To be presented at the 80th AMS Annual Meeting,
15th Conference on Hydrology, January 9 - 14, 2000,
Long Beach, CA.

1.15 VALIDATION OF LONG-TERM PRECIPITATION AND EVOLVED SOIL MOISTURE AND TEMPERATURE FIELDS IN MAPS.

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1. INTRODUCTION

The Mesoscale Analysis and Prediction System (MAPS) (Benjamin et al., 1999, 1998) is a state-of-the-art coupled model and data assimilation system operating over the conterminous United States (US) and producing grids for the Global Energy and Water Experiment (GEWEX) Continental-Scale Intercomparison Project (GCIP). MAPS was developed at the National Oceanic and Atmospheric Administration (NOAA) Forecast Systems Laboratory (FSL) where it is run on a real-time, continuous basis. It also has been implemented in a fully operational mode at the National Centers for Environmental Prediction (NCEP) as the Rapid Update Cycle, or RUC. The 40-km, 40-level MAPS coupled to a soil/ vegetation/snow model (Smirnova et al. 1997, 1998, 1999) has been producing Model Output Reduced Data Set (MORDS) grids for GCIP since May 1996. MAPS is unique in that it provides these grids from an ongoing hourly assimilation cycle, including evolution of soil moisture and temperature, and also snow temperature and snow depth if snow exists. The cycling of soil fields has been ongoing since April 1996, so that the MAPS cycle is, in essence, providing seasonal records of these mostly unobserved fields. Observations used in MAPS include those from rawinsondes, surface atmospheric observation stations, commercial aircraft, wind profilers, and geostationary satellites. A summary of the characteristics of the 40-km MAPS is provided in more detail by Benjamin et al. (1999, 1998).

The main question addressed in this paper is whether a coupled atmospheric/land-surface model, constrained by hourly assimilation of atmospheric observations, can provide a realistic evolution of hydrological fields and time-varying soil fields that are not observed over large areas. A prerequisite for success is that the soil/vegetation/snow component of the coupled model, which is constrained only by atmospheric boundary conditions and definition of fields such as vegetation type and fraction and soil type, must be sufficiently robust to avoid drift over long periods of time.

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2. RECENT IMPROVEMENTS TO THE MAPS LAND-SURFACE SCHEME

In April 1996, a multilevel soil/vegetation model (Smirnova et al. 1997) was introduced into the continuously running MAPS assimilation system. Improved versions have been introduced in succeeding years (Smirnova et al. 1998, 1999). Since January 1997, a snow model with accumulation and melting processes and a full energy budget has been running in the real-time MAPS. This scheme was made possible by the addition in the same month of a relatively sophisticated cloud microphysics scheme (the level 4 scheme from the NCAR/Penn State MM5 research model, Reisner et al., 1998, Brown et al., 1998), allowing for the formation, transport and fallout of cloud water and cloud ice as well as rain, snow, graupel, and the number concentration of cloud ice particles. Starting in March 1997, snow depth and temperature were also cycled in the MAPS hourly cycle, driven by predicted snow accumulation and melting, just as with the soil moisture and temperature fields. The results of this cycling have been very satisfactory, and snow water equivalent depth and snow temperature have continued to evolve since that time based solely on MAPS forecasts. Even with an improved snow analysis in the future, model forecast snow information could be combined with observation-based analyses to determine optimal snow fields, an option now being explored with RUC/MAPS snow fields at the National Operational Hydrologic Remote Sensing Center (Cline, personal communication).

In April 1998, a frozen soil physics package was incorporated into the real-time MAPS forecast cycle. For the remainder of the spring, the effect of this change was to retard the warming in the northern part of the MAPS domain, where soil temperatures were still below freezing, and to increase runoff where snow cover was still present. The effects of frozen soil physics were more significant in its first full winter season, the winter of 1998-1999.

The most recent improvements to the MAPS land-surface scheme include replacement of the one-layer MAPS snow model by a two-layer scheme in March 1999. One-dimensional experiments with the winter PILPS 2(d) dataset from Valdai, Russia, have revealed that with a 1-layer representation of the snow pack, the skin temperatures in winter are too warm (Fig. 1a), and melting of snow occurs too late because of the higher heat capacity used in the surface energy budget (Fig. 1b). Incorporation of a two-layer snow representation applied when the snow is deeper than a threshold value (7.5 cm) into the land-surface scheme significantly improves the skin temperatures in winter (Fig. 1a). The beginning of the snow melting season is also captured better, and as a result the spring spike in total runoff occurs at the correct time (Fig. 1b, c).

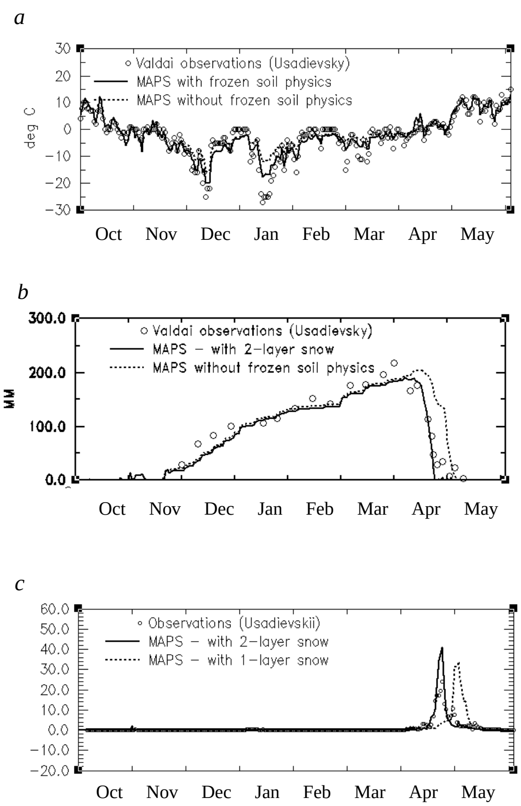

Figure 1. Evolution of (a) skin temperature, (b) snow water equivalent, and (c) total runoff from the top 1 m of soil with 1-layer and 2-layer snow models running in 1-d version of MAPS land-surface process model. Valdai, Russia, winter 1975-1976.

3. EFFECTS OF EOS HIGH-RESOLUTION LAND-USE DATA

In addition to further improvements to the model, potential for improvement in prediction of surface variables may be available through use of high-resolution databases for vegetation and soil types. In September 1999, a new field of vegetation types derived from 1-km resolution land cover product from the Earth Observing System (EOS) Data Center was incorporated into MAPS. The dominant land-use type within each 40-km MAPS grid box was assigned to that box. The new vegetation type field has much more detail, and vegetation types of many grid points in MAPS domain are changed. For example, large areas of needleleaf evergreen forests around the Hudson Bay in the previous land-use data were reassigned as tundra, and some cultivation areas in Texas were retyped as grassland. Sensitivity studies in the 1-D framework demonstrated that the response can be significant to such changes. The new land-use data has been tested for about one month in a parallel 40-km MAPS cycle as of September 1999, and results appear satisfactory.

Verification statistics for surface air temperature show underestimation of the diurnal cycle in MAPS mostly due to a warm bias at night. The new vegetation types now running in the parallel cycle of MAPS slightly improve the night temperature bias averaged over the whole domain and little affect temperatures during the day (Fig. 2). However, the spatial distribution of temperature differences from the real-time and parallel cycles reveals more about the impact of the new vegetation types on the model performance.

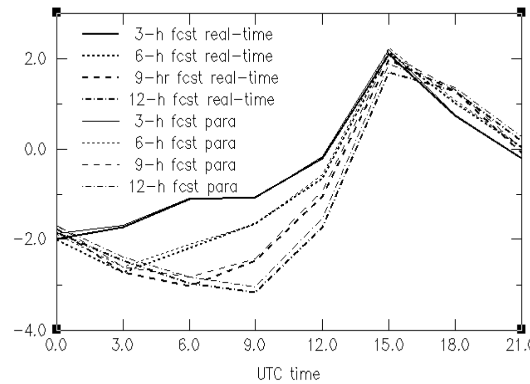

Figure 2. Surface temperature biases (METAR observed minus forecast) for MAPS versions using land-use data derived from 1-degree data (real-time MAPS) and from 1-km EOS dataset (parallel MAPS), 29 August - 20 September 1999.

Figure 3a shows the spatial distribution of afternoon surface air temperature errors when the 3-h forecast from real-time MAPS had an overall warm bias of 0.5^{o}C, and the bias was 0.6^{o}C from the parallel cycle. Although the averaged warm bias is slightly worse in the parallel cycle, the parallel-cycle temperatures in many areas over the western part of the MAPS domain are cooler than in the operational MAPS (Fig. 3b), which reduces the warm bias in many of those areas. The warm bias in Arkansas is also reduced. The cold biases around the southern part of Hudson Bay and in northern Texas and Oklahoma are also improved in the parallel cycle. Of course, there are areas in the parallel cycle where the temperature errors become larger.

4. PERFORMANCE OF MAPS COUPLED ATMOSPHERE/SOIL FORECAST SCHEME

At this writing the land-surface scheme has been running in MAPS for three and a half years, and soil and snow fields have been evolving depending only on input from the atmospheric scheme. One of the most important factors which constrains the model drift in MAPS is a 1-h data assimilation cycle. It includes full use of surface and other observations available hourly. Another factor is the physics package in the MAPS atmospheric model, which together with the advantages of hybrid isentropic-sigma vertical coordinate provide adequate atmospheric forcing for the land-surface scheme. Continuous cycling of cloud microphysics variables also positively affects the evolution of soil temperature and moisture fields by reducing the precipitation spin-up.

model and its convective parameterization scheme. More detailed comparisons of MAPS precipitation climatology against the NCEP stage IV multisensor precipitation analysis (Baldwin and Mitchell, 1996) will be presented at the meeting.

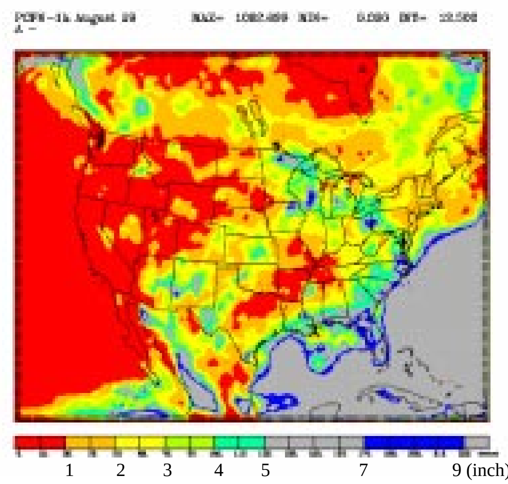

Figure 4. Monthly accumulated precipitation from a series of MAPS 1-h forecasts for August 1999.

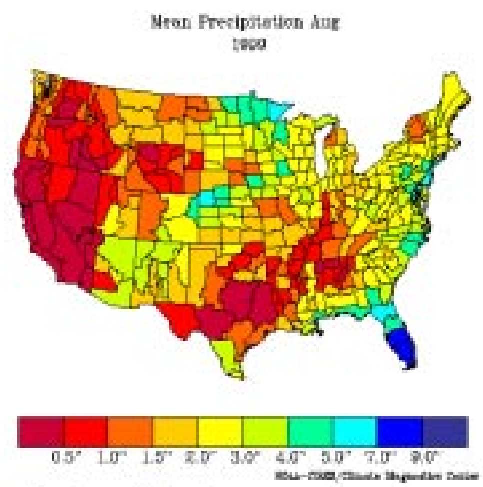

Figure 5. Monthly accumulated precipitation from NCDC analyses for August 1999.

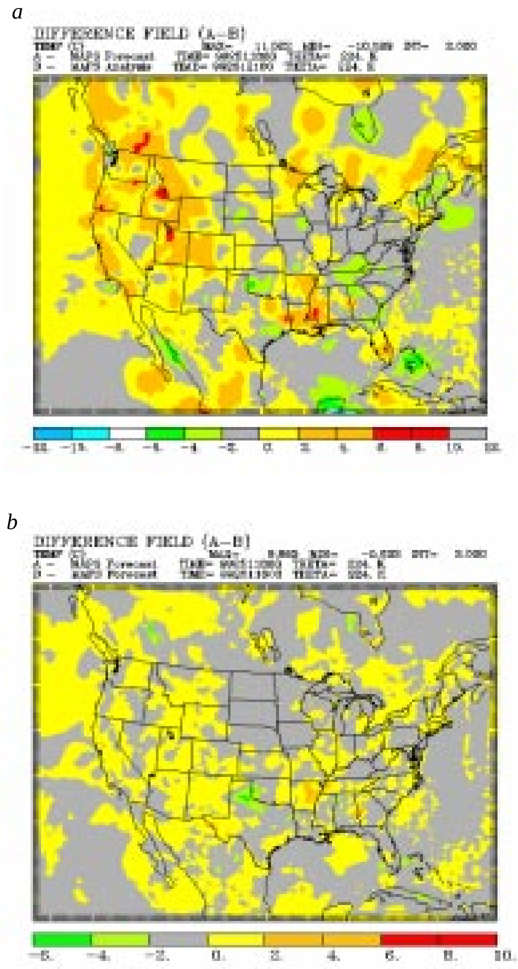

Figure 3. Surface air temperature errors (a) obtained from real-time MAPS valid at 2100 UTC 8 September 1999, and surface temperature difference (b) between the 3-h forecasts from real-time MAPS and the parallel cycle valid at the same time.

Validation of the 0-1h forecasts of model precipitation that provide the water source for the evolving soil-moisture field can reveal potential problem areas in the soil fields. Excessive precipitation may not cause serious problems for soil moisture because the excess water will most likely simply increase the surface runoff. Lack of precipitation or errors in the placement of precipitation are more significant.

The sum of these 0-1h MAPS precipitation forecasts for August 1999 are compared to monthly precipitation analyses from the National Climatic Data Center (NCDC) in Figs. 4 and 5. For this month there were several gaps in MAPS data [total 88 h (12%) missing] due to computer-related problems. Although this affects MAPS precipitation accumulations in some areas, there is a general agreement between the spatial patterns over the United States. The areas of monsoon precipitation are reflected well in MAPS forecasts, although the amounts of rain along the axis from western Texas, to Oklahoma and Kansas are overestimated. There is also overestimation of precipitation amounts along the Gulf Coast, and along the southeastern U.S. Atlantic coastline. These problems are related to known deficiencies in the interface between the MAPS model and its convective parameterization scheme.

With a very sparse network of in situ soil observations, the validation of soil moisture and temperature fields is performed only for separate stations obtained from the National Water Climate Center (NWCC) Web page. Hourly data from these stations are available in real time, and also have been archived for several years. The stations report soil temperature and moisture at several levels, the deepest being at 1-m depth, and also vegetation type and vertical profile of soil type. For brevity, the verification curves of soil moisture and temperature from one station, Bushland, Texas, are presented in this paper.

This station is located in the northern panhandle of Texas. The accumulated amount of precipitation for August in this area equal to 1.5-2 inch corresponds well to the data from NCDC (National Climatic Data Center). Therefore, observed discrepancies between the observed and forecast soil moisture and temperature are not strongly related to the precipitation errors. Volumetric soil moisture content does not vary much with depth in either the observations or the model (Fig. 6a), but the values are significantly higher in the observations. This may be explained by disagreement in specification of soil and vegetation types at this location. For example, two MAPS grid points close to this station have crops under cultivation as a vegetation type, and the other two are classified as shrubs with ground cover. However, the measuring instruments at this site are located in undisturbed rangeland that has never been broken by a plow. The new land-use field used since the end of September has short grass vegetation types at all four grid points, which is a more accurate representation of this site. There are also differences in the soil type of the deeper layers, these being silty clay loam in MAPS and silty clay or clay with quite different properties at the station site.

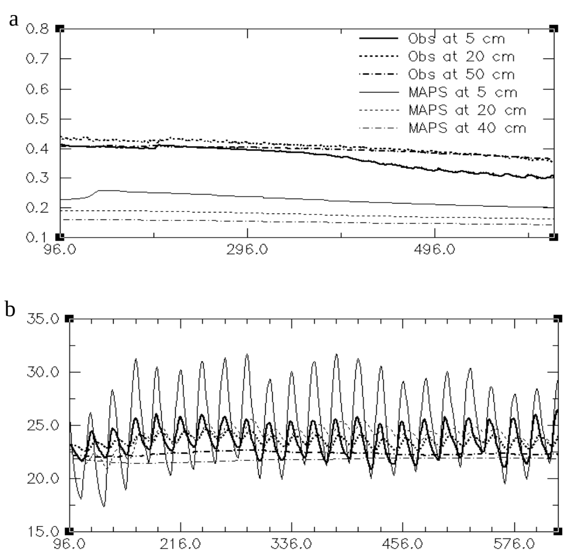

Figure 6. Monthly variation of (a) volumetric soil moisture content and (b) soil temperature at three levels (5, 20, and 50 cm in observations, and 5, 20, and 40 cm in MAPS). 3-28 August 1999, Bushland, Texas.

The drier top layer of soil in MAPS has a larger diurnal variation in soil temperature at 5 cm depth; at 20 cm depth and deeper the curves are much closer to each other. Results from other stations located in different parts of the United States will be presented at the meeting.

We have also compared skin temperatures from MAPS against the NESDIS GOES skin temperature product in regions of clear skies. The differences between MAPS and GOES skin temperatures are within +/- 5°C except during daytime in the western U.S. when they are larger. These differences are partly due to elevation differences between the MAPS terrain field and the actual elevation, and also to errors in the GOES field arising especially from surface emissivity uncertainties.

5. CONCLUDING REMARKS

This study documents the current progress and relative success in using a mesoscale atmospheric/land-surface coupled model with high-frequency assimilation of atmospheric observations (MAPS) to produce physically consistent fields of soil variables and hydrological cycle components.

The multilevel soil/vegetation/snow model with simple parameterization of frozen soil physics in MAPS has been cycling soil fields since April 1996. Comparisons were made between monthly fields of accumulated precipitation from MAPS and NCDC analyses, showing fairly good agreement. Corrections to model precipitation techniques and improved cloud/moisture assimilation (Kim and Benjamin, 2000) are expected to reduce remaining errors.

Key areas of focus in MAPS development over the next two years are assimilation of cloud/precipitation observations, further improvements to atmospheric surface layer and soil physics, use of improved soil datasets available that cover the MAPS domain, and improvements to the MAPS convective precipitation parameterization.

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