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# A Preliminary Description of Climatology in the Western United States

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ABSTRACT: We describe the climatology of the western United States as seen from two 1-month perspectives, January and July 1988, of the National Meteorological Center large-scale global analysis, the Colorado State University Regional Atmospheric Modeling System (RAMS), and various station observation sets. An advantage of the NMC analysis and the RAMS is that they provide a continuous field interpolation of the meteorological variables. It is more difficult to describe spatial meteorological fields from the available sparse station networks. We assess accuracy of the NMC analysis and RAMS by finding differences between the analysis, the model, and station values at the stations. From these comparisons, we find that RAMS has much more well-developed mesoscale circulation, especially in the surface wind field. However, RAMS climatological and transient fields do not appear to be substantially closer than the large-scale analysis to the station observations. The RAMS model does provide many other meteorological variables, such as precipitation, which are not readily available from the archives of the global analysis. Thus, RAMS could, at the least, be a tool to augment the NMC large-scale analyses.

In a previous paper, Roads *et al* (1991) discussed the forecast accuracy of the National Meteorological Center's medium-range forecasts of near-surface meteorological elements such as temperature, relative humidity, and wind speed in terms of the NMC global analysis. Although these global analyses are most applicable for global perspectives, we are interested in more regional scales. Here, we expect the large-scale analyses to only grossly simulate various regional effects, especially in regions that are strongly influenced by topography. This brings up the question as to just how useful or accurate the large-scale analysis is at regional scales.

At regional scales, a mesoscale model, which is overlying mesoscale topography and which is forced at the boundary and initialized with a large-scale analysis, could provide an even better representation of the regional climate. Feasibility of the regional modeling approach has recently been demonstrated for the western United States by Giorgi and Bates (1989) using the Penn State/NCAR mesoscale model. A number of papers also discuss how we might develop a regional assimilation with a limited-area model and other observations, such as various station observations (see, *eg*, Stauffer and Seaman 1990; Stauffer *et al* 1991). Development of this kind of capability will become even more important as we begin to assimilate some of the observations associated with the modernized weather service systems.

In a similar manner, a regional model initialized and forced at the horizontal boundaries by general circulation model (GCM) variables (see, *eg*, Dickinson *et al* 1989; Giorgi 1990) might provide more detailed spatial

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representation of climatic change than is available from statistical interpolations (*eg*, Wigley *et al* 1990) or simple linear interpolations of the large-scale GCM output to the regional scale. We must be worried, though, that a regional climatology that is statistically or dynamically interpolated from an inaccurate large-scale climatology may not be any closer to the truth than a regional climatology that is linearly interpolated from the inaccurate large-scale climatology. That is, even though detailed regional climatology may be different from the large-scale coarse climatology, we do not know if this difference makes it any better.

Therefore, to assess the accuracy of the NMC analysis and to test the regional model interpolation hypotheses, we examine here a regional climatology from the perspective of the large-scale NMC analysis and from the perspective of the large-scale NMC analyses that is filtered through the regional modeling system of the CSU RAMS mesoscale model in comparison to individual station observations. In particular, we examine how well the model can simulate temperature, relative humidity, wind, and precipitation at individual stations. We examine the climatological spatial variations as well as the day-to-day transient variations.

## Analysis

We use the NMC global analysis on a 2.5-degree global grid (available from the National Center for Atmospheric Research) and on constant pressure surfaces at 1000, 850, 700, 500, 400, 300, 250, 200, 150, 100, 70 mbs. Variables in this analysis are virtual temperature, relative humidity, wind speed and direction, geopotential, and surface pressure (see Roads *et al* 1992). Over the region of interest, there are only 117 analysis grid points (denoted by X in Figure 1a). This large-scale analysis is horizontally interpolated to the higher resolution model grid using bilinear interpolation. The values on the horizontal pressure grid are then interpolated in the vertical to the staggered vertical grid of the RAMS model (described below), as well as to the surface, as well as to constant height levels (every 500 meters) above sea-level.

## Model

As described by Bossert *et al* (1992 a, b, c), the CSU-RAMS mesoscale model is a highly flexible modeling system capable of simulating a wide variety of mesoscale phenomena, including regional climatology. Recent model developments are described in Tremback *et al* (1986); Cotton *et al* (1988); Tremback (1990); and Tripoli (1992). The model framework for the present study incorporates a 3-dimensional, terrain-following, hydrostatic version of the code. The domain's topography, shown in Figure 1, is derived from a 5-minute northwestern hemispheric topographic data-set. A silhouette averaging scheme is used to preserve realistic topography heights. These height data are then interpolated to the model grid described below.

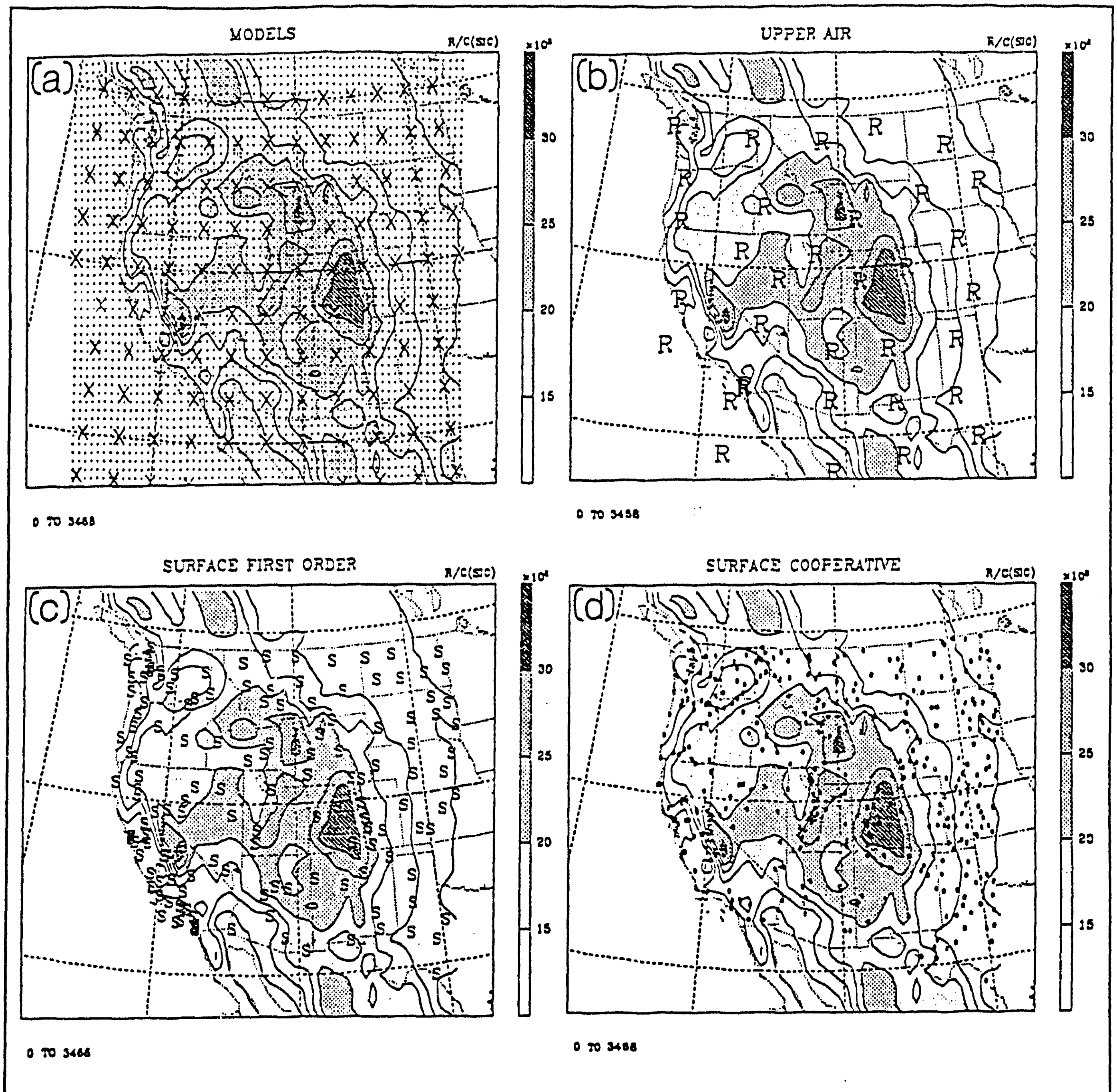


Figure 1. Topography, grid point, and station locations. Topography shown with 500-meter interval. Only areas with elevations higher than 1500 meters are shaded.
(a) Analysis grid points are shown by X. Model grid points are shown by dots.
(b) Rawinsonde station locations are shown by R.
(c) First order summary of day station locations are shown by S.
(d) Cooperative station locations are shown by o.

The topography is smoothed to only contain wavelengths greater than or equal to 4 grid points. In the vertical, we use 21 staggered levels, with a resolution of 300 meters near the surface and 1000 meters at the top of the model (Figure 2). The model's geographical domain (Figure 1) covers the region from 127.5W to 97.5W and 27.5N to 52.5N. The model has 0.5 degrees horizontal resolution at the tangent point of the polar stereographic grid at 40.0N and 112.5W (at this midpoint the grid points are 55.5 kilometers apart in the north-south direction and 40 kilometers apart in the east-west direction). There are 61 by 51 horizontal model grid points (denoted by dots in the upper-left panel of Figure 1). Horizontal boundary conditions around the domain are updated each time-step by linearly interpolating between each successive 12-hour large-scale analysis. These boundary conditions were nudged in with weights changing from 0.5 at the outermost boundary to 0 within 5 grid points.

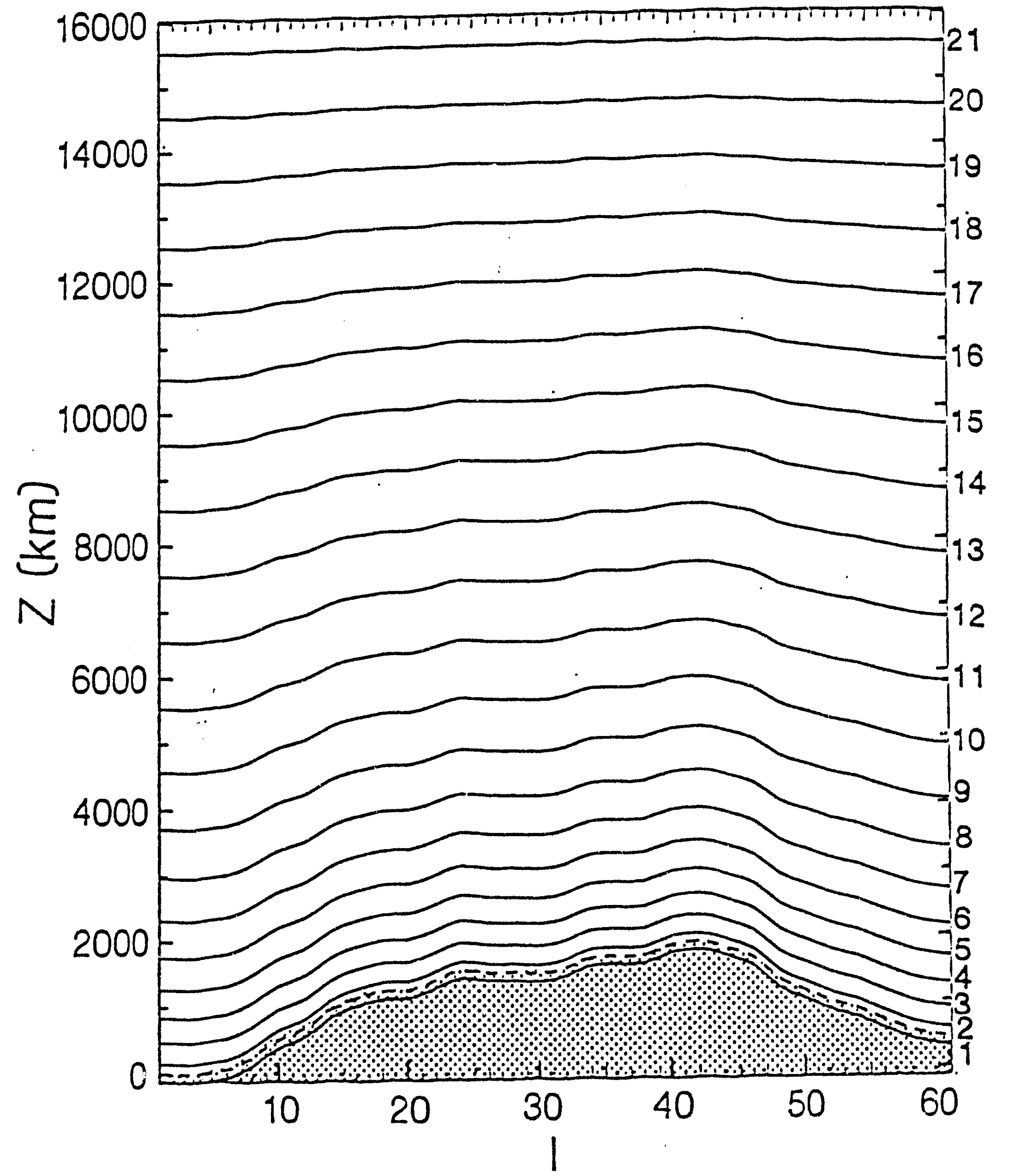


Figure 2. Staggered vertical grid of the RAMS model averaged over the j grid points. That is, we show here an average W-E cross section. The first model level is below the surface; the second model level is 145 meters above the surface over the ocean (slightly less over the mountain peaks).

## Station Observations

All station observations were obtained from the National Climatic Data Center. For verification above the surface, we use the rawinsonde stations. The United States maintains more than 169 stations at scattered global locations (mainly the contiguous 48 states), but less than 35 apply to the chosen western region (station locations are denoted by R in Figure 1b). Data from these rawinsonde stations are initially interpolated to 25 standard pressure levels and then vertically interpolated to the model's vertically staggered grid points as well as to a uniform vertical grid above sea level.

The principal surface stations are first order stations at which temperature, relative humidity, resultant wind speed and wind direction, precipitation, and other meteorological observations are taken. The United States maintains about 470 such stations, about 147 of which cover the chosen domain (station locations are denoted by S in Figure 1c). Most of these summary of day stations also have hourly information from automatic recording instruments at these certified sites.

There are also cooperative stations at which maximum and minimum temperature and daily precipitation are measured. Some of these stations have been included in NCDC historical climatological network. Over the region of interest there are about 350 such HCN stations (locations denoted by small "o" in Figure 1d). For this study, we use only the HCN stations.

## Regional Modeling Methodology

A number of methodologies could be used to simulate the regional climatology. The simple one that we apply here is to use the NMC large-scale global analysis as the initial condition and external boundary condition and then allow the interior of the regional model to equilibrate, on short time scales, to the mesoscale circulation forced by the mesoscale topography. We decided on this simplified regional modeling methodology for several reasons.

- It is easy to initialize stable regional circulation with only the NMC analysis.
- We want to compare the resulting model simulations to the station observations, some of which are truly independent of the initializing analysis. Once a regional data assimilation is more fully developed, we will have a better idea how important it is to also initialize with station data (and perhaps other mesoscale data becoming available with modernization of the weather service).
- We want to test the hypothesis that a fine-mesh regional model forced and initialized by a coarse-mesh, large-scale model can better represent

the regional climatology than can a large-scale model or analysis, especially over the mountainous western United States.

For this preliminary assessment, we integrate for only 12 hours from each initial condition. There are several indications (not shown here) that 12 hours is sufficient time for the mesoscale circulation to equilibrate. Also, we discuss here only the daily averages. Although there are some interesting diurnal variations, they are not analyzed here. Station comparisons are made only at the station grid point locations. For simplicity, we only compare daily averages and do not attempt to diagnose the diurnal variation. We average the maximum and minimum or the 0 and 1200 UTC values for this daily value. In a similar manner, we average the maximum and minimum from the cooperative station values to provide an average daily value.

## Climatology

Climatological temperature fields are shown in Figure 3. During winter, there is a large-scale gradient between the ocean and the adjacent land surface. During summer this gradient reverses and much higher temperatures occur over the land, especially just to the north of the Gulf of California region. Most of the spatial variations can be explained by elevation differences or by inland distance from the Pacific Ocean.

Only small differences are present between the regional model (lower panels, Figure 3) and the NMC analyses (upper panels). In particular, we see the model surface temperature feature of the California Central Valley and Sierras that does not show up in the large-scale analysis, especially during winter. At upper levels (not shown), there is hardly any difference between the NMC analysis and RAMS except the regional model appears to be noisier; most of the noticeable differences occur at the surface.

Relative humidity (Figure 4) shows the characteristic dry structure of the land surface, especially during summer when relative humidity is less than 20 percent over Nevada. There is not much difference between the NMC analyses (upper panels) and regional model (lower panels) except during winter, when relative humidity seems a bit higher just about everywhere. At higher elevations, the regional model maintains this relative moistness during winter but is a bit drier during winter, especially over the ocean. At 6 kilometers (not shown), relative humidity is slightly drier over the ocean than over land, which is the opposite of what occurs at the surface.

Wind climatology is shown in Figure 5. During winter, the NMC (upper left panel) oceanic westerlies tend to split near the coast. Climatological particle tracks north of 40 degrees latitude would move northward over the Coast Ranges and Rocky Mountains and particle tracks to the south would move southward over the mountains. On the leeward side of the mountains, the westerlies once again coalesce into the windiest regions

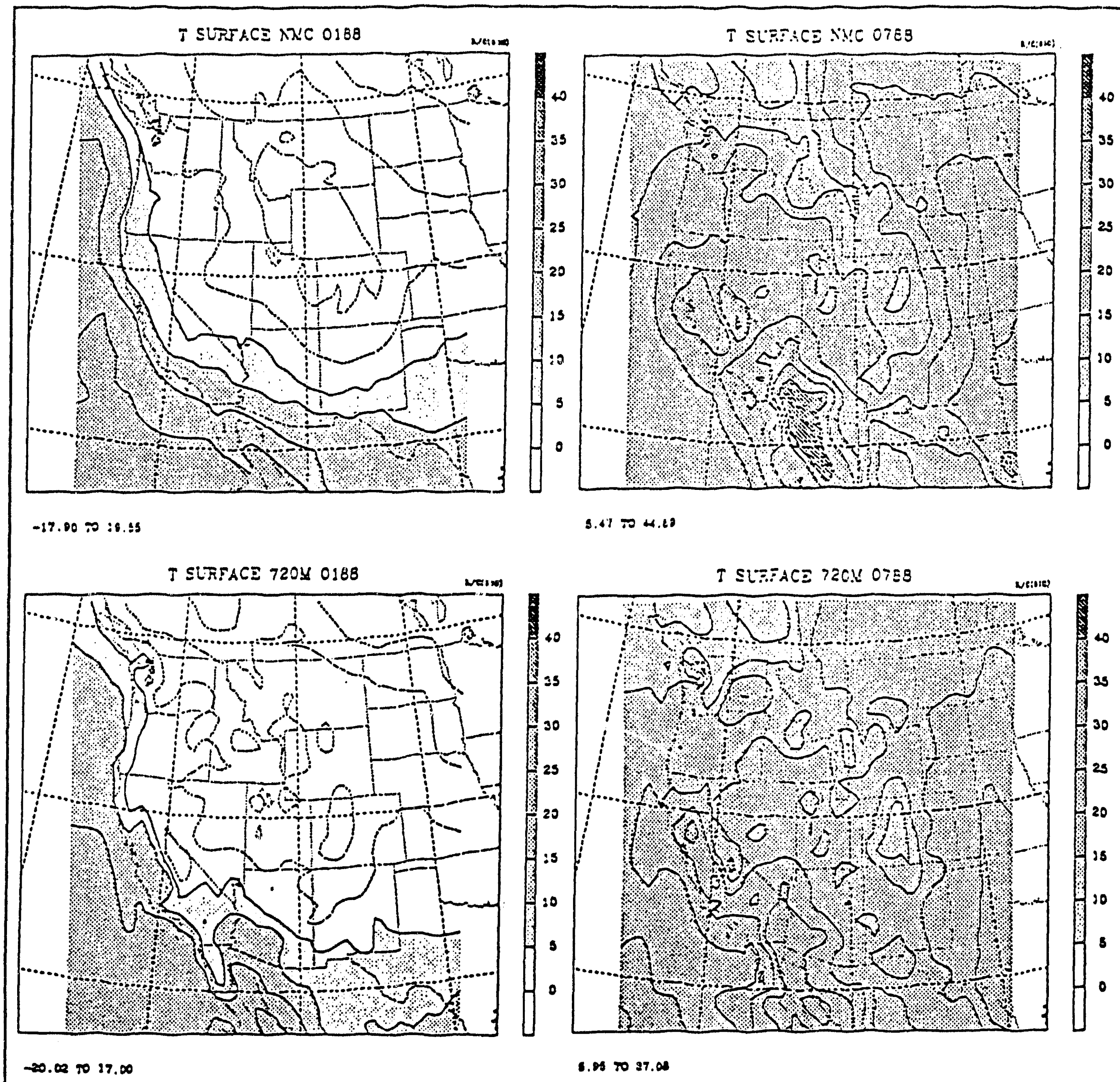


Figure 3. Surface temperature for January and July 1988.
Upper panels show temperature from the large-scale NMC analysis.
Lower panels show temperature from RAMS.

of the domain. The RAMS appears to have more intense winds in the Wyoming wind corridor. Also, the California Santa Ana winds are more predominant in the RAMS climatology than in the original NMC analysis. At upper levels, the predominant westerlies are similar in the analysis and the RAMS; the RAMS winds are bit noisier, but this may be due to model defects.

During summer (upper right panel, Figure 5) the highest wind speeds occur offshore, west of San Francisco. Northerly winds consistent with summertime strengthening of the Pacific subtropical high occur over the

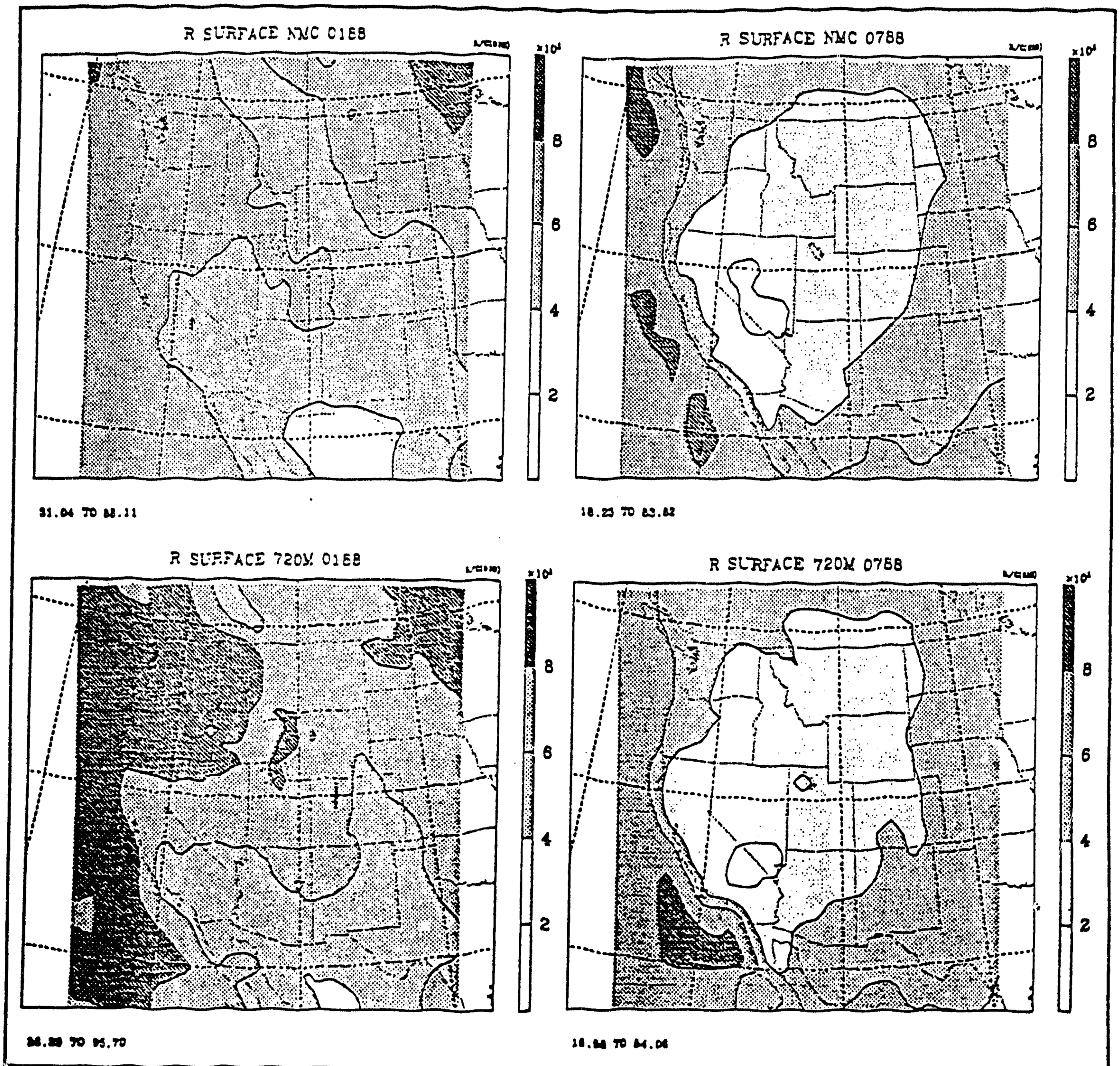


Figure 4. Relative humidity for January and July 1988.
Upper panels show relative humidity from the large-scale NMC analysis.
Lower panels show relative humidity from RAMS.

entire coastal area. The RAMS model winds (lower right panel) in this region are noticeably different in that the coastal central California northerly jet becomes much narrower and confined to the coastal regions. Similar features are also present in a high resolution study with another model of the Southern California summertime Catalina Eddy (Ueyoshi and Roads 1992). Some strong winds in the lee of the northern Rocky Mountains are comparable in the NMC analysis and RAMS, but the strongest winds appear to originate in the southeastern portion of the model domain. At the upper levels, the weakened upper level westerlies are again comparable in the NMC analysis and RAMS.

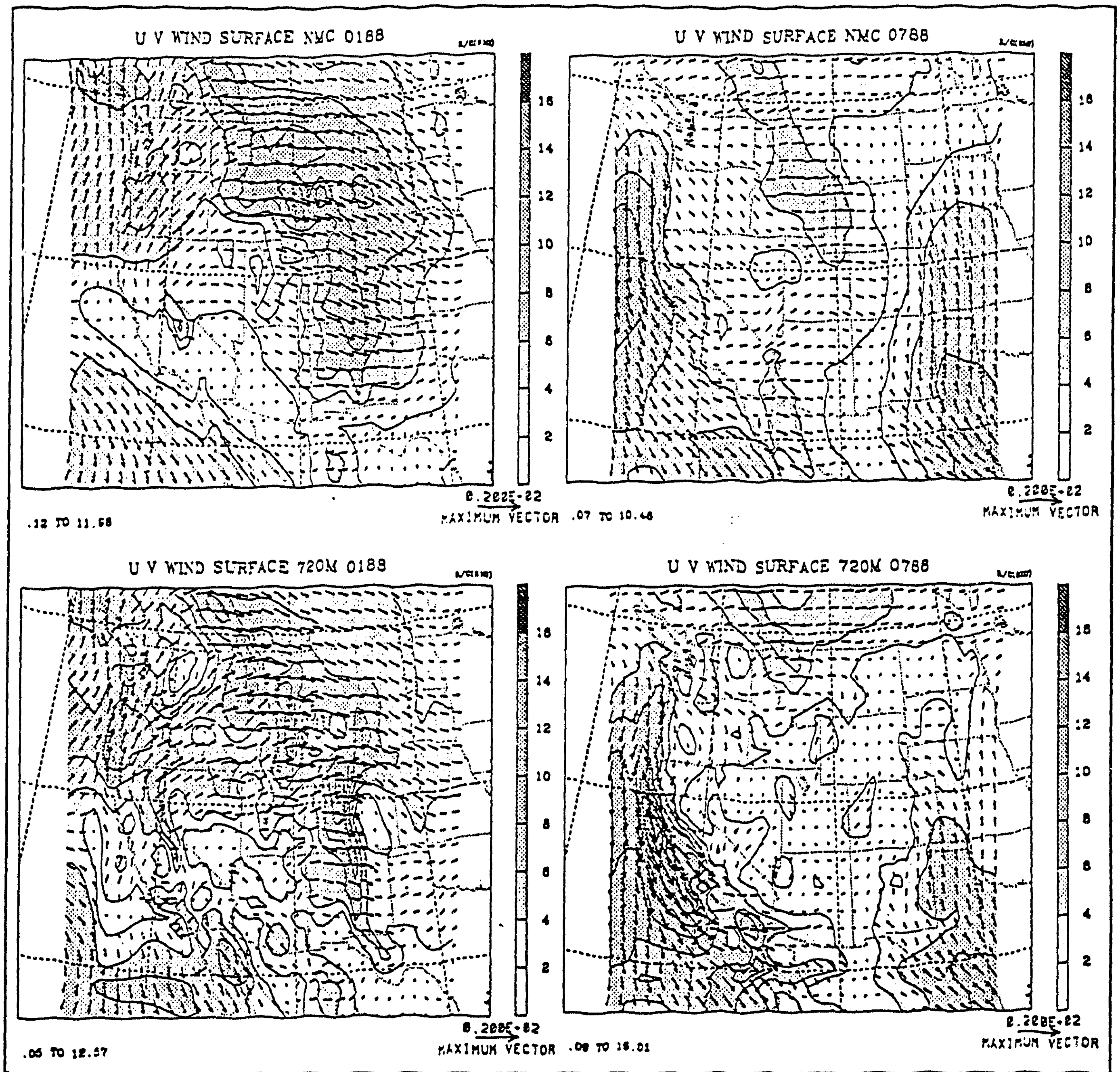


Figure 5. Surface wind speed for January and July 1988.
Upper panels show wind speed from the large-scale NMC analysis.
Lower panels show wind speed from RAMS.
Arrows show wind direction.

Precipitation is not one of the analyzed variables and for now all we can show (Figure 6) is an interpolation of the sparse station observations (HCN and first order stations). Clearly an advantage to having a regional model forced by the large-scale analysis is that the regional model can take the standard meteorological variables available in the standard archives and generate additional relevant variables as needed. Still, the crudely interpolated station dataset does show some correspondence with the RAMS precipitation. During winter the northwestern United States has most of the precipitation, whereas the southwestern and

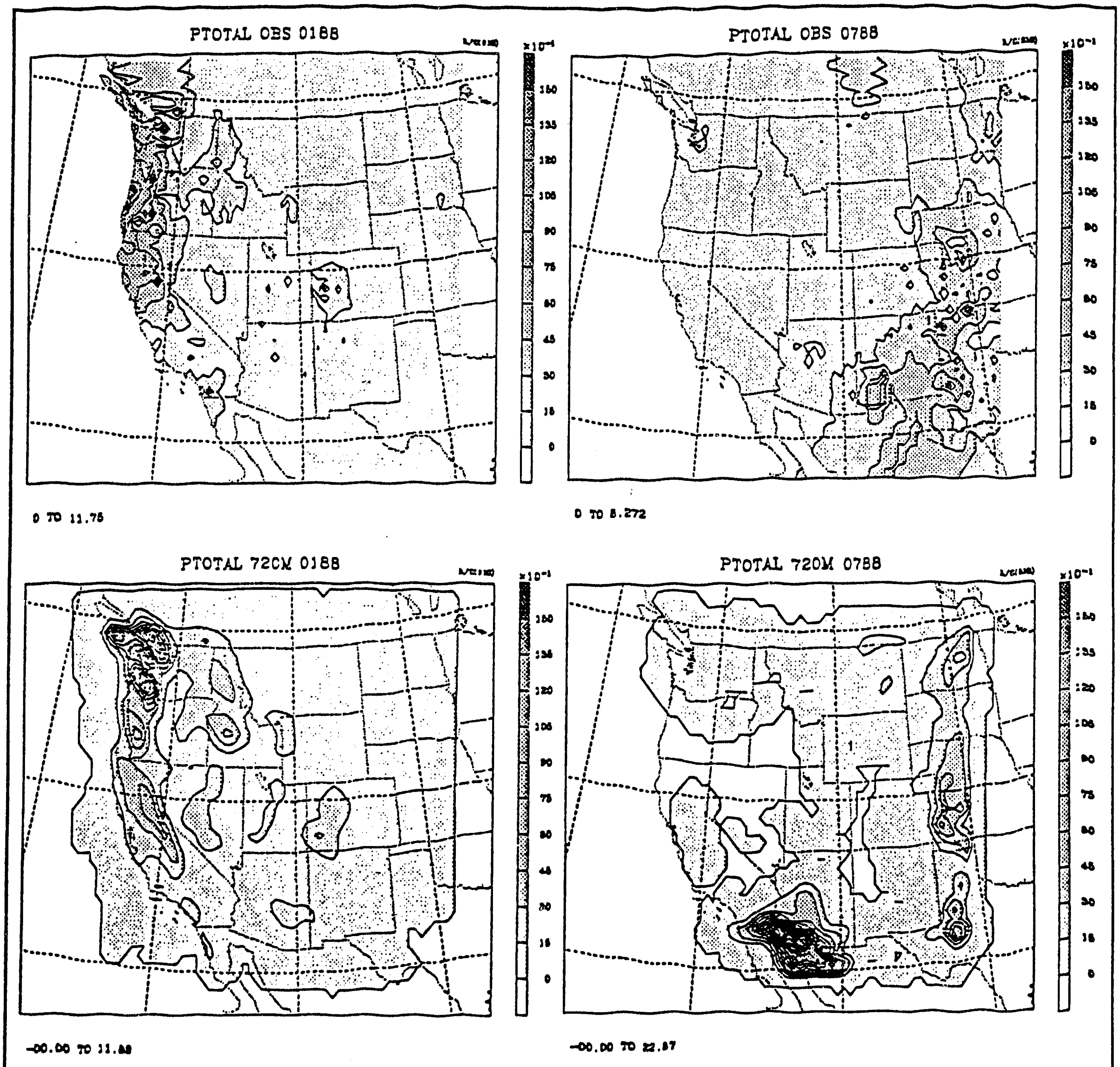


Figure 6. Surface precipitation for January and July 1988.
Upper panels show precipitation from the large-scale NMC analysis.
Lower panels show precipitation from RAMS.
NOTE: Observed precipitation shown in the upper panels is linearly interpolated (iteratively) from about 400 first order and cooperative stations to 3111 grid points.

central United States have most of the summer precipitation (within the boundaries of the model domain). Another feature brought out by the regional model is that during winter most precipitation over the western states falls in the form of snow; rain is dominant only along the extreme West Coast. An irritating feature is the RMS precipitation on the United States/Mexico border during July 1988; the lack of correspondence could be due to lack of Mexican observations in the NCDC datasets or to model defects, we tend to suspect the latter.

## Verification

The large-scale analysis and RAMS appear to be similar, although RAMS has more small-scale features. How realistic are these climatologies and is the regional simulation better? To answer those questions, we now compare the NMC analysis and the regional model simulation with the rawinsonde observations. We examine six characteristics of the climatological field for 3 meteorological variables: temperature *(T)*, relative humidity *(R)*, and wind *(U)*.

The first characteristic is the domain and time averaged values:

$$\overline{\overline{A}} = \frac{1}{N}\sum_{n=1}^{N}\overline{A^{n}}(z)$$

where $A$ is an arbitrary variable; $N$ is the number of rawinsonde locations (~35); and $\overline{A}(z)$ is the ensemble, time, or climatological value at each rawinsonde location, $n$, and elevation, $z$:

$$\overline{A^{n}}(z) = \frac{1}{M}\sum_{l=1}^{M}A_{l}^{n}(z)$$

Here $M$ is the number of events in the ensemble (30 days). The elevation in this case refers to the model vertical grid. The next characteristic is the spatial standard deviation, which measures the level of variability over the domain. This measure is:

$$s = \left(\frac{1}{N-1}\sum_{n=1}^{N}(\overline{A^{n}} - \overline{\overline{A}})^{2}\right)^{\frac{1}{2}}$$

The transient standard deviation measures the day-to-day variability taken out by the climatological averages, and is given by:

$$s' = \left(\frac{1}{N-1}\frac{1}{M-1}\sum_{l=1}^{M}\sum_{n=1}^{N}(A_{l}^{n} - \overline{A^{n}})^{2}\right)^{\frac{1}{2}}$$

Corresponding error measures are the systematic error:

$$d = \overline{\overline{A}} - \overline{\overline{R}}$$

where $R$ denotes the observed rawinsonde value.

Another error measure is the average RMS difference between the rawinsonde climatology and model climatology:

$$e = \left( \frac{1}{N-1} \sum_{n=1}^{N} (\overline{A^n} - \overline{R^n} - \overline{\overline{A}} + \overline{\overline{R}})^2 \right)^{\frac{1}{2}}$$

Finally, the transient RMS differences are given by:

$$e' = \left( \frac{1}{N-1} \frac{1}{M-1} \sum_{l=1}^{M} \sum_{n=1}^{N} (A'^{\,n}_{l} - R'^{\,n}_{l})^2 \right)^{\frac{1}{2}}$$

where:

$$A'^{\,n}_{l} = A^{n}_{l} - \overline{A^n}$$

It should be noted here that in the limit of no skill:

$$e \sim \sqrt{2}s \text{ and } e' \sim \sqrt{2}s'$$

Figure 7 shows the comparison of the NMC analysis and RAMS 12-hour simulations to observations from rawinsondes for the wintertime temperature field. From near-freezing values near the surface, temperature decreases to minus 55°C at the isothermal tropopause. The spatial standard deviation is largest near the surface and decreases to a minimum at 12 kilometers. The transient standard deviation has a minimum at 10 kilometers and a slight maximum at the tropopause. The systematic differences between the analysis, model, and rawinsondes are not large, with the model being about 3.5°C too cold near the surface and about 2°C too warm near the top of the model. The model has the largest bias. RMS spatial differences throughout the troposphere between the analysis or RAMS and rawinsondes are smaller than the spatial standard deviation of about 6°C, which indicates the spatial variability is quite realistic. The RMS error is slightly less in RAMS near the surface than in the NMC analysis. However, transient variations are better portrayed by the NMC analysis.

Figure 8 shows results for the relative humidity field. Here the RAMS relative humidity is biased high, which is related to the cold bias (Figure 7). In addition RAMS tends to have a bit larger spatial and transient error variance than the NMC analysis does everywhere (Figures 7-9). However, the NMC analyses and the RAMS RMS errors are quite close to the transient variations, which indicate much less skill at describing this field. Relative humidity is obviously an intrinsically more difficult field to describe.

The zonal wind field (Figure 9) and the meridional wind field show similar results. RAMS is close to the NMC analysis but still slightly worse. This non-improvement in the wind features was somewhat discouraging, since the climatological wind fields (Figure 5) appear, at first glance, to have more reasonable regional features.

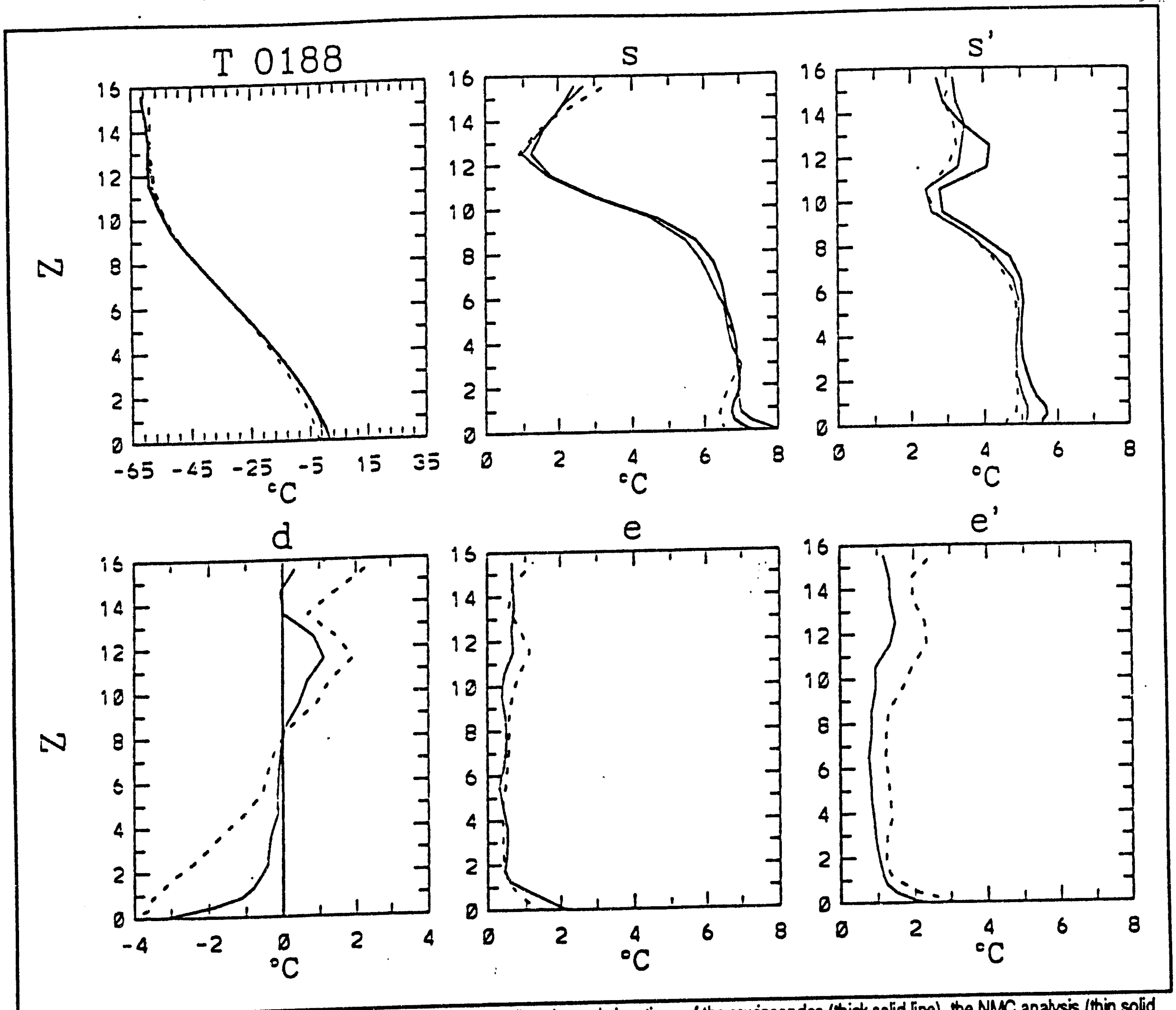


Figure 7. Vertical temperature variations as seen by an average at all rawinsonde locations of the rawinsondes (thick solid line), the NMC analysis (thin solid line) and the RAMS simulation (thin dashed lines).
Upper left = total field.
Upper center = spatial standard deviation (s).
Upper right = transient standard deviation (s').
Lower left = average difference (d) between the domain averages and the rawinsonde averages.
Lower center = RMS difference (between analysis and rawinsonde or RAMS and rawinsonde) of the spatial values.
Lower right = Transient RMS difference (e').

Tables 1 and 2 show the d, e, and e' measures at the surface, where we have many additional station measurements. In particular, we inter-compare the values from the first order stations *(S)*, the cooperative stations *(o)*, the RAMS (M), the interpolated surface rawinsonde values *(R)*, the NMC analysis *(X)*, and the rawinsonde surface observations *(r)*. We inter-compare the station values with each other if the stations are within 50 kilometers of each other; no attempt is made to interpolate station locations to finer scales.

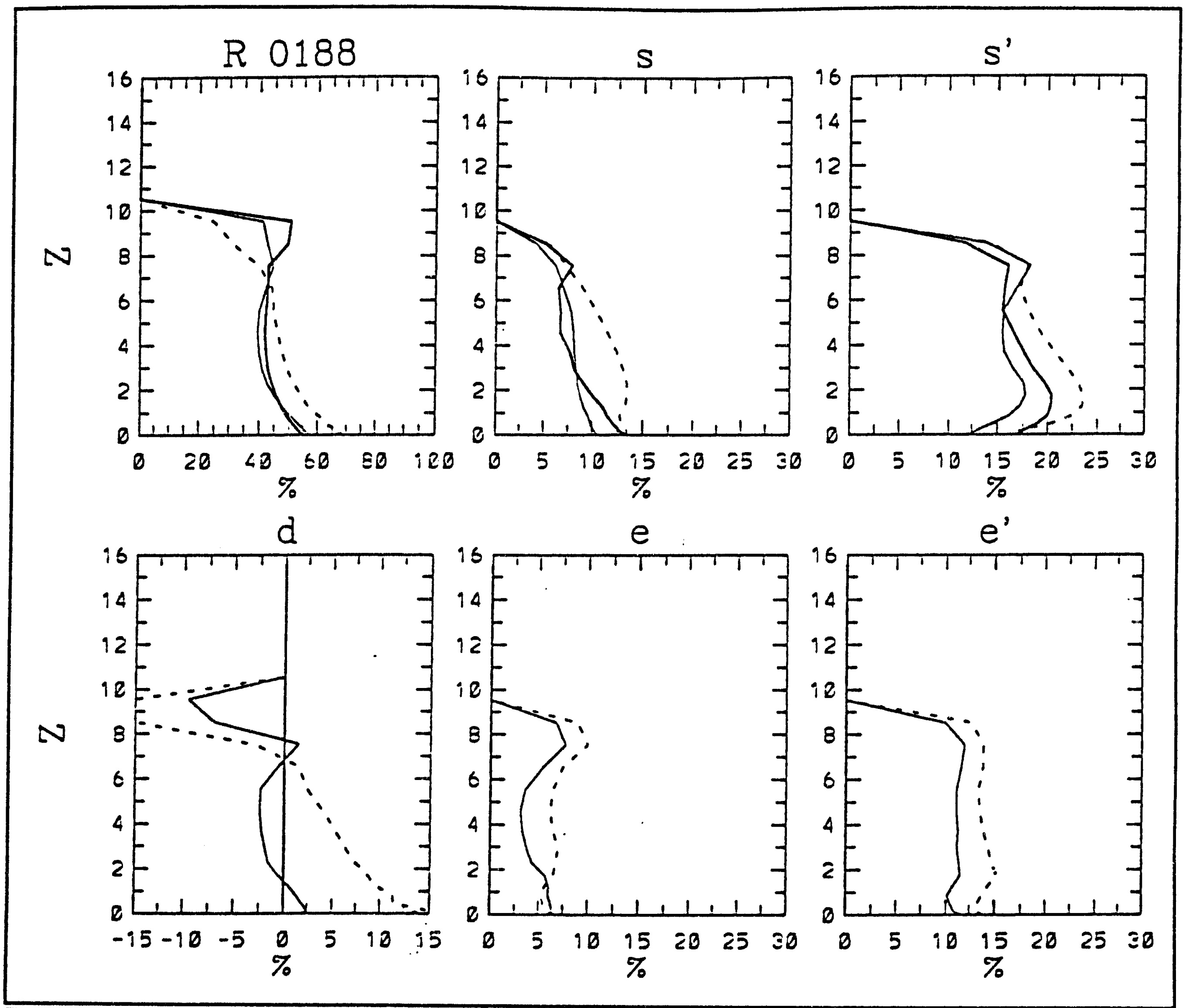


Figure 8. Relative humidity variations as seen by an average at all rawinsonde locations of the rawinsondes (thick solid line), the NMC analysis (thin solid line) and the RAMS simulation (thin dashed lines).
Upper left = total field.
Upper center = spatial standard deviation *(s)*.
Upper right = transient standard deviation *(s')*.
Lower left = average difference *(d)* between the domain averages and the rawinsonde averages.
Lower center = RMS difference (between analysis and rawinsonde or RAMS and rawinsonde) of the spatial values.
Lower right = Transient RMS difference *(e')*.

The individual rows and columns of the Tables 1 and 2 refer to values at the first order stations *(S)*, the cooperative stations *(o)*, the model grid points *(M)*, the hourly station values *(h)*, the interpolated rawinsonde surface values *(R)*, the analysis grid points *(X)*, and the measured rawinsonde surface values *(r)*. Values in each row refer to the error when measured with respect to values at the stations that name the column. For example consider the first set of differences in Table 1, given by the

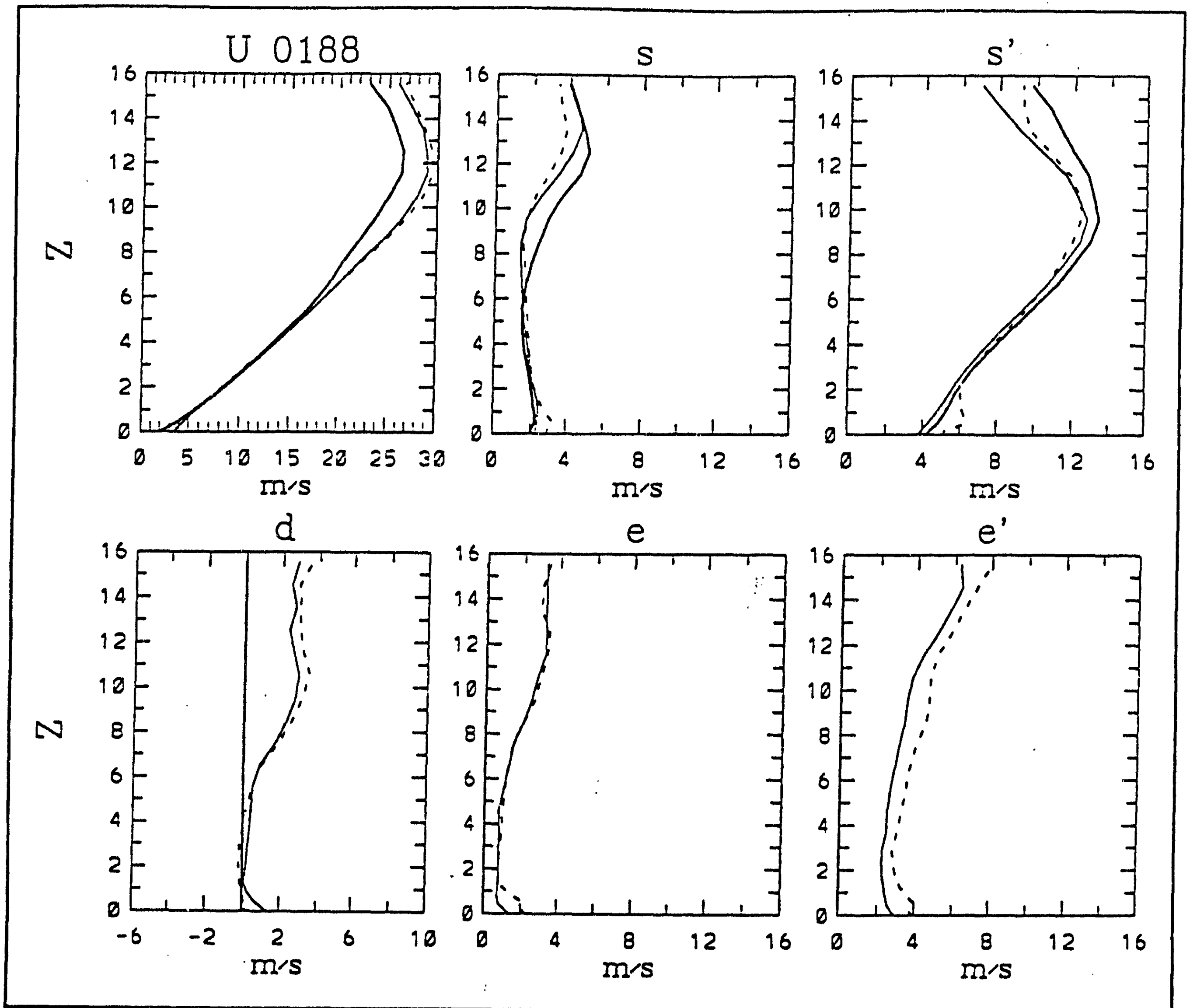


Figure 9. Wind field variations as seen by an average at all rawinsonde locations of the rawinsondes (thick solid line), the NMC analysis (thin solid line) and the RAMS simulation (thin dashed lines).
Upper left = total field.
Upper center = spatial standard deviation (s).
Upper right = transient standard deviation (s').
Lower left = average difference (d) between the domain averages and the rawinsonde averages.
Lower center = RMS difference (between analysis and rawinsonde or RAMS and rawinsonde) of the spatial values.
Lower right = Transient RMS difference (e').

left panel under the heading "T 0188", which denotes temperature during January 1988. The first column shows the differences with respect to the first order stations. At the first order station locations, the cooperative stations are 0.2 degrees too high, the model is 2.4 degrees too low, the hourly station values are 0.5 degrees too high, the interpolated rawinsonde set is 0.8 degrees too high, the NMC analysis is 2.5 degrees too low, and the measured surface rawinsonde temperature is 0.3 degrees too high.

Table 1

SURFACE SYSTEMATIC ERRORS, SURFACE SPATIAL RMS ERRORS, AND SURFACE TRANSIENT ERRORS FOR JANUARY 1988

*Meaning of the rows and columns labeled S, o, M, h, R, X, and r is discussed in text.*

**T 0188 — Temperature** *(Units = 0.1 degree K)*

SURFACE SYSTEMATIC ERRORS

| | S | o | M | h | R | X | r |
|---|---|---|---|---|---|---|---|
| S | 0 | -2 | 24 | 0 | -8 | 25 | -3 |
| o | 2 | 0 | 16 | 0 | -13 | 15 | -4 |
| M | -24 | -16 | 0 | -23 | -34 | -3 | -29 |
| h | 0 | 0 | 23 | 0 | -11 | 24 | -4 |
| R | 8 | 13 | 34 | 11 | 0 | 31 | 5 |
| X | -25 | -15 | 3 | -24 | -31 | 0 | -25 |
| r | 3 | 4 | 29 | 4 | -5 | 25 | 0 |

SURFACE SPATIAL RMS ERRORS

| | S | o | M | h | R | X | r |
|---|---|---|---|---|---|---|---|
| S | 0 | 10 | 28 | 6 | 16 | 30 | 6 |
| o | 10 | 0 | 30 | 10 | 12 | 31 | 5 |
| M | 28 | 30 | 0 | 28 | 15 | 23 | 26 |
| h | 6 | 10 | 28 | 0 | 18 | 32 | 6 |
| R | 16 | 12 | 15 | 18 | 0 | 22 | 14 |
| X | 30 | 31 | 23 | 32 | 22 | 0 | 27 |
| r | 6 | 5 | 26 | 6 | 14 | 27 | 0 |

SURFACE TRANSIENT ERRORS

| | S | o | M | h | R | X | r |
|---|---|---|---|---|---|---|---|
| S | 0 | 19 | 33 | 12 | 29 | 32 | 13 |
| o | 19 | 0 | 39 | 21 | 42 | 40 | 23 |
| M | 33 | 39 | 0 | 35 | 30 | 21 | 35 |
| h | 12 | 21 | 35 | 0 | 33 | 34 | 8 |
| R | 29 | 42 | 30 | 33 | 0 | 23 | 29 |
| X | 32 | 40 | 21 | 34 | 23 | 0 | 33 |
| r | 13 | 23 | 35 | 8 | 29 | 33 | 0 |

**RH 0188 — Relative Humidity** *(Units = Percent)*

SURFACE SYSTEMATIC ERRORS

| | S | o | M | h | R | X | r |
|---|---|---|---|---|---|---|---|
| S | 0 | 0 | 0 | -1 | 11 | 9 | 0 |
| o | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| M | 0 | 0 | 0 | 0 | 11 | 10 | 1 |
| h | 1 | 0 | 0 | 0 | 13 | 10 | 1 |
| R | -11 | 0 | -11 | -13 | 0 | -2 | -10 |
| X | -9 | 0 | -10 | -10 | 2 | 0 | -8 |
| r | 0 | 0 | -1 | -1 | 10 | 8 | 0 |

SURFACE SPATIAL RMS ERRORS

| | S | o | M | h | R | X | r |
|---|---|---|---|---|---|---|---|
| S | 0 | 0 | 8 | 1 | 5 | 6 | 4 |
| o | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| M | 8 | 0 | 0 | 7 | 6 | 7 | 7 |
| h | 1 | 0 | 7 | 0 | 5 | 6 | 4 |
| R | 5 | 0 | 6 | 5 | 0 | 6 | 7 |
| X | 6 | 0 | 7 | 6 | 6 | 0 | 6 |
| r | 4 | 0 | 7 | 4 | 7 | 6 | 0 |

SURFACE TRANSIENT ERRORS

| | S | o | M | h | R | X | r |
|---|---|---|---|---|---|---|---|
| S | 0 | 0 | 15 | 4 | 12 | 11 | 4 |
| o | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| M | 15 | 0 | 0 | 15 | 13 | 10 | 15 |
| h | 4 | 0 | 15 | 0 | 13 | 11 | 4 |
| R | 12 | 0 | 13 | 13 | 0 | 11 | 12 |
| X | 11 | 0 | 10 | 11 | 11 | 0 | 11 |
| r | 4 | 0 | 15 | 4 | 12 | 11 | 0 |

**U 0188 — Zonal Wind** *(Units = 0.1 meter/second)*

SURFACE SYSTEMATIC ERRORS

| | S | o | M | h | R | X | r |
|---|---|---|---|---|---|---|---|
| S | 0 | 0 | -19 | 2 | -15 | -26 | 0 |
| o | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| M | 19 | 0 | 0 | 22 | 5 | -5 | 21 |
| h | -2 | 0 | -22 | 0 | -16 | -28 | 0 |
| R | 15 | 0 | -5 | 16 | 0 | -13 | 15 |
| X | 26 | 0 | 5 | 28 | 13 | 0 | 28 |
| r | 0 | 0 | -21 | 0 | -15 | -28 | 0 |

SURFACE SPATIAL RMS ERRORS

| | S | o | M | h | R | X | r |
|---|---|---|---|---|---|---|---|
| S | 0 | 0 | 30 | 4 | 13 | 21 | 4 |
| o | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| M | 30 | 0 | 0 | 29 | 20 | 18 | 24 |
| h | 4 | 0 | 29 | 0 | 15 | 21 | 3 |
| R | 13 | 0 | 20 | 15 | 0 | 14 | 13 |
| X | 21 | 0 | 18 | 21 | 14 | 0 | 19 |
| r | 4 | 0 | 24 | 3 | 13 | 19 | 0 |

SURFACE TRANSIENT ERRORS

| | S | o | M | h | R | X | r |
|---|---|---|---|---|---|---|---|
| S | 0 | 0 | 44 | 13 | 33 | 31 | 13 |
| o | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| M | 44 | 0 | 0 | 43 | 39 | 27 | 43 |
| h | 13 | 0 | 43 | 0 | 35 | 32 | 13 |
| R | 33 | 0 | 39 | 35 | 0 | 29 | 32 |
| X | 31 | 0 | 27 | 32 | 29 | 0 | 31 |
| r | 13 | 0 | 43 | 13 | 32 | 31 | 0 |

**V 0188 — Meridional Wind** *(Units = 0.1 meter/second)*

SURFACE SYSTEMATIC ERRORS

| | S | o | M | h | R | X | r |
|---|---|---|---|---|---|---|---|
| S | 0 | 0 | -6 | 1 | -2 | 0 | 0 |
| o | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| M | 6 | 0 | 0 | 8 | 4 | 5 | 6 |
| h | -1 | 0 | -8 | 0 | -3 | -3 | -1 |
| R | 2 | 0 | -4 | 3 | 0 | 1 | 1 |
| X | 0 | 0 | -5 | 3 | -1 | 0 | 0 |
| r | 0 | 0 | -6 | 1 | -1 | 0 | 0 |

SURFACE SPATIAL RMS ERRORS

| | S | o | M | h | R | X | r |
|---|---|---|---|---|---|---|---|
| S | 0 | 0 | 25 | 3 | 17 | 22 | 4 |
| o | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| M | 25 | 0 | 0 | 27 | 13 | 14 | 24 |
| h | 3 | 0 | 27 | 0 | 17 | 24 | 2 |
| R | 17 | 0 | 13 | 17 | 0 | 11 | 17 |
| X | 22 | 0 | 14 | 24 | 11 | 0 | 20 |
| r | 4 | 0 | 24 | 2 | 17 | 20 | 0 |

SURFACE TRANSIENT ERRORS

| | S | o | M | h | R | X | r |
|---|---|---|---|---|---|---|---|
| S | 0 | 0 | 42 | 13 | 32 | 34 | 15 |
| o | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| M | 42 | 0 | 0 | 42 | 32 | 26 | 41 |
| h | 13 | 0 | 42 | 0 | 33 | 34 | 13 |
| R | 32 | 0 | 32 | 33 | 0 | 25 | 31 |
| X | 34 | 0 | 26 | 34 | 25 | 0 | 31 |
| r | 15 | 0 | 41 | 13 | 31 | 31 | 0 |

**P 0188 — Precipitation** *(Units = 0.1 millimeter/day)*

SURFACE SYSTEMATIC ERRORS

| | S | o | M | h | R | X | r |
|---|---|---|---|---|---|---|---|
| S | 0 | -3 | 0 | 0 | 0 | 0 | 0 |
| o | 3 | 0 | 1 | 0 | 0 | 0 | 0 |
| M | 0 | -1 | 0 | 0 | 0 | 0 | 0 |
| h | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| R | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| X | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| r | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

SURFACE SPATIAL RMS ERRORS

| | S | o | M | h | R | X | r |
|---|---|---|---|---|---|---|---|
| S | 0 | 10 | 16 | 0 | 0 | 0 | 0 |
| o | 10 | 0 | 13 | 0 | 0 | 0 | 0 |
| M | 16 | 13 | 0 | 0 | 0 | 0 | 0 |
| h | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| R | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| X | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| r | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

SURFACE TRANSIENT ERRORS

| | S | o | M | h | R | X | r |
|---|---|---|---|---|---|---|---|
| S | 0 | 33 | 41 | 0 | 0 | 0 | 0 |
| o | 33 | 0 | 40 | 0 | 0 | 0 | 0 |
| M | 41 | 40 | 0 | 0 | 0 | 0 | 0 |
| h | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| R | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| X | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| r | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

Table 2
SURFACE SYSTEMATIC ERRORS, SURFACE SPATIAL RMS ERRORS, AND SURFACE TRANSIENT ERRORS FOR JULY 1988

*Meaning of the rows and columns labeled S, o, M, h, R, X, and r is discussed in text.*

**T 0788 — Temperature** *(Units = 0.1 degree K)*

SURFACE SYSTEMATIC ERRORS

| | S | o | M | h | R | X | r |
|---|---|---|---|---|---|---|---|
| S | 0 | -1 | 1 | 4 | 16 | -7 | 1 |
| o | 1 | 0 | -5 | 4 | 19 | -16 | -3 |
| M | -1 | 5 | 0 | 1 | 13 | -10 | -1 |
| h | -4 | -4 | -1 | 0 | 12 | -10 | -2 |
| R | -16 | -19 | -13 | -12 | 0 | -24 | -14 |
| X | 7 | 16 | 10 | 10 | 24 | 0 | 10 |
| r | -1 | 3 | 1 | 2 | 14 | -10 | 0 |

SURFACE SPATIAL RMS ERRORS

| | S | o | M | h | R | X | r |
|---|---|---|---|---|---|---|---|
| S | 0 | 17 | 33 | 6 | 23 | 46 | 5 |
| o | 17 | 0 | 31 | 14 | 26 | 44 | 9 |
| M | 33 | 31 | 0 | 34 | 20 | 22 | 37 |
| h | 6 | 14 | 34 | 0 | 25 | 46 | 2 |
| R | 23 | 26 | 20 | 25 | 0 | 36 | 23 |
| X | 46 | 44 | 22 | 46 | 36 | 0 | 53 |
| r | 5 | 9 | 37 | 2 | 23 | 53 | 0 |

SURFACE TRANSIENT ERRORS

| | S | o | M | h | R | X | r |
|---|---|---|---|---|---|---|---|
| S | 0 | 12 | 22 | 10 | 16 | 25 | 10 |
| o | 12 | 0 | 24 | 16 | 20 | 28 | 15 |
| M | 22 | 24 | 0 | 23 | 18 | 17 | 21 |
| h | 10 | 16 | 23 | 0 | 16 | 26 | 8 |
| R | 16 | 20 | 18 | 16 | 0 | 18 | 15 |
| X | 25 | 28 | 17 | 26 | 18 | 0 | 23 |
| r | 10 | 15 | 21 | 8 | 15 | 23 | 0 |

**RH 0788 — Relative Humidity** *(Units = Percent)*

SURFACE SYSTEMATIC ERRORS

| | S | o | M | h | R | X | r |
|---|---|---|---|---|---|---|---|
| S | 0 | 0 | 12 | 0 | 6 | 10 | 1 |
| o | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| M | -12 | 0 | 0 | -12 | -4 | -1 | -9 |
| h | 0 | 0 | 12 | 0 | 6 | 11 | 1 |
| R | -6 | 0 | 4 | -6 | 0 | 3 | -4 |
| X | -10 | 0 | 1 | -11 | -3 | 0 | -7 |
| r | -1 | 0 | 9 | -1 | 4 | 7 | 0 |

SURFACE SPATIAL RMS ERRORS

| | S | o | M | h | R | X | r |
|---|---|---|---|---|---|---|---|
| S | 0 | 0 | 8 | 1 | 5 | 7 | 2 |
| o | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| M | 8 | 0 | 0 | 8 | 7 | 4 | 8 |
| h | 1 | 0 | 8 | 0 | 6 | 7 | 2 |
| R | 5 | 0 | 7 | 6 | 0 | 3 | 7 |
| X | 7 | 0 | 4 | 7 | 3 | 0 | 9 |
| r | 2 | 0 | 8 | 2 | 7 | 9 | 0 |

SURFACE TRANSIENT ERRORS

| | S | o | M | h | R | X | r |
|---|---|---|---|---|---|---|---|
| S | 0 | 0 | 10 | 4 | 7 | 8 | 4 |
| o | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| M | 10 | 0 | 0 | 10 | 9 | 6 | 10 |
| h | 4 | 0 | 10 | 0 | 7 | 8 | 3 |
| R | 7 | 0 | 9 | 7 | 0 | 7 | 7 |
| X | 8 | 0 | 6 | 8 | 7 | 0 | 7 |
| r | 4 | 0 | 10 | 3 | 7 | 7 | 0 |

**U 0788 — Zonal Wind** *(Units = 0.1 meter/second)*

SURFACE SYSTEMATIC ERRORS

| | S | o | M | h | R | X | r |
|---|---|---|---|---|---|---|---|
| S | 0 | 0 | 0 | 0 | -3 | -7 | 0 |
| o | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| M | 0 | 0 | 0 | 0 | -1 | -8 | 2 |
| h | 0 | 0 | 0 | 0 | -3 | -8 | 1 |
| R | 3 | 0 | 1 | 3 | 0 | -5 | 4 |
| X | 7 | 0 | 8 | 8 | 5 | 0 | 9 |
| r | 0 | 0 | -2 | -1 | -4 | -9 | 0 |

SURFACE SPATIAL RMS ERRORS

| | S | o | M | h | R | X | r |
|---|---|---|---|---|---|---|---|
| S | 0 | 0 | 15 | 5 | 10 | 11 | 8 |
| o | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| M | 15 | 0 | 0 | 13 | 20 | 15 | 18 |
| h | 5 | 0 | 13 | 0 | 10 | 11 | 7 |
| R | 10 | 0 | 20 | 10 | 0 | 11 | 7 |
| X | 11 | 0 | 15 | 11 | 11 | 0 | 12 |
| r | 8 | 0 | 18 | 7 | 7 | 12 | 0 |

SURFACE TRANSIENT ERRORS

| | S | o | M | h | R | X | r |
|---|---|---|---|---|---|---|---|
| S | 0 | 0 | 27 | 14 | 20 | 20 | 15 |
| o | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| M | 27 | 0 | 0 | 29 | 26 | 19 | 26 |
| h | 14 | 0 | 29 | 0 | 20 | 21 | 14 |
| R | 20 | 0 | 26 | 20 | 0 | 19 | 18 |
| X | 20 | 0 | 19 | 21 | 19 | 0 | 19 |
| r | 15 | 0 | 26 | 14 | 18 | 19 | 0 |

**V 0788 — Meridional Wind** *(Units = 0.1 meter/second)*

SURFACE SYSTEMATIC ERRORS

| | S | o | M | h | R | X | r |
|---|---|---|---|---|---|---|---|
| S | 0 | 0 | 6 | 2 | -2 | 0 | 0 |
| o | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| M | -6 | 0 | 0 | -2 | -5 | -7 | -1 |
| h | -2 | 0 | 2 | 0 | -5 | -3 | -1 |
| R | 2 | 0 | 5 | 5 | 0 | 0 | 3 |
| X | 0 | 0 | 7 | 3 | 0 | 0 | 3 |
| r | 0 | 0 | 1 | 1 | -3 | -3 | 0 |

SURFACE SPATIAL RMS ERRORS

| | S | o | M | h | R | X | r |
|---|---|---|---|---|---|---|---|
| S | 0 | 0 | 18 | 6 | 13 | 17 | 9 |
| o | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| M | 18 | 0 | 0 | 16 | 16 | 14 | 16 |
| h | 6 | 0 | 16 | 0 | 12 | 17 | 7 |
| R | 13 | 0 | 16 | 12 | 0 | 15 | 11 |
| X | 17 | 0 | 14 | 17 | 15 | 0 | 18 |
| r | 9 | 0 | 16 | 7 | 11 | 18 | 0 |

SURFACE TRANSIENT ERRORS

| | S | o | M | h | R | X | r |
|---|---|---|---|---|---|---|---|
| S | 0 | 0 | 28 | 16 | 28 | 22 | 18 |
| o | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| M | 28 | 0 | 0 | 29 | 31 | 19 | 28 |
| h | 16 | 0 | 29 | 0 | 28 | 23 | 14 |
| R | 28 | 0 | 31 | 28 | 0 | 25 | 25 |
| X | 22 | 0 | 19 | 23 | 25 | 0 | 21 |
| r | 18 | 0 | 28 | 14 | 25 | 21 | 0 |

**P 0788 — Precipitation** *(Units = 0.1 millimeter/day)*

SURFACE SYSTEMATIC ERRORS

| | S | o | M | h | R | X | r |
|---|---|---|---|---|---|---|---|
| S | 0 | 0 | 2 | 0 | 0 | 0 | 0 |
| o | 0 | 0 | 4 | 0 | 0 | 0 | 0 |
| M | -2 | -4 | 0 | 0 | 0 | 0 | 0 |
| h | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| R | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| X | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| r | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

SURFACE SPATIAL RMS ERRORS

| | S | o | M | h | R | X | r |
|---|---|---|---|---|---|---|---|
| S | 0 | 3 | 20 | 0 | 0 | 0 | 0 |
| o | 3 | 0 | 15 | 0 | 0 | 0 | 0 |
| M | 20 | 15 | 0 | 0 | 0 | 0 | 0 |
| h | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| R | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| X | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| r | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

SURFACE TRANSIENT ERRORS

| | S | o | M | h | R | X | r |
|---|---|---|---|---|---|---|---|
| S | 0 | 29 | 73 | 0 | 0 | 0 | 0 |
| o | 29 | 0 | 68 | 0 | 0 | 0 | 0 |
| M | 73 | 68 | 0 | 0 | 0 | 0 | 0 |
| h | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| R | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| X | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| r | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

For the most part, these tables show the RAMS model is marginally worse than the NMC analysis, and both the analysis and RAMS model are worse than the various station datasets. There are notable exceptions. For example, during winter (Table 1) the climatological surface temperature errors appear to be marginally lower in the RAMS model than in the NMC analysis; the transient error is larger, however. Similar results occur for the summer simulation (Table 2). Here, the RAMS transient variations as well as spatial variations are slightly better at the surface for temperature. However, the other fields are not modeled any better, and now the model depiction of the precipitation field appears to be quite a bit worse than the cooperative or first order station values. Whether this model depiction is better than the precipitation field associated with the large-scale analysis is unknown; again, precipitation is not a part of the large-scale NMC archives.

## Conclusions

In some respects, we were quite pleased with the results. Preliminary comparisons indicate the NMC large-scale, global analysis is doing a perfectly adequate job representing various meteorological characteristics at individual stations in the western United States. The explained variance is quite high, especially for the temperature field, but also for wind and relative humidity.

We were disappointed, though, that the regional modeling system did not do a demonstrably better job than the original large-scale analysis at representing climate in the western United States. We now suspect we cannot rely on simply having a mesoscale model overlying mesoscale topography and forced only by a large-scale analysis. We will also probably need to include individual stations, as well as the NMC large-scale analysis, in a continuous model/data assimilation if we are to get a regional climatology that is a whole lot better than the original large-scale analysis. This kind of work is beyond the scope of work being reported here, but it is being explored by others (*eg*, Stauffer and Seaman 1990; Stauffer *et al* 1991).

One clear advantage to using the regional model was brought out by this comparison. The regional model can develop a smooth geographic representation of precipitation fields, which are not readily available elsewhere. Since precipitation is not needed to initialize the large-scale models, and is in fact a forecast field, it has not been previously archived or stored in any useful format. Another advantage is that the RAMS regional model can distinguish between snow and rain, which will be quite useful eventually when these regional models are coupled to various surface hydrology modules. Other variables, especially derived nonlinear variables, may also be better represented by the regional model fields than by the large-scale analysis.

Finally, since errors of the regional modeling attempt are not substantially less than errors of the original analyses, is it better to interpolate dynamically by forcing a mesoscale model with large-scale GCM output than it is to linearly interpolate the original GCM output? Many papers appear to indicate that a regional model gives substantially better answers and could, therefore, be used to interpolate large-scale GCM future climate simulations to regional scales. From the present results, we cannot yet wholeheartedly agree.

Further details of this work are provided in Roads *et al* (1992b).

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