTDs, profiling floats, subsurface floats, drifters, thermosalinograph; oxygen, nutrients, and chlorophyll samples. Complete CTD sections (hydrography and biogeochemistry) will be carried out every 2 to 5 years. Argo profiling floats will be deployed over the entire section.

The project focuses on high resolution measurements in order to resolve the mesoscale features and unalias the observations that are devoted to the measurement of global climate variability and climate change, in addition to providing basic information about the seasonality and mean state along the section. It follows that our goal is an extended deployment in time of all the actual measurements and an expansion of the number of actual moorings.

IDC-106

Possible Mechanisms Leading to Extreme Cold Events in Southern-Central South America

Mrs Gabriela V. Muller, Department of Atmospheric Sciences - University of Sao Paulo, Rua do Matão, 1226 - Cid. Universitária, São Paulo, SP, Brazil, CEP: 05508-090, gabriela@model.iag.usp.br
Msc. Simone E. T. Ferraz, simonefe@model.iag.usp.br
Dr. Tercio Ambrizzi, ambrizzi@model.iag.usp.br

A multilevel primitive equation model is used to examine a possible influence of the convection in the tropical west Pacific and frost events in the region called Pampa Humeda in the center-east Argentina during austral winter. The sensitivity of the phase and amplitude of the quasi-stationary Rossby wave response to the heating anomaly over the tropical west Pacific ocean is examined through numerical simulations. The model was integrated for 15 days and perturbated with a heating source coincided in the same positions of the OLR anomalies observed in winter (JJA) composites These composites are separated in two groups, where the numbers of generalized frost events were above (AA) or below (BA) average, considering the standard deviations. The composite analyses suggest a clear connection between tropical convection and cold surges. It seems that there is an interaction between the subtropical and subpolar wave

guides creating the right wave phase for the trough amplification over the Pampa Humeda region. Our numerical results showed that there is a convergence pattern of the subtropial and subpolar jets in years with generalized frost events above the average (AA). Therefore, synoptic systems are conducted through the continent, with cold air advection from the south-southwest direction and possible occurrence of frost events.

During BA events there is only the presence of the subtropical jet. In terms of the wave theory and from comparison of the observational and numerical results it is suggested that frost events may occur when the subtropical and subpolar waveguides are in phase, which allow the incursion of large amplitude trough from the South part of South America.

IDC-107

South Atlantic Links and Impacts on Regional and Global Climate

Dr. Alice M. Grimm, Physics Dept., Federal University of Paraná, Caixa Postal 19044, Centro Politécnico, Bloco 2, 81531-990 Curitiba, PR, Brazil, grimm@fisica.ufpr.br
Dr.Andrew W. Robertson, International Research Institute for Climate Prediction, 61 Rt. 9W, PO Box 1000, Palisades, NY 10964-8000, USA, awr@iri.columbia.edu
Dr. Chris Reason, Oceanography Dept., University of Cape Town, Private Bag Rondebosch 7701, 9 University Avenue, South Africa, cjr@egs.uct.ac.za

This paper reviews the South Atlantic (SA) impacts on the regional climate, in South America and Africa, as well as links with the global climate. As part of a variability pattern also affecting other parts of South America, the rainy season in Northeast (NE) Brazil, in austral autumn, is influenced by changes in the meridional gradient of SST across the equator, which cause shifts in the Atlantic ITCZ. Autumn rainfall over NE Brazil is better correlated with the Tropical South Atlantic (TSA) SSTA in the preceding seasons than with those in the Tropical North Atlantic (TNA). The TSA anomalies also appear to be more predictable than those in TNA. Pre-existing anomalies in TNA and TSA act as a preconditioner of the predictability of NE Brazil rainfall during ENSO events. There are also links between the Sahelian rainfall and the meridional SST gradient.

The influence of tropical Atlantic SSTAs on the South American Monsoon System (SAMS) is much less clear than on the NE Brazil rainfall. SSTAs over TNA and TSA seem to influence precipitation over the Parana River basin, but there are still inconsistencies between different studies. It is difficult to separate the effect of the meridional SST gradient from the effect of ENSO and NAO, which alter this gradient, and which themselves affect rainfall over South America. The South Atlantic Convergence Zone (SACZ) forms a subtropical extension of the SAMS. Interannual SACZ variations over the continent are associated with a dipole of vertical motion over the SACZ and over the southern plains, and with dipolar SSTAs over the SA, such that cold SSTAs underlie an intensified SACZ. AGCM responses to such SSTAs show atmospheric anomalies of opposite polarity to the observed ones. A largely negative feedback exists between the atmosphere and the ocean in the SACZ region, with warm

SSTA favoring the intensification of the SACZ, which, in turn, reduces the incoming solar radiation, due to increased cloudiness. Observations show that enhanced January precipitation in eastern Brazil is associated with cooler SSTs off the coast and is preceded by less than normal spring precipitation accompanied by warmer SSTs in the same region. Observed covariability between the subtropical high and underlying SSTA indicate that the subtropical Atlantic is largely a passive basin, with SSTA tending to result through the surface fluxes associated with changes in the subtropical high.

Evidence exists that SST variability in the tropical to midlatitude SA influences southern African rainfall. The most well known signals concern, firstly, a relationship between warm and cold events in the tropical eastern SA and late summer rainfall over Angola and Namibia, and secondly, winter frontal rainfall in southwestern South Africa and midlatitude SST patterns. The former appear to originate as equatorial Kelvin waves in response to modulations of the trade winds over the tropical South Atlantic whereas the latter involves shifts in the jet and storm tracks over the midlatitudes, which seem to be also related to modulations of the Antarctic Oscillation. There are also indications of connection between interdecadal variability in SA and southern Africa rainfall. Possible links between SA and global variability modes as well as global climate are also presented.

IDC-108

North Brazil Current: Rings, Retroflection, and Transports

Dr. Christopher S. Meinen, NOAA/AOML/PHOD, 4301 Rickenbacker Causeway, Miami, FL 33149, USA, Christopher.Meinen@noaa.gov
Dr. Silvia L. Garzoli, Silvia.Garzoli@noaa.gov

The North Brazil Current Rings (NBCR) experiment involved an array of 14 inverted echo sounders (IESs) as well as current meters, a moored bottom pressure gauge, and several hydrographic cruises. Earlier analyses of the NBCR data provided insights into the variability of the latitude of the North Brazil Current (NBC) retroflection and the number of rings shed during this process. A subset of the data was also analyzed to obtain the transport of the NBC both before and after the retroflection. These analyses indicated that there is a relation between the latitude of NBC separation and the intensity of the NBC flow. The different types of instruments used in the study (IES, current meter, altimetry, color, SST products) have produced some differing estimates of the number of rings observed during the study. This presentation will seek to explain these disparities in observations, and will further quantify the relationship between North Brazil Currenttransport, ring formation, and retroflection location. New details of the vertical structure of the temperature andvelocity of these rings will also be presented. These results are produced by making use of the combined IES, hydrographic, and velocity data and by analyzing the IES data using the gravest empirical mode method.

IDC-109

Interannual Variation of the Sea Level in the South Tropical Atlantic Based on Satellite Altimeter Data.

Semyon A. Grodsky, 224 Computer and Space Science Building, Department of Meteorology, University of Maryland, College Park, MD 20742 USA, senya@atmos.umd.edu
James A. Carton, carton@atmos.umd.edu

Recent examinations of the historical record (see e. g. Melice and Servain, 2003) identify two interannual signals and a longer ~20 year cycle in South Atlantic climate. The latter appears in SST and atmospheric sea level pressure and seems to be related to the anticyclonically rotation of the oceanic subtropical gyre. When these SST anomalies pass through the tropics they enhance the interhemispheric gradient of SST, thus providing an additional link between climate fluctuations in the Southern Hemisphere and the tropics. Our preliminary examination of the 18-yr combined GEOSAT and TOPEX/POSEIDON Monthly Multi-Mission SSH anomaly fields (available at the Pathfinder archive at GSFC/NASA) also reveals interannual and decade signals in anomaly SSH and their relationship to the wind-driven ocean dynamics. The corresponding spatial pattern indicates the northwest-southeast oriented trough that corresponds to the cyclonic slowdown of the southern subtropical gyre that, in turn, corresponds to enhancement of Ekman pumping. The correlation between the time series illustrates the impact of the winds on the interannual intensity of the gyre in the south Atlantic. The same data sets are also used to study the interannaul variation of the Agulhas current eddy shedding.

IDC-110

The Role of the South Atlantic and Inter-Ocean Exchanges on the Thermohaline Circulation

Wilhelmus P.M. De Ruijter, Institute for Marine and Atmospheric Research, Utrecht University, Princetonplein 5, 3584 CC Utrecht , Netherlands, ruijter@phys.uu.nl
Edmo J.D. Campos, Instituto Oceanografico, Universidad de Sao Paulo, Sao Paulo, Brazil, edmo@io.usp.br
Stuart A. Cunningham, Southampton Oceanography Centre, Empress Dock, Southampton, UK, Souscu@soc.soton.ac.uk
John Donners, Royal Netherlands Meteorological Institute, De Bilt, The Netherlands, donners@knmi.nl
Arnold L. Gordon, Lamont Doherty Earth Observatory of Columbia University, Palisades NY, 10964, USA, agordon@ldeo.columbia.edu
Johann R.E. Lutjeharms, Department of Physical Oceanography, University of Cape Town, South Africa, jre@mweb.co.za
Ricardo P. Matano, College of Oceanic and Atmospheric Sciences, Oregon State University, Corvallis, OR 97331, USA, rpm@oce.orst.edu
Doron Nof, Florida State University, Tallahassee, Florida, USA, nof@ocean.ocean.fsu.edu
Alberto R. Piola, Departamento Oceanografia, Servicio de Hidrografia Naval, Av. Montes de Oca 2124, 1271 Buenos Aires, Argentina, apiola@hidro.gov.ar

Formation of North Atlantic Deep Water (NADW) and the associated sea-air heat flux are major elements of the climate system. Export of NADW through the South Atlantic to other ocean basins requires a compensating northward flow across the equator. Heat and mass exchange between the South Atlantic and the Indian and Pacific Oceans are of critical importance for the global thermohaline circulation and its variability. The South Atlantic is the gateway by which the Atlantic meridional overturning circulation (MOC) communicates with the global ocean, exchanging properties and mass with the Indian and Pacific via the Southern Ocean and around South Africa. These inter-ocean links make possible the unique global reach of NADW and of the compensating return flow within the ocean upper layers.

Waters of Pacific, Indian, Atlantic and Southern Ocean origin collide and blend in the Argentine and Cape Basins where large sea-air buoyancy fluxes lead to intense vertical mixing, convection and subduction. These processes may be effective short-circuits of the MOC. Eventually, the transformed water masses feed the Benguela Current and subsequently the upper equatorward limb of the MOC of the Atlantic. Their temperature and salinity characteristics control the buoyancy budget and overturning of the Atlantic. The varying ratio between the input of cool - fresh Pacific waters around South America and the warm - salty Indian Ocean waters around South Africa, and from the varying intensity of the water mass transformation processes in the southwest Atlantic and the Cape Basin may modulate NADW formation. Modeling studies have shown that Agulhas leakage stimulates and stabilizes the Atlantic MOC while northern fresh water fluxes oppose and destabilize it. In the present day situation the stabilizing southern ocean fluxes dominate, but with reduced Indian Ocean input the northern overturning is expected to be close to a switch to a different mode, with associated climate fluctuations. Other studies conclude that cold waters from Drake Passage dominate. Not surprisingly, estimates of the meridional heat flux through the South Atlantic are greatly uncertain.

A South Atlantic monitoring program shoudl involve measurements of these varying fuxes and the air-sea fluxes and estimates of the modifications in the two major blending regions. To monitor the net effect of the varying interocean exchanges and subsequent mixing and water mass modifications on the vertical buoyancy characteristics of the South Atlantic and the basin-scale overturning fluxes a zonal section is proposed across the South Atlantic at about 30S.

IDOC-111

Water Mass Structure and Circulation in the Equatorial and South Atlantic Ocean

Dr. Alexander N. Demidov, Dept. of Oceanography, Vorobyovy gory, Moscow, 119992 Russia, tuda@mail.ru

Objectives of this investigation were to determine water mass boundaries below main thermocline, to compare methods of their evaluation and to obtain water mass transport in the South Atlantic, a transit region of the interoceanic circulation ("conveyor belt"). Boundaries of water masses were obtained by different methods: by maximal gradients of different tracers, by Brent-Vaisala frequency, by minimal oxygen concentration and by the fixed values of potential temperature on the potential density fields (sigma-2). WOCE hydrographic section data in the Equatorial and the South

Atlantic ocean (40°S -10° N) were used. Boundaries of water masses were defined more precisely. The method of maximal property gradients revealed closest correspondence practically of all water mass boundaries: the maximal gradients of different characteristics usually coincided. The results allowed to conclude that the Upper and Lower components of the North Atlantic Deep water (NADW) were mainly of the same origin. This hypothesis is in a good agreement with values of CFCs. It was also obtained that the Lower NADW, which penetrated to the Indian Ocean, was mainly the product of interaction between the Mediterranean and Antarctic origin waters. From this point of view the division of Antarctic Bottom water into Lower Circumpolar Deep water and Weddel Sea water was not correct. Water mass transport was obtained within the determined boundaries. Ekman transport was computed from satellite data (ERS-1), geostrophic component - from CTD latitudinal section data. As a result, a new scheme of the large-scale deep circulation was reconstructed.

OC-112

Mechanisms Generating the Dominant Modes of Variability in the South Atlantic Ocean: A Study with a Hierarchy of Ocean-Atmosphere Models

Dr. Reindert J. Haarsma, Royal Netherlands Meteorological Institute (KNMI), P.O. box 201, 3730 AE De Bilt, The Netherlands, haarsma@knmi.nl
Dr. Edmo J.D. Campos, Oceanographic Institute, University of Sao Paulo. Praca do Oceanografia 191, Cidade Universitaria, CEP 05508-900, Sao Paulo, Brazil edmo@io.usp.br
Dr. Wilco Hazeleger, Royal Netherlands Meteorological Institute (KNMI), P.O. box 201, 3730 AE De Bilt, The Netherlands, hazelege@knmi.nl
Dr. Alberto R. Piola, Servico de Hidrografia Naval, Av. Montes de Oca, 2124, C1270ABV, Buenos Aires, Argentina, apiola@hidro.gov.ar
Dr. Franco Molteni, The Abdus Salam International Centre for Theoretical Physics, Strada Costiera 11, Miramare, Trieste, 34014, Italy, moltenif@ictp.trieste.it
Dr. Camiel Severijns, Royal Netherlands Meteorological Institute (KNMI), P.O. Box 201, 3730 AE De Bilt, The Netherlands. severijn@knmi.nl

Using an atmosphere model of intermediate complexity and a hierarchy of ocean models the dominant modes of interannual and decadal variability in the South Atlantic Ocean are studied.

The atmosphere model SPEEDY has T30L7 resolution. The physical package consists of a set simplified physical parameterizations schemes, based on the same principles adopted in the schemes of state-of-the-art AGCM's. It is at least an order of magnitude faster, whereas the quality of the simulated climate compares well with those models. The hierarchy of ocean models consists of simple mixed layer models with an increasing number of physical processesinvolved such as Ekman transport, wind-induced mixing and wind-driven barotropic transport. Finally the atmosphere model is coupled to a regional version of the MICOM ocean model covering the South Atlantic with a horizontal resolution of 1 degree and 16 vertical layers.

The coupled modes of mean sea level pressure and sea surface temperature simulated by SPEEDY-MICOM strongly resemble the modes as analyzed from the NCEP/NCAR reanalysis, indicating that this model configuration posseses the required physical mechanisms for generating these modes of variability. Using the ocean model hierarchy we were able to show that turbulent heat fluxes, Ekman transport and wind-induced mixing contribute to the generation of the dominant modes of coupled SST variability. The different roles of these terms in generating these modes are analyzed. Variations in the wind-driven barotropic transport mainly seem to affect the SST variability in the Brazil-Malvinas confluence zone.

OC-113

The Role of the South Atlantic in the Variability of the ITCZ

Yochanan Kushnir, Lamont Doherty Earth Observatory, 61 Route 9W, Palisades, NY 10964, USA, kushnir@ldeo.columbia.edu
Marcelo Barreiro and Ping Chang, Dept. of Oceanography, Texas A&M University, College Station TX 77843 USA, marcelo@mako.tamu.edu, ping@tamu.edu
John C.H. Chiang, Dept. of Geography, 547 McCone Hall, University of California, Berkeley CA 94720, jchiang@atmos.berkeley.edu
Alban Lazar, University of Paris VI, Case 100, 4 Pl. Jussieu, 75252 Paris Cedex, France, Alban.Lazar@lodyc.jussieu.fr
Paola M. Rizzoli, Department of Earth, Atmospheric & Planetary Sciences, MIT, Cambridge, MA 02139 USA, rizzoli@mit.edu

In the tropical Atlantic region, the ITCZ and the related atmosphere and ocean elements, such as the trade wind systems and the latitudinal distribution of SST are the most outstanding climatic feature. The ITCZ controls rainfall and other climatic impacts (e.g., storms and dust transport) in regions with high population density. The annual latitudinal ITCZ migration and its significant interannual variability have direct impact on society. The ITCZ in the Atlantic is extremely sensitive to small changes in regional surface temperature gradients and external atmospheric influences. Much smaller SST anomalies than those associated with ENSO have significant impact on rainfall in NE Brazil and West Africa. There is modeling evidence of strong coupling between SST and convection variability near the equator that allows for external influences to create significant impacts. This setting implies that anomalies in the South Atlantic atmosphere and ocean can set off an interaction that is as effective in modulating ITCZ variability in addition to the well documented effects of ENSO and the North Atlantic Oscillation. This paper reviews the pattern and impact of ITCZ variability in the tropical Atlantic region to set the stage for understanding how the South Atlantic can impact this sensitive system.

We discuss evidence for perturbations in the wintertime South Atlantic midlatitude atmosphere that work somewhat similar to the NAO in perturbing the tradewinds. This leads to a near-equatorial, positive wind-SST feedback that affects the cross equatorial SST gradient and the position of the ITCZ in the following boreal spring. Also discussed are ocean mechanisms that on a multi-year time scale can transmit

signals from the South Atlantic to the tropics such that SST there is affected. It is hypothesized that these ocean mechanisms are also a source for ITCZ variability.

OC-114

Transport of South Atlantic Water into the Caribbean and Across 16°N

Monika Rhein, Institut fuer Umweltphysik, University Bremen, Otto-Hahn-Allee, D-28203 Bremen, Postfach 28334, Germany, mrhein@physik.uni-bremen.de
Christian Mertens, cmertens@physik.uni-bremen.de
Ulrich Fleischmann-Wischnath, ufleischmann@physik.uni-bremen.de

About 35 Sv South Atlantic water above 1200m depth are transported into the North Atlantic. This transport is by far higher than the estimated strength of the thermohaline circulation of 14-20 Sv leaving a significant part of that flow to be transfered back into the South Atlantic. The South Atlantic water remaining in the North Atlantic forms the warm water path of the meridional overturning circulation. It consists of warmer upper water, which is separated from the intermediate water by the isopycnal sigth=27.1, located between 400-600m depth in the equatorial Atlantic. Both layers may have about equal transports, but some papers report a more dominating flow of intermediate water. The upper warm water is thought to flow into the Caribbean to later join the Florida Current. The flow of intermediate water into the Caribbean is more restricted due to the narrowness of the passages at deeper levels and will mainly flow polewards east of the Caribbean in the western boundary current. This Atlantic route might also be taken by the upper warm water.

We present hydrographic and direct current measurements carried out between December 2000 and June 2003 in the Windward Islands passages south of Guadeloupe and adjacent regions. These measurements are complemented by data taken along 16°N in the western Atlantic. Southern and northern hemispheric source water masses are defined for various density layers to determine the contribution of South Atlantic water. The transports are calculated from the horizontal flow fields measured continually along the track lines by vessel mounted ADCPs, extended – if necessary - with lowered ADCP profiles. The transports and fractions of South Atlantic water are then combined to estimate the transport of South Atlantic upper warm water and intermediate water into the Caribbean and in the Atlantic pathway across 16°N.

OC-115

Validation of 1980-2000 High-Resolution Atlantic Ocean Simulations against the Woce Current Meter Dataset: Method and First Results.

Dr. Thierry Penduff, LEGI-MEOM, BP53, 38041 Grenoble Cedex 9, France, Thierry.Penduff@hmg.inpg.fr
Bernard Barnier, Bernard.Barnier@hmg.inpg.fr.
Jean-Marc Molines, Jean-Marc.Molines@hmg.inpg.fr

The solutions of forced and coupled Ocean General Circulation Models (OGCMs) are becoming increasingly detailed and abundant. To evaluate their realism requires careful and quantitative comparisons with complementary datasets. Current meter datasets are not widely used to validate OGCM solutions because of their local character, limited duration, and sparsiness. However, they provide an additional reference that is essential with respect to the vertical structure of simulated dynamics.

In this study we define and compute different estimates of the misfit between the velocity fields (mean and variance) observed at WOCE moorings over the period 1980-2000 and their exact counterparts extracted from different 20-year 1/6-degree Atlantic CLIPPER simulations. The significance of these misfits is evaluated. Despite the relative sparsity of the dataset, our results highlight general features of our model's deficiencies as a function of depth, location, etc. These results might help initiate future ocean model development, and allow the use of model simulations to estimate the representativeness of in-situ currentmeters measurements.

OC-116

Relationship of Equatorial Atlantic Surface Current Divergence, Sea Surface Temperature, and Surface Winds

Dr. Robert W. Helber, College of Marine Science, University of South Florida, 140 7th Avenue South, St. Petersburg, Florida, 33701 USA, helber@marine.usf.edu
Dr. Robert H. Weisberg, weisberg@marine.usf.edu
Dr. Fabrice Bonjean, Earth and Space Research, 1910 Fairview Ave. E., Suite 210, Seattle, WA 98102, USA, bonjean@esr.org
Dr. Gary S. E. Lagerloef, lager@esr.org

The dynamical relationships of equatorial Atlantic surface currents, sea surface temperature (SST), and wind variability on time-scales from monthly-to-interannual are described and diagnosed. Surface divergence (upwelling) is calculated (10/1992 to 01/2003) using 0-30 m layer surface currents, estimated by a quasi-linear steady state model from satellite sea surface height (SSH), surface vector wind, and SST. Three dynamical contributions to the surface divergence, including goestrophy, Ekman dynamics, and buoyancy gradient, are considered together and separately. Together, the total surface divergence exhibits a season of upwelling in the central/eastern equatorial Atlantic that peaks in May prior to the annual SST cooling within the equatorial cold tongue. In the far western equatorial Atlantic, correlation of divergence with SST is weaker since the thermocline is deeper. Canonical Correlation Analysis supports these relationships and the surface wind field variability is qualitatively consistent. Separately, geostrophy and Ekman dynamics each have a different contribution at various phases of equatorial cold tongue evolution and at various longitudes. Geostrophy tends to converge while Ekman dynamics diverge so that the resulting total divergence is the difference. Buoyancy effects play a minor role.

OC-117

The Heat Budget of the Equatorial Mixed Layer

Markus Jochum, Raghu Murtugudde, Raffaele Ferrari, Paola Malanotte-Rizzoli
MIT and UMD, 77 Mass Ave 54-1410, MIT, 02138 Cambridge, MA, USA,
markus@ocean.mit.edu

An ocean general circulation model of the tropical Atlantic coupled to an advective atmospheric boundary layer model is used to investigate the effect of changing the horizontal resolution on the SST. It is found that simple horizontal diffusion in coarse resolution models can be a reasonable approximation to the equatorward heat transport of the tropical instability waves but leads to a warmpool that is too cool by approximately 1K because diffusion moves heat from the warmpool to the equatorial cold tongue.

The tropical instability waves, which draw their heat mostly from the atmosphere and not from the warmpool, bring slightly more heat to the equatorial cold tongue than the diffusion in the coarse resolution experiment, but this increased heat is pumped below the surface by an increased equatorial entrainment.

This is attributed to the Equatorial Undercurrent being stronger in the high resolution experiment, thereby increasing the entrainment rate through shear instability. Thus, higher resolution does not significantly increase the total oceanic heat flux convergence in the equatorial mixed layer. The different resolution does, however, lead to changes in the atmospheric heat flux convergence, because the sharper cross-equatorial temperature gradient in the high resolution experiment leads to reduced latent and sensible heat losses over the equator.

OC-118

Applications of a Data Assimilation Method to Study the Tropical Atlantic

Dr. Clemente A. S. Tanajura, Av. Getúlio Vargas 333, Petrópolis, RJ, 25651-075, Brazil, cast@lncc.br
Dr. Konstantin Belyaev, kostia@lncc.br

Data assimilation methods play a key-role in the investigation and prediction of the climate system. In the present work, a specific data assimilation method based on the Kalman filter theory is applied to study dynamical aspects of the tropical Atlantic ocean. Unlike the standard Kalman technique, this method exploits the Fokker-Planck equation and the phase space representation for the evolution of the co-variances of the model error.

The present study uses the GFDL/NOAA Modular Ocean Model (MOM), version 3, and temperature data from the PIRATA array. The impact of the assimilation is assessed by comparing the model simulations with and without assimilation. The local and remote influence produced separately and jointly by each PIRATA buoy is presented, including their temporal and spatial tri-dimensional distributions.

A correction scheme to threat the perturbation on the velocity field due to assimilation of temperature is also considered. The method is based on the normal mode approach. It is shown that the method decreases the velocity oscillations caused by the perturbations of density due to assimilation of temperature.

OC-119

Internal Variability of the Tropical Atlantic

Markus Jochum, Raghu Murtugudde, Paola Malanotte-Rizzoli, Antonio Busalacchi; 77 Mass Ave, 54-1410, MIT, O2138 Cambridge, MA, USA; markus@ocean.mit.edu

A 100 year integration of an eddy resolving numerical model of the tropical Atlantic is analyzed to quantify the interannual variability caused by internal variability of ocean dynamics. It is found that, except for the spring position of the SST maximum, the strength of internal variability in the tropical Atlantic is comparable to published mid-latitude values but is dwarfed by the strength of the seasonal cycle. During spring however, the equatorial meridional SST gradient is very weak, and internal oceanic variability causes a variability in the position of the SST maximum that is comparable to its observed variability. It is shown that these variations in the SST are due to tropical instability waves whose strength varies from year to year, even under climatological forcing. The results suggests that in winter, the predictability of the location of the tropical SST maximum is limited to the persistence time of SST anomalies which is approximately 100 days.

OC-120

Decadal Variability of Shallow Cells and Equatorial SST in a Numerical Model of the Atlantic

Dr. Juergen Kroeger, 2207 CSS Building 224, College Park, MD 20742, USA kroeger@essic.umd.edu

The relative role of extra-equatorial mechanisms modulating decadal SST anomalies in the equatorial Atlantic is investigated using an ocean general circulation model (OGCM) forced by observed wind stress and/or computed heat flux from the associated advective atmospheric mixed layer model.

Longterm variability of the shallow meridional overturning circulation, the Subtropical Cells (STCs), which conduit subducted water to lower latitudes, can lead to significant SST anomalies in the eastern tropics by either (1) equatorward advection of temperature anomalies formed by the subduction process in the subtropics or (2) by changes in the strength of the STCs themselves, varying the amount of cold water that is transported into the tropics.

A suite of sensitivity studies is applied to isolate each of the mechanisms at work and to estimate their particular impact on equatorial SST anomalies in the model.

OC-121

Links of Tropical HCA and Equatorial East-West Thermal Modes With Pacific and Atlantic Zonal Circulations

Dr. Abebe Yeshanew, National Meteorological Services Agency, P. O. Box 1090, Addis Ababa, ETHIOPIA, ayesha@hotmail.com, or a_yeshanew@hotmail.com

Modes of variability of equatorial subsurface temperature and tropical heat content are studied using global ocean assimilation continuous data from 1950-1999 to understand tropical oceans links to Pacific Walker Circulation and Atlantic Zonal Overturning.

The most dominant modes of equatorial subsurface temperature (0-250-m depth) and tropical heat content anomaly (HCA) are identified using singular value decomposition. The ENSO timescale temporal variability of these upper ocean properties is isolated using wavelet analysis.

The principal finding of the study reveals that the large part of the variability of Atlantic and Pacific zonal circulations and their associated upper tropospheric velocity potential dipole (and hence convection polarity) is owing to east-west sea-saw of equatorial thermocline and tropical HCA dipole. The east-west upper-ocean dipole is manifested in the leading EOF modes of subsurface thermocline in Pacific and Indian Ocean. In Atlantic, the main climate signal is in kinematic fields. The coupling between equatorial Pacific and Pacific Walker Circulation generates a preferred longitude for maximum thermocline changes and maximum convective coupling that slows or anchors the propagation of coupled Rossby Wave compared to baroclinic Rossby Wave. When decoupling occurs, it is speculated that a tendency of the angular momentum associated with the Walker Cell is produced and as a result the phase speed of the Rossby Wave increases.

The results elicited from this study opens up a new avenue for better understanding of coupled-ocean interaction and teleconnection.

OC-122

Remotely Forced Interannual Variability in the Tropical Atlantic Ocean

Bohua Huang, Center for Ocean-Land-Atmosphere Studies, Institute of Global Environment and Society, 4041 Powder Mill Road, #302, Calverton, Maryland 20705, USA, huangb@cola.iges.org

An ensemble of eight hindcasts has been conducted using an ocean-atmosphere general circulation model fully coupled only within the Atlantic basin, with prescribed observational sea surface temperature (SST) for 1950-1998 in the global ocean outside the Atlantic basin. The purpose of these experiments is to understand the influences of the external SST anomalies on the interannual variability in the tropical Atlantic Ocean. Statistical methods, including empirical orthogonal function analysis with maximized signal-to-noise ratio, have been used to extract the remotely forced Atlantic signals from the ensemble of simulations. It is found that the leading external source is the El Niño/Southern Oscillation (ENSO) in the Pacific, while there are also remotely forced longer-term modulations in the tropical Atlantic SST field.

The ENSO signals in the tropical Atlantic show a distinct progression from season to season. During the boreal winter of a maturing El Niño event, a basinwide warming occurs in the tropical Atlantic with a major center in the southern subtropical Atlantic. The basinwide warming in the ocean is probably associated with the global temperature increase in the tropical atmosphere during an El Niño event. The subtropical maximum of the SST anomalies, however, is caused by a weakening of the

southeast trade winds, associated with an atmospheric wave train generated in the western Pacific Ocean and propagating into the Atlantic basin from the southern hemisphere during boreal fall. In the spring, the northern tropical Atlantic Ocean is warmed up by a weakening of the northeast trade winds, which is also associated with a wave train generated in the central tropical Pacific during the winter at the peak of an El Niño event. Moreover, starting from boreal winter, the sea level pressure is increased in the eastern and southern part of the tropical Atlantic due to an anomalous Walker circulation driven by the anomalous convection in the central-to-eastern tropical Pacific during the maturing phase of an El Niño event. The event induces anomalous easterlies on and to the south of the equator, which leads to a dynamical oceanic response that causes cold SST anomalies in the eastern and equatorial Atlantic from boreal spring to summer. Most of these SST anomalies persist into the boreal fall season.

It is found that the systematic errors of the coupled model have significant effect on the pattern of the response in the tropical Atlantic Ocean to the remote forcing. Sensitivity experiments with a simple flux correction procedure demonstrate that the remotely forced patterns can be more realistically simulated if the model mean SST errors in the Atlantic basin is reduced.

IDC-123

The Oleander Project: Sustained Observations of Ocean Currents in the Gulf Stream and Adjacent Waters from New Jersey to Bermuda

Dr. H. Thomas Rossby, Graduate School of Oceanography, University of Rhode Island, Kingston, RI 02881, USA, trossby@gso.uri.edu
Dr. Charles N. Flagg, Brookhaven National Laboratory, Upton, NY, 11973, USA,, flagg@bnl.gov
Dr. Kathleen A. Donohue, Graduate School of Oceanography, University of Rhode Island, Kingston, RI 02881, USA, kdonohue@gso.uri.edu

Since the fall of 1992, an acoustic Doppler current profiler mounted on a freighter, the CMV Oleander, has been measuring upper-ocean currents between New Jersey and Bermuda on a weekly basis. The rich database that results from the frequent, systematic, and sustained sampling enables us to explore a number of questions regarding currents in the northwest Atlantic.

A very striking feature to emerge from the first ten years of current measurements is the large section-to-section scatter in upper-ocean fluxes, but apparent stability of longer timescale averages. By partitioning the New Jersey-Bermuda line into subsections, the Slope Sea (continental slope to Gulf Stream), The Gulf Stream itself, and the Sargasso Sea, we find evidence that transport variations in Gulf Stream mirror those in the Slope Sea. When Slope Sea transport increases to the west, Gulf Stream transport increases to the east. These increases appear to peak following a minimum in the NAO index one to two years later. These transport variations may result from a variable outflow from the Labrador Sea, which flows south and west along the Canadian shelf and continental slope. In low NAO years, less ice is created so that more and fresher water remains on the Labrador shelf which leads to a larger cross-shelf pressure gradient and hence an increase in southward flow. As this transport increases, it leads to

a significant drop in salinity in the Slope Sea and on the continental shelf because the relatively salty water that leaks into the Slope Sea from the Gulf Stream is now subject to increased dilution. Additionally, the increased southward flow in the Slope Sea following low a NAO 'pushes' the Gulf Stream farther offshore.

The Oleander's track also provides detailed coverage of the shelf-edge jet of the Mid-Atlantic Bight, which, after removal of the impact of warm-core rings, is found to be very narrow and intense. The surface intensified jet has a mean near-surface velocity of almost 0.3 m/s, a half-amplitude width of ~25 km, and a transport within the core of ~0.34 Sv. This transport represents a very large fraction of the entire equatorward shelf transport. Investigation continues on the seasonal and inter-annual variability of the frontal jet.

IDC-124

Interannual SST Variability in the North Atlantic in the Coupled CCM3-MICOM Model

Wei Cheng, JISAO/School of Oceanography/UW, campus box 355351, Seattle, WA 98195, USA, wcheng@ocean.washington.edu
David Battisti, Dept of Atmospheric Sciences/UW, Seattle, WA 98195 USA, david@atmos.washington.edu
Rainer Bleck, Los Alamos National Laboratory, Los Alamos, NM 87545 USA, bleck@lanl.gov
Claes Rooth, RSMAS/MPO, U. of Miami, 4600 Rickenbacker CSWY, Miami, FL 33149 USA, crooth@rsmas.miami.edu

A central problem in understanding the Earth climate is whether its interannual variability in the midlatitude can be understood as a consequence of internal instabilities in one of the components accompanied by forced responses in the other, or alternatively as distinct coupled modes in analogy with the ENSO. In this study we present results from the coupled NCAR Community Climate Model (CCM3) --Miami Isopycnic Coordinate Ocean Model (MICOM) simulation and ocean-only experiments, on the dominant interannual SST variability mode and its relationship to surface heat flux and meridional heat transport in the ocean. It is found that the ocean component of the coupled model, when driven by monthly averaged surface heat and fresh-water fluxes taken year by year from the coupled simulation but monthly climatology of the wind forcing (including wind stress vector and surface wind speed), failed to reproduce the leading SST mode seen in the coupled simulation. This result thus suggests that surface wind forcing and the incurring responses in the ocean circulation, must play an important role on establishing the SST variability seen in the coupled system. This conclusion is tested by a process study on the mixed layer heat budget. It shows that the mixed layer temperature tendencies, when averaged annually and spatially in the North Atlantic, are affected significantly by the horizontal advection term. The lateral heat transport in the ocean is, in term, influenced by a subtropical gyre modulation. Qualitative support for the conclusion is provided by the fact that a “tri-pole" temperature anomaly pattern similar to observations is produced by the coupled model.

IDC-125

The Northern Atlantic Tropical Upwelling System: A Coupled Approach of Air-Sea Interactions, Climate, and Primary Production

Dr Alban Lazar, LODYC case 100, Univ. Paris 6, 4 pl. Jussieu, 75252 Paris cedex 05, France, alban.lazar@lodyc.jussieu.fr
Daniele Iudicone, Laboratory of Biological Oceanography, Stazione Zoologica 'A. Dohrn', 80121 Napoli, Italy, iudicone@szn.it
Keith Rodgers, LODYC case 100, Univ. Paris 6, 4 pl. Jussieu, 75252 Paris cedex 05, FRANCE, Keith.Rodgers@lodyc.jussieu.fr
Serge Janicot, serge.janicot@lodyc.jussieu.fr
Oliver Aumont, olivier.aumont@lodyc.jussieu.fr

The northern upwelling of the tropical Atlantic consists of the coastal Mauritania-Senegal upwelling region and the off-shore Guinea Dome upwelling. This region occupies a significant fraction of the zonal extent of the basin. The overlying atmospheric planetary boundary layer exhibits large seasonal and interannual variability associated with the African Monsoon, and it is thought that these variations are coupled to the upwelling system. On a larger scale, this northern upwelling region is extended by a weaker open ocean upwelling region associated with the marine Inter-Tropical Convergence Zone during summer and fall.

In order to address the role of upwelling processes in the air-sea-land coupled climate cycles, along with the possible role of marine biogeochemical cycles, an ocean GCM is being used in conjunction with a recently constructed climatology of mixed layer depth. The ocean model includes an ocean biogeochemistry model, and is forced with observed surface momentum and buoyancy fluxes. The simulated variations in mixed layer depth are compared with the observational climatology, and the results are discussed within the context of mixed layer response to direct atmospheric forcing (mixing) as well as to horizonal divergence in the ocean circulation field. The related exchanges with the seasonal thermocline at the base of the mixed layer are then examined in order to understand the time evolution of the heat budget and ultimately the SST.

In parallel, a quantification of entrainment/detrainment fluxes is used to interpret the seasonal variability of the primary production with the biogeochemical model which is embedded in the GCM. A preliminary description of the interannual variability of the simulated system is presented.

OC-126

Seasonal Biophysical Coupling in the Tropical Atlantic

Cara Wilson, NOAA/NMFS Pacific Fisheries Environmental Laboratory, 1352 Lighthouse Ave, Pacific Grove, CA 93950 USA, cwilson@pfeg.noaa.gov
Victoria J. Coles, University of Maryland Center for Environmental Science, Horn Point Laboratory, PO Box 775, Cambridge, MD 21613, USA, vcoles@hpl.umces.edu

Ecosystem variability in the tropical Atlantic strongly influenced by the seasonal cycle, and on interannual timescales by ENSO and the NAO. Seasonality in the Atlantic is more important than in the Pacific, where variability due to ENSO dominates, due to stronger seasonal cycles in river discharge, equatorial upwelling and aeolian input. Predicting seasonal and interannual changes that may be expected from shifts in ENSO and the NAO requires understanding the relationships between the physical forcing we can measure from space and the ecosystem production. A joint analysis of TOPEX sea surface height (SSH) and SeaWiFS chlorophyll suggests that much of the western tropical Atlantic surface chlorophyll variability is not driven by thermocline uplift causing changes in surface nutrient concentrations. These regions are characterized by a summer maximum in chlorophyll, whereas throughout the rest of the tropical Atlantic chlorophyll levels peak in local winter. Here we investigate the bio-physical coupling dynamics on a seasonal to interannual scales in the tropical Atlantic using remote sensing data (sea surface height, temperature and color) and output from an Atlantic implementation of the MICOM (Miami Isopycnal Coordinate Ocean Model) numerical ocean model coupled to an ecosystem model. The model results provide a simulation of subsurface response to surface forcing processes to better interpret the surface observations.

OC-127

Tropical Atlantic Ecosystem Variability Associated with Nitrogen Fixation

Dr. Victoria J. Coles, University of Maryland Center for Environmental Science, Horn Point Laboratory, PO Box 775, Cambridge MD 21613, USA, vcoles@hpl.umces.edu
Dr. Cara Wilson, NOAA/NMFS Pacific Fisheries Environmental Laboratory, 1352 Lighthouse Ave., Pacific Grove, CA 93950, USA, cwilson@pfeg.noaa.gov
Dr. Raleigh R. Hood, University of Maryland Center for Environmental Science, Horn Point Laboratory, PO Box 775, Cambridge, MD 21613, USA, raleigh@hpl.umces.edu

This study focuses on the role of nitrogen fixation in altering the carbon cycle in tropical oceans. Diazotrophic organisms have the ability to make atmospheric dinitrogen gas available to the food web. This generates a source of nutrients for phytoplankton growth that is decoupled from the vertical flux of nutrients from depth. This is significant because upwelling of nutrients from the deep oceans is accompanied by outgassing of CO2. In regions with nitrogen fixation, e.g. the tropics, the net carbon flux into the atmosphere may be reduced through the sequestration of carbon associated with the growth of diazotrophs.

Here, we combine the use of remote sensing data (sea surface height, temperature and color) with coupled biological – physical numerical models to demonstrate a climatological phytoplankton bloom in the tropical North Atlantic that is fueled by nitrogen fixation. Interannual variations in the strength of this bloom are observed in the remote sensing fields, and ultimately may be used with the numerical model to predict the rate of nitrogen fixation, its role in carbon sequestration, and how it

varies with the physical forcing associated with interannual and decadal climate fluctuations.

OC-128

NAO-ENSO Interaction: Manifestations and Mechanisms

Prof. Alexander B. Polonsky, Marine Hydrophysical Institute, 2 Kapitanskaya St., Sevastopol, the Crimea 99011 UKRAINE, vao@alpha.mhi.iuf.net
Mr. Dmitry V. Basharin, and Mr.Alexander Yurovsky, Marine Hydrophysical Institute, 2 Kapitanskaya St., Sevastopol, the Crimea 99011 Ukrane

The goal of presentation is to discuss the manifestations and mechanisms of NAO/ENSO interaction using historical hydrometeorological data and NCEP/NCAR reanalysis output. It is shown that Pacific ENSO-events are accompanied by weakening/strengthening of NAO during transient/mature ENSO phase due to Hadley cell variations. This manifests itself in weakening/strengthening of northwest trade wind and mid-latitude westerly in the North Atlantic. NAO intensification during mature ENSO phase (November-December), leads to enhanced early winter temperature in the most northern and central Euro-Asia and more abundant winter snowfall there. During following January-February NAO weakens. This leads to cool conditions over the most northern and central Euro-Asia, more abundant winter snowfall in the southern Asia and reduced early spring temperature there. As a results, there is an anomalous spring temperature contrast between western Pacific and Asian region and this impacts the monsoon and ENSO retreat in that time. In turn, the winter anomalies of NAO (due to inherent Atlantic interannual-to-decadal scale variations) before the ENSO onset and associated changes of Asian hydrometeorological conditions may be one of the provocative factor for the ENSO event generation.

NAO is characterized also by interdecadal variability. Its magnitude is at a maximum in winter. This variability manifests as a change of intensity and location of Azores High and Iceland Low and associated variations of hydrometerological conditions in Euro-Asian region and Pacific Ocean. The interannual and interdecadal tendencies of displacement of the North Atlantic centers of action for different NAO phases are opposite. Thus, the interdecadal mode of NAO modulates the Pacific ENSO events through the change of hydrometeorological conditions over Euro-Asia and Pacific region and associated ENSO-monsoon interaction. At the same time, they may impact the Pacific decadal oscillation (PDO).

OC-129

Tropical Atlantic SST Forcing of Coupled North Atlantic Seasonal Responses

Dr. Shiling Peng, NOAA-CIRES Climate Diagnostics Center, R/CDC1, 325 Broadway, Boulder, CO 80305-3328, USA, Shiling.Peng@noaa.gov
Dr. Walter A. Robinson, Department of Atmospheric Sciences, University of Illinois at Urbana-Champaign, 105 South Gregory Street, Urbana, IL 61801, USA, robinson@atmos.uiuc.edu
Dr. Shuanglin Li, NOAA-CIRES Climate Diagnostics Center, R/CDC1, 325

Broadway, Boulder, CO 80305-3328, USA, Shuanglin.Li@noaa.gov

Recent observational studies reveal that a fall Pan-Atlantic sea-surface temperature (SST) anomaly, composed of a horseshoe-like dipole in the North Atlantic and a southern center in the equatorial Atlantic, tends to precede the winter North Atlantic Oscillation (NAO) and its related SST tripole. We seek to understand this relationship using large ensembles of atmospheric GCM (AGCM) experiments and experiments with the AGCM coupled to a mixed-layer ocean (AGCM_ML). The models are forced either by the North Atlantic horseshoe (NAH) or by the tropical SST anomalies over the boreal winter months. The AGCM results show that the NAH anomaly induces a baroclinic response in geopotential heights throughout the winter, with little projection on the NAO. Since the NAH anomaly is ineffective in forcing the wintertime NAO, it cannot account for observations that the NAH SST leads the NAO. In contrast, in the AGCM_ML, the coupled North Atlantic response forced by the tropical anomaly exhibits a strong seasonal dependence. In early winter, the positive anomaly induces a trough east of Newfoundland with a wavetrain to the northeast, and in late winter the response projects strongly on a negative NAO. Correspondingly, the extratropical SST response features a NAH-like pattern in early winter and a tripole in late winter. These results suggest that tropical Atlantic SST anomalies can significantly influence the coupled extratropical variability. The observational result that the NAH SST leads the winter NAO (or the SST tripole) may be a consequence of persistent forcing of the seasonally varying atmosphere by tropical SST anomalies. Comparisons with the parallel AGCM results indicate that the extratropical thermal coupling contributes to the tropically-forced NAO response in late winter.

Diagnostic experiments using a linear model further illustrate that, in the absence of transient-eddy feedbacks, an idealized tropical heating induces qualitatively similar anomalous flows in early- and in late-winter. The enhanced seasonality in the SST-induced coupled response likely arises, at least in part, from the seasonal modulation of transient-eddy feedbacks on the heating-forced anomalous flow.

EDC-130

Estimates of Eddy-Driven Subduction in the Eastern North Atlantic Ocean (ECCO)

Geoffrey Gebbie, Massachusetts Institute of Technology/ Woods Hole Oceanographic Institution Joint Program, 77 Massachusetts Ave., MIT 54-1419, Cambridge, MA 02139, gebbie@mit.edu
Prof. Carl Wunsch, cwunsch@pond.mit.edu
Dr. Patrick Heimbach, heimbach@ocean.mit.edu

Relatively little is known about the role of eddies in controlling subduction in the eastern half of the subtropical gyre. Here the eastern North Atlantic Ocean is studied by combining a regional eddy-resolving GCM with data to produce a complete state estimate of the ocean circulation. The estimate is a synthesis of a variety of in situ observations from the Subduction Experiment, TOPEX/POSEIDON altimetry, and the MIT General Circulation Model. The result is dynamically self-consistent and it explicitly resolves eddy-scale motions with a 1/6 degree grid. Estimates of eddy-driven

subduction for the eastern subtropical gyre of the North Atlantic are larger than previously calculated from parameterizations in coarse-resolution models. Thermodynamic estimates of subduction show that eddies play a vital role in density classes that outcrop in the Azores Front in late winter. Therefore, the inability to resolve or accurately parameterize eddy-driven subduction in climate models would lead to an accumulation of error in the structure of the main thermocline, even in the eastern subtropical gyre, which is a region of comparatively weak eddy motions. This work is part of the continuing ECCO Consortium effort directed at greatly improved estimates of the oceanic general circulation both regionally and globally through state estimation methods.

OC-131

Understanding the North Atlantic Variability

Dr. Igor Yashayaev, Ocean Circulation Section, Ocean Sciences Division, Bedford Institute of Oceanography, 1 Challenger Drive, P.O.Box 1006, Dartmouth, NS, B2Y 4A2, Canada, yashayaevi@mar.dfo-mpo.gc.ca

Over the past century the North Atlantic experienced dramatic changes in its heat and salt content. We investigate the magnitude of such changes their recurrence, and attempt to identify the contribution of both external (surface fluxes of heat and fresh water, continental discharge, ice formation and melt etc.) and internal (Arctic inflows and outflows, advection, mixing, etc.) processes to the observed changes of temperature and salinity.

OC-132

Effects of Freshwater Forcing on the Atlantic Deep Circulation: A Study with an OGCM Forced by Two Different Surface Freshwater Flux Datasets

Dr. Akira Oka, Center for Climate System Research, University of Tokyo, 4-6-1 Komaba, Meguro-ku, Tokyo 153-8904, Japan, akira@ccsr.u-tokyo.ac.jp
Dr. Hiroyasu Hasumi, hasumi@ccsr.u-tokyo.ac.jp

We conduct numerical experiments using a sea ice coupled ocean general circulation model forced by two different freshwater flux datasets. It is found that the strength of the simulated Atlantic deep circulation considerably differs between the two experiments. To explain the resulting difference, these two freshwater flux are compared and additional experiments are carried out, focusing on the difference at northern high and middle latitudes, at low latitudes, and in the Southern Ocean, separately. An examination of these experiments shows that the difference in the simulated Atlantic deep circulation mainly comes from the difference in the river runoff data, especially at northern high latitudes. The difference in evaporation and precipitation data at low and southern-high latitudes also affects the reproducibility of the Atlantic deep circulation. Although the amount of the difference in the river runoff data at northern high latitudes is small compared with that of the evaporation and the precipitation in other regions, it has

a considerable influence on the strength of the Atlantic deep circulation. It indicates that the reproducibility of the Atlantic deep circulation is affected more significantly by the accuracy of the river runoff data than that of the evaporation and the precipitation data.

OC-133

Variability of Regional Freshwater Flux over the Global Ocean as Derived from HOAPS II

Dr. Stephan Bakan, Max-Planck-Institut f. Meteorologie, Bundesstr. 55, D-20146 Hamburg, Germany, bakan@dkrz.de
Karsten Fennig, Meteorologisches Institut der Universitaet, Bundesstr. 55, D-20146 Hamburg, Germany, fennig@dkrz.de
Dr. Hartmut Grassl, grassl@dkrz.de

The new version of the Hamburg Ocean Atmosphere Parameters and Fluxes from Satellite Data set – HOAPS II - contains improved global fields of precipitation, turbulent heat fluxes, evaporation minus precipitation, and all basic state variables needed for the derivation of the fluxes. Except for the NOAA Pathfinder SST data set, all variables are derived from SSM/I satellite data over the ice free ocean between 1987 and present. Improvements over an earlier version include the utilisation of multi-satellite averages with proper inter-satellite calibration, a new rain retrieval replacement algorithm for periods with missing 85 GHz channel, and a new ice detection procedure. This results in more homogeneous and reliable spatial and temporal fields. The gridded data set with temporal resolutions ranging from daily to monthly and spatial resolutions compatible with major global circulation models is ideally suitable for studies of climate variability over the global oceans on the seasonal to interannual time scales.

On a global scale HOAPS II shows that the average evaporation since 1987 exceeds rain rate by about 1 mm/d over the ocean with almost negligible yearly cycle and small monthly variations of less than ±20%. Regionally, this figure varies from approximately zero over the eastern North Atlantic and North Pacific up to more than 3mm/d in the subtropics and down to –6mm/d in the tropical ITCZ. Overall trends of evaporation and rain rate are very small and probably not significant over the 15 year study period. One remarkable temporal change can be found in reduced evaporation during several months after the Pinatubo eruption in 1991, which is mostly due to an apparently smaller SST value during that time, which might be an artefact of the derivation method. The variability of regional freshwater flux over several ocean basins exhibits peculiar differences. One example is the considerably larger yearly cycle amplitudes of both evaporation and precipitation in the northern mid latitudes as compared to the southern mid latitudes. Another one is the clearly recognizable half yearly cycle in both, evaporation and precipitation, over the tropical Atlantic (between 10S and 10N), while this is not found over the Pacific or the Indic ocean area.

These and other results and inferences will be displayed and discussed on the conference poster.

IDC-134

Multi-Year, In-Situ Surface Fluxes in the Northwest Tropical Atlantic

Dr. Albert J. Plueddemann, 202A Clark Lab, MS-29, Woods Hole Oceanographic Inst., Woods Hole, MA 20543 USA, aplueddemann@whoi.edu

The Northwest Tropical Atlantic Station (NTAS) project for air-sea flux measurement was conceived in order to investigate surface forcing and oceanographic response in a region of the tropical Atlantic with strong SST anomalies and the likelihood of significant local air-sea interaction on seasonal to decadal time scales. A flux reference station has been maintained at approximately 15 N, 51 W since March 2001 through annual turn-arounds of a surface mooring. Redundant meteorological systems on the surface buoy measure the variables necessary to compute air-sea fluxes of heat, moisture and momentum using bulk aerodynamic formulas. The three years of available surface meteorology and fluxes at the site are documented, including an assessment of the flux accuracy. The in-situ fluxes are compared with flux products from operational models run by the National Centers for Environmental Prediction and the European Centre for Medium-Range Weather Forecasts. The goal of the comparison is to identify shortcomings in meteorological variables and/or flux algorithms that contribute to discrepancies in the net fluxes.

IDC-135

The Role of Air-Sea Fluxes in Driving Mid-Latitudinal Atmospheric Variability

Sergey K. Gulev, P.P.Shirshov Institute of Ocenology, RAS,, 36 Nakhimovsky ave., 117218, Moscow, Russia, gul@sail.msk.ru
Thomas Jung, IFM, Dusternbrooker Weg, 20, D-24105, Kiel, Germany, tjung@ifm.uni-kiel.de
Eberhard Ruprecht, IFM, Dusternbrooker Weg, 20, D-24105, Kiel, Germany, eruprecht@ifm.uni-kiel.de
Olga Zolina, Meteorologishes Institut, University of Bonn, Auf dem Huegel, D-53121, Germany, olga.zolina@uni-bonn.de

The role of air-sea fluxes in atmospheric climate variability is analysed on the basis of NWP and VOS flux anomalies for the North Atlantic and North Pacific mid latitudes. First question to address is how reliable are sea-air flux anomalies, derived from different data sources? We analyse the impact of different uncertainties in air-sea flux fields onto adequate representation of climate variability at sea-air interface. Then we analyse the mechanisms driving the impact of sea-air interaction onto mid-latitudinal atmospheric dynamics. Special attention has been paid to the role of anomalous sea-air fluxes in cyclone generation and development in mid latitudes. Cyclones with different characteristics of the life cycle may react differently on surface diabatic heating, that leads to very different inetensities of the midlatitudinal storm tracks. Finally we quantitatively assess the role of sea-air fluxes in the organization of the cyclone tracks in

the North Atlantic and the North Pacific and variability of the leading modes of the atmospheric circulation, such as NAO and its changes during the last several decades.

OC-136

High Resolution Satellite-Derived Surface Turbulent Fluxes over the Atlantic Ocean

Dr. Abderrahim Bentamy, Institut Francais pour la Recherche et l'Exploitation de la MER (IFREMER) BP 70 29280 Plouzane France, abderrahim.bentamy@ifremer.fr
Dr. Alberto.Mestas Nunez, AOML/NOAA 4301 Rickenbacker Causeway Miami, FL 33149,USA, Alberto.Mestas@noaa.gov
Dr. Kristina Katsaros, retired from NOAA living on Whidbey Island P.O. Box 772, Freeland, WA 98249 USA, Kristina.Katsaros@noaa.gov

A method is presented for estimating global sea surface winds and latent heat fluxes from several satellite measurements. The methodology for obtaining the surface turbulent fluxes uses physical properties of radar and radiometer measurements, empirical and inverse models relating satellite observations and surface parameters, and objective analysis merging various satellite estimates. A high resolution dataset is prepared for the Atlantic Ocean, with a spatial resolution between 0.5 and 1 degree, and temporal resolution between one day and one week. The satellite data come from the European Remote Sensing satellite scatterometer (ERS-2), NASA scatterometer Seawinds onboard QuikScat, and several defense Meteorological Satellite Program (DMSP) radiometers (Special Sensor Microwave/Imager [SSM/I] F10 - F14). The reliability of the derived surface winds and heat fluxes is examined and validated through comprehensive comparisons with available in-situ data. Using the validated remotely sensed wind and heat fluxes, spatial and seasonal characteristics of these fields are investigated in the Atlantic Ocean. The results are compared to NCEP/NCAR re-analysis and to ECMWF analysis and re-analysis (ERA40) wind and heat patterns.

OC-137

North Atlantic Atmosphere-Ocean Interaction on Intraseasonal Timescales

Laura M. Ciasto, David W. J. Thompson, Department of Atmospheric Science, Colorado State University, Fort Collins, CO, 80523, USA, lciasto@atmos.colostate.edu

We examine wintertime atmosphere-ocean interaction on weekly timescales over the North Atlantic sector. Consistent with previous studies, our results demonstrate that the strongest interactions between the ocean and atmosphere occur when the atmosphere leads. However, we also find a spatially coherent and statistically significant pattern of sea-surface temperature anomalies over the region of the Gulf Stream extension that precedes changes in the leading mode of Northern Hemisphere atmospheric variability by ~ 2 weeks. The dynamics of the observed relationship

between sea-surface temperature anomalies over the Gulf Stream extension region and the leading mode of Northern Hemispheric atmospheric variability are investigated.

OC-138

Freshwater Transports for the Global Ocean

Dr. Lynne D. Talley, Dr. Joseph L. Reid, Dr. Paul E. Robbins
Scripps Institution of Oceanography, UCSD, 9500 Gilman Dr., La Jolla, CA 92093-0230, USA
ltalley@ucsd.edu

Meridional freshwater transports in the ocean are calculated from geostrophic velocities based on Reid (1994, 1997, 2003) and Ekman transports from near-surface climatologies. The overall freshwater transports and convergences agree reasonably well with previous estimates and with net evaporation/precipitation/runoff. The global total freshwater transports show an input of about 0.7 Sv from the Southern Ocean and 0.5 Sv from the Arctic Ocean into the lower latitudes, which thus have net evaporation. The freshwater transports are separated into contributions from the shallow, nearly horizontal ventilated circulation of the subtropical gyre thermoclines, and from intermediate and deepwater overturn. Because the major evaporation cells are centered in the subtropical gyres, the freshwater transports across the commonly-used 24°N and 30°S sections are neither robustly poleward nor equatorward, but depend on the location of the sections relative to the basin evaporation maximum. The order of magnitude of freshwater transport carried by each shallow gyre overturn is 0.1 Sv. North Pacific Intermediate Water formation carries about the same freshwater transport even though the net mass transport involved is much smaller. Formation of Labrador Sea Water and North Atlantic Deep Water carry 0.2 and 0.3 Sv equatorward in the North Atlantic due to northward flow of saline surface waters feeding the overturns, returned by somewhat fresher waters southward. Bering Strait freshwater transport from the Pacific is only a small fraction of the freshwater transport from the Arctic into the Atlantic.

Most of the equatorward southern ocean freshwater transport is carried by shallow overturn, with a large contribution from northward-subducting fresher Subantarctic Mode Water in the Pacific and Indian Oceans and southward saline flow in the Agulhas, with an important connection through the Indonesian Throughflow. The large deep overturning mass transport in the southern ocean due to formation of bottom waters from deepwaters carries only a small amount of freshwater poleward. Pacific and Indian deepwater freshwater transports are equatorward, associated with low latitude downward diffusion of higher salinity into the upwelled, southward-flowing deepwaters. In the South Atlantic, freshwater transport associated with conversion of low salinity Antarctic Intermediate Water into North Atlantic Deep Water (NADW) is counterbalanced by conversion of higher salinity Benguela Current water also into NADW.

OC-139

The Upper Branch of the North Atlantic Overturning Circulation

Dr. Lynne D. Talley, Ms. Elena Brambilla, Scripps Institution of Oceanography, UCSD, 9500 Gilman Dr., La Jolla, CA 92093-0230, USA, ltalley@ucsd.edu

The upper waters of the Gulf Stream must connect to the North Atlantic's subpolar gyre to feed the deeper portions of the North Atlantic Deep Water formed in the Nordic Seas and Labrador Sea. Two aspects of this connection are presented.

(1) Almost none of the subtropical surface drifters, drogued at 15 m, cross into the subpolar gyre, even though one would expect 15 to 20% to cross, based on the relative strengths of the Gulf Stream and the NADW overturning cell. We show, using the surface drifter's mean flow, with random noise to simulate the eddy field, and wind stresses from NCEP reanalysis, that this observational disconnect between the gyres is most likely due to small but important southward Ekman velocity. Thus an adequate representation of the cross-gyre flow in the upper layers requires floats below the Ekman layer.

(2) The surface circulation of the subpolar gyre, based on Lagrangian drifters, is composed of three strong branches of the North Atlantic Current, strongly associated with the complex topography. We show that the subpolar surface waters feeding the Nordic Seas and the Labrador Sea originate from well-separated types of Subpolar Mode Waters, which are the surface waters of the subpolar gyre. That is, the Subpolar Mode Water (SPMW) of the eastern North Atlantic that feeds the Norwegian Current is distinct from the SPMW that is found in the Irminger gyre. Throughout the subpolar gyre, the thickest SPMW layers are associated with topography and/or strong fronts. A particularly homogeneous pool of western SPMW is found along the Reykjanes Ridge.

□

□DC-140

An Array to Monitor the North Atlantic Meridional Overturning Circulation at 26N

Prof. Harry L. Bryden, Southampton Oceanography Centre, Empress Dock, Southampton, SO14 3ZH, UK, h.bryden@soc.soton.ac.uk
Dr Stuart A. Cunningham, James Rennell Division, Southampton Oceanography Centre, Empress Dock, Southampton, SO14 3ZH, UK, scu@soc.soton.ac.uk
Professor Jochem Marotzke, Max Planck Institute for Meteorology, Bundesstr. 55, D-20146 Hamburg, Germany, marotzke@dkrz.de
Prof. William E. Johns, Rosenstiel School of Marine and Atmospheric Science, Division of Meteorology and Physical Oceanography, 4600 Rickenbacker Causeway, Miami FL 33149 USA, wjohns@rsmas.miami.edu

During February-March 2004 we are deploying an array of moored instruments that will measure temperature, salinity and velocity profiles at about 20 locations across the Atlantic Ocean at 26°N. This is the beginning of a 4-year pilot monitoring effort to measure the strength of the Atlantic meridional overturning circulation and heat flux across 26°N under the "Rapid Climate Change" programme. Deployment of the array in two ocean circulation models (OCCAM and FLAME) has demonstrated that the planned array measurements accurately reproduce the variability in overturning circulation within the models. Moorings are concentrated on the western side of the 26°N section to measure the deep western boundary currents, on the eastern side of the section to measure eastern boundary currents, and on either side of the Mid Atlantic Ridge to

separate the contributions to the overturning circulation from the eastern and western basins. In particular, top-to-bottom profiles of temperature and salinity at the edges of the basin from 10 tall moorings will be used to measure the temporal variability in the basin-wide geostrophic velocity profile. The monitoring relies on ongoing measurement of the Gulf Stream transport through Florida Straits by submarine electromagnetic cable and on continuous estimates of surface Ekman transport derived from operational wind products. It is hoped that a few real-time profiles will have been transmitted and analysed so that we can demonstrate the method at the meeting using actual measurements beginning in April 2004.

IDC-141

Inter-Basin Freshwater Exchange as a Control of the Global Ocean Thermohaline Conveyor

Dr. Dan Seidov, Pennsylvania State University, 2217 Earth and Engineering Science Bldg., University Park, PA 16802-6813, USA, dseidov@psu.edu
Dr. Bernd J Haupt, bjhaupt@psu.edu

There is an ongoing discussion of the role of freshwater transport in the global ocean thermohaline circulation (THC). It is often presumed that the meridional freshwater transport and northern high-latitudinal freshwater impacts in the Atlantic Ocean are the most critical for THC dynamics. This presentation shows that such a presumption underrates the role of inter-basin freshwater redistributions.

Redistribution of freshwater between the Atlantic and Pacific Oceans, both in the atmosphere and by the ocean circulation itself, has long been recognized as a major cause of the observed asymmetry in sea surface salinity (SSS) between these two basins. However, it has not yet been examined whether it is this asymmetry that accounts for the functioning of the global ocean conveyor, and whether there is a threshold that would trigger such a conveyor.

In a series of recent publications, we have shown that even if the SSS is zonally averaged in individual ocean basins, and thus retains only basin-scale inter-basin SSS contrasts, such contrasts can yield a fully functional global conveyor. Moreover, our results favor zonal versus meridional SSS contrasts as critical for building up and maintaining the global THC.

We introduce a hypothesis that inter-basin SSS gradients, regardless of their genesis and even with only rudiment latitudinal distributions of SSS in different basins, can account for the global character of THC. To test this hypothesis, we have used the GFDL ocean model in a series of sensitivity experiments with specified yet highly idealized patterns of inter-basin freshwater redistribution by the atmospheric flows.

Our experiments have revealed that the Atlantic-Pacific SSS asymmetry is indeed the critical element responsible for sustaining the global character of the ocean thermohaline circulation. We conclude, albeit preliminary, that high-latitudinal freshwater impacts, as a driving mechanism of the global ocean thermohaline circulation, are secondary to the inter-basin freshwater communications.

IDC-142

Variability of the Thermohaline Circulation - A Model-Data Synthesis

Arne Biastoch, Leibniz Institute for Marine Sciences, Düsternbrooker Weg 20, 24105 Kiel, Germany, abiastoch@ifm.uni-kiel.de
Rene Redler, C&C Research Laboratories, NEC Europe Ltd., Rathausallee 10, 53757 Sankt Augustin, Germany, rene.redler@ccrl-nece.de.
Claus W. Böning, Leibniz Institute for Marine Sciences, Düsternbrooker Weg 20, 24105 Kiel, Germany, cboening@ifm.uni-kiel.de

Recent high resolution models of the large-scale ocean circulation show a growing robustness in simulating the gross features of the mean circulation and it's seasonal to interannual variability. Only regional deficits, as the exact positions of fronts and details of key processes as convection and dense overflow, still exist. Thus, combined with an assimilation of observation data these models appear as a useful basis for hindcasting studies of the thermohaline circulation. Due to the high computational burden optimal assimilation methods as the adjoint approach or Kalman filter remain unaffordable for high resolution models, therefore only less costly suboptimal methods are suitable.

In this German CLIVAR contribution the goal is to assimilate satellite data into a high resolution ocean model using the reinitialization method of Oschlies and Willebrand (1996). In this technique altimetry data are projected into deeper levels by linking sea surface height and velocity/density fields using statistics from the non assimilated model. As a first step towards this approach a global ocean-sea ice model has been set up. Embedded in the framework of the French-German DRAKKAR modeling project it is based on the latest version of the LODYC OPA code. The horizontal grid has a nominal resolution of 0.5° on a tripolar grid and 45 levels in the vertical, state-of-the-art parameterizations (including a partial bottom cells formulation) and a consistent set of atmospheric forcing fields.

As a first focus the improvements of the regional structures will be studied. Another major topic is the influence of mesoscale processes (e.g. eddies in the North Atlantic Current or the Agulhas region) on fluctuations of the large-scale thermohaline circulation and the interoceanic and interhemispheric exchange. Based on those results a regional setup with a significantly higher resolution will be prepared.

IDC-143

The Stability of the Atlantic Thermohaline Circulation under Global Warming Conditions

Dr. Johann H. Jungclaus, Max- Planck- Institute for Meteorology, Bundesstrasse 53, 20146 Hamburg, Germany, jungclaus@dkrz.de

The stability of the Atlantic Thermohaline Circulation is investigated using the coupled AOGCM ECHAM5/MPI-OM. To accomodate for a number of sensitivity studies a relatively coarse resolution version is applied. Global warming szenarios are carried

out using idealized CO2 increase rates (CMIP). The occurence of irreversible mode switches and the possibility to provoke them by changes in the emission rate is investigated.

Previous model studies have given considerably different answers to the question how the strength of the THC will develop under global warming conditions.The THC stability depends crucially on the details of the underlying processes, in particur the deep water formation mechanisms. We investigate if specific parameterizations of subgridscale processes (such as the overflow of dense water over the Greenland Scotland Ridge or convection) or other model specific features (such as resolution) determine the response.

IDC-144

The North Atlantic in the Greenhouse - Overturning Response and Sensitivities

Dr. Ulf Schweckendiek, Institute for Marine Research, Düsternbrooker Weg 25, 24116 Kiel, Germany, uschweckendiek@ifm.uni-kiel.de
Prof. J. Willebrand, Institute for Marine Research, Düsternbrooker Weg 25, 24116 Kiel, Germany, jwillebrand@ifm.uni-kiel.de

The response of the thermohaline circulation (THC) in climate models on global warming scenarios differs fundamentally. To examine the role of the ocean component for this deviating behaviour, diagnosed fluxes from coupled greenhouse gas simulations are used to drive a regional model of the Atlantic Ocean. The results demonstrate, that the general response of the THC due to changes in atmospheric forcing is quite robust and insensitive to the improved representation of the ocean component.

In order to test the crucial mechanisms for the evolution of the meridional overturning, we have performed sensitivity studies by focussing on different combinations of surface fluxes. The response indicates that the density in the Nordic Seas and subsequently the overflow waters determine trends and long-term variability of the overturning circulation, underlining the importance of that region for the THC.

Deep water formation within the Labrador Sea, responsible for interannual to decadal variability is quite sensitive to anthropogenic changes in the surface fluxes, so that its convection eventually breaks down under surface warming and freshening.

IDC-145

On the Freshwater Contributions Determining the Atlantic Thermohaline Circulation in a Coupled Model of Intermediate Complexity

Pedro De Vries, Royal Netherlands Meteorological Institute (KNMI), P.O. Box 201, 3730 AE De Bilt , The Netherlands, pvriesde@knmi.nl
Susanne L.. Weber, weber@knmi.nl

The response of the Atlantic thermohaline circulation (THC) to changing climatic conditions (e.g. increasing greenhouse gas concentrations or glacial boundary

conditions) varies widely among different climate models. In this study we investigate how atmospheric and oceanic freshwater transports modify the characteristics of the THC, more specifically its strength and its stability. For a given strength, the THC may either be in a thermohaline regime or a thermal regime, i.e. salinity advection is a positive or a negative internal feedback. Which physical processes and variables effectively establish these regimes is not yet fully understood. Employing a coupled atmosphere/ocean/sea-ice model of intermediate complexity a large number of sensitivity experiments were performed. These differ in the atmospheric freshwater forcings, which induce changes in the oceanic contributions to the freshwater budget of the Atlantic basin. It is shown that in this manner the THC's strength and regime can be independently fixed. Our results imply a scheme that can help to diagnose the different THC responses in different models.

OC-146

Basin and Local-Scale Variability Modes of the Atlantic Thermohaline Circulation in a Global Air-Sea Coupled Model

Dr. Tianjun Zhou, State Key Laboratory of Numerical Modeling for Atmospheric Sciences and Geophysical Fluid Dynamics (LASG), Institute of Atmospheric Physics, Chinese Academy of Sciences, Beijing 100029, China
zhoutj@lasg.iap.ac.cn
Helge Drange, Nansen Environmental and Remote Sensing Center,Edvard Griegsvei 3a,N-5037 Solheimsviken, Bergen,Norway, helge.drange@nrsc.no
Mats Bentsen, Mats.Bentsen@nrsc.no
Tore Furevik, Geophysical Institute, University of Bergen, Norway
Tore.Furevik@gfi.uib.no

The basin-scale and local-scale oscillations of the Atlantic thermohaline circulation (THC) are identified and compared by using a 300-years integration of the global air-sea coupled Bergen Climate Model (BCM). The basin-wide oscillation occurs at decadal scales with strong cross-equatorial flow, the more localized fluctuation of the THC occurs mainly at interannual scales with weaker cross-equatorial flow. The basin-wide THC oscillation is associated with an intensified Azores high and Icelandic low, the local-scale THC adjustment is accompanied with a northward shift of the Azores high and also deepened Icelandic low. Both of these SLP patterns indicate an enhanced NAO scenario and thereby intensified deep convection in the Labrador Sea. The Irminger Sea is dominated by positive SSS anomalies and hence strengthened convection for the basin-scale THC oscillation. For the local-scale THC adjustment, however, as a result of the northward shift of the Azores high, the Irminger Sea is dominated by negative SSS anomalies and thereby a weakened convection. Surface salinity anomalies in the Labrador Sea and the Irminger Sea are created locally by evaporation anomalies at these sinking regions in both cases. Further analyses support that the local scale THC oscillation is caused passively by the atmosphere forcing. There are evidences indicating that the whole THC conveyor accelerating generates the warmer subpolar SST, and it warms the air, melts the sea ice, and enhances the surface evaporation.

Key Words: Atlantic thermohaline circulation, Basin and Local Scale, Coupled model.

IDC-147

Interannual - Decadal Circulation Variability in the North Atlantic: Results from High-Resolution Modelling

Claus W. Böning, Leibniz Institute for Marine Sciences, Düsternbrooker Weg 20, 24105 Kiel, Germany, cboening@ifm.uni-kiel.de
Julia Fidler, jfidler@ifm.uni-kiel.de.
Jens-Olaf Beismann, NEC HPCE GmbH, Prinzenallee 11, 40549 Düsseldorf, Germany, jbeismann@ifm.uni-kiel.de.
Joachim Dengg, Leibniz Institute for Marine Sciences, Düsternbrooker Weg 20, 24105 Kiel, Germany, jdengg@ifm.uni-kiel.de.
Arne Biastoch, abiastoch@ifm.uni-kiel.de.

The mechanisms and characteristics of interannual to decadal variations are investigated using a suite of medium- (1/3°) to high-resolution (1/12°) models, forced by 40-year time series of atmospheric fluxes based on NCEP/NCAR data. The focus is on the role of different forcing mechanisms in the generation of large-scale transport variability, and on the manifestation of variations in the meridional overturning circulation (MOC) in the western boundary current (WBC) system of the subtropical North Atlantic. The model experiments suggest that part of the variability, e.g., of the Florida Current (FC) and the Deep Western Boundary Current (DWBC) off the Bahamas, can be related to MOC changes associated with buoyancy-driven variations in the formation of Labrador Sea Water, and a fast propagation of corresponding dynamical signals to subtropical latitudes. The thermohaline signal is, however, effectively masked by interannual variations in wind-driven transports: for all latitudes, the amplitude of wind-driven MOC anomalies exceeds that of thermohaline origin. In contrast to the long-term mean meridional flow, MOC anomalies on interannual time scales are not concentrated at the western boundary: the solutions reveal basin-wide recirculation patterns, associated with Rossby waves emanating from the eastern boundary and the Mid-Atlantic Ridge.

IDC-148

Understanding the Role of the Atlantic THC for Climate: Current Research within the UK RAPID Climate Change Programme

Dr. Meric A. Srokosz, Southampton Oceanography Centre, Empress Dock, Southampton, SO14 3ZH, UK, M.Srokosz@soc.soton.ac.uk
Dr. Christine P. Gommenginger, cg1@soc.soton.ac.uk

Studies of past climate suggest that large and rapid (as fast as 10-20 years) changes have occurred and that changes in the ocean thermohaline circulation (THC) are often a major factor. Using a combination of present day observations, palaeo data and a hierarchy of models (from local process models to global general circulation models), the UK Rapid Climate Change (RAPID) programme aims to improve our understanding of the roles of the THC and other processes in rapid climate change. This

paper presents some of the science currently under way within RAPID to combine present day observations (including data from long-term monitoring arrays, ARGO floats, hydrographic sections and satellites) with climate models in order to better understand the role of the Atlantic meridional overturning circulation and North European climate.

IDOC-149

Western Boundary Circulation and MOC in the Tropical Atlantic

Prof. Friedrich A. Schott, Institut fuer Meereskunde, Duesternbrooker Weg 20, D-24105 Kiel, Germany, fschott@ifm.uni-kiel.de
Dr. Peter Brandt, pbrandt@ifm.uni-kiel.de,
Dr. Lothar Stramma, lstramma@ifm.uni-kiel.de,
Dr. Jürgen Fischer, jfischer@ifm.uni-kiel.de
Rainer Zantopp, rzantopp@ifm.uni-kiel.de,
Dr. Marcus Dengler, mdengler@ifm.uni-kiel.de,
Karina Affler, kaffler@ifm.uni-kiel.de
Prof. Claus Boening, cboening@ifm.uni-kiel.de,
Sabine Huettl, shuettl@ifm.uni-kiel.de,
Dr. Zulema Garraffo, Rosenstiel School of Marine and Atmospheric Sciences, 4600 Rickenbacker Causeway, Miami, FL 33149,zulema@rsmas.Miami.edu,
Prof. Eric Chassignet, echassignet@rsmas.Miami.edu

A better understanding of the circulation and water mass transformation in the equatorial region, both shallow and deep, is essential for realistic CLIVAR modeling of the ocean's response to anthropogenic changes as well as for improved understanding of tropical-subtropical interaction mechanisms at interannual to decadal time scales. As part of the German CLIVAR/ocean program, the western boundary circulation of the tropical Atlantic between 10 S and the equator has been studied with moored arrays and repeat shipboard sections to determine transports and water mass pathways for both, the upper limb and the cold return flow of the Atlantic Meridional Overturning Circulation (MOC) near the western boundary. A special focus of the project are the shallow subtropical –tropical exchange routes of the Subtropical Cells (STCs), which are additionally investigated by APEX floats and isopycnic RAFOS floats at thermocline levels. Here, mean transports, seasonal and longerterm variability of the boundary circulation are presented and compared with corresponding products from models of different types and complexity.

IDOC-150

Decadal Changes along 20W in the North Atlantic

John L. Bullister, NOAA-PMEL,7600 Sand Point Way N.E., Seattle, WA 98115 USA, John.L.Bullister@noaa.gov
Nicolas Gruber,UCLA-IGPP,5853 Slichter Hall, Los Angeles, CA 90095 USA, ngruber@igpp.ucla.edu
Gregory C. Johnson, Gregory.C.Johnson@noaa.gov
Mark J. Warner, University of Washington, School Oceanography, Box 355351,

Seattle, WA 98195 USA,mwarner@ocean.washington.edu
Richard A. Feely, NOAA-PMEL,7600 Sand Point Way N.E., Seattle, WA 98115 USA, Richard.A.Feely@noaa.gov
Rik Wanninkhof, Rik.Wanninkhof@noaa.gov
Christopher Sabine, Chris.Sabine@noaa.gov
Calvin W. Mordy, Calvin.W.Mordy@noaa.gov
Jia-Zhong Zhang, NOAA-AOML, 4301 Rickenbacker Causeway, Miami FL 33149 USA, Jia-Zhong.Zhang@noaa.gov

As part of the CLIVAR and Carbon Global Repeat Hydrography, Tracer, CO2 Programs, 3 hydrographic sections (A16N, A20, A22) were occupied in the North Atlantic in 2003. A20 and A22 were occupied in the western basin, while the A16N section, the focus of this presentation, was sampled in the eastern basin, nominally along 20W from 67N to 5S. The 2003 A16N section repeated lines occupied along 20W in 1988 and 1993. Full depth CTD casts were made at intervals of 30 miles or less, using a 36 position 10 liter rosette system. Water samples were collected for analysis of nutrients, dissolved oxygen, carbon system parameters (dissolved inorganic carbon-DIC, dissolved organic carbon, alkalinity, pH and pCO2), chlorofluorocarbons (CFCs), helium-tritium, trace metals and a number of other chemical constituents. Lowered ADCP profiles were collected at most stations.

The subarctic mode water (SAMW) signature along the A16N section was lighter in 2003 than in 1988. On density surfaces near the SAMW conditions were colder and fresher south of about 57N, and warmer and saltier north of 57N, but on the whole the SAMW PV minimum had shifted to lighter, warmer, and shallower horizons. Substantially lower dissolved oxygen concentration extended from the SAMW nearly down to the oxygen minimum in 2003 compared to the 1988 observations. The Labrador Sea Water (LSW) signature was colder, fresher, denser, and more oxygen-rich in 2003 than in 1988. Dissolved CFC concentrations generally increased along the section between 1988 and 2003, with the largest increase occurring in LSW. The leading edge of the CFC transient moved progressively deeper in the water column. CFC concentrations in maxima along the equator at mid-(~1800 m) and abyssal depths showed large relative increases between 1988 and 2003.

These data, together with those from the other CLIVAR repeat hydrography sections, will be used to help separate the DIC changes associated with the uptake of anthropogenic CO2 from the atmosphere from those that are associated with changes in remineralization and/or ventilation in this region of the North Atlantic.

OC-151

Variability of the North Atlantic Meridional Overturning Cell between 1997 and 2002

Dr. Herlé Mercier, Ifremer, DRO/DOPS/LPO, BP70, Plouzane, 29280, France, herle.mercier@ifremer.fr ;
Dr. Pascale Lherminier, Ifremer, DRO/DOPS/LPO, BP70, Plouzane, 29280, France, pascale.lherminier@ifremer.fr
Dr. Thierry Huck, Université de Bretagne Occidentale, UFR Sciences F308, 6 av. Le Gorgeu BP 809, Brest cedex, 29285, France, thuck@univ-brest.fr ;

Dr. Bruno Ferron, Ifremer, DRO/DOPS/LPO, BP70, Plouzane, 29280, France, bruno.ferron@ifremer.fr ;
Dr. Marta Álvarez Rodríguez, Dpto. Oceanoloxía, Instituto de investigacións, Mariñas, CSIC C/Eduardo Cabello, Nº 6. 36208, Vigo, Spain, malvarez@iim.csic.es ;
Mrs. Catherine Kermabon, Ifremer, DRO/DOPS/LPO, BP70, Plouzane 29280, France, catherine.kermabon@ifremer.fr

The Ovide project aims at repeating a trans-oceanic hydrographic section from Greenland to Portugal every other years for ten years. The goal is to contribute to the monitoring of the inter-annual variability of the water masses as well as the variability of the mass, heat, and tracer transports in the northern North Atlantic Ocean. We present an analysis of the first Ovide hydrographic line that was carried out in June-July 2002 on R/V Thalassa. The absolute transports across the Ovide line are estimated using a box inverse model, based on geostrophy, direct velocity measurements and mass conservation. The results on meridional overturning and heat transport estimates are provided. After a similar computation on the 1997 WOCE hydrographic data collected roughly along the same section, we observe that the amplitude of the MOC was reduced by a factor of 2 in 2002. Hypotheses about this important variability will be discussed.

OC-152

Modelling Long-Term Hydrography Changes in the North Atlantic

Dr. Dan Wright, Ocean Circulation Section, Bedford Institute of Oceanography, Dartmouth, NS B2Y 4A2, Canada, WrightDan@mar.dfo-mpo.gc.ca
Dr. Youyu Lu, LuY@mar.dfo-mpo.gc.ca
Dr. Igor Yashayaev, YashayaevI@mar.dfo-mpo.gc.ca

Our recent studies have revealed a large scale freshening in the North Atlantic since the 1960s and documented the contemporaneous changes in the density stratification in the intermediate, deep and bottom waters. Through the 1990s winter convection in the Labrador Sea increased in strength and depth and the intermediate layers became denser, while the deep and bottom waters became less dense due to freshening. Geostrophic current estimates indicate that the fresh water transport along the Labrador shelf increased by at least 20% over this same time period. To investigate the causes and impacts of these large changes in the hydrography, we conduct a series of sensitivity experiments using a coarse resolution (1degx1deg.cos(lat) with 23 vertical levels) version of the Parallel Ocean Program (POP) model of the Atlantic Basin from 30S to 70N. Each simulation includes a 10 year spin-up under climatological conditions plus an integration over the 50-year period from 1949-1998 with monthly surface fluxes obtained from the NCEP/NCAR reanalysis. Initial simulations have climatological conditions specified at the open boundaries in order to determine that part of the variability that is determined by local forcing and internal dynamics. An additional simulation is then performed with conditions in the northern sponge layer determined by the observed hydrographic data. In each case, we examine the ability of the model to reproduce observed long-term changes in the temperature and salinity of the Irminger

and Labrador Seas and the Newfoundland Basin. The interannual variations in the hydrography of the model will be related to changes in surface forcing, open boundary conditions and changes in the model's meridional circulation.

OC-153

Investigation of the Temporal and Spatial Variability of the North Atlantic Subtropical Mode Water Using Float Data and Numerical Model Outputs

Dr. Ge Peng, MPO/RSMAS, University of Miami, 4600 Rickenbacker Causeway, Miami, FL 33149, USA
gpeng@rsmas.miami.edu
Prof. Eric P. Chassignet, MPO/RSMAS, University of Miami, 4600 Rickenbacker Causeway, Miami, FL 33149, USA,
echassignet@rsmas.miami.edu,
Dr. Young-Oh Kwon, Climate and Global Dynamics Division, NCAR, P.O. Box 3000, Boulder, CO 80307-3000, USA
yokwon@ucar.edu,
Prof. Stephen C. Riser, School of Oceanography, University of Washington, Seattle, Washington 98195, US
riser@ocean.washington.edu

The properties of the North Atlantic Subtropical Mode Water (STMW), i.e., the 18-degree water (EDW), are calculated with float profiling observational data and ocean circulation model simulation outputs.

The basic characteristics of STMW are well documented in the literature from one time hydrographic sections or long-term measurements at one location. Since the summer of 1997, up to 71 profiling floats were launched in the Western Subtropical North Atlantic region. The broad coverage in both time and space of the float profiles enables us to investigate the spatial and temporal variability of the STMW.

In this study, we evaluate the performance of a North Atlantic numerical simulation against these float data, using the Miami Isopycnic Coordinate Ocean Model (MICOM). The good agreement between the two allows us to discuss the sensitivities of the float-derived results to observational sampling area and data coverage.

Float-derived STMW properties are found to display more spatial variation when compared to the model-derived ones, even with the float profiles binned and mapped onto the model grid. Most variability of the model-derived STMW properties occurs at the northeast portion of the STMW domain and the least in the southeast. The spatial and temporal variability of model subduction rates and ventilation patterns will be described.

The time series of domain averaged STMW temperature in both the model and observations do not show statistically significant seasonal and interannual variabilities while that of STMW volume displays a primary peak in the spring (March to May) each year and a secondary peak at October. Multi-year and decadal variabilities of the North AtlanticSTMW properties (temperature, volume, subduction rate, etc.), and their relationship to the NAO will also be discussed using the model outputs.

IDC-154

North Atlatic Subtropical Mode Water, Upper Ocean Heat Content and North Atlantic Oscillation during 1961-2000

Dr. Young-Oh Kwon, NCAR /CGD, Boulder, CO 80307-3000, USA, yokwon@ucar.edu
Dr. Stephen C. Riser, University of Washington, School of Washington, PO BOX 355351, Seattle, WA 98195-5351, USA, riser@ocean.washington.edu

The Eighteen Degree Water (EDW), also often called the North Atlantic Subtropical Mode Water, is a product of major atmosphere-ocean interaction that carries an imprinted signal of climate variability through a shallow overturning circulation in the upper few hundred meters of the subtropical N. Atlantic. With a turnover time of 3-5 years, EDW is potentially a substantial contributor to climate variability at annual to decadal time scales.

The long-term variability of EDW, the upper ocean heat content of the North Atlantic subtropics, and their relationship with the N. Atlantic Oscillation (NAO) were examined based on historical observations during the period 1961-2000. Temperature fields from the upper 800 m of the ocean and the EDW distribution for each season from 1961 to 2000 were analyzed based on objective mapping of temperature observations from the World Ocean Atlas 2001. 40-year time series of both the EDW volume and the total upper ocean heat content in the N. Atlantic subtropics were constructed by spatially integrating individual EDW and temperature fields.

The upper ocean heat content in the N. Atlantic subtropics was significantly correlated with the NAO when NAO was leading by 0-1 year. This correlation was related to the North Atlantic tripole pattern, which is the leading EOF of SST in the North Atlantic. The EDW was shown to be capable of integrating NAO forcing over interannual time scales. The EDW volume was not significantly correlated with the simple NAO index, but the correlation became significant when computed using the NAO index integrated for 3-5 years. The EDW volume was greater when the NAO was lower.

The EDW and the upper ocean heat content were significantly and inversely correlated at zero lag. Greater amounts of EDW were correlated with the less heat content in the upper ocean. The EDW acted as a deficit heat reservoir, since the temperature of the EDW was colder than the background temperature in the absence of the EDW. These two characteristics of EDW variability, i.e. integrating of NAO forcing at interannual time scales, and being a deficit heat reservoir in the upper ocean, appear to create a positive feedback from the upper ocean to the NAO, which acts to provide a winter-to-winter persistence to the NAO.

IDC-155

Changes in Water Mass Properties in the Subtropical Western North Atlantic along 66°W between 1997 and 2003

Dr. William M. Smethie, Jr., Lamont-Doherty Earth Observatory of Columbia, University, P.O. Box 1000, Palisades, NY, 10964, USA, bsmeth@ldeo.columbia.edu

Dr. Terry M. Joyce, Woods Hole Oceanographic Institution, Woods Hole, MA 02543, USA
Dr. Rana A. Fine, Rosenstiel School of Marine and Atmospheric Science, University of Miami, 4600 Rickenbacker Causeway, Miami, FL, 33149, USA

As part of the CLIVAR repeat hydrography program, a section along 66°W in the western Atlantic that was occupied during the WOCE program in 1997 was reoccupied in November 2003. Comparison of the two sections reveals changes in water masses at various depths. Near the surface the Subtropical Mode Water (STMW) was much weaker and more diffuse, having only half the potential vorticity signal in 2003 compared with 1997 in the Northern Sargasso Sea. Other water mass signatures (e.g. oxygen and CFCs) are consistent with a lower ventilation of STMW in recent years. Deeper in the water column, Labrador Sea Water (LSW) generally had a stronger signature. Between 1988 and 1994 convection in the Labrador Sea extended as deep as 2300m as a result of strong winter westerly winds during this period of high NAO index. The vintage of Labrador Sea Water formed was the coldest and freshest in more than 50 years and was observed at the northern end of the section in 1997, but not the southern end, near Puerto Rico. In 2003, this signal had reached this point with salinity at 3.5°C potential temperature decreasing by 0.008, CFC concentration doubling, and oxygen concentration increasing by 2.5 micromole/kg. Similar trends were observed close to Bermuda, but little change occurred south of Bermuda except at the southern end. A freshening signal was also observed in the deeper waters. The source waters of Denmark Strait Overflow Water (DSOW) and Iceland Scotland Overflow Water (ISOW) have been freshening for the past four decades. The salinity in these water masses at the southern end of the section and near Bermuda decreased by about 0.002, but, as for LSW, there was not a detectable salinity change between these locations. This is consistent with the overflow waters and LSW following the same circulation pathways.

IDC-156

Decadal-Timescale Evolution of the North Atlantic Ocean

John M. Toole, WHOI, MS 21, Woods Hole, MA 02556, USA, jtoole@whoi.edu
And the The participants in the 2003 North Atlantic Survey of the U.S. CLIVAR/CO2 Repeat Hydrography Program

Contributing to the CLIVAR and Carbon Cycle global program of repeat hydrography, meridional sections were occupied in the North Atlantic Ocean approximately along 66W (A22), 52W (A20) and 20W (A16N) in summer/fall 2003. A16N had previously been sampled in July/August 1988; A20 and A22 were last occupied during the World Ocean Circulation Experiment in July-August 1997 (and prior to that, in the mid-1980's). Using these data, changes in water mass volumes and properties over the 15- (1988 to 2003) and 6- (1997 to 2003) year intervals are documented and those changes are related to variations observed in other regions of the Atlantic and to the recent history of air-sea exchange for this basin. Highlights of the 2003 observations include:

A shift towards warmer temperatures, lighter densities and weaker potential vorticity anomalies of the convectively-generated sub-arctic and sub-tropical mode

waters, with accompanying decreases in dissolved oxygen and increases in dissolved nutrient concentrations. An increase in total inorganic carbon in the intermediate waters that can be attributed to invasion of anthropogenic CO and possibly increased remineralization as inferred from oxygen and chlorofluorocarbons

A continued enhancement of the surface salinity contrast between subpolar and subtropical latitudes (freshening at subpolar latitudes, increased salinity under the trade wind zone).

Expansion into the interior of the anomalously-low-salinity, high-oxygen, high-CFC intermediate and deep waters (that were initially carried equatorward by the Deep Western Boundary Current) via the subpolar gyre, the Gulf Stream and Southern Recirculation, the Guiana Basin Recirculation and possibly by other unnamed zonal flows.

OC-157

Advantages and Disadvantages of Argo Floats Collecting Data in the Subpolar North Atlantic

Hendrik Sander, Monika Rhein, Institut für Umweltphysik, Abt. Ozeanographie, Otto-Hahn-Allee, 28359 Bremen, Germany, hsander@uni-bremen.de

Since 2000 Argo floats are deployed to collect data of the upper 2000 m of all oceans in real time. The up to date available data of the subpolar North Atlantic is reviewed and major advantages and disadvantages are discussed, including proposals for solving the problem of uneven distributed data. In this context also a special method of interpolating erratic distributed data by using local variograms and kriging is introduced. A comparison with different methods completes the appraisal.

OC-158

Spin-Down of the North Atlantic Subpolar Circulation

Dr. Sirpa Hakkinen, NASA Goddard Space Flight Center, Code 971, Greenbelt, MD 20771, USA, sirpa.hakkinen@nasa.gov
Prof. Peter B. Rhines, Univ. of Washington, Box 357940, Seattle, WA 98195, USA, rhines@ocean.washington.edu

Dramatic changes have occurred in the mid-to-high-latitude North Atlantic Ocean as evidenced by TOPEX/Poseidon observations of sea surface height (SSH) changes over the subpolar gyre and the Gulf Stream. Analysis of altimeter data shows that the subpolar SSH has increased during the 1990s and at the same time the geostrophic velocity derived from altimeter data shows a decline in the gyre circulation. Combining the data from earlier satellites, Seasat (1978) and Geosat (1985-1988), we find that the present day subpolar circulation may actually be considerably weaker than in the (late 1970s and) 1980s. Direct current-meter observations in the boundary current of the Labrador Sea support the trend in the 1990s, and show that in the mid-late 1990s the trend extends throughout the water column. We find that buoyancy forcing over the northern North Atlantic has a dynamic effect consistent with the altimeter data and hydrographic observations: a weak thermohaline forcing and the subsequent decay of

the domed structure of the subpolar isopycnals would give rise to an anticyclonic circulation trend.

Because we lack SSH data prior to 1978, we cannot determine how significant the 1990s decrease of the gyre circulation is historically. Since the Labrador Sea processes are intimately linked to the meridional overturning circulation, these observations of rapid climatic changes over one decade may merit some concern for the state of the MOC unless the observed trend reverses during the coming years. The continuation of the altimeter missions will allow us to follow the evolution of this subpolar signal and its influence on the North Atlantic. Field observations of the oceanic hydrography and ice fields from Arctic-sub-Arctic Fluxes (ASOF) Program will be of great importance in establishing the origin of these climate shifts.

IDC-159

An Analysis of Freshwater Transport and its Variability in an Eddy-Permitting Regional Model of the Sub-Polar North Atlantic

Dr. Paul G. Myers, Department of Earth and Atmospheric Sciences, 1-26 ESB, University of Alberta, Edmonton, Alberta, T6G 2E3, Canada, pmyers@ualberta.ca

The climate of the North Atlantic and the Arctic are linked in a number of ways. Decadal variability in ocean properties, winds, precipitation, etc. have been linked to both the North Atlantic and Arctic oscillations and to each other through feedback loops. A key feature of all these loops is the export of freshwater (both in liquid form and as ice) from the Arctic to the North Atlantic, where it can have a major effect on deep convection. The main export source for this freshwater has been generally considered to be Fram Strait and this is where it is normally applied in global climate models. However, there is also a significant transport of freshwater from the Arctic to the Labrador Sea through the Canadian Archipelago (e.g. 920 km**3 yr**-1, Aagaard and Carmack, 1989) but many climate models (and most ocean only models) treat this region as a solid land boundary.

The transport of freshwater is analyzed in an eddy-permitting regional model of the sub-polar North Atlantic. This works focuses on the export of freshwater (in liquid form) through Davis Strait. The export from Hudson Strait is shown to be insignificant. The freshwater pathways within the sub-polar gyre are examined. The role of the mean and transient circulations in allowing the freshwater to leak from the boundary currents into the Labrador Sea gyre is considered. The impact of potential changes in the freshwater export from the Arctic (for events ranging from NAO related variability to potential future climate changes) is examined, focusing on Labrador Sea Water formation and dispersal.

IDC-160

Variability of Water Masses in the North Atlantic on Hydrographic Sections Along 53 and 60 N

Dr. Sergey M. Shapovalov, Shirshov Institute of Oceanology, 36 Nakhimovsky ave., Moscow, 117997, RUSSIA, smshap@ocean.ru
Prof. Sergey A. Dobrolyubov, Dept. of Oceanology, MSU, Vorobievy Gory, 119992, Moscow, RUSSIA, science@geogr.msu.ru
Prof. Sergey S. Lappo, Shirshov Institute of Oceanology, 36 Nakhimovsky ave., Moscow, 117997, RUSSIA, lappo@ocean.ru
Dr. Eugene G. Morozov, emorozov@mtu-net.ru
Dr.Sergey M. Shapovalov, smshap@ocean.ru
Dr. Alexey V. Sokov, sokov@sio.rssi.ru

The Russian investigations in 2001-2003 on repeated sections along 53-60°N allowed to obtain a number of new indications of climatic changes in the waters of the North Atlantic.

A sharp warming of the water column above 2000 m (by 0.3--1.5°C) occurred in the Irminger Basin. In the thermocline and Labrador Sea Water (LSW) layer this warming is accompanied by an increase in salinity by 0.02--0.04 psu. In addition, Labrador Sea Water in this region changed to a two-modal structure. Warming and increase of salinity in Labrador water corresponds to the general warming in the Greenland and Norwegian seas observed in the last years.

The changes in temperature and salinity on the sections are determined, first of all, by the temporal transformation of cores of water masses. The only exception is the upper part of DSOW with temperatures 1.5--2.0°C, which occupied the isopycnal interval and depths of Iceland-Shetland Overflow Water (ISOW) transported into this region through the Charlie Gibbs Fracture Zone. We note also the opposite tendencies in temperature changes of bottom waters in both basins during the last five years: ISOW transported from the north is cooled, while LSW transported from the south becomes warmer.

The data on geostrophic transport across the 53° and 60° N section in three layers: upper, intermediate, and deep, calculated for 2001, 2002 and 2003 revealed decreased heat transport in the last years and enhanced transport of DSOW to the south compared to 1997, which could be a sequence of decreasing of the NAO after its maximum was recorded in the beginning of the 1990s. These facts indicate that a new period of the Meridional Overturning Circulation is currently beginning, which is manifested in the intensification of the correlation between the flow of Atlantic water into the Arctic Basin in the upper part of the ocean and the return flow of cold water in the bottom layer into the Atlantic Ocean. This is a sequence of decreased NAO. Unlike the situation in the beginning of the 1990s, this leads to weakening of Labrador Sea water formation and to a change of three-modal circulation to two-modal.

The monitoring of water dynamics in the North Atlantic becomes important to forecast climatic changes. Regular measurements on the sections along 53 and 60° N are especially important.

IDC-161

Seasonal and Interannual Variability of the Subpolar Mode Waters in the North Atlantic

V. Thierry, IFREMER, DRO/DOPS/LPO, BP 70, 29280 Plouzané cedex, France, Virginie.Thierry@ifremer.fr
H. Mercier, IFREMER, DRO/DOPS/LPO, BP 70, 29280 Plouzané cedex, France, Herle.Mercier@ifremer.fr
E. Autret, IUEM, LEMAR, Technopôle BREST-IROISE, Place Nicolas Copernic, 29280 Plouzane, France, emmanuelle.autret@univ-brest.fr
F. Gaillard, IFREMER, DRO/DOPS/LPO, BP 70, 29280 Plouzané cedex, France, Fabienne.Gaillard@ifremer.fr
T. Hascoet, IFREMER, DRO/DOPS/LPO, BP 70, 29280 Plouzané cedex, France

Using ARGO/Gyroscope float data, we describe the SubPolar Mode Waters (SPMW) properties and their seasonal and interannual variability, and we investigate the SPMW formation processes. The floats display a substantial data set of high quality salinity and temperature measurements. The space-time sampling allows us to interpolate the data on pressure and potential density levels throughout the mid-latitude North Atlantic Ocean via an objective analysis. Comparison with previous studies shows the consistency of the interpolation method and the ability of the data set to observe the SPMW.

We confirm the presence of several varieties of SPMW in the North East Atlantic, quite unequally distributed and being set apart by the density ranges they occupy. They are distributed around the outer periphery of the North Atlantic subpolar gyre in extended patches north of the North Atlantic Current (NAC) and in small patches south and near Newfoundland. South of the NAC density jumps are detected between the different varieties of SPMW. The analysis helps us distinguish recently ventilated SPMW from subducted SPMW. Those varieties can coexist in the same geographical area at different depths. A significant variability has been observed in regard to previous data sets.

Mode waters are formed in late winter when mixed layers reach their deepest depth. Our observations suggest that the deepening of the mixed layers occurs during a 2 month temporal window and that the deepest mixed layers appear in very restricted areas in the subpolar Gyre. The local nature (in time and space) of the late winter deep mixed layers may explain the discontinuous aspect of the properties of the different SPMWs.□

OC-162

Modelling the North Atlantic Ocean Subpolar Gyre

Dr. Anne Marie Treguier, LPO, IFREMER, BP 70, 29280 Plouzane, France treguier@ifremer.fr
Dr. Thierry Penduff, LEGI, BP53, 38041 Grenoble Cedex 9, France thierry.penduff@hmg.inpg.fr
Dr. Eric Chassignet, University of Miami, RSMAS/MPO, 4600 Rickenbacker Causeway, Miami, FL 33149-1098, USA, echassignet@rsmas.miami.edu
Dr. Lynne Talley, Scripps Institution of Oceanography, San Diego, California,USA, lynne@gyre.ucsd.edu

The subpolar gyre of the North Atlantic is a key region for the global thermohaline circulation. Changes in its surface properties affect the climate of Europe, may be stored at depth for several years through subduction and deep convection processes and induce adjustments of the large-scale meridional circulation and transports. Important processes occuring there are the formation of Labrador Sea water by deep convection, the overflows of dense water from the Nordic seas, and the northward transport of warm water by the North Atlantic current and its instabilities. All those processes are parameterized or marginally represented in most coupled climate models.

We present here an assessment of the circulation of the subpolar gyre as represented by high resolution ocean models (1/6 to 1/12 degree grid size), forced by atmospheric winds and fluxes. Model resolution particularly affects the transport of the subpolar gyre and the influence of turbulent processes. The strength of the boundary factor of two or more between coarse resolution and eddy resolving models. This has implications for the transport of salt from the eastern to the western part of the gyre. Possible consequenses for climatic variability are discussed.

IDC-163

A Regional Eddy-Permitting Ocean Model of the Sub-Polar North Atlantic under Flux Forcing

Ms. Duo Yang and Dr. Paul G. Myers, EAS, 1-26 ESB, University of Alberta, Edmonton, AB, T6G 2E3 Canada, duo@ualberta.ca
myers@wessex.eas.ualberta.ca

Experiments to examine oceanic variability and climate system changes in ocean-only models are often more robust when surface flux forcing is used rather than restoring boundary conditions. However, ocean model often behave poorly when forced by fluxes, with significant drifts in temperature and salinity. Here we examine the use of surface flux forcing in a regional eddy-permitting ocean general circulation model of the sub-polar North Atlantic Ocean. Our flux forcing is taken from two different climatologies, from the Southampton Oceanography Center (SOC) and the NCEP-NCAR reanalysis. The former reflects a comprehensive set of ship/buoy observations based on a short time period, 1980~1993, coincident with a high North Atlantic Oscillation (NAO) phase. The latter is based on a long time series (1948~1998), and some studies show that it may overestimate heat loss (Josey, 2001). We also crudely parameterize the effect of high-frequency variability resulting from the passages of synoptic scale events on the heat flux over the convective region of the Labrador Sea during winter months, due to its role in triggering deep convection.

With the use of a weak restoring term on salinity (to parameterize non-represented sea ice processes), the model remains stable and all major features of the sub-polar gyre are represented. Sub-polar mode water formation and dispersal are improved with respect to an equivalent run with restoring conditions. Improvements are also seen in the model eddy kinetic energy fields. The structure of the surface fluxes leads to potentially unrealistic deep convection in the Irminger Sea, with this situation exacerbated with the hydrographically corrected SOC fluxes. Decadal variability associated with ‘deep’ convection in the eastern basin and changes in the path of North Atlantic Current are observed in one experiment. A drift in temperature and salinity, seen in most high-resolution models of the sub-polar gyre, is observed, although it appears to

be dominated by internal advection processes rather than surface forcing. Ongoing work is examining the model under variable forcing related to the NAO.

OC-164

The Atlantic Inflow to the Nordic Seas and Arctic Ocean

Svein Østerhus, University of Bergen, Bjerknes Centre for Climate Research, Allegata 70, N-5007 Bergen, NORWAY, ngfso@uib.no
William R. Turrell, FRS Marine Laboratory, PO Box 101, Aberdeen AB119DB, Scotland, turrellb@marlab.ac.uk
Steingrímur Jónsson, Marine Research Institute and University of Akureyri, Akureyri, Island, steing@unak.is
Bogi Hansen, Faroese Fisheries Laboratory, Box 3051, FO-110 Torshavn, Faroe Islands, Bogihan@frs.fo

The flow of Atlantic water towards the Arctic crosses the Greenland-Scotland Ridge in three current branches. By the heat that it carries along, it keeps the subarctic regions abnormally warm and by its import of salt, it helps maintain a high salinity and hence high density in the surface waters as a precondition for thermohaline ventilation. In mid 1990's an extensive monitoring program for all three branches was lunched as a Nordic contribution to WOCE and is still going on. The western branch, the Irminger Current, has been monitored by means of traditional current meters moorings on a section crossing the current northwest of Iceland. A number of ADCPs have been moored on a section going north from the Faroes, crossing the Faroes Current. The eastern branch, the Continental Slope Current, is monitored by ADCPs moorings across the Faroe-Shetland Channel. CTD observations from research vessels along all the current meter sections are obtained on seasonal basis. Here we present for the first time the results from all the branches and offer numbers for the Atlantic water transport as well as seasonal and interannual variations.

OC-165

The Impact of the Wind Stress Curl in the Northern North Atlantic on the Atlantic Inflow to the Norwegian Sea Toward the Arctic

Dr. Kjell A. Orvik, Geophysical Inst., Univ. of Bergen, Allegt. 70 , 5007 Bergen, Norway, orvik@gfi.uib.no
Dr. Øystein Skagseth, Bjerknes Centre for Climate Research, Univ. of Bergen, Allegt. 70, 5007 Bergen, Norway, skagseth@gfi.uib.no

The Norwegian Atlantic Current (NwAC) through the Norwegian Sea serves as a conduit of warm and saline Atlantic water from the North Atlantic to the Arctic Ocean, an important factor for climate and ecology. In this study, we concentrate on how the North Atlantic wind stress curl (NAWSC) affects interannual variability on the major branch of the NwAC-the Norwegian Atlantic Slope Current (NwASC). Based on wind stress data from the NCEP reanalysis and estimated volume transport of the NwASC from current

records during 1995-2003 in the Svinøy section (62oN), our analysis shows that the volume transport in the NwASC exhibits a maximum correlation of 0.88 with the zonally integrated NAWSC at 55o N 15 months earlier. Our findings reveal the NAWSC to be a major forcing for interannual variability of the NwASC in the range of 3- to 5.3 Sv (Sv=106 m3 s-1). The 15 month time lag appears to be in accordance with a forced baroclinic Rossby wave in response to the local Ekman pumping changing the baroclinicity and strength of the North Atlantic Current (NAC). After being converted to a nearly barotropic shelf edge current along the Irish-Scottish shelf through interaction with bottom topography, it appears as a barotropic response in the Svinøy section. This result suggests the possibility of predicting conditions influenced by the NwASC more than a year in advance, using the NAWSC as a proxy.

OC-166

The Faroe Bank Channel Overflow

Bogi Hansen, Faroese Fisheries Laboratory, P.O.Box 3051, FO-110 Torshavn Faroe Islands, bogihan@frs.fo
Svein Osterhus, Geophysical Institute, University of Bergen, Allegaten 70, N-5007 Bergen, Norway, Svein.Osterhus@gfi.uib.no
Detlef Quadfasel, University of Hamburg, Institut für Meereskunde, Bundesstr. 53, D-20146 Hamburg, Germany, dq@gfy.ku.dk

The overflow of dense water through the Faroe Bank Channel is generally considered to carry about one third of the total volume flux of overflow from the Nordic Seas to the Atlantic. Since October 1995, an upward-looking ADCP has been moored at a fixed site on the sill permanently, except for short annual servicing periods. Additional moorings with ADCP's and temperature recorders have been moored at other sites on the sill for shorter periods and CTD sections across the channel have been acquired at least four times a year since 1989. Early analyses of these datasets indicated a weakening overflow through the channel, as previously reported. Here, the analysis is extended to cover the period from October 1995 to June 2003 and to give more detailed flux estimates for overflow water with different characteristics. In addition to the trends, short-term, seasonal, and interannual variations are presented.

OC-167

Mixing in the Faroe Bank Channel Overflow

Dr. Detlef Quadfasel, Universität Hamburg, Zentrum für Meeres- und Klimaforschung, Institut für Meereskunde, Bundesstr. 53, D-20146 Hamburg, Germany, dq@gfy.ku.dk
Dr. Bogi Hansen, Fiskirannsóknarstovan, Tórshavn, Faroe Islands, BogiHan@frs.fo
Dr. Svein Østerhus, Geofysisk Institutt, Universitet Bergen, Bergen, Norway svein@gfi.uib.no

Measurements of temperature, salinity and currents in the Faroe Bank Channel and in the overflow plume downstream of the channel's exit were made using moored instrumentation. The time series are used to quantify the entrainment and mixing of ambient waters into the plume that lead to a volume increase and a strong change in the plumes hydrographic characteristics. Mixing within the channel is triggered by strong vertical shear and further enhanced by a frictionally induced cross-circulation. Downstream mixing is caused by the break up of the plume into meso-scale eddies that have their largest energy just 150 km downstream of the channel's sill. It is also here, where the largest changes in the plume characteristics are observed.

IDC-168

Decadal Variability of Water Mass Transformation in the Greenland Sea

Dr. J. Karstensen, Leibniz Institut für Meereswissenschaften Kiel, Düsternbrooker Weg 20, 24105 Kiel, Germany, jkarstensen@ifm.uni-kiel.de
Dr. P. Schlosser, Departments of Earth and Environmental Sciences, and Earth and Environmental Engineering, Columbia University, New York, USA and Lamont Doherty Earth Observatory of Columbia University, P.O. Box 1000, 61 Route 9W, Palisades, New York, NY 10964, USA, peters@ldeo.columbia.edu
Dr. D. Wallace, Leibniz Institut für Meereswissenschaften Kiel, Düsternbrooker Weg 20, 24105 Kiel, Germany, dwallace@ifm.uni-kiel.de
Dr. J. Bullister, Pacific Marine Environmental Laboratory, NOAA Building 3,7600 Sand Point Way NE, Seattle, WA, 98115-0007, USA, John.L.Bullister@noaa.gov
Dr. J. Blindheim, Havforshningsinstituter, Bergen, Norway

We present and discuss a time series of hydrographic and transient tracer observations from the central Greenland Sea obtained between the 1970's and 2000 with annual resolution for the period of the 1990's. We use the time series to discuss changes in the properties and formation rates of the deep and bottom, as well as intermediate waters.

As a general trend, the deep Greenland Sea has undergone a rather uniform warming since about the mid 1970's. However, during the last decade a combination of above-average heat loss and wind stress curl, low or nearly absent sea ice formation, and large freshwater export from the Arctic Ocean into this region allowed the formation of a very stable density stratification at intermediate depths. This was possible because convection during the 1990's cooled and freshened this part of the water column in the central Greenland Sea gyre. The stability maximum at intermediate depth decouples the upper and deep layers and may prevent further deep convection in the near future.

The current warming and salinification trend in the deep Greenland Sea, mainly due to advection from the Arctic Ocean, should continue as long as no local deep convection takes place. Extrapolation of the observed trends suggest that, in a simple 2 basin system, the deep and bottom waters in the Greenland sea will have properties similar to those of the Arctic Ocean in about 20 years from now. However, temperature and salinity of the Greenland and adjacent Norwegian Sea have already become very similar and in view of this fact actual changes in deep water ventilation processes in this region may be more complex: Due to its smaller volume it is likely that the Greenland

Sea gyre warms more rapidly than the Norwegian Sea and a flow reversal, from the Norwegian into the Greenland Sea would be the result. This will however slow down the warming of the Greenland Sea.

ODC-169

Freshwater Transport within the Polar Water of the East Greenland Current

Dr. Jürgen Holfort, Norwegian Polar Institute, Polar Environmental Centre, N-9296 Tromsø, Norway (Norsk Polarinstitutt, Polarmiljøsenteret, 9296 Tromsø), J.Holfort@schleswig-holstein.de
Dr. Emond Hansen, edmond.hansen@npolar.no

The oceanic freshwater transport is an important part of the hydrological cycle and influences also other oceanic phenomena as convection and global thermohaline circulation. In the Nordic Seas and North Atlantic Ocean the most important part of the oceanic freshwater transport occurs in the East Greenland current.

Polar Water has a very low salinity and flows southwards within the East Greenland Current, most of this water is located over the east Greenland shelf. A first direct estimate of the freshwater transport within the PW at 74°N in liquid form gave a transport of about 2500 km3/year southwards for a reference salinity of 34.9. This accounts for about half of the total transport, the other half occurs in form of ice. This is only a rough estimate, as it is based only on a one year long time series of velocity and stratification profiles at one shelf location. A mayor problem with such measurements is that the instruments have to be protected against ice damage, this was successfully done with a so called "tube" mooring. For the first time, in 2003 such moorings were also deployed within the Fram Strait. Continuous stratification, ice thickness and velocity measurement with moorings were done since 1997 in Fram Strait within the East Greenland current, although excluding most of the shelf. Nevertheless we try to give freshwater transport estimates from these measurements, both in liquid and solid phase.This is a first step into direction of better estimates which will be possible once the data from the tube moorings will be available after recovery in 2004.

ODC-170

Monitoring the Oceanographic Fluxes through the Canadian Arctic Archipelago

Dr. Simon J. Prinsenberg, Ocean Sciences Division, Bedford Institute of Oceanography, P.O. Box 1006, Dartmouth N.S., Canada B2Y 4A2, prinsenbergs@dfo-mpo.gc.ca

As part of the Arctic, Sub-Arctic Ocean Flux (ASOF) and the Study of Environmental Arctic Change (SEARCH) programs, a research project consisting of instrumentation development, modelling and mooring work has since 1998 monitored the oceanographic fluxes passing through Lancaster Sound. It is one of the three main pathways through the Canadian Arctic Archipelago (CAA). To contribute to these international programs and to CLIVAR, the project's aim is to better understand the

variability of the oceanographic and pack ice heat and freshwater fluxes passing through the CAA. And further more to better understand their importance to the heat and freshwater budgets of the Arctic Ocean itself, to the circulation and vertical ventilation of the North Atlantic, and to the global meridional overturning circulation (MOC).

Finite numerical models have successfully simulated the tides within the CAA and the yearly mean fluxes through the entire CAA as a function of Sea surface slope between the Arctic and Baffin Bay. Instrumentation have been developed to measure current direction of ADCPs moored in the low horizontal magnetic field strength and have been implemented in Lancaster Sound moorings. Developments are continuing on the ocean surface layer profiler for deployment in regions where a mobile ice cover exists such as exists in the CAA. A prototype successfully returned daily profiles back from a year-long deployment although the sampling depth range was small due to a software glitch; this was corrected in the field and the prototype re-deployed for another year.

The first three years of time series data from August 1998 to August 2001 of the salinity, temperature and velocity fields have been processed and used to derive estimates of the volume, freshwater and heat fluxes passing through the Lancaster Sound. The fluxes exhibit large seasonal and inter-annual variabilities, they are small in fall/winter and reach their maximum in late summer. The seasonal volume flux estimate ranges from a fall low of -0.01Sv in 1998 to a summer max of 1.3Sv in 2000. It has a 3-year mean of 0.75Sv and varies inter-annually by b0.25Sv. Freshwater flux estimates vary similarly with minimum values in winter and maximum values in late summer. They are generally 1/15 of the volume flux; but may be underestimated as their surface freshwater content is based on data from CTD sensors at 25-30m depth. The pack ice contribution to the freshwater flux is small as most of the year the pack ice has been land-fast; it accounts for less than 5% of the freshwater flux when spread over the entire year.

Model simulations with finite element model and with other Arctic models indicate that fluxes through Lancaster Sound make up 40-50% of the fluxes through the Canadian Archipelago. This indicates that the volume flux through the Archipelago would of the order of 1.5 to 2.05Sv similar to present literature values and could vary in summer by b0.25Sv due to the seasonal variability seen in Lancaster Sound.

Further information on results can be found on the Bedford Institute's web-site: http://www.mar.dfo-mpo.gc.ca/science/ocean/seaice/public.html

IDC-171

Spreading Velocities and Dilution of North Atlantic Deep Water

Dr. Reiner Steinfeldt, Universitaet Bremen, Institut fuer Umweltphysik,
Otto-Hahn Allee, Bremen, rsteinf@physik.uni-bremen.de
Dr. Monika Rhein

The spreading of North Atlantic Deep Water (NADW) in the western tropical Atlantic is investigated using CFC time series from 16 N to 42 N. The concept of age spectra allows to infer mean velocities and dilution factors for the different NADW components, the Upper Labrador Sea Water (ULSW), the Labrador Sea Water (LSW) and the Lower North Atlantic Deep Water (LNADW). These values describe the mean

state, but the repeated CFC measurements indicate interannual variability of the spreading of NADW. The section at 16 N is used to investigate the fluctuations in more detail. The connections between CFCs and other quantities such as salinity and velocity show that the temporal variability of the CFC signal is caused by changes in mixing processes as well as by recirculations. Repeated CFC measurements in the subpolar Atlantic at 42 N are used to determine the strength of the CFC anomaly generated in the Labrador Sea from 1988 to 1994 in the outflowing NADW at 42 N as well as in the tropics.

IDC-172

Deep Circulation Inferred from CFCs in the Western North Atlantic Ocean

Dr. Rana A. Fine, Rosenstiel School of Marine and Atmospheric Science, University of Miami, 4600 Rickenbacker Causeway, Miami, FL 33149 USA, RFine@rsmas.miami.edu
Dr. William M. Smethie, Jr., Lamont-Doherty Earth Observatory of Columbia University, P.O. Box 1000, Palisades, NY, 10964, USA, bsmeth@ldeo.columbia.edu;
Dr. James D. Happell, Rosenstiel School of Marine and Atmospheric Science, University of Miami, 4600 Rickenbacker Causeway, Miami, FL, 33149, USA, jhappell@rsmas.miami.edu;
Dr. Deborah A. LeBel, Lamont-Doherty Earth Observatory of Columbia University, P.O. Box 1000, Palisades, NY, 10964, USA, lebel@ldeo.columbia.edu;
Dr. Terry M. Joyce, Woods, tjoyce@whoi.edu
Dr. John M. Toole, jtoole@whoi.edu;
Dr. Alison M. Macdonald, amacdonald@whoi.edu

As part of the CLIVAR and Carbon global repeat hydrography, tracer, CO2 program, sections along 66°W (A22) and 52°W (A20) were occupied in October-November 2003 under a weak low North Atlantic Oscillation (NAO). CFCs (CFC-11, CFC-12, CFC-113) from these sections are compared with those from the 1997 occupation under a weak high NAO. There were changes in tracer concentrations within water masses, and regional changes that are used to deduce information about the deep circulation in the western North Atlantic Ocean. The Deep Western Boundary Current (DWBC) transports high CFC concentration North Atlantic Deep Waters (NADW) from their source regions into the tropics. As a consequence, CFC concentrations were highest in both occupations at the northern end of both sections where the DWBC was crossed. They showed a minimum along 52°W in both occupations between about 18 and 27°N. The minimum lies between the Gulf Stream recirculation at the northern end, and the Guiana Basin recirculation at the equatorward end. Concentrations were elevated at the equatorward extremes where the sections again crossed the DWBC in the tropics. CFC-113 has been in existence and hence entered the ocean for a shorter time than CFC-11 or CFC-12. Below 1000 m, in 1997 measurable CFC-113 had not penetrated as far into the interior as CFCs 11 and 12. In the 2003 occupations, there

were low-level CFC-113 concentrations in uNADW extending from the DWBC (about 8N), and in several isolated cores in uNADW and lNADW out to 25°N. These are coincident with cores of high CFC-11 and CFC-12 in the 2003 and earlier occupations. The cores are coincident with circulation features that are persistent under low and high NAO conditions. Between occupations CFC concentrations increased in all of the NADW located below 1000 m, though at different rates. The most pronounced changes are associated with LSW. The rates of CFC increase are compared to the changing atmospheric source to put time scales on renewal of the interior basins.

IDC-173

Changes in the CFC Inventories and Formation Rates of Upper Labrador Sea Water, 1997-2001

Dagmar Kieke, Institut für Umweltphysik, Abt. Ozeanographie, Otto-Hahn-Allee, 28359 Bremen, Germany, dkieke@physik.uni-bremen.de;
Monika Rhein, mrhein@physik.uni-bremen.de;
Lothar Stramma, Institut für Meereskunde, FB1, PO1, Düsternbrooker Weg 20, 24105 Kiel, Germany, lstramma@ifm.uni-kiel.de;
William M. Smethie, Lamont-Doherty Earth Observatory, Columbia University, Palisades, New York, USA, bsmeth@ldeo.columbia.edu;
Deborah LeBel, lebel@ldeo.columbia.edu;
Walter Zenk, Institut für Meereskunde, FB1, PO2, Düsternbrooker Weg 20, 24105 Kiel, Germany, wzenk@ifm.uni-kiel.de

Chlorofluorocarbon (component CFC-11) and hydrographic data from 1997, 1999 and 2001 are presented to track the large-scale spreading of the Upper Labrador Sea Water (ULSW) in the subpolar gyre. ULSW is defined as the fresh and CFC-rich layer in the density range sigma_Theta = 27.68-27.74. The ULSW ventilated during the late 1990s follows the same spreading pathways as classical LSW and has started to enter the eastern North Atlantic. Despite of some data gaps, the CFC-11 inventories of ULSW north of 42N could be estimated to within 5-15%. The inventory increased from 5.6-6.2 million moles in 1997 to 8.4 million moles in 1999 and to 9.6 million moles in 2001. The inventory differences between 1997 and 1999 as well as 1999 and 2001 outside the subpolar gyre are assumed to be small and therefore neglected. The mean ULSW formation rate for the period 1930-1997 is 3.8-4.0 Sv. In 1998 and 1999, the formation rate increased considerably to 9 Sv and weakened in 2000-2001 to 4.2-4.3 Sv. At least in 1998-1999, the convection area needed exceeded the available area in the Labrador Sea.
Thus, ULSW formation inthese years could not be confined to the LaDbrador Sea, the most likely candidate is the Irminger Sea. Nevertheless, the northern and central Labrador Sea remained the most important site for ULSW formation.

IDC-174

Testing a Data Assimilation System to Monitor the Meridional Overturning Circulation in the Irminger Sea

Dr. Daniel J. Lea, The Johns Hopkins University, Applied Physics Laboratory, Building 7-372, 11100 Johns Hopkins Road, Laurel, MD. 20723-6099, USA, daniel.lea@jhuapl.edu
Dr. Thomas W. N. Haine, Department of Earth and Planetary Sciences, Olin Hall, 34th and North Charles Streets, Johns Hopkins University, Baltimore, Maryland 21218, USA, thomas.haine@jhu.edu
Dr. Richard Gasparovic, Applied Physics Laboratory, Building 7-372, 11100 Johns Hopkins Road, Laurel, MD. 20723-6099, USA

We examine the Irminger Sea branch of the meridional overturning circulation (MOC) using variational data assimilation. The scientific issues are to: 1) Estimate the Arctic/Sub-Arctic exchange of mass, heat and freshwater through Denmark Strait; and, 2) Diagnose the water mass transformation in the Irminger Sea. We also wish to design a long-term MOC monitoring system that incorporates in-situ and remotely-sensed observations. The technical objective is to assimilate in-situ and satellite data from the region into a 10-km resolution regional general circulation model (the MITgcm). This will allow us to monitor MOC variability over periods from days to seasons in near real time. The assimilation control variables include the intial conditions, the open boundaries and the surface forcings. We characterize the accuracy of the high resolution regional model and data assimilation system using twin experiments. They determine whether the current observing system is sufficient to address the scientific issues. Specifically, we estimate how effective satellite observations of the sea surface and in-situ data are in constraining subsurface flow.

OC-175

Sensitivity of Modeled Sea Ice to External Forcing and Parameterizations of Solar Radiation

Dr. Alexander P. Makshtas, International Arctic Research Center University of Alaska Fairbanks, 930 Koyukuk Dr. P.O.Box 757335, Fairbanks, AK, 99775-7335, USA, makshtas@iarc.uaf.edu
Dr. Sergey V. Shoutilin, Division of ocean and atmospheric sciences graduate school of environmental earth science Hokkaido University, Sapporo, 060-0810, Japan, sergey@ees.hokudai.ac.jp

A dynamic-thermodynamic sea ice model with 50-km spatial and 24-hour temporal resolution and zero-dimensional thermodynamic sea ice models are used to investigate the spatial and temporal variability of the sea ice cover and the surface energy exchange in the Arctic Basin. The models satisfactorily reproduce the main characteristics of sea ice in the different parts of the Arctic Basin, including the observed decrease of sea ice extent in the last century and sea ice thinning in early 1990th. At times the evaluation of atmospheric forcing data, namely air surface level temperature and surface pressure from NCEP, and cloudiness amount from Gorshkov's Atlas of the Arctic Ocean, generally accepted for sea ice climate models, showed large disagreement with data of direct meteorological observations on the drifting stations "North Pole". The disagreement was found during the comparison of calculated with

different parameterizations and measured on the drifting stations values of incoming shortwave radiation and shortwave radiation balance also.

The numerical experiments with zero-dimensional sea ice model reveal that the negative feedback existing in nature and reproduced by models could to reduce artificially the influence of inaccuracy of forcing parameters and parameterizations on the results of sea ice modeling, but distort information about the main surface heat fluxes.

OC-176

Atmospheric Response to Arctic Summer Sea Ice Extremes

Dr. Uma S. Bhatt, Geophysical Institute, P.O. BOX 757320, U. of Alaska Fairbanks, Fairbanks, AK 99775-7320, bhatt@gi.alaska.edu
Dr. Michael Alexander, NOAA CIRES,Campus Box 216 University of Colorado Boulder, CO 80309-0216, maa@cdc.noaa.gov
Dr. John Walsh, IARC, 930 Koyukuk Dr. Fairbanks, AK, 99775, jwalsh@iarc.uaf.edu
Mr. Jack Miller, IARC, 930 Koyukuk Dr. Fairbanks, AK, 99775, jsmiller@arsc.edu)
Mr. Michael Timlin, 204 Atmos Sci Bldg, mc233, 105 S. Gregory St Urbana, IL 61801, timlin@atmos.uiuc.edu
Mr. James Scott (NOAA-CIRES, Climate Diagnostics Center, Boulder, Colorado; James.D.Scott@noaa.gov)

It is generally accepted that changes in air temperature and circulation determine sea ice conditions, but it is not understood how the atmosphere is influenced by changes in sea ice. These processes are particularly important to understand since the slowly varying nature of sea ice could be potentially used for predictive purposes. We employ the NCAR CCM 3.6 to investigate the atmospheric response to reduced sea ice during summer.

A control experiment was integrated for 55 years by repeating the mean annual cycle of observed sea ice extent and SST, based on the period 1979-99, when reliable satellite data is available. Sets of 51 member ensemble experiments were constructed by integrating the CCM from April to October using climatological SST and observed sea ice extent from the summer of 1995 (a minimum summer).

Local as well as remote responses were found during the month of August. Above the region of reduced summer time sea ice, there is enhanced convection, lower sea level pressure, and warmer air temperatures penetrating deeply through the atmosphere. In addition, there is a significant downstream atmospheric circulation response, characterized by changes in precipitation and storm track intensity. The large scale response is characterized by anomalous high pressure in the north Pacific.

To understand the mechanisms of the atmospheric response, moisture transport and heating anomalies and two additional experiments will be presented. Sea ice anomalies are specified only in the Kara-Barents or the E. Siberian-Laptev seas in these additional simulations to help identify key forcing regions. The modeling results suggest that both of these regions add to the total response.

Similar results are obtained when the model is forced with sea ice extent from the mid-21st century which is constructed from coupled GCM simulations with enhanced greenhouse gases.

OC-177

Long Term Variability of Oceanological Characteristics on the West Arctic Shelf

G. G. Matishov, Denisov V. V., Zuyev A. N., Golubev V. A., Murmansk Marine Biological Institute; Russia 183010 Murmansk, Vladimirskaya 17, mmbi@mmbi.info
Levitus S., Smolyar I., World Data Centre A, NODC-NOAA, 1315 East West Highway, Room 4362 Silver Spring MD 20910-3282 USA

Strong seasonal and inter-annual variability in the Norwegian and Barents Sea region - the area of the intensive energy exchange between the ocean and the atmosphere determines the climate on the significant part of the Northern Hemisphere of the Earth. Seasonal variability of the Barents Sea temperature and salinity depends on several factors among which the following are to be mentioned: during the summer period -intensive warming up of the water surface layer and re-freshening due to the ices melting on the north and the increased input of the Atlantic waters in the winter period. The differences between the winter and the summer thermohaline structure of the Barents Sea water are manifested themselves to the greatest degree in the in the surface water layer. In winter there is observed vertical homogeneity of the water column. In summer the surface temperature raises up to 10°Ñ in the southern part of the sea and up to 2-4°Ñ in the northern areas, whereas in the near bottom layers in the north minimal values close to the temperature of freezing are preserved. On the sea surface in the areas of ices melting salinity decreases to 15‰, while in subsurface layers it is close to oceanic values all year round.

The data base of water temperature and salinity of the West Arctic Seas formed in MMBI and NODC and consisting of about 400 thousand oceanographic stations at the moment has been used for the quantitative analysis. Variability estimations are obtained for the two the most representative points on the boundary of the Norwegian and Barents Seas, and for the temperature and salinity fields in the boundary section plane.
As the result of the analysis carried out it is shown that the anomalies in the fixed points are observed as a rule from the surface till the bottom. Anomalies of one sign are observed synchronically over the significant area. The advective component manifesting itself in the regular shift of the start of anomaly on the stations in different parts of the area is established.

The coldest period in the area mentioned is the beginning of the XX century (unfortunately, provided with the observation to the least degree). Temperature maximums are registered at the end of the 30s and the beginning of the 50s, after which there registered some cooling at the second half of the 60s, changed into the tendency of warming during several cycles at the beginning of the 90s.

Confirmations of the conclusions of many scientists on the significant stationarity and sharpness of the Polar front in the western part of the Barents Sea obtained as the result of this calculation are of special interest. This simplifies greatly the procedure of

the data objective analysis, allowing to avoid a laborious procedure for the estimation of the current position of the front at the preliminary data selection.

OC-178

The Arctic Ocean's Response to the Northern Annular Mode

Dr. Gerd Krahmann, Lamont-Doherty Earth Observatory, 61 RT 9W, Palisades, NY 10964, USA, krahmann@ldeo.columbia.edu
Prof. Martin Visbeck, visbeck@ldeo.columbia.edu

The sea ice response of the Arctic Ocean to the Northern Annular Mode (NAM) is studied both in observations and in a numerical ocean general circulation model. The analysis of the observed sea ice concentrations shows the well known seesaw in response between the Labrador Sea and the Greenland and Barents Seas. After band pass filtering the data in order to distinguish decadal and shorter or longer periods, it reveals a variation in response in the Greenland Sea between interannual and multidecadal NAM periodicities. In the numerical model experiments idealized NAM-like wind and windstress forcing anomalies of varying periodicities have been applied to the model. This setup allows us to investigate variations in the response to the NAM in a controlled environment. The analysis of the numerical experiments reveals a similar change in response in the Greenland Sea as we found in the observational data. The changes in the response appear to be caused by a slow oceanic component which, on interannual timescales, has not enough strength to modify the quicker windstress driven response of the sea ice.

OC-179

Multi-Decadal Variability of the Atmosphere-Ice-Ocean System in the Arctic

Dr. Igor V. Polyakov, Dr. Roger Colony, Dr. Harper Simmons, John Walsh, and Dr. Mark Johnson, IARC, 930 Koyukuk Dr. Fairbanks, AK, 99775 USA, igor@iarc.uaf.edu, jhsimmons@iarc.uaf.edu, rcolony@iarc.uaf.edu, jwalsh@iarc.uaf.edu, johnson@ims.uaf.edu
Dr. Uma S. Bhatt, (Geophysical Institute, P.O. BOX 757320, U. of Alaska Fairbanks, Fairbanks, AK 99775-7320 USA, bhatt@gi.alaska.edu.
Dr. Genrikh V. Alexeev, Dr. Roman Bekryaev, and Dr. Leonid Timokov, Arctic and Antarctic Research Institute, St. Petersburg, Russia, alexgv@aari.nw.ru, bekryaev@aari.nw.ru.
Dr. David Walsh, Naval Research Laboratory Stennis Space Center, MS 39529 USA, dwalsh@iarc.uaf.edu

Arctic atmospheric variability during the industrial era (1875–2000) is assessed using spatially averaged surface air temperature (SAT) and sea level pressure (SLP) records. Air temperature and pressure display strong multidecadal variability on timescales of 50–80 yr [termed low-frequency oscillation (LFO)]. Associated with this variability, the Arctic SAT record shows two maxima: in the 1930s–40s and in recent

decades and a colder period in between. This large-amplitude multidecadal climate variability may confound the detection of the true underlying climate trend over the past century. Thus, caution must be used when trends are calculated over short periods. The accelerated warming and a shift of the atmospheric pressure pattern from anticyclonic to cyclonic in recent decades is consistent with the positive phase of the LFO.

An examination of records of fast ice thickness (1936–2000) and ice extent (1900–2000) in the Kara, Laptev, East Siberian, and Chukchi Seas provide evidence that long-term ice thickness and extent trends are small and generally not statistically significant. The ice variability in these seas is dominated by the multidecadal LFO and (to a lesser degree) by higher-frequency decadal fluctuations. The LFO signal decays eastward from the Kara Sea where it is strongest. Chukchi Sea ice variability is dominated by decadal fluctuations, and there is no evidence of the LFO. Sensitivity analysis shows that dynamical forcing (wind or surface currents) dominates ice-extent variations in the Laptev, East Siberian, and Chukchi Seas. Variability of Kara Sea ice extent is governed primarily by thermodynamic factors.

Through the analysis of a vast collection of previously unsynthesized observational data, we show that the intermediate Atlantic Water variability is also dominated by multi-decadal oscillations. Over recent decades, the data show a warming and salinification of the Atlantic layer, accompanied by its shoaling and, probably, thinning. These data support a negative feedback mechanism through which changes of density act to moderate the inflow of Atlantic Water to the Arctic Ocean, consistent with the decrease of positive Atlantic Water temperature anomalies in the late 1990s. Finally, we find that the sustained Atlantic Water temperature and salinity anomalies are associated with hydrographic anomalies of the same sign in the Greenland-Norwegian seas and of the opposite sign in the Labrador Sea.

These analyses show that the multidecadal variability is ubiquitous in the arctic and understanding the mechanisms of the LFO is critical to enhancing our knowledge of global climate.

OC-180

Large-Scale Atmospheric Circulation Impacts on the Nordic Seas Ocean Climate

Dr. Tore Furevik, University of Bergen/Bjerknes Centre for Climate Research, Allegt 70, 5007 Bergen, Norway, tore@gfi.uib.no.
Jan Even O Nilsen, Nansen Environmental and Remote Sensing Center, Edv Griegsvei 3A, 5059 Bergen, Norway. even@nersc.no.

During the last decade there has been an increased focus on the many atmospheric and oceanic processes taking place in the Nordic Seas and Arctic Ocean. Among the observations that have contributed to this are the strengthening of the atmospheric westerlies, the reduction of deep convection in the Greenland Sea, the freshening of the overflow waters, the warming of the inflowing Atlantic Water, and the shrinking of the Arctic sea ice extent and thickness, all observations that have been linked to the increased concentration of atmospheric CO2.

Recent ocean observations are here reviewed in the context of the atmospheric forcing. Both rapid responses in sea-level height, mixed-layer depth, sea-surface

temperature and sea-surface salinity, and slower responses due to advection of heat or fresh water anomalies from distant regions, changes in the flow speed or position due to changes in the baroclinic structure of the upper ocean, or changes in the abyssal circulation as a response to forcing of the convection regions, are discussed. The presentation will be concluded with some words about the future climate.

OC-181

Simulation of Sea Ice and Ocean Variability in the Arctic during 1955-2002 with an Intermediate Complexity Model

Mr. Jan Sedlacek, McGill University, Department of Atmospheric and Oceanic Sciences, 805 Sherbrooke Street West, Montreal, QC, H4G 2K6, Canada
jan.sedlacek@mail.mcgill.ca
Mrs. Kate M. Wright, kwright@zephyr.meteo.mcgill.ca
Prof. Lawrence A. Mysak, lawrence.mysak@mcgill.ca
Mr. Michael Eby, University of Victoria, Earth and Ocean Sciences, PO Box 3055 STN CSC, Victoria, BC, V8W 3P6, Canada, eby@uvic.ca

In this study, we investigate a number of recent sea ice and ocean changes in the Arctic region using the UVic Earth System Climate Model version 2.6. This is an intermediate complexity model which includes a 3-dimensional ocean model (MOM 2.2), an energy-moisture balance model for the atmosphere with heat and moisture advection, and a thermodynamical sea ice model with elastic-viscous-plastic dynamics. The model is global, with a resolution of 3.6° (east-west) and 1.8° (south-north). After a spin-up time of 1800 years with monthly NCEP climatology wind-forcing and constant CO_2 values, the model is run for the period 1948-2002 with a wind forcing interval of 2.5 days and changing CO_2 according to the IPCC Third Assessment ReportHowever, the analysis of the output is done for the years 1955-2002.

The variability and magnitude of the export of sea ice through Fram Strait, which can affect the Atlantic meridional overturning circulation, is well captured in the simulation. Furthermore, the change in correlation between the NAO index and the sea ice export as proposed by Hilmer and Jung (2000) is reproduced. The simulated maximum and minimum sea ice extent is within 6% and less than 1%, respectively of the observed climatology over the years 1978-2001. The model captures the features and the timing of the two major regimes of wind-forced sea ice drift circulation (cyclonic and anticyclonic) as proposed by Proshutinsky and Johnson (1997). The temperature and salinity increase at depths of 200-300 m as observed by Morison et al. (1998) between the USS Pargo cruise in 1993 and the EWG climatology of the years 1948-1987, is visible in the model simulation. Finally, our results are compared to submarine ice draft measurements, and we obtain a decrease of the sea ice thickness in the SCICEX measurement area as summarized by Seymour et al. (2003). Overall, our model results capture the basic features of the recent changes in Arctic sea ice and upper ocean, but the magnitude of the changes are usually lower than observed, probably because of the coarse resolution of the model. Nevertheless, we believe that the model simulates the Arctic behaviour well enough to warrant its application to Arctic-North Atlantic ocean-climate interactions.

Multiple Equilibria and Asymmetric Climates in the CCM 3.6.6 Coupled to the Oceanic Mixed Layer with Thermodynamic Sea Ice

Peter L. Langen, University of Copenhagen
Vladimir A. Alexeev, International Arctic Research Center, 930 Kouykuk Dr., PO Box 757340, University of Alaska Fairbanks, Fairbanks, AK 99775-7340 USA
valexeev@iarc.uaf.edu

An atmospheric GCM (Climate Community Model, CCM 3.6.6) is coupled to an upper mixed-layer ocean with thermodynamic sea ice on an aquaplanet. An annually averaged diurnal cycle of insolation is used such that effects of seasonality are neglected. Sea ice is modeled by a simple four-layer thermodynamic sea ice model coupled to the atmosphere-ocean system. A simple form of heat flux to the mixed-layer from below, the so called "Q-flux", is constructed and introduced into the model. All externally specified fields, such as the insolation, the Q-flux, the ozone concentration and the mixed layer depth (50m uniformly), are constant over the year, zonally symmetric and symmetric about the Equator. The Q-flux can be viewed as a crude representation of the poleward oceanic heat transport and thus takes on negative values at low latitudes and positive values at high latitudes. While the shape of the Q-flux is kept constant various choices of its amplitude are used and the model is run to equilibrium for each choice. The outcome of this ranges from very icy climates, with sea ice margins in both hemispheres at 35 degrees, to completely ice-free climates. Between these extremes arises a complex transition which includes both asymmetric climates, with sea ice in one hemisphere and no sea ice in the other, and multiple equilibria, where sea ice at both low and high latitudes are possible under the same external forcing.