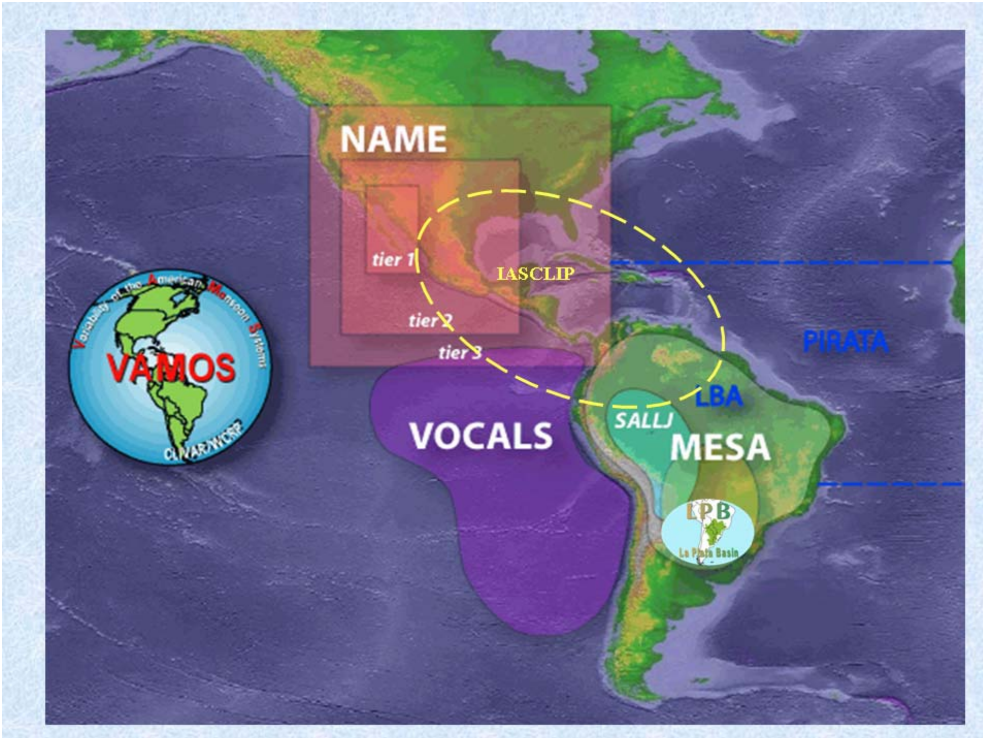
VAMOS Modeling and Data Assimilation For Improved Prediction:
A Multi Scale Approach



Extensive Contribution from the VAMOS Modeling Community

Modeling Working Group for VAMOS

2008 June

Comentario [g1]: Need to create and include a list of acronyms.

1. Introduction

This document presents a strategic overview of modeling and related data analysis and assimilation components of the VAMOS program. The overarching goals of VAMOS are to better understand the American Monsoons Systems (AMSS) in the context of the global climate system, to improve the capacity for seasonal to interannual climate predictions, and to assess the implications of anthropogenic climate change for the AMMS. Success in meeting these goals is critical to the World Climate Research Program (WCRP) strategic framework.

VAMOS focuses on rainfall and the probability of occurrence of significant weather events such as tropical storms, mesoscale convective systems, persistent and heavy rains associated with synoptic systems and temperature extremes. The term "monsoon system" encompasses not only the summer monsoon rainfall in the tropical Americas, but also the perturbations in the planetary, synoptic and mesoscale flow patterns that occur in association with it, including those in the winter hemisphere. In addition, the region of interest covers both the tropical and the extratropical Americas and surrounding oceans. This complexity in terms of spatial and temporal scales and climate system interactions (i.e., land-atmosphere or ocean-atmosphere) necessitates an integrated multi-tiered modeling and data analysis and assimilation strategy

The VAMOS modeling implementation plan presented in this document is based on an integrated modeling, data analysis and assimilation strategy, which will facilitate the panel in meeting its overarching goal. The strategy selected takes advantage of VAMOS enhanced observations, and is designed to simultaneously provide model-based guidance to the evolving multi-tiered VAMOS observing program. This modeling implementation plan also makes significant contributions to the WCRP strategic framework relevant activities conducted within CLIVAR, in particular with respect to assessing and improving seasonal forecasts and model simulations.

2. Modeling challenges for VAMOS

The model challenges in VAMOS are several and of the first magnitude. The region itself represents a unique challenge for climate modeling and data assimilation. since it is 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.

Land surface processes play important roles in Pan-American climate variability. 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. The Amazon region acts as a source of humidity for the SAMS, through the large amount of evapotranspiration. Deforestation in the region can affect the energy balance and the atmospheric circulation over South America (e.g., Nobre et al, 1991; Robertson et al, 2003), and, perhaps have a remote influence on the evolution of ENSO (e.g., Hu et al., 2004). The La Plata Basin (LPB) Regional Hydroclimate Experiment endorsed by CLIVAR and GEWEX is an activity that will focus on this aspect, which will also lead to model improvements. In fact, interactions with the Large Scale Biosphere-Atmosphere Experiment in Amazonia (LBA) have lead to improved understanding of the physical, biochemical, hydrological and climate mechanisms in the region. Numerous studies have also begun to explore the complex relationship between antecedent and concurrent land surface conditions and the NAMS (e.g. Zhu et al., 2007, Matsui et al., 2005, Dominguez et al., 2008)

In addition to the surface conditions on SST and soil moisture, atmospheric aerosols can have a significant influence on the climate of the Americas. Aerosols are an important atmospheric constituent in southwestern North America and Central South America. When the synoptic circulation is weak, anthropogenic sources from urban areas can significantly 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 green vegetation is sparse, soils are dry and surface winds are strong. In South America, biomass burning, mainly in central regions, is the main source of aerosols for the atmosphere. The pollutants are transported southward by the mean flow and reach more populated areas of the continent. Although this occurs mainly in the austral winter, the annual energy budget may be affected by the radiation changes. Large cities of South America are also sources of urban pollutant to the atmosphere, and, together with the heat island effect, can produce local forcing in the energy budget.

Aerosols are also important in the oceanic regions whose variability is linked to the American Monsoon systems region. In the southeastern Pacific where the VOCAS component of VAMOS is focused, the geographical diversity in the distribution of atmospheric aerosol and its potential impacts on stratocumulus cloud and radiation results in feedbacks between aerosols and boundary layer cloud evolution. Near the equator, humid lower-tropospheric easterly flow overlies the cloud-topped boundary layer, likely affecting its radiation balance, turbulence and microphysics. South of 15 S, the air above the boundary layer tends to be very dry and clean, having mainly come from the southwest out of storm systems in mid-latitudes and the South Pacific Convergence Zone. The exception is near the South American coast, where along-shore winds allow both industrial and biogenic aerosols to accumulate both within and above the boundary layer.

In regard to prediction, the variability of the American Monsoon Systems exhibit large-scale coherence with several known phenomena that have important impacts on diurnal to intraseasonal, interannual and even decadal time scales. Hence there are building blocks that 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 pan-American monsoon has also identified several others, including the Madden-Julian Oscillation (MJO), and the Pacific Decadal Oscillation (PDO), the Tropical Atlantic SSTs. The relative influences of these phenomena on the warm season precipitation regime over the region are not well understood. Conversely, the large scale convective maximum associated with the monsoon affects circulation elsewhere, and understanding and predicting these effects remains a daunting challenge. The role of teleconnections in the climate variability of both regions has been demonstrated in several studies (Mo and Paegle, 2001; Cunningham and Cavalcanti, 2006; Leathers et al, 1991, Hu and Feng, 2001, 2007; Sheridan, 2003). The Pacific North America (PNA) and the Pacific South America (PSA) patterns can link tropical Pacific convection to anomalies over North America and South America, respectively. Our ability to simulate these global scale interactions are integral to successful seasonal predictions over the Americas.

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 land state including soil moisture). In addition to understanding the role of remote SST forcing throughout the Pacific and Atlantic Oceans, we must understand the nature and role of nearby SST anomalies such as those that form in the Gulf of California, the Gulf of Mexico, the Intra American Sea, the south eastern Pacific, tropical Atlantic and the South Atlantic, just to name a few. The land surface has many memory mechanisms in addition to soil moisture, especially over the western US and the lee of the southern Andes. Snow extends surface moisture memory across winter and spring.

3. The VAMOS program

In order to address the overarching goal, VAMOS has established three complementary science programs: NAME, MESA and VOCALS, and is in the process of developing IASCLIP program. The **NAME (North American Monsoon Experiment)** program focuses on improving the prediction 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). Characteristics of NAMS are presented in Adams and Conrie (1997) and Gutzler et al (2003). The **MESA (Monsoon Experiment for South America**) program emphasizes the understanding of large scale, regional and local mechanisms associated with warm season precipitation in South America and their predictability on time scales ranging from sub-seasonal to multi-decadal and longer. Features of the South American Monsoon System (SAMS) are described in Nogues Paegle et al (2002). The overall goal of **VOCALS (VAMOS Cloud Atmosphere Land Study**) program is to develop and promote scientific activities leading to improved understanding, model simulations, and predictions of the southeastern Pacific (SEP) coupled ocean-atmosphere-land system, on diurnal to interannual timescales. The two leading concerns of VOCALS are (1) the physical processes affecting the radiative and microphysical characteristics of the persistent stratocumulus clouds of this region, and (2) the ocean budgets of heat and other constituents, and how they determine the sea-surface temperature (SST) throughout this region. The overall goal of **IASCLIP (IntraAmericas Study of Climate Processes)** program is to promote, coordinate, and organize research activities that aim at improving our understanding of climate and hydrological processes in the inter-American seas and improving our ability to represent these processes in global climate models. The IASCLIP program embraces two research themes: (1) mechanisms for seasonal to interannual variability of rainfall in the inter-American seas region and (2) the roles of the inter-American seas region in the climate variability of the Americas and the Western Hemisphere

The VAMOS sub-programs NAME, MESA and VOCALS have all contributed to generate a unique set of field observations. For example, the NAME 2004 field observations provided a comprehensive short term (one warm season) depiction of precipitation, circulation, and surface conditions in the core North American monsoon region, and ongoing modeling activities carefully examine how well the models perform in this region. Many diagnostic studies from the 2004 NAME field campaign as well as several modeling studies are documented in a special issue for the J. of Climate (May 2007). The South America Low Level Jet Experiment (SALLJEX; Vera et al. 2006) was another successful VAMOS field campaign, and the resulting data is currently being used in many applications: impact of enhanced observations on the analyses (both GDAS and CPTEC), low-level jet diurnal cycle, MCS characterization, and case studies. (preliminary results of these activities can be found in CLIVAR Exchanges, Special Issue Featuring SALLJEX). It is expected that LPB will also provide a valuable set of observational data through Doppler radar, flux towers and enhanced upper air measurements (Berbery et al. 2005). Data from the La Plata Basin Project (LPB) will also be used to improve multi-scale aspects of monsoon predictions. Similarly, data from the SEP region during the Chilean CIMAR-5 cruise along 27 S from 70-110 W and the EPIC 2001 stratocumulus cruise as well as the planned "radiator fin" experiment will be integrated into a comprehensive modeling and data assimilation strategy. An experiment for the South America Monsoon, to establish the detailed aspects of the system is needed. There is a lack of stations, mainly related to soundings, in large areas of the SAMS, and a field campaign in the core of the system could provide the observation data for diagnostics and initial conditions to models. A key aspect of the modeling strategy is to develop partnerships among the VAMOS observational, model development and data assimilation, and forecasting communities with the specific goal of assessing and improving predictions.

The VAMOS sub-programs NAME, MESA and VOCALS have all developed separate modeling strategies specific to the individual sub-program, and in the case of IASCLIP are in the process of developing these plans. The plan outlined here, however, extends beyond these individual plans by: (i) focusing on science questions and numerical experiments that are relevant across all three sub-programs and (ii) providing linkages to the global scale modeling, observation and prediction activities of CLIVAR, WCRP and operational centers. For a more complete description of the NAME, MESA and VOCALS modeling plans please see http://www.clivar/organization/vamos/vamos_publications.php. The IASCLIP plan will be available in the near future.

4. Objectives of VAMOS modeling

Within the VAMOS program, the modeling component has several important objectives in the context of American Monsoon Systems:

1. To successfully simulate their mean and seasonal aspects,
2. To simulate their lifecycles and diurnal cycles, as well as their intraseasonal, interannual and interdecadal influences,

3. To investigate their predictability and to make predictions to the extent possible,
4. To improve the predictive capability through model development and analysis techniques, and
5. To assess the implications of climate change on their behavior.

The VAMOS modeling plan 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 pan-American 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. (Note: Research plans related to improving the basic diagnostic understanding of VAMOS programs are contained within their respective program science plans.)

One of the underlying premises of VAMOS modeling is that while many of these processes are, indeed, local to the specific region of interest, there are particular problems and questions relevant throughout the pan-American region. For example, 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. The relatively poor simulation of the diurnal cycle, some aspects of the low level jets, planetary boundary layer processes, clouds and ocean mixing are all Pan-American monsoon problems that necessarily require a regional multi-scale focus but also are critical issues for improving global model simulations and predictions. 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 that integrates across all three science programs in VAMOS*. As such, we require information about the pan-American monsoon region and related variability that extends across all spatial scales 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 modeling issues/problems described below require a multi-scale or multi-tiered approach with an emphasis on how the various space and time scales interact and are represented in the global and regional models. This strategy is also necessarily "VAMOS inclusive" in the sense that they necessarily integrate all three science programs.

To achieve its objectives, VAMOS has adopted a multi-scale approach, which includes monitoring, diagnostic and modeling activities on local, regional, and continental scales. In this multi-scale approach, local processes are embedded in, and are fully coupled with, larger-scale dynamics.

5. VAMOS modeling strategy

The modeling strategy is organized into four science themes: (A) simulating, understanding and predicting the diurnal cycle, (B) predicting and describing the pan-American monsoon onset, mature and demise stages, (C) modeling and predicting SST variability in the Pan-American Seas, and (D) improving the prediction of droughts and floods. It is clear that all four of these science themes are interdependent; indeed, some of the scientific questions such as issues related to scale interactions transcend all four themes. Nevertheless, this organizational structure provides the focus required to tackle the most important modeling issues. Over time these themes will need to be revisited and modified according to improvements in modeling and understanding. The principal cross-cuts among these themes include improving prediction made with global models, multi-scale interactions, data assimilation, and analysis and model improvements. Each science theme includes a comprehensive assessment of how well the models simulate and predict the relevant phenomena on multiple space and time scales. This assessment necessarily requires the identification of indices and metrics for model evaluations and prediction verification. The assessment also involves collaboration within CLIVAR (e.g., WGSIP, WGCM) and with operational forecast providers (NCEP, IRI, CPTEC, ECMWF) in terms of access to coupled prediction and simulation data. The NOAA Climate Test Bed (CTB) also provides a rich data set of coupled predictions and simulations, and, in the future, a multi-model facility for numerical hypothesis testing. Indeed, hypothesis testing and predictability assessment is a major focus of the VAMOS modeling strategy, and each theme enumerates a series of questions that require numerical experimentation.

Comentario [g2]: Need a list of acronyms.

A) Simulating, Understanding and Predicting the Diurnal Cycle

Research has shown that the diurnal cycle of precipitation varies across regions of the continents of North and South America. In North America precipitation maxima are found in late afternoon in the western and eastern portions of the United States, while in the central Great Plains there is a nocturnal maximum (Carbone et al., 2002). Over Mexico, the diurnal cycle is strongly phase locked to the elevated terrain of the Sierra Madre Occidental, Sierra Madre Oriental, Sierra Madre del Sur and the trans-Mexico volcanic belt. (e.g. Gochis et al., 2007, Lang et al., 2007) Likewise, in much of South America, precipitation maxima are seen during various times of the day, with some areas of the Amazon experiencing both morning and afternoon rainfall peaks (Saulo et al. 2005; VPM8). A nocturnal maximum is observed in subtropical South America, near the outflow region of the Andes low level jet. There is also a strong diurnal cycle in clouds and vertical velocity in the south eastern equatorial Pacific (Garreaud and Munoz 2004).

The diurnal cycle is important throughout the Americas. For instance, 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 and SAMS 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 (synoptic patterns and teleconnections), and thus is a universal and multi-scale problem. The presence of complex terrain further complicates the mechanisms for the diurnal cycle. Current models have difficulty simulating the regional variations in the diurnal cycle so it is an important problem for multi-scale modeling.

A strong diurnal cycle exists in the coverage and liquid water content of marine stratocumulus over the subtropical oceans (Rozendaal et al. 1995, Wood et al. 2002), with an anomalously strong cycle over the VOCALS region for reasons that are not completely understood. Recent mesoscale model simulations over the SEP region have identified that a diurnal subsidence wave, forced by dry convection on the western slopes of the Northern Chilean and Southern Peruvian Andes cordillera, propagates over 1000 km out over the SE Pacific ocean (Garreaud and Muñoz 2004). This wave feature appears in reanalysis datasets and in Quikscat data and could modulate the strength and phase of the diurnal cycle in MBL depth and cloud cover. An improved understanding of the factors controlling the strength of the diurnal subsidence wave is needed. Regional climate models could help elucidate the wave's synoptical, seasonal and ENSO variability and possible connections with circulations over the South American continent.

The major VAMOS diurnal cycle modeling activities are enumerated below. It should be noted that diurnal cycle cross-cuts the earlier science themes, thus there are overlapping activities.

1. As with the other science themes, indices and metrics need to be identified in order to assess how well the models capture the diurnal variations. There have already been some successful activities under the NAME project (i.e., NAMAP, NAMAP2) which can be leveraged in this regard.
2. Similar to the NAMAP and NAMAP2 projects, a comprehensive evaluation of how well the models simulate and predict the diurnal variations will be conducted. The need for diurnal resolution in model data has been noted by CLIVAR-WGSIP and WCRP-TFSP and the necessary fields at the appropriate temporal and spatial resolution are being saved in ongoing simulation and prediction activities. For the NAMS, there were the diurnal cycle studies to examine the ability of the GFDL, NCEP, and NASA models to depict diurnal cycle. Many experiments were performed using different models to examine the impact of model resolutions and physics on the diurnal cycle simulations during summer (Lee et al. 2007).
3. Numerical experiments will be proposed to examine a number of important questions. For example, what role does the local land state play in the diurnal variation of temperature and rainfall? What is the diurnal variation in moisture supply and what is the role of the low level jets? How does the diurnal cycle over the continents and ocean interact? What is the impact of the land-sea breeze?

4. There are also important multi-scale questions related to the diurnal cycle that require numerical experimentation. What is the rectification of the diurnal cycle on sub-seasonal and seasonal time scales? What role does the diurnal cycle play in extreme events?

5. How do the MCSs impact the related diurnal cycle given their relatively long life cycle?

6. How does the coupling between the LLJ and organized convection impact the diurnal cycle?

B) Predicting the Pan-American Monsoon Onset, Mature and Demise Stages

The main climatological circulation features of the SAMS are reasonably well simulated by AGCMs and regional models. In the SAMS region, the typical summer features, such as the Bolivia High, Atlantic Trough, SACZ, Subtropical Atlantic High, ITCZ position, are well simulated by the models. These climatological monsoonal features have large annual variations, which are also captured by the model simulations. Despite these modeling success there are, however, notable systematic error in Amazonia and in the SACZ region. These systematic errors are, in part, responsible for the relatively low correlation between the observed and predicted precipitation anomalies in the region (Marengo et al, 2003). The models capture some features of the low level jet to the east of the Andes, yet systematic errors continue to limit forecast skill (Cavalcanti et al, 2003, Saulo et al. 2000; Douglas et al. 1999). Put simply, most models capture the large scale circulation features, but fail to simulate the statistics of regional precipitation patterns and how they are modulated by the large scale circulation.

Comentario [g3]: Apologies for word-smithing here but it is not reasonable to ever expect global model to properly simulate 'local' precipitation, given excess unresolved processes. However, it is reasonable to expect that they should be able to properly simulate the regional statistics of rainfall (frequency, intensity , diurnal cycle and relationships to regional terrain gradients).

In the NAMS region, the models are capable of simulating the evolution of a summer season precipitation maximum near the observed continental core of the North American monsoon. There are, however, important differences in the monthly evolution and diurnal cycle of precipitation generated by the models (Gutzler et al, 2003). The models show significant delays in monsoon onset (defined in terms of precipitation) compared to observations. The interaction of convection with topography is different among the various models indicating a large degree of sensitivity to the convective parameterization (Gochis et al. 2002). Differences among the models also occur in surface turbulent fluxes, especially in the afternoon hours when sensible and latent fluxes tend to be at their maximum. The simulation of intense convective precipitation in regions of complex terrain remains a daunting challenge to dynamical models, and improvements in convective parameterization are a fundamental prerequisite to enhancing predictablility of climate in the NAMS domain (Gutzler et al, 2003).

In terms of modeling the monsoon life-cycle, the following activities and research questions are proposed:

1. Define metrics/indices for the American monsoon systems. These metrics and indices will be verifiable, objective quantitative measures that can be used to evaluate model performance, but that can also be used to monitor the current state of the monsoon system. These measures should encompass the essential features of the mean monsoon and its variability on all relevant space and time scales.

Possible metrics include:

- Circulation features such as the regional Hadley cell intensity, Walker cell intensity, LLJ transport
- More traditional statistical measures such as biases and skill scores

2. Once the above metrics have been defined, the current state-of-the-art in prediction and simulation will be assessed. This activity will be conducted in collaboration with CLIVAR simulation and prediction providers (i.e., WGSIP, WGCM) and forecasts made available by operational centers (i.e., NCEP, IRI, CPTEC, ECMWF). This comprehensive evaluation of operational forecasts is essential for the end user knowledge base and for model development and improvement activities. Again, the issues of how well the models capture the scale interactions are essential to model development activities and to establishing utility in the forecast user community

3. The model simulations will also be evaluated in terms of the low frequency (including climate change) variability of monsoon onset and duration. The influence of sub-seasonal and synoptic systems will also be investigated. Multi-scale interactions (from days to decades) in the model simulations will be assessed. In addition to the assessment of the current state-of-the-art in American monsoon system simulation and prediction, numerical experiments will be made to investigate key monsoon questions and sources of predictability:

(a) Numerical experiments will be performed to investigate the relative roles of land surface versus ocean processes in the monsoon life cycle and its variations. How does soil moisture from the previous season influence the monsoon onset and demise? What are the roles of Atlantic versus Pacific SSTs in monsoon life cycle? How does land-use change influence the monsoon life cycle?

(b) What are the interhemispheric influences of the SAMS and NAMS? What role does the NAMS play in the seasonal transition of the SAMS and vise-versa?

(c) Numerical experiments will be conducted to investigate how different time-scale variability impacts the monsoon life cycle. What is the influence of synoptic systems on monsoon onset? What is the interplay between the diurnal cycle and the monsoon life cycle? What role does intraseasonal variability play in monsoon onset? Are there decadal variations on monsoon life cycle?

(d) In terms of model improvements, physical parameterization and resolution sensitivity experiments are envisaged. What spatial resolution is required to adequately resolve the convective systems and their diurnal cycle? What resolution is required to capture the nocturnal maximum in the low level jets? What is the sensitivity of the monsoon life cycle to convective or planetary boundary layer parameterization?

C) Modeling and Predicting SST Variability in the Pan-American Seas

Intercomparisons of general circulation models of the coupled atmosphere-ocean system (CGCMs), including seasonal-to-interannual forecast models used for ENSO prediction have documented large SST biases in most models, leading to errors in the distribution of the annual mean and seasonal cycle of tropical convection and winds (Mechoso et al. 1995; Davey et al. 2001). Most coupled models exhibit ENSO-like variability, but its period tends to be shorter (quasi-biennial) and often more regular than observed (e. g. Kiehl and Gent 2004). Most atmospheric general circulation models (AGCMs) have major difficulties in predicting the seasonal cycle and interannual variability of SEP boundary-layer cloud cover and its radiative effects, even when SST is appropriately prescribed. Large errors also occur in the Atlantic in terms of both the mean and the variability. Indeed, most current coupled GCMs produce a tropical thermocline that has an east-west slope that is opposite of the observed. These biases are not well understood, but are believed to have a significant deleterious impact on our ability to predict climate in the Pan-American region. They presumably stem from errors in many physical parameterizations as well as inadequate vertical and horizontal model resolution. Deep cumulus convection, ocean upwelling and air-sea exchange along the equatorial cold tongue are challenging to parameterize, and undoubtedly play a role in these biases. Better observations of these physical processes were a focus of the East Pacific Investigation of Climate (EPIC) (Cronin et al. 2002; Raymond et al. 2003), and a major goal after EPIC is synthesis of those observations into parameterization improvements in global models ultimately leading to improved prediction.

The Climate Process Teams, CPT (in collaboration with the Climate Change Prediction Programs DoE ARM Parameterization Testbed CAPT - see http://www-pcmdi.llnl.gov/projects/model_testbed.php) is currently using EPIC2001 Sc datasets for direct comparison with forecast-mode intercomparisons with the NCAR and GFDL GCMs using both the current physics packages and proposed improvements. By running climate models in forecast mode and evaluating with field data, it is possible to gain considerable insight into model parameterization deficiencies in an computationally efficient manner. As new datasets are produced as part of VOCALS, these too will be used for such comparison. Within VOCALS there has been renewed collaboration with ECMWF in this regard, getting new ECMWF analyses for that period, both for initializing our AGCMs in forecast model. This should help to mitigate the 'too shallow inversion' problem we have had with using ERA40 for initializing the GCMs. This problem results in cloud albedo biases that will affect the SST in the coupled climate system. Both ECMWF and the CPT are very interested in carrying out similar analyses for the other PACS cruises in 2003-2005.

The SST biases in the SEP, which are particularly large and important, are believed to stem both from errors in the surface heat budget and in ocean heat transport. Hence a central goal of VOCALS is to improve parameterizations of atmospheric cloud-topped boundary layers and lateral ocean mixing by mesoscale eddies. Part of the collaboration between VAMOS at large and VOCALS is to gather SEP observations and compare them with both regional and global coupled model simulations of the ocean heat budget, to better understand the regulation of SST and cloud cover across the SEP.

Climate variability and change in the pan-American region is strongly linked to SST over the Pacific and Atlantic Ocean. For example, two phenomena that cause large rainfall interannual variability over South America, and that have apparent links with SST anomalies over the tropical Atlantic are the Intertropical Convergence Zone (ITCZ) and the South Atlantic Convergence Zone (SACZ). Yet, the linkages of such convergence zones with SSTA are quite diverse, as the former seems to be strongly modulated by interhemispheric gradients of SSTA and the latter is negatively correlated with SSTA locally. As such, an important integrating element of this VAMOS modeling strategy is to examine the global scale coupled simulations made available through PCMDI and coupled prediction made available through CLIVAR-WGSIP and the WCRP task force for seasonal prediction (TFSP) activities. The importance of a local analysis of results from the global models cannot be overstated. The collaboration with CLIVAR-WGSIP and WCRP-TFSP provides the relevant modeling and prediction expertise and the VAMOS community local scientific expertise.

The model simulations and predictions will be evaluated with respect to the following issues:

1. How do the Pan-American seas interact with SAMS and NAMS variability? This question necessarily includes examining the relative roles of Pacific versus Atlantic SSTA in modifying the monsoon systems; however; special attention will be given to the impact of "non-ENSO" forcing from the tropical Atlantic. The expectation is that the role of the Atlantic will be markedly different from the Pacific in particular with respect to how the monsoon systems modify the variability in the Pan-American seas. For instance, coupled modes of variability in the tropical Atlantic are likely to be more strongly affected by monsoonal atmospheric flow relative to the Pacific. Moreover, what are the mechanisms by which the Western Hemisphere Warm Pool (WHWP) influences rainfall in the Pan-American region?

2. How do coupled ocean-atmosphere feedbacks impact local co-variability? For example, the rainfall variability over South America is intimately connected to the Atlantic Inter-Tropical Convergence Zone (ITCZ) and the South Atlantic Convergence Zone (SACZ). Yet, the relationships of these convergence zones to SST are very different. The Atlantic ITCZ is modulated by the interhemispheric gradients of SST, whereas the SACZ is negatively correlated with local SSTA. Why is the rainfall in the inter-American seas region largely concentrated to land region as opposed to the ocean?

3. How do clouds and atmospheric planetary boundary layer processes interact with the upper ocean in the Pan-American seas and how can increased understanding be used to improve models and predictions? We need to ascertain the role of cloud microphysical and macrophysical variability in affecting the SST in the coupled ocean-atmosphere climate system over the SE Pacific. The essential goal is to explore the couplings between clouds and SST over the region. How does the diurnal variability impact the seasonal variability and how does the seasonal variability and interannual variability modulate the diurnal variability? What are the multi-scale interactions associated with intra-seasonal variability? What resolution is required to capture the necessary dynamical and physical processes on these multiple space and time scales?

4. How does variability over land remotely influence the surrounding seas? Are the impacts of land surface largely thermal or mechanical? How does the neighboring land influence the coastal winds in the East Pacific? How does deforestation or land-use change modify the local heat sources and ultimately remotely influence the ocean fluxes?

The above issues/questions also serve as science themes for hypothesis driven numerical experimentation.

D) Improving the Prediction of Droughts and Floods

Extreme events strongly impact society, since they affect economy and can cause loss of human life. Urban areas, mountainous areas, agricultural areas and river basins as a whole can be affected by these events. There are several regions throughout the Americas that are impacted by the occurrence of precipitation extreme events, which are frequently linked to floods and/or droughts. The La Plata basin is one of such areas which, comprises the richest area of southeastern South America being the fifth largest basin in the world: about 50% of the combined populations of Brazil, Argentina, Paraguay, Uruguay and Bolivia, live within the basin. Droughts in central South America Monsoon region (Southeastern and Central Brazil) have a strong impact on water resources of large areas of Brazil, and in hydroelectricity power, considering that the rainy season is concentrated in a few months. On the other hand, excessive precipitation during the rainy season causes floods and mountain sliding on southeastern coastal areas of very populated cities. Similarly, droughts and floods throughout the NAMS region have significant societal impacts.

Consequently, it becomes of paramount importance to address the issue of the prediction of floods and droughts. Again, the ideal approach to this issue is multi-scaled, since it has been well documented that extreme events are modulated by space and time scales that go from interannual (e.g. El Niño driven flooding episodes in southeastern South America) to decadal (e.g. in northern Mexico which suffered drought for much of the late 1990's). Many of these drought are linked to the decadal trends in the North Pacific. Over the United States, ENSO has impact on precipitation over the Great Plains) to synoptic and even smaller - the occurrence of a series of meso-scale convective complexes over an area can critically impact river discharge producing severe floods (over the western United States, floods are often caused by heavy snow in winter and rapid warming in spring or summer).

Comentario [g4]: This paragraph needs some work. Here are some suggestions…

It is important to mention that the improvement in the prediction of droughts and floods, involves a wide range of issues including the identification of features that produce extreme events and their prediction -in the variety of time and space scales that they occur- to the definition of parameters and metrics that identify what will be recognized as a risk of flood/drought. Finally, to generate products that can be used by hydrological models has to be discussed.

In what follows, specific question that might lead to an improvement of flood and drought forecasts are listed along with modeling activities that address these questions:

1. The identification and quantification of what constitutes an extreme event is non-trivial. Identification and quantification of extreme events is one element of this research plan. Some possibilities include: the Mississipi river flood in 1993, the Paraná river flood in 1982-1983, Argentina 2003-2004 drought, Southeastern and Central Brazil drought in 2001, and Southern Brazil flood in 1982. What are the necessary fields for drought and flood monitoring on all space and time scales? What are the indices or metrics required for monitoring and predicting the occurrence of droughts and floods

2. How well do models represent the conditions associated with the occurrence of extreme precipitation events? Again, the currently available model based predictions and simulations will be assessed. Do the models capture the extreme events in terms of areal extent, magnitude and duration? Do the models capture the related large scale circulation features?

3. What are the multi-scale interactions associated with simulating and predicting extreme droughts and floods? What is the interplay between intraseasonal variability and the occurrence of extreme events? How are droughts and floods detected in the diurnal cycle? What are the multi-scale interactions associated with very long term (i.e., decadal) drought?

4. The Mid-Summer Drought (MSD) can be seen in climatologies from the eastern North Pacific to Florida and the eastern Caribbean, and it has importance socioeconomic impacts. Understanding the mechanisms for the seasonal and interannual variability of the MSD is critical to its prediction. While simulating the MSD in global models may not be difficult, prediction the time and intensity remains a challenge. Issues include understanding the relative importance of the North Atlantic Sub-Tropical High (NASH), the ITCZ, SST, LLJs, and land effects.

5. In terms of improving predictive capability and determining sources of predictability numerical sensitivity experiments are proposed. Specifically, local versus remote processes will be assessed. What are the relative roles of local land surface processes versus remote SST forcing (Pacific and Atlantic)? How is long-term drought related to local soil moisture anomalies versus remote soil moisture anomalies? What are the simulated drought and flood sensitivities with respect to resolution and parameterization?

5. Data assimilation, Analysis and Assessing Observing Systems

Assimilation systems need to evolve so that special observations obtained in field campaigns at high resolution are accepted by the assimilation and so that the physics that the observations reflect are included in the analysis. This involves using observations to advance phenomenological studies, incorporating advances into analysis models and invoking such models for data assimilation. These advances are of particular importance for latent-heat driven circulations where feedbacks exist between forcing and circulation*)* The assimilation schemes should take into account the temporal changes, as field observations that capture this time-dependent process will be rejected in assimilation systems based on balanced states, resulting in analyses that will fail to show the potential gains obtained from field campaigns. Similar concepts apply to boundary layer observations that control the onset and demise of organized convection.

The observations obtained from the NAME 2004, SALLJEX, EPIC field campaigns should provide valuable new insights into the mechanisms and phenomena in these core regions and 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 these core regions. In this section, we discuss the role of data assimilation in enhancing the value and extending the impact of the core region observations to allow addressing issues of model quality and monsoon variability on scales that are Pan-American. In addition, data assimilation can provide an important framework for quantifying the impact of observations, and for assessing and understanding model deficiencies. (Preliminary results indicate that for both NAME and SALLJ the impact of soundings over a small domain like the Tier I for NAME and SALLJ area on analysis and forecast is positive but small. For NAME, we found that the impact depends on the model and other input data. The assimilation of soundings will improve analyses over the area that the model has the largest uncertainties, but it will not correct all model errors.)

The basic goal is the creation of the best possible research quality assimilated data sets for studying the Pan-American 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, estimates of the various phenomena such as Gulf surges, low level jets, convective zones and tropical easterly waves, while the latter provide information (at a somewhat lower resolution) about linkages between the Americas and global-scale climate variability and the role of remote boundary forcing. 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. If observations are found to improve monsoon forecasts or simulations, recommendations will be made to continue such data collection beyond 2004. Parallel simulations should be performed employing a number of regional and global models including those employed in the assimilation systems. Off line data assimilations should also be performed using different data assimilation schemes to avoid biases due to the data assimilation procedures. Here efforts should also take advantage of existing operational and special reanalysis data assimilation products. 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 after a brief spin up or down period (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 Earth System Modeling Framework (ESMF) can facilitate carrying out such an analysis on a wider range of climate models.

Comentario [g5]: This isolated reference to ESMF is vague. What is the point here? How will ESMF directly contribute to data assimilation research?

In summary, the specific goals to be addressed through data assimilation are to assess the impact of the VAMOS 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 Pan American monsoon systems.

Current and planned numerical studies include:

i. The additional soundings performed during the SALLJEX were introduced in the global dataset, through the PSAS scheme, generating a reanalysis dataset (Cavalcanti and Herdies, 2004). This set has been used to analyse the atmospheric conditions during the experiment and to verify the impact of extra-data. Skill of model predictions performed with the Eta regional model and with the CPTEC/COLA AGCM using initial conditions from this reanalysis data and from higher resolution analysis are in development.

ii. Data impact studies over the NAME EOP period were performed to examine the impact of precipitation assimilation and the NAME special soundings. The impact of precipitation assimilation shows the largest effect over the areas that the model has the largest forecast errors. The impact of soundings is limited to the NAME core region and has relatively small but positive impacts on short term forecasts. However, even with the precipitation assimilation and soundings, there are still large uncertainties in analyses. Similar studies will be performed in the SAMS region.

6. Prediction and Global-scale Linkages

One of the key measures of success of the VAMOS program will be the extent to which predictions of the pan-American Monsoon are improved. The prediction problem for VAMOS 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

In the forecast environment, SSTs and soil moisture are unknown. The boundary conditions are either predicted or based on persistence. Even if the current coupled models are able to accurately predict SSTs in the Tropics, there are still large errors in the North Pacific and Atlantic basins. The atmospheric components of coupled ocean-atmosphere models typically have relatively coarse resolution, rendering them inappropriate for accurate monsoon forecasts in many regions including coastal seas. Accurate estimates of SST and soil moisture (and other land surface conditions) are very important prerequisites for improved warm season precipitation prediction on seasonal-to-interannual timescales.

A key issue to be addressed by VAMOS 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. For example, how sensitive are model simulations of NAMS and SAMS 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 south eastern Pacific?

The strategy for improving prediction is three fold:

(i) As outlined in the discussion of the science themes, indices and metrics for the Pan-American monsoon will be defined and currently available hindcast experiments (i.e., NOAA-CTB, DEMETER, SMIP) will be evaluated against observations. A necessary aspect of improving prediction is to make quantitative statements about current skill levels, which can then be used to measure progress. This assessment is precisely the kind of analysis that is being called for in the international seasonal prediction community (i.e.,WGSIP, WCRP-TFSP, US CLIVAR PPAI). In addition, we intend to engage the operational prediction community by evaluating the fidelity of operational seasonal forecast and by demonstrating how VAMOS data (field campaigns) could potentially be used to improve forecast through data assimilation and model improvement.

(ii) The VAMOS community will engage in experimental prediction testing parameterizations, resolution sensitivity, scale interactions, model improvements and data assimilation strategies. The VAMOS community will demonstrate how local observations can be used to improve the large scale models and forecasts. Again, the interaction with the international research and operational communities is essential in this regard.

(iii) The VAMOS community will explore and mine new potential sources of predictability. As part of this process numerical experiments will be made to document the current estimates of the limit of predictability. Numerical experiments will address the impacts of land-atmosphere and ocean-atmosphere coupling. The importance of remote versus local boundary conditions will be documented in numerical experiments.

The VAMOS community provides unique contributions to the model development in areas of land surface processes (MESA and NAME) and boundary layer clouds and ocean mixing (VOCALS). Moreover, VAMOS activities continue to contribute for improvements in the representation of orography, cloud-radiation interactions, diurnal cycle and atmosphere-ocean interactions. VAMOS will continue to use models for coordinated numerical hypothesis testing experiments and assess the impact of data collected in process studies on predictability and prediction skill on the global scale. The multi-scale aspects of the VAMOS science and modeling strategies are at the forefront of the WCRP strategic framework for unified modeling in the prediction of weather and climate from days to decades.

References

Comentario [g6]: Refs incomplete, I've tried to list all missing citations

Adams, D. K. and A. C. Comrie, 1997: The North American monsoon. Bull. Amer. Meteor. Soc., 78, 2197-2213.

Berbery, E. H. and co-authors, 2005 (draft)**.** La Plata Basin (LPB) Continental Scale Experiment. Implementation Plan (available at http://www.atmos.umd.edu/~berbery/).

Carbone, R.E., J. D. Tuttle, D. A. Ahijevych, and S. B. Trier, 2002: Inferences of Predictability Associated with Warm Season Precipitation Episodes. J. Atmos. Sci., 59, 2033–2056.

Cavalcanti, I. F. A., J. A. Marengo, P. Satyamurty, C. A. Nobre, I. Trosnikov, J. P Bonatti, A O. Manzi, T. Tarasova, L. P. Pezzi, C. D'Almeida, G. Sampaio, C. C. Castro, M. B. Sanches, H. Camargo, 2002. Global climatological features in a simulation using CPTEC/COLA AGCM. *J.Climate, 15, 2965-2988.*

Cavalcanti, I. F. A., C. A. Souza, V. E. Kousky, 2002. The low level jet east of Andes in the NCEP/NCAR reanalyses and CPTEC/COLA AGCM simulations. VAMOS/CLIVAR WCRP Conference on South American low level jet. Sta Cruz de la Sierra, Bolivia, Feb. 2002. Available at *http://www-cima.at.fcen.uba.ar/sallj_conf_extabs.html.*

Cavalcanti, I. F. A., and D. Herdies, 2004: Data assimilation study using SALLJEX data. CLIVAR Exchanges, 29 (9).

Cronin, M. F., N. Bond, C. Fairall, J. Hare, M. J. McPhaden, and R. A. Weller,2002: Enhanced oceanic and atmospheric monitoring underway in Eastern Pacific. EOS, Transactions, AGU, 83(19), pages 205, 210-211, 7 May.

Cunnighan, C. C.; I. F. A. Cavalcanti, 2006. Intraseasonal modes of variability affecting the South Atlantic Convergence Zone. Accepted in Int. J.Climat.

Davey, M. K., and Coauthors, 2001: STOIC: A study of coupled GCM climatology and variability in tropical ocean regions. *Clim. Dyn*., **18**, 403-420.

Dominguez, F., P. Kumar, and E.R. Vivoni, 2008 : Precipitation recycling variability and ecoclimatological stability – A study using NARR data. Part II: North American Monsoon region. J. Climate, In press.

Douglas, M., M. Nicolini and C. Saulo, 1999. The low-level jet at Santa Cruz, Bolivia during January-March 1998 Pilot Balloon observations and model comparisons. Preprints of the Global Change Conference, Dallas, USA, january 1999, 4pp.

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.

Garreaud, R. D., and R. Muñoz, 2004: The diurnal cycle in circulation and cloudiness over the subtropical southeast Pacific: A modeling study. J. Climate, 17, 1699–1710.

Gochis, D.J., W.J. Shuttleworth and Z.-L. Yang, 2002: Sensitivity of the modeled North American Monsoon regional climate to convective parameterization. *Mon. Wea. Rev.*, 130, 1282-1298.

Gochis, D. J., 2007: Spatial and temporal patterns of precipitation intensity as observed by the NAME Even Rain gauge Network from 2002 to 2004. J. Climate, 20, 1734-1750.

Gutzler, D., H.-K. Kim and R. W. Higgins et al., 2003: The North American monsoon Model Assessment Project (NAMAP). NCEP/Climate Prediction Center ATLAS No. 11, 32 pp. (Available from Climate Prediction Center, 5200 Auth Road, Room 605, Camp Springs, MD, 20746 and on the CPC website at http://www.cpc.ncep.noaa.gov/research_papers/ncep_cpc_atlas/11/atlas11.htm

Higgins, R.W., W. Shi, and C. Hain, 2004: Relationships between Gulf of California Moisture Surges and Precipitation in the Southwestern United States. J. Climate, 17, 2983–2997.

Hu, Z.-Z., E. K. Schneider, U. Bhatt and B. P. Kirtman, 2004: Potential for influence of land surface processes on ENSO. *J. Geophys. Res.*, doi:10.1029/2004JD004771,2004.

Hu, Q. and S. Feng, 2001: Variations of teleconnection of ENSO and interannual variation in summer rainfall in the central United States. J. Climate, 14, 2469-2480.

Hu, Q., and S. Feng, 2007: Decadal Variation of the Southwest U.S. Summer Monsoon Circulation and Rainfall in a Regional Model. J. Climate, 20, 4702–4716.

Kiehl, J. T., and P. R. Gent. 2004: The Community Climate System Model, Version 2**.** *J. of Climate*, **17**, 3666–3682.

Lang, T.J., D.A. Ahijevych, S.W. Nesbitt, R.E. Carbone, S.A. Rutledge and R. Cifelli, 2007: Radar-observed characteristics of precipitating systems during NAME 2004. J.

Climate, 20, 1712-1733.

Leathers, D., B. Yarnal, and M.Palecki, 1991: The Pacific/North American teleconnections Patterns and United States Climate. Part I: Regional temperature and precipitation associations. J. Climate, Vol.4, 517-528.

Lee, M. I., S. D. Schubert, M.J. Suarez, I.M. Held, N.C. Lau, J.J. Ploshay, A. Kumar, H.K. Kim, and J.K.E. Schemm, 2007: An Analysis of the Warm-Season Diurnal Cycle over the Continental United States and Northern Mexico in General Circulation Models. J. Hydrometeor., 8, 344–366.

Mapes, B.E., N. Buenning, I. -S. Kang, G. N. Kiladis, D. M. Schultz, and K. M. Weickmann, 2004: Strides, steps and stumbles in the seasonal march. In preparation for BAMS, available at http://www.cdc.noaa.gov/people/brian.mapes/publications.shtml.

Marengo, J.A.; I..FA. Cavalcanti; P.Satyamurty, I. Troniskov; C.A. Nobre; J.P. Bonatti; H.Camargo; G.Sampaio; M.B. Sanches; A.O. Manzi; C.C. Castro; C.DÁlmeida; L.P. Pezzi; L. Candido. Assessment of regional seasonal rainfall predictability using the CPTEC/COLA atmospheric GCM, 2003. Climate Dynamics, 21, 459-475.

Matsui, T., V. Lakshmi, and E. E. Small, 2005: The Effects of Satellite-Derived Vegetation Cover Variability on Simulated Land–Atmosphere Interactions in the NAMS. J. Climate, 18, 21–40.

Mechoso, C. R., and Coauthors, 1995: The seasonal cycle over the tropical Pacific in general circulation model. *Mon. Wea. Rev*., **123,** 2825-2838.

Mo, K.C., J. K. Schemm, H. M. H. Juang, R.W. Higgins, and Y. Song, 2005: Impact of Model Resolution on the Prediction of Summer Precipitation over the United States and Mexico. J. Climate, 18, 3910–3927.

Mo KC, Paegle JN. 2001. The Pacific-South American modes and their downstream effects. International Journal of Climatology. 21: 1211-1229.

NAME Science Working Group, 2004: North American Monsoon Experiment (NAME): Science and Implementation Plan: Available online at http://www.joss.ucar.edu/name

Nobre, C.A., P.J. Sellers, J. Shukla, 1991. Amazonian deforestation and regional climate change. J.Clim., 4, 957-988.

Nogues-Paegle, J., and Co-Authors, 2002. Progress in Pan American CLIVAR research: Understanding the South American Monsoon . Meteorologica, 3-32.

Raymond, D.J., G.B. Raga, C.S. Bretherton, J. Molinari, C. López-Carrillo, and Z. Fuchs, 2003: Convective Forcing in the Intertropical Convergence Zone of the Eastern Pacific. J. Atmos. Sci., 60, 2064–2082.

Roberts, D.A., M.Keller, J.V.Soares, 2003. Studies of land-use and biophysical properties of vegetation in the Large Scale Biosphere Atmosphere experiment in Amazonia. Remote Sensing of Environment, 87, 377-388.

Rozendaal, M. A., C. B. Leovy, and S. A. Klein, An Observational Study of the Diurnal Cycle of Marine Stratiform Cloud, J. Clim., 8, 1795–1809, 1995.

Ruiz, J., A. C. Saulo, and Y. Garcia Skabar, 2005. Convection and circulation interaction in the exit region of the LLJ. Preprint CONGREMET IX. In Spanish.

Saulo, C., M. Nicolini y S. C. Chou, 2000. Model characterization of the South American low-level flow during the 1997-1998 spring-summer season. Climate Dynamics, Volume 16, 867-881.

Saulo, C., J. Nogués Paegle and B. Kirtman, 2005 : An evaluation of the diurnal cycle over the SALLJEX region in models and observations. First Meeting of the MESA Science Working Group (SWG-1) Mexico City, MX, 9-11 March, 2005.

Sheridan, S., 2003. North American weather type frequencies and teleconnection indices. Inter. J. Climat., 23, 27-45.

Vera, C.; J. Baez; M. Douglas; C. B. Emmanuel; J. Marengo; J. Meitin; M. Nicolini; J. Nogues-Paegle; J. Paegle; O. Penalba; P. Salio; C. Saulo; M. A. Silva Dias; P. Silva Dias; and E. Zipser, 2006. The South American Low-Level Jet Experiment (SALLJEX). Bull. Am. Met. Soc , Vol. 87, No. 1, pp. 63–77.

Wood, R., C. S. Bretherton, and D. L. Hartmann, Diurnal cycle of liquid water path over the subtropical and tropical oceans Geophys. Res. Lett. 10.1029/2002GL015371, 2002

Zhu, C., T. Cavazos and D.P. Lettenmaier, 2007: Role of antecedent land surface conditions in warm season precipitation over northwestern Mexico. J. Climate, 20, 1774-1791.

List of Acronyms

ALLS: American Low-Level Jets AMIP: Atmospheric Model Intercomparison Project AO: Arctic Oscillation ASIMET: Air Sea Interaction - METeorology CCM: Community Climate Model CDC: Climate Diagnostics Center CEOP: Coordinated Enhanced Observing Period CLIVAR: Climate Variability, a WCRP research program CLLJ: Caribbean Low-Level Jet CMAN: Coastal-Marine Automated Network COADS: Coupled Ocean-Atmosphere Data Set COMPS: Coastal Ocean Monitoring and Prediction System CPC: Climate Prediction Center ECMWF: European Center for Medium Range Weather Forecasts EDAS: Eta-model Data Assimilation System EMVER-93**:** Experimento Meteorologico del Verano de 1993 ENSO: El Niño Southern Oscillation EOP: Enhanced Observing Period EPIC: Eastern Pacific Investigation of Climate ERS: European Remote Sensing Satellites GAPP: GEWEX America Prediction Project GCIP:

GEWEX Continental-Scale International Project GCM: General Circulation Model GEWEX: Global Energy and Water Experiment GOES: Geostationary Operational Environmental Satellite GPLLJ: Great Plains Low-Level Jet GPS: Global Positioning System IAS: Intra-Americas Sea IOP: Intensive Observing Period ITCZ: Inter Tropical Convergence Zone IPST: International Project Support Team IR: Infrared IRI: International Research Institute LDAS: Land Data Assimilation System MESA: Monsoon Experiment South America MJO: Madden-Julian Oscillation NAME: North American Monsoon Experiment NAMS: North American Monsoon System NAO: North Atlantic Oscillation NASA: National Aeronautics and Space Administration NCAR: National Center for Atmospheric Research