NAME Modeling and Data Assimilation:

A Strategic Overview

NAME Science Working Group*

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I. Introduction

This document presents a strategic overview of modeling and related data analysis and assimilation components of the North American Monsoon Experiment (NAME). Building on the NAME science plan, a strategy is outlined for accelerating progress on the fundamental modeling issues pertaining to NAME science goals. The strategy takes advantage of NAME enhanced observations, and should simultaneously provide model-based guidance to the evolving multi-tiered NAME observing program.

The overarching goal of NAME is to improve predictions of warm season precipitation over North America. Central to achieving this goal are improved observations, and improvements in the ability of models to simulate the various components and time scales comprising the weather and climate of the North American Monsoon System (hereafter NAMS). The specific scientific goals outlined in the NAME Science Plan (http://www.joss.ucar.edu/name) are to promote better understanding and prediction of:

- *warm season convective processes in complex terrain;*
- *intraseasonal variability of the monsoon;*
- *the response of warm season atmospheric circulation and precipitation patterns to slowly varying, potentially predictable oceanic and continental surface conditions;*
- *the life cycle of the North American monsoon system and its variability*.

In order to accomplish these goals NAME has adopted a multi-scale tiered approach with focused monitoring, diagnostic and modeling activities in the core monsoon region (Tier I), on the regional scale (Tier II) and on the continental scale (Tier III). *However at the outset it should be emphasized that to be successful, NAME modeling activities must maintain a multi-tiered approach in which local processes are embedded in, and are fully coupled with, larger-scale dynamics.*

The NAME region represents a unique challenge for climate modeling and data assimilation. It is a region marked by complex terrain and characterized by a wide range of phenomena including, a strong diurnal cycle and associated land-sea breezes, low level moisture surges, low level jets, tropical easterly waves, intense monsoonal circulations, intraseasonal variability, and continental-scale variations that link the different components of the monsoon. In fact, the NAMS exhibits large-scale coherence in the form of several known phenomena that have an important impact on intraseasonal to decadal time scales. Hence there are building blocks to serve as the foundation for climate forecasting. The El Niño/ Southern Oscillation (ENSO) phenomenon is the best understood of these phenomena, but previous research on the NAMS has also identified several others, including the Madden-Julian Oscillation (MJO), and the Pacific Decadal Oscillation (PDO). The relative influences of these phenomena on the warm season precipitation regime over North America are not well understood. Conversely, the large scale convective maximum associated with the monsoon affects circulation elsewhere, as shown by the relationship between the strength of deep convection and the amplitude and location of the summer subtropical High to the west. Similarly, intraseasonal and interannual fluctuations of monsoon rainfall in the Tier-1 region fluctuate out-of-phase with summer rainfall across the central United States; at present the mechanisms for this feather remain unclear

Prospects for improved prediction on seasonal-to-interannual time scales hinge on the inherent predictability of the system, and our ability to quantify the initial states and forecast the evolution of the surface forcing variables (e.g. SST and soil moisture). In addition to understanding the role of remote SST forcing such as that associated with ENSO and the North Pacific, we must understand the nature and role of nearby SST anomalies such as those that form in the Gulf of California. The land surface has many memory mechanisms beyond soil moisture, especially over the western US. Snow extends surface moisture memory across winter and spring. Vegetation in semi-arid regions, which shows pronounced seasonal and interannual variability, acts as an atmospheric boundary condition that affects momentum transfer, radiation, heat and moisture fluxes.

Aerosols are an important atmospheric constituent in southwestern North America. Circulation is often weak and anthropogenic sources from urban areas attenuate and reflect shortwave radiation. Fires (both natural and man-made) and their associated particulates have pronounced seasonal and interannual variability. Dust is an important factor in the spring and early summer, when vegetation is sparse and surface winds are strong.

The proposed NAME 2004 Field Observations (Table 1) will provide a comprehensive short term (one warm season) depiction of precipitation, circulation, and surface conditions in the core monsoon region The EOP will include new and/or enhanced networks of radiosondes, pilot balloons, raingauges, wind profilers, radars, and lightning detectors, as well as measurements of ocean fluxes, humidity, soil moisture, and vegetation.. The principal goal of the EOP is to provide improved estimates of the 3-dimensional structure of the core monsoon circulation in the Tier I region. A key aspect of the modeling strategy is to develop partnerships among the NAME observational, model development and data assimilation, and forecasting communities.

The NAME modeling strategy outlined in the following sections recognizes three distinct, but related, roles that observations play in model development and assessment. These are (1) to guide model development by providing constraints on model simulations at the process level (e.g. convection, land/atmosphere and ocean/atmosphere interactions); (2) to help assess the veracity of model simulations of the various key NAMS phenomena (e.g. low level jets, land/sea breezes, tropical storms), and the linkages to regional and larger-scale climate variability; and (3) to provide initial and boundary conditions, and verification data for model predictions. Section II discusses the multi-scale model development strategy. Section III describes how data assimilation will play a vital role in addressing the larger-scale NAMS modeling issues, and section IV discusses the role of global models in addressing the global-scale linkages and the NAMS prediction problem.

II. Multi-scale Model Development

The underlying premise of the NAME modeling strategy is that deficiencies in our ability to model "local" processes are among the leading factors limiting forecast skill in the NAME region. For the most part, the source of the problem is in the simulation of deep convective processes and their organizing and maintaining mechanisms. While this problem is not unique to the NAME region, the presence of land/sea contrasts and complex terrain make this a particularly challenging problem for NAME. The anticipated Tier I observations are geared to addressing this problem with a specific focus on improving the treatment of:

- *moist convection in the presence of complex terrain and land/sea contrasts;*
- *land/atmosphere interactions in the presence of complex terrain and land/sea contrasts;*
- *ocean/atmosphere interactions in coastal regions with complex terrain.*

The interactions with the surface provide, among other things, organization and memory to atmospheric convection so that the problems of modeling land/atmosphere and ocean/atmosphere interactions are intertwined with the deep convection problem. Improvements on these "process-level" issues will require both fundamental improvements to the physical parameterizations, *and improvements to how we model the interactions between the local processes and regional and larger scale variability in regional and global models. In short, model development efforts must take on a multi-scale approach*. As such, we require information about the NAMS and related variability that extends across all Tiers (I, II, III) and beyond to include global scales.

Development efforts are envisioned that simultaneously tackle these issues from both a "bottom–up" and a "top-down" approach. In the former, process-level modeling is advanced and scaled-up to address parameterization issues in regional and global modeling, while in the latter, regional and global models are scaled-down to address issues of resolution and the breakdown of assumptions that are the underpinnings of the physical parameterizations. The following expands on the specific issues that need to be addressed.

1) Moist convection in the presence of complex terrain and land/sea contrasts

The key issue for organized convection concerns the difficulties that regional and global models encounter with the so-called scale-separation problem: parameterization schemes and grid-scale convection running concurrently. Parameterization schemes are not designed to cope with this multiscale behavior. The problem has its roots in the principle of scale separation: the dynamical scale of the process being parameterized should be much smaller than the grid-resolution of the numerical model in which it is applied. In climate models, where the grid-resolution is typically hundreds of kilometers, the scale-separation assumption is sensibly valid. However, parameterizations are not designed to represent either the up-scale effects of convection or its organization. In global numerical weather prediction models the validity of the scale-separation assumption is directly challenged by the mesoscale organization of convection. Recent work shows that surrogate organization (aliased grid-scale circulations) can distort, or take over completely, convective parameterization in global models. This is a long-recognized problem in regional mesoscale models wherein organized convection clearly invalidates the scale-separation principle. A resounding message is that organized convection may occur for the wrong reasons in regional and global weather prediction models.

The violation of the scale separation principle is inevitable when model resolution increases while the convective parameterization remains the same. This is a clear indication that parameterization schemes must be designed for specific resolutions.

The approach taken to addressing this problem should involve a hierarchy of models including fully cloud-resolving models, single column land/atmosphere models, regional mesoscale models, and fully coupled global atmosphere-land-ocean models. Numerical models that resolve convection and have computational domains large enough to explicitly represent interaction with the environment (to the extent practicable with present computers) set a path to basic understanding. Such a multi-scale/multi-model approach will necessarily require close collaboration between process (local), mesoscale and global modeling groups, together with the observational analysts.

These multiscale modeling efforts must be interlinked with the observational efforts of NAME. Tier I will provide detailed observational measurements and forcing. When interactively nested domains or high resolution global models are used, the multiscale models are capable of incorporating Tiers I, II, and III.

2) Land/atmosphere interactions in the presence of complex terrain and land/sea contrasts

Observational studies have shown that certain monsoonal circulation regimes have strong persistence tendencies: once the “monsoon onset” occurs, an identifiable monsoon regime is maintained for several months (depending on latitude). Understanding the mechanism for this persistence is important for making credible seasonal forecasts of monsoon-related climate variables. A positive surface moisture feedback process has been postulated as playing a critical role in maintaining the monsoon. Vegetation “greens up” dramatically and rapidly across a large portion of the monsoon region following the initiation of rainfall in early summer, providing via evapotranspiration a quick pathway for returning precipitation to the atmosphere. The spatial and temporal variations of the water and energy fluxes involved in this feedback are currently poorly measured and simulated. NAME modeling and diagnostic studies should strive to quantify this feedback.

The persistence of the monsoon is presumably also dependent on large-scale heat sources and sinks, as in the Asian summer monsoon, where onset and maintenance depends on surface sensible heat fluxes over elevated terrain (the Tibetan Plateau). The timing of the monsoon onset and demise is an important issue for the NAMS, as it is for the Asian monsoon. Modeling studies are required to explore the mechanisms controlling the timing of the onset and the demise.

In addition to their theoretical importance, there will be immediate and important social and economic applications of better information on the variability of land surface and hydrologic characteristics in the NAME region. Improvements in understanding the mechanisms that control vegetation, groundwater infiltration and surface runoff are critically important to both U.S. and Mexican efforts to foster sustainable economies and ecosystems in the arid Southwest.

3) **Ocean/atmosphere interactions in coastal regions with complex terrain**

Monsoons are air-sea-land interaction phenomena, but it is not straightforward to separate out a purely air-sea interaction component because the air-sea interactions are strongly mediated by air-land processes. The predictability of intraseasonal variability of the NAM is heavily tied up in predictions of sea surface temperature (SST) and land soil/vegetation moisture reservoirs - both extreme challenges for today's models. Field campaigns (e.g., PACJET) on the US West Coast have shown that the dynamical influence of steep coastal terrain extends as much as 100 km out to sea for mid-latitude fronts. Monsoons, however, are primarily powered by the land-sea temperature contrast: land has a strong seasonal and diurnal variation while the ocean has a moderate seasonal variation and a relatively small diurnal variation. Furthermore, CAPE is very sensitive to PBL moisture and a 1 C change in SST produces 2.5 times the moisture in the Gulf than off the coast of California. Deep convection over the steep terrain has a strong effect on fluxes over the Tier-I ocean, which in turn influences the evolution of SST. At night, land convection tends to propagate westward over the ocean. Because the convective clouds block incoming solar radiation and produce cold pool outflows with resulting enhancement of mixing processes, the diurnal timing is critical in determining their cooling effect on the ocean. Models must produce the strength and timing correctly or they get the feedbacks and SST wrong. For climate models this is a formidable problem because they may poorly resolve the land-sea interface.

The primary Tier-I air-sea interaction issues for NAME are:

- *the ocean as a sources of moisture (the balance of local vs larger scale);*
- *the interaction of the flat ocean with surrounding steep topography in generating the structure of the Gulf moisture surges and low-level jets;*
- *the strong effect of the land-sea temperature contrast in the dynamics of deep convection, and*
- *the coupling of deep convection to changes in ocean fluxes and resulting effects on the SST.*

To assess and improve model treatment of these issues, NAME is adding ship-based observations near the mouth of the Gulf. The NAME plan calls for observations from the NOAA ship Ronald H. Brown (or a substitute) and a Mexican research vessel through CICESE. The mix of observations on these vessels will include a continuously scanning C-band Doppler radar to provide quantitative precipitation estimates and horizontal-vertical structure information on precipitation features (similar to the land-based radars), 4-times daily rawinsonde launches with enhanced launch frequency during designated special operation periods, a high resolution wind and precipitation profiler to provide continuous measurements of the wind and drop size distribution characteristics through the lower and mid troposphere, direct turbulent and radiative flux measurements, and near-surface bulk variables. The principal strategy of this suite of observations is to provide detailed time series of surface fluxes and bulk meteorology combined with profiles of wind, thermodynamics, and precipitation structure for direct comparisons with model outputs. The ship is an ideal platform for collecting a breadth of air sea interaction observations in the Gulf region, which will allow *single-column* investigations of model physics in great depth, and provide critical validation for convective parameterization schemes. The ships will also provide the only continuous high-quality soundings over the local ocean, which will be important in defining the time series of mesoscale forcing.

The 3-D scanning capability of the C-band radar will provide critical information on the vertical and horizontal structure of precipitating convection and its evolution over the ocean throughout the diurnal cycle. For example, it has been hypothesized that deep convection which develops over the SMO evolves to more stratiform structure (less intense, more aerially extensive) as precipitation systems migrate off the elevated terrain and into the Gulf. These changes in precipitation structure have profound effects on the amount and intensity of rainfall over the oceans (freshwater flux) as well as the resulting latent heating profile of the cloud system. Moreover, a number of previous studies have shown that Easterly waves are linked to Gulf surge activity. However, the mechanism(s) in which Easterly waves force resulting surges are unclear. The balance of oceanic vs land convection through the diurnal cycle and its interaction with Easterly waves must be well represented in the models. The ship-based radar is the only continuous oceanic observation that addresses this key objective of the NAME program. Point-by-point intercomparisons of observations with model simulations will be of some interest, but experience shows that statistical comparisons are usually more valid. This could include comparisons of weekly averages, composites based on the phase of easterly waves, or composites of the mean diurnal behavior.

Direct observations and turbulent and radiative fluxes will allow us to examine the efficacy of standard bulk flux routines in a coast zone. Present operational routines are tuned to the open ocean where there is typically an approximate balance between the wind and wave fields. Coastal regions (and particularly semi-enclosed bodies such as the Gulf) are hypothesized to have higher fluxes because the wave field is suppressed. Observations of covariance fluxes, bulk variables, and ocean surface wave fields will allow us to examine this issue (relevant to local sources of moisture and the acceleration of Gulf surges over the water). Finally, very accurate measurements of the surface heat budget and the SST will shed light on the relative roles of surface forcing and oceanic processes (advection and entrainment) in the predictability of SST in the Gulf. Detailed ocean mixing layer observations are required to define the balance of advection and entrainment.

4) The diurnal cycle as a prototype multi-scale problem

A key focus of the NAME modeling effort will be on improving the representation of the diurnal cycle. The diurnal cycle is important to the NAME region for the following reasons: There are strong diurnal signals in many key variables such as precipitation and convection, low-level winds, moisture transport, , and surface temperature, etc. Many physical processes crucial to the NAMS operate on the diurnal timescale, such as sea/land breezes, and land-atmosphere interactions through surface evaporation, vertical transport of water vapor by deep convection, etc. The diurnal cycle is modulated by processes on local scales (surface conditions), regional scales (coastal land-sea contrast), and the large scale (the circulation), and thus is a universal problem for all three NAME tiers. The presence of complex terrain further complicates the mechanisms for the diurnal cycle. Current models have difficulty simulating the diurnal cycle so it is an important problem for multi-scale modeling.

As we move beyond Tier I, we need to consider the large regional differences within the broader-scale NAM region including differences in terrain, land surface conditions, and the basic climatology. In particular, efforts should be geared to understanding and improved modeling of the differences between the representation of organized convection in the coastal terrain of NAME, its representation over the Great Plains in the presence of a strong low-level jet, and its representation over the relatively wet land surface conditions of the eastern United States. Here too the diurnal cycle will likely play a central role, especially in terms of its interaction with topography, the land surface, and with the large-scale flow. Addressing and verifying such large-scale interactions and regional differences will require that the NAME Tier I observations are put in the context of other in situ and remote observations. This is best accomplished through data assimilation as discussed in the next section.

III. Multi-tier Synthesis and Data assimilation

The observations obtained from the NAME 2004 field campaign should provide valuable new insights into the mechanisms and phenomena of the monsoon in the Tier I region and, as outlined in the previous section, help to improve the representation of key physical processes in models. Nevertheless, in order to pursue a true multi-scale modeling strategy, we require information about the monsoon that extends well beyond the Tier I region. In this section, we discuss the role of data assimilation in enhancing the value and extending the impact of the Tier I observations to allow addressing issues of model quality and monsoon variability on scales that extend across the greater NAM region. In addition, data assimilation can provide an important framework for quantifying the impact of observations, and for assessing and understanding model deficiencies.

The basic goal is the creation of the best possible research quality assimilated data sets for studying the NAM region and its interactions with the large-scale environment. It is expected that this effort will rely primarily on regional data assimilation systems with some limited work done with global systems. The former have the potential to provide high resolution, and spatially and temporally more complete (compared with the Tier I observations alone), estimates of the various NAMS phenomena such as Gulf surges, low level jets, and tropical easterly waves, while the latter provide information (at a somewhat lower resolution) about linkages between the greater NAMS and global-scale climate variability and the role of remote boundary forcing, and will be discussed more in section IV. Additionally, we anticipate that off-line land data assimilation systems, as well as, simplified 1-dimensional land/atmosphere and ocean/atmosphere data assimilation systems will provide invaluable "controlled" environments for addressing issues of land-atmosphere and ocean-atmosphere interactions and model errors.

Specific examples of data sets to be generated include a series of assimilations for North America covering the EOP both with and without assimilating various components of the NAME observations. Parallel simulations should be performed employing a number of regional and global models including those employed in the assimilation systems. Here efforts should also take advantage of existing operational and special reanalysis data assimilation products.

The specific objectives are:

1) To better understand and simulate the various components of the NAMand their interactions:

- *Gulf of California moisture surges and precipitation in Tier 1;*
- *tropical easterly wave / moisture surge relationships;*
- *moisture budget and sources (Gulf of Mexico vs. Gulf of California);*
- *tropical easterly wave / midlatitude (westerly) wave relationships;*
- *the diurnal cycle of convection over Southwest North America and the east Pacific ITCZ;*
- *relationships between low-level jets in the Gulf of California and U.S. Great Plains;*

These components are crucial to our understanding of the seasonal evolution of the monsoon. They may also help explain the out of phase relationship between precipitation in SW North America and that in the US Great Plain.

2) To quantify the impact of the NAME observations

Specifically, the aim is to assess the impact of the NAME observations on the quality of the analyses. The impact on predictions is one measure of quality, though that will be addressed in the next section. Improvements to the analyses can come about directly through the assimilation of the observations, or indirectly through improvements in the models used in the assimilation systems. As such, it is also important to understand the extent to which model errors impact the quality of the assimilated data.

To a large extent quantifying improvements will require comparisons with independent observations. These include, for example, various satellite cloud and radiative flux data, and any other special field observations that are not included in the assimilations. Here the Coordinated Enhanced Observing Period (CEOPS) could play a key role in providing independent data for verifications, e.g. Model Output Location Time Series (MOLTS) at locations of NAME upper air soundings). Another approach is to withhold certain components of the NAME observations to assess their impact on the assimilation. Again, the primary tools used here would consist of regional data assimilation systems and models that are capable of resolving the key local features of the monsoon, and are most likely to extend and enhance the Tier I NAME observations.

The impact of model deficiencies can be determined in a relative sense by comparing assimilations with different models, though here it will be difficult to produce completely clean comparisons without actually swapping different models into and out of the same data assimilation system. The recent Earth System Modeling Framework (ESMF 2001) development efforts could potentially provide such a capability. Another approach to identifying the impact of model errors is to compare assimilations and simulations carried out with the same model.

3) To identify model errors and attribute them to the underlying model deficiencies

In many ways data assimilation provides one of the most direct ways of addressing model errors. One of the underlying assumptions of climate data assimilation is that a model forced (via data insertion) to remain close to the observed prognostic fields will produce more realistic forcing fields (e.g. radiation, latent and sensible fluxes) compared with the same model run in simulation mode. To the extent that the parameterizations are given the "right" input during an assimilation, yet still produce the wrong output (as measured for example by the systematic differences between model first guess and analysis fields), data assimilation provides a mechanism for diagnosing errors early, before they have a chance to grow and interact with other components of the flow. As such, the "analysis increments" obtained during an assimilation can provide valuable information about basic model deficiencies.

This approach to addressing model errors relies on having the models of interest run in data-assimilation mode. While this currently limits the analysis to just a few (mainly numerical weather prediction) models, we again expect that ESMF can facilitate carrying out such an analysis on a wider range of climate models.

In summary, the specific goals to be addressed through data assimilation are to assess the impact of the NAME observations, better understand the nature of model errors, and to obtain a better understanding and improved simulation of the full range of phenomena comprising the NAMS.

4) To identify model deficiencies in the representation of moist processes

As discussed earlier, regional and global models have a difficult time representing moist convective processes. Cloud-resolving models can represent convection explicitly, but there is still the question of the realism of the results. Direct measurements of moist convective processes in Tier I offer the opportunity for direct comparison and validation of model results and their convective parameterizations. Specific items to be investigated are:

- *the structure, location, and timing of precipitation systems in the Tier I region;*
- *surface fluxes over the ocean and their modification by precipitation systems;*
- *divergence and vertical motion in convective regions;*
- *statistics of cloud fields;*
- *microphysical properties of convection*

Key measurements will be radar (including polarimetric) data, sounding data through the entire troposphere, surface flux measurements from ships, and boundary-layer wind and thermodynamic profiles.

IV. Prediction and Global-scale Linkages

One of the key measures of success of the NAME program will be the extent to which predictions of the NAMS are improved. The prediction problem for NAME is rather broad and includes time scales ranging from diurnal to weather to interannual. While regional models will play an important role, dynamical predictions beyond more than a few days are potentially influenced by (and interact with) global climate variability, so that global models and data assimilation become increasingly important. In fact, it is likely that global-scale variability and the slower components of the boundary forcing (e.g. SST and soil moisture) will provide the main sources of predictive skill in this region on subseasonal and longer time scales.

The key issue to be addressed here is to determine the extent to which model improvements made at the process level (e.g. convection, land/atmospheric interaction), and associated improvements made in the simulation of regional-scale phenomena (diurnal cycle, basic monsoon evolution, low level jets, moisture surges etc), validated against improved data sets, ultimately translate into improved dynamical predictions. Additionally, we wish to determine the impact on predictions of improved initial and boundary conditions, though this would initially be rather limited to focus on the period of available NAME observations (the 2004 field campaign). For example, how sensitive are model simulations of NAMS precipitation (and the components of the large scale circulation driven by monsoonal convection) to accurate specification of SSTs in the Gulf of California, Gulf of Mexico, or east Pacific?

We envision that a number of "hindcast" experiments will be carried out, utilizing existing multi-year regional and global assimilated data sets. The NAME 2004 enhanced observing period will serve as an important case study to assess the direct impact of the enhanced observing system for initializing and forcing the models.

The specific objectives of NAME predictability research are:

- *to examine whether that the observed connections between the leading patterns of global climate variability (e.g. ENSO, MJO) and the NAMS are captured in global models;*
- *to determine the predictability and prediction skill over the NAMS region associated with the leading patterns of climate variability;*
- *to investigate the impacts of anomalous continental and oceanic conditions in regional and global models;*
- *to determine the predictability and prediction skill associated with anomalous land surface conditions (soil moisture) in the NAME region;*
- *to compare the relative influences of local and remote SST forcing on predictive skill in the NAME region;*
- *to assess the advantage for NAME region predictions of increased resolution (either global or locally enhanced - for example by embedding regional high-resolution models in global models).*

Several broader cross-cutting themes also warrant attention. These include studies that examine the relative importance of oceanic and land-surface boundary forcing, and studies to quantify error growth due to model errors and those due to the uncertainties in analyses and boundary conditions.

For many of the above issues, it will be useful to consider collaborative multi-nation/multi-model experimental prediction efforts.

V. A Roadmap

In this section we outline a development roadmap that ensures the synchronization of the observing program with the modeling and data assimilation efforts. The objective is to facilitate a timely two-way flow of information so that the modeling and data assimilation activities provide guidance to the evolving observing program, and that the observations provide information for advancing model development. Current proposed and/or funded NAME modeling and diagnostic studies are listed in Table 2. In the following we separate the activities into those that are needed prior to the Enhanced Observing Period (EOP, JJA 2004), those that are necessary to support the EOP, and those that will occur after the observations have been collected.

1) Pre-EOP activities

The immediate needs are for an assessment of current model performance in the NAME region. This can be used to facilitate decisions on observing system priorities and serve as a valuable bench mark for future model improvements. An important start to this activity is the NAME model assessment program (NAMAP). The NAMAP effort is already in progress and involves both regional and global models. This is currently an unfunded effort. The initial activity was to perform control simulations of the 1990 summer season using the same SST analysis as a lower boundary condition. As anticipated, preliminary analysis indicates that each of the models successfully simulates a convective seasonal precipitation maximum over Southwest North America. However there are very substantial differences in the amounts and spatial distribution of precipitation, monsoon onset dates, and in basic internal fields such as surface fluxes and low level winds. For many of these variables there are no data that would allow quantitative validation of the model results. NAMAP will provide the first step in quantifying model and data uncertainties, and the ongoing analysis will yield specific targets for better observations during the summer 2004 EOP.

We anticipate further model bench-marking activities will be formulated as part of a NASA/CLIVAR sponsored workshop (to be held 4-5 June 2003) focused on the subseasonal (2 week to 2 month) prediction problem. The emphasis of that workshop is on global models and on the role of the tropics, especially the MJO. The goals of the workshop are to bench mark global model prediction performance on subseasonal time scales, to initiate a concerted model development effort to improve the simulation of the MJO in global models, and to foster an experimental MJO prediction program. The results of these activities should play a key role in helping to assess the ability of global models to capture the regional variability of the NAMS as well as the global connections that likely play key roles in the predictability of the NAMS on these time scales.

The high priority placed on improving the diurnal cycle and the fact that the diurnal cycle serves as an important prototype multi-scale development problem, makes it imperative that research and development efforts geared to addressing this problem be in place as early as possible in the NAME program. Ideally such efforts should already be well underway as the first EOP observations become available.

Data assimilation preparation activities will be critical to ensuring the NAME observations will be incorporated into operational and research data assimilation systems. It will be important to ensure that, as much as possible, NAME observations are included in operational data streams. It is also important to engage data assimilation developers at an early stage in order to ensure the successful assimilation of "non-standard" NAME observations.

2) EOP activities

- NCEP will provide near real time monitoring support for the NAME EOP. This involves the implementation of a regional version of NCEP's Climate Data Assimilation System (R-CDAS), and includes near real-time monitoring of land surface and hydro- meteorological conditions.

- NAME Forecast Operations Center activities will include evaluation of the quality of NCEP analyses and forecasts (both with and without NAME data) in an operational setting in support of the NAME field campaign. Also, the MM5 is available at the Tucson NWS office and adaptable for both single and ensemble runs.
- The NASA Terrestrial Hydrology Program is sponsoring a NAME Soil Moisture Field Campaign that includes the development of a network of in situ observations of soil moisture, temperature and precipitation over portions of NW Mexico, together with aircraft and satellite mapping. These data will facilitate the production of high-resolution soil moisture fields (e.g. from AMSR, TMI, and/or the Land Data Assimilation Systems) for initiating and validating high-resolution modeling studies in NAME Tier 1. The experiment will develop aircraft-based L-band passive microwave maps of soil moisture over two limited regions (order 100 km) during summer 2004 from which data products based on Advanced Microwave Scanning Radiometer (AMSR) on both Aqua (NASA) and ADEOS-II (NASDA) and from the TRMM Microwave Imager (TMI), will be extended over the entire NAME domain.
- Hydologic modeling of streamflow in Tier I, using the high resolution network of rainfall measurements as input to constrain models of soil moisture and groundwater infiltration.
- A NAME Hydrometeorology Working Group has been formed to identify and establish the framework for improved hydrologic simulations and prediction. Key activities include an inventory of current hydrographic and physiographic data over Mexico and the southwestern United States, and establishing new partnerships between water resource managers (Mexico and the U.S.) and the NAME research community towards dynamic water resources management.

3) Post-EOP activities

Many of the science and development activities will naturally be carried out and/or continue well after the EOP. These include on-going model development efforts, the various data assimilation experiments addressing issues related to the impact of the NAME observations, and predictability and prediction studies.

Specific studies include:

- Extension of NAMAP to include summer of 2004 (JJAS)
- Extension of LDAS retrospective data southward of 25 N to include all of Tiers 1 and 2, and backward in time to 1920s (vs 1950 at present)
- Continuation of diurnal cycle and more general multi-scale model development employing global and regional models

- NCEP will perform global and regional data assimilation and forecast experiments that explicitly test the impacts of NAME enhanced observations. The evaluation and verification will be based on physical processes related to the monsoon. Efforts will be made to diagnose and evaluate the Regional Reanalysis (RR) and examine key physical processes important to the North American Monsoon System including relationships between tropical easterly waves, moisture surges, midlatitude westerly waves and monsoon precipitation, precipitation regimes and forcing associated with the North American monsoon, feedback processes between precipitation and soil conditions, and links between the core monsoon region and the large scale.

- NCEP will carry out seasonal forecasts using the CDAS model both with and without NAME data to determine data essential for improved warm season precipitation forecasts. Selected downscaling experiments will be performed from the global model forecasts using the Regional Spectral Model (RSM). Short Range Ensemble Forecasts (SREF) will be made using R-CDAS initial conditions with/without NAME data to improve Quantitative Precipitation Forecasts (QPF). Tools will be developed and products disseminated to the NWS/SMN forecasters to determine the impact of NAME Data in the operational environment. Performance metrics will be developed for assessing improvements in warm season precipitation forecasts.

References

ESMF, 2001: A high-performance software framework and interoperable applications for the rapid advancement of Earth System Science. A NASA HPCC proposal in response to CAN-00-OES-01.

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