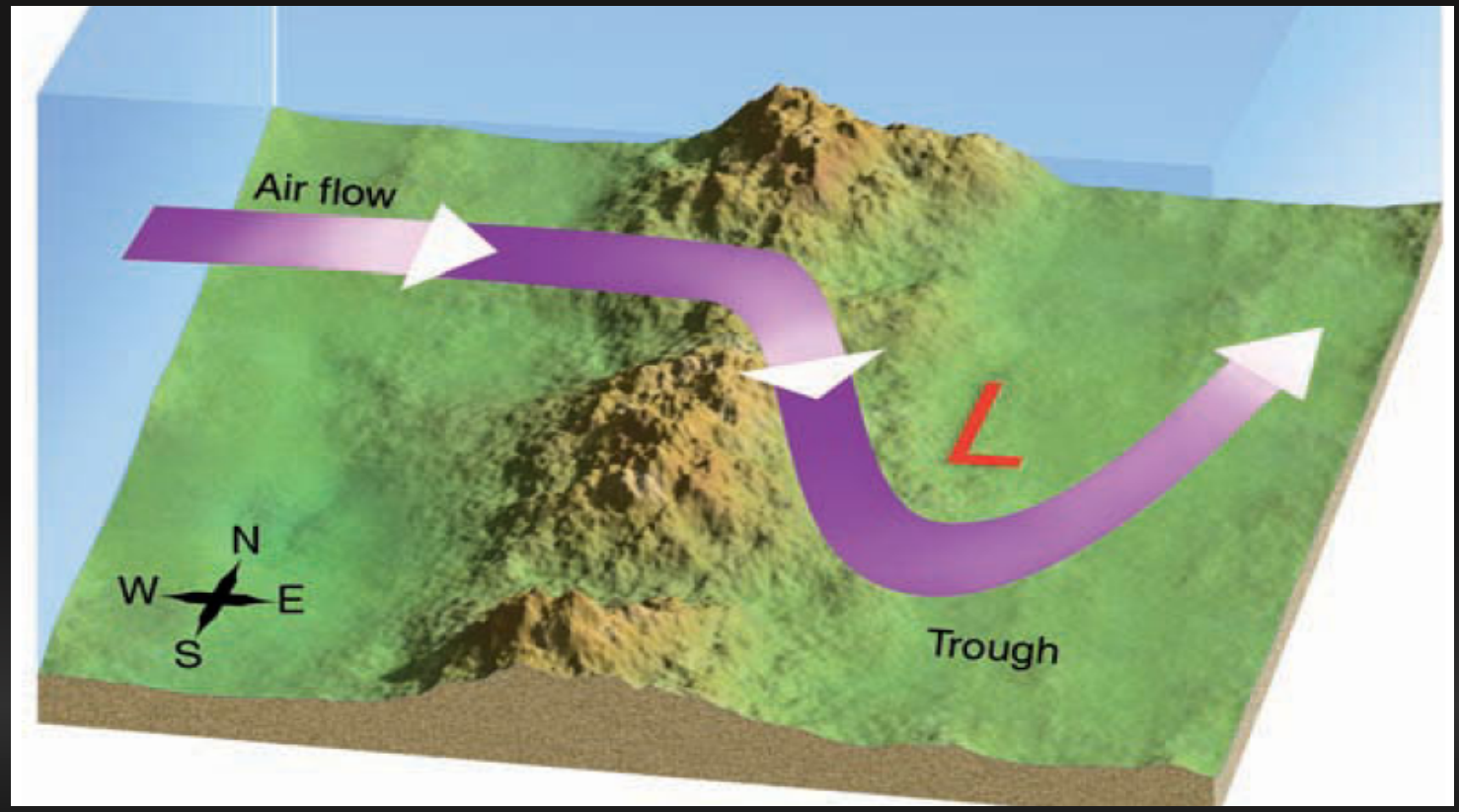
Stratospheric Instrusion Catalog: A 10-year Compilation of Events Identified by using TRACK with NASA's MERRA-2 Reanalysis

K. Emma Knowland
(USRA/GESTAR, GMAO)

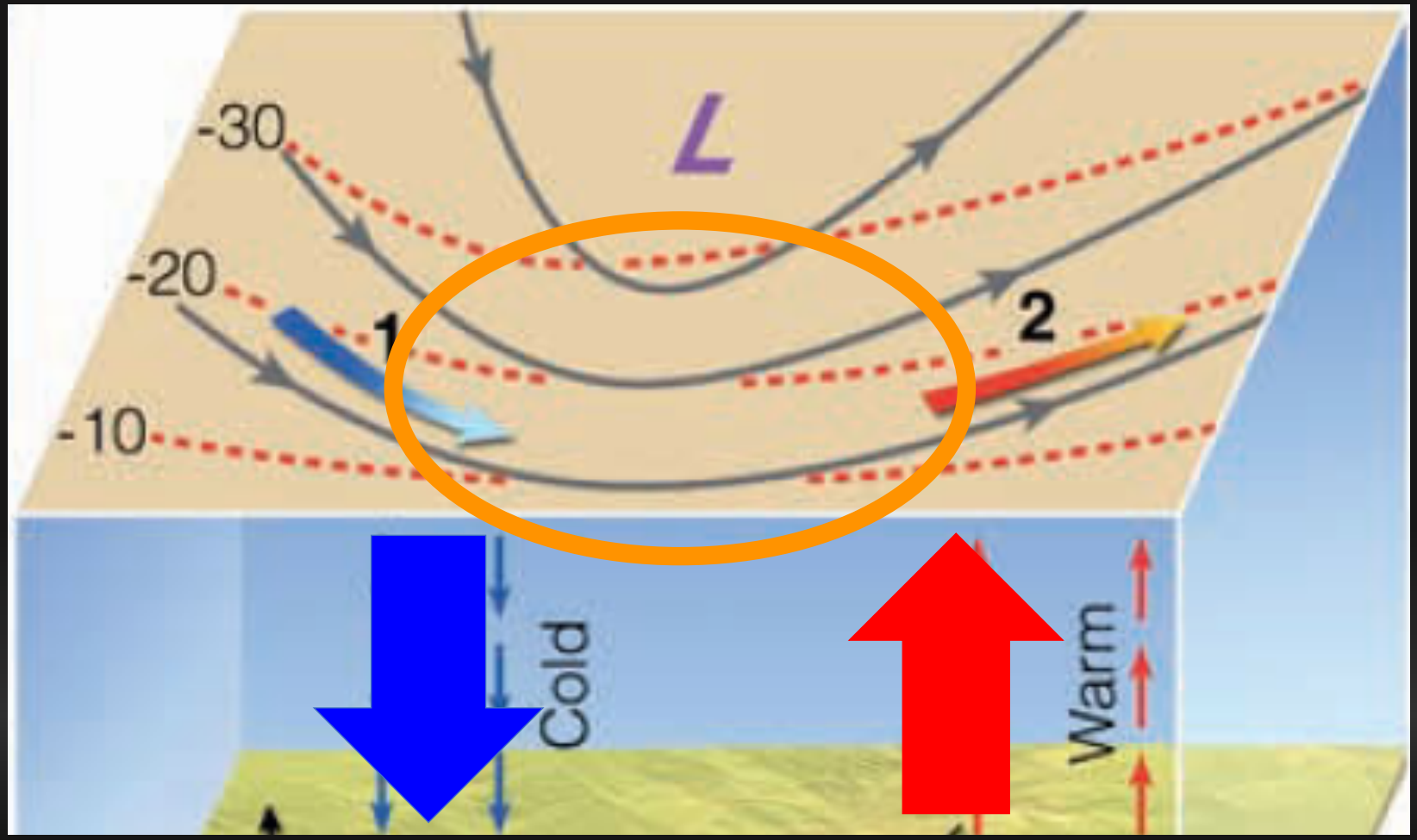
In collaboration with
Lesley E. Ott, NASA GMAO
Bryan N. Duncan, NASA GSFC
Kris Wargan, NASA GMAO, SSAI
Kevin Hodges, University of Reading, UK

Introduction to Upper-level flow



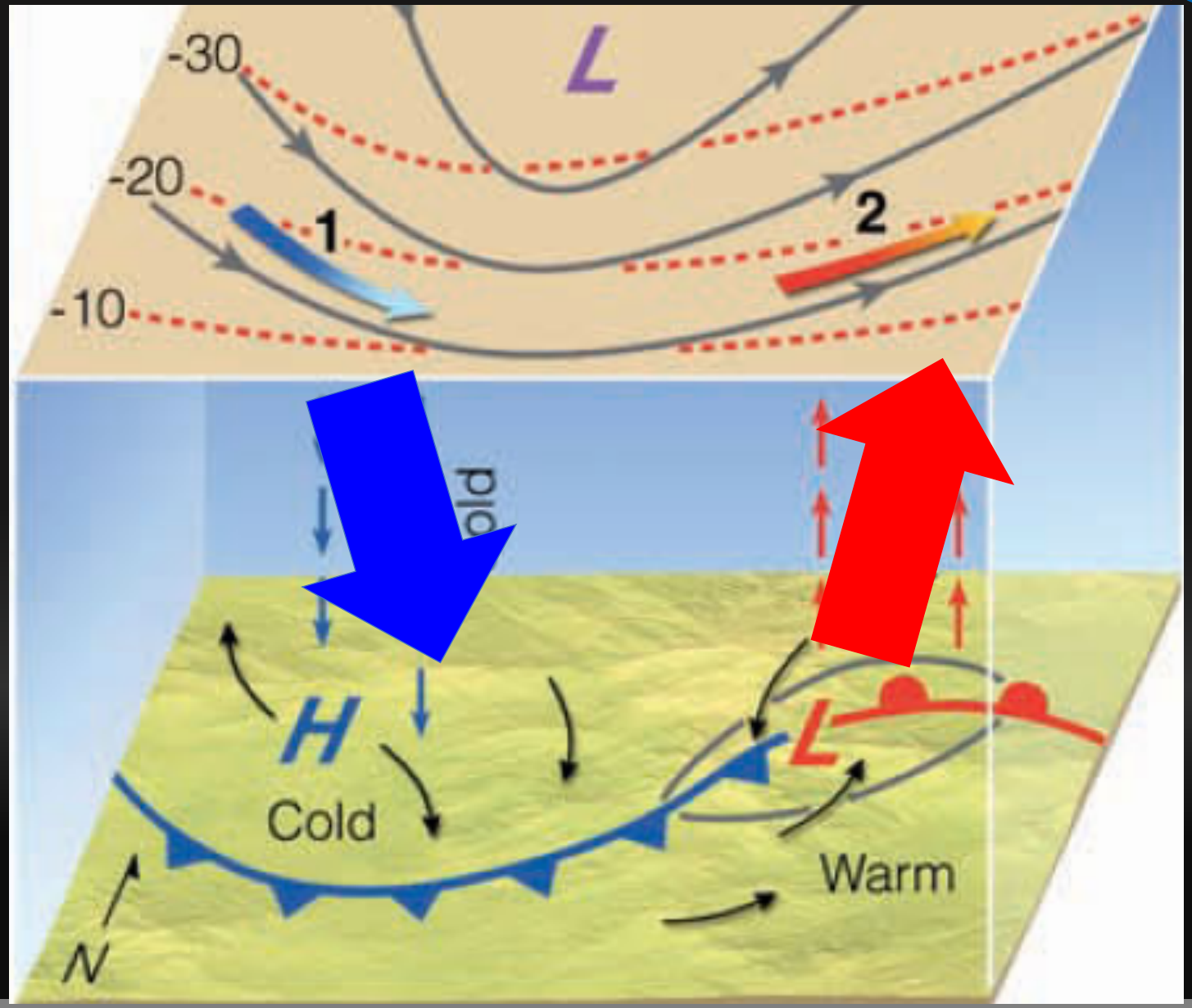
Upper-level wave trains exists, with troughs often forming as the flow is disturbed by mountains

- Converging air accumulates and subsides
- Diverging air draws air upwards from the surface



- As air enters the trough, wind speeds increase resulting in a jet maximum at the trough base.

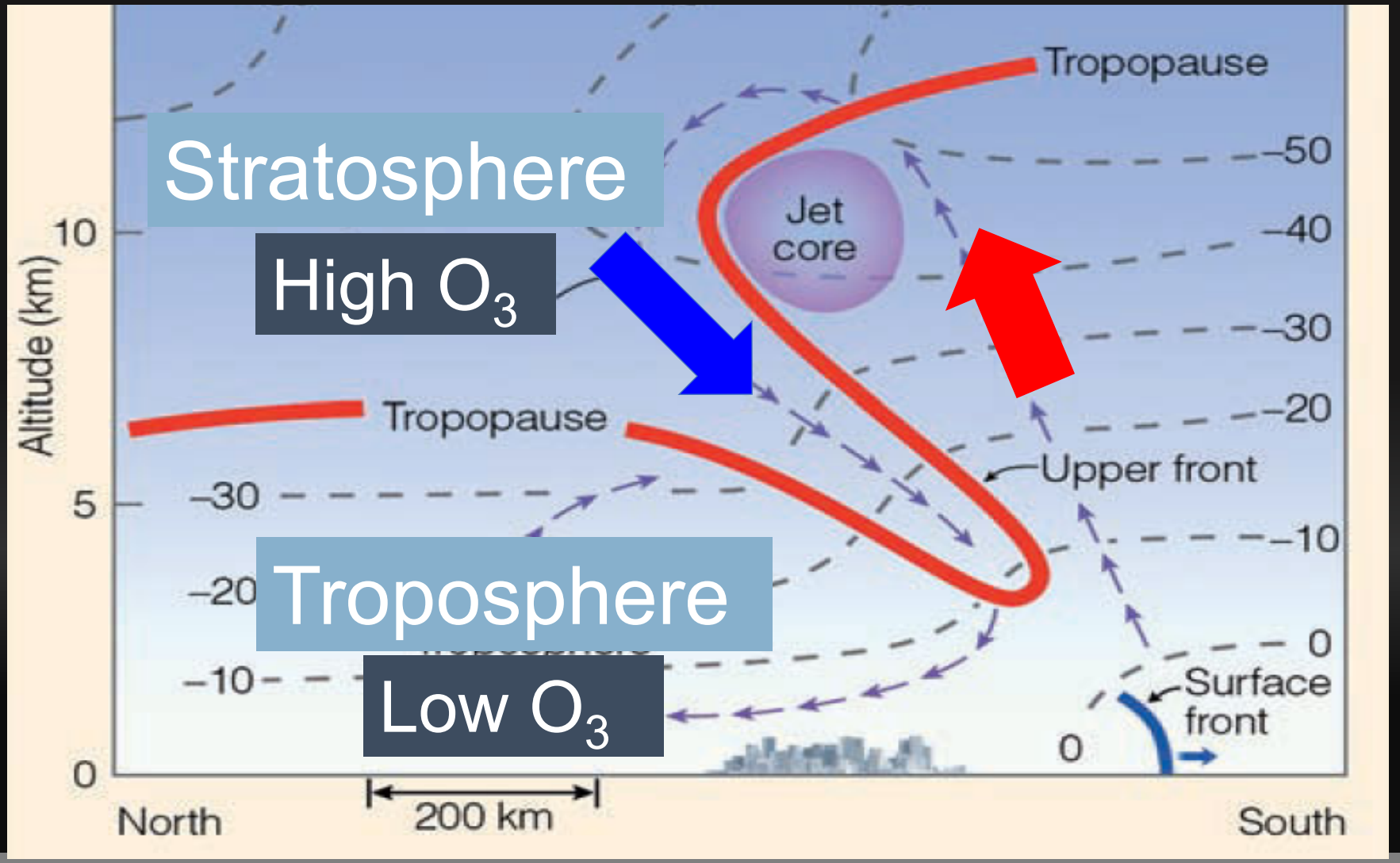
- upper-level trough supports development of a mid-latitude cyclone
- Descent behind cold front



Tropopause Fold (Stratospheric Intrusions: SI)

SIs are associated with:

- High O_3, PV
- Low CO, moisture ("dry intrusion")



O_3 is a regulated air pollutant

- SIs can lead to concentrations of ground-level O_3 exceeding the national ambient air quality standard (NAAQS) set by the EPA, especially at high elevations
- In October 2015, the EPA revised the U.S. NAAQS for daily maximum 8 h average (MDA8) O_3 from 75 parts per billion by volume (ppbv) to 70 ppbv

SIs misrepresented in models….until now!

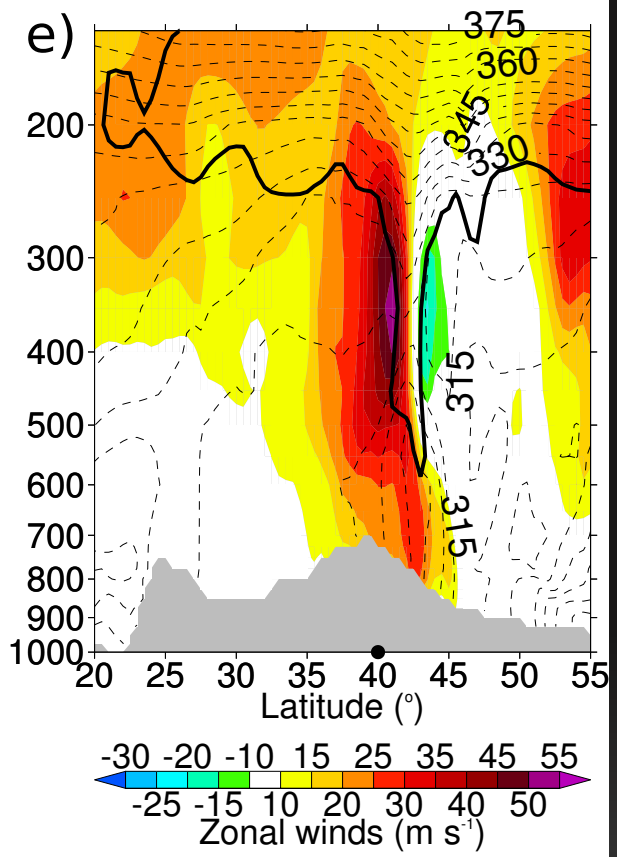
- SIs are fine-scale features, resolution needs to be high enough to capture the filaments
- Simulating and predicting such events remains challenging
- Need horizontal resolution of 50 km or less

NASA's MERRA-2 Reanalysis

- High resolution data set
  - ➢ 0.5º latitude x 0.625º longitude, 72 vertical levels up to 0.01 hPa
- Satellite era
  - ➢ 1 January 1980 to within a couple weeks of real time
- Product of GEOS-5 data assimilation system v 5.12.4
- Assimilates conventional meteorological observations, aerosols and ozone
  - ➢ Since October 2004, high resolution stratospheric O_3 profiles from the MLS and total column ozone from OMI.

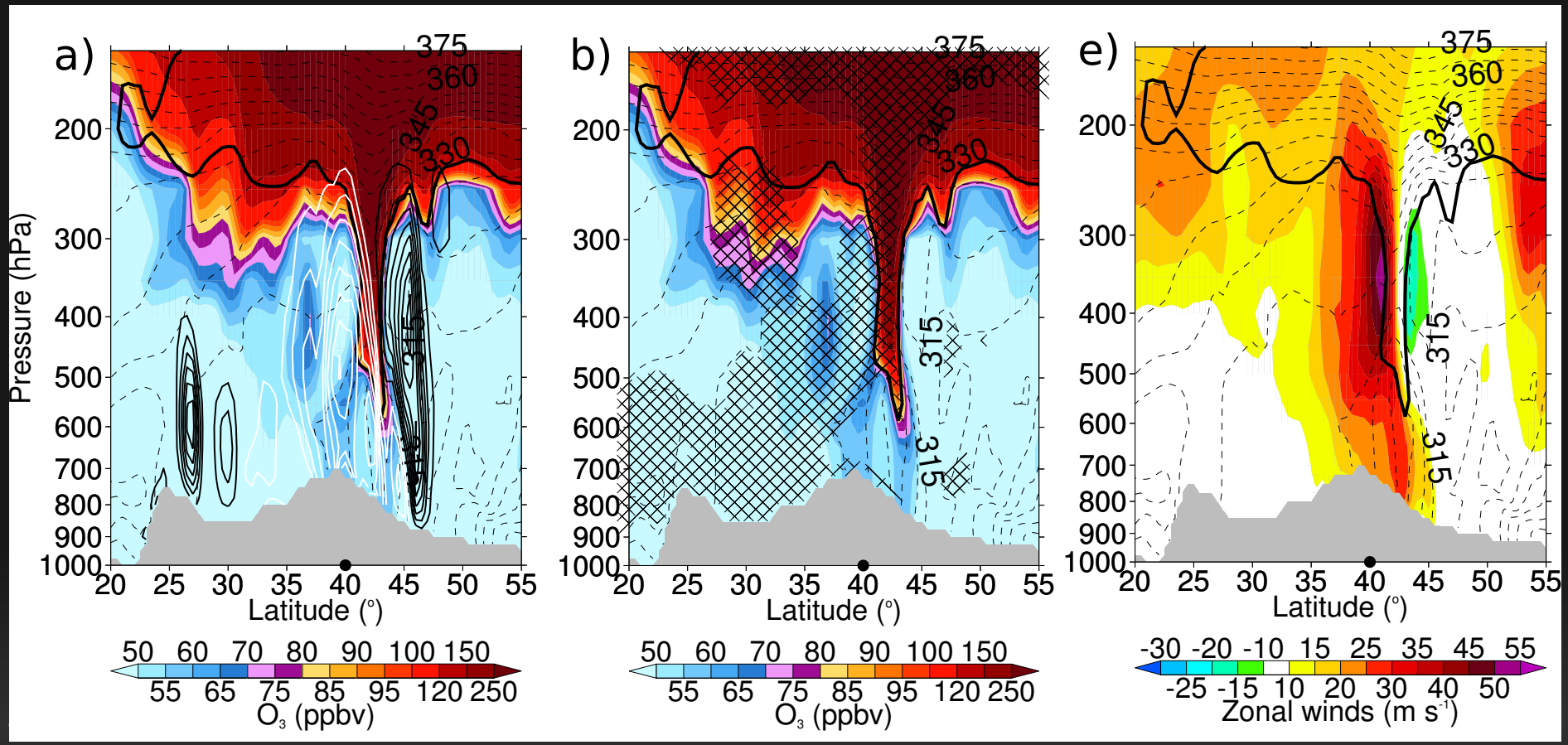
Atmospheric dynamics

- Tropopause descends to ~600 hPa
- Wrapped around jet core



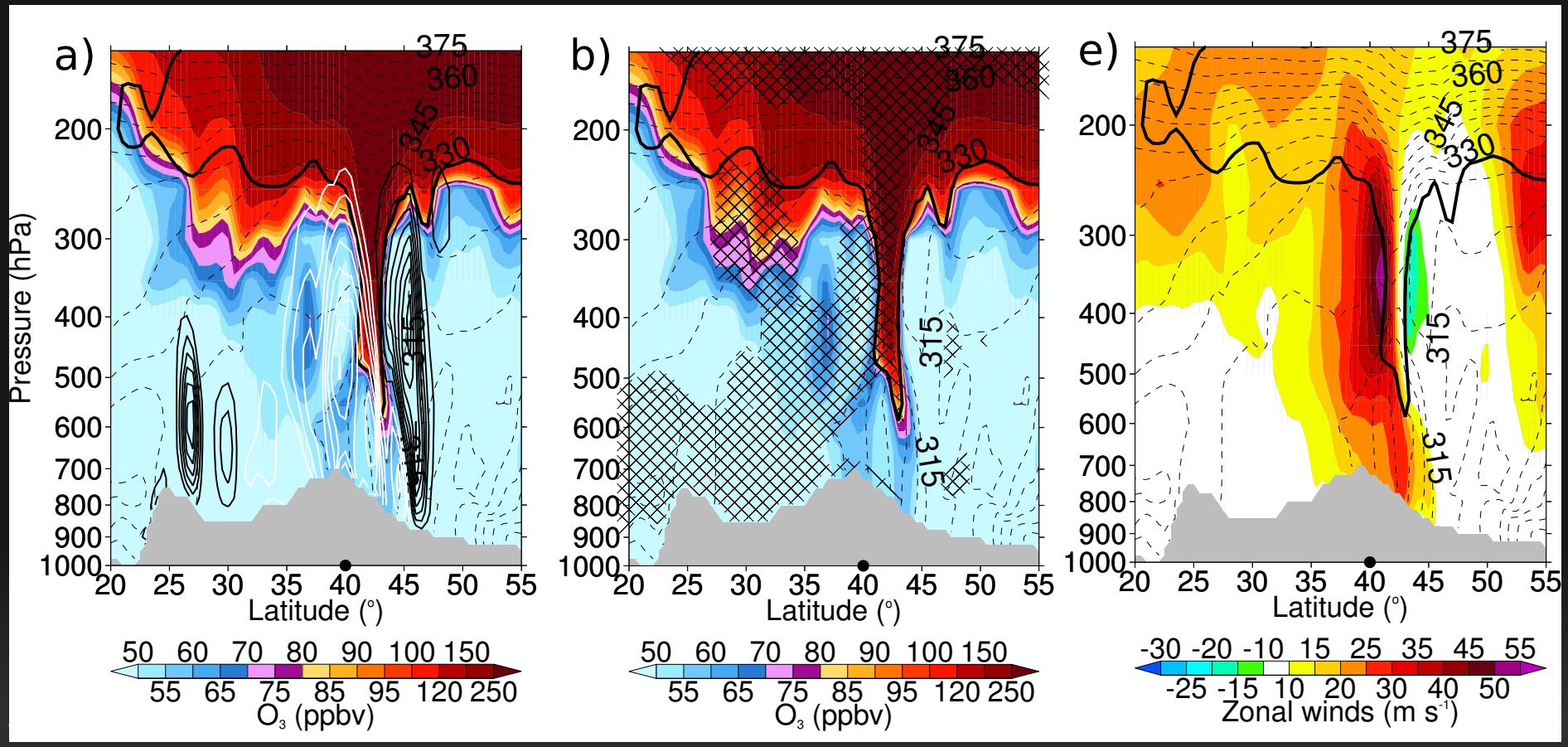
- Tropopause folds are associated with:
  - High O_3, PV
  - Low RH, CO

Knowland et al., 2017, GRL



- Tropopause folds are associated with:
  - High O_3, PV
  - Low RH, CO

Knowland et al., 2017, GRL



- Since assimilated O_3 is mainly stratospheric, MERRA-2 O_3 captures SIs, however biased elsewhere in the troposphere.

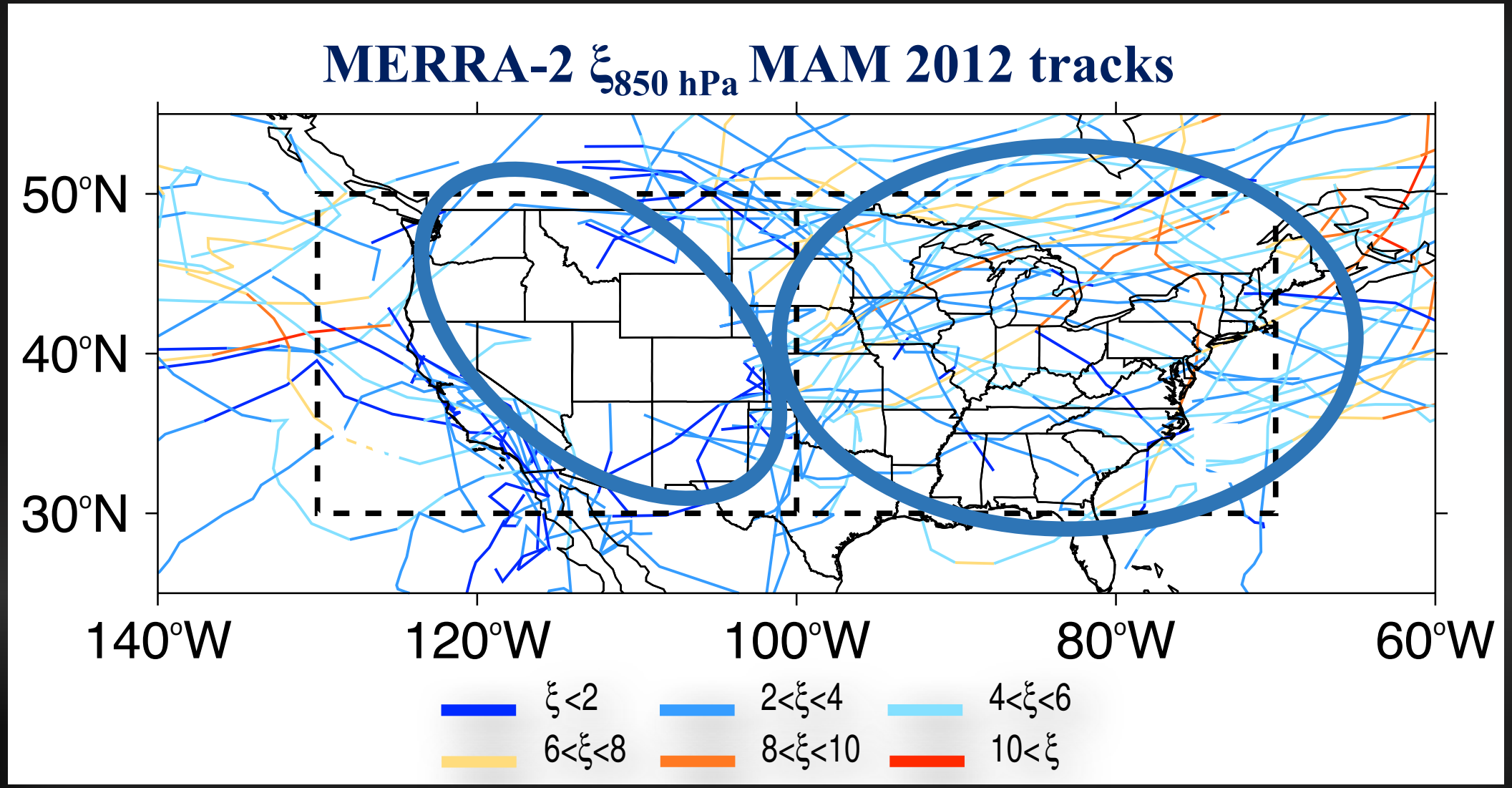
Knowland et al., 2017, GRL

Questions

- Can we objectively capture SI events in MERRA-2 in order to assist the identification of stratospheric intrusion influenced ozone exceedence events?
- Are there regional differences in the western and eastern USA?

1. Construct storm tracks

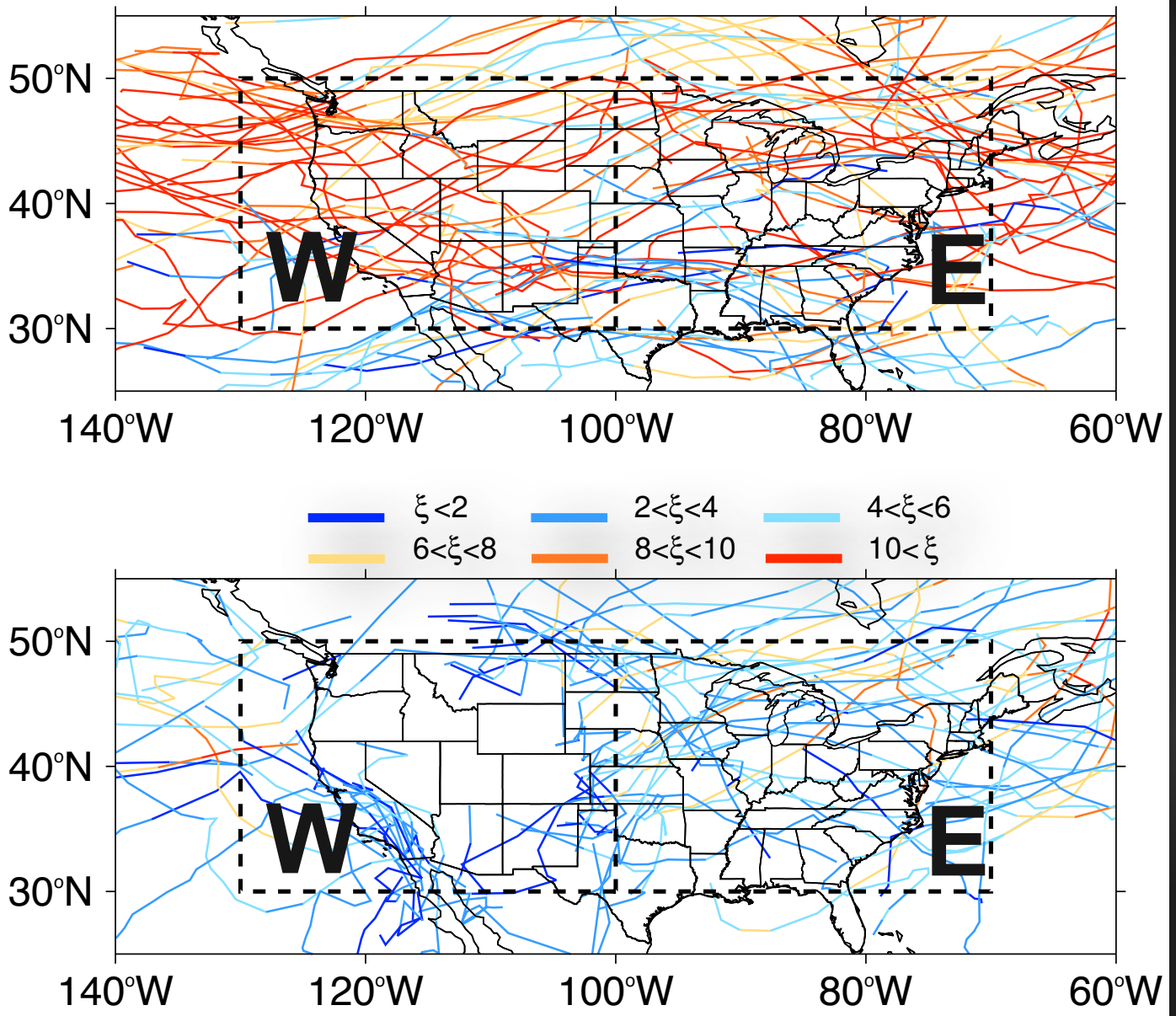
- Using the objective feature tracking algorithm, TRACK (Hodges 1995, 1999) identify cyclones in reanalysis dataset by maxima in 850-hPa relative vorticity ($\zeta_{850\ hPa}$)
  - Smaller scale systems are more easily identified
  - Not strongly influenced by the large scale background field
  - Less extrapolation below orography


MERRA-2 ξ850 hPa MAM 2012 tracks
50°N
40°N
30°N
140°W
120°W
100°W
80°W
60°W
ξ<2
2<ξ<4
4<ξ<6
6<ξ<8
8<ξ<10
10<ξ

MAM 2012

Upper-level (300 hPa) $\zeta_{300\ hPa}$ tracks

$\zeta_{850\ hPa}$ storm tracks

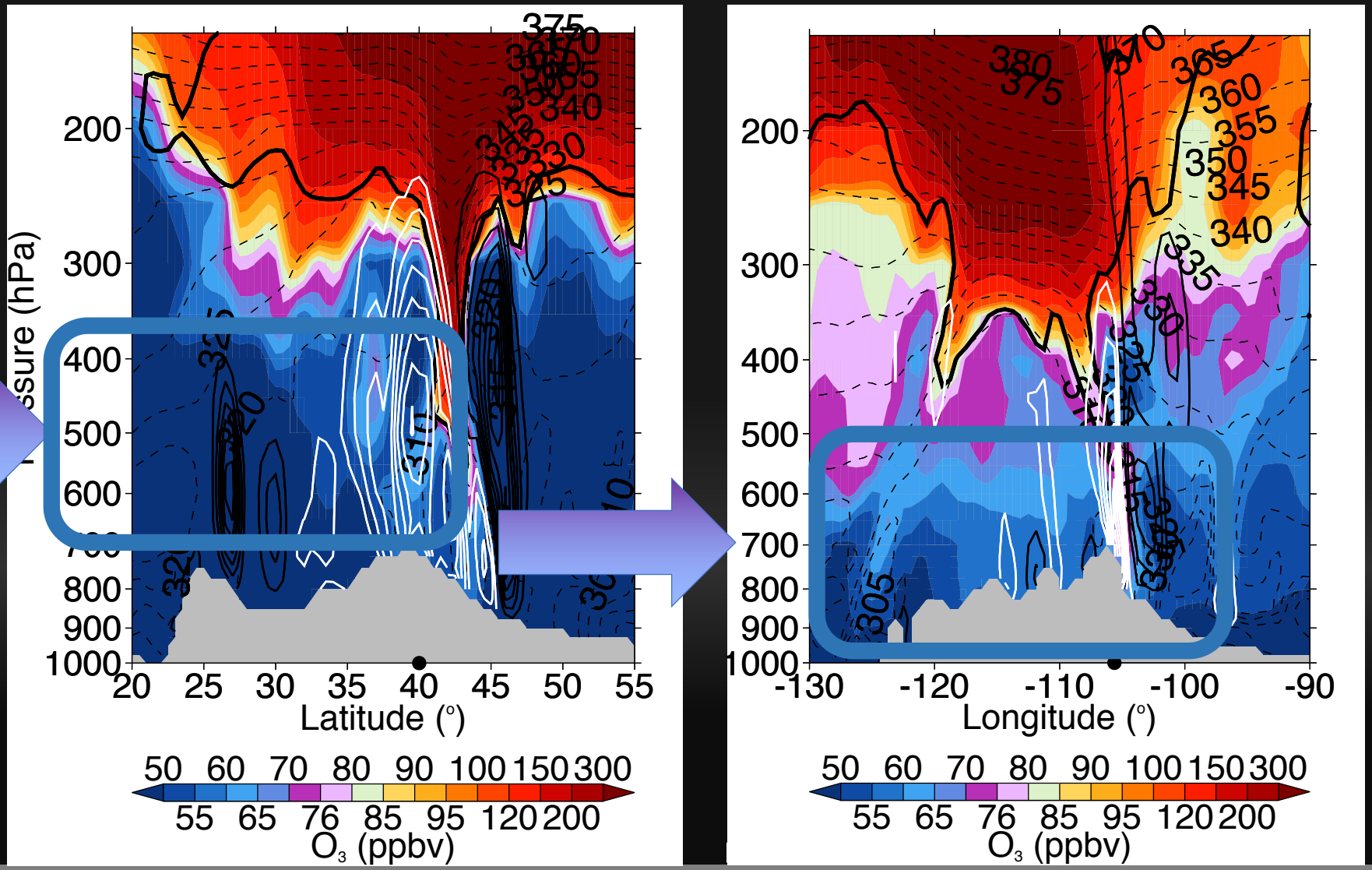


2. SI Filtering

In order to select tracks which are likely associated with SIs, the tracks for 2005-2014 were filtered by:

1. 300 hPa winds for COLs during track life time (similar to Pineiro et al., 2016).
2. Anomalies of EPV > 2PVU, RH < 10 %, H < 0 dam and three thresholds for O_3 > 25 ppbv, > 50 ppbv, > 100 ppbv (7°search radius)
3. Maximum $\omega_{500\ hPa}$ and $\omega_{700\ hPa}$

(a) March 27, 2012 0UTC **(b)** May 27, 2012 9UTC



Knowland et al., 2017, GRL

Stratospheric Intrusions in MERRA-2 (2005-2014)

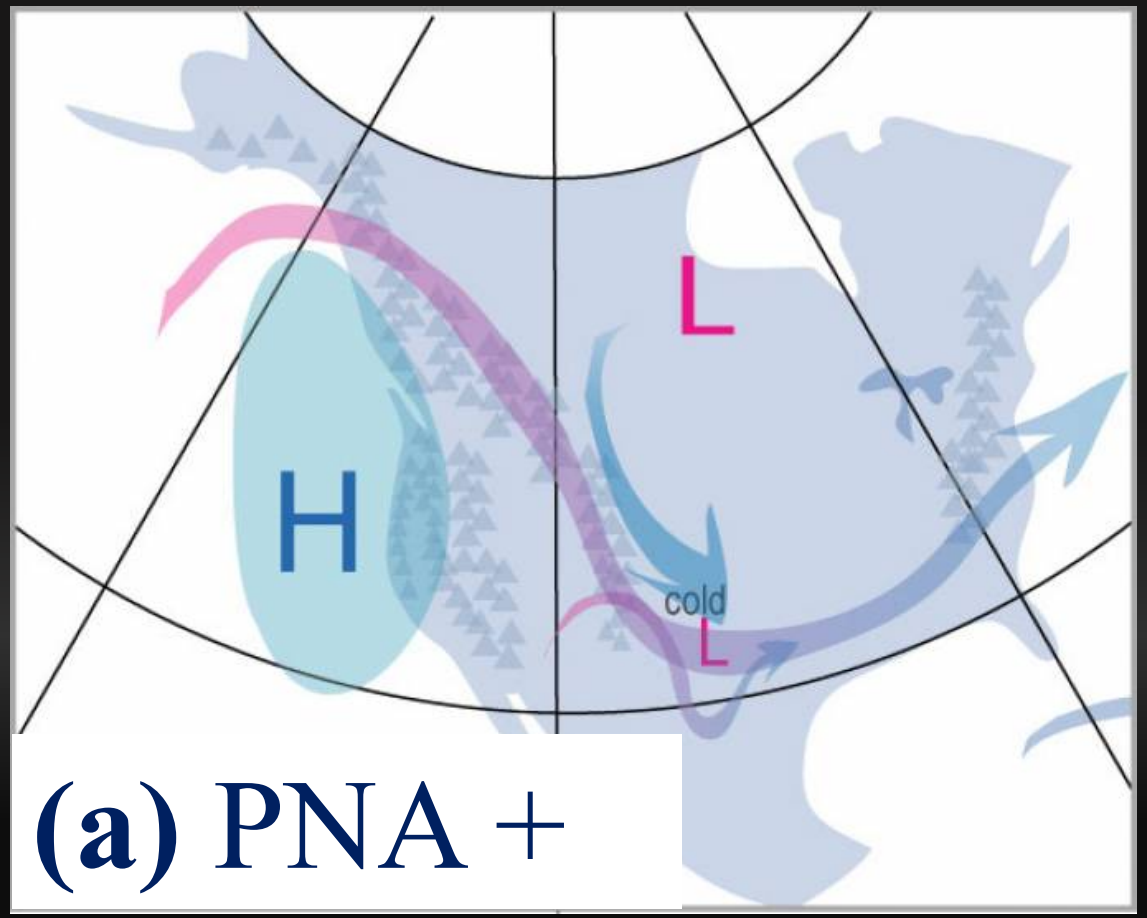
	DJF		MAM		JJA		SON	
	$\omega_{500\ hPa}$	$\omega_{700\ hPa}$	$\omega_{500\ hPa}$	$\omega_{700\ hPa}$	$\omega_{500\ hPa}$	$\omega_{700\ hPa}$	$\omega_{500\ hPa}$	$\omega_{700\ hPa}$
WUSA	135	100	**185**	**173**	141	102	153	81
EUSA	55	30	94	57	59	34	75	22

Compared to other seasons,

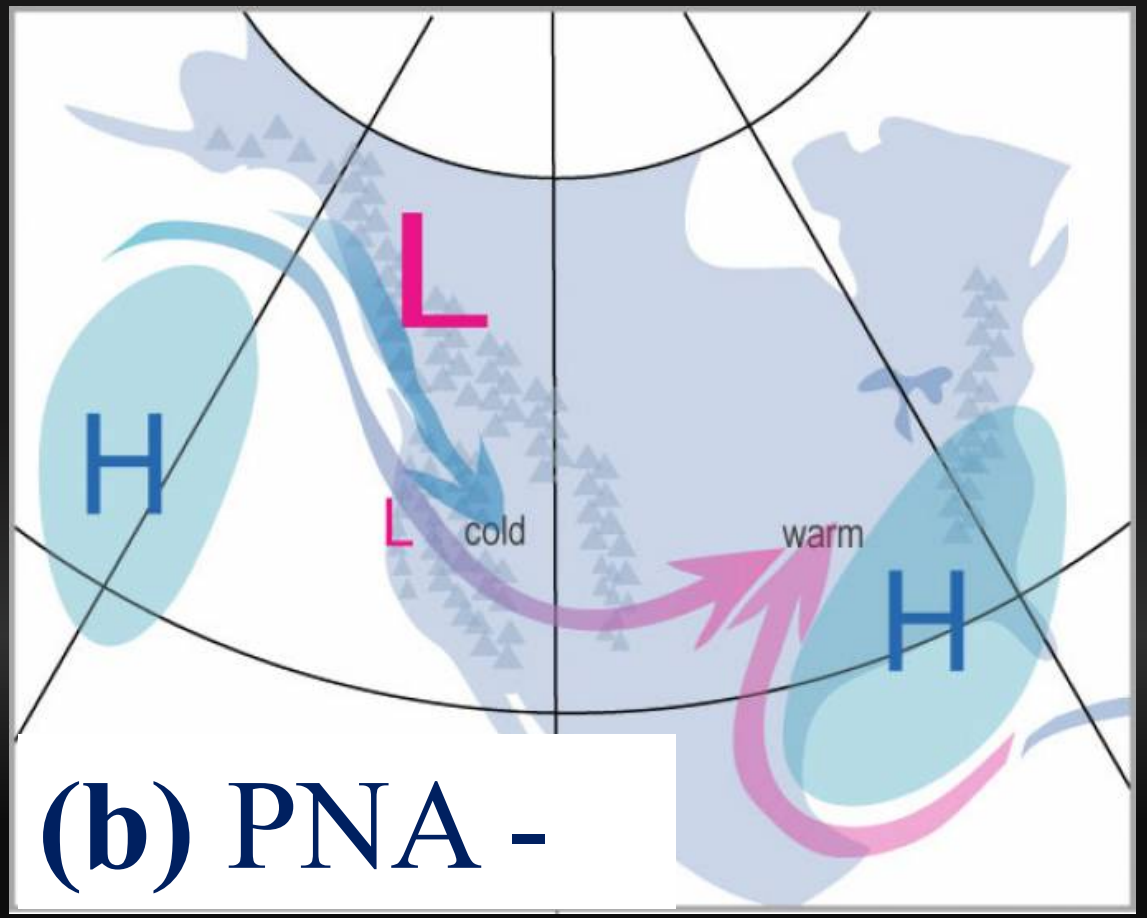
- **More MAM filt-ζ_{300hPa} tracks over the WUSA with the potential to impact lower tropospheric O_3 concentrations**
- The impact of the filt-ζ_{300hPa} tracks in the EUSA and in the other seasons must be considered

Knowland et al., in prep.

Pacific North American (PNA) pattern



(a) PNA +



(b) PNA -

PNA weighting

Cyclone tracks are weighted by the NOAA Climate Prediction Center's monthly EOF-based PNA index, using the method described in Bengtsson et al. (2006) and Hodges (2008).

Gives a weight close to 1 for PNA index values ≥ 1σ

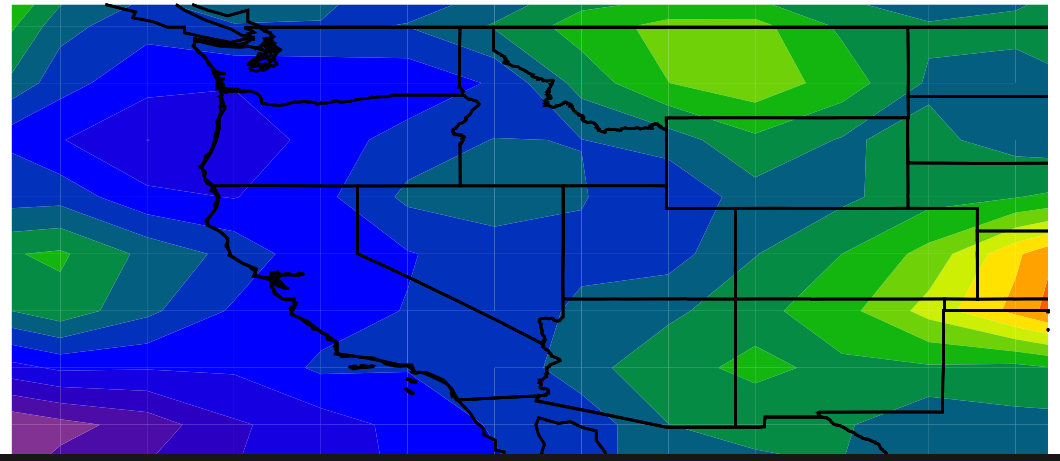
No hard cut-off in data near the threshold value

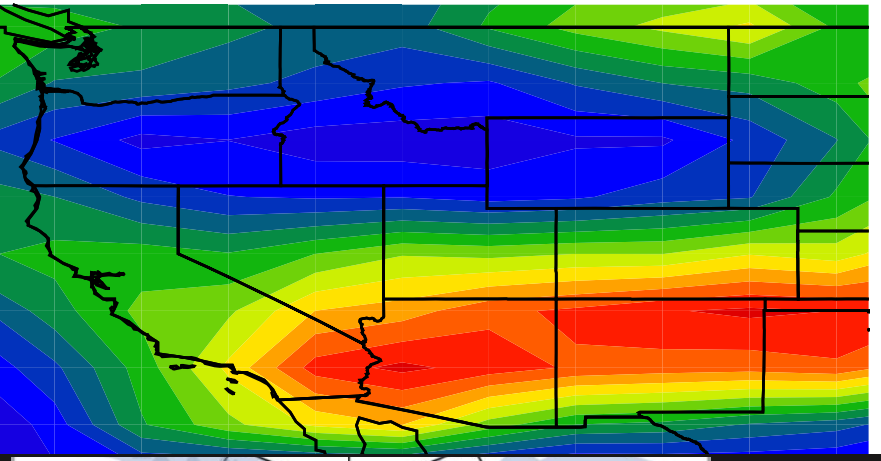
More data is included during the 10-year data period (2005-2014)

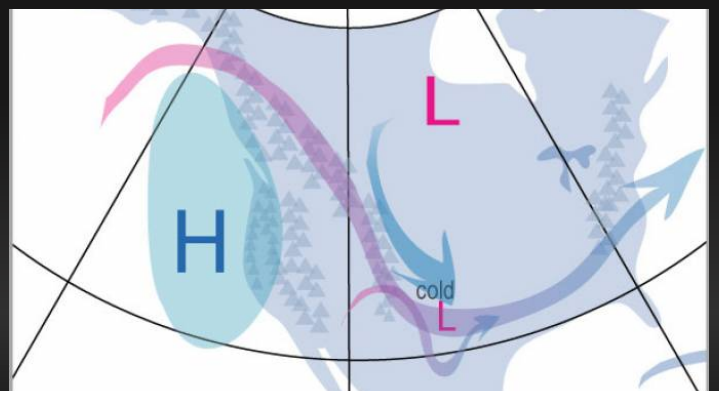
PNA+

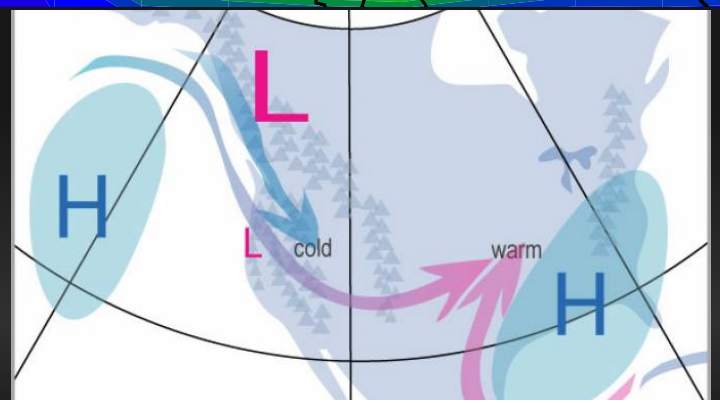
PNA-

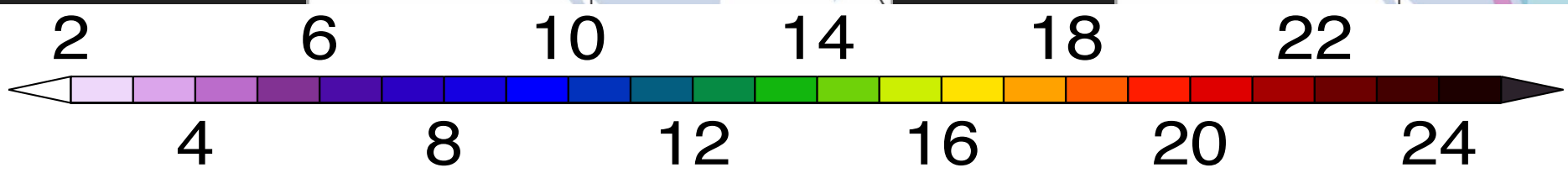
DJF



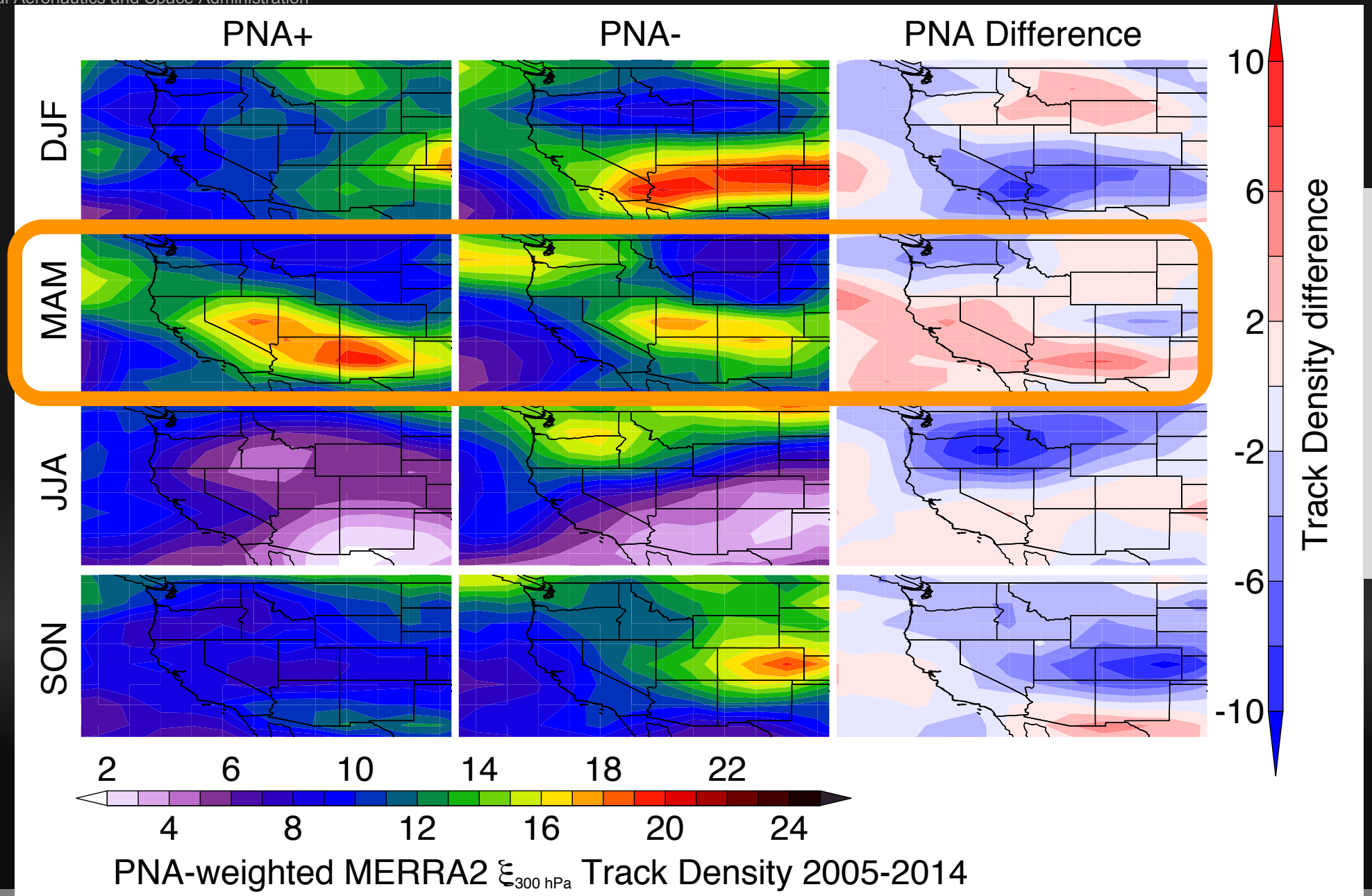






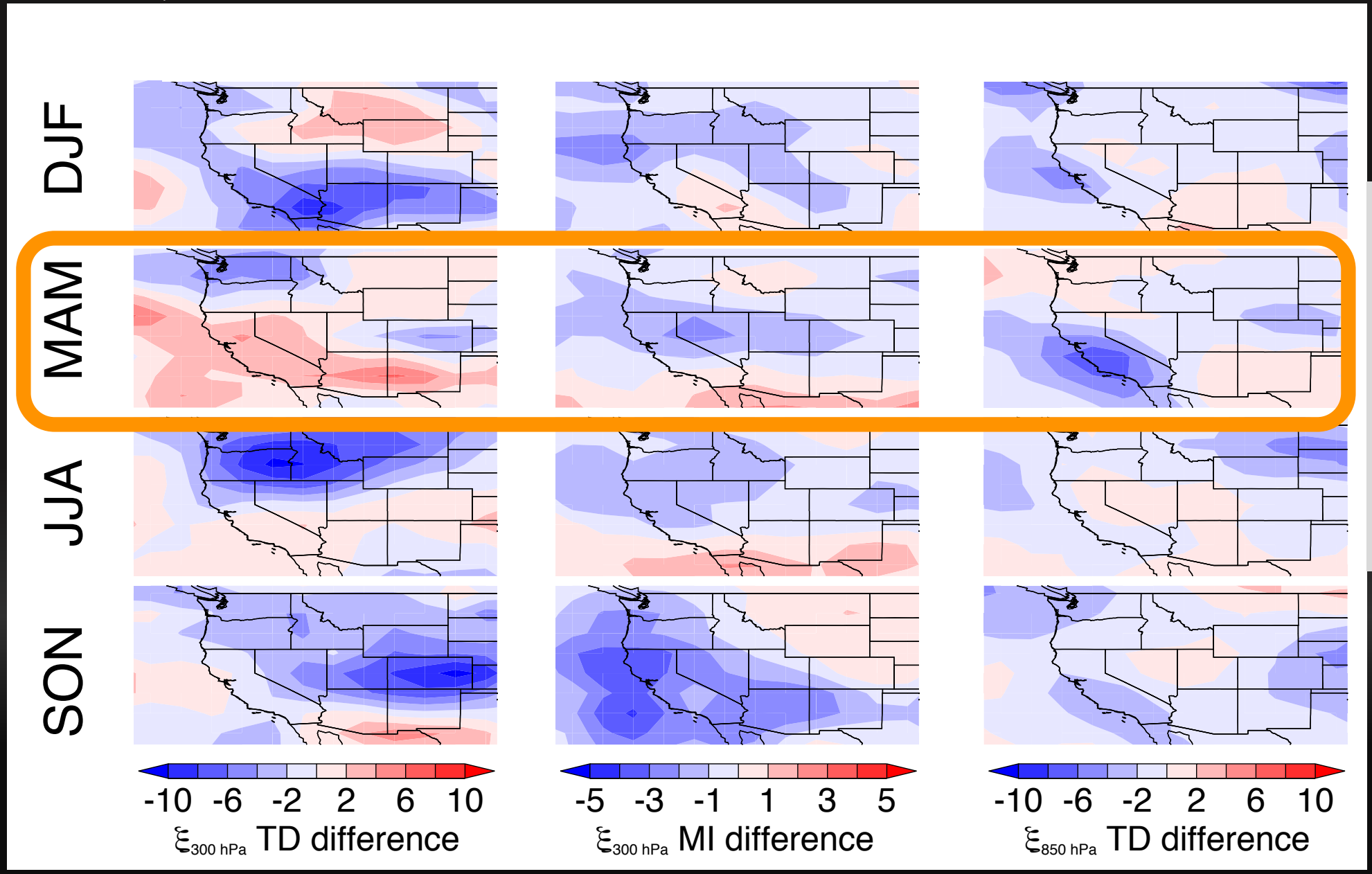


PNA-weighted MERRA2 $\xi_{300\ hPa}$ Track Density 2005-2014



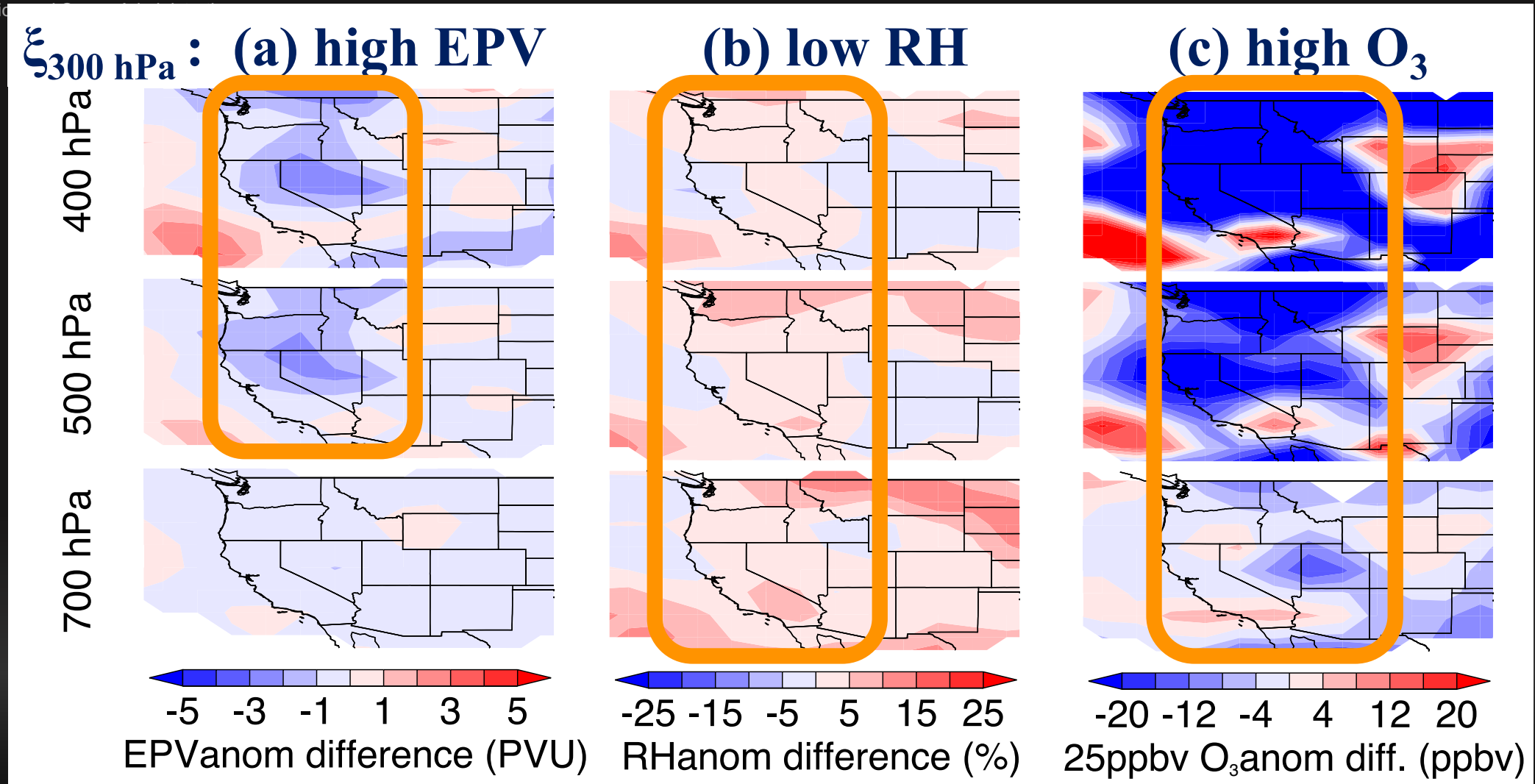
Red -> PNA +

Blue -> PNA-



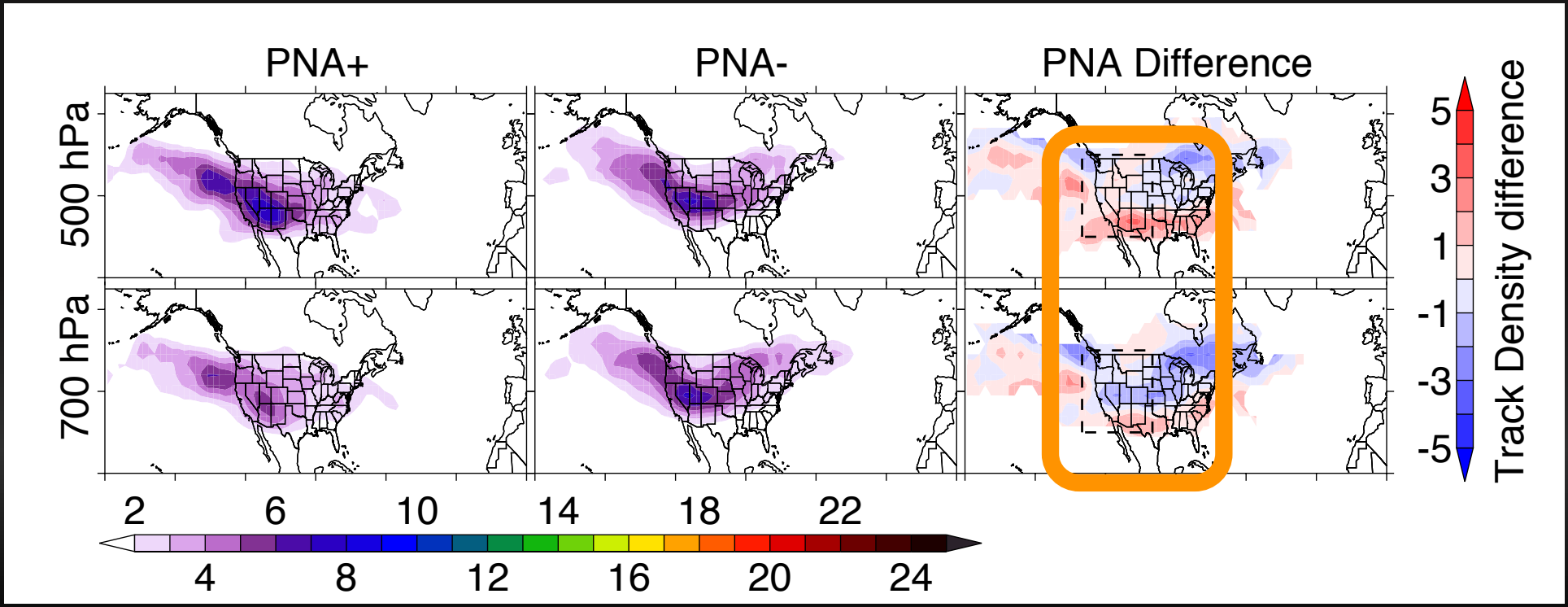
Red -> PNA +

Blue -> PNA-



PNA- is associated with $\xi_{300\ hPa}$ tracks with high EPV, low RH, and high O_3 over Western USA

Track density (# per month) for filt-ζ_{300hPa} tracks with O_3 anomaly > 25 ppbv where the max ω at 500 and 700 hPa in the WUSA for MAM 2005-2014 **weighted by the PNA index**



- **PNA+ → more filt-ζ_{300hPa} tracks at 35°N impacting O_3 at 500 hPa**
- **PNA- → more filt-ζ_{300hPa} tracks at 40°N with anomalously high O_3 at 700 hPa**

Summary

- MERRA-2 reanalysis is a high-resolution global reanalysis which can be used in scientific studies to identify and track SIs by both atmospheric dynamics and O_3
- Location of SIs over the W. USA can be linked with teleconnection patterns, such as the PNA.
- In particular, it may be the intensity or location of the upper-level trough, and not the frequency, that is the main driver in deep SI events.

Knowland, et al (2017). Stratospheric intrusion-influenced ozone air quality exceedances investigated in the NASA MERRA-2 reanalysis. GRL https://doi.org/10.1002/2017GL074532