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Short Term Climate Variability and Predictions

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Abstract

This paper first describes the nature of short term variability of the coupled atmosphere-ocean-biosphere system as shown by analysis and diagnosis of observations during the past 100 years. By "short term" we mean those fluctuations of the coupled climate system whose time scales range from 10 days to 1000 days. We have deliberately excluded any discussion of short range weather forecasting (less than 10 days) and decadal changes (more than 1000 days).

We next present a discussion of the present status of our knowledge of the predictability of short term fluctuations of the coupled climate system. Based on a large number of observational and modeling studies using complex models of this system, we suggest that most of the major short term climate fluctuations observed during the past 100 years of reliable data are consequences of the interactions among the different components of the climate system. For example, interactions between the atmosphere and the biosphere play an important role in the maintenance of prolonged drought conditions over the land areas. Interactions between the oceans and the atmosphere produce large and significant changes in the locations and the intensities of the large scale rain belts and also produce large changes in the global atmospheric circulation patterns.

We then present a brief description of TOGA (Tropical Oceans and Global Atmosphere), which is a 10 year program (1985–1995) launched by the World Climate Research Programme (WCRP) to monitor and model the interactions between the tropical oceans and the global atmosphere. Its ultimate objective is the design and development of an ocean-atmosphere observing system for operational climate prediction using advanced models of the coupled climate system.

We also point out that the natural variability of regional climate is so large that the uncertainty of predicted climate change due to such factors as increase of greenhouse gases would be significant, unless the climate models can realistically simulate the interannual variability of the coupled climate system. For example, decadal mean global temperature can be significantly affected by the number and intensity of El-Niño events, which can be produced by interactions between the atmosphere and the oceans. Better simulation and prediction of short-term climate variability will increase our confidence in climate models used to predict climate change.

Finally, we make a recommendation that as a natural extension of the earlier and ongoing programs like the Global Atmospheric Research Program and TOGA, WCRP should now initiate a comprehensive Global Climate Prediction Program to investigate the feasibility of operational prediction of monthly, seasonal and interannual variability of regional climatic anomalies over the globe. Such a Global Climate Prediction Program would utilize realistic models of the atmosphere, oceans and biosphere including snow and sea ice. Most of the important ingredients of a global climate prediction program are already in place. The ongoing program of TOGA would need to be expanded to cover global oceans; the ongoing WCRP project of hydrological and atmospheric pilot experiments (HAPEX) would provide better treatment of the biosphere; the ongoing WCRP radiation projects would help improve the treatment of clouds and radiative processes; and the ongoing projects on sea ice research would help improve the atmosphere-ocean-sea ice interactions in the climate system model.

1. Introduction

Before coming to the topic of short-term climate variability and prediction, let us begin by asking a more fundamental question. What determines the mean climate of any region of earth's atmosphere-ocean-biosphere system?

The primary energy source for atmospheric motions is the radiation heating of the warm equatorial regions and the cooling of the cold polar regions. The actual rates of heating and cooling are determined by astronomical variables (the earth's distance from the sun, the periods of rotation of the earth around its axis and of the earth's orbit around the sun) and the planetary variables (size, shape and mass of the earth; chemical composition of the atmosphere, ocean and biosphere; and distribution of land, ocean, mountains, and vegetation). In addition to these fixed parameters, the amount of heat transported around by atmospheric and oceanic currents, which we would refer to as the dynamical variables, also plays an important role in determining the mean climate of any region on the earth.

The mean climate of the earth, therefore, is an equilibrium resulting from the various factors described above. This mean climate contains strong spatial and temporal gradients of pressure, temperature, salinity, velocity and water vapor. These gradients combined with the rotation of the earth give rise to day-to-day fluctuations of "weather" in the atmosphere and oceans which are routinely measured and diagnosed in order to predict their future evolution. It is the statistical average of these day to day weather fluctuations which gives rise to the weekly, monthly, seasonal and annual average climates, whose variability from one year to another is referred to as the interannual variability. It is no surprise, therefore, that superimposed on a well defined seasonal cycle - which itself has a rich space-time structure - there are large weekly, monthly, seasonal and interannual variations in the earth's climate system. For convenience of discussion in this paper, we shall make the following somewhat arbitrary classification of various time scales:

Time/Scale	Qualitative Description
0–10 days	Hourly & Daily Changes
10–100 days	Monthly, Intraseasonal & Seasonal Changes
100–1,000 days	Annual & Interannual Changes
1,000–10,000 days	Decadal & Interdecadal Changes
10,000-100,000 days	Centennial & Beyond

For discussion in this paper I have chosen to include the variations in the range of 10 days to 1000 days to define short-term climate variability. This means that we will not discuss weather prediction, and we will not discuss decadal and longer climate change. As a partial justification for this choice of time scales, it should be noted that the needs of water, energy and agriculture, and, in fact the entire socio-economic fabric of the global community are affected significantly by climatic fluctuations on these time scales.

Understanding and predicting short-term climate variability are also important, for such variability can be helpful in verifying climate models which are used for the prediction of climate change. Just as the numerical weather prediction models were useful for simulation and prediction of short-term climate variability, likewise, models with realistic simulation of short term climate variability will enhance our confidence in predictions of long-term climate change. It should be noted that most of the climate models that have been used so far to predict the climate change due to the increase in greenhouse gases have not been sufficiently validated in terms of the simulation and prediction of short-term climate variability.

In addition to the two factors of societal importance and validation of climate models, there is yet another important reason for our discussion of short-term climate variability. A large body of modeling and empirical studies, and our current understanding of the mechanisms that govern interannual changes, suggest that there is a scientific basis, and indeed some hope, for making useful predictions of climate variations on seasonal and interannual time scales.

It is, of course, true that day to day atmospheric fluctuations are not predictable after a few weeks because of the chaotic nature of atmospheric motions; however, it is now recognized that there is predictability in the midst of chaos. The interactions between the atmosphere and ocean, and atmosphere and biosphere produce long-period variations in the coupled system which enhance the predictability of the coupled system for months to years. These interactions are found to be much stronger in the tropics than in the extratropics, and therefore, the predictability of the short-term climate variability is also much higher for the tropics. We will come to this point in a later section.

In this paper, we shall address the following aspects of the short-term climate variability:

- Examples of short-term climate variability
- Mechanisms of short-term climate variability
- Predictability of short-term climate variability
- Tropical Oceans Global Atmosphere (TOGA)
- A proposal to initiate an international program for prediction of global short-term climate variability.

2. Examples of Short-term Climate Variability

During the past 100 years of global observations of the earth's climate, there are many examples of significant short-term climate variability, such as the El-Niño-Southern Oscillation (ENSO), the monsoons, the tropical droughts and heat waves/severe cold winters in the extra-tropical regions. It will be pointed out in the next section that these regional short-term climate anomalies are manifestations of regional and global scale atmosphere-biosphere and atmosphere-ocean interactions. The interrelationships among El-Niño-Southern Oscillation and monsoons are the most remarkable examples of interannual changes in the coupled climate system which affect global circulation and rainfall. A comprehensive summary of mechanisms of air-sea interaction and worldwide climate anomalies associated with the 1982–83 El-Niño has been presented by Rasmusson and Wallace (1983).

It was noted by Walker (1924) that "when pressure is high in the Pacific Ocean, it tends to be low in the Indian Ocean from Africa to Australia", and for this recurrent pattern of planetary scale atmosphere fluctuations he coined the term "Southern Oscillation." It was later suggested by Bjerknes (1966) that Walker's Southern Oscillation is but one component of a coupled ocean-atmosphere climate system, the other being the sea surface temperature fluctuations in the tropical Pacific Ocean. It is the interaction between the ocean (ocean warming off the South American coast being referred to as El-Niño) and the atmosphere that is responsible for such fluctuations and produces short-term climate anomalies in different regions of the globe. Figure 1 shows fluctuations of surface pressure over Darwin, Australia (dashed line). The anomalies (departures from climatological mean) are first smoothed by a 12 month running mean and then divided by the standard deviation, and then smoothed again by a 12 month running mean. Darwin pressure has been chosen to illustrate the fluctuations in Southern Oscillation. The solid curve in this figure represents the sea surface temperature (SST) anomalies for the eastern equatorial Pacific. It can be seen that both variables, surface pressure and SST, show long-period (2–5 years) fluctuations, and it is also remarkable that the two are highly correlated. These coupled fluctuations of tropical ocean and atmosphere are referred to as ENSO (El-Niño-Southern Oscillation).

Interannual variations in seasonal mean rainfall averaged over the whole of India also show very large interannual variability. Figure 2 shows the summer (June, July, August, September) monsoon rainfall averaged for more than 300 stations over the whole of India except the northern and the eastern hilly regions. It can be seen that even after averaging over a large spatial region and the whole monsoon season, there are significant fluctuations in monsoon rainfall from year to year, and from decade to decade. The solid line shows the 30 year running mean of the seasonal mean rainfall and the dashed line shows the standard deviation of rainfall for each 30 year period. It is remarkable that the 30 year mean as well as the variability within a thirty year mean show such large changes from one to the other thirty year period. It is unlikely that such large-scale, long-period fluctuations could be explained as a mere consequence of different sampling of high-frequency, small-scale, rain-producing disturbances. It is more likely that such fluctuations are produced by planetary scale, long-period fluctuations of the coupled ocean-land-atmosphere system.

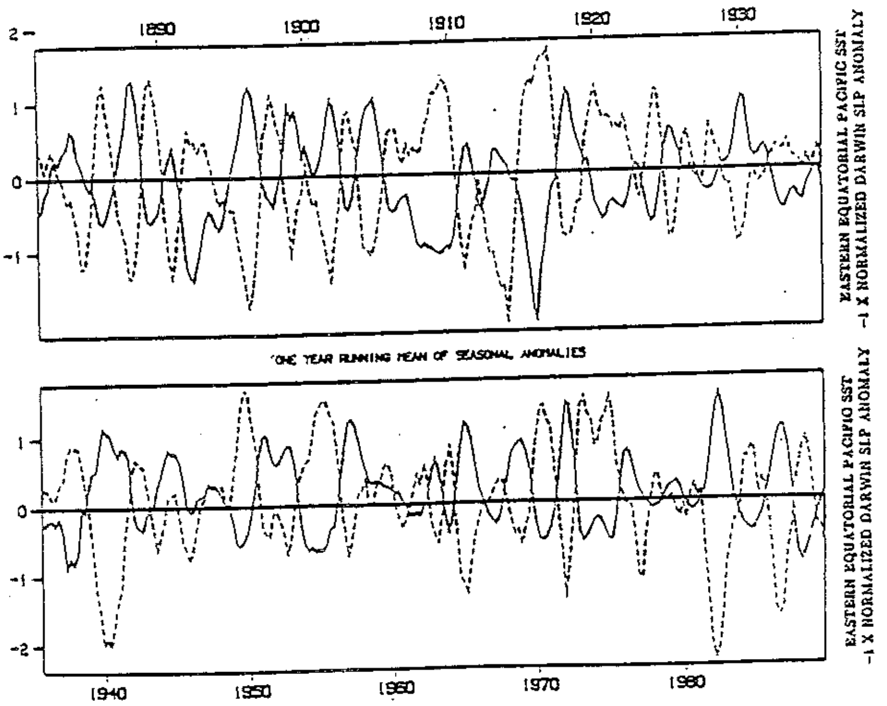

Figure 1: Darwin sea level pressure anomaly with sign reversed (dashed line) and eastern equatorial Pacific SST anomaly. Each anomaly is normalized by its own standard.

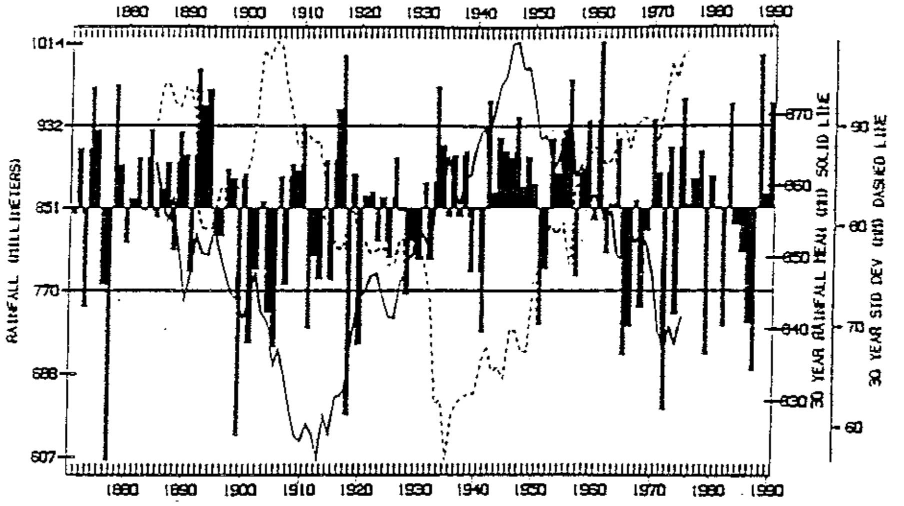

Figure 2: Summer monsoon rainfall over India (solid bars), 30 year running mean rainfall (solid line) and standard deviation for successive 30 year periods (dashed line).

These selected examples of short-term climate variability suggest that quite large changes in our climate system can, and do, occur which are not necessarily either due to external or anthropogenic factors. We will refer to such fluctuations as the natural variability of our climate system. For lack of a better definition of natural variability, we would define it as the climate variability that would occur if the planet were never inhabited by the human species. This provides a baseline for detecting and predicting changes in climate and climate variability due to human influences. According to this definition, the examples described above will be categorized as being part of the natural variability of the climate system.

3. Mechanisms of short-term climate variability

The mechanisms responsible for the short-term climate variability can be described conceptually in two categories (Shukla, 1981).

- Internal dynamics of the individual components of the climate system
- Interactions among the various components of the climate system.

Internal Dynamics:

Even if the external forcings of the solar radiation and boundary conditions at the earth's surface were constant in time, the regional atmospheric circulation will exhibit short-term climate variability due to the combined effects of the hydrodynamical instabilities of the climate system and nonlinear interactions among various scales of motion. Although the distribution of oceans, continents, and mountains are fixed with time, their interactions with fluctuating winds can produce short-term climate variability. The occurrence of nearly zonal or persistent non-zonal regional circulation regimes ("blocking") are possible examples of anomalies due to the internal dynamics of the atmosphere. Likewise, the internal dynamical instabilities of ocean currents can produce variability in the ocean circulation and possibly the overlying atmosphere. We know that the spectrum of the atmospheric observations is red. A certain amount of interannual variability will be produced solely due to the unpredictable weather and, therefore, that will remain unpredictable too.

Interactions (Atmosphere - Ocean; Atmosphere - Biosphere; Atmosphere- Cryosphere):

We suggest that all the major events of short-term climate variability observed during the past 100 years - a period for which reasonably reliable instrumental measurements of climate variables exist - are due to the interactions among the atmosphere, ocean, biosphere and cryosphere components of the climate system.

Atmosphere-Ocean Interactions:

Changes in SST produce changes in evaporation, sensible heat flux and low level moisture convergence which in turn produce changes in atmospheric heating. The anomalous atmospheric heating produces changes in atmospheric circulation which in turn produce changes in wind stress and heat flux at the ocean surface. If this air-sea coupling has a positive feedback, it can produce long-lived anomalies of SST and the associated atmospheric

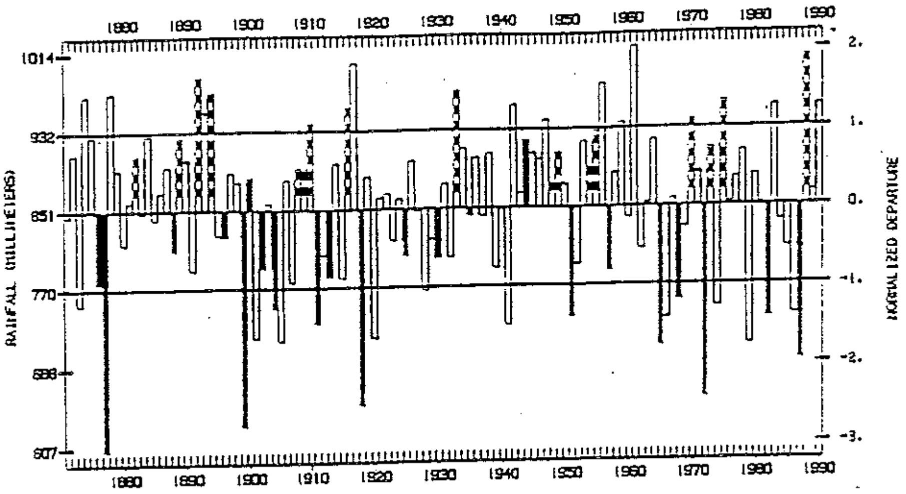

Figure 3: Summer monsoon rainfall over India. Solid and hatched bars denote the years when the eastern equatorial Pacific SST anomaly was rising and falling respectively.

circulation. Because of the differing rotational forces in the tropics and the extra-tropics, and because tropical ocean temperatures are warmer, even a small change in SST in the tropics can produce much larger changes in moisture convergence and heating than similar SST changes in the extratropics. This is the main mechanism for the occurrence of tropical droughts and floods which are manifestations of spatial and temporal shifts of mean climatological maxima of rainfall. The tropical atmosphere and oceans also do not have strong dynamical advections (as they do in midlatitudes) and therefore changes in atmospheric heating and surface wind stress can produce significant changes in atmospheric circulation and SST respectively. This is the primary reason why short-term climate variability of the tropical oceans and atmosphere are so strongly linked, and also why there is hope for predicting this coupled variability. In Figure 1 it was seen that the tropical SST and surface pressure fluctuations were highly correlated. Many researchers have further shown that in association with ENSO, several large regions of the globe experience droughts and heavy floods. For example, Figure 3 shows the Indian monsoon rainfall fluctuations (as in Figure 2) except that the years in which the tropical Pacific SST was rising and falling during the monsoon season are represented by black and hatched bars respectively. It is again remarkable that most of the severe droughts and floods over India occur during the anomalous warming (El-Niño) and cooling of the equatorial Pacific ocean respectively.

Atmosphere-Biosphere Interaction:

Changes in vegetation produce changes in albedo, surface roughness and soil moisture. These changes in turn produce changes in ground temperature, evaporation and sensible heat flux. Changes in horizontal gradients of ground temperature produce changes in convergence of moisture, and changes in vertical gradients of temperature along with moisture convergence produce changes in convection and rainfall, which in turn changes the soil moisture. The nature and degree of this interaction again depend on the character of the dynamical circulation regime where the land surface changes are taking place. The occurrence of prolonged droughts in sub-tropical regions (where the atmospheric dynamics are relatively weak) and even the tendency of heat waves to persist in the extra-tropical regions can be explained, at least in part, by such atmosphere-biosphere interactions. The West African Sahel has experienced persistent drought conditions for more than 20 years with significant interannual changes during these 20 years. Figure 4 shows fluctuations of rainfall over the west of the Sahel during the period 1940-1990. It can be seen that Sahel rainfall, like the Indian monsoon rainfall shown in Figure 2, displays large year to year changes in seasonal mean rainfall. However, in addition there is a significant shift in the mean rainfall after 1968. While such shifts in seasonal and annual mean values are not uncommon for regionally averaged climatic parameters, this is a rather unique case because there is not a single year during the past 20 years when the seasonal rainfall was significantly above the climatological normal. Atmosphere-ocean interactions over the global oceans, as well as local atmosphere-biosphere interactions have been suggested as

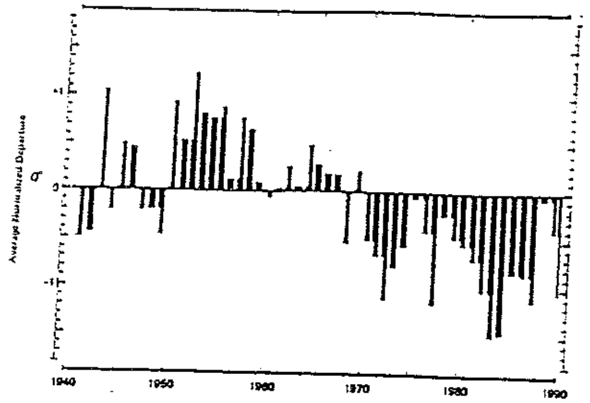

Figure 4: Rainfall index for sub-Saharan West Africa. Anomaly is normalized by standard deviation (courtesy of P.J. Lamb).

possible causes for these changes. Since monsoon rainfall over India as well as China also showed a notable shift (reduction) from the decade of 1950s to the decade of 1970s, it is reasonable to assume that this decadal shift in rainfall was perhaps due to some planetary scale circulation changes. However, it is quite likely that the local atmosphere-biosphere interactions, exacerbated by human activities leading to changes in the land-surface properties, could contribute towards the continuation of the reduced rainfall regime.

4. Predictability of short-term climate variability

It is well known that the instantaneous weather conditions are not predictable beyond a few days. It is also well understood that this lack of predictability is due to dynamical instabilities and non-linear interactions which amplify even very small initial uncertainties which may be either due to inadequate observations or imperfect equations for physical principles (Lorenz, 1965). However, it should be noted that lack of deterministic predictability of day-to-day weather beyond a few weeks does not necessarily mean that space and time averages for a month or season or beyond are also not predictable. In fact, we would like to propose that the large body of observational, theoretical and modeling results collectively suggest that there is indeed a scientific basis for the predictability of space-time averaged short-term climate variability. The primary scientific reasons for such an optimistic view on the predictability of short-term climate can be summarized as follows:

> The space time spectra of atmospheric observations show that most of the variance in the interannual variability is accounted for by long-period, large scale fluctuations which are intrinsically more predictable than the day-to-day small-scale weather systems, and it is these relatively longer period large scale variations which are important for the prediction of short-term climate variability. In addition, atmosphere-ocean and atmosphere-biosphere interactions produce predictable changes in the coupled climate system. The atmospheric circulation anomalies are likely to be more predictable for those time scales for which the boundary forcings due to the anomalies in SST and soil moisture can also be predicted. For time periods beyond the persistence of boundary forcings, we must be able to predict the evolution of the boundary forcings themselves. Recent developments in the modeling of the coupled system suggests that for the particular example of ENSO, the coupled tropical ocean-atmosphere climate system is theoretically predictable up to 1–2 years (Goswami and Shukla, 1990).

However, while considering the predictability of any climate signal, we must also consider the possible sources of climate noise which would tend to introduce a lack of confidence in the predictions. The following table gives some simple examples of possible signals we may wish to predict and important sources of noise which will make the predictions unreliable.

SIGNAL	NOISE
Daily Weather	Thunderstorms
1–10 Day Mean	Cyclones
Monthly Mean Climate	Blocking
Seasonal Mean Climate	30–60 Day Oscillations
Interannual (1–3 Year) Climate (ENSO)	Coupled Air-Sea Instabilities
Decadal Climate Change	ENSO

It should be noted that predictions of monthly and seasonal mean climate anomalies (from a given initial state) will be affected by the presence or absence of blocking regime, and the amplitude and phase of 30–60 day oscillations. Similarly, the predictability of ENSO will be determined by the instabilities of the coupled ocean-atmosphere system much like the predictability of short and medium range weather is influenced by baroclinic instability in the atmosphere. It should also be noted that the predictability of decadal climate changes (e.g., greenhouse warming) will be strongly influenced by the intensity and frequency of ENSO events. Pan and Oort (1983) have shown that interannual changes in the global mean temperature of the entire atmospheric column are highly correlated with SST anomalies in the eastern equatorial Pacific.

This is particularly relevant for the ongoing controversy over the detection and prediction of greenhouse warming. Based on the observational record of the global mean temperature, it is not possible to conclude that the climate change has been detected. The observed changes are entirely within the range of the natural variability of the coupled climate system. Likewise, the present climate models - the ones used for predicting effects of increased greenhouse gases - have not been adequately validated against the actual observed climate variability during the past. Therefore, there is no strong basis to accept the model predicted changes in global climate. The present climate models show large systematic errors in simulating the mean climate. It is assumed that although the simulated mean climate of the models is wrong, the differences between the simulated climate for the future (with increased greenhouse gases) and the simulated climate for the present can be accepted because the errors in simulating the present climate get removed when we subtract one model simulation from the other. This assumption is generally correct if the models were used to simulate the direct response of a strong external forcing. The simulation of the effects of increased greenhouse gases falls in an altogether different category. The direct radiative forcing due to increased greenhouse gases is quite small (3–4 Watts m^{-2} compared to the mean value of about 300 Watts m^{-2}), and the corresponding increase in surface temperature will also be quite small. Thus, the model predicted climate changes due to greenhouse gases are entirely due to a number of positive feedbacks as formulated in the model parameterizations. Therefore, in order to accept the model results, it is quite important that the models are validated against some known climate variations in the past before we can have confidence in the model predictions for the future. It is in this context that it is considered particularly important that the climate models are validated for their ability to simulate and predict the short-term climate variability including the frequency and intensity of El Niño events.

5. Tropical Ocean Global Atmosphere (TOGA)

Recognizing the role of tropical SST anomalies in forcing global scale atmospheric circulation anomalies, and that the tropical SST anomalies are deterministically forced by atmospheric circulation anomalies, the World Meteorological Organization (WMO) and the International Council of Scientific Unions (ICSU) established a scientific steering group for the international TOGA program which is an element of the World Climate Research Programme (WCRP).

The scientific objectives of TOGA are (WMO, 1985):

1. To gain a description of the tropical oceans and the global atmosphere as a time-dependent system, in order to determine the extent to which this system is predictable on time scales of months to years, and to understand the mechanisms and processes underlying that predictability
2. To study the feasibility of modeling the coupled ocean-atmosphere system for the purpose of predicting its variations on time scales of months to years
3. To provide the scientific background for designing an observing and data transmission system for operational prediction if this capability is demonstrated by coupled ocean-atmosphere models.

TOGA was conceived as a ten year program (1985–1995) of data collection and modeling research. It is hoped that by use of advanced four-dimensional data assimilation techinques, all the surface and sub-surface ocean observations can be synthesized to produce an internally consistent basin-wide synoptic description of tropical oceans. Likewise, an internally consistent homogeneous data set for the four-dimensional structure of the global atmosphere can also be produced. Current efforts of tropical ocean data assimilation in USA and France have already begun to produce basin scale synoptic maps of ocean circulation. This is a major breakthrough for dynamical oceanography.

The ongoing modeling efforts using atmospheric models with prescribed SST, ocean models with prescribed wind stress and heat flux, and coupled ocean-atmosphere models have produced the highly promising result that interactions between the tropical oceans and the global atmosphere enhance the predictability of short-term climate variability. A description of the accomplishments in the first five years of the US TOGA program and challenges for the future are summarized in a recent report (TOGA, 1990).

It should be recognized, however, that although the largest predictable part of the interannual variability of climate arises from ENSO, and more generally TOGA phenomena, to successfully carry out the prediction of short-term climate variability on seasonal and longer time scales will require adequate treatment of the other important interactive components of the climate system, including the extra-tropical oceans, land surface processes (biosphere) and variations in snow cover and sea ice.

6. A Proposal

In order to exploit the scientific advances in understanding the dynamics of the coupled Tropical Ocean/Global Atmosphere system as well as relevant results of other studies by WCRP and Climate and Global Change Programs, serious consideration should be given to the initiation of an international program for the prediction of global short-term climate variability.

The overall objectives of this program might be to:

- Provide real-time predictions of variations of the earth climate system on time scales of seasons to several years
- Validate predictive models of global climate change by demonstrating skillful forecasts of short-term variations of the coupled ocean-land-atmosphere climate system

A transition from TOGA and other ongoing WCRP programs to this project will require a transition from ocean models that focus entirely on tropical oceans to global atmospheric models with fully interactive land-surface processes including snow cover, and global oceans including sea ice. It is likely that in the initial phase, such a program may need to take into account only the thermodynamics of the global upper ocean and the fast dynamics of tropical ocean basins. The information base and the results from this program will be highly valuable in putting quantitative confidence limits on predictions of climate change on decadal time scales.

The program might include three main components, in addition to development of global observing systems foreseen in the framework of the World Weather Watch (WWW), World Ocean Circulation Experiment (WOCE) and Global Energy and Water Cycle Experiment (GEWEX). These components are:

(i) A global atmosphere-ocean-land climate data analysis and prediction component, based on one or several dedicated central facilities for data acquisition, analysis, quality control and climate forecasts

(ii) An operational global observing system to provide the required data inputs for atmosphere, surface and upper ocean, sea ice, snow cover and soil moisture

(iii) A research component to address outstanding problems and new scientific issues which may arise in the course of the program.

It is recognized that for entirely fundamental scientific reasons (differences in the rotational force, dynamical instabilities and non-adiabatic heat sources), the potential predictability of the tropical atmosphere and oceans is much higher than that of the extratropics. Therefore, initially, the greatest beneficiaries of any organized, internationally coordinated effort in short-term climate prediction will be the tropical countries. However, the tropical countries do not have, at this time, the required resources of trained scientific personnel and computation-communication facilities to exploit this gift from nature for the well being of their respective societies. Therefore, we conclude with a suggestion that the nations of the world join together to exploit the recent scientific advances by initiating an international program on the prediction of short-term climate variability.

References

Bjerknes, J.: 1966, A possible response of the atmospheric circulation to equatorial anomalies of ocean temperature. Tellus, 18, 820–829.

Goswami, B.N. and Shukla, J.: 1990, Predictability of a Coupled Ocean-Atmosphere Model. J. of Climate, 3, 2–23.

Lorenz, E. N.: 1965, A study of the predictability of a 28-variable atmospheric model. Tellus, 17, 321–333.

Pan, Y.H. and Oort, A.H.: 1983, Global climate variations connected with sea surface temperature anomalies in the eastern equatorial Pacific Ocean for the 1958–73 period. Mon. Wea. Rev., 111, 1244–1258.

Rasmusson, E.M. and Wallace, J.M.: 1983, Meteorological aspects of the El Nino/Southern Oscillation. Science, 222, 1195–1202.

Shukla, J.: 1981, Dynamical predictability of monthly means. J. Atmos. Sci., 38, 2547–2572.

Tropical Ocean Global Atmosphere (TOGA): 1990, A review of progress and future opportunities. National Research Council, National Academy Press Washington, D.C.

Walker, G.T.: 1924, Correlations in seasonal variation of weather. Mem. India Met. Dept., 24, 333–345.

World Meteorological Organization (WMO): 1985, Scientific plan for the Tropical Ocean Global Atmosphere Programme. WCRP Publication Series No. 3, WMO/TD 64, Geneva.