# Climatic Predictability of Extreme Floods in the United States

*Research Proposal submitted to*

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**Climatic Predictability of Extreme Floods in the United States**


Project Participants:

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## ABSTRACT


Of all climate-related disasters, floods account for the largest average annual losses. Only a limited climatic perspective on floods in the United States exists. This includes the identification of the seasonality and typical mechanisms (e.g., frontal or connective precipitation) important for floods by subregion. Climate change analyses have led to either no clear assessment of changes in flood potential, or to projections of dramatically increased frequency of extreme floods. The anticipated intensification of the atmospheric hydrological cycle and the increased atmospheric moisture holding capacity under warming, render increasing flood risk plausible. However, it is unclear whether the climatic processes associated with extreme floods are well modeled in global and regional climate models, and whether such models provide predictability for assessing the frequency and intensity of rainfall responsible for extreme floods in the United States with spatial specificity relevant for hydrological analysis of floods.

Our work shows that extreme floods (annual exceedance probability less than ~ 0.1) in most river basins in the United States are associated with a distinct atmospheric moisture transport pattern, where the moisture source is typically in the oceans rather than associated with local convection. Over much of the Western United States, we have been able to demonstrate statistical predictability of the annual maximum flood conditional on pre-season Pacific SSTs. For a region in Brazil we are able to demonstrate that the annual maximum flood at each of the stations can be modeled using concurrent large scale, seasonal climate predictors, and a spatial scaling model for the flood process indexed to the drainage area of the site. Consequently, our hypothesis is that river basins aggregate the spatio-temporal climate signal in terms of synoptic and seasonal atmospheric moisture transport in a way that allows empirical connections to be drawn between slowly varying climate fields and the severity, incidence and location of extreme floods over N. America. If these connections can be quantitatively assessed, modeled and understood, then a basis for assessing changes in flood risk using GCMs or empirical methods could be developed for seasonal prediction and for climate change projections.

The research proposed here seeks to develop an exploratory statistical-dynamical approach for "downscaling" flood risk from climate models through an analysis of the causal structure of the entire ocean-atmosphere-land chain of the flood process. This entails (a) use of historical, re-analysis and GCM data for the diagnostic analyses of the causal structure from the spatio-temporal hydroclimatic data associated with the extreme floods in each of the regions of the United States; (b) Bayesian model development for assessing the conditional probability distributions across the causal chain, leading to a conditional flood risk estimate given either GCM state variables or observed/re-analysis data fields, and (c) assessments of projections of flood risk at selected locations for the upcoming season or for a climate change scenario.

## RESULTS FROM PRIOR RESEARCH

**Kushnir**: Recent work of Y. Kushnir directly relevant to this proposal is the analysis of observations and model output with regard to the mechanisms and predictability of droughts in the world sub-tropical, semi-arid regions. This work has been performed in collaboration with M. Cane, R. Seager, M. Ting, N. Naik, and J. Nakamura of the Lamont climate analysis and modeling group. The work performed under these awards examined different aspects of the character, causes and predictability of multiyear droughts in southwestern North America and the Mediterranean regions. Large ensembles of long model simulations with various configurations of forcing, as well as observations, were used to determine that the driver for persistent, multi-year drought in southwestern North America is equally persistent La Niña-like conditions in the tropical Pacific Ocean. A secondary role is played by the Atlantic, mainly the north tropical Atlantic, which exerts weak but more slowly varying (interdecadal) influence. The atmospheric dynamics that link the tropical SSTs onsists of Rossby wave teleconnections and a more direct, zonally and hemispherically symmetric, eddy-mean flow interaction that forces eddy-driven descent in the mid-latitudes during La Niñas, which suppresses precipitation. The Atlantic influence appears to be via a direct Gill-like response in summer and an atmospheric bridge to the equatorial Pacific, which suppresses precipitation there and as a result, generates a weak stationary wave in the extratropical Pacific. These studies were funded mainly by grants from the NOAA Climate Program Office, the Climate Variability and Predictability element, specifically: 'Predictability of tropical Pacific Decadal Variability and North American drought' (Seager, Kushnir, Cane and Naik: 6/1/2005 to 5/31/08) and 'Abrupt Climate Change in a Warming World - Modeling and understanding late Holocene and near term future hydroclimate change' (Schlosser, Broecker and others: 7/1/08 to 6/30/10). Additional funding was provided by NSF under: 'Modeling the Tropical Atmosphere-Ocean System: Determining the Causes of Near Future Subtropical Drying (Seager, Kushnir, Cane, Ting, Naik: 7/1/08-6/30/11).

**Lall**: Recent work relates to investigations of floods in the Western United States and Brazil, to the development of clustering tools for hurricanes and storm tracks, (all cited in the proposal)and to the development of Hierarchical Bayesian methods for modeling hydroclimatic data. Lall has a long history working on flood risk problems going back to his Phd work, and was the first to connect climate variability and floods in a systematic way in the 1990s (papers with S. Jain). He has pioneered the application of a variety of statistical methods for hydroclimatic data analysis.

**Robertson:** Recent work relates to investigations of monsoon dynamics, storm tracks and flood connections in India, and to hurricane track modeling/clustering, non-homogeneous hidden Markov Models for climate downscaling, nonlinear climate dynamics, and adjoint methods for the analysis of circulation patterns and moisture dynamics. Related work on modeling "weather in climate" with connections to seasonal forecasting and climate change analyses.

## STATEMENT OF WORK

### 1. Identification of the Problem

Floods translate into higher average annual economic losses than any other natural disaster. Consequently, there is significant concern as to how the frequency and intensity of extreme floods may change with climate. Much of the past work on extreme floods falls into one of the following categories:

1. *Rainfall-runoff modeling for near real time forecasts of individual flood events in a river basin, given a spatio-temporal distribution of precipitation and antecedent soil moisture.*
2. *Characterization of the atmospheric circulation, local convection and synoptic meteorology of a specific flood event.*
3. *Statistical flood frequency analysis using either streamflow data or rainfall data in conjunction with rainfall-runoff modeling.*

Such event based hydrometeorological studies do not explicitly connect to climate dynamics. However, there is a recognition that especially for larger river basins, a teleconnection to an oceanic moisture source, rather than just local convection is likely necessary for generating the extreme precipitation associated with a large regional flood. Further, antecedent soil moisture or snow conditions that may contribute to enhanced flood potential may in turn be the consequence of persistent moisture transport into the basin from the same oceanic source. Thus, for extreme floods, large scale climate dynamics associated with oceanic moisture convection and organized transport of this moisture to a continental region may be important. The long term recurrence and progression of such climate conditions may be more predictable from dynamical or statistical models than the prediction of the frequency and intensity of local/regional extreme rainfall and the associated land hydrology. In this regard, research has focused on:

1. *A general characterization of the climatology of floods across the United States: seasonality and associated storm tracks*
2. *Detailed investigations of the climate precursors and mechanisms associated with certain large floods, e.g., 1993 Mississippi, 1988/1997 American River, 2004 Russian River.*
3. *Global or continental scale modeling of flood potential in a changing climate using a chain of GCM-RCM-hydrological model, but without necessarily a detailed examination of the causal chain.*
4. *Statistical predictability or connection of extreme floods to concurrent or season-ahead climate precursors, especially for the Western United States. The role of atmospheric rivers has been highlighted as a part of this story.*

Our preliminary work suggests that retrospective GCM runs for the 20$^{th}$ century are marked by significant biases in the spatial distribution, magnitude and frequency of extreme rainfall over a given region. On the other hand, reanalysis data often reveal persistent and well organized storm tracks and oceanic moisture sources associated with large regional floods in most regions of the United States. There is some evidence that inter-annual to decadal climate modes such as ENSO, PDO and NAO modulate these storm tracks and hence flood potential. Similarly, intra-seasonal variability, possibly tied to features such as the MJO may influence the location and persistence of tropical oceanic convection that serves as a moisture source for continental floods. An open question is whether floods in a particular region correspond to random synoptic structures, or whether such synoptic features are in turn predictable (at least probabilistically) given climate precursors. If there is structure and conditional predictability associated with such events, then a diagnosis of the associated causal chain connecting slowly evolving ocean-atmosphere-land hydrologic conditions to persistent, large scale flooding is of considerable interest. Since at least in certain parts of the country, extreme precipitation episodes represent a large contribution to the annual/seasonal precipitation, this understanding would also contribute to a more general improvement in the understanding and modeling of the hydrologic cycle.

Note that the discussion here is aimed at large regional floods and not at flash floods that may occur over a relatively small urban or rural area. In this context we propose to explore a set of empirical hypotheses en route to the development of a methodology for climate informed dynamic (i.e., conditional on observed or modeled variables that are changing with time) flood risk assessment. These hypotheses can be stated as:

1. *The potential for a flood larger than some return period (T>T*) for a sufficiently large river basin (drainage area A>A*), in a region B (defined by latitude, orography, continentality) is determined predominantly by identifiable large scale storm tracks and atmospheric circulation anomalies.*
2. *For floods that meet the criteria in 1., the circulation anomalies and antecedent soil moisture or snow conditions can in turn be related to identifiable patterns of persistent SST's for the current and prior season.*
3. *Interannual and longer variations in SSTs, will map into identifiable clusters of storm tracks and space and time clusters in flood response consistent with the phase of the SST field.*
4. *The identification of these patterns from re-analysis and from retrospective GCM runs for the 20$^{th}$ century will permit a significantly better analysis of biases in the extremes of the continental hydrologic cycle in these models.*

Since flood seasonality varies across the United States, so do the associated causal climate mechanisms. Exploratory analyses of the above hypotheses will be pursued across the United States. A byproduct of the work will be the development of empirical, statistical teleconnections between regional flood potential and an appropriate set of climate precursors identified from observed or modeled climate state variables. These could be used to facilitate seasonal prediction or to improve the downscaling of flood risk from GCM based climate change scenarios.

## 2. Objectives

The intellectual framework of the proposed research is suggested by the hypotheses outlined in the previous section. This exploration has as its end point a statistically based inference and modeling system for the conditional simulation of floods given climate attributes. The integration is across a variety of hydrologic and climatic data sets, both historical and those from numerical models.

The objectives of the proposed research are to:

- *Assemble a comprehensive, linked and accessible data base of US hydroclimatic data that supports the exploration of the hypotheses listed above.*
- *Use statistical tools to explore each hypothesis listed in the previous section for specific regions and seasons*
- *Develop a formal Bayesian inference framework for assessing the causal chain for regional floods and for predicting the conditional distribution of floods in the region given a suite of modeled or observed climate precursors.*
- *Apply this framework to evaluate, understand and reconstruct the changing patterns of extreme floods conditional to interannual to decadal climate variations in the last century, and to those projected by a selected anthropogenic climate change model.*

We will restrict our analyses in several ways. First, we will focus only on floods recorded at all USGS gages in the lower 48 states whose annual maximum flows are not significantly affected by regulation or diversion. Second, we will limit the storm track analyses predominantly to non-snowmelt driven floods. However, we will consider relationships between winter/spring SSTs and dominant atmospheric circulation modes for the snowmelt related events.

## 3. Background

*Flood Hydroclimatology* is defined by Hirschboeck[1-6] as the study of the climate context of floods, i.e., an understanding of the long term variation in the frequency, magnitude, duration, location and seasonality of floods as determined by an interaction of evolving regional and global ocean and atmospheric circulation patterns. Climate undergoes natural fluctuations through persistent and oscillatory regimes (e.g., ENSO) at interannual to century to paleo scales, and as a function of anthropogenic changes of the atmosphere and land surface. We need to know how the large scale climate is evolving over inter-annual and longer time scales and hence changing the "odds" for local precipitation and soil moisture, and hence for floods. It is argued that flood frequency is quite sensitive to modest changes in climate[7].

One approach[8] to connect climate to floods has been to use a numerical model of the coupled ocean-atmosphere system to drive a basin hydrologic model under control and anthropogenic forcing to assess changes in regional flood potential. This approach is attractive because it brings the known physics of the system to bear on the problem, and is a way to directly consider what may happen in a $CO_2$ enriched world. The same approach could also be used to assess the potential for floods in the upcoming wet season if an ENSO event were forecast. However, often due to limits of knowledge, impacts of model resolution, and other factors, the numerical model integrations tend to have significant biases in the first two moments that are addressed using statistical methods at the tail end of the modeling process[9-11]. Such biases can be quite severe, particularly for precipitation, and as the length of the forward integration or simulation increases. The alternative approach, using model-based re-analysis products, while still marked by differences from observations, tend to be considerably better. While the numerical model chain approach is a legitimate research direction, here we take a different perspective.

We note Hirschboeck's hypothesis[5] that "unusually large floods in drainage basins of all sizes" may be related to large scale atmospheric circulation anomalies. Hence, understanding how storm tracks shift may be key to understanding how the frequency, intensity and location of hydrologic extremes may evolve as climate changes. Her observation is that meridional moisture transport from the Pacific and the Atlantic Oceans leads to most extreme floods. Our preliminary work confirms this observation. Further, it is possible to identify storm tracks or large scale atmospheric moisture transport in climate models associated with floods, and to relate it to the climate context -- persistent Sea Surface Temperature (SST) patterns. This is where we direct our work.

*3.1 Floods and spatial scale*

Floods are ubiquitous. They occur in all parts of the USA and in all seasons. Flood event may last minutes with a spatial scale of a few $km^2$(flash floods) or months with a spatial scale in excess of $10^6$ $km^2$ (e.g., the 1993 Mississippi flood). Here, we are primarily concerned with extreme floods over large areas, and correspondingly longer durations. The flood dynamics are more complicated as drainage basins larger than $10^4$ $km^2$ are considered since (a) the potential for high heterogeneity in the initial soil moisture field is greater, and (b) the direction and location the storm moves through the basin lends a significant heterogeneity to the rainfall distribution as well.

The literature[12-18] on the scaling properties of floods with drainage area suggests that precipitation input type (e.g., convective dominated, vs. snowmelt, vs. frontal) and drainage network attributes, jointly determine different scaling behaviors of discharge with area. There is evidence that these scaling exponents for floods will actually vary across events or types of events in the same location, likely because of differences in storm tracks and drainage area precipitation coverage. As the drainage area increases dramatically (e.g., upper + lower

Mississippi) it is not clear whether these scaling relationships will hold since a mix of mechanisms may be at play in generating such large floods. However, for data from Brazil, we are able to establish how the scaling exponents for floods with area vary across years and relate to large scale climate conditions[79].

The key points are that (1) analyzing flood return periods using a physically based approach becomes quite difficult as the drainage area grows due to the complex interplay between surface conditions and rainfall patterns; (2) heterogeneities and spatial and temporal non-stationarities in surface attributes and in rainfall attributes pose a significant complication; (3) larger scale advective moisture input may be a key factor in overcoming initial heterogeneities in surface conditions and in maintaining an increasing flood potential as drainage area and return period increases; and (4) persistence of storm tracks and their alignment with the drainage basin may be a factor in determining flood potential.

Hirschboeck[1, 3, 4] emphasizes the importance of mesoscale convective complexes and mesoscale convective systems, which are multicelled organized storm systems and can affect areas up to $10^4$ km$^2$ and persist for several hours. Based on data collected over 1999-2003 these features are very common as a source of "extreme rainfall" in the region east of the Rockies [19, 20]. There is evidence[21, 22] that these features' maintenance and evolution may be related to large scale atmospheric circulation features. As the scale increases, tropical and extratropical cyclones and associated fronts, and orographic lifting become important for large rainfall production for large areas and subsequently flooding potential. These are all directly related to large scale circulation patterns, and have well defined moisture tracks i.e., organized regions with high moisture transport over a thick atmospheric layer. The climatology of moisture transport tracks into the US, by season, is illustrated in *Figure 1 (left)*.

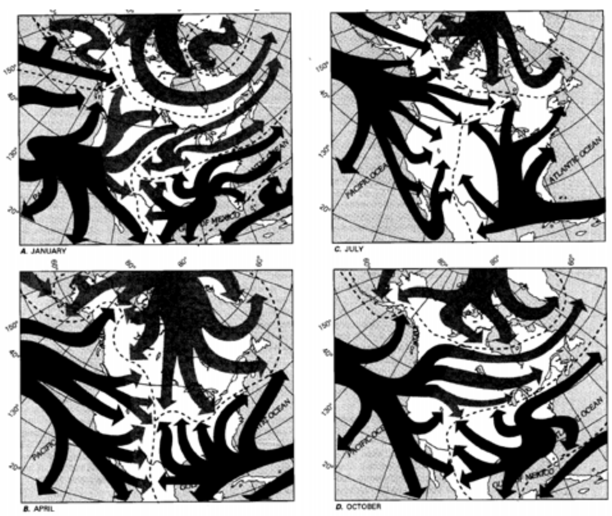


Figure 23. Large-scale, moisture-delivery pathways over North America in four midseason months. A, January. B, April. C, July. D, October. (Sources: Pathways data from Bryson and Hare, 1974; precipitable water vapor data from Reitan, 1960.)

*3.2 Large Scale Moisture Teleconnections, Extreme Rainfall and Floods*

Remarkably, very few, if any, studies have systematically looked at extreme floods nationally, while establishing the hydroclimatology context: atmospheric circulation, regional soil moisture, and related SST anomaly fields. The sparseness of precipitation and gage streamflow data coupled with the high variability of precipitation and the inability to readily compute basin precipitation in an automatic way are factors. However, there has been at least one study[30] that has tried to identify the most extreme events as a function of averaging area (1950-1996 period, 2 day 10km by 10km gridded rain over 10 overlapping circular regions from 2500 to 500,000km$^2$) and the associated hydroclimatic mechanisms. The largest events across the most scales in the Midwest were in 1968 and 1973 fall over Kansas, and are associated with strong transport of Gulf moisture by an interacting system of slow moving cyclones. In the Northeast and Southeast, the most significant rainfall events were all associated with tropical storms and hurricanes at all spatial scales. Tropical cyclones were prominent also in the South-

Central region at all scales. Thus, in almost all cases for the regions considered, large scale flow systems dominate intense rainfall with large area coverage, and also down to the smaller scales.

The 1993 Mississippi flood has seen extensive research aimed at understanding the large scale climate context and its interactions with local factors[31-55]. First, we note that there is considerable variety in the attributions of the flood to teleconnections with large scale mechanisms or to local feedbacks. Indeed[54], indicate concerns with the ability of the General Circulation Models (GCMs) to resolve the debate. In a comparative study with 3 different GCMs, they are able to successfully reproduce the 1993 flood response forcing the model with the observed Pacific SST field. Observational analyses using re-analysis data suggest[38] that leading summer circulation mode defined through an eigenvector analysis of vertically integrated and seasonally averaged summer moisture flux interannual variability projects well on the 1993 flood, while the second mode projects on both the 1993 flood and the 1998 drought. So, at least there is some empirical evidence that the opposite signs of the Pacific SST anomaly induce large scale circulation patterns in the summer that lead to a strong low level meridional moisture flow in the one case and its absence in the other. The wet events are marked by an enhanced westerly flow over the Eastern Pacific and Western N. America over the 30 to 40 N band[44]. This flow is accelerated by synoptic scale eddies and corresponds also to a stronger low level jet (LLJ) that brings moisture from the Gulf of Mexico. These features are predicted quite well by the NCEP 6 hour forecast. Thus, even though the longer run GCM integrations lead to controversial results, the re-analysis or near real time models with higher spatial resolution are able to follow the atmospheric dynamics, and the larger scale flow features implicated in the event are reproduced.

Looking to the Western United States, the change in flood frequency along a latitudinal gradient along the Pacific Coast has been documented[57]. Effectively, in El Nino conditions the storm track shifts to the South, and under La Nina conditions it shifts to the North, following the East-West movement of the convection center in the equatorial Pacific (5 to 10 N). In this context it is also of interest to bring up the Atmospheric or Tropospheric Rivers[57-67]. Tropospheric moisture is organized in distinct bands or rivers that have spatial scales of 10 to 50 km by several hundred kilometers long and lifetimes of 10-14 days. The moisture flux in some of these tropospheric rivers can be as much as the flow of the Amazon River[60]. There is evidence that the life cycle and spatial evolution of these patterns is tied to frontal systems and to larger scale climate dynamics. These systems are linked to the sea surface temperatures (SST) in the tropical and extratropical Pacific Ocean, and to the associated Sea Level Pressure (SLP) patterns. Typically the river starts at a zone of major oceanic convection and follows a coherent curved path till landfall. The tropospheric rivers have been linked directly to flood events. Effectively the system is a highly organized low level flow that undergoes orographic lifting on landfall in California producing high precipitation and hence floods.

In prior work[23-28], we were able to show that annual maximum floods in the Western United States were (a) not independent and identically distributed, (b) they were correlated to ENSO and to the PDO, (c) their power spectra and spectral coherence typically had statistically significant peaks in the ENSO band and in the decadal band –i.e. flood occurrence is likely to be clustered, (d) flood occurrence in the Pacific North West is negatively correlated with flood occurrence in the Pacific South West, (e) the flood response was consistent with atmospheric pressure and wind system changes in response to the Pacific SST field, and that (f) the annual maximum flood at many of these sites was statistically predictable using prior season ENSO and PDO indices. Floods in the Western USA are known to be dominated by fall to spring frontal systems and organized moisture transport forced by large scales even in the summer (Arizona, New Mexico –

North American Monsoon). Thus, at least in the West, there is evidence of annual maximum flood's dependence on large scale climate. Selected results are shown in *Figures 2 and 3*.

*3.3 Conceptual Model*

A conceptual *structure* of *how multiple processes may interact at different scales to determine the recurrence rate for extreme floods in a large river basin* is introduced using *Figure 4*. Consider that the oceans have a frequency spectrum that has interannual (e.g., ENSO) and decadal (e.g., NAO or PDO) variations related to internal ocean-atmosphere dynamics, and a component that represents a secular trend related to anthropogenic warming. By contrast, the land surface soil moisture and snow fields decorrelate at a seasonal time scale if they are not forced by precipitation that is the carrier of interannual or longer memory. *In this paradigm, the large scale ocean-atmosphere system is the carrier of the low frequency information, while the dynamic land surface properties (i.e., soil moisture and snow) would serve to add persistence to the low frequency climate trajectory, as it adjusts to it.* Note that the idea is not that this is always true, but that this may be the case when very strong and persistent large scale advective moisture gradients are established. The atmospheric circulation, which has a time constant of a few days, then evolves to a regime that is consistent with the more slowly evolving surface boundary conditions. This could in some cases set up a persistent storm track into a region, or lead to a block for some region, dramatically changing the flood potential. From *Figure 4*, we note that if we accept that the surface conditions add persistence and are not a negative feedback once the patterns set up, then until the march of the seasons (i.e., changes in radiative forcing) break the pattern the large scale system may persist, and knowledge of the intermediate variables in the chain between SST and Flood Potential may only have a second order influence. We believe that this is the reason for the success in forecasting the annual maximum flood in the Western U.S. using only a few SST variables. Even if this situation were set, there is likely to be a fair amount of heterogeneity in the spatial distribution of moisture for most events and the local feedbacks and interactions would be necessary to monitor. At the event time scale, the feedback from the local surface properties is important to integrate into a physical description of the process. Given the arguments above, if the SST anomaly were strong enough and persistent enough, then the circulation pattern that is set up will persist, and the local soil moisture feedback will adapt to it.

A secular change in atmospheric properties ($CO_2$), in surface radiative forcing and in the ocean temperatures, would translate into changes in the land-ocean temperature contrast, the equator to pole temperature gradient[29], and hence in the jetstream dynamics as well as in the dynamics of summer convection and tropical cyclones. All these imply significant changes in the strength and location of the climatology of the moisture pathways and in the moisture holding capacity of the atmosphere. However, it is not clear whether, where and in which season, the balance between large scale advective forcing of floods and soil moisture feedback to local convection may change.

## 4. Methodology

As was stated earlier, there are three major components to the proposed research:

1. *An exploratory, diagnostic analysis of the climatic drivers of extreme floods over large basins in the United States*
2. *The development of a Bayesian inference framework to connect flood incidence and severity to appropriate climate predictors in a spatio-temporal framework*

3. *The investigation of the implications for flood frequency changes given either projections of anthropogenic climate change or seasonal climate forecasts.*

We recognize that the mechanisms involved in generating extreme floods in the United States vary by season and by location. Consequently, we propose to investigate the climate teleconnections and potential predictability of extreme floods (return period T>T*, varying T*) over large basins (A>A*, varying A*) over the entire lower 48 states. However, the other 2 components of the proposed research will be pursued only for selected regions and seasons. Clearly, the Bayesian model developed will be general in application, but will be tested only for 1 or 2 regions where there is significant potential for predictability and hence high utility. We anticipate that the Western United States will provide one of these regions, and the other will be selected from either the Midwestern region or the Eastern Region.

Given the discussion in the previous sections, we reiterate that in providing a climate context for flood risk in a river basin one needs to consider hydroclimatic information across space and across time, beyond that considered in the analysis of the individual flood event. Thus, a storm track may not correspond just to the atmospheric moisture transport into the river basin on the day of extreme precipitation or flood. Rather, it could refer to a persistent moisture transport into the region over a period of weeks that sets up the antecedent moisture conditions that may then facilitate the production of an extreme flood. Animations of precipitation and vertically integrated atmospheric moisture transport for selected recent flood events are presented at http://rainbow.ldeo.columbia.edu/~jennie/FLOOD/. Consider the June 2008 Midwest flood event, and the associated animations. One notes that a persistent moisture source located at approximately 10° N and 90° W leads to multiple days of pulses of moisture coming to the subsequently flooded region. An examination of the other examples on this page illustrates how synoptic circulation patterns can vary over a season moving the spatial location of the moisture transport and precipitation field back and forth over a region, even as the oceanic source of moisture persists in roughly the same location. Such an observation poses a significant challenge for formally connecting the flood outcome to the causal chain postulated in Figure 4, since appropriate statistics of the intermediate variables would need to be derived considering the spatio-temporal structure indicated by the synoptic conditions. However, if the moisture source can be identified by extending the moisture trajectories back from the flood location to the oceanic source, or through direct correlation/compositing, then the challenge posed by the intermediate spatial variation of the moisture track is mitigated. How some of these challenges can be addressed is discussed here, after considering the data sources that are available for the purpose (Table 1). The key tasks envisaged are outlined below.

*Task 0: Develop a Comprehensive Data Library for integrated access to all relevant hydroclimatic data fields for major US Floods*

We'll extend the IRI data library to provide geo-referenced and event or time window access to all relevant data (historical flows, re-analysis, IPCC regional projections, GCM forecasts) as identified in Table 1, and as per processing indicated in Task 1.

**Table 1**. Data sets to be used to analyze flood-climate relations

| Data Description | Resolution | | Level | Source and Availability |
|---|---|---|---|---|
| | Temporal | Spatial | | |
| Specific Humidity, Wind Vector, Omega, Geopotential height | 3 hourly (NARR) or Daily | 2.5°×2.5° Variable but down to 0.3° for NARR | Pressure | ECMWF ERA-40 (1957-2002), NARR (1979-2007), NCEP Reanalysis (1948-Date), CCM3 (1856-2007), 24 IPCC AR5 Models ($20^{th}$ and $21^{st}$ century), Kaplan SST (1856-Date monthly) |
| Sea Level Pressure, Sea Surface Temperature | | | Surface | |
| Relative Vorticity, Divergence | | 1.9°×1.9° Variable | Pressure | |
| Precipitation Rate, Soil Moisture Content | | | Surface | |
| Precipitation, Max/Min Temperature | Daily | Station | Surface | NCDC TD3200 (1950-2004) |
| Precipitation Rate | Daily | 1.0°×1.0° archive 0.25°×0.25 | Surface | NOAA NCEP CPC Regional US-Mexico (archive 1948-2004, real time 2001-Date) |
| Daily Mean Discharge | Daily | USA | Surface | USGS NWIS (1950-Date) |
| Monthly Mean Discharge | Monthly | | | |
| Annual Maximum Discharge | Annual | | | |

*Task I: Exploratory National Scale Analysis of Climate-flood-spatial scale connections.*

1. The USGS daily flow and annual maximum flood data sets will be processed to retain stations with continuous records that extend to at least 1950, drainage area in excess of 1000 sq. miles, and whose flood records are free from the effects of diversion and flow regulation.
2. At each station, the annual maximum flow record will be used to estimate the T year flood magnitude, for varying T = 5, 10, 20, 50. Next, all daily flows whose magnitudes exceed this threshold (*partial duration series*) will be identified and their dates will also be recorded.
3. A cluster analysis will be performed on these dates to identify a set of stations with common seasonality. A method that accounts for the annual cycle (circular data) will be used.
4. For each cluster, a set of stations that allow nested spatial analysis and covers a range of drainage areas in an area with roughly the same climate, and have comparable record length will be selected. For each station, and for each flood event an estimate of the atmospheric moisture flux/storm track will be made using the re-analysis data fields. The storm track will be identified as a connected set of grid boxes that is in the vicinity of the drainage basin of interest and has a vertically integrated moisture flux that is above some threshold.
5. All storm tracks (including days preceding the major event) for all the flood events at a site will then be clustered. The clustering algorithm we propose to use will cluster based on the *origin, length and geometry of track as well as on the magnitude and persistence of the moisture flux*. A recent algorithm that would be suitable for such a classification has been applied to hurricane tracks[80].The associated probabilities and intensities will be estimated to aid prediction, simulation, flood frequency analysis, and the correspondence with the larger scale atmospheric circulation. The goal of clustering is to permit a statistical analysis of the data set by having a sample size over which one can average, and reduce the uncertainty associated with looking at individual events.

6. For each cluster of tracks, we can compute the average rank (and its spread) of the associated flood event in the historical record. The cluster attributes can then be compared versus the rank (implicitly the return period) of the event. For instance if the tracks associated with a cluster with predominantly high rank floods is long, meridional and has the highest ranks of moisture flux, while the second cluster has relatively short tracks with no preferred orientation and moisture fluxes with low ranks, then cluster 1 would correspond to large scale forcing and cluster 2 to local or synoptic activity. If there is no discernible pattern to the flood ranks, and the track attributes in the clusters then the hypothesis that as the return period of the event increases, the likelihood that the mechanism is large scale flow is rejected. Bootstrap techniques could be used to check the statistical significance of the cluster assignments and attribute differences.
7. If we do identify a cluster that corresponds to large scale fluxes, then composites of atmospheric circulation fields averaged over all events in that cluster could be developed to identify the large scale SST pattern, steering winds, convergence, outgoing longwave radiation and vorticity. These would then help develop an empirical understanding of the associated climate mechanism for that category of floods. If there are an adequate number of events in the cluster of interest, then further dividing the cluster on the basis of the atmospheric or SST patterns (e.g., the eigenvectors of these fields) would be useful.
8. Once tracks, clusters and composites for each station have been identified, they will be pooled to identify superclusters. The idea here is that if the "large scale" clusters of all stations with a drainage area greater than some threshold cluster into the same cluster, then we have identified an area threshold beyond which essentially there is a common large scale operative mechanism. The information as to the average return period at which this happens can then also be improved since the cluster is much larger (even if the same events are being co-classified). Similarly, the reliability of the ocean/atmosphere composites associated with each cluster can be improved by superclustering.
9. Review the composition of the superclusters to see if high return period events for all stations are classified into the same clusters, or if the high events below some drainage area threshold are clustered with the "local" cluster for the larger basin. This analysis will then allow us to identify the threshold area A* , and the corresponding probability of exceedance p* beyond which large scale fluxes dominate the flood process, if such a separation is feasible.

Two situations of interest are illustrated in Figure 6 below. We consider two gauging stations in Iowa. The first with drainage area 347 km$^2$, and the second with drainage area 8424 km$^2$. The moisture flux on two separate days with extreme flooding is estimated using NOAA reanalysis data set. Figure 6 suggests that large scale moisture transport and circulation patterns are involved in these two events, with very similar storm track orientation through the affected region, but the strength of the track is different in the two years. We can get some insight as to the possible difference between high and low return period floods by looking at the average Sea Level Pressure anomalies associated with the largest (30%) and smallest (30%) of the annual maximum floods at the Iowa entire gages. These are illustrated in Figure 5. Note that the climatology has a general mid-continent low pressure consistent with our expectation of summer heating and the associated convection. For the larger floods the low has intensified in a meridional direction southwards reflecting the potential for an enhanced Great Plains low level jet (LLJ) and increased moisture transport from the Gulf of Mexico. At the same time the continental high latitude region has a positive SLP anomaly suggesting that the LLJ will likely interact with an upper westerly flow as discussed earlier in the context of the 1993 flood, and also evident in Figure 5. Conversely, the case of the lowest annual maximum floods has a slight positive SLP anomaly in the area and a rather different high latitude pattern that may translate into a different upper zonal flow pattern. Likely, this situation is marked by local convection flooding (high recycling) and has lower advective fluxes into the region.

*Task 2: Bayesian Inference for a Climate to Flood Causal Chain for a Region:*

The exploratory analysis will identify a promising region for formally developing the flood-climate relationships, and a suite of climatic variables that connect the flood magnitude to an ocean-atmosphere causal chain. This causal chain can be modeled as a Dynamic Bayesian Network or DBN [68]. DBNs are popular because they can efficiently encode multi-variable dependence. They consist of a set of nodes representing a state variable at a given time, connected by arcs representing the conditional dependence structure. A feed-forward, multi-level structure is feasible. The conditional probability distribution (CPD) of each node can be estimated using only the probability distribution of the nodes upstream of it. Thus, the DBN allows a decomposition of a complex high dimensional probability estimation problem into a structured Markovian dependence structure that is lower dimensional and hence easier to perform estimation on given finite data. The spatial scaling of floods with area can be incorporated directly in this framework as in Lima and Lall (2009)[79].

Specifically, let $\mathbf{Q} = Q_{t,i}$ be the flooding discharge at $t \in [1,2,\Lambda\ ,T]$ for drainage basin $i \in [1,2,\Lambda\ ]$, similarly soil moisture states are $\boldsymbol{\omega} = \omega_{t,i}$, space and time rainfall is $\mathbf{R} = R_{t,i}$. Also, let, $\boldsymbol{\xi} = \xi_{t,j}$ be the atmospheric circulation pattern and $\boldsymbol{\Gamma} = \Gamma_{t,j}$ be the Sea Surface Temperature at $t \in [1,2,\Lambda\ ,T]$ for different zones $j \in [1,2,\Lambda\ ]$ or different components of singular value decomposition. Let the attributes of the drainage basins be, $\mathbf{X} = [X_1,...,X_i]$. The joint probability distribution of the flood is written as:

$$P(\mathbf{Q} \mid \boldsymbol{\omega}, \mathbf{R}, \boldsymbol{\xi}, \boldsymbol{\Gamma}, \mathbf{X}) = \prod_i \prod_j \prod_{t=1}^{T} P(\mathrm{Q}_{t,i} \mid \omega_{t,i}, R_{t,i}) \cdot P(\omega_{t,i} \mid \Gamma_{t,j}, \omega_{t-1,i}) \cdot$$
$$P(R_{t,i} \mid \xi_{t,j}, \omega_{t,i}) \cdot P(\xi_{t,j} \mid \Gamma_{t,j}) \cdot P(\Gamma_{t,j} \mid \Gamma_{t-1,j}) \cdot P(X_i)$$

Having defined a candidate structure of the DBN, we now need perform inference in such model. There are a variety of inference techniques one could employ [69-72]. We intend to use the Gibbs sampler which is an effective Markov Chain Monte Carlo method for simulating the posterior probability distribution of the data field conditional on the current choice of parameters[70, 73-78].

*Task 3: Explore the implications of seasonal climate forecasts or IPCC scenarios*

Once the DBN is developed using data for a region, it is effectively a predictive and a diagnostic tool. Instead of using re-analysis climate data we can now use forecasts from GCMs of the same predictive variables and use them to assess how the probability distribution of floods in the region may change in a climate change scenario. Of course, one would want to ensure that the attributes we used to build the model are actually well reproduced in the GCM under the climate change or seasonal forecast scenario. The procedure we anticipate is to:

1) Assess biases and uncertainties in the first two moments of the probability distribution of each of the variables (e.g., SST, precipitation, SLP) in the retrospective runs of the GCM's relative to re-analysis over the corresponding period, and for the relevant calendar months (seasons). A multi-model GCM analysis is envisaged here. For the specific regions of

interest, the extreme rainfall events in the GCM simulations (retrospective seasonal forecasts or 20$^{th}$ century AR4 or AR5 simulations) will be identified and the frequency of exceedance of these events will be compared with those in the historical record. Correspondingly, the storm track information will also be compared using clustering to identify spatial biases. Finally, low frequency variability will be compared using multi-taper SVD analysis with wavelets[81] to the threshold exceedance data.

2) Apply these projections to directly estimate the conditional probability distribution of floods at the sites in the region. Compare the resulting probability distributions with those from a restricted model that considers only the conditioning of site flood flows on the projection of daily precipitation from which event precipitation and antecedent soil moisture could potentially be derived. For a specific application we may use a hydrologic model with precipitation projections to develop a comparison as well. Compare the differences in the application of these methods to the historical data and the GCM scenarios. Assess how the relative change over the 21$^{st}$ century can be assessed including uncertainty characterization.

## 5. Relevance to CPPA and Anticipated Benefits

The proposed project addresses research priorities #3 and #1. By developing and applying new statistical methodologies for flood-risk assessment and prediction at ISI timescales based on GCM seasonal forecasts and historical data, the proposed work directly addresses FY2010 Priority #3. The proposed work will examine GCM climate-change scenario runs from CMIP3 (and CMIP5 when they become available), within the context of changing flood risks, thus also addressing FY2010 Priority #1 (subcompt. 1). The project results evaluate these models from the hydrologic standpoint, and develop changing flood-risk scenarios at regional scale.

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## Figures (Figure 1 is embedded in text – rest are here)

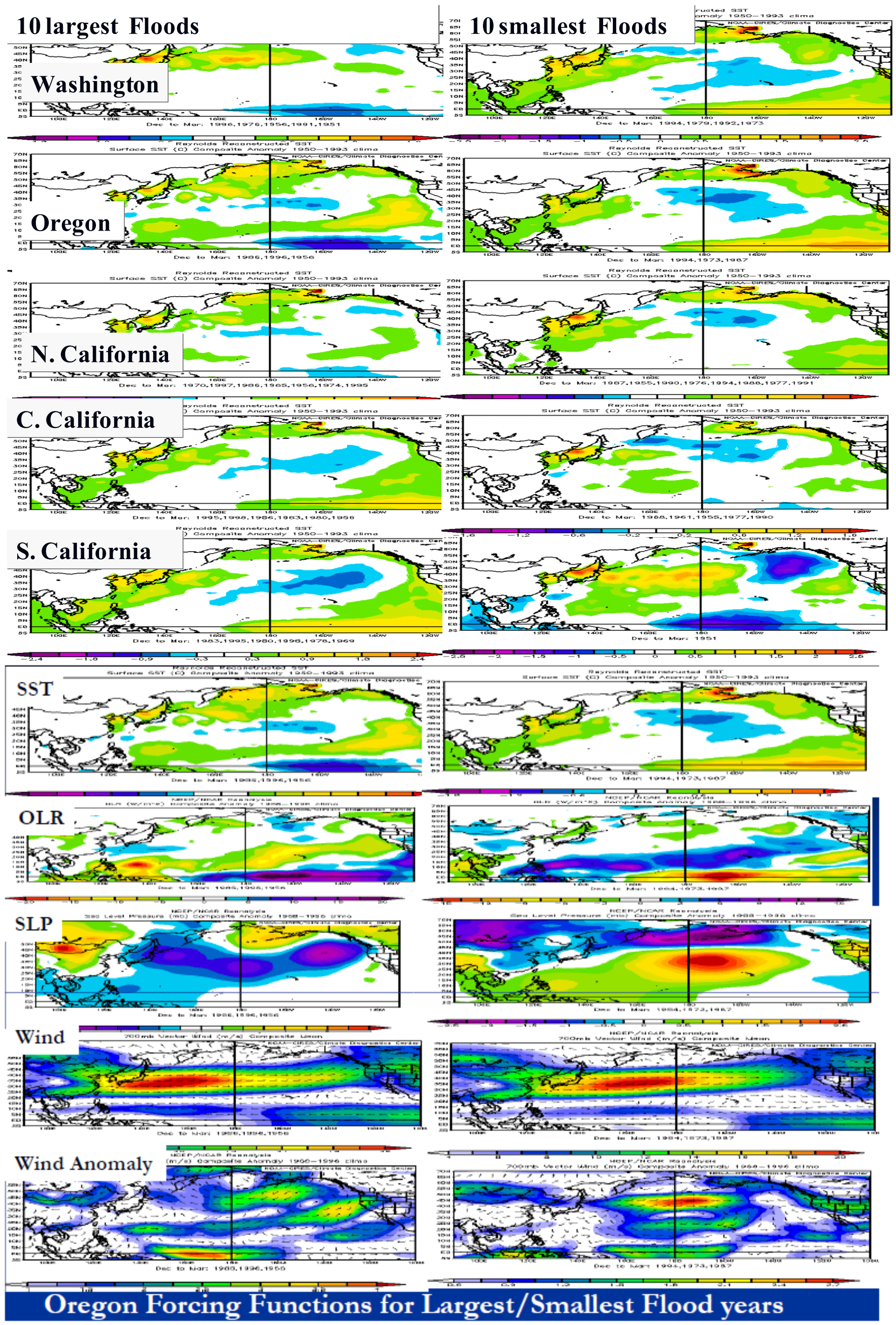
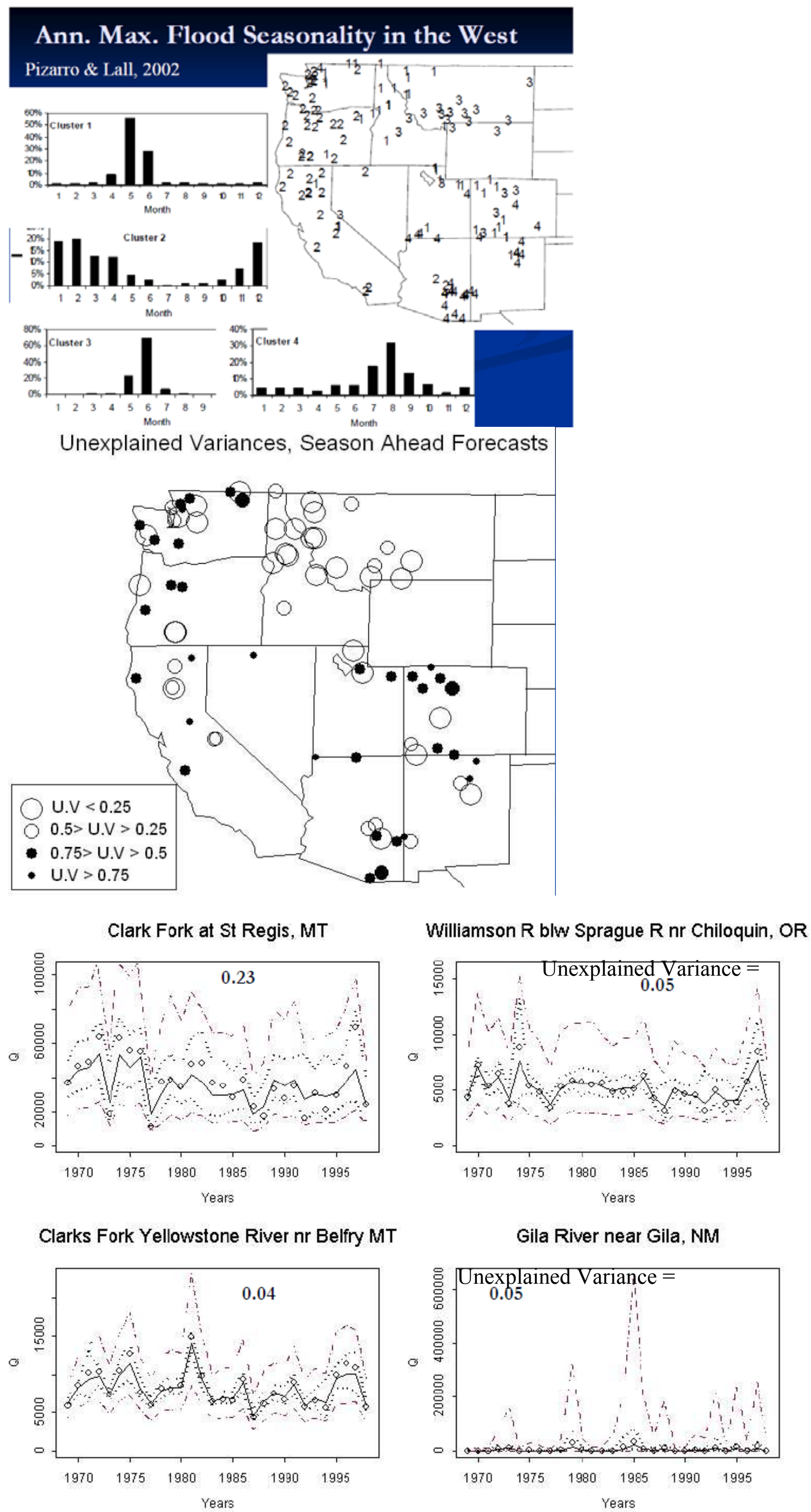



**Figure 2:** Using all USGS stations in each state, the 10 largest and 10 smallest annual maximum flood years were identified. a) composite of SST for DJF for the largest (left) and smallest (right) floods. b) example of all SST, OLR, SLP, Wind composites for the two conditions for Oregon. We see clear, physically meaningful shifts in space and across the seasonal climate composites, even though the flood events last only a few days. Much of the total seasonal precipitation in the West is associated with these extreme events.

**Figure 3:** Empirical prediction of annual maximum floods at 114 stream gages in the Western United States. a) Each site was classified into a cluster by the seasonality of the floods at the site, using k-means with the calendar date of each annual maximum flood event. The map shows the cluster for each site, and the insets show flood counts for each calendar months for each cluster. b) Unexplained cross-validated variance for site by site season ahead forecasts of the annual maximum flood using a nonlinear regression with model averaging method are shown. The four predictors used are the pre-season NINO3.4, PDO and the trend in NINO3.4 and PDO for the prior season. The unexplained variance typically decreases as drainage area increases. c) The empirical, cross validated forecasts for 4 sites (1 per cluster) with 5, 25, 50, 75, 95% prediction intervals. The circles are the observed floods for the upcoming season.

The prediction skills are remarkable for the clusters where the flood season is winter/spring. Further work on understanding the detailed ocean-atmosphere mechanisms that are associated with this predictability provided by the NINO3.4 and PDO indices is needed.



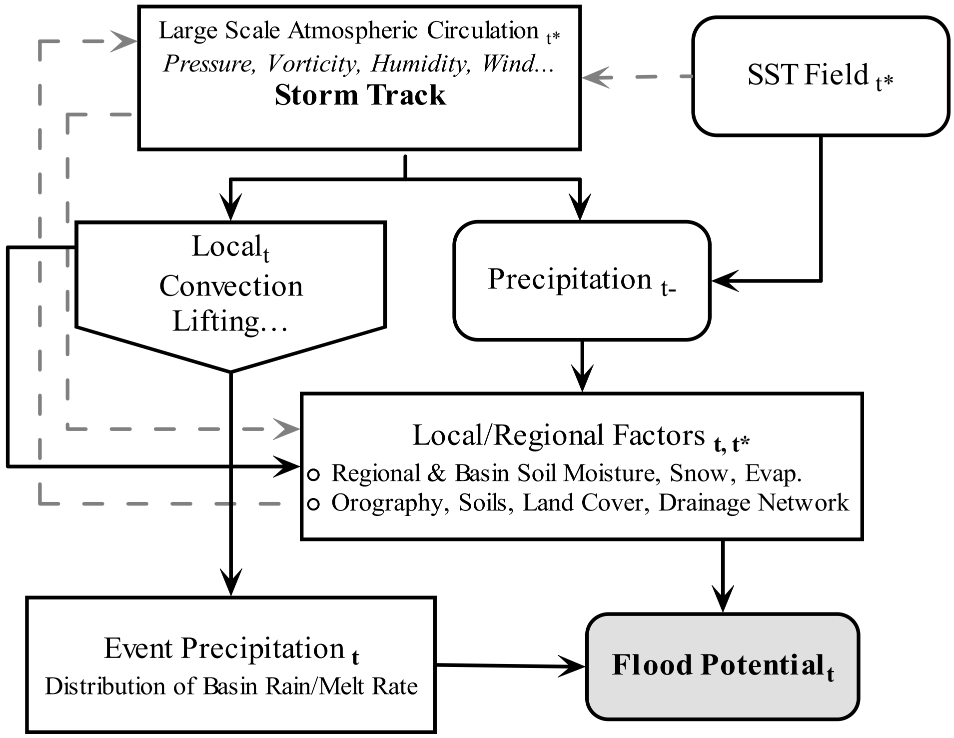



**Figure 4**. Conceptual Representation of the Climate to Flood Causal Chain showing the possible interactions between large scale and local factors, and some potential feedbacks. The flood potential is for an event. The SST field is assumed to persist well beyond the duration of the flood event. The subscript t refers to the event time, t- to prior to the event, and t* to both (t-,t). The local convection box marks the interaction between the large scale flow and local feedbacks in generating the event space-time rainfall distribution. Bi-directional feedbacks between the SST and the atmospheric circulation and between regional soil moisture and large scale atmospheric circulation are considered.

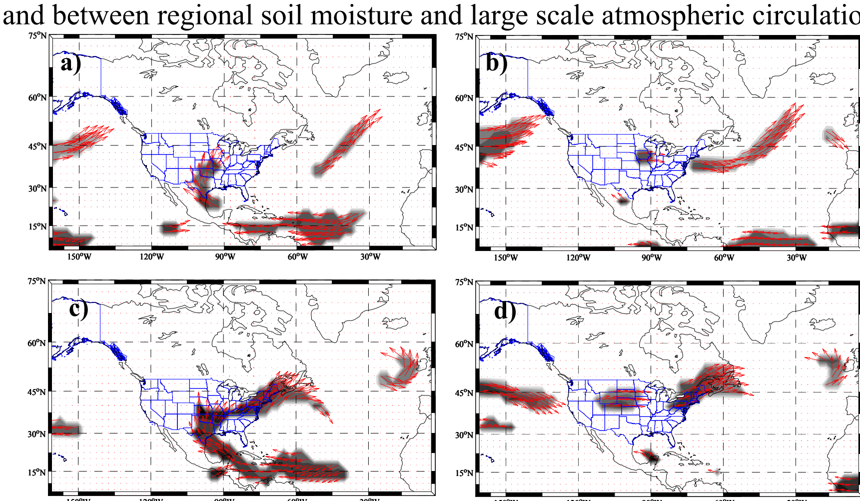



**Figure 5.** Vertically integrated moisture flux for July 9, 1969 (a) and (b) and July 3, 1999, (c) and (d). The flux is computed for a lower level (1000-850 mb) (a) and (c), and upper level (b) and (d). In 1969 a the annual maximum flood was experienced at both locations in Iowa. In 1999, the flood was experienced only at the smaller watershed. The arrows show the wind direction while the shading shows the intensity of the moisture flux. Only pixels whose moisture flux magnitude is in the top 5% of the visible map are shown. Note that a large scale meridional low level flow is active in both cases.

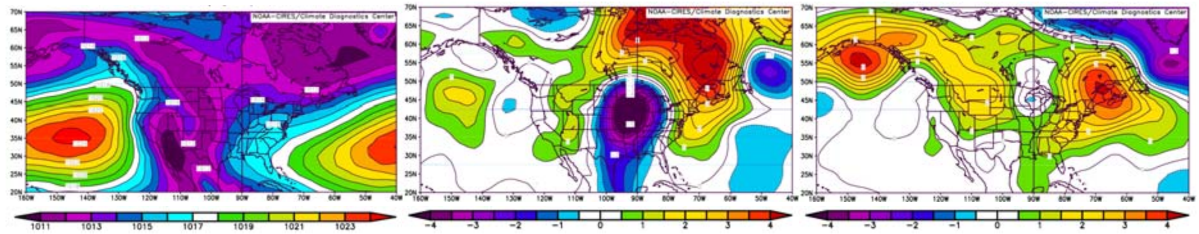


**Figure 6. (a)** Climatology (Mean) Sea Level Pressure (SLP) for summer (May to July) **(b)** SLP Anomaly corresponding to the highest (30%) annual maximum floods at the Iowa gauge **(c)** SLP Anomaly corresponding to the lowest (30%) annual maximum floods at the Iowa gauge

**BUDGET**

| | | Year I | YearII | Year III | Cumulative Total |
|---|---|---|---|---|---|
| | | 5/1/2010 | 51/2011 | 5/1/2012 | 5/1/2010 |
| | | 4/30/2011 | 4/30/2012 | 4/30/2013 | 4/30/2013 |
| *A. Salaries & Wages* | | | | | |
| Upmanu Lall | 1/1/1 | | | | |
| Professor, Columbia University, PI | | | | | |
| Yochanan Kushnir | 1/1/1 | | | | |
| Doherty Senior Research Scientist, LDEO, co-PI | | | | | |
| Jennifer Nakamura | 5/5/5 | | | | |
| Senior Staff Associate, LDEO, co-PI | | | | | |
| Andrew Robertson | 1/1/1 | | | | |
| Research Scientist, IRI Climate & Society, co-PI | | | | | |
| Total Salaries/Wages | | 65,241 | 68,503 | 71,928 | 205,672 |
| B. *Fringe Benefits* | @ 28.5% | 18,594 | 19,523 | 20,500 | 58,617 |
| **Total Salaries/Wages & Fringe Benefits** | | **83,835** | **88,026** | **92,428** | **264,289** |
| *C. Travel - Domestic* | | | | | |
| Travel Expenses to AGU and AMS meetings | | | | | |
| | #Trips/days | | | | |
| Airfare | 2/2/2 | 1,000 | 1,000 | 1,000 | 3,000 |
| for two to San Francisco, CA @$500 roundtrip | | | | | |
| Per diem for two @$249/day | 2/2/2 | 996 | 996 | 996 | 2,988 |
| Ground transportation | 2/2/2 | 500 | 500 | 500 | 1,500 |
| @$250 roundtrip | | | | | |
| **Total Travel Expenses** | | **2,496** | **2,496** | **2,496** | **7,488** |
| *C. Other Direct Costs* | | | | | |
| Publications: Page charges, reprints, etc | | 2,000 | 2,000 | 2,000 | 6,000 |
| Supplies and materials: | | 4,500 | 0 | 0 | 4,000 |
| Computer, Software | | | | | |
| **Total Other Direct Costs** | | **6,500** | **2,000** | **2,000** | **6,000** |
| **Total Direct Costs** | | **92,831** | **92,522** | **96,924** | **282,277** |
| *F. Modified Total Direct Costs* | | 92,831 | 92,522 | 96,924 | 282,277 |
| (less Perm Equip, Tuition Remission, Participant costs and excess of 25K of subcontract) | | | | | |
| *G. Indirect Cost Recovery* @54% of MTDC | | $50,129 | $49,962 | $52,339 | $152,430 |
| ***Total Direct and Indirect Costs*** | | ***$142,960*** | ***$142,484*** | ***$149,263*** | ***$434,707*** |

**NEPA STATEMENT**

This project involves no fieldwork, and only involves desk-based analyses. Therefore, no environmental impact statement is required.

**VITAE**

**YOCHANAN KUSHNIR**

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61 Route 9W, Palisades, NY 10964
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**Education*:***

B.Sc. in Physics, 1971: Department of Physics, Technion, Israel Institute of Technology, Haifa, Israel.

M.Sc. in Meteorology, 1980: Department of Geophysics and Planetary Sciences, Tel-Aviv University, Tel-Aviv, Israel. *Thesis Advisors:* N. Levanon and G. Ohring. *Thesis Title:* "The 150 mb Summer Circulation over the Southern Hemisphere High Latitudes. A Study Using TWERLE Data".

Ph.D. in Atmospheric Sciences, 1985: Department of Atmospheric Sciences, Oregon State University, Corvallis, OR. *Thesis advisor:* S. K. Esbensen. *Thesis Title:* "Sub-Seasonal Variability in a Two-Level General Circulation Model*"*.

**Professional Experience:**

*2003 –* Director, NOAA Cooperative Institute for Climate Applications and Research.

*2000 –* Doherty Senior Research Scientist, Division of Ocean and Climate Physics, Lamont-Doherty Earth Observatory of Columbia University, Palisades, NY.

*2004 – 2007* Adjunct Professor, School of International and Public Affairs, Columbia University

*1998 – 2005* Adjunct Professor, Barnard College, Dept of Environmental Sciences

*1996 – 2000* Senior Research Scientist, Division of Climate Environment and Oceans, Lamont-Doherty Earth Observatory of Columbia University, Palisades, NY

*1993 – 1996* Research Scientist, Div. of Climate Environment and Oceans, Lamont-Doherty Earth Observatory of Columbia University, Palisades, NY

*1989 – 1993* Associate Research Scientist, Div. of Climate Environment and Oceans, Lamont-Doherty Earth Observatory of Columbia University, Palisades, NY

*1988 – 1989* Visiting Research Scientist, AOS Program, Princeton University, Princeton NJ

*1985 – 1988* Postdoctoral Fellow, Joint Institute for the Study of Atmosphere and Ocean (JISAO), University of Washington, Seattle, WA

*1968 – 1979* Chief naval meteorologist, marine weather forecaster and instructor of marine meteorology, IDF, Israel

**Recent Publications (last 3 years):**

Kushnir, Y., R. Seager, M.F. Ting, N.H. Naik and J. Nakamura, 2009: Mechanisms of Tropical Atlantic SST Influence on North American Hydroclimate Variability, *J. Climate*, in review, subject to revisions.

Seager, R.,N.H. Naik, M.F. Ting, M.A. Cane, N. Harnik, Y. Kushnir, 2009: Adjustment of the atmospheric circulation to tropical Pacific SST anomalies: Variability of transient eddy propagation in the Pacific-North America sector, *Quart. J. Roy. Meteorol. Soc.*, revised version in review.

Nakamura, J., U. Lall, Y. Kushnir, and S. J. Camargo, 2009: Classifying North Atlantic tropical cyclone tracks by mass moments. *J. Climate*, in press.
Karnauskas, K. B., R. Seager, A. Kaplan, Y. Kushnir, and M. A. Cane, 2009: The evolution of the equatorial Pacific zonal SST gradient during the twentieth century. *J. Climate*, in press.
Ihara, C., and Y. Kushnir, 2009: Changes in climatological midlatitude westerlies over the Pacific between the 20$^{th}$ century and 21$^{st}$ century, 2009. *Geophys. Rev. Lett.*, **36**, L13701, doi: 10.1029/2009GL037674.
Ihara, C., Y. Kushnir, M. Cane, and V. H. de la Peña, 2009: Climate change in the equatorial Indian Ocean under global warming. *J. Climate*, **22**(10), 2678-2693.
Huang, H.-P., A. W. Robertson, and Y. Kushnir, and S. Peng, 2009: Hindcasts of the tropical Atlantic SST gradient and South American Precipitation: The influence of the ENSO forcing and the Atlantic preconditioning. *J. Climate*, 22(9), 2405-2421.
Ting, M, Y. Kushnir, R. Seager, and C. Li, 2009: Forced and internal 20$^{th}$ century SST trends in the North Atlantic. *J. Climate*, **22**(6), 1469–1481.
Seager, R, Y. Kushnir, M. Ting, M. Cane, N. Naik, J. Miller, 2009: Would Advance Knowledge of 1930s SSTs Have Allowed Prediction of the Dust Bowl Drought? *J. Climate*, **22** (1), 193-199.
Seager, R., R. Burgman, Y. Kushnir, A. Clement, E. Cook, N. Naik, and J. Nakamura, 2008: Tropical Pacific forcing on North American Medieval megadroughts: Testing the concept with an atmosphere model forced by coral-reconstructed SSTs. *J. Climate*, **21**, 6175-6190.
Sveinsson, O. G. B., U. Lall, J. Gaudet, Y. Kushnir, S. Zebiak, and V. Fortin, 2008: Analysis of climatic states and atmospheric circulation patterns that influence Quebec spring streamflows. *J Hydrol Eng*, **13,** 411-425.
Sveinsson, O. G. B., U. Lall, V. Fortin, L. Perrault, J. Gaudet, S. Zebiak, and Y. Kushnir, 2008: Forecasting spring reservoir inflows in Churchill Falls basin in Quebec, Canada. *J Hydrol Eng*, **13,** 426-437.
Ihara, C., Y. Kushnir, and M. Cane, 2008: Warming trend of the Indian Ocean SST and the Indian Ocean Dipole from 1880 to 2004. *J. Climate*, **21**, 2035-2046.
Ihara, C., Y. Kushnir, M. Cane, and A. Kaplan, 2008: Timing of El Niño-related warming and Indian summer monsoon rainfall. *J. Climate*, **21**, 2711-2719.
Ihara, C. Y., Kushnir, and M. Cane, 2008: July droughts over Homogeneous Indian Monsoon region and Indian Ocean dipole during El Niño events. *Int. J. Climatol.*, DOI: 10.1002/joc.1675.
Robinson, L. F., V. H. de la Peña, and Y. Kushnir, 2008: Detecting shifts in correlation and variability with application to ENSO-Monsoon rainfall relationships, *Theor. Appl. Climatol.*, DOI: 10.1007/s00704-007-0351-z.
Seager, R., N Graham, C. Herweijer, A. Gordon, Y. Kushnir, E. Cook, 2007: Blueprint for medieval hydroclimate, *Quart. Science Rev.*, **26**, 2322-2336.
Seager, R. M. Ting. I. Held, Y. Kushnir, J. Lu, G. Vecchie, H.-P. Huang. N. Harnik, A. Leetmaa. N.-C. Lau, C. Li, J. Vellez, and N. Naik, 2007: Model projections of an imminent transition to a more arid climate in Southwestern North Americ, *Science*, DOI: 10:10.1126, *Science*, **316**, (5828), 1181 - 1184 DOI: 10.1126/science.1139601□.
Ihara, C., Y. Kushnir, and M. Cane, 2007: Indian summer monsoon rainfall and its link with ENSO and Indian Ocean climate indices. *Int. J. Climatol.*, **27**, 179-187.
Kushnir, Y., W. A. Robinson, P. Chang, and A. W. Robertson, 2006: The physical basis for predicting Atlantic Sector seasonal-to-interannual climate variability, *J. Climate*, **19**, 5949-5970.

**Present Synergistic Activities:**

*Jan. 09 – pres.Member of the U.S. CLIVAR Decadal Prediction Working Group*

*Jan. 07 – pres* Member International CLIVAR Atlantic Implementation Panel.

**UPMANU LALL**
Alan & Carol Silberstein Professor of Engineering
Department of Earth and Environmental Engineering, Columbia University
**Education:**
1980-1981, University of Texas, Austin, TX PhD. Civil & Environmental Engineering
1977-1980, University of Texas, Austin, TX M.S. Civil & Environmental Engineering
1971-1976 Indian Institute of Technology, Kanpur, India B. Tech. Civil Engineering
**Expertise:** Civil and Environmental Engineering (Hydrology & Water Resources)
**Service at Columbia University:**
Alan & Carol Silberstein Professor of Engineering 2005-date
Director, Columbia Water Center 2008-date
Chair, Earth & Environmental Eng., 2003-2006
Professor, Civil Eng.& Eng. Mechanics, 2002-date
Professor, Earth & Environmental Eng., 2001-date
Senior Research Scientist, International Research Institute for Climate & Society 2001-date
**Related experience:**
Utah State University Professor, Civil & Environmental Eng. , 1995-2001
Associate Director, Utah Water Research Lab., 1997-2001
Associate Professor, Civil & Environmental Eng. 1988-1995
U.S.G.S., Salt Lake City, UT Hydrologist 1988-1989
University of Utah Associate Professor, Civil & Environmental Eng. 1987-1988
Assistant Professor, Civil & Environmental Eng. 1981-1987
**Recent Publications (last three years):**
Li, Pei-Hao, Hyun-Han Kwon, Liqiang Sun, Upmanu Lall, and Jehng-Jung Kao, 2009, A Support Vector Machine Based Prediction Model on Streamflow at the Shihmen Reservoir, Taiwan, *International J. of Climatology*, , in press.
Lima, C.H.R. and U. Lall, 2009, Spatio-temporal analysis of daily rainfall probability in Northeast Brazil using Hierarchical Bayesian Modeling, *Water Resources Research*. , in press
Lima, C.H.R., U. Lall, T. Jebara and A.G. Barnston, 2009, Statistical Prediction of ENSO from Subsurface Sea Temperature Using a Nonlinear Dimensionality Reduction, *Journal of Climate*, in press
Lima, C.H.R. and U. Lall, 2009, Use of Large Scale Climate Information in a Periodic-Autoregressive Exogenous (PARX) model to forecast seasonal inflows into a Hydropower Reservoir in Northeast Brazil, *International Journal of Climatology*, , in press
Ames, D., and U. Lall, 2008, North Pacific Ocean Climate Connections to Streamflow in the Yakima River, *J. of the American Water Resources Association*.
Souza Filho, F. A., U. Lall and R. L. Porto, 2008, The role of price and enforcement in water allocation: insights from Game Theory*, Water Resources Research,* in.
Sveinsson, O.G.B., U. Lall, J. Gaudet, Y. Kushnir, S. Zebiak, and V. Fortin, 2008, Analysis of Climatic States and Atmospheric Circulation Patterns that influence Quebec Spring Streamflows, *ASCE J. of Hydrologic Engineering*, June 2008

Sveinsson, O.G.B., U. Lall, V. Fortin, L. Perrault, J. Gaudet, S. Zebiak, and Y. Kushnir, 2008, Forecasting spring reservoir inflows in Churchill Falls Basin in Quebec, Canada, *ASCE J. of Hydrologic Engineering*, June 2008.

Lall U., Heikkila T., Brown C., Siegfried T., 2008, Water In The 21st Century: Defining The Elements Of Global Crises And Potential Solutions *,* *Journal of International Affairs*, Spring/Summer 2008, Vol. 61(2), 1-17.

Hyun-Han Kwon, Casey Brown, Kaiqin Xu and Upmanu Lall, 2008, Seasonal and Annual Maximum Streamflow Forecasting using Climate Information: Application to the Three Gorges Dam in the Yangtze River Basin, *Hydrological Sciences Journal*, in press

Hyun-Han Kwon, Casey Brown and Upmanu Lall, 2008, Climate Informed Flood Frequency Analysis and Prediction in Montana Using Hierarchical Bayesian Modeling, *Geophysics Research Letters*, in press

Broad, K., A.Pfaff, R.Taddei, A.Sankarasubramanian and U.Lall,2007, Climate, Streamflow Prediction and Water Management in North East Brazil, *Climatic Change*, DOI 10.1007/s10584-007-9257-0, 2007.

Young-Il Moon, Upmanu Lall and Hyun-Han Kwon, 2008, Nonparametric Short Term Forecasts of The Great Salt Lake Using Atmospheric Indices, *International Journal of Climatology*, Volume 28, Issue 3, Date: 15 March 2008, Pages: 361-370

Westra S., A. Sharma, C. Brown, U. Lall (2008), Multivariate streamflow forecasting using independent component analysis, *Water Resour. Res*., 44, W02437, doi:10.1029/2007WR006104

Kwon H.-H., C. Brown, U. Lall (2008), Climate informed flood frequency analysis and prediction in Montana using hierarchical Bayesian modeling, *Geophys. Res. Lett*., 35, L05404, doi:10.1029/2007GL032220.

Sankarasubramanian, A., U. Lall, and S. Espinueva, 2008: Role of Retrospective Forecasts of GCMs Forced with Persisted SST Anomalies in Operational Streamflow Forecasts Development*. J. Hydrometeor*., 9, 212–227.

Prairie J., B. Rajagopalan, U. Lall, T. Fulp , 2007, A stochastic nonparametric technique for space-time disaggregation of streamflows, *Water Resour. Res*., 43, W03432, doi:10.1029/2005WR004721.

Kwon H.-H., U. Lall, A. F. Khalil, 2007, Stochastic simulation model for nonstationary time series using an autoregressive wavelet decomposition: Applications to rainfall and temperature, *Water Resour. Res*., 43, W05407, doi:10.1029/2006WR005258.

Westra S., C. Brown, U. Lall, A. Sharma,2007, Modeling multivariable hydrological series: Principal component analysis or independent component analysis?, *Water Resour. Res.*, 43, W06429, doi:10.1029/2006WR005617

Khalil A. F., H.-H. Kwon, U. Lall, M. J. Miranda, J. Skees (2007), El Niño–Southern Oscillation–based index insurance for floods: Statistical risk analyses and application to Peru*, Water Resour. Res.*, 43, W10416, doi:10.1029/2006WR005281.

Xu K, Brown C, Kwon H, Lall U, Zhang J, Hayashi S,Chen Z (2007) Climate teleconnections to Yangtze river seasonal streamflow at the Three Gorges Dam, China. *International Journal of Climatology* 27(6): 771.

Brown, C. and U. Lall., 2006, Water and Economic Development: The Role of Interannual Variability and a Framework for Resilience, *Natural Resources Forum* Volume 30, Issue 4, Page 306-317, Nov 2006, doi: 10.1111/j.1477-8947.2006.00118.x

*Also appears in:*
*Natural Resources Forum, November 2007, Volume 31 VIRTUAL ISSUE: Climate Change*

Lall U., Y.-I. Moon, H.-H. Kwon, K. Bosworth, 2006, Locally weighted polynomial regression: Parameter choice and application to forecasts of the Great Salt Lake, Water Resour. Res., 42, W05422, doi:10.1029/2004WR003782

Kwon H.-H., U. Lall, Y.-I. Moon, A. F. Khalil, H. Ahn , 2006, Episodic interannual climate oscillations and their influence on seasonal rainfall in the Everglades National Park, *Water Resour. Res*., 42, W11404, doi:10.1029/2006WR005017.

Greene, A. M., L. Goddard, and U. Lall, 2006, Performance-based multimodel climate change scenarios 1: Low-frequency temperature variations, *Journal of Climate,* Volume 19, Issue 17 (September 2006) pp. 4326–4343, DOI: 10.1175/JCLI3864.1

Brown, C ., P. Rogers, U. Lall, 2006, Demand management of groundwater with monsoon forecasting, *Agricultural Systems,* Volume 90, Issues 1-3, , October 2006, Pages 293-311.

**Scientific and Professional Society Membership:** American Geophysical Union, Geological Society of America, American Statistical Association, American Society of Civil Engineers

**Honors and Awards:**

John R. Parks Teachers Fellowship, College of Engineering, University of Utah 1982-1983
Outstanding Researcher, Dept. of Civil & Environ. Eng., Utah State University 1995-1996
Research Excellence Award, College of Engineering, Utah State University 1995-1996
Borland Lecture on Hydrology, AGU Hydrology Days 2006

**Professional Development Activities in the Last Five Years**

Training Offered: 2004, Hydrologic Time Series Analysis to Tampa Bay Water.
2008, 2009 Training on Spatial Statistics and on Climate Modeling & Downscaling at S. Florida Water Management District

**Institutional and Professional Service in the Last Five Years:**

Chair, Earth & Environmental Engineering, Director, Columbia Water Center; Chair, Dept of Civil Eng. & Eng Mech. NAS Panels.

**JENNIFER ANNE NAKAMURA (maiden name Miller, former married name Velez)**

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**Professional Preparation:**

*Undergraduate Institution:*
Department of Meteorology, Pennsylvania State University, University Park, PA: *Meteorology, B.Sc*., 1996.

*Graduate Institutions:*
Department of Meteorology, Pennsylvania State University, University Park, PA: *Meteorology, M.Sc*., 1998.
Department of Earth and Environmental Engineering, Columbia University, New York, NY: *M.Phil.*, 2008 fulfillment of Ph.D. requirements except thesis, current student.

**Professional Experience:**

*2006 -* Senior Staff Associate, Lamont-Doherty Earth Observatory of Columbia University, Palisades, NY.

*1998-2005* Staff Associate, Lamont-Doherty Earth Observatory of Columbia University, Palisades, NY.
*1997-1998* Research Assistant, Pennsylvania State University, University Park, PA.
*1996-1997* Teaching Assistant, Pennsylvania State University, University Park, PA.

**Recent Publications (past three years) and five other selected papers:**

J. Nakamura, U. Lall, Y. Kushnir, and S.J. Camargo, 2009: Classifying North Atlantic tropical cyclone tracks by mass moments, *J. Climate*, **early online**, doi: 10.1175/2009JCLI2828.1.

Seager, R., M.F. Ting, M. Davis, M.A. Cane, N. Naik, J. Nakamura, C. Li, E. Cook and D.W. Stahle, 2009: Mexican drought: An observational, modeling and tree ring study of variability and climate change, *Atmosfera*, **22**, (1), 1-31.

Seager, R, Y. Kushnir, M. Ting, M. Cane, N. Naik, J. Miller(Nakamura), 2009: Would Advance Knowledge of 1930s SSTs Have Allowed Prediction of the Dust Bowl Drought? *J. Climate*, **22** (1), 193-199.

Seager, R., R. Burgman, Y. Kushnir, A. Clement, E. Cook, N. Naik, and J. Nakamura, 2008: Tropical Pacific forcing on North American Medieval megadroughts: Testing the concept with an atmosphere model forced by coral-reconstructed SSTs. *J. Climate*, **21**, 6175-6190.

Seager, R., M. F. Ting, I. Held, Y. Kushnir, J. Lu, G. Vecchi, H. P. Huang, N. Harnik, A. Leetmaa, N. C. Lau, C. H. Li, J. Velez(Nakamura) and N. Naik, 2007: Model projections of an imminent transition to a more arid climate in southwestern North America. *Science*, 316(5828): 1181-1184.

Seager, R., N. Harnik, W. A. Robinson, Y. Kushnir, M. Ting, H. P. Huang and J. Velez(Nakamura), 2005: Mechanisms of ENSO- forcing of hemispherically symmetric precipitation variability. *Quarterly Journal of the Royal Meteorological Society*, **131**(608): 1501-1527.

Seager, R., Y. Kushnir, C. Herweijer, N. Naik and J. Velez(Nakamura), 2005: Modeling of tropical forcing of persistent droughts and pluvials over western North America: 1856-2000. *Journal of Climate*, **18**(19): 4065-4088.

Seager, R., A. R. Karspeck, M. A. Cane, Y. Kushnir, A. Giannini, A. Kaplan, B. Kerman, and J. Velez(Nakamura), 2004: Predicting Pacific decadal variability, in *Earth Climate: The ocean-atmosphere interaction*, edited by C. Wang, S. P. Xie and J. A. Carton, American Geophysical Union, Washington DC, 105-120.

Seager, R., N. Harnik, Y. Kushnir, W. Robinson and J. Miller(Nakamura), 2003: Mechanisms of hemispherically symmetric climate variability. *Journal of Climate*, **16**(18): 2960-2978.

Miller(Nakamura), J. A., T. A. Kovacs, and P. R. Bannon, 2001: A shallow-water model of the diurnal dryline. *Journal of the Atmospheric Sciences*, **58**(22): 3508-3524.

**Present Collaborators:**

M. Cane (LDEO); J. Chiang (UC Berkeley); A. Giannini (IRI, Columbia University); N. Harnik (Tel Aviv Univ.); H.-P. Huang (LDEO); A. Kaplan (LDEO); U. Lall (Columbia University); B. Rajagopalan (University of Colorado); R. Seager (LDEO); M. Ting (LDEO); S. Zebiak (IRI)

**ANDREW W. ROBERTSON**

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**Professional Preparation**

B.Sc., Honours First Class, Mathematics and Geography, Leeds University, UK, 1979

M.Sc., Atmospheric Physics and Dynamics, Imperial College of Science and Technology, London, UK, 1980

Ph.D., Dynamical Meteorology, Department of Meteorology, University of Reading, UK, 1984

Postdoctoral Fellow, Numerical modeling, Laboratory of Dynamical Oceanography and Climatology, University of Paris, France, 1984-86

**Appointments**

Research Scientist, International Research Institute for Climate and Society, Palisades, New York, 2003–present

Associate Research Scientist, International Research Institute for Climate Prediction, Palisades, New York, 2001–2003

Associate Research Scientist, Department of Atmospheric Sciences and Institute of Geophysics and Planetary Physics (IGPP), University of California, Los Angeles, 1997–2001

Assistant Research Scientist, Department of Atmospheric Sciences and IGPP, UCLA, 1993–1997

Adjunct Assistant Professor, Department of Atmospheric Sciences, UCLA, Spring Quarter 1995.

Staff Research Associate, Department of Atmospheric Sciences and IGPP, UCLA, 1992–1993

Research Assistant, Meteorological Institute, University of Munich, Germany, 1986–91

**Five recent publications relevant to the proposed research**

Camargo, S.J., A.W. Robertson, S.J. Gaffney, P. Smyth, and M. Ghil, 2007: Cluster Analysis of Typhoon Tracks. Part I: General Properties. J. Climate, 20, 3635-3653.

Gaffney, S. J., A. W. Robertson, P. Smyth, S. J. Camargo and M. Ghil, 2007: Probabilistic Clustering of Extratropical Cyclones Using Regression Mixture Models. Climate Dynamics, 29, 423-440.

Ghil, M., and A. W. Robertson, 2002: "Waves" vs. "particles" in the atmosphere's phase space: A pathway to long-range forecasting?, Proc. Natl. Acad. Sci., 99 (Suppl. 1), 2493-2500.

Robertson, A. W., S. Kirshner, and P. Smyth, 2004: Downscaling of daily rainfall occurrence over Northeast Brazil using a Hidden Markov Model. J. Climate, 17, 4407-4424.

Robertson, A. W., U. Lall, S. E. Zebiak, and L. Goddard, 2004: Optimal Combination of Multiple Atmospheric GCM Ensembles for Seasonal Prediction. Mon. Wea. Rev., , 132, 2732-2744.

**Five other selected publications**

Hoskins, B.J., M.E. McIntyre, and A.W. Robertson, 1985: On the use and significance of isentropic potential vorticity maps. Quart. J. Royal Meteor. Soc., 111, 877-946.

Huang, H.-P., A. W. Robertson, Y. Kushnir, and S. Peng, 2009: Hindcasts of tropical Atlantic SST gradient and South American precipitation: the influences of the ENSO forcing and the Atlantic preconditioning. J. Climate, 22, 2405-2421.

Kravtsov, S., A. W. Robertson and M. Ghil, 2006: Multiple regimes and low-frequency oscillations in the Northern Hemisphere's zonal-mean flow. J. Atmos. Sci., 63, 840-860.

Robertson, A. W., S. Kirshner, P. Smyth, S. P. Charles, and B. C. Bates, 2006: Subseasonal-to-Interdecadal Variability of the Australian Monsoon Over North Queensland. Quart. J. Royal Meteor. Soc., 132, 519-542.

Robertson, A. W. , V. Moron, and Y. Swarinoto, 2009: Seasonal predictability of daily rainfall statistics over Indramayu district, Indonesia. Int. J. Climatology, 29, 1449–1462.

Full publications list: http://iri.columbia.edu/~awr/pubs.html

**Collaborators**
Graduate Advisor: Brian J. Hoskins, Department of Meteorology
University of Reading, UK
Postdoctoral Advisor: Claude Frankignoul, Laboratory of Dynamical Oceanography and Climatology, University of Paris, France
Scientists with whom the co-PI has been a collaborator/coauthor within the last 48 months:
B. C. Bates (CSIRO), A. Barnston (IRI), R, Boer (Bogor Agricultural Univ), S. J. Camargo, (IRI), P. Chang (TAMU), S. P. Charles (CSIRO), D. DeWitt (IRI), J. Farrara (JPL), A. Giannini (IRI), M. Ghil, (UCLA), S. Gaffney (Yahoo), L. Goddard (IRI), A. M. Greene (IRI), Y. Feliks (UCLA), J. W. Hansen (IRI), H.-P. Huang (LDEO), A. Ihler (UCI), V. M. Ines (IRI), F. Hilario (PAGASA), D. Kondrashov (UCLA), S. Kirshner (UC Irvine), A. Khalil (IRI), S. Kravtsov (UCLA), Y. Kushnir (LDEO), Upmanu Lall, (IRI), A. Lucero (PAGASA), B. Lyon (IRI), V. Moron (U. Aix-Marseilles, France), S. Peng (CIRES), J.-H. Qian (IRI), C. R. Mechoso (UCLA), C. F. Ropelewski (IRI), R. Samuels (Tel Aviv Univ.), P. Smyth (UC Irvine), Y. Swarinoto (BMG), M. Tippett (IRI), S. Trzaska (IRI), N. Ward (IRI), S. Zebiak (IRI).

**CURRENT AND PENDING SUPPORT**

| Supporting Agency | Project Title | Award Amount | Period Covered Award | Acad. Sum. Cal./Location |
|---|---|---|---|---|
| **YOCHANAN KUSHNIR** | | | | |
| A. Current Support | | | | |
| NOAA - CICAR<br>NA06OAR4310143 | Forcing Mechanisms For Tropical Rainfall in GCMs(KUSHNIR, Y. PI; BIASUTTI, M. CO-PI; SOBEL, A. CO-PI) | 380,217 | 6/1/2006<br>5/31/2010 | 1/1/1/NC<br>LDEO |
| NSF<br>ATM 08-04107 | Renewal of ATM 03-47009: Modeling the Tropical Atmosphere--Ocean System: Determining the Causes of Near Future Subtropical Drying (SEAGER, R., PI; CANE, M., KUSHNIR, Y., TING, M., NAIK, N., CO-PIs w/MILLER, J.) | 355,437 | 7/1/2008<br>6/30/2010 | 1/1<br>LDEO |
| NOAA - CICAR<br>NA08OAR4320912 | Pilot Program Cooperative: Institute For Climate Applications and Research (CICAR) Cooperative Agreement Proposal (KUSHNIR, Y., PI) | 0 | 7/1/2008<br>6/30/2013 | 0<br>LDEO |
| NOAA - CICAR<br>NA08OAR4320754<br>TASK I | Renewal of NA03OAR4320179 CICAR Cooperative Agreement Proposal (KUSHNIR, Y., PI) | 200,000 | 7/1/2008<br>6/30/2010 | 4/4<br>LDEO |
| NOAA - CICAR | The Mechanisms and Predictability | 235,000 | 7/1/2008 | 1/1 |

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| NA08OAR4320912<br>TASK III PROJ 1 | Of Multibasin Influences on North American Drought(SEAGER, R., PI; HUANG, H., KUSHNIR, Y., CO-PIs w/NAIK, N.) | | 6/30/2010 | LDEO |
| NOAA - CICAR<br>NA08OAR4320912<br>TASK III - PROJ 6<br>Scope A | Abrupt Climate Change in a Warming World: Lessons from Holocene Paleo And Modern Instru-mental Records, and Model Simulations: Modeling and Understanding Late Holocene And Near Term Future Hydroclimate Change. (SEAGER, R., PI; CANE, M., KUSHNIR, Y., TING., M., KAPLAN, A., NAIK, N., YUAN, X., MARTINSON, D., w/SMERDON, J., MILLER, J.) | 550,000 | 7/1/2008<br>6/30/2009 | 2.72<br>LDEO |
| NOAA - CICAR<br>NA08OAR4320912<br>TASK III - PROJ 6<br>Scope A<br>#12714A | Year 2 Increment: Abrupt Climate Change in a Warming World: Lessons from Holocene Paleo and Modern Instrumental Records, and Model Simulations: Modeling and Understanding Late Holocene and Near Term Future Hydroclimate Change. (SEAGER, R., PI; CANE, M., KUSHNIR, Y., TING., M., KAPLAN, A., NAIK, N., YUAN, X., MARTINSON, D., w/SMERDON, J., NAKAMURA, J.) | 583,300 | 7/1/2009<br>6/30/2010 | 1.75<br>LDEO |

B. Pending Support

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| NOAA<br>#12844 | Climate Predictability of Extreme Floods in the United States (LALL, U., PI; KUSHNIR, Y., NAKAMURA, J., ROBERTSON, A., CO-PIs) | 434,707 | 5/1/2010<br>4/30/2013 | 1/1/1<br>LDEO |
| NOAA<br>#12838 | Tropical Cyclone Tracks in Current and Future Climates (DE CAMARGO, S., PI; KUSHNIR, Y., ROBERTSON, A., LALL, U., HALL, T., CO-PIs w/NAKAMURA, J.) | 482,460 | 5/1/10<br>4/30/2013 | .5/.5/.5<br>LDEO |
| NOAA<br>#12816 | Towards Near-Global Reconstruction and Understanding of Hydroclimate Variability and Change Over the Past Several Centuries (COOK, E., PI; SEAGER, R., KUSHNIR, Y., CO-PIs) | 445,548 | 5/1/2010<br>4/30/2013 | N/C/YR<br>LDEO |
| NOAA | Consortium for Climate Risk in the Urban Northeast (CCRUN) | 3,499,984 | 1/1/2010<br>12/31/2014 | 1.4/1.3/1.3/1.3<br>1.2/1.2 GISS |

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| | (ROSENZWEIG, C., PI; LALL, U., KINNEY, P., CHEN, R., KUSHNIR, Y., SOMESHWAR, S., CO-PIs) | | | |
| NOAA #12834 | Pacific-Atlantic Interactions and Decadal Climate Variability (BIA-SUTTI, M., PI; KUSHNIR, Y., SEAGER, R., CANE, M., CO-PIs w/NAIK, N.) | 399,093 | 5/1/2010 4/30/2013 | .5/.5/.5 LDEO |
| NOAA #12807 | Global Decadal Hydroclimate Variability, Predictability and Change: a Data-enriched Modeling Study (SEAGER, R., PI; CANE, M., KUSHNIR, Y., TING, M., KAPLAN, A., NAIK, N., SMERDON, J., POLVANI, L., EVANS, M., CO-PIs w/NAKAMURA, J.) | 2,383,473 | 5/1/2010 4/30/2013 | 2/2/2 LDEO |
| NOAA - CICAR #12189R | Atlantic Multidecadal Varia-bility: Mechanisms, Impact and Predictability: a Study Using Obser-vations and IPCC AR4 Model Sim-ulations (KUSHNIR, Y., PI; SEAGER, R., TING, M., CO-PIs w/NAIK, N., NAKAMURA, J.) | 586,777 | 8/1/2009 7/31/2012 | 1/1/1 LDEO |
| NOAA - CICAR #12472 | Mechanisms and Predictability of the Global Climate Impacts of Atlantic Multidecadal Variability (TING, M., PI; KUSHNIR, Y., SEAGER, R., CAMARGO, S., CO-PIS w/NAIK, N.) | 614,470 | 8/1/09 7/31/2012 | 1/1/1 LDEO |
| NOAA - CICAR #12469 | Predicting North American Hydro-Climate Change and Variability on the Interannual to Multidecadal Timescale (SEAGER, R., PI; KUSHNIR, Y., CANE, M., NAIK, N., CO-PIS w/NAKAMURA, J.) | 561,313 | 8/1/09 7/31/2012 | .8/.8/.8 LDEO |
| <u>C. Outstanding Increments</u> | | | | |
| NOAA - CICAR NA08OAR4320754 TASK I | Years 3-5: CICAR Agreement Proposal (KUSHNIR, Y., PI) | 421,205 | 7/1/10 6/30/2013 | 4/4/4 LDEO |
| NSF ATM 08-04107 | Year 3: Modeling the Tropical Atmosphere- Ocean System: Determining the Causes of Near Future Subtropical Drying (SEAGER, R., PI; CANE, M., KUSHNIR, Y., TING, M., NAIK, N., CO-PIs w/MILLER, J.) | 187,814 | 7/1/10 6/30/2011 | 1 LDEO |
| NOAA - CICAR NA08OAR4320912 TASK III PROJ 1 | Year 3: the Mechanisms and Predict-ability of Multibasin Influences on North American Drought(SEAGER, R., PI; | 125,000 | 7/1/2010 6/30/2013 | 1 LDEO |

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| | HUANG, H., KUSHNIR, Y., CO-PIs w/NAIK, N.) | | | |

**UPMANU LALL**

A. Current Support

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| PULITZER FNDTN | Sustainable Development of Water Resources in Ethiopia: Learning from Doing in Koraro (LALL, U., PI) | 430,000 | 7/1/2007 10/31/2009 | 1/1 CU |
| PEPSICO FNDTN | Improving Rural Water and Liveli-hood Outcomes in India, China, Africa, and Brazil (LALL, U., PI) | 6,000,000 | 1/1/2008 5/31/2010 | 1/1 CU |

B. Pending Support

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| NOAA #12844 | Climate Predictability of Extreme Floods in the United States(LALL, U., PI; KUSHNIR, Y., NAKAMURA, J., ROBERTSON, A., CO-PIs) | 434,707 | 5/1/10 4/30/2013 | 1/1/1 LDEO |
| NOAA #12838 | Tropical Cyclone Tracks in Current and Future Climates (DE CAMARGO, S., PI; KUSHNIR, Y., ROBERTSON, A., LALL, U., HALL, T., CO-PIs w/NAKAMURA, J.) | 482,460 | 5/1/10 4/30/2013 | .5/.5/.5 LDEO |
| NSF 951516 | Understanding and Improving Environmental Decisions (KRANTZ, D., PI (CRED); w/BAETHGEN, W., BALSTAD, R., CANE, M., GODDARD, L., LALL, U., OSGOOD, D.) | 7,491,316 | 7/1/2010 6/30/2015 | NC/YR CU |
| NOAA CICAR #12841 | Statistical Prediction on DecadalTime Scales: Feasibility, Methodology, Utility (GREENE, A., PI; GODDARD, L, CO-PI w/LALL, U.) | 356,370 | 5/1/10 4/30/2012 | NC LDEO |
| NSF #12519 | Paleoclimate Shocks: Environmental Variability, Human Vulnerability, and Social Adaptation During the Last Millennium in the Greater Me-kong Basin (BUCKLEY, B., PI; ANCHUKAITIS, K., COOK, B., HEIKKILA, T., LALL, U., COOK, E., LEVY, M.; CO PI'S) | 1,401,351 | 08/01/09 7/31/2013 | .5/.5/.5/0 LDEO |
| NOAA - CPO SARP #12119 | Water Rules: Hydroclimate Variability and the Integrated Urban Water Environment under Alternative Water Allocation Policies. (BROWN, C., PI, MADAJEWICZ, M., CO-PI, LALL, U., CO-PI, LYON, B., CO-PI) | 270,808 | 5/1/2008 4/30/2010 | N/C LDEO |

**JENNIFER NAKAMURA**

A. Current Support

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|---|---|---|---|---|
| NSF<br>ATM 05-43256 | Dynamics of Tropically Forced Zonally Symmetric Climate Varability (HUANG, H.P. PI; TING, M. CO-PI; SEAGER, R. CO-PI; w/ HARNIK, N. and NAKAMURA, J.) | 398,379 | 10/1/06<br>9/30/2010 | 1/1/1/NC<br>LDEO |
| NSF<br>ATM 08-04107 | Renewal of ATM 03-47009: Modeling the Tropical Atmosphere-Ocean System: Determining the Causes of Near Future Subtropical Drying (SEAGER, R., PI; CANE, M., KUSHNIR, Y., TING, M., NAIK, N., CO-PIs w/NAKAMURA, J.) | 355,437 | 7/1/2008<br>6/30/2010 | 1/1<br>LDEO |
| NOAA - CICAR<br>NA08OAR4320912<br>TASK III PROJ 6<br>Scope A | Renewal NA03OAR4320179: Abrupt Climate Change in a Warming World: Lessons from Holocene Paleo and Modern Instrumental Records, and Model Simulations: Modeling and Understanding late Holocene and near term Future Hydroclimate Change. (SEAGER, R., PI; CANE, M., KUSHNIR, Y., TING., M., KAPLAN, A., NAIK, N., YUAN, X., MARTINSON, D., w/SMERDON, J., NAKAMURA, J.) | 550,000 | 7/1/2008<br>6/30/2010 | 5.45<br>LDEO |
| NSF<br>ATM 09-02716 | North American Megadrought: Atmosphere-Ocean Forcing and Land-scape Response from the Medieval Period to the Near-term Greenhouse Future (SEAGER, R., PI; CANE, M., COOK, B., MILLER, R., DEMENOCAL, P., CO-PIs w/NAIK, N., NAKAMURA, J.) | 638,135 | 7/1/09<br>6/30/2012 | 1/1/1<br>LDEO |

B. Pending Support

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| NOAA<br>#12844 | Climate Predictability of Extreme Floods in the United States (LALL, U., PI; KUSHNIR, Y., NAKA-MURA, J., ROBERTSON, A., CO-PIs) | 434,707 | 5/1/10<br>4/30/2013 | 5/5/5<br>LDEO |
| NOAA<br>#12838 | Tropical Cyclone Tracks in Current and Future Climates (DE CAMARGO, S., PI; KUSHNIR, Y., ROBERTSON, A., LALL, U., CO-PIs w/NAKAMURA, J.) | 482,460 | 5/1/2010<br>4/30/2013 | 3/3/3<br>LDEO |
| NOAA<br>#12807 | Global Decadal Hydroclimate Variability, Predictability and | 2,383,473 | 5/1/10<br>4/30/2013 | 4/4/4<br>LDEO |

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| | Change: a Data-enriched Modeling Study (SEAGER, R., PI; CANE, M., KUSHNIR, Y., TING, M., KAPLAN, A., NAIK, N., SMERDON, J., POLVANI, L., EVANS, M., CO-PIs w/NAKAMURA, J.) | | | |
| NOAA - CICAR #12189R | Atlantic Multidecadal Variability: Mechanisms, Impact and Predictability: a Study using Observations and IPCC AR4 Model Simulations (KUSHNIR, Y., PI; SEAGER, R., TING, M., CO-PIs w/NAIK, N., NAKAMURA, J.) | 586,777 | 8/1/09 7/31/2012 | 1/1/1 LDEO |
| NOAA - CICAR #12479 | Mechanisms and Predictability of the Interamerican Midsummer Drought (KARNAUSKAS, K., PI; SEAGER, R., GIANNINI, A., CO-PIs w/NAKAMURA, J.) | 373,252 | 6/1/09 5/31/2012 | .5/.5/.5 LDEO |
| NOAA - CICAR NA08OAR4320912 TASK III - PROJ 6 Scope A #12714A | Year 2 Increment: Abrupt Climate Change in a Warming World: Lessons from Holocene Paleo and Modern Instrumental Records, and Model Simulations: Modeling and Understanding Late Holocene and Near Term Future Hydroclimate Change. (SEAGER, R., PI; CANE, M., KUSHNIR, Y., TING., M., KAPLAN, A., NAIK, N., YUAN, X., MARTINSON, D., w/SMERDON, J., NAKAMURA, J.) | 583,300 | 7/1/09 6/30/2010 | 4 LDEO |
| NOAA - CICAR #12469 | Predicting North American Hydro-Climate Change and Variability on the Interannual to Multidecadal Timescale (SEAGER, R., PI; KUSHNIR, Y., CANE, M., NAIK, N., CO-PIS w/NAKAMURA, J.) | 561,313 | 8/1/09 7/31/2012 | 2/2/2 LDEO |
| C. Outstanding Increments | | | | |
| NSF ATM 08-04107 | Year3 of Modeling the Tropical Atmosphere -Ocean System: Determining the Causes of Near Future Subtropical Drying (SEAGER, R., PI; CANE, M., KUSHNIR, Y., TING, M., NAIK, N., CO-PIs w/NAKAMURA, J.) | 187,814 | 7/1/10 6/30/2011 | 1 LDEO |
| D. Proposals Planned to be Submitted in Near Future: | | | | |
| NOAA #12816 | Towards Near-Global Reconstruction and Understanding of Hydroclimate Variability and Change over the Past Several Centuries (COOK, E., PI; | 445,548 | 5/1/2010 4/30/2013 | 1/YR LDEO |

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| | SEAGER, R., KUSHNIR, Y., CO-PIS; w/NAKAMURA, J.) | | | |

**ANDREW ROBERTSON**

A. Current Support

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| NOAA<br>NA05OAR4311004 | Renewal of NA07GP0213: Year 5 of NA05OAR4311004: the International Research Institute for Climate Prediction: 2005 - 2010 (ZEBIAK, S., PI w/ MUTTER, C.; THOMSON, M.; ZUBAIR, L.; WARD, M.; HANSEN, J.; OSGOOD, D.; BLOCK, P.; MASON, S.; TRZASKA, S.; GODDARD, L.; GREENE, A.; ROBERTSON, A.; SUN, L.; QIAN, J.; CAMARGO, S.; TIPPETT, M.; DEWITT, D.; LI, S.; GIANNINI, A.; BELL, M.; BLUMENTHAL, M.; CONNOR, S.; DEL CORRAL, J.; CECCATO, P.; LYON, B.; CONRAD, E.; BAETHGEN, W.; SOMESHWAR, S., DINKU, T.; OMUMBO, J., HELLMUTH, M., LIU, H., BARNSTON, A., LEE, D., INES, A., MADAJEWICZ, M.) | 45,181,780 | 7/1/05<br>6/30/2010 | 10/10/<br>12/12/8 |
| DOE<br>DE-FG02-<br>02ER63413 | Renewal of Collaborative Research: Regional Climate-Change Projections through Next Generation Empirical and Dynamical Models (ROBERTSON, A., PI w/GREENE, A.) | 453,096 | 7/15/02<br>7/14/2010 | NC/NC/NC<br>NC/NC/<br>1/1/1 |
| OXFAM<br>AMERICA<br>OXFAM<br>CU-09-0268 | Designing a Weather Insurance Con-Tract for Farmers in Adi Ha, Ethiopia (OSGOOD, D., PI w/WARD, N., DINKU, T., ROBERTSON, A., BLOCK, P., SMALL C.) | 46,845 | 10/1/08<br>7/1/09 | .4<br>LDEO |
| ##IIT DELHI<br>IITD CU09-0826 | Development and Application of Extended Range Forecast System for Climate Risk Management in Agriculture (ERFS)(SOMESHWAR, S., PI; w/ROBERTSON, A., CONRAD, E., INES, A.) | 203,702 | 3/5/09<br>3/4/11 | 1/1<br>LDEO |

B. Pending Support

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| NOAA<br>#12844 | Climate Predictability of Extreme Floods in the United States(LALL, U., PI; KUSHNIR, Y., NAKAMURA, J., ROBERTSON, A., CO-PIs) | 434,707 | 5/1/10<br>4/30/2013 | 1/1/1<br>LDEO |
| NOAA<br>#12838 | Tropical Cyclone Tracks in Current and Future Climates (DE CAMARGO, S., PI; KUSHNIR, Y., ROBERTSON, A., LALL, U., HALL, T., CO-PIs w/NAKAMURA, J.) | 482,460 | 5/1/2010<br>4/30/2013 | .5/.5/.5<br>LDEO |

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|---|---|---|---|---|
| NASA #12448 | Using Remote Sensing to Calibrate And Audit Weather Insurance Contracts (OSGOOD, D., PI; SMALL, C., CO-PI w/ROBERTSON, A., SHIRLEY, K.) | 109,782 | 1/1/2009 6/30/2010 | NC LDEO |