P1.3 IMPLEMENTATION OF COUPLED SKIN TEMPERATURE ANALYSIS AND BIAS CORRECTION IN THE NASA/GMAO FINITE-VOLUME DATA ASSIMILATION SYSTEM (FVDAS)

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1. INTRODUCTION

Surface skin temperature is a critical state because it reflects the surface radiative properties and energy budget and can dictate convective initiation. In addition, a reliable skin temperature field from the operational fvDAS (finite-volume Data Assimilation System) is a key requirement from scientific instrument team users. However, generating an accurate skin temperature product is a difficult problem due to the sensitivity in the parameter to error and bias in clouds, radiation, soil moisture, and precipitation. In an effort to improve the skin temperature in the fvDAS we have employed a two-fold approach via the integration of the state-of-the-art NCAR Community Land Model (CLM) version 2.0 land-surface model (Dai et al. 2002; Zeng et al. 2002) into the assimilation system, and through the skin temperature analysis and bias correction. Previously, the fvDAS performed an uncoupled skin temperature analysis and bias correction based on GMAO TOVS (TIROS Operational Vertical Sounder) skin temperature observations. In this study, a new method of coupled skin temperature analysis and bias correction has been developed so the analysis increment and bias correction term are passed directly to the land-surface model and considered a forcing term in the solution to the energy balance.

2. MODELS & ASSIMILATION SYSTEM

2.1 The Community Land Model (CLM2)

The CLM2 provides a comprehensive physical representation of soil/snow hydrology and thermal dynamics and biogeophysics. The CLM2 was developed collaboratively by an open interagency/university group of scientists, and based on well-proven physical parameterizations and numerical schemes that combine the best features of three previous land surface models: Biosphere-Atmosphere Transfer Scheme (BATS; Dickinson et al. 1993), the NCAR Land-surface Model (LSM; Bonan 1996), and the IAP94 snow model (Dai and Zeng 1996).

The CLM2 is a one-dimensional point model that uses sub-grid scale tiles. The CLM2 has one vegetation layer with a photosynthesis-conductance model to realistically depict evapotranspiration (Bonan 1996). There are 10-uneven vertical soil layers with the bottom layer at 3.43-m and water, ice, and temperature states in each layer. The CLM2 features up to five snow layers depending on the snow depth with water flow, refreezing, compaction and aging allowed. In addition, the CLM2 utilizes two-stream canopy radiative transfer, the Bonan lake model (1996), topographic enhanced streamflow based on TOPMODEL (Beven and Kirkby 1979), and turbulence is considered above, within, and below the canopy.

2.2 The NASA/NCAR fvGCM and the fvDAS

The Global Modeling and Assimilation Office (GMAO) has collaborated with NCAR to produce the NASA/NCAR finite-volume Global Climate Model (fvGCM; Lin and Rood 2002), which is a unified climate, numerical weather prediction, and chemistry-transport model suitable for data assimilation, with the GMAO's finite-volume dynamical core and NCAR's suite of physical parameterizations

The GMAO's finite-volume dynamical core is capable of resolving atmospheric motions from meso- to planetary-scale with a terrain-following Lagrangian control-volume vertical coordinate system (Lin 1997; Lin and Rood 1999). The fvGCM dynamical core formulation includes a genuinely conservative Flux-Form Semi-Lagrangian (FFSL) transport algorithm (Lin and

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Rood 1996) with Gibbs oscillation-free monotonicity constraint on sub-grid distribution. There is a consistent and conservative transport of air mass and absolute vorticity, and subsequent superior transport of potential vorticity by the FFSL algorithm (Lin and Rood 1997). In turn, the mass, momentum, and total energy are conserved when mapping from the Lagrangian control-volume to the Eulerian fixed reference coordinate. The physical parameterizations of the fvGCM are based on NCAR Community Climate Model version 3.0 (CCM3) physics. The NCAR CCM3 parameterizations are a well-balanced set of processes with a long history of development and documentation (Kiehl et al. 1998). The moist physics package includes the Zhang and McFarlane (1995) deep convective scheme, which handles updrafts and downdrafts and operates in conjunction with the Hack (1994) mid- and shallow convection scheme. For the radiation package, the longwave radiative transfer is based on an absorptivity-emissivity formulation (Ramanathan and Downey 1986) and the shortwave radiative parameterization uses the δ-Eddington method (Briegleb 1992). The boundary-layer mixing/turbulence parameterization utilizes the "nonlocal" formulation from Holtslag and Boville (1993). In addition, the NCAR WACCM (Whole Atmosphere Community Climate Model) gravity wave drag is used (Sassi et al. 2003). The scheme includes parameterizations for orographic gravity waves and a spectrum of traveling gravity waves.

The fvDAS first utilizes a Statistical Quality Control (SQC) system to screen the observational data through checks against the background field prior to the assimilation. The fvDAS analysis is performed by the Physical-Space Statistical Analysis System (PSAS; Cohn et al. 1998). The PSAS algorithm obtains the best estimate of the state of the system by combining observations with the forecast model first guess. PSAS produces analysis increments directly on the model grid, thereby preserving the balance relationships implied by the error covariance formulations.

3. SKIN TEMPERATURE ASSIMILATION

In addition to producing analysis increments, the observations can be used to reduce the long-term bias of the model through bias correction. For the skin temperature bias correction, a variant of the Dee and da Silva (1998) bias correction (BC) scheme was implemented where,

$$\delta w^a = K\left(w^o - Hw^f + b^f\right) \quad (1)$$

$$w^a = w^f - {b_{k-1}}^f + \delta w^a \quad (2)$$

$$ {b_k}^f = {b_{k-1}}^f - \gamma \cdot \delta w^a \quad (3)$$

${b_k}^f$ is the updated bias estimate, ${b_{k-1}}^f$ is the bias estimate based on the previous analysis increment ($\delta {w_{k-1}}^a$) and δw^a is the analysis increment at time t_k. We found however that this scheme was inadequate if the bias correction term is only applied at the analysis times. Since the skin temperature has a small heat capacity, adjustments from the analysis increment and bias correction applied only at the analysis time can quickly dissipate. The bias generation mechanism associated with the surface skin temperature acts very rapidly. As a result, an incremental BC scheme was introduced, where a BC term is added to the surface energy balance at every timestep to counteract the subsequent forcing of the analyzed skin temperature back to the initial state. For this scheme, b^f is computed as in (3) and the BC term is calculated as,

$$f_b = \frac{b^f}{\tau}. \quad (4)$$

where τ is the period between analysis times. The surface temperature is solved by iteration of the energy balance. Since the temperature increment is included in the iteration, all budget terms that are a function of surface temperature adjust to the presence and magnitude of the increment at every time step.

The bias correction term was added to the energy balance for the canopy and for the top layer soil/snow surface, and then updated at the analysis times. Initial results indicated that it was necessary to include the heat capacity terms for the soil/snow and canopy in the bias estimation, and we allowed for accumulation of the bias correction tendency term between the update times. In addition, there was a mapping of the grid-space bias term to the CLM2 tile space. The minimal variance formulation was used in order for the dominant tiles of the grid-cell to be more greatly influenced by the bias correction.

4. RESULTS

The motivation for this study is demonstrated in Figure 1, which shows the surface skin temperature from experiments with a land-surface model driven off-line but with coupled skin temperature assimilation and bias correction. The skin temperature from the experiment with assimilation only (blue line) reveals the rapid dissipation of the analysis increment after the analysis time due to the small heat capacity of the skin temperature. The skin temperature from the experiment with incremental bias correction (green line) shows the benefit of the inclusion of the bias term at every timestep, and so the experiment closely follows the observations.

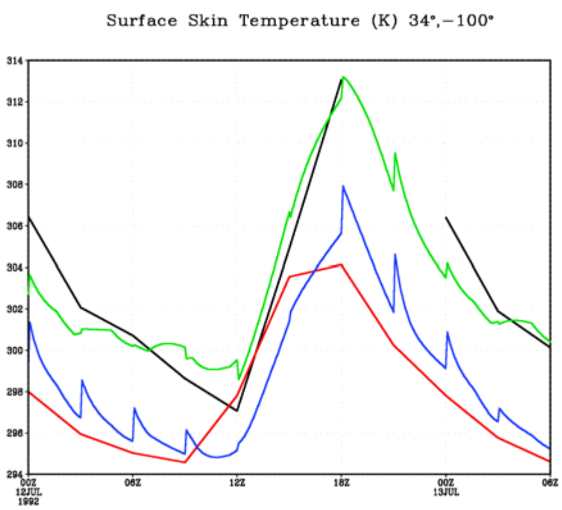

Figure 1. One-day cycle of surface skin temperature from a point. Remotely sensed skin temperature (black), model simulation (red), model with assimilation only (blue) and model with assimilation and incremental bias correction (green).

The coupled skin temperature technique was tested in the fvDAS CLM2 framework and run at 1 x 1.25° horizontal resolution with 55 vertical levels for July 2001. The atmospheric analysis is performed every 6 hours, while the surface temperature analysis is done every 3 hours. The surface temperature bias estimate is updated in step with the atmospheric bias correction at a 6-hour frequency. The initial coupled tests use the 3-hourly GMAO TOVS observations with a 1-hour observation window. Subsequent assimilations will include 3-hourly surface skin temperature observations from ISCCP (International Satellite Cloud Climatology Project; Rossow and Schiffer, 1991). The ISCCP skin temperature is much more dense than the GMAO TOVS so we hope to better simulate the diurnal cycle of the skin temperature.

The results from the experiments will be intercompared with analyses from the fvDAS CLM2 without bias correction, the fvDAS CLM2 with uncoupled bias correction, the European Center for Medium-range Weather Forecasting (ECMWF), and the National Centers for Environmental Prediction (NCEP). In addition, we have an independent validation source, which is the CEOP (Coordinated Enhanced Observing Period; Bosilovich and Lawford, 2002) in situ reference site dataset. As seen in Figure 2, the CEOP in situ data include stations at many different locations around the world representing many different climate regimes,. Ultimately, CEOP will also include many different operational analysis datasets that can also be used to evaluate the surface energy balance with land data assimilation. The CEOP dataset will allow for comparison of observed surface pressure, surface temperature, sensible and latent heat flux, winds, specific humidity, and the radiative fluxes.

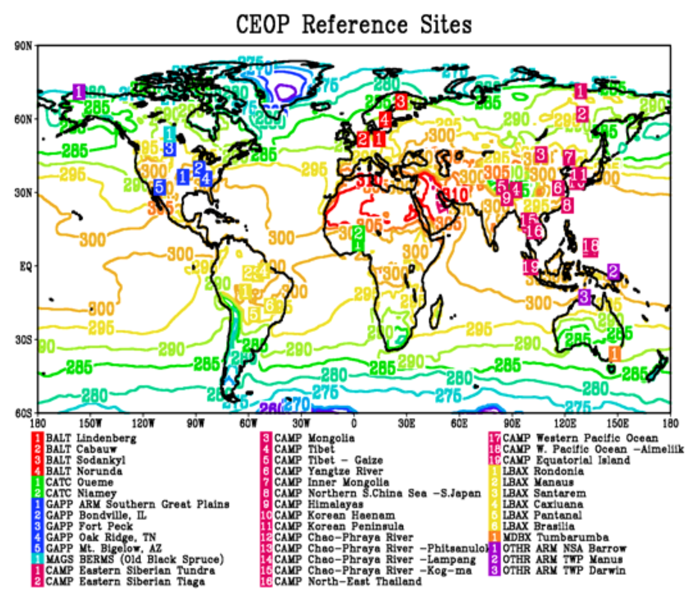

Figure 2. Station locations of the CEOP reference sites.

Preliminary results from the coupled skin temperature assimilation experiment that were compared to the fvDAS CLM2 without bias correction have shown an obvious effect at the surface that is visible in the 2 m temperature and specific humidity. There is also an atmospheric response to the bias correction that was observable in the downwelling longwave radiation, shortwave radiation and the cloud fraction.

5. SUMMARY

In this study, a new technique of coupled skin temperature and analysis was implemented in the GMAO fvDAS (Global Modeling and Assimilation Office finite-volume Data Assimilation System). The analysis increment and bias correction term are passed directly to the land-surface model and considered a forcing term in the solution to the energy balance. An incremental bias correction technique was applied where the bias correction is added to the surface energy balance at every timestep to counteract the subsequent forcing of the analyzed temperature back to the initial state. Experiments were conducted based on remotely-sensed skin temperature observations from GMAO TOVS (TIROS Operational Vertical Sounder) and ISCCP (International Satellite Cloud Climatology Project; Rossow and Schiffer, 1991). The experiments were intercompared with ECMWF and NCEP analyses, along with the CEOP (Coordinated Enhanced Observing Period; Bosilovich and Lawford, 2002) in situ reference site dataset, which include stations at many different locations with varying climate regimes. Initial results have indicated a strong impact on the surface meteorology.

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