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REGIONAL CLIMATOLOGY SENSITIVITY STUDIES

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Introduction

Recent interest in understanding climate and climate change at regional-scales has led to the application of mesoscale models for regional climatology studies. These models can provide an understanding of climate processes in a physically consistent way at much higher resolution than presently offered by GCMs. The methodology and proof of concept for regional climate modeling was initially undertaken by Dickinson *et al.* (1989) with the Penn State/NCAR mesoscale model (MM4). Bossert *et al.* (1992a) employed the RAMS mesoscale model for preliminary regional climate simulations in a similar fashion to that of Dickinson *et al.* Bossert *et al.* (1992b) discussed the development of a regional-scale climate model for the western U.S. and compared model generated surface fields for a month-long simulation of January 1988 with observed data from over 300 surface cooperative stations.

In the course of our regional climate modeling with RAMS, several questions have arisen which require further investigation. The first involves the model validation procedure. To date, regional climate simulation results have not undergone intense scrutiny and comparison with independent observational data sets. One reason for this is the lack of appropriate mesoscale observations. Particularly in regions of complex terrain, such as the intermountain west, the spatial coverage of existing surface and atmospheric observations is sparse. The second question has to do with grid configurations and physical parameterizations of the regional model and their suitability for long-term simulations. While GCMs are global and were developed to run for extended periods, the evolution of mesoscale modeling has been far different and has focused upon short integration periods on the order of a diurnal cycle, with grid domains covering only a small portion of the globe. Correspondingly, the physical parameterizations within the mesoscale model have not been thoroughly tested for long integration periods. In addition, specification of lateral boundary conditions from high quality, large scale data sets or GCM output is of critical importance to the mesoscale simulation.

In recent work, we have tried to address these questions to establish confidence in our modeling procedure. A more rigorous comparison of our modeling results with various data sets is reported in Roads *et al.* (1992). In the present paper, we use two simple numerical experiments to examine the impact of grid configuration on the predicted precipitation field from the RAMS model. We intend to demonstrate that the choice of the lateral boundaries and grid configurations can significantly impact the predicted fields of interest.

Approach

The experiments described herein are based upon a continuous month long simulation of January 1988 with the RAMS model. A more detailed explanation of the RAMS model is contained in Kao and Bossert (1992) and elsewhere. The specific model configuration and parameterizations used for the regional climate simulation are described in Bossert *et al.* (1992a). The regional climate model was initially developed to simulate the western U.S., in part because the topography of this region is complex and induces a high degree of mesoscale variability which we hoped to capture, and in part because we wanted to test our model with a grid configuration similar to that of Giorgi (1989) for comparison purposes. The actual grid configuration (see Fig. 2, Bossert *et al.* 1992b) was rather arbitrary, the primary requirement being that it include the entire mountain massif of the western U.S.

In comparing the simulated monthly precipitation with actual amounts, we found the greatest differences along the Oregon coast, which was too dry; and over the highest mountain terrain of the Rockies, where the model prediction was too wet. A 5-day period from the month-long January simulation (days 11-15), chosen for the sensitivity experiments, provides a prime example of these differences (Figs. 1 and 2). Figure 1 shows that observed heavy precipitation was limited to the coastal margin of the Pacific Northwest and the Cascade Range. Other regions which received significant amounts include northern California and northern Idaho. Little precipitation was measured over the Southwest or interior ranges of the Rocky Mountain chain. The simulated 5-day precipitation rate (Fig. 2) from the RAMS microphysics scheme shows that the model captured the heavy precipitation over the Cascades in Washington which extended southward into northern California, as well as the precipitation in Idaho, although the amounts there are excessive. The simulated precipitation field does show large departures from observations in other regions, however. For example, the heavy precipitation amounts observed along the coastal margin of Oregon are missing, while substantial precipitation is simulated over the high mountain terrain of Utah and Colorado. Although none of the cooperative stations are at elevations exceeding 2700 m, which prohibits an accurate determination of high mountain precipitation (snowfall) in the central Rockies, the amounts there do appear to be too high, based upon the observed storm track over the period.

To try and understand these precipitation differences, we hypothesized that the National Meteorological Center's 2.5° gridded data, used for model initialization and boundary nudging, may be too dry in the low-levels of the troposphere over the eastern Pacific. The drier lower atmosphere combined with the short advective time scale for flow from the model domain boundary to the west coast led us to speculate that the western boundary of the model domain should be located farther out into the Pacific to allow for surface evaporation, thereby increasing the low level humidity. Consistent with this hypothesis was the high precipitation values over the high Rockies, which suggested that too much moisture was being advected into the intermountain west at mid tropospheric levels and not rained out along the coast.

These obvious shortcomings within the climatology simulations provided the motivation for the sensitivity experiments. For the first experiment, we designed a 5 day simulation with a western boundary of the model domain that extended an additional 5 grid points ($\sim 2.5^\circ$) into the Pacific Ocean. Another consideration for the lack of coastal precipitation concerned the 0.5° resolution of the model, which, while much higher than present day GCMs, was still rather coarse for a mesoscale simulation and did not adequately resolve the coastal range, especially in Oregon. Thus, for our second sensitivity experiment we included a nested grid with 0.125° resolution over the Oregon region to better resolve the topography and thereby produce more realistic orographic lifting within the model.

Results

The results from the 5-day simulation with the extended western boundary are presented in Fig. 3. The figure shows the precipitation difference field between the extended boundary and the control case over the control case domain. The precipitation difference shows that the westward extension does indeed produce the desired effect: increasing coastal precipitation, while reducing snowfall over the high interior ranges of the Rocky Mountains dramatically. The boundary extension increases the precipitation in northern California more than in Oregon, perhaps because this area was closest to the model domain boundary (~350 km) in the control simulation. As a result of this, the precipitation over the central Sierras now appears to be excessive. In addition, the increase of precipitation along the Oregon coast is rather minor, leading us to believe that the grid resolution over this region is inadequate to realistically represent the Coast Range which induces the orographic lift necessary for rainout.

In the second sensitivity experiment we implemented a nested grid over western Oregon to better resolve the coastal mountains. This nested grid was at a 4:1 ratio from the coarse grid, having approximately 0.125° (~13 km) horizontal resolution. Precipitation results on the nested grid for the 5-day simulation are shown in Fig. 4. Total precipitation amounts are heavy along the crest of the Cascades, and along the southern Oregon/northern California coast. The rest of the Oregon coast has only minor rainfall. Thus, despite the higher resolution topography with the nested grid, precipitation is still underpredicted along the Oregon coast. In fact, the coastal mountains are still not well represented, even with this increased resolution. Thus, an even smaller grid may be necessary to resolve this topographic feature, which would increase the computational cost enormously. This point raises the question of what is an adequate grid spacing to achieve "reasonable" results in regional climate models.

The nested grid results are averaged back up to the coarse grid and Fig. 5 shows the resulting difference field between the nested grid run and the control run. In general the precipitation differences appear similar overall to those found in the extended western boundary simulation, with more precipitation over the high terrain and coastal sections of the Pacific Northwest and less within the intermountain west. Several differences are apparent, however. On the favorable side, the nested grid run concentrates the precipitation difference maxima over the Oregon region and reduces that found over the Sierra Nevada. On the unfavorable side, a huge difference appears along the Washington/Canada border. At present, we have no explanation for this large precipitation increase outside the nested grid region.

Summary

In this paper we have presented results from two simple regional climate sensitivity experiments designed to test the impact of grid configuration on the prediction of precipitation. The simulated precipitation was first compared with observed data interpolated to model grid points. Both experiments were found to improve the precipitation field by increasing the amounts in the Pacific Northwest and reducing the amounts within the intermountain west. However, assessing the accuracy of the modeling results is complicated by the fact that the mesoscale precipitation data set used for model validation is too sparse to provide a rigorous evaluation of the model's performance. This is especially the case over high terrain where most of the winter season precipitation falls. This lack of necessary data is of great concern, since validation of the results from regional climate models, especially precipitation, is critical to their future use as a tool for climate change prediction. We are currently examining precipitation data sets from a variety of sources to aid in this validation exercise.

The modeling results show that grid configuration must be given very careful consideration before a regional model can be implemented for climate studies over a particular area of interest. The results presented here suggest that seemingly minor changes in domain boundaries and grid resolution can have a dramatic impact upon predicted results. Looking at the broader picture, our results demonstrate the need for adequate testing of the regional climate model with respect to not only grid configuration but also boundary nudging and physical parameterizations before we can establish confidence in its ability to be a useful tool for climate studies. To date, little attention has been paid to any of these requirements. We plan to continue to develop a regional model which is ideally suited for climate studies by further examining the questions and problems brought out in this paper. Future experiments will examine the impact of nudging upon the predicted fields and the performance of the surface parameterization during a month-long integration.

Acknowledgments

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FIGURE CAPTIONS

Fig. 1. Observed precipitation (mm/day) for the period 11-15 January 1988, as determined from ~300 surface stations interpolated to RAMS model grid points.

Fig. 2. Simulated precipitation (mm/day) for the period 11-15 January 1988 from the RAMS model.

Fig. 3. Precipitation differences (mm/day) between the extended western boundary and control simulations for the period 11-15 January 1988. Shading indicates extended boundary precipitation exceeds control, dashed contours indicate extended boundary precipitation is less than control. Contour interval 2.0 mm/day.

Fig. 4. Simulated precipitation (mm/day) on the nested grid for the period 11-15 January 1988 from the RAMS model.

Fig. 5. Precipitation differences (mm/day) between the nested grid and control simulations for the period 11-15 January 1988. Shading indicates extended boundary precipitation exceeds control, dashed contours indicate extended boundary precipitation is less than control. Contour interval 2.0 mm/day.

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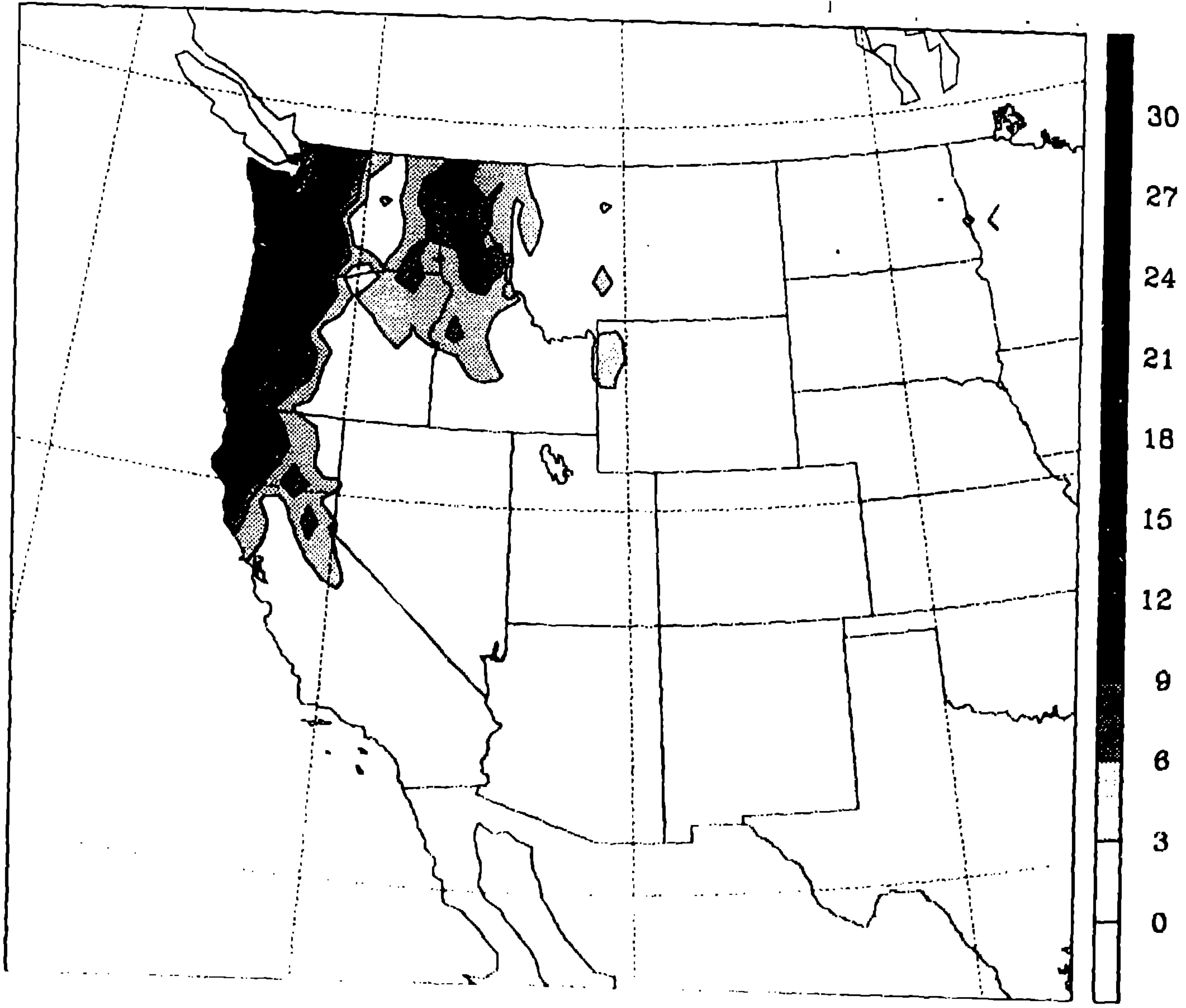

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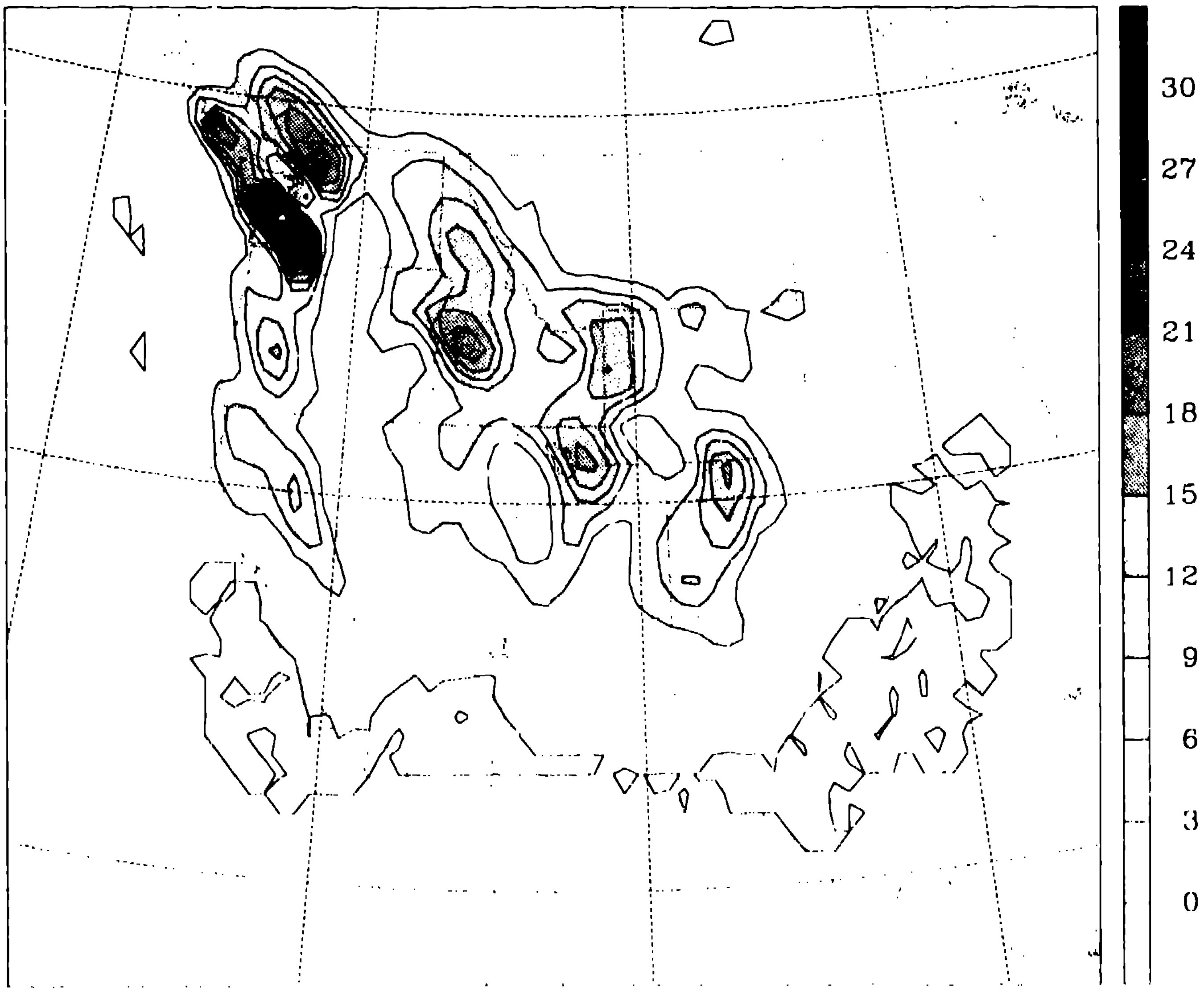
Fig. 1



5-DAY TOTAL PREC. (MM/DAY) CONTROL CASE

Fig. 2

5-DAY TOTAL PREC. (MM/DAY) EXTENDED - CONTROL

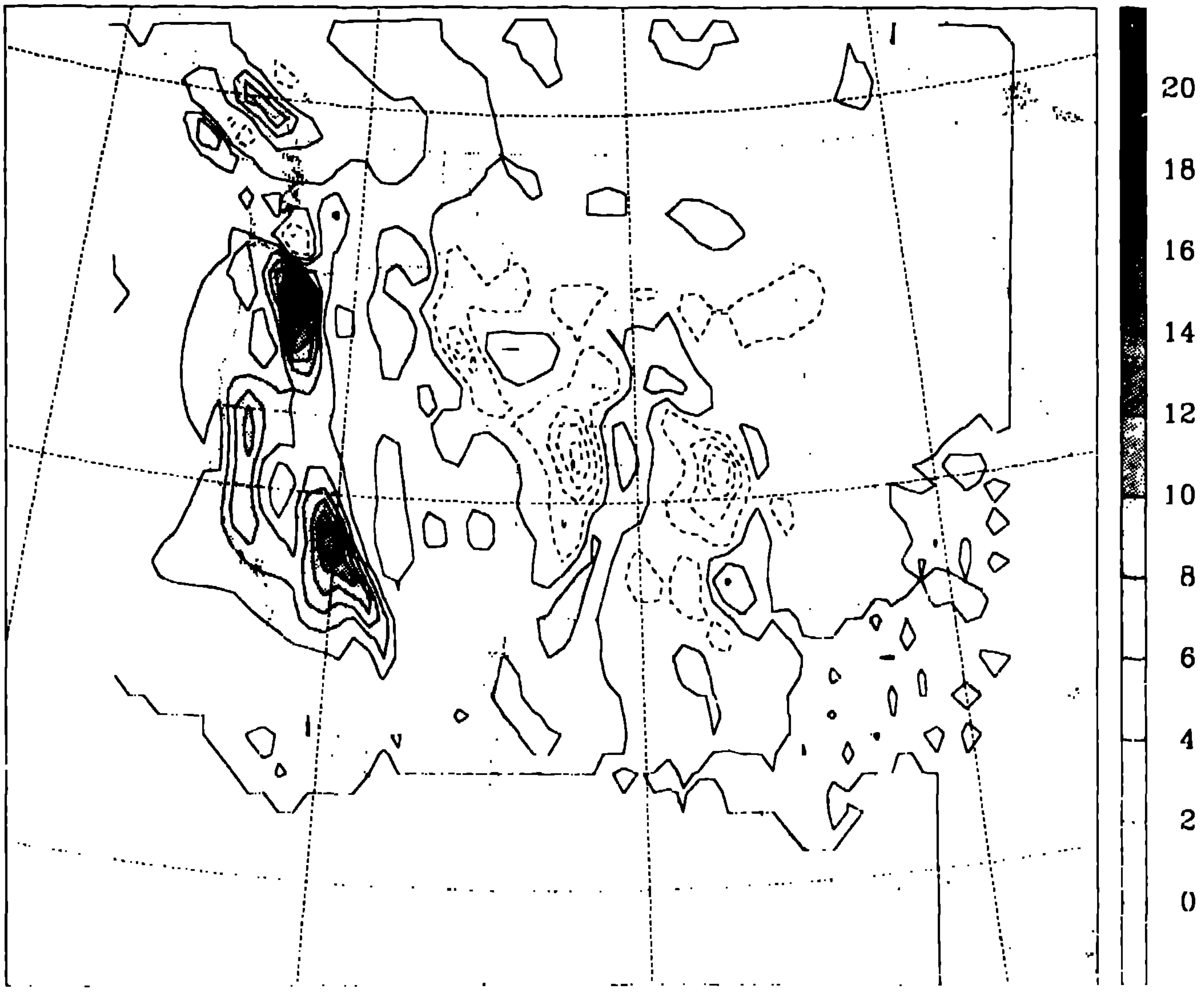


Fig. 3

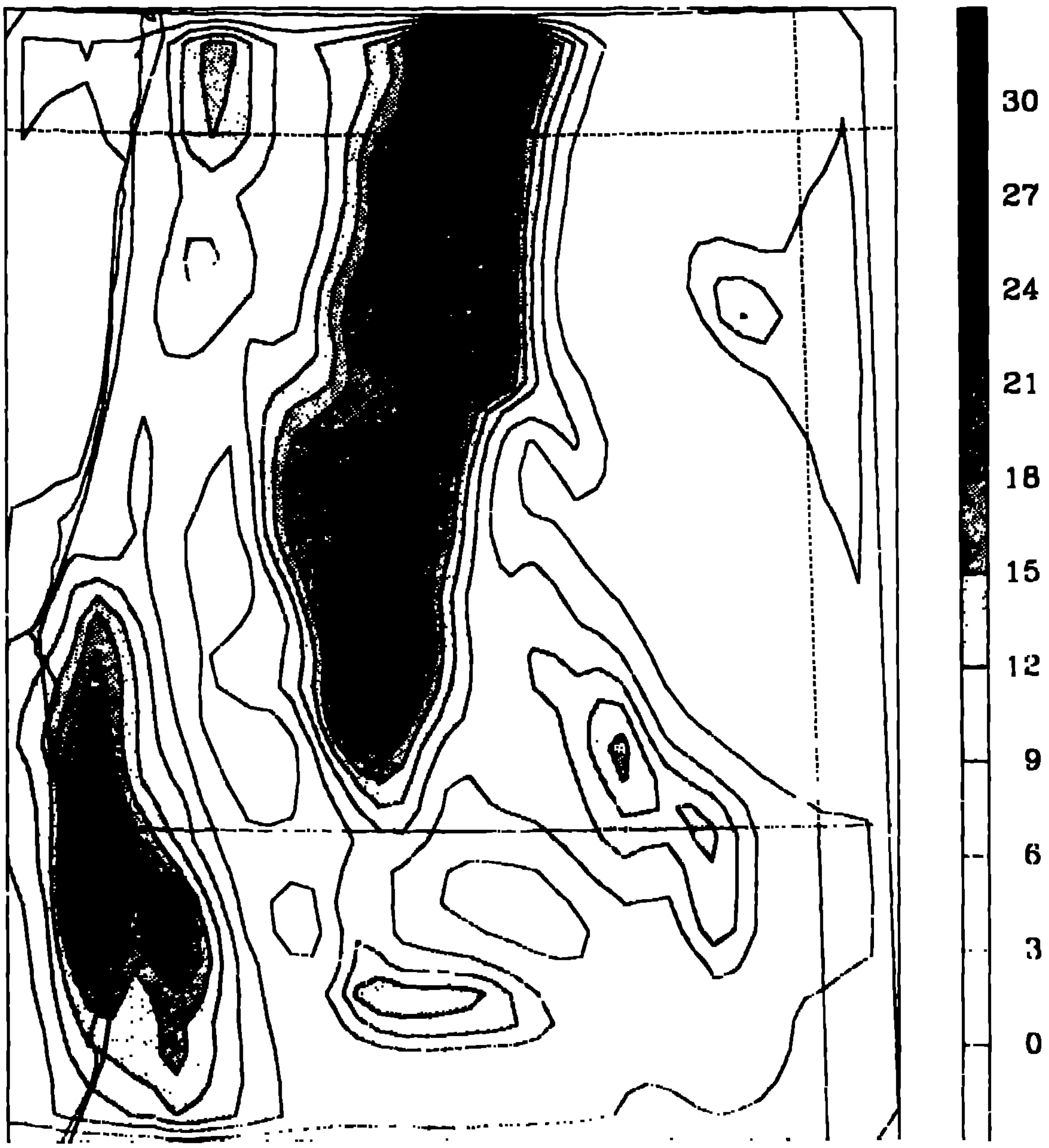
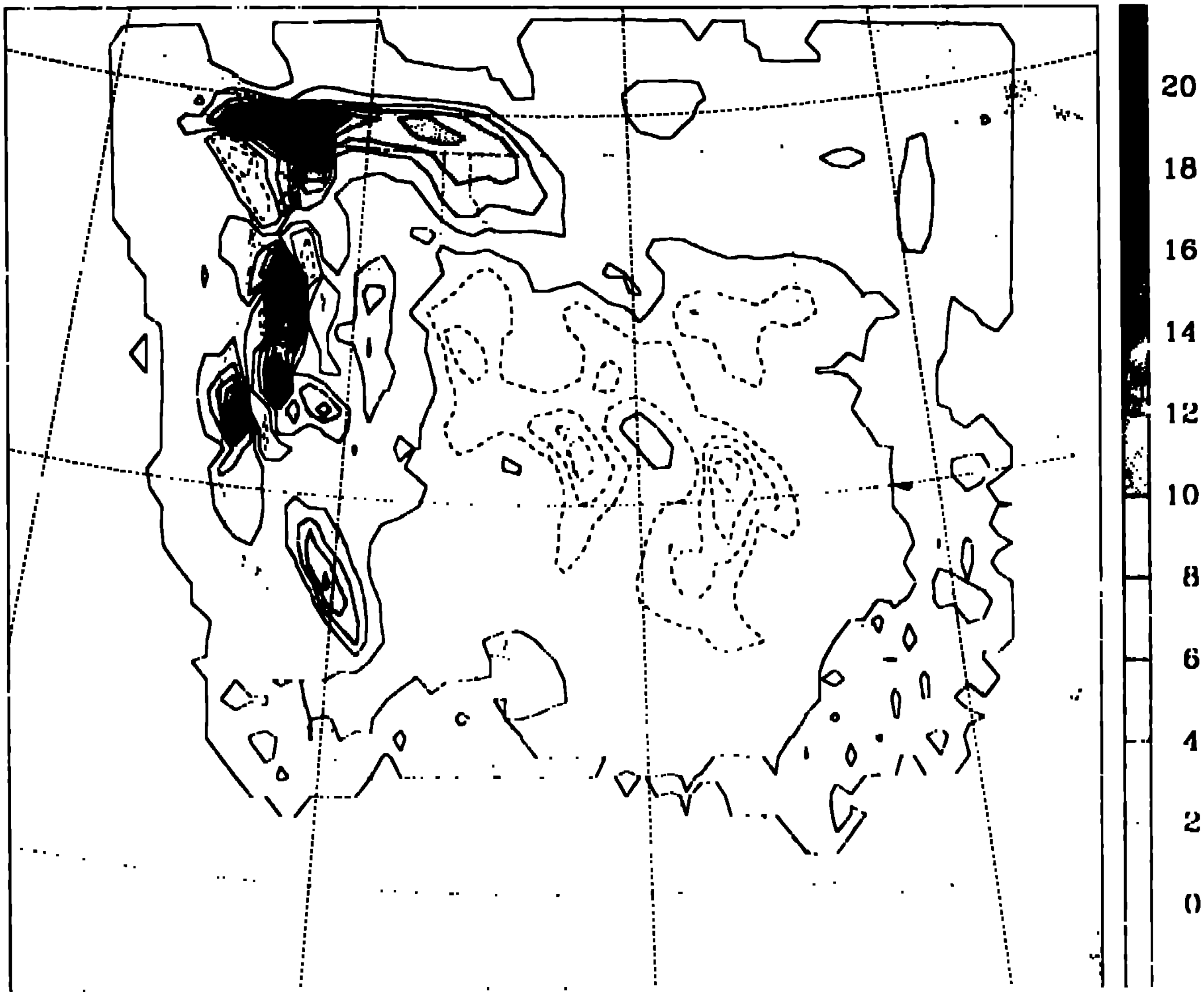

5-DAY TOTAL PREC. (MM/DAY) NESTED GRID

Fig. 4



5-DAY TOTAL PREC. (MM/DAY) NESTED – CONTROL

Fig. 15