Revisiting the Causes of the US Midwest Great Flood of 1993

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I. Introduction

The floods that occurred in the US Midwest during the summer of 1993 remain one of the greatest flooding events in US history. While a considerable amount of work has already been done addressing its causes (e.g., Mo et al. 1995; Trenberth and Guillemot 1996; Liu et al. 1998), there still remain uncertainties as to 1) the relative roles of forcing from the tropics and the extra-tropics, and 2) the extended nature of the event that lasted throughout much of the late spring and summer of that year. In particular, we focus here on the physical mechanisms that were responsible for the excessive rainfall that fell in the Midwest during each month of May through August of 1993, employing both reanalyses, and "regional replay" simulations in which the NASA GEOS AGCM is forced to track MERRA-2 at each time step over selected regions of the globe.

II. Methodology and Experiments

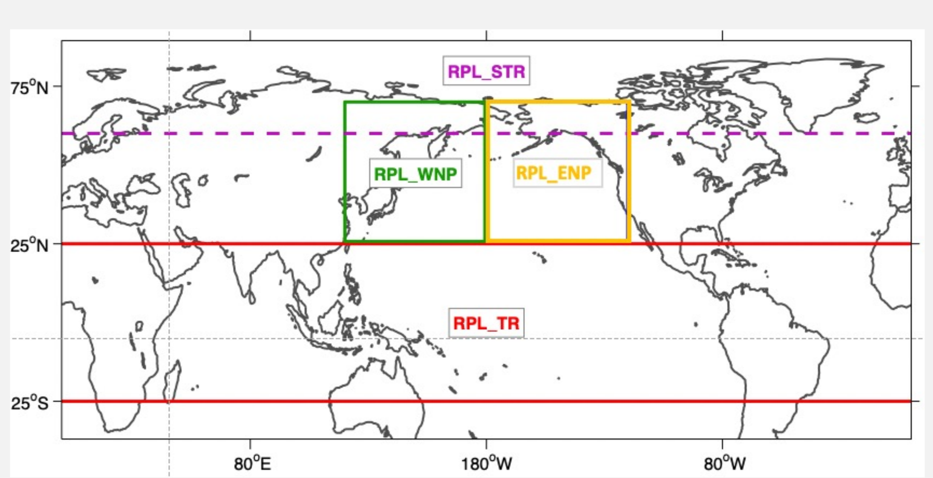
Replay (RPL): takes advantage of the incremental analysis update procedure employed in the GEOS data assimilation system to force a model to track a pre-existing analysis. The equations governing replay have the form:

$$\frac{\partial x}{\partial t} = f(x) + \Delta x$$

Where Δx=*(analysis-forecast)/6hrs* is the instantaneous analysis increment, and f(x) consists of all the dynamics and physics terms of the model. We apply replay to various subregions of the globe (Table 1).

Table 1: List of the AGCM experiments. All runs are forced with observed daily SST.

Name	Time period	Replay region	Ensemble members
NORPL	Jan 1, 1980- Mar 31, 2022	none	45
RPL_TR	Jan 1, 1980- Mar 31, 2022	Tropics: 25°S-25°N	45
RPL_WNP	Jan 1, 1980- Mar 31, 2022	Western North Pacific: (25°N-70°N, 120E°-180°)	45
RPL_ENP	Jan 1, 1980- Mar 31, 2022	Eastern North Pacific: (25°N-70°N, 180°-120W°)	45
RPL_STR	Jan 1, 1980- Mar 31, 2022	Stratosphere above approx. 288mb and north of 60°N	23



Replay to MERRA-2 (u, v, T, q, P_s) applied only over specified regions

GEOS AGCM MERRA-2 model (Ganymed-4_0) at 1 degree (c90) resolution with Tendency bias correction (TBC)* over globe (except where regional replay is applied).

*Chang et al. 2019, Journal of Climate, doi: 10.1175/JCLI-D-18-0598.1, Schubert et al. 2019, Journal of Climate, doi: 10.1175/JCLI-D-19-0189.1, Chang et al. 2021, Tech. memo on TBC, NASA/TM-2021-104606/Vol. 57

Figure 1: The replay regions

III. Background

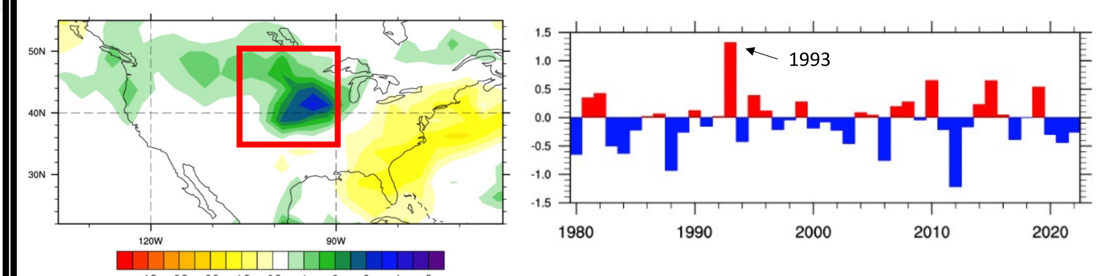


Figure 2: Left panel: The precipitation anomalies (mm/day) for May-August 1993 based on GPCP V2.3. The climatology is 1991-2020. Right panel: The time series of the May-August precipitation (mm/day) averaged over the region denoted by the red box in the left panel (35°N-50°N, 90°W-105°W). Images provided by the NOAA/ESRL Physical Sciences Laboratory, Boulder Colorado from their Web site at http://psl.noaa.gov/.

Key Result: The May-August 1993 positive precipitation anomalies in the upper Midwest were by far the most extreme in the last 4 decades

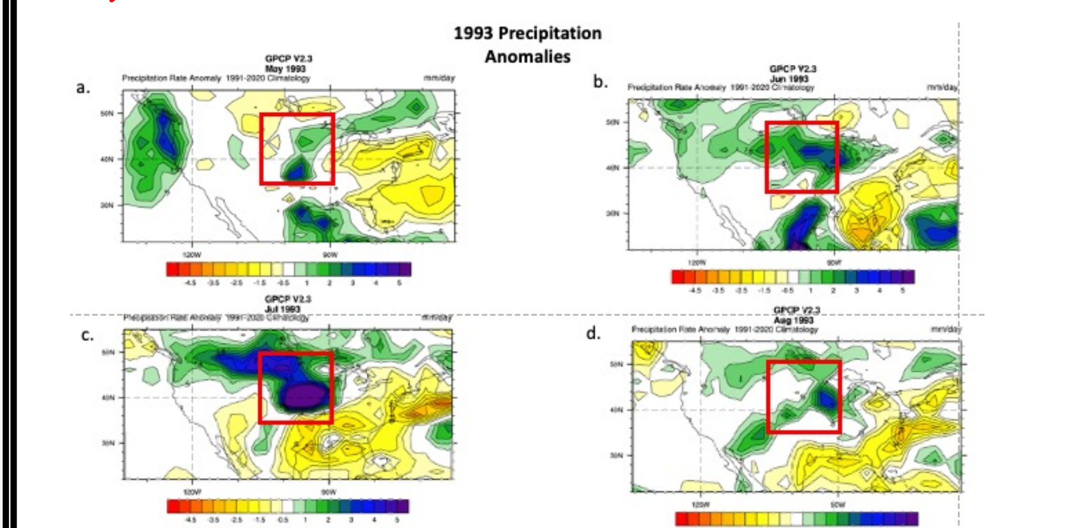


Figure 3: The 1993 precipitation anomalies (mm/day) for a) May, b) June, c) July, and d) August based on GPCP V2.3. The climatology is 1991-2020. The red boxes outline our region of interest (35°N-50°N, 90°W- 105°W). Images provided by the NOAA/ESRL Physical Sciences Laboratory, Boulder Colorado from their Web site at http://psl.noaa.gov/.

Key result: Each month was wet in the upper Midwest, though July was the most extreme.

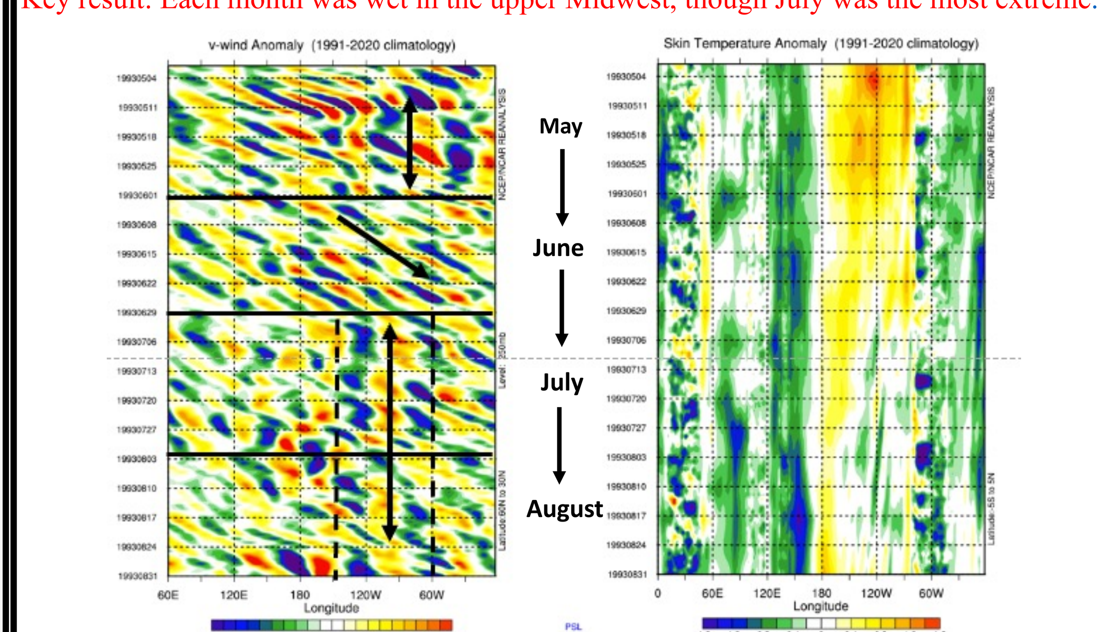
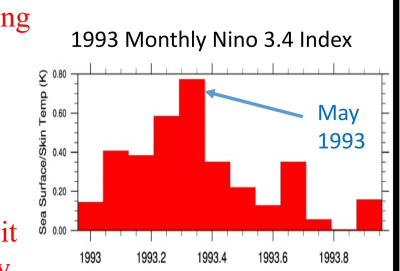


Figure 4: Daily time/longitude (Hovmollor) plots. Left panel: The v-wind anomalies at 250mb averaged between 30°N and 60°N. Right panel: The skin temperature anomalies averaged between 5°S and 5°N. Results are for May 1 – August, 1993 from the NCEP/NCAR reanalysis. Images provided by the NOAA/ESRL Physical Sciences Laboratory, Boulder Colorado from their Web site at http://psl.noaa.gov/.

Key results: The May – August 1993 circulation (v-wind) anomalies varied considerably by month, with May showing stationary anomalies in the western Hemisphere, June showing pronounced eastward traveling waves (synoptic disturbances), while July is characterized by an abrupt development of a stationary wave in the PNA region (that lasted to some extent into August). Also, 1993 was characterized by a weak El Nino, that was unusual in that it developed in the beginning of that year and peaked in May.



IV. May 1993

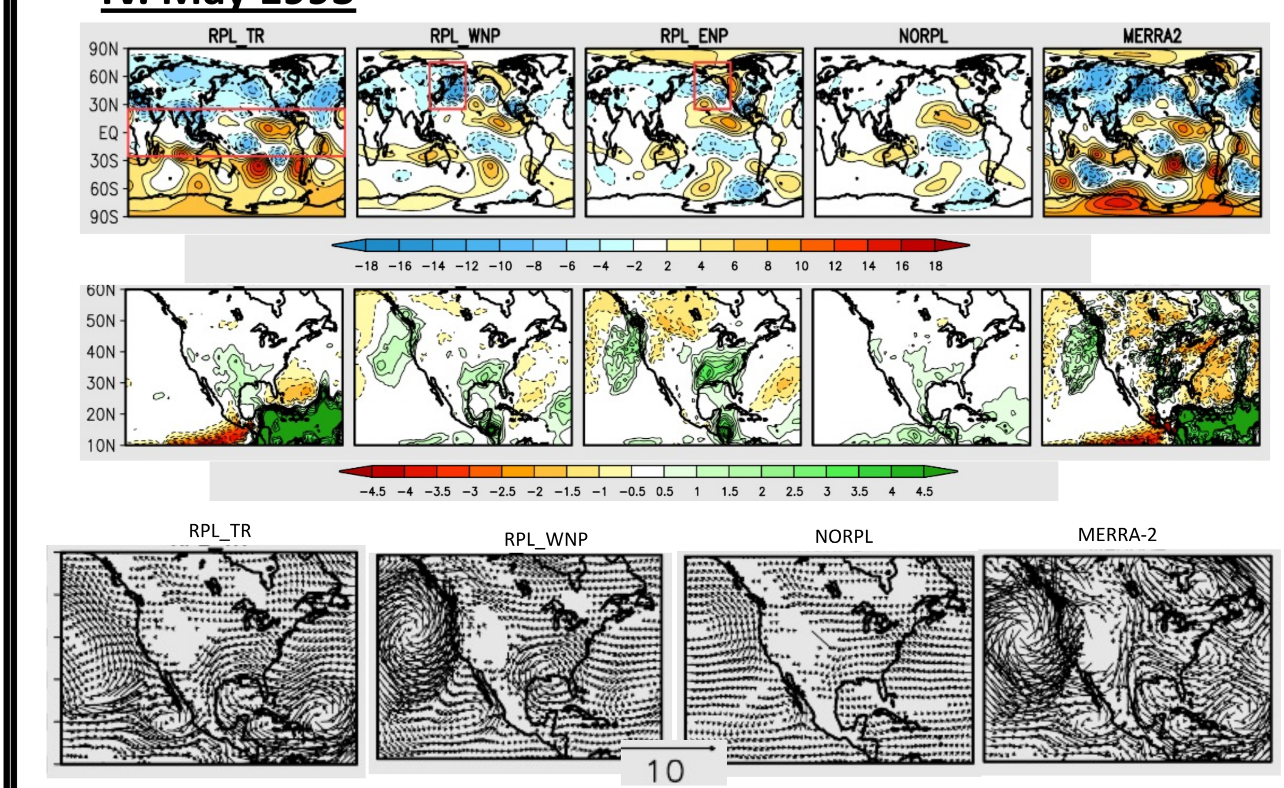


Figure 5: Results for May. The top panels are the 250mb stream function anomalies (10^6 m^2/s). The middle row of panels are the precipitation anomalies (mm/day). The panels from left to right are for RPL_TR, RPL_WNP, RPL_ENP, NORPL, and MERRA-2. The bottom panels are the 850mb wind vector anomalies (m/s) for RPL_TR, RPL_WNP, NORPL, and MERRA-2. Model results are the ensemble means. The red boxes in the top panels indicate the replay regions.

Key results: The May 1993 NH circulation anomalies and positive precipitation anomalies over the Midwest were in part forced from the tropics as a response to the weak El Nino that peaked in May. The relevant response includes low level easterly wind anomalies that extended from the eastern shore into the Midwest. Forcing from the western North Pacific (RPL_WNP) appears to amplify the response over North America and contributes to the precipitation anomalies in the southern Plains and the northwest.

V. June 1993

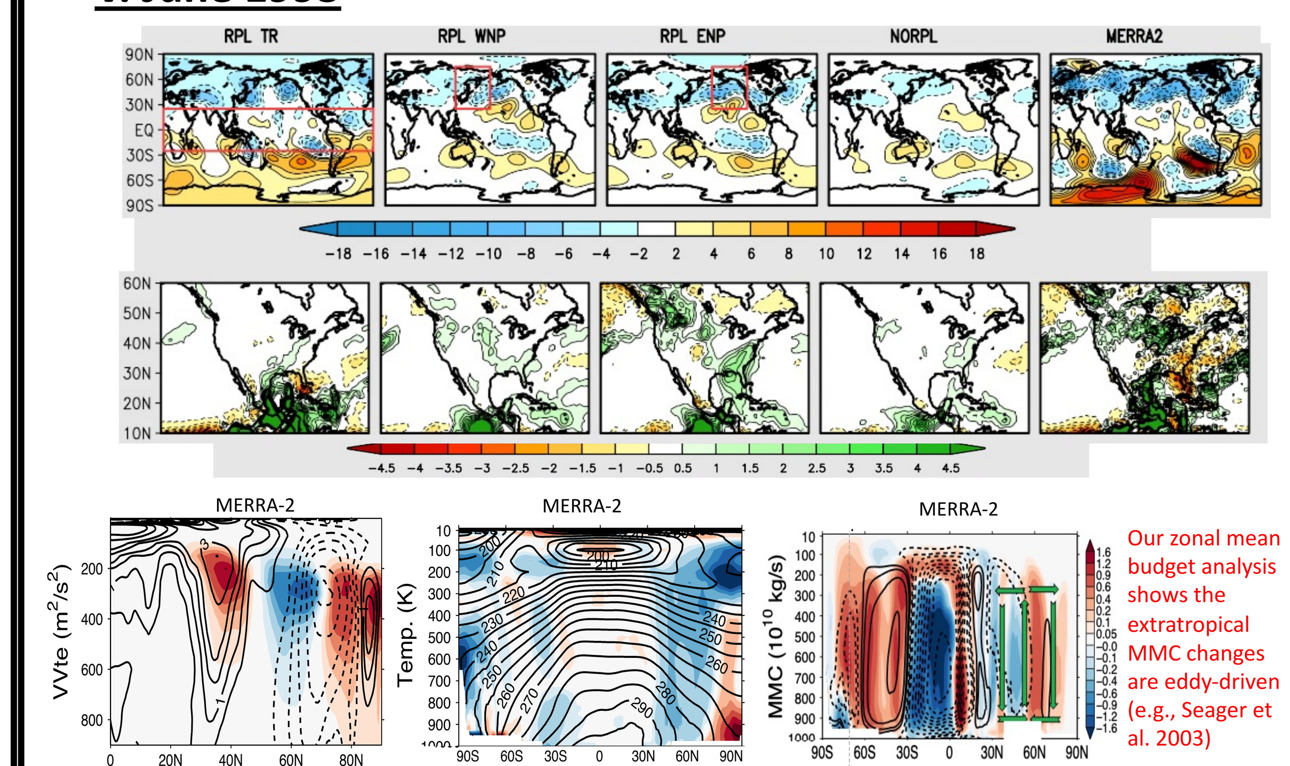


Figure 6: Top two rows, same as Fig. 5 except for June. Bottom row is for MERRA-2 (from left to right): the zonal mean v-wind squared anomalies associated with the transient eddies (m^2/s^2, shaded), with the u-wind anomalies superimposed (contours), the zonal mean temperature anomalies (shaded) with the climatological temperature superimposed (°K), and the Mean Meridional Circulation(MMC) anomalies (shaded) with the climatological values superimposed (contoured). The green arrows highlight the changes in the Ferrel and Polar Cells.

Key results: The June 1993 positive precipitation anomalies over the Midwest were associated with an intensified and southward shifted storm track tied to an intensified and southward shift jet. These zonal mean anomalies are not well reproduced in the model runs. The MERRA-2 results show that the zonal mean jet and associated temperature changes (via the MMC changes) appear to be in part forced from the tropics and in part forced by the extratropical eddies. We are currently looking into the potential role of the record-cold north polar lower stratosphere.

VI. July 1993

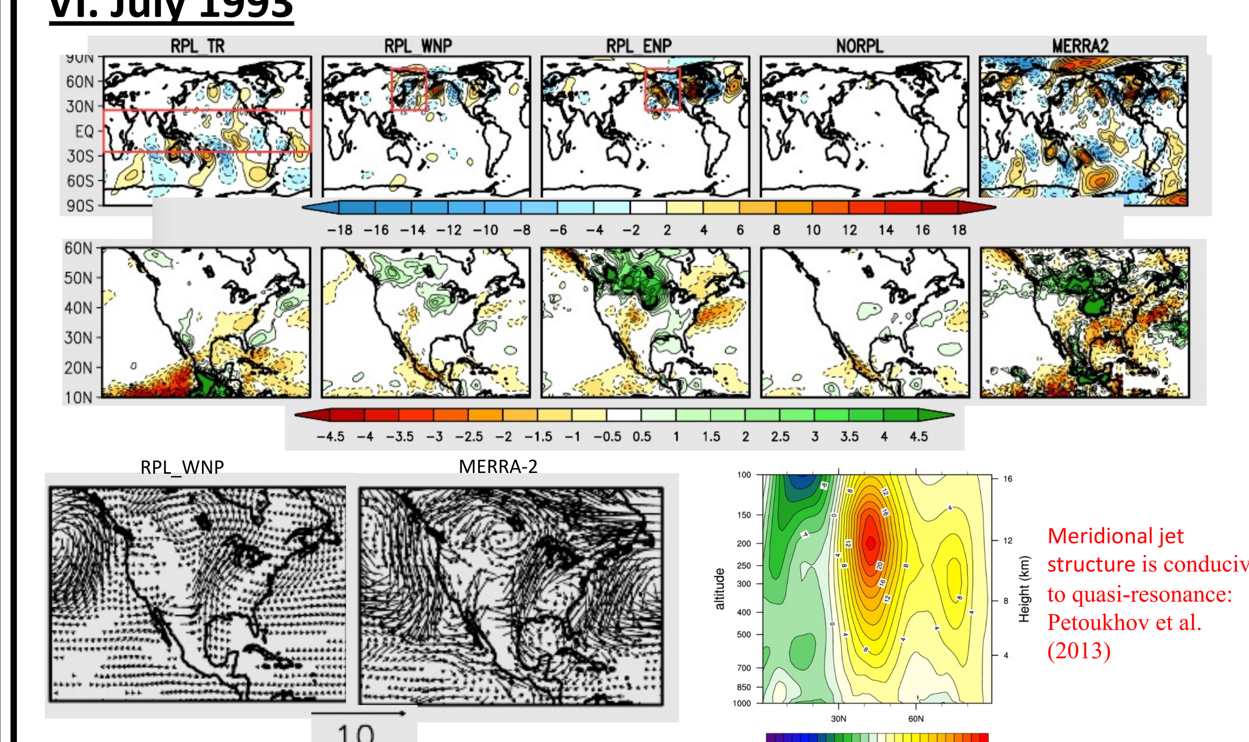


Figure 7: Top two rows: same as Fig. 5 except for July and the top row is for the 250mb v-wind anomalies (m/s). Bottom row: The left two panels are the 850mb wind vector anomalies (m/s) for RPL_WNP and MERRA-2. The third panel is the July 1993 zonal mean u-wind (m/s) from MERRA-2.

Key results: The July 1993 extreme precipitation event is associated with the development of a large amplitude stationary wave and intense southerly inflow from the Gulf of Mexico. The stationary wave appears to be initiated in the western North Pacific (RPL_WNP). Its sudden development in the Pacific North American (PNA) region (see left panel of Fig. 4) is however likely tied to a meridional zonal wind structure that is conducive to quasi-resonance.

VII. August 1993

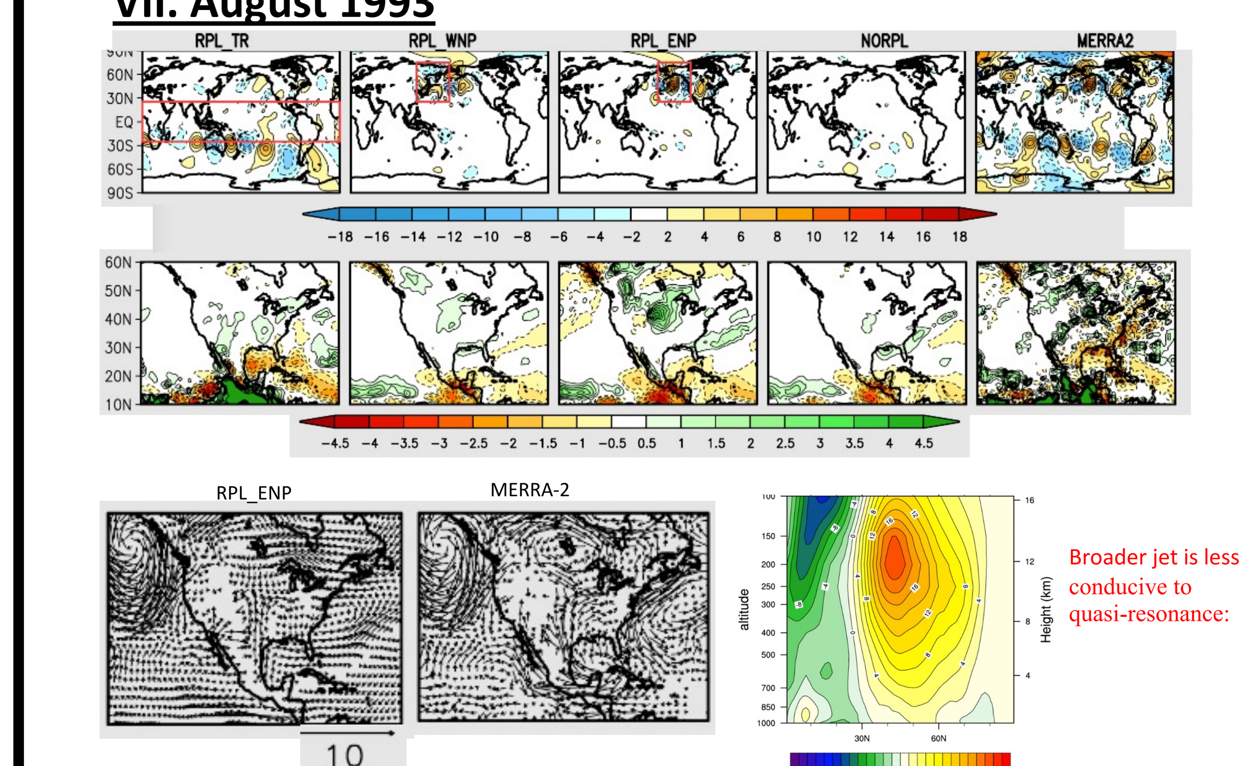


Figure 8: Top two rows: same as Fig. 7 except for August. Bottom row: The left two panels are the 850mb wind vector anomalies (m/s) for RPL_WNP and MERRA-2. The third panel is the August 1993 zonal mean u-wind (m/s) from MERRA-2.

Key results: The August 1993 precipitation anomalies appear to be associated with a continuation of the July stationary wave though weaker and shifted somewhat to the west over the PNA region, and at times interrupted by traveling disturbances (see left panel of Fig. 4). This is likely due to the changes in the jet that no longer supports quasi-resonance.

VIII. Conclusions

The unprecedented rainfall that fell over the upper Midwest during the late spring and summer of 1993 was the result of a number of different physical processes operating at different times.

May: the rainfall was largely the response to a weak but unusually timed (peaked in May) El Nino, resulting in an anomalous influx of moisture from the eastern shore

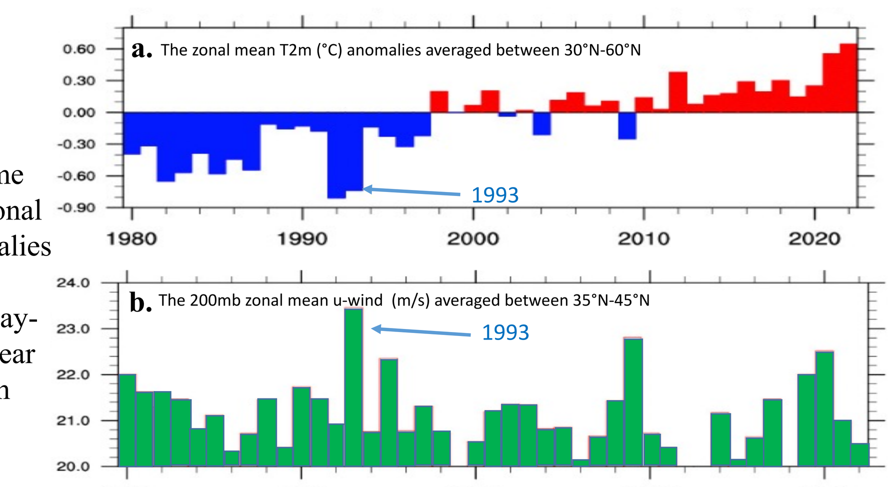
June: the rainfall was the result of an enhanced (and southward shifted) storm track linked to an enhanced and southward shifted east Asian jet. The latter was part of an overall zonally symmetric enhancement and southward shifted jet, linked in part to a response to forcing from the tropics (and SST), and in part to internal extratropical variability (driven by the eddies).

July: the rainfall was the result of the development of a pronounced stationary wave and associated enhanced moisture influx from the Gulf of Mexico. The wave was initiated in the western North Pacific but its sudden development over North America, and the unusual meridional zonal wind (jet) structure, are consistent with quasi-resonance of the wave with orography.

August: the rainfall was also tied to the same stationary wave, though it had weakened and shifted slightly westward compared with July, presumably due to the changes in the jet that no longer supported quasi-resonance.

Long-term variability: the Midwest flooding during May-August occurred in a year that (together with 1992) had unprecedented cold temperatures in the northern middle latitudes (Figure 9a), and had the strongest NH zonal mean jet of the last 4 decades (Figure 9b). The role of an extreme spring negative North Pacific Pattern, and a possible link (via the cold polar lower stratosphere) to the 1991 eruption of Mt. Pinatubo is under investigation.

Figure 9: The time series of a) the zonal mean T2m anomalies and b) the jet maximum, for May-August of each year (1980-2022) from MERRA-2.



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