

## Effects of quasi-stationary wave anomalies on the regional hydrologic cycle in the continental United States

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**Abstract** The interaction of large-scale quasi-stationary waves with regional forcing in the drought of 1988 and flood of 1993 in the north central United States was examined using a mesoscale numerical model. When the observed large-scale quasi-stationary wave anomalies in the dynamic and thermodynamic fields were filtered through adjustment of the observationally-based lateral boundary conditions, predicted rainfall and meteorological fields over the drought and flood regions tended toward those for normal years. This method for quantifying, isolating and filtering the relevant large-scale anomalies allows us to infer specific scale interaction mechanisms that produce regional hydrologic consequences of large-scale circulation patterns.

### INTRODUCTION

The summers of 1988 and 1993 were characterized by extreme anomalies in the weather patterns over the central United States (US). During spring and early summer 1988 a high pressure system persisted over the central US producing severe drought. The 1993 flood was the result of a warm sea surface temperature (SST) anomaly in the tropical Pacific that produced an anomalous wave train and southerly displacement of the storm track. Here we use the MM5 numerical model to evaluate the effects of these quasi-stationary wave anomalies on regional precipitation and related dynamic processes during the 1988 drought and 1993 flood. We introduce a new lateral boundary condition procedure that allows regional climate models to consider external forcing associated with these large-scale quasi-stationary waves that occur on scales larger than the regional model domain.

### METHODOLOGY

A 30-day climatological mean meteorological field averaged over 10 years is denoted  $\bar{\psi}(x, y, p)_{10\text{year}}$  where  $\psi$  may be wind velocity, temperature or specific humidity. The average field for the corresponding 30-day period in the drought or flood year is denoted  $\bar{\psi}(x, y, p)_{1\text{month}}$ . The quasi-stationary wave anomaly  $\Delta\psi$  is then identified as:

$$\Delta\psi = \bar{\psi}(x, y, p)_{1\text{month}} - \bar{\psi}(x, y, p)_{10\text{year}} \quad (1)$$

Using the NCAR/Penn State MM5 (Grell *et al.*, 1993), we performed “control simulations” for the drought of 1 June–30 June 1988 (denoted D88) and for the flood

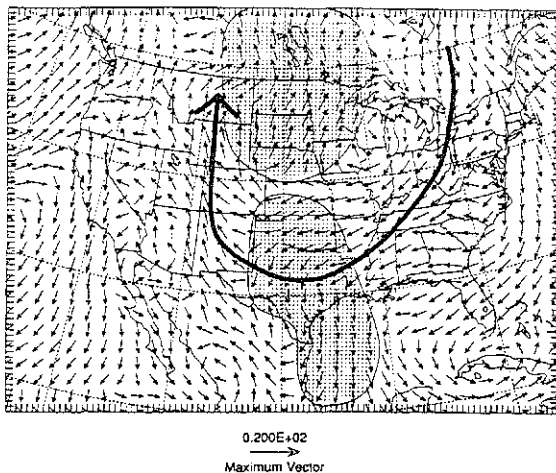
of 15 June–15 July 1993 (denoted F93) using observed data for initial and lateral boundary conditions. The simulations were repeated while  $\Delta\psi$  was subtracted from the initial conditions and from the lateral boundary conditions (“filtered simulations”). If  $\Delta\psi$  accounts for the anomalous large-scale forcing then the filtered simulations should produce climatological patterns that tend toward those of a normal year.

The model resolution was 52 km in the horizontal and 23 layers in the vertical. The lateral boundary conditions (either control or filtered) were updated every six hours in a 16 grid point nudging zone adjacent to each lateral boundary. The initial and lateral boundary conditions were derived from the NCEP/NCAR (National Centers for Environmental Prediction/National Center for Atmospheric Research) reanalysis (Kalnay et al., 1996).

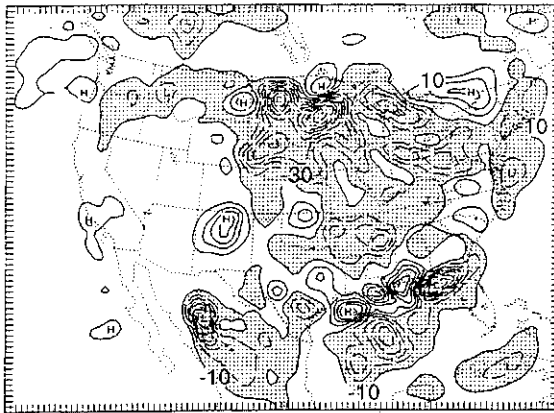
## RESULTS

### The drought of 1988: D88

The control run for D88 slightly underpredicted the amplitude of the ridge over the central US while the location of the ridge axis was reproduced accurately. The filtered run produced mean height fields that more closely resembled the climatological mean. The effect of the quasi-stationary wave anomalies on the low-level flow is represented by the wind velocity difference between the control and filtered runs (Fig. 1). Of particular interest is a dipole pattern of difference in low-level wind: the anomalous wave pattern apparently *weakens* the low-level southerly flow in the south central US, but *strengthens* it in the north central US and southern Canada. This dipole pattern is superimposed on a general anticyclonic pattern in the wind difference field over the central US, consistent with the weakening of the upper-level ridge in the filtered simulation.



**Fig. 1** Averaged 06 UTC simulated wind velocity difference between the control and filtered simulations for F88 at 700 m AGL. Shaded areas indicate the dipole structure in the wind direction; the heavy arrow line indicates the anticyclonic circulation in the flow difference.

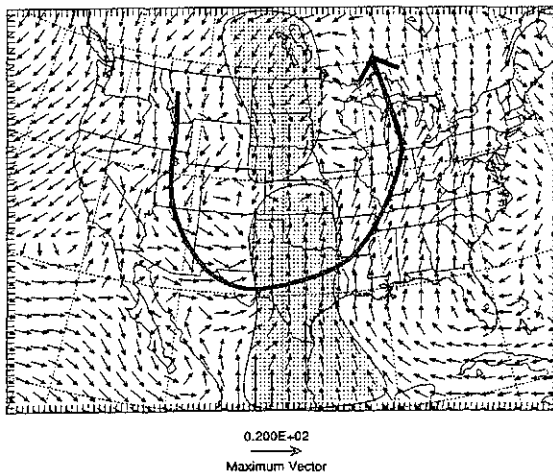


**Fig. 2** The difference in accumulated rainfall for D88 between the control and filtered simulations. Contour interval is 20 mm.

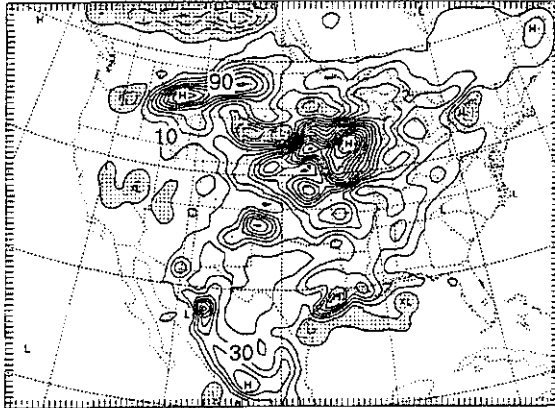
In the filtered simulation, a substantial rainfall increase was simulated for the north central US where the agricultural drought was most pronounced (Fig. 2). The filtered simulation produced more rainfall because the rainfall amounts of the events were considerably greater, not because of a change in the number of events.

### The flood of 1993: F93

The simulated fields for the control simulation captured reasonably the observed patterns. In the filtered simulation the troughing over the central US which resulted in the enhanced rainfall during F93 was replaced by weak ridging, and the axis of the trough was shifted westward. The low-level wind velocity difference between the control and filtered simulation (Fig. 3) shows a dipole pattern opposite to that for D88,



**Fig. 3** Averaged 06 UTC simulated wind velocity difference between the control and filtered simulations for F93 at 700 m AGL. The heavy line indicates the cyclonic circulation.



**Fig. 4** The difference in accumulated rainfall for F93 between the control and filtered simulations.

conductive to increased moisture advection and enhanced flow convergence in the flood region (around 40°N). The response was strongly modulated by diurnal boundary-layer processes, as was observed in low-level winds from microwave profilers (Arritt *et al.*, 1997). Filtering the quasi-stationary wave anomalies produced lower rainfall in the flood area (Fig. 4).

## DISCUSSION

Observational studies (e.g. Atlas *et al.*, 1993; Trenberth & Guillemot, 1996; Ting & Wang, 1997) have indicated that an atmospheric wave train induced by sea-surface temperature anomalies was responsible for generating atmospheric circulation anomalies leading to drought or flood conditions. We examined the effects of these anomalies by prescribing initial and lateral boundary conditions for regional climate simulations so that the large-scale external perturbation was either retained or filtered out. These simulations demonstrated that the large-scale anomaly results in a dipole pattern of the low-level wind that influences the moisture flux and convergence. Finally, we point out that the large-scale anomalies need not be completely filtered or completely included; it may be instructive to perform also a range of simulations in which the anomalies are included with various fractional amplitudes.

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