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LAPS/RAMS. A nonhydrostatic mesoscale numerical modeling system configured for operational use

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ABSTRACT

The National Oceanic and Atmospheric Administration Forecast Systems Laboratory (FSL) has configured an operational local-domain analysis and forecast system designed to function in the local weather office on an inexpensive computer workstation. The real-time system utilizes the 10-km grid increment analyses from the Local Analysis and Prediction System (LAPS) to initialize the Regional Atmospheric Modeling System (RAMS) mesoscale forecast model. A unique aspect of the LAPS/RAMS operational system is the initialization of the high-resolution model with comparable high-resolution analyses. The aim of the LAPS/RAMS real-time system is to provide local-scale guidance to the local weather office in addition to guidance that is currently available from coarser resolution, large-domain operational products. The operational system configuration and the utilization of three-dimensional visualization to display system output is discussed. All components of the LAPS/RAMS system are designed to run efficiently on a computer workstation affordable to individual weather forecast offices. Model validation results suggest that the LAPS/RAMS system is capable of resolving meso-β-scale, often terrain-forced, flow patterns. The three-dimensional visualization of the model output allows the operational forecaster to rapidly peruse the enormous amounts of data and aids the meteorologist's ability to comprehend and conceptualize mesoscale weather events. Potential improvements to the system are being implemented as computer workstation capabilities increase, which should lead to valuable forecast guidance of meso-γ-scale weather phenomena.

1. Introduction

The Local Analysis and Prediction System (LAPS), developed at NOAA's Forecast Systems Laboratory (FSL), is an operational system designed to provide three-dimensional meteorological analyses and forecasts at resolutions greater than previously feasible (McGinley, 1989; McGinley et al., 1991; Snook, 1993). The analysis portion of LAPS is a local-scale (10-km horizontal grid interval) data assimilation system that incorporates all real-time data that are available to the operational meteorological community. The real-time data sources, which include Doppler radar, automated surface observations, ground-based remotely sensed wind and temperature profiles, digital visible and infrared satellite observations, aircraft reports, and conventional observations, provide a vastly improved view of the atmosphere. With these data sources, LAPS generates real-time, three-dimensional upper-air and surface gridded analyses with sufficient spatial and temporal resolutions to diagnose the structure and evolution of mesoscale systems. The analysis portion of LAPS has been under development since 1989, and operational LAPS analyses are routinely utilized by the forecasters at the Denver, Colorado National Weather Service Forecast Office.

Cotton et al. (1994) notes that mesoscale numerical forecast models have been used extensively to support basic research investigations, but

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only recently have these models been applied to real-time forecasting (Warner and Seaman, 1990; Golding, 1992). Although these quasi-operational forecast systems use model grid intervals sufficient to resolve mesoscale features, they are dependent on coarser resolution operational analyses for model initialization. FSL is currently utilizing the LAPS operational analyses to initialize a high-resolution nonhydrostatic mesoscale numerical model, hence providing the prediction capability of LAPS (Snook et al., 1994; Snook and Pielke, 1995). Daily real-time forecasts using the Regional Atmospheric Modeling System (RAMS), developed at Colorado State University (Pielke et al., 1992; Cotton et al., 1994), are generated at FSL and displayed at the in-house daily weather briefing. A unique aspect of the LAPS/RAMS operational analysis and prediction system is the initialization of the high-resolution model with comparable high-resolution analyses. Furthermore, the complete LAPS/RAMS system operates efficiently on an affordable computer workstation. This paper discusses the LAPS/RAMS system, including the model design, methods to visualize the data, model validation results, and future directions.

2. Model design

The aim of the LAPS/RAMS real-time system is to provide local-scale guidance to the individual forecast office beyond what is currently available from coarser resolution, large-domain operational products. This is accomplished by generating local-domain analyses and short-range predictions of meteorological variables and, very important, other derived fields that are pertinent to the local needs of any particular weather office. For these reasons, the LAPS high-resolution domain is limited in size to cover approximately the local weather offices' area of responsibility ($\approx$250,000 km^2), and the primary goal is to add value to the short-range (0–12 h) prediction of local weather phenomena such as convection, terrain-forced circulations, and mesoscale variation of precipitation.

The primary design considerations of the LAPS/RAMS system are to take advantage of all local data sources at the highest possible resolution and to run the system locally on computer workstations affordable for operational weather offices. Significant advances in reduced instruction set computer (RISC) workstation technology are providing affordable platforms capable of performing these tasks. For example, the real-time RAMS forecasting system demonstrated by Cotton et al. (1994) used a desk-top workstation that costs less than US$30,000. Some compromises are still required to maintain model efficiency on today's computer workstations, but further advances in workstation technology are expected to reduce these limitations in the near future.

The LAPS/RAMS system has three components: (1) operational analyses, (2) real-time RAMS

Table 1. *LAPS/RAMS model configuration for real-time forecasts*

Model category	Option
grid dimensions	61 × 61 × 25
horizontal grid increment	10 km
vertical coordinate	terrain following σ_z
vertical grid increment	300 m stretched to 750 m
model top height	15.3 km
topography	LAPS (derived from 30 s data)
initialization	LAPS real-time analyses
thermodynamics	nonhydrostatic
moisture complexity	water vapor and cloud water only, condensation effects, no precipitation
radiation	radiative effects of water vapor and clouds
lateral boundary conditions	Davies relaxation to NGM forecast
top boundary condition	rigid lid with modified Rayleigh friction-absorbing layer
surface boundary condition	0.5 m, 11-level soil model
turbulence	Smagorinsky deformation K closure
time-step	30 s

predictions, and (3) visualization of model output. All three components can be performed on the same affordable computer workstation platform. An overview of the operational LAPS analyses is discussed by McGinley (1989) and McGinley et al. (1991) and specific details are provided by Birkenheuer (1991; 1992) and Albers et al. (1994). The prediction portion of the system currently takes about 5 h on an IBM RISC 6000/580 computer workstation to generate a 12-h forecast.

2.1. *Operational RAMS configuration*

A 12-h RAMS forecast initialized at 1200 UTC with operational nonhomogeneous LAPS analyses is produced every business day. The RAMS mesoscale numerical model is configured (Table 1) such that the LAPS analyses can be used as model initialization with as little manipulation to the initial fields as possible. The current horizontal model domain is equivalent to the LAPS analysis domain (61 × 61 grid points with a 10-km grid increment, Fig. 1) that covers most of Colorado and a small portion of several adjacent states. The vertical grid is a stretched sigma-z coordinate system with a 300-m grid spacing nearest the ground, a stretch factor of 1.1, and a maximum grid spacing of 750 m. Hence, the model top is approximately 15.3 km above the surface. The

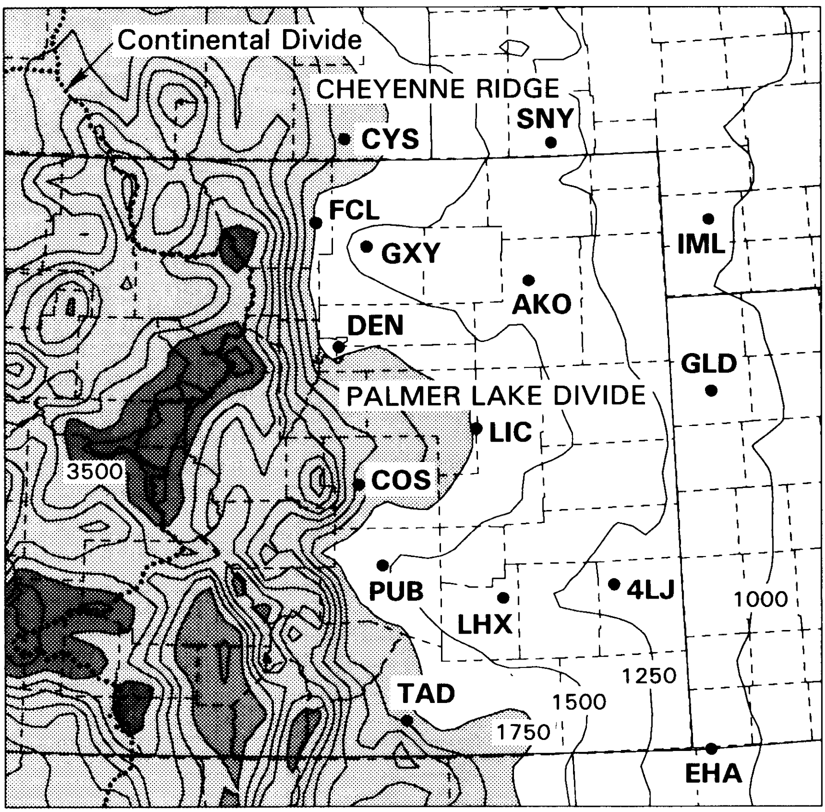

Fig. 1. LAPS/RAMS domain and topography (m). Elevation contour interval is 250 m. Light shaded area indicates terrain above 1750 m and dark shaded regions indicate terrain above 3500 m. Solid lines depict state boundaries and dashed lines indicate county boundaries. The Continental Divide is denoted by the dotted line. Surface Aviation Observations (SAO) locations east of the Continental Divide are indicated by standard three-letter abbreviations (CYS = Cheyenne, Wyoming, SNY = Sidney, Nebraska, FCL = Fort Collins, Colorado, GXY = Greeley, Colorado, AKO = Akron, Colorado, IML = Imperial, Kansas, DEN = Denver, Colorado, GLD = Goodland, Kansas, LIC = Limon, Colorado, COS = Colorado Springs, Colorado, PUB = Pueblo, Colorado, LHX = LaJunta, Colorado, 4LJ = Lamar, Colorado, TAD = Trinidad, Colorado, EHA = Elkhart, Kansas).

vertical grid spacing is designed to include all the available information in the LAPS analyses (50-mb vertical grid increment) while foregoing any greater resolution to allow implementation in real time on currently available computer workstations. The LAPS/RAMS terrain (Fig. 1) is derived from the United States Defense Mapping Agency (DMA) 30-s spatial interval elevation data by averaging all DMA elevations within each LAPS 100 km^2 grid box area.

The LAPS three-dimensional isobaric analyses are linearly interpolated in the vertical to the RAMS sigma-z coordinate system. Horizontal interpolation is not required because the model grid points correspond exactly to the LAPS analysis points. LAPS also generates separate surface analyses that are blended into the three-dimensional model initialization up to 500 m AGL using a height-weighted average of the two analyses such that the surface data receive full weight at the model ground level while the three-dimensional analysis receives full weight at 500 m AGL. LAPS generates three-dimensional liquid and ice water analyses using a vertical column diagnostic package and a cloud analysis derived from remotely sensed Doppler radar data, satellite observations, pilot reports, and surface observations. These analyses are used to initialize the model cloud water variable. A time-dependent lateral boundary condition is implemented that uses a Davies (1976) nudging scheme to force the model variables toward operational nested-grid model (NGM) forecasts received from the U.S. National Meteorological Center (NMC). The 18- and 24-h forecasts from the previous NGM run initialized at 0000 UTC are used as 6- and 12-h RAMS lateral boundary targets, which eliminates having to wait for the completion of a current 1200 UTC initialized model forecast. A rigid lid with a modified Rayleigh friction-absorbing layer (Cram, 1990) 5 grid points deep is used for the top boundary condition. At the surface, a 0.5-m, 11-level soil model (Tremback and Kessler, 1985) is utilized. Soil temperatures at all levels are initially set equal to the analyzed surface temperature. Soil moisture initialization is based on the analyzed surface relative humidity. Surface vegetation is currently not considered.

A nonhydrostatic version of RAMS is employed with a simplified level of moisture complexity. Condensation of water vapor to cloud water occurs wherever supersaturation is attained. However, other forms of liquid or ice water are not considered. Explicit microphysics is available in RAMS (Flatau et al., 1989), but the scheme is too expensive to use in the LAPS/RAMS operational environment with the computer workstations currently available at FSL. The Mahrer and Pielke (1977) radiation scheme is employed with modifications by Thompson (1993) to account for cloud water. The cumulus parameterization options are not employed. Turbulence closure is accomplished using a deformation K scheme (Smagorinsky, 1963; Tremback, 1990).

2.2. *Model output visualization*

Visualization of the model output is important for operational and scientific applications. Because the real-time, 12-h predictions are useful for only a short time span, the visualization system must allow the operational forecaster to rapidly peruse the enormous amounts of data that the model produces. For scientific applications, the ability to utilize a visualization system that allows the scientific to thoroughly examine the data is also advantageous. Several three-dimensional visualization systems are capable of meeting these requirements and are designed for use on the same computer workstations that run the mesoscale model.

The display of LAPS/RAMS model predictions at FSL is accomplished using the three-dimensional Application Visualization System (AVS) software package. A variety of volume, image, and line graphics can be produced using a combination of AVS-provided modules and FSL-developed modules designed specifically for meteorological display applications. Three model forecast products are generated routinely for display at the daily weather briefing. First is a forecast sounding of temperature, dew point, and wind for the model grid point closest to Boulder, Colorado. Second is a surface product that displays a color-enhanced image of low-level (146 m AGL) forecast temperature, contours of low-level forecast potential temperature, and low-level forecast wind barbs at every other model grid point. The final product is a three-dimensional view of the second product with clouds represented by a volume rendering of the region containing model-predicted cloud water. Animation capabilities provide a visual loop of

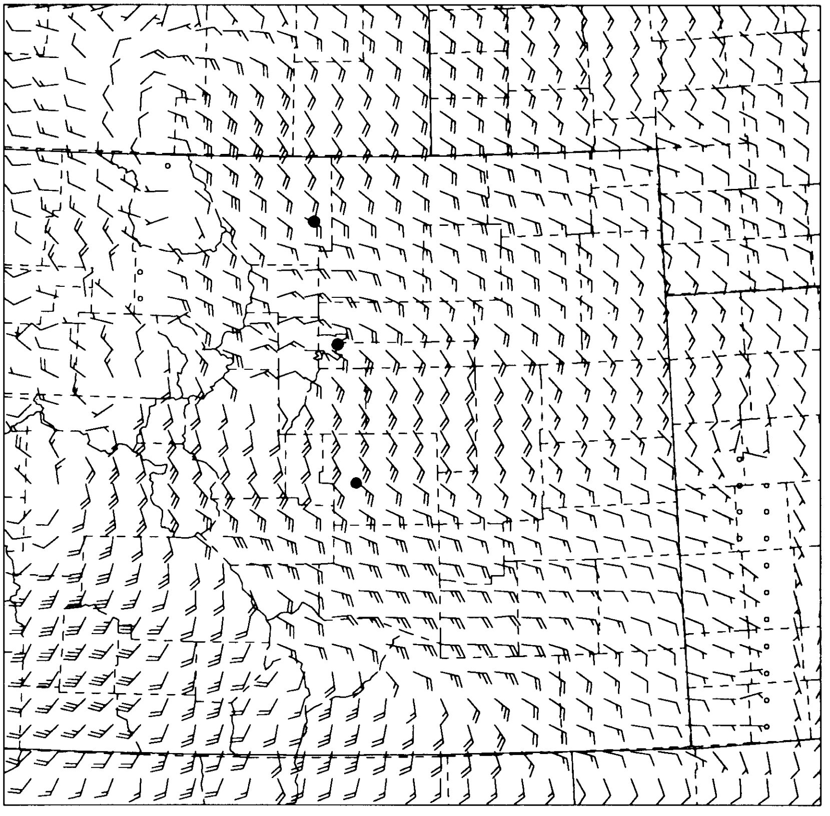

Fig. 2. LAPS/RAMS low-level (146 m AGL) wind (m s^{-1}) prediction from the 9-h forecast valid at 2100 UTC 11 August 1994. Wind barbs (one full flag = 5 m s^{-1}) are displayed at every other grid point. Solid dots indicate the locations of Fort Collins, Denver, and Colorado Springs, from north to south.

each forecast product at 1-h time increments from the analysis through the 12-h prediction.

Fig. 2 is a partial, black and white representation of the surface product showing low-level predicted winds from the 9-h RAMS forecast valid at 2100 UTC 11 August 1994. Wind barbs are plotted at every other model grid point (i.e., every 20 km). The example surface product provides an indication of the meso-β-scale circulation types that can be resolved. For example, when southerly flow passes over the elevated west-east terrain between Denver (DEN) and Colorado Springs (COS), a lee side cyclonic circulation, known as the Denver cyclone (e.g., Crook et al., 1990), may form, depending on the Froude number of the atmosphere. The RAMS forecast successfully resolved the cyclonic turning of the winds in the Denver area and suggested the development of a convergence zone to the southwest of Denver. This convergence zone is often a focus for convective development, and indeed heavy thunderstorms were observed in this region during the afternoon of 11 August.

A black and white representation of the three-dimensional cloud product from the same 9-h RAMS forecast is displayed in Fig. 3. Wind barbs have been removed to reduce clutter in this illustration. Clouds are represented by depicting a volume rendering of model-predicted liquid cloud water. In this example, convective clouds are indicated over the higher mountainous terrain and over the low-level convergence zone southwest of Denver. Higher forecast clouds, representative of cirrus, are depicted over the southeast portion

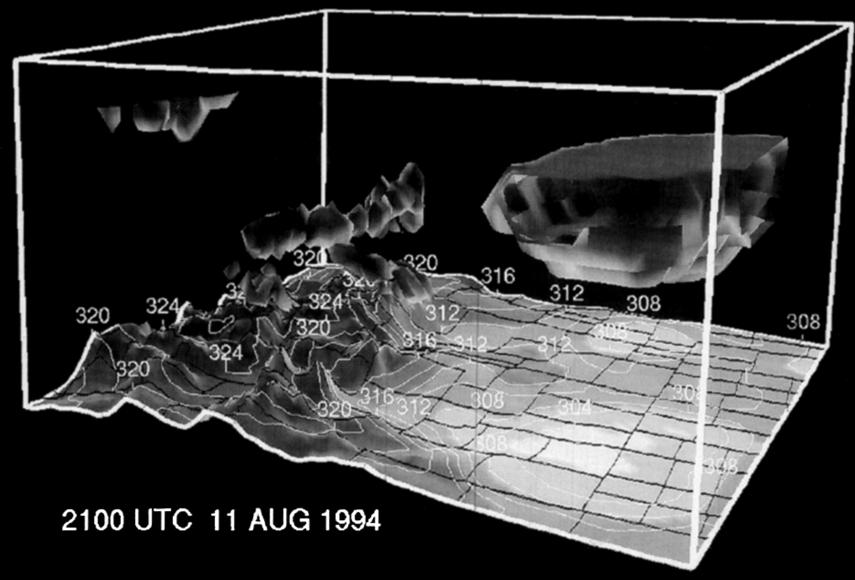

Fig. 3. Black and white representation of the operational three-dimensional cloud product from the same 9-h forecast as illustrated in Fig. 2. Clouds are represented through a volume rendering of model-predicted cloud liquid water. Surface shading and contours represent the RAMS low-level (146 m AGL) prediction of potential temperature (K).

of the model domain. The surface shading and contours represent the low-level potential temperature forecast. Higher potential temperatures are indicated over the mountains while lower potential temperatures are depicted in the southeast, which results from decreased incoming solar radiation beneath the high clouds.

A variety of other products can be generated interactively by the user (e.g., vertical cross sections and three-dimensional volume renderings of derived fields) and the user can manipulate the products by using the zoom, roam, and tilt capabilities of AVS. The ability to combine observations and model output on the same display is also extremely helpful. In addition to providing forecast guidance to the operational meteorologist, the visualization of model output is particularly useful for qualitative model evaluation and the development of conceptual models.

3. Model evaluation

The objectives of the LAPS/RAMS model evaluation are twofold. First is to establish a statistical baseline by which potential improvements to the model can be measured. Second is to compare the LAPS/RAMS forecast accuracy with currently available operational models to determine if the mesoscale model can provide valuable guidance beyond that provided by the national domain models. This paper concentrates on results related to the first objective. As a more statistically significant database is compiled over time, the second objective will be thoroughly addressed in the literature. Model validation is attempted through two approaches: qualitative and quantitative.

3.1. *Qualitative*

The qualitative model evaluation applies the meteorologists' analysis skills and experience with mesoscale weather phenomena to subjectively compare model predictions with physical observations and other visual accounts (e.g., human observations and media reports) of the weather. Although not as rigid as a quantitative approach, the qualitative evaluation can ascertain the existence of particular features (e.g., terrain-forced wind patterns) within the model predictions and is useful for subjective comparison with other model output.

A large portion of the qualitative model evaluation is accomplished through the routine display of the three operational LAPS/RAMS model products at the FSL daily weather briefing. The weather briefing is a useful two-way interaction between the LAPS/RAMS developers and other FSL scientists. Through this exposure, the model forecasts have shown an excellent ability to successfully predict mesoscale, often terrain-forced, circulations. Several examples of the terrain-forced circulations include the Denver cyclone (e.g., Fig. 2); an anticyclonic circulation, known as the Longmont anticyclone (Young and Johnson, 1984), that forms in the lee of the west-to-east elevated Cheyenne Ridge located near Cheyenne, Wyoming (CYS, Fig. 1); a variety of upslope flows; and flow patterns that result from differential heating between the mountains and plains.

During the summer, the 10-km horizontal grid interval is still insufficient to fully resolve convection, but the LAPS/RAMS forecasts have predicted well the location and time of convective initiation (e.g., Fig. 3). Mesoscale detail in the low-level thermal field is possible because of the dense automated surface observation network utilized by the initial analyses and the presence of cloud water in the model. Furthermore, the improved representation of topography that results from using the 10-km horizontal grid contributes significantly to the successful prediction of these features. The direct initialization of model cloud water from the LAPS analyses suggests an improved prediction of clouds, especially during the first 3 h of forecast, when subjectively compared with satellite imagery. The predictions have improved the physical understanding of terrain-forced weather and have provided spatial detail greater than previously possible.

3.2. *Quantitative*

Quantitative model validation is currently performed automatically on a variety of surface variables. Temperature, moisture, and wind observations are available from the 22-station FSL mesonet and from up to 51 surface aviation observation (SAO) locations. Model output is interpolated to the surface observation locations using an overlapping quadratics scheme. Because differences exist between the low-level model height (146 m AGL) and surface observation elevation, several adjustments are made to the interpolated model output. Similarity theory (Louis, 1979) is used to adjust model temperatures and wind speeds by factors derived from a logarithmic wind profile using the lowest above-ground model level of 146 m for temperature and wind, a surface temperature observation level of 1.5 m, a surface wind observation level of 10 m, and the assigned model surface roughness value of 0.05 m. An additional adjustment to the model temperature using a standard lapse rate of $-6.5\ \mathrm{K\ km^{-1}}$ is made to account for any difference between the model terrain height and the surface elevation at the observation location. No adjustments are made to the model mixing ratio variable. Bias and RMS statistics are computed using every location where surface data are available. Spatial and temporal quality control of the observations is completed by the LAPS operational system.

An example of the quantitative hourly bias and RMS statistics from the LAPS/RAMS real-time system is shown in Fig. 4. The results are from the same case day, 11 August 1994, as illustrated in Figs. 2, 3. These results are representative of the long-term statistics that are currently being compiled. A long-term statistically significant model evaluation will be discussed in the future. Several features are, however, evident in this example that are common in most of the real-time forecasts. In general, the forecasts are quite good through 6 h; then there is a steady degradation in quality with time as indicated by the RMS results. Adverse effects from the lateral boundary condition very likely contributed to these observations. A nested-grid configuration, which displaces the lateral boundary effects away from the area of interest, may help to alleviate this problem and is currently being tested (Schmidt et al., 1994).

Precursory statistical results compiled thus far suggest that the LAPS/RAMS wind predictions show the greatest additional value when compared with other model forecasts. The improved representation of topography in the 10-km-grid-interval LAPS/RAMS and additional local surface data sources available to LAPS are likely contributors to the improvements. The surface temperature results have thus far showed the least amount of additional value. Areas of current research to improve the surface temperature forecast include the inclusion of model vegetation, an improved

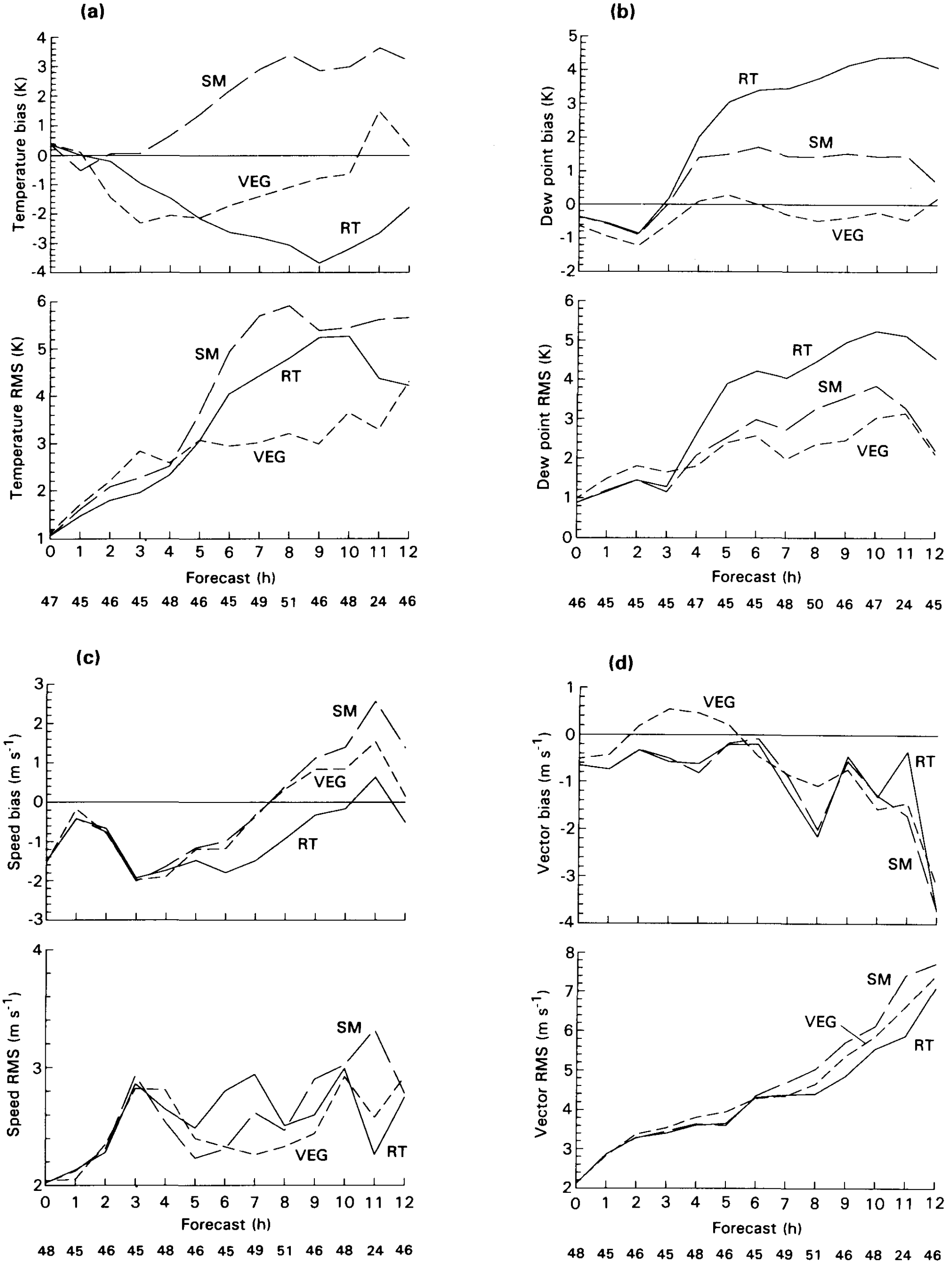

Fig. 4. Hourly bias (top) and RMS differences (bottom) of (a) temperature (K), (b) dew point (K), (c) wind speed (m s^{-1}), and (d) wind vector difference (m s^{-1}) for the 11 August 1994 LAPS/RAMS prediction compared with surface observations. Differences are computed by subtracting the observations from RAMS. RT is model results from the real-time operational forecast; SM, model results using a nonhomogeneous soil moisture initialization; and VEG, model results with vegetation. The number under each forecast time indicates the number of observations available for the comparison computations.

atmospheric radiation scheme, and the explicit initialization of soil temperature and moisture.

Upper air validation of LAPS/RAMS has been mostly confined to subjective methods. A qualitative comparison of model output to wind profiler data has shown excellent agreement. The model forecasts have been particularly good at defining various wind regimes in the vertical and with time. An upper air quantitative comparison to gridded analyses has been completed on several case studies (Snook, 1993; Snook and Pielke, 1995). The results thus far have been unable to show any significant improvement over the larger domain forecast models. This result may be due to the sparsity of upper air observations (e.g., only one rawinsonde exists in the LAPS/RAMS domain), which are insufficient to properly validate high-resolution mesoscale model output.

4. Future directions

Results thus far suggest that the local-domain LAPS/RAMS system can provide valuable additional guidance to the currently available national-domain operational forecast systems. A variety of potential improvements to LAPS/RAMS still exist, however, that may provide additional benefits. For example, a newly released version of RAMS has reduced the compute time to 4 h to complete the 12 h forecast. Several techniques have shown merit when tested on case studies and are ready for operational implementation and evaluation as soon as inexpensive computer workstation resources improve at FSL. The potential and recently added improvements are: (1) soil moisture initialization, (2) model vegetation, (3) explicit microphysics, (4) a nested grid configuration, (5) four dimensional data assimilation, and (6) diabatic initialization.

4.1. Soil moisture initialization

A recent addition to the LAPS suite of products is an operational analysis of soil moisture that uses precipitation fields derived in part from Doppler radar reflectivity data. The explicit initialization of soil moisture was added to the LAPS/RAMS real-time system on 11 August 1994. Statistical results from the 11 August case (Fig. 4) indicate that the addition of soil moisture initialization has improved the prediction of low-level dew point, although improvements in temperature are not noted. These trends will be followed over time and reported on in the future.

4.2. Model vegetation

The option to utilize model vegetation has been recently added to the RAMS model. Results from the 11 August 1994 case with model vegetation included are shown in Fig. 4. Model vegetation type was specified as crop/mixed farming for model elevations below 1750 m, evergreen needle-leaf tree for model elevations between 1750 and 3500 m, and tundra for model elevations above 3500 m. Case results (e.g., 11 August 1994, Fig. 4) suggest that the inclusion of model vegetation can significantly improve the temperature and dew point forecasts, while the wind predictions remain essentially unaffected. Inclusion of the model vegetation into the real-time LAPS/RAMS system is planned for the near future. A recently acquired US Geological Survey dataset of climatology-based vegetation type (Loveland et al., 1991) will also be incorporated in place of the current elevation-based scheme.

4.3. Explicit microphysics

The inclusion of RAMS explicit microphysics (Flatau et al., 1989) has been evaluated for several case studies (Snook, 1993; Snook and Pielke, 1995). The case study results show that the LAPS/RAMS precipitation forecasts can add a significant amount of mesoscale detail to the national-domain operational predictions. The ability to detect mesoscale bands of heavy winter precipitation has been particularly useful. Furthermore, the prediction of microphysical species enhances the ability to forecast a variety of weather phenomena including parameters that have been traditionally difficult to predict such as visibility, cloud ceiling, and icing threat. The current version of RAMS microphysics is too expensive to run operationally. However, a doubling of computer resources and a more efficient microphysical scheme are expected in the near future, which will allow explicit microphysics to be included in the operational LAPS/RAMS.

4.4. Nested grid configuration

The current 600×600 km LAPS/RAMS Colorado domain has provided a basis for testing many of the existing and new model features in an operational environment. The domain is, however, too small in that specified boundary conditions quickly impact the interior solution in the region of interest. One solution is to simply increase the size of the analysis domain, but this approach may be limited by data availability and perhaps computer resources available at the local weather forecast office. To address these problems, a nested version of the model, developed at CSU and modified at FSL, that accommodates a variety of larger domain analyses and forecasts (e.g., NMC products) is being tested in which each grid can be assigned data from an independent analysis or forecast. The approach is to displace the lateral boundary well away from the region of interest by using an outer grid with relatively coarse resolution while attempting to retain any benefits that can be derived from initializing the inner grid with a high resolution analysis. A configuration being tested consists of three grids with NMC model analysis and forecast data specified on the outer two grids and the LAPS analyses on the inner most grid. A 3-to-1 nest ratio is used between each grid to vary the horizontal grid spacing from 10 km on the interior grid to 90 km on the coarse grid.

4.5. *Four-dimensional data assimilation*

An intermittent four-dimensional data assimilation (4DDA) system has been developed to combine the meso-β-scale LAPS analyses and the RAMS model forecasts (Cram et al., 1993), and is currently being tested. The model is used in a 4DDA mode in conjunction with the LAPS analysis package to produce more detailed analyses. The original LAPS package uses first-guess fields from the FSL Mesoscale Analysis and Prediction System (Benjamin et al., 1991; Smith and Benjamin, 1993), currently run on a grid with 60-km spacing. The intermittent 4DDA scheme provides LAPS with first-guess fields from a model run with the same 10-km grid spacing as the LAPS package. In addition, 4DDA nudging schemes are being tested.

4.6. *Diabatic initialization*

Experiments are being conducted to initialize RAMS with LAPS meso-β-scale cloud analyses (Cram and Albers, 1994). A requirement for the real-time and 4dda systems is accurate short-term (1–3 h) forecasts. In an effort to meet this requirement, the unique cloud and precipitation information available from LAPS (Albers et al., 1994) is being incorporated into the model initialization. A variety of initialization experiments have been conducted with varying degrees of complexity, ranging from simple insertions of the cloud condensate analyses into the model to 4dda uses of the fractional cloud cover analyses and inferred cloud vertical motions. Plans to include the LAPS precipitation analyses with consistent vertical latent heating profiles are also being considered.

5. Summary

The LAPS/RAMS operational system is an analysis and prediction scheme configured to provide short-range (0–12 h) forecasts for a local domain approximately equal to a local weather offices' area of responsibility. The real-time system is aimed at providing valuable local-scale guidance to the individual weather forecast office beyond that provided by the currently available national-domain operational products. A unique aspect of the system is that RAMS mesoscale forecast model initialization is provided by comparable high-resolution (10-km horizontal grid interval) LAPS operational analyses. The LAPS/RAMS system is designed to take advantage of all data sources available to the local weather office. The system has three components: (1) operational LAPS analyses, (2) real-time RAMS predictions, and (3) visualization of model output. The primary design consideration is that all three components can be performed efficiently on an affordable computer workstation platform.

FSL has been running the LAPS/RAMS system on a daily basis for nearly 1 year. The short-range forecasts have shown the ability to resolve meso-β-scale, often terrain-forced, flow patterns (e.g., the Denver cyclone and the Longmont anticyclone). The capability to add mesoscale detail to the thermal and moisture fields has been demonstrated. The addition of a soil moisture initialization and model vegetation has generated improved low-level moisture predictions. Although the 10-km grid interval is insufficient for explicitly resolving convection, the predictions are capable of determining areas of convective initiation. Forecast improvement by LAPS/RAMS appears to be mostly due to the additional surface observations available to the LAPS analysis scheme and to the improved representation of topography that is allowed by utilizing the 10-km horizontal grid spacing. The three-dimensional visualization of the model output allows the operational forecaster to rapidly peruse the enormous amounts of data and improves the meteorologist's ability to comprehend and conceptualize each case event.

The LAPS/RAMS system demonstrates the capability to run an operational analysis, prediction, and visualization system in the local weather office on an affordable computer workstation that can provide valuable guidance beyond that provided by currently available national-domain products. Significant improvements to the operational system, such as explicit microphysics, larger nested-grid configurations, diabatic initialization, and 4DDA are on the horizon as the power of the affordable computer workstations increases. The rapid advances in computer workstation technology should allow the generation of valuable meso-γ-scale forecast guidance that will be useful for the prediction of convective initiation, detailed cold weather precipitation forecasts, and other high resolution features.

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