CHAPTER 3

DESCRIPTION OF MODELS

Observed precipitation from the IPEX data set is used to assess the performance of three models with different resolutions and physics. Two of these models, the AVN and the Eta, are run operationally at NCEP. These models are used extensively by forecasters at the SLC NWSFO and were important in providing guidance for forecasters during IPEX. The third model, the PSU/NCAR MM5, is run in real time at the University of Utah, and its output is also transmitted to the SLC NWSFO to supplement the operational models in the region. Brief descriptions of these models as they were configured during February 2000 are given in this chapter.

Aviation

The AVN is NCEP's short-range global forecast model run (Kanamitsu 1989; Kalnay and Kanamitsu 1990). The AVN forecasts are produced from a primitive-equation global spectral model, the same as that used for NCEP's Medium Range Forecast (MRF). The spectral method, in which the various fields are represented by a set of spherical functions, has several advantages over the grid point method used in most models, including the elimination of spatial truncation error, the treatment of singular pole points, and the efficiency of computations (Kanamitsu 1989).

The AVN has a spectral 170-wave triangular truncation (T170) resolution, which corresponds to a grid spacing of approximately 80 km. The terrain-following sigma coordinate is used in the vertical. There are 42 vertical layers between the surface and 2 hPa. Topography is obtained from the United States Navy 10-min resolution surface elevation data set and is area-averaged on a T126 resolution Gaussian grid. Figure 3.1 shows the grid point locations of the output obtained in real time and the model terrain for the Salt Lake City area. Because of the relatively low resolution of the model output, only four grid points are located in the region. Furthermore, the complex terrain of the area is not well represented, with a terrain height gradient of less than 600 m from the northwestern part of the Great Salt Lake to the Wasatch Mountains.

During IPEX, the AVN was run out to 84 h four times per day. Initial conditions for the model are obtained from the Global Data Assimilation System (GDAS). The analysis is made by adding observational data to the 6-h forecast from the previous analysis using the spectral statistical interpolation (SSI) analysis scheme as described by Derber et al. (1991) and Parrish and Derber (1992). Because the analysis variables do not have to be the same as the observed variables, this system allows for the incorporation of non-traditional observations. Furthermore, the need to initialize the analysis is eliminated, because a globally-defined linear balance equation is imposed by the system.

The physical schemes used in the AVN are described in detail in the model documentation by the NMC Development Division (1988) and updated in a document by Hong (1999), which can be found on the World Wide Web at **http://sgi62.wwb.noaa.gov:8080/research/SONGYU/doc/physmrf1.htm**. The planetary boundary layer (PBL) parameterization, which is described by Hong and Pan (1996), is

Figure 3.1. Terrain and output grid point locations from the 003 grid of the AVN available in real time. Terrain heights (m) are shaded according to the scale at the bottom of the figure.

based on the nonlocal vertical diffusion scheme developed by Troen and Mahrt (1986). A two-layer soil model is used to compute surface temperatures and water content. Shortwave radiation is computed for multispectral bands, accounting for the interaction with carbon dioxide, ozone, water vapor, and aerosols, and is briefly described by Derber et al. (1998). The longwave radiation scheme is based on the work of Fels and Schwarzkopf (1975) and Schwarzkopf and Fels (1991). Precipitation in the AVN is produced from both large-scale condensation and convective processes.

Large-scale precipitation in the AVN is determined from the predicted specific humidity fields. Beginning with the uppermost moist layer and proceeding downward, the large-scale scheme checks for supersaturation one layer at a time. If a layer is supersaturated, it is brought down to saturation via condensation and latent heat release, with all of the condensed water becoming precipitation. Unsaturated layers are moistened by evaporation and cooling. Phase changes do not occur instantaneously, but rather depend on a parameterized drop size distribution, which is related to the fall speed of precipitation particles. Evaporation rate is thus higher for light precipitation and lower for heavy precipitation.

Convection in the AVN is parameterized using a mass flux scheme which is based on the Arakawa-Schubert (Arakawa and Schubert 1974) parameterization, as simplified by Grell (1993). Convection is triggered when the cloud work function, which is an integral measure of the buoyancy force in clouds, exceeds a certain threshold. The updraft originates at the level of maximum moist static energy between the surface and about 400 hPa. Convection is suppressed if the depth between the level of updraft origination and the level of free convection (LFC) exceeds 150 hPa. The cloud depth is the distance between the LFC and the level where a lifted parcel has less moist static energy than the environment. The deep convection scheme is utilized only for cloud depths greater than 250 hPa; otherwise, the nonprecipitating shallow convection scheme is used. If deep convection is determined to occur, the buoyancy of the column is modified toward equilibrium within a specified time scale, with effects due to both entrainment of air in the updraft and detrainment in the downdraft being considered. Precipitation is determined from the mass flux, with evaporative effects taken into account.

Eta

The Eta is NCEP's primary model for short-range regional prediction (Janjić 1990; Black 1994; Rogers et al. 1996). It is a hydrostatic, primitive-equation grid point model that is run on a domain covering the North American continent and adjacent waters. The model derives its name from its vertical coordinate. The eta coordinate was designed to reduce errors associated with computing the pressure gradient force, advection, and horizontal diffusion along steeply sloped terrain (Mesinger et al. 1988). In the eta coordinate, topography is represented by discrete steps whose tops coincide with the model's vertical levels. The height of the topography is determined for each grid box as described by Black (1994).

The Eta has been running operationally at NCEP since 1993. The version of the model used during IPEX had a horizontal grid spacing of 32 km. It had 45 vertical layers, with the highest resolution in the boundary layer and near the climatological position of the upper-level jet at around 250 hPa. The higher resolution of the Eta allows the topography to be better resolved than the AVN. Figure 3.2 shows the output grid points available from the real-time 32-km grid and the model terrain. Note that the terrain in the

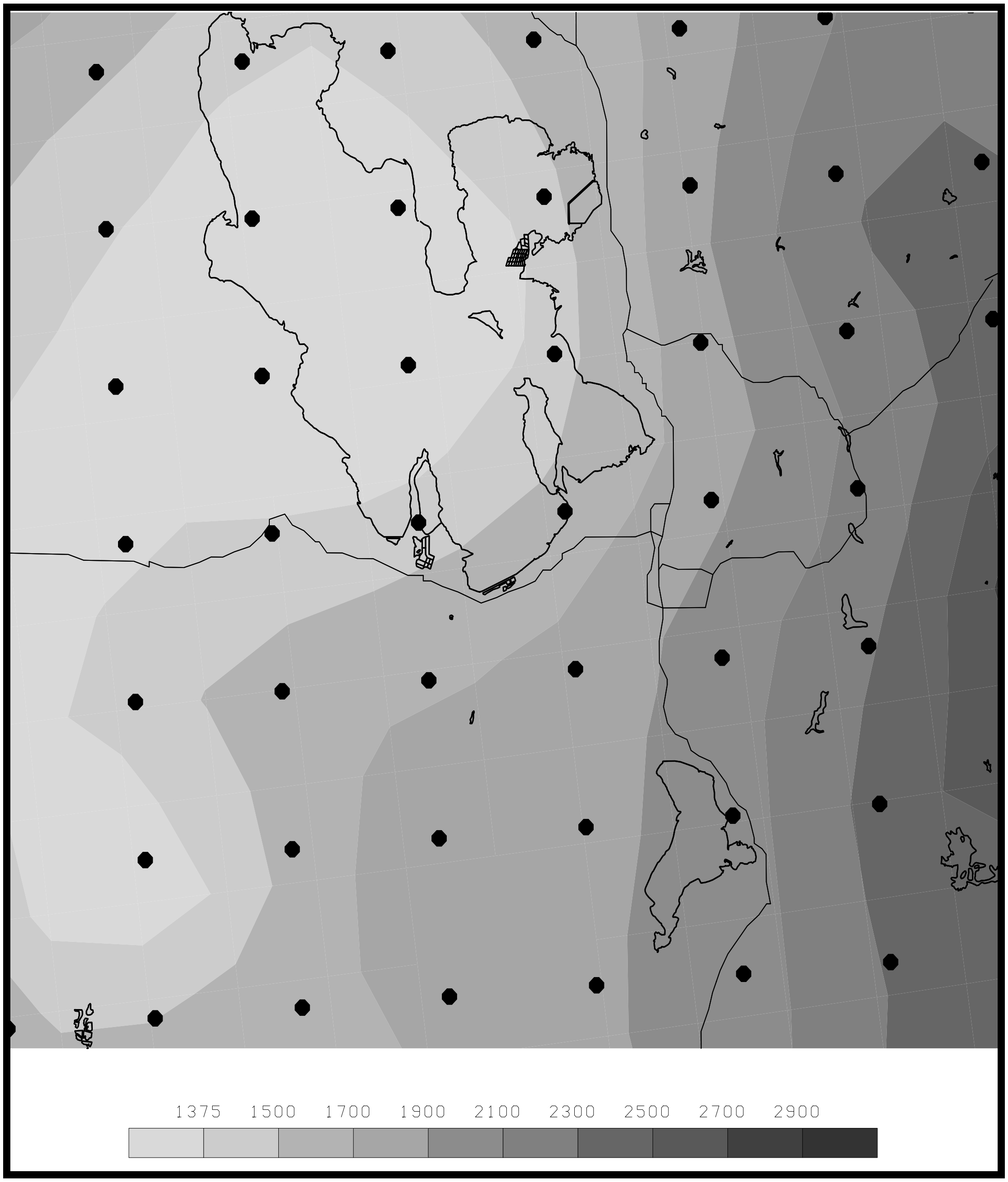

Figure 3.2. Terrain and output grid point locations from the 221 grid of the Eta available in real time. Terrain heights (m) are shaded according to the scale at the bottom of the figure.

figure is smoothed from the native model terrain. In the Eta, a minimum in terrain height is evident over a part of the Great Salt Lake and the desert to the west. The height gradient between the desert and the mountains is much larger than in the AVN, but the Salt Lake and Tooele Valleys remain unresolved.

During February 2000, the Eta was run four times per day out to 48 h. Initial conditions for the model are provided by the continuously-cycled Eta Data Assimilation System (EDAS) with boundary conditions determined from a 12-h forecast from the AVN. Interpolation of data is done using three-dimensional variational analysis (3DVAR) (Parrish et al. 1996), which is a modified version of the SSI technique used for the GDAS, with one major difference being that the error statistics are simulated in grid space rather than model space.

The Mellor-Yamada Level 2 turbulence closure scheme is used to parameterize exchanges between the surface and the lowest model layer, while the Level 2.5 model is used for exchanges in the free atmosphere (Mellor and Yamada 1974, 1982). Soil moisture is obtained from a four-layer model. The shortwave radiation scheme includes interactions with clouds and ozone, with the effects of aerosols also taken into account. Longwave radiation in the Eta is essentially the same as in the AVN. Precipitation in the Eta is determined from large-scale condensation as well as convective processes.

Large-scale precipitation is produced from an explicit cloud scheme as described by Zhao and Carr (1997) and Zhao et al. (1997). In this scheme, cloud water and ice mixing ratios are included in the model's prognostic equations. Condensation over land is allowed to occur at 75% relative humidity, while over water, the relative humidity threshold for condensation is 80%. Clouds produced by large-scale condensation consist entirely of liquid at temperatures above freezing and entirely of ice at temperatures below –15 ^{o}C; otherwise, the composition is determined by the cloud top temperature. Precipitation is determined from the cloud mixing ratio and can consist of rain or snow. Six major precipitation processes by which precipitation and clouds interact are considered in the parameterization, including autoconversion of cloud particles to rain and snow, collection of water droplets and ice particles, melting, and evaporation or sublimation. Precipitation is calculated downward from the cloud top by adding the precipitation produced at each level to the total precipitation calculated at the level above. Evaporation is taken into account whenever the relative humidity is below the values necessary for condensation to occur.

The convective parameterization used in the Eta model is a modified Betts-Miller-Janjić scheme (Betts 1986; Betts and Miller 1986; Janjić 1994). This is a convective adjustment scheme, which means that convection is simulated by nudging the temperature and moisture profiles toward a specified reference profile that has been observed in post-convective environments. Adjustment schemes are less sophisticated than mass flux schemes such as the one used in the AVN because they do not account for most of the physical processes associated with convection, but are more advantageous in the fact that they are less computationally intensive. The scheme has separate components for deep and shallow convection, but precipitation is produced only by the deep convection component. The scheme first finds the most unstable model level within the lowest 130 hPa, and then determines the LCL of a parcel lifted from that level. The cloud base is set as the model level just below the LCL, and the cloud top is set as the model level at or just below the equilibrium level. If the cloud depth is less than 10 hPa or less than two model layers deep, convection is not initiated. Deep convection occurs if the depth is greater than 290 hPa. Precipitation is calculated from the latent heat produced by the adjustment from the original profiles.

MM5

The MM5 research model has been running in real time at the University of Utah since 1996. The model originated at PSU in the 1970s but has been supported and further developed at NCAR. It is now widely used for research and regional prediction at a number of universities and other organizations. Running regional models such as the MM5 locally rather than depending on NCEP models has several advantages, including the availability of high-resolution output, the ability for users to select and experiment with different physical schemes, and the opportunity to assimilate observations from regional data networks (Mass and Kuo 1998). Thus, the model can be configured to best suit the needs and computational resources of the user. A description of the MM5 is provided by Grell et al. (1994).

The MM5 is a primitive-equation grid point model which uses the sigma coordinate in the vertical. The version of the model used during IPEX, version 2.11, can be run either hydrostatically or nonhydrostatically, and configurations such as the domain location and size, resolution, and physical package are user-defined. During IPEX, the MM5 was run twice daily at 0000 and 1200 UTC out to 36 h from a cold start using initial and boundary conditions from the Eta model analysis and forecasts. The nonhydrostatic version was used to limit errors in the pressure gradient force. The model domains consisted of a coarse outer region of 36-km grid spacing, which covered the western United States and the eastern Pacific, and an inner nest of 12-km grid spacing, which covered Utah and parts of the adjacent states. Both domains contained 27 vertical levels. Terrain heights are interpolated to the model grid points from a 10-min resolution data set for the outer domain and a 30-s resolution data set for the inner domain. Unlike the AVN or Eta, precipitation from the MM5 is available on the model's native grid rather than different output grids. The locations of the MM5's grid points are shown in Fig. 3.3. In the MM5, terrain is much better resolved than in the Eta, with the Salt Lake Valley becoming more evident, as well as local maxima in the terrain. However, the narrow Wasatch crest, especially to the north of Salt Lake City, the Tooele Valley, and the smaller valleys within the Wasatch remain unresolved.

Several options are available in the model for physical schemes such as radiation, PBL, ground temperature, explicit moisture, and convective parameterization. The University of Utah's version of the model employs the same boundary layer scheme used in the AVN, but ground temperatures are determined using a five-layer soil model. The radiation scheme, described by Dudhia (1989), accounts for longwave and shortwave interactions with the atmosphere, clouds, and the surface. Precipitation is produced from both grid-scale condensation and convection.

Grid-scale precipitation is determined from an explicit moisture scheme that includes the simple ice physics of Dudhia (1989). Clouds consist of liquid at temperatures above 0 ^{o}C, while ice phase processes occur below freezing. Unlike the scheme used in the Eta, no supercooled water is allowed to exist and ice melts immediately above freezing. Evaporation and sublimation are allowed to take place in subsaturated conditions. Cloud is converted to precipitation by autoconversion and accretion processes.

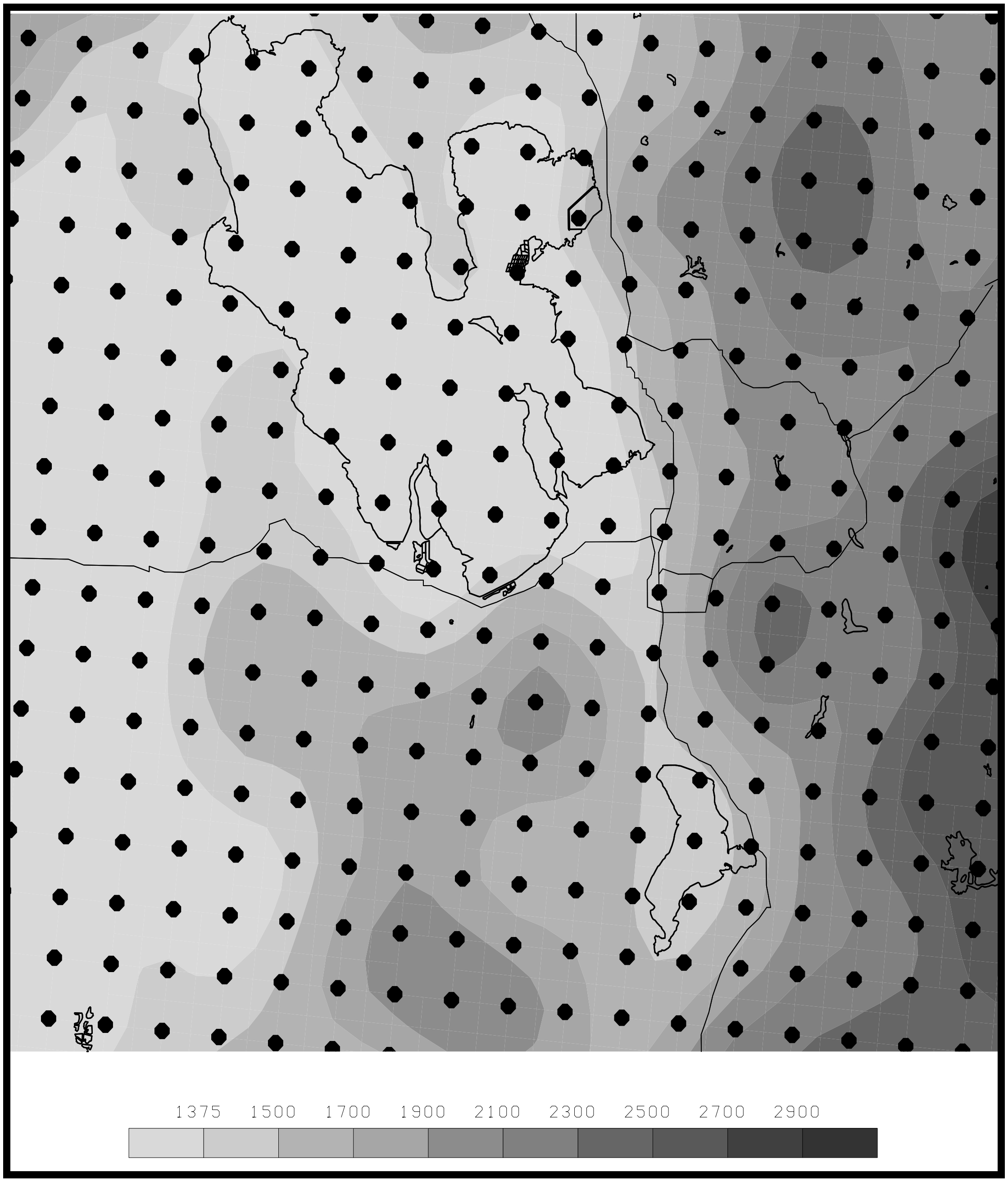

Figure 3.3. Terrain and grid point locations from the MM5. Terrain heights (m) are shaded according to the scale at the bottom of the figure.

Convection is parameterized using the Kain-Fritsch (Kain and Fritsch 1993) scheme, which is a modified version of the Fritsch-Chappell (Fritsch and Chappell 1980) cumulus parameterization for mesoscale models. This is a mass flux scheme in which an instantaneous value of instability is used to determine the possibility and intensity of convection. The scheme checks for buoyancy for each 100-hPa layer every 50 hPa up to the 600-700-hPa layer. If positive buoyancy is found below the 600-700-hPa layer, convection is permitted to occur, and the scheme then proceeds to remove the available buoyant energy within a specified time. An entraining-detraining plume model is used, which allows for buoyancy variations induced by mixing between various proportions of cloud and environmental air. Convective mixtures that remain positively buoyant in each model layer are allowed to continue rising while those that lose their buoyancy through evaporative cooling are detrained into the environment.

As described above, each of the models have significantly different characteristics. While the MM5 has the highest resolution, the Eta and AVN are more advantageous in that they use initial conditions from the same modeling system rather than relying on data from a different model, and their initialization spin-up includes data assimilation. The differences in resolution, physics, horizontal and vertical coordinates, and initialization procedures of the three models make it impossible to assume one model to be better than the others.