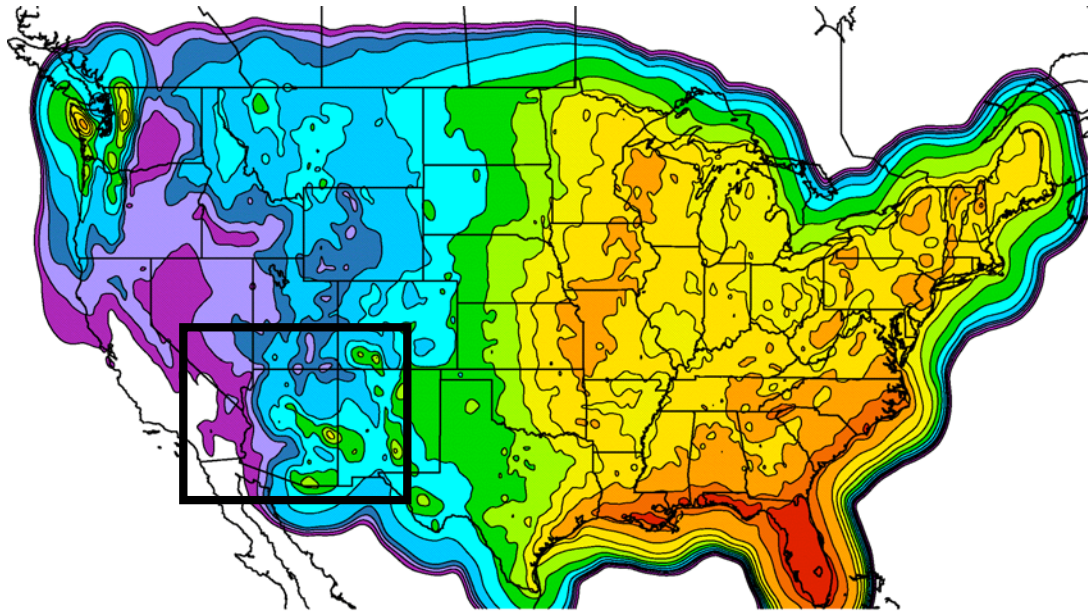


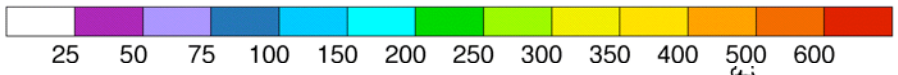
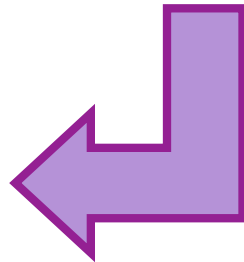
The Contribution of Eastern North Pacific Tropical Cyclones to the Warm Season Rainfall Climatology of the Southwest United States

Kristen L. Corbosiero (UCLA)

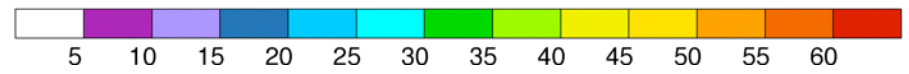
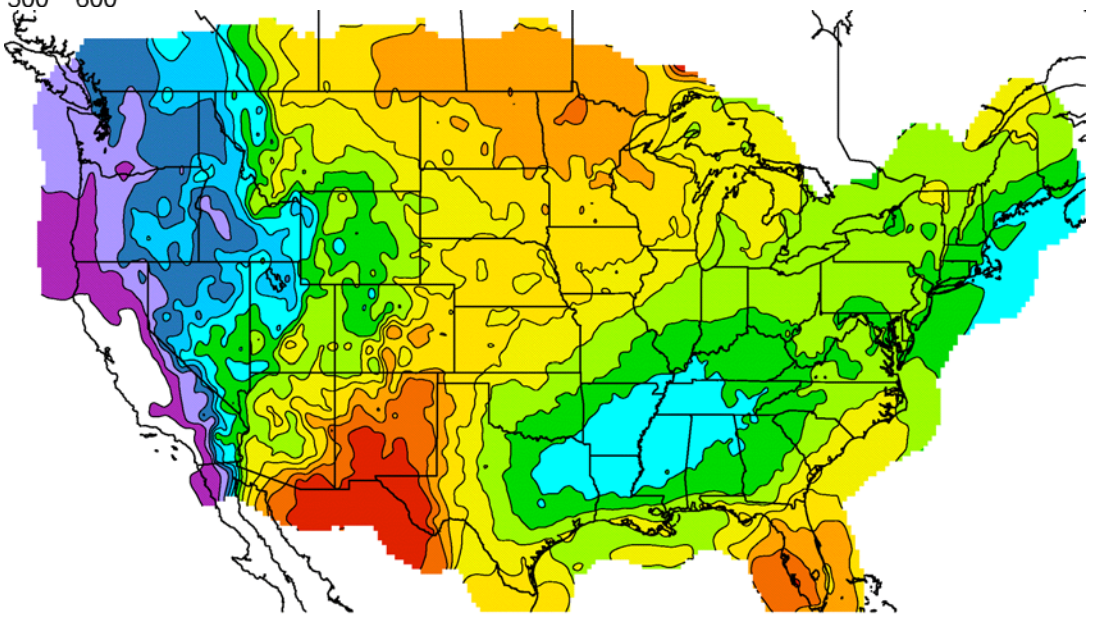
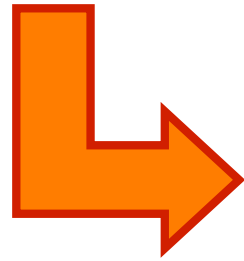
Michael Dickinson (Weather Predict) and Lance Bosart (SUNY Albany)



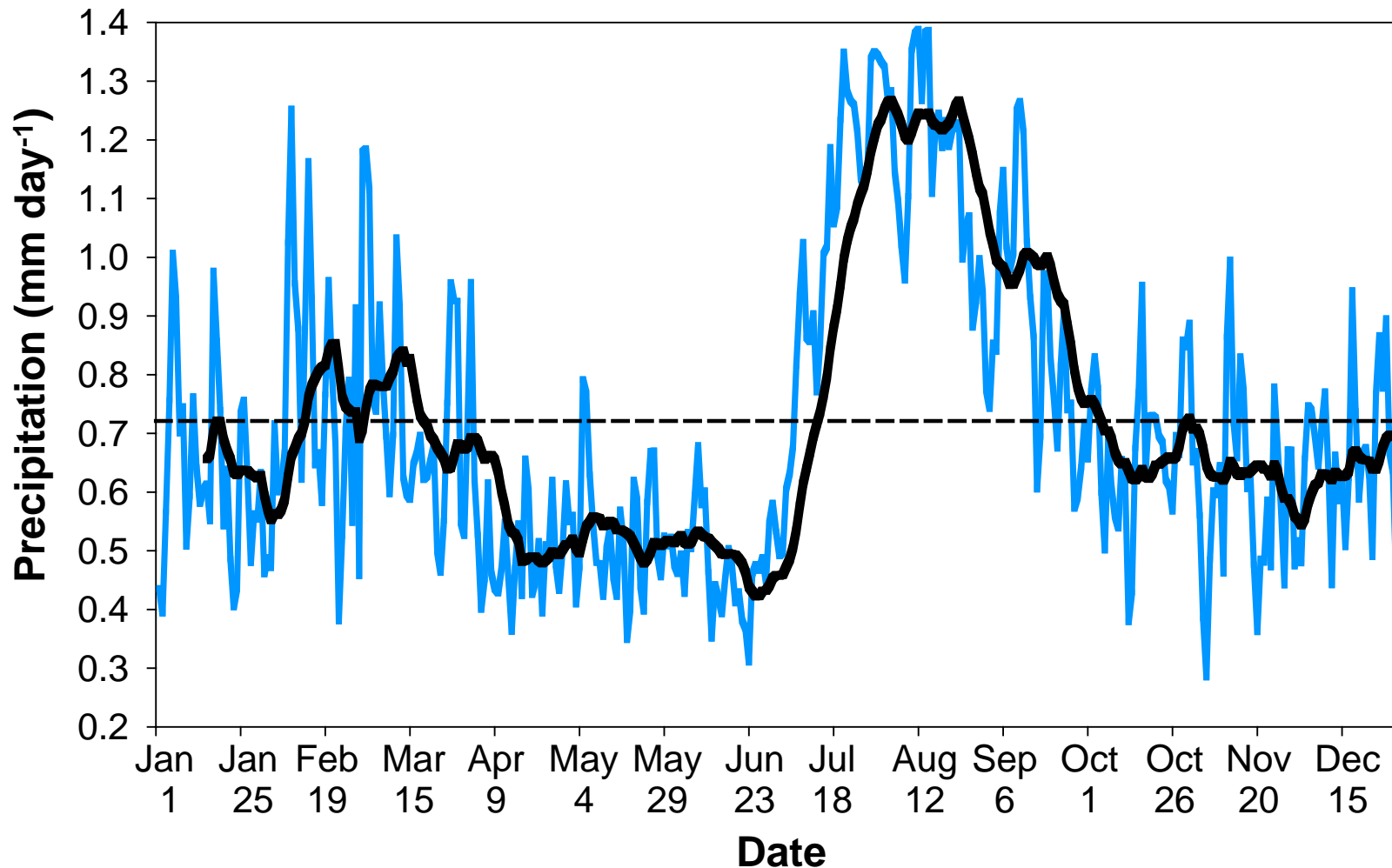
**Average warm season
(16 June - 15 October)
precipitation (mm)
1958-2003**

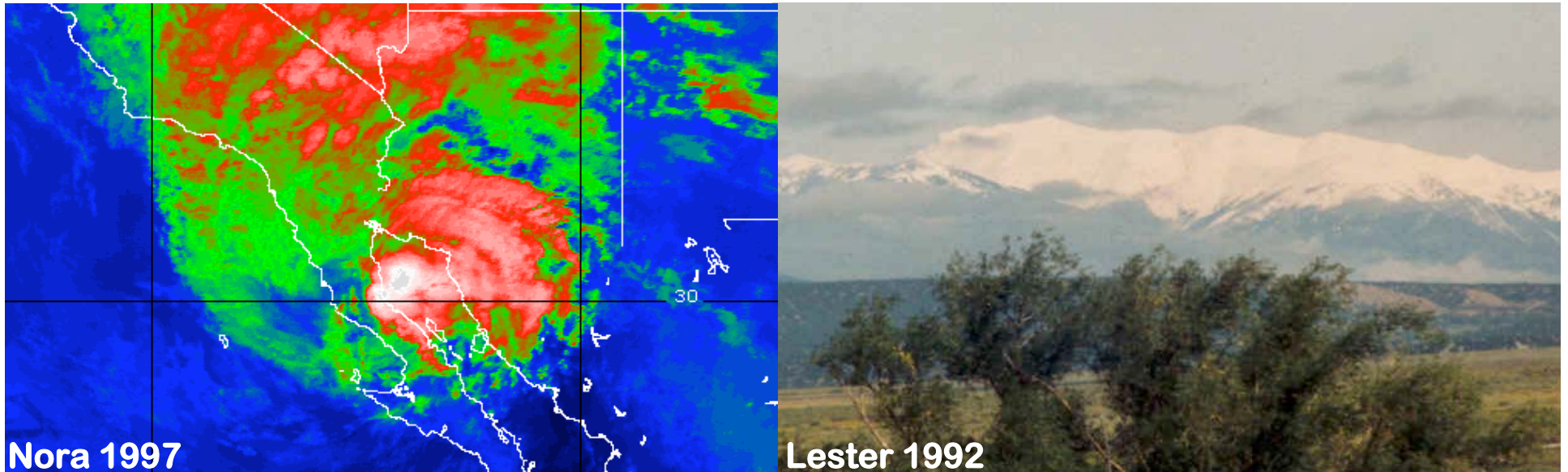


**Average percent of
yearly precipitation
that falls during the
warm season**



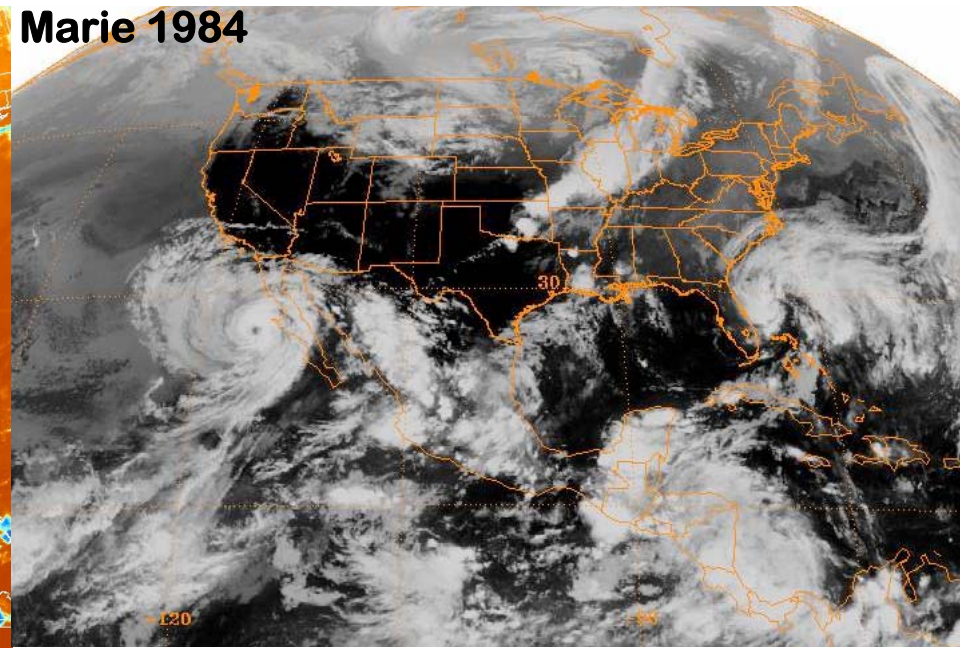
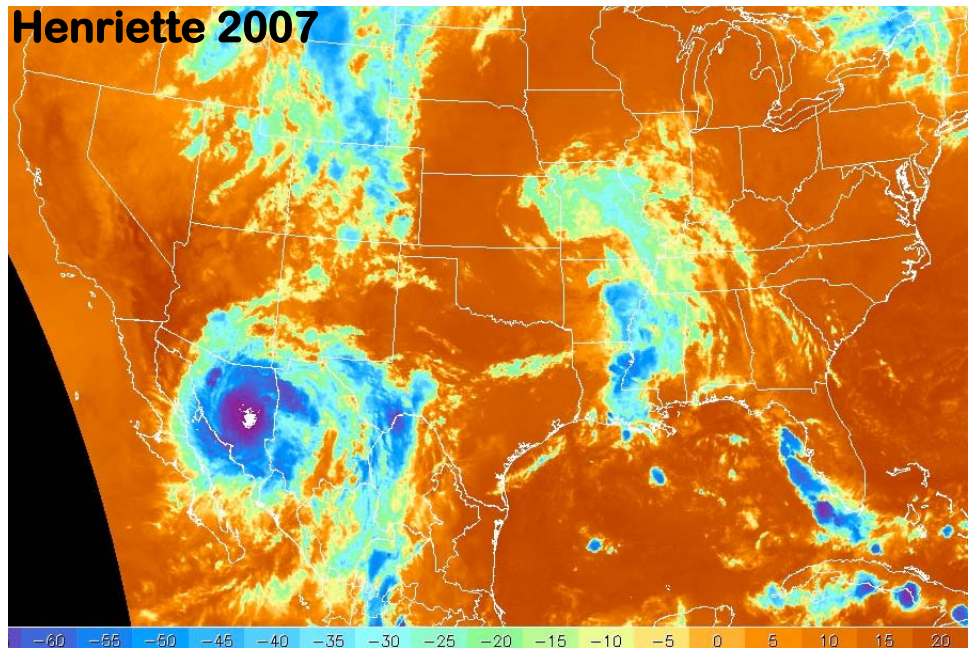
Southwest United States (31°-40°N, 104°-118°W) Average Daily Precipitation 1958-2003





Motivation:

- **Easterly waves and TCs of the eastern North Pacific initiate Gulf of California moisture surges that account for 50 - 100% of summer rainfall in the southwest U.S. (e.g. Higgins and Shi 2005; Bordoni and Stevens 2006)**
- **The eastern North Pacific is the most active basin for TC development per unit area, per unit time (Molinari et al. 2000)**

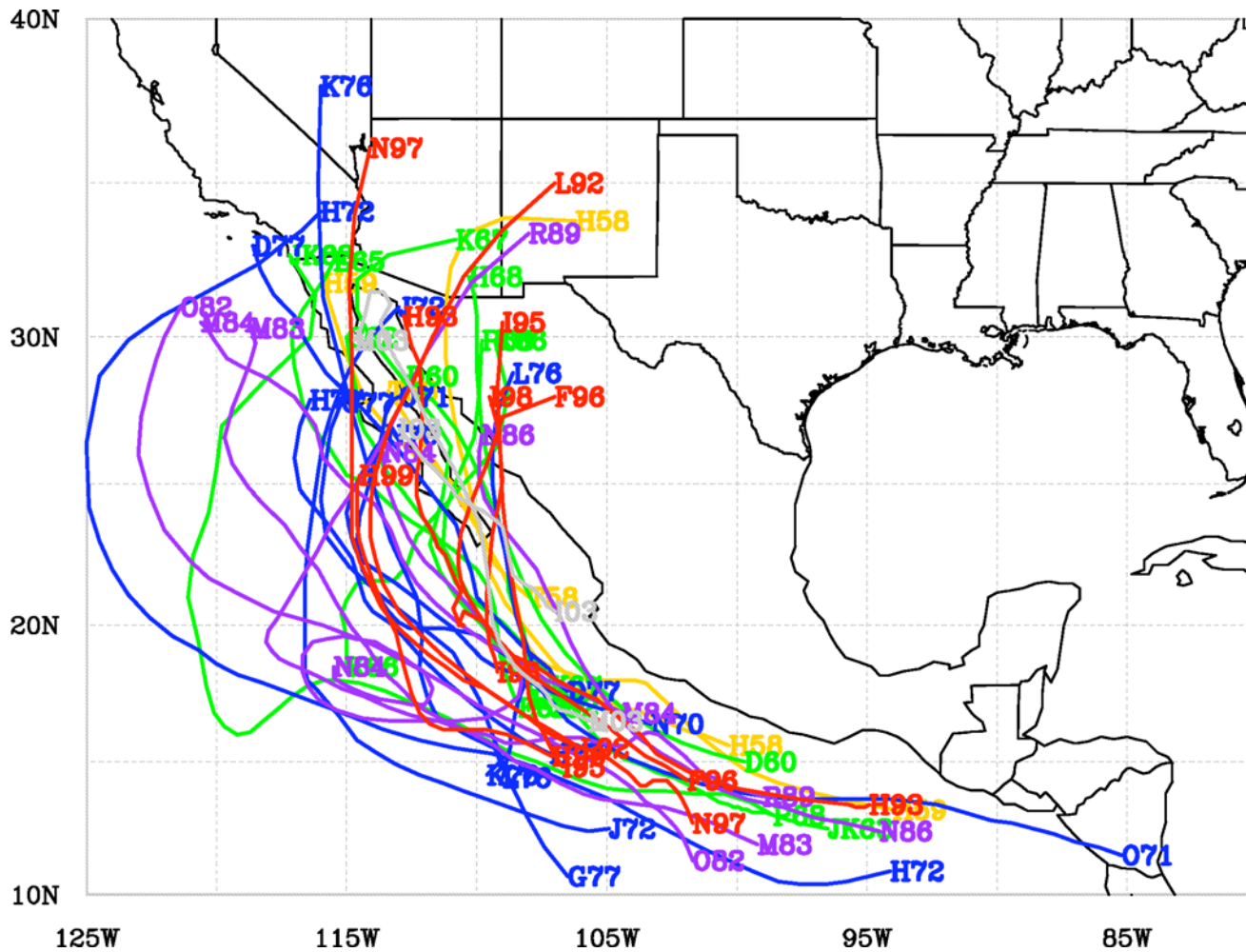


Motivation:

- **Do tropical cyclones ever reach the southwest U.S.?**
- **Englehart and Douglas (2001) examined TC rainfall in western Mexico and found 3-4 storms per year affect the region bringing as much as 60% of the summer rainfall**
- **Extend the study of Englehart and Douglas (2001) north into the southwest U.S. and NAM region**

Data and Methodology:

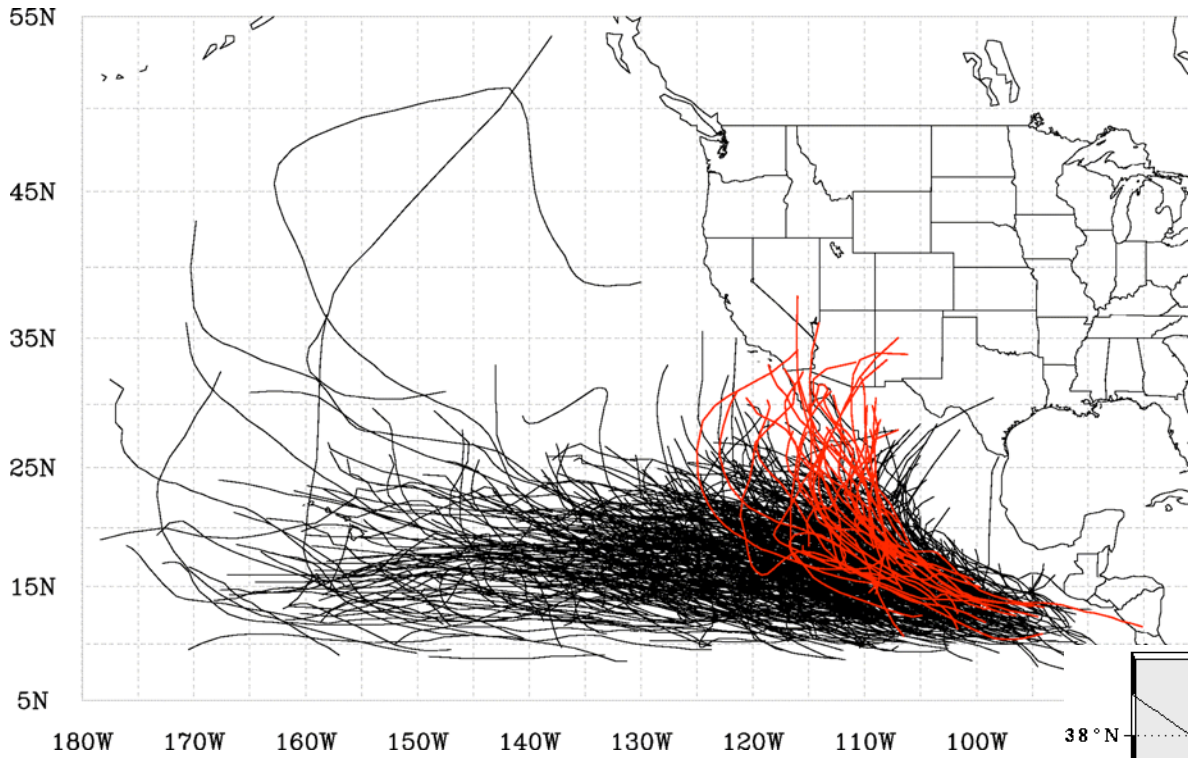
- **National Hurricane Center (NHC) Best Track data to find all storms that crossed 25°N between June 16th and October 15th 1958 to 2003**
- **Climate Prediction Center's daily (12 UTC-12 UTC), gridded (.25° x .25°) Unified Precipitation Dataset (UPD)**
(<http://www.cdc.noaa.gov/cdc/data.unified.html>)
- **European Centre for Medium-range Weather Forecasting re-analysis (ERA40; 1.125° resolution)**
- **Examined maps of rainfall and 700 hPa heights and relative vorticity to determine on which days, if any, rainfall associated with a tropical cyclone (or its $\zeta > 4 \times 10^{-5} \text{ s}^{-1}$ remnant) fell over the southwest U.S.**



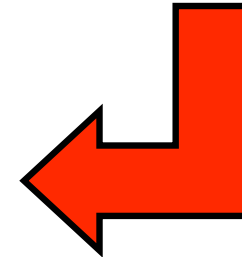
**National
Hurricane
Center
tracks of the
35 TCs
that affected
the southwest
U.S.
1958-2003**

TS10 H11 H10

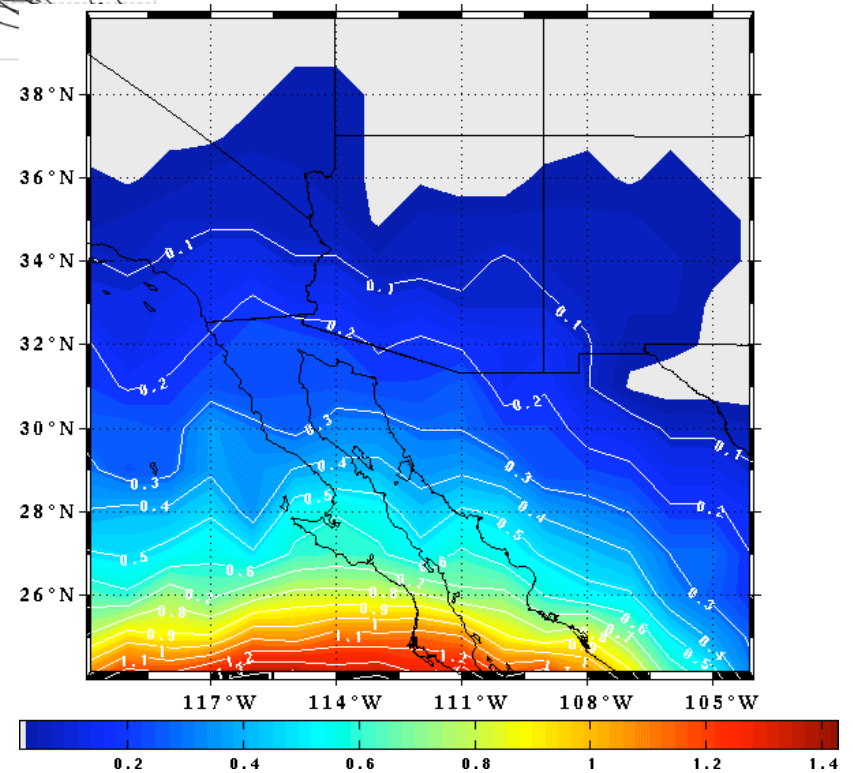
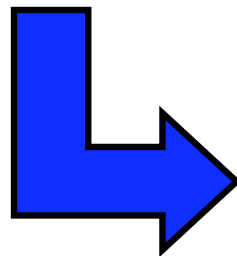
**Diana Claudia Jen-Kath Emily Kirsten Katrina Hyacinth Pauline
Norma Olivia Hyacinth Joanne Kathleen Liza Doreen Glenda Heather
Olivia Manuel Marie Norbert Newton Raymond
Lester Hilary Ismael Fausto Nora Isis Hilary
Ignacio Marty**

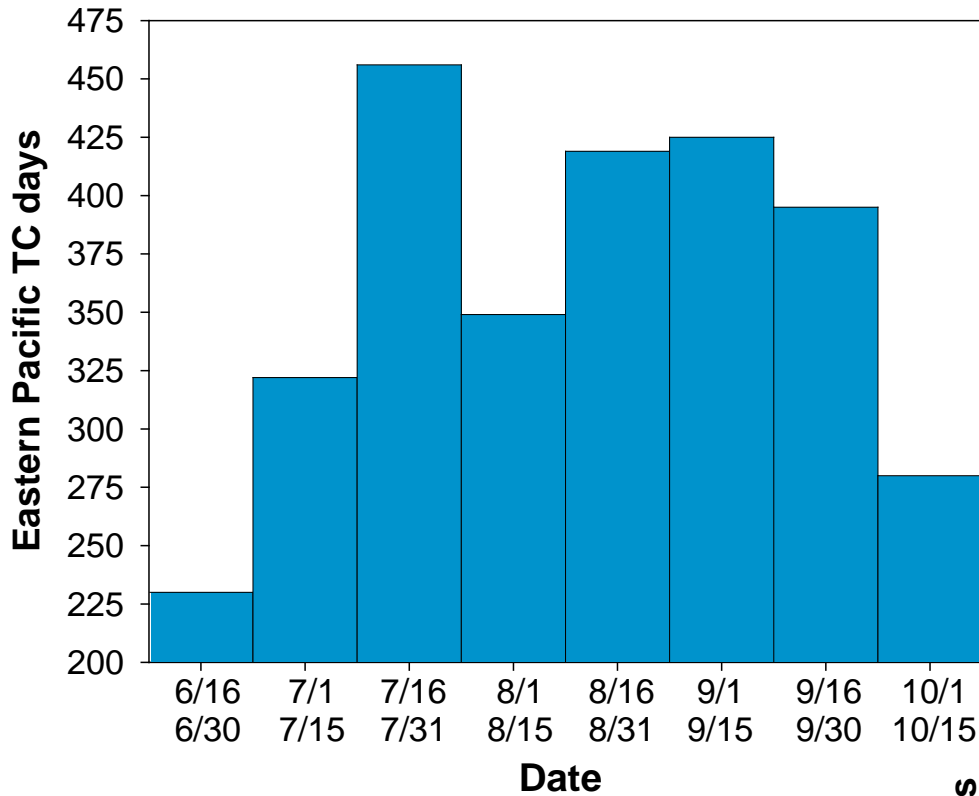


**NHC Best Tracks
All Eastern Pacific
TCs
1958-2003**

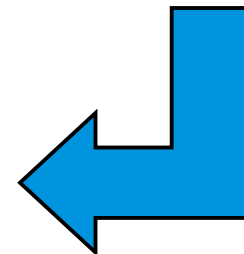


**Return rate of a TC of any
intensity to the southwest U.S.
1958-2003**

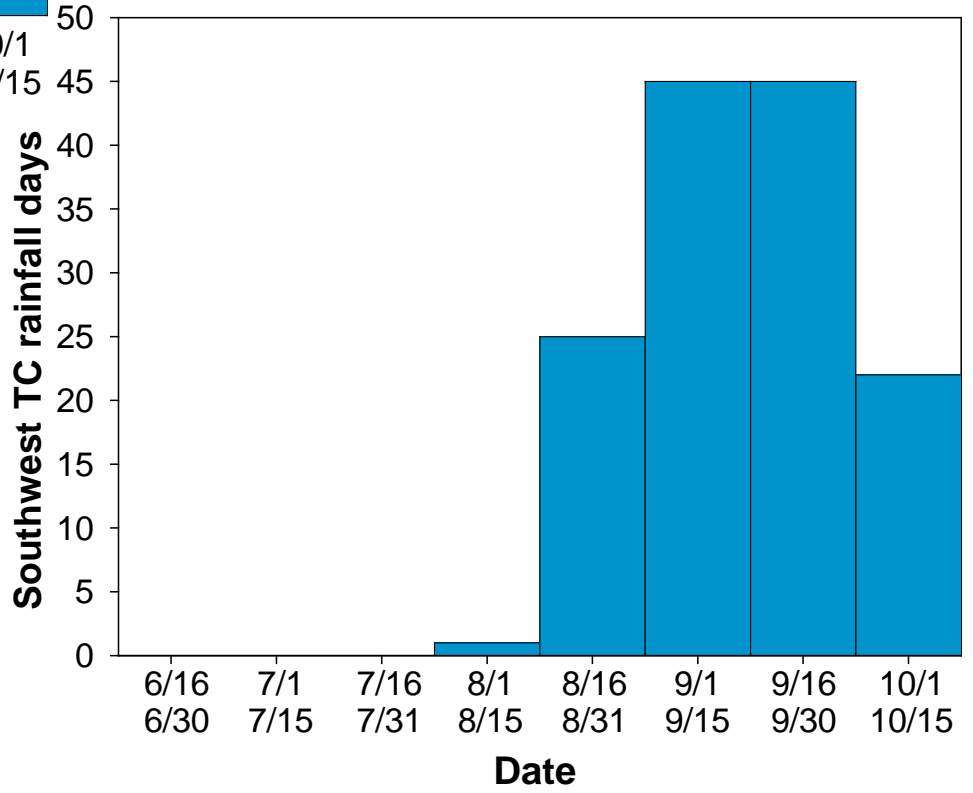
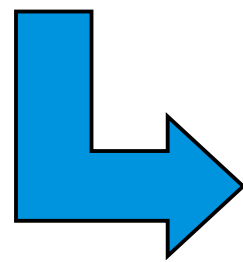


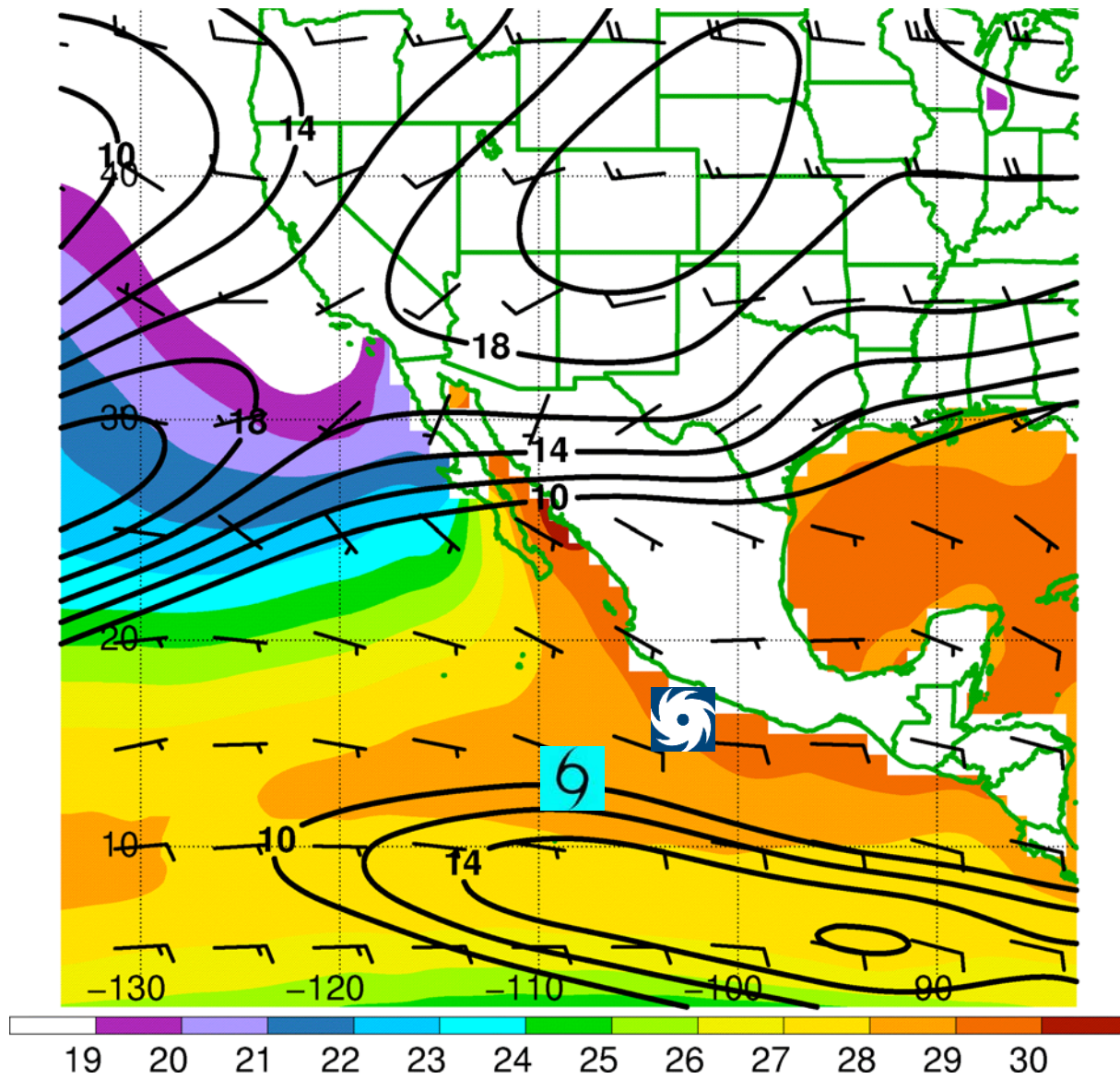


Number of days with at least one active Eastern Pacific TC 1958-2003



Number of days rainfall from an Eastern Pacific TC fell in the southwest U.S. 1958-2003



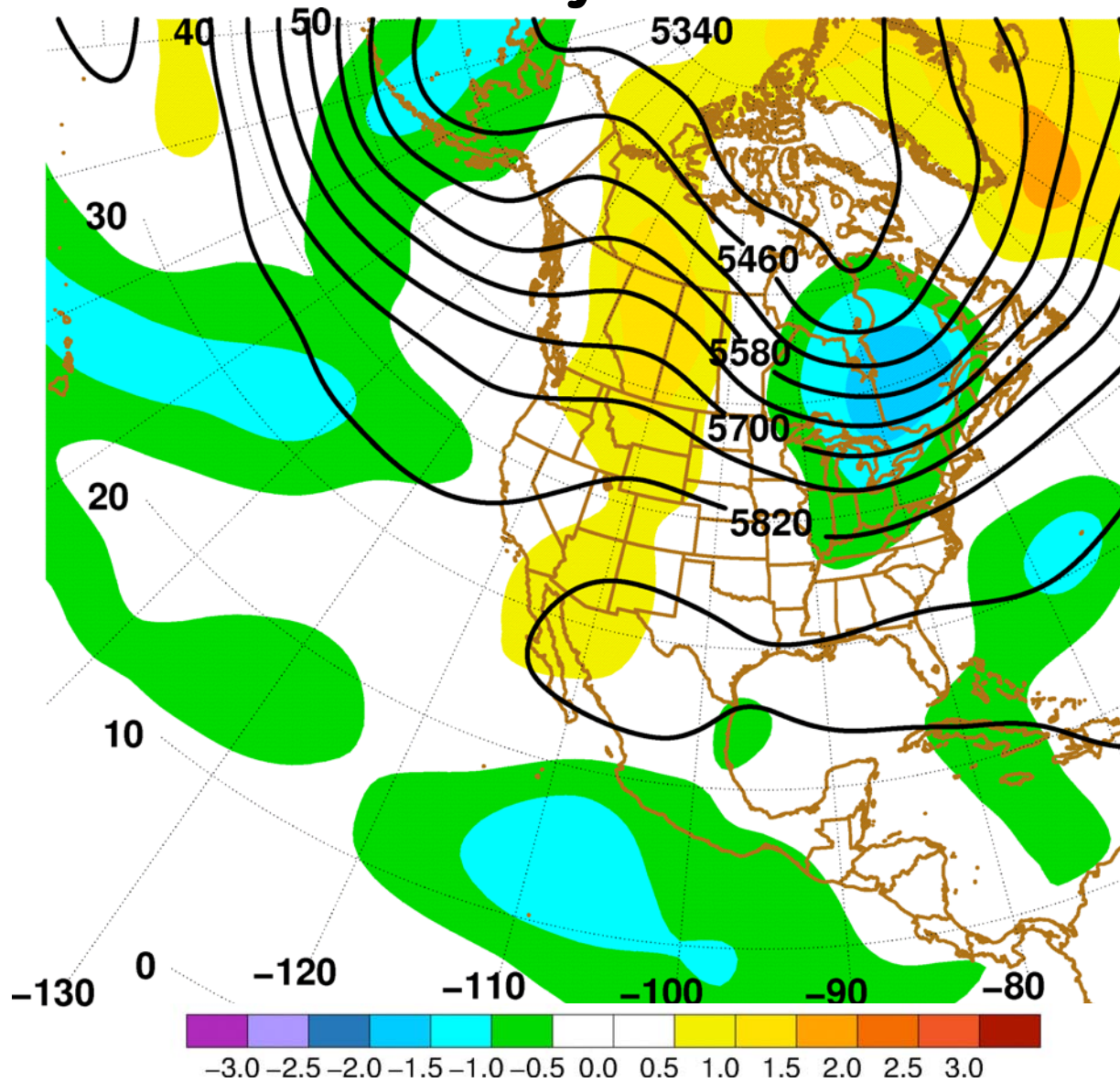


**Average September Eastern Pacific SSTs (shaded),
850-200 hPa vertical wind shear (contours),
and 500-700 hPa layer averaged winds (barbs)**

NCEP/NCAR Reanalysis

Mean and standardized anomaly, 500 hPa heights

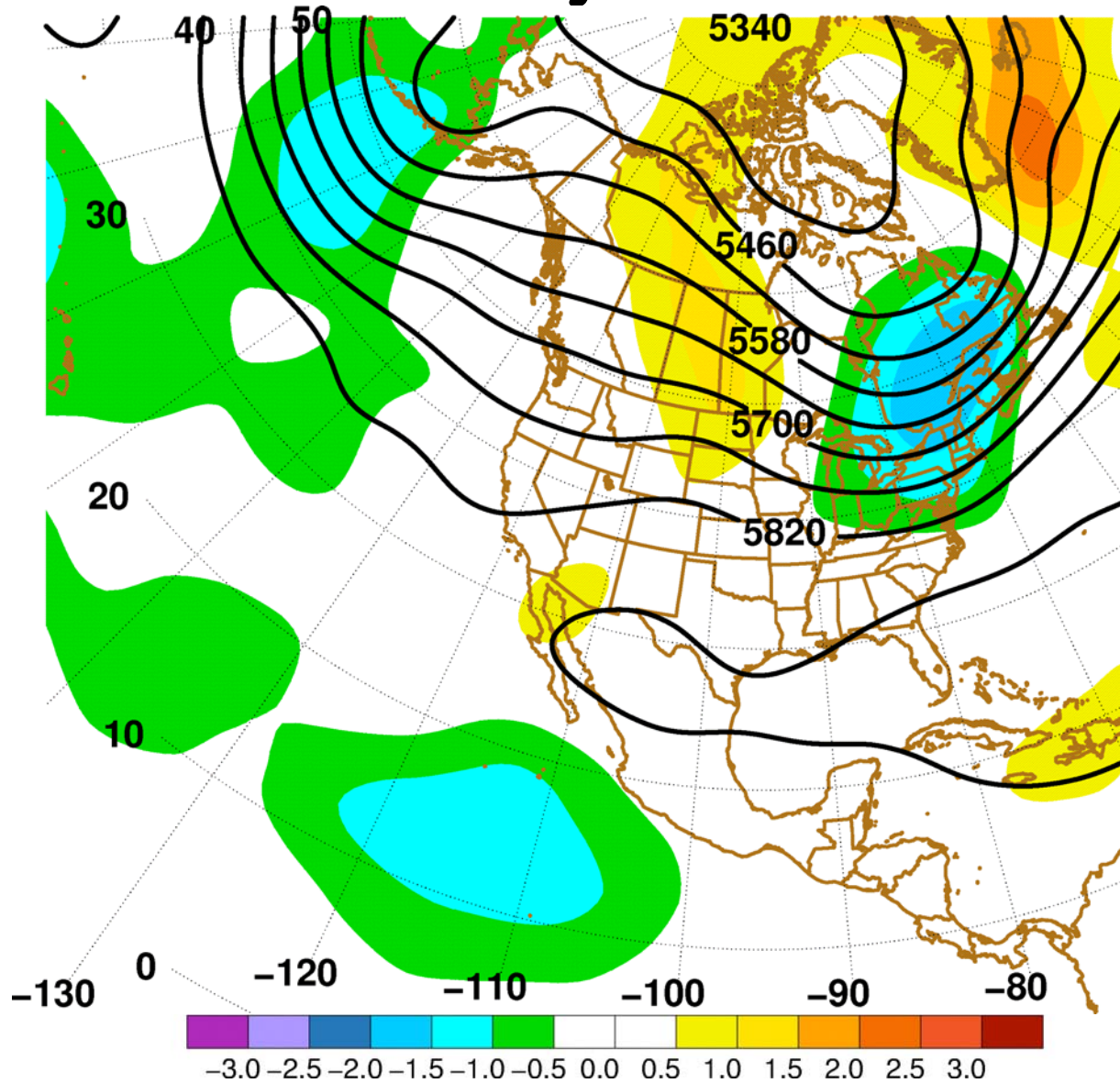
Day T-5



NCEP/NCAR Reanalysis

Mean and standardized anomaly, 500 hPa heights

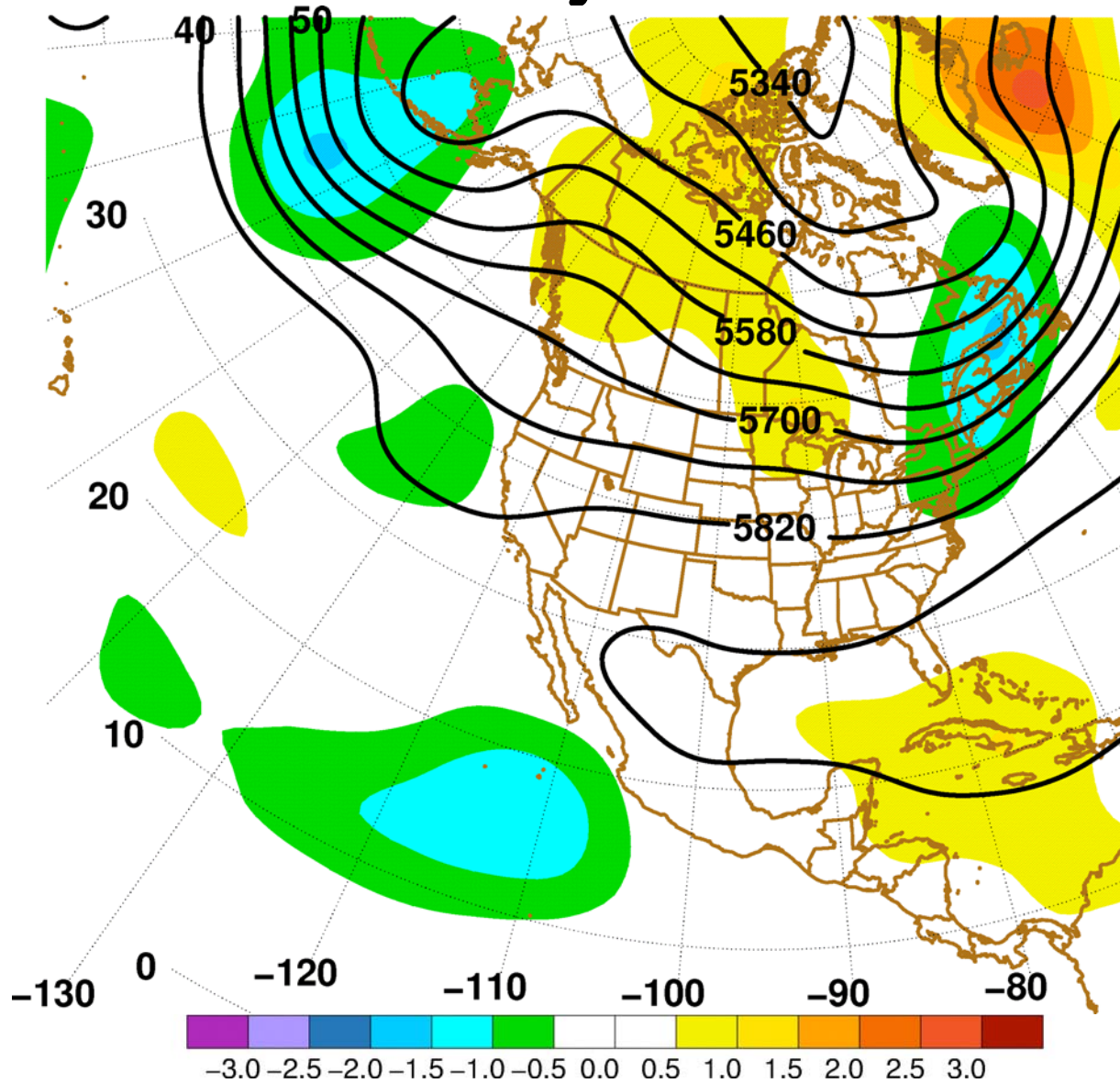
Day T-4



NCEP/NCAR Reanalysis

Mean and standardized anomaly, 500 hPa heights

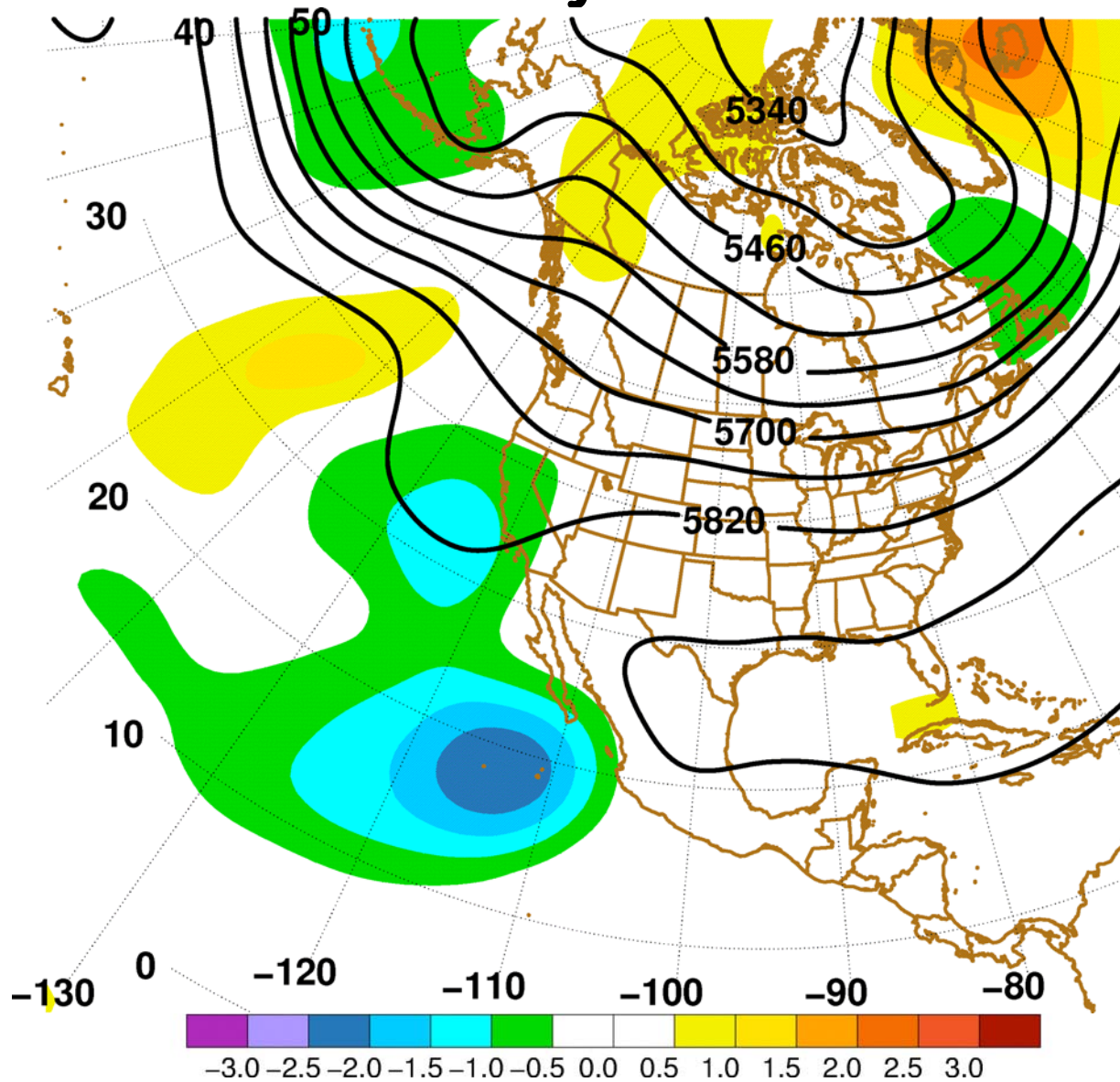
Day T-3



NCEP/NCAR Reanalysis

Mean and standardized anomaly, 500 hPa heights

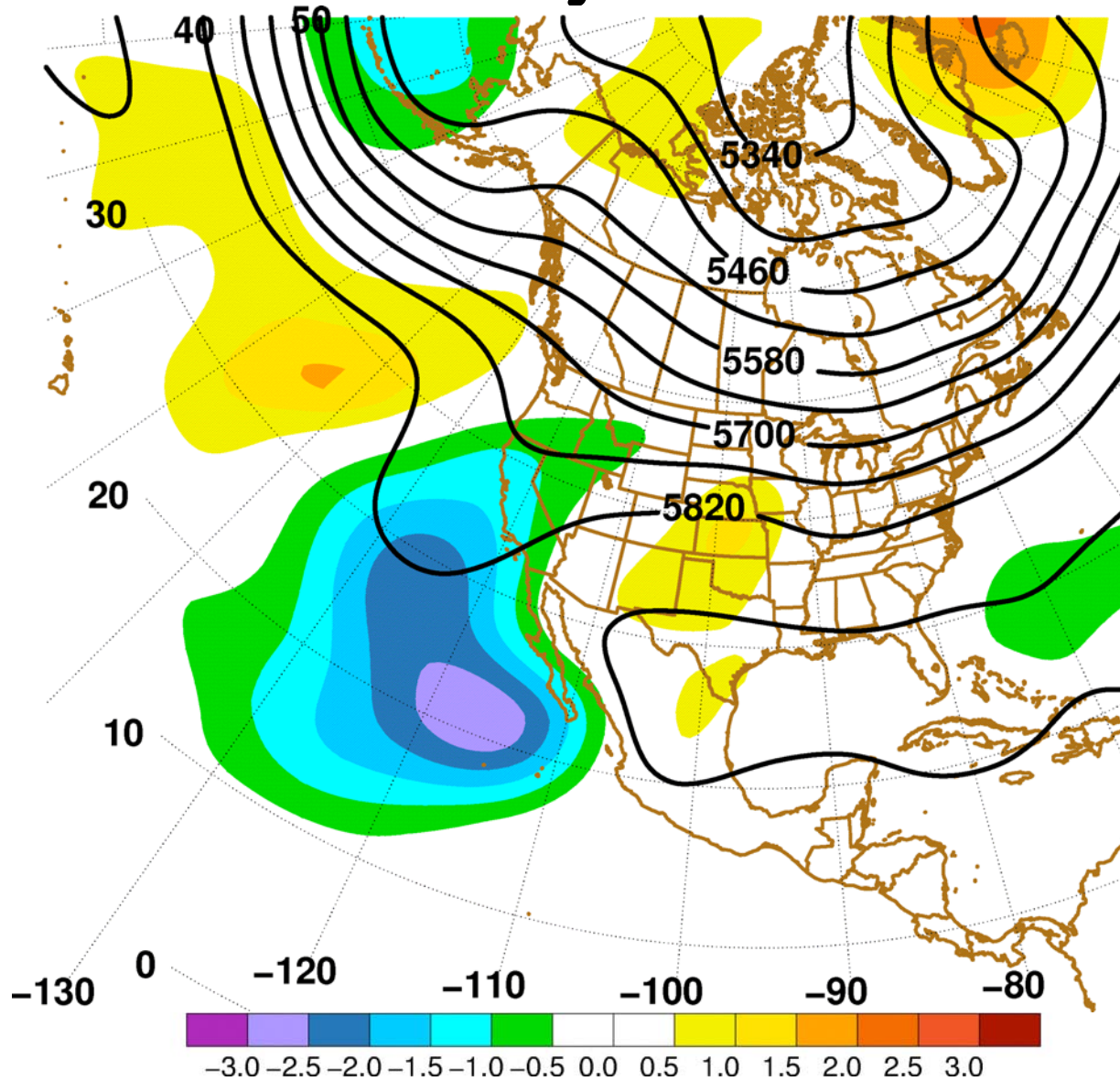
Day T-2



NCEP/NCAR Reanalysis

Mean and standardized anomaly, 500 hPa heights

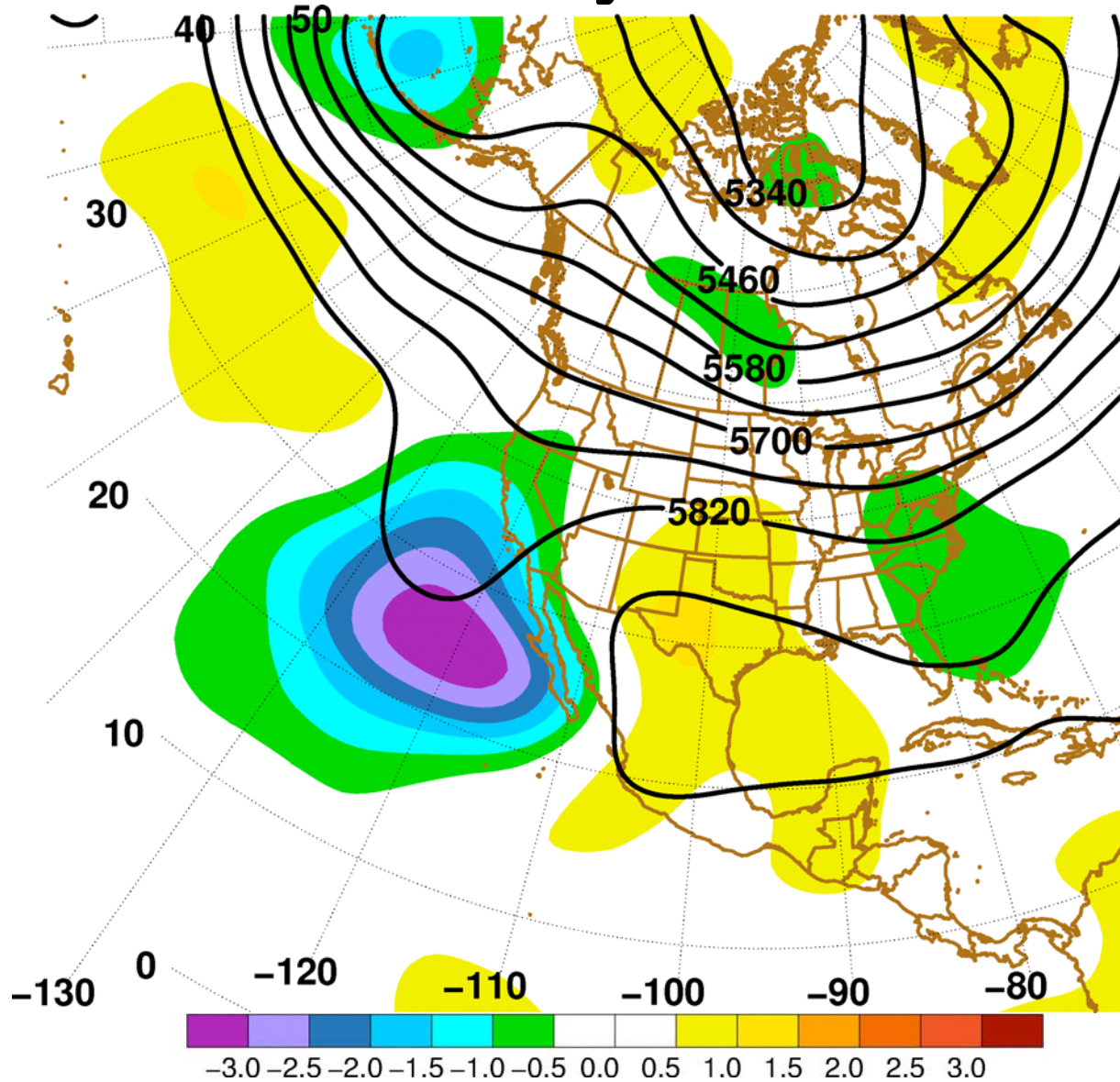
Day T-1



NCEP/NCAR Reanalysis

Mean and standardized anomaly, 500 hPa heights

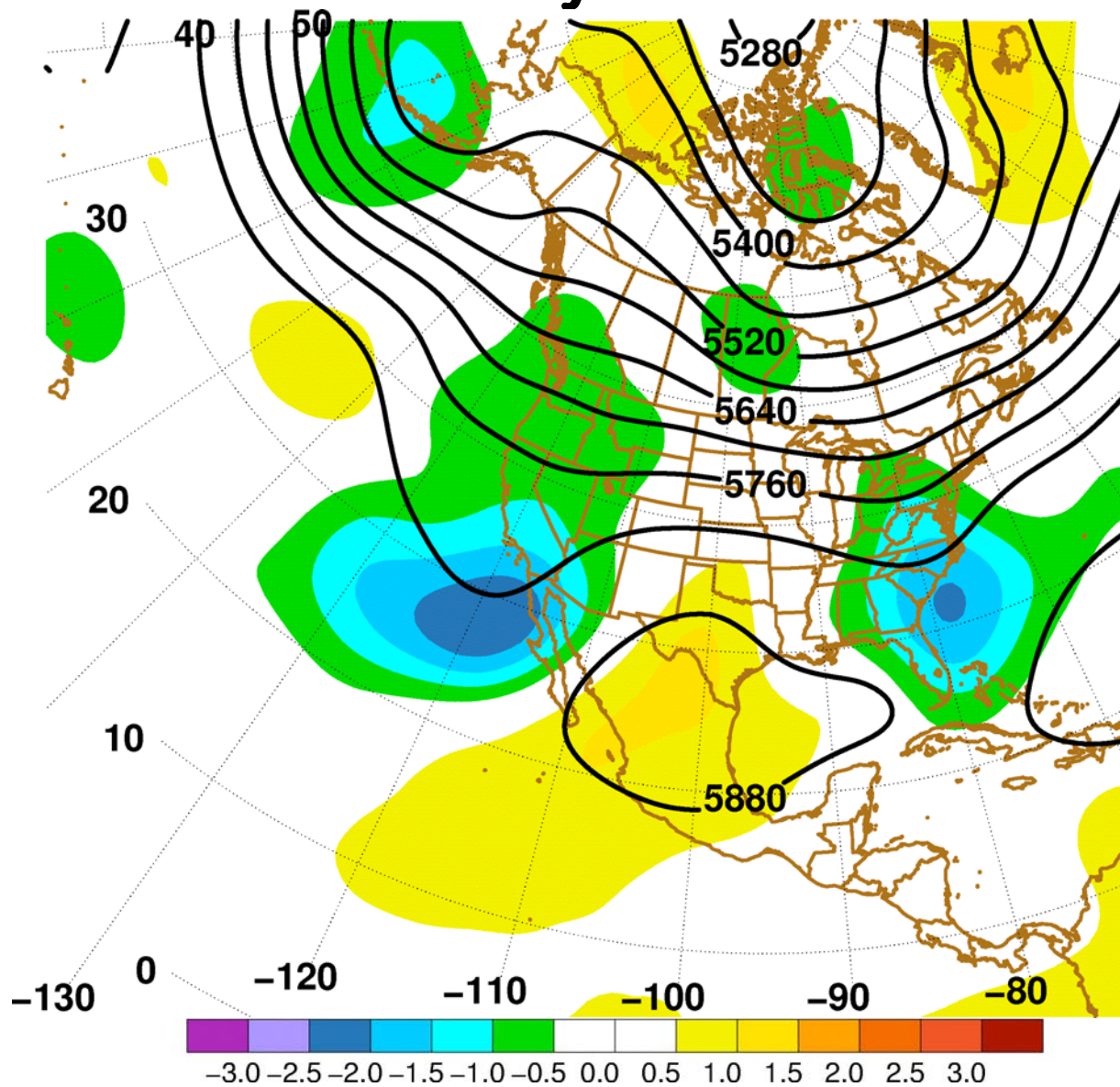
Day T



NCEP/NCAR Reanalysis

Mean and standardized anomaly, 500 hPa heights

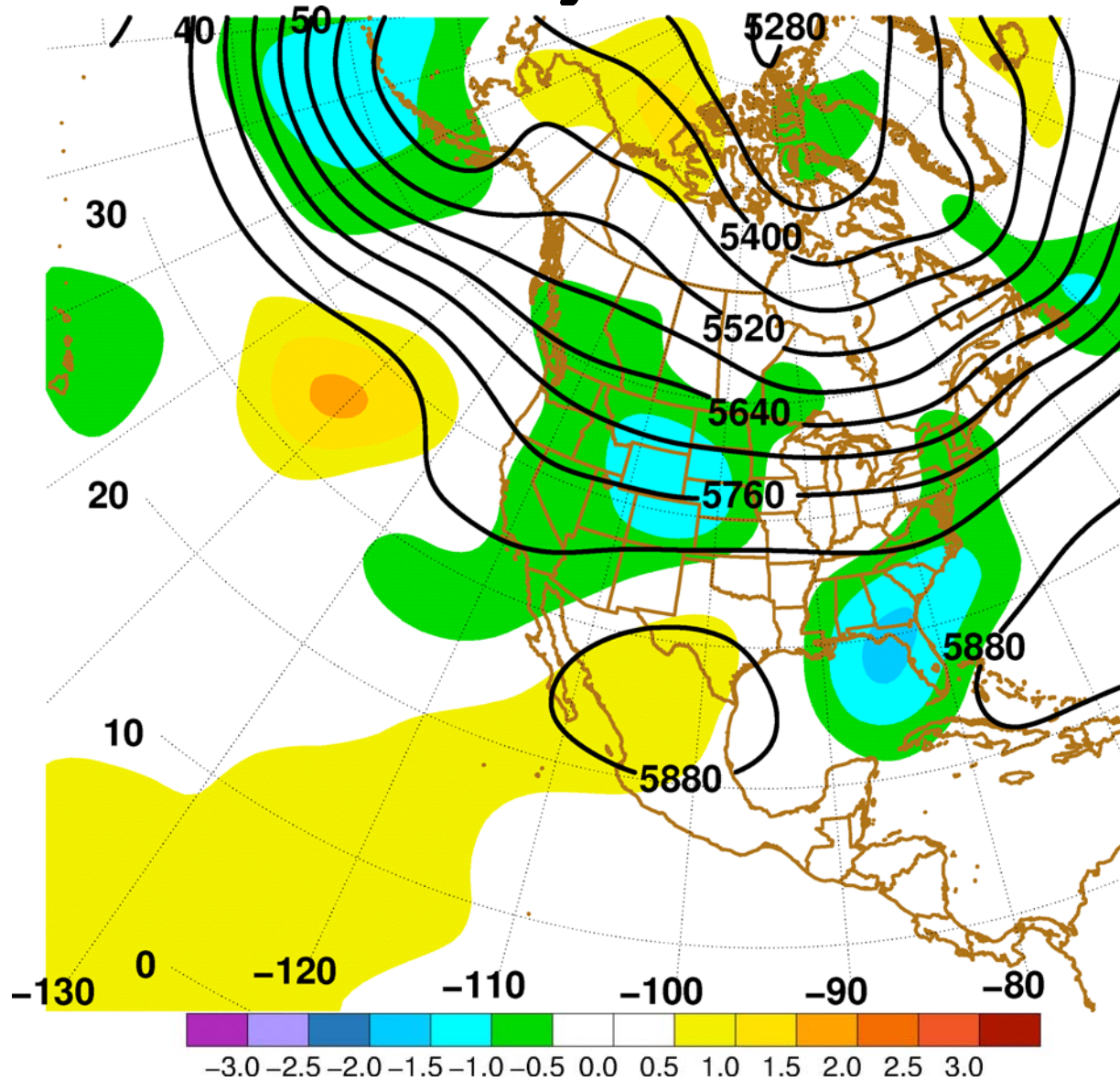
Day T+1



NCEP/NCAR Reanalysis

Mean and standardized anomaly, 500 hPa heights

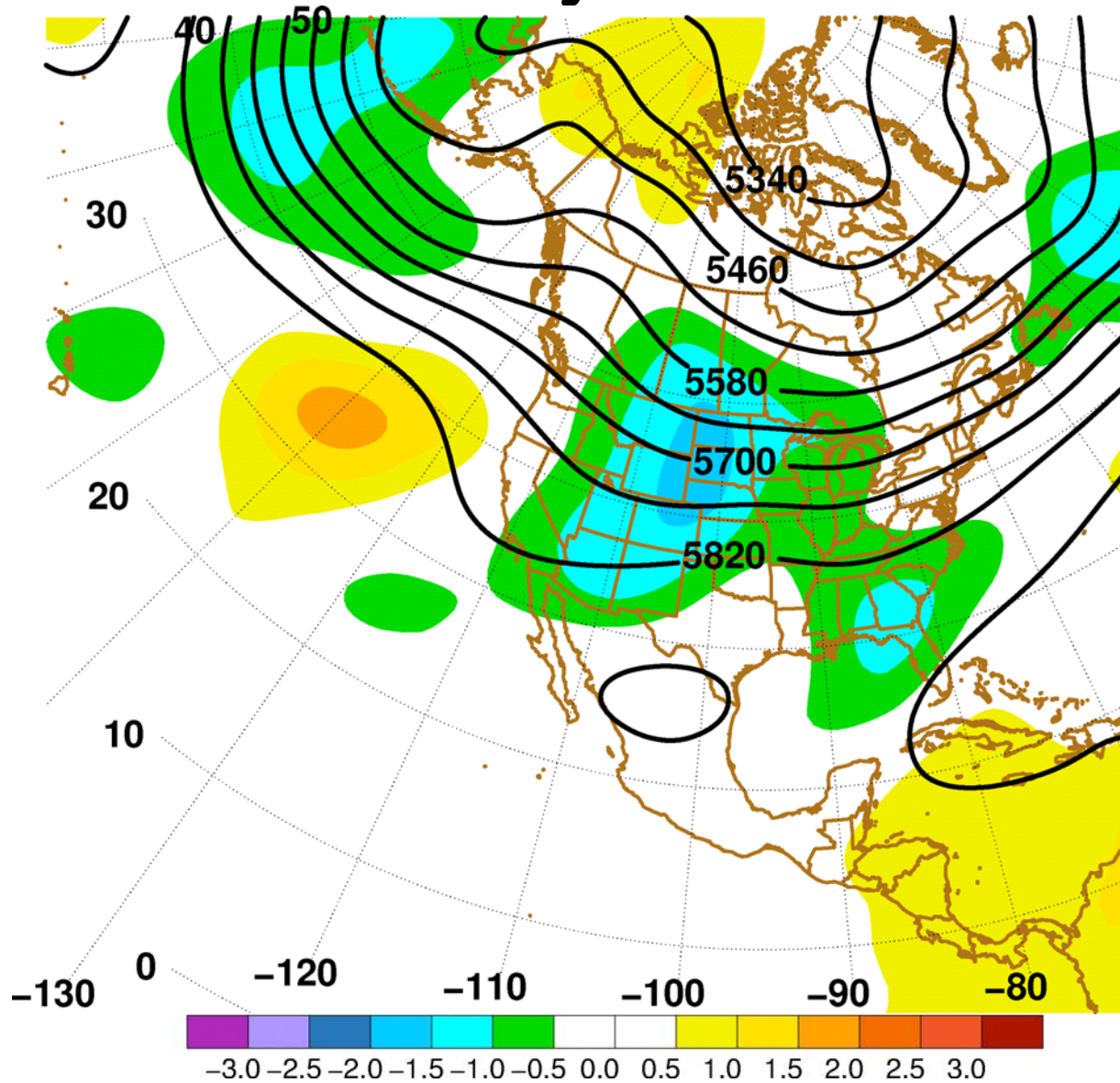
Day T+2



NCEP/NCAR Reanalysis

Mean and standardized anomaly, 500 hPa heights

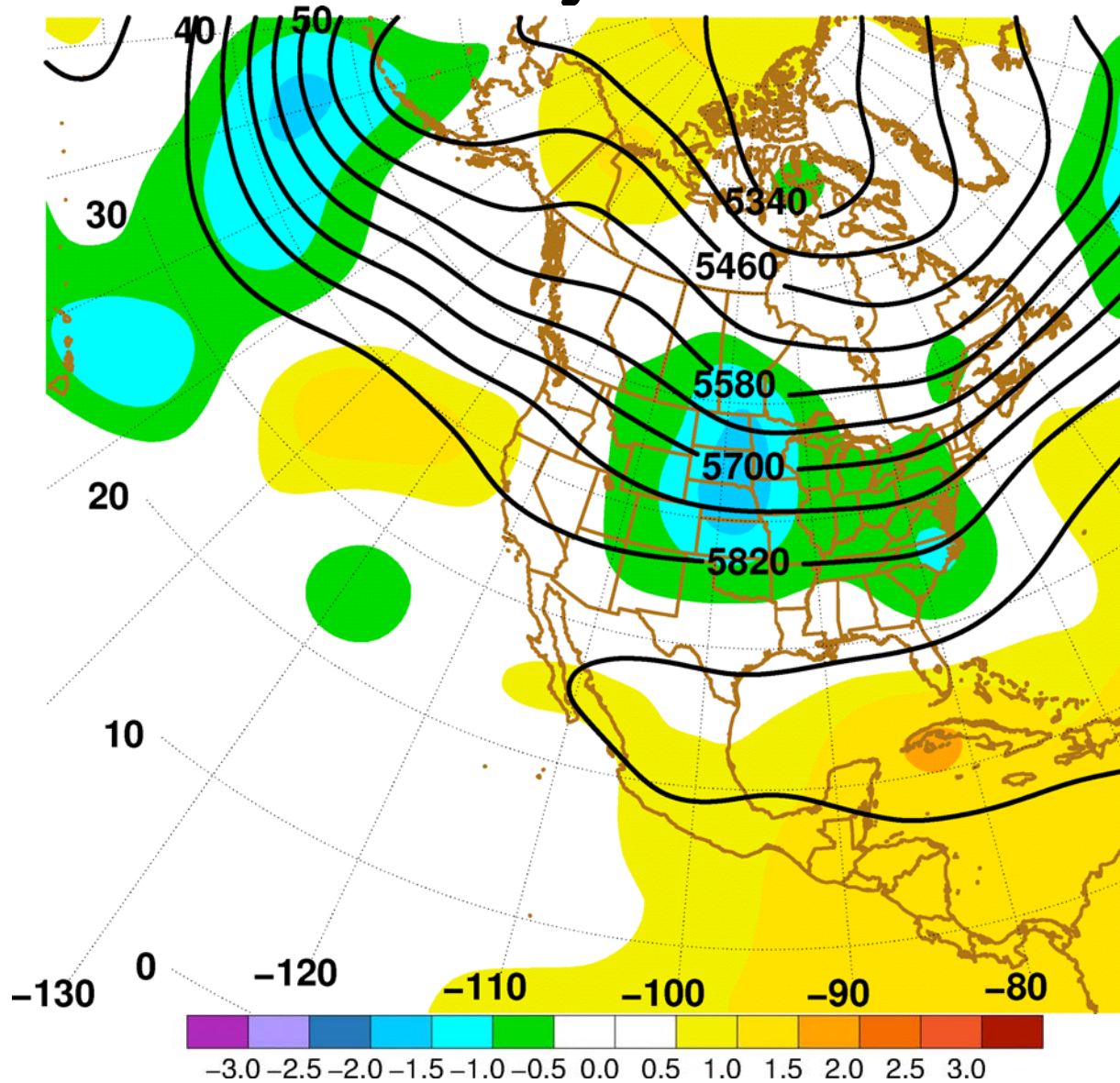
Day T+3



NCEP/NCAR Reanalysis

Mean and standardized anomaly, 500 hPa heights

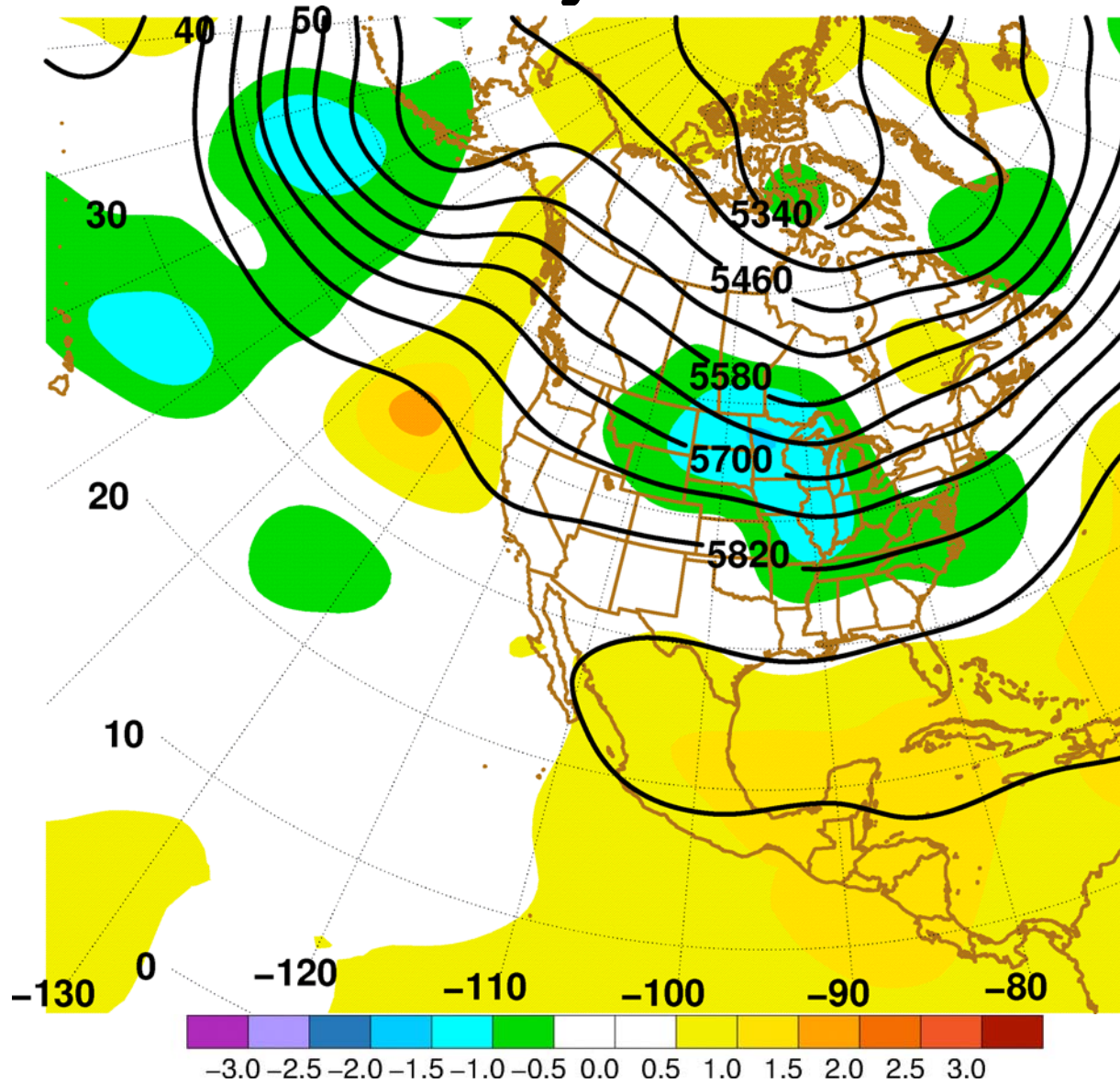
Day T+4



NCEP/NCAR Reanalysis

Mean and standardized anomaly, 500 hPa heights

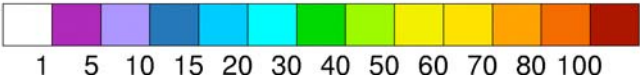
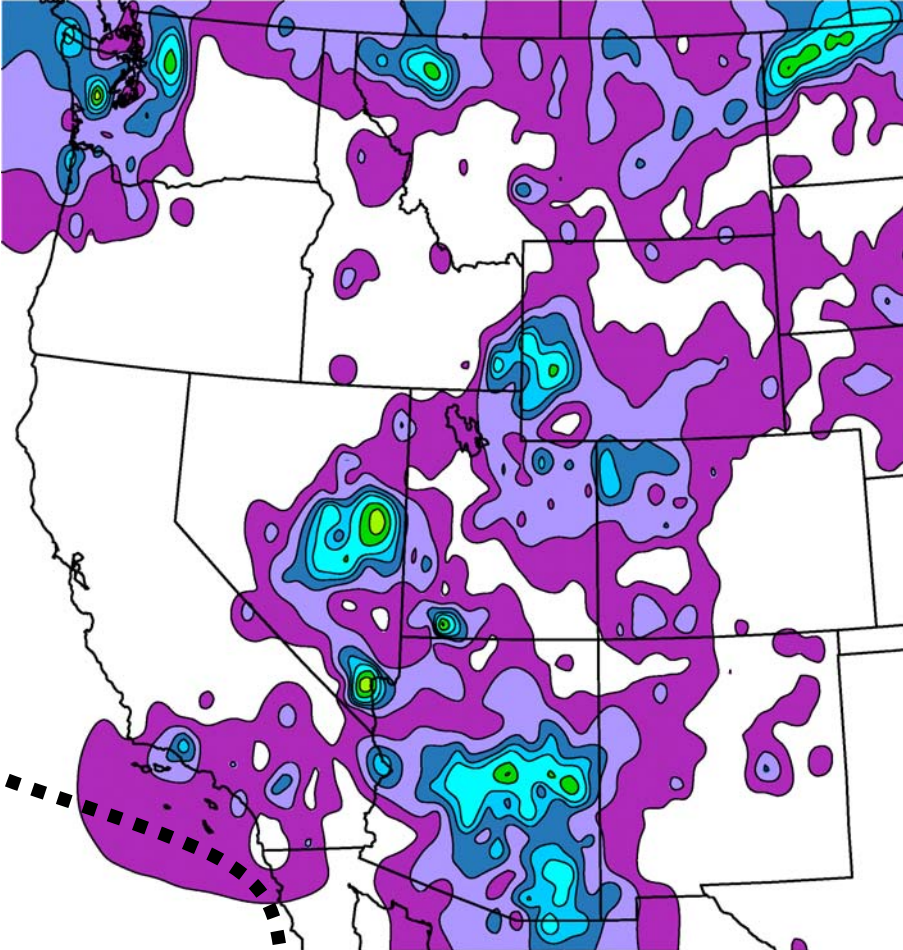
Day T+5



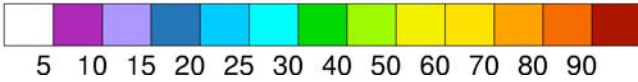
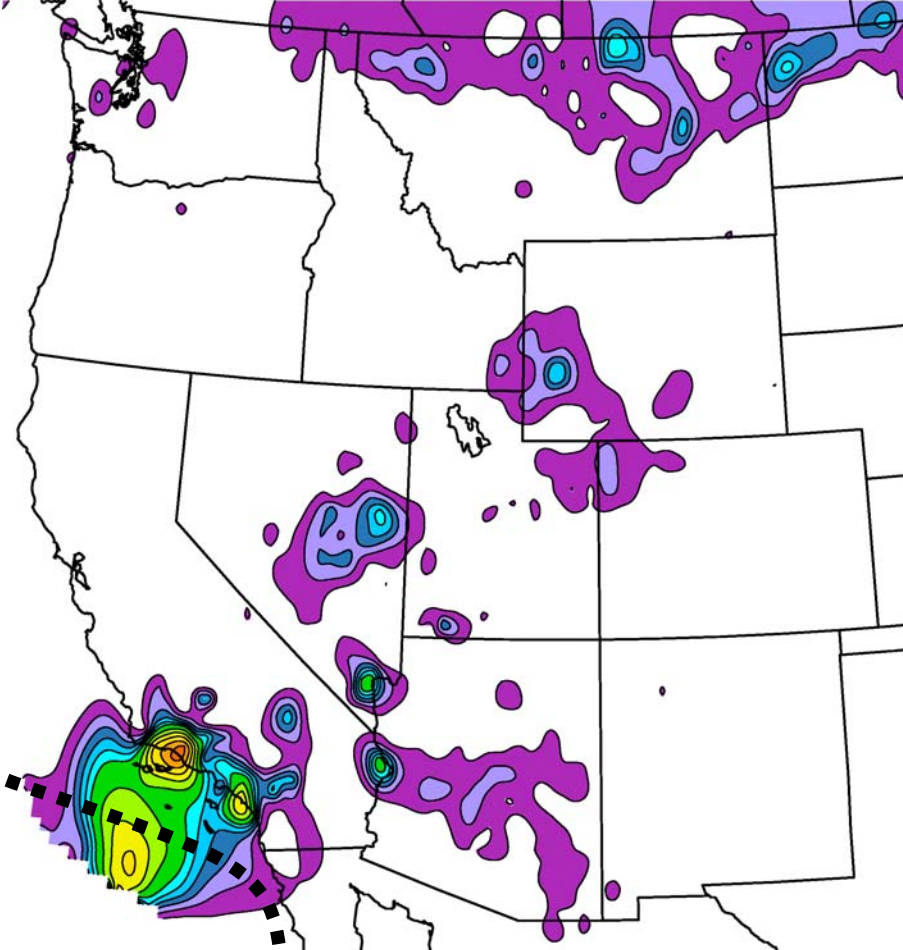
Precipitation patterns and climatology:

- The 35 TCs that brought rainfall to the southwest U.S. possess a wide variety of rainfall distributions from southwest-northeast oriented streaks extending well into the central U.S. to isolated pockets along the border
- The precipitation pattern depends upon a number of factors including topography, the scale and nature of the west coast trough and the proximity of the trough to the TC
- Three main track and precipitation types were defined:
 - 1) California-Nevada track (Cutoff low)
 - 2) Southwest-northeast swath (Mobile trough)
 - 3) Weakening in-situ (Missed / distant interaction)

Hurricane Marie 1984

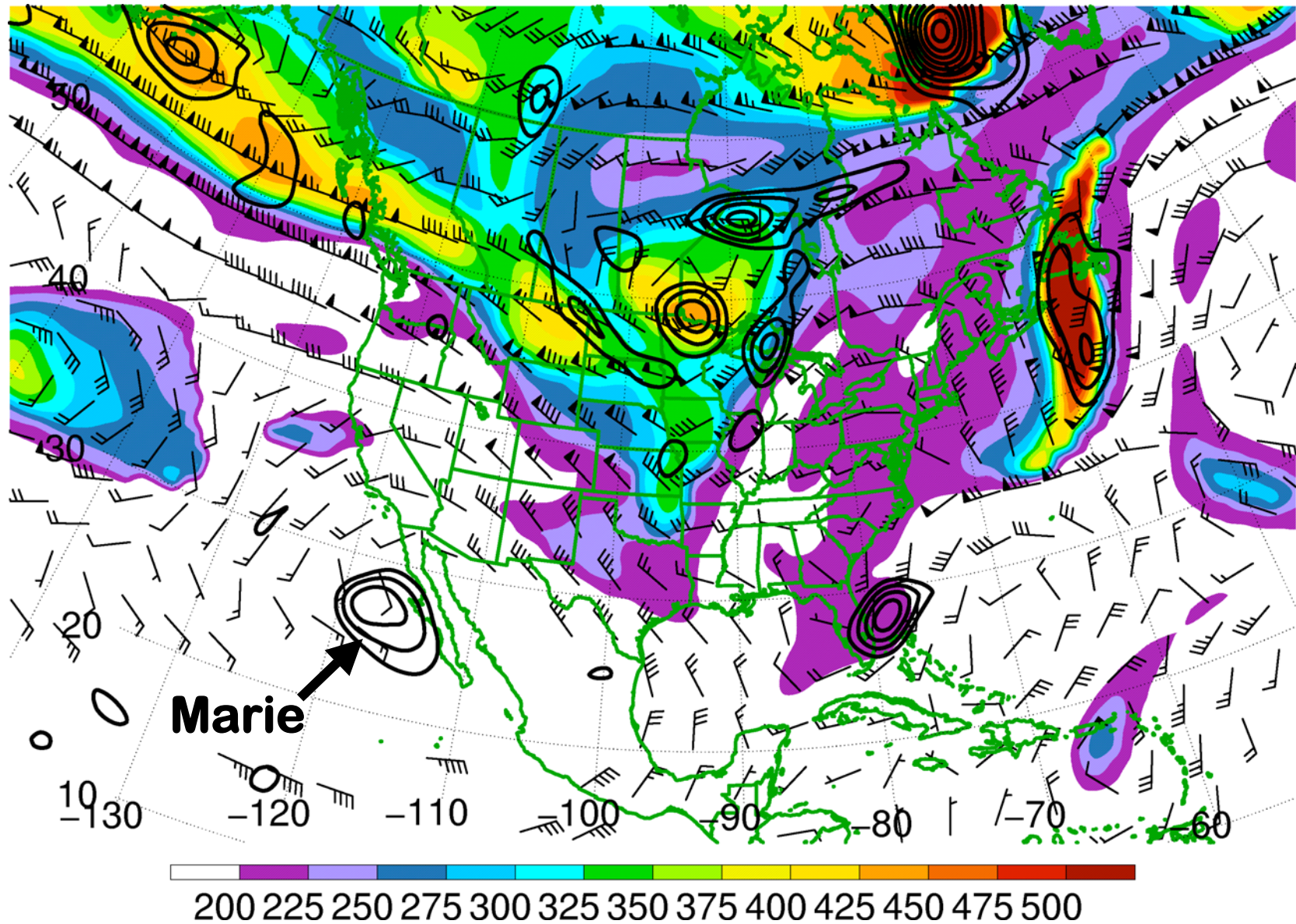


Storm total precipitation (mm)

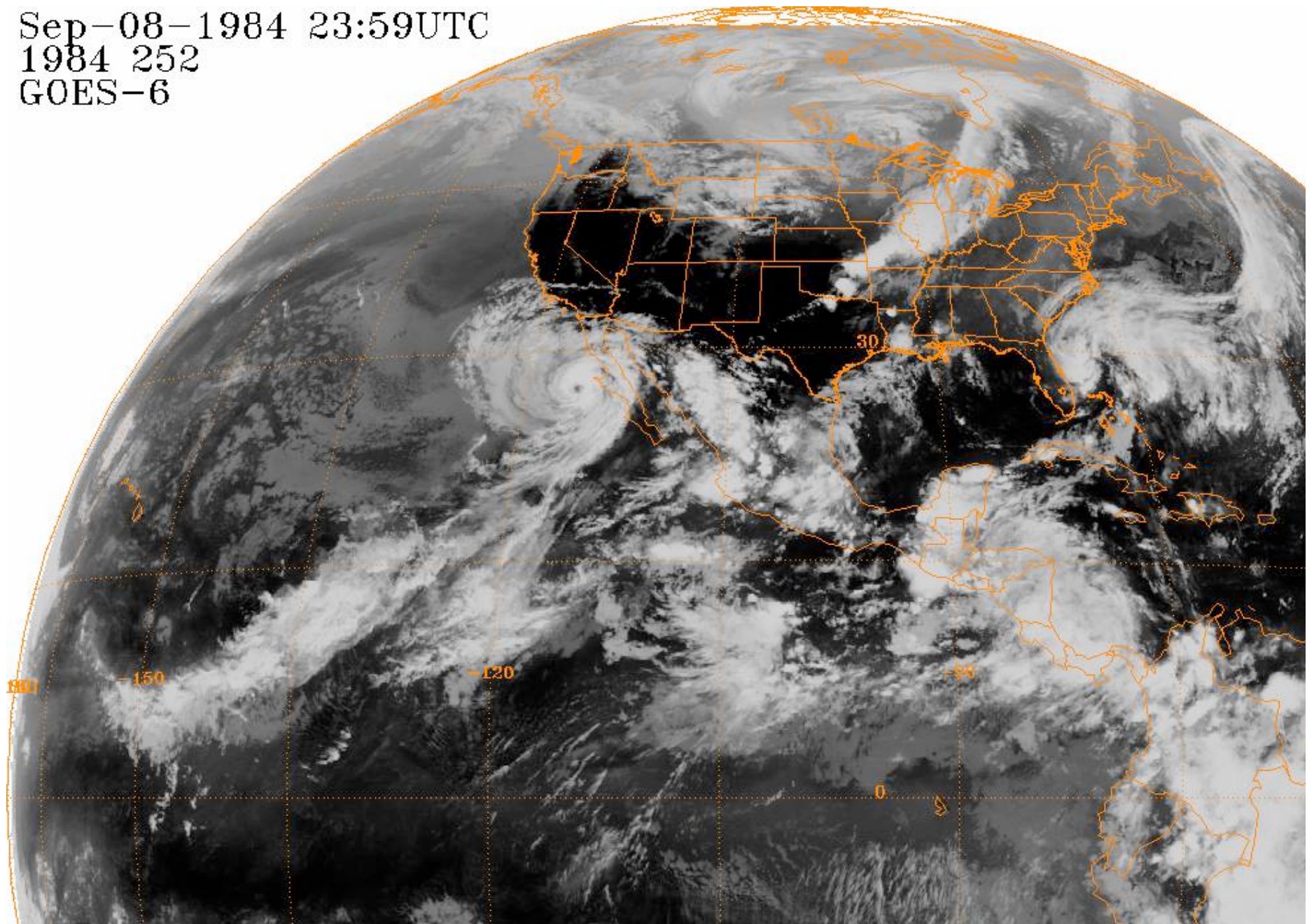


Storm contribution to warm season rainfall (%)

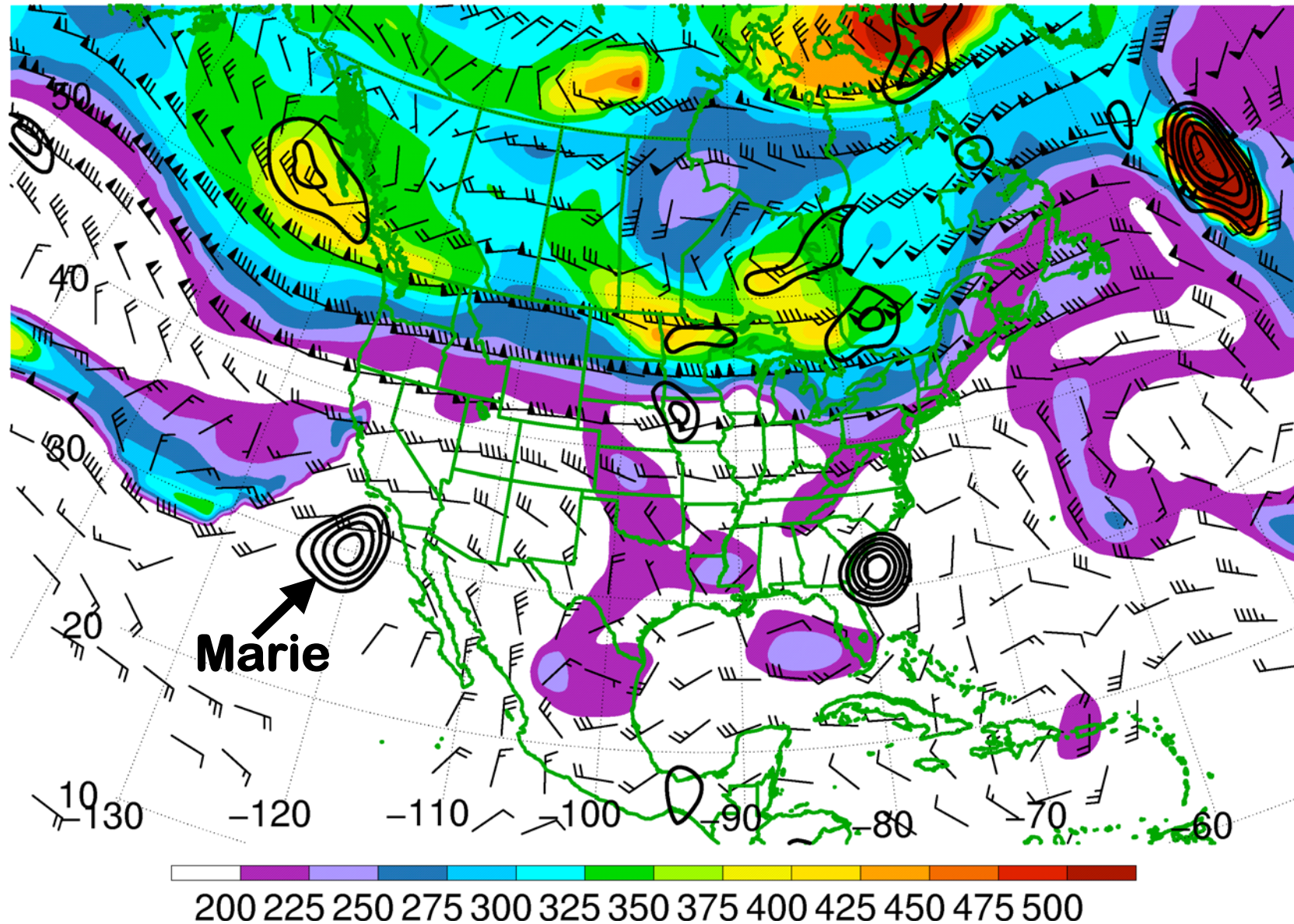
DT pressure (hPa), DT winds, & 700 hPa vorticity 00 UTC 9 September 1984



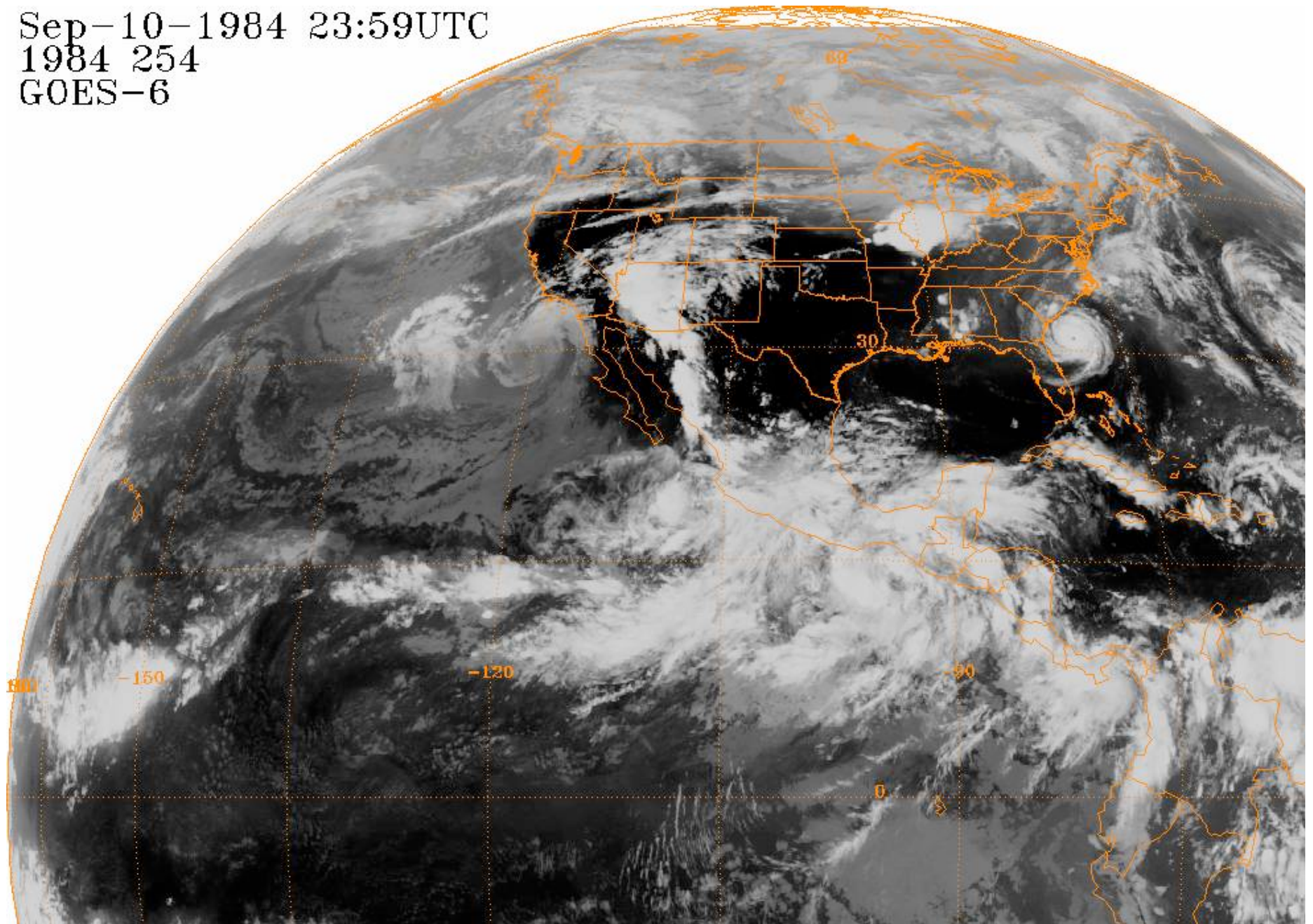
Sep-08-1984 23:59UTC
1984 252
GOES-6



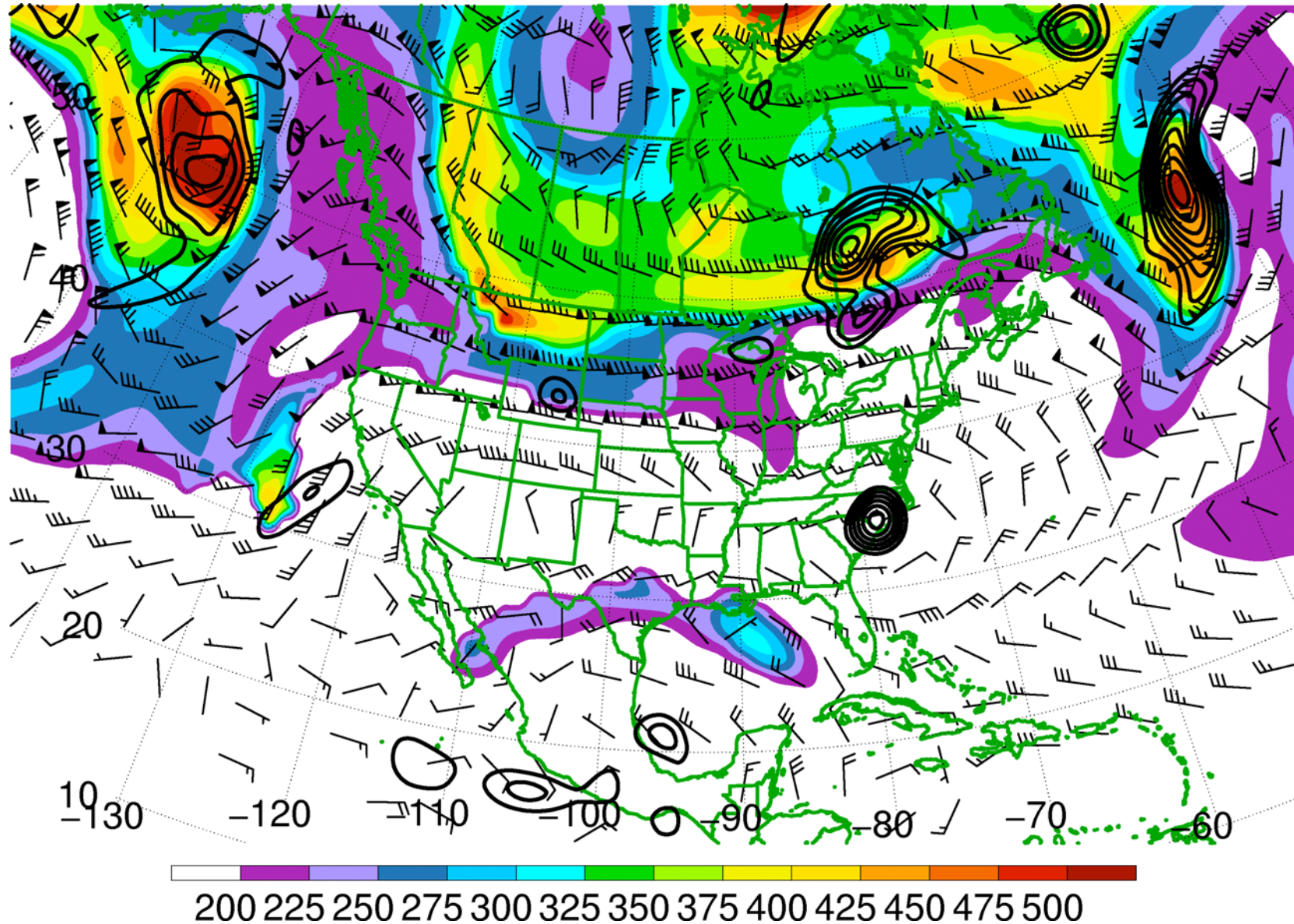
DT pressure (hPa), DT winds, & 700 hPa vorticity 00 UTC 11 September 1984



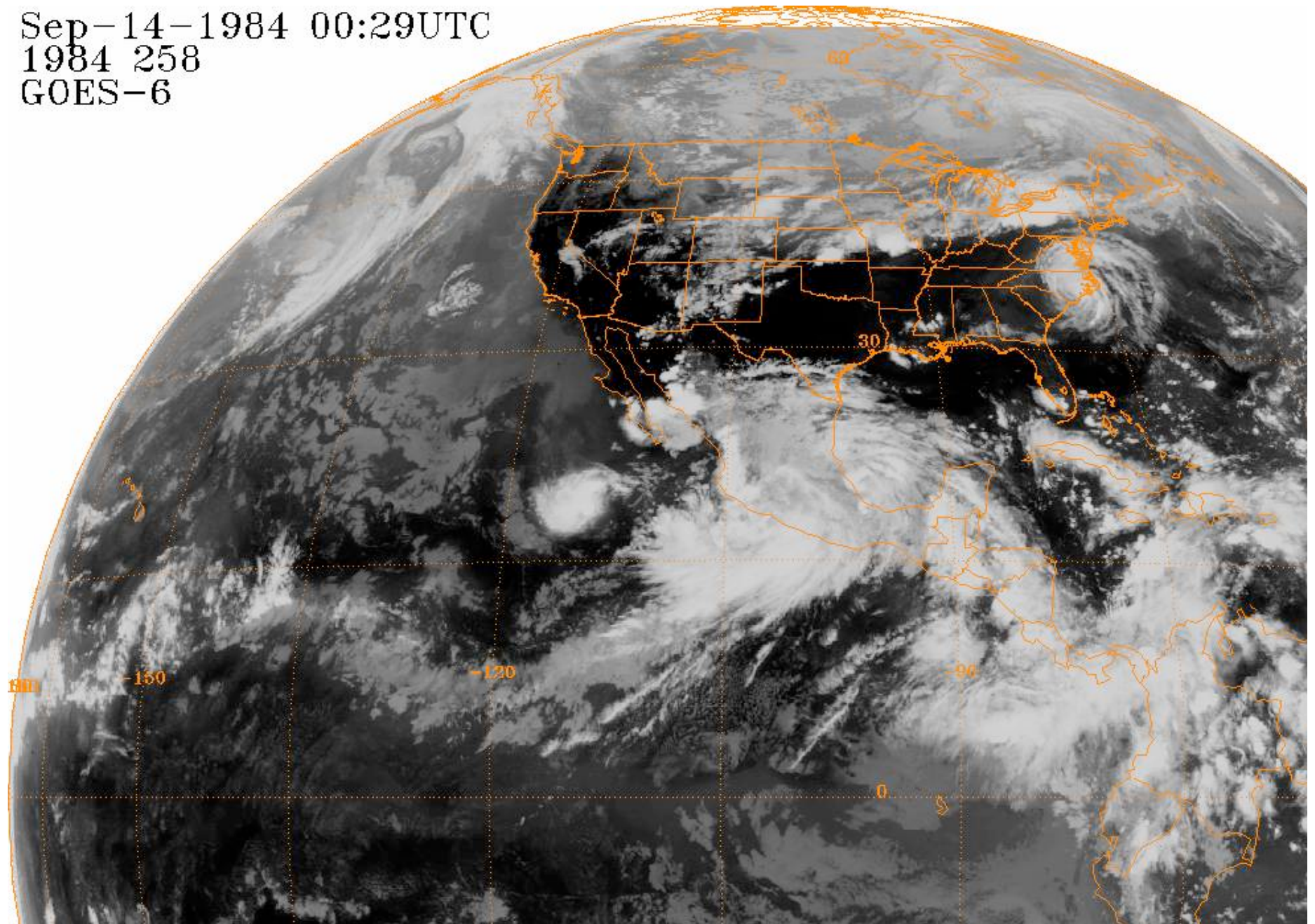
Sep-10-1984 23:59UTC
1984 254
GOES-6



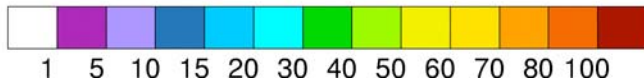
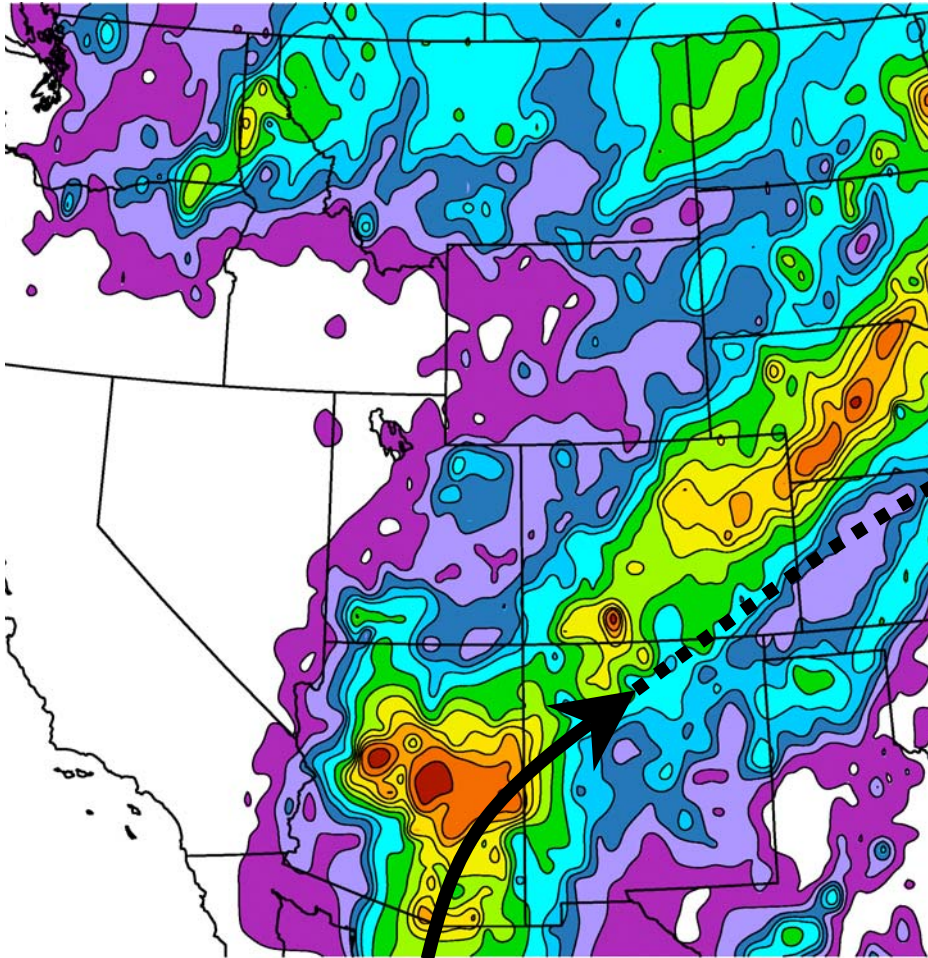
DT pressure (hPa), DT winds, & 700 hPa vorticity 00 UTC 14 September 1984



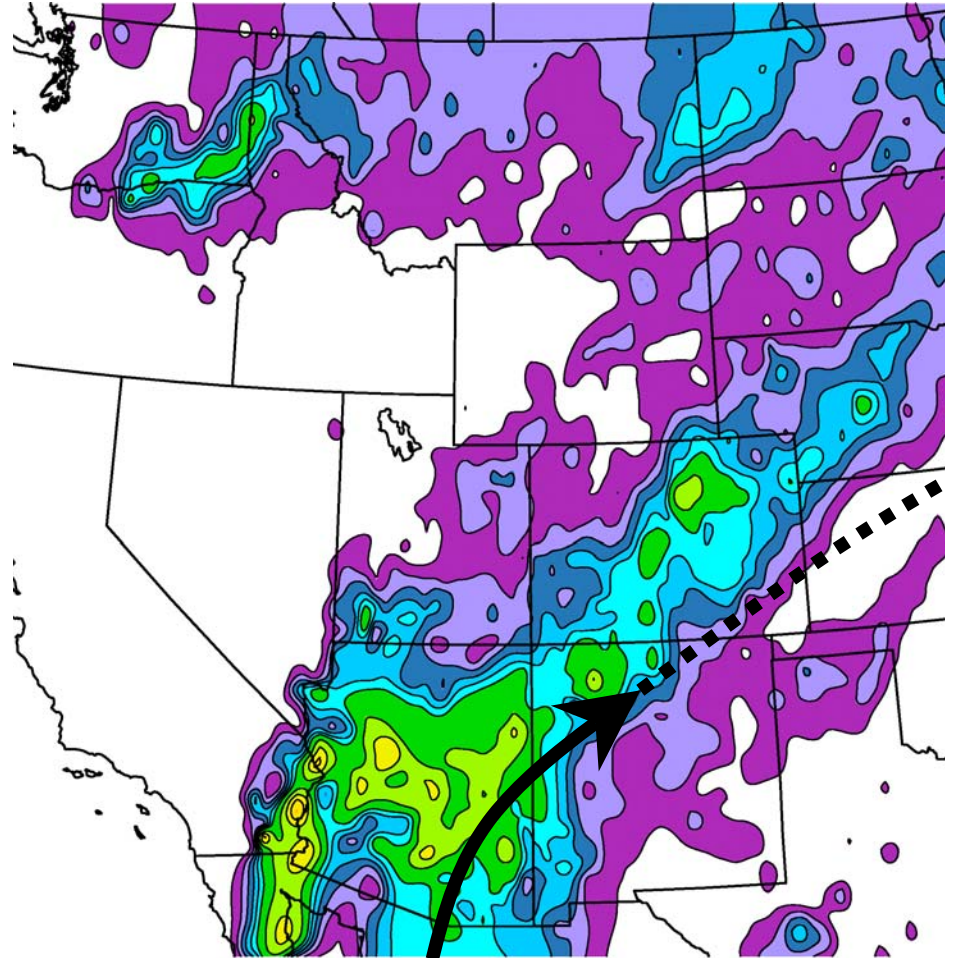
Sep-14-1984 00:29UTC
1984 258
GOES-6



Hurricane Lester 1992

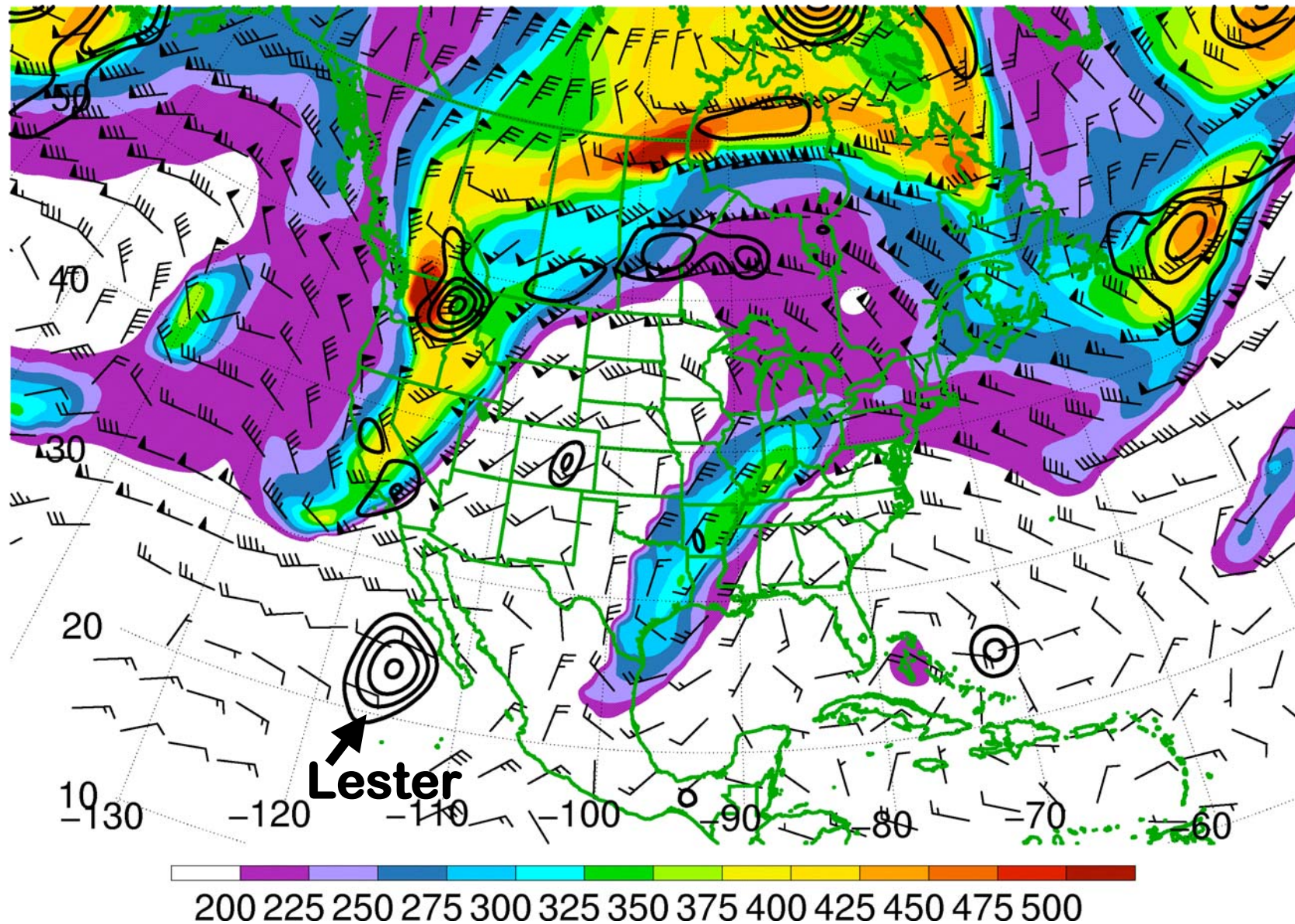


**Storm total
precipitation (mm)**



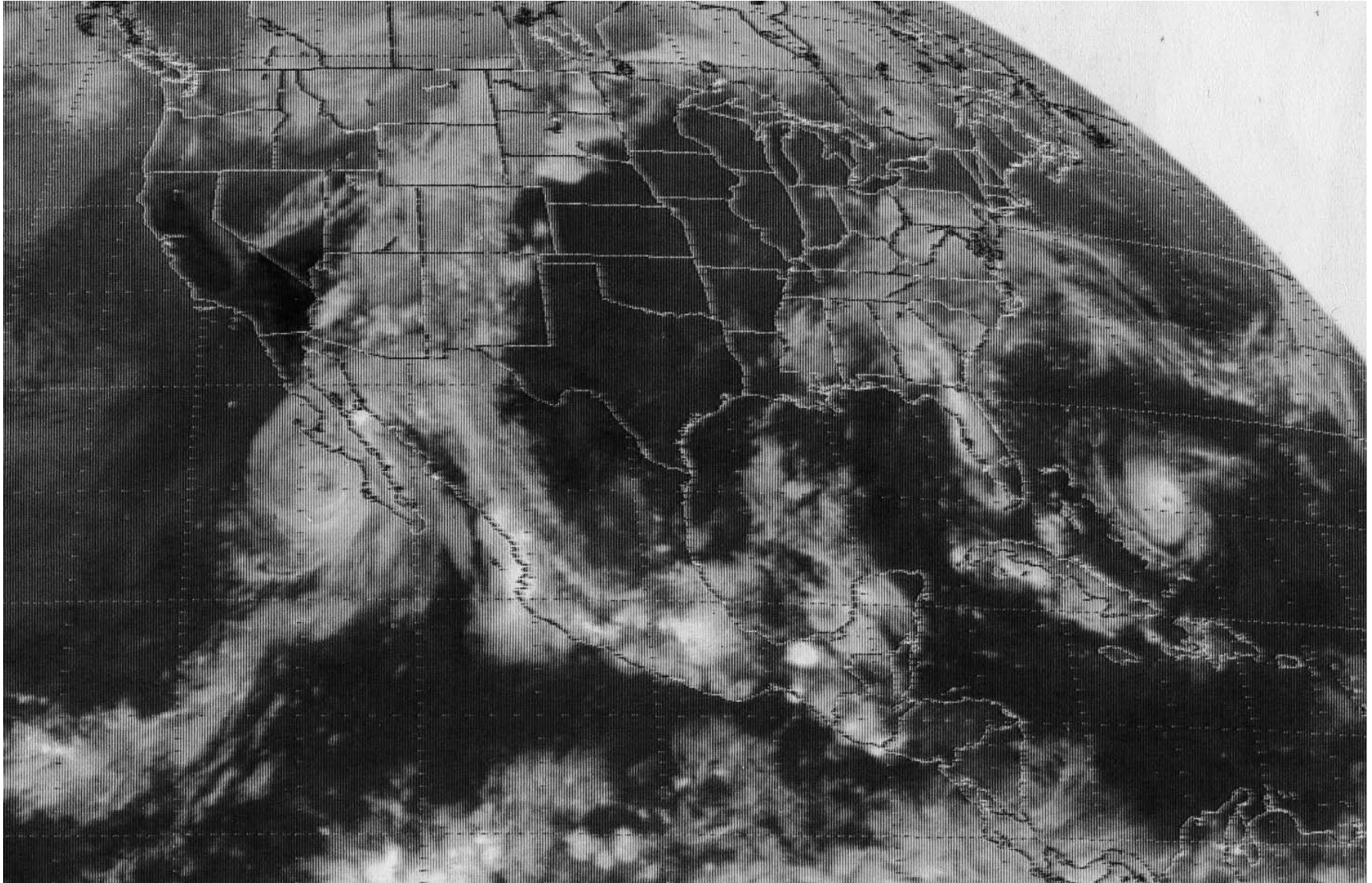
**Storm contribution to
warm season rainfall (%)**

DT pressure (hPa), DT winds, & 700 hPa vorticity 00 UTC 23 August 1992

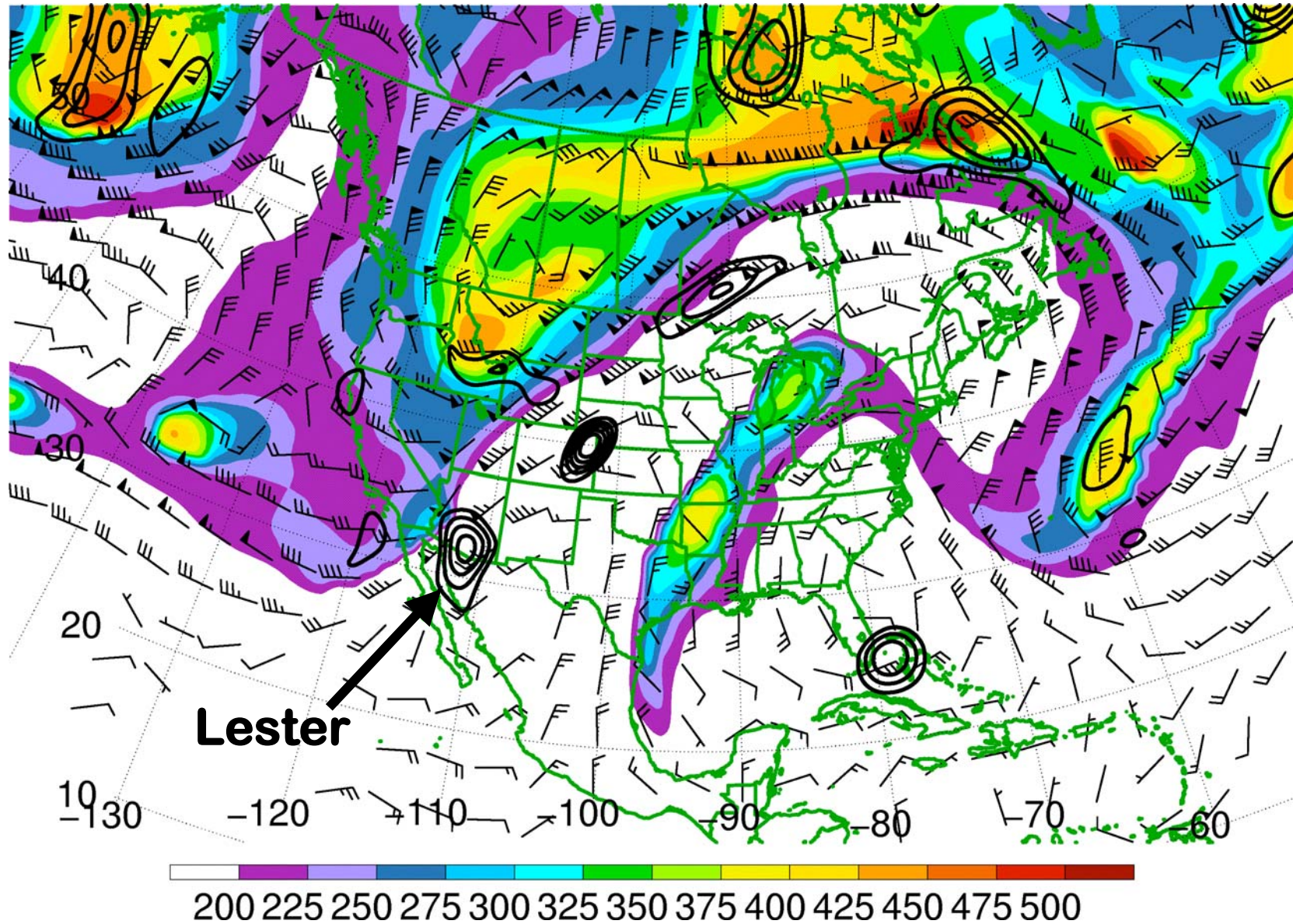


Hurricane Lester

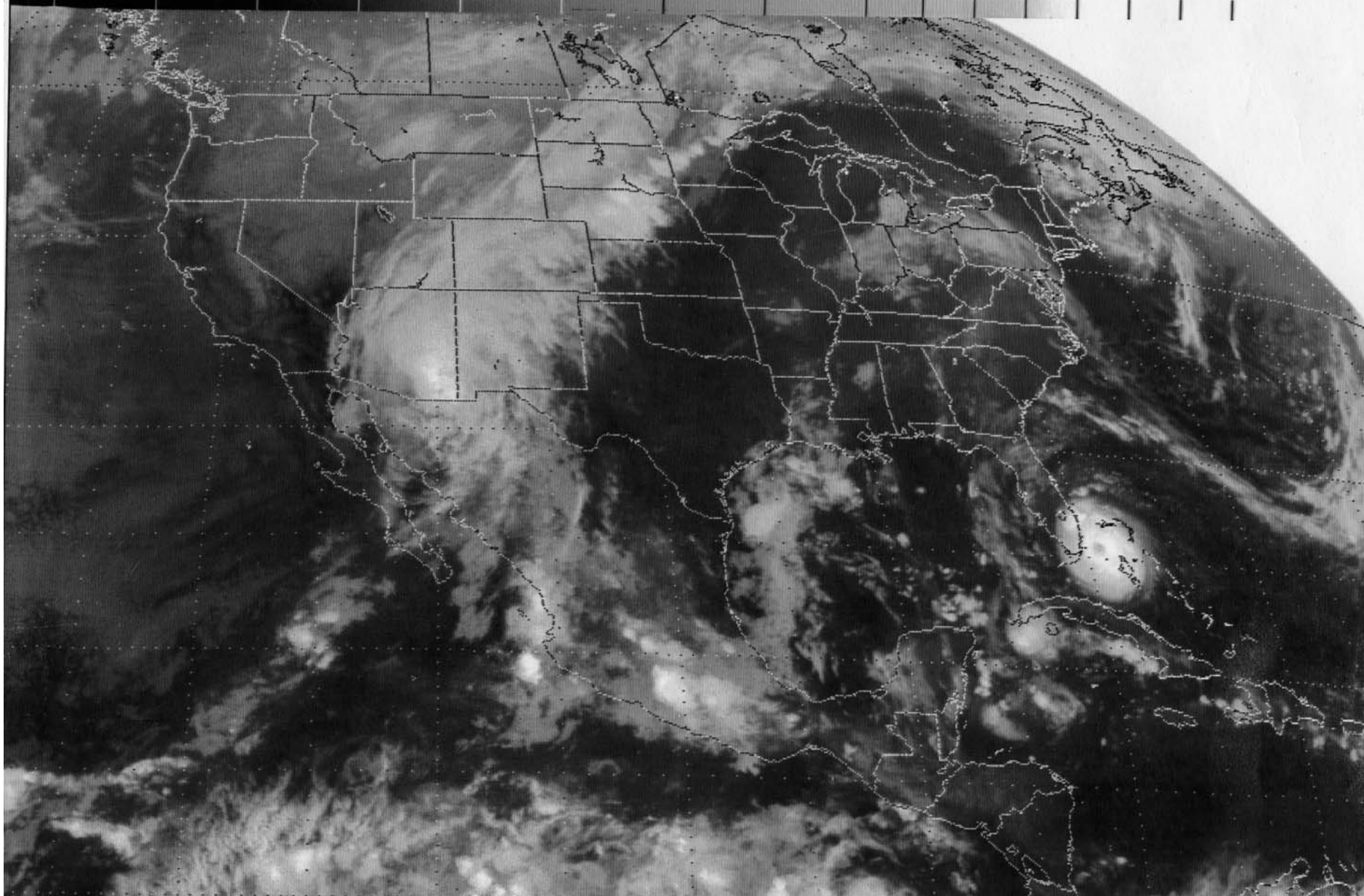
02 UTC 23 August 1992



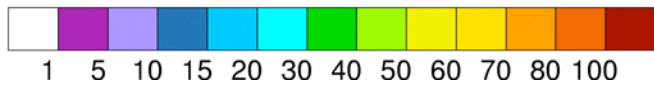
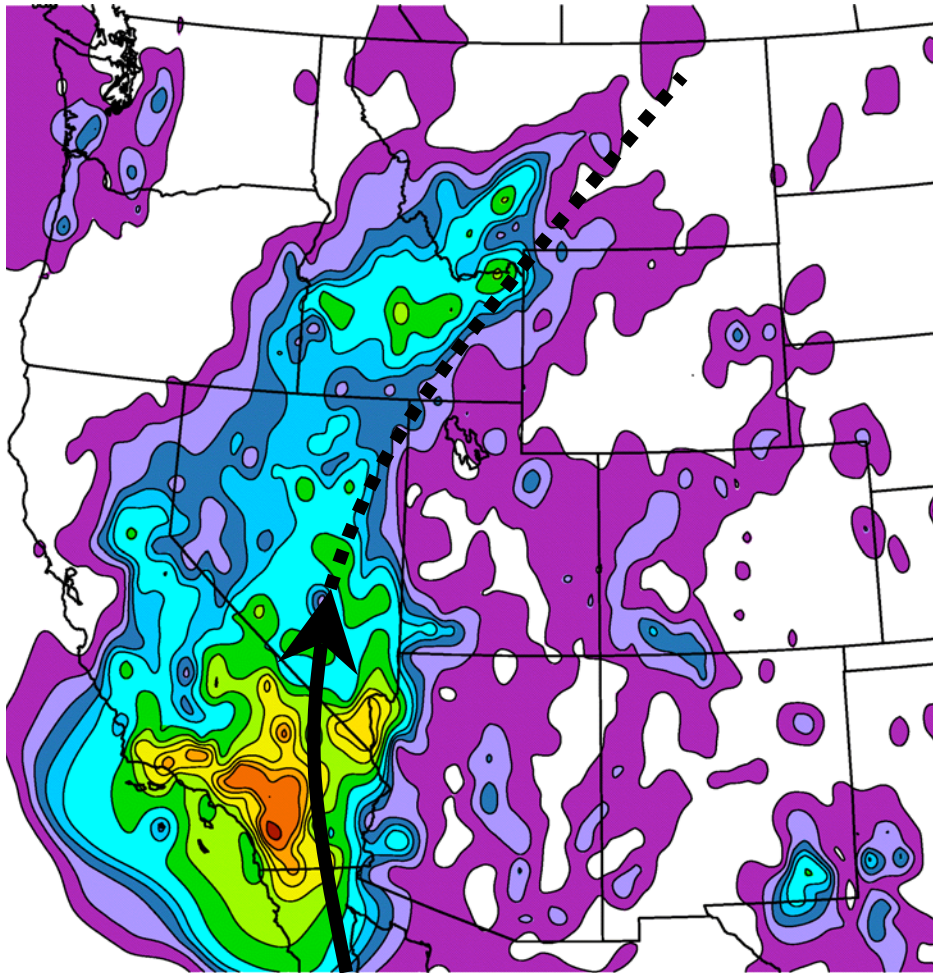
DT pressure (hPa), DT winds, & 700 hPa vorticity 06 UTC 24 August 1992



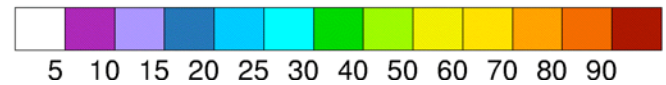
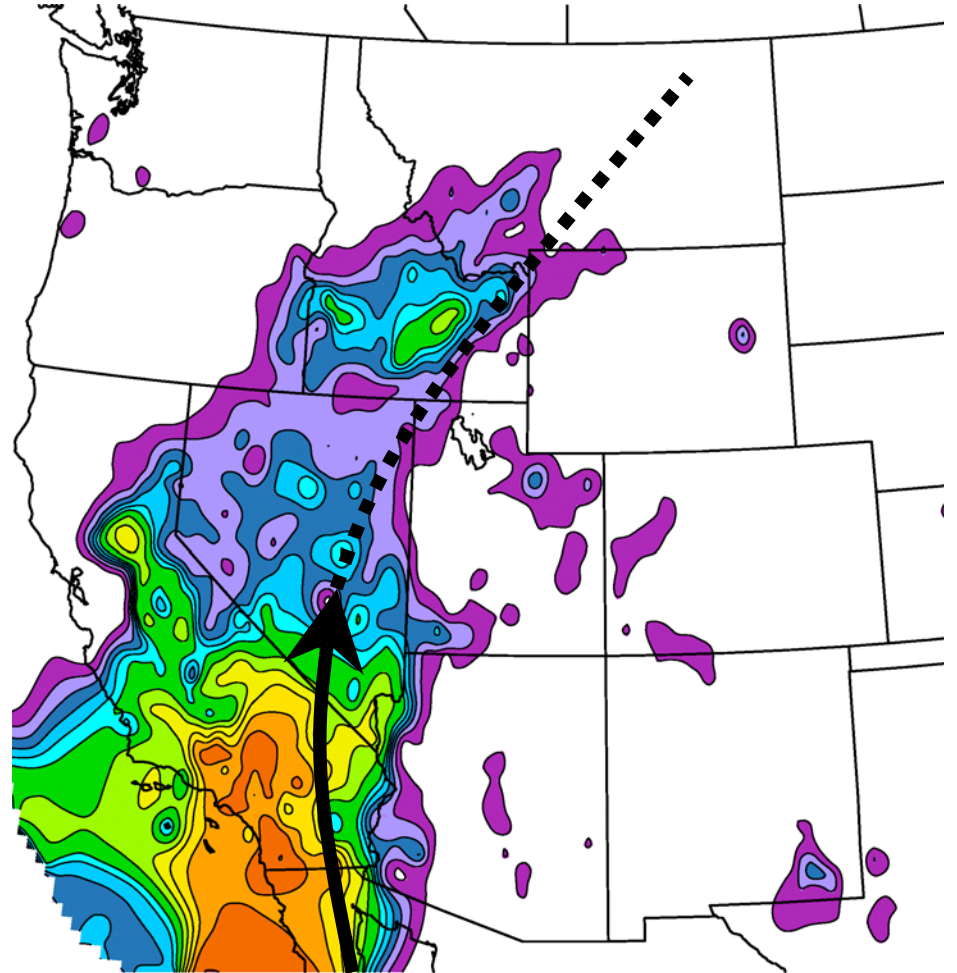
0531 24AU92 19E-42A 01052 23171 CC1



Hurricane Kathleen 1976

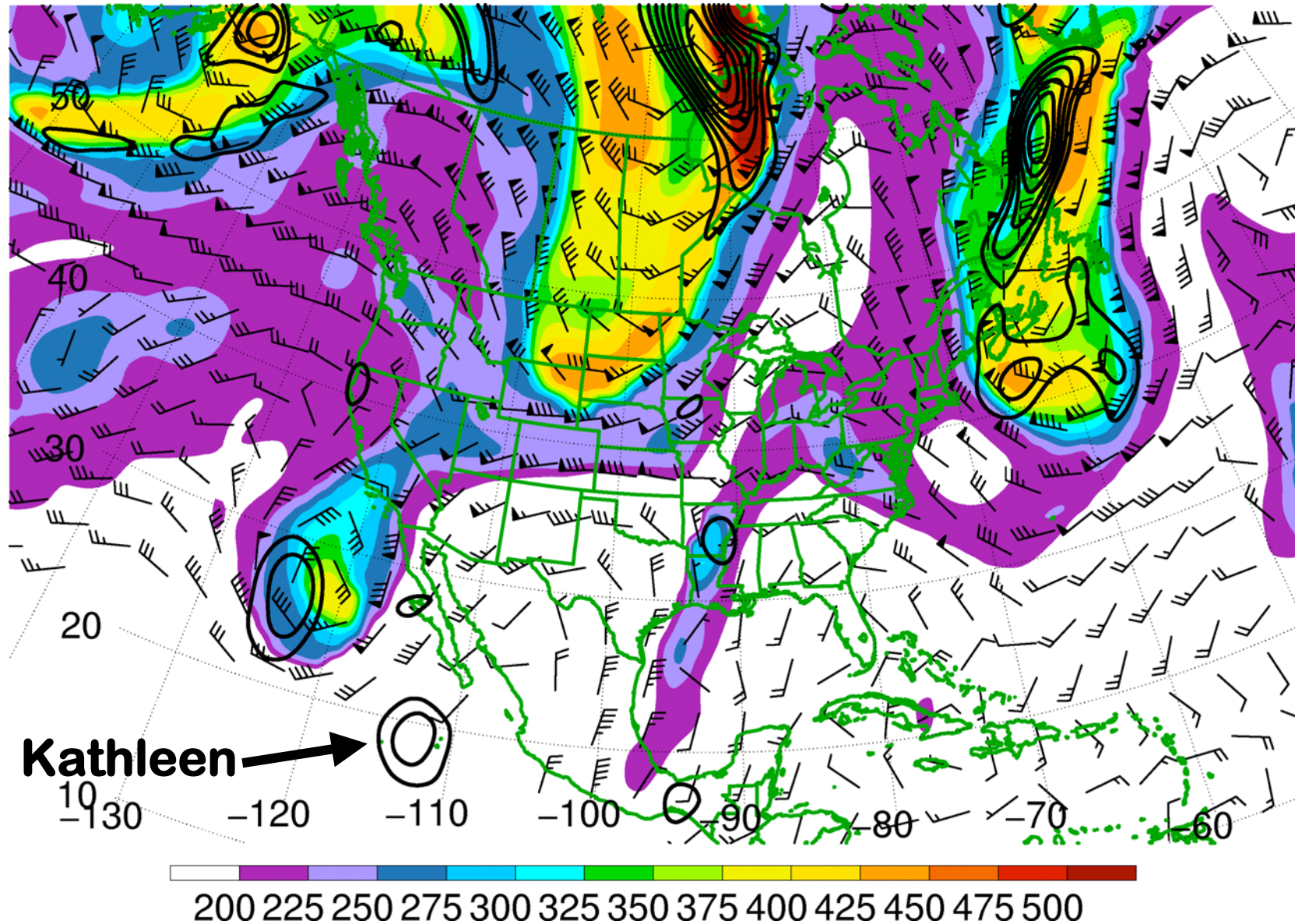


**Storm total
precipitation (mm)**

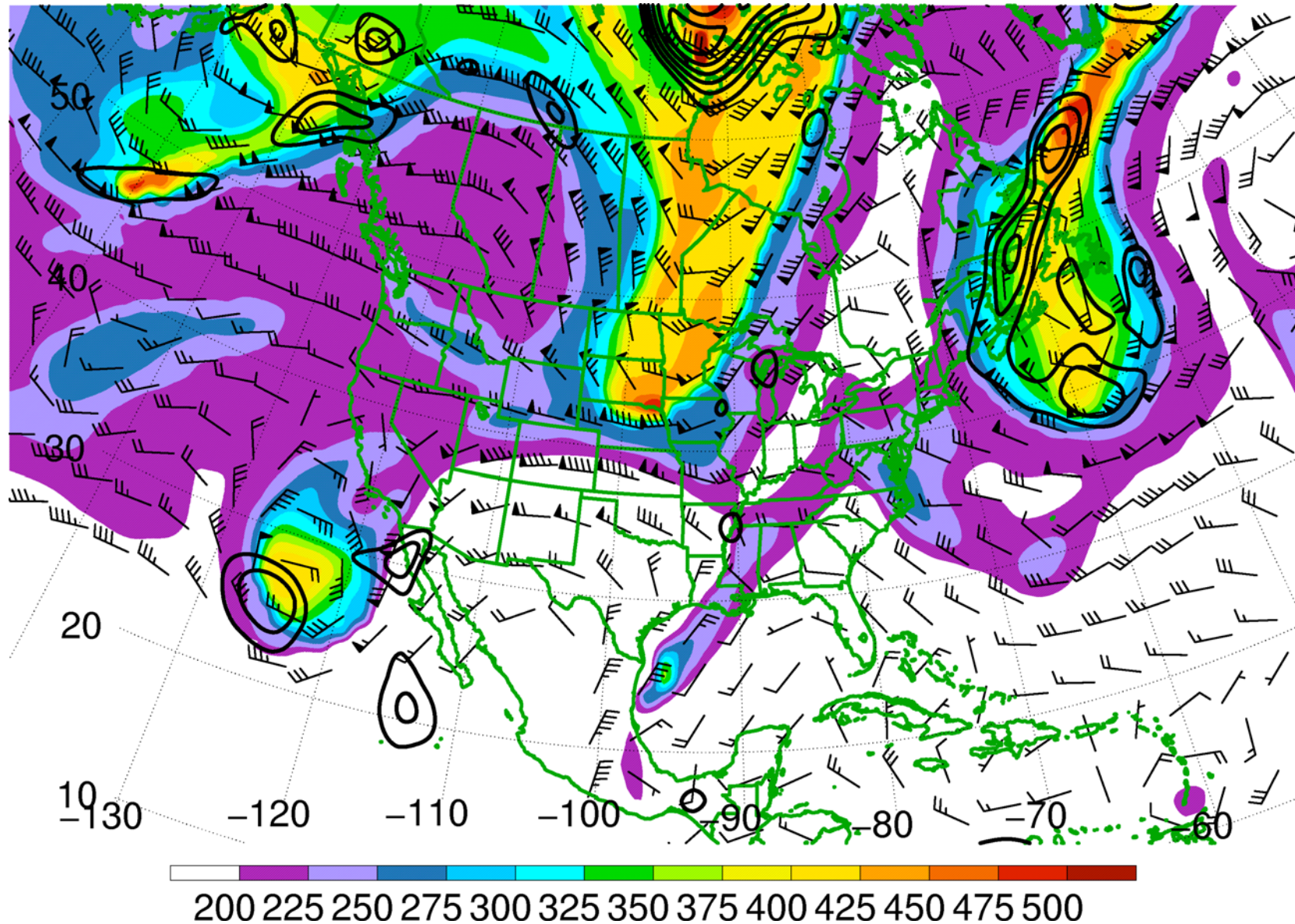


**Storm contribution to
warm season rainfall (%)**

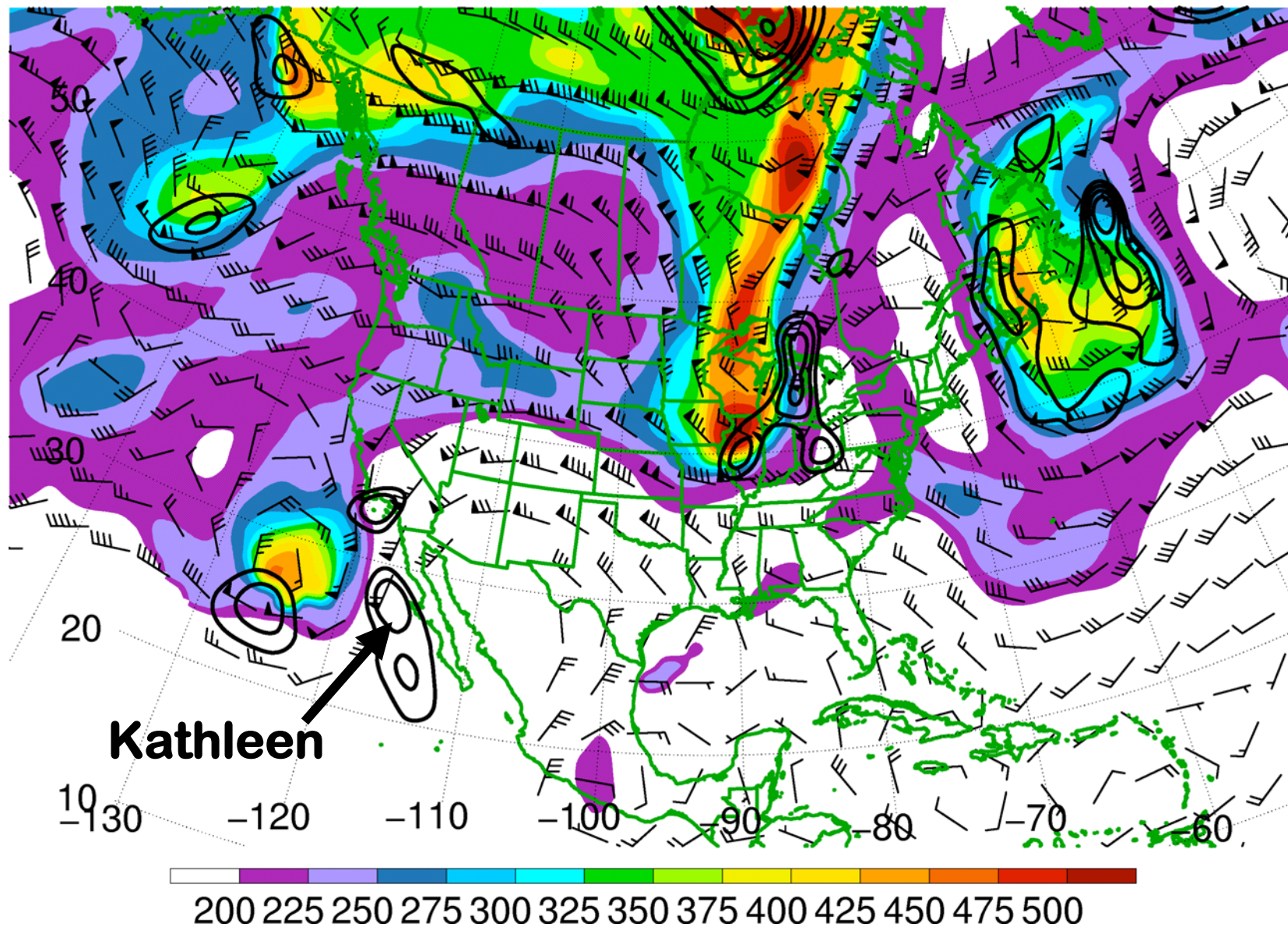
DT pressure (hPa), DT winds, & 700 hPa vorticity 00 UTC 9 September 1976



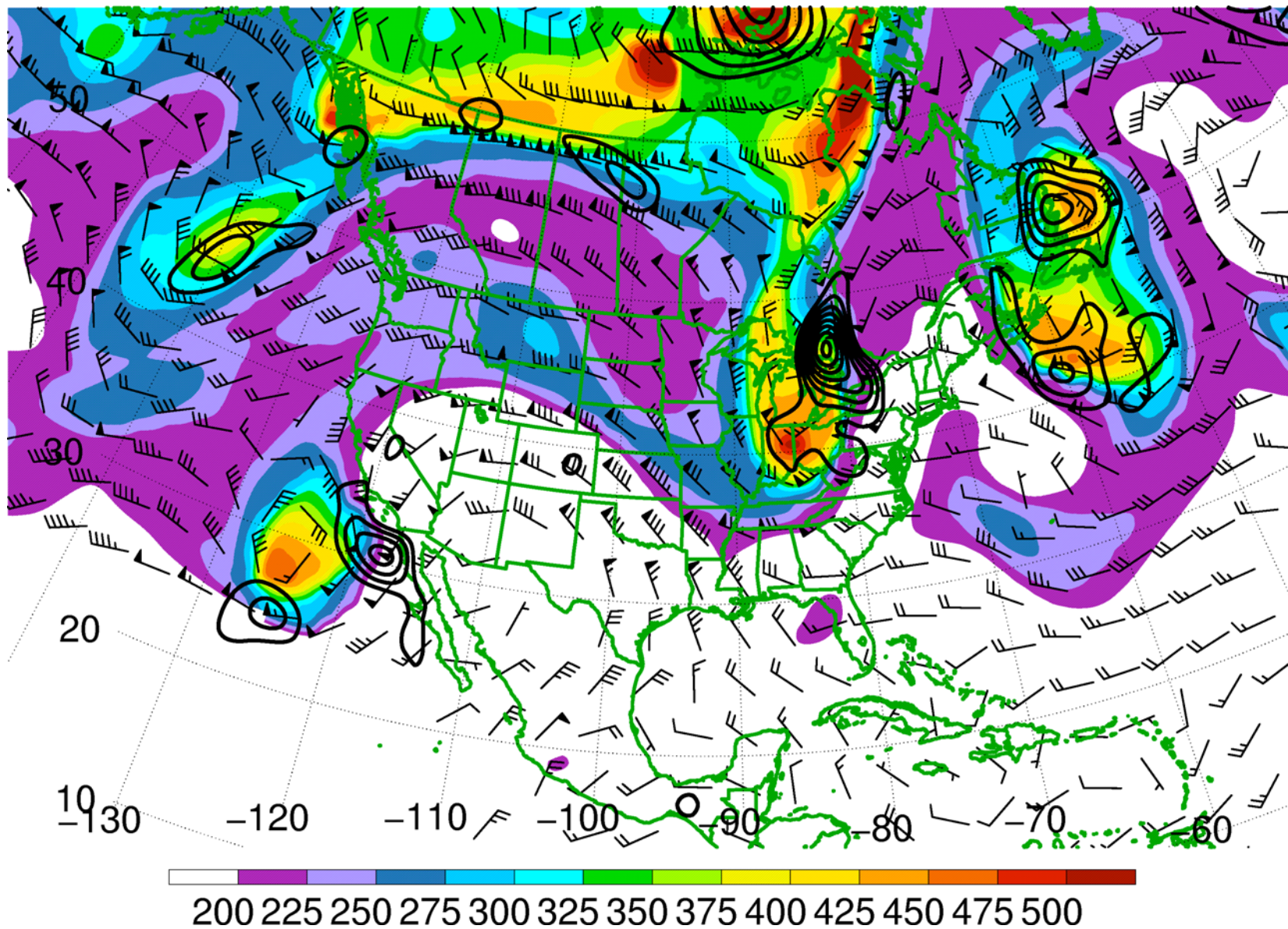
DT pressure (hPa), DT winds, & 700 hPa vorticity 12 UTC 9 September 1976



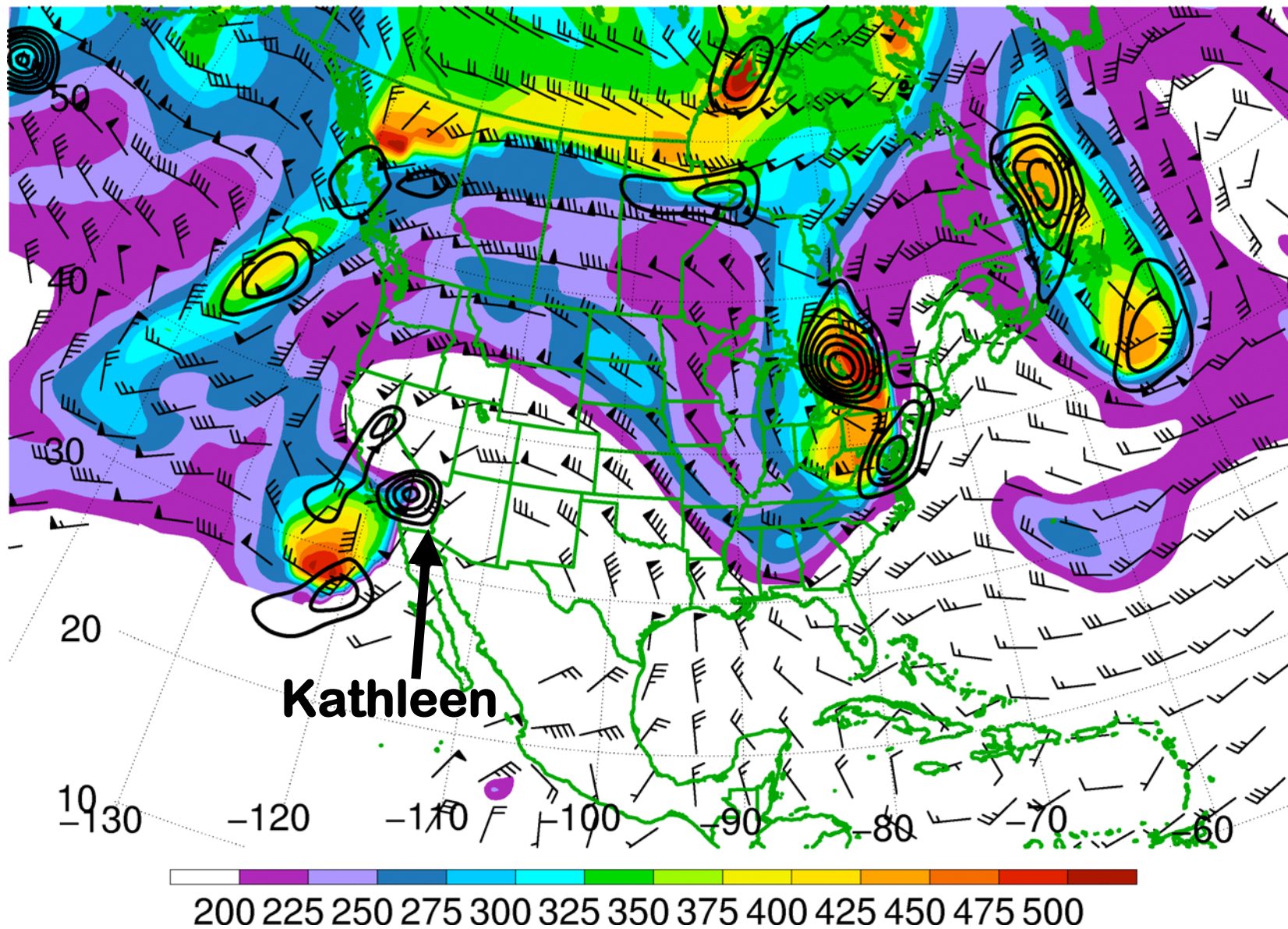
DT pressure (hPa), DT winds, & 700 hPa vorticity 00 UTC 10 September 1976



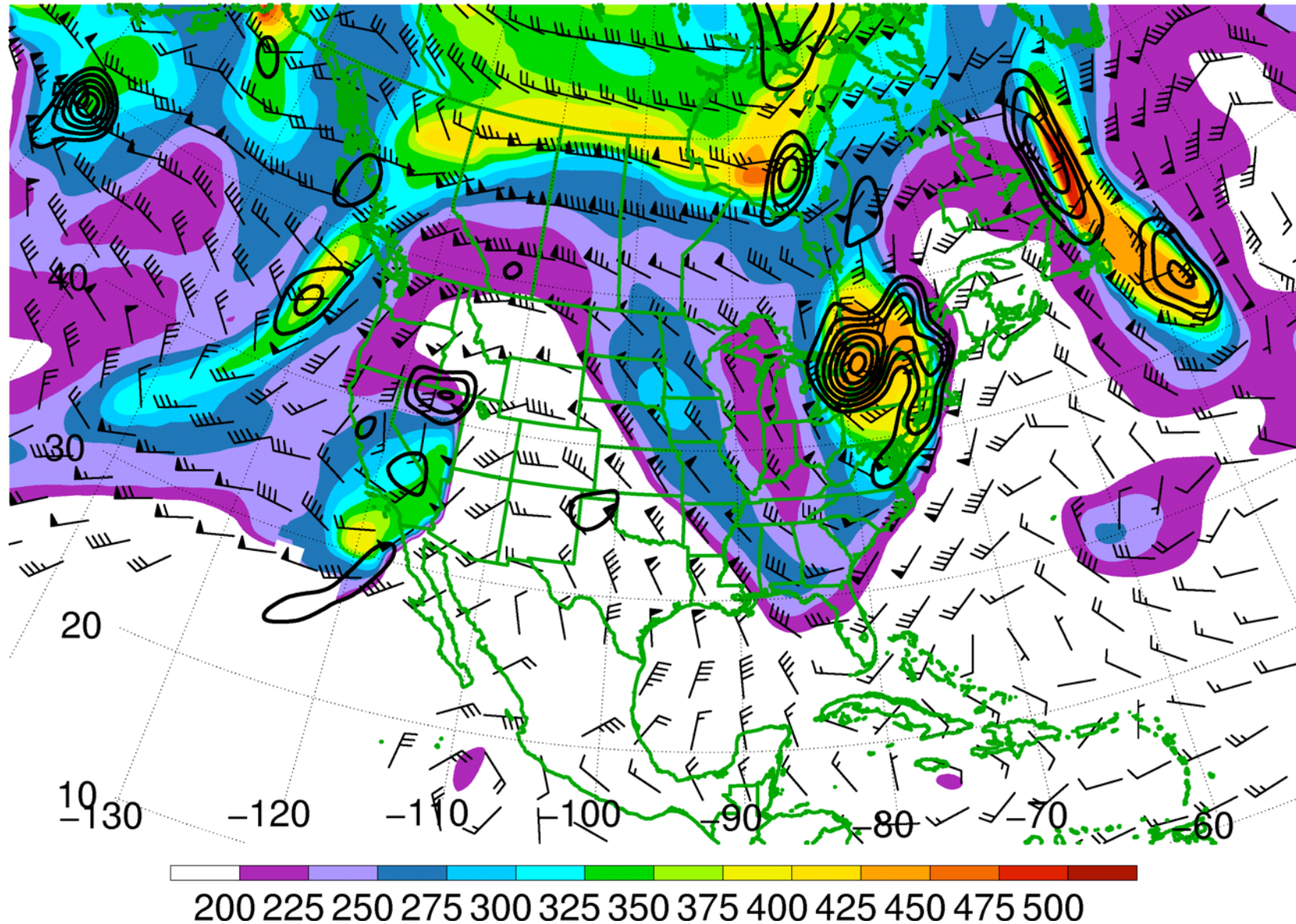
DT pressure (hPa), DT winds, & 700 hPa vorticity 12 UTC 10 September 1976



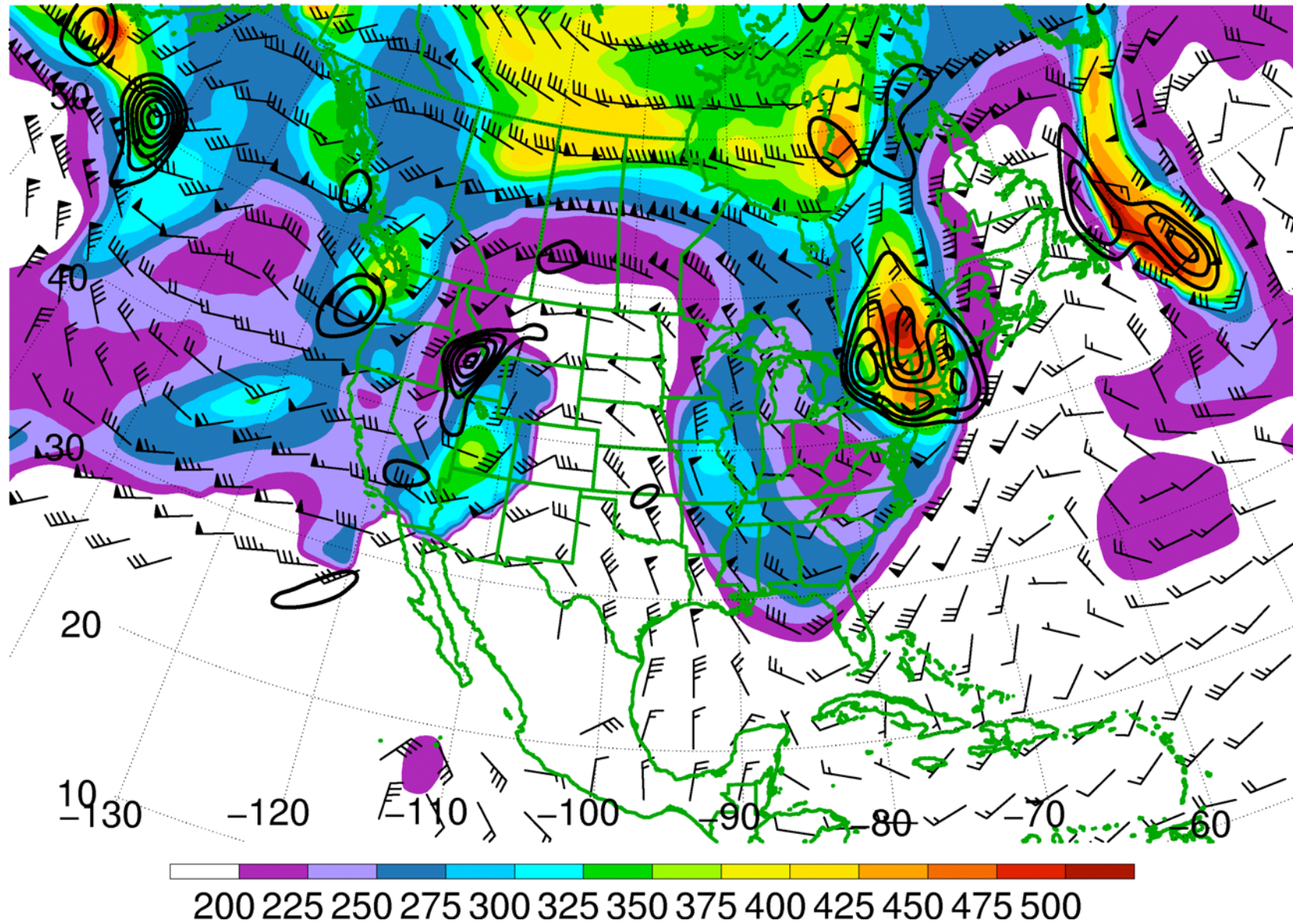
DT pressure (hPa), DT winds, & 700 hPa vorticity 00 UTC 11 September 1976



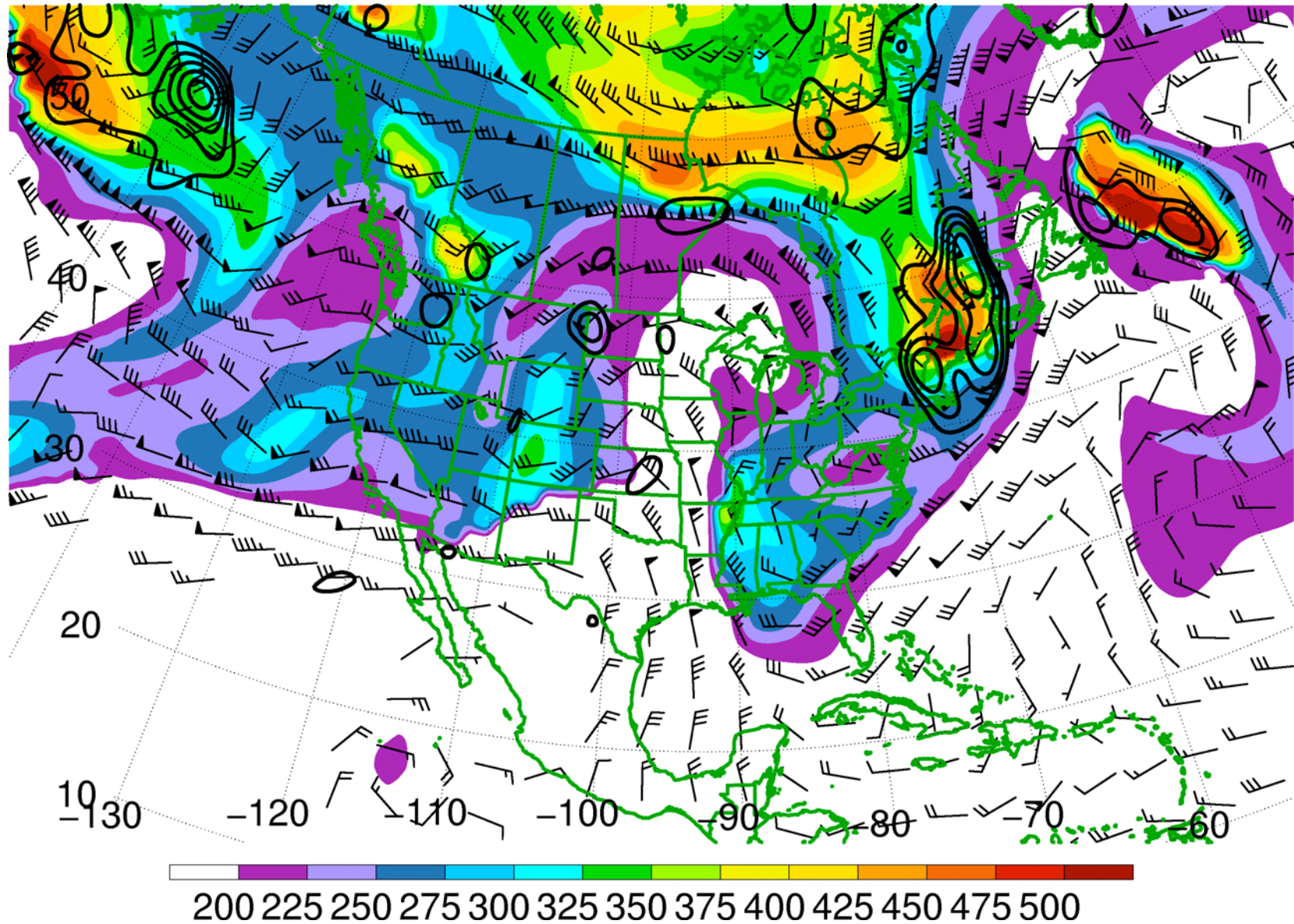
DT pressure (hPa), DT winds, & 700 hPa vorticity 12 UTC 11 September 1976

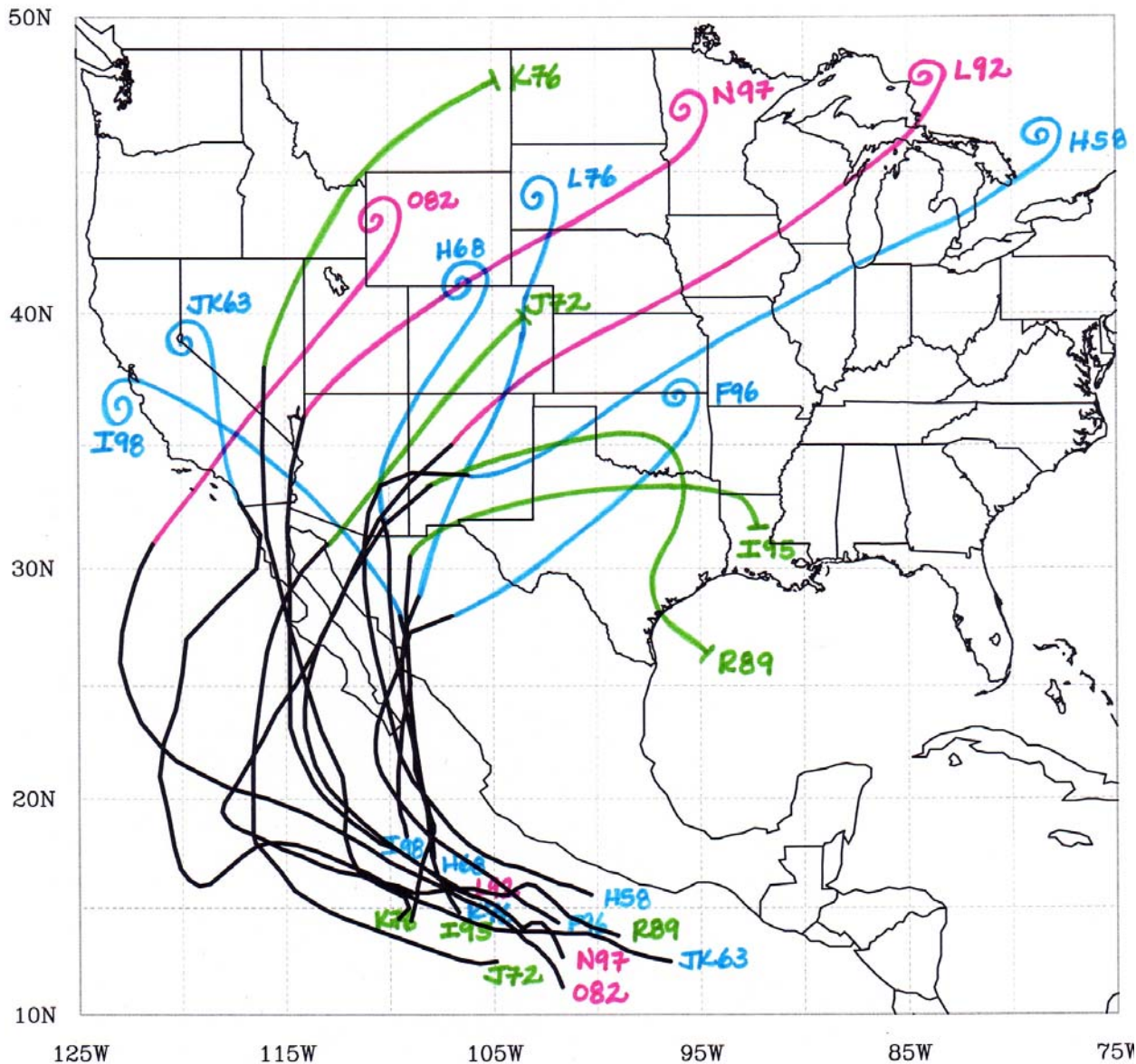


DT pressure (hPa), DT winds, & 700 hPa vorticity 00 UTC 12 September 1976



DT pressure (hPa), DT winds, & 700 hPa vorticity 12 UTC 12 September 1976





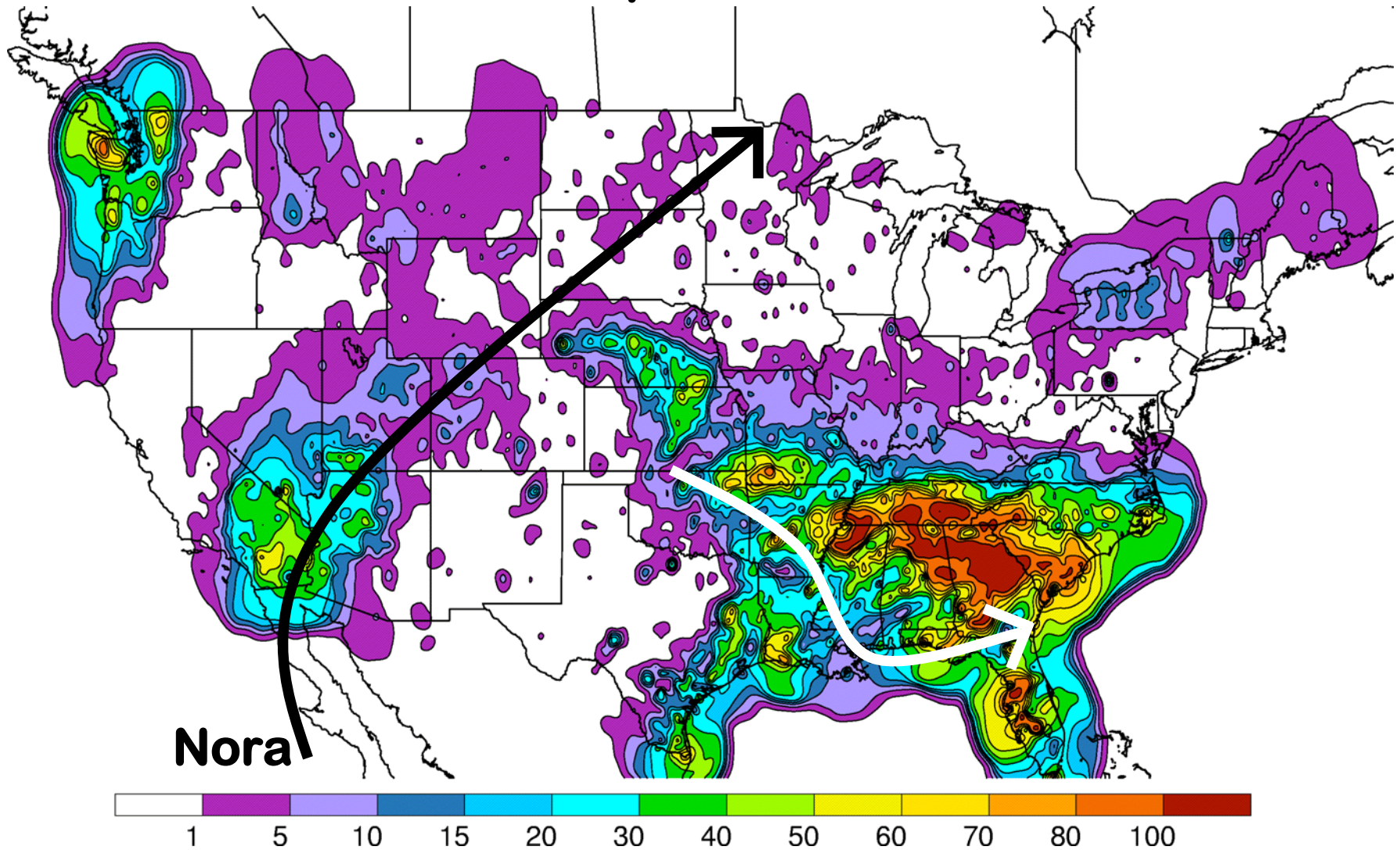
**NHC Best Tracks
(black)**

**ERA40 700 hPa
vorticity tracks
(colors)**

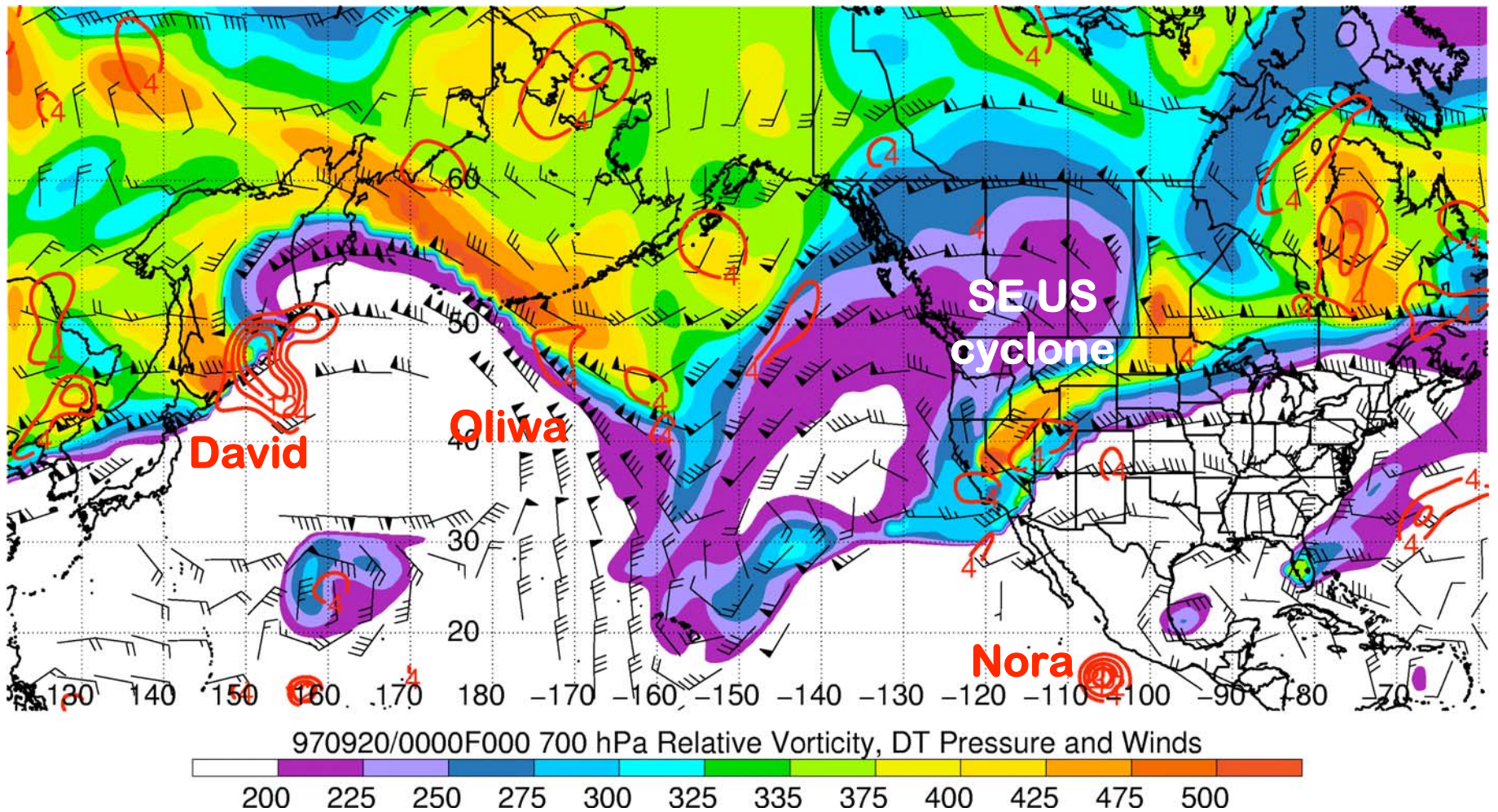
**14 long lived
East Pacific TCs**

 Vorticity lost
 Wrapped up
 Possible ET

Total precipitation 24 - 27 September 1997

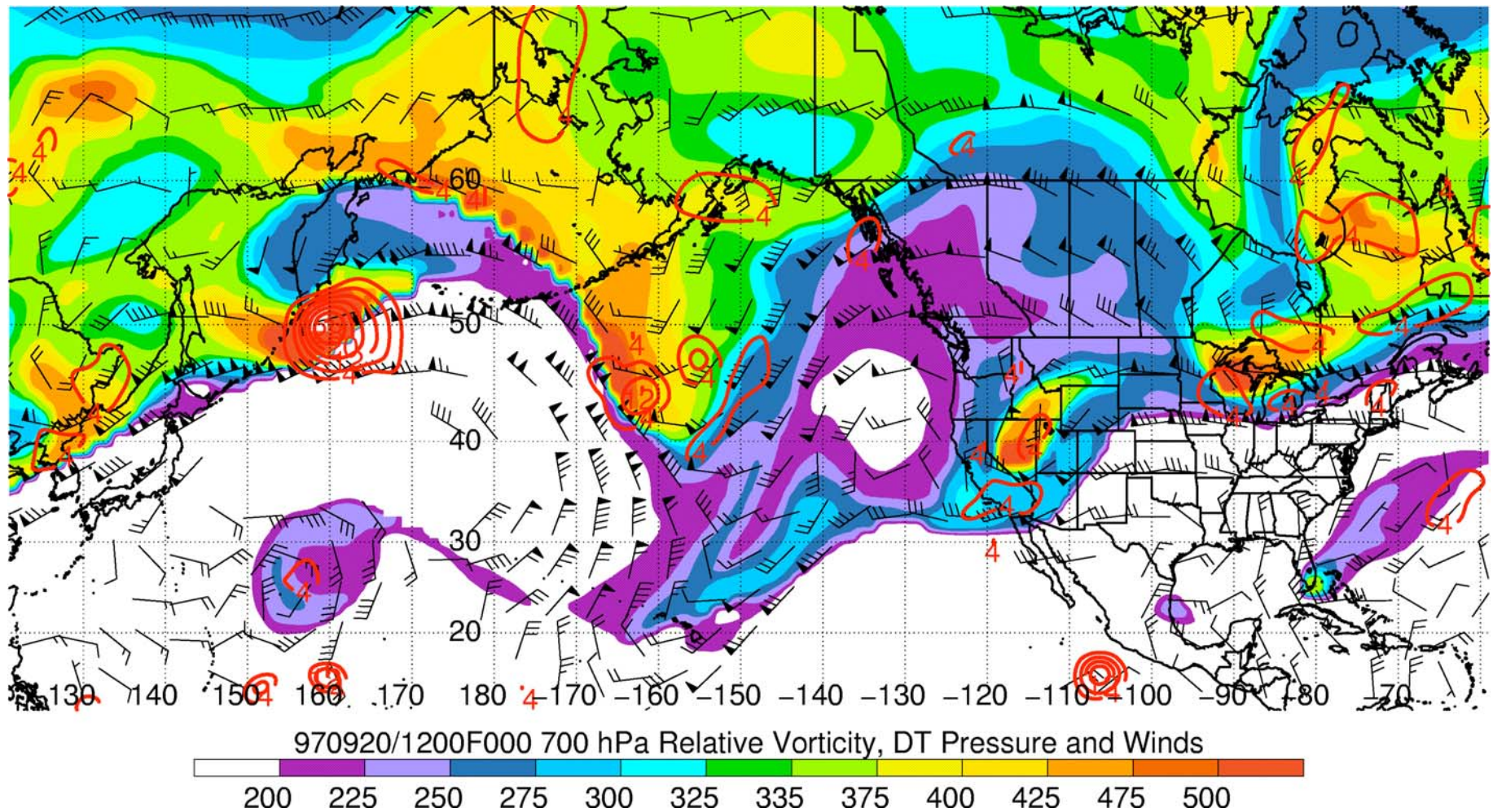


ERA40 Reanalysis DT pressure, DT winds, and 700 hPa relative vorticity



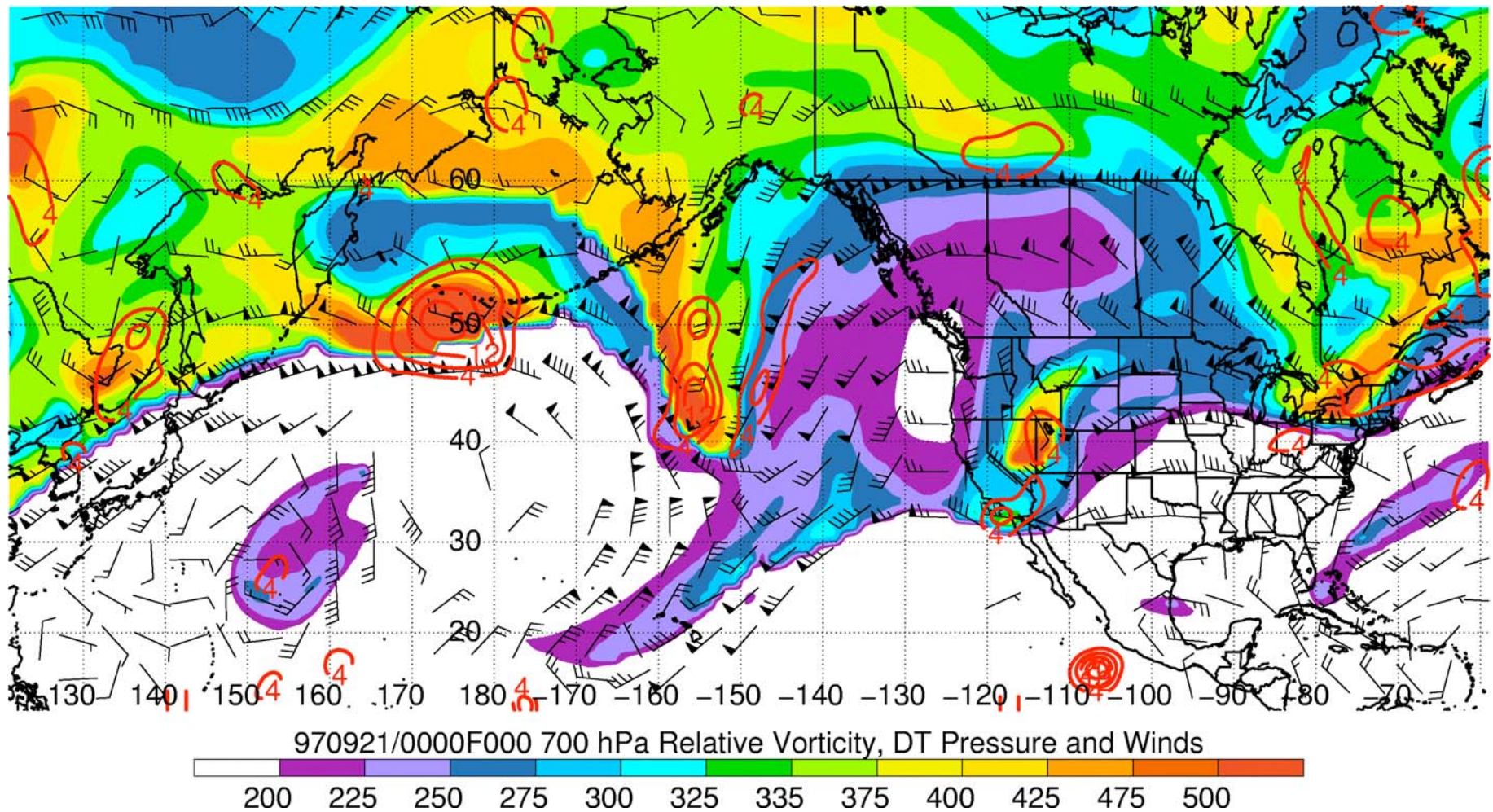
ERA40 Reanalysis

DT pressure, DT winds, and 700 hPa relative vorticity

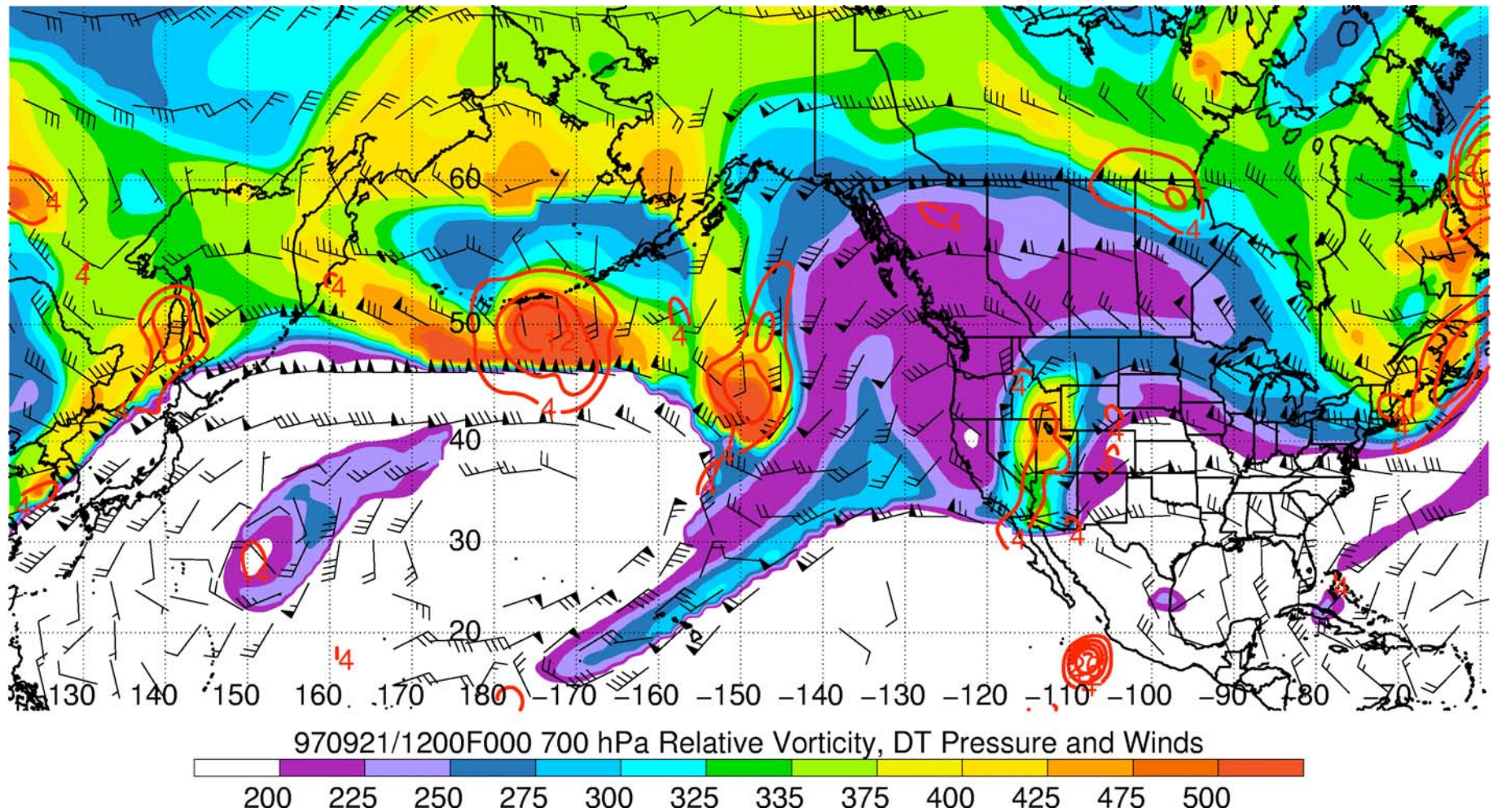


ERA40 Reanalysis

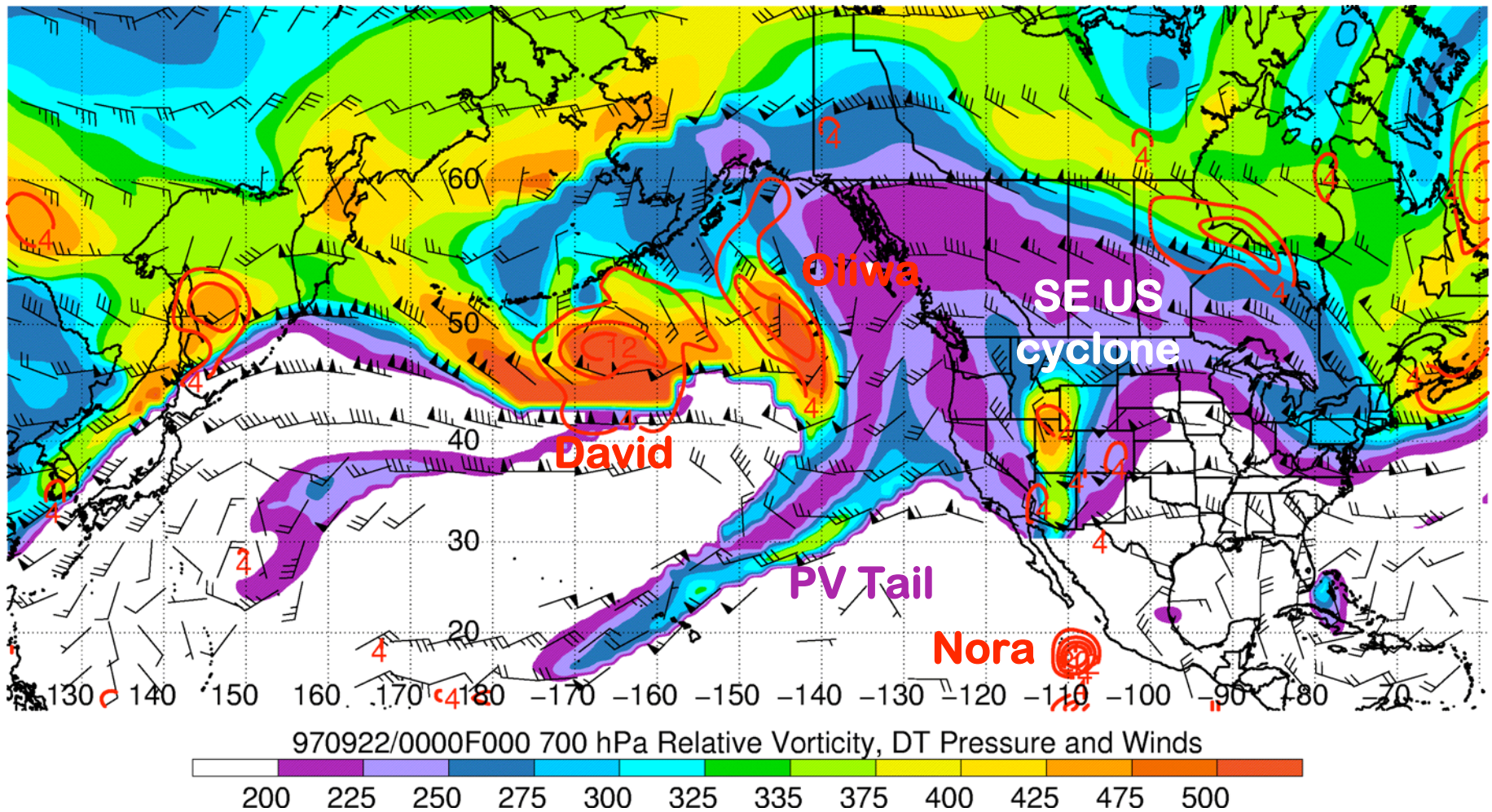
DT pressure, DT winds, and 700 hPa relative vorticity



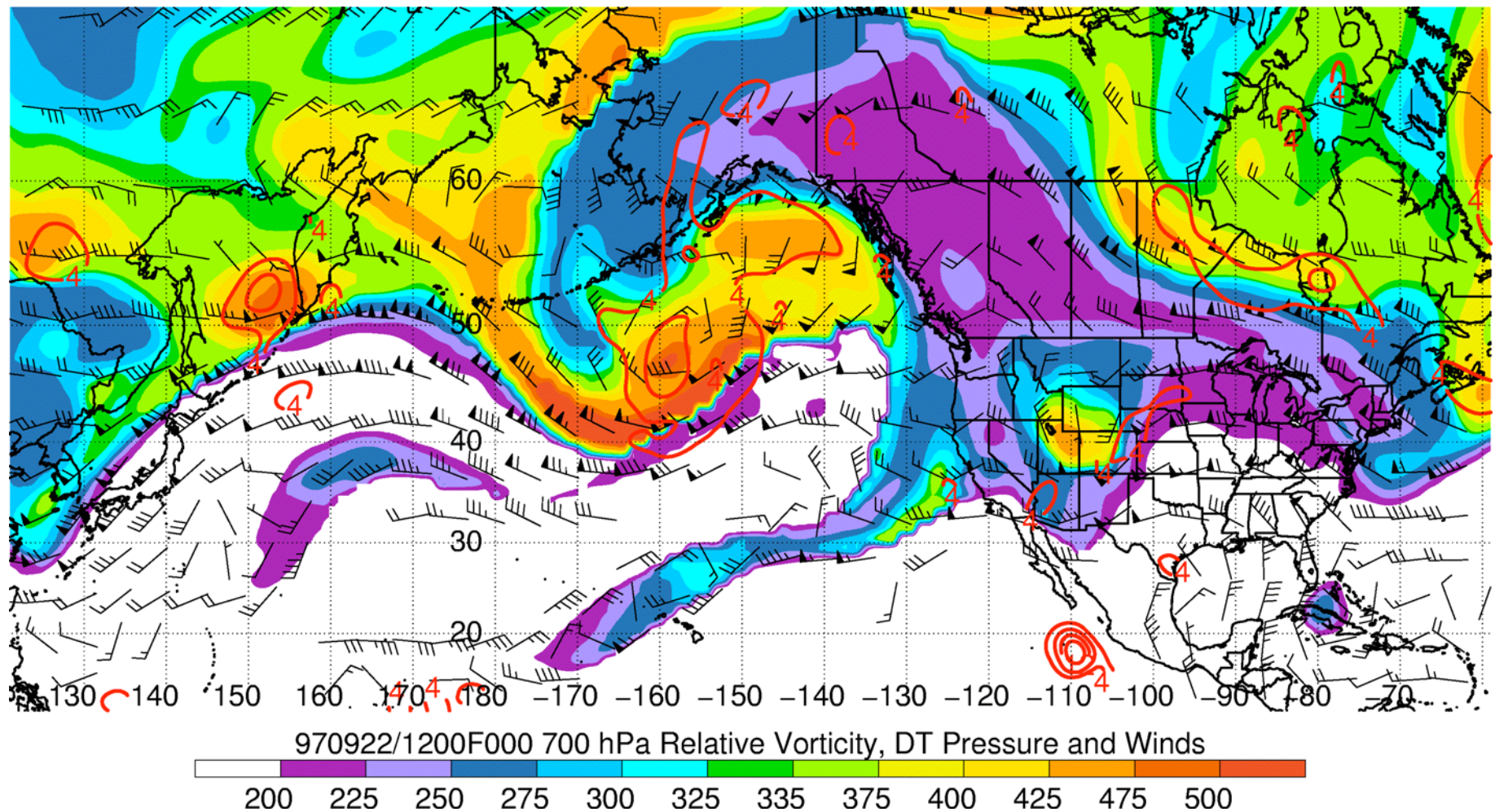
ERA40 Reanalysis DT pressure, DT winds, and 700 hPa relative vorticity



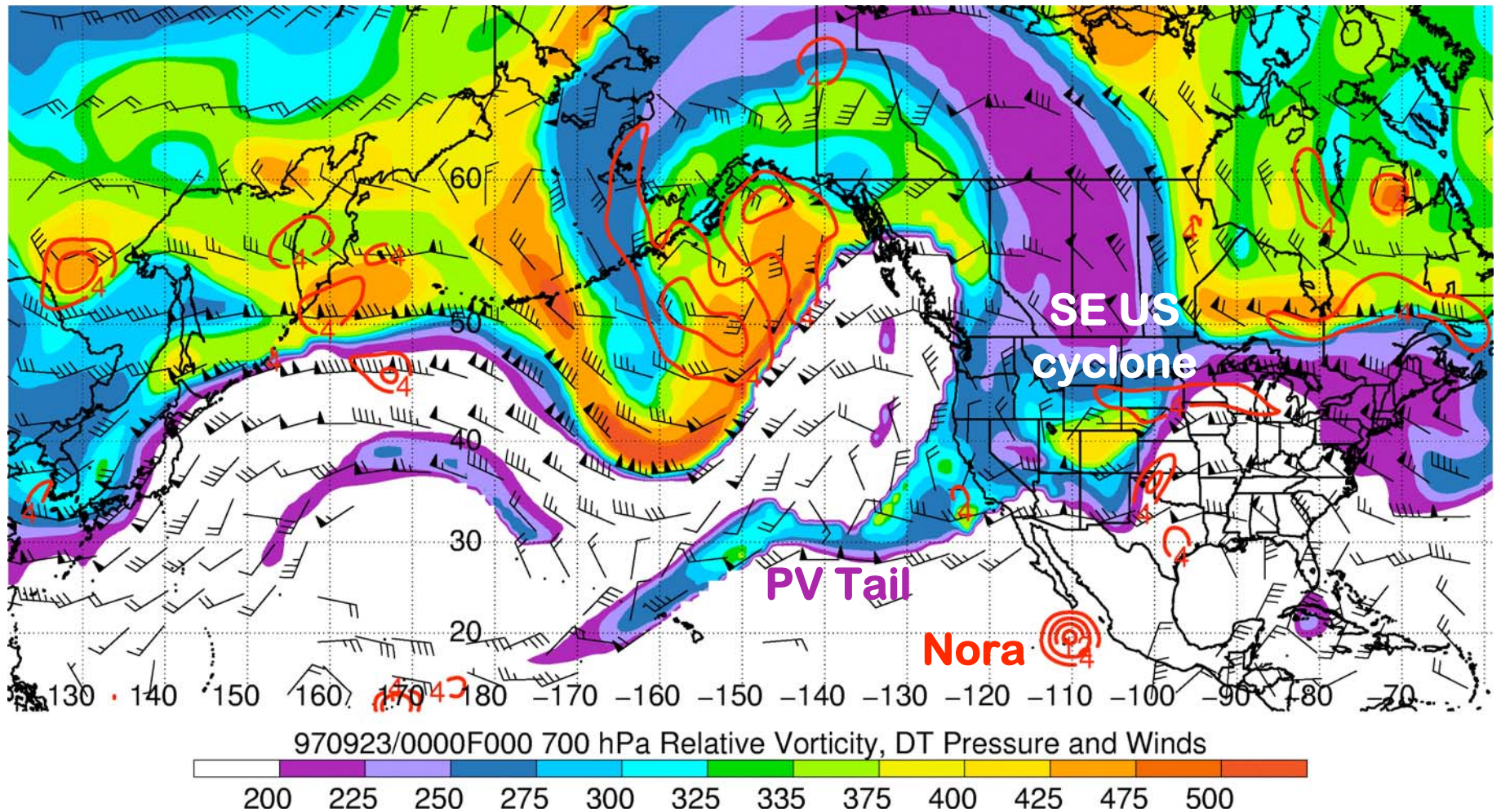
ERA40 Reanalysis DT pressure, DT winds, and 700 hPa relative vorticity



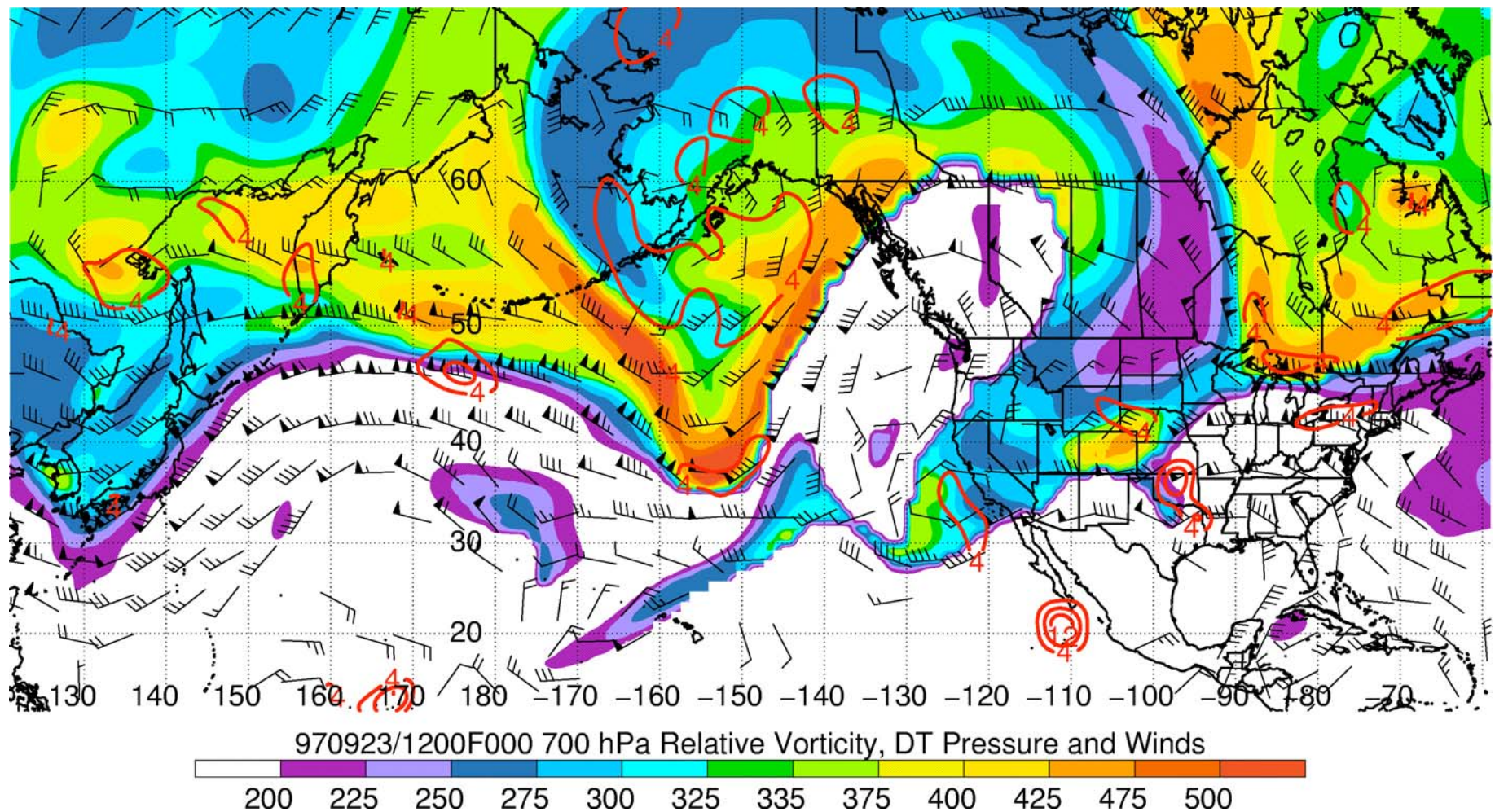
ERA40 Reanalysis DT pressure, DT winds, and 700 hPa relative vorticity



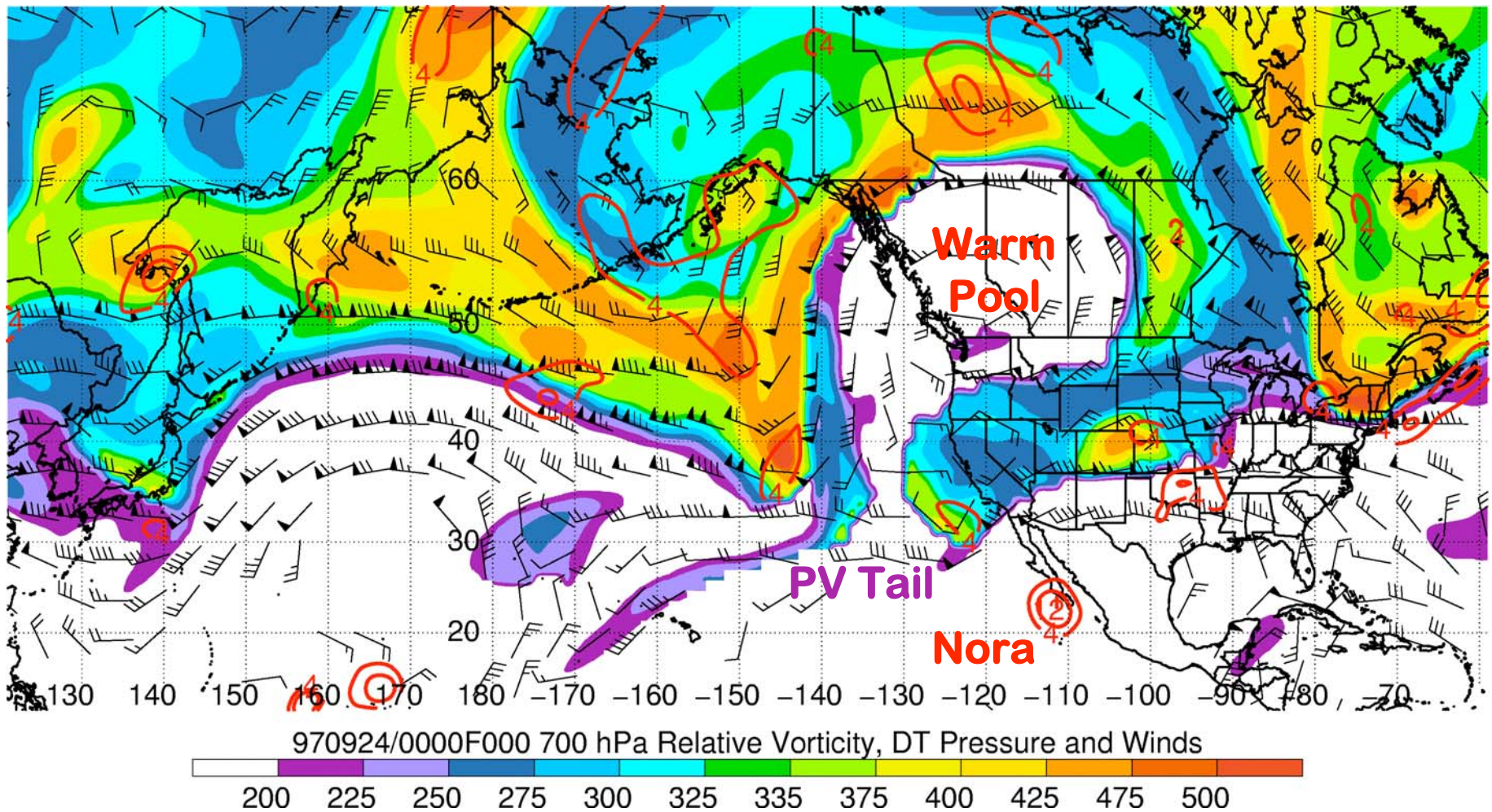
ERA40 Reanalysis DT pressure, DT winds, and 700 hPa relative vorticity



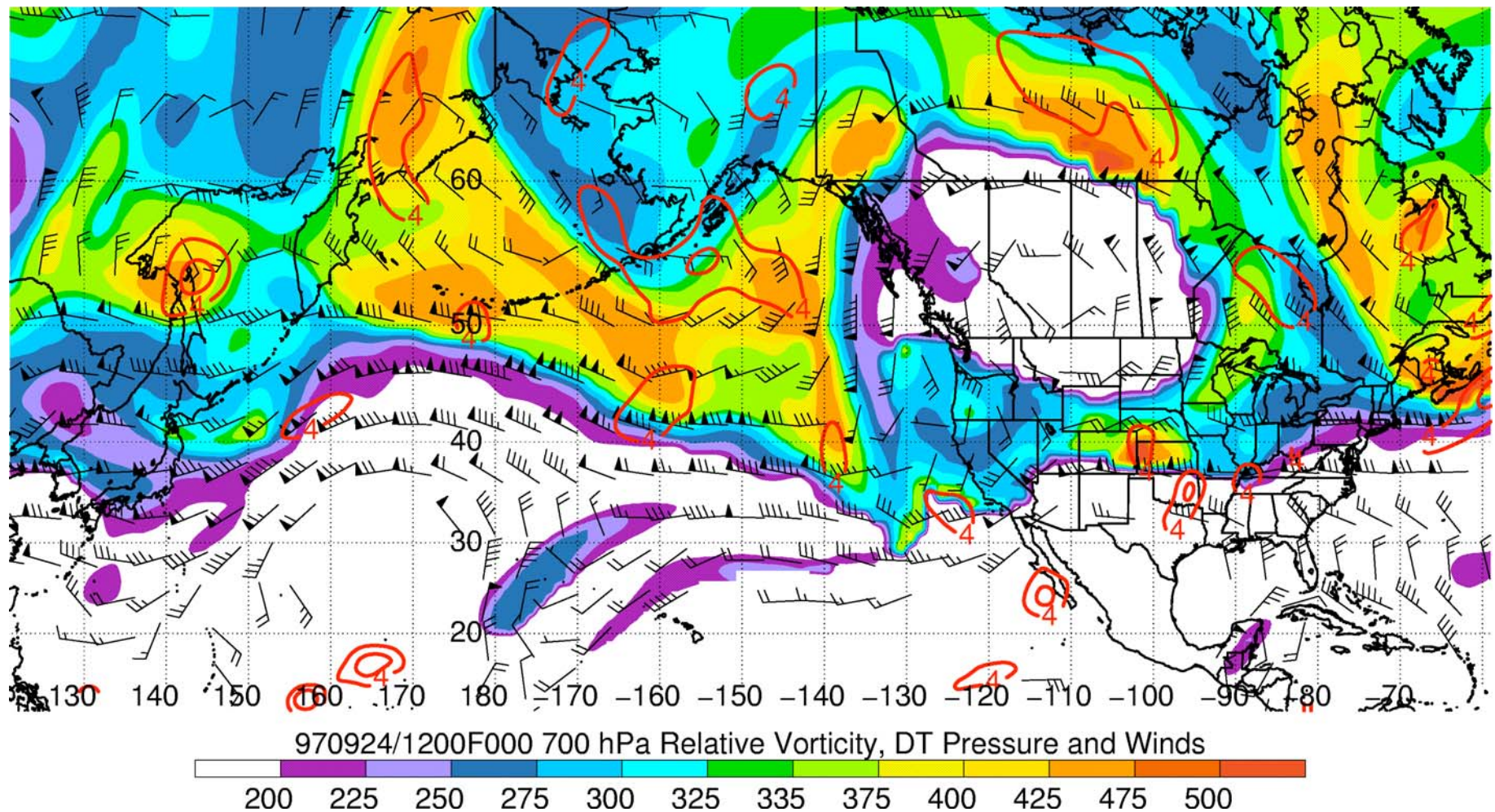
ERA40 Reanalysis DT pressure, DT winds, and 700 hPa relative vorticity



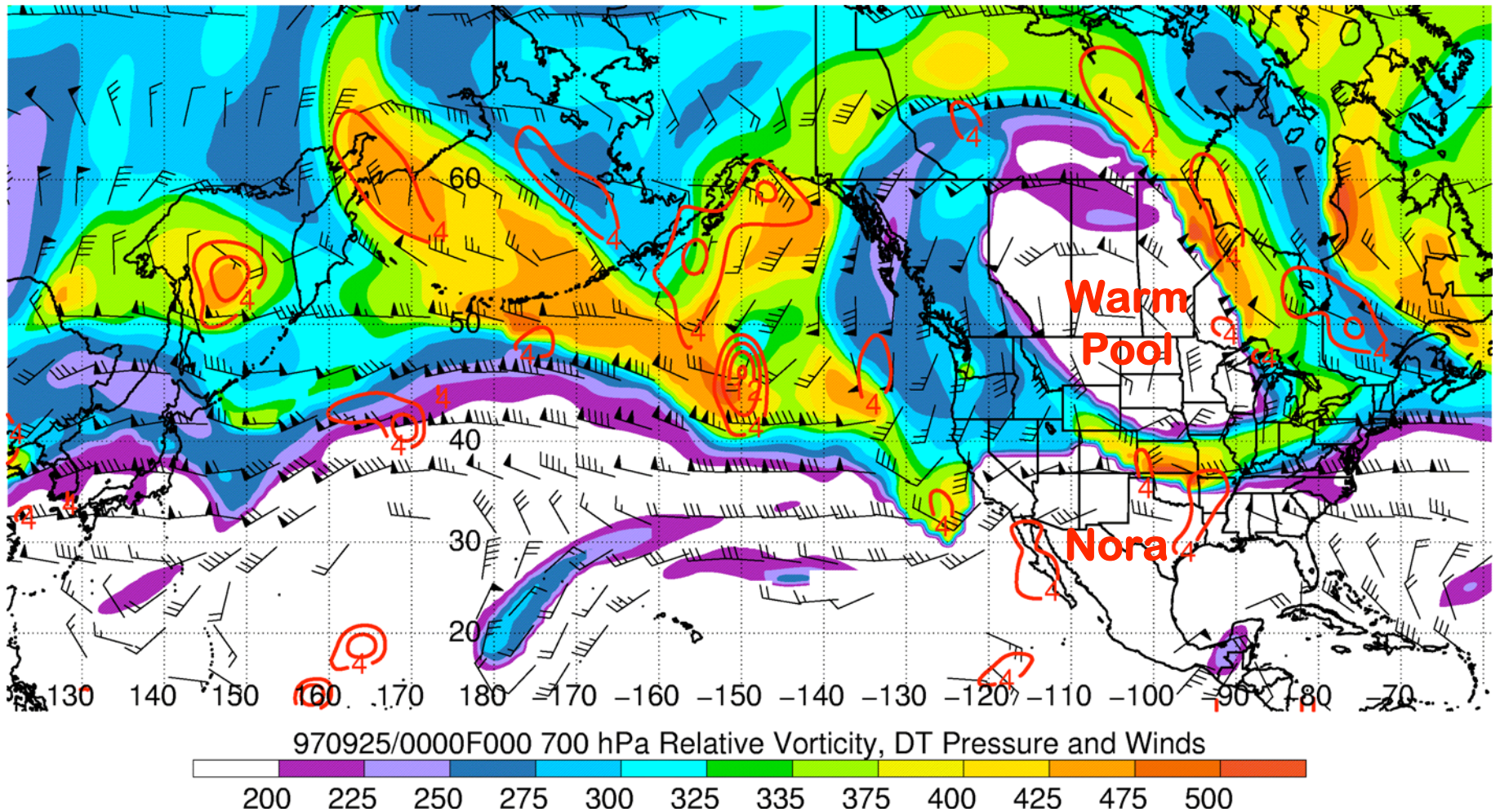
ERA40 Reanalysis DT pressure, DT winds, and 700 hPa relative vorticity



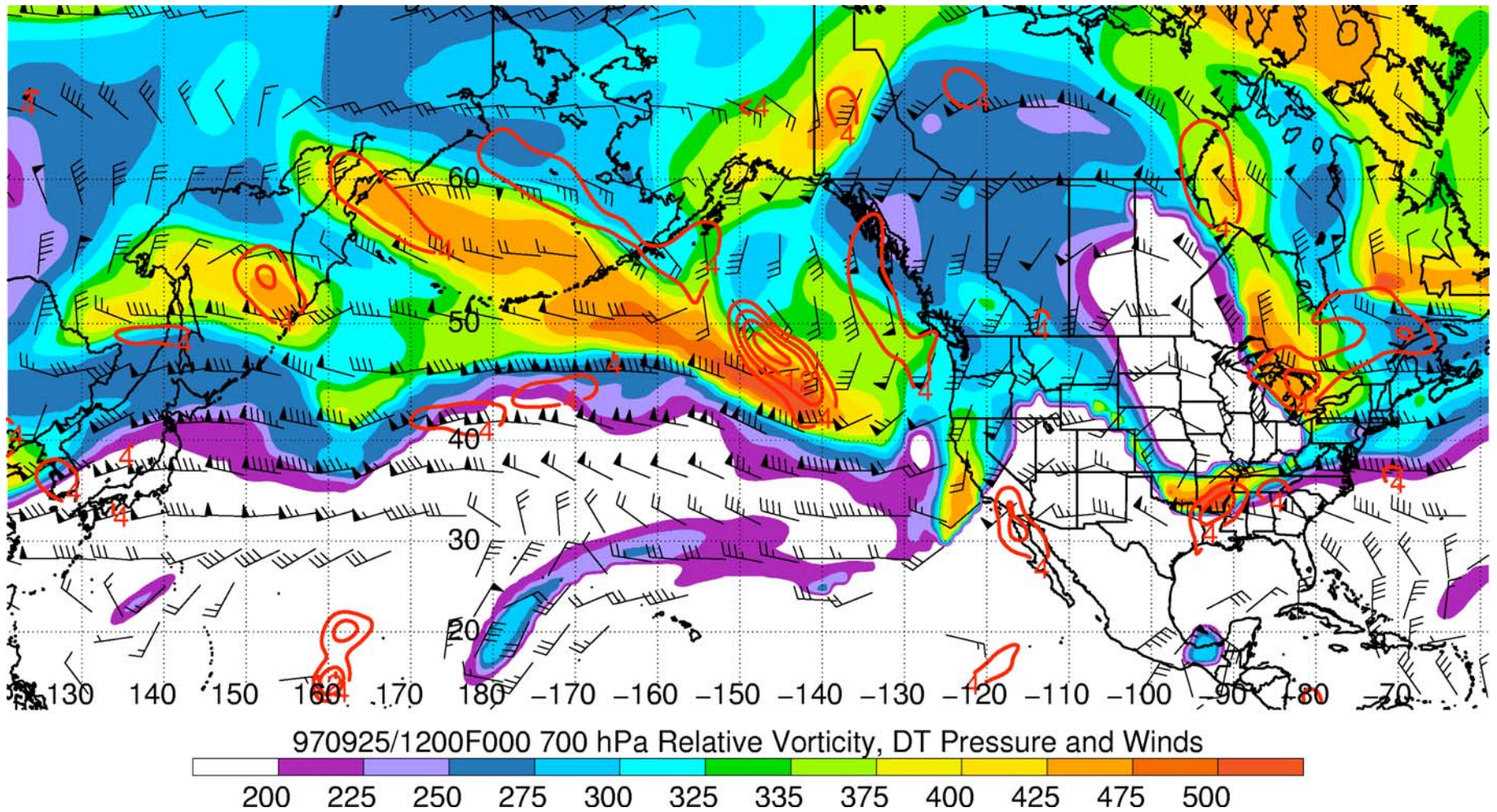
ERA40 Reanalysis DT pressure, DT winds, and 700 hPa relative vorticity



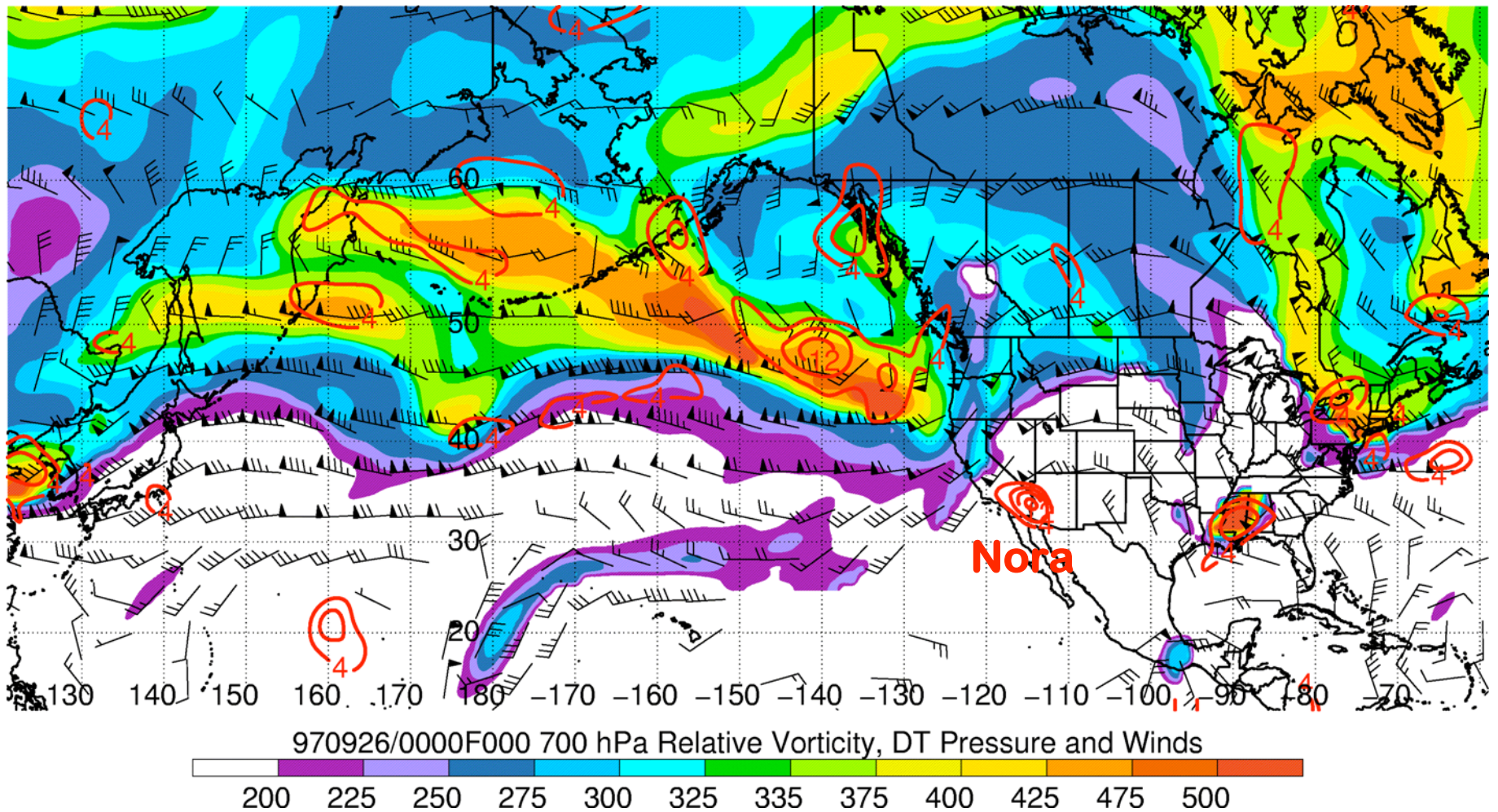
ERA40 Reanalysis DT pressure, DT winds, and 700 hPa relative vorticity



ERA40 Reanalysis DT pressure, DT winds, and 700 hPa relative vorticity

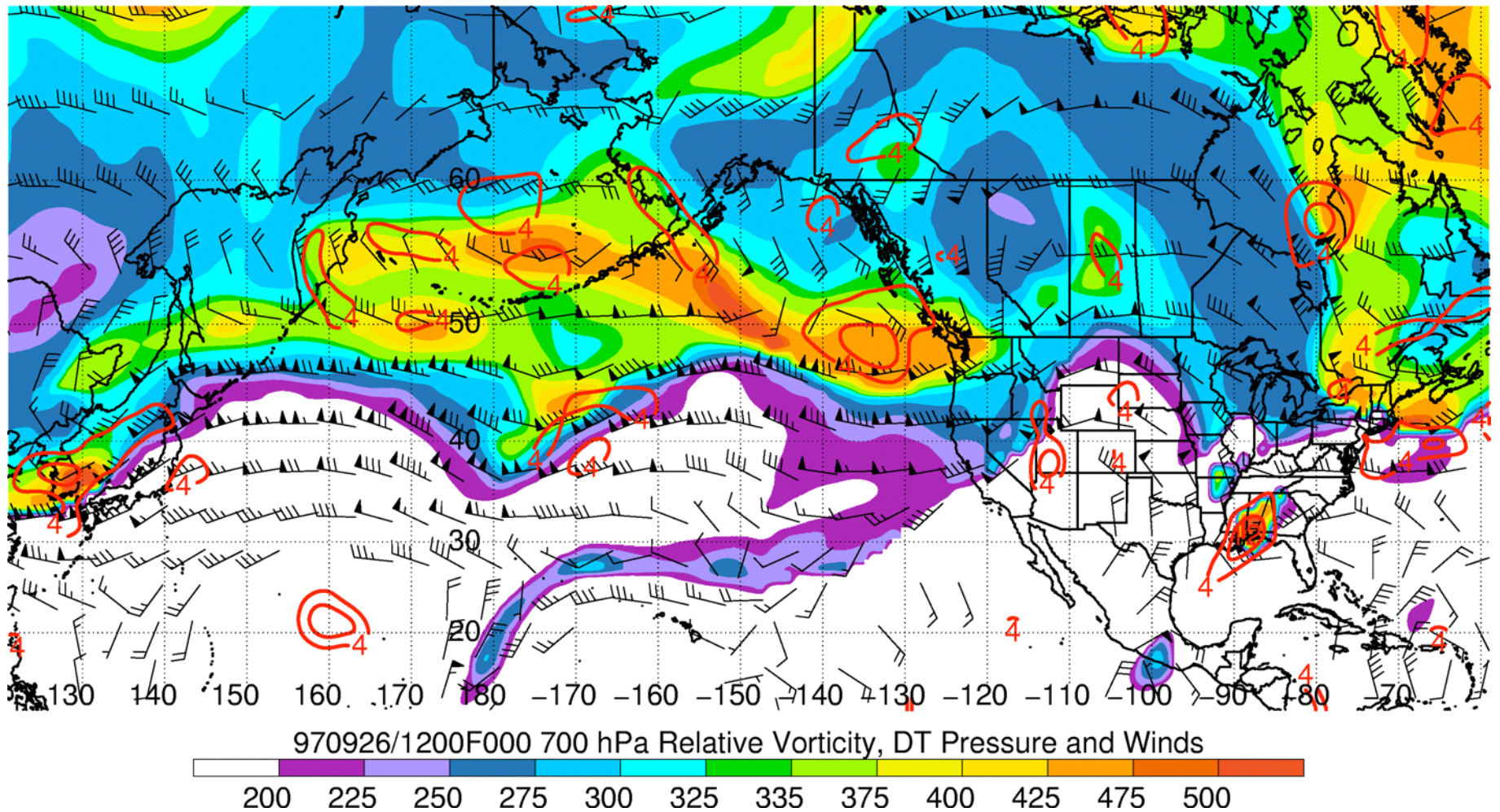


ERA40 Reanalysis DT pressure, DT winds, and 700 hPa relative vorticity

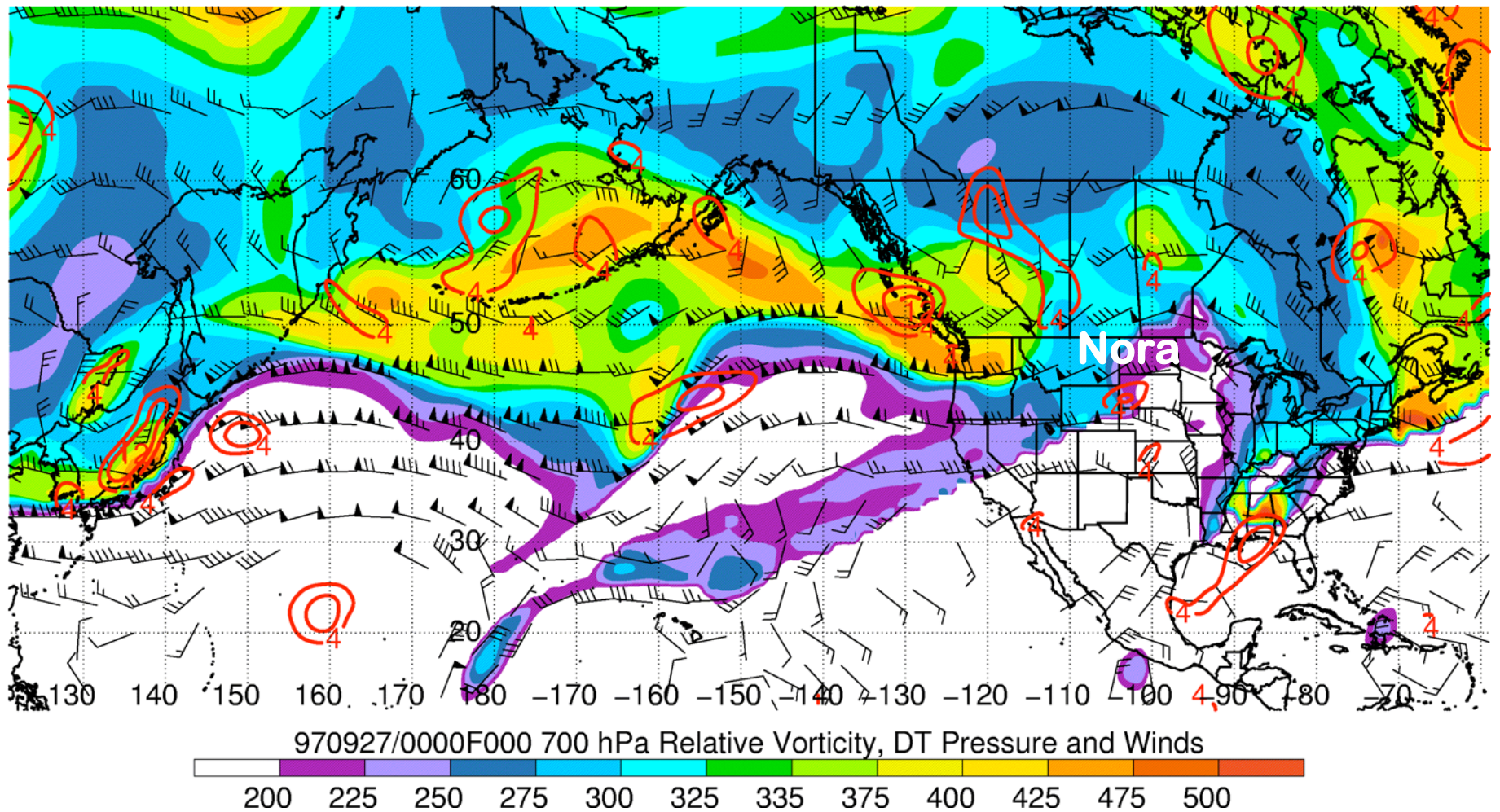


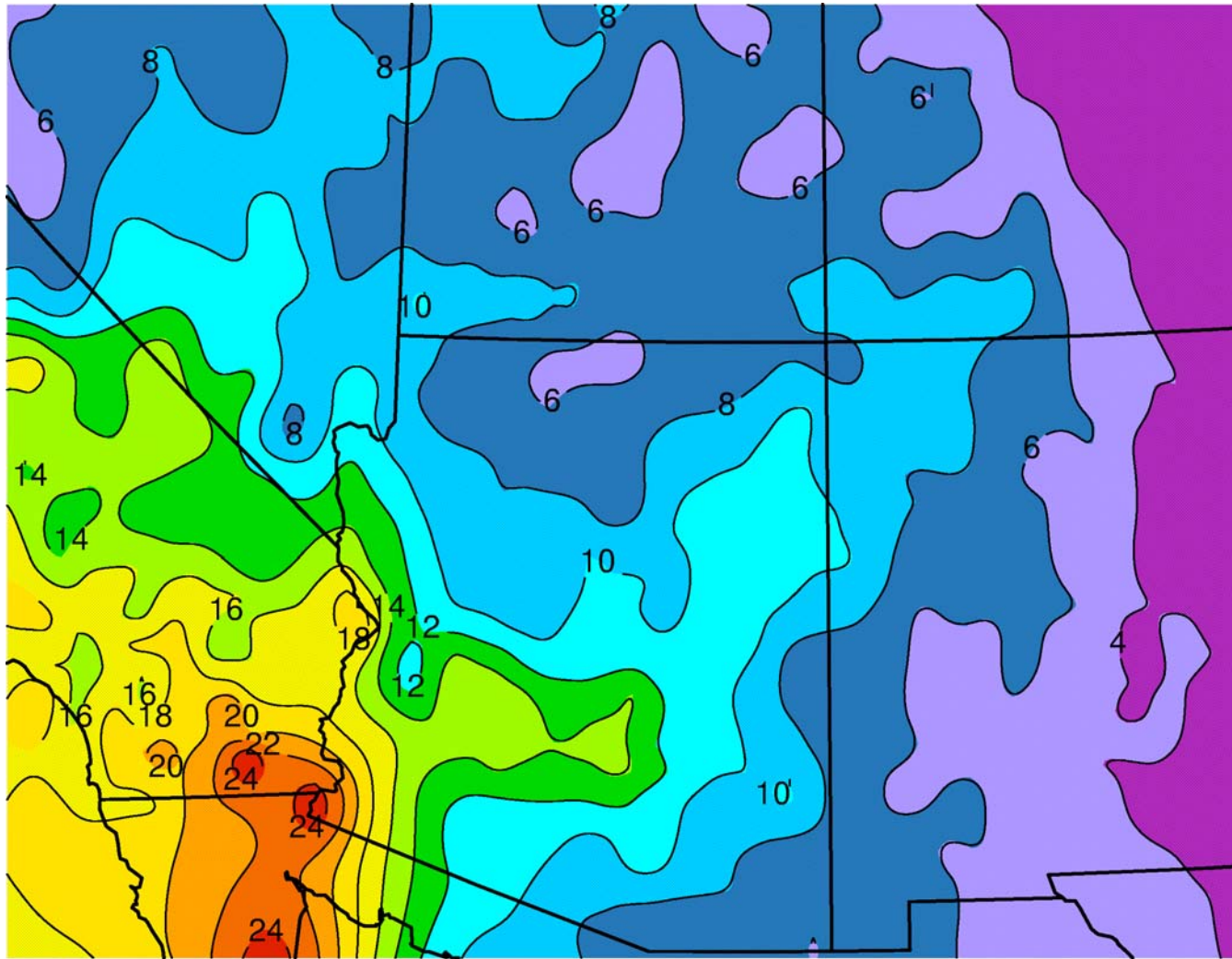
ERA40 Reanalysis

DT pressure, DT winds, and 700 hPa relative vorticity

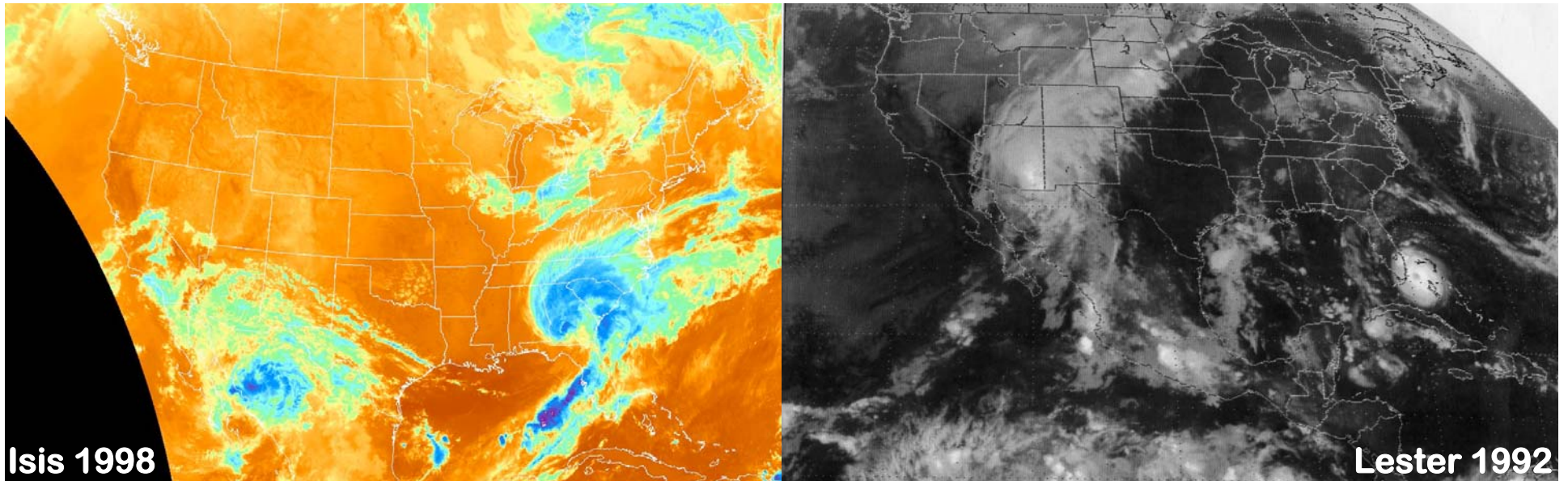


ERA40 Reanalysis DT pressure, DT winds, and 700 hPa relative vorticity



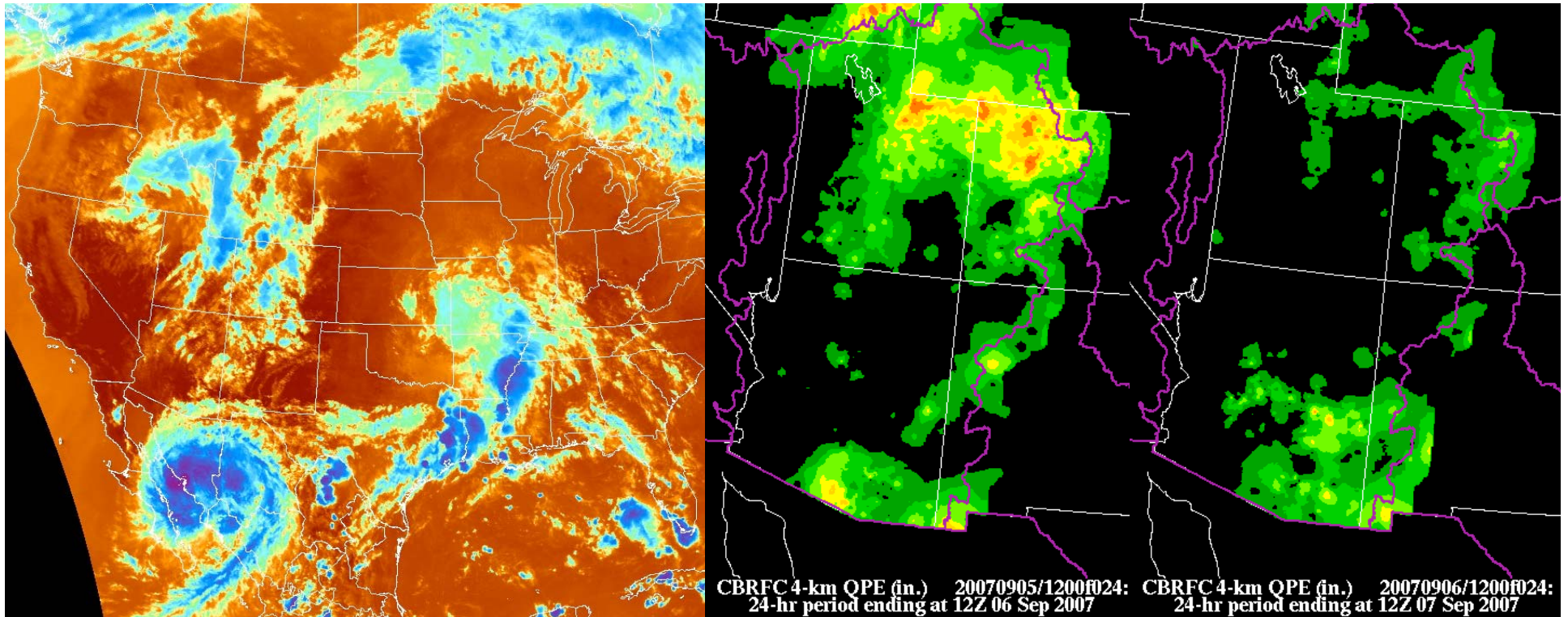


Average percentage of the warm season precipitation associated with Eastern Pacific TCs



Summary:

- **35 Eastern Pacific TCs brought significant rainfall to the southwest U.S. between 1958 and 2003**
- **On average, 10-15% of the summer rainfall is contributed by TCs, increasing from east to west across Arizona**
- **Two main tracks for TCs into the monsoon region: 1) south to north path into CA and NV, and 2) southwest-northeast “recurvature” track through AZ, NM and CO**



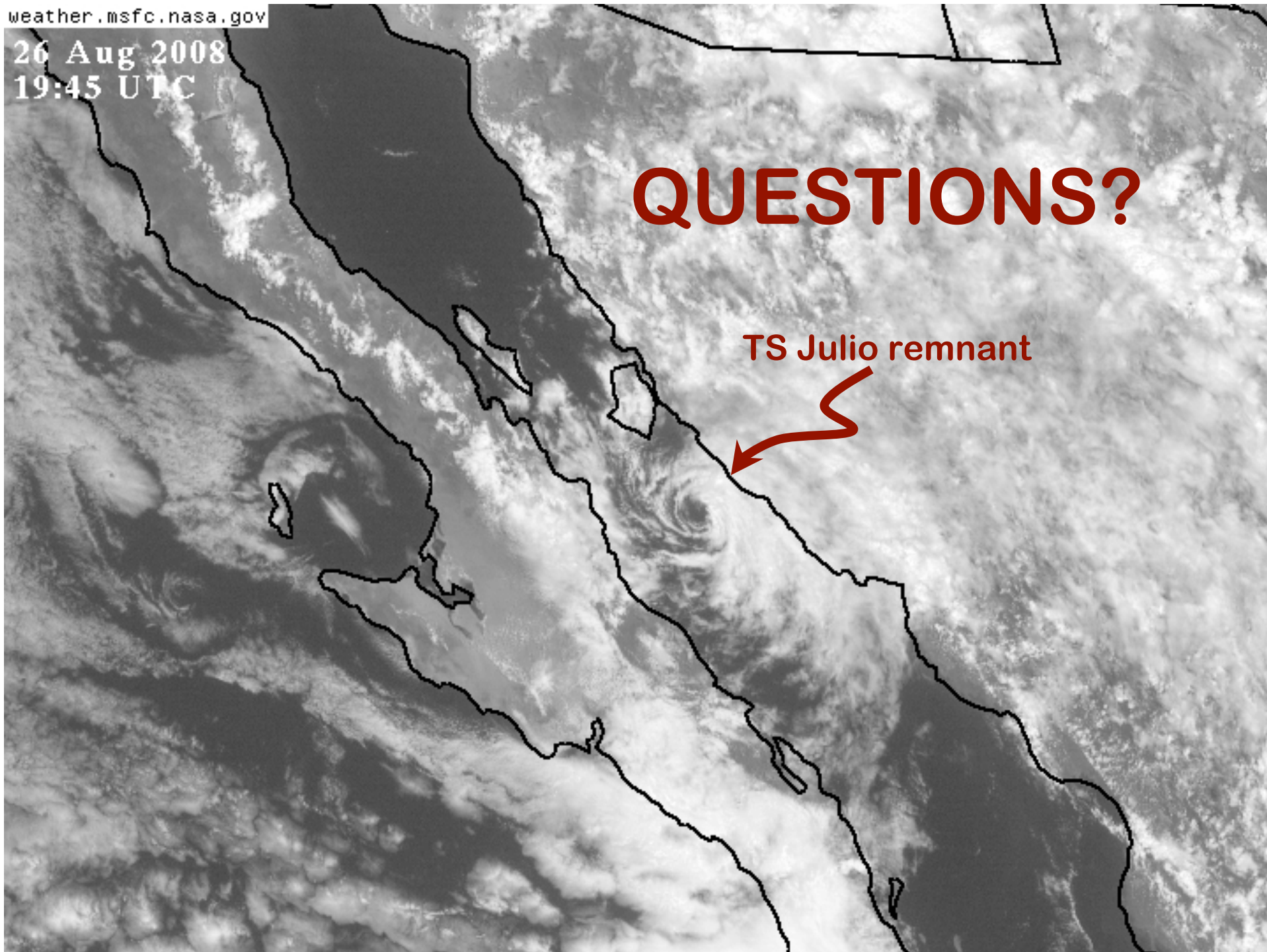
Summary:

- **As the remnant tropical cyclone vorticity and diabatic heating encroach on the mid-latitudes, a rich spectrum of interactions occur**
- **Extra-tropical transition, the development of cutoffs, lee cyclogenesis and downstream development**

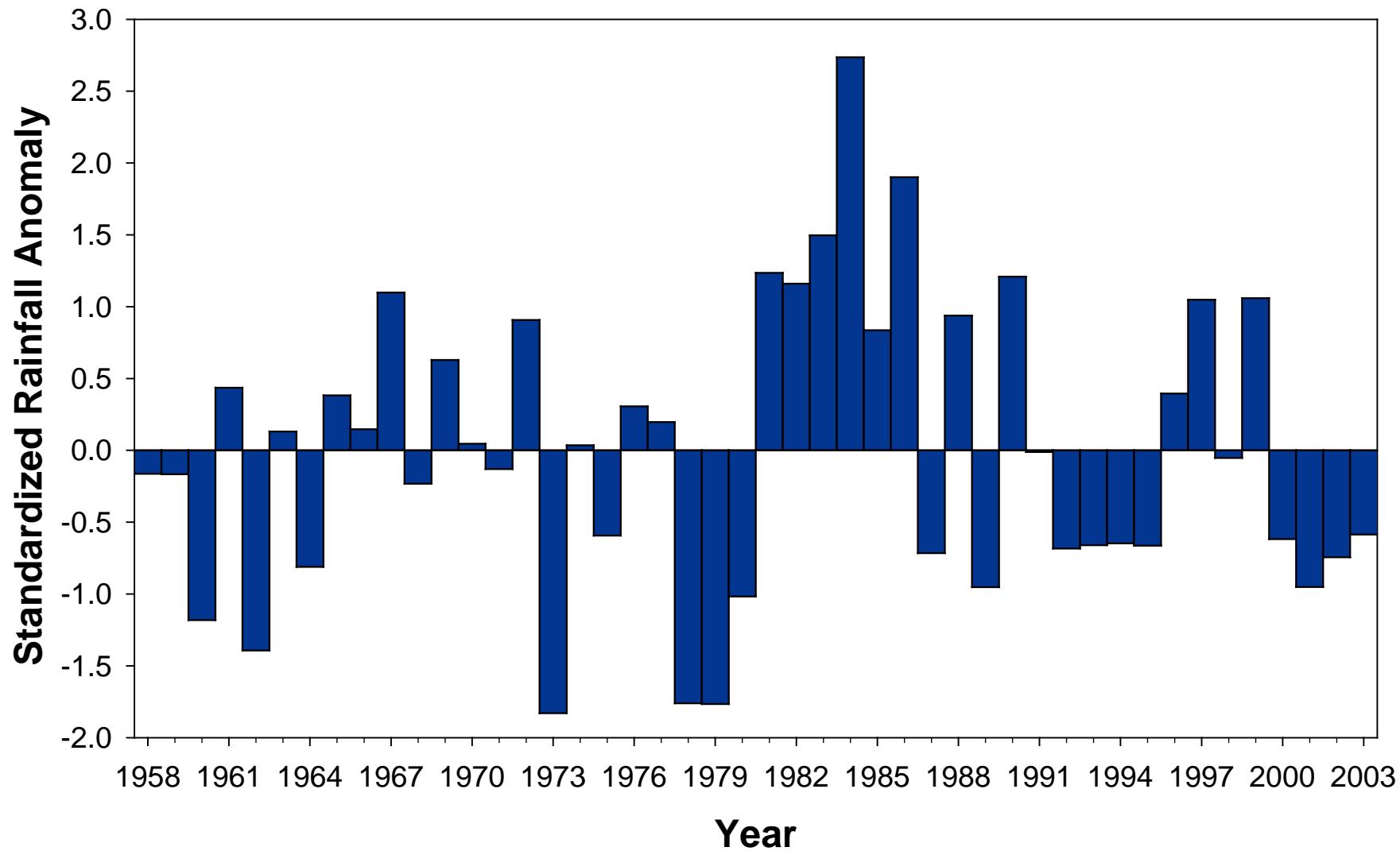
26 Aug 2008
19:45 UTC

QUESTIONS?

TS Julio remnant



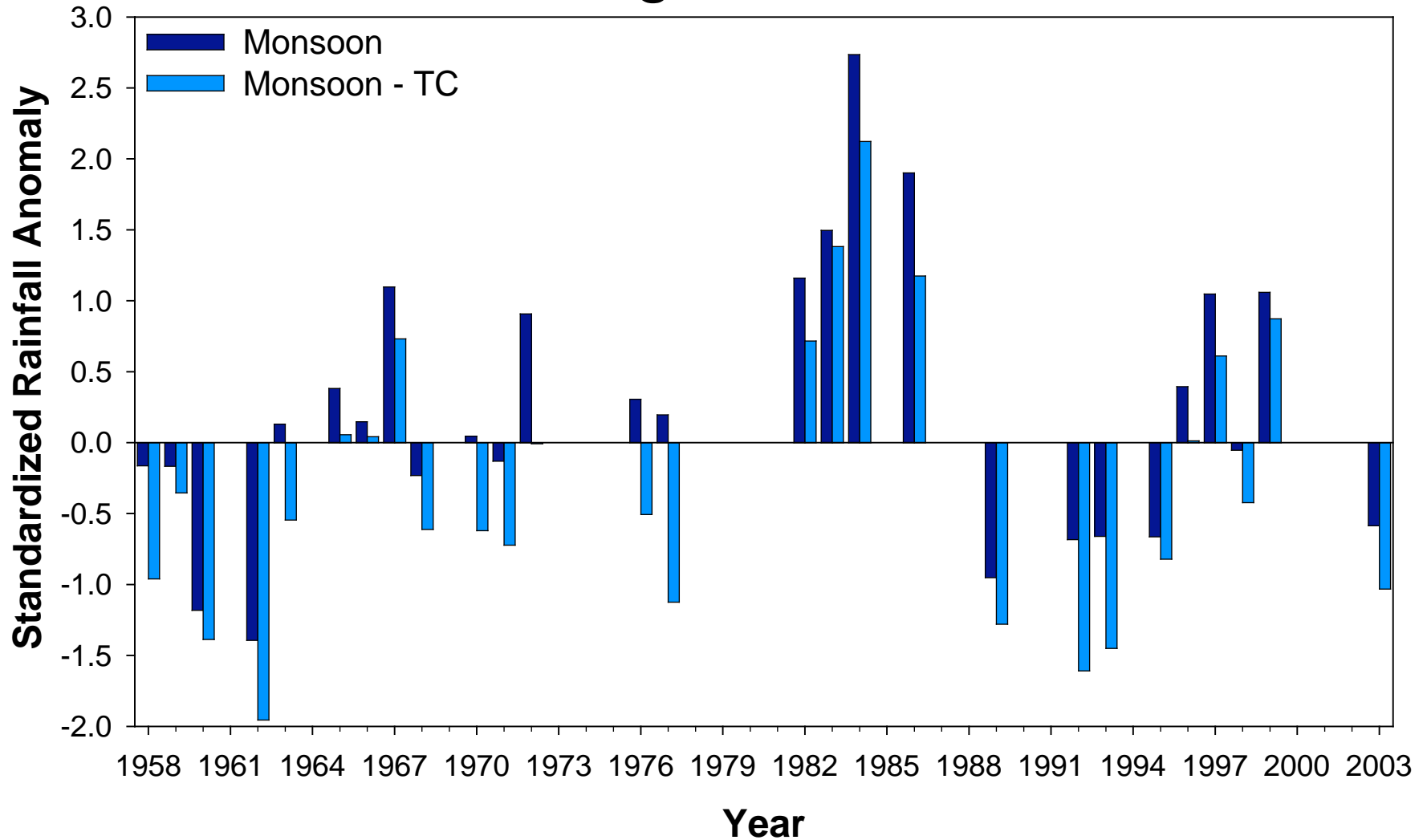
Southwest US Monsoon Rainfall Index



Southwest US Monsoon Rainfall Index

With and Without TC rainfall

$-.52$ change = ~ 11 mm



Southwest US Monsoon Rainfall Index

With and Without TC rainfall

NINO3 JAS SST anomaly

