DEVELOPMENT AND TESTING OF IMPROVED TECHNIQUES FOR MODELING THE HYDROLOGIC CYCLE IN A MESOSCALE WEATHER PREDICTION SYSTEM

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This project addresses the need to improve the surface hydrology component in mesoscale atmospheric prediction models and specifically the temperature and humidity forecasts. One way we did this was to initialize the mesoscale model with continuously updated and reasonable values of soil moisture content. To accomplish this task two approaches were taken one in which a soil hydrology model (SHM): Capehart and Carlson, 1994a) was used to update the initial values of soil water content in the BATS land surface component of the Penn State/NCAR mesoscale model (MM), specifically its most recent, non-hydrostatic version (Smith et al., 1994). The other approach was to use two remote sensing techniques to make better estimates of initial conditions. One of these techniques involved using radar reflectivity data to initialize the humidity field on the basis of existing convection which is specified from radar observations during a pre-forecast period. The other technique is to estimate the surface soil moisture availability using remote measurement of surface radiant temperature and vegetation index obtained via satellite and then to nudge the values of initial soil water content determined from the hydrology toward those values estimated from the satellite measurements (Capehart and Carlson, 1994b).

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1. Introduction

This project addresses the need to improve the surface hydrology component in mesoscale atmospheric prediction models and specifically the temperature and humidity forecasts. One way we did this was to initialize the mesoscale model with continuously updated and reasonable values of soil moisture content. To accomplish this task two approaches were taken, one in which a soil hydrology model (SHM; Capehart and Carlson, 1994a) was used to update the initial values of soil water content in the BATS land surface component of the Penn State/NCAR mesoscale model (MM), specifically its most recent, non-hydrostatic version (Smith *et al.*, 1994). The other approach was to use two remote sensing techniques to make better estimates of initial conditions. One of these techniques involved using radar reflectivity data to initialize the humidity field on the basis of existing convection which is specified from radar observations during a pre-forecast period. The other technique is to estimate the surface soil moisture availability using remote measurements of surface radiant temperature and vegetation index obtained via satellite and then to nudge the values of initial soil water content determined from the hydrology model toward those values estimated from the satellite measurements (Capehart and Carlson, 1994b).

Future research will concentrate on the development of the surface hydrology in the SHM and the MM and integration of the remote sensing -- the 'top down' approach -- and the surface hydrology component -- the 'bottom up' approach. The object is to provide initial soil water content fields for initializing the MM. In so doing, it will be possible to simulate (or predict) a more accurate distribution of the surface temperature and humidity, as well as the energy fluxes than is currently possible. This will lead to a better representation of a variety of mesoscale phenomena, such as severe convective storms and their attendant precipitation patterns.

For example, it is clear that convective outbreaks frequently occur in association with areas of locally higher latent instability, which occur as the result of a combination of terrain effects, orography and the happenstance migration of low-level air trajectories (Farrell and Carlson, 1989). Precursory atmospheric and land surface patterns leading to the outbreak of severe local storms can be correctly simulated in present mesoscale models provided that the initial conditions pertaining to soil moisture, vegetation cover, terrain slope, etc. are properly specified. Conversely, without an accurate representation of the surface energy fluxes, the ability to predict the outbreak of convective storms, as well as a host of mesoscale phenomena, is limited. Indeed, it can be stated without exaggeration that an incorrect soil moisture field may prove as detrimental to the prediction of afternoon temperature and dewpoint patterns in a mesoscale model as an equally incorrect specification of the solar constant. Yet only recently has the hydrology of mesoscale prediction models begun to be seriously addressed. In his seminal paper, Mahfouf (1991) describes a method for nudging the initial soil water content values toward their correct values on the basis of the errors in temperature and humidity prediction. In contrast, most atmospheric prediction models continue to specify soil water content on the basis of a climatological distribution or one related to the distribution of land use categories (Warner *et al.*, 1991).

An interesting conclusion arising from recent work (Carlson *et al.*, 1993) is that the surface energy balance is relatively insensitive to changes in the deep layer (*e.g.*, root zone) soil water content but sensitive to changes in the surface soil water content and the fractional vegetation cover (Gillies and Carlson, 1995). This has led us to conclude that the water content in the soil surface layer and the fractional vegetation cover are the two most important variables in determining the spatial distribution of the surface energy fluxes. It follows, therefore, that a shallow surface layer must be resolved in the hydrology component of the MM and of the SHM in order to accurately predict the surface energy fluxes.

Moreover, it has become increasingly apparent that the surface crust (1 mm - 1 cm depth) can dry out very much more rapidly than the deeper soil layer (*e.g.*, 10 cm) under strong sunlight, leading to a decoupling (lack of correlation) in soil water content between the deep and surface soil layers. Alternately stated, decoupling involves the desiccation of the soil's crust while high values of soil water content remain in the deeper layers. Decoupling is a new idea and has as yet been somewhat validated using simulations. Recently, measurements have come to light in support of this hypothesis. The basis for decoupling is as follows: as the soil dries out it does so unevenly, being much more rapid for soils having a certain range of hydraulic conductivity values. Actual soils tend to consist of a spectrum of conductivities within any soil classification category, especially the surface soil which consists of plant and other debris. Thus some fraction of the sunlit soil surface desiccate quickly after a rainstorm while other parts of the soil surface require a longer period to dry out. The result is that elevated surface radiant temperatures indicative of desiccated surfaces can be found on thermal images within a day or two following heavy precipitation (Carlson *et al.*, 1995). The full ramifications of this imposing fact have not yet been explored, but we plan to pursue the idea in collaboration with some Swiss colleagues to make measurements of soil water content. This will be done with a new 1 cm microwave radiometer developed by Christian Matzler of the University of Bern in collaboration with Michael Wuthrich of the University of Basel. This field work will be done during the summer of 1995.

2. Hydrology and Land Surface Modeling; the bottom up approach

In the course of this research under Air Force contract F49620-92-J-0118, a soil hydrology model (SHM) was developed and tested (Smith *et al*., 1994). We showed that the SHM is capable of simulating the vertical profile of water content in the ground as a function of time using only routine meteorological observations (temperature, rainfall, cloudiness, wind speed) and conventional land use parameters (vegetation height, vegetation fraction). The SHM determines the evolution of the soil water content as a function of depth in the substrate using a one-dimensional diffusion-gravitation scheme, to which is also added infiltration, runoff, ponding, evaporation and interception of rainwater by plant leaves at or above the soil surface and runoff and removal of liquid water for transpiration by the root system beneath the surface. Also specified are the column depth, vertical grid spacing and the nature of the lower boundary (impermeable, permeable or saturated barrier). At present the model can achieve a vertical resolution of 1 cm or less, which is necessary to prove the decoupling hypothesis. Simulations with this fine resolution are now in progress.

The first test of the SHM was as a one-dimensional, stand-alone component using field measurements (Capehart and Carlson, 1994a). Later the SHM was executed with a three-month data set over a series of meshed grid domains encompassing about half of the United States[1] (Smith *et al*., 1994). A limited (12 hour) forecast was made with the MM using the soil water content fields obtained from the SHM.

The next test with the SHM was made in conjunction with the MM. SHM was used to provide initial soil water content fields for the MM for a nested grid centered over the eastern United States (Smith *et al*., 1994). First the SHM was initialized at each grid point in the nested domain and allowed to run for a period of time (in excess of two months) prior to the initial time for the MM. It was found that a minimum of about two months was needed in order that the upper half meter or so of the soil would lose its sensitivity to initial profile of soil water content. The time required for this loss of sensitivity in the SHM to its initial conditions is called the 'balancing period'. Balancing takes a longer time over dry, vegetated terrain (*e.g.*, in summertime) than over wet bare soil. A current objective is to link the SHM and MM in real time mode. In that case balancing will need to be done only once, after which the SHM can be updated on a daily basis.

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[1]A 5-minute color video of this result, showing the evolution of the soil water content fields over the whole domain, including part of Canada and the United States, is available from T. N. Carlson upon request.

As Figure 1 shows, the SHM is executed from a starting time (t=0) for a balancing period prior to the execution of the MM at t= t_0. During this time, meteorological data is fed continuously into the SHM at intervals of 12 hours. Execution of the MM continues after t_0 for a period of several hours to two days. Figure 2 shows the steps required to obtain the soil water content fields with the SHM. Figure 3 shows a distribution of soil water content over the top 10 cm for a region encompassing the eastern half of the United States and a part of Canada. This field of moisture was determined by running the SHM at every grid point over a four-month balancing period. Simulations were then made with the MM for a 6 hour period starting with the initial soil moisture pattern in Figure 3. Differences between afternoon temperatures predicted with a climatological values of soil water content and those obtained from the SHM are shown in Figure 4. The temperature differences are not large but they may be quite significant when expressed as differences in wet bulb potential temperature, which takes into consideration the opposing responses to changes in soil water content by temperature and humidity.

3. Remote Estimates of Soil Water Content; the top down approach

The method for remotely sensing soil water content is based on work by Carlson *et al.* (1993) Gillies and Carlson (1995) and Carlson *et al.* (1995). It, uses a soil/vegetation/atmosphere transfer (SVAT) model in conjunction with remotely sensed measurements of surface radiant temperature and a vegetation index to derive two intrinsic physical parameters. These parameters are the *surface* moisture availability (M_0; defined as the ratio of extractable surface soil water content to field capacity), and fractional vegetation cover (Fr)). Both parameters have precise physical meaning and both are important in driving the local microclimate. Both are used in the MM.

In contrast with the conventional methods for inverting a SVAT model to obtain surface parameters, the problem is constrained by using the model to interpolate between identifiable limiting values of soil water content and fractional vegetation cover. We refer to this new approach for using remote sensing measurements as the 'universal triangle' method because of the characteristic triangular shape of the data when plotted on scattergraphs (Carlson *et al.*, 1993; Gillies and Carlson, 1995; Capehart and Carlson, 1994b; see Figure 5), an example of which is shown in the middle of Figure 5

The advantages of the universal triangle method are listed as follows:

- The parameters, M_0 and Fr are intrinsic to the soil surface.

- One obtains a more accurate solution by identifying the limiting values for M_0 (absolutely dry soil) and Fr (zero and 100% cover) in the temperature and NDVI measurements, as viewed on scattergraphs.

- The two intrinsic parameters constitute a measure of land use and are directly applicable to mesoscale models such as the MM.

The SVAT model is used in conjunction with remote measurements of surface radiant temperature (T_0) and the normalized difference vegetation index (NDVI) to obtain the distribution of M_0 and Fr. Rather than simply inverting the radiant surface temperature to obtain these surface parameters, as has been done in the past, preliminary steps are involved in which the SVAT model is used first to identify limiting values of Fr and M_0 in the data, from which the signatures for zero and 100% vegetation cover and zero extractable surface soil water content are identified. The model is then used to interpolate between these limits.

Limiting values of radiant surface temperature (T_0) and NDVI corresponding to the limits of bare soil, 100% vegetation cover and zero extractable soil water content are obtained with the aid of the SVAT model from inspection of scattergraphs in T_0/NDVI space (Figure 5). Note the triangular shape of the pixel distribution; this configuration arises because the sensitivity of surface radiant temperature to soil water content is very much less at high vegetation cover (near the triangle's vertex; high NDVI) than at low vegetation cover (near the base of the triangle; low NDVI). Thus, the vertex, base and warm side of the triangle correspond, respectively, to physical limits for Fr and M_0, respectively, zero and 100% vegetation cover and zero extractable soil water content. Given these limits, the solution for M_0 and for the surface energy fluxes is not only improved but it is much more easily obtained when these constraints are imposed. This method is further elaborated upon below.

A full description of the SVAT model is felt to be unnecessary, as any comparable model would yield similar results given the same interpretation of the scattergraphs and the same assumptions used here. The reader is therefore referred for details of the SVAT model to articles by Carlson *et al.* (1981), Carlson (1986), Taconet *et al.* (1986), Lynn and Carlson (1990), Carlson *et al.* (1990), Carlson *et al.* (1993) and Gillies and Carlson (1995). Briefly stated, however, the model operates in 1.5 dimensions, is time dependent and simulates the radiant surface temperature. It also simulates the surface (soil and vegetation) fluxes of heat, water vapor and carbon dioxide and a vertical profile of wind, temperature, humidity over a 24 hour period, starting with a set of initial conditions, i.e. with differing initial values of M_0 and Fr. Structurally, the model consists of an atmospheric surface and mixing layer, a layer of vegetation with underlying soil surface and a soil substrate. Its extra dimensionality (beyond 1.0) arises because both bare soil and vegetation components operate simultaneously and are blended above the surface layer and in the ground according to the fractional vegetation cover (Carlson *et al.*, 1990)

Generally speaking, given a 'correct' (calibrated and corrected for atmospheric attenuation) surface radiant temperature (T_0), a solution for M_0 and Fr achieved by executing repeated simulations with a range of M_0 and Fr values and matching the simulated and measured surface temperatures within the aforementioned limits. Fr is obtained by equating measured and simulated radiant surface temperatures for an assumed value of soil water content. While not very sensitive to exact choice of vegetation and soil parameters, solutions for M_0 and Fr rest on three hypotheses, which allow us to identify the range of M_0 and Fr values in the measurements based on an analysis of scattergraphs. These hypotheses are:

(1) Given a large range of surface dryness, the locus of warmest pixels with variable vegetation amount defines a lower limit to extractable soil water content. This limit is often well-defined in the data and is called the 'warm edge'. The warm edge corresponds to an isopleth of zero surface soil water content.

(2) limits of NDVI for bare soil ($NDVI_0$) and 100% vegetation cover ($NDVI_S$) are obtainable from an interpretation of the scattergraphs with the aid of the SVAT model. These correspond to the base of the triangle and a point near the upper vertex.

Inversion of the model yields isopleths of surface moisture availability and a relationship between NDVI and Fr, from which the vertical axis in the scattergraph in Figure 5 can be re labeled as fractional vegetation cover. Images of radiant surface temperature and NDVI can also be transformed to fields of soil water content and fractional vegetation cover, as shown by Carlson *et al.* (1993). Incorporation of these fields into the mesoscale model, which involves three models (SVAT, SHM, MM), is considered to be the next step. How this can best be done most efficiently and effectively is currently under study. A current approach is to use the model as a guide rather than as an integral part of the analysis scheme. Instead of executing the model repeatedly for each case study, a nomogram representing isopleths of M_0 as a function of scaled vegetation index and scaled surface temperature are derived once from the SVAT model, and this nomogram is simply stretched over the triangle. Surface soil water content and surface energy fluxes for the stretched method can be obtained quickly and efficiently and the method appears to yield very good results (Gillies *et al.*, 1995).

4. Incorporation of remote measurements into the MM; combining top down and bottom up approaches

An object of the remote sensing is to reduce the balancing period in the SHM as well as improve the accuracy of the surface energy fluxes. However, there are limitations in the satellite method, which are: (1) satellite estimates of soil water content can be obtained only for clear sky images; (2) because of the requirement that surface radiant temperature have a high sensitivity to solar heating, use of thermal infrared imagery is limited to the warmer months; (3) the synoptic scale temperature variation across individual images is much smaller than that between dry and wet patches within the image; (4) only small sub regions can be treated; and (5) only the surface water content in areas of sunlit bare soil can be resolved.

Unfortunately, to produce a regional soil water content analysis, a large number of sub images must be treated in order to map such a large region, *e.g.*, the domain in Figure 4. In addition, the presence of cloud limits the availability of clear images to about every 2 - 4 weeks for a given sub region. Although Ottle' and Vidal Madjar. (1994) show a close correlation between evapotranspiration measurements obtained by satellite and those measured at the ground, the largest variations in these fluxes occurred in response to variations in net radiation due to variations in cloud cover. They conclude that soil water content values determined from satellite infrared temperature measurements seem to exert no more than a marginal effect in improving the soil water content estimates. This non-result of Ottle and Vidal Madjar reinforces our hypothesis that information on only the surface soil water content of sunlit bare soil is contained in the surface radiant temperatures.

Because of the ambiguity in the nature of the derived surface soil water content values and the difficulty in handling large images, it appears necessary to limit the use of satellite images to regions the size of a watershed. Smith *et al.* (1994) show that soil moisture fields can be generated with the SHM in a series of nested grid domains, the smallest of which is sufficient to encompass a small watershed. Capehart and Carlson (1994b) suggest how the satellite can be used to augment the continuous soil water content fields provided by the SHM They suggest that remotely derived estimates of surface soil water content for these limited target areas could be meshed with the SHM by modifying ('nudging') the profiles of soil water content simulated with the hydrology model toward those obtained from the satellite. Simulations with the MM can then be used to focus on processes occurring in the smallest domain of a nested grid.

Supplementary information from remote measurements can be useful also in reducing the balancing period for the SHM as well as serving as a check on the soil water content values obtained with the hydrology model. The method for incorporating satellite measurements into the SHM is suggested in Figure 4. Initial efforts will concentrate on validation of the remote sensing approach using existing field measurements and the derivation of soil water content and fractional vegetation cover for the Susquehanna Watershed region of Pennsylvania.

At present, about one month of work is required to process an image (including calibration, atmospheric correction) and then convert the processed images to soil water content and fractional vegetation cover using the SVAT model. A considerable amount of skill and judgment is needed along the way. A reasonable goal, therefore, is to streamline the method such that a relatively unskilled user can process and image and obtain the desired end produces in a matter of a few days or so. As stated above, the method, which we call the 'universal triangle method with nomogram stretching', offers such a possibility for efficient and rapid analysis because it reduces the spurious effects of atmosphere and solar forcing on the measurements. A goal of this program will be to streamline the processing of satellite data.

5. Modifying the surface hydrology scheme in the MM

In the absence of satellite data, the soil water content estimates would be provided to the MM entirely from simulations with the SHM. At present the surface hydrology component in the MM is provided by the Biosphere-Atmosphere Transfer Scheme (BATS) developed by Dickinson (Dickinson *et al.*, 1993). BATS currently uses a bucket model with three sublayers of specific depths. As such, BATS does not have sufficient resolution to adequately represent the shallow near-surface soil layer to which the radiant surface temperature and the surface energy balance are most sensitive. That the vertical resolution of the SHM is important in simulating the soil water content in the near-surface layer can be seen in Figure 6, which also provides an example of decoupling. Note that docoupling between the surface and the deeper layers is accentuated by the higher vertical resolution of the model. Depending on the choice for the grid spacing, the near-surface (*e.g.*, 0-4 cm layer) soil water content can very between 5 percent of field capacity (0.34 by volume for this case) to about 25 percent of field capacity in this drying situation. Consequently, it will be necessary to modify the structure of the BATS soil water component as to make it compatible with SHM. Once this step is finished a real-time analysis of mesoscale phenomena can be made. In order to avoid incompatibility between the models a new land surface component (BATS-SHM) will be developed.

6. Real time applications of the SHM

An objective is to modify the SHM system to provide soil water content fields to the MM in real time. This system, which is currently being designed, will use meteorological data from the high-speed data line at the Department of Meteorology to produce input to the SHM on a daily basis. This step will not only allow ready access to the derived soil water content fields but will eliminate the need for a balancing period, since the latter will no longer be a factor after the first two months of operation, as indicated in Figure 1. Pre-processing programs will be modified to accept data from the high speed lines. All steps shown in Figure 2 will therefore be executed each day.

This year we have been working on modifying the SHM system developed by Smith .*et al.* (1994) to provide initial values of soil-water content (SWC) to the real-time Penn State/NCAR Mesoscale Model (MM) (Anthes *et al.*, 1987). the end result will be a linked real-time SHM-MM system. This new system uses real time meteorological data from the National Weather Service (NWS), which are analyzed on a twice-daily basis to produce the SHM output. The SHM will be run to update the SWC profile at each model grid point every day. After the balancing period (Figure 1), the updated values of SWC will be available for use in the MM on a daily basis.

The new domain used for the linked real-time SHM-MM system is shown in Figure 7. Some of the components of the real-time SHM system are shown in Figure 2. During 1994 we have worked on the following:

1. Pre-processing programs (Figure 2): Conversion of some of the programs and/or scripts already developed for the real time Penn State/NCAR mesoscale model, that can be used to produce a subset of the meteorological dataset (Figure 1) for the real-time SHM (i.e., the surface air temperature, moisture and wind speed).

2. Modification of the program MIXER (Figure 2) to accept real-time analysis, instead of historical data.

3. Modification of the SHM to accept real-time atmospheric forcing from day to day, as well as updated soil-water content data, as shown in Figure 2.

4. Inclusion of BATS into the real-time Penn State/NCAR mesoscale model

5. Testing of the use of the USDA Soil Conservation Service (SCS) State Soil Geographic Data Base (STATSGO) soil texture information in the SHM in the research mode: i.e., using the 4-km domain

Land cover characteristics for the United States will be extracted from the 1 km United States Geological Survey from EROS data center (USGS-EDC) Land Surface Characteristics Database (Loveland *et al.*, 1991). Land cover characteristics datasets for Canada and Mexico will be acquired from a 10 arc-second resolution land use file already being used by the real time MM. These two datasets will then be merged to produce one land-cover data set for the whole domain. Soils information will be specified using STATSGO. The USGS-EDC Land Surface Characteristics Database and STATSGO have already been acquired and software will be developed to make them available for this application. New sources of precipitation and cloud cover data (i.e. ASAS, NEXRAD, SSM/I) will be examined and included in the system wherever possible.

Once this new real-time SHM/MM system is implemented, and after a suitable balancing period has occurred, it will be possible to run a series of verification tests continually by comparing the predicted afternoon temperature and dewpoint values with observations using the initial fields of soil water content determined from the SHM and those from the MM with a climatological soil water content.

A new method for nudging the soil water content values imposed by the SHM with real time forecasts has been outlined by Mahfouf and his associates in a series of articles following the initial publication (Mahfouf, 1991). Basically Mahfouf's approach is to nudge the initial soil water content values toward more 'correct' ones at each grid point in the mesoscale domain. The nudging factor will depend on the forecast 'error', which is the difference between the predicted and the observed temperature and humidity values at each of those points. Mahfouf uses two relaxation (or nudging) coefficients (α and β) which are, respectively, multiplied by the forecast 'errors' to yield the increment that must be added to or subtracted from the initial soil water content values specified for each grid point. Thus, a continuous bias in predictions that are either too warm or too dry at a particular grid point will force the initial soil water content toward higher values, thereby reducing the forecast error in time. Of course, the Mahfouf method does not distinguish between errors in temperature or humidity due to soil water content or due to other factors such as an incorrect albedo or soil type. Errors in the forecasts produced by errors in these other quantities also become mapped into the imposed changes in soil water content. This may produce a better forecast but sometimes for the wrong reasons.

Only by examining a large number of such simulations can a statistically significant evaluation be made. Two MM forecasts will be performed for every verification period: one initialized with the soil water content fields currently used as default in the MM and the other initialized with SHM.

Real time integration of the remote measurement into the SHM is still not feasible. Development of a rapid and efficient method for incorporating remotely derived soil water content over limited areas into the SHM is an attainable goal for research purposes. It appears that the decoupling hypothesis presents a serious conceptual block in the use of surface radiant temperatures for updating the mesoscale model, but it may nevertheless lead to a very useful result in that the degree of decoupling may give information on the soil hydraulic conductivity.

In any case, the top down approach will have a variety of applications, particularly in the study of mesoscale circulations associated with land use changes and variable surface soil water content. Avissar and his colleagues (*e.g.*, Avissar and Pielke, 1989; Avissar, 1992) and others (Mahfouf *et al.*, 1987) have shown that important mesoscale circulations may develop as the result of arbitrary variations in land surface cover and soil moisture. To date, very little effort has been made to examine the implications of Avissar's work using a fine-mesh, non-hydrostatic mesoscale model with the appropriate patterns of land surface cover and soil water content.

8. A procedure for using radar reflectivity data to locate convection in the dynamic initialization of a mesoscale model

The model is usually initialized with conventional rawinsonde data, but the large distances between the observation sites may very likely obscure any localized convective forcing mechanisms. Radar reflectivity data, however, can provide information about the location of convection with high spatial and temporal resolution over a larger area. In this study, radar data were used in a pre-forecast period, where the radar data define the location of the convection. The convective parameterization scheme (CPS) in the model then calculates the convective effects at those locations, so that at the initial forecast time the areas of convection and its effects will be in the correct locations.

To accomplish this, digitized, low-level 0.5° elevation angle scan radar data from 5 WSR-57 radar equipped with the RADAP II digitizer are used to locate convection in the model for the 10-11 June 1985 PRE-STORM squall line. The scans occur every 10 minutes and are assimilated at that frequency in a pre-forecast period beginning at 12 UT 10 June. However, the model grid is not completely covered by the radar scans. The CPS will locate and produce convection and its effects at these grid points according to the model conditions.

The CPS and radar data often concur on the location and timing of the convection, but when they do not agree, the model is forced to be in agreement with the data. When the radar shows no convection at a particular grid point but the CPS calculates that there should be, convection will simply be turned off at the location. At grid points where the radar shows convection, but the CPS does not, a certain model layer of air below 300 mb above the ground (either the layer with the highest equivalent wet bulb potential temperature value (TM method) or the layer with the least amount of negative area to overcome (NA method)) is lifted to its level of free convection. If this fails to produce a cloud at least 4 km deep, a small amount of moisture is added to the layer to increase its buoyancy, and the process is repeated. If a deep cloud fails to be initiated after a certain amount of moisture is added, the forcing is stopped and no cloud is formed at that grid point.

There were a total of 8 model integrations: 2 control runs (no assimilation) and 6 assimilation runs. All runs are initiated with conventional rawinsonde data. The first control run is an 18 hour forecast (Figure 8; C18) initiated at 12 UT 10 June, and the second is a 6 hour forecast (not shown) initiated at 00 UT 11 June. The six assimilation runs are all initialized at 12 UT 10 June with conventional rawinsonde data: 3 use method 1 for forcing and the other 3 use method 2. For each method, the first run assimilates data for 6 hours and produces a 12 hour forecast and the second assimilates data for 9 hours and produces a 9 hour forecast and the third assimilates data for 12 hours and produces a 6 hour forecast (TM12, NA12). All forecasts end at 06UT 11 June.

Figure 8 shows the simulated hourly convective rain accumulations for C18, TM12 and NA12 for the period ending at 10 June. A comparison of C18 to TM12 and NA12 clearly shows that the erroneous convection in central Oklahoma was suppressed by the radar data in both the TM and NA data assimilation cycles. Similar results were obtained for the other simulations.

9. Our present perspectives

An improved distribution of soil water content for initializing a mesoscale model (the Penn State/NCAR mesoscale model) is being developed in which real time estimates of soil water content will be obtained by updating those fields with an off-line hydrology model. This is to be done by executing a soil hydrology component at each point in nested grid. In the smallest grid domain, soil water content estimates will be obtained from the hydrology component, but modified by estimates derived remotely by satellite using a new method, which yields both a surface soil water content and a fractional vegetation cover. Once the system is in place a series of validation studies will be made and the predicted afternoon temperature and dewpoint values compared with those obtained using a climatological soil water content. Finally, studies will be made of mesoscale circulations associated with variable land use and soil water content. Unfortunately, no plans are underway for utilizing the radar nudging of the convective scheme.

Our present goals include:

- Using radiant surface temperature measurements of vegetation index and radiant surface temperature to obtain the spatial distribution of surface soil water content and fractional vegetation cover.

- Modifying the MM and the SHM such that the remote measurements of surface soil water content correspond to those in the top layer in the soil hydrology mode and in the MM.

- Updating the surface hydrology on a continuing and real time basis to initialize the MM over a large area; use the remote estimates of soil water content in conjunction with a hydrological model for initializing the MM over small regions, such as watersheds. Perform a series of validation studies with the MM using the real time soil water content for the purpose of improving the initial soil water content fields and for investigating mesoscale circulations associated with small-scale variations in soil water content and land use.

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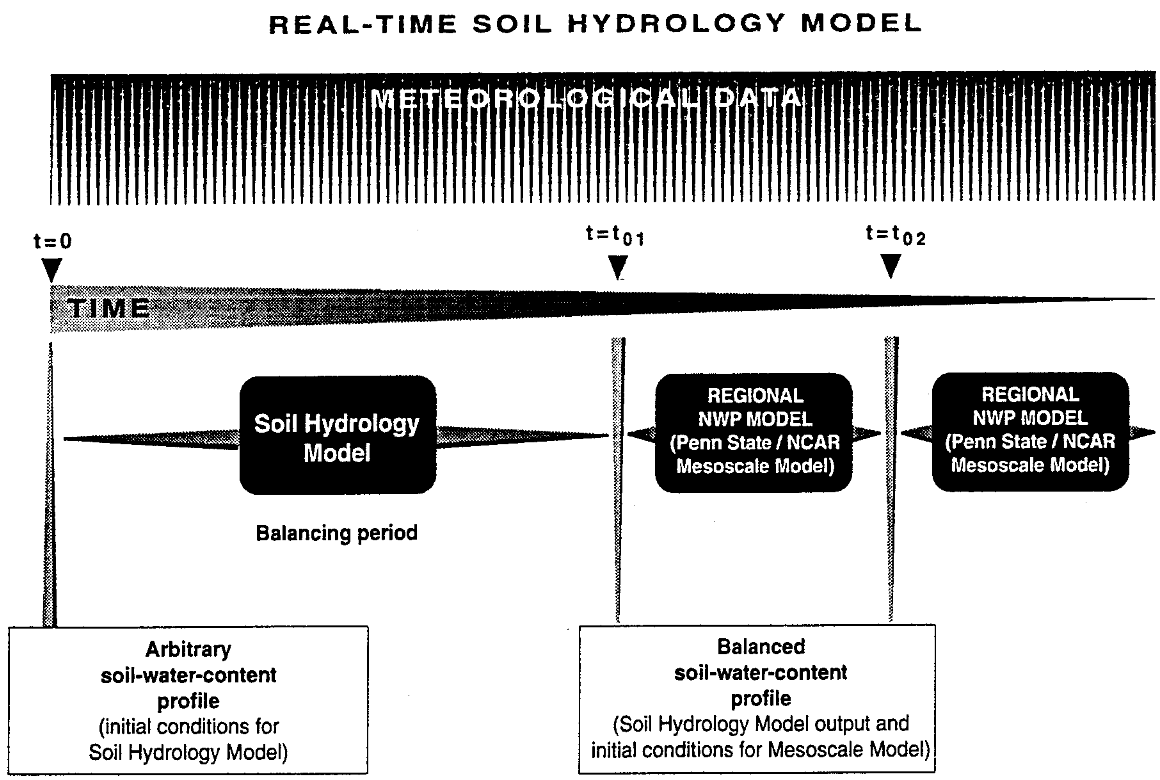

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Figure Captions

Figure 1. Scheme for initializing the Penn State/NCAR Mesoscale Model (MM) using the Soil Hydrology Model (SHM). The latter is executed starting at $t = 0$ *and operates using meteorological and land use data. Simulations with the MM begin at* t_o.

Figure 2. Steps required to initialize the MM with soil water content (swc) fields using the SHM and input meteorological and land use data.

Figure 3. Distribution of volumetric soil water content in the upper 10n cm soil layer for 17 July, 1990, as determined by the SHM for initialization of MM.

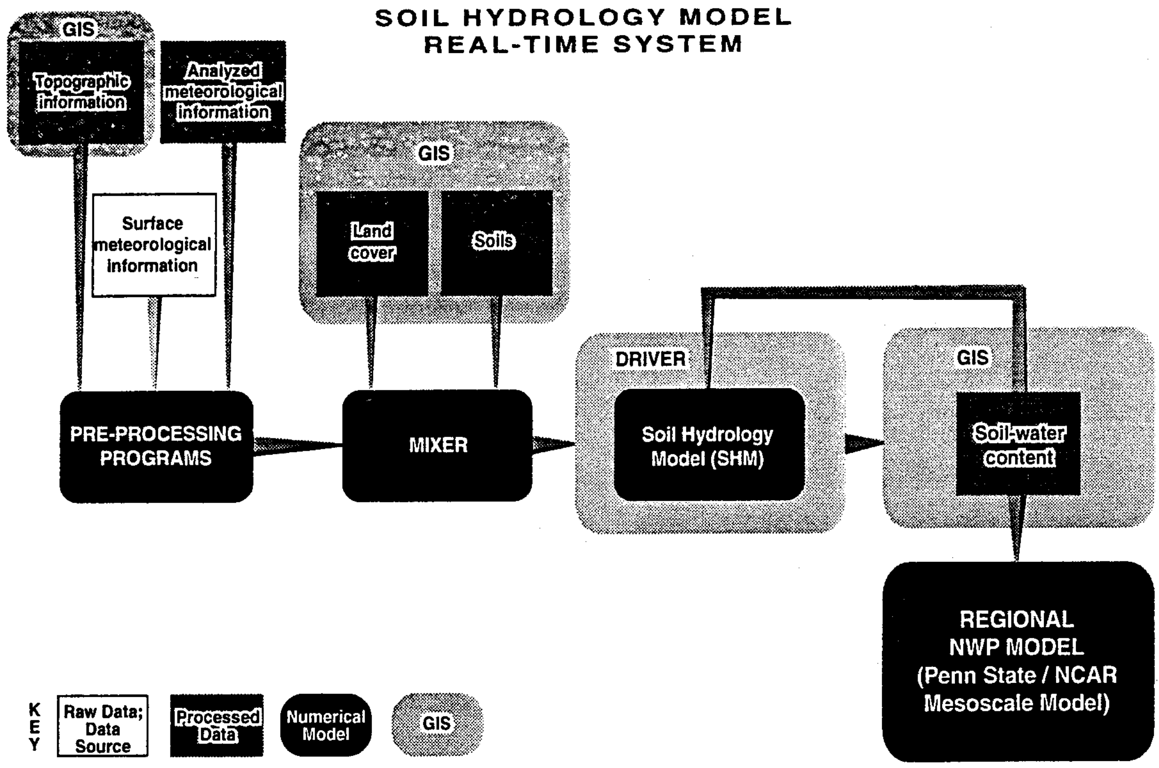
Figure 4. Difference between the Penn State/NCAR mesoscale model surface temperature results for 18; UTC 17 July 1990 (6 h into the simulation, approximately 1400 local time) using the climatological soil moisture values and the values produced by the hydrology model. The contour intervals are 1 K for positive values (full lines) and 0.5 K for negative values (dashed lines). The letters D and W, respectively, refer to dry and wet areas in the surface soil water content analysis (not shown).

Figure 5. Scheme for producing images of surface moisture availability (output; M_o*) from input fields of normalized difference vegetation index (NDVI) and radiant surface temperature* T_o. *Analyses are based on AVHRR measurements over the Mahantango Watershed area in Pennsylvania, 5 June, 1990. A similar scheme is used to obtain the fractional vegetation cover. The middle figure shows the triangular-shape of the pixel distribution in the scattergraph.*

Figure 6. Vertical profiles of volumetric soil water content (θ*; lower axis) or fraction of field capacity (*$\theta/\theta_{fc} = M_o$*; top axis;* $\theta_{fc} = 0.34$*) versus depth (Z) in cm over the Mahantango Watershed for the SHM with differing vertical resolution (see key to right) during a drying period after a simulation of four months ending on 7 July, 1990.*

Figure 7. Real time Modeling Domain for expanded area

Figure 8. Simulated convective rain from 16UT-17UT 10 June 1985, isohyets every 1mm (labeled) in cm in b and c). a) C18 b) TM12 c)NA12.



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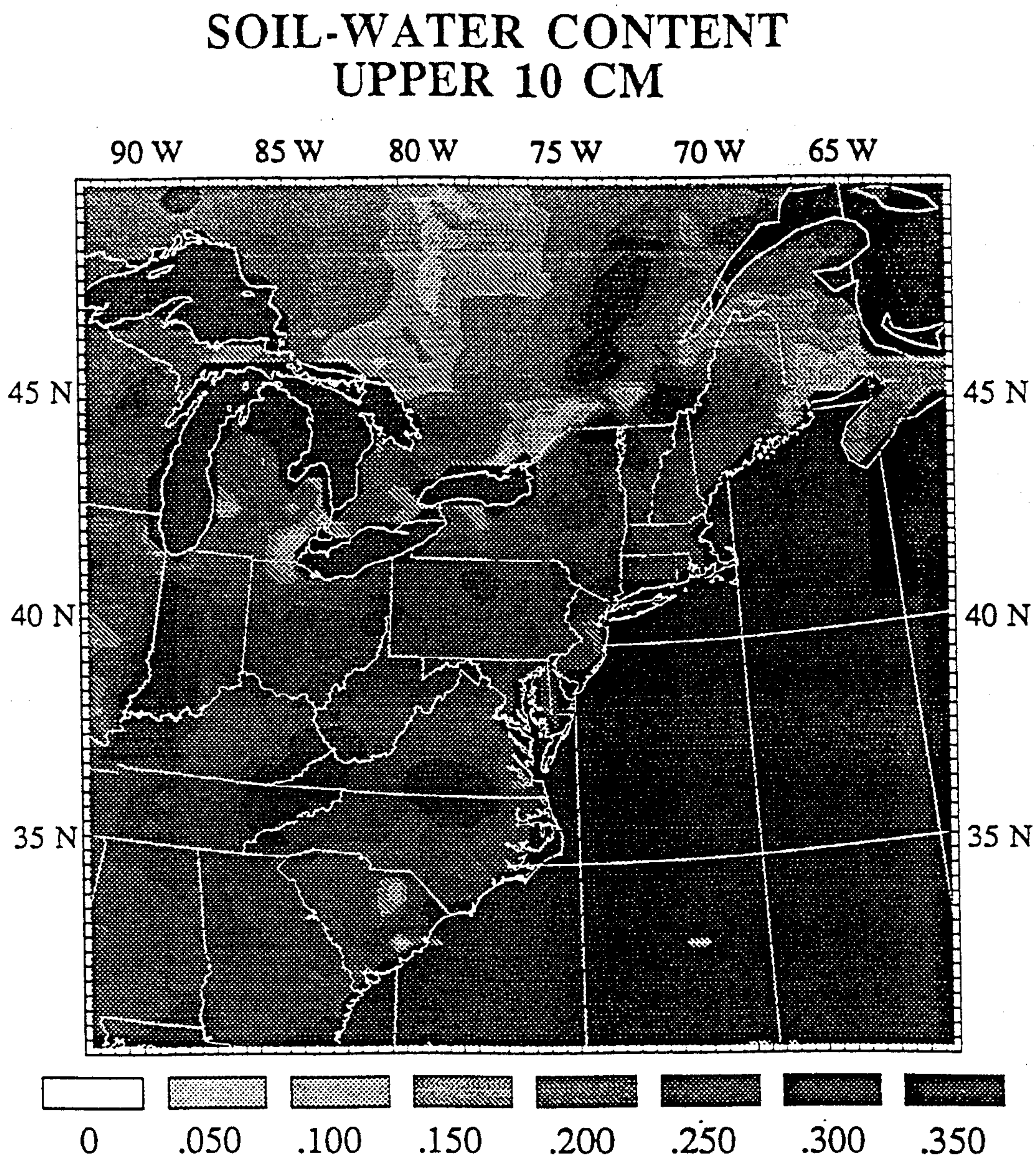

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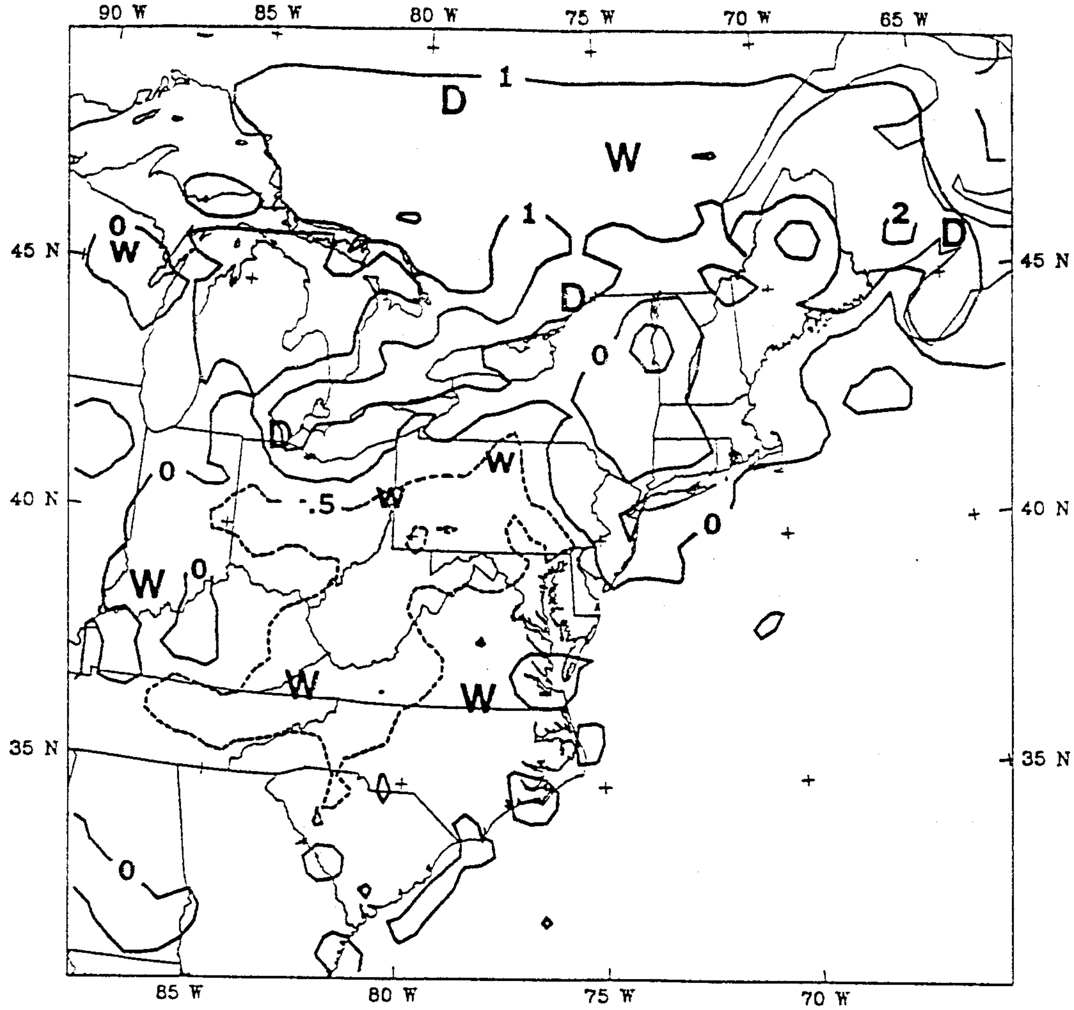

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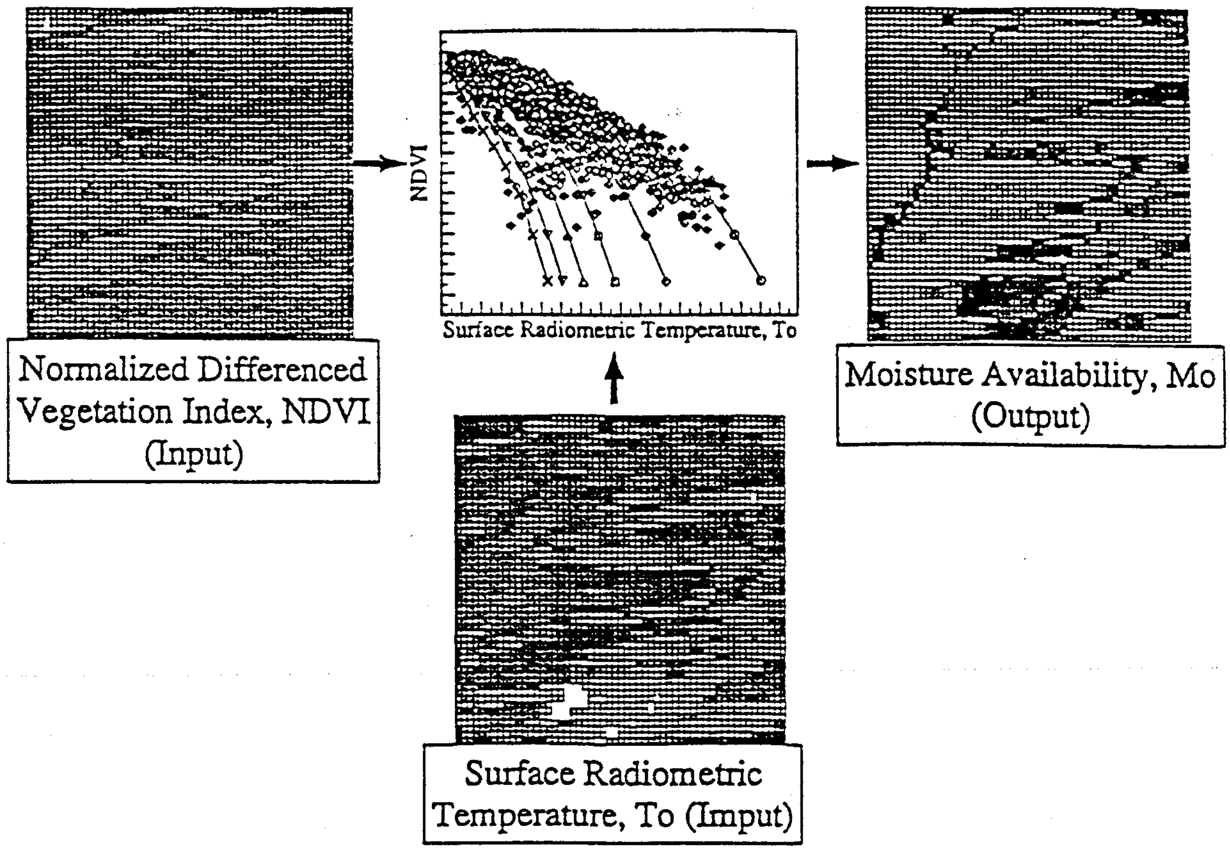
Top-Down (Remote Sensing) Approach to Surface Moisture Availability Determination



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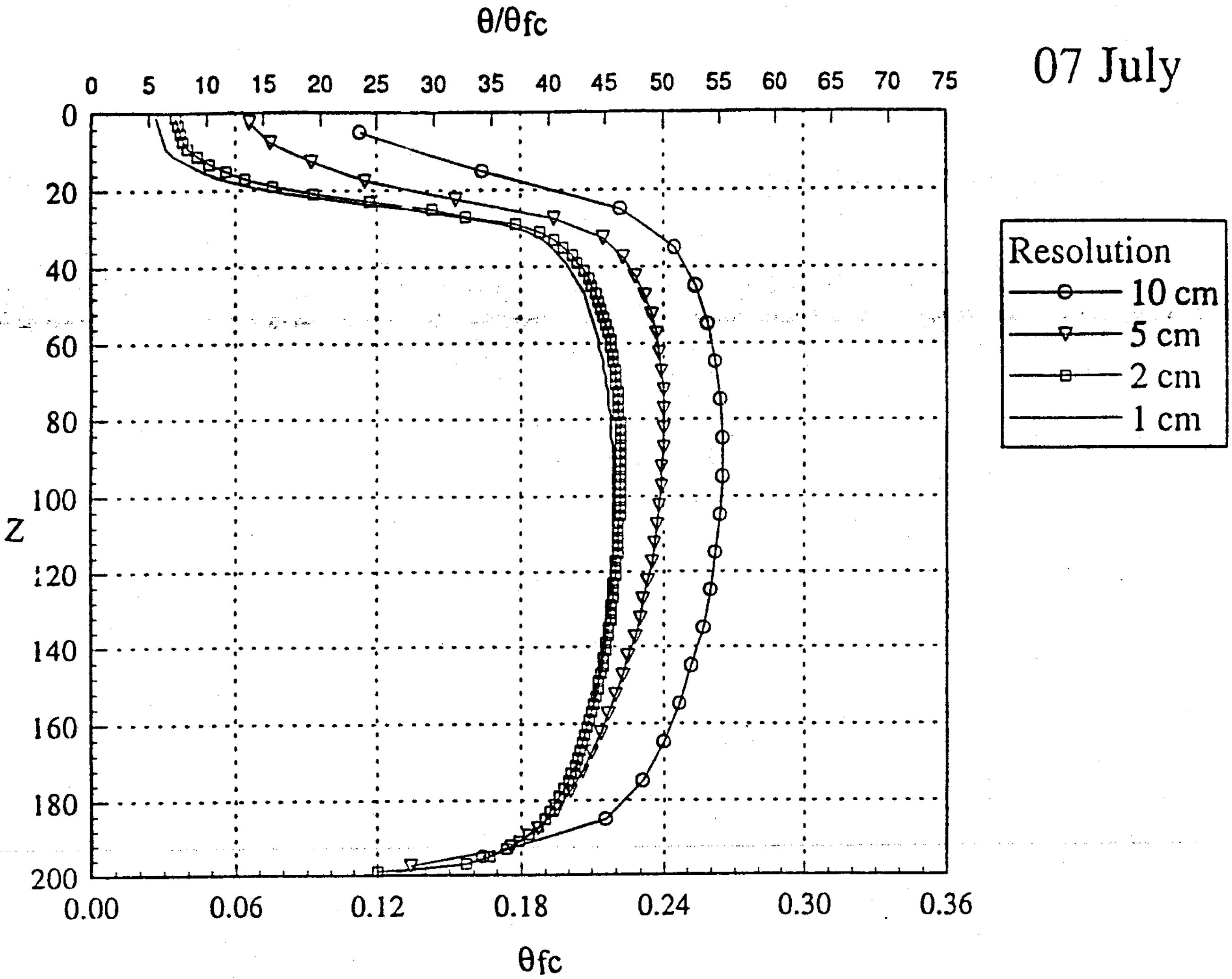

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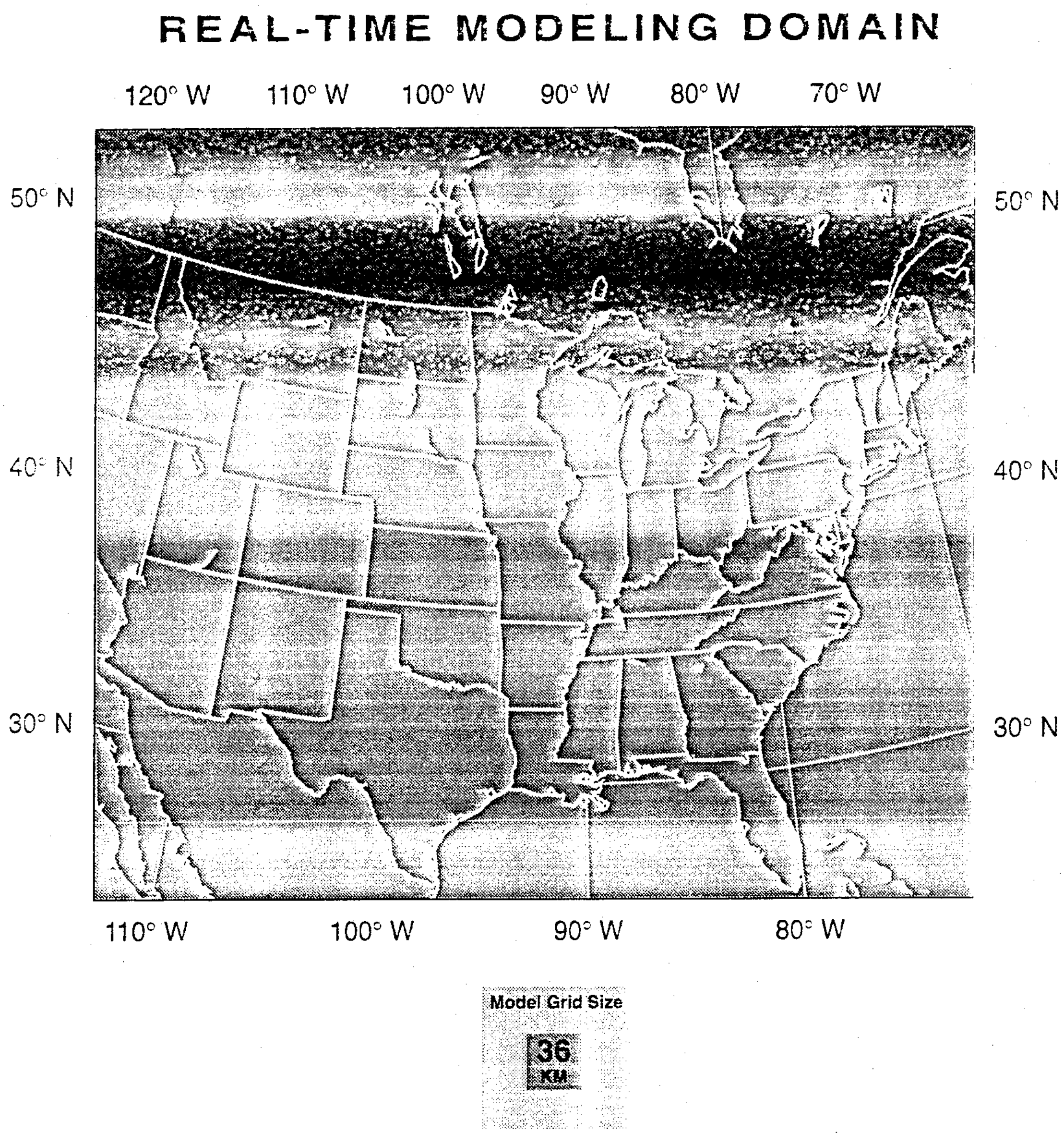

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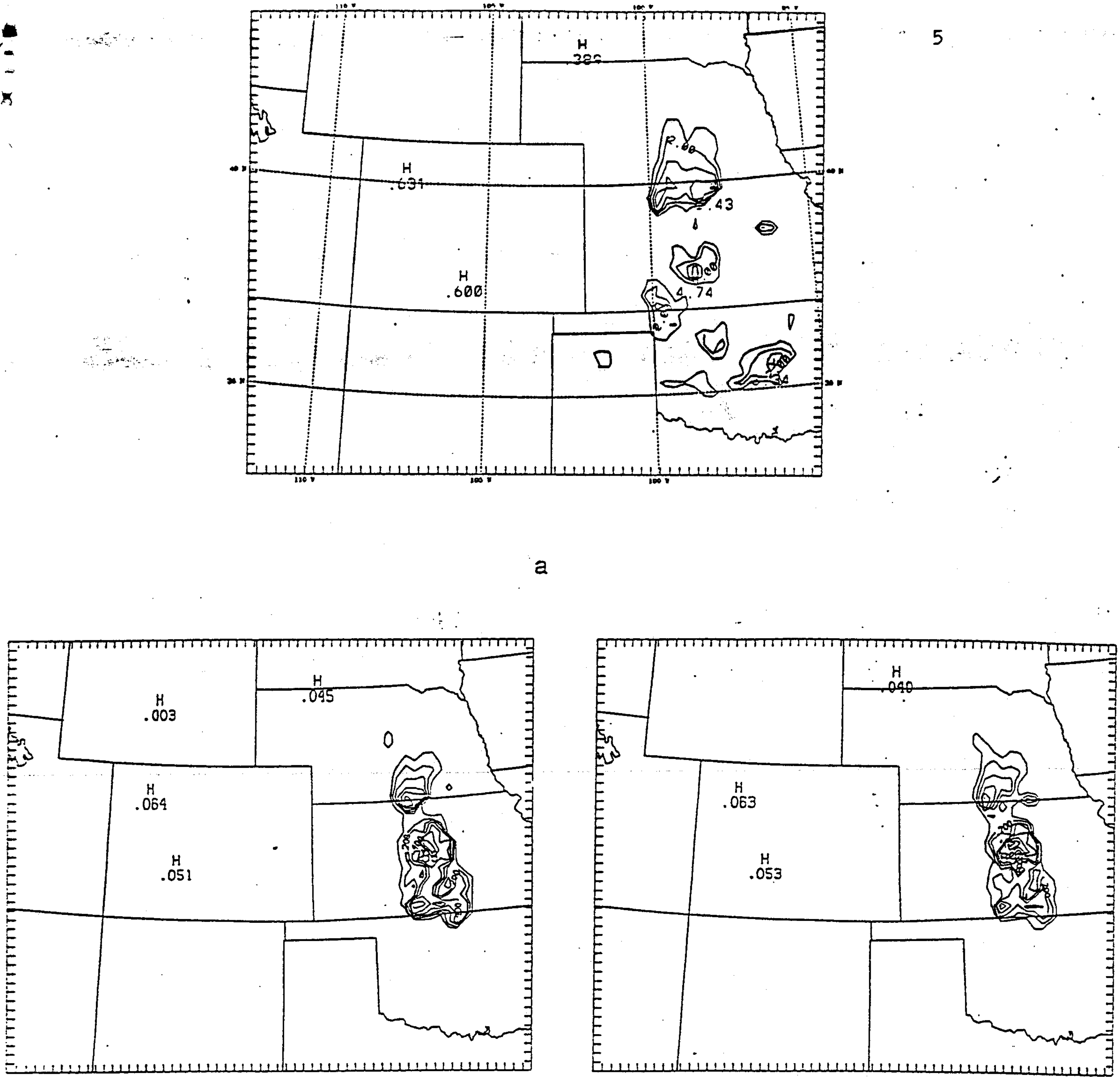

a

b

c

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