NASA's High-Resolution GEOS Forecasting and Reanalysis Products: Impact of Stratospheric Intrusions on Surface Ozone Air Quality

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USRA/GESTAR

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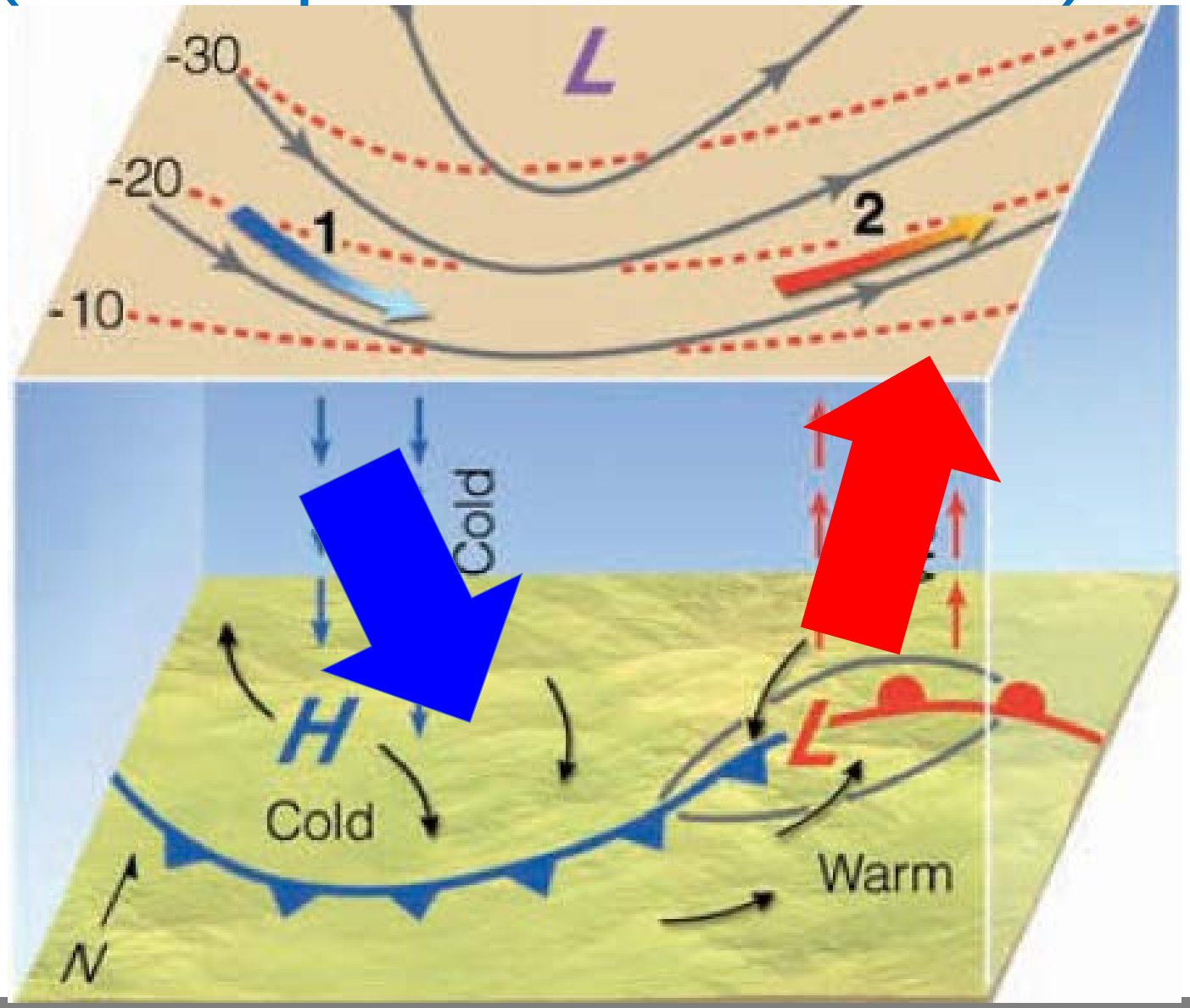
16 January 2020

Tropopause Fold (Stratospheric Intrusions: SI)

- Upper-level trough supports development of a mid-latitude cyclone

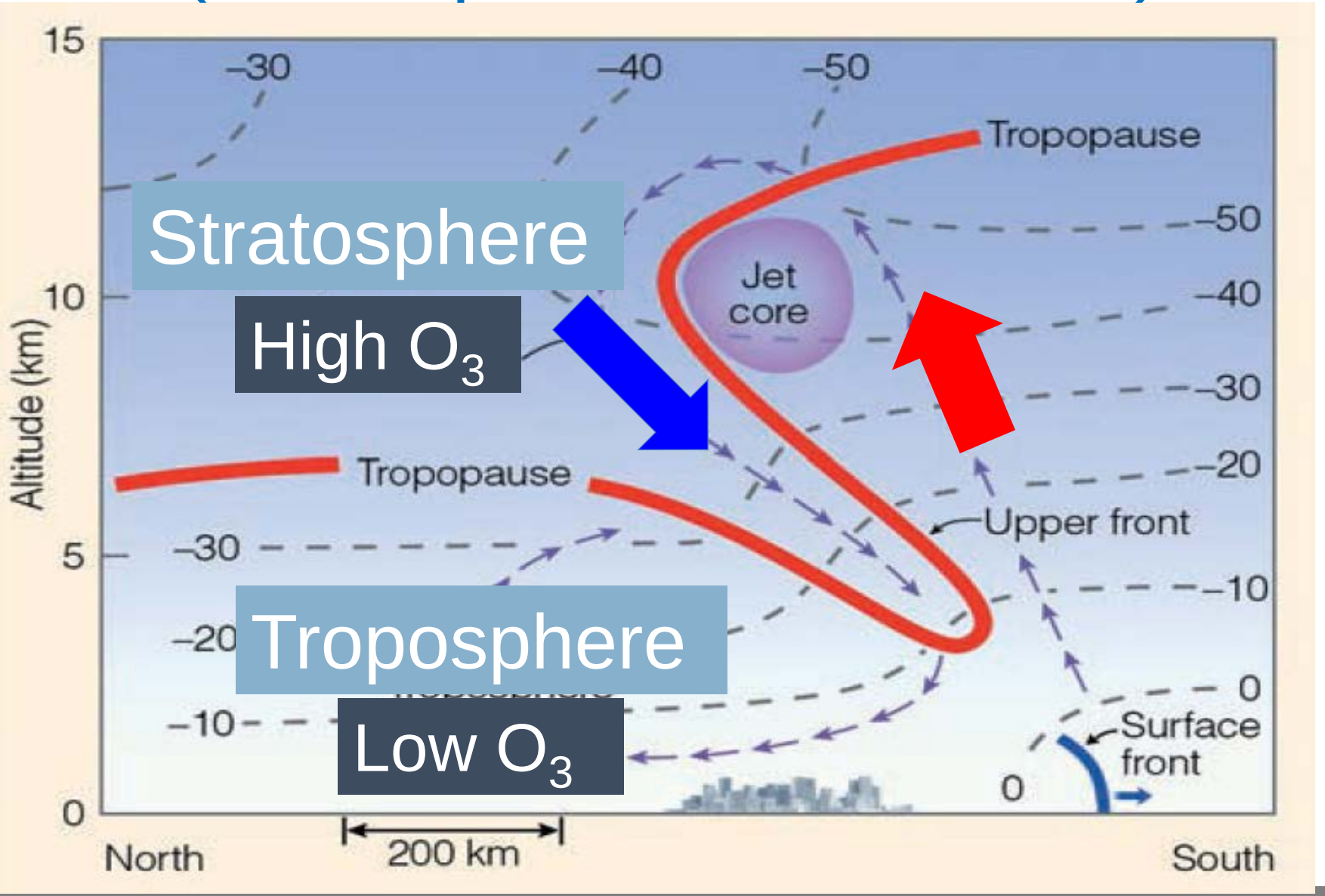
- Descent behind cold front



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

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➢ **Critical to accurately forecast these events!**

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Previously, SIs misrepresented in models

- SIs are fine-scale features, resolution needs to be high enough to capture the filaments

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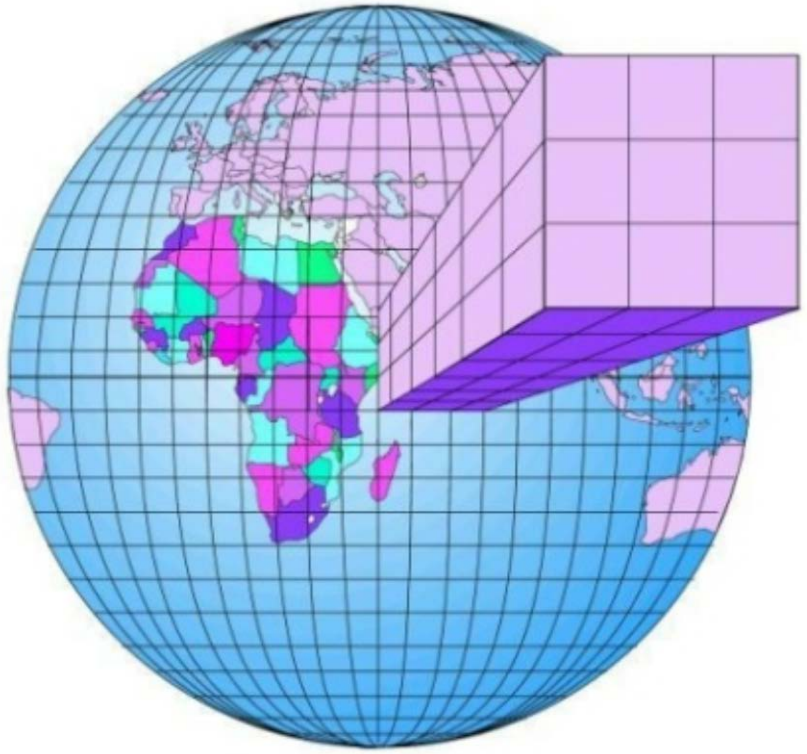
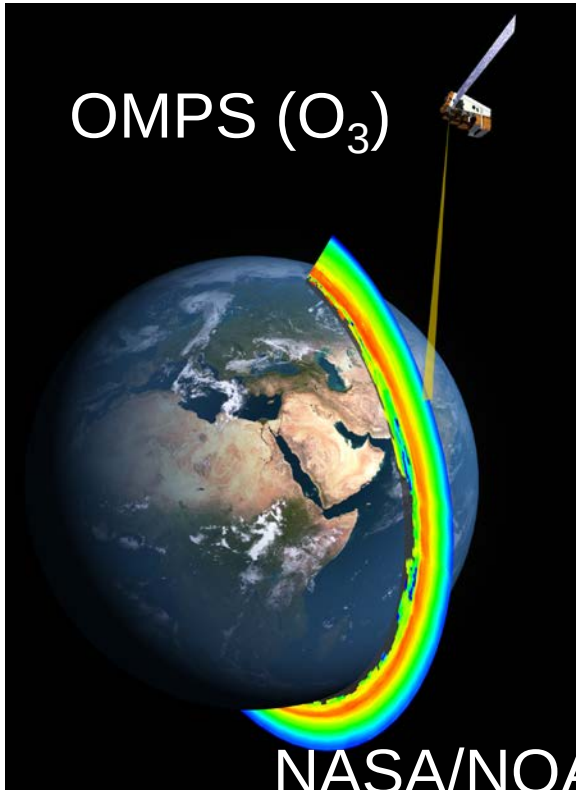
- SIs are fine-scale features, resolution needs to be high enough to capture the filaments
- Simulating and predicting such events remains challenging
- Need horizontal resolution of 50 km or less
  (Büker et al., 2005; Lin et al., 2012; Ott et al., 2016)

NASA GMAO global meteorology and chemistry products

GEOS





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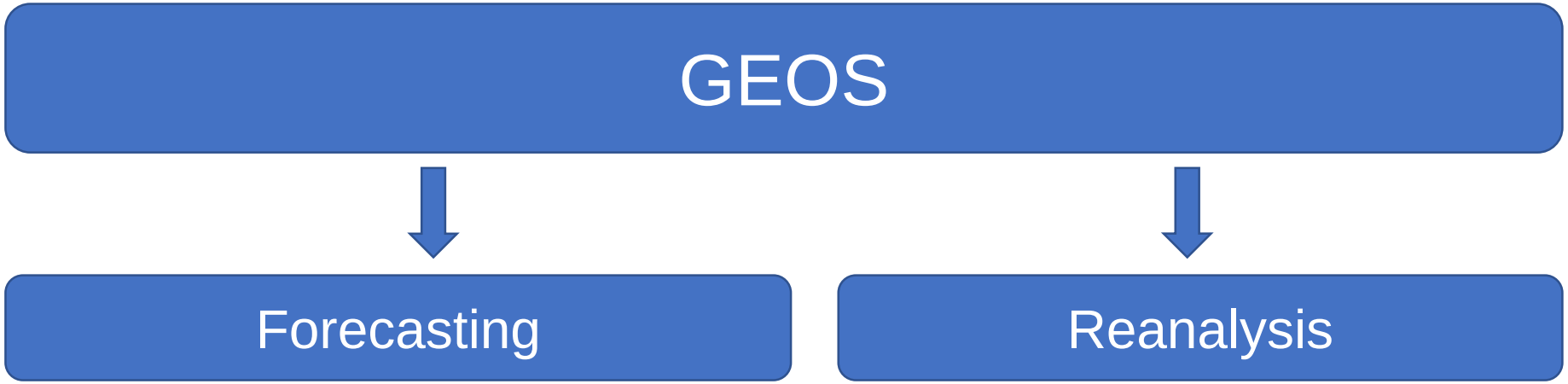
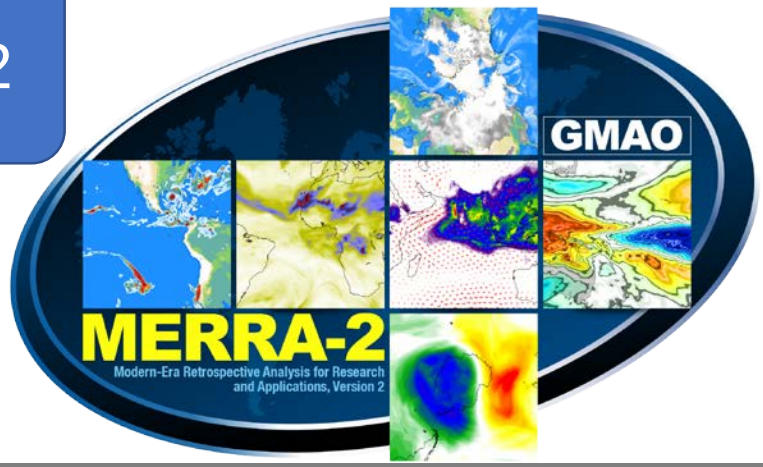
NASA GMAO global meteorology and chemistry products

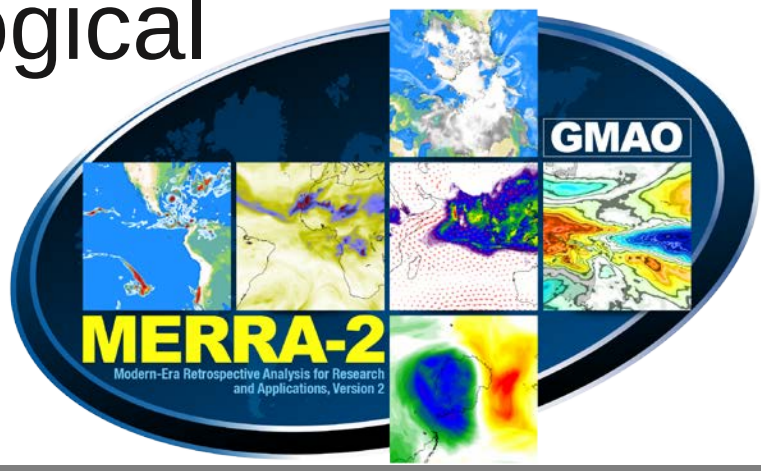


NASA GMAO global meteorology and chemistry products



NASA's MERRA-2 Reanalysis

- High resolution global data set
  - ➢ 50 km horizontal
    0.5º latitude x 0.625º longitude
  - ➢ 72 levels up to 0.01 hPa
- Product of GEOS data assimilation system
  - Assimilates conventional meteorological observations, aerosols and ozone
- Available since 1980 to a few weeks behind present

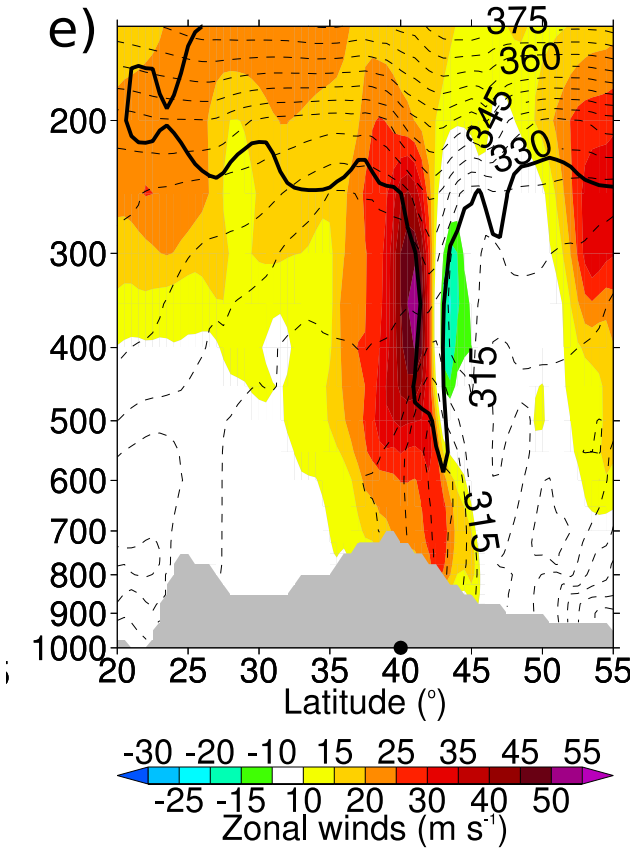


Question 1

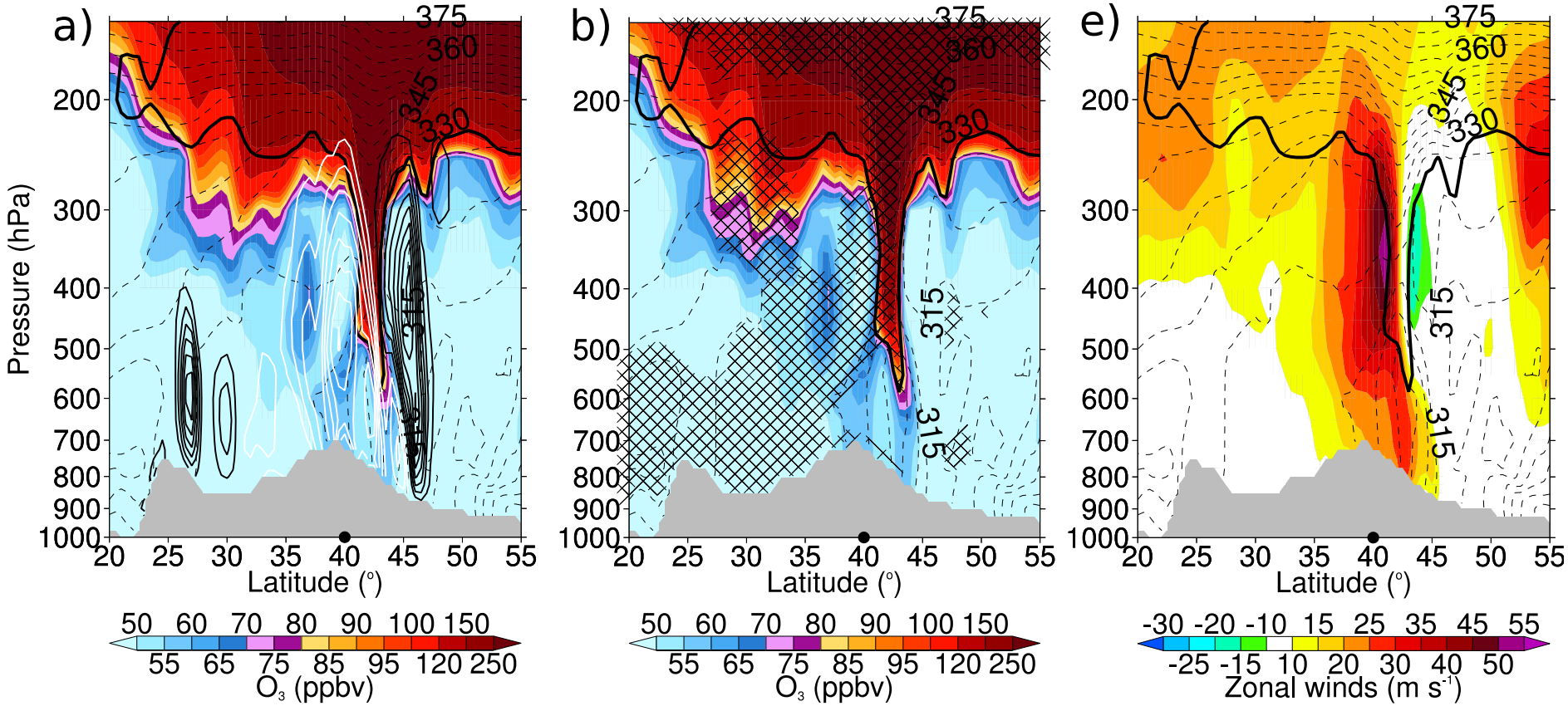
Can MERRA-2 capture the dynamical features of a stratospheric intrusion?

Atmospheric dynamics

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

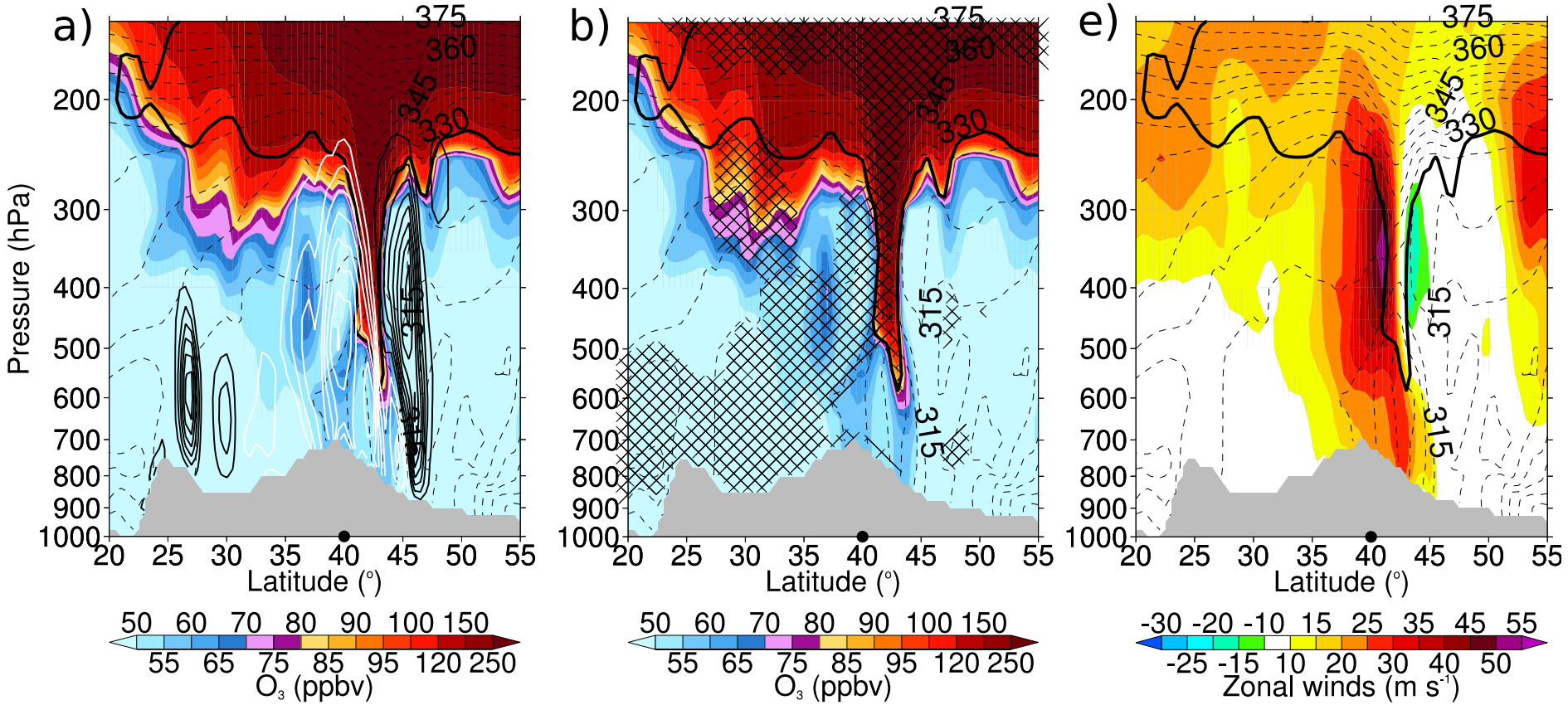


Knowland et al., 2017, GRL



- Tropopause folds are associated with:
  - High O_3, PV (2PVU thick line)
  - Low RH (hatching), CO (not shown)

Knowland et al., 2017, GRL



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

Knowland et al., 2017, GRL

Question 2

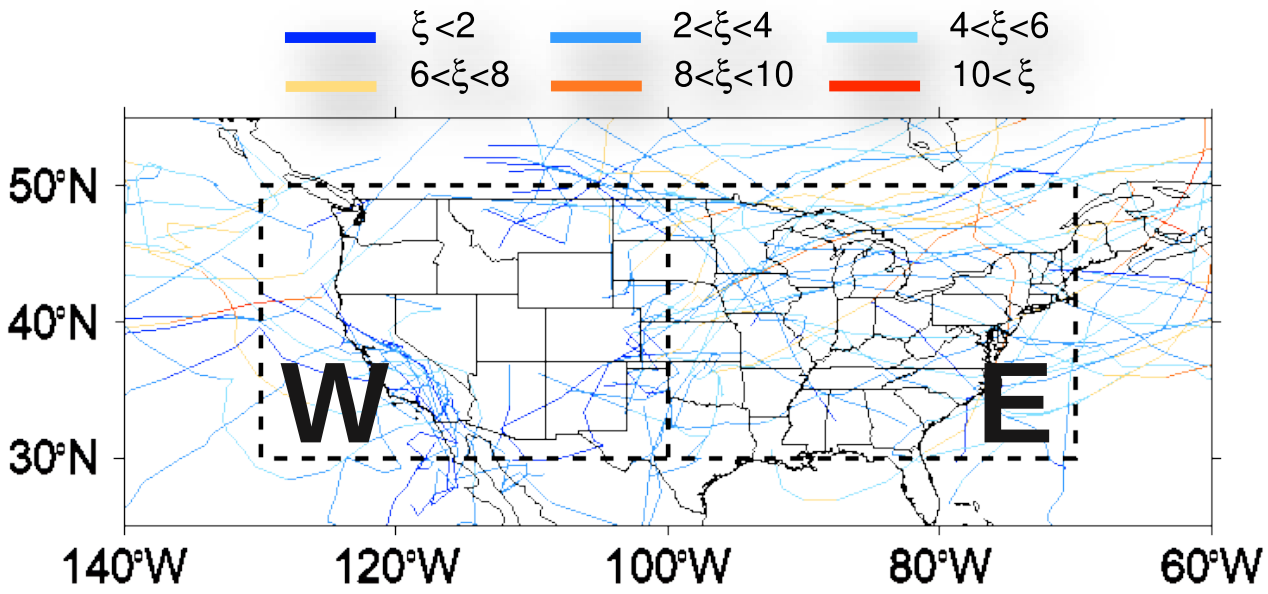
Can we build a catalogue of SI events in using the MERRA-2 Reanalysis?

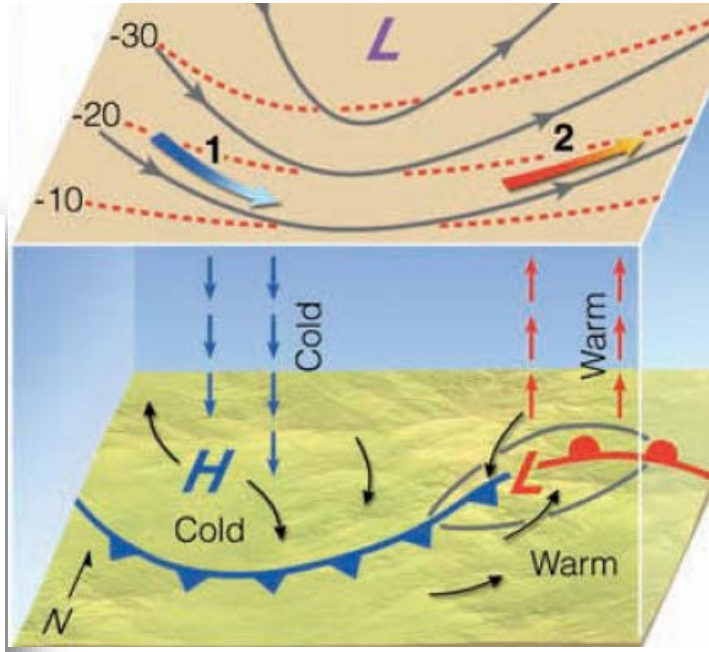
Construct Upper-level Tracks

- Use TRACK (Hodges 1995, 1999) to identify cyclones in MERRA-2 by maxima in 850-hPa relative vorticity ($\zeta_{850\ hPa}$)

MAM 2012

$\zeta_{850\ hPa}$ storm tracks





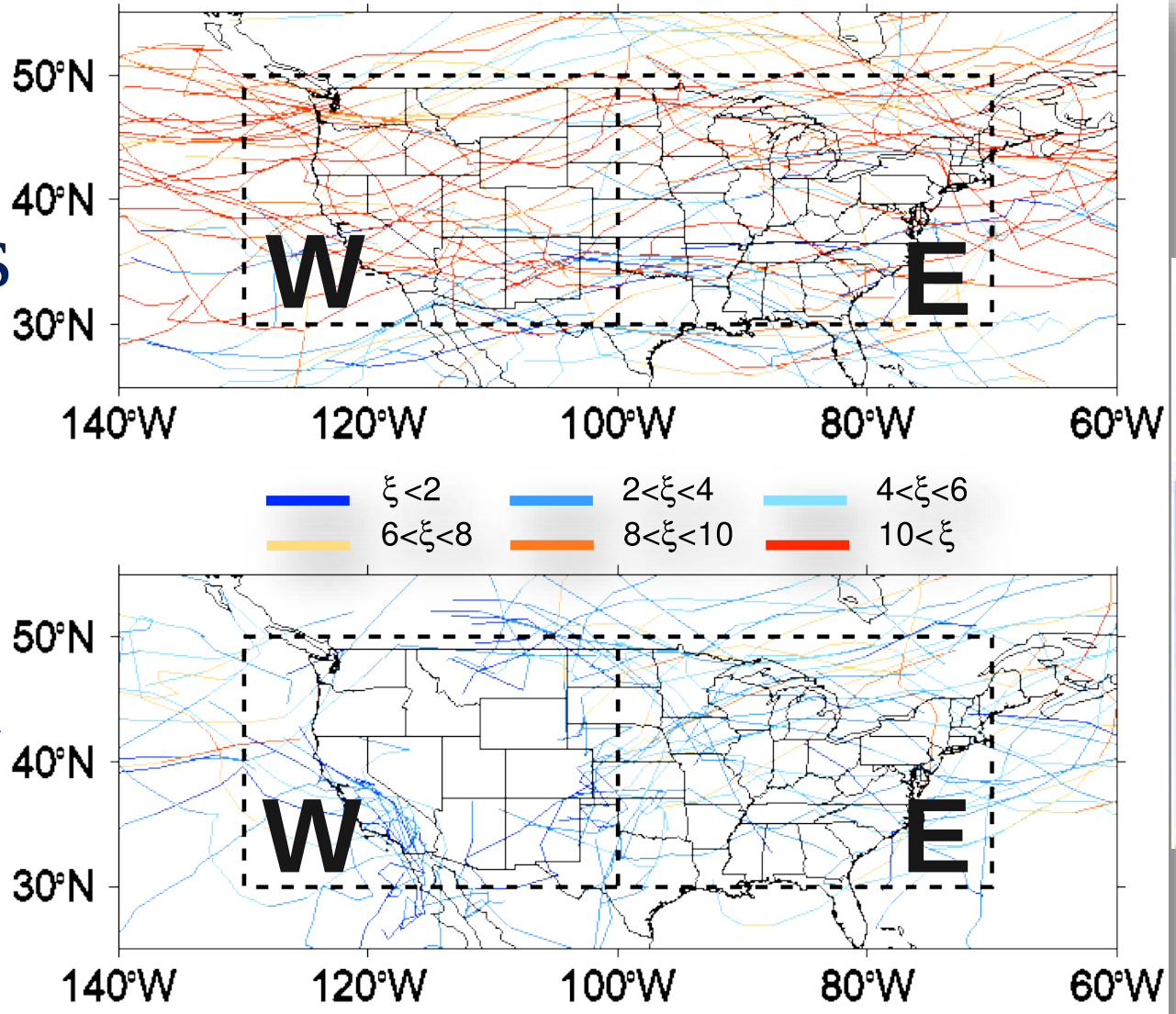
Knowland et al., in prep.

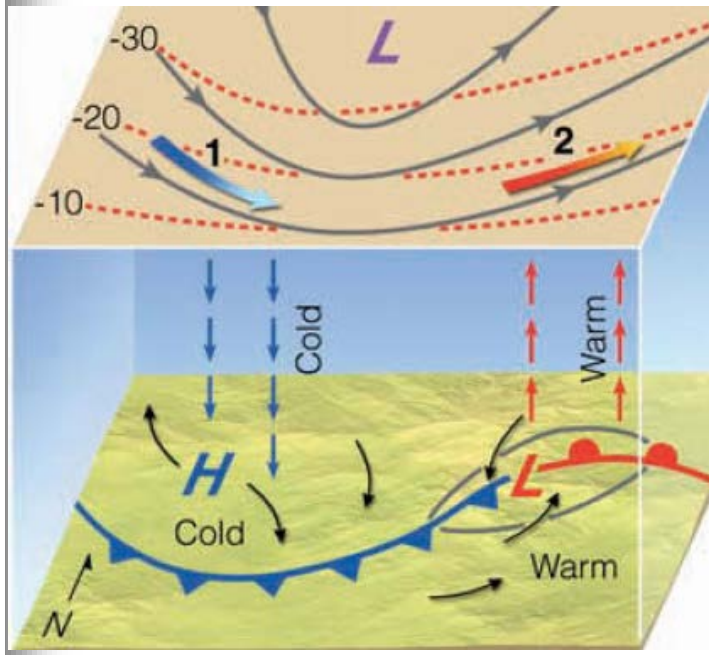
Construct Upper-level Tracks

$\zeta_{300\ hPa}$ tracks

MAM 2012

$\zeta_{850\ hPa}$ storm tracks





Knowland et al., in prep.

SI Filtering Methodology

In order to select tracks which are likely associated with SIs, the $\zeta_{300\ hPa}$ tracks for

1. 2005-2014 were selected:
   - Since October 2004, high vertical resolution stratospheric O_3 profiles from MLS and total column ozone from OMI constrain the model ozone.
   - In 2015, change in MLS from v2.2 to v4.2 resulted in anomalously higher ozone in upper troposphere. In 2016, MLS 261-hPa level was turned off in the DAS.

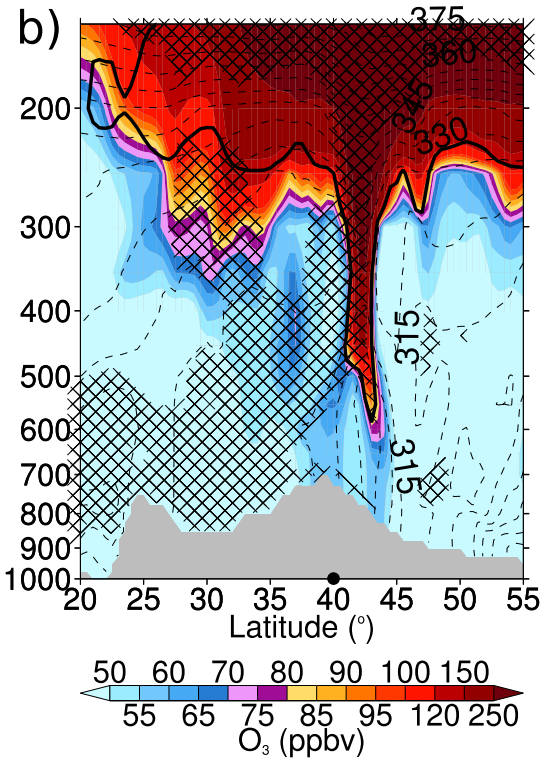
Knowland et al., in prep.

SI Filtering Methodology

In order to select tracks which are likely associated with SIs, the $\zeta_{300\ hPa}$ tracks for

1. 2005-2014 were selected.
2. Set filtering thresholds based on anomalies of
    1. max EPV > 2 PVU,
    2. min RH < 10 %,
    3. Geopotential Height < 0 dam,
    4. max O_3 > 25 ppbv, > 50 ppbv, > 100 ppbv,

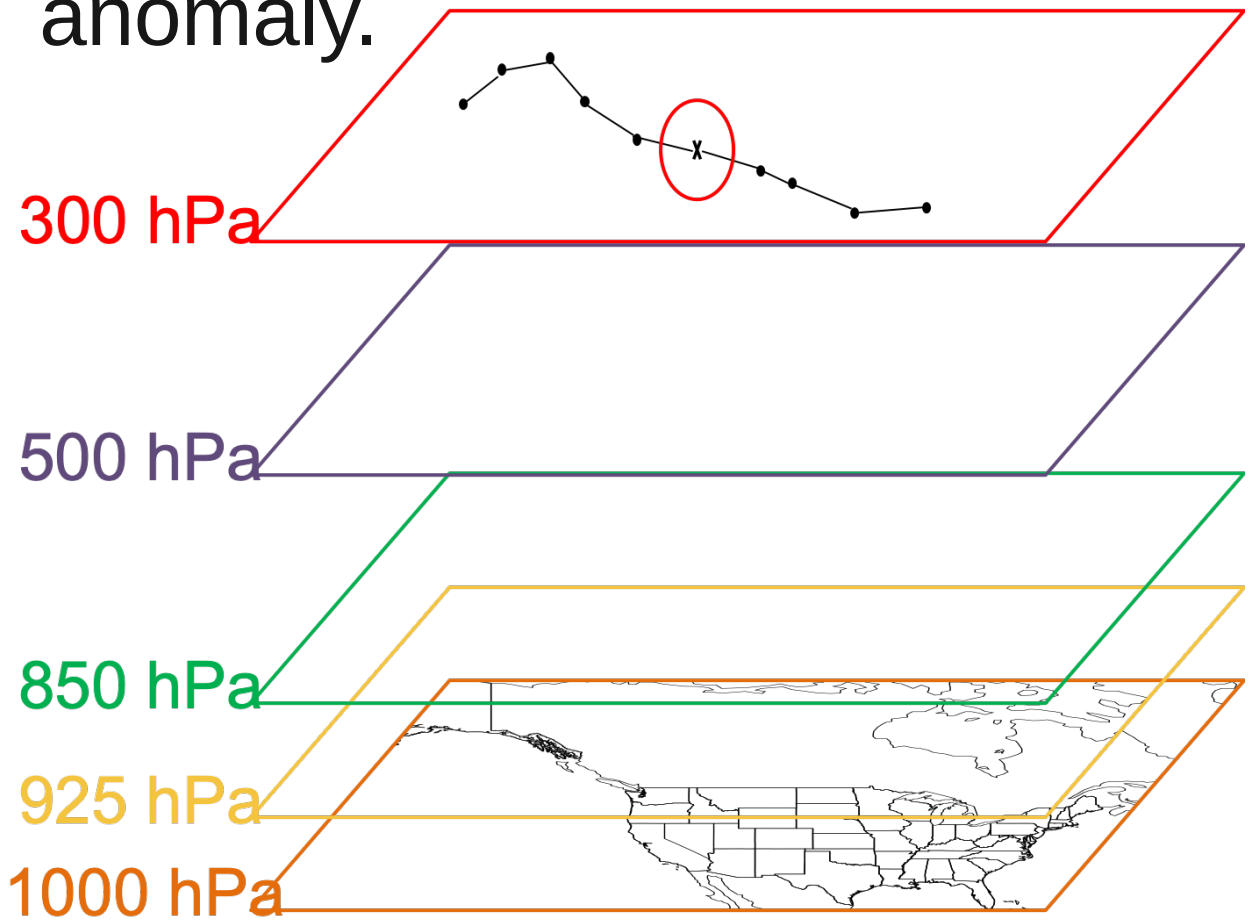
    within 7°search radius

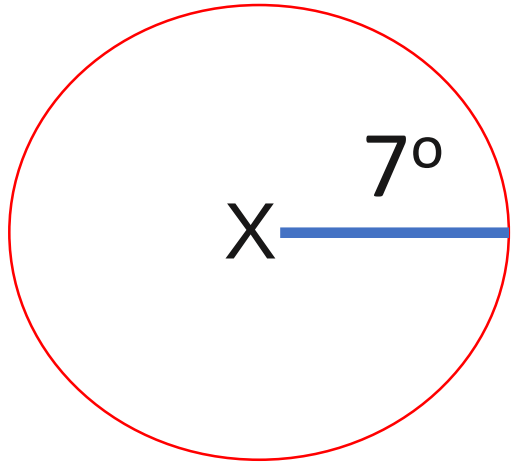


Knowland et al., in prep.

2. Sample for anomalies

- Search radius around the “track point” for the maximum anomaly.





Radial coordinate system for a given radius is chosen

Knowland et al., in prep.

2. Sample for anomalies

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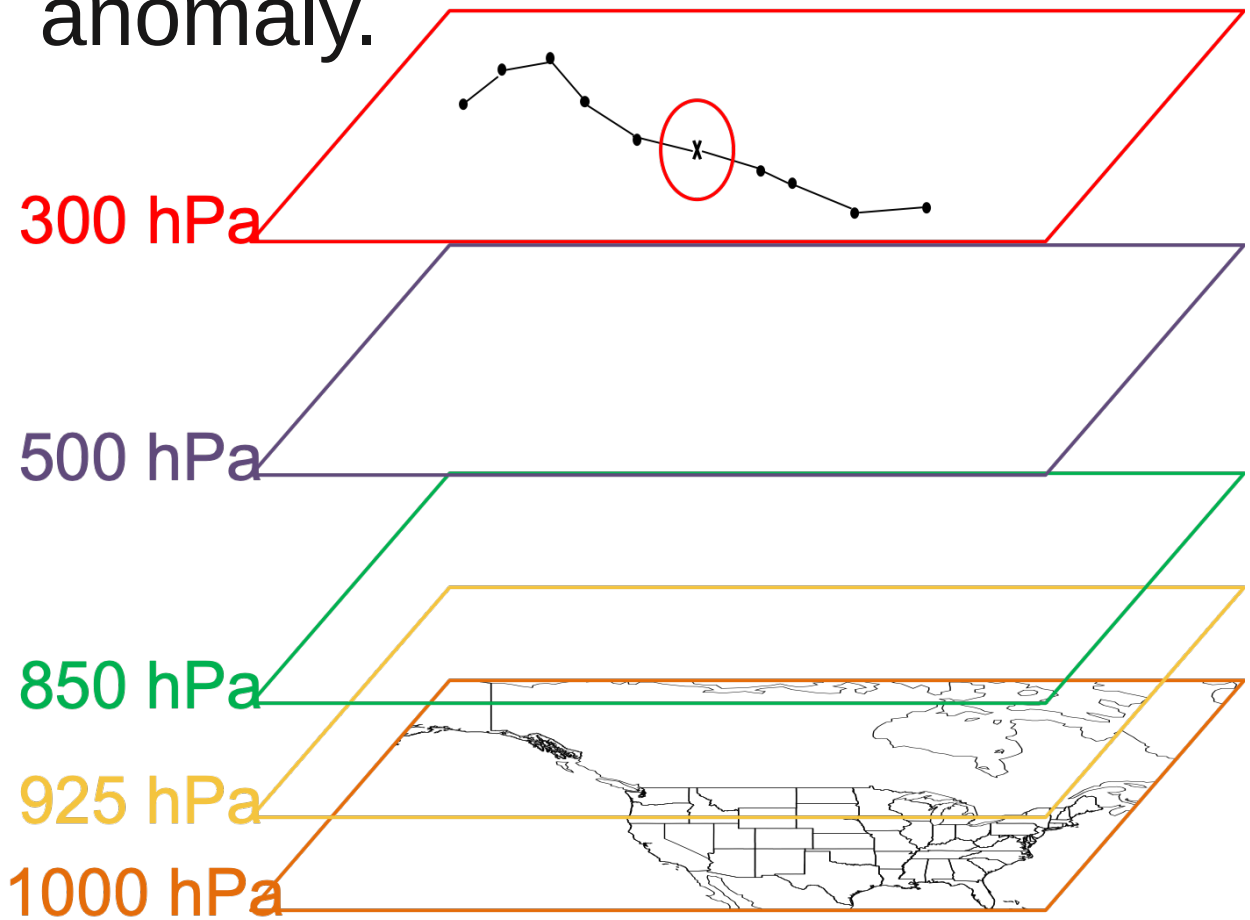
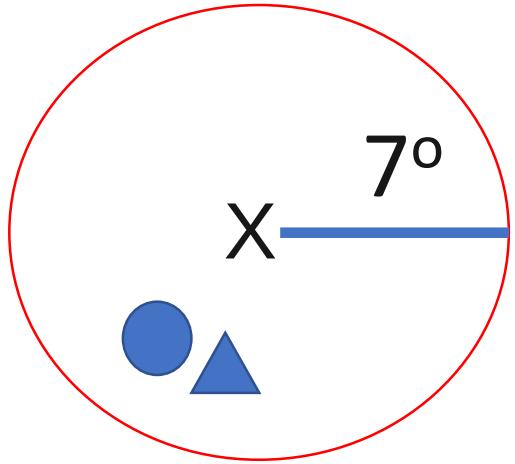


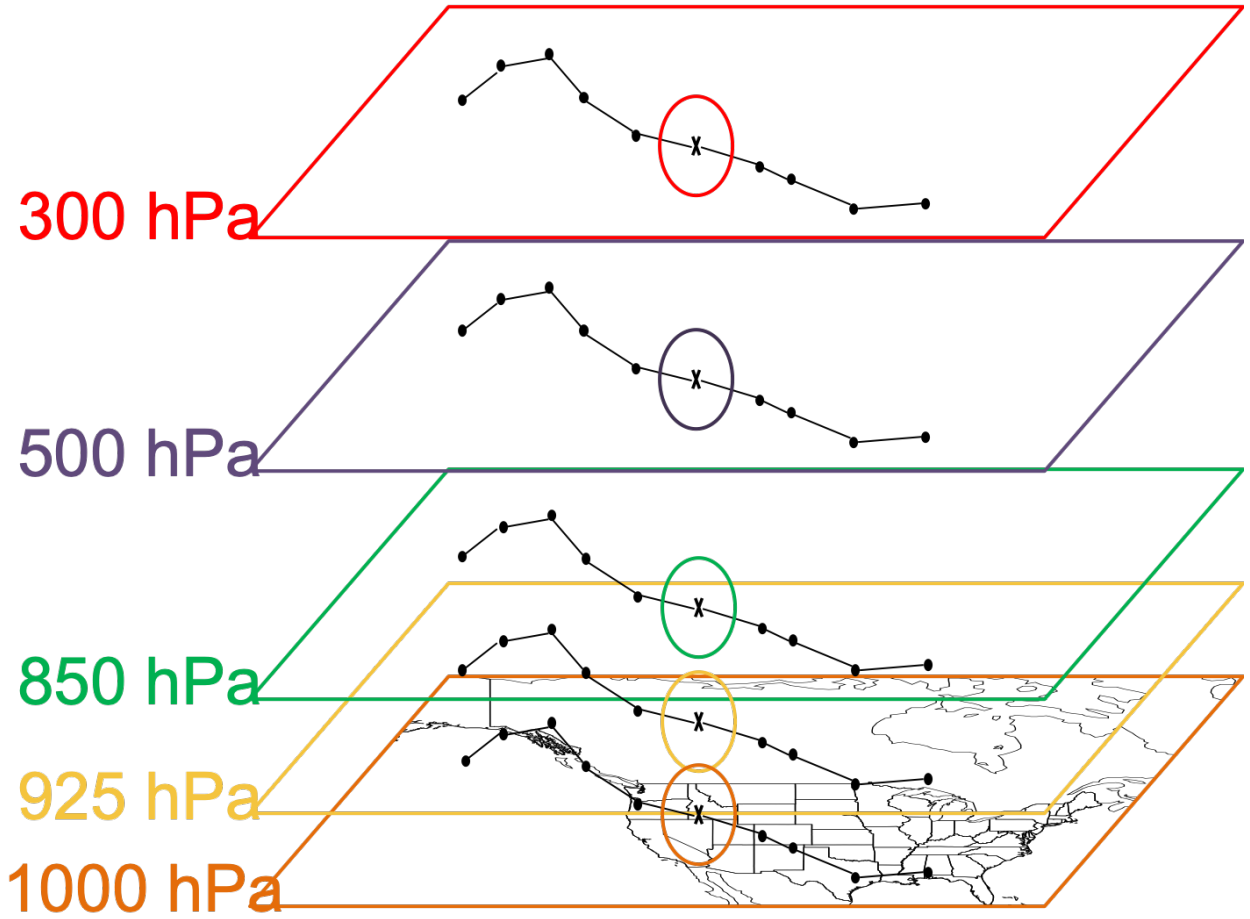


Location of Max O_3 anomaly

Location of Max ω anomaly

Knowland et al., in prep.

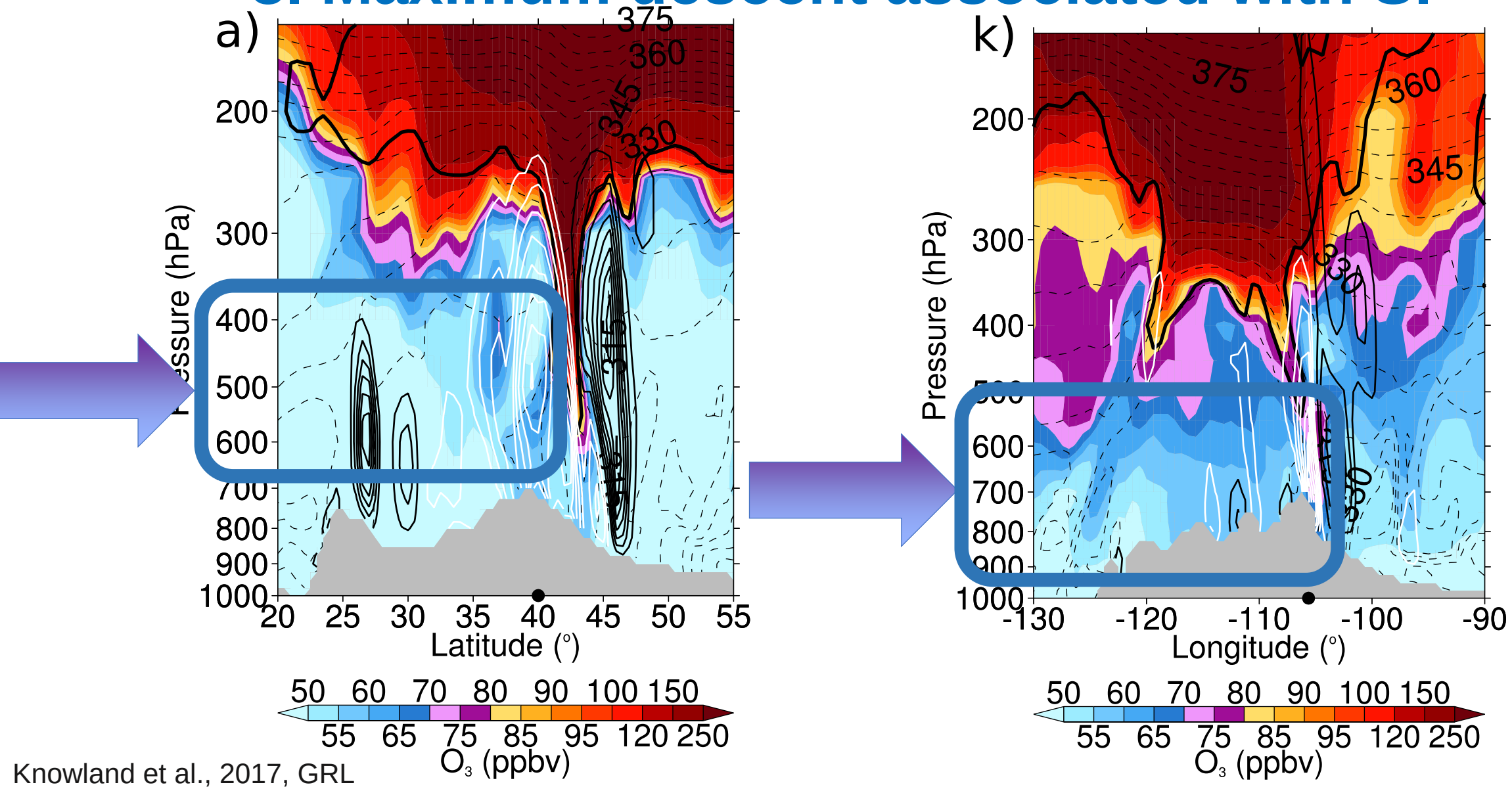
2. Sample for anomalies



- Search radius around the “track point” for the maximum anomaly.
- Apply to multiple levels at same track point
- Apply to all points along the track

Knowland et al., in prep.

3. Maximum descent associated with SI



Knowland et al., 2017, GRL

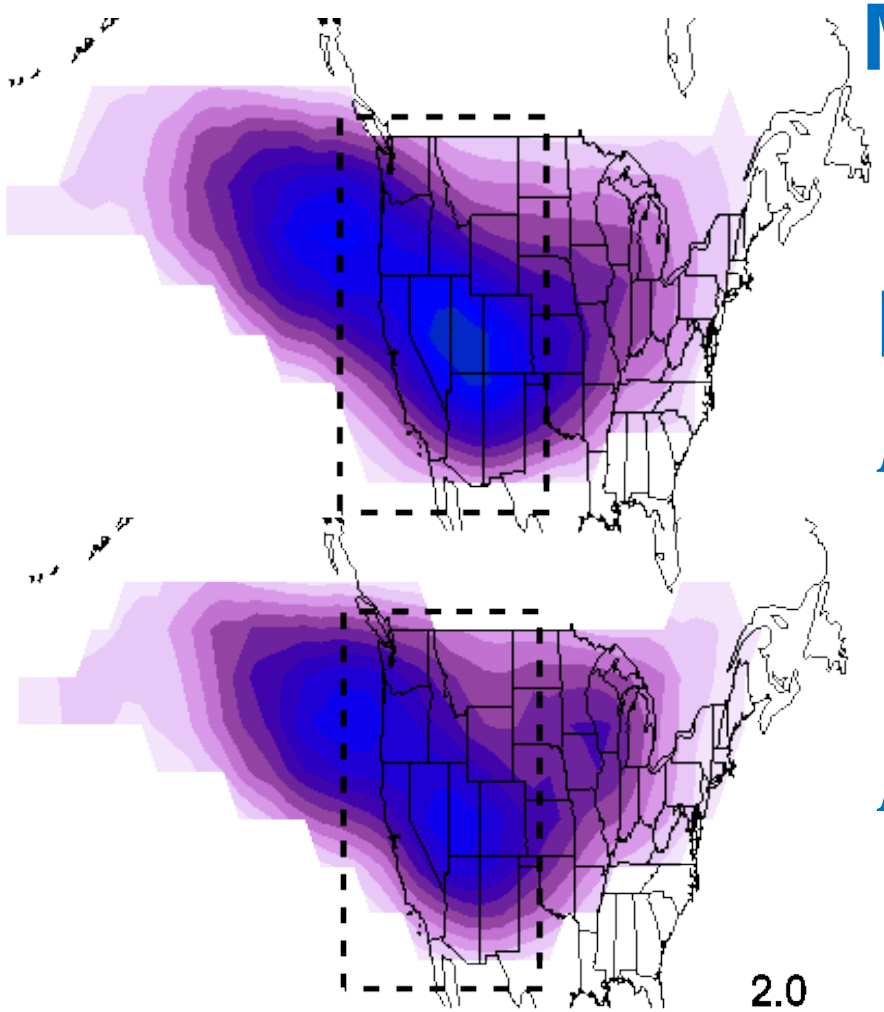
Subjective SI Filtering Methodology

In order to select tracks which are likely associated with SIs, the $\zeta_{300\ hPa}$ tracks for

1. 2005-2014 were selected.
2. Set thresholds for anomalies of max EPV > 2 PVU, min RH < 10 %, H < 0 dam and max O_3 > 25 ppbv within 7°search radius
3. Maximum $\omega_{500\ hPa}$ and $\omega_{700\ hPa}$

Knowland et al., in prep.

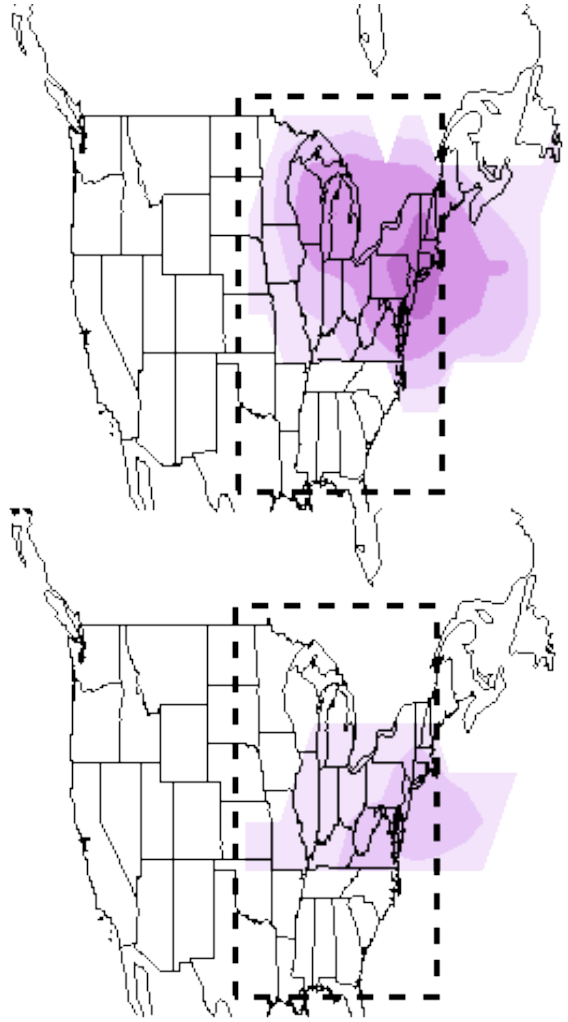
SI Filtered tracks: Western vs Eastern USA MAM 2005-2014

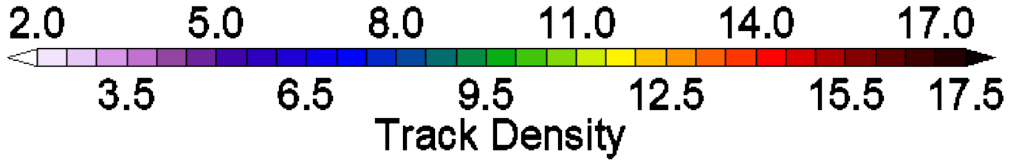


Density of tracks with

$Max\ \omega\ at\ 500hPa$

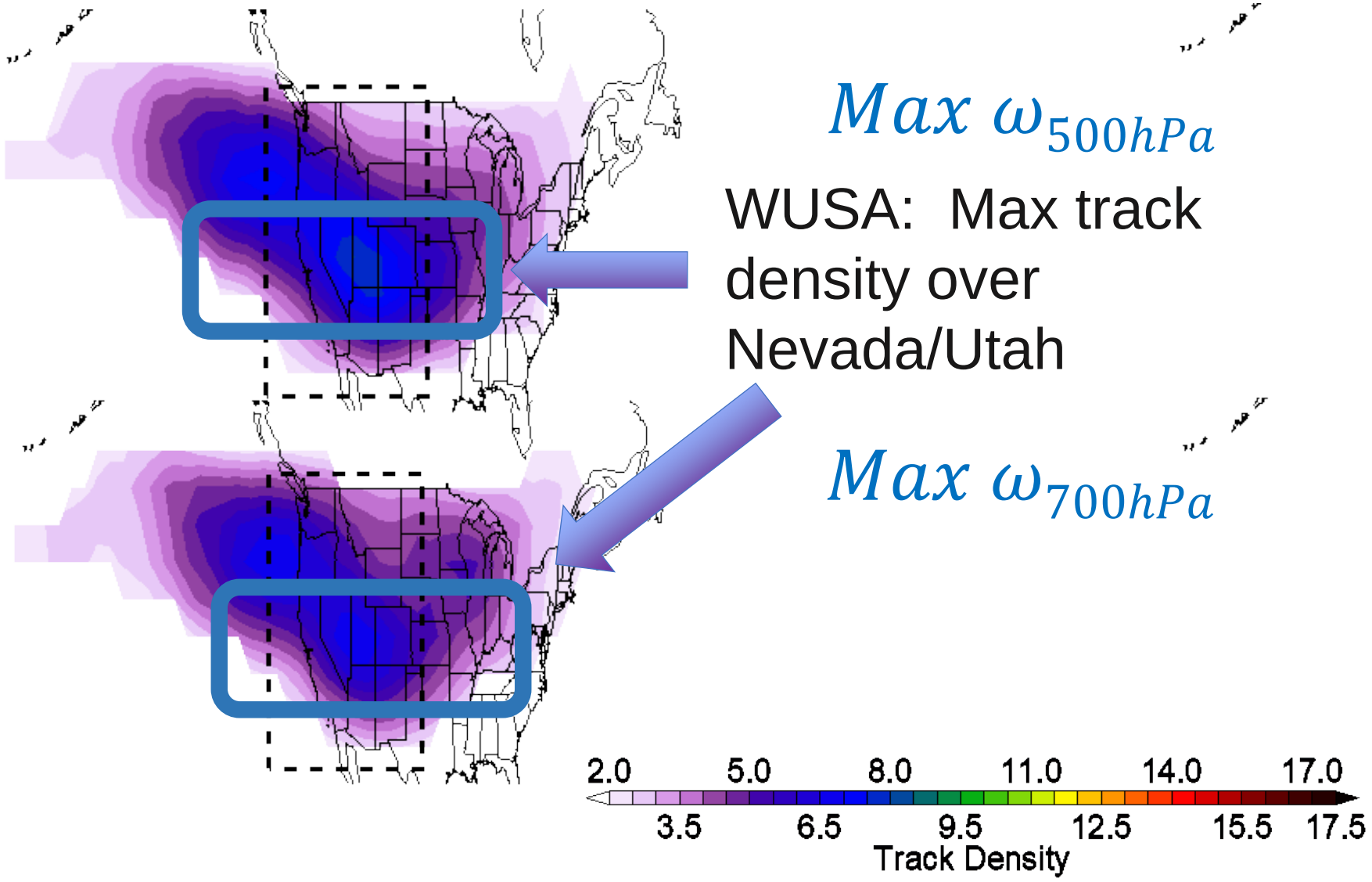
$Max\ \omega\ at\ 700hPa$





Knowland et al., in prep.

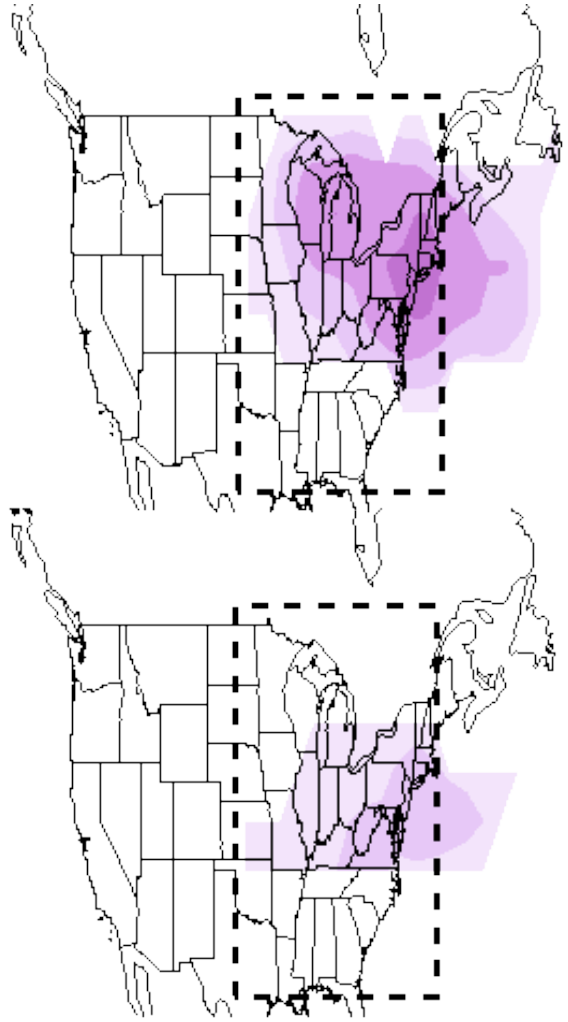
SI Filtered tracks: Western vs Eastern USA



$Max\ \omega_{500hPa}$

WUSA: Max track density over Nevada/Utah

$Max\ \omega_{700hPa}$



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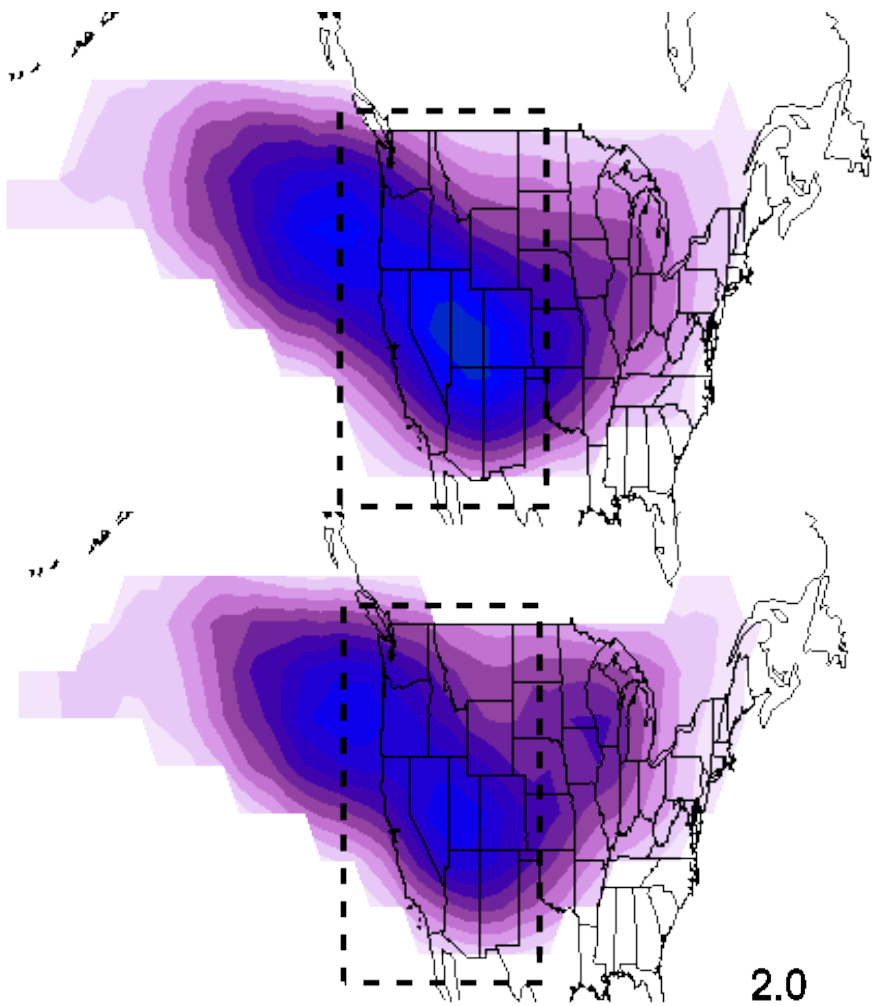
SI Filtered tracks: Western vs Eastern USA

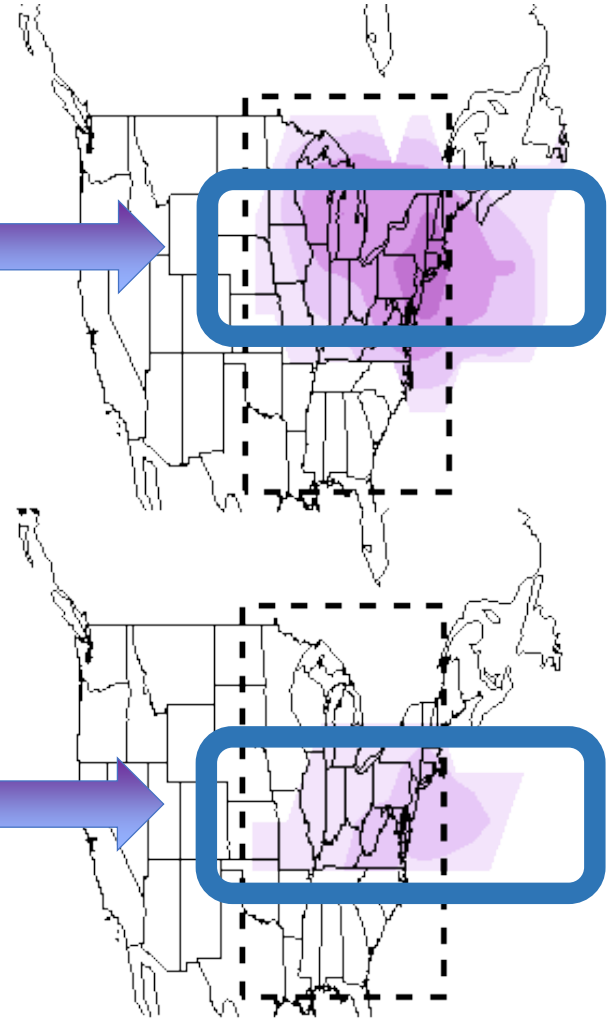


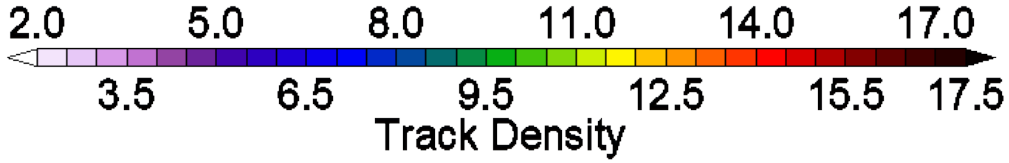
$Max\ \omega_{500hPa}$

EUSA: Max track density over Northeast

$Max\ \omega_{700hPa}$

EUSA: Max track density over Mid-Atlantic





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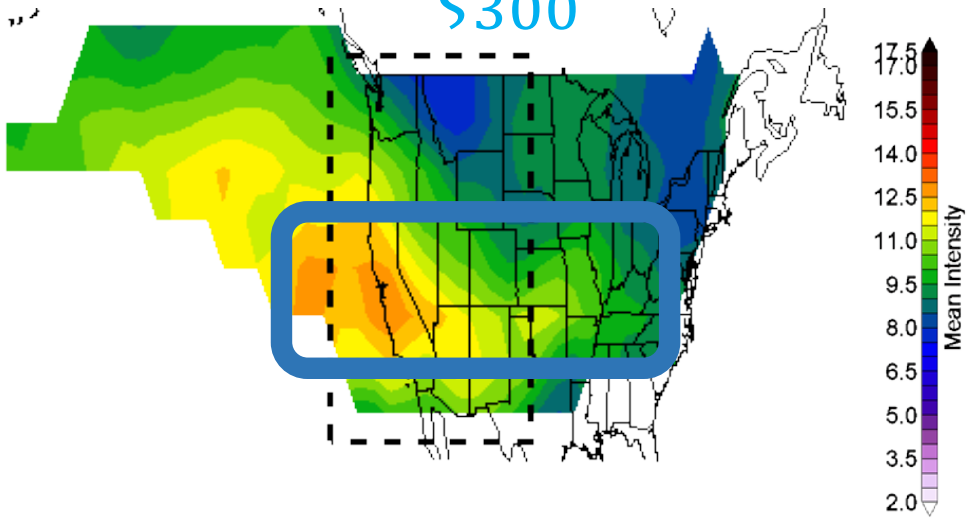
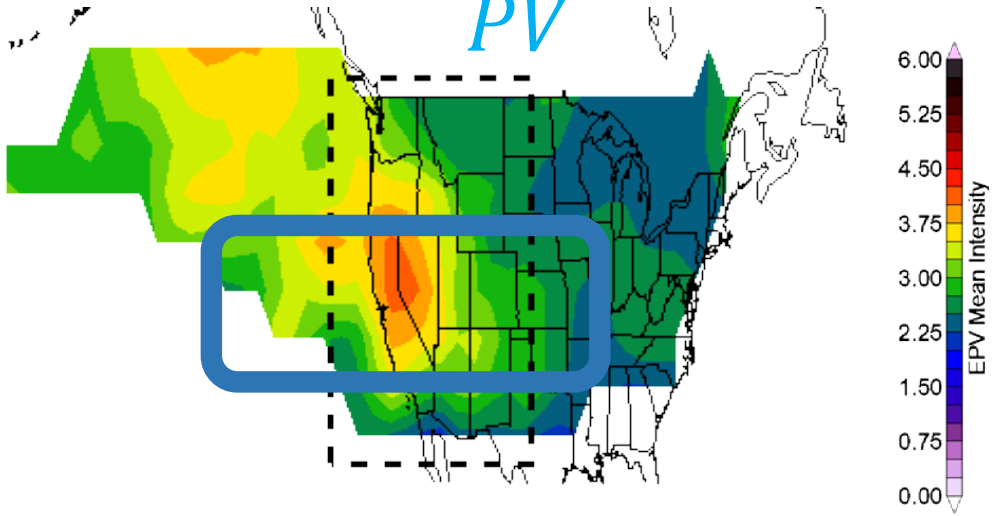
SI Filtered tracks: Western USA Max ω_{500hPa} MAM 2005-2014

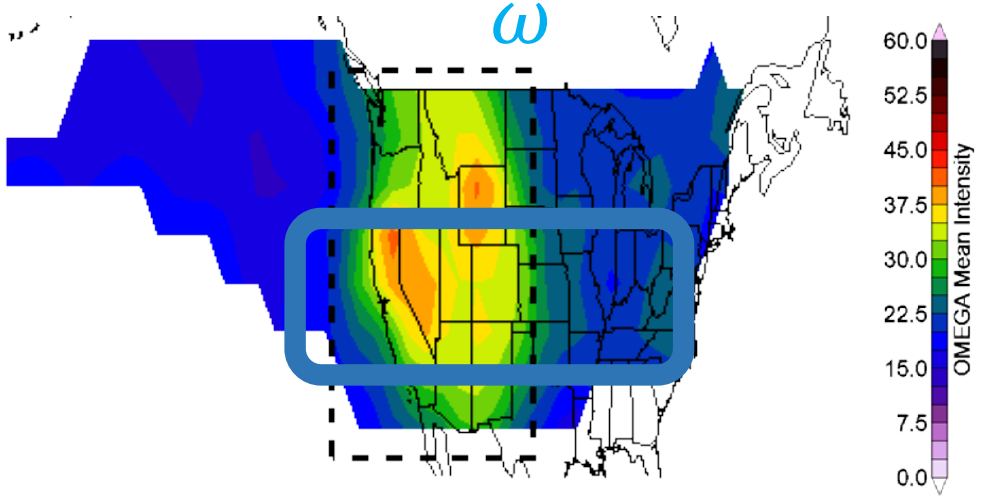
ζ_{300}



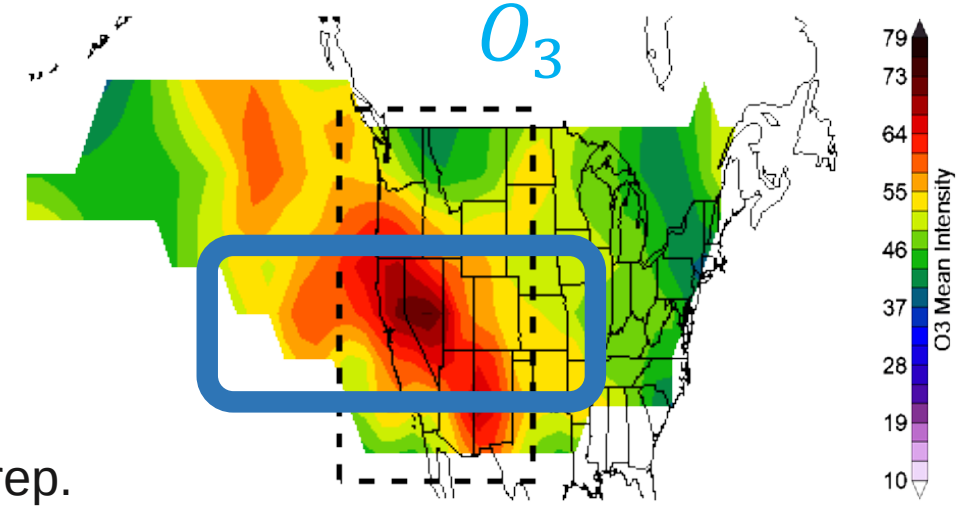
PV



ω



O_3



Knowland et al., in prep.

SI Filtered tracks: Seasonal variation 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	13±4	10±3	**17±3**	**17±3**	13±4	9±4	14±3	7±3
EUSA	6±3	3±2	**8±2**	**5±2**	5±3	3±2	7±2	2±2

Compared to other seasons,

- **More MAM SI tracks over the WUSA have the potential to impact lower tropospheric O_3 concentrations**

Knowland et al., in prep.

SI Filtered tracks: Seasonal variation 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	13±4	10±3	17±3	17±3	13±4	9±4	14±3	7±3
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Compared to other seasons,

- More MAM SI tracks over the WUSA have the potential to impact lower tropospheric O_3 concentrations
- **The impact of the SI tracks in the EUSA and in the other seasons must be considered**

Knowland et al., in prep.

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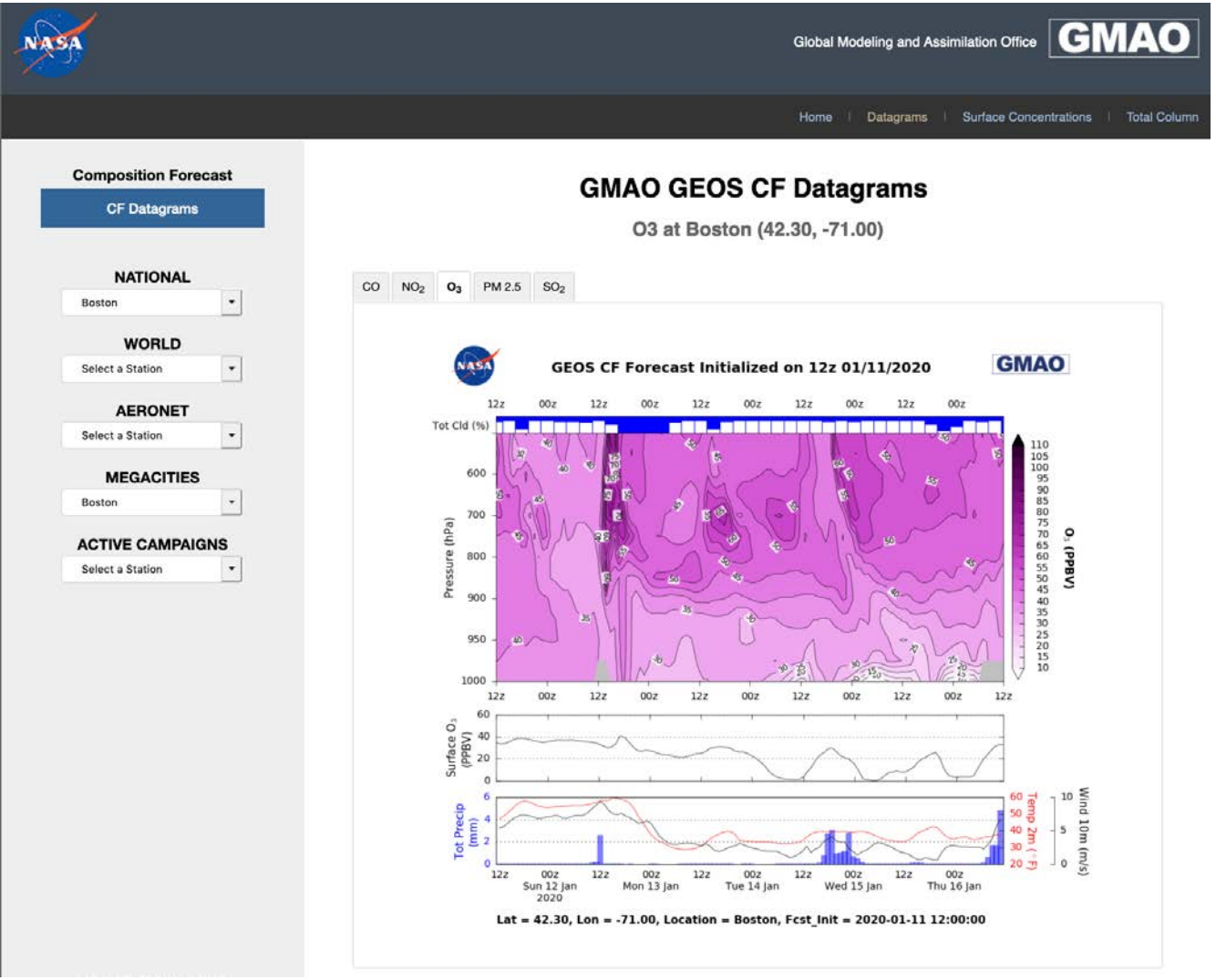
Forecasting and validating SI events

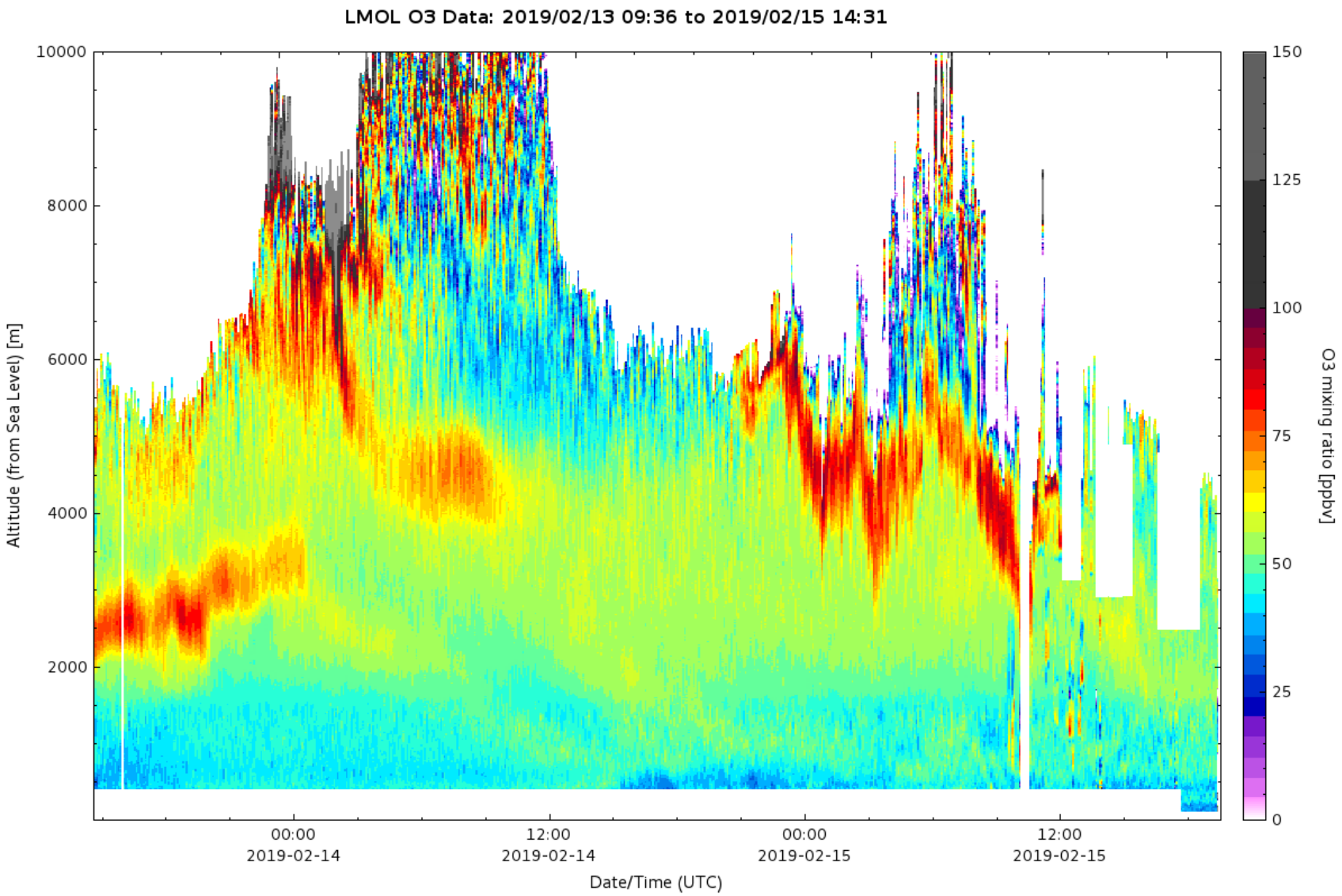


GEOS - CF

One **5-day forecast** per day

- 1-day replay
- 5-day forecast
- c360 (0.25°, ~25x25 km^2)
- Chemistry and Meteorology fields
- Available since Jan 2018

Comparison to LaRC LIDAR

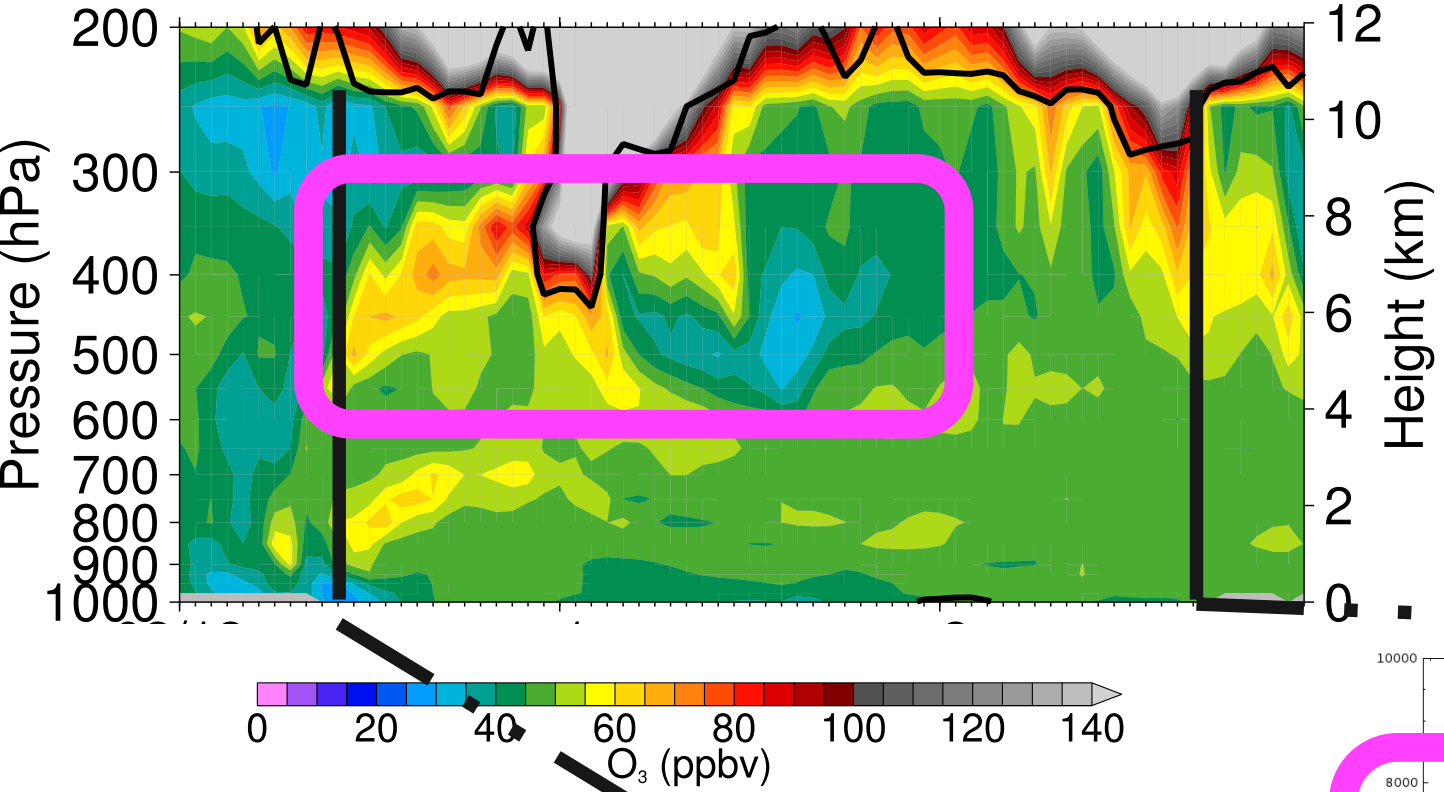


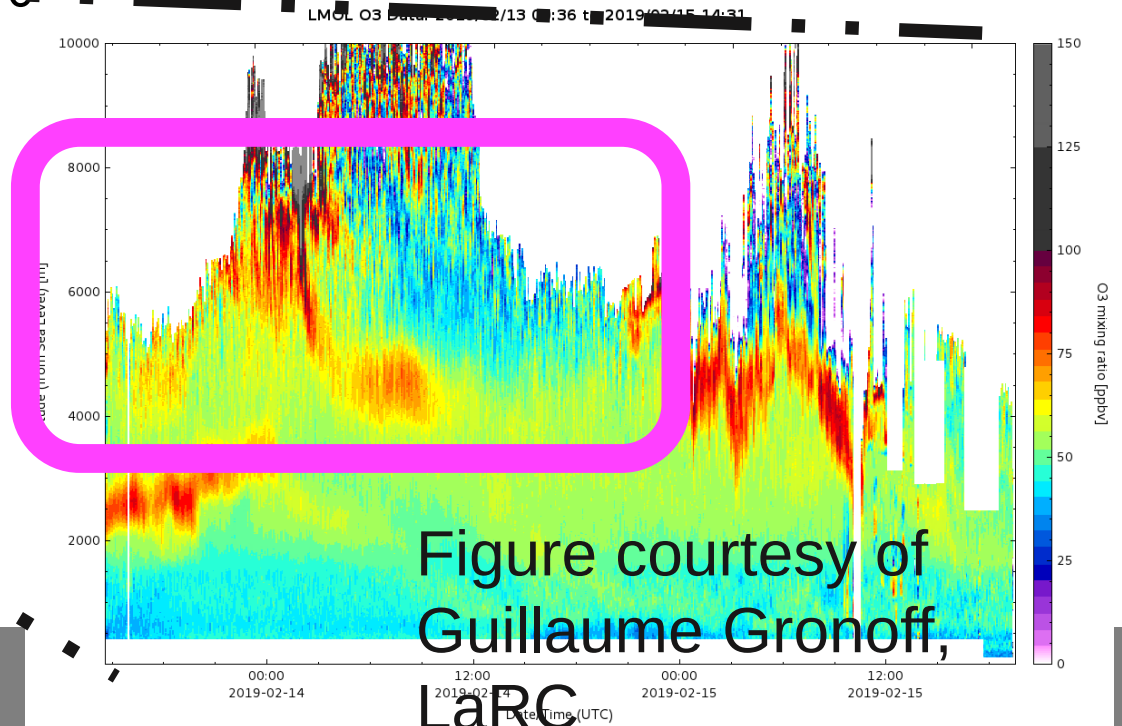
Possible Stratospheric Intrusions in February 14, 2019

Figure courtesy of Guillaume Gronoff, LaRC

Comparison to LaRC LIDAR

Stratospheric Intrusion on February 14, 2019





1. Able to confirm the high O_3 was from a SI event

Figure courtesy of Guillaume Gronoff, LaRC

Composition Forecast

CF Datagrams

NATIONAL

Select a Station

WORLD

Select a Station

AERONET

NORTH AMERICA

LMOL

MEGACITIES

Select a Station

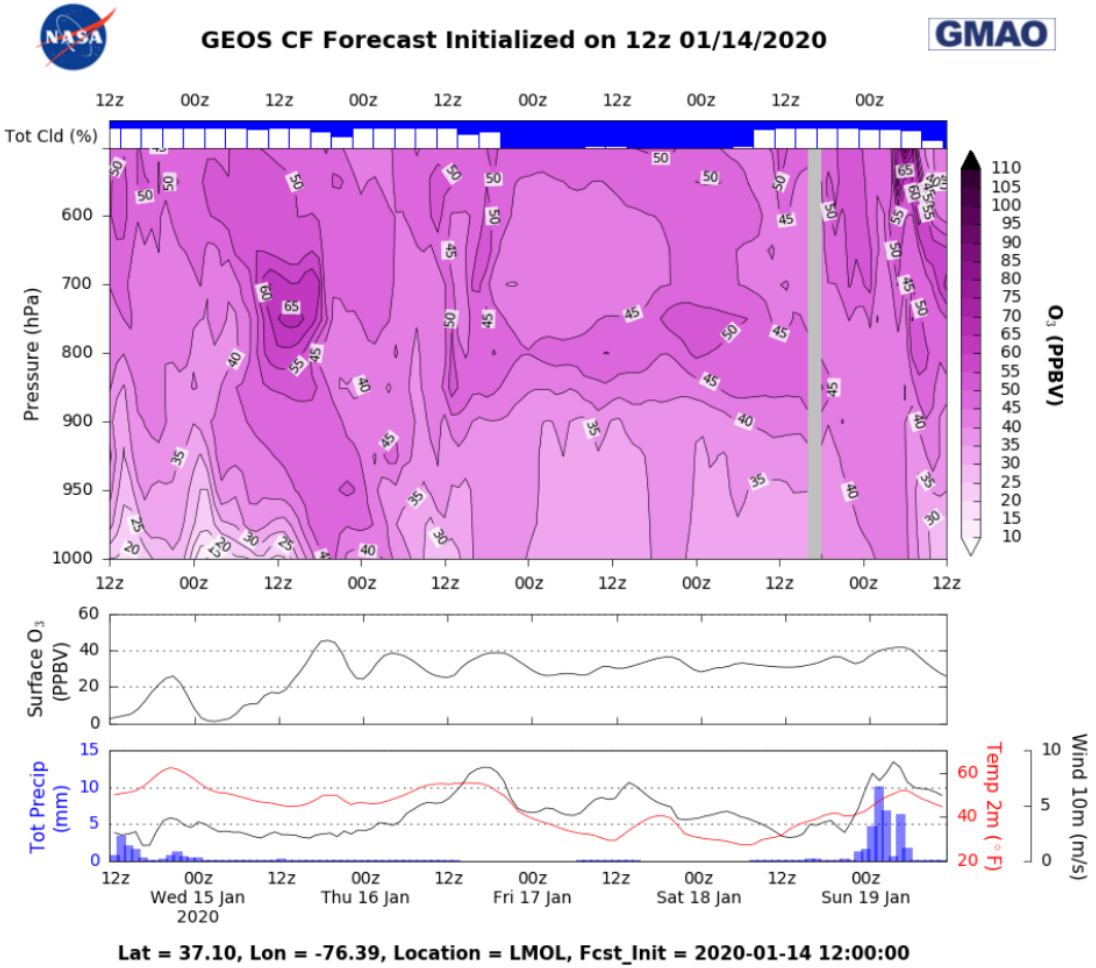
ACTIVE CAMPAIGNS

Select a Station

GMAO GEOS CF Datagrams

O3 at LMOL (37.10, -76.39)

CO | NO_2 | **O_3** | PM 2.5 | SO_2



Next step:

Can we provide a flag or alert to indicate to end-users that a stratospheric intrusion is likely in their area?

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Summary

- ✓ MERRA-2 is a high-resolution global reanalysis which can used in scientific studies to identify SIs by both atmospheric dynamics and O_3
- ✓ SIs over the USA can impact the O_3 concentrations in the mid to lower troposphere in all seasons.
- ➢ Working on best approach to communicate SI potential to interested end-user groups.

Thank you for listening!

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

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