Invited Speaker

Why CLIVAR?

Professor Lennart Bengtsson
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The Earth climate is now generally regarded as primary a dynamical system undergoing complex variations driven by both natural and anthropogenic influences. Two major issues of fundamental importance stand out. First, are the climate variations of time-scales from seasons to several decades or longer predictable and if so will such predictions have useful skill? Second, would changes in the statistics of climate, either caused by anthropogenic influences or due to natural effects such as inherent instability of the climate system be significant and beyond what has been observed in recent centuries?

During the late 1980s there were a number of developments suggesting that a focused attack on these two issues were both urgent and timely constituting a principal objective of the world climate research programme. A new programme to address the variability and predictability of climate was required as this was not addressed by other WCRP programmes. Great progress was forthcoming in numerical modelling of the atmosphere leading to significant improvements in weather prediction on a global coverage, thus providing impetus and encouragement to embark on a step-wise modelling of the climate system at large.

Excellent advance in the understanding of the El Nino phenomenon and encouraging progress in predicting El Nino under the successful TOGA programme acted as a driver to systematically embarking on the exploration of the predictability in coupled ocean/land surface/atmosphere phenomena in general, including the long-term variation in lake water volumes, such as the Caspian Sea, lake Tschad and the great US lakes, long term variations in the Indian monsoon, the large multi-decadal variations in the Sahel rainfall and the warming event in the Arctic in the 1930s and 1940s.

While the initial emphasis of CLIVAR was on the natural variability of the climate system, the ongoing anthropogenic forcing of the climate system, which was broadly recognized by the community at large in the late 1980s made it crucial to include climate change as a central part of the CLIVAR programme.

One of the achievements of planning group, which was set up in 1991 to work out the blueprint of the programme, was to bring the atmospheric and ocean communities together in a joint effort. Over the years this cooperation has deepened and extended to include land surface scientists and other experts on Earth system modelling. Because of the nature of CLIVAR the programme is very broad. This is partly unavoidable but efforts are nevertheless needed to focus future activities on a few central issues of global significance.

Invited Speaker

Using Remote Sensing in the Bay of Bengal to Predict Cholera Epidemics

Dr. Rita Colwell
Director, U.S. National Science Foundation

Dr. Rita Colwell, Director, U.S. National Science Foundation,
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The study of environmental change, atmospheric forces, microbiology, and social science are inextricably linked, and the study takes place in real time and around the world. With satellites and supercomputers we monitor and model phenomena ranging from pollutants to marine populations to solar turbulence. We collaborate across disciplines and across national boundaries, often in virtual space. The connections between cholera...an ancient water borne disease...and the environment illustrate the richness and reach of today's scientific activity Full understanding of an infectious disease extends from countries to continents and beyond, and connects medicine to many disciplines across science and engineering. The scope of the research spans the planet, connecting flora, fauna, earth, water, and sky. And with this broader perspective comes a responsibility to society to examine the full range of inputs and outcomes. I will discuss the use of remote sensing to predict cholera outbreaks as preview of the expanded framework for conducting studies linking biomedicine, information science, nanoscience, and the emerging science of learning.

Invited Speaker

What Is CLIVAR? Progress To Date

Professor Antonio J. Busalacchi
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The overall purpose and goal of CLIVAR is to describe and understand climate variability and predictability on seasonal to centennial time scales, identify the physical processes responsible, including anthropogenic effects, and develop modeling and predictive capabilities where possible. CLIVAR is part of the World Climate Research Programme which is jointly sponsored by the World Meteorological Organization (WMO), the International Council for Science (ICSU) and Intergovernmental Oceanographic Commission (IOC). As such, CLIVAR is one of the largest and most encompassing elements of the WCRP. The specific scientific objectives of CLIVAR are to:

• Describe and understand the physical processes responsible for climate variability and predictability on seasonal, interannual, decadal and centennial time scales, through the collection and analysis of observations and the development and application of models of the climate system;
• Extend the record of climate variability over the time scales of interest, through the assembly of quality-controlled paleoclimate and instrumental data;
• Extend the range and accuracy of seasonal to interannual climate prediction through the improvement of global and regional climate models; and
• Understand and project the response of the climate system to increases of greenhouse gases and aerosols and to compare these projections with the observed climate record in order to detect any anthropogenic modification of the natural climate signal.

CLIVAR began in earnest when delegates from 63 countries met in Paris on December 2-4, 1998 at an International CLIVAR Conference to consider the implementation of the program. The development of CLIVAR was built upon the legacies of its predecessors the Tropical Ocean-Global Atmosphere (TOGA) Program and the World Ocean Circulation Experiment (WOCE). Implementation for CLIVAR has proceeded since then via a series of ocean basin panels for the Atlantic, Pacific, Southern, and most recently Indian Oceans; and monsoon panels that take into account the combined effects of atmosphere-land-ocean coupling for the Variability of the American Monsoon System, Variability of the African Climate System, and the Asian Australian Monsoon systems. Modeling activities within CLIVAR are focused on numerical experimentation for seasonal-to-interannual variability and predictability of phenomena such as the El Nino-Southern Oscillation (ENSO), with special attention to assessing and improving predictions, the development of coupled atmosphere-ocean climate models aiming to understand natural climate variability and its predictability on decadal to centennial time scales, and coupled climate models directed toward predicting the response of the climate system to changes in natural and anthropogenic forcing. Data analysis and synthesis efforts include atmosphere and ocean data assimilation activities; paleoclimatic reconstructions providing long-term records of quantitative paleoclimatic data with seasonal to interannual resolution in areas such as monsoon and ENSO regions, the North Atlantic, and areas of the globe with possible hydrologic predictability; and the development of indices and indicators of climate change and variability, with particular emphasis on the creation of indices of daily to seasonal extremes covering the global land surface.

This entire conference is dedicated to the progress to date across the whole of CLIVAR and the challenges that lie ahead. Examples of which include advances in our understanding of the North Atlantic Oscillation and its predictability, mechanisms of Tropical Atlantic variability, continuation of the TAO/TRITON moored array in the tropical Pacific and its support of routine ENSO prediction, expansion of the same mooring technology into the Atlantic via PIRATA, and initial implementation of moored buoy measurements into the Indian Ocean; a recently completed South American Low Level Jet Experiment focussed on the moisture corridor east of the Andes and the future extension into the La Plata River Basin, development of a North American Monsoon Experiment, design of an African Monsoon Multidisciplinary Analysis (AMMA) project, improved representation of propagating intraseasonal oscillations across the Indo-Pacific basin in coupled atmosphere-ocean models, advances in global approaches to ocean observations via Argo floats and ocean remote sensing, prospects for decadal predictability, coupled model improvements in support of the next IPCC assessment, and applications of CLIVAR science in support of today's society.

Invited speaker

Predictability Of The Coupled Climate System: 100-Year Evolution From Weather Forecasting To Climate Prediction

J. Shukla
George Mason University (GMU) / Center for Ocean-Land-Atmosphere Studies (COLA)

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The seminal work of V. Bjerknes (1904) laid the foundation for mathematical modeling of atmospheric dynamics based on the laws of physics. Richardson (1922) made an unsuccessful attempt to demonstrate the feasibility of making weather prediction by numerically integrating the mathematical equations of motion. Rossby (1939) and Charney (1947) established a theoretical basis for simplifying the equations of motion and understanding the dynamics of large scale motions of the atmosphere. This lead to a successful demonstration of prediction of short-term changes in the large scale flow pattern by using a variety of simplified dynamical models. The pioneering work of Phillips (1956) represents the beginning of the modern era of numerical prediction of weather and simulation of climate.

This paper will describe how the major advances in modeling of weather and climate, and phenomenal increases in computing power and observations of atmosphere and ocean, have lead to the possibility of extending the techniques of short-term weather prediction (1-10 days) to short-term climate prediction (10-1000 days).

The paper will summarize the major challenges in making useful short-term climate prediction using dynamical models of the coupled climate system. The post-TOGA euphoria, anticipating societally beneficial climate predictions for one to four seasons in advance, is beginning to be replaced by the stark realization that coupled climate models continue to have unacceptably large systematic errors, and that each El Niño seems to have its own unpredictable uniqueness. This paper will attempt to address the question of whether the current inability to make skillful forecasts of short-term climate variations is due to inaccurate models and insufficient observations or is it an indication of the fundamental limits of the predictability of climate.

Finally, the paper will make some proposals for the post-CLIVAR pathways to harvest the realizable predictability of climate for the benefit to society.

Invited speaker

Mechanisms of Short-Term Climate Variability

Brian Hoskins and John M. Wallace

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John M Wallace, Department of Atmospheric Sciences, University of Washington, USA

The atmosphere may often usefully be viewed as having regimes in the sense of preferred structures that describe much of its variability on the time-scales of weeks to seasons. Regimes may occur as part of the chaotic dynamics of the system. Alternatively they may be triggered, or their occurrence made more likely, by anomalous forcing or weather phenomenon that may be local or remote. In the latter case the link is usually made through quasi-stationary Rossby wave propagation. In some cases, the induced Rossby wavetrain interacts with the extratropical storm tracks to produce long lived, zonally oriented anomaly patterns at higher latitudes

Blocking in middle latitudes and the Intra-Seasonal Oscillation (ISO) in the tropics are examples of important local/regional atmospheric variability structures. Teleconnection patterns such as the Pacific North American and the North Atlantic Oscillation (NAO) have been widely used as a basis for interpreting climate anomalies. The NAO perspective emphasises the North Atlantic region and the involvement of its storm-track whereas the alternative Northern Annular Mode perspective stresses polar symmetry. The Southern (Hemisphere) Annular Mode also has large asymmetry in the winter season. There is evidence of significant nonlinearity in the behaviour of these patterns.

Atmospheric variability can often be considered to be forced by anomalous surface conditions such as in sea surface temperature (SST), sea ice, snow or soil moisture. In some cases the response in GCM simulations is suggestive of the superposition of a regional, forced linear response and a non-linear hemispheric scale response that assumes the form of the model's "annular mode". Whether extratropical SST anomalies are capable of generating an atmospheric response strong enough to be of practical use in seasonal to interannual prediction has been questioned, but the empirical and modelling evidence for some predictive power is increasing. It has also been suggested that the trend in the NAO over the last half of the 20th century is related to warming of the Indian Ocean. Extreme seasonal droughts and floods have been linked with anomalous tropical conditions leading to stationary atmospheric anomalies in higher latitudes. On the time-scale of weeks the ISO leads to similar behaviour and the possibility of predictive power in higher latitudes. It has been suggested that the 2002 summer floods in Europe were related to a weakening of the usual seasonal Asian summer monsoon forced Mediterranean descent.

The coupling of the troposphere to the stratosphere, upper ocean and land surface offer further possibilities for climate variability mechanisms and predictive power.

Invited speaker

Seasonal to interannual predictability

P. Delecluse, D. Anderson, M. Davey, B. Kirtman, R. Kleeman, C. Penland, C. Wang, and S. Zebiak

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As a result of the TOGA program which highlighted ENSO as a major source of atmospheric variability and potential predictability, the CLIVAR program encouraged the development of dynamical and statistical ENSO prediction systems with the objective to assess their potential in predicting seasonal to interannual climate variability and to extend the range and the accuracy of these predictions. Several centres perceived the potential interest of seasonal forecast and developed a forecast system. The forecast methodology varies largely from one centre to the other ranging from comprehensive global coupled models to intermediate or statistical models. The strategy from several centres (ECMWF, IRI, …) is described. Interestingly the skill of most forecast systems beats persistence and shows some interesting forecast potential in low latitudes. Much efforts were done to improve the skill but the results were remarkbly stubborn to improvements. Despite the improvement of the individual components and the analysis procedure, the observed SST frequently lies outside the range spanned by the forecast ensemble and most systems still remain far from the potential limit of predictability in the absence of model, indicating that there is still much to improve on the models themselves.

One way to overcome this problem of model error is to work with a multi-model forecast system, a way which is presently explored in some centres. This strategy was strongly encouraged by the results from the WGSIP-CLIVAR on several projects of comparison. Two of them are presented here: the Seasonal Model Intercomparison Project (SMIP) and the ENSO prediction comparison project. The overarching conclusion from both these projects is that multi-model ensembles yield a superior forecast compared to an ensemble forecast from a single model. Forecast systems are confronted to some severe issues and several of them are reviewed. The first problem comes from the nature of ENSO itself. Latest developements concerning the oscillatory nature of ENSO provided a unified framework suggesting that ENSO could be a multi-mechanisms phenomenon, where the relative importance of different mechanisms could be time-dependent, thus affecting its potential predictability. Several authors suggested that ENSO could be triggered by stochastic atmospheric forcing, especially after the development of the 1997-98 ENSO, following a sequence of strong WWB activity in the spring 1997. More generally, the non linear interactions between high frequency

processes (atmospheric transients, WWB, MJO…) and the slow dynamical behavior can severely limit the predictability and this issue is currently explored with statistical and dynamical models. The long term irregularity of ENSO and its predictive skill is also subject to debate and several processes (interaction with the annual cycle, interaction with decadal or long term behavior…) have been investigated. It has been suggested that the variations in the background state due to the Pacific Decadal oscillation (PDO) may be responsible for substantial variations in predictability. Another issue is the role of error in initial conditions and their potential to spoil the short-lead forecast by projecting onto the optimal structure for non normal growth.

Clearly, more research is needed on the observed initial conditions and how they should be prepared to reduce the error in forecast models (deterministic or statistical). It is difficult to draw lessons from the numerous results of forecast systems, which have developed strong but different capacity building, and clearly more research is needed to extend predictability on solid grounds. In addition to the development of new ideas, detailed analysis of the predictability on long, multi-decadal periods should be regularly repeated, with updated models, and encouraged in the context of international comparison.

Invited Speaker

Evolution Of The Observing System For Seasonal-To-Interannual Climate Prediction

Dr. Michael J. McPhaden, Dr. Anthony Hollingsworth, Dr. Benjamin P. Kirtman, Dr. Richard W. Reynolds, Dr. Femke C. Vossepoel, Susan E. Wijffels

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In this presentation, we review the physical basis for seasonal-to-interannual climate predictability and the development of the present day observing system for seasonal-to-interannual prediction. Most predictability on these time scales originates from tropics, especially from the tropical Pacific, through interactions between sea surface temperature (SST) and the overlying atmosphere. Our emphasis in this presentation is on model requirements for forecasting tropical SSTs at lead times up to one year. We describe the oceanic and atmospheric parameters most useful for initializing and validating seasonal-to-interannual forecast models and the present day combination of satellite and in situ measurement platforms that provide these data. The value of mid-latitude SST, soil moisture, and sea ice coverage in extending and enhancing regional predictability are also discussed. We conclude with a discussion of how present day forecast models may be used to guide measurement stategies and what the important next steps in observing system development are.

Invited Speaker

Monsoons

Julia Slingo, Roberto Mechoso and Peter Webster

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Monsoons are fundamental to the circulation of the tropics and influence the global climate system in profound ways. They provide the major seasonal reversals in the prevailing winds that give monsoon climates their characteristic wet and dry seasons. However, the monsoon systems of Asia, Australia, Africa and The Americas have their unique characteristics due to the complex geometry of the earth's land-masses.

In this paper the world's monsoons will be compared and contrasted, with particular emphasis on the role of the topography in shaping their regional characteristics. The interannual and subseasonal variability, with their potential drivers, will be reviewed, and the degree to which this variability is predictable will be discussed. These topics will be presented in the context of current and planned CLIVAR activities aimed at developing an improved understanding of monsoon climates though a range of observational and modelling programmes.

Finally, the importance of understanding and predicting monsoon climates and their variability, in the context of their impacts on human activities and sustainability, will be considered. This aspect is particularly important because of the vulnerability to climate variability and change of the majority of the world's population who live within the influence of monsoon climates.

Invited Speaker

Variability of the Asian-Australian Monsoon and the Major Roadblock to Seasonal Prediction

Dr. B. N. Goswami, Dr. Tetsuzo Yasunari and Dr. Guoxiong Wu
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The striking character of the Asian-Australian (AA) monsoon is the seasonal cycle (SC) that is influenced by slowly varying 'external' forcing or slow variations arising from ocean-land -atmosphere interactions as well as 'internally' generated low frequency (LF) variability. The SC has distinctly different characteristics in different components of the AA monsoon. Interannual or longer term variability and predictability of seasonal mean AA-monsoon can be viewed as manifestations of variations of the SC. Interannual variability (IAV) of the AA-monsoon due to modulation of the SC by external forcing or slow variation of the coupled ocean-atmosphere system (e.g. ENSO) is contrasted with the role of land surface processes (e.g. Eurasian snow cover and Tibetan plateau). New insight gained from special experiments such as GAME, BOBMEX and JASMINE on the role of land surface processes and moist thermodynamics in determining the SC through modulation of the diabatic heat source is highlighted.

The predictability of the AA-monsoon is limited by the amplitude of the unpredictable 'internal' LF component. Estimates of contribution of 'internal' atmospheric variability to IAV of AA-monsoon from observations as well as from atmospheric general circulation model (AGCM) studies indicate that the AA-monsoon region is unique in the tropics with the amplitude of the 'internal' IAV being comparable to that of the 'external' component. Origin of the LF 'internal' variability is investigated. It is demonstrated that the vigorous monsoon intraseasonal oscillations (ISO) modulate the SC and play a seminal role in generating the 'internal' LF oscillations of the monsoon. GAME reanalysis indicates that ISO's interact with the SC to produce the seasonal phase lock of the monsoon breaks in (south &) southeast Asian monsoon. This distinct feature is likely to be linked to seasonal change of large-scale heating process in the land-atmosphere-ocean system. Indian monsoon ISO's not only have spatial scale that is similar to that of the seasonal mean, a common spatial mode governs both ISO's and IAV. Modulation of the large scale monsoon flow by ISO also causes clustering of synoptic disturbances in space and time and leads to dry and wet spells. Higher probability of occurrence of active (weak) phase of the ISO in a season can , therefore, lead to a strong (weak) seasonal mean monsoon. Evidence of this mechanism in

producing 'internal' LF variations in observed as well as AGCM simulated Indian summer monsoon is provided. Thus, factors that influence the statistics of the monsoon ISO's can influence the 'internal' LF variability and hence predictability of the seasonal mean.

Invited Speaker

The Monsoon Systems Of The Americas

Dr. Carolina S. Vera , Dr. Wayne Higgins, in alphabetic order: Dr. Jorge Amador , Dr. Tercio Ambrizzi, Dr. Rene Garreaud, Dr. David Gochis, Dr. David Guztler, Dr. Dennis Lettenmaier, Dr. Jose Marengo, Dr. Carlos R. Mechoso, Dr, Julia Nogues-Paegle and Dr. Chidong Zhang

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12 Dr. Chidong Zhang, Division of Meteorology and Physical Oceanography (MPO), Rosenstiel School of Marine and Atmospheric Science (RSMAS), University of Miami, 4600 Rickenbacker Causeway, Miami, FL 33149-1098, USA, (czhang@rsmas.miami.edu)

In recent years the WCRP/CLIVAR/VAMOS and U.S. CLIVAR programs have made major contributions to our understanding of the American Monsoon systems via focused research activities in South, Central, and North America. In this paper we will review these CLIVAR achievements, with emphasis on common features of the American monsoon systems and intersections amongst the activities.

Over tropical and subtropical South America, there has been considerable effort to understand the diurnal cycle and mesoscale variability of the precipitation and atmospheric flow. Precipitation in both regions is strongly controlled by the continental-scale gyre that transports moisture from the tropical Atlantic Ocean, first westward across the Amazon Basin, and then southward across the extratropical continent. That gyre displays a regional intensification just to the east of the Andes Mountains, usually in the form of the South American Low-Level Jet (SALLJ). The VAMOS/SALLJEX field experiment (Nov 02-Feb 03) provided a unique dataset for improved understanding and more realistic simulations of the jet and related precipitation patterns. Variability on both intraseasonal and interannual time scales produces a strong modulation of the low-level circulation mainly through zonal-wind changes at the SA tropics and meridional-wind changes at the subtropics, both associated with a dipole-like precipitation anomaly structure, being one of its centers associated with the SACZ activity.

Over the core region of the North American monsoon similar efforts are underway to understand the diurnal cycle of convection, intraseasonal variability, and the influence of oceanic and continental boundary forcing on the atmospheric circulation and precipitation patterns in the region. As in South America, a low-level jet is an important feature for transporting moisture onto the continent, so a common research goal on both continents is to improve understanding and predictability of such jet circulations. The diurnal cycle in this region is larger than the amplitude of the annual cycle. There are large-scale shifts in the regions of deep convection during the day from over high topography on the continent (western Mexico) to over the eastern Pacific Ocean. The intraseasonal and interannual fluctuations of monsoon precipitation are in turn linked to continent-scale precipitation patterns. The North American Monsoon Experiment (NAME) field campaign (summer 2004) will provide a unique dataset for improved understanding and more realistic simulations of warm season precipitation and atmospheric circulation patterns over the region. Associated NAME modeling, data assimilation and predictability studies will serve to accelerate progress towards measurably improved climate models that predict North American monsoon variability out to months to seasons in advance.

Invited Speaker

African Monsoon System

Chris Thorncroft, Laban Ogallo, Chris Reason, and Fred Semazzi

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Africa is a vast continent. Straddling the equator with roughly equal landmasses in each hemisphere, it represents one of the three major tropical land areas (along with South America and Indonesia-Borneo or the so-called maritime continent). Latent heat release in deep cumulonimbus clouds in the ITCZ over Africa represents one of the major heat sources on the planet. This heat source and its associated regional circulations exhibit substantial variability on intraseasonal-to-decadal timescales. Such variability impacts African societies but other tropical regions are also impacted as exemplified by the well known correlation between West African rainfall and Atlantic hurricane activity.

This presentation will highlight key scientific issues relevant to climate variability of three regions of the African continent: West Africa, East Africa and Southern Africa. This will include consideration of the remote and local forcing of climate variability in the different regions including the 2-way interactions with the surrounding oceans. The climate variability in the different regions will be described in the context of present and future CLIVAR activity in the three different regions. This will include a consideration of the linkages between this activity and applications including food security, water resources and health.

Invited speaker

Climate Variability and Predictability on Decadal to Century Time Scales

E.S. Sarachik, G. Boer, and A. Weaver

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The progress of our understanding of decade-to-century climate variability since the beginning of the CLIVAR program will be reviewed in four distinct areas:

- Decadal variability of the ENSO phenomenon
- Mid latitude SST variations
- Variability of atmospheric patterns, esp. NAO and PNA
- Variability of the ocean thermohaline circulation.

Since less than a decade has passed since CLIVAR began, not enough time has passed for new observations to make significant advances in our understanding so much of the analysis will be based on diagnostic studies of the existing climate record and modeling studies using a variety of special purpose and comprehensive climate models.

For each of the four areas of interest, our present understanding of the existence of such variability, the mechanisms for the variability, and the implications of the mechanisms for the predictability of the climate variations will be presented.

Recommendations for future targeted observational, diagnostic, and modeling studies will be made. In particular, the nature of the observations that need to be maintained after the planned conclusion of the CLIVAR program will be discussed.

Invited speaker

Atlantic Variability And Predictability: Progress And Challenges For CLIVAR

Dr. J. W. Hurrell, Dr. M. Visbeck, Dr. A. Busalacchi, Dr. A. Clarke, Dr. T. Delworth, Dr. R. Dickson, Dr. W. Johns, Dr. K. P. Kotermann, Dr. Y. Kushnir, Dr. D. Marshall, Dr. C. Mauritzen, Dr. M. McCartney, Dr. A. Piola, Dr. C. Reason, Dr. G. Reverdin, Dr. F. Schott, Dr. R. Sutton, Dr. I. Wainer, Dr. D. Wright

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Other authors are current/former members of the International CLIVAR Atlantic Implementation Panel (http://www.clivar.org/organization/atlantic/index.htm)

The climate of the Atlantic sector and surrounding continents exhibits considerable variability on time scales ranging from interannual to centennial. This variability is manifest as coherent fluctuations in ocean and land temperature, rainfall and surface pressure with a myriad of impacts on society and the environment. Improved understanding of this variability is essential for assessing the likely range of future climate fluctuations and the extent to which they may be predictable, as well as understanding the potential impact of anthropogenic climate change.

Of central importance are three interrelated phenomena: Tropical Atlantic Variability (TAV), the North Atlantic Oscillation (NAO), and the Atlantic Meridional Overturning Circulation (MOC). The former refers to substantial variations on interannual and interdecadal time scales in tropical Atlantic sea surface temperature (SST) with associated impacts on North African and Brazilian rainfall, among other things. The NAO is the most prominent and recurrent pattern of atmospheric variability over the middle and high latitudes of the Northern Hemisphere, dictating climate variability from the eastern seaboard of the United States to Siberia and from the Arctic to the subtropical Atlantic. Fluctuations of the NAO and TAV alter the wind stress on the ocean, as well as air-sea heat and freshwater fluxes. These in turn induce substantial changes in the wind- and buoyancy-driven ocean circulation, as well as the site and intensity of water mass transformation, so that the strength and character of the Atlantic MOC is influenced. While much of the observed ocean variability is driven by the atmosphere over the Atlantic, evidence that the ocean modulates Atlantic atmospheric variability on interannual and longer time scales is emerging.

One of the most urgent challenges is to advance our understanding of the interaction between anthropogenic forcing and these Atlantic phenomena. It now appears, for instance, as though there may be a deterministic relationship between the NAO and anthropogenic forcing, which might allow for moderate low frequency predictability of the phenomena. A consequence of the intense MOC is that about 60% of the global oceanic CO_2 uptake may take place in the Atlantic sector. Some model projections suggest, however, that in only a few decades Atlantic climate might radically shift into a different equilibrium with a much-reduced MOC and associated ocean heat transport. Over the tropical Atlantic, the link between SST anomalies and various climate-related disasters in surrounding countries is well established, so it is likely that 21st Century climate in those regions will be tightly tied to the future state of tropical ocean temperatures.

CLIVAR is attacking these issues through prioritized and integrated plans for short-term and sustained observations, as well as modeling and theoretical investigations of the coupled Atlantic system. In this paper, we provide an in depth review of the state of our understanding of Atlantic climate variability, achievements to-date and future challenges.

Invited speaker

Pacific Decadal Variability: A Review

Shoshiro Minobe, Niklas Schneider, Clara Deser, Zhengyu Liu, Nathan Mantua, Hisashi Nakamura, and Masami Nonaka

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Decadal variability of Pacific climate, dubbed the Pacific Decadal Oscillation, affects adjacent land masses and the oceanic ecosystem. One major shift occurred after the winter of 1976/77 when the Aleutian low intensified and shifted eastward and sea surface temperatures cooled in the central North Pacific and warmed in the east Pacific and Tropics. Winter time precipitation, snow pack and stream flow in the Northwestern North America decreased, and rain fall in the Southern US and Northern Mexico increased. The oceanic mixed layer in the central North Pacific deepened, salinity in the Alaskan gyre decreased, and waters subducted in the central Pacific became cooler. Thermocline depth anomalies cooled surface waters in Kuroshio extension after about five years, consistent with Rossby wave propagation. Similar shifts occurred in 1920, 1940, with minor shifts in 1960 and 80s, where cooling (warming) of the central North Pacific was associated with a strengthening (weakening) of the Aleutian Low. Harmonic analysis shows that that these shifts occurred as simultaneous zero crossings of bi-decadal and multi decadal period variations. If these long period variations are governed by deterministic dynamics long range forecast should be possible.

Such dynamics rely on an atmospheric response to the slow adjustment of the ocean circulation, a topic of continued debate. Atmospheric circulation models indicate a weak sensitivity to extratropical SST anomalies, but low frequency variance in long coupled model simulations can be understood without resorting to such feedbacks. However, recent observations indicate that SSTs in the Kuroshio region influence the structures of the atmospheric boundary layer, and partial coupling experiments suggest that mid-latitude ocean-to-atmosphere feedback is important in decadal variability.

The anomalous warm waters subducted in the thermocline is hypothesized to induce a coupled response in the tropics. However, thermocline variability in the tropics is dominated by local wind forcing. This leaves density neutral temperature and salinity anomalies as an agent to transmit these signals. Observations show low frequency anomalies of salinity on isopycnal surfaces in the extratropics, but a lack of basin wide observations make the evaluation of this advective process challenging. Tropical forcing, either as a residual of El Nino variability, or as an independent mode involving Rossby waves or adjustments of the shallow tropical overturning cells, remain a viable process to explain the extratropical variations. Indeed, recent studies show a tantalizing correspondence of anomalies of precipitation in the tropical regions and changes in the North Pacific.

Invited speaker

Comparisons of Observed, Palaeoclimate and Model-based Studies of Climate Changes over the Past Two Millennia

Michael E. Mann and Keith R. Briffa

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We review selected evidence for climate change and its causes for up to the last 2000 years, using instrumental and high-resolution climate 'proxy' data sources, and climate modelling studies. We devote particular attention to proxy-based reconstructions of temperature patterns in past centuries, which place recent large-scale warming in an appropriate longer-term context. Several research groups have recently developed annually-resolved, quasi-hemispheric reconstructions of Northern Hemisphere mean temperature changes over the past 500-2000 years, and several modelling centres have run climate simulations based on models with varying levels of complexity, forced by estimated changes in natural and anthropogenic radiative forcing over a similar time frame. We discuss insights from comparisons of the empirical and model-based estimates.

Uncertainties are considerable in both cases: well-verified proxy climate records remain relatively sparse, especially in many key tropical and oceanic regions (including much of the Southern Hemisphere) and, while there is good qualitative agreement between many different reconstructions, non-trivial quantitative disagreements exist. Climate model simulations are limited by likely model deficiencies and by the uncertain reliability of past forcing histories. Despite these limitations, inter-comparisons of simulated and reconstructed climates are in reasonable agreement with respect to hemispheric-scale changes over the past millennium.

The dramatic differences between regional and hemispheric/global past trends, and the distinction between changes in surface temperature and precipitation/drought fields, underscores the limited relevance of the use of terms such as the "Little Ice Age" and "Medieval Warm Period" for describing past climate epochs of the last millennium. Comparison of empirical evidence with proxy-based reconstructions demonstrates that natural factors appear to explain the major surface temperature changes (including hemispheric means and some spatial patterns) of the past millennium reasonably well, at least through to the 19th. Only anthropogenic forcing of climate, however, can explain the recent anomalous warming in the late-20th century.

There is also tentative evidence that particular modes of climate variability, such as the El Niño/Southern Oscillation and the North Atlantic Oscillation may have exhibited late-20th century behaviour that is anomalous in a long-term context, although the uncertainties are considerably greater. Regional conclusions, particularly for the Southern Hemisphere and parts of the tropics, where high-resolution proxy data are

sparse, are particularly limited. There is though, important new evidence from the tropical central Pacific for various intervals of the last thousand or so years.

Invited Speaker

Paleoclimatic Perspectives on Abrupt Climate Change

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The science of abrupt change stems primarily from the discovery, made over a decade ago, that the last glacial period was characterized by enormous atmospheric and oceanic changes that occurred much more rapidly than any change in external forcing. The great ice sheets likely were key players in these "cold climate" abrupt changes. However, concern over the possibility of future abrupt climate change has led to an increasingly large focus on Holocene "warm climate" abrupt change. Rapid progress is being made documenting past changes, and attention is starting to focus on mechanisms and predictability. Several types of abrupt change have occurred in the past, and could thus also occur in the future. The most publicized type of change would be a shift in thermohaline circulation in response to increased freshwater input to the North Atlantic via rivers, rainfall or ice melt in a warming world. Concern is heightened by new work suggesting the Greenland Ice Sheet may melt significantly faster than previously thought, although great uncertainty remains over the ice-sheet sensitivity and the sensitivity of oceanic circulation to future increases in freshwater input. Paleoclimatic research shows that the thermohaline circulation did remain vigorous during mid-Holocene conditions slightly warmer than recently; however, the peak mid-Holocene warmth was reached more slowly than projected future warming, and the rate of freshwater supply appears important in thermohaline-circulation stability. Abrupt shifts in frequency of droughts and floods have often occurred in the past, with regional changes during warm-climate conditions especially prominent. Major advances in the study of such changes over the last five years culminated in a Fall, 2003 drought workshop co-sponsored by CLIVAR. Large shifts in hydrologic variability are possible, perhaps producing times of more-frequent/persistent droughts including continental-scale droughts that last decades ("megadroughts") or regional droughts lasting even longer. Global warming-induced summer drying probably will make persistent drought more likely, but predictability remains uncertain. The same holds true for periods of more-frequent large flood events, regional frequency of large hurricane landfall, and other types of possible abrupt climate change. The paleoperspective suggests that the probability of future abrupt change may be linked to the rate of future anthropogenic climate change. A thermohaline-circulation weakening is among the many processes that can bring important shifts in drought regimes including drying of key areas.

Invited speaker

Progress in Paleoclimate Modeling

Pascale Braconnot, Mark A. Cane, Amy Clement, Hezi Gildor, Sylvie Joussaume, Myriam Khodri, Didier Paillard, Simon Tett, Eduardo Zorita

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We briefly survey areas of paleoclimate modeling notable for recent progress. New ideas, including hypotheses giving a pivotal role to sea ice, have revitalized the low order models used to simulate the time evolution of glacial cycles through the Pleistocene, a prohibitive length of time for comprehensive models. In a recent breakthrough, however, GCMs have succeeded in simulating the onset of glaciations. This occurs at times (most recently, 115 kyr BP) when high northern latitudes are cold enough to maintain a snow cover, and tropical latitudes are warm, enhancing the moisture source. More generally, the improvement in models has allowed simulations of key periods such as the Last Glacial Maximum and the mid-Holocene that compare more favorably and in more detail with paleoproxy data. These models now simulate ENSO cycles, and some of them have been shown to reproduce the reduction of ENSO activity observed in the early to middle Holocene. Modeling studies have demonstrated that the reduction is a response to the altered orbital configuration at that time. The greatest and most urgent challenge for paleoclimate modeling to explain and to simulate the abrupt changes observed during glacial epochs (i.e. Dansgaard-Oescher cycles, Heinrich events, and the Younger Dryas). Efforts have begun to simulate the last millennium. Over this time the forcing due to orbital variations is less important than the radiance changes due to volcanic eruptions and variations in solar output. Simulations of these natural variations test the models we rely on for future climate change projections. They provide better estimates of the internal and naturally forced variability at centennial time scales, elucidating how unusual the recent global temperature trends are.

Invited speaker

Key Ocean Mechanisms in Climate

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Ocean transport processes represent, arguably, the majority of key ocean mechanisms in climate. Apart from the tropical oceans, it is the transports across the larger gradients, in the vertical and meridional directions, that are most important. The discussion here will be presented from a more abstract viewpoint perhaps than in the majority of the other papers at this conference, trying to find generalizations across regions and specific phenomena.

Our discussion will focus on

1. The meridional overturning circulation (MOC), how it is influenced by wind, surface buoyancy fluxes, and diapycnal mixing, and how the MOC effects important property transports in the climate system, especially those of energy, freshwater, and carbon.
2. Vertical transport processes, for example vertical property transports by convective mixing, the connection to ocean carbon uptake, and the interplay with meridional transports.
3. The special role of the Southern Ocean in meridional and vertical transports, including its role in the global MOC and global ocean carbon uptake.

We will review recent conceptual advances, new observational approaches and results, and insights that arose from modelling. Then we will identify major gaps in our understanding and sketch possible or necessary future developments.

Invited Speaker

The Role Of The Tropical Oceans In Climate

Prof. Ping Chang, Prof. Toshio Yamagata, and Prof. Paul Schopf with S.K. Behera, J. Carton, W.S. Kessler, G. Meyers, F. Schott, S. Shetye T. Stockdale, and S-P. Xie

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The tropical oceans have long been recognized as the most important region for large scale ocean-atmosphere interactions that give rise to coupled climate variations at various time scales. During the TOGA decade, the focus of much tropical ocean research was on the understanding of El Nino related processes and on the development of tropical ocean models capable of simulating and predicting El Nino. These studies led to the appreciation of the vital role the ocean plays in providing the memory for predicting El Nino and the feasibility of seasonal climate prediction. With the ending of the TOGA era and beginning of the CLIVAR era, the scope of climate variability and predictability studies has been expanded from the tropical Pacific and ENSO-centric basis to the global domain. In this paper we discuss the progress that has been made in tropical ocean climate study during the early years of CLIVAR. The discussion is divided geographically into three tropical ocean basins with an emphasis on the dynamical processes that are most relevant to the coupling between the atmosphere and oceans. For the tropical Pacific, we assess the continuing effort to improve our understanding of large and small scale ocean dynamics and modeling strategies for extending the skill of ENSO prediction. We then go beyond the time and space scale of El Nino and discuss recent research activities on the fundamental issue concerning the maintenance of the tropical thermocline. This includes the study of shallow tropical cells (STC) and the ventilated thermocline processes, which are potentially important for the understanding of low-frequency modulation of El Nino. For the tropical Atlantic, we examine the dominant oceanic processes that interact with regional atmospheric feedbacks as well as remote influence from both the Pacific El Nino and extratropical climate fluctuations, giving rise to multiple patterns of variability distinguished by season and location. We also discuss the potential impact of the Atlantic thermohaline circulation on Tropical Atlantic Variability (TAV) and the effect of TAV on climate variations in regions bordering the tropical Atlantic ocean. For the tropical Indian ocean, we examine local and remote mechanisms governing the low-frequency sea-surface temperature variations. After reviewing the recent rapid progress in the understanding of coupled dynamics in the region, we focus on the active role of ocean dynamics in the east-west internal mode of variability locked to seasons, known as the Indian Ocean Dipole (IOD). We also discuss influences of the IOD on climatic

conditions in Asia, Australia, East Africa and Europe. While the attempt here is to give a comprehensive overview of what is currently known about the role of the tropical oceans in climate, the fact of the matter is that much remains to be understood and exploited. The complex nature of the tropical coupled phenomena and the interaction among them argue strongly the need for coordinated and sustained observations, as well as careful modeling investigations in order to further advance our current understanding of the role of tropical oceans in climate.

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Invited speaker

The Northern-Hemisphere Extratropical Oceans And Climate

Robert R. Dickson and Peter B. Rhines

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The atmosphere/sensible-, ocean/sensible and atmosphere/latent meridional heat-transports are comparable in magnitude, and the third, freshwater-related component is a joint atmosphere-ocean mode. Northward heat-transport and southward freshwater transport will be the foci of this talk, in which natural variability and greenhouse forcing have combined to make the past few decades remarkable. The signal of increasing evaporation and salinity has been felt in the subtropical Atlantic, and declining salinities have been observed over the past 3 to 5 decades in the subArctic region. Invasion of the Arctic by increasing amounts of Atlantic Water, and by an increasingly cyclonic, expanded storm track has occurred in parallel, for dynamic reasons not yet understood.

Climate impact of SST perturbations outside the tropics remains controversial. Yet 21st C climate change will involve the ocean circulation, hydrography and ice cover, sufficiently to awaken atmospheric response. Climate-model predicted decline in MOC (meridional overturning circulation), and amplified polar climate response during the coming decades are examples with active ocean components, as even the relatively unprovoked 1920s warming demonstrated.

If present estimates of transports are correct, the mean ocean-circulation contribution to atmospheric climate is significant, materially affecting the net warming of the atmosphere and its fresh-water gain. Sea-ice variations are particularly important at this phase of climate change, and they are strongly dependent on the MOC, storm-tracks, and NAO as well as thermodynamics.

The ‘spectrum’ of heat-, fresh-water and volume transports in the ocean displays the transports in potential temperature/salinity space. Glaring sensitivity in both models and observations is seen in boundary currents, shallow-shelf circulations and the sites of deep convection and sinking. As a result the balance among the multiple sources of the MOC is difficult to resolve. At the top of the ocean, warm, low-salinity regions act as a ‘convection barrier’ and abyssal mixing determines the return MOC circuits. The complex geography of low-salinity surface layers, and their net dynamic height, can determine sites of deep-convection and sinking.

Climate is an exercise in ‘powers of ten’: there are patterns of variation coherent over hemispheres, and demonstrable excitation of jet-stream/storm track activity/NAO from tropics reaching high into the Arctic. Yet there are fine scales impossible to incorporate in climate models, and oceanic influence on wind-stress as well as air-sea heat/freshwater transports, with influence that may reach global proportions. The only solution is to apply new technologies now available in sufficient numbers to observe the crucial components of ocean climate.

Invited Speaker

The Role Of The Extratropical Southern Hemisphere Oceans In The Earth's Climate System

Dr. Stephen R. Rintoul, Prof. Arnold Gordon, Prof. Dirk Olbers, and Prof. Kevin Speer

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The existence of the "Drake Passage gap," a circumpolar band of latitudes unblocked by continents, has profound consequences for the global ocean circulation and climate. The Antarctic Circumpolar Current (ACC) flows through this gap to connect the ocean basins and so allows a global-scale overturning circulation to exist. Density surfaces slope upward to the south across the Southern Ocean, in geostrophic balance with the strong eastward flow of the ACC, and as a result the deep layers of the ocean are in direct communication with the atmosphere there. Air-sea interaction where these layers outcrop results in the formation of water masses which ventilate a large fraction of the world ocean and regulate the storage of heat and carbon by the ocean.

Recent advances in observations, models and theory have led to significant new insights into the dynamics of the southern hemisphere ocean-atmosphere-cryosphere system and its connections to lower latitudes. These advances include: the first quantitative estimates of the zonal and meridional circulation of the Southern Ocean, including formation rates of key water masses; a demonstration that air-sea buoyancy exchange in the Southern Ocean transforms upwelled deep water to lighter intermediate water to "close the loop" of the global overturning circulation, in contrast to the traditional view that this conversion is accomplished by vertical mixing in the thermocline; a recognition of the intimate link between the zonal and meridional circulations in the Southern Ocean, with eddy fluxes playing a key role in the heat budget, momentum balance, and meridional overturning cells; and a demonstration that 40% of the ocean's uptake of anthropogenic carbon dioxide occurs south of 40°S. A number of coherent modes of variability have been identified, with time-scales from years to centuries, involving teleconnections between the tropics and high latitudes and from the stratosphere to the deep sea. Progress has begun to be made in using some of these patterns to predict and interpret southern hemisphere regional climate variability.

These new insights underscore the critical role of the southern hemisphere extratropics in the Earth's climate system and lay a foundation for progress on a key challenge for CLIVAR: a quantitative understanding of how atmosphere, ocean and cryosphere interactions at high southern latitudes respond to, and drive, climate variability and change.

Invited speaker

Assessing Climate Change: A Current Perspective on Progress and Directions In IPCC Working Group 1

Susan Solomon and Dahe Qin, co-chairs of IPCC Working Group 1

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The Intergovernmental Panel on Climate Change (IPCC) was jointly established by the World Meteorological Organization and the United Nations Environment Programme (UNEP) in 1988. The purpose of Working Group 1 (WG1) of the IPCC is to assess available information on the science of climate change and to provide policy-relevant but not policy-prescriptive assessments of interest to policymakers, scientists, and the public. IPCC is currently beginning preparation of its fourth comprehensive assessment report (AR4) of the state of understanding of climate change, to be completed in 2007.

During 2003, two scientific scoping meetings were held to identify the topics and structure for the new assessment, and the outline of the report was presented to and approved by Governments. The author teams will be assembled in 2004, and the process of writing the assessment will begin.

In this talk, the key scientific results of the scoping process will be highlighted, including emerging questions that are among the topics to be assessed. The comments, questions, and interests expressed by Governments in the course of the scoping process will also be described. Finally, a personal perspective on the pitfalls, pleasures, and challenges of scientific assessment will be discussed.

Invited speaker

Climate Change Detection and Attribution: Beyond Mean Temperature Signals

Gabriele Hegerl, Thomas Karl, Myles Allen, Nathan Bindoff, Nathan Gillett, David Karoly, and Francis Zwiers

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Anthropogenic influence on climate has been detected in large-scale surface and atmospheric temperature, and in ocean heat content. The signal can be distinguished from natural influences, such as volcanism and changes in solar irradiance, showing with a high degree of statistical confidence that human activity, particularly the burning of fossil fuels, does influence climate. The anthropogenic signal is beginning to emerge at sub-global scales, such as in continental surface temperature, and in non-temperature variables such as global sea-level pressure.

A distinguishable anthropogenic climate signal puts us into the position to critically evaluate the pattern of climate change simulated in global coupled models. Detection techniques can be used to quantify the observed signal and its uncertainty range in order to discern possible shortcomings in model simulations. For example, questions still remain about the realism of the simulated pattern of ocean heat increase and natural ocean variability, and of how the anthropogenic signal penetrates watermasses. Also, the pattern of observed sea-level pressure change is significantly stronger than the simulated changes in most models. Attempting to detect the anthropogenic climate change signal at regional scales is not only important for model validation, but climate change will also have stronger impacts if the change is large compared to natural variability. The detection of change in climate extremes is emerging and should become increasingly important. However, there still are major obstacles related to the statistics of model-simulated climate extremes, the reliability of observations of extremes, and difficulties in making comparisons between modeled and observed for extremes.

In order to address these challenges, statistical techniques used in the detection of climate change and attribution will need to be adapted to more fully account for uncertainties. An example is the use of fingerprints based on multiple models. The ultimate goal is to derive a probabilistic forecast of future climate change with uncertainty ranges based on detection results. However, the availability of observed data still limits our ability to constrain and estimate the observed signal in many key areas, particularly the tropics, and in many aspects of ocean climate change. High-quality observed data need to be available to evaluate models capable of resolving changes in extreme events. Rainfall data need to be improved, and daily data or indices for climate extremes based on daily data need to continue to be collected, particularly from vulnerable areas. Also, the uncertainty in observed trends in tropospheric temperature over the satellite period needs to be reduced through improved operation of satellite and in-situ observing systems for monitoring climate change.

Invited Speaker

Climate Change Prediction

J. Mitchell and E. Roeckner

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In the third IPCC assessment, prediction of the global mean temperature increase due to human activity ranged from 1.4 to 5.8C.About half this range was attributed to uncertainties in emissions, the remaining half being due to uncertainties in modelling climate change. Despite the range of uncertainty, some basic conclusions can be drawn about future changes. For example, it is clear that reductions in changes in emissions will not have a detectable effect over the next two to three decades.

Two particular challenges face climate modeller. The first is to formally quantify the range and probability distribution of uncertainty in predictions to improve the utility of climate forecasts for risk assessment. The second challenge is to reduce the range of uncertainty through model improvement and observational constraints. Current attempts to meet both these challenges will be discussed.

Invited Speaker

The Integration of Seasonal Climate Forecasts in the Development of Epidemic Early Warning Systems for Africa: Malaria and Meningococcal Meningitis

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Epidemics of infectious diseases remain a scourge of the developing world. Two major diseases, malaria and meningitis, contribute to an enormous burden of morbidity and associated mortality and have a devastating effect on socio-economic development, particularly in Africa. The development of an integrated approach that includes vulnerability monitoring, seasonal climate forecasts, environmental monitoring and surveillance may predict risk changes affecting these climate sensitive diseases and may offer valuable time for their prevention and control response.

Here we compare and contrast these two diseases in two different regions of Africa in order to elaborate when, where and how effective epidemic early warning systems may be developed. In Southern Africa rainfall anomalies are shown to be associated with anomalies in de-trended, confirmed malaria incidence and such anomalies may in part be predicted using seasonal forecasts of rainfall. In West Africa dust levels and rainfall patterns have changed dramatically in recent years and may be associated with increased meningitis epidemics in the region. Inter-annual variability in dust and rainfall are associated with sea surface temperatures and may be predictable.

Invited Speaker

The Global Energy And Water Cycle Experiment (Gewex) Contributions To Climate Research

Dr. Soroosh Sorooshian
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The Global Energy and Water Cycle Experiment (GEWEX) has been underway for more than a decade and recently transitioned into its Phase II studies. During Phase I, the GEWEX program contributed to new data products, processes studies and modeling of the hydrologic cycle, and offered the climate community new understanding and new ideas with respect to the connection between land surface and atmosphere as a part of the climate system. In this presentation examples of the new products and capabilities arising from GEWEX research will be presented. The objectives of the Coordinated Enhanced Observing Period (CEOP) and its role in water and energy prediction studies, monsoon studies and model validation will be outlined.

Additionally, plans for closer linkages between GEWEX, and CLIVAR activities during the coming decade will be discussed.

Invited Speaker

CLIVAR SCIENCE: *APPLICATION TO ENERGY*

A.D. Moura and L. C. B. Molion

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Applications of CLIVAR climate science are very important in many regions of the world. Notably in the tropical semiarid zones, the incoming solar radiation can be used to generate electricity and hot water in a clean and environment friendly way. This energy source is more evenly distributed, especially in the Sunbelt, than wind or biomass. The photovoltaic energy (PV), that is, DC electric current generated by solar panels, built with semi-conductors material is one example. But PV energy is still expensive. Experience made in Kramer Junction, Mojave Desert, California, with large-scale solar thermal power plants, the SEGS (solar electric generating systems) using parabolic solar concentrators, proved to be efficient and low-cost technology.

Wood and its other form charcoal have been used as fuel since man dominated fire in remote ages. The success of petroleum, and its derivatives, as fuel resides in the fact that they are liquid with relative high caloric power and easy to be transported and was found to be abundant. But these are well known contributors to global warming.

Biomass is essentially solar energy converted into vegetation mass through photosynthetic activity. Burning biomass for fuel presents the advantage of having a closed carbon cycle. The CO2 that is released by burning is assimilated by plants in the next growing season and does not contribute to further enhancing greenhouse effect.

The search for liquid fuel has led the production of alcohol from plants. Methanol can be extracted by processing wood and ethanol is a product of fermentation and distillation of worth extracted from starch and sugar rich plants. The successful experience of Brazil in producing ethanol from sugar cane for powering car engines is a notable example. Sugar cane production cycle is of the order of one year and, in tropical regions, ethanol can be produced all year round. Interest in sustainable biodiesel production is growing in many countries. One class of biomass product that has been marginally exploited as renewable fuel is the organic fatty acids produced by oleaginous crops, such soy been and colza, and by palm trees, such coconut and African dende palm.

Of course, hydro-electricity generation has been a most notable example of clean, renewable, efficient and cheap energy source directly dependent on climate and its variations. It depends on the perennial existence of large rivers and favorable water falls. Proper use of climate predictions on seasonal time scales have been demonstrated to be beneficial to hydroelectric power plants efficient management and flooding control. Some climate-energy links will be discussed and examples of a few energy generation activities in Brazil will be given.

Invited Speaker

Application of CLIVAR Science to Agriculture and Land Ecosystems

Sulochana Gadgil, G Hammer, M V Sivakumar, J. Hansen

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Agricultural and natural ecosystems are diverse and varied ranging from farming systems to water systems to species population systems; they are dynamic and responsive to fluctuations in climate. Production, profit, conservation provide the major focus for intervention in these systems. Risk, or a chance of incurring a financial or environmental loss is a key factor pervading decision-making. Advances of CLIVAR science in the ability to predict intraseasonal to interannual variation of climate can be used to generate improved outcomes (larger production/profit or smaller loss), only if and when it can lead to a change in the farm-level decisions. In order to determine the kind of decisions (in terms of cropping patterns or management practices) that are associated with improved outcomes in the predicted climate state, a system approach is required. With such an approach, the value of a probabilistic prediction can also be assessed. We illustrate the application of a systems approach for use of seasonal forecasts with an example of tactical management of row configuration in a cotton crop in Queensland, Australia based on the phase of the Southern Oscillation index. The difference between the profits associated with alternative strategies for the complete climate record simulated with a crop model brought out clearly the advantage of adopting the strategy appropriate for the prediction.

Such an end-to–end approach in which climate variability is linked to farm-level decisions via models of crops, pests/diseases etc. is also appropriate for identifying the appropriate strategies to achieve enhanced production/profit or reduced risk in semi-arid tropical regions with less intense agricultural practices. In some of these regions major changes have occurred in the last three decades. Large areas of natural forests/grasslands have been brought under cultivation with many new crops/varieties cultivated. The effects of climate variability on production of these newer crops/varieties is not as well known as that for the traditional crops/varieties. Strategies for enhancing production/minimizing risk in relation to the nature of the climate variability experienced can be explored by simulation with crop models. Options available to farm level decision making such as cropping patterns and crop management (e.g. planting date, spraying pesticides) can be simulated using the entire period for which meteorological data are available. By adopting strategies tailored to the climate variability it is anticipated that production gains can be achieved in these systems. It would then be possible to further fine-tune management based on the predictions generated by CLIVAR science. Tailoring strategies appropriate for the climate variability of a region is illustrated with an example of identification of the optimum planting period for peanuts in a semi-arid part of the

Indian peninsula. This study has also given new insights into the life-history stage which is most sensitive to dry spells.

The systems approach requires active collaboration between agricultural and atmospheric scientists as well as the farmers. In fact the inputs from farmers are essential to determine the importance to decision making. Analysis of the gap between the yield at agricultural research stations and that on the farmers' fields for several crops in rainfed regions of semi-arid parts of India has shown that the gap is large only when the seasonal rainfall is good. This suggests that it is more important to predict seasons with good rainfall than droughts for enhancing production with available technology. In order to decrease the impacts of extreme events such as droughts, it is necessary to adopt a different strategy of land use with an appropriate fraction of the land under tree cover and grassland so that different livelihood options (besides farming) are available. Such strategies are also more appropriate for sustainable use of water and soil resources. These broader aspects are also discussed in the lecture.

Invited Speaker

Climate Variability, Fish And Fisheries

Dr. Patrick Lehodey, Dr. Juergen Alheit, Dr Manual Barange, Dr Tim Baumgartner, Dr Gregory Beaugrand, Dr Ken Drinkwater, Dr Jean-Marc Fromentin, Dr Steven Hare, Dr Geir Ottersen, Dr Ian R. Perry, Dr Claude Roy, Dr Carl Van der Lingen, and Dr Francisco Werner

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Fish population variability and fisheries activities are closely linked to weather and climate conditions. While weather at sea directly affects fishing, environmental variability determines the distribution, migration, and abundance of fish. Fishery science grew up during the last century by focusing on the great fisheries of the northern hemisphere and by integrating knowledge from oceanography, fish biology, marine ecology and fish population dynamics. During this period, interannual fish recruitment variability became a major focus for fisheries oceanography. The close link between climate and fisheries is illustrated by the effect of 'unexpected' events – i.e. non-seasonal, and sometimes catastrophic – on fish exploitation that are associated with the El Niño Southern Oscillation (ENSO). The observation that fish populations fluctuate at decadal time scales and show patterns of synchrony while being geographically separated, drew

attention to another range of variability that appears to be driven by low frequency signals such as the Pacific Decadal Oscillation (PDO) and the North Atlantic Oscillation (NAO). Effects of this variability were first highlighted by large fluctuations observed in the catch of small pelagic (anchovies, sardines) fisheries, but rapidly similar effects were also emerging for larger fish such as salmons, various groundfish species, and some tuna species. Today, the availability of long time series of observations and major scientific advances in sampling and modelling the oceans ecosystems allows fishery science to investigate a wide range of variability ranging from daily to decadal and even centennial scales. These studies are central to the research programme of GLOBEC (Global Ocean Ecosystems Dynamics), a component of the International Geosphere-Biosphere Programme. In this review, we present examples of relationships between climate variability and fisheries at these different time-scales and for species covering various marine ecosystems from equatorial to sub-arctic regions. We describe some of the mechanisms linking climate variability and exploited fish populations and the implications for management of these stocks and the modelling of their dynamics. We conclude with recommendations for collaborative work between climatologists, oceanographers and fisheries scientists to resolve some of the outstanding problems of developing sustainable fisheries.

Invited Speaker

Monitoring and Prediction of the Earth's climate

Kevin E. Trenberth, Berrien Moore, Thomas R. Karl and Carlos Nobre
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The climate is changing and will continue to do so regardless of any mitigation actions. Accordingly, an overview will be given of a much-needed potential Earth Information System. This system embraces a comprehensive observing system to observe and track changes and the forcings of the system as they occur, as well as the ability to relate one to the other and understand changes and their origins, and analyze fields into global products, and includes archival and access to data. Some products will be used to validate and improve models, initialize models and predict future evolution on multiple time scales using ensembles. Modeling and assimilation aspects will be dealt with in accompanying talks. However, "all models are wrong, but some are useful", and hence it is vital to fully assess past changes and model performance and results in making predictions, and assess impacts regionally on the environment, human activities, and sectors of the economy while working with stakeholders. Such a system will be invaluable. In particular, we expect to see a revolution in the way developing countries use and apply climate information.

Observations need to be taken in ways that satisfy the climate monitoring principles and ensure long-term continuity and ability to discern small but persistent signals. The health of the monitoring system must be tracked and resources identified to fix problems. Satellite observations must be calibrated and validated, with orbital decay and drift effects fully dealt with, and adequate overlap to ensure continuity. Reanalysis of the records must be institutionalized along with continual assessment of impacts of new observing and analysis systems. The Earth Science community should embrace the principle that no new observing system is built without adequate planning and consideration for monitoring of the observing system for random and time dependent errors and biases, metadata that fully describes the observing system status and environment in which it operates, the manner in which the data is processed, the means to deliver fundamental data analyses and products, and provisions for the long-term archive of the data with access to the data in well-conceived effective manner. Without this end-to-end process our investments our do not deliver adequate return and our understanding is much less than it would be otherwise.

Invited Speaker

Invited Paper: Atmospheric Observations And Data Assimilation For Climate Monitoring And Prediction

John Derber, Adrian Simmons, Anthony Hollingsworth, Eugenia Kalnay, Andrew Lorenc, Michael Manton and Kazutoshi Onogi

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The assimilation of data from a wide range of in-situ and remotely sensed atmospheric measurements is central to weather prediction beyond a few hours ahead. The composite global observing system was enhanced considerably in the late 1970s, particularly in preparation for the Global Weather Experiment in 1979. Since then there has been considerable development of atmospheric models and data assimilation systems and further refinement of observational capability. The resulting improvement in the quality of operational global analyses of the atmosphere and of the forecasts run from these analyses has been dramatic.

Over the same period, climate studies have made increasing use of analyses from assimilation systems, either analyses produced operationally in near-real-time or those produced retrospectively as reanalyses of past periods using fixed, modern systems. Operational data assimilation systems provide routine monitoring of the atmospheric observing system that serves both weather forecasting and climate monitoring and prediction, and are a key contributor to the calibration and validation of data from new components of the observing system, new satellite instruments in particular. They also provide initial conditions for seasonal prediction, high-resolution datasets for detailed process studies, and support for observational field campaigns. Reanalyses provide data for the validation of climate models and seasonal forecasting systems and for general process studies. They also have an emerging role to play in climate monitoring, as skill in capturing multi-decadal trends and low-frequency variability improves.

Future improvements in the quality and utility of analyses for climate studies will arise from further improvements to data assimilation systems, from improved collection and processing of past observations for use in reanalysis, and from improvements to the observing system, particularly those providing lower biases and better temporal continuity. The requirements for improved weather forecasts will ensure continued improvements to the analysis of the primary meteorological variables. In addition, new satellite-based measurements, extensions of data assimilation systems, expanding missions for NWP centres and broadening international collaboration are enabling the important and challenging tasks of providing global analyses of condensed moisture variables, aerosols and trace gases, and thereby capabilities for global monitoring of climate forcing, for monitoring and prediction of air quality, and for inferring sources and sinks of the atmospheric constituents chiefly involved.

Invited Speaker

Observations and Data Assimilation (Oceans) – A Future Perspective

Detlef Stammer, Michele Rienecker, Neville Smith, Ed Harrison and Dean Roemmich

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Future ocean observing systems and ocean data assimilation applications will be shaped by many factors. We anticipate that technological advances will continue to provide more cost-effective observational networks and that data access and dissemination will be both more dynamic and timely. The development of the real-time Argo network is the latest example. We anticipate that advanced technology in the form of more powerful computers will play a significant role for data assimilation, particularly in terms of the application of sophisticated techniques and in the ability to undertake assimilation at high resolution.

The community has identified critical elements such as altimetry, the tropical moored buoy network and Argo. There is the promise of surface salinity observations from space, multi-purpose platforms for measuring non-physical parameters, and controlled autonomous platforms such as gliders. However, the biggest challenge remains completion of the global ocean observing system as envisaged at the beginning of CLIVAR, and maintaining and refining it for future scientific generations. Data assimilation methods provide a robust and objective approach for assessing the impact of data streams and for optimizing the observational strategy. .

Ocean data assimilation has undergone a remarkable journey, essentially over the last decade, to the point where it is now an accepted core strategy for climate research. For ENSO and longer-period predictions, the scientific community is looking beyond simple initialization to more sophisticated use of the data to generate ensembles and provide estimates of uncertainty. We are more effectively using multivariate datasets. Coupling between the ocean and atmosphere boundary layers may need to be captured explicitly by assimilation, increasing the demand on the data networks and for coupled assimilation approaches.

For ocean state estimation (data synthesis) in general, resolution is a major limitation and we are not yet able to explicitly capture important mesoscale and other finer-scale variability. While there are plans to routinely estimate and predict the ocean at such scales, there remains a significant gap between these efforts and the high-quality products that are required for climate research. Imperfect knowledge of error covariances, and especially of multivariate error covariances, provides an additional challenge that requires the close collaboration of the observational and modelling communities. While there has been much progress made with ocean models, the systematic errors of most models remain uncomfortably large and their cause often obscure. These errors are being reduced with the ability to use higher resolution and with improved surface forcing fields.

Invited Speaker

Integrated earth system modeling and very high resolution atmosphere/ocean modeling—Challenges with the Earth Simulator

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Looking back the past history atmosphere/climate modeling and prediction have been developed with the aid of ever-increasing computer power. Now the Earth Simulator, a parallel vector processor with the theoretical peak performance of 40 TFLops is under operation and the authors are working in development of new kinds of models which can be run only by fully utilizing the big resources provided by the earth simulator.

Currently development of an integrated earth system model is under way at the Frontier Research System for Global Change (FRSGC). The integrated model is to consist from physical climate model, atmospheric chemistry model and terrestrial and ocean carbon cycle models. The carbon cycle models include terrestrial and ocean ecological processes to some extent. Possible interactions among component models will be introduced.

One of major applications of the integrated model is projection of possible global environmental change due to increase of greenhouse gases (mostly CO2) incorporating the feedback of climate change to carbon cycle and also to the atmospheric chemistry. Among others impacts of climate change on the terrestrial carbon cycle is considered to be large and positive as a feedback, which is inferred from the result of off-line calculations. This suggests the need of global warming experiment by use of an interactive carbon cycle-climate change model for more realistic future projection.

Preliminary results of experiments by use of the model will be presented and general discussion on the future direction as well as feasibility of integrated earth system modeling will be made.

The other direction of new model development is very high resolution atmosphere and ocean models. In the atmosphere modeling both in short-term weather prediction and long-term climate simulation, parameterization of convective clouds is recognized as the hardest block for the progress of modeling. Simple increase of the spatial resolution within the framework of current atmosphere models does not solve the problem or make it even harder because the “scale separation” does not hold for 0 (10km) grid size. Thus we have decided to develop global model to resolve convective clouds with the horizontal mesh size 5km or less which may be marginally possible on the Earth Simulator. For this end new non-hydrostatic model incorporating cloud physical processes are being developed. As the grid system an icosahedral grid was adopted for avoiding the pole problem and for keeping computational efficiency. By now dry dynamical core is successfully run with a 3.5km resolution in a reasonable computing time.

Simultaneously a new high-resolution ocean model is being developed. The model is based on hydrostatic equation and discritized by use of a cubic grid. By making the sizes of nearly square grids as much as uniform over the whole sphere high computational efficiency is expected. As the consequence more than 1,000 year integration for the whole world ocean circulation will become possible by using 10km mesh to resolve meso-scale ocean eddies. So far “eddy resolving” and long-term spinning-up of the deep ocean circulation has not been compatible.