Annual Report of NOAA Core Project for GAPP:

NCEP-Component

(with NESDIS Section)

FY04 Progress

and

FY05 Statement of Work with Budget

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Seven Pillar Initiatives of NCEP component of GAPP Core Project

(in the form of the ***Table of Contents*** for this report)

NOAA Core Project for GAPP:

NCEP-Component

Progress Report and FY05 Work Plan

0.0 PREFACE

Background

As explained in the Note on page 3, this document is the 7-month progress report for May 04 through November 04 and 10-month Statement of Work for December 04 through September 05 for the NCEP and NESDIS component of the 5-year, FY01-FY05 GAPP Core Project Proposal of NCEP-OHD-NESDIS. By prior agreement with the GAPP Program Manager, the OHD component of the annual progress report and work plan was submitted under separate cover by OHD Co-PIs John Schaake and Pedro Restrepo.

The budget on page 4 and the summary of our pillar initiatives on pages 5-6 provide a "quick look" of the content presented in detail in Sections 1-7 below. The purpose of this introductory preface is to provide the important context and legacy that underpins these sections.

An overarching 5-year FY01-FY05 GAPP Core Project Proposal of NCEP-OHD-NESDIS was submitted in February 2001 to NOAA/OGP and to the GAPP Core Project Review Panel convened that year by OGP. This proposal is an important reference document for the subsequent annual progress reports. The annual progress report and work plan herein represents the fourth in the series of annual reports following the submission of the 5-year proposal. For important background and context material, readers are referred to the 5-year proposal, which is on file in NOAA/OGP and is available from this author (Kenneth.Mitchell@noaa.gov).

Objectives of the GAPP Core Project

The central guide for the FY01-FY05 GAPP Core Project Proposal was the GAPP Science Plan distributed by GAPP in the year 2000. Section 3 of that plan and Section 1 of the follow-on GAPP Implementation Plan distributed in 2004 gives the two objectives of the GAPP Program as:

1 - To develop and demonstrate a capability to make reliable <u>monthly to seasonal predictions</u> of precipitation and land-surface hydrological variables through improved understanding and representation of land surface and related hydrometeorological and boundary layer processes <u>in climate prediction models</u>,

2 - Interpret and transfer the results of improved seasonal predictions for the <u>optimal management of water resources.</u>

Within the Core Project in broad terms, the NCEP component (with the NESDIS component) spearheads Objective 1 above, while the OHD component spearheads Objective 2, though all three components collaborate with each other on a routine ongoing basis.

The team members of the FY01-FY05 GAPP Core Project in NCEP, OHD, and NESDIS strive to accomplish both of the above *objectives* by the following two broad *approaches*:

i) internal development and operational implementation within their respective agencies,

ii) science and technology infusion from other collaborating GAPP and GEWEX investigators.

Strategy and Infrastructure of GAPP Core Project for Seasonal Prediction and Predictability

The overarching GAPP Core Project strategy for seasonal hydrologic prediction follows the "systems" infrastructure shown in Figure 1 (see companion Powerpoint file for all figures) , which represents an expanded version of the familiar spatial-downscaling schematic commonly known as the ‘Shukla Staircase'. Figure 1 is now fairly widely shown and discussed in GAPP and GEWEX circles (such as CEOP), and is included in the GAPP Science and Implementation Plan. Yet for sake of completeness here, a full description and discussion of Figure 1 is given in Appendix C.

The present author created the expanded version (Figure 1) of the Shukla schematic by augmenting the original figure of Shukla to include not only the prediction model components (the boxes in the four corners of Figure 1), but also the crucial data assimilation components (the circles in the middle of Figure 1) depicting the necessary atmosphere, ocean and land data assimilation systems, which provide the initial conditions for the atmosphere, ocean and land states of the prediction models. For purposes of brevity here, the ocean component is assumed to include the sea-ice component, just as the land component includes snowpack/glaciers.

Briefly, the seasonal prediction/predictability infrastructure in Figure 1 is composed of free-running ensemble prediction models (layered boxes) and 4-D data assimilation systems (circles) ingesting in-situ and satellite observations into assimilating "background" models. The models in the prediction and companion 4DDA components of Figure 1 are frequently and ideally the same model.

The infrastructure of Figure 1 embraced here in this Core Project is comprehensive, in that it includes

1 - **land**, **atmosphere**, and **ocean**
2 - **prediction** and 4DDA **assimilation**
3 - **global**, **regional**, and **local**
4 - **coupled** and **uncoupled**
5 - **realtime** (prediction) and **retrospective** (predictability, hindcasts, reanalysis**)**
6 - **ensemble approach** in each prediction component

Representing a major milestone in 2004 for EMC's overall climate modeling program, EMC operationally implemented in 2004 its second-generation seasonal forecast system, known as the Coupled Forecast System, or **CFS**. The CFS is a fully coupled ("1-tier") ocean-atmosphere-land global modeling system (OAL-GCM in Figure 1), and has its companion global atmosphere and ocean data assimilation systems, described shortly. For this CFS implementation, EMC executed a comprehensive 23-year CFS hindcast (1981-2003). Every month of this 23-year hindcast database is comprised of a 15-member ensemble of 10-month seasonal forecasts. The global atmosphere/land model of the present CFS executes at T62 horizontal resolution with 64-atmospheric layers and 2 soil layers. The global ocean model of the present CFS is the GFDL MOM3 ocean model executed with 40 layers over a quasi-global domain (74S to 64N latitude) at 1-degree x 1-degree resolution (1/3-degree by 1-degree in the tropics). The NCEP/DOE Global Reanalysis 2 (also known as the Climate Data Assimilation System 2, or CDAS-2) represents the global data assimilation system, providing initial atmospheric states and land states for the CFS ensemble forecasts. The EMC Global Ocean Data Assimilation System (GODAS), driven by the surface fluxes of the CDAS-2, provides the initial ocean states for the CFS ensemble forecasts.

For the land modeling community, the most telling characteristic of NCEP's new dynamical seasonal forecast system is that it still utilizes only the GR2 for its initial land states (e.g. soil moisture). Additionally, the new system continues to use the old mid 1980's OSU land model. Moreover, no regional climate model (RCM) has been designated as an official component of the new CFS seasonal prediction system. (Nonetheless, NCEP will execute RCM tests as part of both the GAPP Core Project here and CDEP Project at NCEP -- see Section 1.4).

Clearly then, the penultimate goal and focus of effort of the NCEP component of the GAPP Core Project is to develop, deliver and demonstrate the land components and regional climate model components in the seasonal infrastructure of Figure 1. The land components include a modern-era and widely validated land-surface model and the global and regional land data assimilation systems.

More specifically, all facets of the GAPP Core Project are aimed at i) developing, ii) demonstrating, iii) improving and iv) operationally implementing the additional components of the seasonal forecast paradigm in Figure 1 that are not yet formally operational at NCEP, namely the components labeled A, B, C, D, E in Figure 1. These components depict the following:

A) Global Land 4DDA: the Global Land Data Assimilation System (GLDAS)
B) Regional Land 4DDA: the North American Land Data Assimilation System (NLDAS)
C) Regional Atmospheric 4DDA: the Eta-model based N. American Regional Reanalysis (NARR)
D) Regional Climate Model: coupled atmos/land Eta/Noah Regional Climate Model (AL-RCM)
E) Regional Macroscale Hydrology Model (MHM): the Noah and SAC LSMs in a predictive companion to the NLDAS driven by prediction model ensemble forecasts of the surface forcing

To demonstrate the "value added" by any of the above components, the Core Project will set out to illustrate, via extensive hindcast experiments using the Figure 1 infrastructure, whether any one or more of the components A, B, C, D and E improve seasonal predictability and prediction skill relative to the operational global dynamical seasonal prediction system. Readers are referred to the GAPP Implementation Plan (namely Chapter 6 therein written by the present author) available at the GAPP web site for more discussion of the strategy and methodology of demonstrating the "value added" by the downscaling components of Figure 1.

As described in the progress reports in Sections 1-7 below, the first four years of the GAPP Core Project have already succeeded in developing and executing viable working prototypes of the four components A-D.

Last but far from least, the water resource initiative in the separately submitted OHD component of this annual Core Project report is developing and demonstrating a "post-processor" to provide probabilistic precipitation forecasts to the hydrological model in the upper right of Figure 1, from the 60-member ensemble of the seasonal atmospheric predictions. This is a critical endeavor, as the post-processor for the probabilistic precipitation forecasts must address five traditional problems in such long-lead seasonal precipitation forecasts, namely 1) significant bias, 2) lack of sufficient spread among the ensemble set, 3) lack of extreme events, 4) insufficient temporal intermittency, and 5) lack of the fractal structure that characterizes the spatial patterns of observed precipitation. This is a major challenge for the hydrology and water resource community, including the Extended Streamflow Prediction (ESP) component of the NWS Advanced Hydrologic Prediction System (AHPS), and it's associated National Hydrologic Long-rang Prediction System (NHLPS). This is a key subject of the OHD portion of the GAPP Core Project Report submitted under separate cover.

Science infusion role of GAPP Core Project with PIs in GAPP, CEOP and GEWEX Programs

While the ultimate objective of GAPP is to achieve more skillful seasonal prediction by implementing and improving the LSM, RCM and MHM components of Figure 1 in realtime operational systems, such an operational system must be accompanied by an extensive multi-decade hindcast system -- such as the one EMC has executed for the new CFS seasonal prediction system -- in order to cast the predictions more skillfully in terms of anomalies from the models' own climatologies. **The hindcast system in turn can double as 1) a system for a priori demonstration of prediction skill to justify transition to operations and 2) as a powerful research testbed to carry out land-memory predictability studies, land-atmosphere coupling studies and physical process studies.** This latter vision is in fact the concept of science-infusion adopted by the newly announced NCEP Climate Test Bed, which is described at the beginning of Section 1.0.

As an example of the role of a priori demonstration of prediction skill in the hindcast mode of Figure 1, the RCM component will be introduced into NCEP operational practice as a downscaling component only if the RCM demonstrates in hindcast mode useful additional skill over and above the parent GCMs (especially empirically or statistically downscaled and bias-corrected GCMs).

All the prediction and 4DDA suites in Figure 1 (OAL-GCM, AL-GCM, RCM, MHM) need not be in place at a given institution for that institution to contribute model or assimilation research and demonstrations in support of Figure 1's implementation strategy. In the U.S. for example, under the umbrella of U.S. seasonal prediction centers (such as NCEP, IRI, GFDL, NSIPP) and the NOAA OGP-sponsored Applied Research Centers (ARCS, such as COLA, ECPC) – which are partially funded by OGP programs such as CDEP, GAPP, and PACS – it is likely that the complete realtime and hindcast global system for the coupled OAL-GCM, with its companion global ocean 4DDA and global atmospheric 4DDA, will be in place at only a handful of institutions (e.g. NCEP, IRI, GFDL, NSIPP). Yet the global SST predictions and global atmospheric predictions provided from the OAL-GCM component of these latter institutions can be provided to a host of GAPP collaborating PIs to drive their own research and development in the following components of Figure1:

A) global and regional land data assimilation systems (GLDAS and NLDAS),
B) regional climate models (RCMs),
C) macroscale hydrological models (MHMs).

Two keys roles of the GAPP Core Project will be to offer coordination and planning mechanisms to unify, to a reasonable degree, the above LDAS, RCM, and MHM efforts around common goals and strategies, and joint experiments, studies, or demonstrations, culminating with technology infusion into NOAA operations. These roles are discussed more near the beginning of Section 1.0.

So a fundamental role of the Core Project is to partner and collaborate with the research community to provide an operational pathway for the infusion of their research and development into NWS operations. To accomplish and demonstrate such infusion, we point out that pre-implementation testing of candidate research advances will require that the Core Project carry out benchmark retrospective studies in four areas: 1) the realism and behavior of key physical processes, 2) data assimilation methods, 3) land-memory predictability studies, and 4) the value-added of the downscaling components of Figure 1. Nevertheless, we assert here that the main role of this Core Project is not to embark on basic research into these four areas, as this is the fundamental role of the PIs supported by GAPP research grants. Rather, the emphasis here in the Core Project will be to collaborate with GAPP PIs to incorporate and demonstrate their research advances within the operationally-oriented parallel testbed infrastructure of Figure 1 – namely to demonstrate the viability of their research advances within the setting of the realtime observation streams, operational computer capacity, and operational product delivery deadlines of NCEP and NWS operational centers.

The discussions of collaborations of the Core Project with GAPP PIs is distributed throughout the progress report of Sections 1-7.

In conclusion of this preface section, over the 5-year FY01-FY05 period of the GAPP Core Project proposal, the Core Project is focusing on the land and regional/local downscaling components of Figure 1. Specifically, the Core Project is:

A) - For realtime application: developing, demonstrating, and <u>striving to operationally implement</u>

1) all the land model and land 4DDA components of Figure 1 in NCEP's dynamical seasonal prediction system, including the LSM component of all global and regional prediction models,

2) the probabilistic prediction interface between the ensemble seasonal atmospheric forecasts and the hydrological model for water resource application.

B) - In retrospective hindcast and reanalysis initiatives: collaborating with PIs under the GAPP and GEWEX programs to infuse their scientific research and development into operationally-oriented hindcast and reanalysis test beds of the NWS to <u>demonstrate the impact on seasonal predictability</u> from:

1) improved land modeling (physics, parameters, land characteristics) and improved land-state initial conditions from land data assimilation,

2) downscaling, by means of both regional climate models (RCMs) and application of statistically based hydrological "post-processors" to provide unbiased and reliable probabilistic precipitation forecasts to hydrological prediction models.

The main message of that the reader should garner from the progress reports in the following sections is that the land modeling and land 4DDA community has advanced to the point of being on the threshold of making the full schematic of Figure 1 an operational reality. The pathfinder initiatives already accomplished by GEWEX programs (GCIP, GAPP, this Core Project, ISLSCP, GSWP, PILPS, PIRCS) in the area of land modeling, land-atmosphere coupling, land 4DDA, and regional climate modeling, together with the companion ocean modeling and ocean 4DDA initiatives of the TOGA, CLIVAR and GODAE programs, have provided all the components to assemble and demonstrate the end-to-end downscaling seasonal prediction system in Figure 1 for hydrological applications and water resource management.

Annual Report Begins Next Page

As explained in the Note on page 3, this document is the 7-month progress report for May 04 through November 04 and 10-month Statement of Work for December 04 through September 05 for the NCEP and NESDIS component of the 5-year, FY01-FY05 GAPP Core Project Proposal of NCEP-OHD-NESDIS. By prior agreement with the GAPP Program Manager, the OHD component of the annual progress report and work plan was submitted under separate cover by OHD Co-PIs John Schaake and Pedro Restrepo.

The following sections are organized according to the pillar initiatives of the NCEP component of the GAPP Core Project as listed in the Table of Contents on pages 5-6.

Each subsection is organized into two parts as follows:

1 - FY04 Accomplishments (7 months: May 04 - Nov 04)
Work completed and Results

2 - FY05 Work Plan (10 months: Dec 04 - Sep 05)
Statement of Work

1.0 SEASONAL CLIMATE PREDICTION AND PREDICTABILITY

1.1 Impact of the Noah LSM in the NCEP Global Forecast System (GFS)

Background

In addition to the 2004 implementation of the new CFS seasonal prediction system at NCEP, as a second major 2004 milestone for NCEP, EMC jointly with CPC and the NOAA Climate Office formally established the NCEP Climate Test Bed (CTB). The NCEP Director formally announced the creation of the NCEP Climate Test Bed at the 2004 annual GAPP PIs meeting. The CTB is comprised of computational hardware resources (1/3 of NCEP's IBM SP "Red" system), software resources (models, data, diagnostics, technical assistants, system administrators), management staff (Director, Deputy Director), an Oversight Board, and a Climate Science Team. The Climate Science Team of the CTB is made of sub-teams known as Climate Process Teams (CPTs). The head of the NCEP component of the GAPP Core Project (this author, Ken Mitchell) has been designated as the lead of the "Climate Process Team for Land" for Climate Science Team of the Climate Test Bed. A key objective of the Climate Test Bed at NCEP is to accelerate the infusion of research and development external to NCEP into NCEP operations for climate prediction. The GAPP Core Project immediately brings a longstanding track record of strong collaborations and science infusion involving external PIs from both GAPP and other GEWEX programs (PILPS, GSWP, ISLSCP, GLACE, NAME) to the NCEP Climate Test Bed.

A key feature of the newly implemented CFS is that the global atmosphere/land model component is "unified" (meaning common version) with a very recent operational version of EMC's medium-range Global Forecast System, known as the GFS. Indeed, a firm NCEP policy is that development of the next-generation CFS (targeted for implementation in 2008) continue with this unified climate/weather prediction model approach -- namely, that the atmosphere/land global model component of NCEP's CFS and GFS continue to be a common version of the NCEP global model (albeit a periodically upgraded, extended, and improved common version).

One pillar goal of the NCEP Climate Test Bed will be to develop and assess the next-generation of the CFS, with a target of implementation in 2008. Consistent with the aforementioned "unified global model" approach, the plan for the next-generation CFS is to utilize **a newer version of the global model in the medium-range GFS with demonstrated improvements in the weather prediction.** The present vision for the next-generation CFS for 2008 is a doubling of the horizontal resolution (T126), a new 3rd-generation Global Reanalysis 3 at T126, and a new 25-year seasonal hindcast, using the global model physics of a well-tested and operational GFS.

Over the past several years of CFS development, the focus of the development and testing that yielded the newly operational CFS seasonal prediction system of NCEP was the ocean model component and the companion Global Ocean Data Assimilation System (GODAS). Thus the land surface model (LSM) component of the newly implemented CFS, and its companion CDAS-2, is the older OSU LSM, developed in the 1980's at Oregon State University (OSU). The OSU LSM is the ancestor of the much improved Noah LSM developed over the past ten years by the GAPP Core Project and its GAPP collaborators.

The newer Noah LSM from the GAPP Core Project is now operational in 1) NCEP's N. American Regional Reanalysis System (NARR) -- whose operational realtime extension is known as the

Regional Climate Data Assimilation System, or R-CDAS. Additionally, the Noah LSM is now operational in NCEP's regional Eta model and its Eta Data Assimilation System (EDAS), and is the LSM of choice routinely applied in NCEP's extensive testing of the Eta Regional Climate Model (Eta RCM) and the NCEP N. American and Global Land Data Assimilation Systems (NLDAS and GLDAS).

Thus a logical major focus of development in NCEP's next-generation CFS seasonal prediction system targeted for 2008 will be 1) incorporation of the Noah LSM as the land component of the CFS, and 2) formal implementation of the Global Land Data Assimilation System (GLDAS) with the Noah LSM as the source of initial land states for the ensemble members of CFS seasonal predictions. Using the Noah LSM as the land component of the next-generation CFS has indeed been adopted as a major thrust of the Climate Science Team of the new NCEP Climate Test Bed. The NCEP component of the GAPP Core Project will lead and spearhead the testing of the Noah LSM in the next-generation CFS and its Global Reanalysis, to include a Global Land Data Assimilation System.

For the above vision of the Noah LSM in the next-generation CFS to be realized, the Noah LSM must first be included, tested, assessed and then operationally implemented in the NCEP Global Forecast System (CFS) for medium-range weather prediction, to maintain consistency with the NCEP commitment to a unified global model. Consequently, the global model testing of the Noah LSM in the NCEP component of the GAPP Core Project over the past seven months has concentrated exclusively with the testing of the Noah LSM at the medium-range weather prediction time scale.

In a major milestone of last year's progress report, the Core Project had for the first time coupled the latest version of its Noah LSM with the unified Global Forecast System (GFS). We designate this coupling of Noah and GFS as "GFS/Noah". Much of the effort to achieve this milestone was doggedly invested in the challenging software re-engineering of the GFS to "centralize" the LSM treatment under a single, 1-d column-model "umbrella" of LSM subroutines. Our satisfying success in doing so has marvelously transformed the LSM component of the GFS into a drop-in "plug-and-play" entity, which greatly facilitates the infusion of LSM science and Noah LSM improvements and upgrades into the GFS.

Also in the previous annual report, we had begun to execute and evaluate the GFS/Noah in the GFS hindcast testbed environment of EMC of NCEP. This initial evaluation had necessarily begun with medium-range prediction scales (1-15 days) in order to develop some "legs" of experience in evaluating the Noah LSM on the global scale. It also included ensemble 3-month seasonal hindcast testing for the summer season, as described in the previous progress report. However, in the present reporting period the latter seasonal hindcast tests were suspended. This temporary suspension was imperative in order to focus on the pressing requirement to finish sufficient GFS/Noah assessment on the medium-range weather prediction scale to justify implementation of the Noah LSM on this scale first -- a necessary prerequisite for the Noah LSM to be included in the "Unified GFS" of the next-generation CFS seasonal prediction suite.

FY04 Accomplishments (7 months):

Summer and Winter Evaluations of the coupled GFS/Noah in Weather Prediction Mode

As discussed in the above background section, the new fully coupled dynamical Coupled Forecast System (CFS) for seasonal prediction implemented operationally at NCEP during 2004 utilizes a "Unified" atmosphere-land coupled global forecast system (GFS). Therefore, any new LSM that is a candidate for upgrading the land component of the CFS must first provide forecast improvement in weather prediction (NWP) hindcast tests. In the previous progress report, the NCEP Core Project completed NWP hindcast tests of the coupled GFS/Noah for August 2003 (summer case) and December 2003 (winter case). Specifically, for the summer season, one 5-day forecast for both the control GFS/OSU case and the test GFS/Noah case was executed from each 0000 GMT analysis time for each day of August 2003, yielding 31 5-day summer forecasts. Both the control and test runs were initialized from the atmospheric and land states produced by a GDAS with the respective LSM (OSU LSM in control run and Noah LSM in test run) that had continuously cycled virtually one full year since August 2002. For the winter season, one 5-day forecast for both the control GFS/OSU case and the test GFS/Noah case was executed from each 0000 GMT analysis time for each day of December 2003, yielding 31 5-day winter forecasts. Both the control and test runs were initialized from the atmospheric and land states produced by a GDAS with the respective LSM (OSU LSM in the control run and Noah LSM in the test run) that had continuously cycled virtually sixteen months since August 2002.

In the present progress reporting period (7 months), the testing of the impact of the Noah LSM in the medium-range predictions of the NCEP Global Forecast System (GFS) continued for summer and winter 2003 cases. The companion execution of the GFS/Noah version in NCEP's Global Data Assimilation System (GDAS) was extended from the previous 12 months of cycling (Aug 2002 to Aug 2003) to a full 18 months of cycling (Aug 2002 through Feb 2004).

Relative to the benchmark tests that were reported in the previous progress report, the past seven months focused on testing refinements to the following attributes of the coupled GFS/Noah configuration:

1 - combining with the new GFS thermodynamic sea-ice model
2 - implementing a time filter with the surface turbulence exchange coefficients
3 - removing the empirical inflation factor applied to the green vegetation fraction (GVF)
4 - testing in the GFS hybrid vertical coordinate version (hybrid sigma-pressure vertical coordinate)

All of the above GFS/Noah testing in this reporting period, as in the case of the GFS/Noah testing reported in the previous progress report, was executed at a spatial resolution of T62, with 64 atmospheric layers and 4 soil layers.

We provide here an example for #3 above. As in present operations, the control GFS/OSU configuration applies an inflation factor to the monthly global fields green vegetation fraction (GVF) used in the land model, such that GVF is always maintained above a floor value of 0.5 at every landmass grid (even deserts) for every day all year (all seasons). This GVF floor value was presumably implemented in the NCEP global model in the mid 1990's to reduce a troublesome near-surface warm bias in the GFS over land in the warm season. In the GFS/Noah tests presented in the prior progress report, this floor value was retained. During the present reporting period, GFS/Noah tests were executed without this floor value of GVF (consistent with the GVF configuration of all other non-GFS Noah LSM testing to date, such as the Eta model, Regional Reanalysis, NLDAS, GLDAS, PILPS, GSWP, etc), so that a realistic seasonal cycle of green vegetation was realized at all grid points, including virtually zero green vegetation in desert areas. The impact of removing the GVF floor value is illustrated in Fig. 2.

Fig. 2 shows the control versus test verification measures of BIAS and RMSE for atmospheric temperature at standard pressure levels, via assessment against all radiosonde observations across the N. Hemisphere for the month of August 2003, for the GFS forecasts of 24-hour (black curves) and 48-hour (red curves), with the control case given as solid lines and the test case given as dotted lines. In Fig. 2a (left frame), which was presented in the prior progress report, the control is GFS/OSU and the test is GFS/Noah, and both control and test retain the 0.5 floor value on GVF. Fig. 2a shows that the GFS/Noah test (albeit with the GVF floor value retained) reduced the summer cool bias of the control case throughout the majority of the troposphere and especially in the lower third of the troposphere. In Figure 2b (right frame), GFS/Noah runs with the GVF floor value retained is now the control case (solid lines) and the GFS/Noah runs without the GVF floor value is the test case (dotted lines). The GFS/Noah runs without the floor value of GVF succeed in furthering the positive impact of the GFS/Noah runs by further reducing the lower-troposphere cool bias. The additional warming impact of removing the floor value of GVF stems from the reduction of surface evaporation that results from the lower vegetation cover. (Aside: sample size of Fig. 2b is 5 days less than Fig. 2a, otherwise the test run of Fig. 2a would match the control run of Fig. 2b.)

The refinements #2 above (time filter) also further improved the impact in the GFS of the Noah LSM relative to the OSU LSM (not shown). **Taken altogether, the further improvements achieved in the GFS/Noah tests in the present reporting period led to the decision by EMC to include the Noah LSM in the final phase of high resolution pre-implementation testing of the next package of GFS upgrades targeted for operational implementation in June 2005**, to include 1) a resolution increase from T254 to T382, 2) the Noah LSM replacing the OSU LSM, 3) the new sea-ice model, 4) modifications to the gravity-wave drag parameterization and envelope orography, and 5) modifications to the background levels of vertical diffusion.

FY05 Work Plan (10 months)

The Noah LSM will be assessed in the pre-implementation testing of the high resolution T382 GFS, including in its companion T382 Global Data Assimilation System (GDAS). This testing will include the realtime parallel cool-season testing of the period Dec 04 through Apr 05, and the retrospective warm-season hindcast testing of May-Jun 04 and Aug-Sep 04. Given that it is computationally not feasible to execute desired one-year of GFS/Noah cycling in the GDAS/Noah 4DDA at the high resolution of T382, the alternative of executing the uncoupled GLDAS with Noah for two years of cycling will be utilized to provide the Noah LSM initial land states at the beginning of the above three GFS/GDAS test periods. This GLDAS application with the Noah LSM is further presented in Section 2.1.

1.2 CEOP: Using CEOP observations to assess GFS/Noah physical processes

The results in Fig. 2 discussed above in Sec. 1.1 represent a validation performed over the entire N. Hemisphere. In order to focus down on model performance in various different climatic regions of the world, the NCEP Core Project has participated heavily in CEOP in order to: 1) acquire the observations of the 41 world-wide CEOP Reference Sites (which are surface flux stations) from the CEOP Reference-Site Archive at UCAR/JOSS and 2) assess the GFS/Noah forecast tests against the surface energy budget observations at these CEOP Reference Sites.

FY04 Accomplishments (7 months):

The Core Project's GFS/Noah assessment against CEOP Reference Sites were presented in scientific forums by NCEP Core Project team members over the past year, including the May 2004 AGU Meeting special session on CEOP in Montreal Canada, and at the August 2004 Annual GAPP PIs meeting. Additionally, an extended abstract (Lu et al., 2005; available upon request) was prepared and submitted to the CEOP special session at the AMS January 2005 Annual Meeting, and similarly to the International CEOP Meeting of February 2005 in Tokyo, Japan.

The previous progress report utilized CEOP observations from the Jul-Aug 2001 period of the CEOP Enhanced Observing Period 1 (EOP 1). In the present reporting period, the observations from the CEOP Enhanced Observing Period 3 (EOP 3) became available and we applied them to our GFS/Noah assessments for the Aug 2003 test period described in Section 1.1. Fig. 3 provides one example. Specifically, for the CEOP Southern Great Plains (SGP) site near Lamont, OK (provided by the ARM program), Fig. 3 shows the CEOP in situ observations (plus signs), the test GFS/Noah runs (open circles) and the control GFS/OSU runs (closed squares) and the NLDAS/Noah runs (cross signs) for the monthly mean diurnal cycle of August 2003 for surface solar insolation in W/m^2 (top-left), latent heat flux in W/m^2 (top right), ground heat flux in W/m^2 (bottom-left), and sensible heat flux in W/m^2 (bottom-right). The GFS/OSU control runs yield a dramatically high bias in surface latent heat flux and a corresponding low bias in sensible heat flux, while the GFS/Noah test runs match the observed diurnal cycle closely for latent heat flux and yield a moderately high bias in sensible heat flux. The LSMs in both the control and test runs are impacted by the high bias in surface solar insolation exhibited by the radiation physics of the parent atmospheric model (upper left panel). The ground heat flux of both the control and test GFS runs agree closely with the observed ground heat flux. Given that both the latent heat flux and ground heat flux of the GFS/Noah test runs agree closely with the observed diurnal cycle, then the aforementioned high bias in the solar insolation of the parent atmospheric model is the main culprit in the moderately high sensible heat flux in the GFS/Noah tests. This illustrates how radiation biases in the parent model can hamper otherwise good performance of the LSM.

Proper execution of the study of Noah LSM impact in the GFS requires that the Noah LSM be executed not only in the GFS forecasts, but also in the companion Global Data Assimilation Cycle System (GDAS) for long periods of a year or more. As an example, Fig.4 shows the monthly mean diurnal cycle of 2-meter air temperature for August 2003 at the CEOP reference observation site of Lindenberg, Germany, as obtained from 1) GFS/Noah runs initialized from the operational GDAS that uses the OSU LSM (solid triangles), 2) GFS/Noah runs initialized from the test GDAS that has cycled with the Noah LSM for a year (open circles), and 3) the CEOP reference site observations. The GFS/Noah runs that are naively initialized from the operational GDAS/OSU provide a very poor and untrustworthy preview of the good performance of the Noah LSM in the GFS when the Noah LSM is cycled in the companion GDAS.

Additional validations of the GFS/Noah tests with CEOP reference site observations are provided in the aforementioned CEOP extended abstract (Lu et al., 2005) that the NCEP GAPP Core Project submitted to the International CEOP Workshop to be held in February 2005 in Tokyo, Japan.

FY05 Work Plan (10 months)

If the CEOP reference-site observations are publicly released for EOP-4 (Oct 03 - Dec 04) during the upcoming 10-month work plan period, then these EOP-4 observations will be applied to validate the 2004 warm season retrospective runs of the high-resolution T382 GFS/Noah tests cited in the work plan of Sec. 1.1.

1.3 GLACE: Assessing GFS/Noah land-memory impact on precipitation predictability

Background

In a study of land-memory impact on summer season precipitation predictability over the entire globe, the NCEP component of the GAPP Core Project participated vigorously in the Global Land Atmosphere Coupling Experiment (GLACE), which is advocated and coordinated by the GEWEX Land Atmosphere System Study (GLASS) panel. In this experiment, during the previous reporting period of the prior progress report, the NCEP GAPP Core Project executed two 16-member summer season ensemble hindcasts with the NCEP coupled atmosphere-land GFS model for the 3-month summer period of Jun-Aug 1994. The experiments followed the GLASS directed protocol in which the time-series of global land-states from one of the 16 members of the control simulations were used to prescribe the land states in *all* sixteen members of the experimental simulations. The degree to which the variability of the simulated precipitation fields decreased in the experimental simulations versus the control simulations provided a robust measure of the responsiveness of a given global model's precipitation fields (over land) to land state-anomalies (soil moisture) and to the persistent nature, or "land memory" of those land state anomalies.

The large set of participating global models (16) broke down into roughly two categories: A) models whose precipitation fields showed a substantial responsiveness to land-surface states and B) models whose precipitation fields showed rather little responsiveness to land-surface states. The presently operational NCEP GFS model falls into the Set "B" of models (whose precipitation fields showed comparatively little responsive to changes in prescribed land-surface states).

FY04 Accomplishments (7 months):

During the 7-month reporting period, members of the NCEP GAPP Core Project worked closely with GLACE principal investigators to discern why the NCEP GFS precipitation forecasts showed relatively little response to prescribed land surface states. First, the NCEP Core Project re-executed the GFS GLACE experiments using the new Noah LSM in place of the operational land component given by the OSU LSM. Regardless of whether the Noah or OSU LSMs were used in the GFS, the GFS precipitation forecasts remained notably unresponsive to changes in the prescribed land states.

Secondly, the nature of the response was broken down into two contributing pathways: 1) quantifying how much the land surface evaporation responded to prescribed changes in land states, and 2) quantifying how much the predicted precipitation responded to the changes in the surface evaporation. The following results were obtained, as reported in the extended abstract (available on request) submitted to the GLACE session of the AMS 19th Conference on Hydrology of the AMS Annual Meeting of January 2005.

1 - GFS soil moisture is highly constrained when either all land states are prescribed (as expected) or when only the root zone soil moisture is prescribed.

2 - GFS evaporation is highly constrained when all land states are prescribed (as expected), but (surprisingly) not highly constrained when only the root zone soil moisture is prescribed.

3 - The result in #2 above strongly hinted that GFS evaporation of intercepted canopy water and/or direct soil evaporation might dominate over transpiration.

4 - Further analysis (not given here) shows that the hypothesis hinted in #3 fails, namely GFS evaporation is dominated by transpiration over non-arid non-sparse vegetation.

5 - Hence other degrees of freedom (e.g. air humidity, air temperature, skin temperature, PAR) besides soil moisture in the GFS canopy resistance formulation (Jarvis-type) must explain the large inter-ensemble variance in GFS surface evaporation even when root zone soil moisture is prescribed. The latter non-soil-moisture degrees of freedom in the GFS canopy resistance must be the focus of further study, as must the impact of nudging GFS soil moisture to a climatology.

FY05 Work Plan (10 months)

Execute additional GLACE experiments with the NCEP global model (GFS) in which the degrees of freedom cited in #5 above are disabled. For example, execute additional GFS ensemble sets wherein A) all canopy resistance factors are disabled except for soil moisture and B) the nudging of soil moisture to climatology is disabled. Examine whether configurations A or B enhance the responsiveness of GFS precipitation to land surface variability.

1.4 Seasonal hindcasts with Eta Regional Climate Model (Eta-RCM/Noah) using Noah LSM

Background

The NCEP GAPP Core Project developed and continues to extensively test and improve the NCEP Eta-based Regional Climate Model (Eta-RCM). Like the Regional Reanalysis and the NLDAS, the Eta RCM is coupled with a recent version of the Core Project's Noah LSM. Moreover, the Eta RCM utilizes the same resolution (32 km, 45 levels), large spatial domain (all of North and Central America), and terrain fields of the North American Regional Reanalysis (NARR).

In prior annual progress reports, the NCEP GAPP Core Project provided the first test executions of the Eta RCM on seasonal time scales in not only the traditional RCM "simulation mode" of using lateral boundary conditions from global reanalysis, but also executions in "quasi-prediction" mode, wherein predicted lateral boundary conditions were used from NCEP's ensemble dynamical seasonal prediction system, but still using observed SST. These quasi-prediction demonstrations of the Eta RCM were demonstrated with 6-member ensemble predictions of 4-month forecasts of the Jun-Sep summer period initialized from late May for the two summers of 1990 and 1991 for the NAME Model Assessment Project (called NAMAP) and the two summers of 1999 and 2000. By using pairs of successive summers, we examined the skill of the Eta RCM to predict interannual anomalies of precipitation.

In the prior progress report, we completed ensemble summer-season, 4-month, Jun-Sep prediction experiments for in **full-prediction mode**, using NCEP's dynamical coupled ocean-atmosphere-land seasonal forecast model (OAL-GCM) predictions of both lateral boundary conditions and SST. The above executions of the Eta-RCM in 1) full prediction mode were complemented by also executing the Eta RCM in 2) the traditional simulation mode (Global Reanalysis lateral boundary conditions and observed SST) as used in a plethora of RCM studies such as PIRCS, and 3) quasi-prediction mode (NCEP seasonal forecast-model predicted lateral boundary conditions and observed SST), as used in the Eta RCM demonstration studies of COLA (Fennessey and Shukla, 1999), thus yielding a 3-way mode suite for Eta-RCM investigations. The Core Project systematically executed these three RCM modes to produce (for each mode) 6-member ensembles (initialized from late May) of 4-month summer season hindcasts (Jun-Sep) for the two successive summers of 2001 and 2002.

Additionally in the prior progress report, the NCEP GAPP Core Project succeeded in adding a second convection scheme as an option in the Eta RCM – namely the Kain-Fritsch convection scheme widely used in today's mesoscale modeling groups – in addition to the Eta RCM's traditional Betts-Miller-Janjic scheme.

Altogether then, given the degrees of freedom described above, we have examined the impact of the following wide-ranging attributes of the Eta RCM:

1 - analysis versus forecast supplied time-dependent lateral boundary conditions
2 – analysis versus forecast supplied SST fields
3 – Betts-Miller-Janjic versus Kain-Fritsch deep convection scheme
4 – large versus moderate domain size
5 – simulation mode versus quasi-prediction mode versus full prediction mode

Our examination of the Eta-RCM results from the above widely ranging set of attributes shows that the fully predictive mode is not grossly less skillful than the simulation mode or quasi-prediction mode. The reason is that the Eta-RCM in all three modes exhibits an over-intensification of the N. American mean-summer ridge amplitude in the height fields at 500 mb and 200 mb.

FY04 Accomplishments (7 months):

All of the prior Eta RCM executions cited in the above background discussion used the NCEP Global Reanalysis 2 (denoted here GR2) as the source of the initial conditions for the Noah LSM land states of the Eta RCM, such as soil moisture. The GR2 does not directly assimilate observed precipitation, nor does it use the Noah LSM for its land model component. Hence GR2 soil moisture states are not optimum sources of soil moisture for the Noah LSM in the Eta RCM.

In contrast, NCEP's recently completed N. American Regional Reanalysis (NARR) does include the direct assimilation of observed precipitation and utilizes the Noah LSM for its land component. Hence in the present reporting period, the NCEP GAPP Core Project investigated the impact of using NARR land states as the initial conditions for the Noah LSM land states of the Eta RCM. In particular, we investigated whether the use of NARR land states in the initial conditions of the Eta RCM would eliminate the Eta RCM's strong tendency to over-intensify the N. American mean-summer ridge amplitude in the 500 mb and 200 mb height fields. The latter overly-intense amplification of the ridge appears, in turn, to stem from overly strong surface sensible heat flux over the continental land mass, which seems to be the consequence of overly dry soil moisture. The dry soil moisture may be inherited from the global reanalysis initial conditions, or it may evolve over time from a spin-down of the Eta model precipitation.

Specifically, the Eta RCM was executed from GR2 and NARR initial land states in simulation mode for 3-member ensemble simulations of 4-month duration, beginning from three late May initial times and extending out through the end of September, for both the drought summer of 1988 and the flood summer of 1993. The results are reported in an extended abstract (Rongqian et al., 2005; available upon request) submitted to the AMS Annual Meeting of January 2005. An example result from this paper is presented in Fig. 5, which shows the 1993 minus 1988 difference in JJ (June+July) total precipitation (mm) for the observed precipitation from the gauge-based CPC unified precipitation analysis (bottom panel) and the 3-member ensemble mean of the Eta RCM simulations initialized from GR2 (top panel) and NARR (middle panel). Both the GR2- and NARR- based simulations show a broad general capability to reproduce the observed interannual variation, with much greater precipitation amounts (as observed) in 1993 versus 19988 in the northern Midwest and northern Great Plains. But both simulations under represent the magnitude of the precipitation anomaly and have a southern and eastern bias to the heavy precipitation in 1993. The NARR-based simulation does not exhibit any clear advantage, and in fact, could be judged to be somewhat worse than the GR2-based simulation. Both the NARR- and GR2-based simulations exhibited the previously noted Eta RCM tendency to over-intensify the N. American mean-summer ridge amplitude in the height fields at 500 mb and 200 mb (not shown).

During the reporting period, Rongqian Yang of the presented posters on the Eta RCM research of the NCEP GAPP Core Project at the following meetings:

1 - The 29th Climate Diagnostics and Prediction Workshop, 18-22 October 2004, Madison, WI
2 - The 1st International CLIVAR Science Conference, 21-25 June 2004, Baltimore, MD

Also during the present reporting period, the NCEP GAPP Core Project continued to interact and collaborate with several GAPP-sponsored PIs external to the Core Project in addressing a number of RCM issues, such as the following:

1 - Evaluation of Eta RCM executions for the NAME Model Assessment Project (NAMAP). The Core Project interacted extensively with NAMAP PI Dave Gutzler and his assessment of the models executed for the NAMAP-designated study period of summer of 1990. The NCEP GAPP Core Project participated in the review, revision and editing of the NAMAP paper spearheaded by Dave Gutzler and submitted to the BAMS for publication. Presently, the GAPP Core Project is contributing actively to the current dialogue among NAMAP PIs about the content, approach, and strategy of the Phase II of the NAMAP study, to include the summer 2004 period of the NAME field campaign. The Core Project is strongly advocating that Phase II of NAMAP include RCM experiments executed in full prediction mode, using lateral boundary condition and SST predictions from NCEP's CFS seasonal forecast system.

2 – With Prof. Roger Pielke of CSU on the issue of the apparent decrease in the kinetic energy of the circulation in the RCM domain compared to the large-scale driving global prediction model or global reanalysis.

3 – With Prof. Yongkang Xue of UCLA on the issue of determining the optimal Eta RCM domain size for summer season seasonal forecasts for the CONUS.

4 – With Dr. Henry Juang of NCEP/EMC, whose CDEP-funded grant is supporting RCM predictability experiments using the RCM version of the NCEP Regional Spectral Model (RSM). The RCM group of Dr. Juang and the RCM group of the NCEP Core Project meet roughly bi-monthly to share presentations and perspectives of their RCM research.

5 – With Song Yang of CPC. The NCEP GAPP Core Project provides and supports the Eta RCM as a community RCM for use by GAPP-supported PIs external to the GAPP Core Project. The first such PI to carry out GAPP-funded seasonal predictability research with the Eta RCM is Song Yang of NCEP/CPC. He is executing the Eta RCM to investigate the sensitivity of precipitation predictability to the space and time scales of the soil moisture anomalies in the initial conditions. The period of study is the 1988 drought year and the 1993 flood year.

FY05 Work Plan (10 months)

We will continue to seek the cause of the Eta RCM's systematic tendency to over-intensify the N. American mean-summer ridge amplitude in the height fields at 500 mb and 200 mb (not shown). In this investigation, we will focus closely on the surface water and energy budget to determine if the seasonal simulations of the Eta RCM are properly reproducing the essential partitioning of surface net radiation at the surface into latent heat flux and sensible heat flux. For this examination, we will heavily utilize the newly completed NCEP Regional Reanalysis and the retrospective executions of the NLDAS.

We will begin to assess the use of the NCEP's new CFS seasonal prediction system to drive the Eta RCM in full prediction model (i.e. predicted lateral boundary conditions and predicted SST). Unfortunately, owing to a shortage of mass storage file space in the NCEP Central Computing System, the current 23-year hindcast database of the CFS does not include sufficient 3D output to drive an RCM. For this reason, in collaboration with the CDEP project of EMC, the NCEP GAPP Core Project will share the work of re-executing a CFS 15-member, 4-5 month forecast ensemble from early May initial conditions during each May of a 20-year hindcast period, to then store sufficient CFS 3D output to drive summer-season RCM tests. The latter can be used in the NCEP Climate Test Bed by any internal or external GAPP PI to execute fully predictive RCM tests.

Additionally, we will begin to consider the possible use of the new regional Weather Research and Forecast (WRF) model as a possible successor to the Eta model as a regional RCM for NCEP seasonal prediction. To explore this possibility we will attend the 22-23 March 2005 workshop at NCAR on the potential use of WRF as a Regional Climate Model. At this workshop, Rongqian Yang of the NCAP GAPP Core Project will present a poster on the Core Project's research to date with the Eta RCM.

2.0 GLOBAL AND N. AMERICAN LAND DATA ASSIMILATION SYSTEMS (LDAS)

2.1 GLDAS: Global Land Data Assimilation System applications

Background

The initial NASA proposal and resulting NASA grant that spearheaded and launched the GLDAS project as an obvious follow-on to the forerunner NLDAS project was a joint NASA-NCEP proposal and project. The GLDAS article of Rodell et al. (2004) in BAMS marked the end of Phase I of the GLDAS project. Phase II ensued with the beginning of the multi-institution Land Information System (LIS) project spearheaded again by NASA and including the NCEP component of the Core Project and the Noah LSM, as well as Princeton University and the VIC model, and COLA.

In the prior progress report, the NCEP GAPP Core Project, in close collaboration with the LIS team of NASA/GSFC/HSB, succeeded in transferring a working GLDAS suite in the form of the LIS infrastructure to NCEP's Central Computing Facility (CCF) and executing a one-month benchmark of this suite.

FY04 Accomplishments (7 months)

The aforementioned successful porting and benchmarking of the NASA LIS/GLDAS infrastructure to NCEP was reported in an extended abstract (Meng et al., 2005; available upon request) submitted to the AMS Annual Meeting of January 2005.

Section 1.1 illustrated the critical importance of providing Noah-based initial land states for assessment of the Noah LSM in NCEP's Global Forecast System (GFS). During the present reporting period, the NCEP GAPP Core Project completed a 25-month execution of the GLDAS with the Noah LSM from 01 November 2002 through 30 November 2004 at the T62 spatial resolution. This 2-year GLDAS/Noah was driven by NCEP Global Reanalysis 2 (GR2) and CPC CMAP precipitation analyses. The configuration of the Noah LSM (physics, parameters, terrain field, grid, land mask, vegetation and soil properties) in this 2-year GLDAS is exactly the configuration used in the T62 GFS/Noah tests described in Sec. 1.1.

Moreover, the Core Project developed a useful utility to map the spatial resolution of the GLDAS from any given resolution A to resolution B, taking into account the soil moisture rescaling that must be applied of the resolution change causes a change in soil type and/or vegetation type. While our strong preference remains to spin-up the GLDAS/Noah for 2+ years on whatever spatial resolution is needed, computational limitations sometimes prohibit the quick execution of LIS/Noah on very high resolutions, such as the T382 resolution of the new GFS parallel tests. Hence the newly developed utility to statically change the resolution of the GLDAS/Noah has already experienced heavy use in the Core Project. The initial land states of the T382 GFS/Noah parallel test that was initialized on 30 November 2004 was produced by executing the change-resolution utility on the 30 November 2004 land states of the T62 GLDAS/Noah, which had been spun-up for the previous 2-year period, as described earlier.

FY05 Work Plan (10 months)

The 2+ year spin-up of the GLDAS/Noah will be repeated at the high resolution of the present T382 GFS/Noah tests. The goal is to use the initial land states of this T382 GLDAS/Noah retrospective to provide the cold-start initial land states for the May-Jun 2004 and Aug-Sep 2004 retrospective tests of the full-resolution T382 GFS/Noah tests described in Section 1.1.

Additionally, a T126 resolution version of the GLDAS/Noah will be constructed and tested for 2-3 years of spin-up, in preparation for a 25-year hindcast execution by the NCEP GAPP Core Project in FY06 of the GLDAS/Noah at T126 resolution to support land-surface impact tests in the CFS seasonal prediction system and global reanalysis exercises of the NCEP Climate Test Bed.

2.2 Global Soil Wetness Project II (GSWP-II): Noah LSM execution, assessment, experiments

Background

The NCEP GAPP Core Project participated in the original 2-year 1987-1988 Phase I of the Global Soil Wetness Project. In the past 2-3 years, the NCEP Core Project has also participated in the follow-on, 10-year, 1986-1995 GSWP-II with executions of the Noah LSM. Specifically, the NCEP Core Project executed and submitted 10-year executions of the Noah LSM on the global 1-degree landmass grid specified by GSWP-II and using GSWP-II provided forcing fields. These Core Project GSWP-II executions with the Noah LSM were presented by the Core Project at the GSWP-II special session of the AMS 18th Conference on Hydrology (Wei et al., 2004) of the AMS Annual Meeting of January 2004.

FY04 Accomplishments (7 months)

Following the presentation of the GSWP-II control runs by the various participating institutions at the GSWP-II Session of the AMS 18th Conference on Hydrology in January 2004, the GSWP-II principals vigorously lobbied the participating institutions to undertake a series of GSWP-II sensitivity experiments. By intent of the GSWP-II organizers, different institutions undertook different types of sensitivity tests.

The NCEP GAPP Core Project decided to execute GSWP-II sensitivity experiments with the Noah LSM to address the sensitivity of the Noah LSM to interannual variability in the vegetation properties of green vegetation fraction (GVF) and leaf area index (LAI). Owing to the difficulty of achieving reliable satellite remote-sensing of GVF and LAI in realtime owing to the contamination problems of sensor-calibration drift, persistent cloud cover, persistent smoke from widespread burning of tropical rain forests, and snow cover, modelers frequently resort to the use of multi-year monthly climatologies of GVF and/or LAI (which have benefited from retrospective and careful quality control and careful filtering of contamination effects). Such is the case at NCEP when executing the Noah LSM in the GFS, Global and Regional Reanalysis, and NLDAS and GLDAS, which all use a 5-year monthly climatology of GVF.

Helin Wei of the NCEP GAPP Core Project executed the 10-year GSWP-II sensitivity tests of the Noah LSM to interannual variability of GVF and LAI. He executed a matrix of four 10-year GSWP/Noah experiments, given as 1) Control-"C": 10-year climatology for both monthly GVF and LAI, 2) Test-"G": year-to-year monthly time series for GVF and 10-year climatology for monthly LAI, 3) Test-"L": 10-year climatology for monthly GVF, but year-to-year monthly time series for LAI, and 4) Test-"LG": year-to-year monthly time series for both GVF and LAI. The sensitivity of the simulated surface latent heat flux and sensible heat flux was examined in these four runs for four regions of order 5 x 10 to 10 x 10 degrees in size, spanning west-African tropical rain forest (region 1), Amazon tropical rain forest (region 4), boreal forest of south central Siberia (region 2), and tundra of northern central Canada (region 3).

For these latter four regions, Fig. 6 shows the 10-year (1986-1995) time series of (top panel) actual monthly green vegetation fraction (GVF) and leaf area index (LAI) and (bottom panel) their monthly anomalies with respect to their 10-year monthly climatology. As an example of the sensitivity of two components of latent heat flux, Fig. 7 shows for Region 1 the 10-year monthly time series of the test-minus-control differences in transpiration (Tveg, top panel) and direct bare soil evaporation (Esoil, bottom panel) for the G, L, and LG tests. The differences for each component are rather small (bounded by about 4-8 Watts/m**2 in magnitude) and represent only about 10 percent of the total latent heat flux. Furthermore, the signs of the Tveg and Esoil anomalies tend to be opposite and hence significantly compensatory, so that the final impact on total latent heat flux is only of order 5 percent. Small sensitivities in the latent heat flux were found in the other three regions as well.

The above examination concluded that A) the effects of interannual variability of LAI and greenness fraction are marginally small and using the climatology of these two quantities seems sufficient, and B) LAI has larger interannual variability than greenness fraction, so interannual variability of LAI has larger effects on latent and sensible heat fluxes than greenness fraction.

FY05 Work Plan (10 months)

Write a paper on the above GSWP-II sensitivity experiments and submit the paper for publication. Collaborate with the GSW-II principals on the writing and revision of a GSWP-II paper on the GSWP-II control runs.

2.3 NLDAS: North American Land Data Assimilation System Phase II

In prior progress reports, a rich set of results have been obtained and reported for Phase I of the N. American Land Data Assimilation System (NLDAS), culminating in ten papers on NLDAS in the 2003 JGR Special Issue on GAPP. This Phase I was focused on the development, execution, and assessment of the backbone (background) simulations of the NLDAS, including the sources and procedures for producing the land surface forcing, the various tools and data sets for performing assessments and the characteristics and performance of the four participating land models: Noah, Mosaic, VIC, and SAC.

FY04 Accomplishments (7 months)

As set out in the NLDAS work plan of the previous progress report, the NCEP Core Project did indeed construct, test and publicly announce a new web-based, interactive NLDAS testbed focused on the 3-year core period of Oct 1996 through Sep 1999 that was well exercised in the 10 JGR NLDAS papers of the recent JGR GCIP/GAPP Special Issue. This newly available NLDAS test bed has opened up the NLDAS infrastructure for wider use and participation by a larger community of GAPP-sponsored PIs, as well as other PIs from other initiatives, such as the land component of the NOAA-NASA-DOD Joint Center for Satellite Data Assimilation (JCSDA).

The NCEP Core Project did host a visit from Jeff Basara and Kodi Nemunaitis of the OU Mesonet in mid-July 2004 to introduce them to the web-based interactive NLDAS and to lay out some NLDAS research strategies for the OU Mesonet team.

Additionally as planned in the prior progress report, during the present reporting period, Phase II of the NLDAS collaboration was kicked off at a key NLDAS meeting on 11 May 2004 at NWS/OHD. In Phase II, the NLDAS collaboration is turning more attention squarely on actual data assimilation.

The NCEP GAPP Core Project is focusing on data assimilation in the Noah LSM option of the NLDAS.

In previous progress reports, we have reported on the development of the adjoint/tangent-linear model for the Noah LSM. In the current reporting period, we present the encouraging progress in the NCEP GAPP Core Project with the assimilation of land surface temperature (LST) in the Noah LSM, via its adjoint / tangent linear model. To test our basic approach, we first performed 1-D identical-twin experiments with the Noah column model for 1998, following a 1997 spin-up year, all forced with 30-minute surface observations at a flux station operated by GAPP-funded PI Tilden Meyers of NOAA/ARL in east central Illinois. Three runs were executed for 1998: 1) the control run, 2) a degraded forcing run in which a 30% reduction was imposed on all moderate or greater amounts of the 30-minute precipitation, and 3) as in 2), but assimilating the simulated LST of the control run for a 3½-day period beginning 0000 UTC on 25 May. The results are shown in an extended abstract (Lohmann and Mitchell, 2004; available upon request) presented by invitation at the 11-13 November 2004 workshop on Land Data Assimilation at ECMWF. These results demonstrate that the LST assimilation effectively and rapidly corrects (in about 3 days) the erroneous drift in the soil moisture that results from the imposed erroneous forcing. During the 3-day assimilation period, the assimilation routine calculates the cost function and the tangent linear of the Noah LSM and finds the optimal correction to the soil moisture state at the beginning of the 3-day interval that minimizes the difference between the "control" and simulated LST over the subsequent 3 days.

We next introduce a simplified 4D-Var assimilation of LST. We start with a typical cost function where J is the cost function, x the model state (soil moisture content, SMC), x_b the model background state, B the background error covariance matrix, n the number of observations over the assimilation interval, Y the observed state (LST), H the observation operator (to transform the soil moisture state to LST), and R the error covariance matrix for observation errors. We then apply the following assumptions:

1) For given surface forcing, we assume that LST is mainly a function of SMC, and hence for each assimilation interval, a functional relationship T(SMC) exists, which is the observation operator H.
2) The Noah LSM can be linearized around $x_i = \mathbf{M}_i \mathbf{M}_{i-1} \ldots \mathbf{M}_1 x_1$; its background state can be written as a succession of linear operators $\mathbf{M}_i$.
3) The observation operator can be linearized around a state variable x, and hence

$$y_i - H_i M_{1->i}(x) \cong y_i - H_i M_{1->i}(x_b) - \mathbf{H}_i \mathbf{M}_{1->i}(x - x_b)$$

We then apply these additional simplifying assumptions during each 6-hour mid-day assimilation window:

a) $\mathbf{M}$ = I (the identity matrix), i.e. total evaporation does not change total soil moisture by more than one percent (Note: we do not assimilate if there is precipitation.)
b) $\mathbf{H}$i = [d(LST$_i$)/d(SMC$_i$)], the rate of change of LST with soil moisture is approximately constant during any given day's assimilation interval and is estimated numerically, resulting in an estimate for the 6-hour mean $\overline{\mathbf{H}}$.

c) **B**, **R** = I for the estimation of the cost function with adjusted units. Weighting coefficients are chosen based on empirical evidence of time scales. This leads to the following gradient of the cost function (without the background term):

The cost function for the analysis increment has a minimum where the gradient equals zero. Therefore the sum of the differences has to be zero, leading to

$$x_1 = x_b + \frac{\overline{\mathbf{H}}^T}{n} \sum_{i=1}^{n} (y_i - H_i M_{1->i} x_b)$$

where x_b is the background state at t=1. This is the update equation for the case of perfect measurements and zero background weight. One can set adjustment timescales using fractions of the increment, e.g. 50% here.

This method was used in the Noah LSM to assimilate 1) identical-twin control-run LST and 2) GOES satellite LST over the entire NLDAS CONUS domain during daily, 6-hour mid-day intervals over five months beginning 01 May 98. No soil moisture was assimilated in the bottom soil layer (layer 4, 100-200 cm). We examine the ability of the LST assimilation to overcome two severe degradations that we impose in the assimilation runs: a) zero precipitation everywhere at all times from 01 May onward and b) initial soil moisture set to wilting point everywhere on 01 May. Additionally, in a second run assimilating control-run LST, we impose less severe but still dry initial conditions on 01 May by taking them from a non-assimilating benchmark run with zero precipitation after 01 Mar 98. Fig. 8 presents the results.

Both Fig. 8a and Fig. 8b depict five runs in five rows, of which Row 1 is the control, Rows 2, 3, 4 are the three assimilation runs, and Row 5 is a non-assimilating benchmark with zero precipitation. Fig. 8a shows the dry initial states imposed on all three assimilation runs. The Figure 8b shows how quickly (by three weeks) the assimilating runs recharge (moisten) the dry initial soil states and overcome the zero precipitation forcing. As expected, the two runs assimilating the control-run LST agree most closely with the control run. The run assimilating the GOES LST develops a moist bias compared to the control, likely from the modest cool bias noted in the GOES retrieval of LST. Future efforts will pursue bias corrections for the GOES LST.

Caption for Figure 8

Soil moisture (volumetric) at assimilation-start time of 01 May 98 (Figure 8a) and after three assimilating weeks on 21 May 98 (Figure 8b). Left to right, columns 1-4 depict soil layers 1-4 (0-10, 10-40, 40-100, 100-200 cm). In each 5-row set: Row 1 = Control run (no assimilation, no degraded forcing, no degraded initial conditions), Row 5 = Degraded Benchmark run (no assimilation, zero precipitation after 01 March 98), Row 2 = as in Degraded Benchmark, except assimilates LST of Control run as of 01 May and thereafter, Row 3 = as in Row 2, except with added degradation of all soil moisture set to wilting point on 01 May, Row 4 = as in Row 3, except assimilated LST is GOES LST.

FY05 Work Plan (10 months)

Develop and test bias-correction procedures for the 1-3 K cool bias in the GOES retrievals of land surface temperature (LST). Re-execute the GOES LST assimilation experiments above with the bias corrected fields.

Develop and write-up the design of the procedures to use the realtime NLDAS with the Noah and VIC LSMs as an operational NOAA U.S. drought monitoring tool, in conjunction with the two 50+ year NLDAS retrospectives developed for 1) the Noah LSM by CPC (via GAPP-funded PI Huug Van den Dool) and 2) the VIC LSM by University of Washington and Princeton University (via GAPP-funded PIs Dennis Lettenmaier and Eric Wood, respectively). Develop the design in collaboration with OHD component of Core Project and aforementioned CPC and University PIs. Include a drought prediction component in the design by specifying how to use ensemble predictions from subseasonal (week 1) to seasonal (12-month) time scales to drive the NLDAS in a prediction mode.

3.0 IMPROVING NOAH LSM PHYSICAL PROCESSES, PARAMETERS AND TRANSFERABILITY

Background

The NCEP Core Project continues intensive work to improve the accuracy, reliability and skill of the many warm season and cold season physical processes in the Noah LSM, including objective and systematic approaches to optimizing key physical parameters. These efforts include both internal Core Project research and the infusion of the science of improving Noah LSM physics, as undertaken by the external research community. This community includes either currently or previously GAPP-funded PIs, especially by means of the multi-institution NLDAS project and collaborations spawned by the various GAPP and GEWEX subprograms such as PILPS, CEOP, GSWP, MOPEX, GLASS, GABLS, etc.

Additionally, the Core Project is achieving Noah LSM improvement by collaborating with and leveraging other U.S. research programs outside of the GAPP and GEWEX arenas, namely the U.S. Weather Research Program (USWRP) and the NOAA-NASA-DOD Joint Center for Satellite Data Assimilation (JCSDA). Examples of Noah LSM improvement via the USWRP and JCSDA are:

1 - adding an urban treatment component to the Noah LSM through the Land Working Group of the Weather Research and Forecast (WRF) Model of the USWRP WRF program at NCAR,

2 - working with the WRF Land Working Group to achieve May 2004 milestone of NCAR's formal and supported release of the Noah LSM as an LSM option in the community WRF model,

3 - coupling the Noah LSM to the NCEP/GFDL Hurricane Model and testing the Noah LSM impact on land-falling hurricanes (under USWRP sponsorship), and

4 - improving the snowfall canopy interception and snow albedo treatments of the Noah LSM in the winter surface albedo work at the University of Arizona under JCSDA sponsorship.

The assessment and improvement of Noah LSM physical processes and parameters in the Core Project is pursued by the following means:

A - uncoupled test executions and validation of the Noah LSM community 1-d column model at surface flux stations such as those of the CEOP reference sites, the OU Mesonet OASIS sites, ARM sites, SURFRAD sites, etc

B - uncoupled test executions and validation of the Noah LSM over large continental and global domains such as in NLDAS, GLDAS, PILPS 2c and 2e, GSWP

C - coupled tests in the Eta Regional Climate Model and Eta mesoscale NWP model

D - coupled tests in the NCEP Global Forecast System (GFS), both seasonal forecast mode and NWP mode

To further facilitate the infusion of external science and research into the improvement of Noah LSM physics, the NCEP Core Project continues to "grow" the capabilities of its Community Noah LSM. the NCEP Core Project provides, maintains and supports a web-browser based interactive tool for executing the 1-d column model version of the Noah LSM. In this way, a researcher at an institution and site external to NCEP can interactively access an NCEP public workstation and execute and test the Noah LSM on that platform.

Moreover, as a natural extension to the latter single-site tool, the earlier Section 2.3 on NLDAS announced the delivery by the Core Project of a companion web-based interactive tool for external researchers to remotely execute, test and evaluate the continental-scale NLDAS on an NCEP public workstation. The NLDAS system in particular has proven to be an excellent testbed for evaluating and improving Noah LSM physics. One advantage of uncoupled land-only executions of the Noah LSM for the purpose of improving physical processes is that uncoupled test beds invariably provide improved surface forcing fields that omit much of the systematic bias that often plagues surface forcing in coupled models.

FY04 Accomplishments (7 months)

As planned, the NCEP Core Project embarked on a joint research initiative with GAPP-funded PI Alan Robock of Rutgers University, and his doctoral student Tom Atkins to test and improve the Noah LSM's treatment of the rooting depth and the root density profile within that depth. Core Project members instructed Tom Atkins on how to vary the number and thickness of the soil layers and root layers in the Noah LSM and what subroutine of the model source code treats the density of the root profile. He then executed the Noah LSM with various numbers and thickness of its soil layers and tested various root-density profile functions, including the root density profile function developed by GAPP-funded PI Xubin Zeng of the University of Arizona. Preliminary results from Tom Atkins early research thus far with the 1-D Noah column model has shown the following:

- A uniform root distribution does not accurately model the observed soil moisture profile.
- Changing the root depth can significantly affect simulated fluxes in vegetated areas.
- Formulations tested thus for representations of root profiles with non-uniform density yield to little variability in the lower layers and too much evaporation from surface layer.

The above work will be reported in a presentation by Tom Atkins at the 19th Conference on Hydrology at the AMS Annual Meeting of January 2005. Follow-on research will test other functional choices for the root depth, root-profile density, and number and thickness of the root layers.

Shifting now to internal efforts within the NCEP Core Project to improve Noah LSM physics and parameters over the recent months, a key area of recent focus has been the treatment of the surface emissivity for the upwelling broadband longwave radiation. Historically, many land surface models including the Noah LSM have assumed that the surface longwave emissivity is 1.0 (virtual a black body treatment). This assumption is quite good for non-sparsely vegetated regions, or in regions with non-dry soils, or over old mature snowpack. However, over fresh snowpack of low density, or over bare dry soils, the surface emissivity in reality can approach values between 0.97 to 0.93, even 0.90 or slightly less in extreme situations. Hence the Noah LSM formulation was recently modified to allow for surface emissivity of less than one. Our first tests thus far have examined the impact of assuming an emissivity of 0.95 or 0.90 over nontrivial snowpack (sufficiently deep to have nontrivial snow cover fraction).

We tested this snow emissivity change first in the coupled Eta/Noah model, which has exhibited a longstanding nighttime wintertime near-surface cold bias, primarily because of insufficient nighttime downwelling longwave radiation at the land surface over snowpack, which in turn stems from too little wintertime low-level stratus cloud and fog over snowpack in the Eta model. While lack of sufficient low level stratus cloud is the primary cause, a secondary (smaller) contribution to the near surface cold bias is too much upwelling longwave radiation from the land surface over snowpack from universally applying 1.0 for the surface emissivity.

Figure 9 provides an example of the significant reduction in the wintertime near-surface cold bias in the Eta model when a surface emissivity of 0.90 is applied to the fraction of a grid cell covered by snow. The grid-cell mean surface emissivity is given by the weighted average of 0.90 and 1.0, where the averaging weights are the snow-covered fraction and the snow-free fraction, respectively. Figure 9 shows the February 2004 monthly mean and multi-station average of the 96-hour diurnal cycle of 2-meter air temperature (C) derived from 1) all surface-station observations (green line) received at NCEP over the eastern half of the CONUS, and from the Eta/Noah-predicted values at all the station co-located Eta model grid points from all 12Z-initialized runs during that month of the 2) control Eta/Noah model (blue/aqua line) using 1.0 surface emissivity and 3) the test Eta/Noah model using 0.9 surface emissivity over snowpack. Clearly the control Eta/Noah runs yield a substantial early-morning cold bias, while the Eta/Noah test runs show very little bias and maintain excellent phase. The test emissivity of 0.90 over snow is probably a bit too low compared to reality and represents an overcompensation for the low bias in downward surface longwave radiation. If the latter downward longwave radiation bias were solved, then staying with the 0.90 test value would likely yield a warm bias. Further testing will likely arrive at a final choice of surface emissivity of around 0.93 or 0.95 for snow cover, or a value that we allow to vary with the density of the snowpack, which is a predicted state variable of the Noah LSM.

FY05 Work Plan (10 months)

The NCEP Core Project will expand its testing of surface emissivity values of less than 1.0 over snow cover to include the NCEP GFS/Noah global forecast system, and to include other surface types (e.g. bare dry soil). Simultaneously, the albedo treatment over snowpack will be further refined and tested in the GFS, as presently the GFS radiation package applies a different snow albedo treatment than the Noah LSM. Our testing will unify the snow albedo treatment throughout, either changing that in the radiation physics, or changing that in the Noah LSM, or both.

Additionally, the NCEP Core Project will undertake the incorporation and testing of a dynamic vegetation model in the Noah LSM, including assessing its impact in summer seasonal simulations of the Eta Regional Climate Model. We will test the dynamic vegetation model recently incorporated and tested in the RAMS RCM model under the GAPP grant of PI Prof. Roger Pielke.

4.0 DERIVE AND EXAMINE LAND-SURFACE WATER AND ENERGY BUDGETS

FY04 Accomplishments (7 months)

The NCEP component of the GAPP Core Project participated intensely in the derivation and assessment of the land surface water and energy budgets of the following five systems:

1 - With GAPP PI Hugo Berbery: the land surface water and energy budget of the NCEP operational Eta model over the western U.S., with emphasis on the Columbia and Colorado River basins, for the period 1995 - 2002. Jointly authored and revised a paper on this investigation, which has accepted for publication in the Journal of Hydrometeorology.

2 - With GAPP PI Jeff Basara: the land surface energy budget of the Noah and Mosaic LSMs of the NLDAS during the summer of 2000 using flux-station observations from the OASIS component of the Oklahoma Mesonet. Jointly authored and submitted a paper on this investigation to the Journal of Hydrometeorology.

3 - With GAPP PI Huug Van den Dool: the land surface water and energy budget of the Noah LSM in the 50+ year retrospective execution of the NLDAS. Jointly authored and submitted a paper on this investigation to the Journal of Hydrometeorology.

4 - With GAPP PI Hugo Berbery: the land surface water and energy budget of the N. American Regional Reanalysis (NARR). This material has been prepared for presentation at the Regional Reanalysis Workshop scheduled during the AMS Annual Meeting of January 2005.

5 - With GAPP PIs M. Kanamitsu and J. Roads: the validation and intercomparison of the soil moisture of the Global Reanalysis 1 and the Global Reanalysis 2 against the Global Soil Moisture Data Bank of GAPP PI Alan Robock. Jointly authored, submitted, and revised a paper on this investigation, which has been accepted for publication in the AMS Journal of Hydrometeorology.

FY05 Work Plan (10 months)

The investigative thrusts 1, 3, and 4 above uncovered the presence of a nontrivial residual (non-closure) in the surface water balance of the Noah LSM in the presence of accumulating or depleting snowpack. We will further investigate this nontrivial residual, strive to determine its cause, and if a cause is found, then formulate and test corrective changes to eliminate this residual in future applications of the Noah LSM.

5.0 PRODUCE/VALIDATE SATELLITE LAND PRODUCTS FOR GAPP/GEWEX/LDAS

<u>NESDIS</u>

This section presents the contribution of NESDIS Office of Research and Applications (ORA) to the GAPP Core Project and its routine and robust interaction with the NCEP component of the Core Project.

Background

Since the middle 1990's, NESDIS/ORA -- in collaboration with A) GAPP PI Professor Rachel Pinker of the University of Maryland and B) the NCEP component of the Core Project developed -- validated and implemented a suite of hourly, 0.50-degree resolution GOES-based solar insolation, surface radiation, cloud cover and land surface skin temperature (LST) products, known as the "GOES GEWEX Products", for use by a host of GCIP and GAPP initiatives, including prediction model validation (Berbery et al., 1999), surface forcing for land models including NLDAS (Cosgrove et al., 2003; Luo et al., 2003), and as a source for satellite LST for ingest into land surface data assimilation systems.

The PI (Dan Tarpley) of the NESDIS component of the GAPP Core Project, and his Co-I (Istvan Laszlo) of the NESDIS/ORA continue to spearhead both the operational suite and parallel developmental test bed suite of the GOES-based satellite-retrievals of the GEWEX product suit, which includes fields of surface solar insolation, land surface skin temperature, and many cloud products like cloud liquid water path and cloud cover fraction, plus ancillary supporting fields.

FY04 Accomplishments (7 months)

The PIs and Co-Is of both the NESDIS and NCEP components of the GAPP Core Project continued to meet routinely every two weeks to inspect and validate (against ground stations) samples of 1) the above product suite and 2) validation of NCEP global and regional models against the aforementioned satellite products.

The Core Project is pleased to state at this time that the production of the GOES GEWEX product suite is healthy and robust. Both the NESDIS and NCEP components of the Core Project continue to expand their set of web-based set tools to 1) validate the GOES GEWEX product suite and NCEP global and regional model output against A) eight SURFRAD flux station sites and B) polar orbiting satellite-based product sets and 2) use the GOES-based retrievals of surface solar insolation and LST to validate throughout the CONUS domain the simulated solar insolation and LST fields of NCEP global and regional models and global and regional data assimilation systems.

As an example of the expanded suite of web-based tools for 1) validation and assessment of the GOES GEWEX product suite and 2) match-ups of NCEP model output against those products one may browse the following web site:

http://www.emc.ncep.noaa.gov/mmb/gldas/

As intended in the work plan of the previous year's progress report, during the present reporting period the NCEP component of the Core Project did indeed add the capability to validate realtime NCEP model testbed output against the GOES GEWEX surface solar insolation product. The first such parallel model testbed suite was the parallel Eta model testbed.

FY05 Work plan (10 months)

The NCEP Core Project will add the parallel testbed of the NCEP global forecast model to the capability to validate NCEP model test beds with the NESDIS GOES-based surface solar insolation product.

Additionally, the NESDIS component of the Core Project will continue to examine the causes of and investigate possible solutions to a systematic high bias in the surface solar insolation product that has been documented to occur over new snow cover. This has turned out to be a particularly longstanding and vexing problem that has defied solution to date, but the NESDIS component of the Core Project continues to aggressively pursue the issue. Figure 10 provides a recent illustration of the bias for a recent case on 24 December 2004. Figure 10 shows the diurnal cycle of flux-station observed versus GOES-based retrievals of surface incoming solar insolation (units W/m**2) at the seven SURFRAD flux stations (supported by NOAA/OAR) used for validation. (Aside: the frequency of the depicted flux-station observations is 5-minutes, while that of the GOES-retrievals is hourly, so one quickly learns to visually average the 5-minute observations when inspecting these figures. Additionally, the GOES-retrievals require non-low sun angles, so the GOES-retrieved values are not available and not shown for early morning or late afternoon.) Inspection of Figure 10 reveals that the GOES-retrievals match the ground observations nicely at all the stations, except one (Penn State), including nicely matching the ground observations at a site that is clearly very cloudy on this date (Fort Peck). The situation at the Penn State site is that it is both cloudy on this date (low insolation in the observations) and has recently experienced new snow cover (not shown) after having been snow free for a few or more prior days. Clearly the GOES-retrieved solar insolation in this situation exhibits a pronounced high bias. The NESDIS PIs will strive to isolate the causes of this problem during the present work plan period, including collaboration with the GOES GEWEX product team of GAPP-funded PI Prof. Rachel Pinker of the University of Maryland.

6.0 TAILOR, QC, PROVIDE AND ARCHIVE SPECIAL PRODUCTS FOR GAPP, CEOP, GEWEX, WEBS

(Observations and analyses of precipitation from gauges and radar, output from NCEP global and regional models and global and regional 4DDA -- including GFS, GDAS, Eta, EDAS, Regional Reanalysis, NLDAS, GOES land-surface satellite products.)

Background

For years since the beginning of the GAPP Core Project, and its predecessor the GCIP Core Project, the NCEP component of the Core Project has routinely on a daily basis captured and transmitted to GAPP-designated and CEOP-designated archive centers the following observations and prediction model and data assimilation output:

1 - Precipitation observations and analyses (gauges and radar-based Stage II/III/IV to UCAR JOSS)
2 - Regional operational prediction model and regional 4DDA output models (to UCAR JOSS)
3 - Global operational prediction model and global 4DDA output (to MPI for CEOP)
4 - NLDAS hourly input forcing and hourly output land states and fluxes to NOMADS
The NESDIS component of the Core Project routinely on a daily basis has captured and transmitted to the GAPP-funded archive at the University of Maryland the following:

5 - the GOES GEWEX product suite of land-surface radiation components and skin temperature

FY04 Accomplishments (7 months)

The NCEP component of the Core Project continues its daily capture and transmission of product suites 1-4 above.

Activity #3 above is a CEOP-spawned activity that began at NCEP in 2002 and its level of activity and technical issues among worldwide NWP centers that monthly CEOP phone conferences and one annual CEOP model output workshop continue to be held by CEOP to spur and maintain this effort.

The "NOMADS" acronym for the NLDAS archive and distribution site in #4 above stands for the "NOAA Operational Model Archive and Distribution System" maintained by NCDC, NCEP and many NOAA entities, including NOAA Labs such as GFDL. NOMADS was developed as a Unified Climate and Weather Archive to provide Web access to NOAA prediction model and 4DDA information so that users can make decisions about their specific needs. The prediction model and 4DDA data sets in NOMADS span time scales from days (weather), to months (El Nino), to decades (global warming). For more, see NCDC' NOMADS home page at

http://www.ncdc.noaa.gov/oa/climate/nomads/nomads.html

This year the NCEP Core Project has had to maintain the NLDAS archive and the interactive NLDAS testing environment on the NOMADS suite in NCEP in the face of difficult and challenging transitions to the computer and disk storage hardware that hosts the NOMADS systems.

Yet as a good result of the above upgrades of computer hardware and especially disk/raid capacity for file storage, the NCEP component of the Core Project succeeded, as intended, to greatly expand the number of years of NLDAS forcing and LSM output fields staged to the new NOMADS portals, including hourly output for the entire 8-year period from October 1996 to present realtime. NLDAS output is being increasingly used by GAPP PIs to either force their own LSM executions, or to validate or inter-compare their LSM simulation outputs.

Prof. Xubin Zeng (funded in the recent past by GAPP) and his modeling group at the University of Arizona are making increasing use of the friendly, remote and interactive access to the NLDAS testbed that is maintained, upgraded and support on NOMADS by the NCEP GAPP Core Project.

FY05 Work Plan (10 months)

Continue to execute and monitor the recurring daily outputs from GAPP and CEOP designated NCEP modeling suites to the MPI and UCAR/JOSS archive centers listed in the background section above.

Note: The GEWEX and the CEOP program have requested that the major NWP centers around the world continue to provide their model and 4DDA output for CEOP to the CEOP archive at MPI throughout 2005, well past the originally targeted Dec 2004 end date for such archive activities. December 2004 marks the official end of CEOP Enhanced Observing Period 4 (EOP-4), but CEOP has requested that the NWP centers continue sending their output to MPI, as unlike NCEP, some

NWP centers were slow to initiate their CEOP archive to MPI, so some of the early portions of EOP-3 and even EOP-4 lack the output from several desired NWP centers. The additional year (or more) of having to provide the CEOP output to the CEOP archive center is an additional unexpected burden for the NCEP GAPP Core Project during 2005.

7.0 PROVIDE SCIENTIFIC LEADERSHIP TO GAPP

Background

Because of the GAPP Core Project's pillar role of serving as the GAPP program's central conduit for infusing GAPP science and technology into NOAA operational practice, the Core Project must necessarily act as a strategic planning, coordination, review and leadership entity of GAPP. The NCEP Core Project Co-PI (this author) strives hard to fulfill this role.

In general the NCEP Co-PI is regularly called upon to 1) author chapters or sections of GAPP science or implementation plans, 2) defends those plans before review panels like the NRC, 3) frequently interact with or serve as member of GAPP science advisory panels, 4) interact with or serve on other NOAA/OGP-related advisory panels, such as the science advisory team of the NCEP Climate Test Bed, 5) serve as a member of the annual GAPP proposal review panel, 6) given presentations on GAPP-related work to and interact with GAPP "sister" programs in other agencies, such as the NASA Terrestrial Hydrology Program, 7) give invited technical presentations on GAPP research at special sessions of scientific meetings or workshops (including those of other programs under GEWEX besides GAPP, such as PILPS, GLASS/GSWP, or CEOP), 8) write support letters of collaboration on the proposals of external GAPP PIs, and 9) write and submit articles about GAPP Core Project research to the GEWEX and CEOP Newsletters, and 10) lead multi-institution GAPP initiatives such as the N. American Land Data Assimilation System (NLDAS) project.

FY04 Accomplishments (7 months)

1 - Reviewed many research proposals for and served as member of the annual CPPA/GAPP proposal review panel on 26-27 Oct 04, by invitation of the CPPA Program Managers.

2 - Met with GAPP Science Advisory Group (SAG) twice, including on 31 Aug 04 at annual GAPP PIs meeting and on 30 Nov 04 at NOAA/OGP.

3 - Fulfilled request by NOAA/OGP to present the NCEP component of the GAPP Core Project the HQ-NWS / NOAA/OGP Dialogue Meeting on 01 Dec 04.

4 - Key EMC participant in preparing for and creating technical content for the first Regional Reanalysis Workshop (especially the land-surface material for the latter) to be held at the AMS Annual Meeting of Jan 05.

5 - Accepted the invitation from ECMWF to prepare an extended abstract for and represent and present the GAPP NLDAS project at the 09-11 Nov 04 ECMWF/ELDAS Workshop on Land Data Assimilation.

6 - Formally kicked off Phase II of the GAPP multi-institution NLDAS project by spearheading, organizing and giving the lead presentation of the Phase II NLDAS kick-off workshop on 11 May 04, at NWS/OHD. Lead, coordinate and set the agenda for the monthly NLDAS teleconferences.

7 - Participated for GAPP in the monthly international CEOP teleconferences on model output archiving and validation for CEOP.

8 - Fulfilled the invitation by the Editor of the GEWEX Newsletter to write and submit a newsletter article on the land surface and precipitation assimilation components of the Regional Reanalysis.

9 - Interact with and respond to the Science Advisory Committee for the N. American Regional Reanalysis (NARR).

10 - Meet bi-weekly with the NARR production group at NCEP/EMC to track, address and resolve all land-surface and precipitation assimilation issues in NARR, including documentation, interfacing with external NARR users, composing FAQs, and generation of special NARR subsets for the land surface and hydrological communities.

11 - Was a member of, and served as an advocate for GAPP on, the 5-member HQ NWS panel that recently authored a comprehensive NWS Water Science Plan.

12 - Fulfilled invitation from the NASA Program Manager for the NASA Terrestrial Sciences Program (THP) to give a technical presentation on the NCEP component of the GAPP Core Project and the NLDAS initiative at the THP's annual PIs meeting on 06 Oct 04.

13 - Present invited talks at land-surface related special sessions of scientific meetings like AGU and AMS (see Appendix B for list).

14 - Serve as an advocate of GAPP products and PI methodologies in the land-surface arena of the new NOAA-NASA-DOD Joint Center for Satellite Data Assimilation (JCSDA)

FY05 Work Plan (10 months)

Continue activities similar to those listed above, including the recurring activities of #7 and #10 above, and the commitments listed below:

1 - Presentations to the CEOP and GSWP and LDAS sessions of the AMS Annual Meeting of 2005, including at the 19th Conference on Hydrology (See Extended Abstract section of Appendix A for list.)

2 - Present at and serve as one of several EMC Co-Hosts of the first Regional Reanalysis Workshop at the AMS Annual Meeting of 2005.

3 - Represent the NCEP GAPP Core Project, by invitation, at the WRF Regional Climate Modeling Workshop on 22-23 Mar 05 at NCAR.

4 - Represent the NCEP GAPP Core Project at the annual PIs meeting of the land component of the NOAA-NASA-DOD Joint Center for Satellite Data Assimilation on 20-21 Apr 05 at NCEP.

5 - Represent the NCEP GAPP Core Project at the Drought Workshop on 17-19 May 05 at University of Maryland.

6 - Represent the NCEP GAPP Core Project at the 5th International GEWEX Science Conference of 20-24 Jun 05 in Irvine, CA.

7 - Attend the GAPP Science Advisory Group meeting planned during above GEWEX conference cited in #6 above.

8 - Represent the NCEP GAPP Core Project at the 2nd International HEPEX Workshop in early Aug 05 at NCAR.

9 - As a member of the Climate Science Team of the NCEP-OGP Climate Test Bed (CTB), spearhead the infusion of GAPP research and development into NCEP's climate forecast suite. Participate in the monthly teleconferences of the Climate Science Team of the (CTB).

APPENDIX A: Publications by NCEP GAPP Core Project during 7-month reporting period

(May 2004 – November 2004)

JOURNALS

- *NCEP GAPP Core Project member is lead author:*

Lu, C.-H., M. Kanamitsu, J. Roads, W. Ebisuzaki, **K. Mitchell**, 2004: Evaluation of Soil Moisture in the NCEP-NCAR and NCEP-DOE Global Reanalyses. J. Hydrometeorology, Accepted.

Mesinger, F., G. DiMego, E. Kalnay, P. Shafran, W. Ebisuzaki, D. Jovic, J. Woollen, **K. Mitchell**, E. Rogers, M. Ek, Y. Fan, R. Grumbine, W. Higgins, H. Li, Y. Lin, G. Manikin, D. Parrish, and W. Shi, 2004: North American Regional Reanalysis. Bull. Amer. Meteor. Soc., Submitted.

- *NCEP GAPP Core Project member is co-author:*

Fan, Y., H. M. van den Dool, **D. Lohmann**, and **K. Mitchell**, 2004: 1948-1998 US Hydrological Reanalysis by the Noah Land Data Assimilation System. J. Hydrometeorology, Submitted.

Gutzler, D. S., H.-K. Kim, R. W. Higgins, H. Juang, M. Kanamitsu, **K. Mitchell**, K. Mo, P. Pegion, E. Ritchie, J.-K. Schemm, S. Schubert, Y. Song, and **R. Yang**, 2004: The North American Monsoon Model Assessment Project (NAMAP): Integrating numerical modeling into a field-based process study. Bull. Amer. Meteor. Soc., Accepted.

Koster, R.D, P. A. Dirmeyer, Z. Guo, G. Bonan, E. Chan, P. Cox, C. T. Gordon, S. Kanae, E. Kowalczyk, D. Lawrence, P. Liu, **C.-H. Lu**, S. Malyshev, B. McAvaney, **K. Mitchell**, D. Mocko, T. Oki, K. Oleson, A. Pitman, Y. C. Sud, C. M. Taylor, D. Verseghy, R. Vasic, Y. Xue, and T. Yamada, 2004: Regions of strong coupling between soil moisture and precipitation, Science, 305, 1138-1140

Koster, R., Z. Guo, P. Dirmeyer, G. Bonan, E. Chan, P. Cox, H. Davies, T. Gordon, S. Kanae, E. Kowalczyk, D. Lawrence, P. Liu, **C.-H. Lu**, S. Malyshev, B. McAvaney, **K. Mitchell**, D. Mocko, T. Oki, K. Oleson, A. Pitman, Y. Sud, C. Taylor, D. Verseghy, R. Vasic, Y. Xue, and T. Yamada, 2004, GLACE: The Global Land-Atmosphere Coupling Experiment. 1. Overview and Results. J. Hydrometeorology, Submitted.

Guo, Z., P. Dirmeyer, R. Koster, G. Bonan, E. Chan, P. Cox, H. Davies, T. Gordon, S. Kanae, E. Kowalczyk, D. Lawrence, P. Liu, **C.-H. Lu**, S. Malyshev, B. McAvaney, **K. Mitchell**, D. Mocko, T. Oki, K. Oleson, A. Pitman, Y. Sud, C. Taylor, D. Verseghy, R. Vasic, Y. Xue, and T. Yamada, 2004, GLACE: The Global Land-Atmosphere Coupling Experiment. 2. Model characteristics and comparisons. J. Hydrometeorology, Submitted.

Luo, Y., E. H. Berbery, and **K. Mitchell**, 2004: The operational Eta model precipitation and surface hydrologic cycle of the Columbia and Colorado basins. J. Hydrometeorology, Accepted.

(Continued)

APPENDIX A: Publications by NCEP Core Project (Continued)

Nemunaitis, K. L., J. B. Basara, B. A. Cosgrove, **D. Lohmann**, **K. E. Mitchell**, P. R. Houser, J. W. Monro, 2004: Verification of the North American Land Data Assimilation System (NLDAS) using data from Oklahoma Mesonet sites. J. Hydrometeorology, Submitted.

Syed, T.H., V. Lakshmi, E. Paleologos, **D. Lohmann**, **K. E. Mitchell**, and J. S. Famiglietti, 2004: Analysis of process controls in land surface hydrological cycle over the continental United States, J. Geophys. Res., 109, D22105, doi:10.1029/2004JD004640.

NEWSLETTERS

Mitchell, K., M. Ek., Y. Lin, F. Mesinger, G. DiMego, P. Shafran, D. Jovic, W. Ebisuzaki, W. Shi, Y. Fan, J. Janowiak, J. Schaake, 2004: NCEP completes 25-year North American Reanalysis: Precipitation assimilation and land Surface are two hallmarks. GEWEX News, Vol. 14, No. 2, 9-12.

EXTENDED ABSTRACTS

(Aside: The numerous extended abstracts presented at the AMS Annual Meetings of 2004 in Seattle, WA, were listed in the previous annual progress report.)

Mitchell, K., 2004: The Emergence of Land-Surface Modeling in Modern-Era NWP: The NCEP Experience and Collaborations, AMS 50-Year Anniversary Symposium on NWP, 15-17 June 2004, College Park, MD.

Lohmann, D., P. Grunmann, and K. Mitchell, 2004: Land Data Assimilation at NOAA/NCEP/EMC. Princeton University Land Data Assimilation Workshop, 25-29 October 2004, Princeton, NJ.

Lohmann, D., and K. Mitchell, 2004: The North American Land Data Assimilation System (NLDAS), Proceedings ECMWF/ELDAS Workshop, 8-11 November 2004, 153-165.

Members of the NCEP GAPP Core Project wrote and submitted five extended abstracts by Nov 2004 to the GAPP-related conferences and symposia of the AMS Annual Meeting of January 2005, as follows:

Lu, C.-H., and K. Mitchell, 2005: Response of precipitation to soil moisture constraints in the NCEP Global model simulations for GLACE, 19 Hydrology 4.4, AMS Annual Meeting, 9-13 January 2005, San Diego, CA.

Lohmann, D., P. Grunmann, H. Wei, and K. Mitchell, 2005: Data assimilation with the Noah Land Surface Model in NLDAS, 9 IOASAOLS P2.4, AMS Annual Meeting, 9-13 Jan 2005, San Diego, CA.

Meng, J., K. Mitchell, C.-H. Lu, H. Wei, J. Eastman, C. Peters-Lidard, P. Houser, and M. Rodell, 2005: Optimal land initialization for the NCEP Global Forecast System using the NASA Land Information System, 19 Hydrology 1.1, AMS Annual Meeting, 9-13 January 2005, San Diego, CA.

(continued)

EXTENDED ABSTRACTS (Con't.)

Mitchell, K. and C.-H. Lu, 2005: Using EOP-1 and EOP-3 observations to assess land surface processes simulated in the NCEP Global Model, 16 Global 7.4, AMS Annual Meeting, 9-13 January 2005, San Diego, CA.

Yang, R., and K. Mitchell, 2005: Simulations of the 1988 drought and 1993 floods in North America using the Eta Regional Climate Model, 16 Global 8.3, AMS Annual Meeting, 9-13 January 2005, San Diego, CA

The NCEP GAPP Core Project submitted by Nov 2004 an extended abstract to the CEOP workshop of the Joint CEOP/IGWCO Meeting, 28 Feb 04 - Mar 05, Tokyo, Japan, as follows:

Lu, C.-H., and K. Mitchell, 2005: Land Surface Processes Simulated in the NCEP Global Model: A comparative study using the CEOP EOP-3 reference site observations. CEOP Session, Joint CEOP/IGWCO Meeting, 28 Feb 04 - Mar 05, Tokyo, Japan.

APPENDIX B: Presentations by NCEP GAPP Core Project during 7-month reporting period

(May 2004 – November 2004)

Oral presentation at CEOP Special Session 1 of the 2004 Joint Assembly CGU/AGU/SEG/EEGS, 17-21 May 2004, Montreal, Canada:

Ken Mitchell presented talk entitled: "Land Surface Processes Simulated by the Noah LSM in the NCEP Global Forecast System (GFS) and North American Land Data Assimilation System (NLDAS): A Comparative Study using the CEOP Reference Site Observations"

Oral invited presentation at the AMS 50-Year Anniversary Celebration of NWP, 15-17 June 2004, College Park, MD.

Ken Mitchell presented talk entitled: "The Emergence of Land-Surface Modeling in Modern-Era NWP: The NCEP Experience and Collaborations"

Poster presentation at the 1st International CLIVAR Science Conference, 21-25 June 2004, Baltimore, MD:

Rongqian Yang presented the poster entitled: "The Eta Regional Climate Model: Model Development and Its Sensitivity to Domain Size, Convection Scheme, and Lateral Boundary Conditions"

Oral invited presentation at Session A3.1 on Biological and Physical Processes on Land at the 35th COSPAR Scientific Assembly, 18-24 July 2004, Paris, France:

Ken Mitchell presented talk entitled: "Using Satellite-derived Snow Cover to Assess and Improve the Snowpack Physics of the Noah Land Surface Model of NCEP"

Oral invited presentations (2) at Annual GAPP PIs Meeting, 30-31 August 2004, Boulder, CO:

Ken Mitchell presented talk entitled: "The NCEP 25-year North American Regional Reanalysis: Configuration, Production, Results, Applications"

Ken Mitchell presented talk entitled: "The NOAA Core Project for GAPP: NCEP Component"

Oral invited presentation at the NASA Terrestrial Hydrology Program PIs meeting, 5-8 October 2004, College Park, MD:

Ken Mitchell presented talk entitled: "The NOAA Core Project for GAPP: NCEP Component"

Poster presentation at the 29th NOAA Climate Diagnostics and Prediction Workshop, 18-22 October, 2004, Madison, WI:

Rongqian Yang presented a poster entitled: "The Relative Impact of Initial Land States on Warm Season Precipitation over North America with the Eta Regional Climate Model"

Oral invited presentation at ECMWF/ELDAS only workshop on Land Data Assimilation, 9-11 November 2004, ECMWF, Reading, England:

Ken Mitchell presented talk entitled: "The North American Land Data Assimilation System: NLDAS"

Oral invited presentation at Special Session on Regional Climate Modeling at the AGU Fall Meeting, 13-17 December 2004, San Francisco, CA:

Ken Mitchell presented talk entitled: "The Development of the Eta Regional Climate Model and its Application to Warm Season Precipitation Simulation"

APPENDIX C: Supplementary Discussion of Seasonal Prediction System in Figure 1

Strategy and Infrastructure of the Core Project for Prediction and Predictability

(Largely taken from Section 0.3 of last year's NCEP GAPP Core Project Report, which includes a reference list containing all the publications cited in this appendix.)

The overarching GAPP Core Project strategy for seasonal hydrologic prediction follows the "systems" infrastructure shown in Figure 1. This figure represents an expanded version of the spatial downscaling schematic commonly known as the 'Shukla Staircase' (shown in Fig. 2. of last year's Core Project report).

The present author created the now widely shown expanded version (Figure 1) of the Shukla schematic by augmenting the original figure of Shukla to include not only the prediction model components (the boxes in the four corners of Figure 1), but also the crucial data assimilation components (the circles in the middle of Figure 1) depicting the necessary atmosphere, ocean and land data assimilation systems, which provide the initial conditions for the atmosphere, ocean and land states of the prediction models. For purposes of brevity here, the ocean component is assumed to include the sea-ice component, just as the land component includes snowpack/glaciers.

The layers of boxes in each corner of Figure 1 represent an ensemble of model predictions. The layered diamonds between the corners represent ensembles of the output forecast fields that feed the next higher resolution prediction model. The ensemble-forecast members may be from the same model (via perturbed initial conditions and/or alternate model physics) or from multiple models. The global atmospheric data assimilation system is at the very center of the figure, representing the backbone of the entire assimilation suite, as it not only initializes the atmospheric component of the global prediction models, but also provides the lateral boundary conditions for the regional atmospheric data assimilation and much of the surface forcing for the ocean and land data assimilation systems.

One should inspect the downscaling sequence of Figure 1 by beginning with the upper left corner and proceeding counter-clockwise through the lower corners and on to the upper right corner. The first modeling suite in the upper left is a coupled global *ocean-atmosphere-land* general circulation model (denoted as OAL-GCM), providing forecasts at about 100-500 km resolution at forecast ranges of 3-12 months. Downscaling to successively higher resolution is achieved by next executing the higher-resolution coupled global *atmosphere-land* general circulation model (AL-GCM) at the lower left corner. The latter is followed in turn by the imbedded coupled *atmosphere-land* regional climate model (AL-RCM) in the lower right corner. Both the AL-GCM and AL-RCM are void of an ocean model component, as they use the SST and sea-ice cover predictions of the OAL-GCM. Lastly, the ensemble land-surface forcing outputs of either of the two GCMs or the RCM, or all three, would be used to force the final modeling suite in the upper right, namely a high-resolution, uncoupled land-only macroscale hydrology model (MHM), such as those discussed both in Section 2 below and in the separately submitted OHD component of this Core Project report.

Hence the seasonal prediction/predictability infrastructure in Figure 1 is composed of free-running prediction models and 4-D data assimilation systems (4DDA) ingesting in-situ and satellite observations into assimilating "background" models. The models in the prediction and companion

4DDA components of Figure 1 are frequently and ideally the same model. The comprehensive infrastructure of Figure 1 embraced here in this Core Project is comprehensive, in that it includes

1 - **land**, **atmosphere**, and **ocean**
2 - **prediction** and 4DDA **assimilation**
3 - **global**, **regional**, and **local**
4 - **coupled** and **uncoupled**
5 - **realtime** (prediction) and **retrospective** (predictability, hindcasts, reanalysis**)**
6 - **ensemble approach** in each prediction component

Members of the ensemble prediction set in Figure 1 typically represent model forecasts started from somewhat different atmospheric initial conditions, but the state-of-the-art in constructing forecast ensembles is rapidly embracing the addition of a) ensemble members started from slightly different ocean or land initial conditions, b) multiple models, and c) multiple physical parameterization schemes in a single model. The Core Project is considering strategies for suitable perturbations of land initial states and land model physics (and/or parameters) for launching ensemble forecasts dependent on these attributes.

Representing a major milestone in 2004 for EMC's overall climate modeling program, EMC operationally implemented in 2004 its second-generation seasonal forecast system, known as the Coupled Forecast System, or **CFS**. The CFS is a fully coupled ("1-tier") ocean-atmosphere-land global modeling system (OAL-GCM in Figure 1), and has its companion global atmosphere and ocean data assimilation systems, described shortly. For this CFS implementation, EMC executed a comprehensive 23-year CFS hindcast (1981-2003). Every month of this 23-year hindcast database is comprised of a 15-member ensemble of 10-month seasonal forecasts. The global atmosphere/land model of the present CFS executes at T62 horizontal resolution with 64-atmospheric layers and 2 soil layers. The global ocean model of the present CFS is the GFDL MOM3 ocean model executed with 40 layers over a quasi-global domain (74S to 64N latitude) at 1-degree x 1-degree resolution (1/3-degree by 1-degree in the tropics). The NCEP/DOE Global Reanalysis 2 (also known as the Climate Data Assimilation System 2, or CDAS-2) represents the global data assimilation system, providing initial atmospheric states and land states for the CFS ensemble forecasts. The EMC Global Ocean Data Assimilation System (GODAS), driven by the surface fluxes of the CDAS-2, provides the initial ocean states for the CFS ensemble forecasts.

Again, in the aforementioned NCEP CFS seasonal forecast system, the companion realtime and 25-year retrospective global atmospheric data assimilation system is the NCEP/DOE Global Reanalysis 2 (Kanamitsu et al., 2002), designated here as GR2 (also CDAS-2). The GR2 4DDA is in fact a coupled land-atmosphere data assimilation system that provides realtime and retrospective temporally and spatially dependent global fields of both the atmospheric states and the land state (two soil layers and one snowpack layer). The study by Lettenmaier et al. (2001) showed that GR2 land surface hydrology was much improved over that of its predecessor – the NCEP/NCAR Global Reanalysis (Kalnay et al., 1996), designated here at GR1 – owing largely to the fact that GR2 replaced the soil moisture nudging technique of GR1 (which nudged to a bucket-model based global soil moisture climatology) with a nudging technique based on the 5-day (pentad) discrepancy between the parent atmospheric model's precipitation and that of NCEP/CPC's global pentad precipitation analysis known as "CMAP" (Janowiak, 2002). Thus the coupled GR2 global land-atmosphere 4DDA could, **in concept**, provide temporally and spatially varying initial land states with realistic wet/dry soil moisture anomalies for the NCEP dynamical seasonal prediction system.

The impact of this latter and appealing scenario was indeed tested at NCEP in 18-year summer-season hindcast experiments by Kanamitsu et al. (2003), who compared the resulting seasonal predictive skill for precipitation and near-surface air-temperature with that of counterpart control runs that used the land-state climatology of the GR2 for land state initial conditions. Disappointingly, the control runs had somewhat superior seasonal predictive skill. Hence the initial land states of NCEP's current global dynamical seasonal prediction system are specified from the GR2 land-surface climatology. From the results of their experiments, Kanamitsu et al. (2003) speculated that the anticipated advantage of using realistic initial soil moisture anomalies was overshadowed by the poor quality of the model's precipitation forecasts that forced the predicted land surface states. (Additionally, Kanamitsu et al. pointed out that the rather crude characteristics of the mid 1980's OSU LSM used in the coupled GR2 was also likely a detrimental influence.)

It must be emphasized here that in coupled dynamical seasonal prediction systems over the last 10-15 years to present, substantial surface forcing biases have also plagued the surface forcing at the ocean-atmosphere interface (e.g. wind stress, precipitation). This fact spurred ocean 4DDA (Ji et al., 1998) and ocean dynamical seasonal prediction to be executed as quasi-coupled systems, sometimes called "two-tier" systems. In two-tier systems, so-called "flux corrections" are first applied to the surface forcing fields from either the atmospheric prediction or atmospheric 4DDA before using these fields to force the surface in the ocean component of the ocean 4DDA or OAL-GCM prediction. As described below in Section 2, in land data assimilation the Core Project is embracing an analogous approach of correcting the substantial precipitation and solar insolation biases in the land surface forcing fields supplied by the atmospheric 4DDA systems.

The two-tier approach in ocean assimilation and in coupled ocean-atmosphere GCM predictions has ended at NCEP with the implementation of the 1-tier, fully coupled CFS system cited above, which omits the application of bias-corrections to the ocean-surface forcing, as the predominant ocean-surface forcing errors have been substantially reduced in NCEP's GCM over the last several years from ongoing model improvements. Aside from horizontal spatial resolution, the global atmospheric forecast model in the new fully coupled CFS seasonal prediction system is virtually identical to the global atmospheric forecast model in NCEP's operational medium-range weather forecast system. This recent unification of the NCEP global atmospheric model for seasonal climate prediction and medium-range weather prediction is now designated simply as the NCEP Global Forecast System (GFS). The acronym "GFS" is used frequently in this report.

To test and evaluate its new, fully coupled, global ocean-atmosphere data assimilation and seasonal prediction system prior to operational implementation, NCEP executed 22 years (1981-2003) of 10-member ensemble seasonal hindcasts for every calendar month. This provided the crucial model climatology of 20+ years with respect to which the operational seasonal predictions will be cast in terms of anomalies from model climatology. **Furthermore, NCEP has configured its seasonal hindcast infrastructure to allow for its relatively straightforward re-execution about every 2-3 years, to support seasonal prediction-system upgrades of that frequency**.

The latter aggressive update frequency planned now for NCEP's dynamical seasonal prediction system bodes well for near-term opportunities to operationally infuse land modeling and land data assimilation advancements from the GAPP Core Project. The GAPP Core Project will staunchly press this backdrop of opportunity; because for the land modeling community, the most telling characteristic of NCEP's new dynamical seasonal forecast system is that it still utilizes only the

GR2 for its initial land states (e.g. soil moisture). Additionally, the new system continues to use the old mid 1980's OSU land model. Moreover, no regional climate model (RCM) has been designated as an official component of the new CFS seasonal prediction system. (Nonetheless, NCEP will execute RCM tests as part of the GAPP and CDEP Projects at NCEP -- see Section 1.4).

Clearly then, the penultimate goal and focus of effort of the NCEP component of the GAPP Core Project is to develop, deliver and demonstrate the land components and regional climate model components in the seasonal infrastructure of Figure 1. The land components include a modern-era and widely validated land-surface model and the global and regional land data assimilation systems.

More specifically, all facets of the GAPP Core Project are aimed at i) developing, ii) demonstrating, iii) improving and iv) operationally implementing all the additional components of the seasonal forecast paradigm in Figure 1 that are not yet formally operational at NCEP, namely the components labeled A, B, C, D, E in Figure 1. These components depict the following:

A) Global Land 4DDA: the Global Land Data Assimilation System (GLDAS)
B) Regional Land 4DDA: the North American Land Data Assimilation System (NLDAS)
C) Regional Atmospheric 4DDA: the Eta-model based Atmospheric 4DDA System (EDAS), specifically its reanalysis counterpart known as the N. American Regional Reanalysis (NARR)
D) Regional Climate Model: the coupled Eta/Noah Regional Climate Model (AL-Eta-RCM)
E) Regional Macroscale Hydrology Model (MHM): the Noah and SAC LSMs

To demonstrate the "value added" by any of the above components, the Core Project will set out to illustrate, via extensive hindcast experiments using the Figure 1 infrastructure, whether any one or more of the components A, B, C, D and E improve seasonal predictability and prediction skill relative to the operational global dynamical seasonal prediction system. Readers are referred to the GAPP Implementation Plan (namely Chapter 6 therein written by the present author) available at the GAPP web site for more discussion of the strategy and methodology of demonstrating the "value added" by the downscaling components of Figure 1.

As described in the progress reports in Sections 1-6 below, the first three years of the GAPP Core Project have already succeeded in developing and executing viable working prototypes of all five components A-E.

Last but far from least, the water resource initiative in the separately submitted OHD component of this annual Core Project report is developing and demonstrating a "post-processor" to provide probabilistic precipitation forecasts to the hydrological model in the upper right of Figure 1, from the 60-member ensemble of the seasonal atmospheric predictions. This is a critical endeavor, as the post-processor for the probabilistic precipitation forecasts must address five traditional problems in such long-lead seasonal precipitation forecasts, namely 1) significant bias, 2) lack of sufficient spread among the ensemble set, 3) lack of extreme events, 4) insufficient temporal intermittency, and 5) lack of the fractal structure that characterizes the spatial patterns of observed precipitation. This is a major challenge for the hydrology and water resource community, including the Extended Streamflow Prediction (ESP) component of the NWS Advanced Hydrologic Prediction System (AHPS), and it's associated National Hydrologic Long-rang Prediction System (NHLPS). This is a key subject of the OHD portion of the GAPP Core Project Report submitted under separate cover.

APPENDIX D: Figures for this report (provided in a separate Powerpoint file)

To view the figures for this report, see the companion Powerpoint file.

There is no list of captions. Figures are described in the main text.