CH-1

A Status Report on the Community Climate Model CCSM3

Philip E. Merilees
National Center for Atmospheric Research, Climate and Global Dynamics Division, PO Box 3000, Boulder, CO 80307 USA, merilees@ucar.edu

On June 2, 2004, a new version of the Community Climate System Model will be released to the scientific community. This model will be released in a number of different configurations including a T85 with a 1 degree ocean, a T42 with a 1 degree ocean, a T31 with a 3 degree ocean and a finite-volume dynamical core version at 2.5X2.5 degrees with a one degree ocean. The T85 version is the main model used for simulation of the possible climate changes under different scenarios of GHG concentrations. The T42 is used for investigations of sensitivity to horizontal resolution and for climate experiments that can manage with lower resolution (and lower cost). The T31 version is mainly directed towards paleoclimate applications. The finite-volume dynamical core is designed to handle the transport of many chemical species and is expected to be used as the basic approach for coupled climate-chemistry models. All configurations of the model give climate properties that are different from previous versions of the CCSM.

There are some effects of the higher horizontal resolution that are apparent in the mean climate particularly at the higher latitudes. There is more heat transported by the atmosphere into the Arctic in the T85 simulation than the T42 leading to somewhat less ice and a somewhat different heat balance. It remains to be seen as to the effect on climate sensitivity to polar processes. In the southern hemisphere, the surface westerlies are farther south than in T42 leading to a stronger Antarctic Circumpolar Current.

Other comparisons of simulated climates from the different configurations will be made and an attempt to provide a physical understanding of the similarities and differences undertaken.

CH-2

Initial Applications of the Earth System Modeling Framework

Chris Hill, 54-1515, MIT, Cambridge, MA02139, USA, cnh@mit.edu
Cecelia Deluca, Mesa Lab, NCAR, Boulder, CO, USA
Balaji, Geophysical Fluid Dynamics Laboratory, Forrestal Campus, Princeton University, NJ, USA

We will present a poster describing the Earth System Modeling Framework (ESMF) project and illustrate the projects role in a number of planetary scale simulation initiatives. The ESMF project is a NASA funded computational technology effort that involves many of the major modeling centers in the US. The project is developing infrastructure software designed to meet current and future challenges presented by research questions that require complex, integrated simulation, especially in the area of global scale synoptic, seasonal to interannual and centennial timescales. A growing challenge in these areas of integrated modeling is making effective use of a suite of numerical simulation and data assimilation tools that must be coupled together into a single application. For such applications, ESMF provides a standard software platform that streamlines the techical steps involved in developing and using coupled applications. As we will illustrate in our poster this permits previosuly impractical coupled applications to be configured that cross institutional boundaries and that span science sub-domains. Examples will be shown illustrating how ESMF is starting to be used in both operational and research scenarios to enable the development of a new generation ocean-atmosphere-biosphere-cryosphere modeling tools.

CH-3

Spatial Assessment of HadCM3 Simulations via NCEP Reanalyses over Europe

Dr. Paulo. S. Lucio, CGE - University of Évora, Rua Romao Ramalho, 59
7000-554 Evora, Portugal, pslucio@uevora.pt

This study is addressed to the extreme regional-scale evaluation of global climate model (GCM). Given that assessment of models is crucial to consider future scenarios in climate change impact analyses, the exploratory analysis is essen-tial, as it identifies the strengths and weaknesses of GCM to regional-scale differences in model performance, providing insights on regional-scale climate interactions and processes. Since evaluation of models is crucial to assess future scenarios, the aim of this study is to investigate whether the extreme values predicted by the HadCM3 climate model can simulate the NCEP Reanalyses, assuming that the extremes of both models are realisations of the same spatial stochastic process. The risk of adopting the wrong decision-strategy has costly economic and social consequences. To get more useful significant information about uncertainties surrounding spatial climate projection, one also has analysed the pattern of temperature extremes in terms of their anomalies. A common technical issue in the assessment of numerical spatial models is based on the geostatistical interpolation by the kriging with the residual analysis. This methodology is very important and useful for guiding an evolutionary statistical model-building process. The kriging is unlike other gridding methods because it makes explicit use of the particular autocorrelation between observations on the surface being mapped. If the surface is second-order stationary, or can be made stationary by some transformation, the spatial autocorrelation will express the degree of dependence between all locations on the surface, hence also particularly between observations and grid nodes. The present study leads to the conclusion that the HadCM3 Simulations do not reproduce realistically the NCEP Reanalyses over the target domain, even despite the fact that the climatology of extremes has demonstrated very similar spatial patterns. Such instability may persist in the future. In all extreme temperature attributes the same climatological space pattern is recognised, suggesting that the ensemble describes the main characteristic of spatial variation in temperature extremes, from the temperate climates of the southwest zones to the extreme cold of the northeast ones. Furthermore, The HadCM3 Simulations produce unrealistically extreme temperature climatology (long-term climate signal) for the winter in the Northeastern Europe and for the summer in the Northwestern Europe, where the cost of a false diagnostic seems to be very high.

(*) This work is an autonomous contribution to the EU funded MICE project (Modelling the Impact of Climate Extremes). Model data were supplied by the Climate Impacts LINK project (funded by the UK De-partment of the Environment, Food and Rural Affairs) on behalf of the Hadley Centre for Climate Prediction and Research, which is part of the Met Office in the UK. (http://www.cru.uea.ac.uk/projects/mice/)

CH-4

Coupled Atmosphere-Ocean-Sea Ice Model for the Earth Simulator (CFES): Model Description and Verification

Dr. Nobumasa Komori, Earth Simulator Center, JAMSTEC, 3173-25 Showa-machi, Kanazawa-ku, Yokohama 236-0001 Japan, komori@jamstec.go.jp
Dr. Keiko Takahashi, takahasi@jamstec.go.jp
Mr. Kenji Komine, komine@jamstec.go.jp
Dr. Wataru Ohfuchi, ohfuchi@jamstec.go.jp
Mr. Genki Sagawa, sagawa@jamstec.go.jp
Mr. Hideharu Sasaki, sasaki@jamstec.go.jp
Dr. Toru Miyama, Frontier Research System for Global Change, 3173-25 Showa-machi, Kanazawa-ku, Yokohama 236-0001 Japan, tmiyama@jamstec.go.jp
Dr. Takashi Mochizuki, motizuki@jamstec.go.jp
Dr. Tatsuo Motoi, tmotoi@jamstec.go.jp
Dr. Yoshio Kurihara, ykuri@jamstec.go.jp
Dr. Hirofumi Sakuma, sakuma@jamstec.go.jp
Prof. Hisashi Nakamura, Frontier Research System for Global Change, 3173-25 Showa-machi, Kanazawa-ku, Yokohama 236-0001 Japan and Department of Earth and Planetary Science, University of Tokyo, 7-3-1 Hongo, Bunkyo-ku, Tokyo 113-0033 Japan, hisashi@eps.s.u-tokyo.ac.jp

CGCM is now becoming an inevitable research tool for climate variation studies CLIVAR promotes. And pressing concern on the earth environment not only in the global but regional scales is one of our main motivations to pursue the possibility of developing a CGCM capable of representing "mesoscale" phenomena in a relatively explicit fashion. With these in mind, we have developed a fully parallelized code of coupled atmosphere-ocean-sea ice model to be run on the Earth Simulator (CFES), which consists of AFES (atmospheric GCM for the ES) and OIFES (ocean-sea ice GCM for the ES). AFES was a tightly-tuned optimized code based on CCSR/NIES AGCM while OIFES was developed from GFDL's MOM3 and an EVP-type regional sea ice model at International Arctic Research Center.

CFES was mainly designed to achieve efficient computational performance on the ES by using multiprogramming techniques and fully parallelized coupling schemes: In order to reduce communication cost arising from gathering/broadcasting (GB) data in the conventional coupler, we circumvent this GB process and the direct parallel transfer of the variables between AFES and OIFES was realized in our coupled code. With the respective resolution of T106L48 for AFES and 1.125 degree in horizontal and 37 levels in vertical for OIFES, when using 9 nodes (72 processors) of the ES, it takes about 3 hours for CFES to complete 1-year integration.

The high computational performance of CFES enables us to execute several high-resolution coupled simulations covering the time scale of centennial order. We are now executing validation experiments to check the physical performance of our code in reproducing annual mean, seasonal cycle and interannual variability. The target horizontal resolutions of CFES are T42, T106 and T319 for the atmospheric component and 1, 1/4 and 1/8 degree for the oceanic component. In this presentation, we will cover the model description of CFES, our experimental setting and preliminary results of our physical verification as well as the details of our parallelized coupling schemes and its efficiency of computational performance on the ES.

CH-5

Development of Super High Resolution Global and Regional Climate Models on the Earth Simulator for the Projection of Global Warming

Dr. Akira Noda, Meteorological Research Institute, 1-1, Nagamine, Tsukuba, Ibaraki 305-0052, Japan, noda@mri-jma.go.jp
Dr. Takashi Aoki, Meteorological Research Institute, 1-1, Nagamine, Tsukuba, Ibaraki 305-0052, Japan, tkshaoki@mri-jma.go.jp
Dr. Masanori Yoshizaki, Meteorological Research Institute, 1-1, Nagamine, Tsukuba, Ibaraki 305-0052, Japan, myoshiza@mri-jma.go.jp

We are conducting a five-year research project "Development of super high resolution global and regional climate models" funded by the Ministry of Education, Culture, Sports, Science and Technology (MEXT) to develop a global climate (atmospheric) model with a horizontal resolution of 20 km realistically simulating such phenomena as typhoons and Baiu front globally, and cloud resolving non hydrostatic regional models (NHMs) with a horizontal resolution of a few km simulating meso-scale phenomena such as heavy rainfall and heavy snowfall. These models are utilized to investigate the effects of global warming on these phenomena through time-slice numerical experiments. The models have been implemented on and optimized to the Earth Simulator. The time integration of the global model has been further accelerated by introducing a semi-Lagrangian scheme. The present version of a horizontal resolution TL959 (20km mesh) with 60 vertical layers attains 44 hours for one year integration using 60 nodes (480 8Gflops-CPUs) on the Earth Simulator. Test runs in climate mode (no re-initialization during multi-year simulation periods) as well as in forecast mode (short-term forecasts initialized with analyses) show that the model simulates the eyes and spiral band of typhoons very well. The cloud resolving NHMs have been tested with horizontal resolutions from 1 km to 5 km and about 1000 x 1000 x 38 grid domain around Japan. A 1-km mesh model has successfully reproduced heavy rainfalls associated with a typhoon, and clouds bands associated with heavy snowfalls over Japan Sea in winter. The spectral boundary coupling method is introduced to perform a long-term integration of the NHM multi-nested in the global model. A 70-day integration has been stably performed with reproducing the observed climatology of precipitation. Preliminary results from long-term integrations with the global model and the NHMs will be presented in poster to show the model performance.

CH-6

ENSEMBLES: Ensemble-Based Predictions of Climate Changes and Their Impacts

Dr. Renate Hagedon
The ENSEMBLES Management Board
Hadley Centre for Climate Prediction and Research, ECMWF, Shinfield Park, Reading, RG2 9AX, UK, renate.hagedorn@ecmwf.int
The ENSEMBLES Management Board, Hadley Centre for Climate Prediction and Research, FitzRoy Road, Exeter, EX1 3PB, UK, ensembles@metoffice.com

Prediction of both natural climate variability and the human impact on climate is inherently probabilistic, due to uncertainties in forecast initial conditions, representation of key processes within models, and climatic forcing factors. Hence, reliable estimates of climatic risk can only be made through ensemble integrations of Earth-System Models in which these uncertainties are explicitly incorporated. A new European project called ENSEMBLES (Ensemble-based Predictions of Climate Changes and their Impacts) will develop a common ensemble climate forecast system for use across a range of timescales (seasonal, decadal and longer) and spatial scales (global, regional and local).

This model system will be used to construct integrated scenarios of future climate change, including both non-intervention and stabilisation scenarios. This will provide a basis for quantitative risk assessment of climate change and climate variability, with emphasis on changes in extremes, including changes in storminess and precipitation and the severity and frequency of drought, and the effects of "surprises", such as the shutdown of the thermohaline circulation. Most importantly, the model system will be extensively validated. Hindcasts made by the model system for the 20th century will be compared against quality controlled, high resolution gridded datasets for Europe. Probability forecasts made with the model system on seasonal and decadal timescales will also be validated against existing data.

The exploitation of the results will be maximised by linking the outputs of the ensemble prediction system to a wide range of applications. In turn, feedbacks from these impact areas back to the climate system will also be addressed. Thus ENSEMBLES will have a structuring effect on European research by bringing together an unprecedented spectrum of world leading expertise. This expertise will be mobilised to maintain and extend European pre-eminence in the provision of policy relevant information on climate and climate change and its interactions with society. The contribution will outline the scientific and technological objectives of the project, and will give an overview of the project's research themes.

CH-7

How Strong is Carbon Cycle-Climate Feedback in a Global Warming Scenario?

Ning Zeng, Haifeng Qian, and Ernesto Munoz, Department of Meteorology and Earth System Science, Interdisciplinary Center, University of Maryland, 2421

Computer and Space Sciences Building, College Park, MD 20742-2425, USA,
zeng@atmos.umd.edu

An Earth system model is used to study the interactions between the physical climate and the carbon cycle. The system consists of the physical atmosphere, land and ocean, and the embedded terrestrial and oceanic carbon cycle. A fully coupled carbon-climate simulation and several sensitivity runs were conducted for the period of 1801-2100 with prescribed IPCC-SRES-A1 emission scenario. Our results indicate a positive feedback to global warming from the interactive carbon-cycle. However, the amplitude of such feedback is found modest, largely due to the multiple limiting factors constraining terrestrial productivity and carbon loss. The differences with the Hadley Centre and IPSL results are manifestations of some of the poorly constrained processes such as the global strength of the CO2 fertilization effect and the temperature dependence of soil decomposition rate.

CH-8

Estimating the Probability of Thermohaline Collapse and Rapid Climate Change – an Example of the Statistical Analysis of a Climate Model

Peter Challenor, Southampton Oceanography Centre, European Way,
Southampton, SO14 3ZH, UK, P.Challenor@soc.soton.ac.uk

North West Europe has a milder climate than equivalent latitudes of North America because the thermohaline circulation transports heat northwards in the Atlantic. In some dynamical models of climate this circulation shuts down as the concentration of greenhouse gases in the atmosphere increases. If this were to happen in reality, it may take place very rapidly and would have severe consequences for the climate of Europe. The risk of such events should be known by policy makers so they can frame future decisions and engage in a reasoned debate on the effects of climate change. We are looking at the problem of estimating the probability of such a collapse in the thermohaline circulation and its sensitivity to other climate parameters. The model we use is C-GOLDSTEIN, an intermediate complexity coupled ocean/atmosphere climate model. The problem is to estimate the probability from model extrapolations, and assess how good such extrapolations are. Simple Monte Carlo methods cannot be used, as the model takes too long to run and we would need thousands of runs to span its parameter space. Instead we use Bayesian statistical methods, known as SACCO (Statistical Analysis of Computer Code Output), to estimate the probabilities. In these methods, we approximate the full dynamical model with a much simpler statistical approximation, known as an emulator. By careful design of a computer experiment we can make this approximation with a limited number of runs of the model. The emulator can then be used to estimate what the model would have given had it been run with an associated uncertainty. This uncertainty can be used to guide which parameter values we might use for future runs of the full model. We can use the emulator in a large number of runs, the thousands mentioned above, and use Monte Carlo methods to estimate the probability density of future climate variables. These runs can be used to estimate the uncertainty of climate predictions (conditional on some uncertain inputs) and for the estimation of

future probabilities, for example of the strength of the thermohaline circulation. There are a number of extensions that need to be made to standard SACCO methodology. The outputs are not smooth as we are looking for rapid transitions and we need to consider the evolution of the output not simply its value at some point in the future. Problems encountered as the dimension of the problem gets large are also discussed.

CH-9

Monitoring the Meridional Overturning Circulation in the Tropical West-Atlantic

Torsten Kanzow, Uwe Send, and Walter Zenk, Insitut fuer Meereskunde, Duesternbrooker Weg 20, 24105 Kiel, Germany, tkanzow@ifm.uni-kiel.de
Monika Rhein, Institut fuer Umweltphysik, Otto Hahn Allee 1, 28359 Bremen, Germany

Fluctuations of the meridional overturning circulation (MOC) are thought to have an important impact on the climate system. Such fluctuations are common features in models but until today observational evidence is missing. Here the Feb 2000 to Jun 2003 results from the ongoing Meridional Overturning Variability Experiment (MOVE, observational German CLIVAR project) will be presented. The scientific aim of MOVE is to acquire multi-year time series of variations of the meridional transport and of the hydrographic conditions of the NADW, and to demonstrate that the overturning variability can be directly observed. The experimental strategy makes use of horizontally integrating geostrophic end-point moorings, measuring temperature, salinity and bottom pressure. This allows for basin scale monitoring of transport fluctuations with a very limited number of moorings. The moored MOVE array is located at 16°N, monitoring transports through the 1000 km section between the Lesser Antilles and the Mid-Atlantic Ridge. We believe that similar monitoring strategies will become key elements of a future ocean observing system. For example, the initial pilot plan of the International Timeseries Science Team (www.oceantimeseries.org) includes a number of transport monitoring sections. The results presented include rapidly changing hydrographic conditions at the mooring locations, indications of an interior recirculation of the southward DWBC, and a large temporal variability of the meridional NADW transport, at times exceeding 10 Sv on a monthly scale. As a reference, simultaneously acquired moored direct current measurements along the section from the joint MOVE/GAGE (Guyana Abyssal Gyre Experiment, WHOI) effort are used. The observed variability is then interpreted in the context of model results. Finally, to demonstrate its future potential as well as to point out deficiencies, the monitoring array is simulated using model data.

CH-10

Ocean Data Assimilation for Understanding Climate Variability

Dr. Magdalena A. Balmaseda, ECMWF, Shinfield Park, Reading RG2 9AX, UK, Balmaseda@ecmwf.int

Dr. David L.T. Anderson, sta@ecmwf.int
Dr. Dick Dee, dao@ecmwf.int
Dr. Arthur Vidard, nes@ecmwf.int
Dr. Alberto Troccoli, nej@ecmwf.int

The merits of ocean data assimilation are discussed in the context of state estimation and creation of ocean initial conditions for climate forecasts. With state of the art ocean data assimilation systems, the data mainly corrects for systematic error. The presence of systematic error can be damaging for the representation of interannual and decadal variability in data-sparse areas. Accurate knowledge of the climate variability requires an adequate treatment of the systematic error during the data assimilation process Results from an ocean reanalysis for the last 20 years show that in the equatorial Pacific, a relatively data-rich area, the current data assimilation schemes improve the representation of the interannual variability of the upper ocean in spite of a large systematic error component. Besides, the initialization of the ocean by means of data assimilation improves the skill of seasonal forecasts. However, the presence of systematic error has a detrimental effects on the velocity field, which contaminates the estimation of heat and volume transports, useful for budget calculations in climate studies.

Ouside the equatorial Pacific, where the presence of data is more sporadic, the data assimilation can contaminate the climate variability. The example of the equatorial Atlantic is presented. A bias correction scheme has been implemented in an OI-based data assimilation system. The details of the scheme are described, and the results from different experiments are discussed, with special emphasis on the equatorial Atlantic and Pacific oceans.

□CH-11

A Variational Data Assimilation System for the Global Ocean

Dr. Anthony T. Weaver, CERFACS, 42 avenue Gaspard Coriolis, 31057, Toulouse Cedex 1, France, weaver@cerfacs.fr
Mr. Nicolas Daget, daget@cerfacs.fr
Ms. Sophie Ricci, ricci@cerfacs.fr
Dr. Philippe Rogel, rogel@cerfacs.fr
Dr. Charles Deltel, LODYC, CNRS/IRD/IPMC/MNHN, 4 place Jussieu, 75252 Paris Cedex 05, France, cdeltel@lodyc.jussieu.fr
Dr. Jerome Vialard, Jerome.Vialard@lodyc.jussieu.fr

A variational data assimilation system for a global ocean version of the OPA ocean general circulation model (OGCM) is described. An iterative incremental approach is used to minimize a cost function that measures the statistically weighted squared differences between the observational information and their model equivalent. The control variables for the minimization problem consist of an increment to the background estimate of the initial conditions at the beginning of each assimilation window. Both three- and four-dimensional variational assimilation (3D-Var and 4D-Var) are supported by the system. In 3D-Var, the approximation is made that increments to the model initial state persist for the duration of the assimilation window, while in 4D-Var, increments at

initial time are translated to increments at later times in the window by the tangent-linear of the OGCM. All other components of the assimilation system are shared by 3D-Var and 4D-Var. The role of 3D-Var is to provide an economical alternative to 4D-Var and an important reference for evaluating 4D-Var.The current system assimilates temperature and salinity measurements from in situ observation networks (TAO, Argo, XBTs,...) and along-track sea-level anomaly data from satellite altimeters (TOPEX/Poseidon, ERS1/2,...). The formulation of the background error covariances is crucial in both 3D-Var and 4D-Var. Here a multivariatecovariance formulation is specified implicitly through a sequence of variable transformations from physical space, where state variables are known to be strongly correlated, to a nondimensional space of approximately uncorrelated control variables. Univariate correlation functions for the uncorrelated variables are assumed to be anisotropic and inhomogeneous, and are modelled using a generalized diffusion equation. Multivariate constraints are defined through a set of linear balance operators that exploit flow-dependent relationships between temperature, salinity, sea-surface height and velocity. A flow-dependent parametrisation of the background error variances is also described. These developments to the background error covariances have had a significant positive impact on the quality of the ocean analyses, particularly in the representation of equatorial currents, compared to analyses produced using simpler univariate, flow-independent covariance formulations. Both 3D-Var and 4D-Var systems are currently being applied to produce extensive sets of global ocean analyses over the period 1987-2001 as part of the European ENACT project. Results from these analyses will be presented.

□CH-12

Ocean Observing System and Data Assimilation

Dr. Arthur Vidard, European Centre for Medium-range Weather Forecast, Shinfield Park, Reading Berkshire, RG2 9AX, UK, nes@ecmwf.int
Dr. Magdalena A. Balmaseda, European Centre for Medium-range Weather Forecast, Shinfield Park, Reading Berkshire, RG2 9AX, UK, neh@ecmwf.int
Pr. David L.T. Anderson, European Centre for Medium-range Weather Forecast, Shinfield Park, Reading Berkshire, RG2 9AX, UK, sta@ecmwf.int
Pr. Keith Haines, Environmental Systems Science Centre, Reading University 3 Earley Gate Reading RG6 6AL, UK, kh@mail.nerc-essc.ac.uk
Dr. Alberto Troccoli, European Centre for Medium-range Weather Forecast, Shinfield Park, Reading Berkshire, RG2 9AX, UK, nej@ecmwf.int

The ways of combining the use temperature, salinity and sea level measurements in an ocean data assimilation context are presented and discussed. The contribution of different ocean observation data-types to the estimation of the ocean state is evaluated by conductingObserving System Experiments.

The ocean data assimilation scheme is an OI-based scheme, usedat ECMWF for creating ocean initial conditions for seasonal forecasts.Recently the assimilation of in situ salinity data and sea level hasbeen included in this scheme in addition to in situ temperature dataleading to a better representation of the state of the ocean.

The data-type evaluated are temperature data from moorings (TAO/TRITON and PIRATA), XBTs, ARGO floats, sea level from the altimeter and salinity data from ARGO floats and TRITON moorings. Resultsshow that all data types contribute to the estimation of the mean state andinterannual variability of the ocean, probably because is not frequent to have in situ observations regularly distributed in space and time and because in situ and altimeter observations are complementary.

CH-13

The ECCO High-Resolution Global Ocean Data Assimilation

Ichiro Fukumori, Jet Propulsion Laboratory, Mail Stop 300-323, 4800 Oak Grove Dr., Pasadena, CA 91109, USA, fukumori@jpl.nasa.gov
Benny Cheng, bcheng@jpl.nasa.gov
Tong Lee, tlee@pacific.jpl.nasa.gov
Dimitris Menemenlis, menemenlis@jpl.nasa.gov
Armin Koehl, Scripps Institution of Oceanography, 9500 Gilman Dr., MS 0230, La Jolla, CA 92093, USA, koehl@ucsd.edu
Detlef Stammer, Univ Hamburg, Institut fuer Meereskunde, Bundesstr. 53, 20146 Hamburg, Germany, stammer@ifm.uni-hamburg.de
Alistair Adcroft, MIT 54-1523, 77 Massachusetts Ave, Cambridge, MA 02139, USA, adcroft@mit.edu
Chris Hill, cnh@mit.edu

The consortium for Estimating the Circulation and Climate of the Ocean (ECCO) has demonstrated the feasibility and utility of providing global, sustained, dynamically sensible estimates of the full three-dimensional, time-varying oceanic state and of associated surface forcing fields required to bring the model into consistency with ocean observations. Remotely-sensed (sea level, winds, temperature, gravity) and in-situ (temperature, salinity, velocity) observations are assimilated with a state-of-the-art numerical ocean model using advanced estimation methods (adjoint, Kalman filter, and Rauch-Tung-Striebel smoother). The estimates are available in nea real-time and are being used for a wide variety of scientific applications. The ECCO assimilation system is being ported to a near global, eddy-permitting model to better resolve meso-scale variabilities and their effects on the large-scale circulation. This new analysis has an isotropic grid with a nominal 1/4-deg resolution that extends from 80S to 80N. This effort is a first attempt to assimilate observations to achieve a physically consistent estimate of the ocean's temporal evolution at global eddy-permitting resolution. Development of this new system and future plans will be described. Results will be analyzed, comparing the new estimates with observations and with the ongoing ECCO coarse resolution products (1-deg).

CH-14

High-Resolution Modeling and Assimilation for the Equatorial Pacific Using the ECCO System

Dr. Bruce D. Cornuelle, Scripps Institution of Oceanography, 9500 Gilman Drive, Dept. 0230, La Jolla, CA 92093-0230, USA, bdc@ono.ucsd.edu

Dr. Ibrahim Hoteit, ihoteit@ucsd.edu;
Dr. Detlef Stammer, Universitaet Hamburg, Zentrum fuer Meeres- und Klimaforschung, Institut fuer Meereskunde, Bundesstr. 53, 20146 Hamburg, Germany, stammer@ifm.uni-hamburg.de;
Virginie Thierry, Laboratoire de Physique des Océans - UMR 6523, CNRS/IFREMER/UBO, Ifremer, BP 70, 29280 Plouzané, Cédex, France, vthierry@ifremer.fr

The MIT general circulation model is being used to study the dynamics of the equatorial Pacific ocean from 1992 to 2000. To achieve high resolution at lower cost, the model domain is only the tropical Pacific, with open boundaries at 26 N, 26 S, and in the Indonesian throughflow. The model outputs are compared to ocean observations to evaluate the realism of the flow fields before assimilation. In the non-assimilated runs, forcing fields, boundary conditions, and model initial conditions are taken from the ECCO global state estimates as well as from NCEP. The model has 39 depth levels, and includes parameterizations for the surface boundary layer (KPP). The comparisons to observations are evaluated for four different 9-year integrations to study the sensitivity to the forcing fields and to the horizontal resolution up to 1/6 degree. The conclusion of the resolution studies is that the ocean grid spacing could be set to 1/3 degree grid spacing in the tropical Pacific to accrue the benefits of enhanced resolution without paying a steep price in computer-time. Serious differences from the observations indicate that more work must be carried out to improve the quality of the forcings, particularly the wind stress for this region.

The data assimilation system for the MIT GCM has been adapted for the tropical Pacific Ocean. This system makes use of the adjoint method to adjust the model to fit observations in the tropical Pacific region. The initial forcing and boundary conditions were taken from the ECCO 1 degree synthesis. The adjustable parameters (controls) include the initial temperature and salinity conditions; temperature, salinity and horizontal velocities at the open boundaries; and the time-dependent surface fluxes of momentum, heat and freshwater.

In a first experiment, the model was constrained with Levitus temperature and salinity data, Reynolds sea surface temperature data and Topex/Poseidon and ERS altimeter data. The hindcast experiments that have been performed in 1998 demonstrate that the adjoint method can be efficiently used to improve the model consistency with data despite difficulties related to the chaotic nature of an eddy-permitting model.

CH-15

Ensemble Data Assimilation for Prediction and Understanding of the Ocean Circulation

Dr. Peter Jan van Leeuwen, Institute for Marine and Atmospheric Research, Utrecht (IMAU), PrincetonPlein 5, 3584 CC, Utrecht, Netherlands, leeuwen@phys.uu.nl

Recently, ensemble data-assimilation methods based on importance sampling have been tested for the Agulhas system. This system is dominated by highly nonlinear processes such as meander formation, eddy-mean-flow interactions, ring formation, interactions of rings with each other, flow-bottom interactions, etc. Consequently, the data-assimilation method has to be highly nonlinear too.

Traditional methods like variants of the Kalman filter and 4D-VAR methods are based on linearizations. Although they work fine for weakly nonlinear dynamics, by increasing model resolution the problems become so nonlinear that several ad-hoc solutions to the data assimilation problems are necessary. In the ensemble filters based on importance sampling this is not the case. The relatively high costs of these filters, of the order of 500-1000 model runs, can be reduced significantly by guiding the ensemble members to the observations. This can be done without loosing the full nonlinearity of the method; in fact no extra approximations are made. By exploring the expectation that a smoother is more efficient than a filter in the end, a further reduction in the number of ensemble members is expected.

The advantage of a fully nonlinear data assimilation method lies in better predictions and a better understanding of the bias problem. There is no doubt that suboptimal methods, including the Kalman filter for instance, can point to artificial model biases. Furthermore, the measurement operator can be fully nonlinear and errors are provided directly by the method. The ensemble nature of the method can be used to unravel physical relations in the system that are difficult to find from one model run. This leads to new physical insight in an ocean area of such complex dynamics.

Results with the new method will be shown for the Agulhas system using a high-resolution ocean model and real observations from satellite altimetry. The probability density sampled by the ensemble members contains information on how different model variables are related, for instance in the vertical, so that no artificial correlation matrices have to be introduced. In fact, these relations can be different from linear, as is assumed in the Kalman filter.

The method will also be implemented for the ocean area around Madagascar, as extension of the LOCO project that services a number of moorings in the Mozambique Channel, among others. Furthermore, a global version is now implemented with the OPA ocean model.

CH-16

Comparison of Ocean Reanalyses

Gennady A. Chepurin, Department of Meteorology, University of Maryland, College Park, MD 20742 USA, chepurin@atmos.umd.edu
Jim A. Carton, carton@atmos.umd.edu
David W. Behringer, Climate Modeling Branch EMC/NCEP/NWS WWBG, 5200 Auth Road, Camp Springs, MD 20746-4304 USA, David.Behringer@noaa.gov
Matt J. Harrison, Geophysical Fluid Dynamics Laboratory, National Oceanic and Atmospheric Administration, Post Office Box 308, Princeton, NJ 08542 USA, mjh@gfdl.gov
Eli Galanti, International Research Institute for Climate Prediction, The Earth Institute of Columbia University, Lamont Campus / 61 Route 9W, Palisades New York 10964-8000 USA
Michael K. Tippett, International Research Institute for Climate Prediction The

Earth Institute of Columbia University, Lamont Campus / 61 Route 9W, Palisades New York 10964-8000 USA, tippett@iri.columbia.edu

Recently a number of efforts have been made to reconstruct the physical climate of the oceans during the past couple of decades through application of data assimilation to the ocean mass and momentum fields. Examples include the Simple Ocean Data Analysis of University of Maryland/Texas A&M, and the Global Ocean Data Assimilation System of the National Center for Environmental Prediction. In this presentation we compare the result of these reanalysis efforts to each other and to independent observations to demonstrate the current accuracy in representation of climate variability and to explore the major sources of error.

Our results show that a major source of error is due to bias in the model forecasts. We examine the model forecast bias through a statistical analysis of systematic tendencies of the forecast-minus-observation differences. Despite the differences in numerics, resolution, observation sets, and surface forcing, the bias in different data assimilation systems shows many similarities. In all cases the bias has substantial time-mean, seasonal, and interannual climate-related variability. In all cases the bias in the mixed layer behaves somewhat differently from the bias in the thermocline. We consider each of these separately.

Bias in the temperature of the mixed layer has broad spatial scales. It varies seasonally most noticeably in midlatitudes. It varies as a function of the Southern Oscillation Index in the tropical Pacific with a phase indicating that the analyses underestimate the amplitude of ENSO. Time mean and seasonal bias in the forecast thermocline depth are largest in the western sides of the subtropical basins in all oceans. In addition the seasonal cycle of bias is large in the central and eastern tropics. Bias of the thermocline depth is also strongly a function of the Southern Oscillation Index.

CH-17

Pacific Islands Regional Global Climate Observing System Program

Mr. Howard J. Diamond, NOAA/NESDIS, 1335 East-West Highway, Room 7214, Silver Spring, MD 20910 USA, howard.diamond@noaa.gov

The tropical Pacific Ocean is the primary heat source reservoir for the Earth ocean-atmosphere system. As such it exerts a tremendous influence on the Earth's circulation patterns and changes therein. The well-known El Nino phenomenon appears to be a consequence of inefficient poleward energy transfer from the tropical oceans during non-El Nino years. The threat of impending climate change has focused scientist's attention on the dynamics of the tropical Pacific Ocean and atmosphere and the connections to the mid-latitudes.

Given the importance of the tropical Pacific, climate observations from the region are of utmost important to physical dynamics of the Pacific ocean-atmosphere. Unfortunately, due mostly political and economic reasons, the existing network of island-based climate observations has deteriorated in quantity and quality to a point where data are insufficient to conduct even the most basic trend analysis. The independent island nations have insufficient resources to repair, let alone enhance, their local climate networks. Thus, it is in the best interests are of all countries to assist local Pacific nations in training of personnel, maintenance and enhancement of their local climate observation networks. The mutual benefit of such an endeavor has been realized by the international community.

As such, the U.S. in partnership with Australia, New Zealand, and the nations of the South Pacific Regional Environment Program have taken the lead in working towards establishing a robust and sustainable Pacific Islands Global Climate Observing System (PI-GCOS) that meets both the global requirements for climate change and variability observations, the regional application needs of the PI nations, and meets the associated regional and international requirements for climate observing.

CH-18

CHAMPCLIM: Climatologies Based on Radio Occultation Observations

Dr. Andrea K. Steiner, Institute for Geophysics, Astrophysics, and Meteorology (IGAM), University of Graz, Universitaetsplatz 5, A-8010 Graz, Austria, andi.steiner@uni-graz.at
Dr. Ulrich Foelsche, ulrich.foelsche@uni-graz.at
Prof. Gottfried Kirchengast, gottfried.kirchengast@uni-graz.at
Andreas Gobiet, andreas.gobiet@uni-graz.at
Armin Löscher, armin.loescher@uni-graz.at
Dr. Jens Wickert, Geoforschungszentrum Potsdam (GFZ),Department Geodesy and Remote Sensing, Telegrafenberg, G-14473 Potsdam, Germany, jens.wickert@gfz-potsdam.de
Dr. Torsten Schmidt, tschmidt@gfz-potsdam.de

The Global Navigation Satellite System (GNSS) Radio Occultation (RO) technique is based on a satellite-to-satellite limb sounding concept using GNSS microwave signals to probe the Earth's atmosphere. Fundamental atmospheric variables such as temperature and humidity can be retrieved with high accuracy in the troposphere and stratosphere. The changing thermal structure in this height domain is a sensitive indicator of climate change. The global coverage, all-weather capability, high accuracy, and self-calibrated nature of RO data suggests them as a promising tool for global short- and long-term monitoring of atmospheric temperature change.

The German research satellite CHAMP (CHAllenging Minisatellite Payload for geoscientific research) with a GPS (Global Positioning System) occultation receiver aboard continuously records about 180 RO observations per day since March 2002. The mission is currently expected to last at least until 2007, thus CHAMP data provide the first opportunity to create real RO based climatologies on a longer term. CHAMPCLIM is a joint project of the IGAM/University of Graz and the GeoForschungsZentrum (GFZ) Potsdam. The overall aim of CHAMPCLIM is to help ensure that the CHAMP RO data are exploited in the best possible manner for climate monitoring. The main objectives of the CHAMPCLIM project can be summarized in form of three areas of study as follows:

(1) RO data processing advancements for optimizing climate utility of the data,

(2) RO data and algorithms validation comprising the comparison of CHAMP RO profiles against temperature profiles from the GOMOS and MIPAS instruments on ENVISAT as well as against temperature and refractivity profiles of ECMWF analysis fields.

(3) Creating global RO based climatologies for monitoring climate change.

The latter area exploits the achievements of parts (1) and (2). The complete CHAMP RO data flow (~180 events/day) will be used for month-to-month, season-to-season, and year-to-year climate variability and change monitoring. We will build, on the one hand, direct RO-based climatologies by monitoring of climatological refractivity, temperature, geopotential height, and humidity fields. On the other hand, we will perform optimal fusion of the CHAMP RO-derived refractivity data and ECMWF analysis fields into global climate analyses by use of 3D-variational assimilation techniques.

We will show a summary of the current activities and exemplary results.

CH-19

Monitoring Climate Change with GNSS Occultations: A 25-year (2001-2025) Simulation Study

Dr. Ulrich Foelsche, Institute for Geophysics, Astrophysics, and Meteorology (IGAM), University of Graz, Universitaetsplatz 5, A-8020 Graz, Austria, ulrich.foelsche@uni-graz.at
Prof. Gottfried Kirchengast, gottfried.kirchengast@uni-graz.at
Dr. Andrea K. Steiner, andi.steiner@uni-graz.at
Dr. Luis Kornblueh, Max-Planck Institute for Meteorology, (MPIM), Bundesstr. 55, D-20146 Hamburg, Germany, kornblueh@dkrz.de
Dr.Elisa Manzini, National Institute for Geophysics and Volcanology, Via Donato Creti 12, 40128 Bologna, Italy, manzini@bo.ingv.it

The radio occultation (RO) technique is based on a satellite-to-satellite limb sounding concept using microwave signals to probe the Earth's atmosphere. The propagation of Global Navigation Satellite System (GNSS) signals is influenced by the atmospheric refractivity field resulting in slowing and bending of the signal. The atmospheric phase delay as the principle observable is measured with millimetric accuracy. It is the basis for high-quality retrievals of atmospheric key variables, particularly of temperature profiles. Highest temperature accuracies of < 1 K are obtained in the upper troposphere and lower stratosphere. The long-term stability, self-calibrated nature, all-weather capability, high vertical resolution, global coverage, and high accuracy of RO data suggests themas a promising tool for global short- and long-term monitoring of atmospheric temperature change. In order to investigate the climate change detection capability of a GNSS occultation system, we are currently performing an observing system simulation experiment over the 25-year period 2001 to 2025. This study involves realistic modeling of the neutral atmosphere and the ionosphere. We carried out two climate simulations with the ECHAM5 atmospheric general circulation model (GCM) of the MPIM Hamburg, covering the period 2001-2025: One control run with natural forcings only and one run including anthropogenic forcings due to

greenhouse gases, sulfate aerosols, and tropospheric ozone.Based on this, we perform realistic simulations of occultation observables for a small GNSS receiver constellation (6 satellites), state-of-the-art data processing for temperature profile retrieval, and a statistical analysis of temperature trends in both the "measured" climatology and the "true" climatology. We will assess how well a GNSS occultation observing system is able to detect climatic trends.We started with a "testbed" study to obtain a first set of reliable results on realistic observational errors (due to instrumental and retrieval errors) and sampling errors (due to spatial-temporal undersampling). These results, obtained for a typical summer season, were found encouraging for performing the full 25-year experiment. They indicated that both observational and sampling errors should be sufficiently low for monitoring expected temperature trends in the global atmosphere over the next two decades in most regions of the upper troposphere and stratosphere. The presentation will, after introducing the study setup and recalling the main results of the summer 1997 "testbed" analysis, focus on discussing results of the statistical analysis of trends from the full 25-year experiment.

CH-20

The Aquarius/SAC-D Salinity Satellite Mission: A Key to Future Studies of the Global Water Cycle, Ocean Circulation and Climate

Gary S E Lagerloef, Earth and Space Research, 1910 Fairview Ave E, Suite 210, Seattle WA 98102, USA, lager@esr.org
F. Raul Colomb, Comision Nacionales de Actividades Espaciales (CONAE), Buenos Aires, AR, rcolomb@conae.gov.ar
David Le Vine, NASA/Goddard Space Flight Center, Greenbelt, MD, USA David.M.LeVine@nasa.gov
Yi Chao, NASA Jet Propulsion Laboratory, 4800 Oak Grove Drive, Pasadena, CA 91109, USA, Yi.Chao@jpl.nasa.gov

The scientific motivation for measuring sea surface salinity (SSS) from satellites is to study the interactions between the Earth’s water cycle, ocean circulation and climate on intra-seasonal to interannual time scales. The key CLIVAR science objectives to be addressed are 1) to improve closure of the mean and seasonal global ocean-atmosphere freshwater balance, 2) to study the influence of SSS variability on tropical dynamics and ENSO, and 3) to analyze large scale SSS changes in mid to high latitudes that influence mode water formation, ocean convective overturning circulation and long-term climate variability. The measurements will provide an unprecedented view of the ocean salinity field and will serve to improve climate models by providing a key measurement to constrain air-sea water fluxes.

The Aquarius/SAC-D mission is primarily devoted to measuring SSS, and is being developed by the United States and Argentina for launch in 2008 with a three-year baseline mission life. Aquarius/SAC-D is specifically designed to optimize the salinity retrieval accuracy and provide global observations for climate studies. The satellite will provide global maps every 8-9 days at 100 km resolution using a three-beam push-broom configuration of 60-90 km single-beam resolution. The measurement requirements prescribe an rms uncertainty <0.2 psu globally on monthly time scales. The satellite data will be validated and jointly analyzed with the growing array of in situ salinity observations from Argo, surface drifters, moored buoys and ships of opportunity.

Aquarius/SAC-D will be launched in the same time frame as other international missions to measure global precipitation and soil moisture, providing an unprecedented opportunity to address simultaneously the atmosphere-ocean-land components of the global water cycle.

CH-21

The PAGES/CLIVAR Intersection

Keith Alverson, PAGES International Project Office, Sulgeneckstrasse 38, 3007 Bern, Switzerland, alverson@pages.unibe.ch

PAGES (Past Global Changes) is a core project of the International Geosphere Biosphere Programme (IGBP). The core mission of PAGES is to facilitate international collaborations and interdisciplinary science, especially between individuals involved in national programs with overlapping interests. The PAGES scope of interest includes the past evolution of the physical climate system, biogeochemical cycles, ecosystem processes, biodiversity and human dimensions. The emphasis is on high-resolution archives of global change - such as ice cores, tree rings, speleothems, corals, lake and marine sediments - and the use of these data, together with numerical models, to help constrain estimates of past global change. Knowledge of past changes can shed light on the underlying dynamics of the Earth System and to define the envelope of natural environmental variability against which anthropogenic impacts on the Earth System may be assessed. Facilitating publicly accessible paleodata access, engaging with the climate modeling community, strengthening the engagement of scientists from developing countries, and interdisciplinary, international community building continue to be the foundation of all PAGES activities.

A number of PAGES publications and a laptop display of various PAGES web-based services will be available alongside this poster. Interested CLIVAR scientists will be able to add themselves to the PAGES database, which includes free receipt of our tri-annual newsletter. In addition to providing a general overview of the PAGES project, the poster will highlight a few of the many overlapping PAGES/CLIVAR research activities. Past collaborations between IGBP-PAGES and WCRP-CLIVAR have been substantial. These are overseen by a joint working group, and have included a series of workshops and conferences intended to bring the paleoclimate and climate dynamics communities together. The CLIVAR/PAGES working group is being restructured in 2004 and is soliciting input from the CLIVAR community on potential new directions for interactions between PAGES and CLIVAR.

CH-22

Study of Environmental Arctic Change (SEARCH)

The SEARCH Steering Committee members
Dr. Peter Schlosser, Lamont-Doherty Earth Observatory, 61 Route 9W, Palisades, NY 10964 USA, schlosser@ldeo.columbia.edu

Recent studies of the arctic environment have revealed unexpected changes including lower sea-level atmospheric pressure, increased air temperature over most of the Arctic, but lower temperatures over eastern North America and Greenland, changed ocean circulation and rising coastal sea level, warmer Atlantic waters penetrating farther in the Arctic Ocean, reduced sea ice cover, and thawing permafrost. These changes are affecting every part of the arctic environment and are having repercussions on society. To understand the recent observations and put them into the context of natural variability and anthropogenic forcing, a multi-disciplinary, multi-agency program, has recently been developed. This program, SEARCH (Study of Environmental Arctic Change) is presently in the implementation phase. The implementation strategy includes activities aimed at detecting and understanding change in the Arctic system including the climate system, as well as program elements addressing the social response to the observed change. We will describe SEARCH on the basis of recent observations and results, with special emphasis on the linkages between SEARCH and CLIVAR.

CH-23

The U.S. CLIVAR Program

David M. Legler, 1717 Pennsylvania Ave NW, Suite 250, Washington, DC 20006 USA, legler@usclivar.org

The US has a significant set of CLIVAR activities that address the current US CLIVAR objectives:

* identify and understand the major patterns of climate variability on seasonal and longer time scales and evaluate their predictability;
* expand our capacity to predict short-term (seasonal to interannual) climate variability and search for ways to predict decadal variability;
* better document the record of rapid climate changes in the past, as well as the mechanisms for these events, and evaluate the potential for abrupt climate changes in the future;
* evaluate and enhance the reliability of models used to project climate change resulting from human activity, including anthropogenic changes in atmospheric composition; and
* detect and describe any global climate changes that may occur.

This poster will describe the implementation strategy of the U.S. CLIVAR program, its range of activities, and how it is coordinated.

CH-24

NOAA Office of Global Programs - Contributions to CLIVAR in the Atlantic and Pacific Sectors

James F. Todd, NOAA Office of Global Programs, 1100 Wayne Avenue, Suite 1210, Silver Spring, MD 20910 USA, james.todd@noaa.gov

The U.S. CLIVAR program seeks to observe, model and understand patterns of climate variability on seasonal to decadal time scales and to assess the predictability of such variability. The ultimate goal of the National Oceanic and Atmospheric Administration (NOAA) Office of Global Programs (OGP) participation in CLIVAR is to improve predictions of climate variability and projections of climate change on seasonal to multi-decadal time scales, and regional spatial scales, for optimal use in resource planning and policy decision-making. The program is designed to improve our understanding of global climate variability and potential changes due to climate system feedbacks, to determine the spatial and temporal extent to which this variability is predictable and to develop the observational, theoretical, and computational means to predict variability and project potential future changes. U.S. CLIVAR research that is supported by NOAA/OGP focuses on large-scale recurrent patterns of variability in the Atlantic and Pacific sectors that influence climate on the regional scale, particularly over the U.S. Among these patterns are the El Niño-Southern Oscillation (ENSO), Pacific Decadal Oscillation (PDO), Tropical Atlantic Variability (TAV), the North Atlantic Oscillation (NAO)/Arctic Oscillation (AO) and the American monsoon systems. A cross-section of completed and ongoing empirical, diagnostic and modeling investigations that addresses climate variability in the Atlantic and Pacific sectors - supported by NOAA/OGP - will be highlighted.