8.1 # CHALLENGES ASSOCIATED WITH MAKING QUALITY, AUTOMATED, HIGHWAY-SCALE, WINTER WEATHER PREDICTIONS

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1. INTRODUCTION

Recently, development of the NCAR Road Weather Forecast System (RWFS, Myers et. al, 2001) has begun. RWFS is intended to provide winter weather forecasts that are both highly automated and tailored to the specific needs of state Departments of Transportation (DOTs), with the eventual goal of being integrated with a support system for road maintenance decisions, such as chemical choices and crew scheduling. Such forecasts are required to be made on scales on the order of a few kilometers, presenting several large challenges, meteorologically. Both surface observations (e.g. METARs) and readily available forecast models (e.g. NCEP's Eta and Aviation [AVN]) typically provide information on scales of tens to hundreds of kilometers. RWFS currently handles this mismatch in scale using interpolation and extrapolation.

While the interpolation and extrapolation approach may be adequate for some weather features, such as surface air temperature in regions of flat terrain, it may have a difficult time handling some nuances that are critical to the occurrence of hazardous conditions along a roadway, especially in steep terrain. These include 1) fine-scale topography (including which way the road faces, e.g. north versus south side of a hill), 2) location relative to trees, buildings and water bodies, 3) wind exposure, and 4) whether or not the road surface is on a bridge. This paper will discuss some of the challenges of applying interpolation and extrapolation techniques to AVN and Eta model output and surface observations.

2. DOMAIN AND HIGHWAY OF INTEREST

During the winter of 2000, an initial version of the NCAR Road Weather Forecast System (RWFS) was applied to a series of interstate highways in the western United States as a demonstration of its most rudimentary capabilities. The domain chosen included both the gently sloping terrain of Kansas and Nebraska as well as the rather steep and/or varied terrain of Colorado, Utah, Wyoming and Nevada. Major interstate highways within this domain include I-70, I-80, I-15 and I-25. The portions of I-70 in Colorado and Kansas cross both the steepest and some of the most gentle terrain within the 6-state region, with elevations ranging from ~300m to ~3300m MSL. Widely varying weather conditions are found along this stretch of highway during winter storms, including heavy snow, high winds, drifting snow, freezing precipitation, freezing fog, and rain. Conditions sometimes also vary dramatically on relatively small scales. Thus, I-70 can be used to nicely demonstrate road weather forecasting issues.

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3. INTERPOLATION & EXTRAPOLATION

The RWFS uses bilinear interpolation to make forecasts at locations along highways where observations are not available. For the winter of 2000-2001, highway locations were spaced roughly 10-20km apart. In an effort to examine the importance of interpolation to forecasts at these points, the location of the nearest Eta and AVN model grid-points and nearest regularly available METARs was determined. Note that the full-blown RWFS employs information from these sources in combination with many others (e.g. dynamic MOS, mesonets) and combines them using complex regression schemes (Myers et al 2001, Young 2001). The discussion presented here is more general in nature and does not imply that these errors will directly affect output from the RWFS.

3.1 AVN and Eta Models

Figure 1 shows the elevation of the highway grid points along I-70 from the Utah/Colorado border to the Kansas/Missouri border, and demonstrates the differences in elevation between highway locations and the AVN and Eta model grid points and METAR sites closest to them. The AVN grid used in the RWFS has spacing of 1-degree latitude by 1-degree longitude. The highly smoothed topography in the coarse AVN model results in large elevation differences between the highway and the model "surface" across the steep terrain of Colorado. Elevation discrepancies commonly exceed 500m. The AVN topography is much higher than the real terrain along the Colorado "West Slope", between Grand Junction (GJT) and Rifle (RIL), and in the "Front Range" area to the west of Denver, where the terrain slopes steeply. On the flip side, the highly smoothed model topography is 400-600m too low in the highest terrain of Colorado, at Vail and Loveland Passes. The AVN topography gradually approaches the actual height of the highway toward the Kansas border, and matches it within 100m across most of Kansas.

The topography in the Eta model more closely represents the actual terrain of the Rockies, but still has differences which exceed 400m to the west of the Front Range. It tends to follow the peaks of the terrain of the

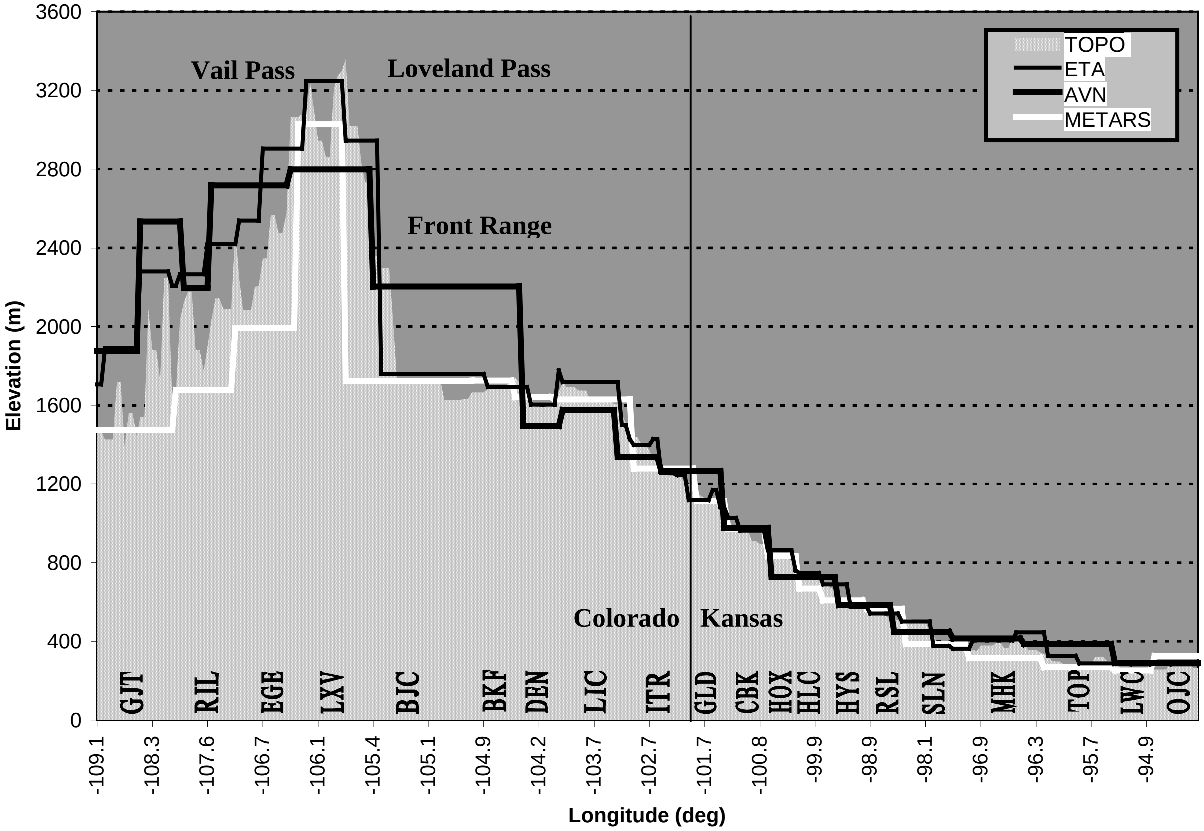

Fig. 1. East-west topographic cross-section of I-70 from the Utah-Colorado border (left) to the Kansas-Missouri border (right). Topography is indicated in light gray hatching, elevation of nearest Eta and AVN model grid points and nearest surface stations are indicated in thin and thick black lines and white lines, respectively. Three-letter station IDs for nearest sites are indicated at the bottom of the chart.

West Slope, but only slightly undercuts the highest passes along I-70. The steepness of the Front Range is represented nicely, considering the ~40km grid spacing of the model. This is likely due to the step-wise design of the model. Terrain is handled well to the east of the Front Range, with differences of <200m to the east of Limon CO (LIC).

The vertical differences between the model's lowest level are important because data are extrapolated from this height to the height of the topography. A good example of this is the determination of surface temperature (T_{sfc}) used in the default (i.e. backup) system of equations used in RWFS when the standard regression technique cannot be applied. For the winter 2000-2001 season, these more basic equations were used to allow for RWFS demonstration under short time constraints. When the lowest level of the model is 500m above the highway, then T_{sfc} of the highway must be determined by extrapolating T_{sfc} from the model down to highway level. In the RWFS, this is done using the thermodynamic profile of the lower portion of the boundary layer. If the profile is dry-adiabatic, as it might be on a sunny afternoon, then that dT/dz is used, providing a T_{sfc} roughly 5^{o}C warmer than the T at the base of the model. If the profile is isothermal, as it might be early on a winter morning, then T_{sfc} is roughly equal to T at the bottom of the model. The regression techniques normally employed by the RWFS use a more sophisticated approach to the determination of T_{sfc}.

Another important issue is the horizontal distance from highway points to the nearest model grid points. As one would expect, the distance to the nearest model grid point is typically significantly smaller for the Eta (~10-20km) than for the AVN (~20-45km). Thus, interpolation of Eta output is frequently over a shorter distance than it is for AVN output. Whether or not this would result in better overall results from Eta output is not clear. However, the superior horizontal resolution and more representative topography in the Eta make it likely to perform better in areas with sharp gradients in topography, and thus, sharp gradients in meteorological features.

The discussion here focused on a relatively simple variable, T_{sfc}. Other variables that are equally, if not more important to highway meteorology, such as the location, timing, intensity and type of precipitation, wind speed and direction and solar insolation will be much more difficult to handle. This is especially true in steep terrain, where grid-box averaged values may not be representative of the fine scale variations present. Upwind and downwind sides of mountains can have a dramatic effect on the amount of precipitation, and these effects may change with a simple shift in the wind.

While the models may generally perform well with regard to synoptic-scale features, temperatures, winds and precipitation patterns, their skill is notoriously poor in mountainous regions. The effects are likely to be exacerbated by the attempt to extract sub-grid-scale information, such as is needed for highway-scale forecasts. Success is much more likely in areas with gentle terrain and which are less susceptible to regional (e.g. oceans, lakes, basins), mesoscale (e.g. major river valleys, urban heat islands) and local-scale (e.g. drainage basins) effects. "Smart" systems like RWFS may be able to account for some of these important effects by recognizing their presence through situational biases and weighting schemes.

3.2 Surface Observations

Surface stations may include those from standard National Weather Service (NWS) sites (METARs) and local mesonets. METARs often provide the most reliable information, overall, thanks to high standards for instrumentation and regular upkeep, since they are critical to aviation needs as well as NWS models and local forecasters. They also are typically the only stations to report important phenomena such as precipitation occurrence and type, ceiling, visibility, obscurations (e.g. fog), wind gusts, etc.

The full-blown version of RWFS uses information from nearby surface stations in combination with model output to improve short time-scale forecasts. They also supply "truth" data that are used to determine the weights of different forecast input fields, site-by-site. Thus, the locations and representativeness of nearby surface observations may be important to the quality of RWFS forecasts.

Looking at the relative altitudes of highway forecast points and the nearest surface observations, we again see that they are quite close to one another to the east of Denver, but sometimes quite different in the mountainous terrain. One particularly troublesome area is the Front Range, where the nearest observations are from either Broomfield-Jefferson County Airport (BJC) or Leadville (LXV), which are at 1724 and 3028m elevation, respectively. The Front Range spans this range of elevations, and some parts of it are more than 1km above the nearest station (e.g. closest to Loveland Pass is BJC, dz~1600m). Clearly, the weather at BJC is not representative of that which occurs at Loveland Pass. The RWFS applies an intelligent weighting scheme to the surface observations, which draws from those that are most representative. In this case, information from LXV is likely to be used much more heavily than that from BJC. Neither station may be truly representative of such a unique location.

Distance from the nearest surface station is an issue for surface observations, just as it was for model output. Of course, surface observations are not regularly spaced, like model grids, so distance can vary greatly across the domain. Areas around large cities (e.g. Denver) tend to have a relatively high density of surface stations. The Front Range discussion above demonstrates the relative sparsity of stations within the mountains. Still, observations are available from stations within ~45km across most of the length of I-70 in Colorado and Kansas. Some other portions of the United States that may suffer from the data issues discussed here include data-sparse areas with sharp terrain and/or large nearby water bodies (e.g. other parts of the West, Alaska, the Cascades, the Appalachians, and Canada.

4. SUMMARY

Overall, there is fairly good coverage of surface data and model output across the United States. However, it is quite evident that the chances for success for an automated system, even one that used well-conceived interpolation, extrapolation and weighting schemes, such as RWFS, are much better in areas of gently sloping terrain. The inclusion of supplemental observations from mesonetworks, including those that are run by state DOTs, can provide more frequent observations of some key parameters, both spatially and temporally. These observations may include air temperature, winds, precipitation occurrence and even road temperatures. They can be quite useful for improving forecasts and verification, and should be shared with the meteorological community. Much care must be used when applying these data, however, as some mesonetworks are not well maintained or calibrated, and may have siting issues that affect their representativeness (e.g. over- or under-exposed). Bad information may sometimes be worse than no information.

5. REFERENCES

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