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NCEP REGIONAL REANALYSIS

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1. Introduction

The objective of the NCEP's Regional Reanalysis (RR) is to create a long-term set of consistent climate data on a regional scale, for the North American domain. The RR, on its domain, will be superior to the completed NCEP/NCAR Global Reanalysis (GR), in both resolution and accuracy. This will be achieved using the GR to drive the RR system, and taking advantage of the regional Eta Model, and of the various advances that have been made in regional modeling and data assimilation since the GR system starting time of 1995. These advances include assimilation of precipitation, direct assimilation of radiances, the use of additional data as well as improved data processing efforts, and several Eta Model developments, in particular those arrived at within the NCEP's GCIP-funded land-surface effort.

One of the expectations is that the RR will help answering questions of the variability of water in weather and climate, in particular as it concerns U.S. precipitation patterns. To that end, a special effort will be made to output all native grid time-integrated quantities of water and energy budgets. The RR should have a good handle on extreme events, such as floods and droughts, and should interface with hydrological models as well.

Results of preliminary pilots, produced at 80-km horizontal resolution and 38 layers in the vertical, have been inspected in a variety of ways, as well as reported on at a number of meetings (e.g., Mesinger et al. 2002a). The assimilation of precipitation during the reanalysis was found to be very successful, obtaining model precipitation quite similar to the analyzed precipitation, in particular during the warmer seasons. In the 1998 pilot, temperature and vector wind rms fits to raobs were considerably improved over those of the GR throughout the troposphere, both in January and in July, and both in the analyses and in the first guess fields. Improvements in the 2 m temperatures and 10 m winds were seen as well.

We here report on our first tentative production results, at 32 km/45 layer resolution. At the time of this writing tentative production is in progress, even though some of the finishing touches are still being worked on, so that the 32-km reanalysis so far done, the second half of 1987 and the first half of 1988, is being rerun at this time, and will be rerun once again when the system is frozen. It is planned to complete most of the 25 years of RR, 1979-2003, before the end of 2003. Once the 25 years are completed, the RR will continue to be run in real-time, like the "Climate Data Assimilation System" is being run as a real-time

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continuation of the GR. Just as the GR, the final product is planned to contain also free forecasts at regular intervals, useful for predictability studies.

The project is financed by the NOAA Office of Global Programs (OGP), and at the time of this writing has just completed its 4th year of support, thus having ended its Development Stage. An 11 member Scientific Advisory Panel has been formed, chaired by John Roads, providing advice to the OGP as well as to the personnel engaged on the project.

2. Reanalysis system, and data used

The RR System is identical to the Eta Model operational 3D-Var Data Assimilation System (EDAS), e.g., Rogers and DiMego (ftp://ftp.ncep.noaa.gov/pub/emc/wd20er/caftimay01/v3_document.htm), except for being augmented to use a variety of additional data, and for using an Eta Model at 32 km/45 layer resolution, in which presently some but not all of the model changes following October 2001 are implemented (see http://www.emc.ncep.noaa.gov/mmb/research/eta.log.html). In particular, cloud microphysics is one of October 2001. The system is fully cycled, with a 3-hr forecast from the previous cycle serving as the first guess for the next cycle.

The 32 km/45 layer resolution used for the RR production runs is that of the operational Eta prior to September 2000. The domain however is that of the current operational Eta, North America and parts of Atlantic and Pacific, encompassing 106° x 80° of rotated longitude x latitude. The RR domain and topography are shown in Fig. 1.

The data for the most part used in the pilots performed so far, and used in the production runs, additional to those used in the Global Reanalysis, are as follows.

- Precipitation. The assimilation of observed precipitation is the most important addition to the RR. The successful assimilation of these observations (Lin et al. 1999, see also section 3) ensures that the model precipitation during the assimilation is close to that observed, and therefore that the hydrological cycle is more realistic than it would be otherwise. Over the continental United States (ConUS), Mexico, and Canada, precipitation data assimilated are 24 h rain gauge data disaggregated to hourly. Over the ConUS area, disaggregation is performed according to hourly precipitation data (HPD), and using "inverse distance" scheme, and the "mountain mapper" (PRISM). Over Mexico and Canada, disaggregation is based on GR-2 (Kanamitsu et al. 2002) forecasts. Over the remaining areas, with two exceptions, CMAP pentad data (Xie, Arkin, Janowiak) are used, converted to hourly also using the GR-2 precipitation forecasts. The two exceptions are areas north of 49° N if according to the Eta precipitation is likely to be snow, since the CMAP data is then considered unreliable; and over central regions of tropical cyclones, the idea being that over these regions CMAP pentad data do not have adequate time resolution to be advantageous to model produced precipitation. For this, the locations of tropical cyclones are prescribed according to tropical cyclone retrievals of Fiorino (e.g., Fiorino 2002).
- TOVS-1b radiances;
- Profilers and Vertical Azimuth Display (VAD) winds;
- Land surface temperature, wind, and moisture;
- Lake surface state (Grumbine, personal communication), and lake temperature, to the extent available, as opposed to the SST used in the GR. For lakes for which temperature is not available, a system was set up to transfer temperatures of lakes deemed most likely to have temperatures similar to the lake at hand.

SST and sea ice data, while of course both having been used in the GR, have for the RR undergone improved processing efforts (Stokes, Grumbine, personal communications).

3. Preliminary results

Analyzing a variety of pilot runs that we have performed prior to the current tentative production (e.g., Mesinger et al. 2002a), we have paid attention not only to their realism and sensitivities to RR system changes, but also to their comparison against the results of the NCEP / NCAR Global Reanalysis. Given that the Global Reanalysis data are available (Kalnay et al. 1996, Kistler et al. 2001), an obvious objective of the RR, additional to resolution, is to provide a more realistic / accurate data set. Thus, results of various pilots were examined in comparison with the GR data, aiming for a generally increased agreement with observations. We shall do the same now when presenting and commenting upon the results of available production runs. We will show some of our precipitation results, some of the rms fits of analyzed as well as of the first guess temperature and winds to raobs as functions of pressure, and some of the rms fits of 2 m temperatures to surface observations, once again for analyses as well as for the first guess fields.

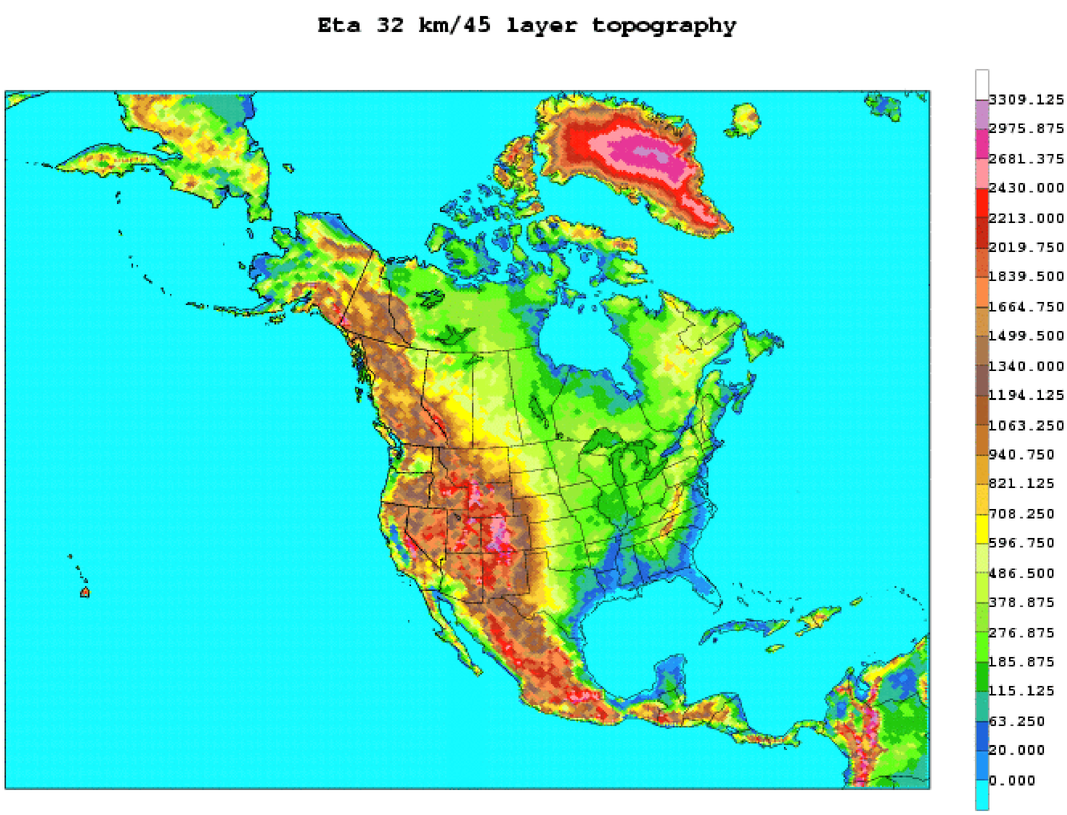

Fig. 1. The NCEP Regional Reanalysis domain and its 32 km / 45 layer topography.

In Mesinger et al. (2002a) we have displayed monthly precipitation totals of our 80 km pilot runs for January and July 1998, “observed” (as available at the time), those of the GR, and those of the RR pilot with precipitation assimilation. The observed precipitation was shown remapped to an 80-km grid, to be a more appropriate verification for the pilot than the original 1/8 degree input precipitation analysis. We are displaying the same three plots here in Fig 2a ("observed") and 2b (GR, and RR), except for the 32 km tentative production, and for July 1987.

The GR is seen for the most part to capture the big picture of the July 1987 totals. However, it fails to depict regional features, in particular over the ConUS area; showing, for example, increased precipitation over the southeastern United States, as opposed to the Midwest. The RR, on the other hand, reproduces extremely accurately regional features over the ConUS area, even those of a very small scale; with few exceptions. Agreement is quite good over the oceans also. albeit not to the same extent.

Unfortunately, following July 1987 production run precipitation assimilation was inadvertently switched off in our system, and we have only relatively recently become aware of it. Thus, at this time, this period is being rerun, and we do not have the January and July 1988 32 km results that we otherwise would have. For these and other more recent results, please see http://www.emc.ncep.noaa.gov/mmb/rreanl where also an updated version of this paper should be found. As a substitute at this time, we may however recall results of the 80 km pilot shown in Mesinger et al. (2002a). In January 1998, generally a highly realistic result was seen to be rendered by the GR as far as the larger scale features were concerned, with some exceptions. A still more realistic result was obtained by the RR; but not quite as realistic as the one for July 1998, and the 32 km one shown here for July 1987.

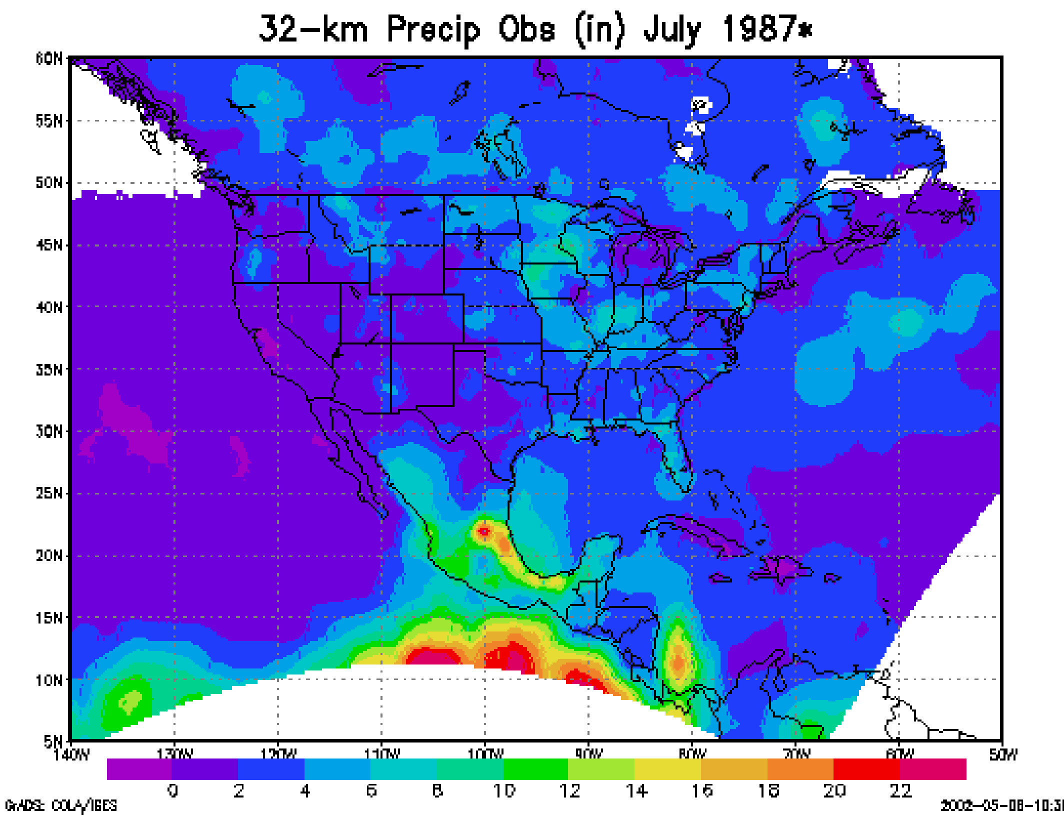

Fig 2a. “Observed” (see text) precipitation total for July 1987 (inches).

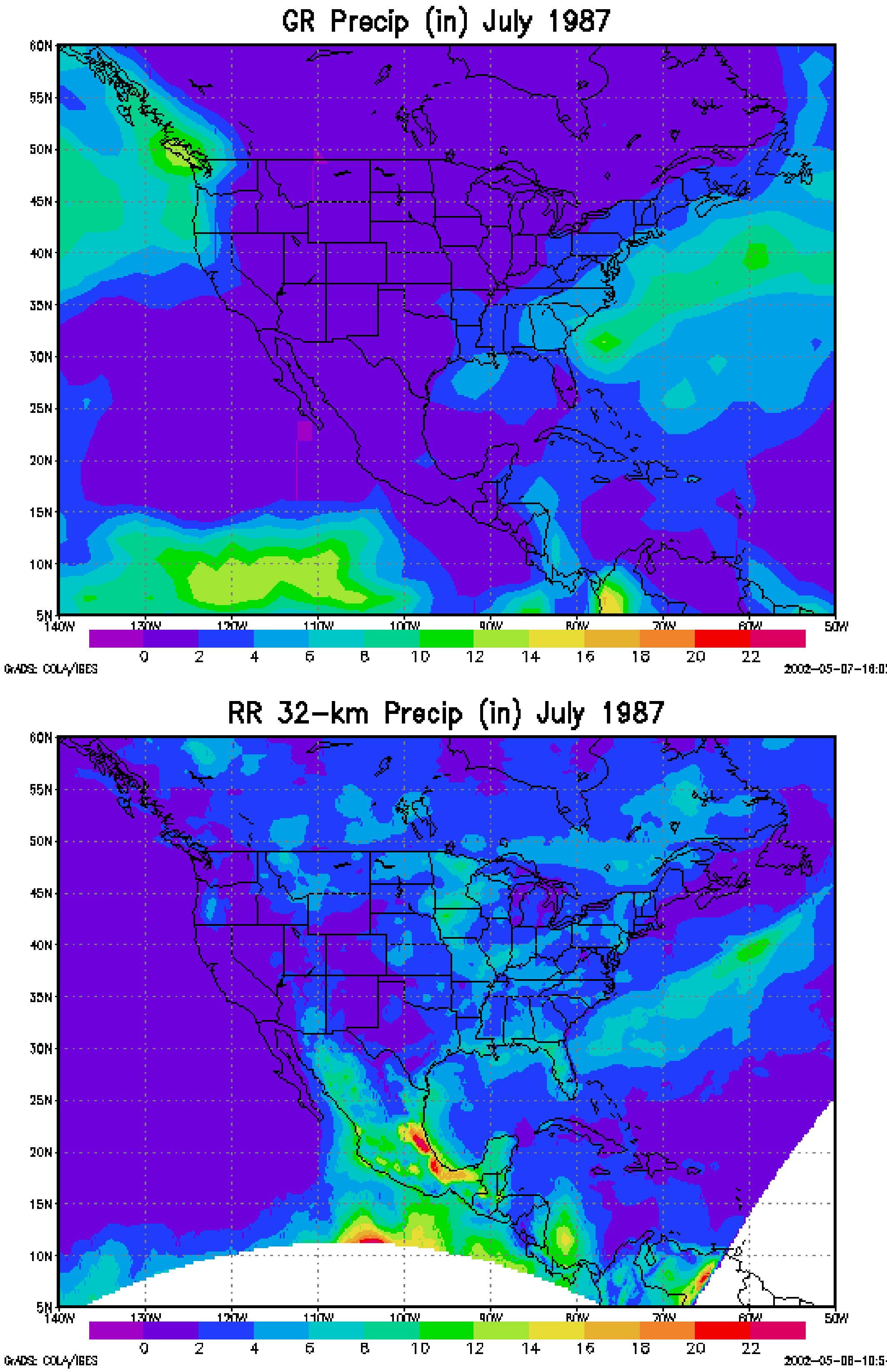

Fig 2b. GR (upper panel) and RR (lower panel) precipitation totals for July 1987 (inches).

It should be stressed that the RR precipitation is model produced; it is the latent heat, derived from observations, that is assimilated (e.g., Lin et al. 1999). A better agreement of the RR in summer, when precipitation forecasts are more difficult, thus may be found surprising. It likely indicates that our RR assimilation method works better with the convective precipitation, dominant in summer, than it does with the large scale precipitation.

In Mesinger et al. (2002a) we have shown 80 km pilot temperature and vector wind RR rms fits to raobs, for January and July 1998, as functions of pressure. RR had shown a considerably better fit to raobs than the GR, in particular for winds. A puzzling feature was no improvement over the GR at the surface (1000 mb). This was later identified to have been due to an error in the NCEP Forecast Verification System (FVS): it was assuming the observed temperatures to be virtual temperatures and thus was including an erroneous conversion. When this was corrected – corrected plot was made available at the Orlando meeting -- RR improvement over the GR at the surface was seen to be no worse than that generally found at other levels.

Here in Fig. 3 we present the same set of four plots but for our 32 km run, and for 1988. Advantage of the RR over that of the GR is seen to be considerable, in particular for winds. Once again, the advantage in winds over the GR is greatest in the upper troposphere, and in particular in winter, January. This is a feature which we believe would generally not have been expected. It is however consistent with results of the operational Eta that have been reviewed by Mesinger et al. (2002b).

As to the comparison with the corresponding plots of the 80 km pilot for 1998, the advantage of the RR over the GR is similar, or perhaps, just a little better. In this respect, two points might be mentioned. First, it is probably generally accepted that the impact of resolution when comparing rms fits to data is not necessarily beneficial, as more detail even if mostly correct might not bring rewards in the rms sense because of the negative impact of placement errors. Second, recall that the 1988 results we have at the time of this writing and are showing in Fig. 3 are obtained with no precipitation assimilation. Improved results are hoped for once these months are rerun with the precipitation assimilation included.

Yet another issue is the general one of the analysis fits to observations as the fit will be better if less balance is required in the analysis scheme, and the degree of balance imposed is a matter of choice. For example, the operational Eta 3D-Var implementation of May 2001 (web site given in section 2) improved the RR fits to raobs in the first guess (3-h forecasts) but made them worse in the analysis. Therefore, we also follow RR first guess fits to data, such as the rms differences of the type shown in Fig. 3 but prior to entering the 3D-Var. Because the improvement in the first guess is a validation independent of analysis assumptions, it is perhaps generally considered as the best measurement of the overall improvement. In a practical sense, most users of the RR will want to use the analyses for some of the variables, and the first guess fields for some of the others, e.g., for fluxes. Thus, in Fig. 4 we here show a set of four plots of the first guess fits to raobs, corresponding to the analysis fits that were displayed in Fig. 3.

A general improvement of the RR fits to raobs over that of the GR is seen also for the first guess fields, even though the improvement is not quite as considerable as it was for the analysis fields. In comparing these plots to those of Fig. 3, a point may come to mind additional to that of the balance imposed in the 3D-Var scheme. It is the difference in time intervals of using the 3D-Var analyses in the two assimilation systems: the GR is using 6 h assimilation intervals, as opposed to the 3 h intervals of the EDAS and the RR. This results in a considerable fraction of the data being used at more correct times, and also makes the first guess closer to the initialization time so that there is less time for the model error grows to take place, both favoring the RR. However, being closer to the initialization time also allows less time for the gravity waves created by the initial imbalance to settle down, putting the RR first guess at a disadvantage in terms of

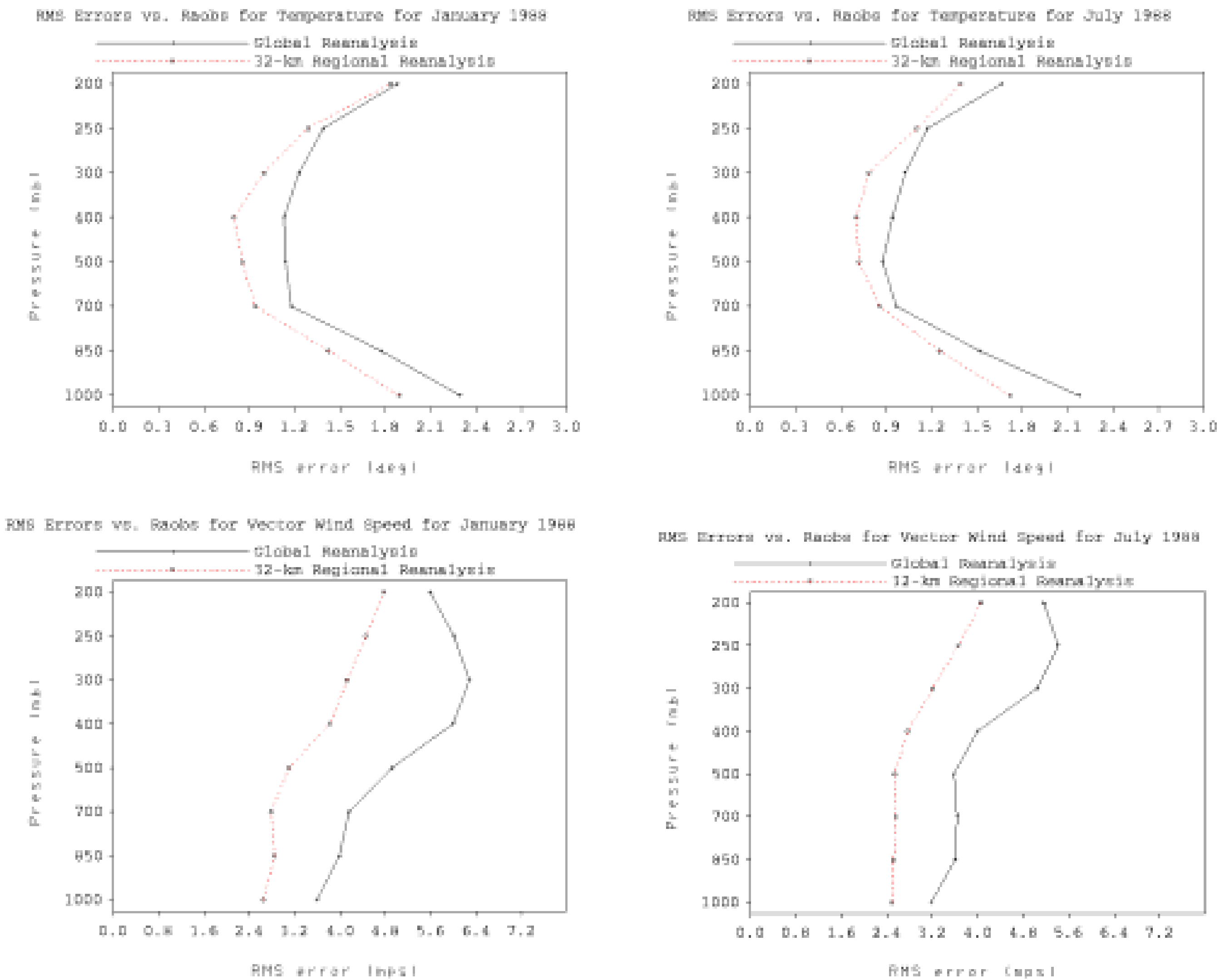

Fig. 3. RR rms fits to raobs as a function of pressure, dashed lines, for temperature (upper panels), and for vector wind (lower panels), for January (left panels) and July 1988 (right panels). Same, but for the GR, solid lines.

fitting the observations. We are aware of this gravity wave activity out of the 3D-Var in the RR system being considerable, so that which of the two systems is at an advantage in terms of the first guess fit to observations as a result of this difference in 3D-Var time intervals is not obvious. Simple techniques are available to make the gravity wave noise settle down faster, and using one of these to achieve a better RR first guess fit to observations is still a possibility.

For a sample of surface results, we show in Figs. 5 and 6 the bias and the rms fits to observations, respectively, of the first guess 2 m temperature, again for January and July 1988, and for both the RR (dashed lines) and the GR (solid lines), as functions of time. Recall that, just as the results shown in Figs. 3 and 4, these also are results obtained without precipitation assimilation, so that somewhat improved RR fits to observations are hoped for once these months are rerun. Stations inside the so-called grid 212 are chosen

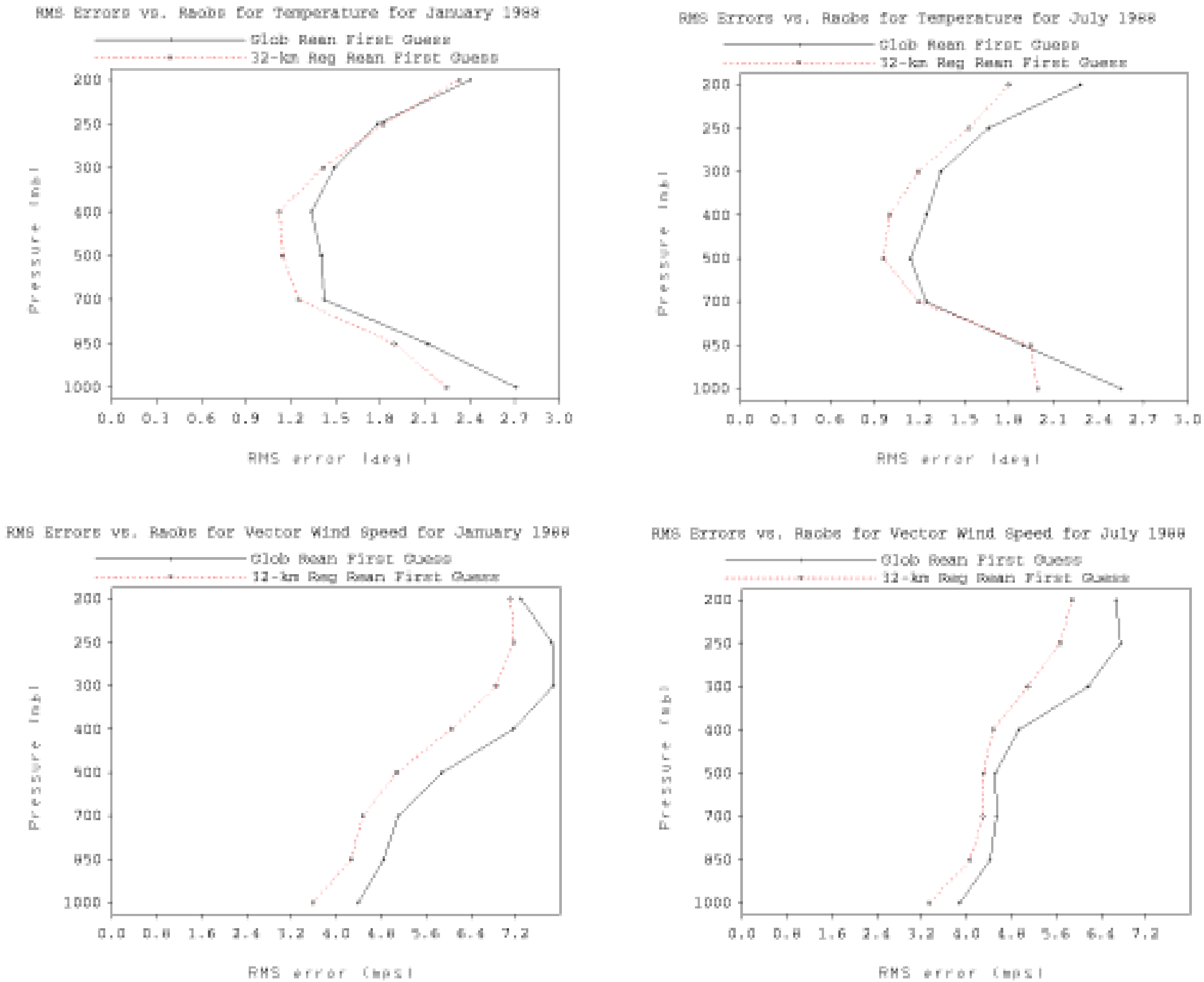

Fig. 4. RR first guess rms fits to raobs as a function of pressure, dashed lines, for temperature (upper panels), and for vector wind (lower panels), for January (left panels) and July 1988 (right panels). Same, but for the GR, solid lines.

for the verifications shown, encompassing most of Mexico to the south and up to a considerable fraction of Canada to the north, resulting in about 450 stations. A large majority of these stations however are within the ConUS area.

We have started these plots with biases given that the bias is perhaps of particular interest when it comes to surface observations. In January, hardly any systematic bias is seen of the RR, as opposed to a negative bias of the GR. In July, the RR displays a clear negative bias, but much less intense than the positive bias of the GR when verified at 0000 UTC.

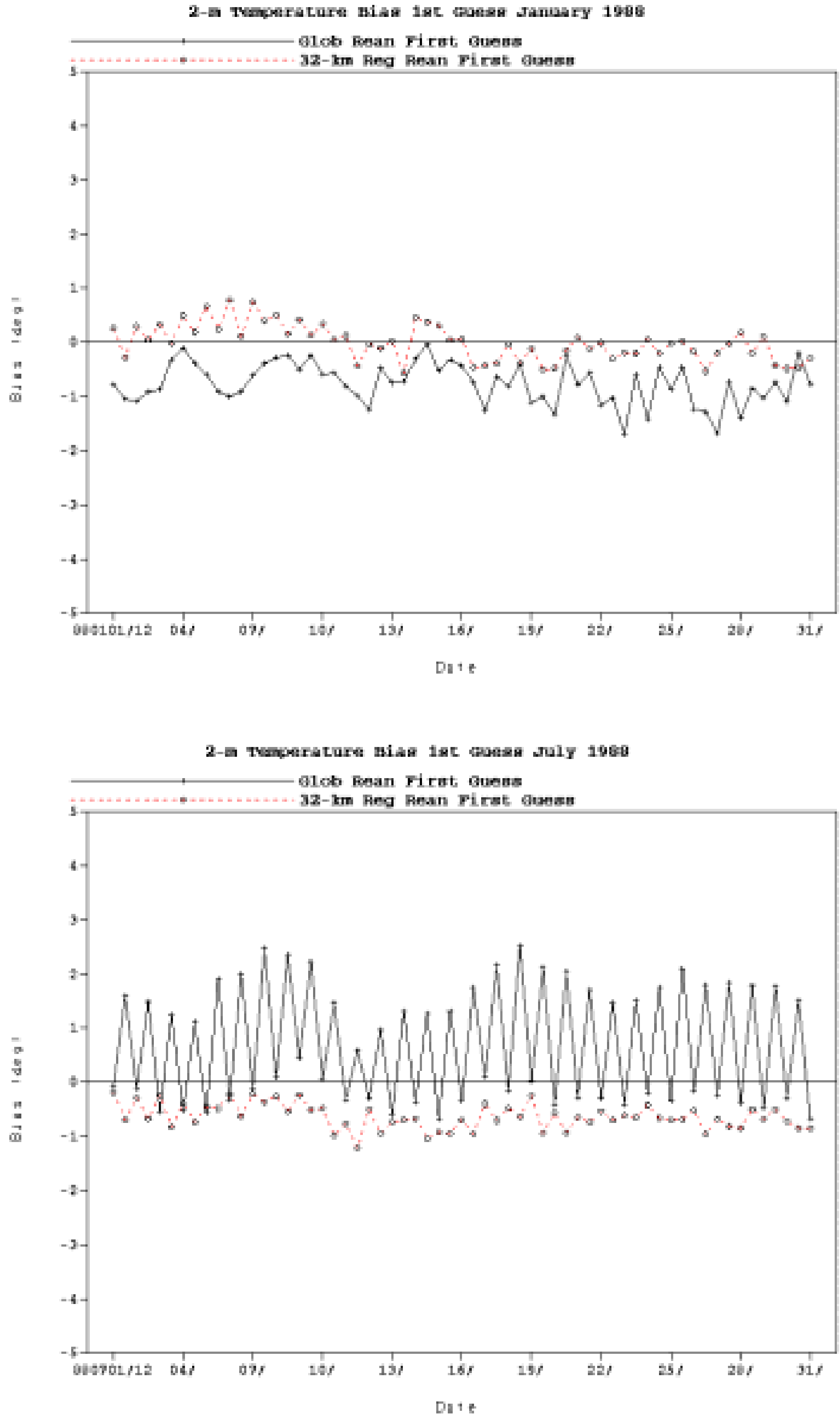

Fig 5. Bias of the first guess 2 m temperatures of the RR (dashed lines) and the GR (solid lines), for January (upper panel) and July 1988 (lower panel), as functions of time.

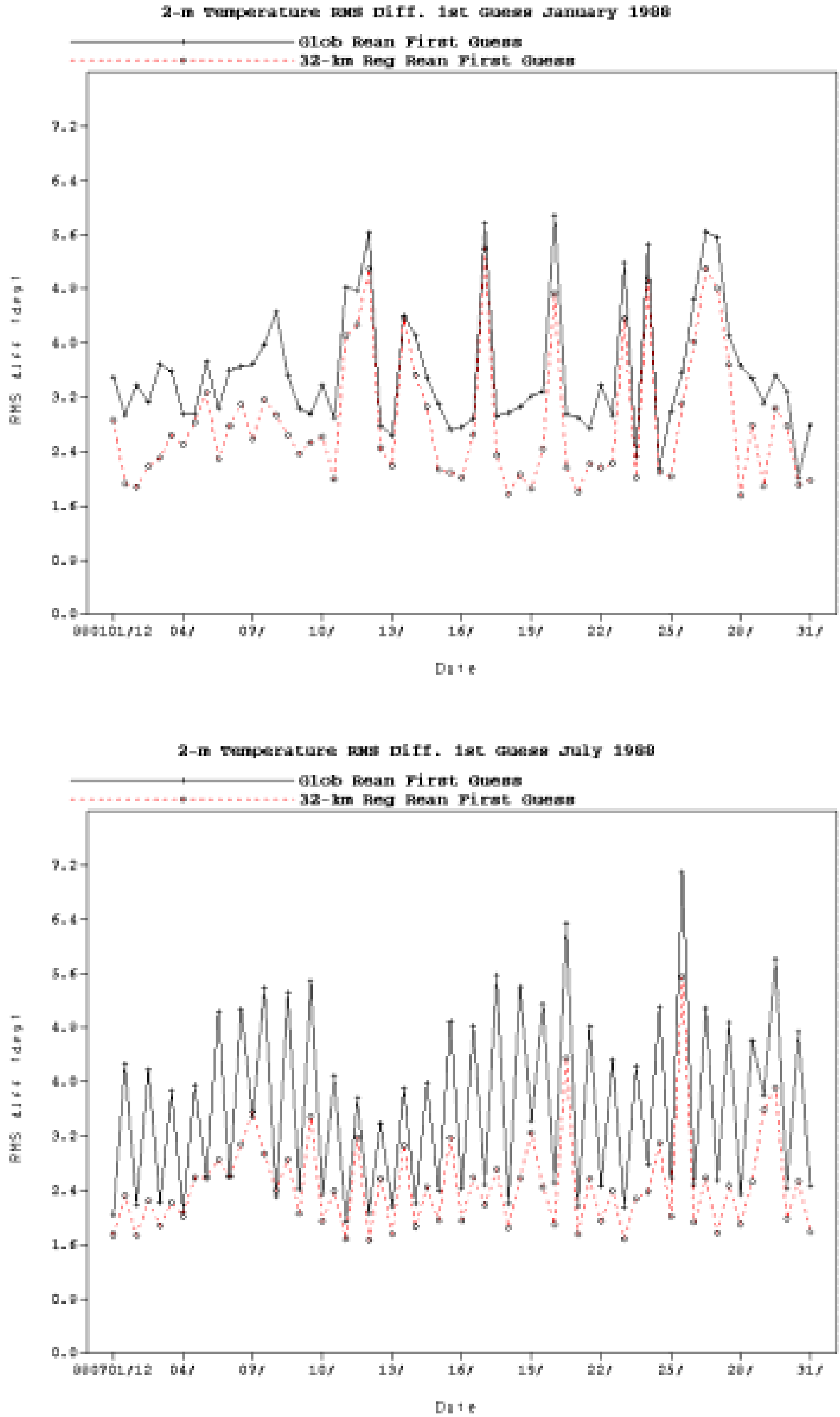

Fig 6. RMS fits to observations of the first guess 2 m temperatures of the RR (dashed lines) and the GR (solid lines), for January (upper panel) and July 1988 (lower panel), as functions of time.

The rms plots seem to be dominated by their bias contributions. Thus, in January, the 62 RR rms values are all less than their GR counterparts. The advantage of the RR is just as clear in July. It is worth noting that the 1200 UTC July RR rms values are almost all less the their GR counterparts, even though their negative biases tend to be greater than those of the GR.

We have also inspected (not shown) the bias and the rms plots of the first guess 10 m vector wind biases and rms fits corresponding to the set of four plots shown in Figs. 5 and 6. Both the RR and the GR were seen to display a very systematic negative bias, but with that of the RR, on the order of up to about 1 m/s, less than that of the GR, which tended to be about 1-2 m/s. However, this bias advantage of the RR was not seen to have resulted in a clear rms advantage. The rms values of the RR and of the GR in fact were seen to be remarkably similar. We are somewhat puzzled by this result. Our tentative explanation is that the gravity wave noise in the RR, at its 3 h first guess time, is more intense that that of the 6 h noise of the GR, thereby making the RR bias advantage unable to result in an rms advantage in this case.

4. Work in progress and plans

While proceeding with our tentative production we are at the same time working intensely on preparation of various data sets ahead of time, so as to be ready for a manifold increase in our production speed once we transfer production to half of the current NCEP mainframe computer IBM SP system, to occur in early 2003. A challenge will be setting up a monitoring system to keep up with the production speed that we expect. The production is to be set up in two streams, one being the present stream that has started in July 1987, and the other to start in 1978, eventually to overlap with the former one.

Results are being and will posted for evaluation by the expected user community as they are becoming available, at http://www.emc.ncep.noaa.gov/mmb/rreanl. Comments on the results posted are most welcome and are hereby solicited.

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