# Weather Regime-Dependent Predictability: Sequentially Linked High-Impact Weather Events over the United States during March 2016

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## Motivation

- High-impact weather events (HWEs), defined by episodes of excessive precipitation or anomalous temperature, can pose substantial predictability challenges on medium-range (8–10 day) time scales.
- This study introduces the North Pacific Jet (NPJ) phase diagram as a tool to characterize the large-scale flow pattern over the North Pacific.
- The NPJ phase diagram is applied to a period in late March and early April 2016 that was characterized by three sequentially linked HWEs:
  1. The 23–24 March 2016 Colorado Front Range snowstorm and Southern Plains severe weather outbreak.
  2. The 27–28 March 2016 Ohio River Valley severe weather outbreak.
  3. The 3–4 April 2016 Northeast U.S. cold air outbreak.

## Data

- 1.0° x 1.0° NCEP Global Forecast System (GFS) and Global Ensemble Forecast System (GEFS) analyses (available every 6 h).
- 0.5° x 0.5° NCEP Climate Forecast System Reanalysis (CFSR; available every 6 h) during 1979–2014.
- 1.0° x 1.0° ESRL/PSD GEFS Reforecast v2 dataset (available every 24 h) during 1984–2014.

## Conclusions

- The predictability challenges that characterized the 23–24 March 2016 Colorado snowstorm were magnified because uncertainties in the positions of key weather features were concentrated near the Continental Divide.
- The evolution of the flow pattern prior to the onset of cold over the Northeast U.S. on 3 April 2016 is consistent with an antecedent environment conducive to extreme cold east of the Rocky Mountains.
- Jet Extension and Equatorward Shift regimes are more frequently characterized by reduced forecast errors than Jet Retraction and Poleward Shift regimes.
- Jet Extension regimes are favored during Phases 7 and 8 of the MJO and during El Niño. Equatorward Shift regimes are favored during El Niño.
- Predictability horizons can vary greatly as a function of weather regime and season. Consequently, regime-dependent predictability is an important science and operations problem, progress on which may improve the prediction of a variety of HWEs.

## North Pacific Jet Phase Diagram

- The large-scale flow pattern over the North Pacific can be objectively characterized using the North Pacific Jet (NPJ) phase diagram.
- The NPJ phase diagram is constructed from the first two EOFs of Sept.–May 250-hPa zonal wind anomalies from the CFSR over the North Pacific (Fig. 1).

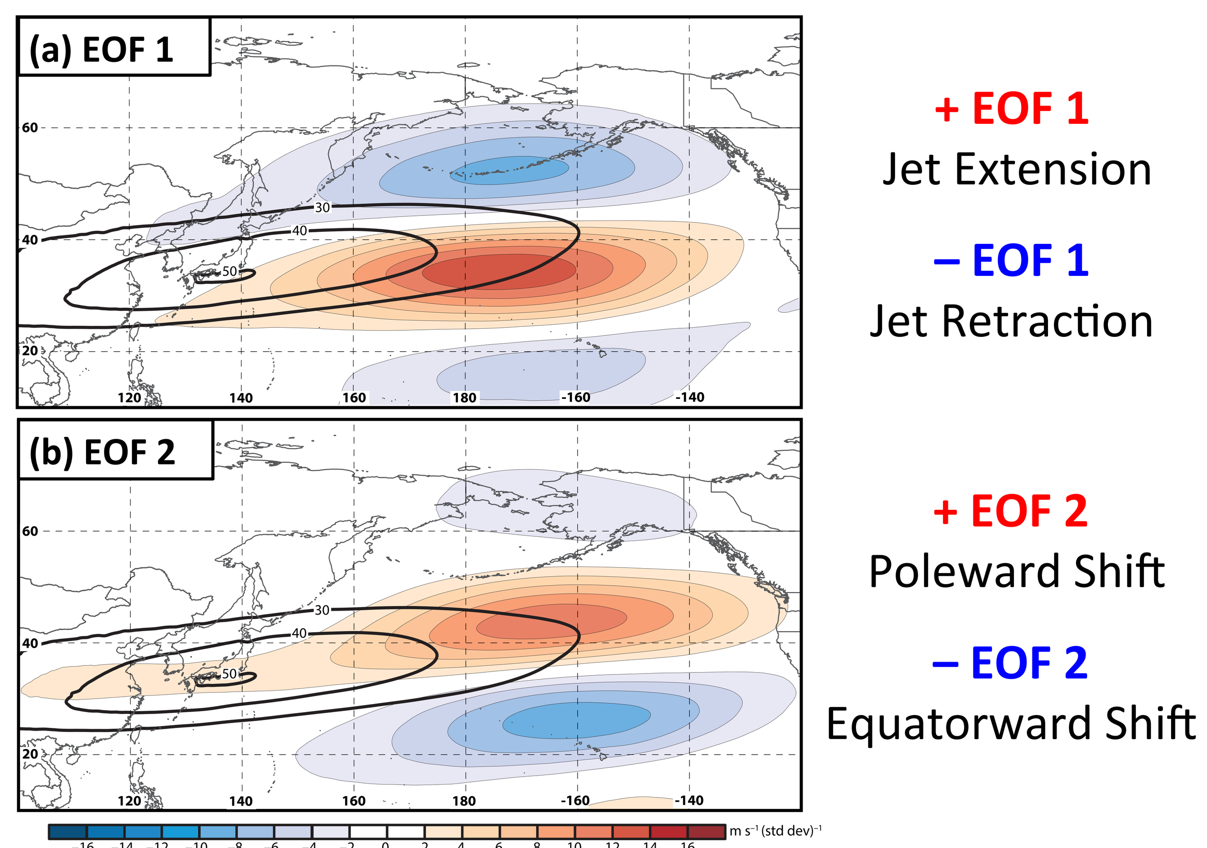



*Figure 1: (a) Sept.–May 250-hPa mean zonal wind contoured in black every 10 m s$^{-1}$ above 30 m s$^{-1}$ and the regression of the first EOF onto 250-hPa zonal wind anomaly data shaded in the fill pattern. (b) As in (a) but for the second EOF.*

- 250-hPa zonal wind anomalies at a given time can be projected onto EOF 1 and 2, resulting in a point on the NPJ phase diagram (Fig. 2).
- The NPJ phase diagram serves as a tool to examine the flow evolution over the North Pacific.

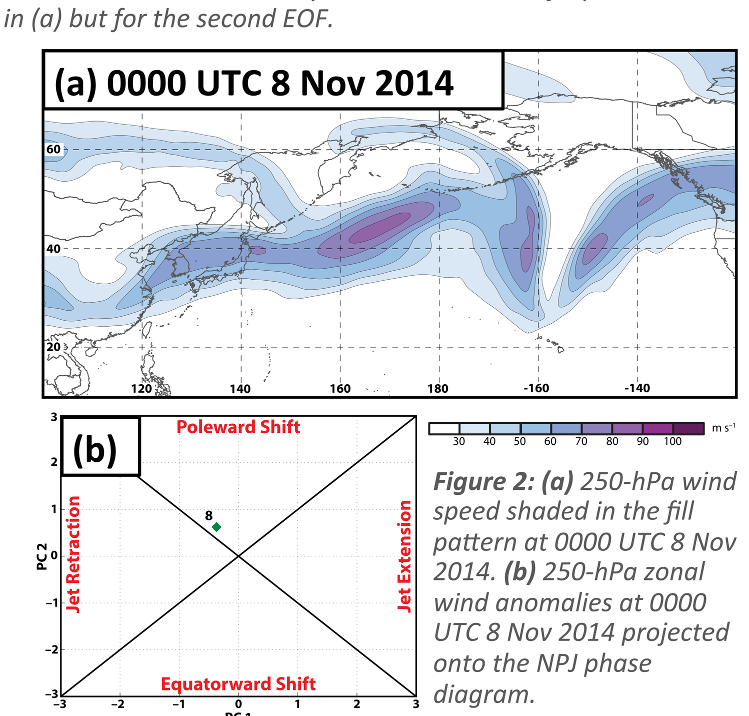
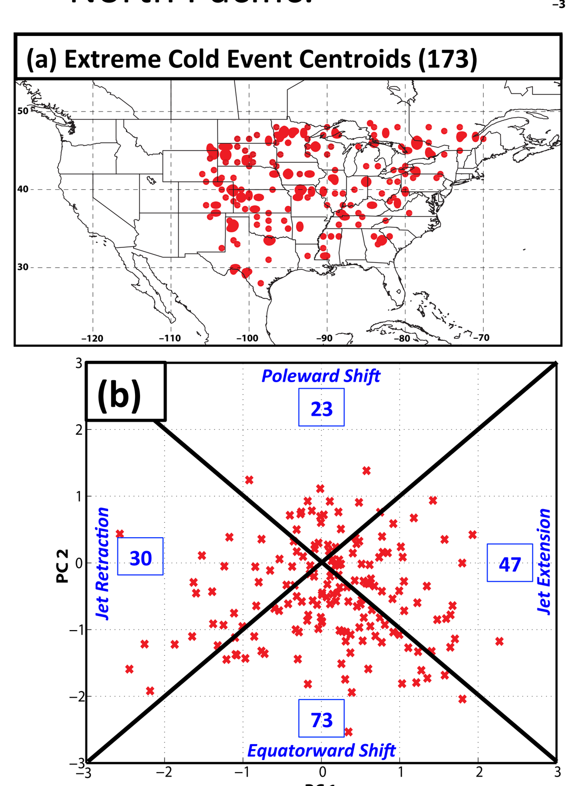



*Figure 2: (a) 250-hPa wind speed shaded in the fill pattern at 0000 UTC 8 Nov 2014. (b) 250-hPa zonal wind anomalies at 0000 UTC 8 Nov 2014 projected onto the NPJ phase diagram.*




- The NPJ phase diagram may be used to categorize antecedent environments associated with extreme events.
- Eastern U.S. extreme cold events are more frequently preceded by Jet Extension and Equatorward Shift regimes (Fig. 3).

*Figure 3: (a) Centroids for 173 eastern U.S. extreme cold events during Sept.–May 1979–2014 indicated by the red dots. (b) Average projection of 250-hPa zonal wind anomalies onto the NPJ phase diagram 3–7 days prior to each eastern U.S. extreme cold event in (a) identified with a red 'x'. The numbers in the blue boxes identify the number of extreme cold events associated with each jet regime.*

## Large-Scale Flow Evolution: 20 March 2016 – 3 April 2016

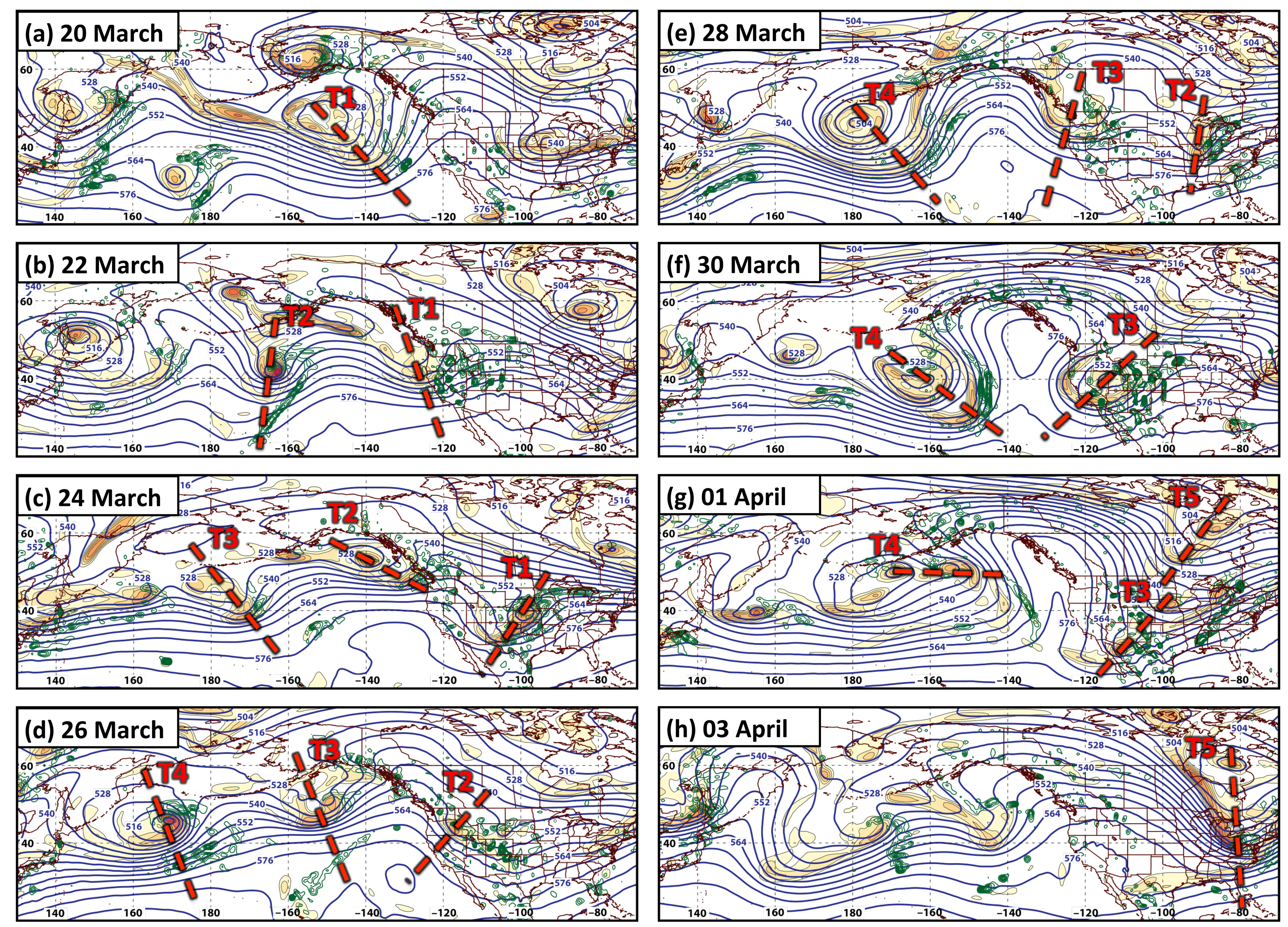



*Figure 4: 500-hPa geopotential height contoured in blue every 6 dam, relative vorticity shaded in the fill pattern every 4×10$^{-5}$ s$^{-1}$, and ascent contoured in green every 4 dPa s$^{-1}$ at 0000 UTC on the date listed in the top left of each panel. Trough axes are identified subjectively with the dashed red lines.*

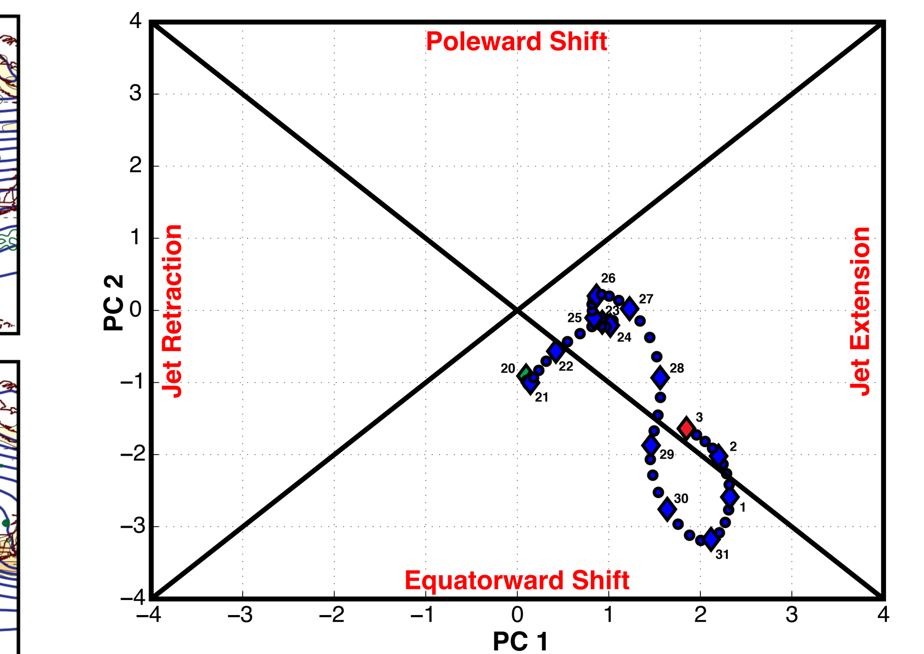
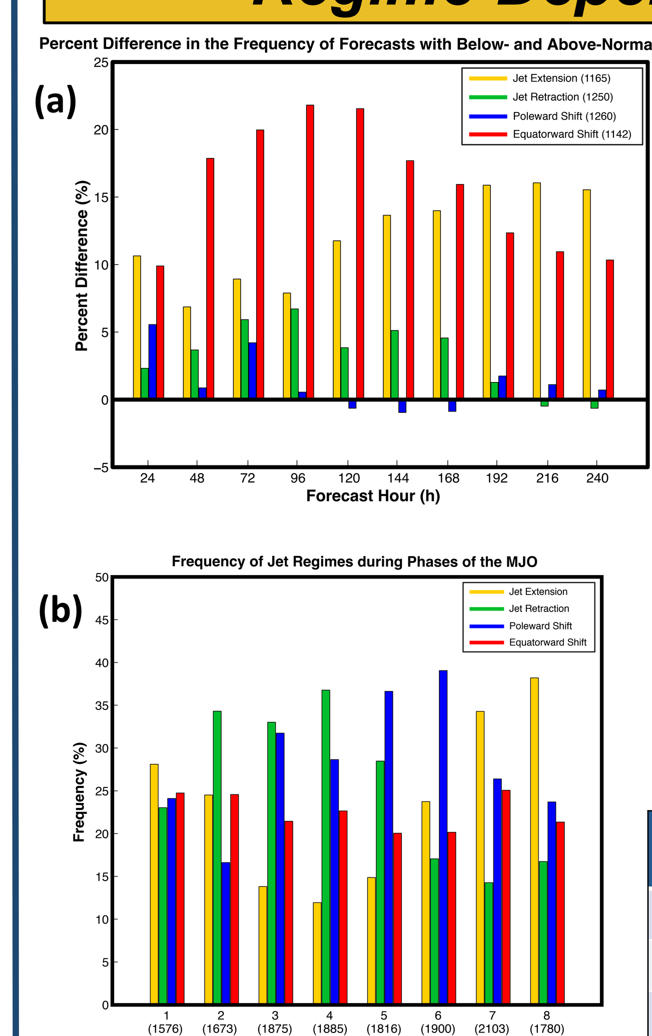



*Figure 5: The evolution of the flow pattern shown in Fig. 4 in terms of the NPJ phase diagram. Each diamond corresponds to 0000 UTC on the date listed immediately adjacent to the symbol. The green and red diamonds indicate the start and end of the trajectory, respectively.*

- The 15-day period was characterized by discontinuous retrogression that culminated in the development of an omega block over the North Pacific on 28 March and a cold air outbreak over the Northeast U.S. on 3 April (Fig. 4).
- Throughout the period 20 March – 3 April, the NPJ was characterized by Jet Extension and Equatorward Shift regimes, which favors the development of below-normal temperatures over the eastern U.S (Figs. 3 and 5).

## Regime-Dependent Predictability




- GEFS reforecasts initialized during Jet Extension or Equatorward Shift regimes are more frequently characterized by below-normal RMSE of 500-hPa geopotential height (Fig. 6a).
- Jet Extension regimes are favored during Phases 7 and 8 of the MJO. (26–31 Mar. 2016: MJO in Phases 7 and 8) (Fig. 6b).
- Jet Extension and Equatorward Shift regimes are favored during El Niño (Mar. 2016 Niño 3.4 = 1.68) (Fig. 6c).

| (c) | Jet Extension | Jet Retraction | Poleward Shift | Equatorward Shift |
|---|---|---|---|---|
| El Niño | **38.9%** | 16.8% | 14.4% | **29.9%** |
| La Niña | 12.9% | **33.4%** | **46.0%** | 7.7% |
| Neutral | 25.0% | 24.4% | 25.4% | 25.2% |

*Figure 6: (a) The percent difference in the frequency of GEFS reforecasts with below-normal (<–0.5σ) and above-normal (>0.5σ) RMSE of 500-hPa geopotential height over the CONUS (25–55°N; 140–60°W) in subsets of reforecasts that were initialized during the same NPJ regime. (b) The frequency of the four NPJ regimes during each phase of the MJO. (c) The percentage of analysis times during Sept.–May 1979–2014 in the CFSR in which the NPJ projected strongly onto a NPJ regime during an El Niño (N=3081), La Niña (N=3023), or Neutral (N=17024) phase of the El Niño–Southern Oscillation.*

## Colorado Front Range Snowstorm

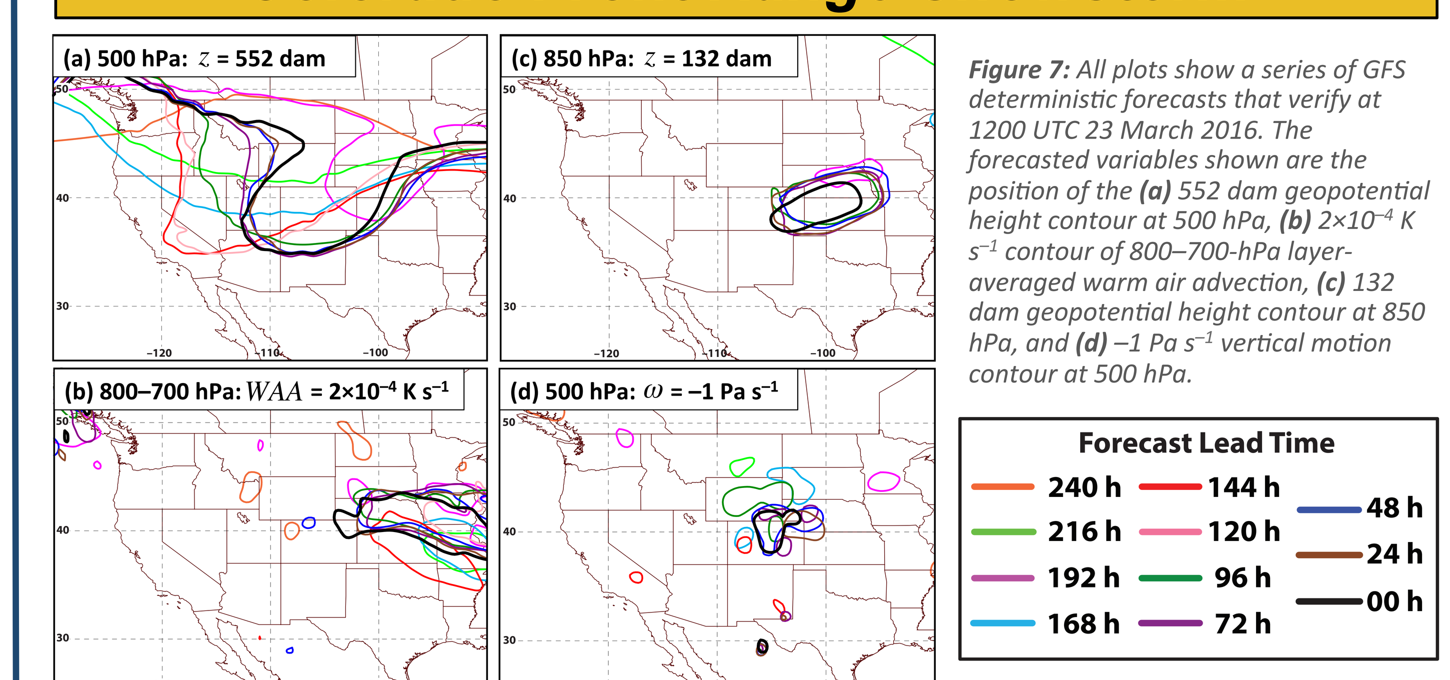



*Figure 7: All plots show a series of GFS deterministic forecasts that verify at 1200 UTC 23 March 2016. The forecasted variables shown are the position of the (a) 552 dam geopotential height contour at 500 hPa, (b) 2×10$^{-4}$ K s$^{-1}$ contour of 800–700-hPa layer-averaged warm air advection, (c) 132 dam geopotential height contour at 850 hPa, and (d) –1 Pa s$^{-1}$ vertical motion contour at 500 hPa.*

- GFS forecasts with lead times greater than 120 h generally positioned the 500-hPa trough too far west (Fig. 7a).
- A subtle westward shift in the position of the 850-hPa geopotential height minimum and strongest 800–700-hPa warm air advection continued until 24 h prior to the event (Figs. 7b,c).
- The westward shift in both the geopotential height minimum and the band of warm air advection had important ramifications for where the strongest ascent would occur along the CO Front Range (Fig. 7d).