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11.1 NUMERICAL INVESTIGATION INTO EFFECTS OF COMPLEX TERRAIN ON SPATIAL AND TEMPORAL VARIABILITY OF PRECIPITATION

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1. INTRODUCTION

This study is part of an ongoing research effort at Los Alamos to understand the hydrologic cycle at regional scales by coupling atmospheric, land surface, river channel, and groundwater models. In this study we examine how local variation of heights of the two mountain ranges representative of those that surround the Rio Grande Valley affects precipitation. The lack of observational data to adequately assess precipitation variability in complex terrain, and the lack of previous work has prompted this modeling study.

The Jemez mountains (highly three dimensional) are situated on the west side of the Rio Grande Valley while the Sangre de Cristo mountains are situated on the east side. The Sangre de Cristo/ Jemez mountains extend 3800/ 3000 m above mean sea level (MSL). Melting of snow (accumulated in winter months from mid October through late March) during spring and early summer months is a major source of water for the Rio Grande river. The other source is surface runoff during the summer months in which the North American monsoon prevails. Thus, it becomes imperative to understand how the local terrain affects snow accumulations and rainfall during winter and summer seasons respectively so as to manage this valuable resource in this semi-arid region. While terrain is three dimensional, simplifying the problem to two dimensions can provide some valuable insight into topographic effects that may exist at various transects across the Rio Grande Valley. We induce these topographic effects by introducing variations in heights of the mountains and the width of the valley using an anlytical function for the topography. The Regional Atmospheric Modeling System (RAMS) is used to examine these effects. RAMS is discussed further in section 2.

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2. MODEL DESCRIPTION AND SETUP

2.1 Model description

RAMS is a widely-used, comprehensive atmospheric modeling system based upon fundamental conservation relationships. A general description of RAMS can be found in Pielke et al. (1992). The model prognoses u, v, w, the ice-liquid water potential temperature (Tripoli and Cotton 1981), the perturbation Exner function, total water mixing ratio, and mixing ratios and number concentrations of all hydrometeor species. Some of the important diagnosed variables are the dry air density, potential temperature, and temperature.

A rigid lid condition (w= 0.0 m s^{-1}) is used for the top boundary. The bottom boundary condition is a rigid wall (i.e., w= 0.0 m s^{-1}) with frictional effects included, i.e., no slip at the bottom boundary indicating the fact that the horizontal velocities go to zero as well. The thermodynamic variables at the bottom boundary are extrapolated linearly from the prognosed values at two grid points above the boundary (Knupp 1985). The current study employs the Klemp-Lilly type lateral boundary condition.

A surface layer scheme based on a soil model developed by Tremback and Kessler (1985) is used in this study. This scheme also includes a vegetation model based on Avissar and Pielke (1989) that has 18 different types of vegetation. We have used the radiation scheme of Mahrer and Pielke (1977) in the current study. A modified Kuo-type cumulus parameterization scheme is also included.

A first-order turbulence clousure scheme is used in horizontal diffusion computations. A Mellor and Yamada (1974) scheme is used to describe vertical diffusion which is based on a second-order turbulent kinetic energy (TKE) formulation, in which the TKE is prognosed by solving the Reynolds stress term with the assumption of isotropic turbulence.

The microphysical parameters used in this study have been chosen based upon Stalker and Bossert (1998) who examined their sensitivity on precipitation.

2.2 Model setup

The two dimensional simulation domain has an east-west extent of 603 km and the vertical dimension of the domain extends to ~15.0 km. The horizontal grid spacing used is 3 km while the vertical grid spacing varies from 400 m near the surface to 600 m with a stretching factor of 1.1. The time step used in these simulations is 4 s. The domain has a base elevation of 2100 m MSL. The two mountains are raised above this base height from 100 m to 1000 m for the western mountain and from 100 m to 1600 m for the eastern mountain. The valley between the two mountains is located at 1750 m MSL. In addition to the variation in height, three different valley widths of 36 km, 84 km, and 132 km are also tested in this study. This variation in height of the western mountain changes the Froude number by as much as 90% for any set of upstream conditions. These experiments thus provide a variety of scenarios of topography-induced dynamics.

Soundings used to initialize RAMS have been obtained from the Albuquerque airport. The airport is located at 35 N, 106 W, and ~1619 m MSL. The 1200 UTC 3 December 1992 sounding is used for winter simulations while the 1200 UTC 18 July 1993 is used for summer simuations. Strong winds in excess of 10 ms^{-1} were (below 3 km MSL) observed in the winter sounding. The freezing level of the winter sounding is found near 2.8 km MSL. In the summer sounding a shallow layer of weak winds (< 3 ms^{-1}) is found below the freezing level of 5 km MSL.

3. RESULTS

The domain of interest that includes the two mountains and the valley is divided into 4 regions (see Fig. 1). The windward and the lee sides of mountain 1 (western) are designated as regions I and II and those of mountain 2 (eastern) are designated as regions III and IV.

As the height of mountain 1 is reduced from 1000 m to 400 m total precipitation on the windward face of mountain 2 increases irrespective of the width of the valley (Fig.2a, b, and c). If this height is further reduced to 100 m the total precipitation is reduced drastically. The Froude number correspondingly increases as the height of mountain 1 is reduced. This shows that there is a critical Froude number above which the upstream conditions do not affect precipitation on the windward face of mountain 2. In other words mountain 2 behaves as if there was no mountain 1 (Fig. 2d). As the Froude number is decreased by increasing the height of mountain 1 the two mountains seem to be strongly coupled dynamically leading to increased ascent on the winderward face of mountain 2. When the height of mountain 1 is 1000 m the contribution of mountain 1 to enhancement of ascent on the western face of mountain 2 is significantly reduced in terms of weak upward motion on the windward side of mountain 2 (see Fig. 2a). There is a correpsonding reduction in total precipitation on the middle to upper portions of mountain 2. This nonlinear interference of the two mountains on one another in precipitation variability will be further analyzed in future two and three dimensional studies for other atmospheric conditions. In addition to wave dynamics, microphysical processes that can occur over mountain 1 seem to reduce the effectiveness of that ascent in precipitation growth in three important ways: 1) moisture is considerably depleted over mountain 1 when it receives signficant precipitation and thus less precipitation on the windward face of mountain 2, 2) possible increase in stability due to cooling associated with melting in the valley ,and finally 3) possible water loading. These three possible mechanisms will be further analyzed in future studies.

Increased spatial varibility in relative precipitation amounts in the 4 regions vary significantly as a function of the width of the valley (See Fig. 3). Fig. 3 shows that a relative maximum precipitation amount is produced in region IV for both winter and summer (not shown) simulations of 230 mm and 675 mm respectively and a relative minimum amount in regions II and III when the valley width is only ~36 km. Fig. 3 also shows that a relative maximum precipitation amount is also produced in regions I and III for a width of ~84 km. We will explore this spatial variability as a function of valley width to determine if it is either dynamically or microphysically induced in future studies.

4. SUMMARY AND FUTURE WORK

The two dimensional simulations produce variability of precipitation due to changes in the upstream conditions. These changes are introduced by varying the height of mountain 1. The upward motion (ascent) on the windward face of mountain 2 is affected by the height of mountain 1. The amount of enhancement of ascent due to upstream effects on the windward face of mountain 2 is significant for heights between 1000 m and 400 m and becomes less significant for heights below 100 m. Thus, precipitation augmentation on the windward face of mountain 2 is favored for a range of upstream conditions (heights). This amount increases to a relative maximum at 400 m before it goes to a relative minimum at 100 m. This preliminary two dimensional study indicates that the north-south variability of precipitation on the western face of

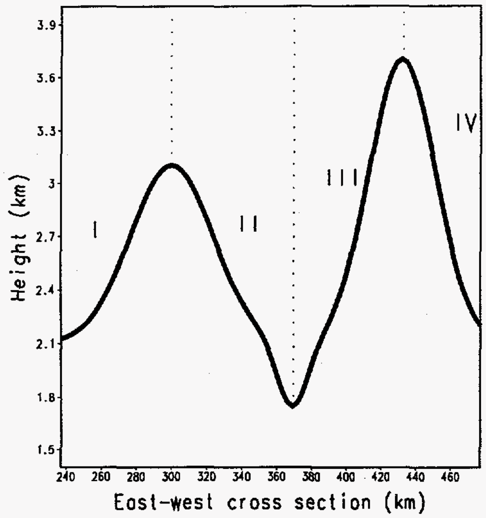

Figure 1. The two-dimensional domain is divided into four regions to analyze variables of interest.

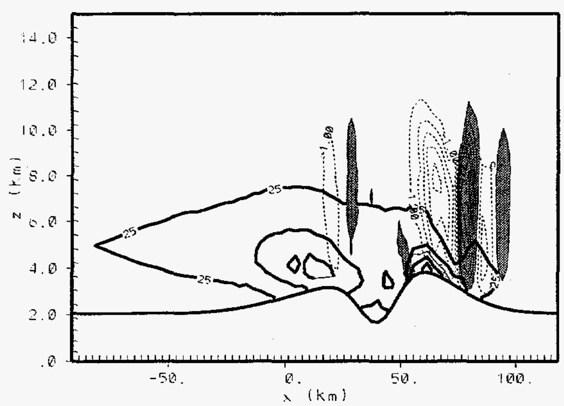

Figure 2. (a) Solid contours show aggregate mixing ratio ; shaded regions are areas of upward motion and dashed contours indicate downward motion. The height of the western mountain is 1000 m above the basin height.

the Sangre de Cristo mountains may be influenced by local terrain heights of the Jemez mountains. The heights of the Jemez mountains fall toward north and south directions from the 36 N latitude.

In addition to examination of the dependence of valley width we will also explore sensitivity of variation of the height of mountain 2 on precipitation on the lee side of mountain 1. The insight gained from these two dimenstional experiments will help us understand how precipitation varies over common landforms. These idealized studies can then aid in three dimensional studies of precipitation variability in complex terrain.

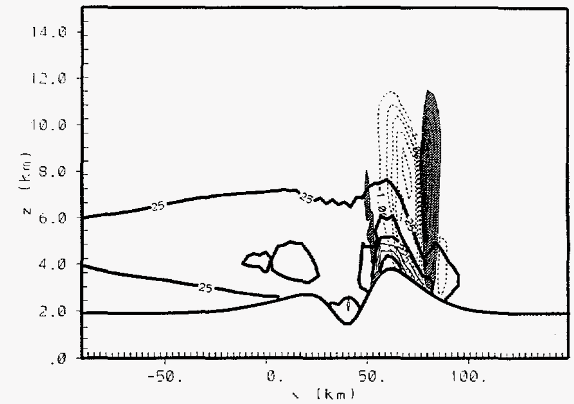

Figure 2. (b) Solid contours show aggregate mixing ratio ; shaded regions are areas of upward motion and dashed contours indicate downward motion. The height of the western mountain is 700 m above the basin height.

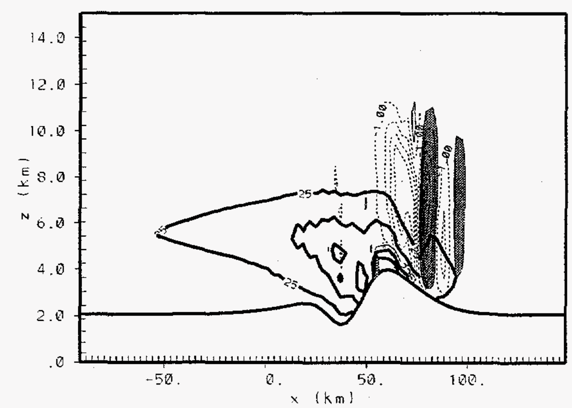

Figure 2. (c) Solid contours show aggregate mixing ratio ; shaded regions are areas of upward motion and dashed contours indicate downward motion. The height of the western mountain is 400 m above the basin height.

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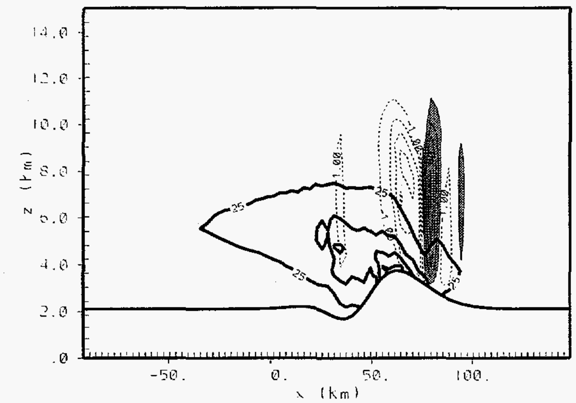

Figure 2. (d) Solid contours show aggregate mixing ratio ; shaded regions are areas of upward motion and dashed contours indicate downward motion. The height of the western mountain is 100 m above the basin height.

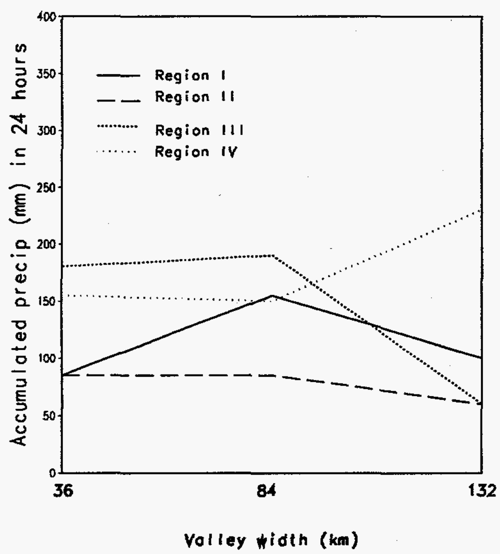

Figure 3. Accumulated precipitation in 24 hours in 4 regions for heights of 1000 m (western mountain) and 1600 m (eastern mountain) above the basin height. It shows how valley width affects regional total precipitation amounts.

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