P 2.26 INFLUENCE OF AMBIENT FLOWS AND TOPOGRAPHY ON THE INTERANNUAL SIGNAL AND MEDIUM-RANGE PREDICTABILITY OVER THE WESTERN U.S. DURING WINTER

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1. INTRODUCTION

The purpose of this research is to study the mechanical influences of orography and large-scale ambient flows on surrounding low-level circulations. This perspective is based upon a relatively old dynamical theory, which states that sufficiently strong westerly winds tend to produce anticyclonic responses over orography while relatively weaker winds tend to produce cyclones over orography (e.g. Charney and Devore, 1979; expanded upon by Byerle and Paegle, 2002). These conclusions also depend upon the horizontal extent and latitudinal position of the most prominent orography. The simple theory appears to explain climatological, annual and interannual variations observed around the largest mountain ranges. Previous work by Byerle and Paegle (2002, 2003) has explored the seasonal cycle and deviations from climatology around the Andes, Rockies and Tibetan plateau, focusing on the summer season. In the former two regions, they found that a low-level jet (LLJ) and precipitation response occur east of the mountain ranges with respect to variations of ambient zonal flows interacting with orography during summer. The LLJ is a component of the mean, lower troposphere, eddy, cyclonic circulation which persists around the Andes and Rockies during summer. They also hypothesize that if anomalously strong and broad, upper-level zonal flow exists over the orography, that the associated large inertia would lead to a predictable response in all components, including the LLJ (e.g. the Great Plains LLJ) and precipitation response, for a relatively long period. They used a global model to examine 13-day simulations during the summer 1993 Mississippi River basin floods and the extreme summer droughts over the region in 1988.

This presentation extends the research above, exploring the winter case around the Rocky Mountains. Diagnostics from the NCEP/NCAR Reanalysis and 15-day integrations of the Utah Global Model (UGM, Paegle, 1989) suggest pronounced mechanical flow modifications associated with ambient flows over orography also exist during the winter season, and that a predictable response may also be present.

2. SEASONAL CLIMATOLOGY AND DEVIATIONS

The Rocky Mountain region has a pronounced reversal in the low-level circulation between summer and winter. A transition from a winter anticyclone to a summer cyclone has often been described in terms of thermal influences, such as “thermal low” in summer; or “cold-core anticyclone” and associated stagnant conditions in winter. Peyrefitte (1986) analyzed Great Basin surface anticyclones from 1962-77. He found an anticyclone 64% of the time when snow cover over the plateau was 80% or more. He could not identify one instance during the 15 years when the plateau anticyclone persisted for more than three days with no snow cover. Gutzler and Preston (1997) examined winter snow cover as it related to summer time convection over the Southwest and suggested a thermal explanation for the seasonal oscillations. They described surface heating in relation to dry and wet soils that occur in dry and snowy winters, respectively. This study provides an alternate explanation, emphasizing dynamical processes associated with ambient flows over the Rocky Mountains.

Fig. 1 displays the 700 mb eddy geopotential winds and heights using a 50-year seasonal average (1951-2000) from the NCEP/NCAR Reanalysis monthly archives. The eddy field is defined by removing the zonal average in order to view the wave portion of the field. An anticyclonic circulation persists around the Rocky Mountains in the lower troposphere during winter (Fig. 1a). The 200 mb eddy field (not shown) includes an anticyclone over the western U.S. during winter, whose center is displaced west of the 700 mb anticyclone. The westward tilt suggests the baroclinic nature of the midlatitude eddy anticyclone. The lower troposphere cyclone is replaced by a trough in the summer (Fig. 1b), centered just off the west coast of California.

Fig. 2 shows 50-year time correlations (1951-2000) during winter (DJF) which illustrate deviations from climatology. In Fig. 2a, the area-averaged, 200 mb zonal flow in the outlined box (30˚-50˚N, 120˚-100˚W) is correlated with 700 mb wind at all locations on the map. The eastward/northward component of the vectors denotes the magnitude of the correlation coefficient between the area-averaged, upper tropospheric wind in the box against the local zonal/meridional flow component at 700 mb. Correlation coefficents of 0.3 are statistically significant at the 99% level. The counterclockwise (cyclonic) orientation of the correlation vectors over western North America suggests that as the upper troposphere zonal flow over the mountains (given by the area average in the box) blows stronger than climatology, then the 700 mb eddy anticyclone weakens over the region. Fig. 2b depicts a 50-year time correlation of area-averaged, 200 mb zonal flow in the outlined box with precipitation during winter. Precipitation is from gauge observations over land (PREC/L, Chen et. al., 2002). The highest correlation coefficients are centered over the West, suggesting a precipitation response that impacts winter hydrology and snow pack generation over high terrain. Enhanced, upper troposphere westerlies tend to weaken the climatological anticyclone (see Appendix of Byerle and Paegle, 2002), and may lead to more transient storm tracks (e.g. Paegle, 2000). Anomalously strong, zonally-aver-

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aged winds may be promoted, for example, during warm, El Niño Southern Oscillation (ENSO) events.

3. UTAH GLOBAL MODEL (UGM) SIMULATIONS

The contrasting flow regimes of February 1977 and February 1986 offer case studies of the mechanical effects of orography over North America during winter. The DJF, area-averaged, 200 mb zonal flow impinging upon the Rocky mountain region was about 10 m/s weaker in 1977 than 1986. Observed, ensemble precipitation totals from the CPC Unified data set (Higgins et al., 1996) in Figs. 3a and 4a, indicate the contrast in precipitation between the two months.

15-day simulations of UGM, ensemble-averaged, accumulated precipitation are presented in Figs. 3b and 4b during February-March 1986 and 1977, respectively. The UGM is similar to most global models used in operational prediction centers. It is hydrostatic, and predicts vorticity, divergence, thermal and moisture fields on pressure-based sigma coordinates. The model contains 20 vertical levels, wave number 42 truncation in longitude and 2˚ latitude spacing. Initial conditions are daily, 00 UTC fields from the NCEP/NCAR Reanalysis. The ensemble consists of the 15-day precipitation accumulation averaged for ten forecasts, each beginning 24 hours apart, from 6-15 Feb. Surface latent heat flux is specified over the globe using the 49-year (1951-1999) NCEP/NCAR Reanalysis average for February. The forecast differences in 1986 and 1977 are thus entirely due to differences of the initial atmospheric state, and of the initial air flow over the Rocky Mountains.

The areal extent of model accumulated precipitation is fairly representative in both simulations, but peak magnitudes are under-represented compared to observations (Figs. 3a and 4a). The time evolution of area-averaged, accumulated precipitation for a box encompassing most of the western U.S. (125˚-110˚W, 34˚-50˚N) is displayed in Fig. 5. Observations (CPC Unified) show more than five times more precipitation in 1986 than in 1977 over the area-averaged region. The model ensemble underpredicts precipitation by about 20% to 30% after the first week in 1986 (Fig. 5a), but predicts about 70% of the 15-day accumulation. In 1977, the observed, area-averaged accumulated precipitation is under 2 cm after two weeks, and the model over-predicts 15-day accumulations (Fig. 5b). The sensitivity of the initial, global surface temperature was tested for each case. The 1986 simulations were repeated with the global, monthly-averaged, reanalyzed 1000 mb temperature (interpolated to the lowest sigma level) from 1977, and again with the 1977 simulations using the 1986 monthly-averaged surface temperature. The curves, plotted with open circles in Fig. 5, indicate little impact on the model precipitation averaged over most of the western U.S. Ensemble results during the wet and dry cases suggest an important role for the initial, large-scale circulation. These may be tied to the strength of ambient zonal flows over the high topography of western North America during winter.

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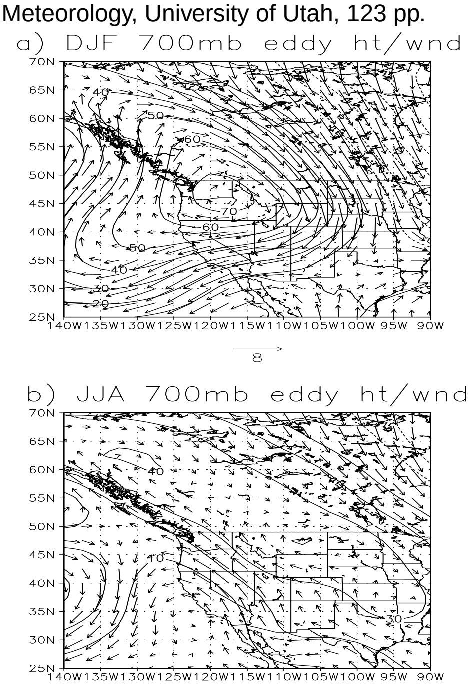
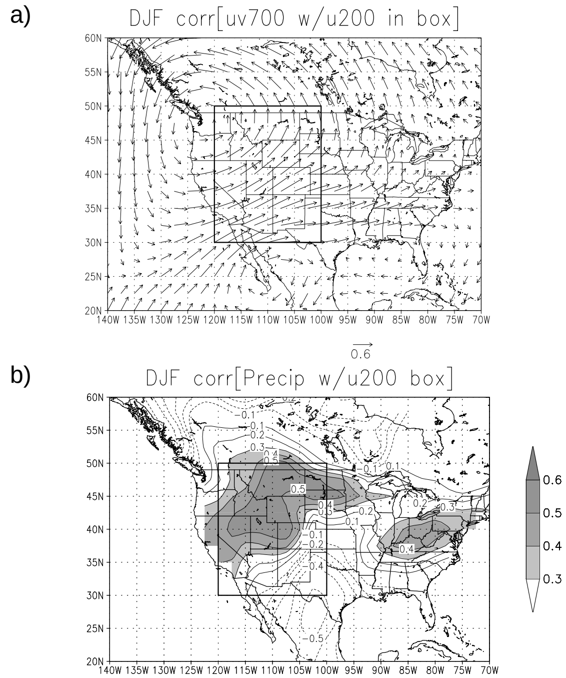


Fig. 1. Eddy heights (m) and wind vectors (m/s) during (a) winter (December to February, DJF), and (b) summer (June to August, JJA) at 700 mb. Eddies are defined by subtracting the zonal average.



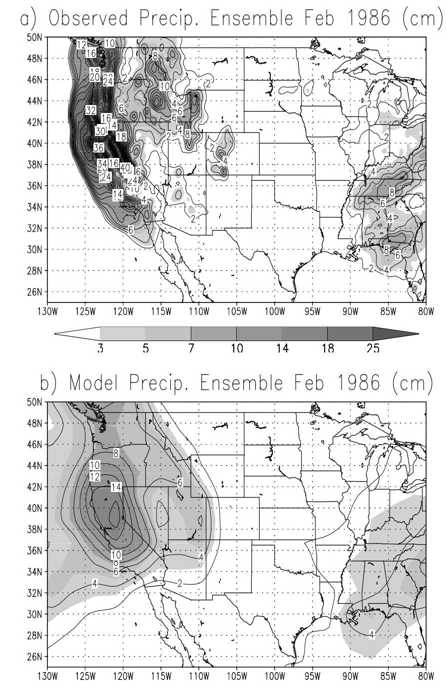
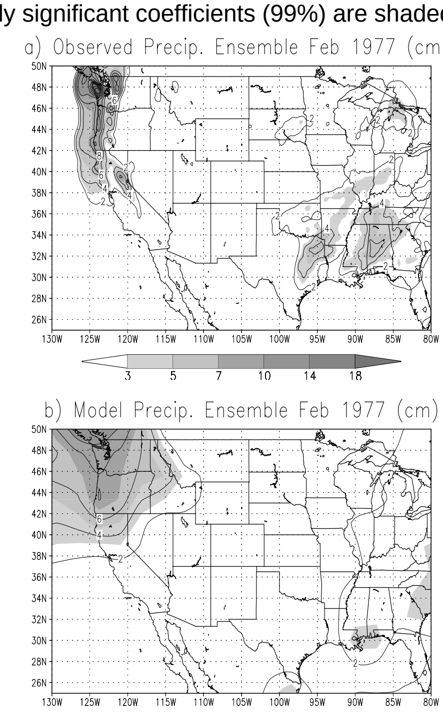


Fig 2. (above) (a) The time correlation vectors of the area-averaged, 200 mb zonal wind in the outlined box with 700 mb wind at all locations for DJF 1951-2000. (b) As in (a) but for area-averaged, 200 mb zonal wind in the box with precipitation over land (from PREC/L of Chen et. al., 2002). Statistically significant coefficients (99%) are shaded.

Fig. 3. (above) (a) Average total precipitation accumulation (cm) for the ten, 15-day periods in Feb-Mar 1986 from the CPC Unified data set. (b) The UGM, ensemble average precipitation accumulation for the same ten cases. The contour interval is 3 cm in (a) and 2 cm in (b). Shading is for accumulations at or above 3 cm.



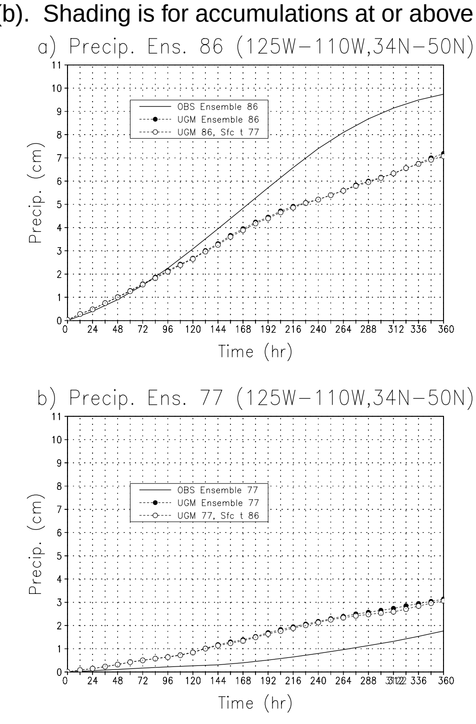


Fig. 4. (above). As in Fig. 3 but for the 1977 ensemble observations (a) and UGM forecasts (b).

Fig. 5. (above) Area-averaged precipitation accumulation (cm) over the western U.S. for the (a) Feb-Mar 1986, and (b) Feb-Mar 1977 ensembles. Solid contours show observed (CPC), solid circles show UGM, and open circles show UGM with monthly-averaged surface temperatures from Feb 77 (a) and Feb 86 (b).