10.8 FAVORED REGIONS OF CONVECTIVE INITIATION IN THE ROCKY MOUNTAINS

Donna F. Tucker*
University of Kansas
Lawrence, Kansas

N. Andrew Crook
National Center for Atmospheric Research
Boulder, Colorado

1. INTRODUCTION

A number of studies have shown that thunderstorms in the central Rocky Mountains have preferred initiation locations (e.g. Karr and Wooten 1976; Lopez and Holle 1986; Klitch et al. 1985). A detailed study of this problem was performed by Banta and Schaaf (1987) who used satellite imagery to trace individual thunderstorms back to their points of origin in the central Rocky Mountains over a period of three summers. They not only found that there were preferred regions of thunderstorm formation but that these areas varied with the prevailing wind direction. They defined three major flow patterns for this region: southwest, northwest and curving southerly.

These observational studies did not address all the causes for why one region is preferred for convective initiation over others. In the absence of baroclinic systems, mountains can initiate thunderstorms by a number of different mechanisms as summarized by Banta (1990). It could be argued, however, that the baroclinicity associated with the different wind regimes causes the observed dependence of initiation locations on wind direction. Thus, it has not been determined whether the preferred regions of thunderstorm initiation are caused by direct interaction between the mountains and wind patterns, resulting in preferred areas of mass and moisture convergence, or by baroclinic forcing mechanisms which are associated with the wind regimes.

We are investigating the physical causes behind these preferred initiation locations. This paper will concentrate primarily on the sensitivity of these favored areas to the wind direction. Although this problem is important in itself, we also believe these preferred sites of convective initiation influence the location of subsequent convective development over the adjacent plains. Tucker and Crook (1999) have shown that outflow from mountain thunderstorms can trigger the development of a Mesoscale Convective System (MCS) on the plains.

2. SUMMARY OF PREVIOUS RESULTS

For this investigation we have been using the Clark-Hall model (Clark and Hall 1991) as a simulation tool. The model is anelastic and nonhydrostatic. It has a terrain-following grid (Clark and Hall 1996) so that it can represent the effects of fine scale topography. It contains parameterizations for atmospheric liquid water, ice microphysics, radiative cooling and turbulent fluxes.

A grid structure has been chosen with two nested grids. The inner grid has a spacing of 2.6 km and covers central and western Colorado and northern New Mexico. The outer grid has a spacing of 7.8 km and covers a wider portion of the central United States. Output will be shown from the inner grid only. The vertical grid has 48 levels.

In a previous paper (Tucker and Crook 2000) we reported results of simulations using composite soundings designed to represent the three regimes identified by Banta and Schaaf (1987). Thus, we initialized the model from a single sounding and the initial fields of the model included no horizontal gradients. We found that many of the convective initiation sites identified by Banta and Schaaf (1987) appeared in our simulations. These simulations reflected realistic differences in the initiation sites for each of the three wind regimes. Furthermore, a few sites identified by Banta and Schaaf (1987) which did not appear in our simulations of the composite soundings were present in simulations from individual members of the composites. Therefore, our results indicated that the preferred areas of convective initiation, that were previously identified, arose as a result of interaction between the mountains and the wind fields and were not the caused by any type of baroclinicity or by horizontal gradient patterns associated with the flow regimes. This outcome also indicates that there is more sensitivity of the initiation locations to the wind direction than can be represented in the three types of wind regimes identified by Banta and Schaaf (1987).

We have also looked into the role of wind shear and found that in greater wind shear the convection propagates more strongly downstream. With greater wind shear, new cells are more likely to form from thunderstorm outflow (Weisman and Klemp 1986). Convective propagation in the model was also sensitive to the amount of evaporation of falling precipitation. Since we are most interested in the initiation locations, we decided to do a series of simulations without any directional wind shear in the initial field. The convective activity which initiates will advect downstream but production of new cells from thunderstorm outflow will be reduced making the initiation points of the convective activity clearer to see.

3. NO DIRECTIONAL SHEAR SIMULATIONS

We did a series of simulations with initial wind directions from 180, 210, 240, 270 and 300 degrees.

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* *Corresponding author address:* Prof. Donna F. Tucker, Department of Physics and Astronomy, University of Kansas, Lawrence, KS 66045-2151; email: dtucker@ukans.edu

Although there was no directional shear in the initial fields, there was speed shear with wind speeds varying from 3 m/s near the surface to 25 m/s just below the tropopause. All simulations were started at 12 UTC. The temperature and dewpoint profile is derived from a composite of cases with curving southerly flow on days when a Mesoscale Convective Complex developed in the area. Initially, the sounding has a CAPE of only 46 J/kg, however, this value increase during the day as a result of surface fluxes of heat and moisture.

The accumulated precipitation 12 hours into each simulation is presented in Fig. 1. In each case the precipitation propagates downwind of the initiation sites. Simulations at 180, 210, and 300 degrees had relatively more initiation sites than the other two simulations. In many cases initiation sites are located downwind of the highest terrain. This behavior is the type we would expect if convective activity is triggered by heating induced upslope flow over the high terrain with precipitation developing slightly later. Not all areas of high terrain, however, act as initiation sites. Furthermore, the direction of the wind is important. Some areas act as initiation sites for wind in one direction but not in others. But there are some sites that initiate convection for all wind directions (e.g. northern San Juan mountains). Overall it appears as though some minimum fetch over terrain of some minimum height is needed for convective initiation to take place. Some terrain configurations can provide this minimum fetch in all directions, some only in particular directions.

The average precipitation per grid point over the entire domain has been calculated for each wind direction and is listed above each figure. Note that the flow from 270 degrees was the one that produced the most precipitation at a specific location but only the second highest total. It had fewer initiation sites than other flow patterns. The Rocky Mountains are predominantly north-south oriented. Thus, it is more difficult to get the minimum fetch from winds straight out of the west. Flow from 300 degrees had the highest total amount of precipitation. Northwest flow is not generally associated with high precipitation amounts in this region. The results presented here would suggest that is because northwest flow is generally associated with less moisture availability than other types of flow. With the same amount of moisture available to it, this flow type produces a relatively large amount of precipitation. Mesoscale Convective Systems are less likely to be generated over the adjacent plains under northwest flow conditions than under more southerly flow conditions. Likewise, the smallest amount of precipitation is produced with flow from 240 degrees. This wind direction is generally considered to be a favorable one for producing precipitation. It would appear that this flow is favorable mostly for the higher moisture content which often accompanies it.

Flow from 180 degrees has a couple of strong initiation sites in the Sangre de Cristo mountains but most of the sites are further north. The same general pattern holds for flow from 210 degrees. The 240 degree flow pattern has few initiation locations with some preference for the central part of the domain. The straight westerly flow also has few initiation locations but they show no preference for a particular part of the domain. Initiation locations for flow from 300 degrees are numerous and well distributed.

Flows from 180 and 210 are similar to the curving southerly flow observed by Banta and Schaaf(1987). Their results show that this flow pattern was more likely than others to have convective initiation points in the northern part of the domain (northern Colorado). Our results indicate that the interaction of the winds and the mountains would favor more convective initiation points in northern Colorado than in southern Colorado with the more southerly flow. On the other hand, northwesterly flow composite by Banta and Schaaf had more initiation points in southern Colorado. Our results for northwesterly flow show initiation points do not prefer southern Colorado over northern Colorado. Some other factor associated with northwesterly flow, perhaps the moisture distribution, appears to cause this preference.

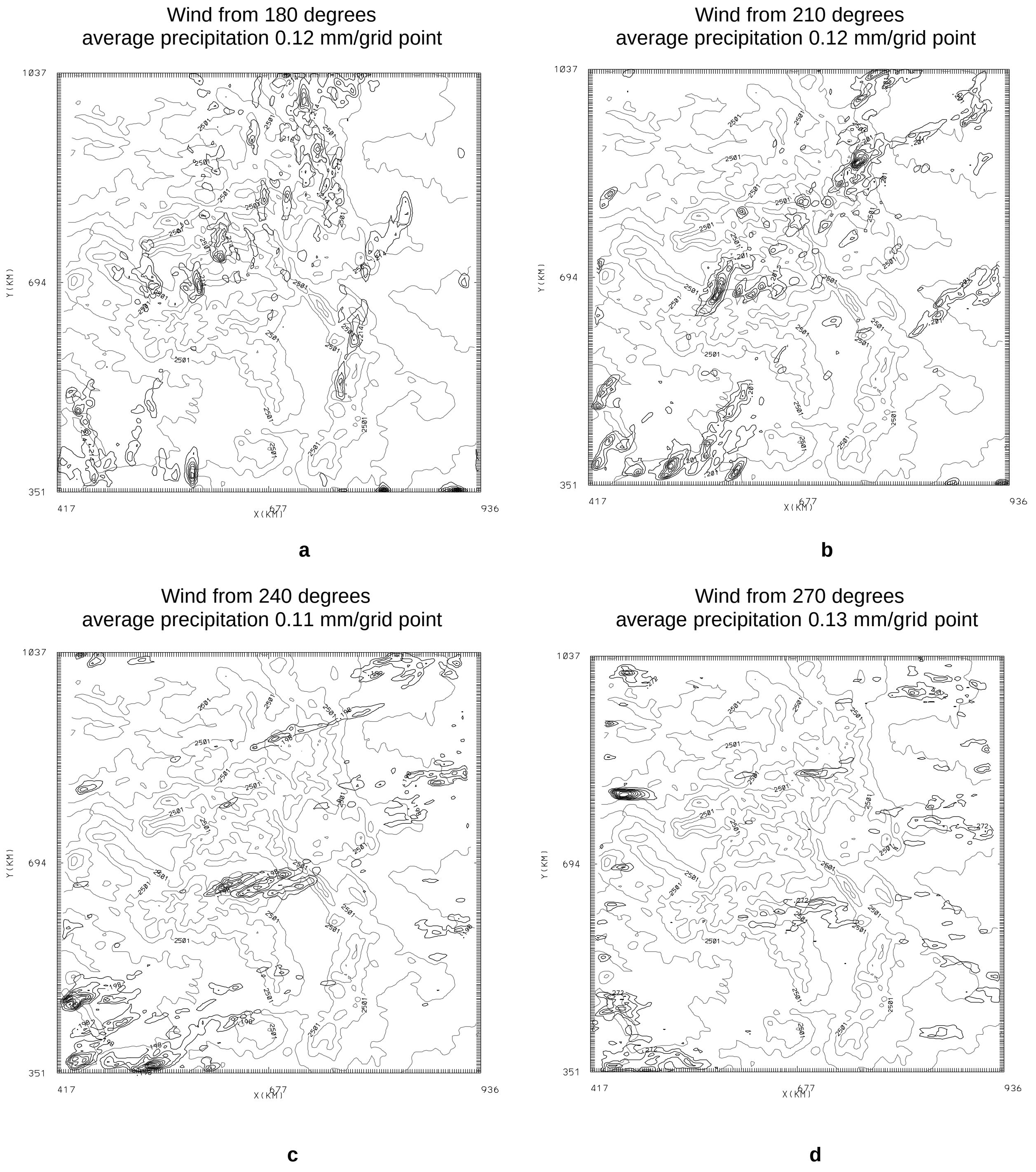
4. CONCLUSIONS

The preferred areas of convective initiation previously observed by other investigators can be explained almost entirely by the interaction of the winds with the mountains. Banta and Schaaf (1987) investigated three different wind regimes. Our results indicate that there is much more sensitivity of the convective initiation locations to the wind direction than can be explained by these three wind regimes. In this paper we have presented results from the numerical simulations of five different wind directions.

Our results indicate that a certain minimum fetch over terrain of minimum height is necessary to initiate convection. Some terrain features can initiate convection for all wind directions, some for only a few, some for only one. It may be that there is still more sensitivity of the convective initiation locations to the wind direction than we have presented in this paper and we plan investigate this possibility. The flow directions varied somewhat in their potential to produce precipitation, but flows with high potential to produce precipitation were not generally associated with high moisture availability in this region.

We also plan to examine the depdendence of the initiation sites on the CAPE in the sounding. We obviously expect that the domain integrated precipitation will increase with larger CAPE, however, whether that increase will occur through an increase in initiation sites or through an enhancement in the strength of existing convection is currently not clear.

Although real world situations have horizontal variations in wind direction, speed and stability which would make them more complex, our results imply that it should be possible to predict at least the initial locations of convective activity in the Rocky Mountains given the wind direction. Thus, there is hope for improvement of precipitation forecasts in this region.



Wind from 180 degrees
average precipitation 0.12 mm/grid point

a

Wind from 210 degrees
average precipitation 0.12 mm/grid point

b

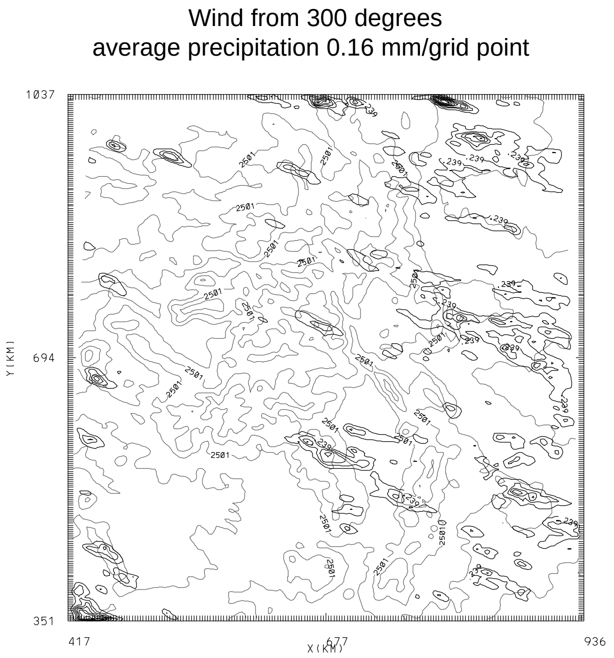
Wind from 240 degrees
average precipitation 0.11 mm/grid point

c

Wind from 270 degrees
average precipitation 0.13 mm/grid point

d

Fig. 1 Model generated precipitation 12 hours into the simulation valid 00 UTC (18 LST). Thin light grey lines are surface elevation contoured every 500 m. a) initial wind from 180 degrees, maximum contour 21.5 mm, minimum contour 2.15 mm. b) initial wind from 210 degrees, maximum contour 20.2 mm, minimum countour 2.02 mm. c) initial wind from 240 degrees, maximum contour 19.8 mm, minimum contour 1.98 mm. d) initial wind from 270 degrees, maximum contour 27.3 mm, minimum contour 2.73 mm.


Wind from 300 degrees
average precipitation 0.16 mm/grid point

e

Fig. 1 cont. e) initial wind from 300 degrees, maximum contour 24.0 mm, minimum contour 2.40 mm.

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