This report serves as an update of the 2008-2009 annual report incorporating research over the full 5-years of the grant. Over the entirety of the project, we have concentrated on a number of key topics: Monsoon studies, intraseasonal variability of the tropics, hurricane climatology and some general studies. These are listed below. An offshoot of our tropical cyclone research has been funded in a separate grant. Most of the tropical cyclone work will be reported in a separate report for NSF Grant 0826909.

(i) Monsoon Studies:

A major thrust of our research under this grant has been on the dynamics of the monsoon with a concentration on intraseasonal and interannual variability. Jun et al. (2009) shows the large-scale controls of sea-surface temperature (SST) on the annual river discharge of Brahmaputra and the Ganges. In the same paper, the influence of intraseasonal variability of monsoon rainfall is also discussed based on the earlier paper of Hoyos and Webster (2007). Major results of this study are that most of the monsoon rainfall exists over the oceans, and not the continents, and that interannual variability of the monsoon is made up principally of intraseasonal contributions. These results lead to a number of implications:

(i) Most prediction studies concentrate on regional monsoon regions (e.g., India, West Africa). However, it may be more useful to consider variations of the global monsoon that takes into account both ocean and land precipitation and the dry ocean and land areas. Subtle shifts of the global monsoon may lead to large changes in local precipitation regimes. This broader view of the monsoon, and its implication for regional monsoon circulations, is the subject of a new study with our renewed grant (Wang et al. 2011: listed at end of references as ancillary references))

(ii) If intraseasonal variability of the monsoon is a primary issue in interannual variability then one must take this frequency range into account in making a seasonal forecasts. Using statistics that ignore intraseasonal variability or models that do not represent intraseasonal variability will probably not lead to great advances in prediction. We intend to follow the lead of Hoyos and Webster (2004), a statistical study for empirical prediction of the ISO, plus the hybrid technique developed by Kim and Webster (2010). The first study develops sets of predictors for the monsoon ISO. The second study uses coupled ocean-atmosphere prediction models (here the ECMWF System 3) to predict the predictors. Using this technique for the seasonal prediction of Atlantic hurricanes produced a longer lead time and better estimates than stand-alone empirical or numerical models. One extension will be to widen the predictor base spatially to encompass the oceanic part of the monsoon by using EOFs as predictors. We are hopeful that we may increase predictability of the monsoon in the 15-30 day range that is critical for agriculture.

We have also completed a paper that speculates on the future river discharge and fresh water availability in the major river basins of South and East Asia (Webster and Jian 2010). The paper concludes that discharge will increase in the Ganges, Brahmaputra and Yangtze basins with increased variability. We calculate that in the Brahmaputra basin, for example, that the flood risk will increase two-fold in the next 50 years and, in the two basins of rapidly increasing populations (the Ganges and Brahmaputra) the fresh water availability will halve. Only in the Yangtze, where population is expected to remain
constant will the fresh water supply stabilize.

We have conducted two further studies on the hydrology of South Asia. One involves a report on the 10-day (now 15-day) and seasonal flood forecasts made for Bangladesh (Webster et al. 2010). The techniques developed are detailed in Hopson and Webster (2010). Operational forecast (partly funded by USAID) were conducted during 2007 and 2008 and provided 8-10 day lead-time of the three major Brahmaputra floods. The modules have been handed over to the Flood Forecast and Warning Center in Bangladesh in 2008 although they have had personnel and technical problems. An NGO now makes the operational flood forecasts for them.

We have concluded a separate study where we ask whether or not the devastating floods of Pakistan during July and August 2010 were predictable (Webster et al. 2010). Whereas the seasonal rainfall was high but not exceptional, the determining factors were the rainfall rates which were extreme during the five monsoonal pulses and the location (over the highlands of northern Pakistan. As it turns out, each rainfall pulse was predictable 6-8 days in advance and if a hydrological module and a communication system had been in place (as developed for Bangladesh) the human and property losses would have been much less.

We have become interested in the African monsoon and its relationship with the Asian system. In a paper that deals more strictly with the West African monsoon, Nicholson and Webster (2008) attempt to explain the interannual variability of Sahel rainfall. We conclude that the mean location of the ITCZ (and hence maximum rainfall) depends on the magnitude of the cross-equatorial pressure gradient. In joint work with Dr. Carlos Hoyos we have nearly completed a study of intraseasonal variability in Africa where we show strong linkages with intraseasonal variability in the Indian Ocean.

Also, with respect to Africa, we have concluded a study of why certain African Easterly Waves (AEWs) intensify whereas others do not (Agudelo et al 2010). We make use of earlier theoretical developments (e.g., Webster and Chang 1987) and Bayesian statistics to show the form of the basic state conducive for disturbance growth.

(2) Intraseasonal variability of the tropics:

We have continued our strong interest in the intraseasonal variability of the tropics (see note above re hybrid modeling of ISO). Agudelo et al (2008) attempts to determine the predictability of intraseasonal variability within the Indo-Pacific warm pool using serial runs of the ECMWF System 3 coupled ocean-atmosphere seasonal prediction model. The experiment consists of ensemble extended serial forecasts including winter and summer ISO cases compared with the ERA-40 analyses. The analysis focuses on understanding the origin of forecast errors by studying the vertical structure of relevant dynamical and moist convective features associated with the ISO. The useful forecast time scale for circulation anomalies is, on average, 13 days during winter compared to 7-8 days during summer. The forecast skill is not stationary and presents evidence of a flow-dependent nature, with states of the coupled system corresponding to long-lived convective envelopes associated with the ISO for which the skill is always low regardless of the starting date of the forecast.

The model is not able to forecast skillfully the generation of specific humidity anomalies and results indicate that the convective processes in the model are associated with the erosion of the ISO forecast skill in the model. Circulation-associated anomalies are forecast better than moist convective associated anomalies. The model tends to generate a more stable atmosphere than observed, limiting the model's capability to reproduce deep convective events, resulting in smaller humidity and circulation
anomalies in the forecasts compared to those in ERA-40. Two other papers (Kim et al. 2008, 2009) using serial integration consider the involvement of the ocean in the ISO. Both studies indicate the critical necessity of a coupled ocean in order to simulate the phase and amplitude of the ISO with any fidelity.

The Agudelo et al (2008) study rises an interesting point about the predictability of the initiation of the MJO. The success of the Webster and Hoyos (2004) scheme probably comes from relatively large predictability of the MJO once the phenomenon forms. Yet, there seems to be no precursor for the formation expect that it forms usually in the equatorial Indian Ocean during both summer and winter. A recent study by Chidong Zhang (personal communication) finds only “noise” before the formation of an MJO. Is this suggesting that the MJO is indeed an instability? Webster and Yang (1992) and Webster (1995) talk about the lack of predictability of ENSO because of the noise in the system (spring) being larger than the signal. Could similar transient states of the Walker Circulation engender this lack of predictability for the MJO? We will follow up these ideas with subsequent studies under the new funding.

Finally, in collaboration with Dr. W. Han of the University of Colorado, we have continued our study of oceanic intraseasonal variability, this time in the tropical Atlantic in the Atlantic Ocean. Earlier papers considered intraseasonal variability in the Bay of Bengal and the Indian Ocean and the impact of the seasonal cycle on the Indian Ocean Dipole (Halkides et al. 2006). A study of the mean ocean heat transport state in the Indian Ocean shows the importance of the intraseasonal mode.

(3) Hurricane and climate studies:

We have continued our interest in tropical cyclones and climate. In an article in Nature Geosciences (Webster 2008), the development and forecasts of the deadly Bay of Bengal tropical cyclone Nargis that developed in late April and made landfall in the Myanmar Irrawaddy Basin in early May 2008. The paper discusses the science behind the storm and its predictions and the lack of preparation by Myanmar authorities. It also suggests ways that the regional tropical cyclone forecast system, currently mandated by the WMO to India, could be improved.

In a study of the form of El Nino, we find that changed in the last 20-30 years the warming has occurred more in the center of the basin and not in the east. There is a strong impact on the number and location of tropical cyclones in the North Atlantic. In a “normal” cold tongue warming, there is a general decrease in number and a more easterly location of tropical cyclones. But with a central Pacific warming, the number is actually increased and the mean locus lying within the western Atlantic, Caribbean and the Gulf of Mexico (Kim et al. 2009). Furthermore, interpretation of serial runs of the ECMWF System 3 climate model shows that the central Pacific warming is more predictable than the eastern warming and not subject to the “predictability barrier” that has plagued normal ENSO forecasts.

We have continued our collaboration with Dr. G. Holland’s group at NCAR and have submitted a new paper (Done et al. 2010) on the relationship of tropical cyclone genesis and longitudinal variations of zonal wind, based on earlier work supported by NSF Climate dynamics some years ago (e.g., Webster and Chang 1997). Areas of negative stretching deformation ($dU/dx < 0$) were found to be regions of tropical cyclone genesis and intensification.

(4) General Studies:

Some years ago, under funding from NSF Climate dynamics, we theorized that the mean latitude of the ITCZ was determined by the mean cross-equatorial pressure...
gradient (CEPW) set up by slowly varying gradient of SST (Tomas and Webster 1997, Tomas et al. 2000). This theory was suggested to us by observations that the deepest convection occurred in regions of CEPW and, in these regions, the ITCZ was located away from the equator in the summer hemisphere. In essence, we determined that the mean location of the ITCZ was the result of time-averaged inertial instability. In two later papers (Toma and Webster 2010a, b) we extend the argument by examining the transients associated with the mean ITCZ. We determine that on the time scale of 3-5 days (the inertial period of the instability) there is an oscillation of heating (the “inertial oscillator”) which drives a reversing anomalous meridional circulation. We hypothesize further that this oscillation is the source of easterly waves that propagate across the Pacific Ocean (Toma and Webster 2010a). The theory was substantiated with a series of controlled numerical experiments using the WRF model (Toma and Webster 2009b).

An ancillary result of the Toma and Webster (2010a,b) provides an explanation for the existence of low-level super-geostrophic near-equatorial westerlies in the eastern equatorial oceans. Occurring in conjunction with organized convection, these winds arise as explainable as part of the inertial instability arguments described above. This will be discussed in a forthcoming paper.

The area of the warm pool (if measured in terms of absolute temperature) has been increasing as the global temperatures have increased over the last 50 years. Yet, we find in a recent study (Hoyos and Webster 2010) that the area of deep convection has remained constant against this background of increasing temperature. For this to occur the threshold SST for convection has increased. This can only occur if the sensitivity of the dominant heating within the convection region and the dominant cooling in the regions surrounding the convective area balance. In fact, the sensitivity of latent heating and radiational cooling to an increment in SST is the same to with 4%/°C. Thus the area of convection remains the same. However, the total heating and cooling in the respective regimes increase so that the mass flux in and out of the convective region also increases. Reanalysis products and models of all complexities show the same characteristics. These findings are the basis of a new thrust in our “low-frequency” climate research. We believe that our “dynamic warm pool” theory will answer a lot of questions that have plagued climate science for some time: the threshold temperature for convection is follows the trends in SST, the threshold temperatures for tropical cyclone formation have increased and why tropical cyclone intensity has increased while the number has remained essentially constant. It also seems that these rules hold in past climates and may go a long way to understanding rainfall amounts and distributions in cooler past climates and those we may expect of the opposite extreme.

Finally we have just completed a study of the South Pacific Convergence Zone (SPCZ) and why it has a north-west to southeast diagonal orientation (Widlansky and Webster 2010). We have concluded that the SPCZ is the “graveyard” of westward propagating midlatitude disturbances that accumulate their energy in regions of negative stretching deformation as described above.

References:
5. Widlansky, M., P. J. Webster and C. D. Hoyos, 2010: *On the location and orientation of the South Pacific Convergence Zone*. In press Climate Dynamics.


Ancillary References:


