A Proposal to the Climate Program Office Climate Dynamics and Experimental Prediction Program

Climate Diagnostics Applied Research Center

Duration:	Five Years
Support per year:	$1,650,000
Total Support Requested:	$8,250,000

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SUMMARY

A focus on drought-related research and applications will be the near-term priority within the Climate Diagnostics Applied Research Center (CDARC). Research will be coordinated around five long-term foci that contribute predominantly to the CDEP objective to enhance NOAA climate products and services and to support NOAA operational climate forecasts by transition of research advancements into NCEP operations.

Reforecasts and Weather-Climate: This CDARC focus will improve the current suite of probabilistic sub-seasonal forecast products and will develop reliable short term climate forecast products such as extreme events and hazard alerts at scales required by users. This work will be accomplished through the use of next-generation reforecast datasets, linear inverse models, improved analysis techniques, and monitoring of coherent modes of weather climate phenomena.

Historical Reanalysis: This CDARC focus will provide a 100-year global climate reanalysis based on ensemble data assimilation techniques that can produce high-quality products even with the sparse pre-radiosonde era observations. This reanalysis product will extend our ability to quantify climate variability, will provide uncertainty estimates for climate detection, and will aid attribution efforts to inform policy decisions.

Climate System Diagnosis: This CDARC focus will improve understanding of dynamical processes and predictability of the principal interacting components of the climate system on time scales of weeks to millennia, using a combination of observational and modeling approaches.

Climate Attribution: This CDARC focus will develop improved climate attribution capabilities to meet policy and decision maker needs for regular and systematic explanations in near real time of the state of the climate system at national to regional scales.

Regional Applications and Services: This CDARC focus will improve the delivery of the regional climate data, products and services needed to enhance public and private sector decision making and reduce climate-related risks.

Cross cutting these CDARC foci will be an outreach activity to support capacity building in the policy and decision making communities so they can effectively use attribution and prediction research information products. Our goal is to position NOAA to proactively deliver research products and experimental services that provide timely and accurate explanations of current and evolving climate and predictions of future climate and extreme events. NOAA Regionally Integrated Science Assessments (RISAs) will be an important information conduit for identifying regional stakeholder needs for prediction and attribution research products, and for providing the decision makers with forecast and attribution information. The Climate Change Science Program (CCSP) is another important client for prediction and attribution research that we will engage by working with the Synthesis Report Leads. We also will be working with many of the RISAs, regional climate centers, river forecast centers and others to help NOAA meet the real time decision-making needs for drought-related forecast and attribution products in support of the National Integrated Drought Information System (NIDIS).

RESULTS FROM PRIOR YEARS

In previous years the Climate Diagnostics Applied Research Center work supported under CDEP was a collection of loosely coordinated high quality research projects involving one to a few scientists working to advance NOAA and CDEP goals and objectives. The work has been highly leveraged with a comparable amount of peer-reviewed competitive grant matching funds from NSF, NASA, DOE, DOD, and NOAA sources. The approach taken in previous years contrasts with our proposed new CDARC structure for collaborative team research coordinated around five major foci.

A total of 30 peer-review journal publications were supported in part or completely in 2004 and 31 in 2005. The complete progress reports for 2004 and 2005 are available online at: http://www.cdc.noaa.gov/cdep/. For 2006 the year to date results for research supported in part or completely through the CDEP ARC is over 30 publications (http://www.cdc.noaa.gov/pubs/) as well as numerous scientific presentations at national and international meeting. Highlighted examples of this highly leveraged research includes:

Predicting North Pacific SSTs including the PDO

We have developed a statistical model to predict pan Pacific sea surface temperature (SST) anomalies given the challenges for accurate dynamical predictions of the North Pacific oceans due to the chaotic nature of the extratropical atmosphere-ocean system. The statistical method, linear inverse modeling (LIM), is similar to Principal Oscillation Pattern and Canonical Correlation Analyses techniques. Currently the input and forecasts from the model are seasonal SST anomalies over the Pacific basin north of 30°S. The model has skill over much of the Pacific for 2-3 seasons in advance and for up to year in some locations. In addition, the PDO can be skillfully predicted up to one year in advance: the correlation between the predicted and observed PDO for all seasons during 1971-2001 is 0.81, 0.64, 0.55 and 0.44 at leads of 1, 2, 3, 4 seasons, respectively. These values are significant at the 95% level and are comparable to LIM-based forecasts of SSTs in the NINO 3 region and are generally better than extratropical SST forecasts from GCMS. The PDO predictions will be made operationally and displayed on the web for use by scientists, NOAA managers and the general public. In addition, we are exploring additional improvement to the LIM forecasts by including additional predictors such as thermocline depth, and using LIM and other statistical methods to predict physically and ecologically important variables such as mixed layer depth.

Global Response to localized SST anomaly patches

We continued our comprehensive investigation of the sensitivity of the global atmospheric response to a regular array of localized SST anomaly patches prescribed throughout the tropics in the NCAR CCM3.10 AGCM. This effort confirmed and extended the results of an earlier study performed using the NCEP AGCM. An important result from these studies is that the global atmospheric response in the last 50 years to globally prescribed observed lower boundary conditions (i.e. in GOGA runs) is remarkably well captured by the linear combination of the responses to these localized SST patches. An even more surprising result is the opposite sensitivity of many aspects of the global response to SST anomalies in the Indian and west Pacific oceans. This results indicates that it is critical for coupled climate models used in global change research to accurately predict the details of the projected ocean warming in this part of the world. A paper entitled "Sensitivity of global warming to the pattern of tropical ocean warming" was published in *Climate Dynamics*.

Impact of stochastic noise on the statistical structure of atmospheric variability
We published a study (*Journal of the Atmospheric Sciences*) investigating the impact of stochastic noise on the statistical structure of atmospheric variability, in particular whether it can lead to non-Gaussian probability distributions that are often misinterpreted as indicating the importance of nonlinear dynamics and/or persistent regime-like behavior in the atmosphere. We found that such noise can indeed produce non-Gaussian distributions. We have since extended this analysis to explain and model the non-Gaussian character of daily surface wind, surface air temperature, and SST variability over the oceans. We suspect that the "multiplicative" noise responsible for such non-Gaussian behavior is poorly represented in weather and climate models, and are now trying to quantify this deficiency.

Understanding the Mid-Holocene Climate
We conducted a model-based investigation into the causes of the very different mean climate during the mid-Holocene (about 6000 years ago), when North America and North Africa were significantly drier and wetter, respectively than at present. This study was published in the *Journal of Climate*. The paper highlights the synergistic interaction of tropical Pacific SSTs and coupled air-sea dynamics in the tropical Atlantic in producing extended North American droughts.

Historical Reanalysis
We have demonstrated the feasibility of a 100-year daily historical reanalysis using only surface pressure observations and an advanced data assimilation system based on an ensemble Kalman filter. A paper describing the results was published in the *Bulletin of the AMS*. It was also featured on the journal's cover. We are currently attempting to produce a model-based reanalysis for the period 1938-1948. We recently completed a pilot reanalysis for 1947 that further demonstrates the capabilities of our Ensemble-filter reanalysis technique used in conjunction with the NCEP/CFS atmospheric model. It is remarkable that our reanalysis, using only the surface pressure observations and a lower-resolution model is able to replicate many of the features seen in the hand-drawn mid-tropospheric analysis produced at the time, and is arguably better than the higher-resolution NCEP system.

SST Trends and Hydroclimatic Change
We have started investigating the impacts of long-term tropical SST changes on long-term hydroclimatic changes around the globe. The data sets used in this model-data comparison study are the observed 55-yr (1951-2005) linear trends of precipitation over the Americas and western Africa and Europe and model generated ensemble-mean trends in 60-member NCEP/GFS (T62 resolution) and in 30-member NCAR/CAM3 (T42 resolution) ensemble atmospheric GCM simulations with a prescribed observed tropical SST trend field as the forcing. Both AGCMs indicate substantial precipitation trend responses over these regions that are in generally excellent mutual agreement. The comparison of model results with observations is only fair over South America and Europe. To what extent this mismatch is due to observational errors, inadequate model resolution especially over the Andes, or sampling uncertainty is unclear to us at present. The model-data comparisons over Africa and North America are, however, encouraging. We are currently attempting to determine the contributions of the ENSO- and non-ENSO related components of the tropical SST trend fields in producing these precipitation trends, using a method recently developed (Penland and Matrosova, *Journal of Climate* 2006, in press) to partition tropical SST anomaly fields into these components.

Tropical intraseasonal variability in 14 IPCC AR4 climate models
We evaluated simulations of the MJO and convectively coupled equatorial waves in 14-coupled GCMs (CGCMs) used for climate projections in the IPCC AR4. Results show that current state-of-the-art GCMs still have significant problems and display a wide range of skill in simulating the tropical intraseasonal variability. The MJO signals are generally too weak and lack eastward propagation in these IPCC models. The signals of the convectively coupled equatorial waves are generally too weak and propagate too fast in these models. This study was published in the *Journal of Climate.*

Effects of Ekman transport on the NAO response to a tropical Atlantic SST anomaly
We have analyzed the effects of Ekman transport on the extratropical coupled response to a tropical Atlantic SST anomaly through comparisons of AGCM_EML and AGCM_ML simulations. Results showed that the inclusion of Ekman heat transport resulted in an earlier development of the coupled NAO-SST tripole response to a tropical anomaly. The mutual reinforcement between the anomalous Ekman transport and the surface heat flux causes the tropical forcing to induce an extratropical SST response in November-January (NDJ) in the AGCM_EML that was twice as strong as that in the AGCM_ML. The feedback of this stronger extratropical SST response on the atmosphere drove the development of the NAO response in NDJ. In FMA, the sign of the anomalous surface heat flux was reversed in the Gulf Stream region such that it opposed the anomalous Ekman transport. The presence of Ekman transport hence causes a seasonal shift in the evolution of the coupled response. The faster development of the NAO response in the AGCM_EML suggested that tropical Atlantic SST anomalies should be able to influence the NAO, in nature, on the seasonal time scale, and that efficient interactions with the extratropical ocean played a significant role in determining the coupled response. This study has been accepted for published in the *Journal of Climate*.

Radiative and Dynamical Feedbacks Over the Equatorial Cold-tongue
Coupled general circulation models (GCMs) have significant SST biases in equatorial Pacific, a region with strong negative feedbacks. Underestimate of the strength of the negative feedbacks have been investigated as a possible source for the unrealistic sensitivity in coupled model to small energy flux errors. Feedbacks in the equatorial Pacific in nine atmospheric GCMs (AGCMs) were quantified using the interannual variations in that region and compared with the corresponding calculations from the observations. All the corresponding coupled runs of these nine AGCMs have an excessive cold tongue in the equatorial Pacific. All but two of the models had weaker negative net feedbacks from the atmosphere due to a weaker regulating effect on the underlying SST than actually occurs. In most models, weaker negative feedbacks from the cloud albedo and atmospheric transport were the dominant sources for a weaker atmospheric regulating effect. The weak negative feedbacks in the models was linked to an underestimate of the equatorial precipitation response. All models have a stronger water vapor feedback than that indicated in ERBE observations. Analyses reveal that that underestimate of the atmospheric regulatory effect over the equatorial Pacific region is a widespread; however this weaker atmospheric regulatory effect cannot completely explain model hypersensitivity, and an examination of the feedbacks from the ocean transport is needed. This study was published in the *Journal of Climate.*

Reforecasts and Weather Climate
1.1 Introduction
Enhanced understanding and improved predictions are required at the subseasonal weather-climate time scales (from ~ 1 to 6 weeks) and at spatial scales from the local to national are needed for planning and management decisions to mitigate the impacts of damaging extreme events and to protect lives and property. The high impact sub-seasonal extreme events include flash droughts, heat and cold waves, floods, blizzards, ice storms, high winds, and tornadoes. In addition to utilities and other private sector needs, the better understanding and predictions will directly benefit: (1) the planning and pre-positioning of resources by local, state and federal emergency managers, (2) flood-control operations (Bureau of Reclamation, Army Corps of Engineers), (3) wildfire suppression (National Interagency Fire Coordination Center), (4) efficiency of water, energy, and crop management (Bureau of Land Management, Department of Agriculture), and (5) operations at NWS National Centers Environmental Predictions (Climate, Hydrometeorological, Storm, and River Forecast Centers). Also, the reforecast and weather-climate program described here will directly support the NWS vision to provide the nation with a seamless suite of forecast products, helping fill the gap between short-term weather forecasts and longer-term climate forecasts.

Producing skillful forecasts at the weather-climate time scale is a particularly difficult problem, but nonetheless one where the application of new technologies and understanding can lead to dramatic improvements in forecast skill. As one progresses from leads of days to months, the skill is less and less determined by the initial atmospheric state and increasingly determined by the boundary forcing: the state of the ocean, the land, and ice cover, and perhaps even the sun to some extent. While the day-to-day weather cannot be predicted at these longer leads, shifts in time averages (say, the average weather over the period of a week) may still be predicted skillfully, and it may be possible to predict an increased or decreased likelihood of severe events. At these leads, because noise is large and signal is small, expressing forecasts probabilistically is a practical necessity.

ESRL/PSD's pioneering work in reforecasts have resulted in significant improvements of forecasts at the shorter weather-climate leads, 1-2 week forecasts (Hamill et al. 2004). Prior to this work, these forecasts were generally not very reliable nor sharp, and consequently were not very useful decision support resources. Using a first-of-its kind, multi-decadal ensemble reforecast data set, we improved the 1-2 week forecasts by statistically calibrating the current numerical weather prediction using a large set of previous weather predictions and observations (for an example with precipitation forecasts, see Figure 1.1). This approach has allowed us to determine the predictable signal amongst the noise due to chaotic error growth and model drift. This model-based technique worked well because at 1-2 weeks the predictive skill is still somewhat influenced by the initial state of the atmosphere.

At the longer weather-climate leads, from ~ 2 weeks to 2 months, the predictable modes of atmospheric variability are fewer, and the anomalous boundary conditions that may have an influence on these predictable modes are relatively few in number, too. Newman et al. (2003) suggest perhaps a 0.1-0.2 improvement can be expected in anomaly correlation for week 3 predictable signals assuming no model error and large member ensembles. Furthermore, regions where skill may be improved the most may not necessarily be over the USA, although improved predictive information for any region is helpful given our globally interconnected economy. We know, for example, that a shift of the atmospheric state away from its long-term average climatology can be prognosed from the state of sea-surface temperature anomaly patterns such as the El-Nino/Southern Oscillation (ENSO) or other recurring patterns of sea-surface temperature variation. Additionally, both the stratospheric and land-surface states, including soil moisture and snow cover anomalies, have been shown to be related in some situations to shifts. For example, the European heat wave in the summer of 2004 was preceded by a dry spring with anomalously low soil moisture. Shifts may also be related to seasonal cycle sensitivities, the Madden-Julian Oscillation (MJO), and other convectively coupled tropical modes. These perturbations can excite the poleward movement of wind anomalies that may affect teleconnection patterns like the Pacific-North American, North American, and Arctic Oscillation patterns. Other boundary forcings and their relation to atmospheric patterns may yet be discovered. This weather-climate research program is partly dedicated to discovering, understanding, and developing the tools to fully exploit all sources of potential predictability.

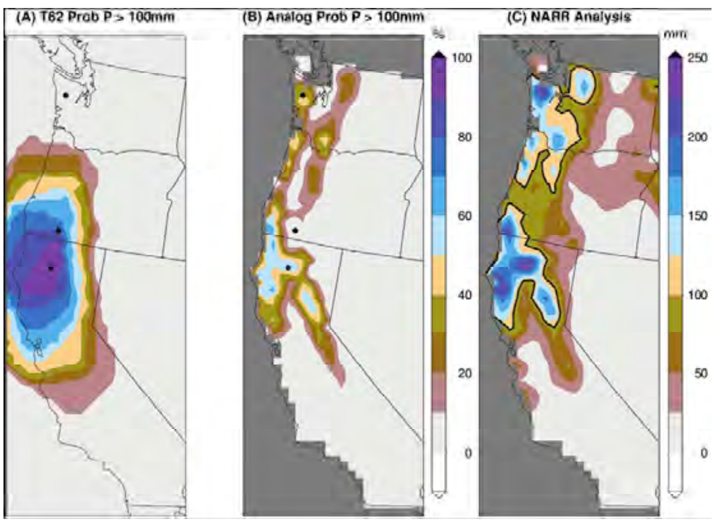

Figure 1.1: Example of how reforecasts can improve short-term weather-climate forecasts of precipitation. The left-hand panel shows the probability of greater than 100 mm of rainfall estimated directly from ensemble forecast output for a 4-6 day forecast initialized at 00 UTC 26 Dec 1996. The second panel shows the probabilistic forecasts produced by a reforecast-based analog technique (Hamill et al. 2006). The right-hand panel shows the verifying analysis. The 100-mm threshold is highlighted.

The relationship of the current boundary condition to future shifts from the unconditional climatology may be linear in character, and the fully nonlinear numerical weather prediction models may have very large systematic errors. In these situations, statistical models such as the Linear Inverse Model, or "LIM" (Winkler et al. 2001, Newman et al. 2004) are useful for diagnosing sources of forecast skill, and they may provide forecasts competitive with those from general circulation models (GCMs). There is, of course, ample room for improving the skill of these GCMs through model development.

1.2 Research Program

The reforecast and weather-climate research is closely linked with operational and experimental forecasting underway at the NOAA/NCEP Climate Prediction Center (CPC) and the NCEP Environmental Modeling Center (EMC's) Global Climate and Weather Branch. Our current work has directly contributed, for example, to improvements in the CPC's USA and Tropical hazards assessments and the USA 6-10 and 8-14 day temperature and precipitation forecasts. The current research program will further improve these assessments and forecasts, and new experimental forecast products will be developed as well. This enhanced array of sub-seasonal forecasts at regional spatial scales will provide more customized products suitable to a larger variety of end users.

Improvements in the computational aspects of ensemble forecasts will be the applied to diagnose problems in current ensemble forecasts and further develop techniques to estimate and parameterize model uncertainty. We will improve the initialization of ensemble forecasts through the continued development of ensemble-based data assimilation techniques. These techniques will be applied to improve the accuracy of retrospective climate analyses (see accompanying section on Historical Reanalysis). The resulting climate analysis datasets will improve our understanding of the predictability of various climate phenomena in the sub-seasonal time range.

Generation of new reforecast datasets for current-generation NCEP models and models enhanced with the improved techniques is a high priority. Done in conjunction with NCEP and other NWS organizations, this work will include development of new and improved methods for statistically adjust model forecasts using these new reforecast data sets. The next-generation products will be able to be downscaled to very fine grids (Figure 1.1; Hamill et al. 2006) and tailored to the concerns of specific decision makers (e.g. finescale forecasts for hydrologic support, temperature and wind forecasts for fire-suppression support). We will focus especially on precipitation and drought-forecast products. We will work closely with the Applications and Services component of PSD CDEP, as well as the NOAA Climate Program Office supported RISAs.

The development of web-based linear-inverse models will be used to improve diagnostic and predictive capabilities for 1-6 week forecasts during the warm and cool seasons. This work will determine the specific boundary forcings and internal dynamics that contribute to predictability in each season. The work will focus on additional sources of potential forecast skill including the impact of the stratosphere on tropospheric variations and the role of air-sea coupling for the MJO. The LIM forecasts will be made available in real time and used as an additional tool to diagnose the initial state of the atmosphere-ocean and the dynamical and physical processes that may contribute to forecast skill. This work will feed into CPC's monthly forecasts.

A forecast-based diagnostics effort will be used to understand model biases in simulation of intra-seasonal variability, e.g., Madden-Julian Oscillation (MJO) in tropical convection and winds, the North Atlantic/Arctic Oscillation and Pacific-North American patterns in the Northern Hemisphere. This approach will also be used to investigate the evolution and evaluate the predictability of flash droughts as well as the onset and termination of more persistent drought.

This work will utilize a newly developed global synoptic-dynamic model (GSDM; Weickmann and Berry 2006) of subseasonal variability that will help evaluate the predictions from GCMs and LIM as part of a forecast process. The GSDM defines a repeatable pattern of four circulation stages of the global circulation, which consist of multiple subseasonal time scales. The stages are linked to the global atmospheric angular momentum tendency whose fluctuations represent rapid changes in the strength of the subtropical westerly flow, which in turn impact mid-latitude storm tracks and wave energy dispersions. The GSDM is complemented by real time budgets of AAM whose balance will be improved using a chi-problem approach applied to the reanalysis data.

1.3 Workplan

Over the next five years, the highest priority under Reforecasts and Weather Climate will be to develop of a new multi-decadal reforecast with the current state-of-the-art NCEP numerical weather prediction model to incorporate improvements in forecast models and increases in model resolution. This same model will be run in real time, and experimental forecasts will be produced that are statistically adjusted using the reforecasts. Other priority work will involve implementing a coupled LIM for experimental 1-6 week forecasts and developing precipitation probability forecasts for operational USA and Tropical hazards assessments. Specific activities include:

1. Produce a reforecast data set composed of ensemble forecasts using the current state-of-the-art numerical weather prediction model. This work will include an ensemble-based reanalysis
2. Identify operational and reforecast model deficiencies and perform model-data analyses to assess the role of known missing phenomena such as the propagation of tropical convection (Madden-Julian Oscillation).
3. Update existing operational Week-2 and extreme-event forecast products to use the latest reforecast data set and then transition the experimental forecast techniques to NOAA operations
4. Produce new regional-scale forecast products and services for use in drought and water-supply management based developed in close collaboration with NWS regional forecast offices, river forecast centers, regional climate centers, state climatologist offices, RISAs and SARP projects.
5. Develop a modeling capacity to diagnose the physical and dynamical processes that contribute to subseasonal weather-climate events and drought conditions.
6. Diagnose the physical and dynamical processes that are responsible for the model deficiencies, and work with NCEP model developers to correct these problems

2. Historical Reanalysis for Climate Research and Applications

2.1 Introduction

Long-term climate data sets are critical to understand the causes of climate variability, to assess its potential predictability, and to evaluate its simulation in climate models. Over the past decade, major efforts by NOAA and its national and international partners have led to the creation of the first-generation climate reanalyses, which for the NOAA/NCAR reanalysis extends back over the period of substantial upper-air observations (1948-present). Prior to this period, the only long-term atmospheric reanalysis data sets consist of Northern Hemisphere sea-level pressure maps that were hand drawn in the 1940s from incomplete surface records. The CCSP Strategic Plan (SP) strongly emphasizes the importance of developing new reanalysis data sets to improve representations of past climate variability and change "including, if feasible, extending reanalyses back through the entire 20th century" (SP, p. 46). Reinforcing the key role of reanalysis in the CCSP, the SP identifies "Reanalyses of historical climate data for key atmospheric features; implications for attribution of causes of observed change" as one of 21 high-priority CCSP synthesis/assessment products to be delivered within 2-4 years. NOAA, together with NASA, has been identified as a co-lead agency for this deliverable. The GCOS Implementation Plan (IP, Mason et al. 2004), a component of GEOSS, is emphatic in urging parties "to give high priority to establishing a sustained capacity for global climate reanalysis" and "to develop improved methods for such reanalysis" (IP, p. 10). In the last year NOAA has received letters from leading international scientists highlighting the importance of NOAA's investments in historic reanalysis. The Global Climate Observing System (GCOS) Surface Pressure Working Group, the Atmospheric Observation Panel for Climate (AOPC), and the

Ocean Observations Panel for Climate (OOPC) are coordinating international efforts on behalf of the WMO to compile and provide the surface observations needed for NOAA to generate a surface observation based historic reanalysis that is critical for investigating 20th century climate variability and trends that extend to present.

While the current reanalyses have been valuable for climate research and applications, the fact that they extend back to only the mid-20th century greatly limits their usefulness for addressing numerous science questions of high societal relevance, such as the major features of the atmospheric circulation during the 1930's dust bowl. Over the past several years, ESRL has developed a unique capability to produce high-quality daily reanalyses for the troposphere from surface pressure observations alone (Compo et al. 2006) using a data assimilation system based on the 'Ensemble Filter' (Whitaker and Hamill, 2002). The combination of recently improved surface observational records together with this data assimilation method provides an exciting new opportunity to extend the reanalyses back in time, perhaps providing for the first time a reanalysis data set of a century or longer. Figure 2.1 illustrates this capability, showing the degree to which the principal mid-tropospheric features for the famous post-Christmas Snowstorm of December 1947 (Kocin and Uccellini 2004) are present in a map from a reanalysis using surface pressure observations and the Ensemble Filter (left panel) compared to the features seen in maps from the Air Weather Service (middle panel) and a reanalysis using the full NCEP assimilation system (middle panel). Our feasibility studies suggest that the extratropical, upper-tropospheric Northern Hemispheric height field errors obtained from Ensemble Filter-based analyses that use even fewer surface pressure observations will be comparable to current 2-2.5 day forecast errors (e.g., 500 hPa spatial correlations of ~0.95, rms errors ~35-40m).

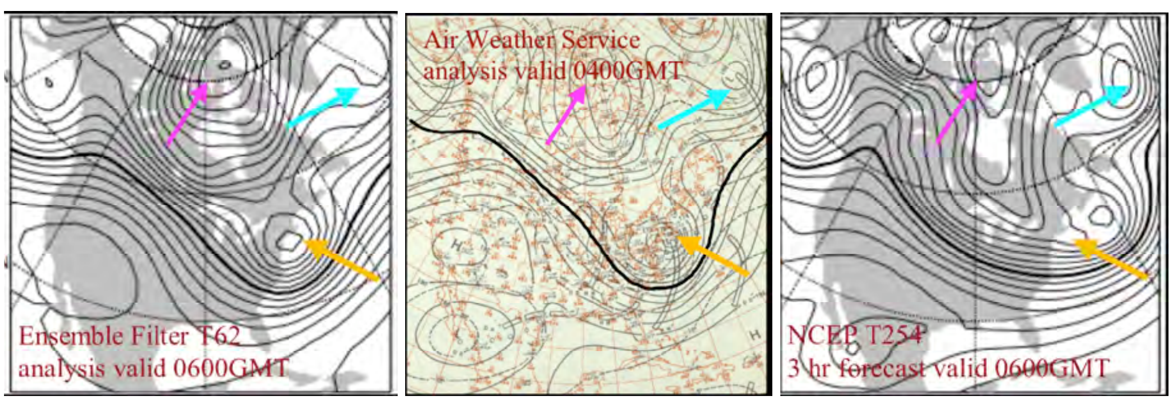

Figure 2.1: The 500 hPa height analysis of 27 December 1947 06GMT from the Ensemble Filter data assimilation system using only surface pressure observations (left) and from the experimental NCEP T254 analysis using all available surface and upper air observations (right). An Air Weather Service map drawn in near-real time is also shown (middle). Colored arrows illustrate the same features in all three maps.

2.2 Research Program

The proposed research will use improved observational data sets together with state-of-the art data assimilation methods to back-extend the atmospheric reanalyses to before the era of extensive upper-air observations. ESRL will work closely with NCDC colleagues and the Global Climate Observing System (GCOS) Surface Pressure Working Group to ensure the quality and consistency of the global surface pressure data needed to produce a complete reanalysis dataset for 1893-2011. The resulting historic reanalysis dataset will extend the record of tropospheric gridded fields 55 years before the start of the NCEP-NCAR reanalysis, back to a period for which no gridded upper-air analyses are available, and will overlap with reanalyses using upper air data for comparison. Production of the dataset and evaluation of its quality, together with the quantified uncertainties produced by the assimilation system, will support NOAA commitments to the GCOS Implementation Plan, CCSP and NOAA Strategic Plans. By providing a reanalysis dataset that is twice as long as that currently available, this new dataset will allow for better evaluation of climate models and sources of climate predictability, thereby contributing to the CDEP goal of enhancing NOAA climate application products and services.

Applications of the resulting historic reanalysis dataset include investigating 20th century variations in storminess, tornado outbreaks, heat waves and cold snaps, developing a three-dimensional understanding of atmospheric conditions during anomalous events such as the extended 1930s U.S. drought, and exploring variations in the background-state of the atmosphere associated with inter-decadal variations of hurricane activity.

Partnerships have already been established between the Australian Bureau of Meteorology; the EMULATE project; Environment Canada; ETH-Zurich; the Hong Kong Observatory; the ICOADS project; KNMI; Meteofrance; NCAR; NOAA CDMP, ESRL, NCDC, NCEP; U. of California-San Diego/Scripps; U. of Colorado-CIRES; U. Rovira i Virgili Climate Change Research Group; and the UK Hadley Center to provide the needed data and evaluate the reanalysis dataset. All of these groups are anticipating the reanalysis fields. Computing needs will be met using ESRL high performance computing and storage at the ESRL/GSD high performance computing facility. NCAR has offered to make a subset of the dataset available to the general scientific community. In partnership with NCEP, the atmospheric model will be that in the operational NCEP coupled forecasting system.

2.3 Work Plan

Over the next five years, the highest priority under **Historic Reanalysis** will be to assemble the required quality controlled dataset of surface observations and assimilate these data to produce ~115 year long surface pressure based reanalysis dataset. We will also produce a daily 72 hour forecast product from 1949 to present using the same model. Specific activities include:

1. Prepare surface observations for assimilation. Finalize combination of ICOADS marine observations, Japanese and Russian marine observations, NCDC Integrated Surface Hourly stations, CDMP Surface Airways, Environment Canada, Australian Bureau of Meteorology, Spanish, West African, and Russian station observations.
2. Refine ensemble data assimilation system. Finalize tests of operational NCEP Climate Forecast System atmospheric model on 1940s data.
3. Phased implementation to produce 1938-1948 reanalyses (phase 1 product), 1925-1937 reanalyses (phase 2 product), 1893-1924 reanalyses (phase 3 product), 1949-1979 reanalyses with daily 72-h forecasts (phase 4 product), 1979 – present reanalyses with daily 72-h forecasts (phase 5 product), including Computation performed on the ESRL node of the NOAA R&D high-performance computer system. We expect to complete about 1.5 months of analyses per day.
4. Assess phase 1 product. Evaluate quality of reanalyses by comparing forecasts to surface and upper-air observations.

5. Prepare a historic reanalysis-based assessment of atmospheric circulation patterns throughout the evolution of drought during the 1930s in the western US and during the 1890s in the eastern US.
6. Disseminate observations and reanalyses for phase 1 product. Using the NOMADS model of data distribution, we will make the dataset available to the scientific community. The dataset will include detailed information on the quality of each observation that can used by the archiving centers for further quality control.
7. Set up quasi-operational analysis system to update the historical dataset in near real time.

3. **Climate Attribution**

3.1 **Introduction**

Climate science is being increasingly called upon to explain the state of the Earth System. Such demand, if met, offers a direct and realtime pipeline to decision makers on the advances in our scientific understanding. The dialogue will center on an expert interpretation of *why* the climate is behaving as observed, rather than providing a mere description of *what* the climate state is. Attributional science will clarify predictability, and thus we envision the dialogue ultimately serving stakeholder needs to anticipate *what's next* whether it be the proliferation of Atlantic hurricanes, protracted Western drought, persistent warm temperatures, and extreme precipitation events all spurring great public concern.

Attribution science must also explain why certain climate conditions have not appeared….the so-called "*dogs not barking in the night*" such as why an expected El Niño impact failed to materialize, given the consequences for seasonal forecast skill and planning. The mysterious absence of hot, dry summers within the U.S. heartland, an expected consequence of climate change, must be unraveled, both for guiding adaptation strategies and for improving the use and interpretation of climate models. Reasons and implications for the progressive warming of the tropical Indo-west Pacific warm pool, where instead the tropical east Pacific was expected to witness the greatest warming, need to be given. What, for example are the consequences for such asymmetric mean ocean climate change for the frequency and intensity of El Niño and La Niña, phenomena known to be of great decision making importance?

Our applied research activity adopts a broader definition of attribution as the comprehensive explanation of current and evolving climate conditions, focusing on both variability and change, and on forcings that are both natural and anthropogenic. Our activity thus acknowledges that climate variations, embodied within the natural coupled fluctuations of the ocean-land-atmosphere system, yield some of the most profound and immediate societal impacts. It is also expected that our attribution research on the nature of such couplings will be central toward clarifying climate predictability on seasonal to decadal time scales. Ultimately, we envision a regular and systematic attribution activity that interprets the state of the climate system at national to regional scales in realtime.

Attributional research in the CDARC will fill critical gaps in NOAA's climate services to the Nation by integrating NOAA's historical expertise in climate monitoring with its emerging capability in climate prediction and projection. Binding these activities is important for overall advances, and attributional science maximizes the return on NOAA's extensive investment in ocean observing systems. At its culmination, globally complete and physically consistent descriptions of the state of the world ocean will become routinely available. Such data are expected to improve predictions of the Earth System on weekly to decadal time scales. But the effectiveness of such state information for climate predictions is poorly known, and there is ongoing debate about the role of ocean variability in North American climate. On the one hand, the attributable effects of El Niño/La Niña are well understood. Yet, what are the additional attributable (and potentially predictable) impacts of other world ocean variations? It has been argued that slowly varying, non-ENSO states, of the tropical Pacific contributed to the 1930's Dust Bowl (Seager et al. 2005), though a role for the Atlantic Ocean has also been suggested (Schubert et al. 2003). Recent prolonged U.S. western drought is believed to involve influences from a warming tropical Indo-western Pacific ocean (Hoerling and Kumar 2003) in addition to La Niña forcing (e.g., Hoerling and Kumar 2003, Seager et al. 2005). At the same time, analogies drawn between the Dust Bowl and this current drought have led to speculations that Atlantic ocean variability is more responsible (McCabe et al. 2004).

Attribution is the process of establishing cause-effect relationships, with a quantifiable level of uncertainty. It requires accurate observations of climate variability with sufficient historical context to understand its full range. It requires knowledge of the relevant forcings, methods of parameterizing those, and climate models to determine response amplitudes and patterns driven by those forcings. The latter may involve land-sea-cryosphere conditions to which the atmosphere is believed to be sensitive. They may also involve atmospheric chemical constituents such as radiatively active trace gases, ozone, human-induced aerosols, and natural aerosols. It also requires a theoretical understanding of the associations between climate variability and forcings.

Attributional research builds upon four key pillars, which individually form the foundations of our overall ARC activity. One is a scientific understanding of the dynamical processes and physical linkages among components of the Earth System. Our attribution activity will thus be coordinated with the *Climate System Diagnosis* within this ARC. It will also build upon the efforts of the *Reforecast and Weather-Climate* team that are unraveling the attributable causes of individual extreme weather events, recognizing that extreme seasonal mean climate states can have their origins in a single or a few extreme weather events. Second is a historical record of sufficient duration, such as is being developed by our *Historical Reanalysis* effort, among other developmental efforts for climate data sets. These analyses offer a necessary perspective on the sweep of climate variations, guiding assessments on whether current evolving states may be naturally driven as opposed to anthropogenically forced. Third is a modeling capability of climate variability and change involving both a multimodel architecture and a component analysis capability. Our attribution efforts will leverage CDC's partnership in the *Climate Diagostics Consortium* which generates realtime AMIP-model simulations, and involve the greater ARC constellation of partners, the operational prediction centers, and other modeling activities at NCAR and NASA. The capability exists also to run several of these models, perform "surgical" sensitivity analyses of atmospheric and oceanic variability, and assess potential predictability. The fourth pillar upon which our attribution effort builds is the decision-making requirements for credible explanations of climate conditions. Integrating our applied research with the *Applications and Services* effort of this ARC provides important guidance on what we will attribute. Such integration also defines the requisite time and space scales on such attribution information is needed by stakeholders.

3.2 Research Program

Our immediate objectives are compelled by policy maker requests for clear articulation of the attributable causes for a panoply of recent and ongoing climate conditions. Additional attribution research is guided by our recognition of gaps in understanding climate variability and change, and are compelled by a need to improve predictions, and explain uncertainties in climate change projections. Our long-term attribution activities establish a "attribution process", one that positions NOAA proactively in its explanations and predictions of a varying climate state consistent with its mission to enhance society's ability to respond.

U.S. Drought: In the Fall of 2004, NOAA Research was asked to respond to a Western Congressional Caucus on the status of the western U.S. drought. Among the societal issues leading to this information request, a primary one was the possibility for the first-ever "call" on the Colorado River under terms of the 1922 Colorado Compact. The questions asked by the Caucus focused on the origins for the drought, whether it was unprecedented, and whether it was natural or human induced. In the Spring of 2006, NOAA Research was again asked to provide an explanation for evolving drought conditions, this time to the Senate Commerce Disaster Prevention and Prediction subcommittee. NOAA's testimony focused principally on a description of drought conditions, though there was keen interest by the committee to learn about their causes, These recent examples call for the provision of an attributional research activity that focuses on ongoing U.S. drought. Our approach will involve the diagnosis of realtime evolving drought conditions. Figure 3.1 shows the 1895-2005 time series of a precipitation index, averaged for the 11 U.S. states west of 100° W. Both rapid transitions between wet and dry years and prolonged dry and wet periods characterize Western climate (left panel). One tool to understand and explain such behavior is climate model simulations subjected to observed sea surface and sea ice conditions. Analysis of western rainfall from a single such forced model reveals that several of the historical dry periods, and rapid transitions are explainable as responses to oceanic fluctuations (right panel). Leveraging the multi-modeling Seasonal Climate Diagnostics Consortium activity currently supported by NOAA, we will diagnose drought in those runs, deriving an objective drought index from the simulation data. This analysis will include the so-called Palmer Drought Severity Index and Standardized Precipitation Index which permit quantification of both the precipitation and temperature contributions to desiccation. The multi-model approach will be essential to evaluate the uncertainty in attribution.

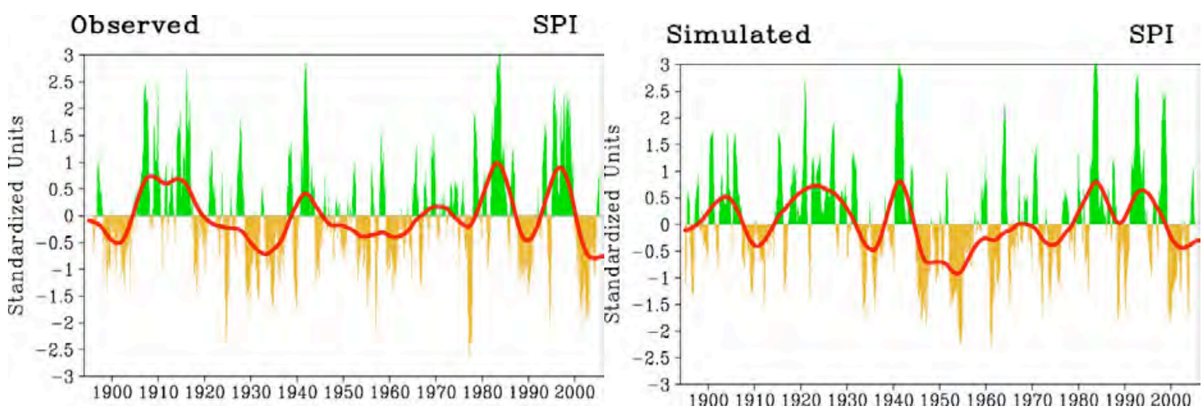

Figure 3.1: Time series of the 12-month standardized precipitation index (SPI) for the 11 states of the western United States. The period is 1895-2005 based on observed climate division data (left) and climate model simulations forced with observed global monthly sea surface temperatures (right). Red curve is a 10-yr low pass filter. Wet (dry) denoted by green (yellow) bars.

Regionality and seasonality of U.S. surface temperature trends: We seek to explain the reasons for recent trends in U.S. surface temperature. Our motivation comes from two sources. First, the trends, extrapolated forward by one or more seasons, account for much of the skill in U.S seasonal temperature forecasts. Yet, the trend origins are unknown, and as such the sustainability of recent forecast skill itself is uncertain. Second, critical aspects of the U.S climate trends appear contrary to expected anthropogenic signals. Most striking has been a century long trend toward cooler (and wetter) summertime climate over the Nation's mid-section, a region that was expected to sustain increased drought and heat in response to greenhouse gas forcing. Unexpectedly, warming in all seasons has been focused on the West. Ecological and human impacts there have been especially noteworthy where heat, combined with drought, have seemingly tipped the balance of sustainability within an already marginal semi-arid climate.

Explain the Success and Failure of Operational Seasonal and Subseasonal Climate outlooks: The process of explaining the success and failure of seasonal climate forecasts, shorter term subseasonal outlooks and hazards assessments is intended to go beyond the routine quantified error of forecasts (i.e., their skill score), but seeks to understand the reasons for skill and lack thereof. In a recent study by Goddard et al. (2006), a diagnosis of the reasons for the failure of the NCEP 2002/03 winter temperature forecast was performed. Their post-mortem analysis addressed two fundamental questions: What were U.S. surface temperature anomalies attributable to, and to what extent were these temperature anomalies predictable? Their analysis defined an attribution procedure that could be applied to a wider range of forecast data and case studies.

Warming of the World's Oceanic Warm Pool and Changing ENSO Behavior: The tropical ocean spanning about 45°E to 165°E contain the world's warmest waters, with values near 30°C (86°F). In the last 30 years, the area averaged sea surface temperatures have increased about +1°F in this warm pool. While climate change research indicates this warming is very likely the consequence of anthropogenic forcing, the role of other processes such as low frequency ENSO behavior need analysis as possible further contributors. What is not known is the attributal impact of this warm pool change on the atmosphere in general, and on the North American climate in particular. We seek to determine a so-called "warm pool" footprint on North America, akin to our understanding of the ENSO footprint. A key element is to establish the nature of the warm pool rainfall response to insitu SST warming. There is ongoing debate in the science community as to whether rainfall has in fact increased over the warm pool (e.g. Copsey et al. 2006), a situation that is essential for initiating the teleconnectons that have been shown to result from enhanced warm pool convection (e.g., Hoerling et al. 2003, 2004; Bader and Latif 2003). We also seek to understand the relation of the tropical Indo-Pacific warm pool to the evolving ocean conditions over the North Pacific Ocean. Are the low frequency North Pacific Ocean variations, such as fluctuations and trends in ocean thermal conditions near the shelf regions of western North America of primary biological productivity, linked to a changing warm pool? What is the warm pool forcing "fingerprint" on North Pacific climate? To the extent that convective forcing has been progressively increasing over the warm pool, we are also interested to know if the regionality of surface warming (being greatest in the western U.S.), and the seasonality (having most warming in Spring), is attributable to a dynamical process from the warm pool.

Stratospheric Effects on Climate and Ozone Recovery: It is well recognized that the interaction between troposphere and ocean needs to be considered for precise attribution of climate conditions. However, the troposphere is also closely coupled to the stratosphere via dynamical, chemical and radiative processes. There is increasing evidence from observations and model sensitivity studies that stratospheric processes, including polar ozone loss, play an important role in tropospheric climate variability across a wide range of time scales (Thompson and Solomon, 2002, Gillett and Thompson, 2003). Of great societal relevance is the recovery of stratospheric ozone, a gauge of the improved health of the atmosphere and of the effectiveness of actions implemented under the Montreal Protocol. Attribution research over the coming decades will focus on the recovery of ozone as chlorine and bromine are removed from the atmosphere. Observations of polar climate variability reveal, however, dramatic fluctuations from year to year, and attributional research must explain these in addition to the expected effect from chemistry changes. The detection and attribution of ozone recovery will thus be complicated by natural climate variations and changing climate. In order to provide accurate explanations for time varying ozone, and projections for its recovery, we need to improve our understanding of the feedback mechanisms between stratospheric ozone depletion, the increase of other greenhouse gases (e.g. CO_2, N_2O and CH_4) the warming of oceans, and multidecadal natural variations. We seek to elucidate the various physical and dynamical feedbacks listed above using mechanistic models and GCMs. We expect to conduct modeling efforts in collaboration with GFDL and other modeling centers.

Attributal impacts of sea ice, cyrospheric, and soil moisture forcing: Arctic sea ice and high latitude terrestrial snow cover, observed to be in rapid decline (e.g. Rothrock and Zhang, 2005), play key roles in Earth's climate by altering the surface albedo and the exchanges of heat, moisture and momentum between the atmosphere and land or ocean. The positive feedback between the snow cover/sea ice extent and the surface albedo is considered to be one of the dominant factors in the poleward amplification of global warming due to increasing greenhouse gas concentrations (e.g. Manabe et al., 1992) with a seasonally ice-free Arctic is projected to occur in many climate models within 30-50 years (Holland et al., 2005). In addition, a reconstruction of the Palmer Drought Index spanning the past 130 years (Dai et al. 2005) indicates very dry areas to have markedly increased in the past quarter century. These changes are believed to denote reduced soil moisture, in part related to surface warming, and also to changing patterns of precipitation. Through modeling and data analyses, we seek to understand and explain anomalous changes in these components of the earth system, given the significant feedbacks on climate.

Attributable impacts of climate variation and change on ecosystems: Decision making requires a clear explanation for the cause of current and evolving state of those marine resources, and climate attribution is thus key toward an integrated ecosystem management approach. The Gulf of Alaska is an area where biological activity can impact the abundance of different fish species, with large economic consequences. The connection between salmon population and climate is involves the interplay between the Aleutian Low circulation, ocean upwelling, ocean temperatures, and fish habitat responses (e.g., Beamish and Bouillon 1993). Another demonstrated effect of climate on Pacific marine ecosystems concerns the population of steller sea lions in the western part of the Gulf of Alaska, which has dropped dramatically in tandem with an abrupt climate regime shift that took place after 1976. Understanding impact of climate on the health and sustainability of marine resources clarifies the prospects for ecosystem recovery, and thus helps to guide management in its efforts to rebuild fisheries and species habitats Critical questions include: i) How does atmospheric forcing impact quantities important for biology, i.e. mixed layer depth and eddy fluxes, and which aspects of the atmospheric forcing are the most critical for altering the ecosystem environment? ii) What factors affect the atmospheric forcing? In particular, are the forcings associated with internal and regional Pacific-sector dynamics, part of a global pattern of variability, or perhaps linked to climate change?

3.3 Work Plan

Over the next five years, the highest priority under attribution will be to help NOAA respond to the frequent requests received for explanations for the current state of the climate system to allow planning and management decisions to be made based on understanding what has happened, why it happened, and what is the likelihood of it happening again in the future under continually evolving climate conditions. Specific activities include:

1. Address the physical causes for ongoing drought in the western U.S. and recent flash droughts in the eastern U.S. For example, can the drought be explained as the consequence of ENSO forcing? Is the drought related to other oceanic sources, and are those sources operating on longer times scales than ENSO which might imply prolonged drought? Or, is the drought merely the random outcome of atmospheric driving, the implication being of a shorter duration event. Six different models, run in AMIP-mode, will be available for determining the above factors in near realtime. Integrate this effort with NOAA's operational Drought Monitoring and Forecasting activity, and the ultimate aim is to improve drought forecasts.

2. Examine the fidelity of climate change projections, focusing our attribution research on the regionality and seasonality of recent observed U.S. climate trends based upon the now completed IPCC AR4 simualtions. We will also seek alternative plausible explanations for the changes in U.S. climate, including the role of natural coupled low frequency variability such as are associated with decadal ENSO-like behavior, and the so-called Atlantic Multidecadal Oscillation.

3. Build upon ongoing work to produce suite of experimental seasonal forecasts (e.g., empirical ENSO forecasts, dynamical U.S. seasonal temperature and precipitation forecasts, empirical Western Region seasonal precipitation forecasts). We intend to conduct near-realtime diagnoses of the origins for forecast success and failure of these experimental products. Our long-term goal is to conduct this work in a timely manner in order to provide attribution results to the operational prediction center for inclusion in their routine monthly forecast conferences.

4. Develop a single-site, multi-model capability that will be a major component to advance the technological capacity for a swift, responsive attribution activity. The *Seasonal Diagnostics Consortium* is a useful initial step toward such a capacity, although it is recognized that the execution of the various AMIP runs by different institutes is sub-optimal for a rapid response and a fully flexible attribution activity. Our near term objective will be to develop the capability for a large (greater than 5) multi-model AGCM activity. Coupled model simulations, initially of a mixed-layer variety, will also be core to the multi-model activity, and through coordination with GFDL, NCEP, and other major modeling centers incorporate fully coupled Earth System Models into the activity.

5. Build on the real time attribution efforts of subseasonal variability underway as part of the MJO Experimental Website. Presently, weather-climate discussions are posted every

few months and the causes for selected extreme weather events or regimes over the USA are explored. Recent examples include the heavy west coast precipitation during December 2005 and the extreme rainfall over the USA east coast during 23-28 June 2006. A goal will be to merge or complement this activity with AMIP-based approach described in the previous bullet item.

6. Employ empirical and model analyses of observational data to clarify the attributable impact of warm pool warming on tropical rainfall patterns. The empirical approaches will include station rainfall data, satellite rainfall estimates, and proxies of rainfall estimated from historical data using the Comprehensive Ocean-Atmosphere Dataset (COADS). The models will include AGCM, mix-layer coupled GCMs, and fully coupled ocean-atmosphere GCMs.
7. Investigate the three-component troposphere-stratosphere-ocean system to provide an improved attribution capability. Determine whether the stratospheric climate conditions and the dynamic coupling to the troposphere and oceans matter for a precise attribution of tropospheric climate conditions. Does the tropospheric response to ocean forcing depend on the stratospheric basic state? How is the stratospheric basic state determined, for example, by the phase of the quasi-biennial oscillation, by other natural dynamical processes, and by anthropogenic forcing? Our efforts will include observational studies, sensitivity experiments with coupled atmosphere/ocean models that have only a limited representation of stratospheric processes, and studies with stratospheric middle atmosphere general circulation models coupled to a mixed layer ocean and to a full ocean model.
8. Explain which regional North American anomalies can be attributed to recent and projected changes in the Arctic cryosphere or regional hydrology. Explain the roles of anthropogenic forcing and natural variations and feedbacks in the unprecedented trends in surface temperature over Alaska? Build upon previous GCM modeling efforts (e.g., Alexander et al. 2004), using a multi-model frameword to explore the impacts of 21st Century change in the sea ice and the cryosphere. Examine the implications of prolonged warming-induced soil moisture depletion for the spatial expression and duration of drought and possible non-local impacts via a response of atmospheric circulation. Perform diagnostic analysis and numerical experiments to understand soil moisture and atmosphere interactions, with an ultimate goal to assess the role of soil moisture in the predictability of climate.
9. Investigate the relative roles of internal and regional Pacific-sector dynamics, global variability, and climate change on the Gulf of Alaska ecosystem through a combination of observations, ocean analyses, high-resolution oceanic hindcast model simulations, atmospheric GCMs coupled with a mixed layer model, and fully coupled climate models where SSTs will be specified in different areas of the tropical Indo-Pacific Ocean. This effort will also examine how climate change affects the climatic quantities relevant to biology, diagnosing recently completed IPCC AR4 simulations.

4. Climate System Diagnosis

4.1 Introduction

Improved understanding, simulation, and predictability of the principal interacting components of the climate system on time scales of weeks to millennia, using a combination of observation analyses and modeling approaches, will be critical to advance NOAA's ability to provide enhance climate products and services. The emphasis of the research in this focus element will be on diagnosing the causes of observed anomalies as well as the causes of model simulation and forecast errors. The ultimate goal is to provide both better climate forecast and analysis products and better estimates of forecast uncertainty to meet user needs.

Extensive modeling experience over the last decade at weather and climate modeling centers around the world has highlighted some areas of continuing difficulty and inadequate knowledge. Perhaps foremost in the areas of continuing difficulty are the poor simulation and prediction of the tropical MJO and ENSO and their global impacts across a broad range of time scales. Improvements in this regard, as well as the development of alternative empirical and hybrid empirical/dynamical forecasting approaches, are key to improving global predictions on intraseasonal to interannual scales. To what extent they might also affect the simulation and prediction of decadal and longer-term variations and climate change, through multi-scale interactions, is unclear at present but critical to address. An area of inadequate knowledge is the impact of non-ENSO related SST variations, both natural and externally forced; it is unclear to what extent they have contributed to past climate variations, and how they might affect the future climate. An important area of inadequate understanding is the multi-scale impacts of unresolved stochastic variations, and their correct representation in weather and climate models. Advances in this area will benefit data assimilation, ensemble predictions, climate simulations, and projections of climate change. A third area of inadequacy is knowledge of past climate variations leading up to the 20^{th} century through analyses of available but under utilized paleoclimate data of last thousand years to evaluate and constrain climate models.

Underlying the challenges in the simulation and prediction of climate phenomena is an inadequate understanding of climate processes. The multi-scale impacts of stochastic processes have already been mentioned. Coupled interactions between the atmosphere and its oceanic, land surface, and snow and ice-covered lower boundaries; between atmospheric diabatic heating and circulation; between convection, radiation, clouds, and boundary layers; and between the troposphere and stratosphere need to be better understood and modeled. Progress will likely depend upon going beyond mere documentation of simple simulation and prediction error statistics to more sophisticated diagnostic analyses. Diagnosis with coupled inverse models, derived from both observed and simulated variations of the coupled system, and careful experimentation with models incorporating varying degrees of coupling, might suggest a way forward.

Given limited resources, we can focus on only a few of these outstanding problems. Our research priorities are determined not only by the need to address NOAA's strategic goals, but also by our desire to restrict the focus to areas in which we feel qualified to make unique and sustained contributions. These are all long-term lines of research. They will be pursued using available reanalysis and other 20th century and paleoclimate observational datasets, and a hierarchy of weather and climate models including those developed at NCEP, NCAR, and GFDL. We have all the relevant datasets and models available to us in-house, and have extensive experience of their use.

4.1 Research Program

A. Diagnosis of regional climate change, including long-term drought

Diagnose impacts of ENSO-related and non-ENSO related tropical SST changes over the last 130 years: Evidence has accumulated that tropical SSTs play a significant role in producing multi-year regional climate anomalies such as extended droughts. The connection with ENSO, though often suggestive, is not obvious. To what extent do the longer-term tropical SST changes unrelated to ENSO, associated with natural climate variability as well as anthropogenic climate forcing, play a role in such multi-year anomalies around the globe?

Determine sensitivity to SST changes in different parts of the tropical oceans: Not all observed tropical SST changes, even on interannual scales, are related to ENSO. There is also no reason to expect multi-decadal and anthropogenic tropical SST change patterns to look like the ENSO pattern. How the global climate system has responded and will respond to unusual SST patterns is an important question. A general way to address it is to determine global atmospheric sensitivity to a regular array of localized SST anomaly patches prescribed throughout the tropical oceans in an atmospheric GCM. Our previous investigations of this sensitivity using older AGCMs showed that although the ENSO SST pattern has been dominant in forcing interannual climate changes over the last 50 years, the extratropical climate is actually much more sensitive to other SST patterns, especially an east-west dipole pattern over the Pacific/Indian ocean warm pool (Figure. 4.1).

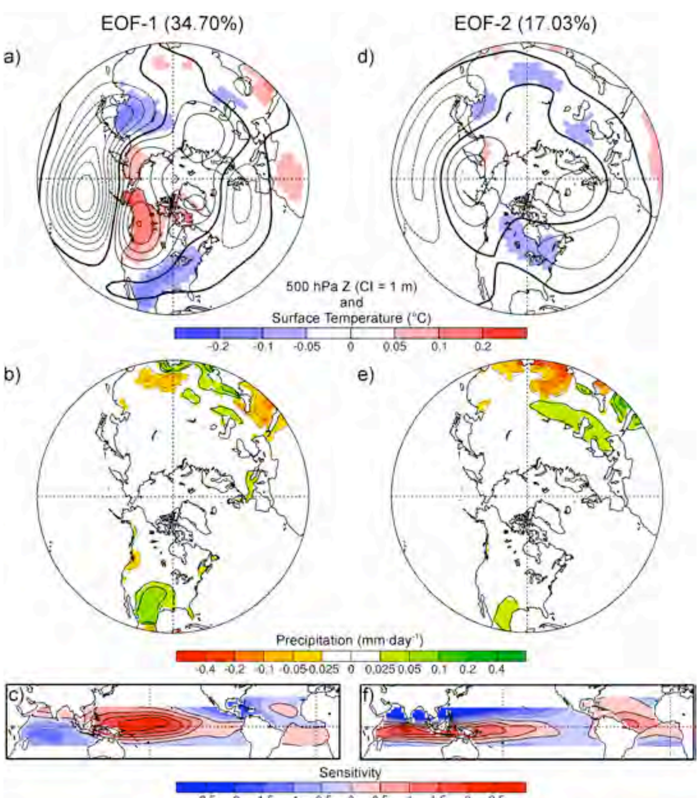

Figure 4.1: The dominant forcing-response singular vector pairs of the linear operator *G* linking annual mean tropical SST anomalies *x* with annual mean extratropical circulation anomalies *y* in the NCAR/CCM3 atmospheric GCM through the relationship $y = Gx$. Left panels: First singular vector pair, associated with a normalized squared singular value of 0.34. Right panels; Second singular vector pair, associated with a normalized squared singular value of 0.17. The tropical SST "forcing" parts of these SV pairs are shown in the bottom panels; the extratropical 500 mb height and surface temperature "response" parts in the top panels, and the extratropical precipitation "response" parts in the middle panels. The bottom panels may also be interpreted as optimal SST anomaly patterns for generating the largest (upper left panels) and second largest (upper right panels) magnitude extratropical responses in a hemispheric sense. From Sardeshmukh et al. (*in prep*).

Assess impacts of coupled air-sea interactions, decadal ocean dynamics, land-surface feedbacks, and land-use changes. While the tropical Pacific climate is dominated by strongly coupled air-sea interactions, the impact of air-sea coupling in other ocean basins on atmospheric variability remains unclear. A substantial portion of the SST variability in these basins is generated from the tropical Pacific through "atmospheric bridges", i.e. atmospheric teleconnections. How the SST anomalies then feed back on the atmosphere is an important question, especially over the Indian, north Pacific, tropical Atlantic and north Atlantic oceans. The importance of subsurface ocean dynamics in influencing SST variability in these basins, and also in the tropical Pacific on decadal scales needs further clarification. Similar issues also arise when assessing the impacts of land-surface feedbacks and land-use changes on the global climate. A substantial portion of land-surface climate variability is also attributable to remote forcing through atmospheric teleconnections. The question is to what extent the induced changes in vegetation and ground hydrology then feed back on the atmosphere, and how large this feedback is relative to the impact of land-use changes..

B. Assess stochastic influences on climate variability and predictability
Linear and nonlinear inverse modeling: We have an established track record of developing linear inverse models (LIMs) and demonstrating their competitiveness with state-of-the-art GCMs in predicting subseasonal to interannual climate variations. Thus far our LIMs have been either ocean-only or atmosphere-only; we are currently also developing a coupled atmosphere-ocean LIM for the tropics ("C-LIM") to improve predictions of the MJO and ENSO and understanding of the MJO-ENSO link. As emphasized in our many papers on this topic, LIMs are particularly well suited for studying stochastic influences on variability and predictability, because they naturally partition future states into predictable 'deterministic' and unpredictable 'stochastic' parts. We are also beginning to assess the importance of nonlinearity in such models by empirically estimating the "drift" and "diffusion" terms in the appropriate Fokker-Planck equations. Our inverse modeling techniques can of course be applied just as fruitfully to the output of coupled GCMs (such as the NCEP/CFS) to diagnose the sources of predictability and unpredictability in those GCMs.

Development and implementation of stochastic parameterizations in weather and climate models: Introducing stochastic forcing terms in weather and climate models is one way to account for the second and higher moments of unresolved eddy feedbacks on the resolved scales at each model time step. Traditional 'deterministic' parameterizations only deal with the first moment. 'Stochastic' parameterizations attempt to account for the errors of the deterministic parameterizations at each time step by introducing them as stochastic forcing terms whose amplitudes and correlation structures depend upon the resolved model state in a specified manner. In forecasting contexts, it is hoped that the additional stochastic forcing will correct the universal under-dispersion of forecast ensembles that greatly compromises their utility in probabilistic forecasting at present. In climate contexts, the forcing could significantly affect both climate variability and the mean climate.

C. Model Error Diagnosis
Comprehensive multivariate analyses of the evolution of short-range forecast errors: Forecast errors arise from both initial errors and model errors. Estimating their relative importance is important for quantifying forecast uncertainty, for assessing the potential for forecast improvement, and for setting priorities in forecast system development. The dominant model errors – diabatic parameterization errors – are of two types: "deterministic" and "stochastic", which may be identified with errors in representing the first and second moments, respectively, of the feedback of the unresolved scales on the resolved scales at each forecast time step. We have developed a rational method to estimate the relative contributions of initial errors and deterministic and stochastic parameterization errors to forecast errors.

Sensitivity analyses of stand-alone single-column versions of weather and climate models: Single column models (SCMs) provide an economical framework for assessing the sensitivity of the strongly coupled interactions among clouds, radiation, convection, boundary layer, and surface and subsurface physics to natural and imposed perturbations, and also for developing improved representations of these interactions in weather and climate models. Diagnosis with SCMs is most fruitfully pursued if the SCMs can be integrated for long periods. Ideally, such "Local Climate Simulators", with suitably specified mean and variable external forcings, are able to simulate the observed as well as GCM-simulated mean thermodynamic structure and variability in the column over any desired location on the globe. Most current SCMs are, however, incapable of being run for extended periods, mainly because their decoupling of the diabatic and adiabatic tendencies excites explosive instabilities. We have developed a method to remove these instabilities by re-introducing some coupling by parameterizing the adiabatic tendencies in terms of the SCM's diabatic tendencies. We have also found a way to specify location-specific variable external forcings that enable the SCM to maintain realistic variability in long integrations.

D. *Diagnosis of Subseasonal Variability and Predictability beyond Week 2.*
The influence of coherent long-term changes on subseasonal variability and predictability: A critical question in climate research is how relatively slow variations in the background "base" state, associated with anthropogenic or natural variations on longer than seasonal scales, affect the statistics of synoptic and subseasonal variability. The answer to this question has enormous implications for reliably assessing the altered risks of extreme weather and short-term climate episodes such as extended hot/dry or cold/wet spells associated with such base state changes.

The influence of subseasonal tropical and stratospheric variability on extratropical tropospheric variability and predictability: Recent interest in the Arctic Oscillation and the 1-2 month lag correlation between the stratospheric and near-surface circulation anomalies in high latitudes has elevated interest in the relative impacts of subseasonal tropical and stratospheric variability on extratropical tropospheric variability and predictability. To investigate this relationship, the Linear Inverse Model (LIM) of 7-day running mean tropical heating and extratropical tropospheric circulation anomalies has been expanded to include stratospheric geopotential height and sea level pressure anomalies. The LIM is trained on observed simultaneous and 5-day lag covariances, yet reproduces the observed lag covariances remarkably well at much longer lags, further attesting to the linearity of much of subseasonal dynamics. We find that persistent variability over Southern Asia, the Pacific and American sectors, and Africa is largely due to tropical forcing, whereas persistent variability over the North Atlantic and polar region is about equally due to tropical and stratospheric forcing. In terms of prediction skill, however, we find that the stratospheric forcing has very little impact except on sea level pressure in high latitudes. We plan to confirm these surprising results in our further studies of this issue using other observational datasets and also through atmospheric GCM sensitivity experiments.

Develop improved coupled linear inverse models of the tropical climate system: Construct a model of the coupled tropical atmosphere-ocean system that is useful for simulating, predicting, and diagnosing observed tropical anomalies on intraseasonal to interannual scales and for diagnosing the errors and feedbacks of climate models. To avoid repeating the errors of dynamical coupled models, we have constructed a linear inverse model (LIM) from the observed simultaneous and 7-day lag-correlation statistics of 7-day running mean tropical anomalies over the 1982-2003 period. We had previously constructed separate LIMs for the atmosphere and ocean from weekly atmospheric circulation and seasonal SST data and showed them to be competitive with NWP and dynamical coupled SST forecast models. Our plan here is to combine the best features of those component atmospheric and oceanic LIMs into a coupled LIM ("C-LIM") of the tropics. Our preliminary efforts appear to be successful: the C-LIM accurately reproduces the 0 through 90-day lag covariance statistics of the data. This now justifies performing extensive diagnoses, such as assessing the importance of air-sea coupling, by deleting the appropriate portions of the linear dynamical operator and re-running the model. Preliminary work suggests that coupling SST to the atmosphere has a large (and expected) impact on interannual variability, but only a minor (and unexpected) effect upon intraseasonal variability. We will continue to develop and use this C-LIM for experimental prediction and a variety of diagnostic purposes.

Develop global hybrid LIM/NWP extended-range forecast systems including forecast downscaling Given that our tropical LIMs have useful forecast skill out to 2-3 weeks or more, and are superior to dynamical models in predicting the MJO and other aspects of tropical intraseasonal variability, we will explore ways of merging the LIM and dynamical model forecasts to maximize forecast skill. We expect that such merged forecasts will have greater skill not only in the tropics but also in the extratropics.

E. Paleoclimate Reanalysis
We are also planning to extend our historical reanalysis (see Focus #2) back to ca. AD 1000 using paleoclimate proxy information. Such efforts to reconstruct global gridded climate datasets from sparse paleoclimatic observations face special challenges. Extrapolations to data-void regions based on observed present-day linear correlations are too simple for this purpose, and cannot be justified in a different climate. We will pursue a novel approach, exploiting an important result from our recent modeling studies that the global atmospheric response to global SST changes is well approximated by the linear response to tropical SST changes. In particular, this implies that long-term (say 10-yr and longer) average atmospheric anomalies around the globe are linearly related to long-term tropical SST anomalies through a linear operator *G*, which we will estimate for the pre-industrial climate through an AGCM's global response to an array of localized tropical SST anomaly patches. Having estimated *G*, we will then determine for each 50-yr period in the last 1000 years, using all the available paleoclimatic observations for that period, the 50-yr average tropical SST and global atmospheric fields consistent with their linear relationship through an optimization procedure. This will yield optimal reconstructions of 50-yr mean global atmospheric and tropical SST fields consistent with the paleoclimatic observations. A straightforward extension of the method will also enable us to reconstruct the SST fields outside the tropics using the relationships between the SSTs and the continental climate changes.

Work Plan

1. Assess the relative role of ENSO-related and non-ENSO related tropical SST changes over the last 130 years using a long-term SST dataset recently developed by us that has the ENSO signal based on a multi-pattern filter removed each month from the SST time series over the last 130 years. We will generate and investigate large multi-model ensembles of global atmospheric simulations with prescribed tropical SSTs with and without these ENSO signals.
2. Using a multi-model approach, evaluate the sensitivity to SST changes in different parts of the tropical oceans using as many state-of-the-art AGCMs as practically possible. Among other benefits this exercise will help us determine the accuracy with which future

warm pool SST changes will need to be predicted for us to have confidence in climate model projections of regional climate changes around the globe over the next century.

3. Investigate how coupled air-sea interactions, decadal ocean dynamics, land-surface feedbacks, and land-use changes propagate through the coupled climate system using a hierarchy of ocean models and different land-surface model coupled to a variety of atmospheric GCMs.
4. Assess stochastic influences on climate variability and predictability by applying inverse modeling techniques to the output of coupled GCMs (such as the NCEP/CFS) to diagnose the sources of predictability and unpredictability in those GCMs.
5. Investigate the role of forcing in atmospheric evolution through expansion of ongoing work with NCEP to develop and implement stochastic parameterizations to include additional atmospheric and coupled GCMs and assess the impact on climate predictions and forecasts.
6. Analyze the evolution of short-range forecast errors using the different mixes of contributions from these error sources to the forecast error covariances at different forecast lead times (up to 3 days for weather models, 3 months for coupled climate models) to separate them out. Preliminary work with a 1998 version of the NCEP MRF model has demonstrated the viability of our method. We will build on this work and apply it to diagnose the sources of error in the NCEP atmospheric GFS and coupled CFS forecast systems.
7. Run single column versions of weather and climate models used forcings derived from either observations or climate-model simulations to assess observed or climate-model simulated mean climate and climate variability. Extensive sensitivity tests with such "local climate simulators" will be used to hep develop improve the physical parameterizations of the atmosphere in GCMs.
8. Investigations of the impacts of ENSO on extratropical storm-tracks and subseasonal variability, as estimated from both observations and AGCM simulations with and without anomalous ENSO boundary conditions will be continued using newer AGCMs, and also broaden them to investigate the impacts of longer-term base state changes associated with decadal variations and climate change over the next century.
9. Explore the relationships between tropical, stratospheric and extratopical variability using the Linear Inverse Model (LIM) of 7-day running mean tropical heating and extratropical tropospheric circulation anomalies that includes stratospheric geopotential height and sea level pressure anomalies. Assess the reproducibility of previous findings using other observational datasets and also through atmospheric GCM sensitivity experiments.
10. Develop a next generation coupled linear inverse model of the tropical climate system by combining the best features of those component atmospheric and oceanic LIMs into a coupled LIM ("C-LIM") of the tropics. Preliminary efforts indicate the C-LIM accurately reproduces the 0 through 90-day lag covariance statistics of the data. Extensive diagnoses, such as assessing the importance of air-sea coupling, by deleting the appropriate portions of the linear dynamical operator and re-running the model . Preliminary work suggests that coupling SST to the atmosphere has a large (and expected) impact on interannual variability, but only a minor (and unexpected) effect

upon intraseasonal variability. We will continue to develop and use this C-LIM for experimental prediction and a variety of diagnostic purposes.

11. Explore ways to merge the forecast strengths of the LIM and dynamical model forecasts to maximize forecast skill through approaches such as repeating the dynamical forecasts with either continuous or intermittent nudging toward the LIM forecasts, or repeating the dynamical forecasts as a "data assimilation" cycle, assimilating the LIM forecasts every 6 hours.
12. Develop and apply linear operator technique to develop reconstructions of mean global atmospheric and tropical SST fields consistent with the paleoclimatic observations for the last glacial maximum climate.

5. Regional Applications and Services

5.1 Introduction

A challenge facing NOAA is to provide an integrated climate information system that delivers the data, products and services needed by businesses, academia and government agencies for risk management planning, operations, and research. Decision makers require a suite of readily accessible and usable climate products and services to effectively manage risk and protect life and property. The NOAA funded Regional Integrated Sciences and Assessments (RISA) have been working with stakeholders and decision makers to foster communication between users and producers of climate information. These efforts have raised awareness of the role of climate in planning and decision making, and provided an effective framework for collaboration between research and management. The resulting enhanced communications have identified a large suite of climate decision support resources that are needed to improve planning, risk management, response, resource allocation, mitigation, and provides early warning to those sectors sensitive to climate variability and change. This increase in demand for increased services in turn must be met through research focused on addressing decision maker needs and developing experimental products and services that can be transitioned into regional applications and ultimately operations.

The NOAA RISAs continue to identify new potiential uses of climate information to improve operating plans, decisions making and risk management. An important part of the University of Colorado based RISA collocated in Boulder, CO, Western Water Assessment (WWA) mission is to inform the NOAA Climate Program Office and OAR of new and evolving user needs, existing product limitations, and general lessons from the water management community. WWA is working closely with reservoir managers in the Interior West that are currently faced with the challenge of meeting new demands for a finite supply of water, while continuing to meet the needs of traditional rights holders and uses (e.g., irrigation, hydropower). Recent work has focused on how better use of climate information can help these natural resource managers to meet these new uses while minimizing conflicts. The framework of a decision calendar (Figure 5.1, after Ray et al, 2001) delineates the times of the year that specific types of climate information are most relevant and most useful. These decision calendars have helped WWA scientists collaborate with reservoir managers to articulate what the quality, relevance, use, and value of climate information can be in their decision making process. This approach was employed as a jointly-produced product between research and stakeholders in hydropower, endangered species and recreation management on the Colorado River (Pulwarty and Melis, 2001).

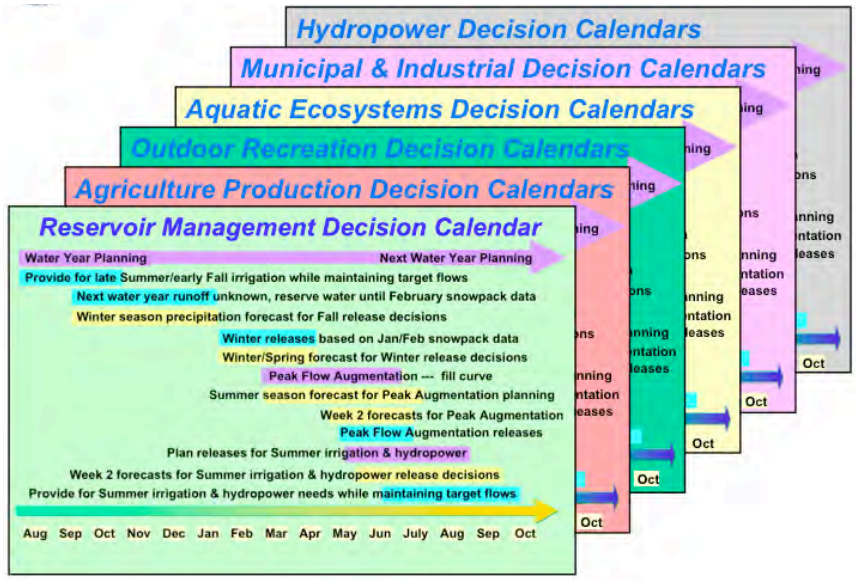

Figure 5.1: Decision Calendars indicate the timing of select planning processes (purple bars) and operational issues (blue bars) for the Upper Colorado River Basin reservoirs and related sectors. Also shown are the potential use of various types and timings of climate and weather forecasts (yellow bars) that could be used to address these concerns. The width and position of the bars indicate the intervals of relevant time periods. After Ray et al (2001).

Based on these collaborations, WWA research has identified gaps in the use and usability of existing climate products and services and highlighted needs for improved methods for climate monitoring, development of procedures to use seasonal climate outlooks in reservoir operating plans, and improved experimental regional forecast guidance to optimize the water management and reduce risks. The resulting end-user guidance will be used to set priorities for the our regional applications and services research to develop new and enhanced climate information products and services to support public and private sector decision making for adapting to climate variability and change.

5.2 Research Plan

The regional applications and services research will respond to and help fill gaps identified in the findings of various NOAA Climate Assessments and Services Division Partnerships such as those developed by RISAs and SARP funded research projects. The CDEP research is intended to take the identified needs for and the prototype examples of climate information products and services coming out of individual RISA and SARP research projects, and develop transitional experimental monitoring and forecast guidance products that incorporate improved understanding of climate processes and climate research advancements. The goal is to provide decision support products and tools addressing regional vulnerabilities to climate variability and change for use in policy development and to manage risk. Collectively these efforts provide the scientific research community and non-traditional users access to enhanced climate information, current climate conditions, and climate forecasts. The types of groups that are engaged and the types of climate phenomena define the research that will be needed to develop new or enhanced climate information products and services for decision support. The proposed work will support NIDIS activities across all of the four time scales described below.

Subseasonal Climate: The groups engaged through RISA and SARP projects include US Bureau of Reclamation, Fish and Wildlife Service, Colorado Basin River Forecast Center, State Engineer offices, Regional Councils, Wildfire Managers, and other users and decision makers are concerned with short-term extreme events such as subseasonal variability, Arctic Outbreaks, Monsoon, floods, heat waves, tornados. The identified needs for and the prototype examples of climate information products and services include development of region and sectoral-specific experimental forecast guidance, monitoring, and application products, and experimental attribution assessments of climate extreme events with regional impacts.

Seasonal to Multiyear Drought: Partnership organizations and agencies such as the Western Governors Association (WGA), RFCs, RCCs, NDMC, USDA, NRCS, Regional Councils, State and Municipal Agencies representing and serving as information conduits for users and decision makers have identified interests in the enhanced understanding of the persistence of seasonal to multi- year drought, the onset and termination of meteorologic droughts, snowpack evolution, soil moisture evolution, El Niño and La Niña, multidecadal ocean variability. The needs of these groups and their constituents for climate information products and services include development of probabilistic drought forecasts, and enhanced regional to local monitoring and application products across temporal scales.

Decadal Climate Variability: Building on effort to address shorter term climate variations, Regional Councils, Wildfire Managers, Regional Watershed Councils and Adaptive Management Programs, Municipal Agencies (e.g., Denver) are increasingly interested in understanding regional climate trends and associated changes in risk in order to develop adaptation strategies dealing with climate phenomena such as Pacific Decadal Variability, Atlantic Multidecadal Variability, and modulation of short term variability by regional trends. These groups require new or enhanced experimental information and applications at regional and local scales derived from research and operational and monitoring and forecast products.

Climate Change: At global change time scales, USBR, EPA, USGS, Regional Watershed Councils and Conservation Districts, and Municipal Agencies requesting information on apparent hemispheric to regional trends, the underlying causes of unprecedented impacts, and pathways for using information on decadal climate variability and trends coming out of the IPCC, paleorecords, and other sources in assessments of social, environmental, and economic risks and the resilience of longstanding management plans (e.g., Colorado Compact). In addition to providing informed projections of the observed, current and evolving trends coupled with explanations of the appropriate temporal and spatial scales and the associated uncertainty, these groups need help understanding the impacts of potential changes such as shifts in the seasonal cycle, an enhanced hydrologic cycle, elevation dependent amplifications, and increased evaporative demands.

Experimental Regional Climate Guidance: Decision makers in both the public and private sectors are increasingly interested in realtime information on regional scale impacts of climate variations. To meet these needs will require a regional consortium of federal, state and local partners who will serve collectively as a two-way interface with the user community. We will work with these partners on the development of an experimental information system to inform emergency managers and other decision makers of hazard risks associated with current and evolving climate anomalies.

5.3 Work Plan

Over the next five years, the highest priority under application and services will be to expand the number of end-user based experimental climate monitoring and forecast guidance products and services that are systematically updated and evaluated along with operational products. Specific activities include:

1. *Web-based seasonal guidance for Water Managers, Climate Prediction Center.* Improve ability of federal, state, and local water managers to plan water operations by augmenting

operational CPC seasonal outlooks with experimental forecast guidance downscaled to address decision maker needs.

2. *Colorado Meteorological Station Data long-term trends*. In conjunction with the Colorado State Climatologist's office, evaluate all suitable stations in Colorado and identify the subset that can be used to generate long term regional to local precipitation and temperature trends.
3. *Experimental NIDIS Products*. Support NIDIS implementation efforts and pilot activities by tailoring existing experimental and operational monitoring and forecast products to meet state and regional plans to mitigate and respond to drought.
4. *IPCC AR4 Simulations Applications for Colorado River Basin*. Produce estimates of the hydrologic and water resource impacts (flows, deliveries, power production, conservation) derived from the large ensemble of IPCC AR4 scenario simulations for use in assessing the risks in being able to meet demands for Colorado River water in the future.
5. *Realtime Regional Climate Hazards Outlooks.* In partnership with the local and regional NWS offices and RFCs, state climatologists, RISAs, local and national NRCS offices, cooperative extension agents and other private and public sector groups, we will explore development of the necessary infrastructure to provide regional climate hazard outlooks in realtime to support decision making to mitigate impacts and protect life and property.

6. Relevance to NOAA and CDEP

The emphasis during the next 5 years will be placed on integrated research coordinated around five foci: Reforecasts and Weather-Climate, Historical Ranalysis, Climate Attribution, Climate System Diagnosis, and Regional Applications and Services. The near-term priority is drought-related research and applications in support of NOAA's commitment to develop an improved suite of drought monitoring and forecast products in support of NIDIS. Critical to the success of the Climate Diagnostics Applied Research Center will continue to be the research advances that continue to expand our knowledge and understanding of climate dynamics and system predictability. This enhanced knowledge and understanding serve as a foundation for applied research development of experimental prediction capabilities that directly support the goals to bring the science of climate forecasts and information into policy and decision-making through enhancements to NOAA climate forecast operations, and to develop new and improved NOAA climate applications products and services.

The historic reanalysis and attribution foci are critical to the development of a national capacity to provide global climate analyses that describe major features of 20th century climate, and to address the causes of observed regional climate variations that are crucial to informing policy decisions. The historic reanalysis and attribution efforts specifically support: 1) the CCSP Synthesis and Assessment Product of a re-analyses of historical climate data for key atmospheric features. Implications for attribution of causes of observed change, 2) the Climate Goal Outcome of a predictive understanding of the global climate system on time scales of weeks to decades with quantified uncertainties sufficient for making informed and reasoned decisions, and 3) the Climate Goal Performance Objective to describe and understand the state of the climate system through integrated observations, analysis, and data management.

The reforecast and weather-climate focus is critical for NOAA to provide a seamless suite of forecast products ranging from short-term weather forecasts to longer-term climate forecasts (NOAA Strategic Plan). Relevant NOAA Performance Measures include: 1) increase skill of week-two forecasts of US temperature and precipitation, and 2) demonstrate skill in week-two forecasts of extreme US temperature and precipitation events in the upper and lower 20% of the climatological distribution. This work will provide decision makers with the regional-scale climate information of potentially damaging extreme events that is needed to mitigate impacts and protect lives and property. These short-term climate events include heat and cold waves, floods, high winds, and tornadoes. In addition to meeting critical energy utility and other private sector needs, improvements of probabilistic sub-seasonal forecasts will directly benefit: (1) planning and pre-positioning of resources, (2) flood-control operations, (3) wildfire suppression, (4) efficiency of water, energy, and crop management, and (4) operations at NWS National Centers for Environmental Prediction.

The Regional Applications and Services focus draws upon results from the other four CDARC foci to develop products and services that directly supports the NOAA performance objective to increase number and use of climate products and services to enhance public and private sector decision making. Relevant NOAA Performance Measures include: 1) improved ability of society to plan and respond to climate variability and climate change using NOAA climate products and information, and 2) increased number of instances where climate information is integrated into planning, decision tools, or management systems for forest and wildfire management, urban planning, public health, water and coastal management. Partners in this effort include: NWS offices and RFCs, state climatologists, RISAs, local and national NRCS offices, cooperative extension agents, federal, stat and local agencies, NGOs, and other private and public sector groups

In addition to providing advances in foundation of knowledge and understanding of climate in support of the applied research within the other four CDARC foci, the Climate System Diagnostics focus directly supports the NOAA performance objective to improve climate predictive capability from weeks to decades, with an increased range of applicability for management and policy decisions. Assessments of the fidelity of NOAA monitoring and forecast products and characterization of inherent uncertainty in observing and prediction systems are critical information to support informed decision making and policy development.

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8. Budget by Foci

CDARC Spending by Foci	Dollars per Year
Reforecast Weather Climate	$240,000
20th Century Reanalysis	$275,000
Attribution	$415,000
Climate System Diagnosis	$625,000
Applications & Services	$95,000
Total	$1,650,000