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2.3 CASE STUDY VERIFICATION OF RUC/MAPS FOG AND VISIBILITY FORECASTS

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1. INTRODUCTION

The Rapid Update Cycle (RUC) which runs operationally at the National Centers for Environmental Prediction (NCEP) (Benjamin et al. 1999, 1998), and its experimental version (Mesoscale Analysis and Prediction System - MAPS) run at Forecast Systems Laboratory, were designed to provide frequently updated weather predictions for better guidance to aviation and other short-range forecast users. In January 2000, several additional aviation-impact diagnostic variables became routinely available as part of the RUC output fields, including visibility, cloud base (ceiling), stable cloud top, convective cloud top potential, and surface wind gust potential.

The skill of RUC visibility and fog (near-surface cloud water) forecast is critically dependent on two advanced physical parameterizations in the RUC, the mixed-phase cloud microphysics scheme and the land-surface (soil/vegetation/snow) parameterization. Forecasts of cloud visibility and fog are obtained in the RUC from 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, 2000), including 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. Fluxes of heat, moisture, and momentum near the earth's surface in the RUC are dependent on its multilevel soil/vegetation/snow scheme (Smirnova et al. 1997, 2000a) and its ongoing cycling of soil moisture/temperature and snow cover. Through these fluxes horizontal variations of soil moisture and snow cover, in particular, exert a strong control on near-surface visibility. The land-surface scheme in the RUC, therefore, contributes to improved predictions of surface conditions important for efficient operations in the vicinity of air terminals. Recently performed validations of MAPS/RUC hydrological cycle components, such as precipitation, evapotranspiration and soil moisture, as well as of skin temperature demonstrate the model's capability to represent surface processes with a good degree of realism (Smirnova et al. 2000b).

Accurate prediction of aviation-impact variables such as fog, surface visibility and cloud ceiling is important for terminal operations. In this paper, a RUC visibility algorithm (an extension to the Stoelinga-Warner (1999) algorithm) is presented and applied to native-grid RUC output to product diagnostic fields of surface visibility. METAR (Meteorological Aviation Reports) visibility reports are used to verify this algorithm and look for deficiencies.

2. ALGORITHM FOR DIAGNOSTICS OF SURFACE VISIBILITY

The RUC visibility algorithm is an extension of the Stoelinga and Warner (1999) approach. It has two components: 1) the effects of visibility from hydrometeors (largely based on Stoelinga-Warner but with additions for graupel), and 2) a new clear-air algorithm based on relative humidity near the surface. Because the RUC uses a mixed-phase cloud microphysics parameterization related to the one upon which Stoelinga and Warner based their visibility algorithm, that algorithm was adaptable for use in the RUC. The Stoelinga-Warner algorithm is based on visible light extinction coefficients that are functions of mass concentration for cloud water (fog), cloud ice, rain, and snow. Since the RUC uses a version of the Reisner/MM5 microphysics that also explicitly forecasts the mixing ratio of graupel, the RUC visibility algorithm has added an estimate of the extinction coefficient for graupel that is similar to that for snow but slightly smaller. The RUC application of the cloud/hydrometeor compo-

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Corresponding author address: Tatiana G. Smirnova, NOAA/ERL/FSL, R/FS1, 325 Broadway, Boulder, CO, 80303, e-mail: smirnova@fsl.noaa.gov, RUC information: http://ruc.fsl.noaa.gov nent of the algorithm is currently only at the lowest atmospheric level in the RUC, which is set at 5 m above the surface. (Later, we discuss the possibility that this application is in too thin a layer and should be changed to a few levels near the earth's surface.)

The relative humidity-based component of the RUC visibility algorithm accounts for reduction of visibility due to growth of the size of hygroscopic particles in the atmosphere and also for possible subgrid-scale cloud water or ice if the RUC grid volume is not saturated but is near saturation. The RUC RH-based visibility algorithm component estimates visibility as 8 km if the relative humidity is 95% or greater and exponentially relaxes the visibility to larger values at lower relative humidity (e.g., about 30 km at 50% RH). The RH-based algorithm is currently applied at level 2 in the RUC, which is about 1.5-2 mb (10-15 m) above level 1, and about 15-20 m above the earth's surface. This algorithm does not account for types or concentrations of aerosols upon which the actual visibility depends. The accuracy of this aspect of the RUC visibility algorithm may improve in the future if a simple air chemistry module is added to the RUC.

The final product of the RUC surface visibility is the minimum of the cloud/hydrometeor component visibility and the RH-based clear-air component.

3. BRIEF DESCRIPTION OF THE MICROPHYSICS SCHEME AND ITS RECENT MODIFICATIONS

The microphysics scheme incorporated into MAPS/RUC is the level 4 scheme from the NCAR/Penn State MM5 research model described in Reisner et al. (1998, herafter R), but with some modifications and enhancements. The original development of the scheme was motivated by a need to improve forecasts of inflight icing. The R98 study developed a three-level bulk microphysical scheme, with each level introducing increasing complexity. Level 3 (lowest level) only predicted mixing ratios of cloud water, rain, ice and snow. Level 4 added the ability to predict number concentration of ice and mixing ratio of graupel. The highest-level scheme was a two-moment scheme that added the ability to predict number concentrations of snow and graupel in addition to that of ice. All four schemes use the Marshall-Palmer inverse-exponential particle-size distribution for rain, snow, and graupel.

Operational experience with the initial implementation of the option 4 microphysics in RUC, corroborated by real-time forecasts and case-study simulations using MM5, revealed a number of unexpected behaviors (Brown et al. 2000). These included excessive graupel at both high levels (temperatures below -25°C) even when vertical motions are weak, and just above the melting layer; lower than expected amounts of supercooled liquid water; unrealistically high cloud-ice number concentrations approaching 10^8 m^{-3}, and unrealistically small snow mixing ratios.

Careful reexamination of the code as well as use of a two-dimensional version of MM5 capable of running either R level 4 or a more detailed microphysics code has led to a number of improvements to the code that have addressed these problems (Brown et al. 2000). In addition, the use of 10-min time steps in the operational implementation of R level 4, necessary to meet operational run-time requirements on NCEP's old C90 Cray computer, was found to be a major contributor to graupel buildup.

Major changes to level 4 of the R microphysics scheme that address the above problems include the following.

1) Abandonment of the Fletcher curve (Fletcher, 1962) for ice nucleation as a function of temperature in favor of a more recent curve proposed by Cooper (1986) that leads to less aggressive ice nucleation at colder temperatures.

2) For both vapor deposition on snow and graupel, and for riming of snow or graupel by collection of supercooled cloud water, the assumed particle size distributions of both snow and graupel have been modified to a Gamma distribution in order to reduce the number of small particles. Further, as described in R (Eq. A.43, Ikawa and Saito, 1991), formerly there was an explicit time-step dependence in the expression describing the rate of graupel formation as a result of riming on snow. This is now replaced by a procedure of Murakami (1990) that is independent of a time step: if depositional growth of snow is larger than riming growth, all riming growth of snow goes to augment snow, whereas if riming growth of snow exceeds depositional growth, riming growth of snow goes to augment graupel.

3) Extensive revision was made to calculations of cloud-ice number concentration to make this more consistent with mixing-ratio changes and to properly account for the riming of cloud ice.

4) Rainwater-related changes were made to more accurately simulate the production of supercooled drizzle droplets, a major icing hazard, through the collision-coalescence process. In supercooled cloud layers, the zero intercept for the size distribution of raindrops has been increased from 0.8*106 to 1010 m^{-4} for rainwater mixing ratios less than 0.1 g/kg, and the autoconversion threshold from cloud water to rainwater changed to 0.35 g/kg based on comparison to detailed simulations of freezing-drizzle formation.

5) Numerous other changes have been introduced to improve internal consistency.

4. PERFORMANCE OF RUC/MAPS COUPLED ATMOSPHERE/LAND-SURFACE FORECAST SCHEME

As of this writing, the RUC land-surface scheme has been running in MAPS for more than 4 years and in the operational RUC for more than 2 years, and soil and snow fields have been evolving depending only on input from the atmospheric model (precipitation, surface temperature, moisture, winds, etc.). One of the most important factors that constrains the model drift in RUC/MAPS is a 1-h data assimilation cycle. It includes full use of surface (METAR and buoy) and other observations available hourly. Another factor is the physics package in the RUC/MAPS atmospheric model, which together with the advantages of hybrid isentropic-sigma vertical coordinate provide reasonably accurate atmospheric forcing for the land-surface scheme. (The surface temperature/wind/moisture fields in the RUC are reasonably accurate, but the precipitation field, as in other models, does not show such high agreement with observations, especially in the warm season.) Continuous cycling of cloud microphysics variables also positively affects the evolution of soil temperature and moisture fields by reducing the precipitation spin-up.

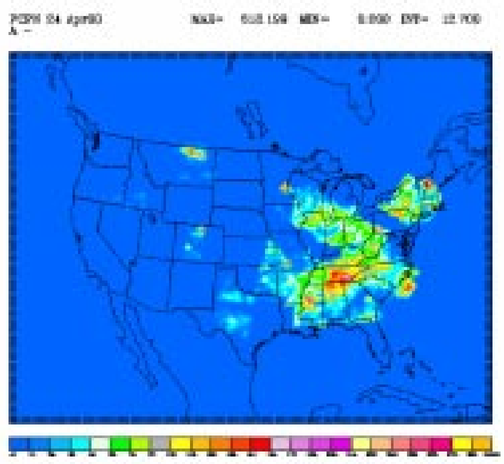

Figure 1. Monthly accumulated precipitation from the NCEP stage IV multisensor precipitation analysis for April 2000.

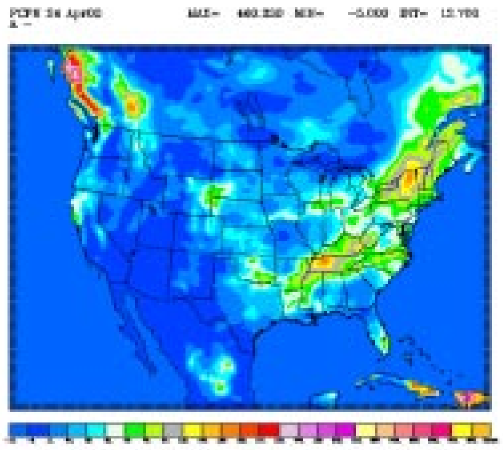

Figure 2. Monthly accumulation of 0-1h MAPS precipitation forecasts for April 2000.

Validation of 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/RUC precipitation forecasts for April 2000 are compared against the NCEP stage IV multisensor precipitation analysis (Baldwin and Mitchell, 1996) in Figs. 1 and 2. For this month there were several gaps in MAPS data 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.

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 Soil Climate Analysis Network (SCAN). 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, and also vegetation type and vertical profile of soil type. For brevity, the verification curves of soil moisture and temperature from one station, Princeton, Kentucky, are presented in this paper (Fig. 3 a,b). The curves demonstrate monthly variations for April 2000, for which the precipitation amounts at this location were slightly underestimated (Figs. 1,2).

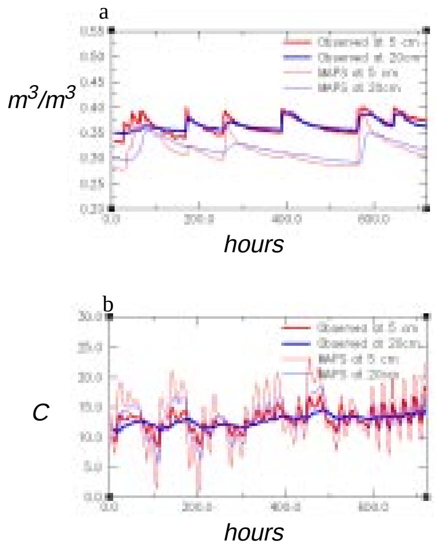

Figure 3. Monthly variation of MAPS (a) volumetric soil moisture content and (b) soil temperature at 5 and 20 cm depth compared to observations.

Soil moisture at both depths reflects a bias in MAPS/RUC values compared to observations that may be due to differences between soil type at the observation site vs. that of the 40-km grid square (Fig. 3a), but most of the precipitation events over the month and their effect on soil moisture are captured in MAPS. Consistent with accurate predictions of frontal systems passages, the model reflects monthly variations of the soil temperatures very realistically (Fig. 3b), although the diurnal cycle is overestimated due to drier soil and deficiencies of the parameterization for computing soil thermal conductivity.

Validations against other SCAN stations in the eastern part of the US demonstrate similar features. In the drier western area of MAPS/RUC domain, the soil moisture is closer to observed values, and diurnal cycles of soil temperatures are much more accurate. Overall, soil fields are represented quite realistically in MAPS/RUC, which encourages application of MAPS/RUC surface fields to predict aviation-sensitive conditions such as fog and low visibility to which aviation operations are very sensitive.

5. VERIFICATION OF A RUC PREDICTION OF SURFACE VISIBILITY AND FOG

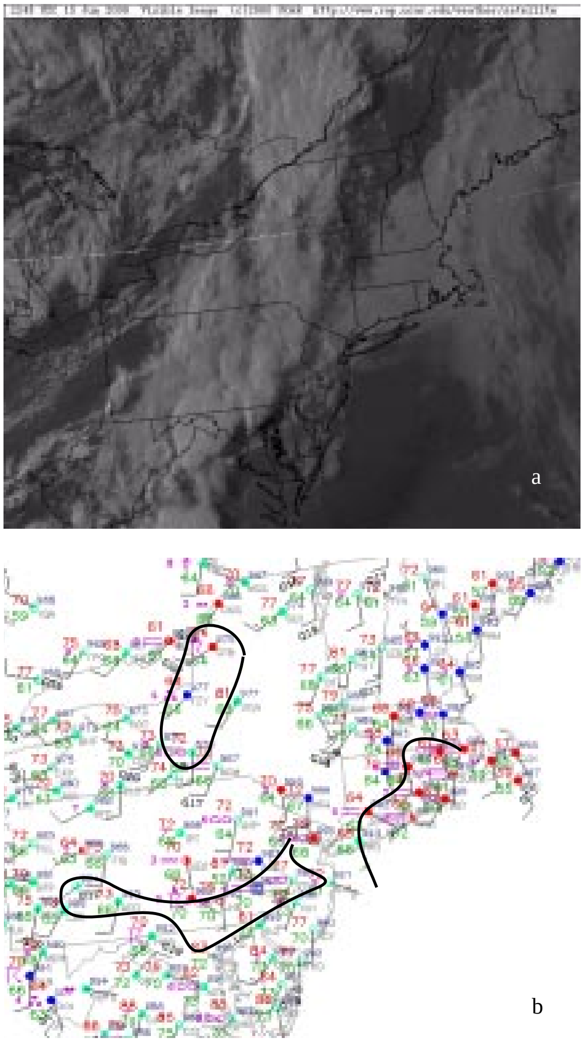

Figure 4. Visible image from GOES-8 (a), and METAR data (b) for North Atlantic states at 2200 UTC 15 June 2000. Circled are the fog areas with the visibility less than 5 miles.

To identify areas of fog and verify RUC forecasts for an early summer case from 15 June 2000, METAR data are used together with satellite imagery (Fig. 4 a,b). The skill of the RUC algorithm in this case is probably slightly lower than average. A visible image from GOES-8 (Fig. 4a) for 2200 UTC 15 June 2000 clearly shows the fog area along the New England coast, with an area of precipitation further west over central New York. METAR data (Fig. 4b) report fog and light fog in southern New England with visibilities from 0 to 8 miles.

Model-produced fields of fog and surface visibility are qualitatively compared to this data. RUC surface visibility for the same time based on 1-h forecast of hydrometeors (Fig. 5) is estimated to be 5-10 miles for this area. This range falls in the flight regulation category of Visual Flight Rules (VFR), which does not require pilot qualification for instrument navigation. [Of course, for conditions to be considered “VFR” cloud ceiling must also be higher than 3000 ft (914 m) above ground.] Thus, the model product underestimates visibility in this case. A reason for this underestimate is suggested by the cross section of cloud water, as discussed two paragraphs down.

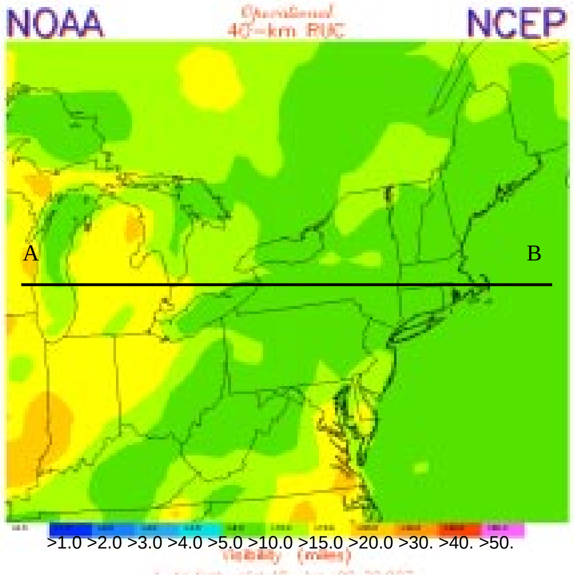

Figure 5. RUC surface visibility in miles valid at 22 UTC 15 June 2000.

A vertical cross section of relative humidity (Fig. 6) from the RUC 1-h forecast along the east-west AB line on Fig.5 shows an area of near-saturation near the coast - the fog area - which spreads from near but not at the surface up to the 900 mb isobaric level. One more saturation zone in the RUC 1-h forecast cross section is located farther west over west-central New York state near 800 mb, where the cloud and precipitation band is apparent in Fig. 4a-b, and it also does not extend to the surface.

A vertical cross section of cloud water (Fig. 7, 1-h RUC forecast again) along the same line also shows the area with low stratus cloud near the coast, separated by an area of clear air from a band of clouds in the RUC forecast associated with the precipitation over western and central New York state. Both the RUC relative humidity and cloud water fields are more consistent with satellite image and METAR visibility reports than the surface visibility diagnostic field. In southern New England, the algorithm would have produced a better result if it were based on cloud water in the lowest 150 m (20 mb) rather than just at the lowest level. This would have produced visibilities of less than 5 mi using the cloud/hydrometeor part of the RUC algorithm. Over New York state, the reduction in visibility was apparently caused by rainfall and associated low-level cloudiness. In this area, the vertical location of rain water and near-surface cloud water would also need to be improved to give an improved result in the visibility estimate. The upcoming RUC cloud analysis (Kim and Benjamin 2000) will certainly improve the skill of the RUC visibility diagnostic for situations similar to this one.

6. CONCLUDING REMARKS

This study documents the current progress and some relative success in using a mesoscale atmospheric/land-surface coupled model with high-frequency assimilation of atmospheric observations (RUC/MAPS) to predict low visibility at the surface. The advanced physics package in RUC with a sophisticated microphysics scheme and realistic treatment of land-surface interactions provides the potential for successful predictions of fog and low surface visibility. Its performance was investigated for a case on 15 June 2000 in the northeastern United States. The areas with estimated low visibility agree fairly well with the observed low visibility areas for this case, although the modified RUC visibility algorithm was not able to estimate the degree of visibility reduction correctly. There was some suggestion that using cloud water from the lowest few levels instead of just the lowest atmospheric level would improve the diagnostic. More case studies are required to further investigate the algorithm's behavior, and some will be presented at the meeting. In particular, the performance of this algorithm in conditions favorable for radiation fog needs to be evaluated.

Besides further improvements to the RUC visibility algorithm itself, the surface visibility product will certainly improve through the increase of horizontal resolution in the RUC model, which at present with 40-km resolution is not able to capture some mesoscale features. Later this year, the RUC model will run with 20-km resolution, and comparisons of surface visibility between the old and the new versions will be presented.

An initial cloud analysis (Kim and Benjamin 2000) will be introduced to the RUC in the 20-km version based upon assimilation of GOES cloud-top pressure data. This technique includes both cloud clearing and cloud building, correcting the cloud/hydrometeor fields from the previous 1-h RUC forecast. This analysis improvement should also provide some improvement to RUC fog/visibility fields. This technique is also designed to accommodate assimilation of METAR observations of obstructions to visibility, and this augmentation, expected within another year, will contribute strongly to further improvements.

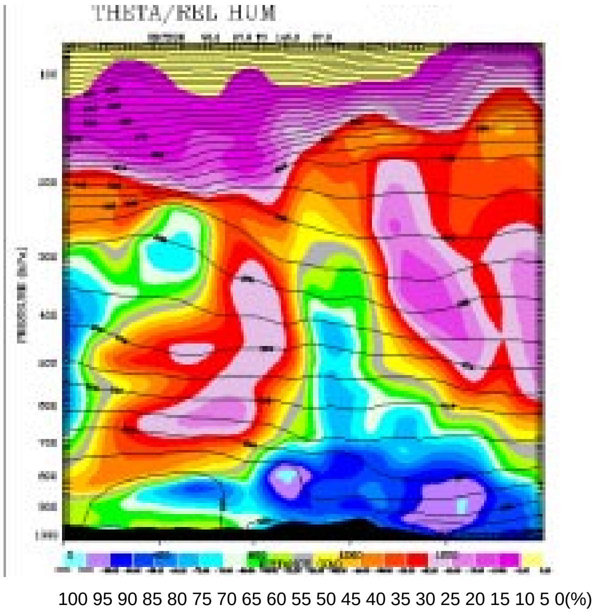

Figure 6. Cross section of RUC relative humidity (%) along the AB line on Fig. 5 valid at 2200 UTC 15 June 2000.

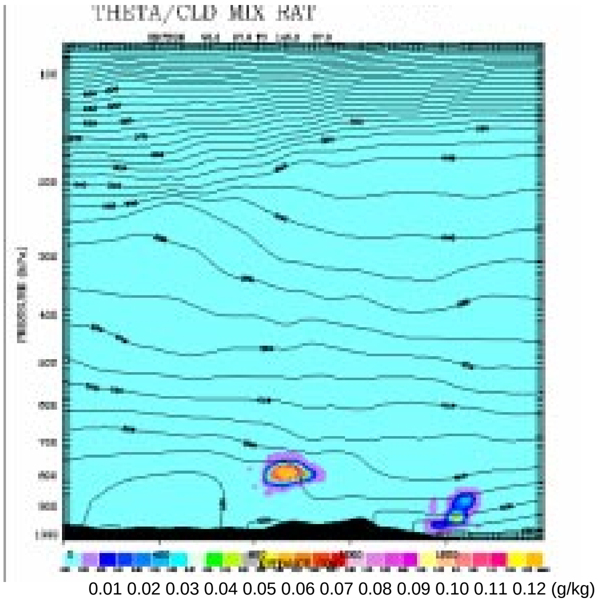

Figure 7. Cross section of RUC cloud water along the AB line on Fig. 5 valid at 2200 UTC 15 June 2000.

Further development of RUC/MAPS over the next two years will also improve its ability to predict conditions potentially hazardous to aviation. Key areas of focus in RUC/MAPS development are assimilation of cloud/precipitation observations, further improvements to atmospheric surface layer and soil physics, use of improved soil datasets, and improvements to the RUC convective precipitation parameterization and microphysics scheme.

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