Rossby wave breaking and extreme precipitation events in the central and eastern United States

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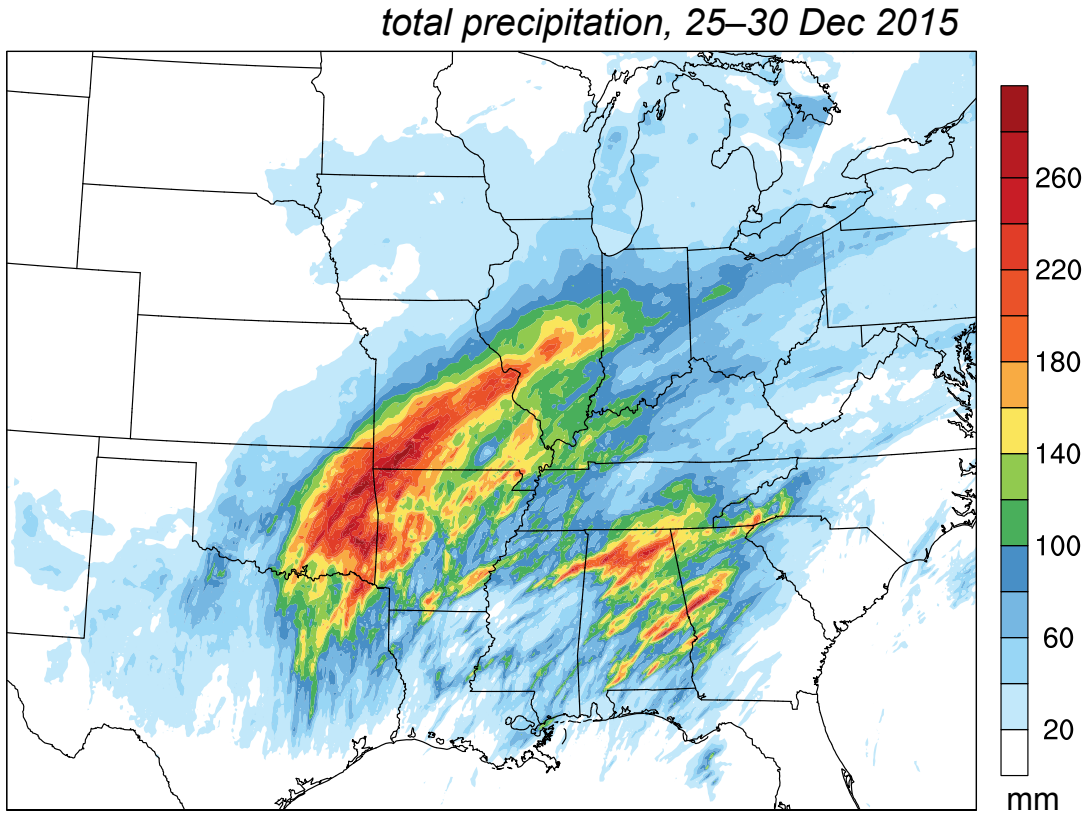
Motivation

- Widespread extreme precipitation events (EPEs) in central and eastern U.S. during cool season can result in high-impact flooding
- Evidence from case studies indicates widespread EPEs occur in conjunction with baroclinic Rossby wave breaking (RWB)
- Climatological and dynamical linkages between RWB and EPEs in U.S. have not yet been examined



Data source:
NCEP Stage IV

Motivation

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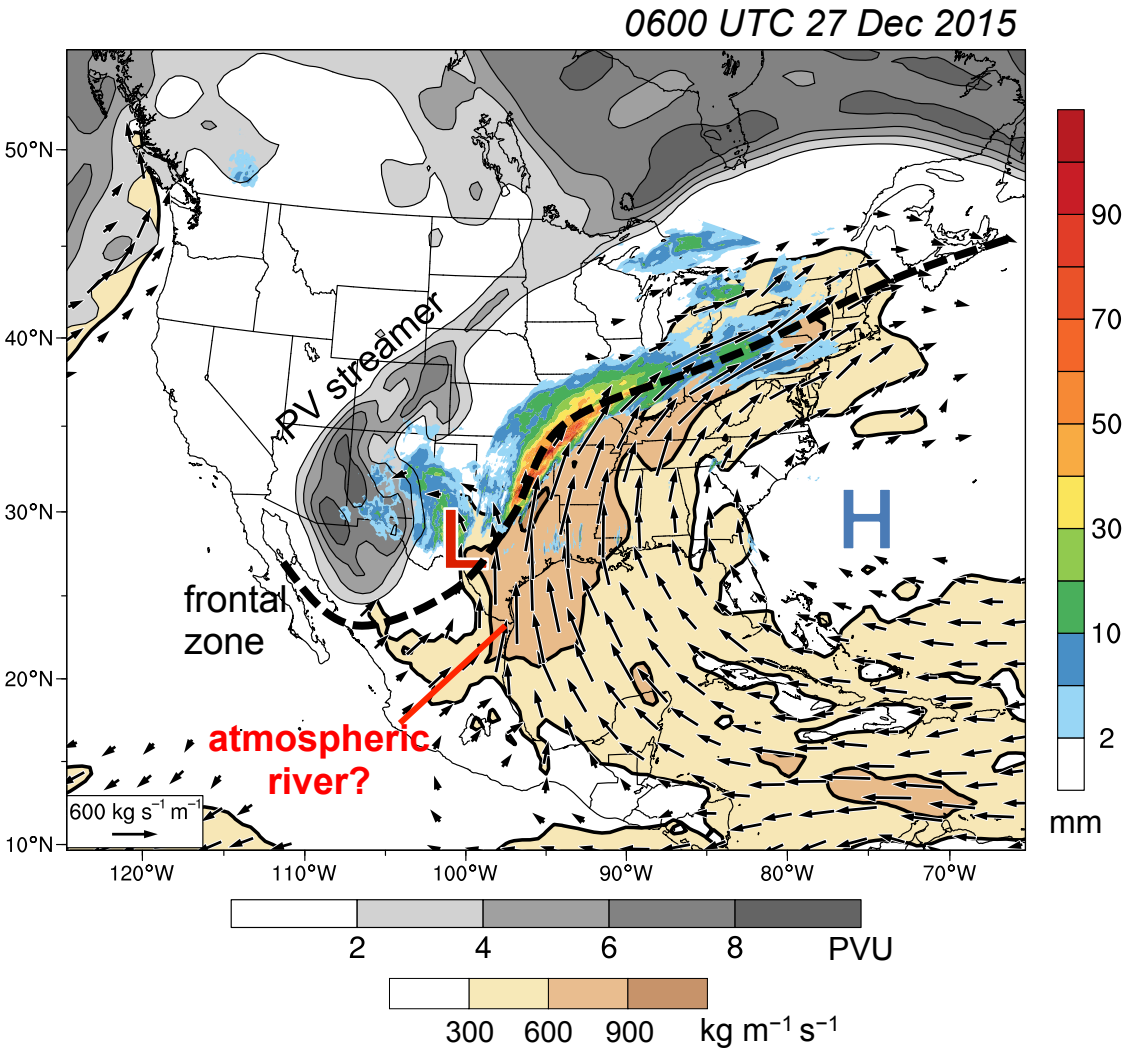


320-K PV (PVU, gray shading),
1000–200-hPa IVT (kg m^{-1} s^{-1}, vectors and tan shading)
6-h Stage-IV precip (mm, color shading)

Data sources:
NCEP Stage IV and NCEP CFSR

Science questions

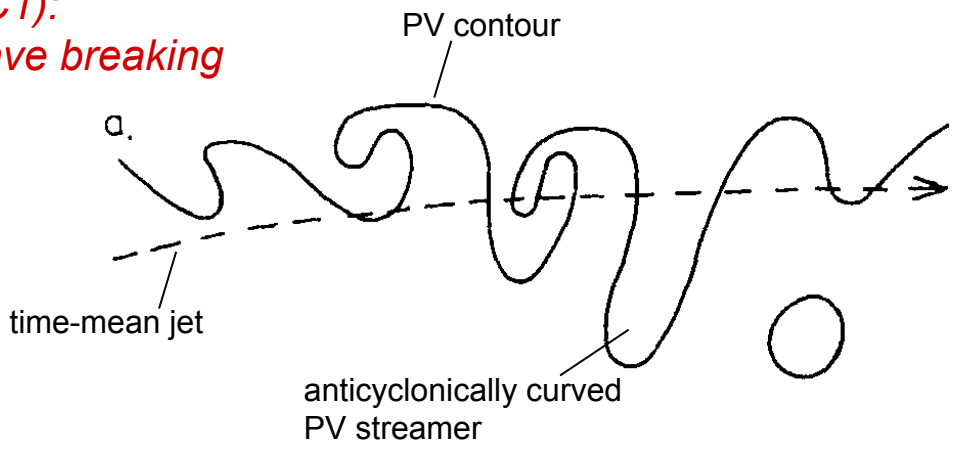
1. Do widespread EPEs in the central/eastern U.S. preferentially occur in conjunction with RWB?

2. How does RWB supply the ingredients for EPEs?

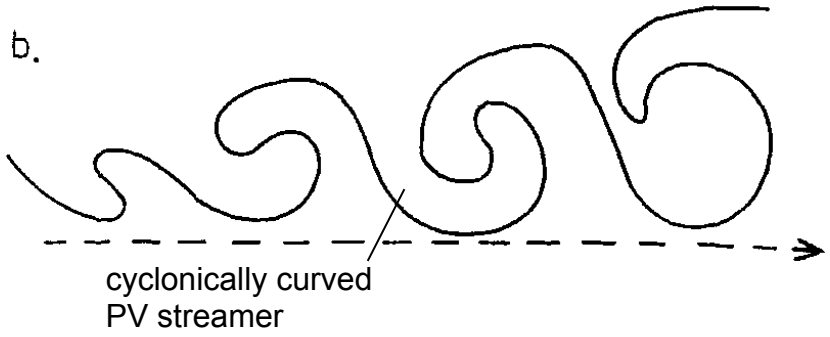
This presentation will focus on the nexus between RWB and moisture transport linked to EPEs.

RWB: An aspect of baroclinic wave life cycles

Life cycle 1 (LC1): anticyclonic wave breaking



Life cycle 2 (LC2): cyclonic wave breaking



Adapted from Fig. 12 in Thorncroft et al. (1993)

baroclinic wave life cycles &
Rossby wave breaking

strong moisture transport (i.e., ARs)
& dynamical forcing for ascent

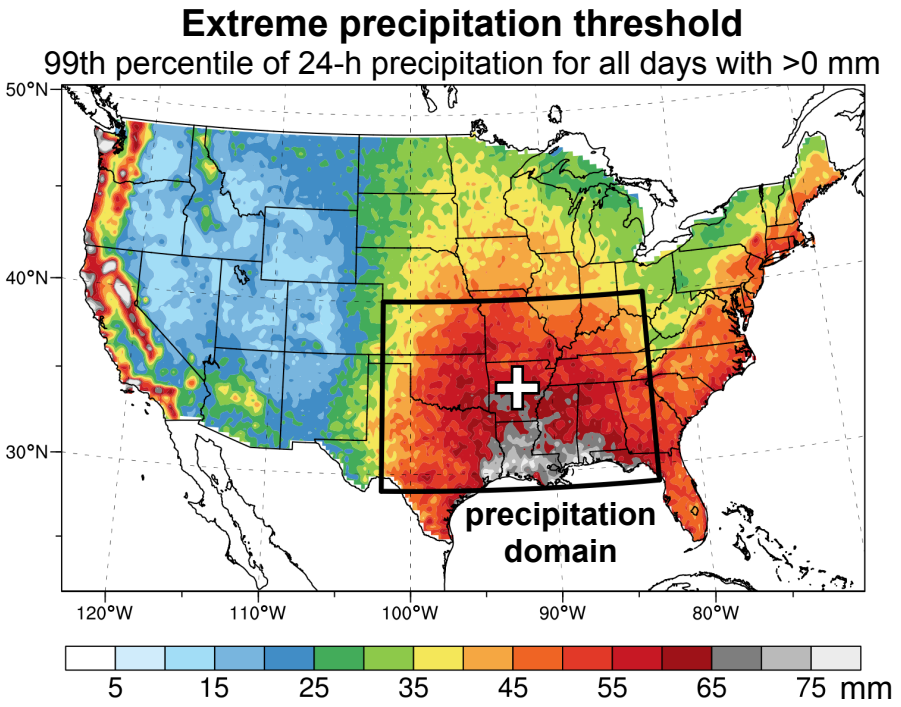
heavy precipitation

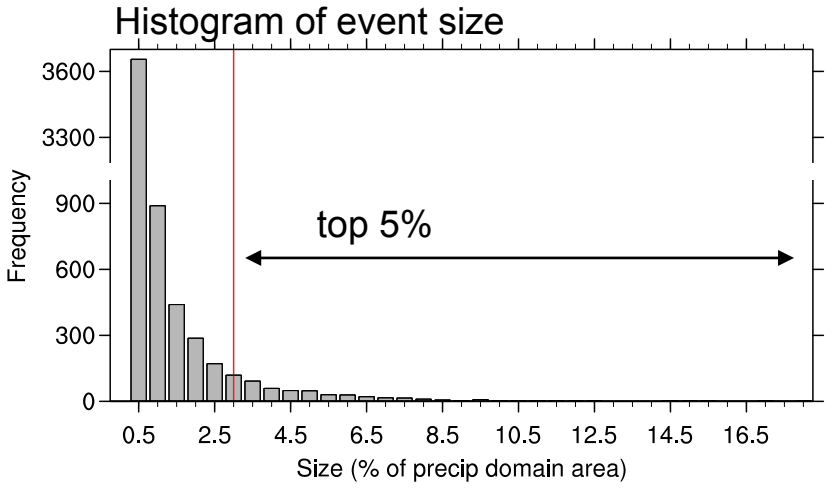
ARs form as an aspect of the dynamical evolution of baroclinic waves that establishes favorable conditions for heavy precipitation

Data and methods

- Use 24-h (ending 1200 UTC) 0.25° gauge-based precipitation analyses for 1979–2015 from NOAA CPC Unified Precipitation Dataset
- Define top 5% (299) of days with ≥1 extreme precip value in domain as widespread EPEs
- Retain only days during Sep–May without a tropical cyclone in domain
- Consider consecutive days as one event; retain only largest-scale day for statistical analysis
- Examine final sample of 201 widespread EPEs
- Define t_0 as start time of 24-h period of EPE

Climatology of widespread EPEs





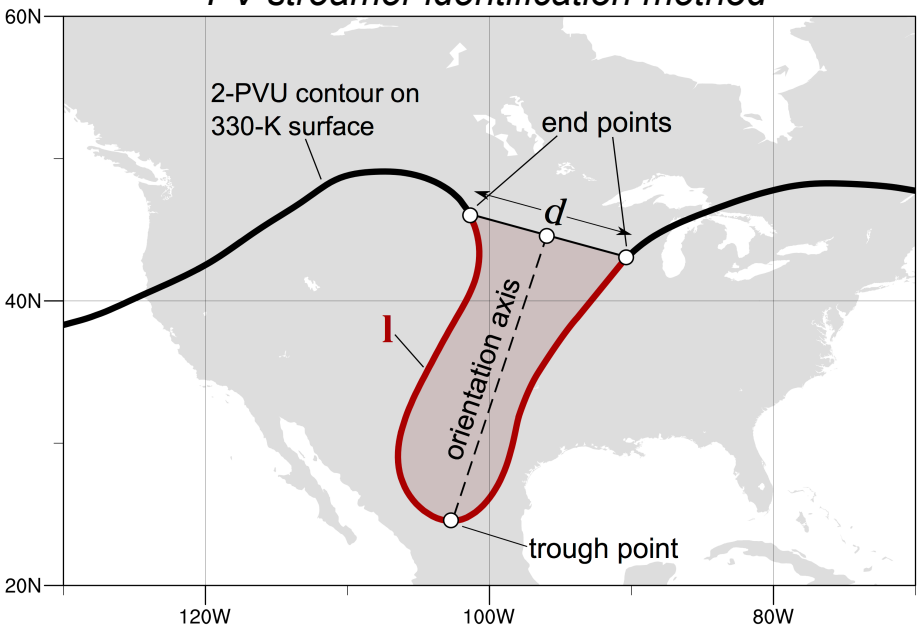
Data and methods

Climatology of breaking Rossby waves

Adaptation of method from Wernli and Sprenger (2007)

- Potential vorticity (PV) streamers are manifestations of RWB
- PV streamers identified on 2-PVU contour on 310-, 320-, and 330-K surfaces in 0.5° NCEP CFSR
- PV streamers identified as pairs of points along 2-PVU contour separated by distance $d < 1000$ km and by contour length $l > 3000$ km
- Classify streamers based on orientation angle relative to meridional baseline through midpoint of interval d:
  - > 15°: anticyclonic (LC1) wave breaking
  - < −15°: cyclonic (LC2) wave breaking
  - all others: “meridional”

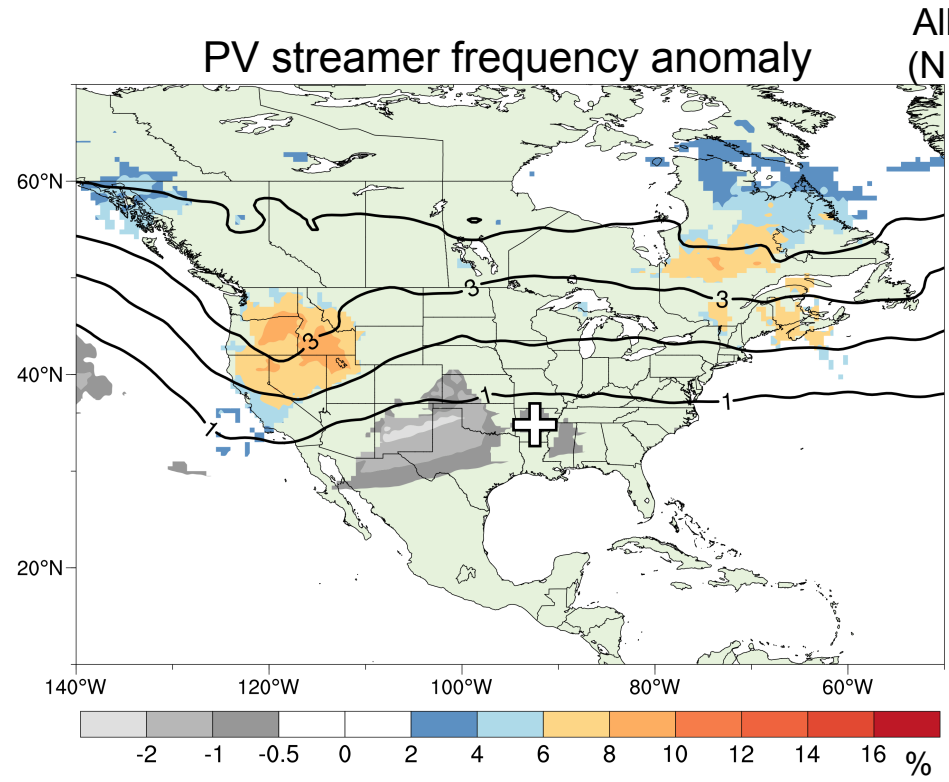
Schematic depiction of PV streamer identification method



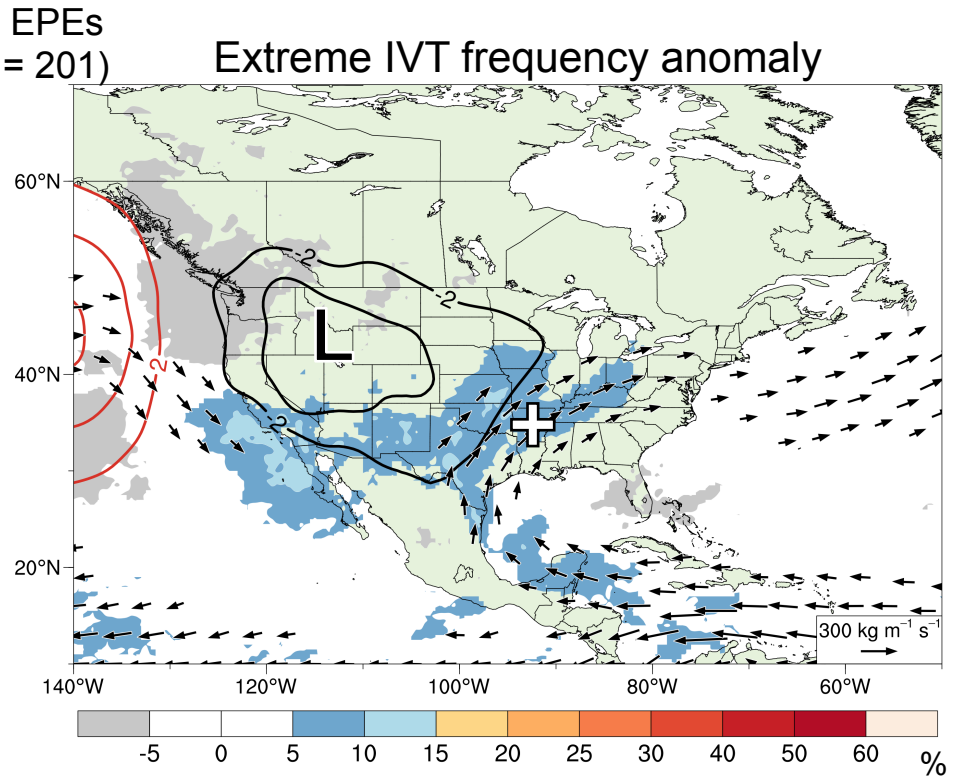
Adapted from Fig. 1 in Wernli and Sprenger (2007)

RWB and extreme water vapor transport linked to EPEs

t_0 – 48 h



320-K PV streamer frequency displayed as an anomaly relative to the climatological frequency (%, shading; only statistically significant values shown) and composite 320-K PV (PVU, black)



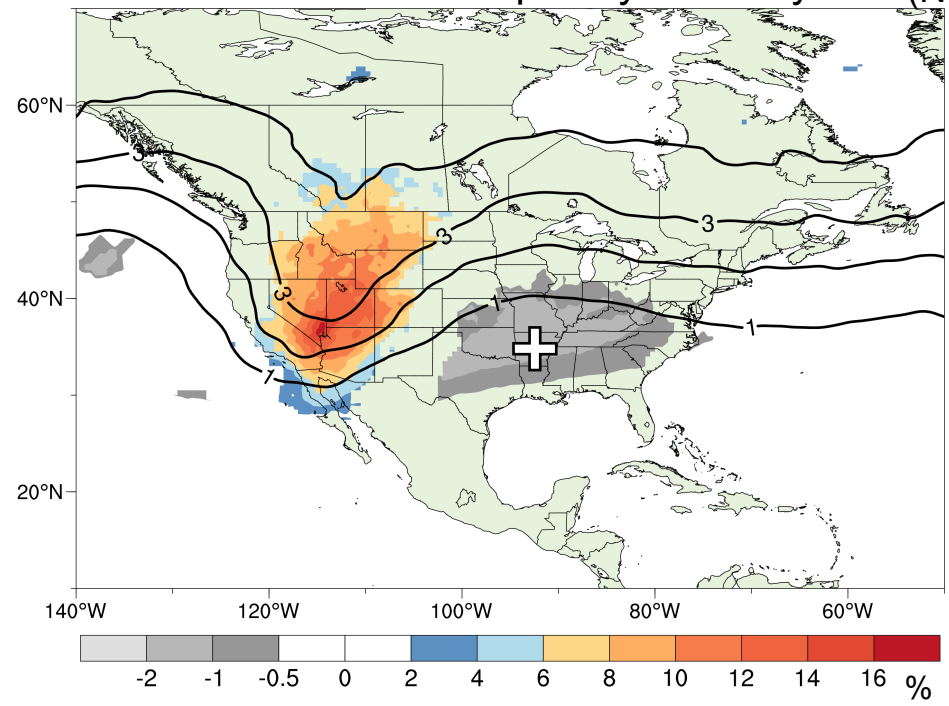
Frequency of >90th percentile IVT displayed as an anomaly relative to the climatological frequency (%, shading; only statistically significant values shown), and composite IVT vectors (kg m^{-1} s^{-1}) and SLP anomaly (hPa, negative in black; positive in red)

RWB and extreme water vapor transport linked to EPEs

t_0 – 24 h

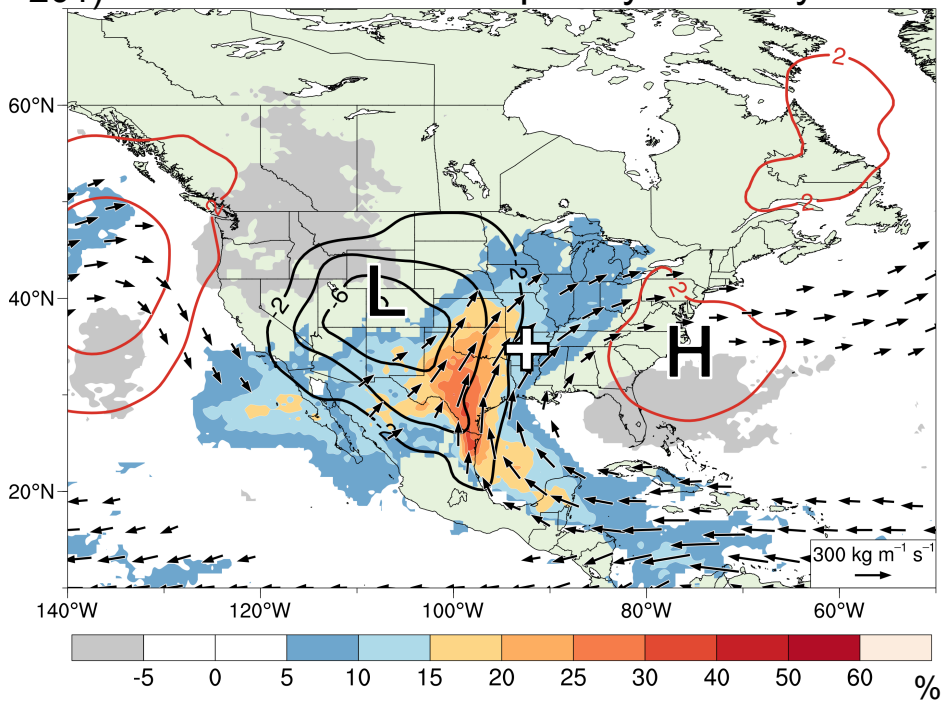
All EPEs
(N = 201)

PV streamer frequency anomaly



320-K PV streamer frequency displayed as an anomaly relative to the climatological frequency (%, shading; only statistically significant values shown) and composite 320-K PV (PVU, black)

Extreme IVT frequency anomaly

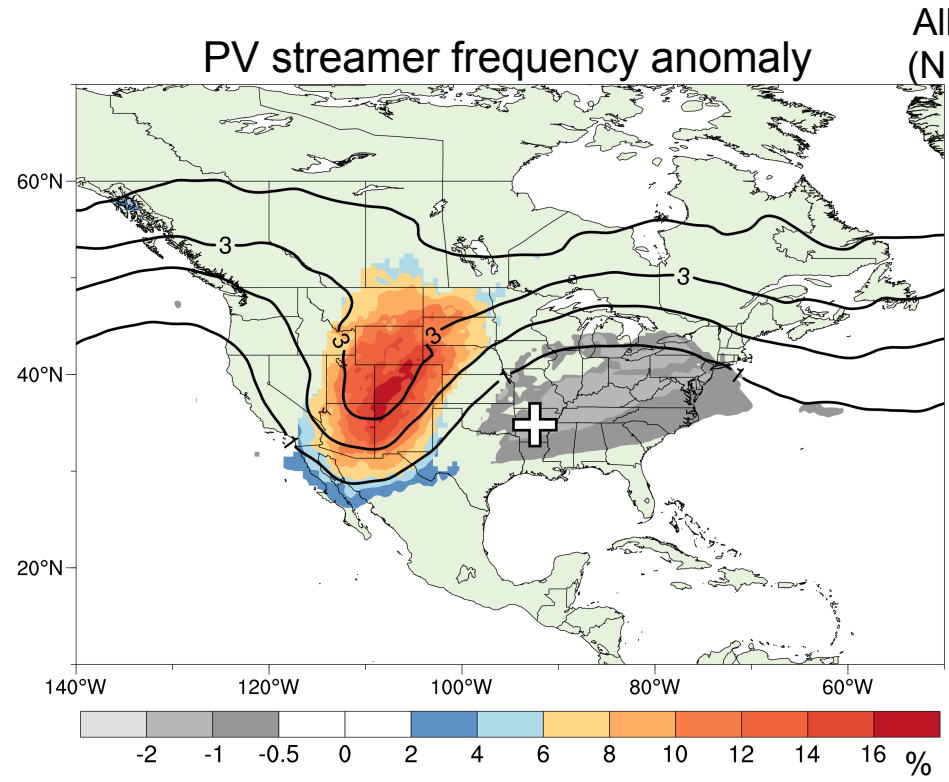


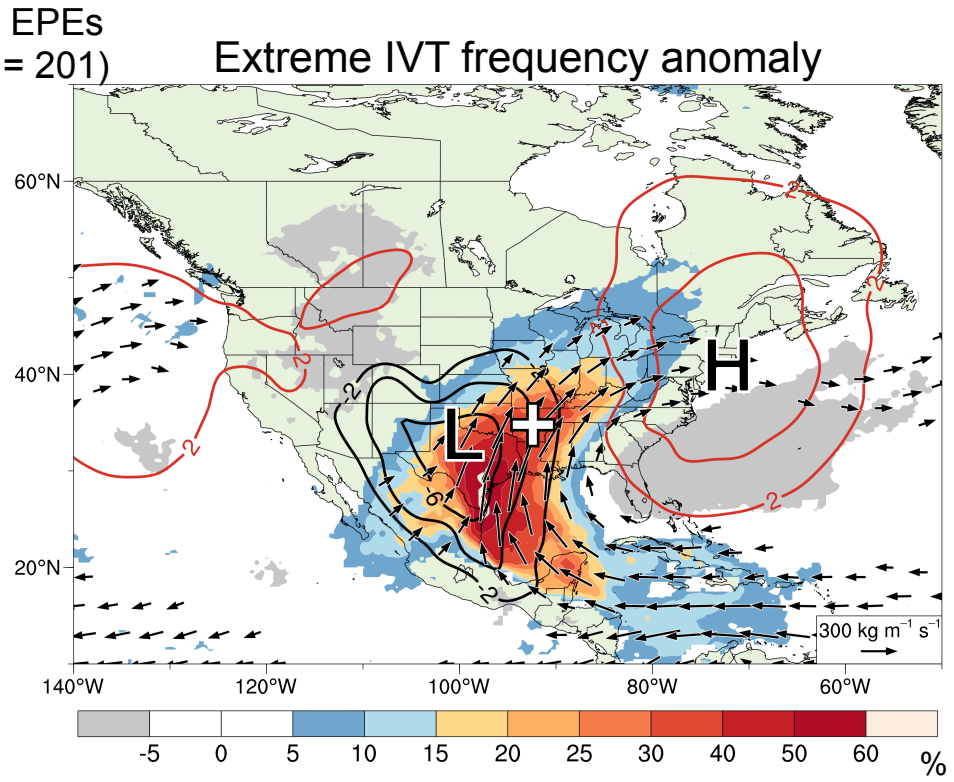
Frequency of >90th percentile IVT displayed as an anomaly relative to the climatological frequency (%, shading; only statistically significant values shown), and composite IVT vectors (kg m^{-1} s^{-1}) and SLP anomaly (hPa, negative in black; positive in red)

RWB and extreme water vapor transport linked to EPEs

t_0 – 0 h

All EPEs
(N = 201)





320-K PV streamer frequency displayed as an anomaly relative to the climatological frequency (%, shading; only statistically significant values shown) and composite 320-K PV (PVU, black)

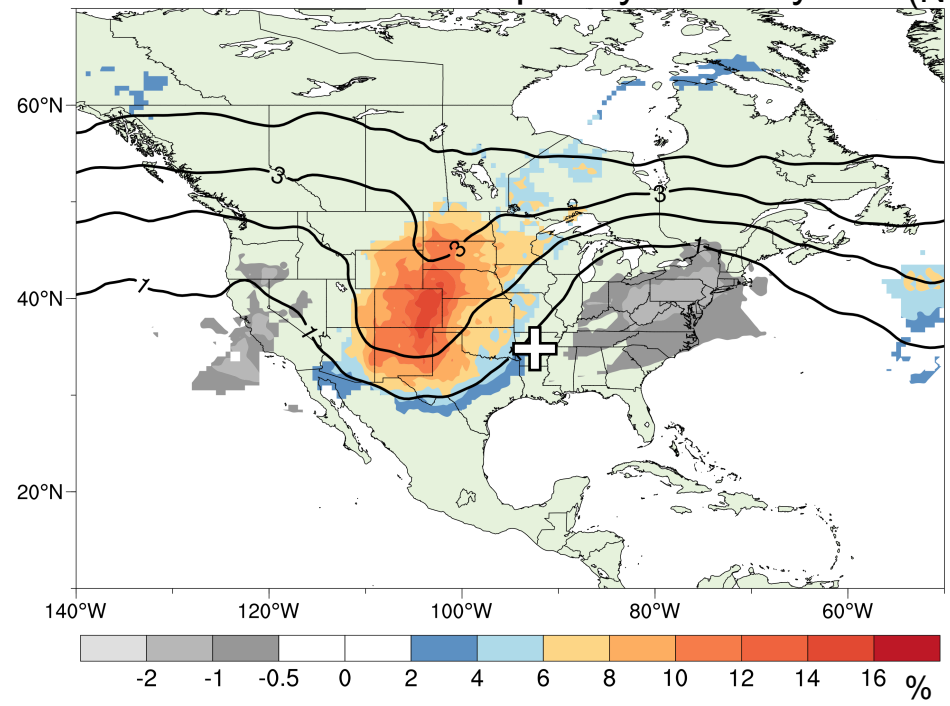
Frequency of >90th percentile IVT displayed as an anomaly relative to the climatological frequency (%, shading; only statistically significant values shown), and composite IVT vectors (kg m^{-1} s^{-1}) and SLP anomaly (hPa, negative in black; positive in red)

RWB and extreme water vapor transport linked to EPEs

t_0 + 24 h

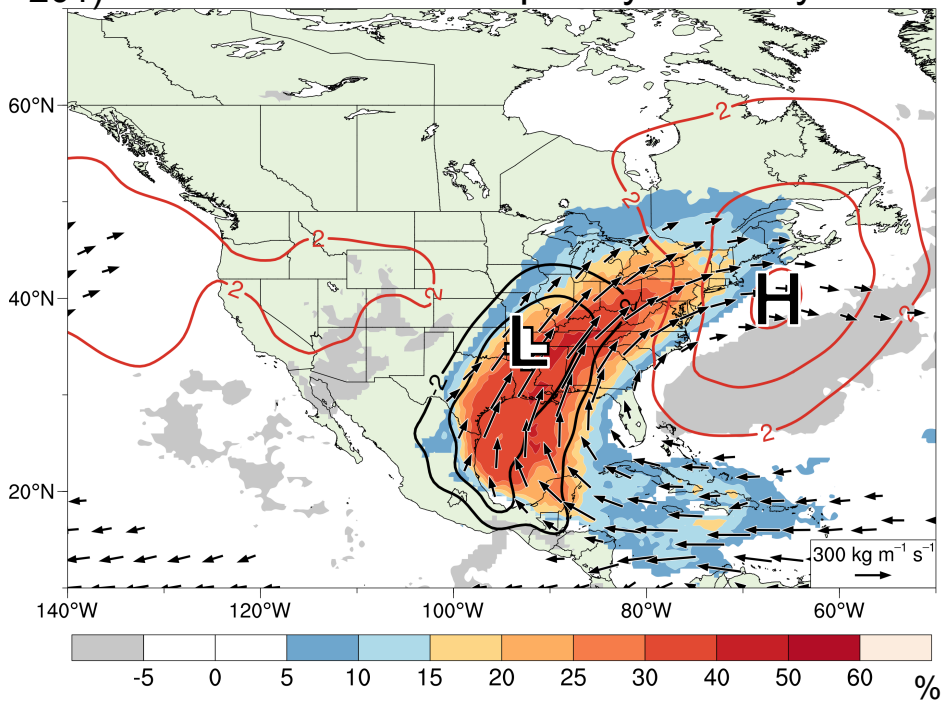
All EPEs
(N = 201)

PV streamer frequency anomaly



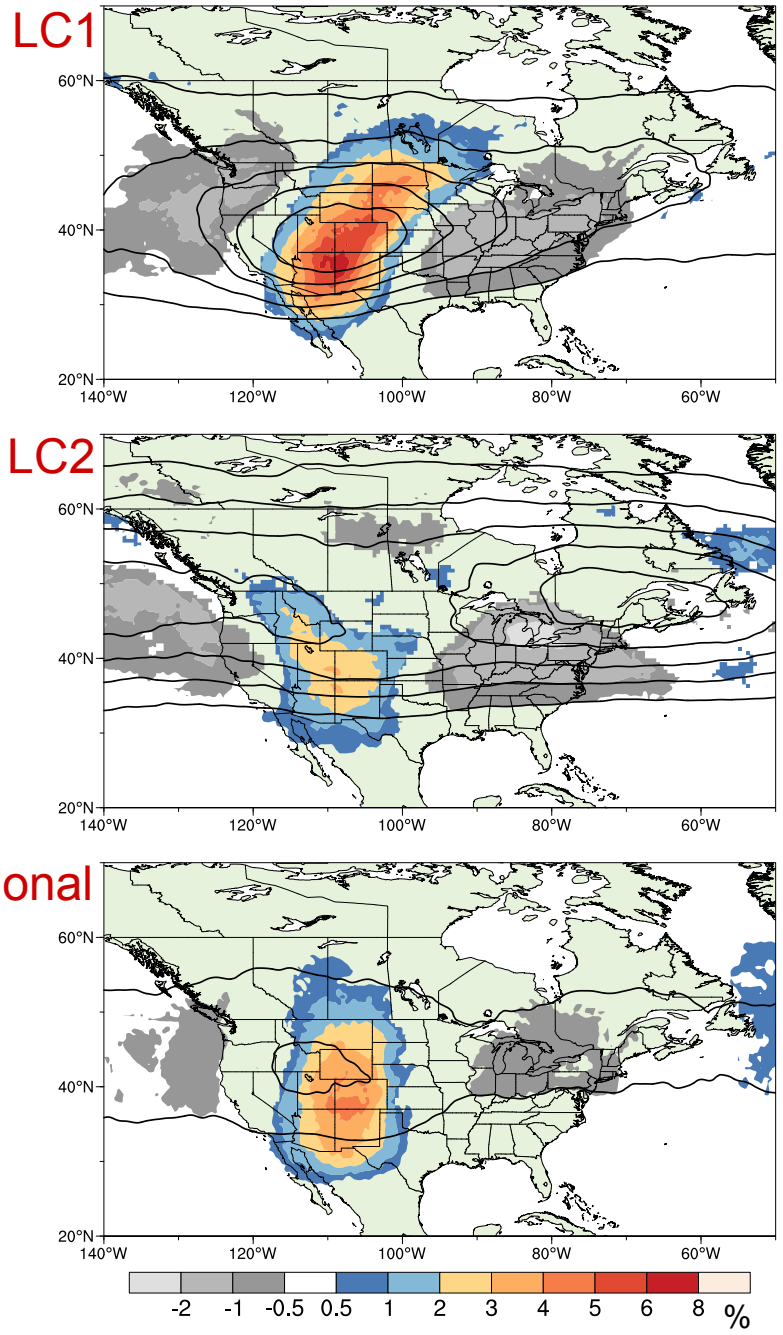
320-K PV streamer frequency displayed as an anomaly relative to the climatological frequency (%, shading; only statistically significant values shown) and composite 320-K PV (PVU, black)

Extreme IVT frequency anomaly



Frequency of >90th percentile IVT displayed as an anomaly relative to the climatological frequency (%, shading; only statistically significant values shown), and composite IVT vectors (kg m^{-1} s^{-1}) and SLP anomaly (hPa, negative in black; positive in red)

Preferred regions for PV streamer occurrence associated with EPEs

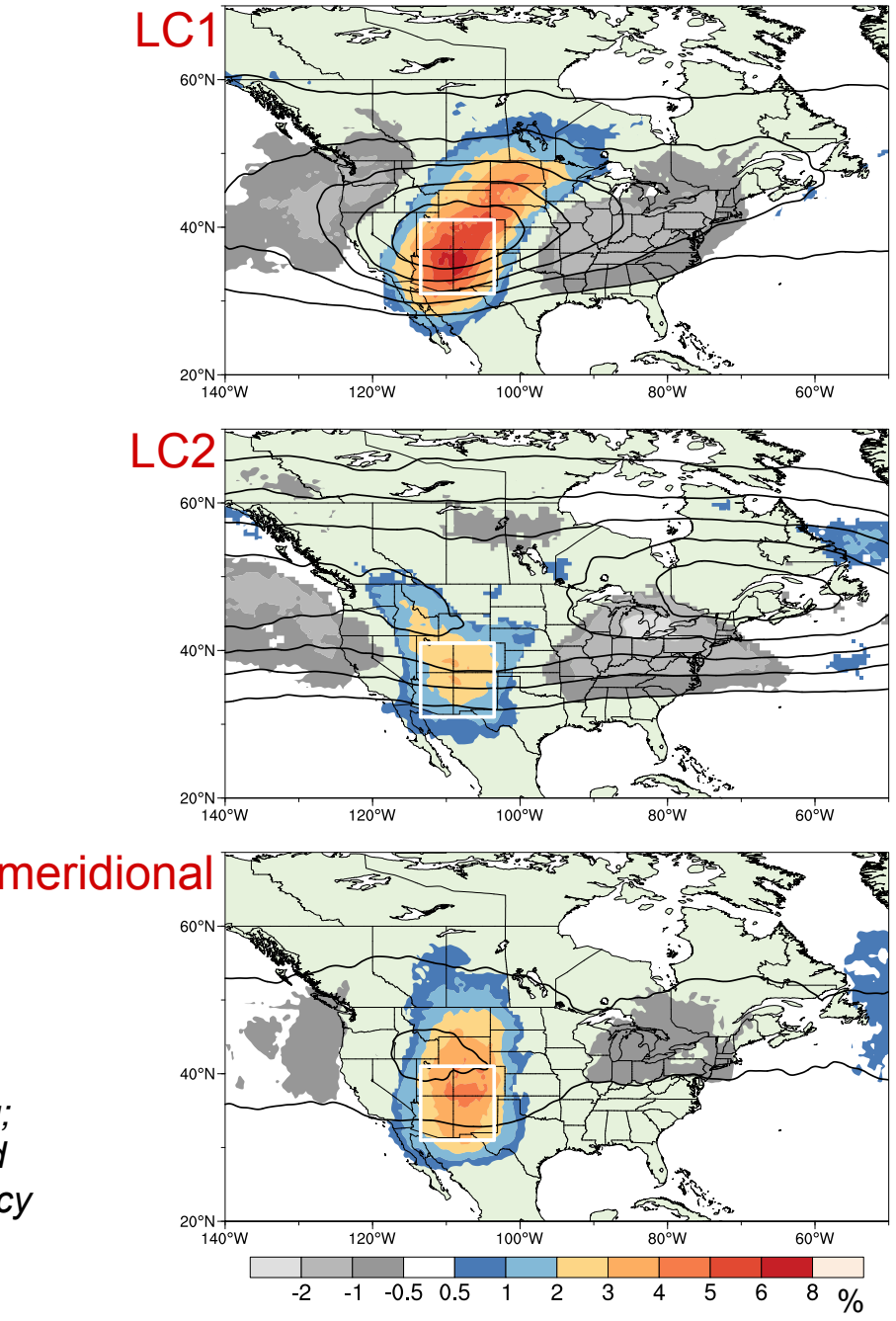


320-K PV streamer frequency anomaly (%, shading; only statistically significant values shown) averaged between t_0 − 12 h and t_0 + 12; climatological frequency contoured in black every 0.5%

Quantification of the RWB–EPE linkage

Approach

- Identify streamers that overlap ¼ of area of 10° × 10° box
- Consider EPE linked to RWB if streamer identified within 24-h period centered on t_0



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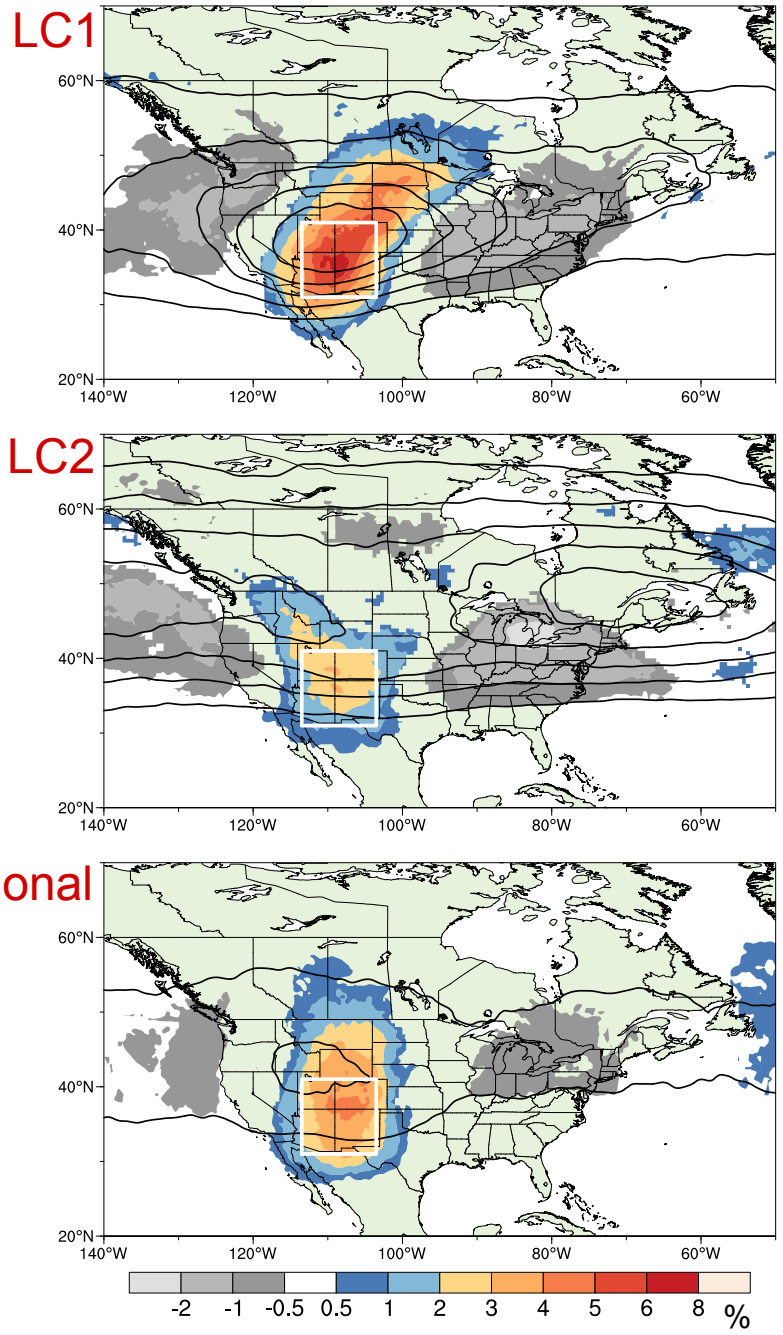
Quantification of the RWB–EPE linkage

Approach

- Identify streamers that overlap ¼ of area of 10° × 10° box
- Consider EPE linked to RWB if streamer identified within 24-h period centered on t_0

Results for 320-K PV streamers

- ~48% (97 of 201) of EPEs linked to RWB
  - **LC1:** ~47% (46)
  - **LC2:** ~26% (25)
  - **meridional:** ~27% (26)



320-K PV streamer frequency anomaly (%, shading; only statistically significant values shown) averaged between t_0 − 12 h and t_0 + 12; climatological frequency contoured in black every 0.5%

Quantification of the RWB–EPE linkage

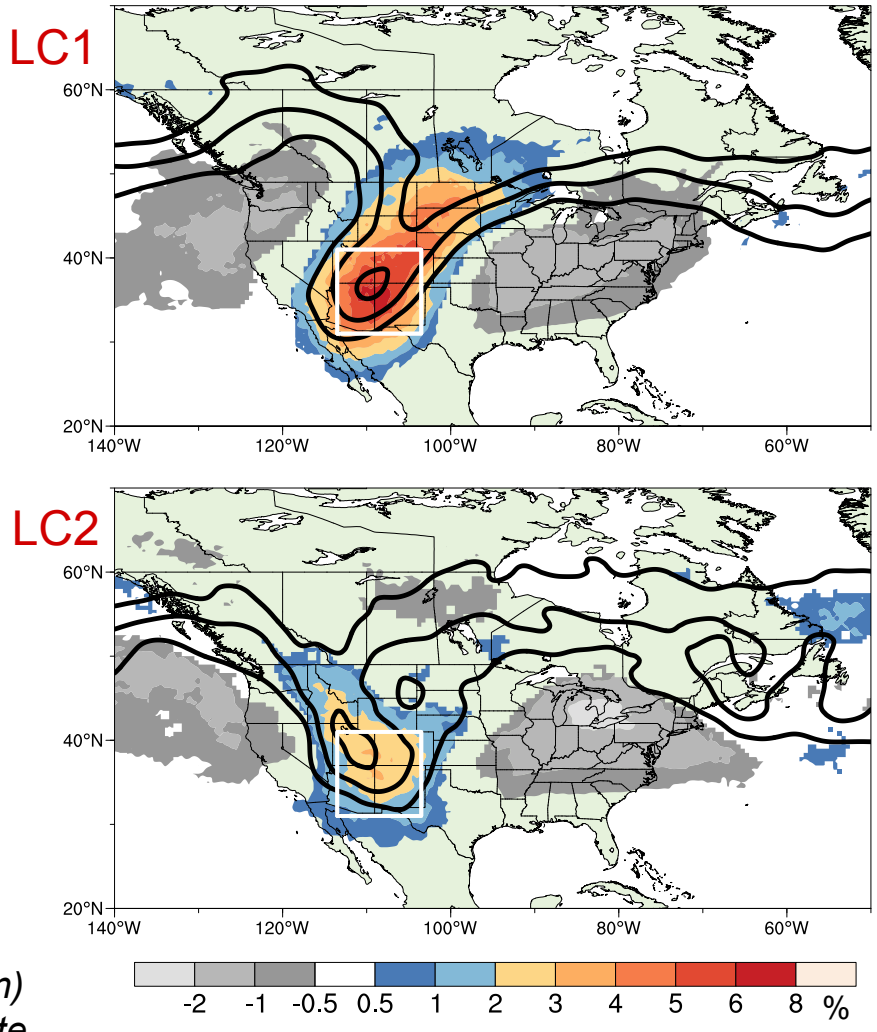
Results when analysis repeated to include PV streamers identified on at least one of three isentropic surfaces (i.e., 310, 320, 330 K)

- ~76% (153 of 201) of EPEs linked to RWB
    - **LC1:** ~49% (75)
    - **LC2:** ~23.5% (36)
    - **meridional:** ~27.5% (42)

Composite analysis of EPEs linked to RWB

Approach:

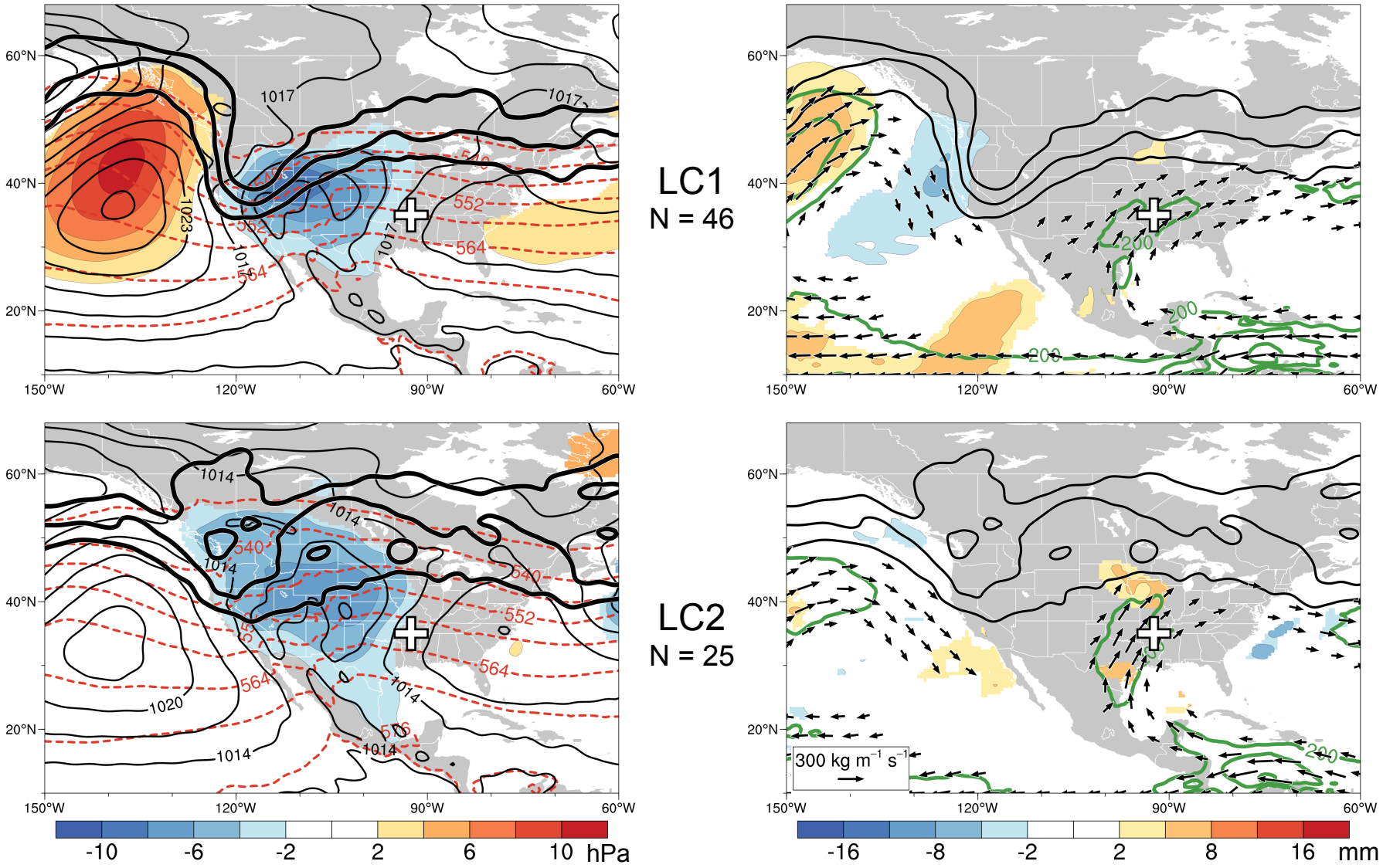
- Construct composites for EPEs linked to PV streamers identified on 320-K surface
- Examine only LC1 and LC2 cases to highlight distinct EPE scenarios



320-K PV streamer frequency anomaly (%, shading; only statistically significant values shown) averaged between t_0 − 12 h and t_0 + 12; composite 320-K PV (PVU, black) at t_0 for PV streamers overlapping box

Composite analysis of EPEs linked to RWB

t_0 − 36 h

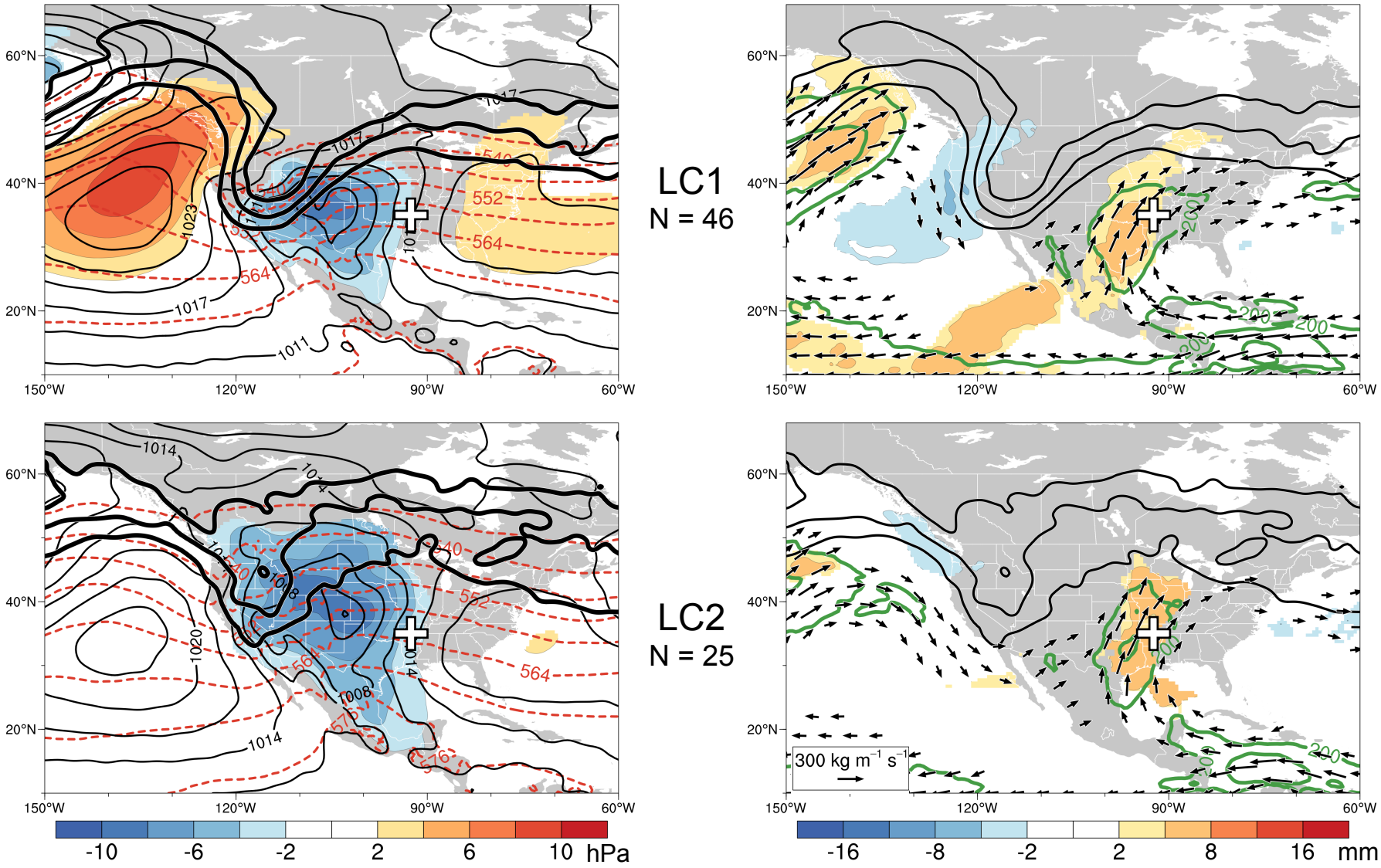


320-K PV (PVU, thick black), SLP (hPa, thin black), SLP anomaly (hPa, shading; only statistically significant values shown), 1000–500-hPa thickness (dam, red)

320-K PV (PVU, black), PW anomaly (mm, shading; only statistically significant values shown), IVT (kg m^{-1} s^{-1}, green and vectors)

Composite analysis of EPEs linked to RWB

t_0 − 24 h



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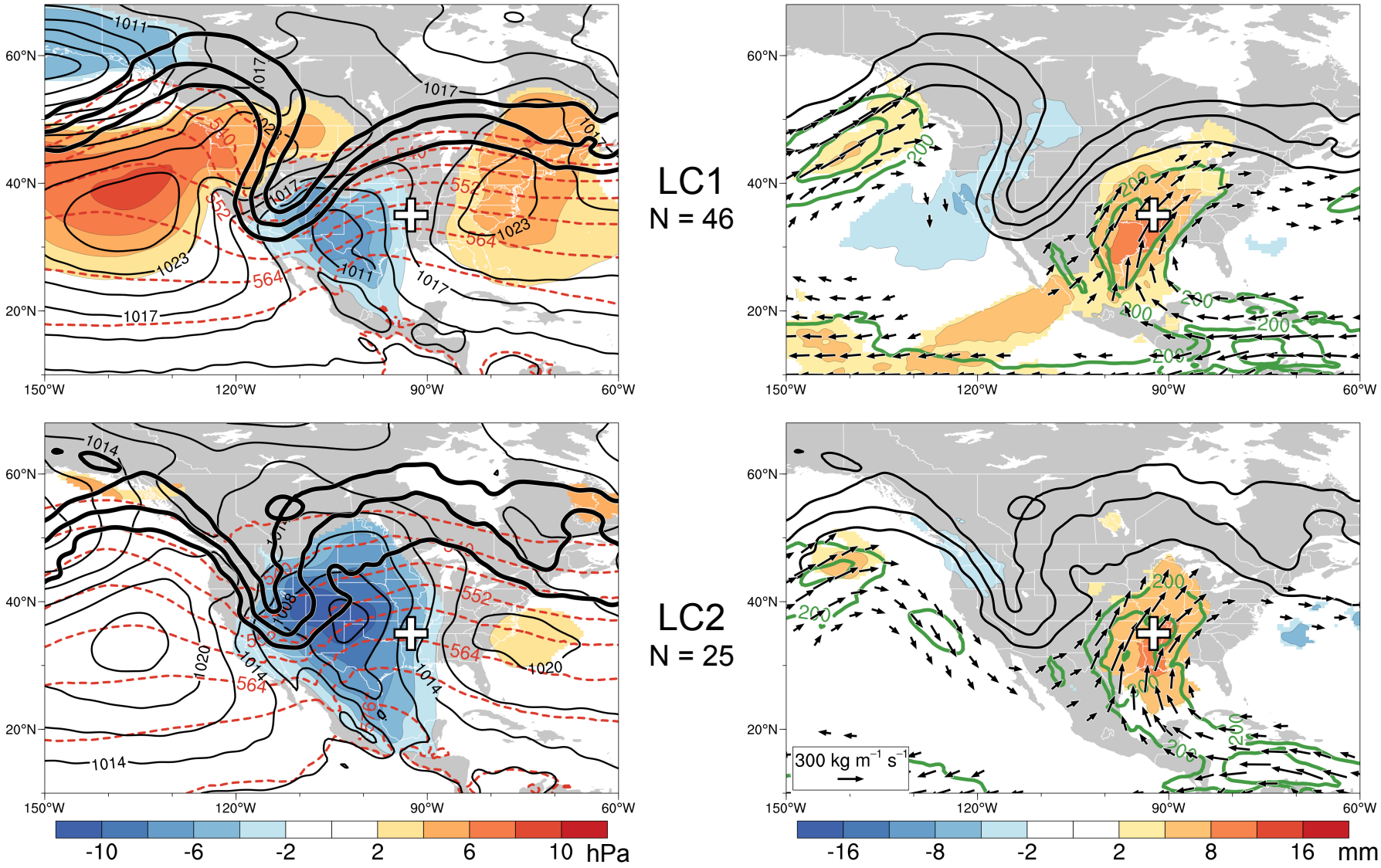
320-K PV (PVU, black), PW anomaly (mm, shading; only statistically significant values shown), IVT (kg m^{-1} s^{-1}, green and vectors)

Composite analysis of EPEs linked to RWB

t_0 − 12 h



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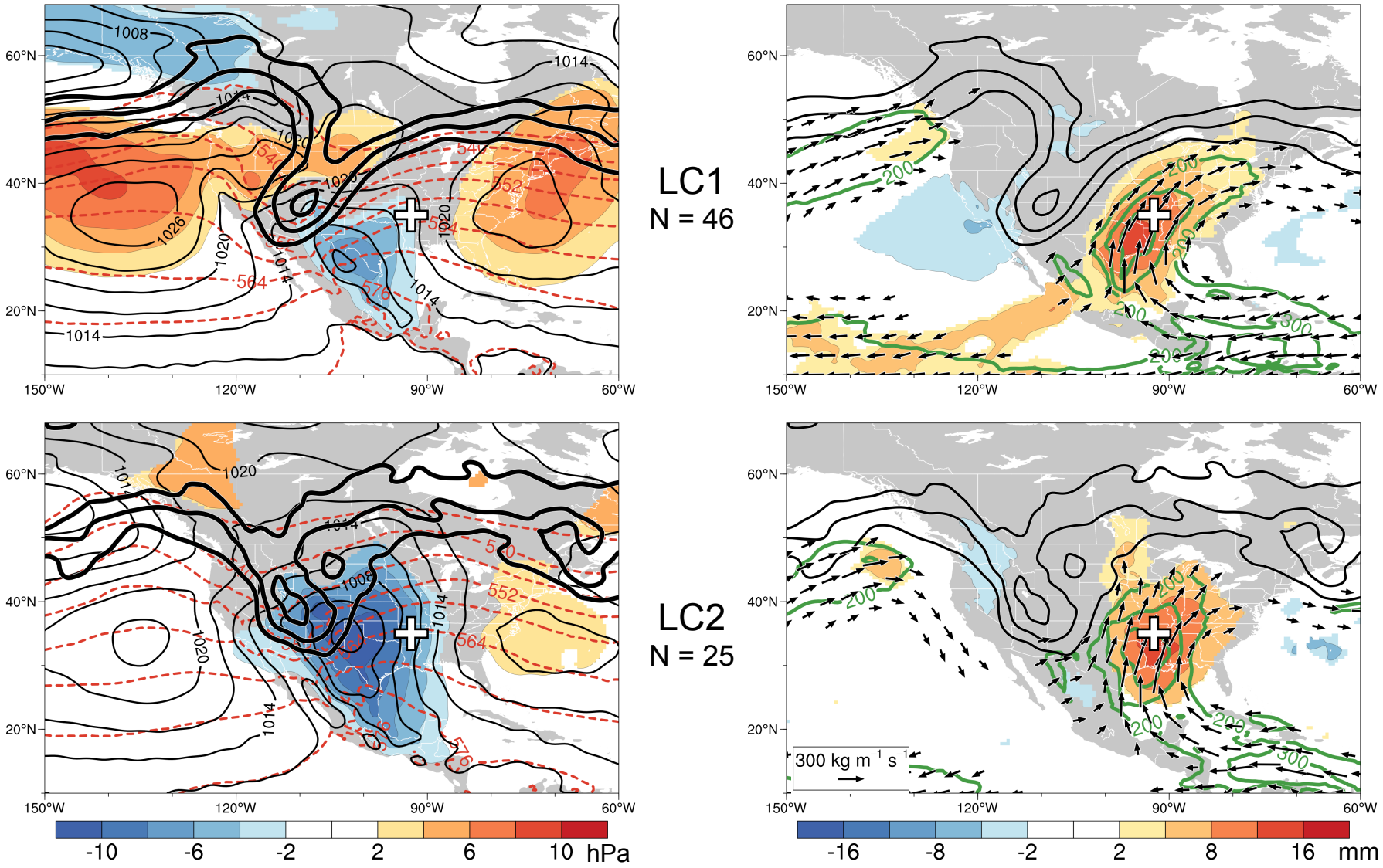
320-K PV (PVU, black), PW anomaly (mm, shading; only statistically significant values shown), IVT (kg m^{-1} s^{-1}, green and vectors)

Composite analysis of EPEs linked to RWB

t_0 – 0 h



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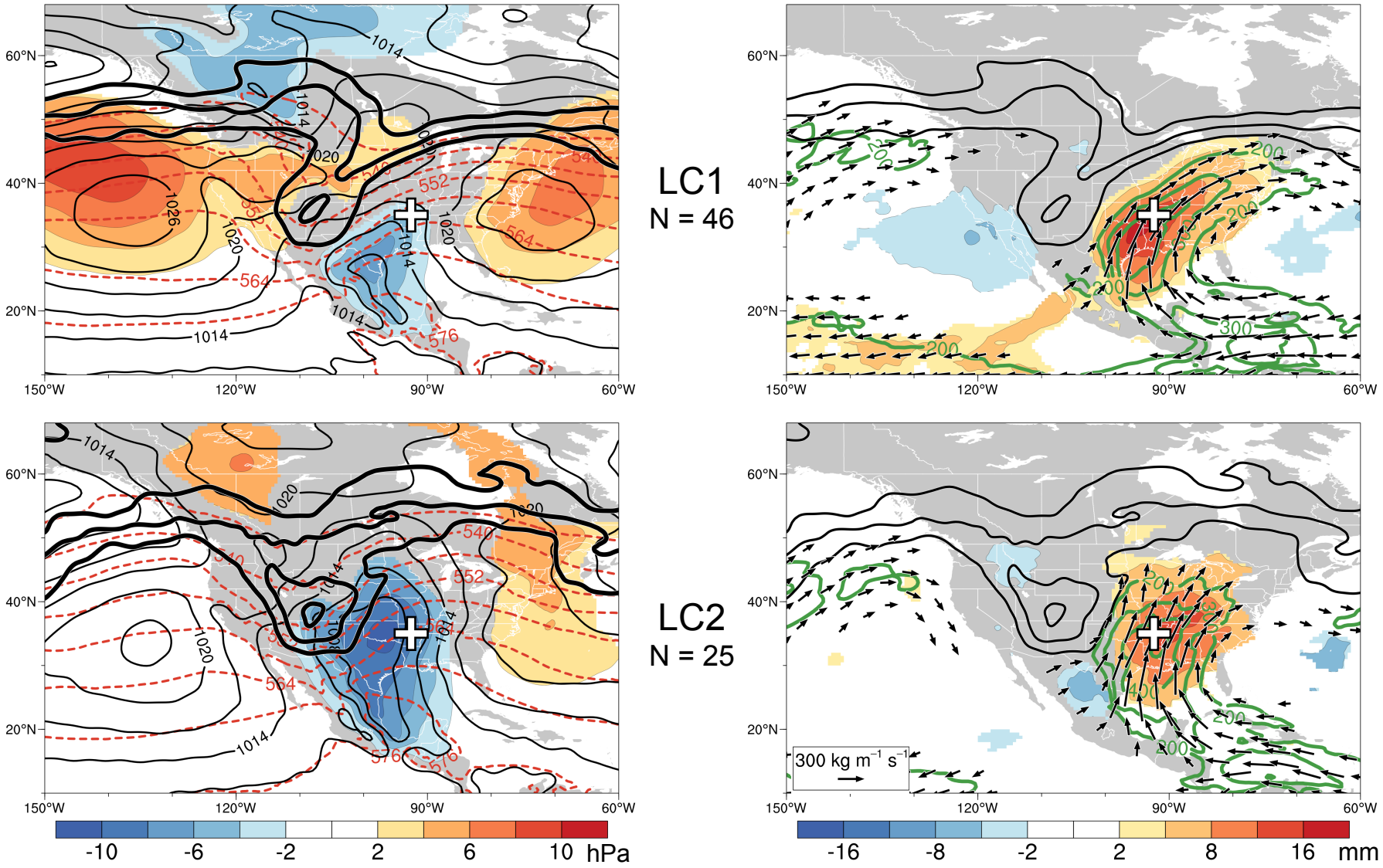
320-K PV (PVU, black), PW anomaly (mm, shading; only statistically significant values shown), IVT (kg m^{-1} s^{-1}, green and vectors)

Composite analysis of EPEs linked to RWB

t_0 + 12 h

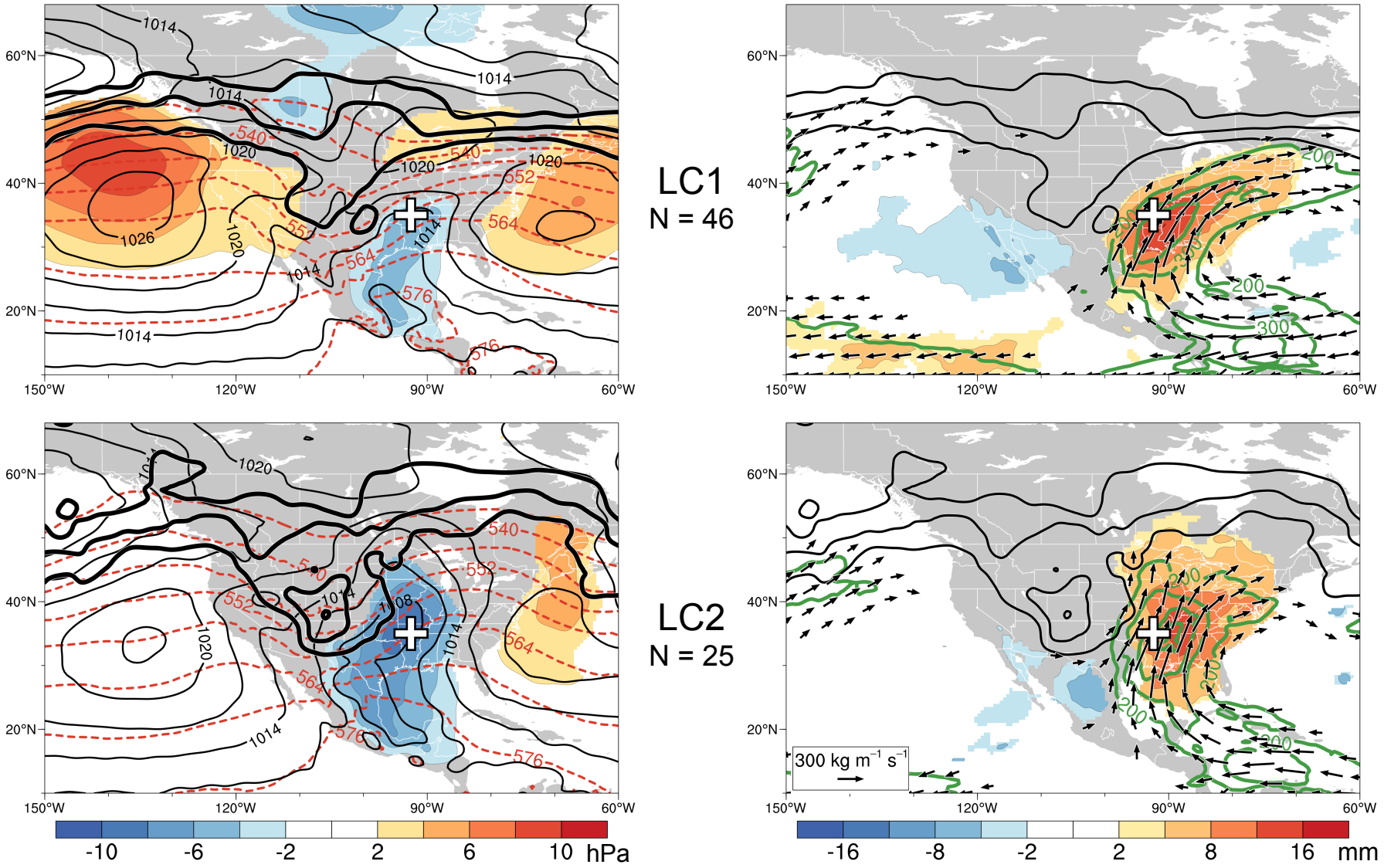


320-K PV (PVU, thick black), SLP (hPa, thin black), SLP anomaly (hPa, shading; only statistically significant values shown), 1000–500-hPa thickness (dam, red)

320-K PV (PVU, black), PW anomaly (mm, shading; only statistically significant values shown), IVT (kg m^{-1} s^{-1}, green and vectors)

Composite analysis of EPEs linked to RWB

t_0 + 24 h



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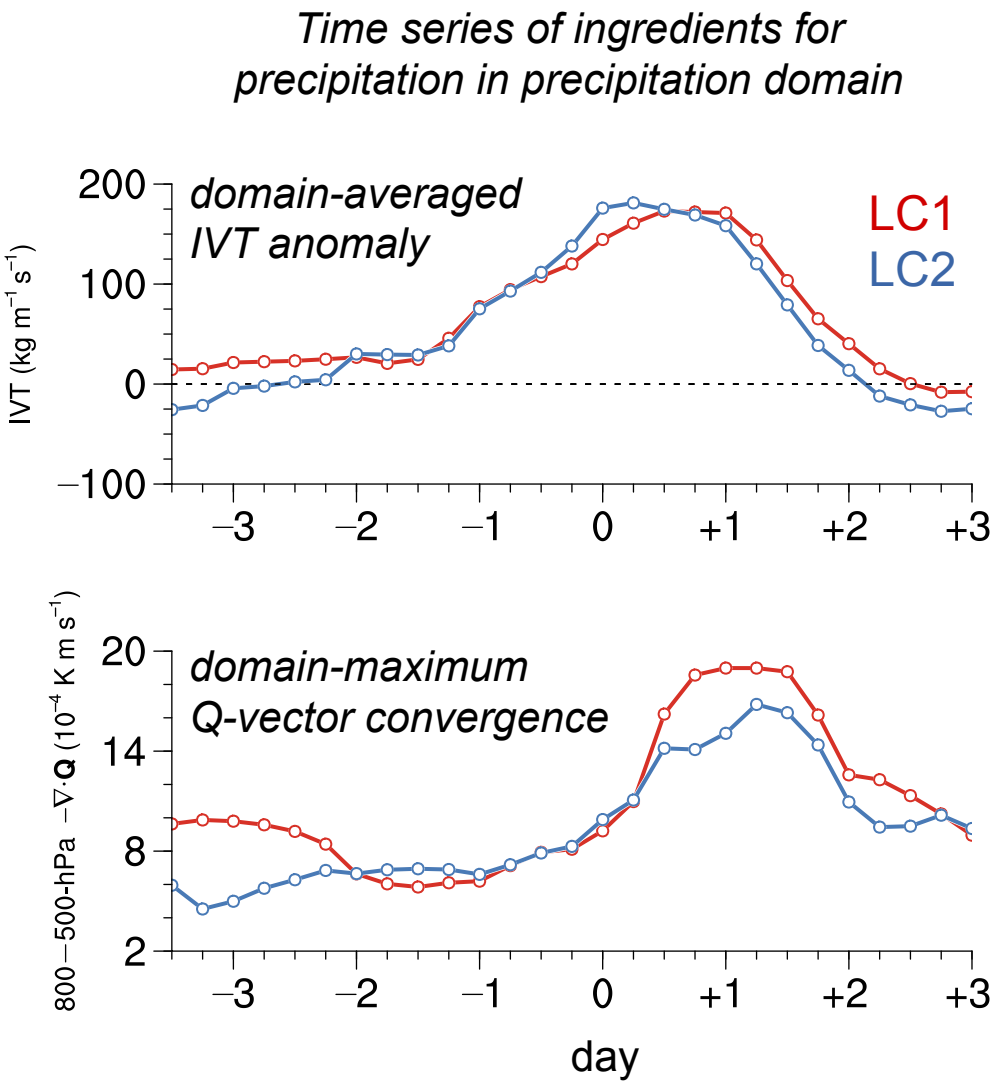
Composite analysis of EPEs linked to RWB



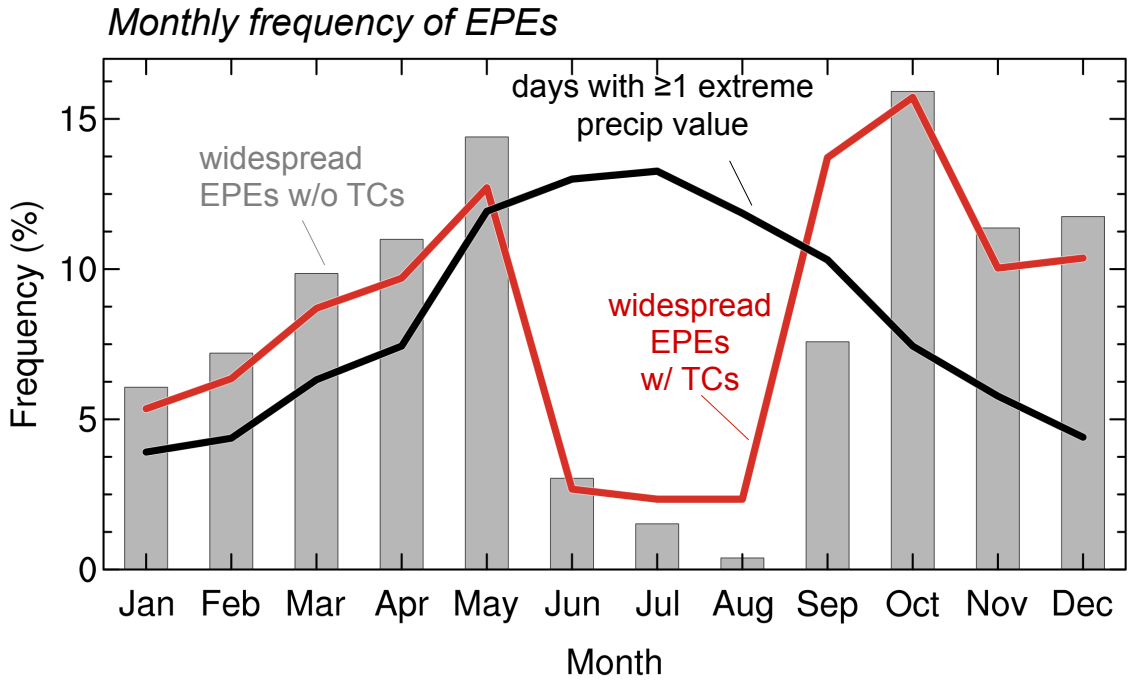
Summary

- Climatological and dynamical linkages between RWB and EPEs over portions of the central/eastern U.S. during 1979–2015 examined
- Large majority (~76%) of EPEs examined found to occur in connection with RWB; LC1 dominant relative to LC2
- PV streamers associated with EPEs occur over discrete regions centered over the western U.S.
- RWB linked to formation of high-amplitude, slow-moving wave pattern that establishes persistent corridor of strong water vapor transport (i.e., AR)
- Water vapor transport supports EPE occurrence in presence of dynamical forcing for ascent

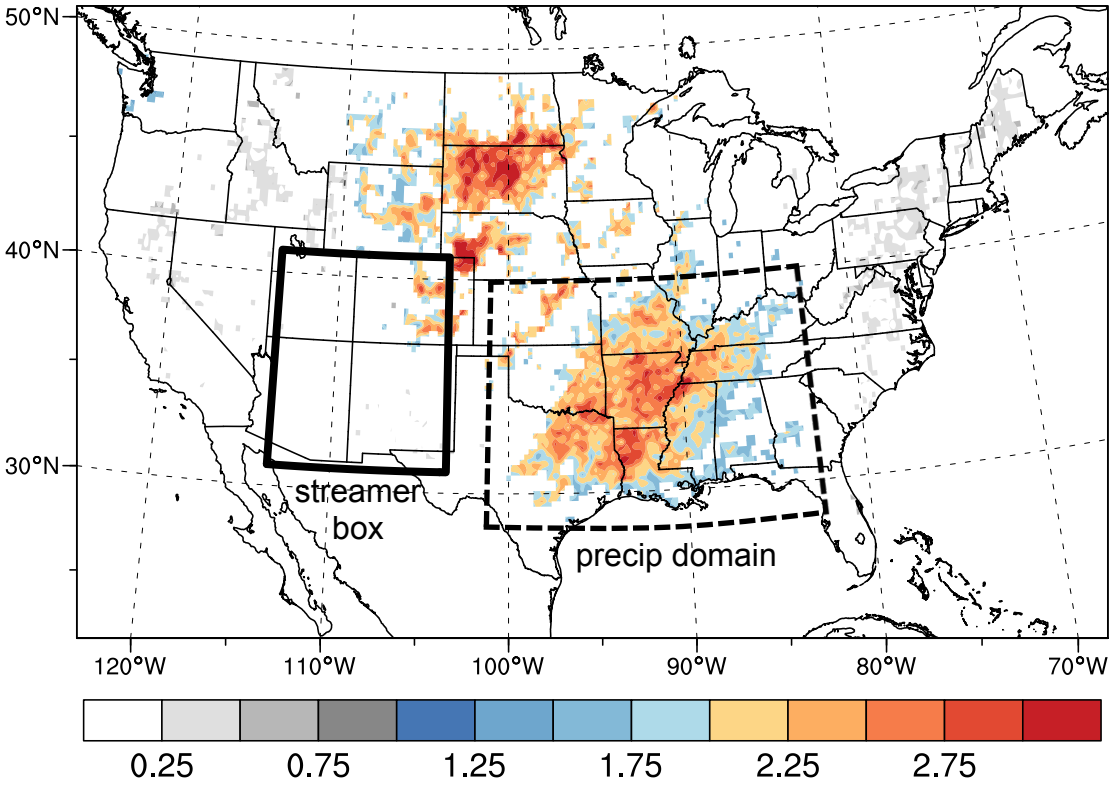
Extra slides

Data and methods

Climatology of widespread EPEs

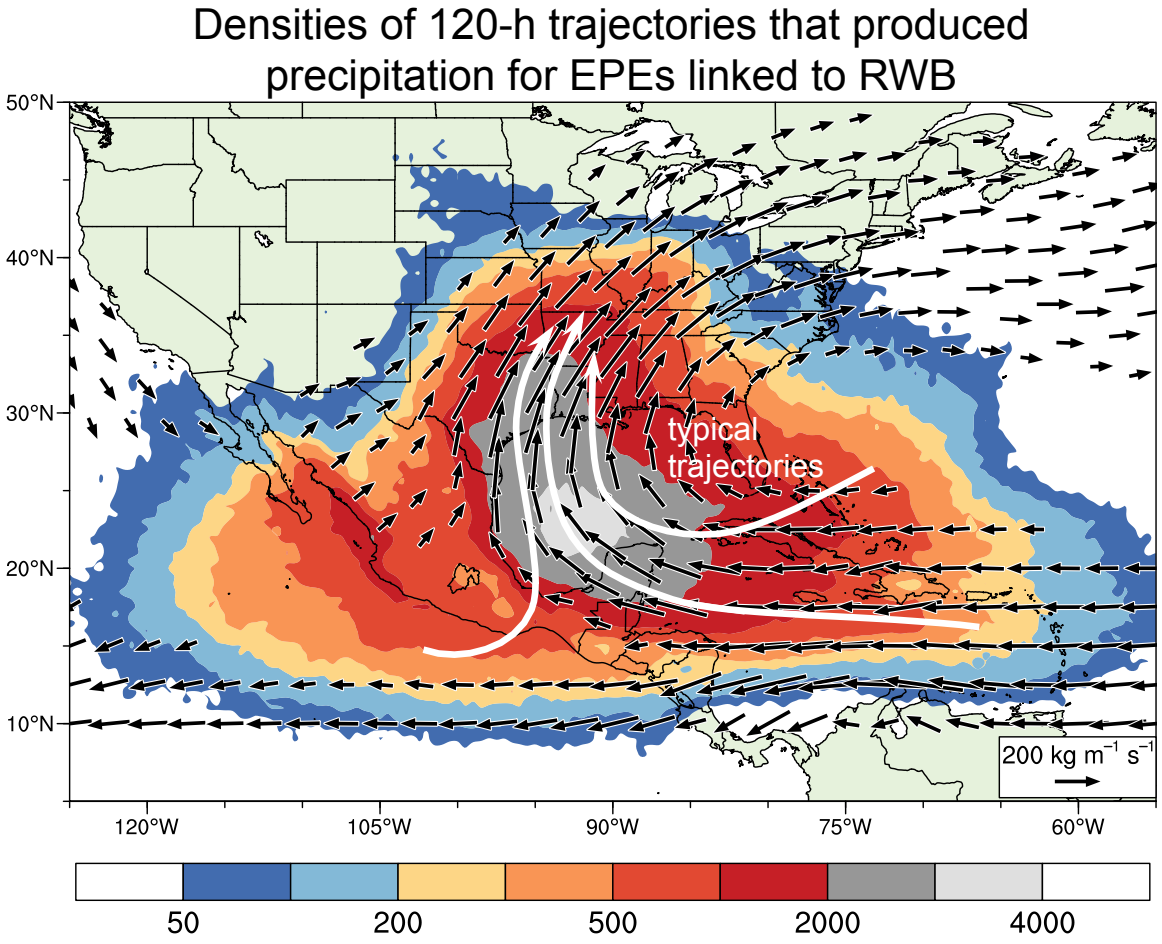


Quantification of the RWB–EPE linkage



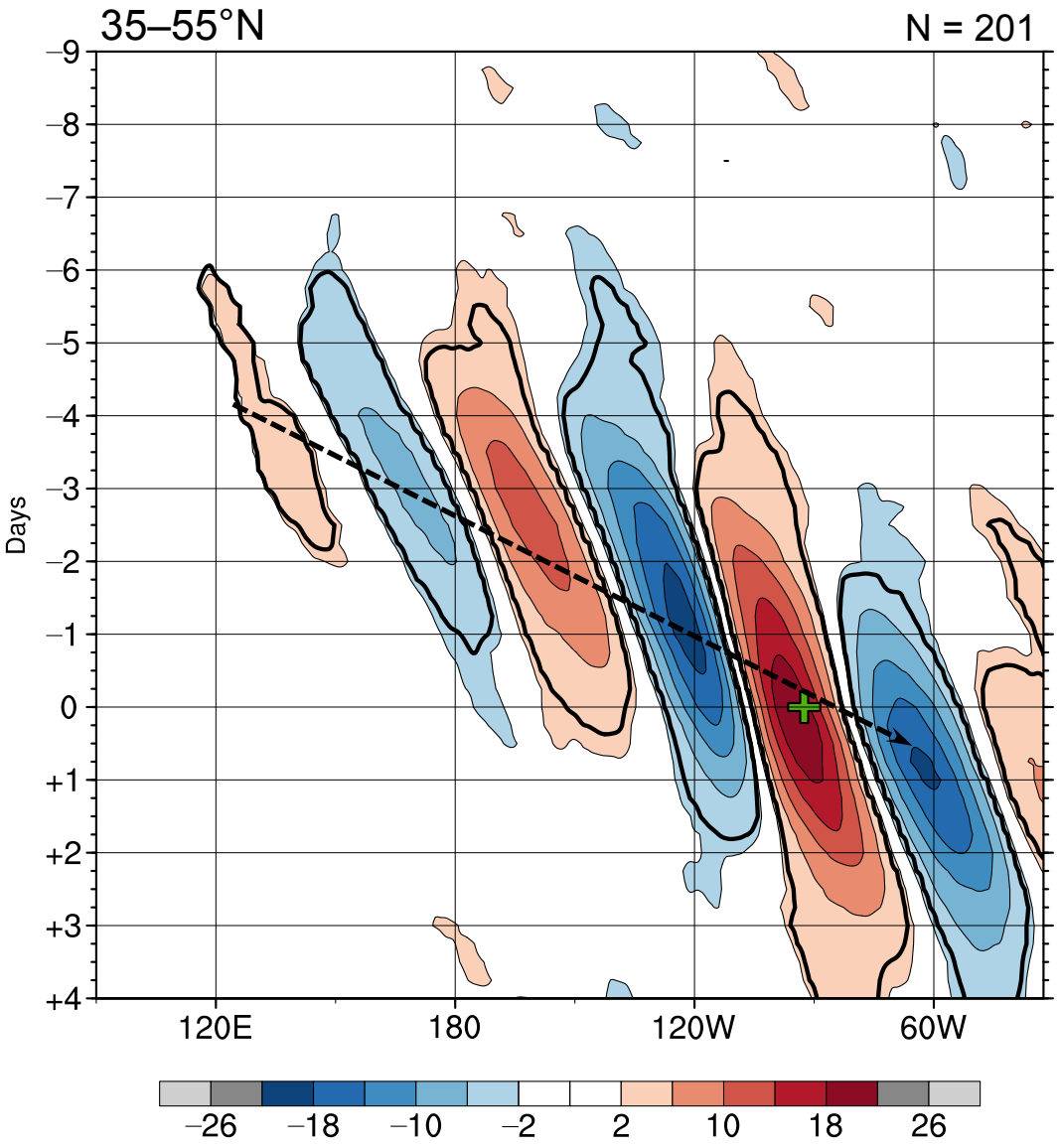
factor of increase in probability of extreme precipitation relative to climatology (shading; only statistically significant values shown) for days during Sep–May on which a streamer overlaps ¼ of the area of the box

Lagrangian perspective



Trajectory density for 120-h backward trajectories released during EPE from 5° × 5° box centered on maximum precipitation location that exhibited >5 g kg^{-1} decrease in specific humidity in final 24 h; time-mean composite IVT vectors for t_0 − 72 h and t_0 + 24 overlaid

Linkage of EPEs to Rossby waves



Hovmöller of 250-hPa merid. wind anomalies (m s^{-1}, shading), statistical significance at 95% confidence level (black contours)