APPLICATION OF SEASONAL TO INTERANNUAL PREDICTIONS: A NORTHERN HEMISPHERE PERSPECTIVE

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ABSTRACT - Climate variability over many parts of the world can impact many social and economic sector. The dominant source of interannual global climate variability is the El Niño/Southern Oscillation phenomena (ENSO). Over the past few decades scientists have developed a capability to forecast ENSO several seasons in advance; this capability was used to mitigate some of the impacts of the major 1997/98 El Niño in many countries. ENSO only accounts for a part of the observed variability. Other sources of climate variability are also important on seasonal, interannual, and decadal time scales. Of the ones that are know, these fall into two broad classes. The first class is related to tropical rainfall variation on intra seasonal, seasonal, and decadal times scales. ENSO represents extreme examples on this class. A better understanding of the sources of tropical rainfall variability on all time scales will likely lead to improved forecast skill since this builds on existing understanding and forecasts systems. The second class consists of changes in zonal flows in mid-latitudes. Examples of these are the North Atlantic Oscillation and the Arctic Oscillation. More research is required in order to develop forecast skill based on an understanding of the origins of these zonal flow changes. Better understanding of all of these and other phenomena and the use of this in improved seasonal forecasts will require expansions of the existing ocean observing system.

1 - THE BENEFITS OF CLIMATE FORECASTS

Year to year variability in seasonal climate is pervasive. Until recently social and economic systems were almost always caught off guard and usually suffered losses or were unable to capitalize on favorable conditions. Better understanding of the sources of climate variability gained through focused research over the past decades has lead to a capability to begin to forecast seasonal climate variability. This presents opportunities to help mitigate the impacts of natural disasters and to derive social and economic benefits. Climate forecasts are already starting to be used for these purposes.

The El Niño/ Southern Oscillation (ENSO) phenomena is the major source and best understood aspect of interannual global climate variability. ENSO arises from coupled ocean-atmosphere interactions primarily in the tropical Pacific. A number of institutions make routine forecasts using statistical and dynamical tools for sea surface temperature (SST) variations in that region. A smaller subset of these also make routine seasonal temperature and rainfall forecasts for continental areas. Typically the impacts of coherent climate variability, like ENSO, can be obscured by normal weather variability. However, during major ENSO events the climate related impacts stand out more clearly. Hence major ENSOs like the 1982/83 and 1997/98 events present the best opportunity for assessing the range of impacts to be expected from climate variability.

A wide range of social and economic sectors were impacted by the 1997/98 El Niño (Fig. 1). These sectors included: agriculture; energy; water resources; health; ecosystems; tourism; social systems. Regionally they were focused in the global tropics/subtropics and in midlatitudes in the Americas. Weather related impacts globally during this last event were estimated at causing $34B in damages (NOAA-OGP, 1999). A significant portion of these appear to be the consequences of El Niño.

These estimates were primarily for losses suffered; however, there can be winners as well as losers. Winners in the U.S. included: increased sale of homes and goods, $5.5B; increased employment, $500M; reduced snow removal costs, $400M. Also a positive impact was that for the U.S. the 1997 hurricane season was much less active than normal; hurricanes are a major cause of loss of property and life. Also the much milder than normal winter during 1997/98 resulted in about 200 fewer lives lost as a result of weather related accidents. Seasonal forecasts for temperature and rainfall were available for the U.S. and some use of these was made for disaster mitigation and economic benefit. California took mitigation actions which kept their overall losses at about $1B U.S. or comparable to those during 1982/83. Accounting for inflation this suggest that the actions taken might have saved as much a $500M-$1B. Mitigation actions were also taken in other countries with great success. The use of climate forecasts in the U.S. is accelerating. The primary users are in the energy sector where weather derivatives are used to help reduce the financial risks of an unusual winter or summer. This market has grown from essentially nothing to over $2B last year for just the U.S.. Applications are being developed in other economic sectors.

2 - THE NATURE OF THE PROBLEM

Examination of historical data sets for temperature and rainfall shows that seasonal variability occurs on interannual and decadal time scales (Fig. 2). Significant ENSO events can only account for about 40% of this; however, significant variability occurs almost every year. So besides ENSO are there other modes of climate variability that can be forecast in order to account for more of the observed regional climate signals? CLIVAR planning has identified a number of such modes. One of these is the North Atlantic Oscillation (NAO). This varies on all time scales but recently seems to be showing persistence on decadal time scales. The CLIVAR program hopes to establish whether coupled interactions play a significant role in its predictability. Decadal variability that might originate from air-sea interactions in midlatitudes has also been identified in the Pacific from coupled model simulations (Latiff and Barnett, 1996). More recently it has been suggested that midlatitude variability might best be considered by looking at fluctuations in the polar vortices, i.e. the Arctic Oscillation (AO) (Thompson and Wallace, 1998) and the Antarctic Oscillation (Thompson and Wallace 1999). The Pacific Decadal Oscillation (PDO) has also been identified as a mode of variability that has impacts over the U.S.. (e.g. Zhang et al. 1997). This potentially has its origins in coupled interactions in the tropics in the Indo-Pacific region.

Two broad classes of climate variability have been identified by CLIVAR which may provide some predictability on seasonal to longer time scales. Those modes of variability of the first class all have a tropical connection, associated with changes in tropical convection. In this class one might cite the ENSO in the Pacific, the north-south dipole in the Atlantic, the ENSO-type mode in the equatorial Atlantic, the east-west dipole in the Indian Ocean, the Pacific Decadal Oscillation. The second class is associated with changes in strength and location of zonal flows in middle and high latitudes. In this class one might think of the NAO (North Atlantic Oscillation), the Arctic Oscillation, and the subtropical gyral modes of the Pacific and Atlantic, and the Antarctic Oscillation. There is considerable controversy on the best way to characterize these modes, whether they are indeed independent, whether they are truly coherent coupled processes in the climate system, or just a selective response to noise forcing, albeit with some characteristic timescale. The signatures of these modes on rainfall and temperature have been documented to some degree. There is some scientific satisfaction in identifying various modes which may prove useful in understanding and quantifying predictability.

The question being addressed in this investigation is how much regional variability in temperature and rainfall can be accounted for by tropical rainfall variability on seasonal and decadal time scales, i.e. ENSO and the PDO, and changes in midlatitude zonal flows, for example, the AO. The procedure we use involves establishing time series for each of these modes and then (via linear regression on time series of various global atmospheric and oceanic fields) assessing the impacts of these modes. The time series for the first two modes are determined from the high and low pass filtered EOF principal components of tropical rainfall in the western Pacific. The time series for the AO is from Thompson and Wallace (1998). Both the AO and PDO time series (Fig. 3) show pronounced decadal variability that has tended to be of one sign, i.e. positive trends, until just recently. The high pass filtered rainfall time series shows not only the major ENSO events but also weaker amplitude variations that normally don't qualify for event status, but which no doubt have global impacts.

Linear and multiple linear regression between these time series and various atmospheric and oceanic fields are used to establish the regression coefficients. These are then used to reconstruct times series of the oceanographic and meteorological fields. The reconstructed time series are correlated with the original ones. Maps of correlation coefficients indicate regions that are impacted and the degree to which they are impacted. This is a measure of the predictability for this field presuming that the original time series for the modes was predictable. Of course, this is a big assumption. Multiple linear regression allows an estimate of the predictability increase if several of these modes are predictable. Of course, linear regression has limitations and future studies should use more sophisticated techniques especially since many of the relationships are non-linear.

3 - PREDICTABILITY OF GLOBAL FIELDS

As numerous other studies have shown, ENSO is most strongly correlated with tropical Pacific SSTs (Fig. 4a). It accounts for roughly half the variance in the central equatorial Pacific. Other areas that are impacted include the midlatitude South and North Pacific through atmospheric teleconnections and the equatorial Indian Ocean. Consideration of both ENSO plus the PDO generally increases the correlations in the areas impacted by ENSO and broadens them especially in the eastern Pacific, i.e. more of the globe is impacted by statistically significant correlations (Fig. 4b). Correlations are also higher in midlatitudes both in the Atlantic and Pacific sectors. It is interesting that few, if any, new areas with significant correlations are introduced. This indicates that the basic physics of the teleconnections is the same, as might be expected, for the high and low pass filtered rainfall variations; both probably excite the natural internal modes of variability in midlatitudes. It is interesting, but probably not surprising since the natural modes of variability are involved, that the addition of the AO contribution (Fig. 4c) does not change the patterns in midlatitudes. However, the amplitude of the correlations continues to increase. This suggests that all three of these modes modify the basic seasonal circulations, i.e. storm tracks, in these regions. The correlation of the AO index by itself with SSTs shows only weak signals in the North Pacific and North Atlantic poleward of 30° N (not shown).

Observations indicate that there have been significant trends during the last decades in the atmospheric circulation. One example is the trend in 200-hPa zonal wind (Fig. 5). The most significant trends have been in the Atlantic sector; however, significant signals are also present in the Pacific and to some extent over Eurasia. How much of this trend can be accounted for by these three modes? The fact that there have been more El Niños than La Niñas does not contribute significantly to the trend. The major factors are the trends in the PDO (Fig. 5b) and the AO (Fig. 5c). Unexpectedly the PDO also has a significant signal in the North Atlantic. The main impact from the AO is in the polar regions and in the Atlantic sector. In the Atlantic sector the AO and the PDO impacts are in phase, i.e. they reinforce each other. In the Pacific in the latitude band from about 20°N to 40° N, they are out of phase, i.e. they cancel each other. When the two are considered together (Fig. 5d) they basically account for most of the observed trend in the 200 hPa zonal wind.

4 - PREDICTABILITY OF U.S. REGIONAL FIELDS

The time series for the three modes can be regressed against the seasonal temperature and rainfall variations for the U.S. to establish the predictability of these fields. For ENSO the strongest correlations for temperature and rainfall are found primarily for the southern states; weaker correlations are found for some of the northern tier states (Figs. 6a and 6d). If only ENSO years were considered, the correlations would be considerably higher but the locations for significant correlations would remain approximately the same. If ENSO and the PDO are considered together (Figs. 6b and 6e), then the areas with correlations greater than 0.3 for rainfall roughly double. The Southwest and Gulf Coast now have large areas with correlations greater than 0.6. The overall spatial structure of the correlations changes little from that for ENSO itself, indicating that potentially similar physics is involved in the teleconnections from the tropics. Similarly for temperature the correlations go up and again primarily in the same regions that were impacted by ENSO. Most of the predictability remains in the southern states.

The addition of the AO adds significantly to the potential predictability in the eastern one third of the U.S.. (Figs. 6c and 6f). The most significant increase is for temperature. Correlations of greater than 0.6 are achieved for this region. This indicates that for this region the AO is the single most important factor in wintertime seasonal temperature variability. Unfortunately it may also be the most difficult one to forecast seasonally with skill. The AO also has an impact on rainfall variability in this region, especially in the Tennessee, Kentucky, Ohio region. This is also a region where ENSO and the PDO have skill; hence the AO impact is to reduce the predictability in that region unless skill is established for this mode. Additional aspects of these relationships are considered by Higgins et al. (1999).

5 - GLOBAL IMPACTS OF AO

The most robust impacts of the AO occur in wintertime and over the eastern half of the U.S. and western Europe through the Mediterranean (Fig. 7). For temperature these include above normal temperatures over the eastern U.S., below normal temperatures over far eastern Canada, warmer than normal temperatures for most of Europe, Scandinavia, and extending across Eurasia, with below normal temperature further to the south through the Mediterranean. Rainfall impacts are found in these same general areas and are discussed by Visbeck later in the conference. Significant impacts have also been documented in the Atlantic on marine ecosystems and storminess.

6 - IMPLICATIONS FOR THE OBSERVING SYSTEM

Observations are needed to better understand the coupled ocean-atmosphere system and to document its behavior, to initialize coupled forecast systems, and test and improve the models. A more detailed discussion of how observations are used in coupled forecast systems and the need for more accurate forcing fields is given in the article “ENSO and Seasonal Forecast Systems” by Anderson, et. al. later in this same volume. Long term, global, and continuous time series are needed because of the complexity of global connections, the possible rectification between separate climate modes, the importance of decadal variability, and the impacts of this on ENSO. An important issue that needs to be surmounted is that many of the in situ and remotely sensed parameters are parts of research demonstrations; long term continuity of those measurements that prove to be valuable need to be assured.

Since the best prospects for improved predictability come from a better understanding of tropical rainfall variability which results from SST variability in all the ocean basins, enhanced in situ measurements in the tropics and subtropics in all three ocean basins are clearly necessary. The large changes in tropical rainfall and SST that occurred the past two years in the Indian Ocean, the maritime continent (Indonesian region), the entire Pacific, and the Atlantic illustrate this global requirement. It is likely that the processes involved in producing SST anomalies in the Indian Ocean, the Indonesian area, and the far western Pacific, and the off equatorial regions in the Atlantic are quite different from those in the central and eastern Pacific. In the latter region rather simple negative feedback mechanisms seem to be important, i.e. the atmosphere acts to kill the SST anomalies. In these other regions a better understanding of the origins of SST anomalies lies in considering both circulation and air-sea flux changes. Whether this can be obtained from studies of the COARE data sets, results from the PIRATA program, and better quality controlled surface marine data sets or requires routine specialized flux measurements is not clear to the authors.

Hence an expansion of both surface and in situ observations is necessary westward from the TAO array and into the northern and southern hemisphere subtropics. Measurements poleward of the TAO array are needed because a) decadal variability and decadal variability of ENSO involve hypotheses and physics that extend outside the tropics; b) it is likely that east-west shifts of convection and changes in the locations of the ITCZ and the SPCZ are both important in generating responses over North America. An enhanced program of measurements is also needed in the tropical and subtropical Atlantic. For regional forecasts these are of high priority. A better understanding of variability in the subtropical North Atlantic could provide the link to developing an understanding and some predictability of the NAO. Also there is some potential impact of ocean variability in these regions on Atlantic hurricanes and this needs to be quantified.

The types of measurements that have been proposed to meet these needs are as follows. More details on the contributions from each measurement type and how they contribute to an integrated observing system can be found in the other papers in this volume.

- ARGO arrays to provide T and S profiles
- expansion of TAO into the Indian Ocean
- long term continuity and expansion of the PIRATA array
- surface salinity sampling
- continued altimetric measurements of JASON quality
- improved winds from scatterometry
- surface flux measurements
- maintenance of the tide gauges
- measurements of boundary current transport

Expansion of in situ measurements poleward of the subtropics both in the Pacific and the Atlantic is also clearly necessary for CLIVAR research. However, the gains in improved predictability through improved measurements in these regions currently are less tangible. This remains a topic of research and possibly the use of higher resolution, improved models might be necessary for this demonstration. However, measurements in these regions are also required for research, to document the impacts of long term climate variability, and to assess the potential impacts of variability on marine ecosystems.

Continuity in remotely sensed ocean data is critical for an improved forecast capability. Improvements in ocean models and ocean initial conditions continue to be limited by the availability of high quality wind forcing data. ERS and NSCAT missions have shown the great utility of remotely sensed wind information. The altimetric measurement of sea level variability, especially those from TOPEX/POSEIDEN, have provided new insights into ocean variability and are proving to be valuable in ENSO prediction. Continuity of remotely sensed wind and altimetric measurements needs to be assured. Observations from current operational satellites for parameters such as SST, of course, continue to be critical and also need to be continued. Because of the central importance of tropical rainfall variability, long term continuity of satellite estimates of rainfall from TRMM and other satellites is of high priority.

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