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CLIMATE PREDICTION AS AN INITIAL VALUE PROBLEM

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1. INTRODUCTION

One set of weather and climate definitions distinguishes these terms in the context of prediction: weather is considered an initial value problem, while climate is assumed to be a boundary value problem. Another perspective holds that climate and weather prediction are both initial value problems (Palmer 1998). If climate prediction were a boundary value problem, then the simulations of future climate will "forget" the initial values assumed in a model. However, if the ocean surface and/or land surface changes over the same time period as the atmospheric changes, then the nonlinear feedbacks between the air, land, and water eliminate an interpretation of the ocean-atmosphere and land-atmosphere interfaces as boundaries. Rather than "boundaries", these interfaces become interactive mediums. The two-way fluxes that occur between he atmosphere and ocean, and the atmosphere and the land surface, must therefore necessarily be considered as part of the predictive system.

To illustrate the dependence of climate prediction on initial conditions, we apply a regional climate model which illustrates how modeled seasonal weather is dependent on initial conditions. One example is presented in this preprint, with others shown at the Conference.

2. MODEL

A climate version of the Regional Atmospheric Modeling System (ClimRAMS; Liston and Pielke 1998) was used in this study to examine the effect of soil moisture initialization on monthly and annual regional weather simulations over the model domain shown in Figure 1. RAMS was developed at Colorado State University primarily to facilitate research into mesoscale and regional, cloud and land-surface atmospheric phenomena and interactions (Nicholls et al. 1995; Pielke 1974; Tripoli and Cotton 1982; Tremback et al. 1985; Pielke et al. 1992; Walko et al. 1995a). The model is fully three-dimensional; nonhydrostatic (Tripoli and Cotton 1980); includes telescoping, interactive nested grid capabilities (Clark and Farley 1984; Walko et al. 1995b); supports various turbulence closures (Deardorff 1980; McNider and Pielke 1981; Tripoli and Cotton 1986), short and longwave radiation (Mahrer and Pielke 1977; Chen and Cotton 1983, 1987; Harrington 1997), initialization (Tremback 1990), and boundary condition schemes (see Pielke et al. 1992); includes a land-surface energy balance sub-model which accounts for vegetation, open water, and snow-related surface fluxes (Mahrer and Pielke 1977; McCumber and Pielke 1981; Tremback and Kessler 1985; Avissar and Mahrer 1988; Lee 1992; Liston and Pielke 1998); and includes explicit cloud microphysical sub-models describing liquid and ice processes related to clouds and precipitation (Meyers et al. 1992; Meyers 1995; Walko et al. 1995a).

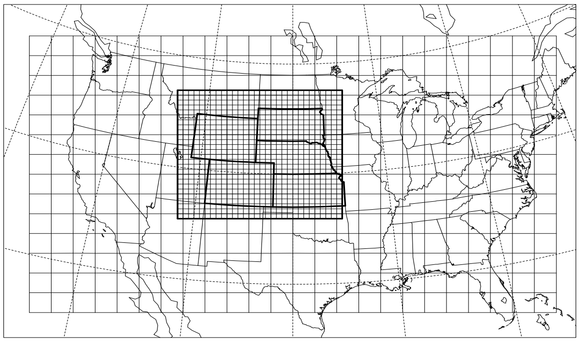

Figure 1: RAMS domain and grid configuration. Coarse and fine grid intervals are 200 km and 50 m, respectively.

The climate version of RAMS used contains all of the above features, with the addition of several modifications designed to allow single to multi-year integrations. To meet the requirements of a regional model running both weather and climate time scales, several modifications to the base modeling system were made. These included: 1) daily updating of sea-surface temperatures and vegetation parameters; 2) the addition of a collection of routines which simulates grid-scale snow accumulation, snow melt, and their effects on surface hydrology and surface energy exchanges; 3) the implementation of a moisture-physics scheme (Cotton et al. 1995) suitable for long model runs; 4) sufficient variables to perform complete surface energy and moisture balances over a wide range of time scales (hourly to yearly) are saved; and 5) data are saved on an hourly, six-hourly, or daily basis, depending on the model-output variable.

The soil submodel used in this version of RAMS provides prognostic temperature and moisture for both soil and vegetation. For bare soil, RAMS uses a multi-layer soil model described by Tremback and Kessler (1985). The moisture diffusivity, hydrologic

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conductivity, and moisture potential are given by Clapp and Hornberger (1978). The soil thermal properties are temporally-evolving and soil moisture dependent. The boundary condition for moisture at the deepest soil level is held constant at the initial value. Heterogeneous soil types were applied to the domain based on the STATSGO data set. The model has 11 soil layers at 2.0 m, 1.65 m, 1.3 m, 0.95 m, 0.65 m, 0.45 m, 0.3 m, 0.2 m, 0.125 m, and 0.05 m from the surface, respectively.

For the vegetated surface, a "big leaf" approach is used where there is a layer of vegetation overlying a shaded soil. Soil moisture is removed by transpiration is accomplished by defining a vertical root profile (Dickinson et al. 1986) and extracting the water depending on the root fraction in each soil layer.

The goal of this investigation is to examine the sensitivities of basic climate variables, such as maximum temperature, minimum temperature, and precipitation to the initial values of soil moisture. We also seek to examine the length of the model's memory with respect to the soil-moisture initialization. The model domain and grid configuration given in Figure 1 shows a coarse grid covering the entire conterminous United States at 200 km grid spacing, and a finer nested grid covering Kansas, Nebraska, South Dakota, Wyoming and Colorado at 50 km grid spacing.

The model is driven by six-hourly lateral boundary conditions defined using National Centers for Environmental Prediction (NCEP) atmospheric analyses for the time period 1 January 1989 through 31 December 1989. The time step of the integration is 2 minutes (see Pielke et al. 1998).

The experiments reported here are five, year-long simulations. All the integrations started on 1 January 1989 and continued through 31 December 1989. Soil moisture was perturbed to 25% drier and wetter, and 50% drier and wetter, respectively, at the beginning of the calendar year from a control simulation. Other initial conditions are identical for the five integrations.

3. RESULTS

The differences in soil moisture persist for about five months before they began to converge in summer. However, the differences began to diverge again in late August, and this trend lasted through the end of the year. In contrast to the surface layer, the differences in soil moisture initialization for the layer five, which is 0.45 m below the surface, persist throughout the year. This indicates the inherent long-period memory of initial conditions of the model with regard to the deep soil layers. Thus the divergence in predictions which happened in the Fall to the top soil layer result from the soil moisture differences in the deeper soil layers which began to propagate upward when the atmospheric forcings, such as precipitation and evaporation became weaker at that time of the year.

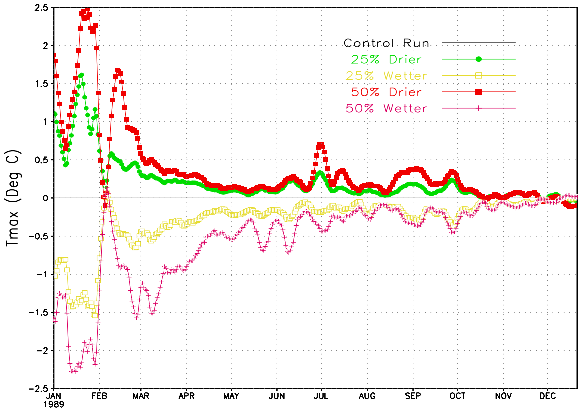

Figure 2: The fine grid, domain-averaged daily maximum temperature from 1 January to 31 December 1989.

Figure 2 displays the differences of fine grid, domain-averaged maximum temperature between the perturbed runs and the control run. The daily values have been smoothed to a seven-day average in order to filter the high frequency variability and show the long-term tendency. While the maximum temperature differences vanish by the end of the year, the differences in minimum temperature (not shown) decrease from January to September, and then increase in October due to the long-term memory of the deep soil layers initial soil moisture conditions. The domain-averaged precipitation (not shown) appears to be affected by initial soil moisture until the cases converge at the end of integration, indicating more than ten months of memory.

The year-long simulation results reveal a strong sensitivity of this regional climate model with respect to initial soil moisture. In other words, the initial specification of the soil moisture exerts a strong control on the subsequent atmospheric circulation in regional climate simulation models which can last as long as 12 months. Although there is a tendency for the prognostic soil moisture to adjust towards each other, the differences persist for more than one season and even longer for the deep soil layers.

4. CONCLUSIONS

An important practical conclusion results if climate prediction is an initial value problem. This means that there are necessarily limits on the time into the future which we can predict climate, since the feedbacks between the ocean, atmosphere, and land surface are nonlinear. These limits have not been determined, yet climate "predictions" are routinely communicated to policy makers on time scales of decades and centuries. Second, in the context of predicting what the future climate would be in response to an anthropogenic forcing such as carbon dioxide input, there are as of yet, undefined limits on what aspects of future climate we can forecast even if all the important ocean-atmosphere-land surface feedbacks were included and also accurately represented in the models. This leads to the conclusion that weather prediction is a subset of climate prediction. Societally-useful climate prediction requires that all of the feedbacks and other physical processes included in weather prediction be represented in the climate prediction model. In addition, longer-term feedback and physical processes must be included. This makes climate prediction a much more difficult problem than weather prediction.

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