NASA's High-Resolution GEOS Forecasting and Reanalysis Products: Stratospheric Intrusions at GMAO

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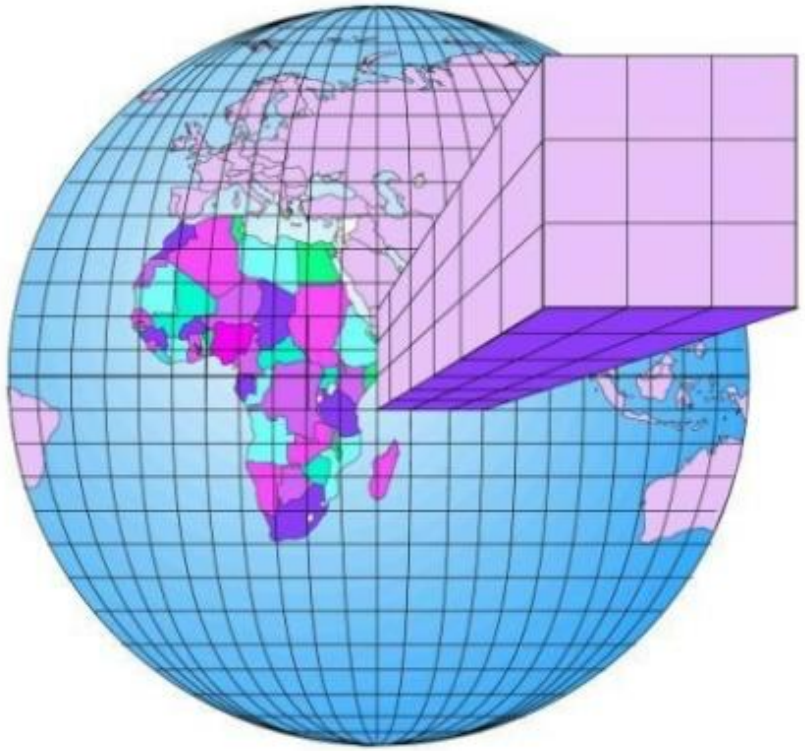
NASA LaRC: Tim Berkoff, Guillaume Gronoff

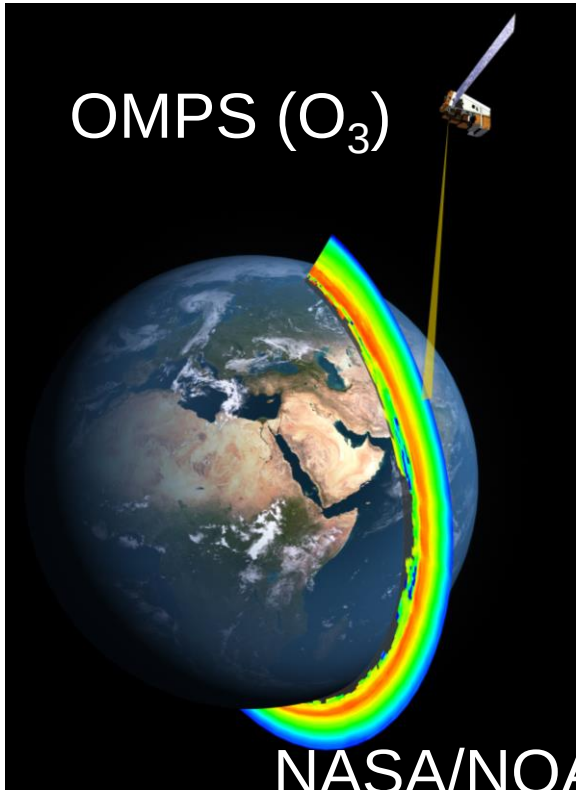
University of Reading, UK: Kevin Hodges

4 March 2020

NASA GMAO global meteorology and chemistry products

GEOS





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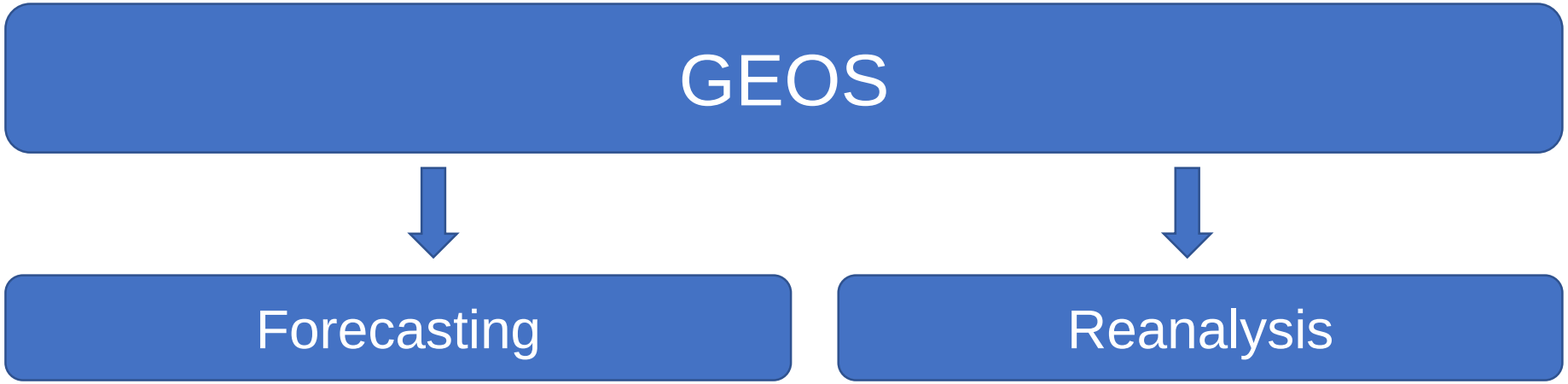
NASA GMAO global meteorology and chemistry products



NASA GMAO global meteorology and chemistry products

GEOS

Forecasting

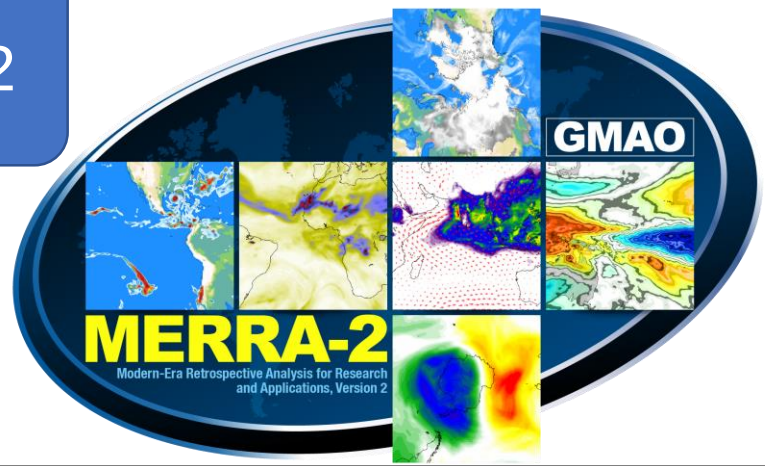
Reanalysis

GEOS FP

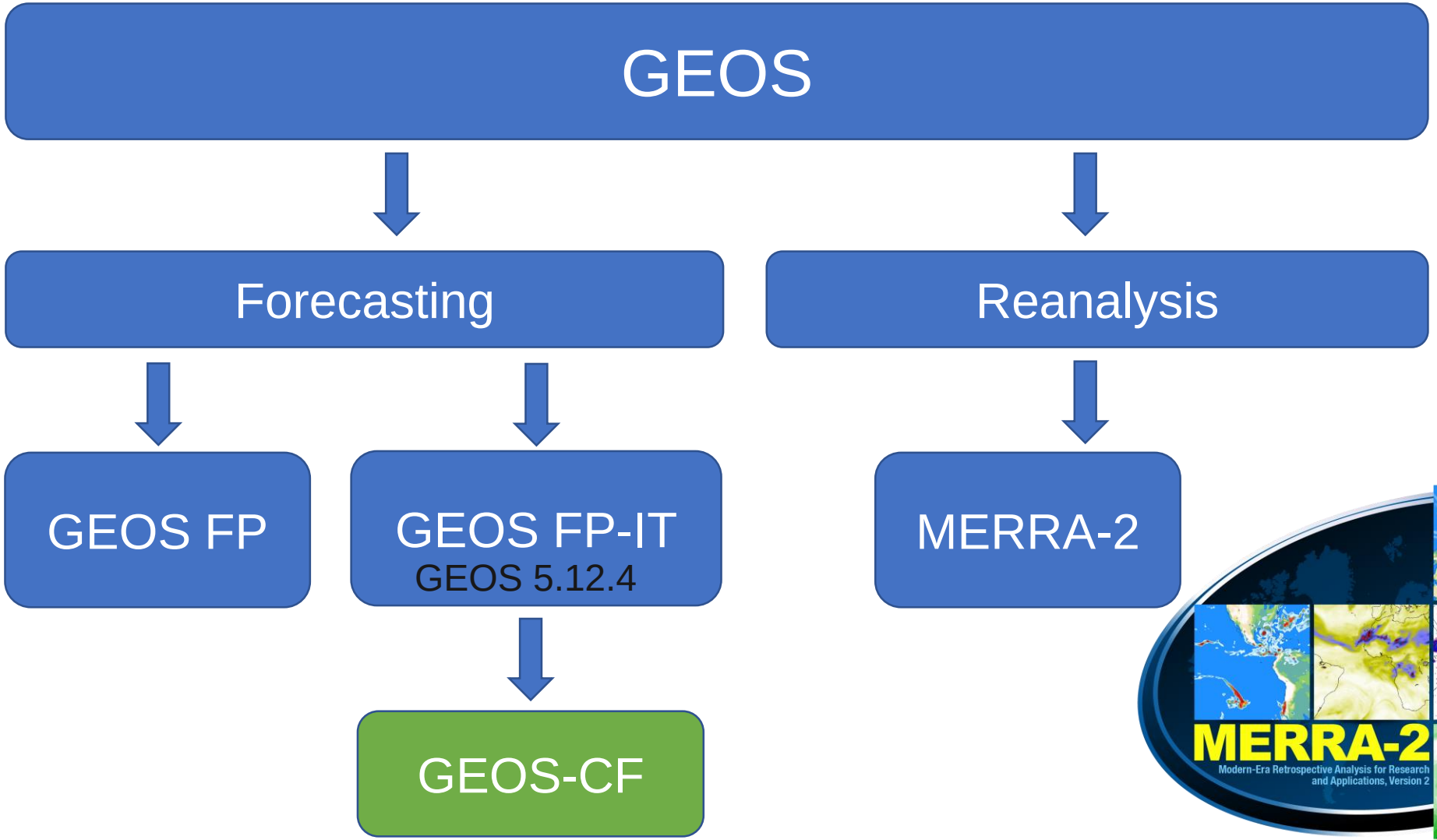
MERRA-2

GEOS 5.17	11/01/2017 - 7/11/2018
5.21	7/11/2018 - 3/13/2019
5.22	3/13/2019 - 1/30/2020
5.25	1/30/2020 - on-going

GEOS 5.12.4



NASA GMAO global meteorology and chemistry products



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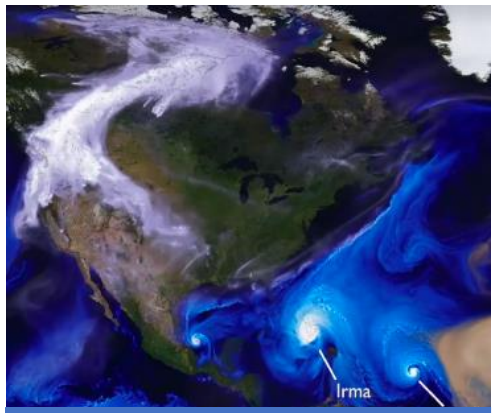
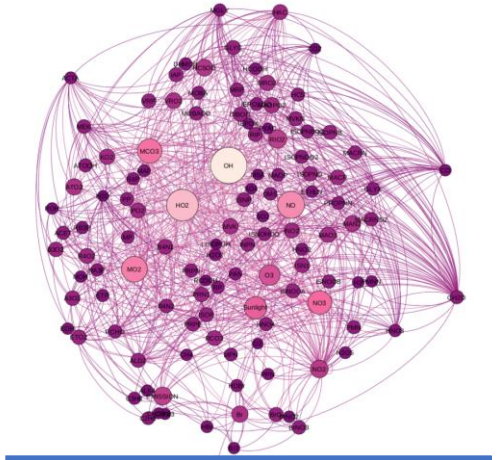
NASA's composition forecast (GEOS-CF)



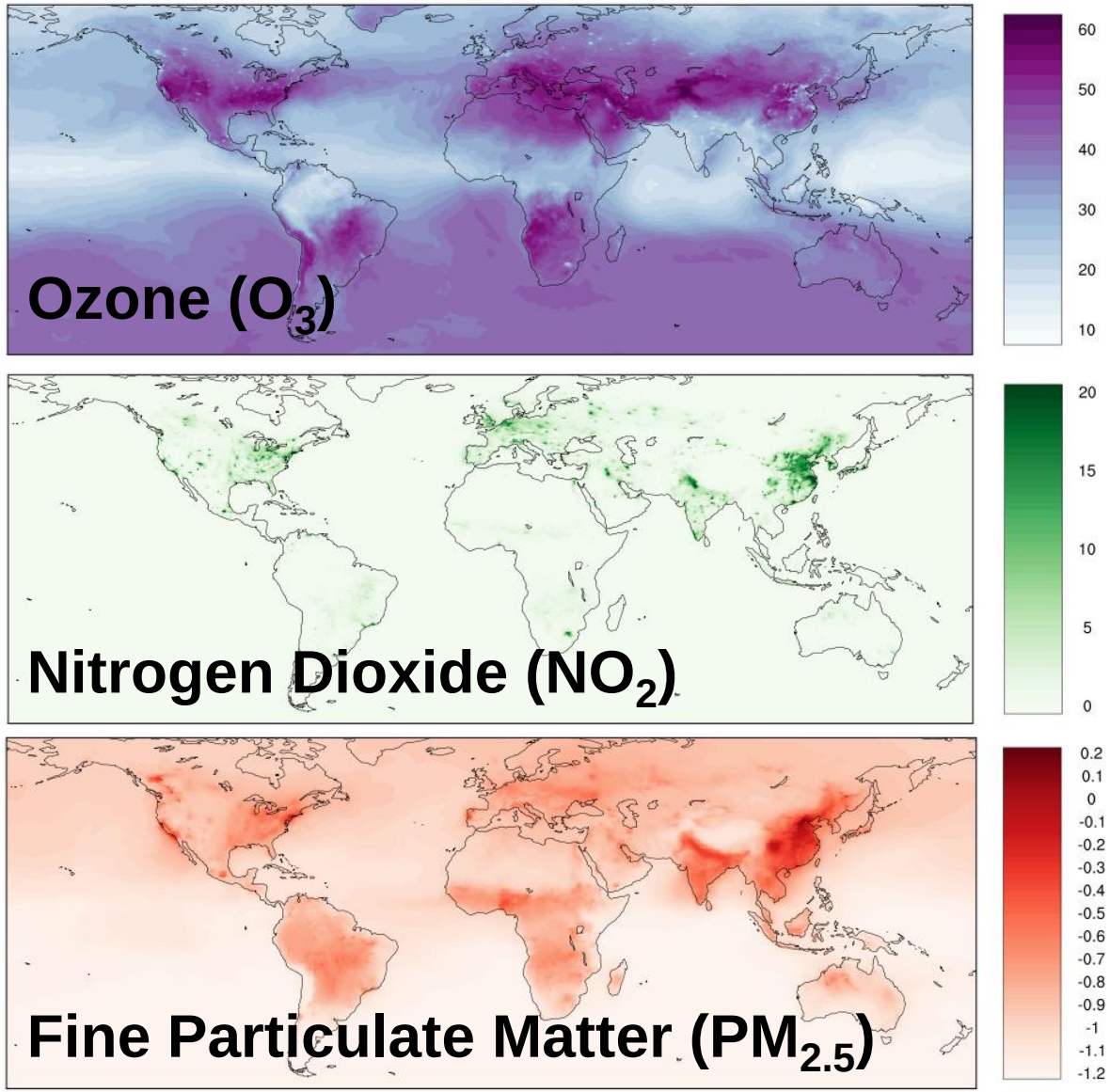
GEOS NWP



GEOS - Chem

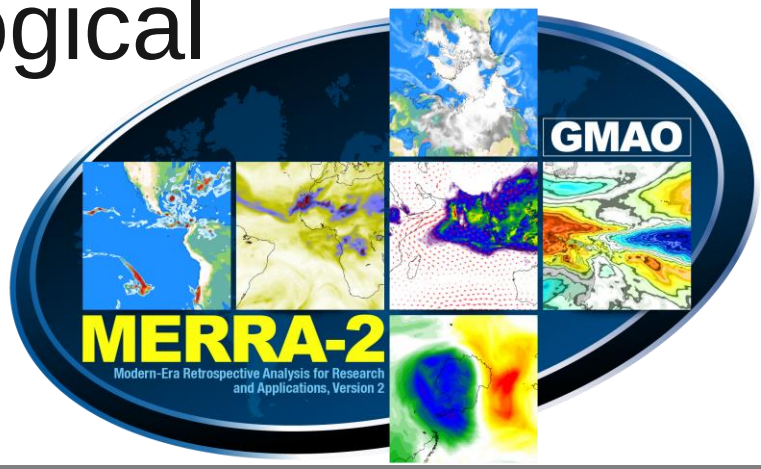
- 250 Chemical Species
- 725 Chemical Reactions

GEOS-Chem



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

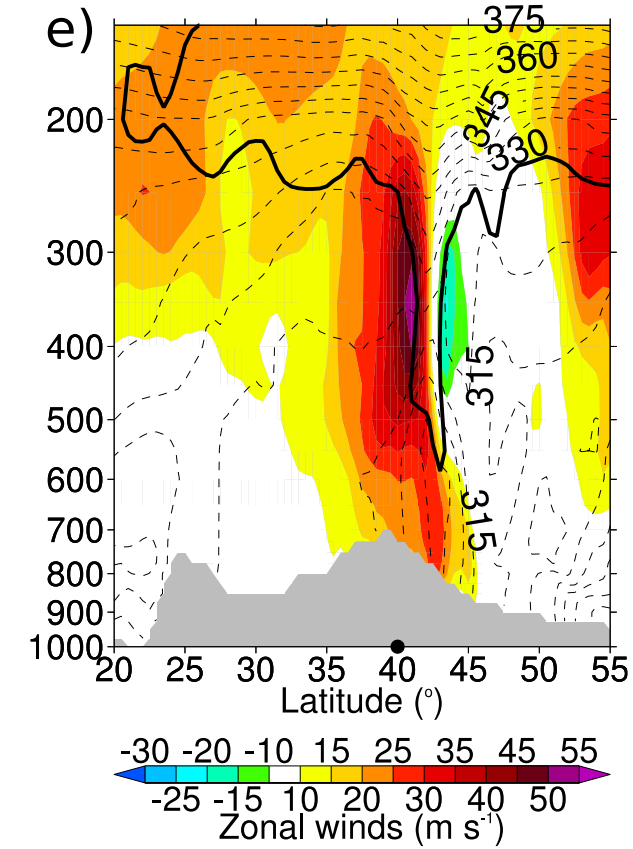


Question 1

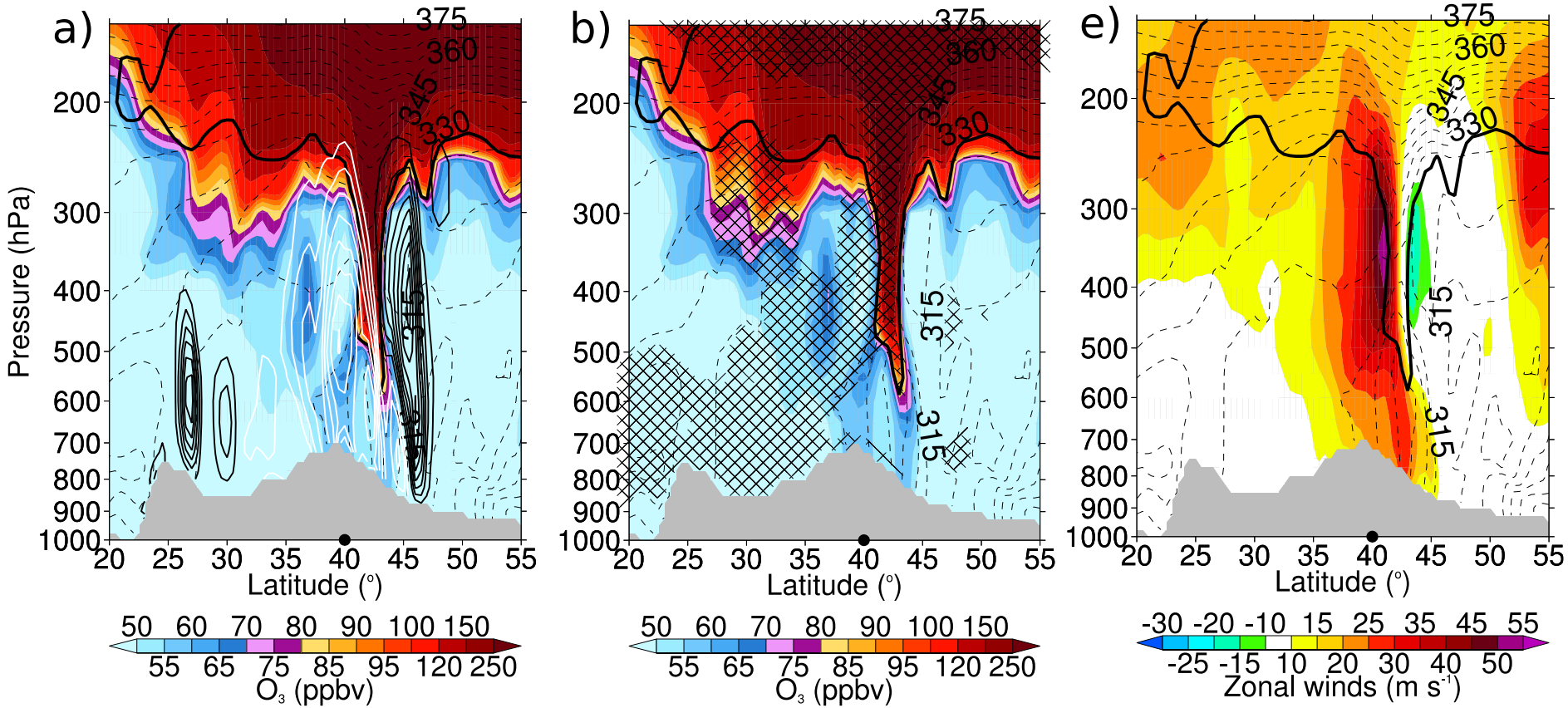
Can MERRA-2 capture the dynamical features of a stratospheric intrusion?

Atmospheric dynamics

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

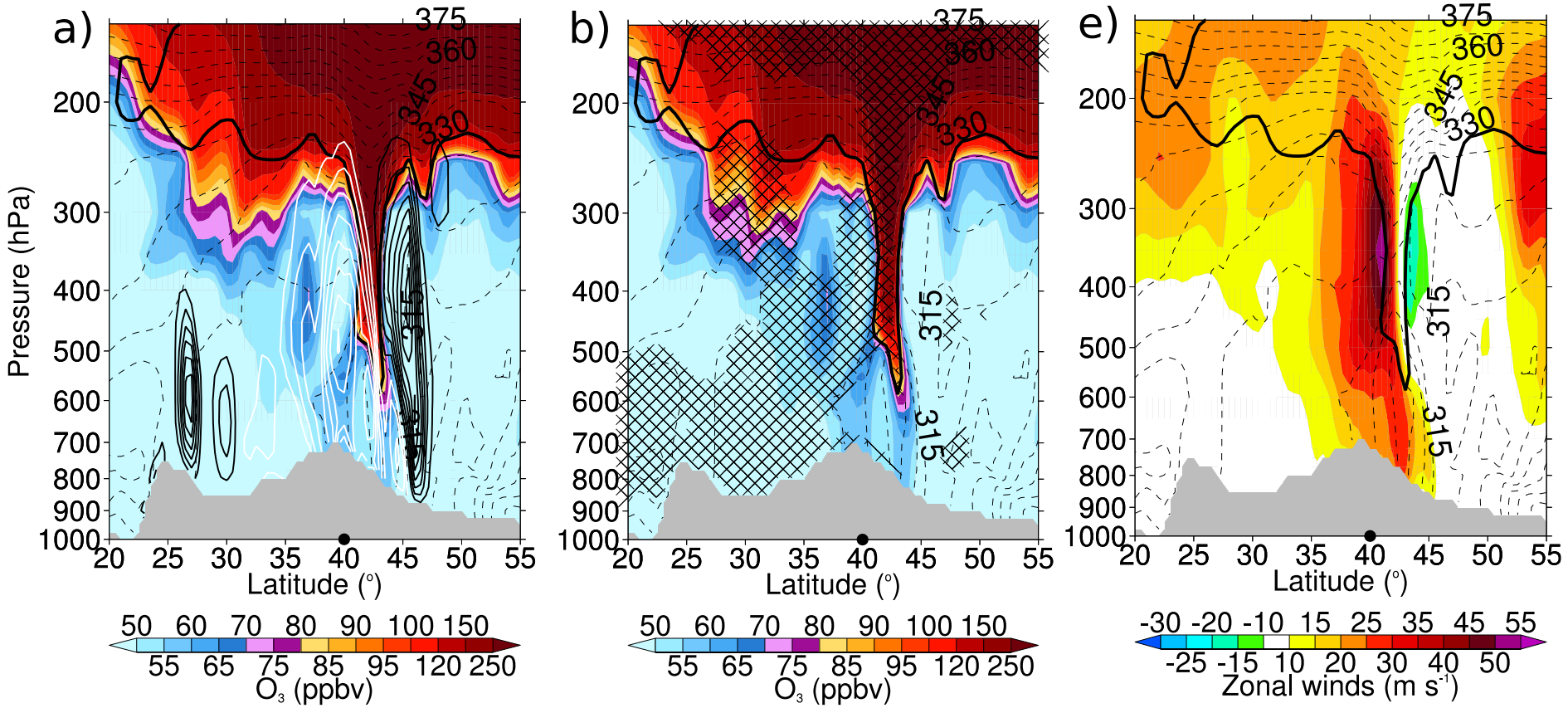


Knowland et al., 2017, GRL



- 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

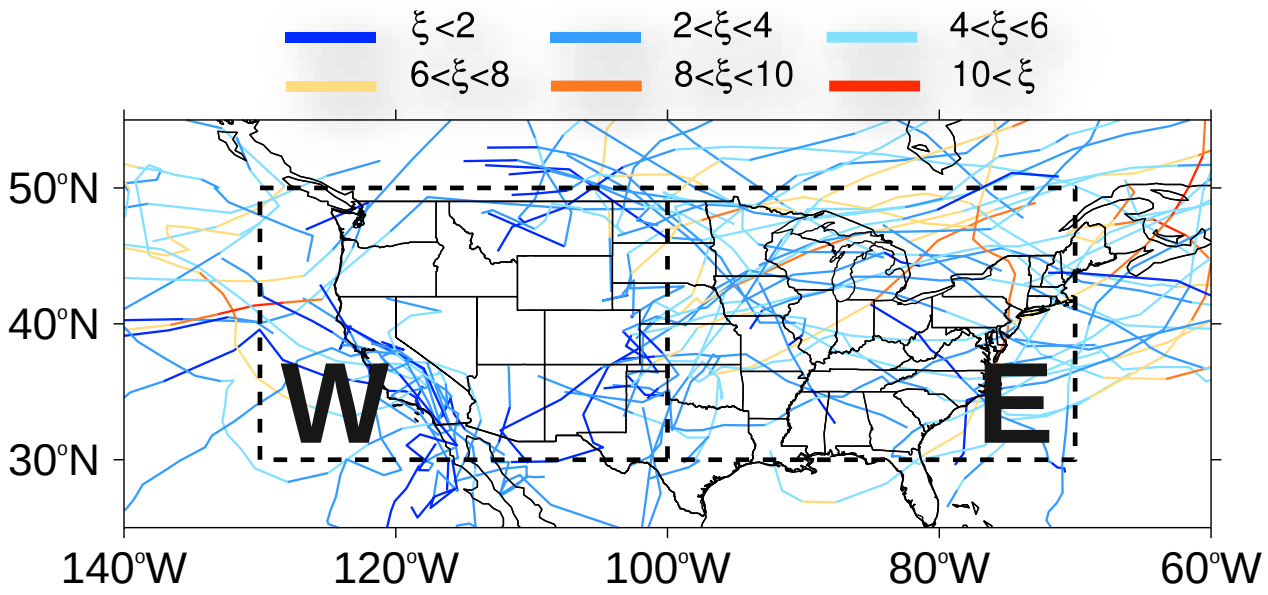
Can we build a catalogue of SI events in using the MERRA-2 Reanalysis?

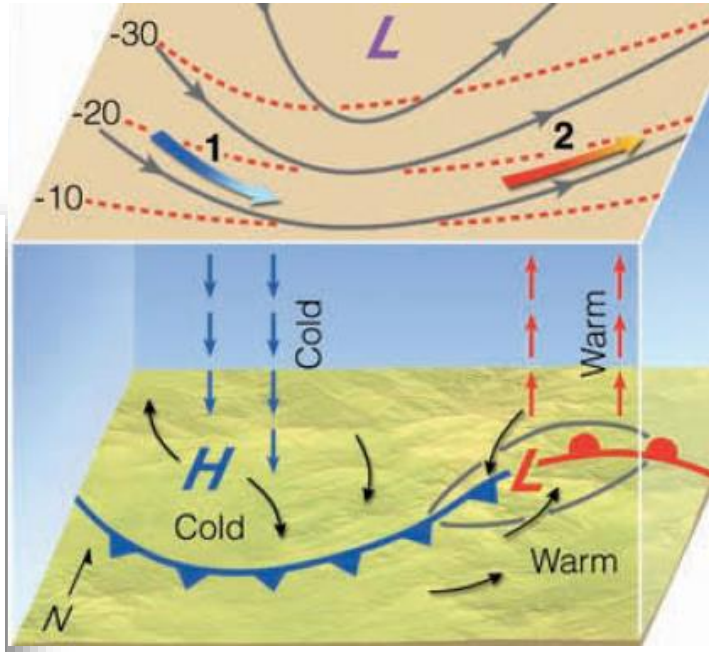
Construct Upper-level Tracks

- 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





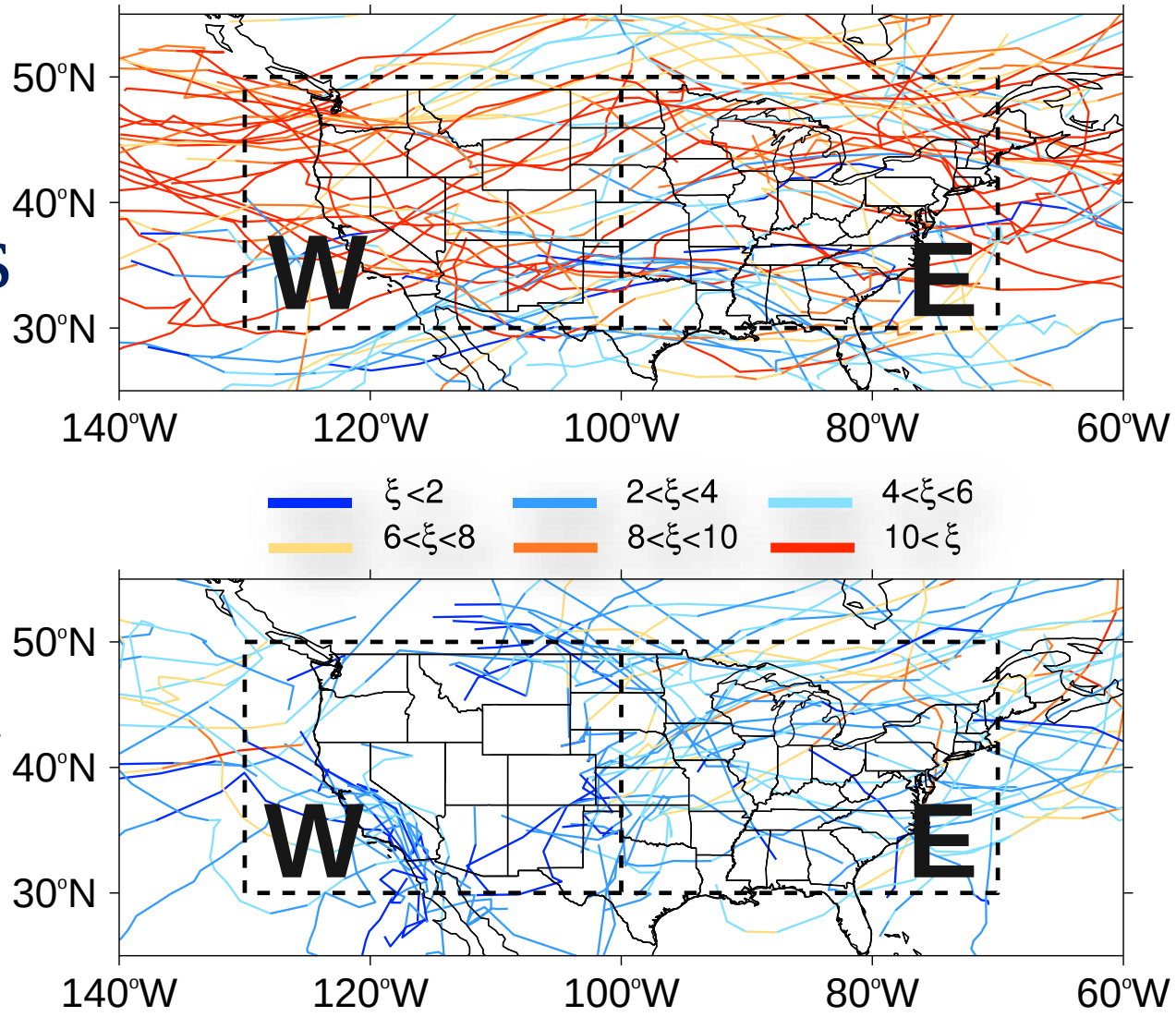
Knowland et al., in prep.

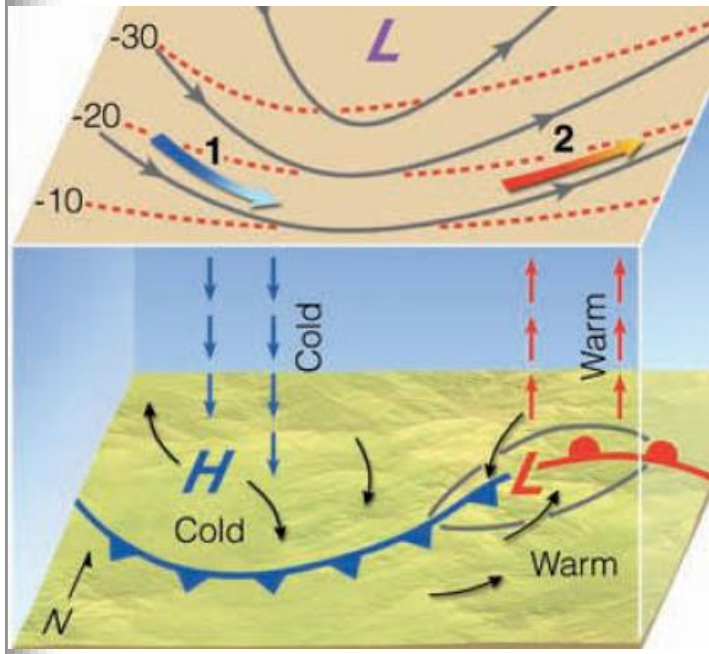
Construct Upper-level Tracks

$\zeta_{300\ hPa}$ 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.

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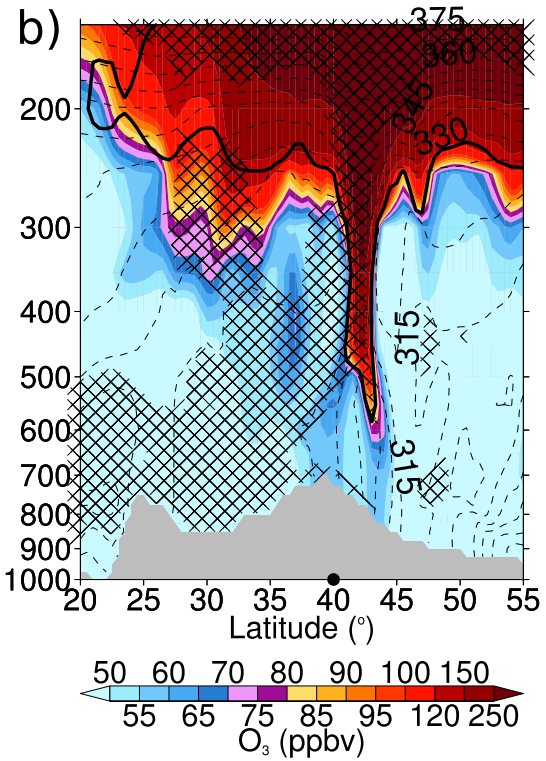
SI Filtering Methodology

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
    1. max EPV > 2 PVU,
    2. min RH < 10 %,
    3. max O_3 > 25 ppbv, > 50 ppbv, > 100 ppbv,

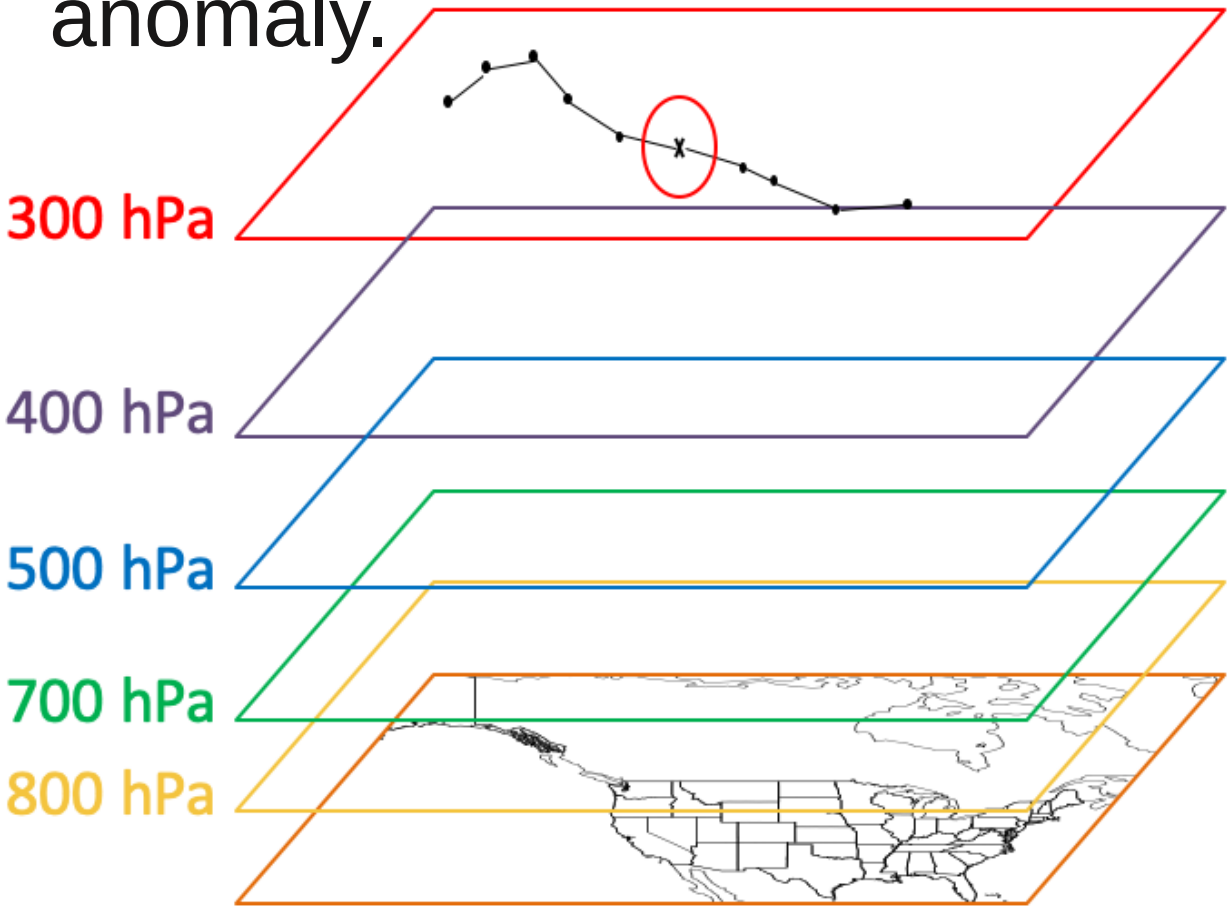
within 7°search radius

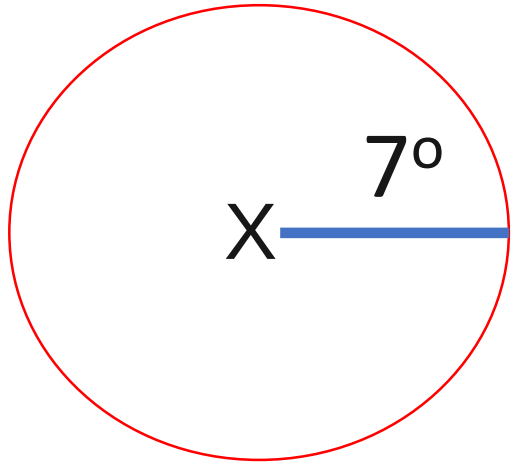


Knowland et al., in prep.

2. Sample for anomalies

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



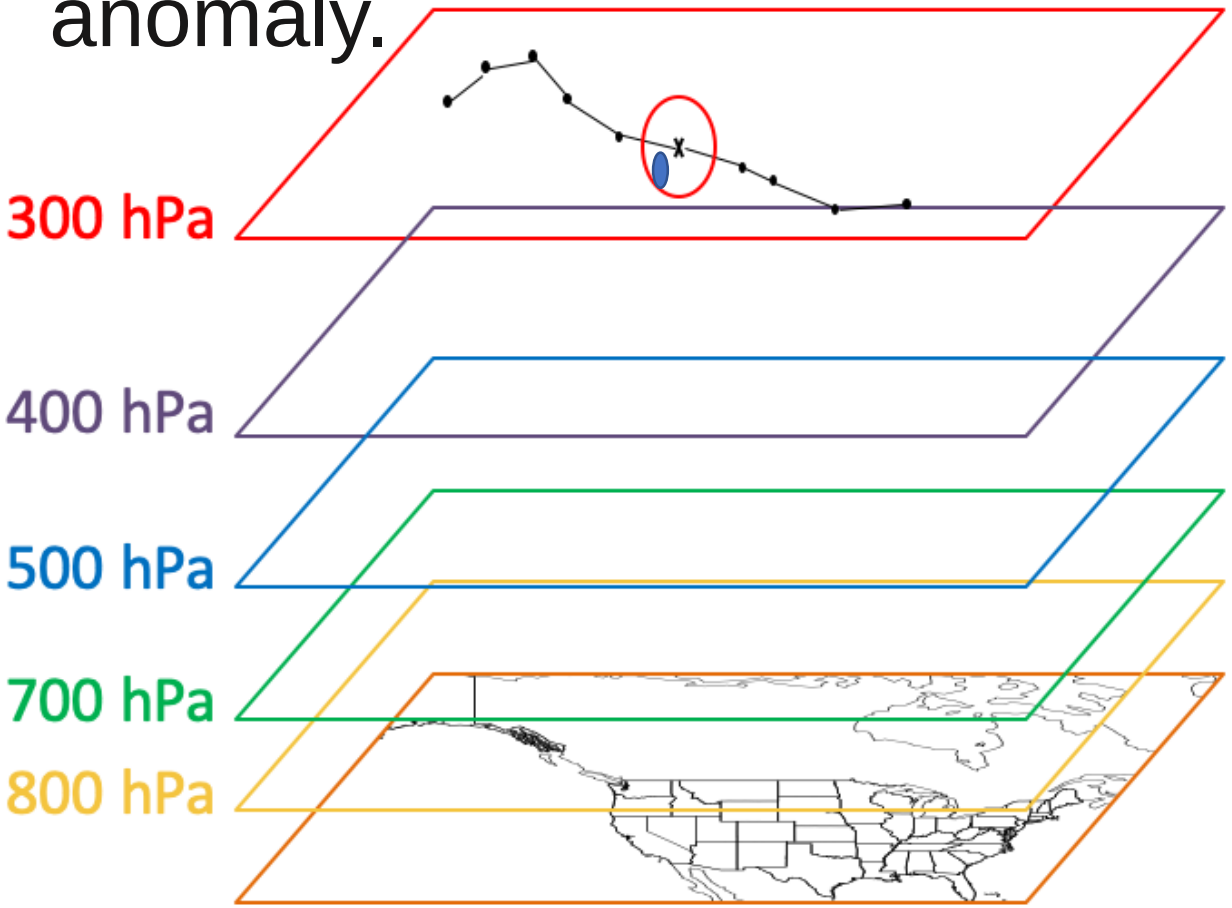


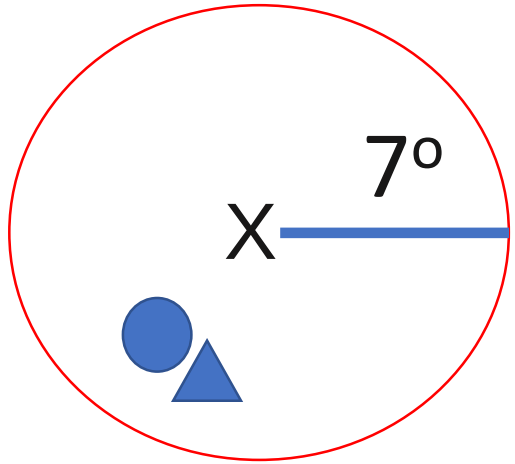
Radial coordinate system for a given radius is chosen

Knowland et al., in prep.

2. Sample for anomalies

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





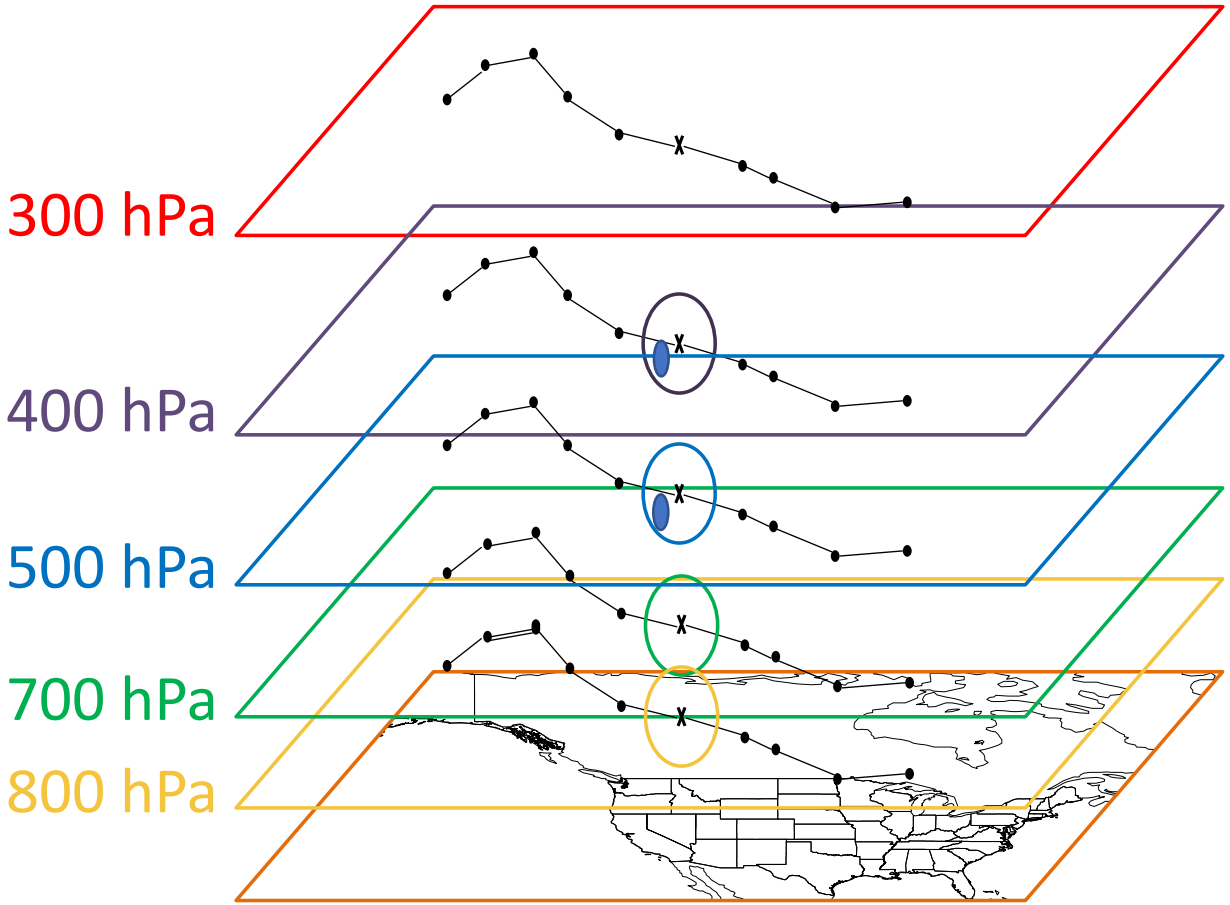
Location of Max EPV anomaly

Location of Max O_3 anomaly

Knowland et al., in prep.

2. Sample for anomalies

- Working toward the surface, check that at least one point along the track has max EPV anomaly > 2PVU.

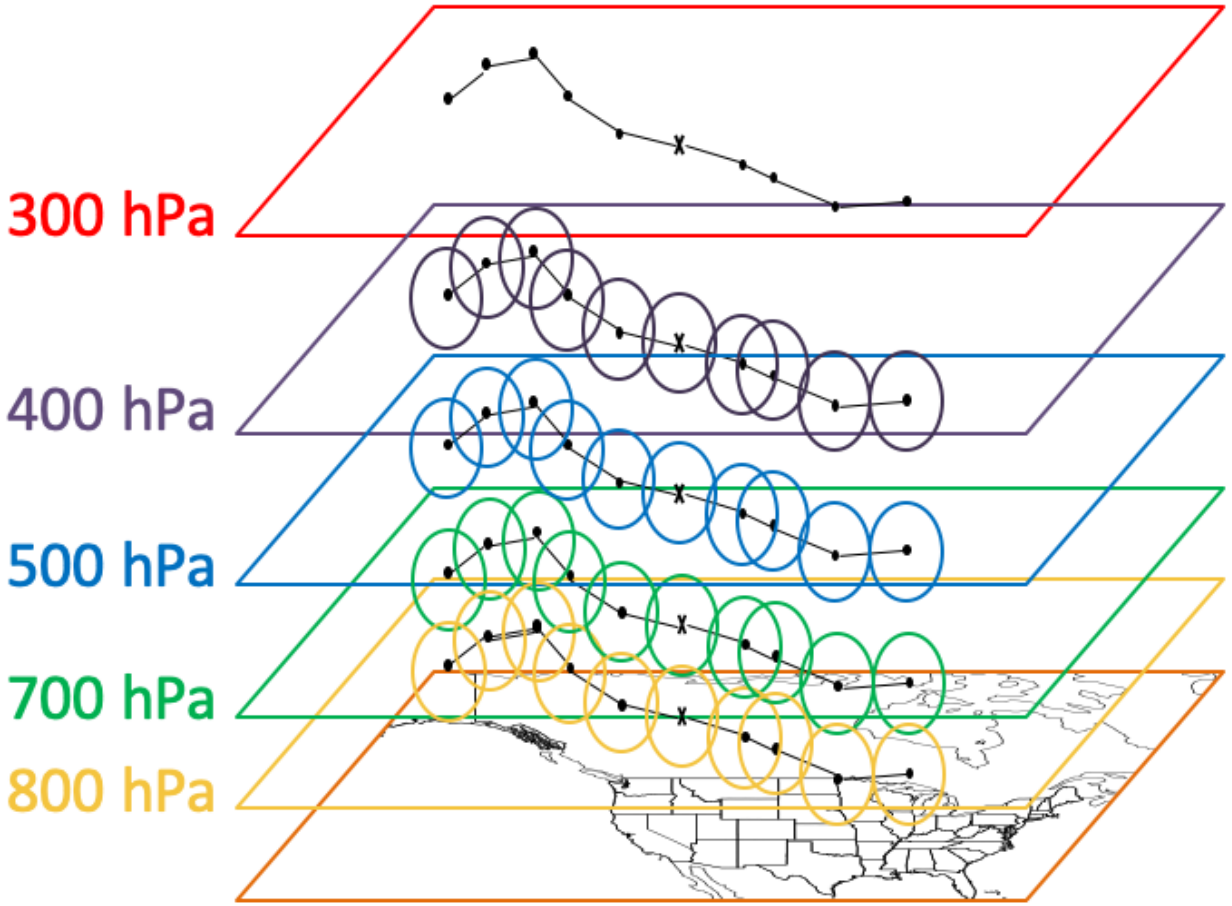


➢ Apply to multiple levels at same track point

Knowland et al., in prep.

2. Sample for anomalies

- Working toward the surface, check that at least one point along the track has max EPV anomaly > 2PVU.



- ➢ Apply to multiple levels at same track point
- ➢ Apply to all points along the track

Knowland et al., in prep.

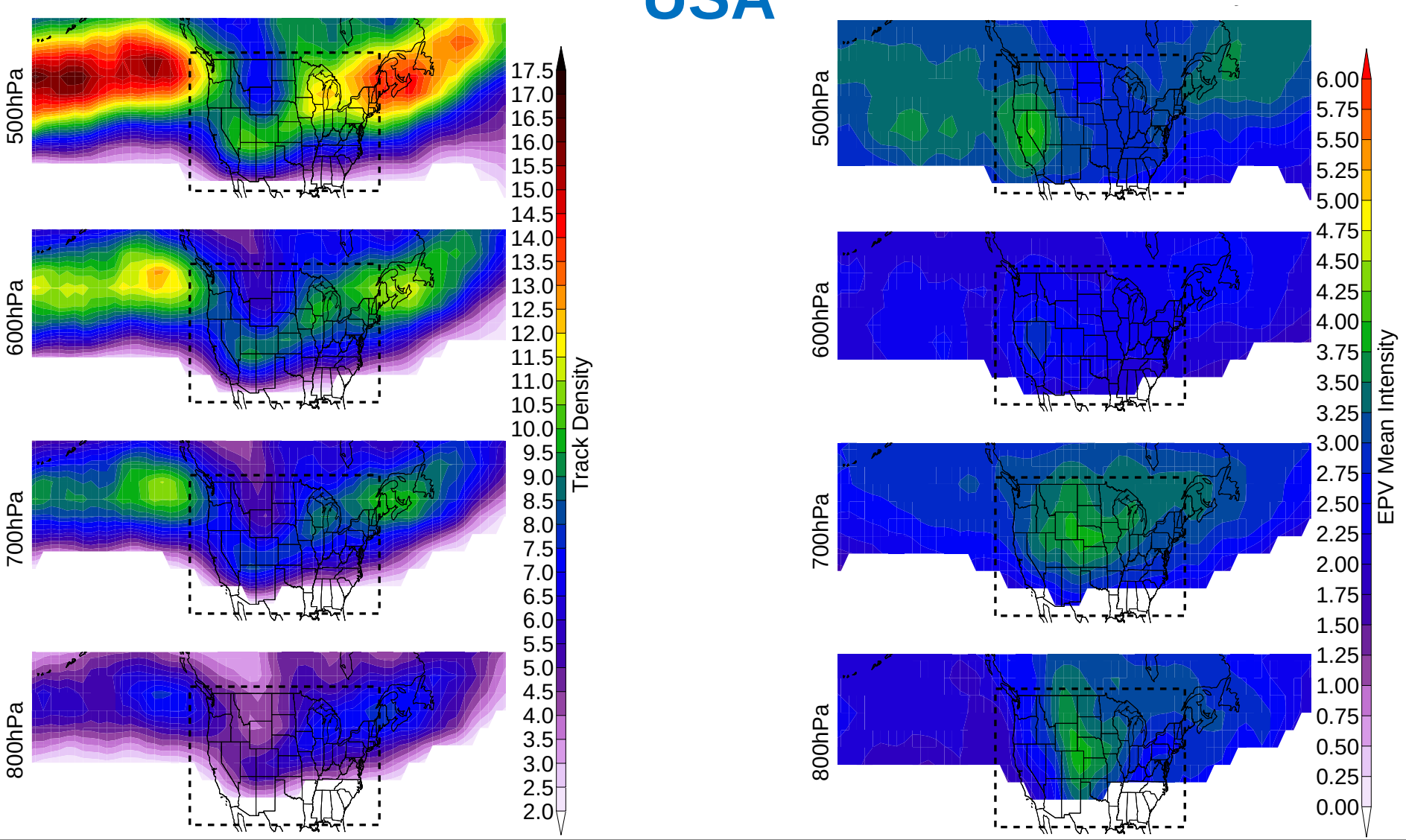
Subjective SI Filtering Methodology

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 %, and max O_3 > 25 ppbv within 7°search radius
3. Subset tracks where EPV > 2PVU for 4 timesteps at each level
4. Identify tracks where maximum O_3 anomaly occurred in Western or Eastern USA

Knowland et al., in prep.

SI Filtered tracks: MERRA2 MAM 1980-2014 USA



Knowland et al., in prep.

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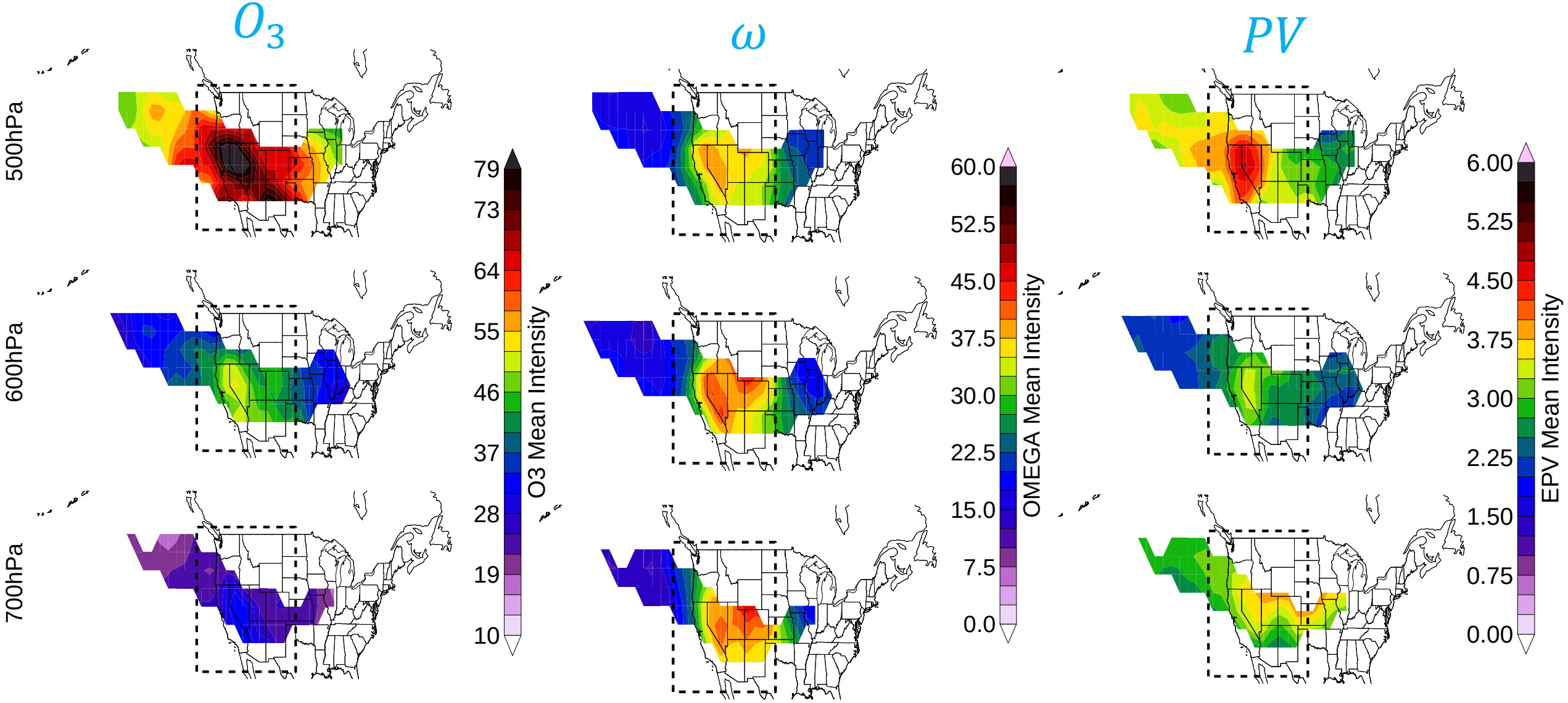
SI Filtered tracks: Western USA MAM 2005-2014



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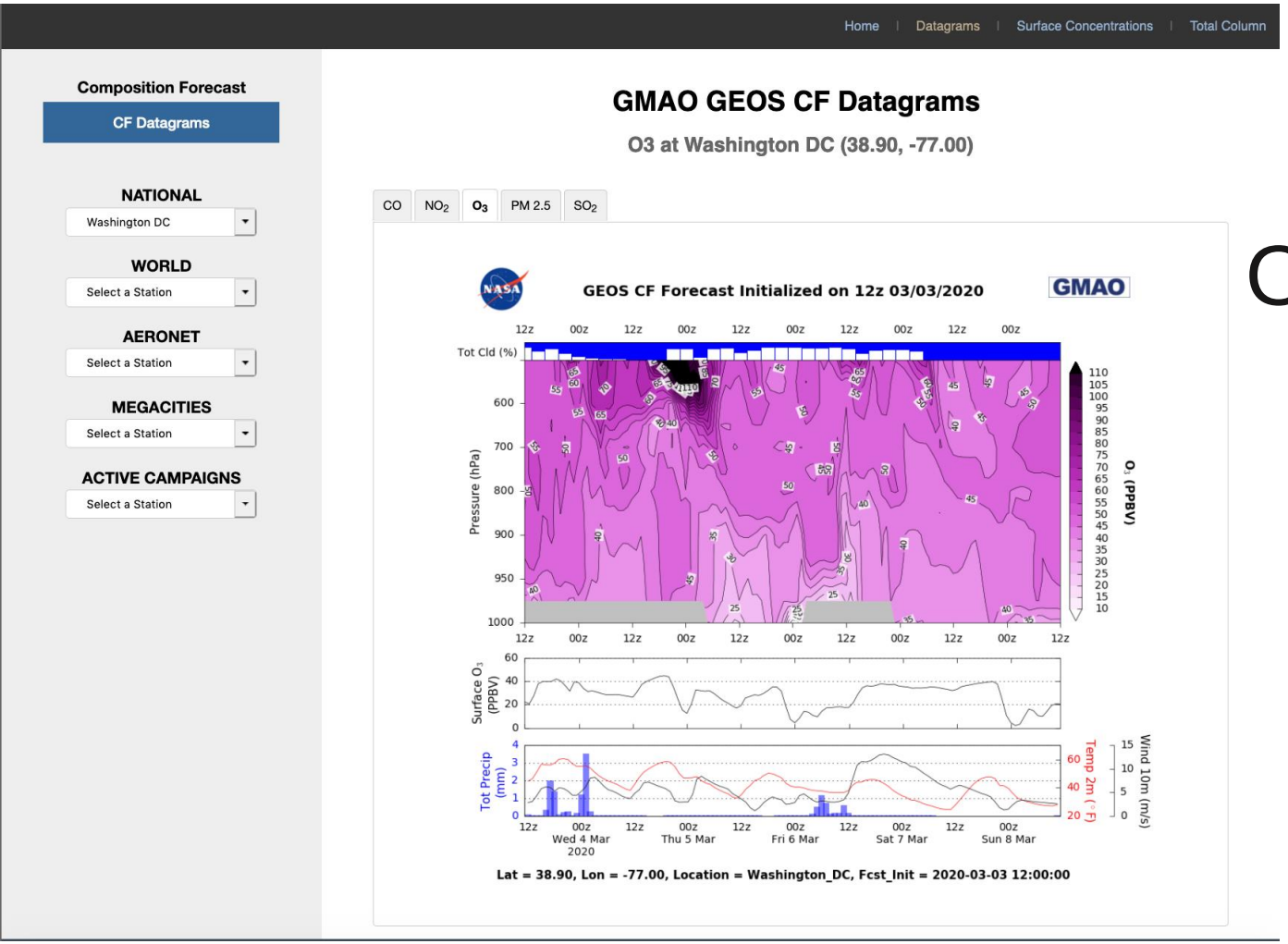
Question 3

Can we forecast SI events in GEOS forecasting products?

Forecasting and validating SI events

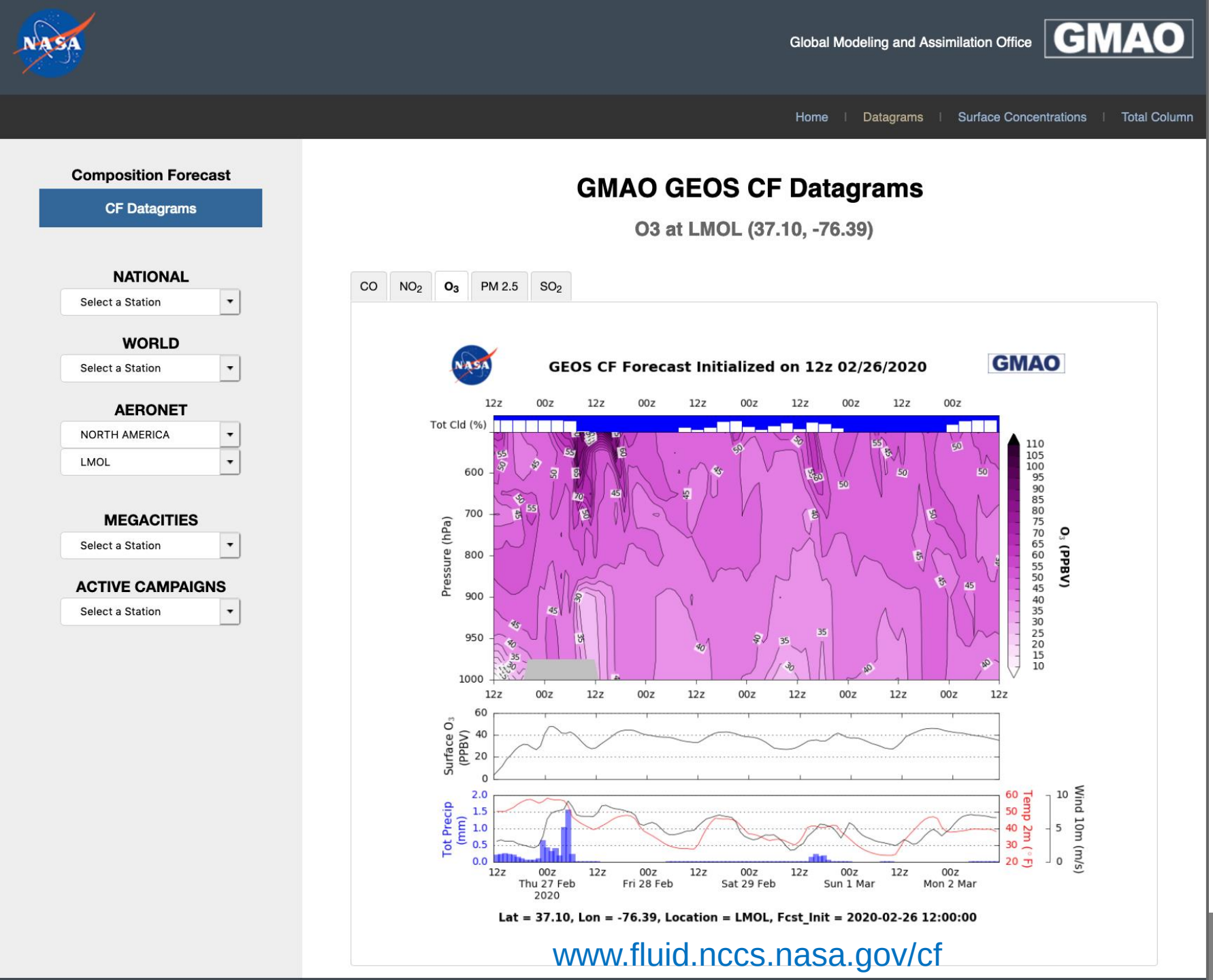


GEOS - CF

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

www.fluid.nccs.nasa.gov/cf



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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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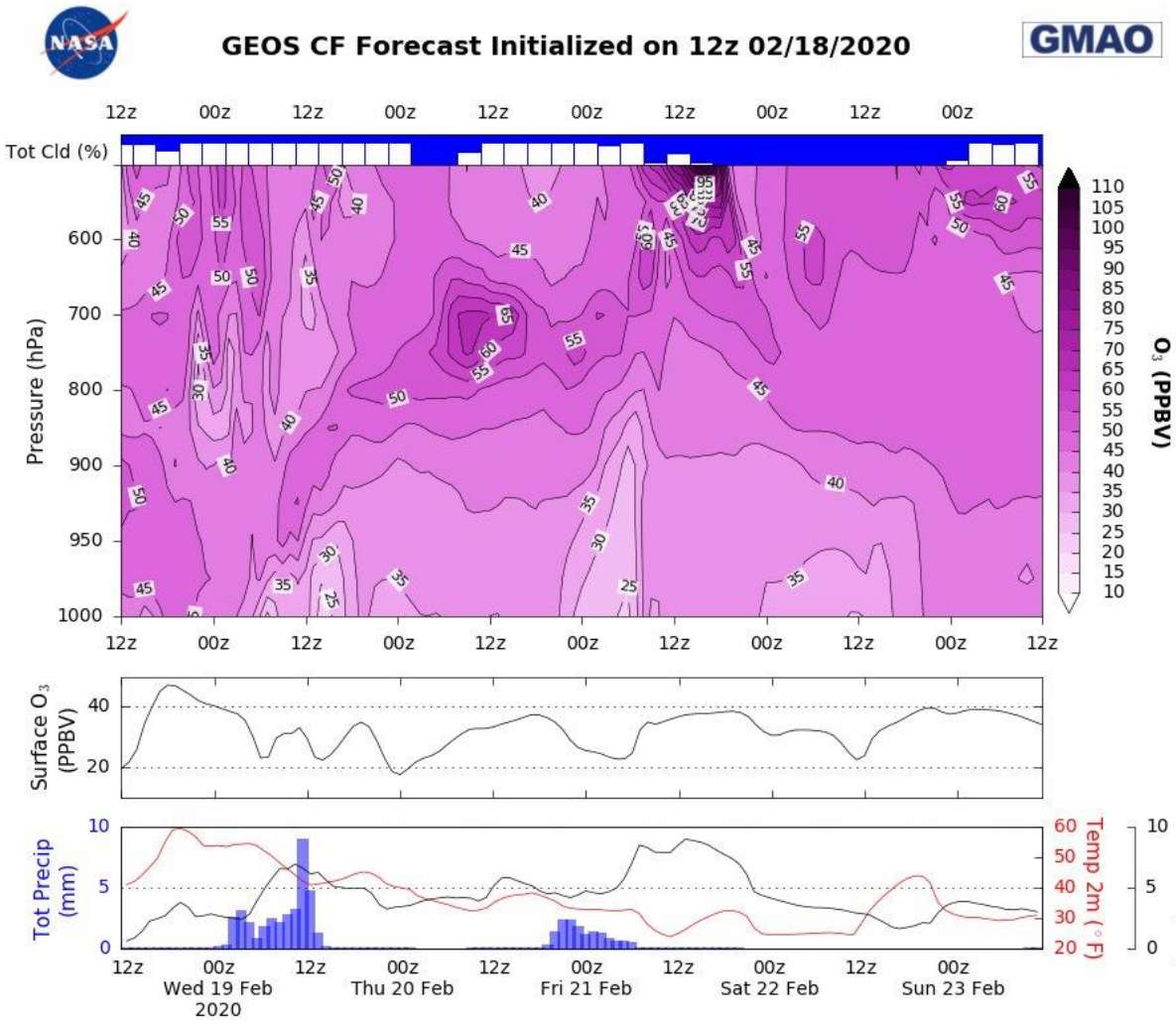
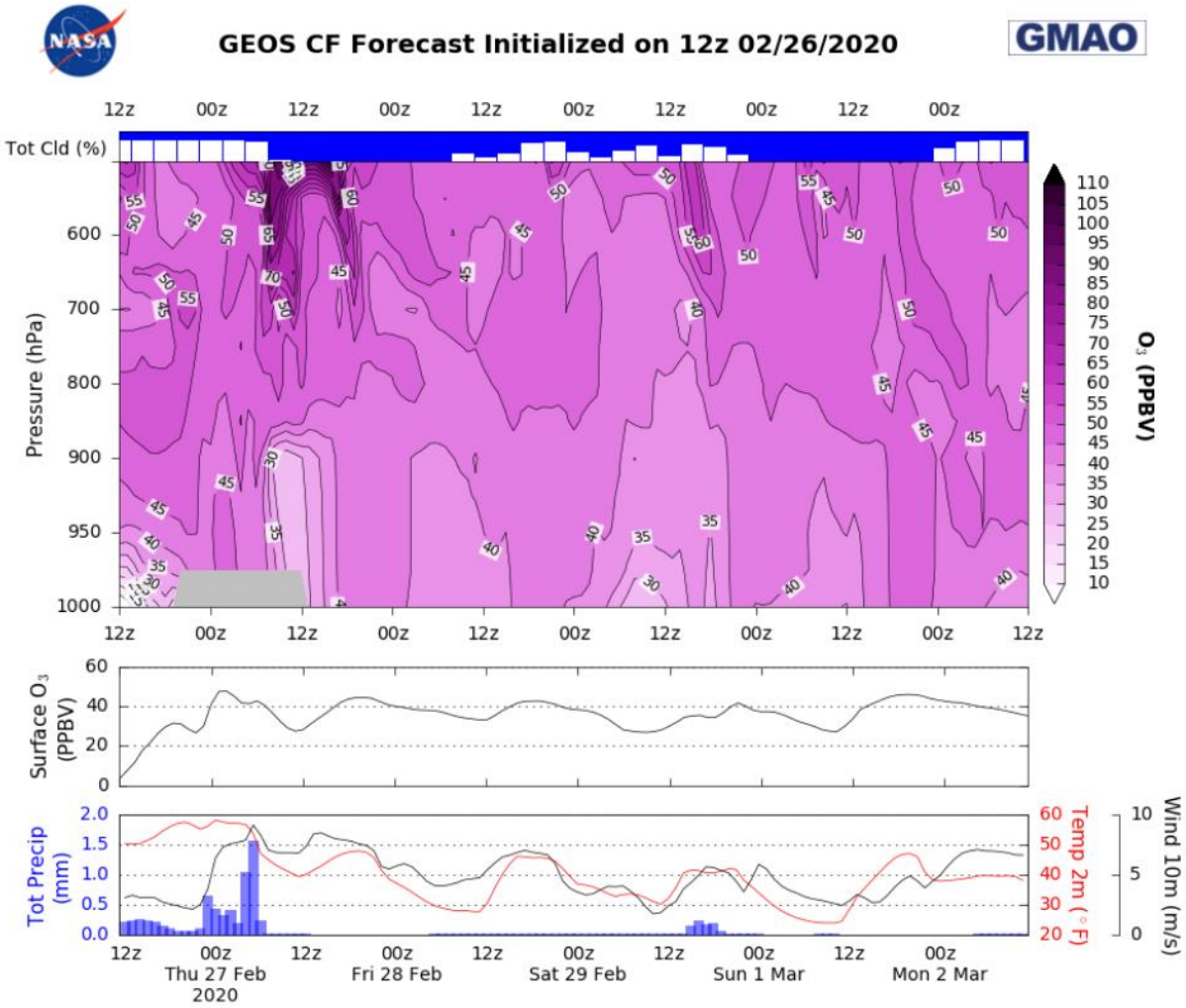
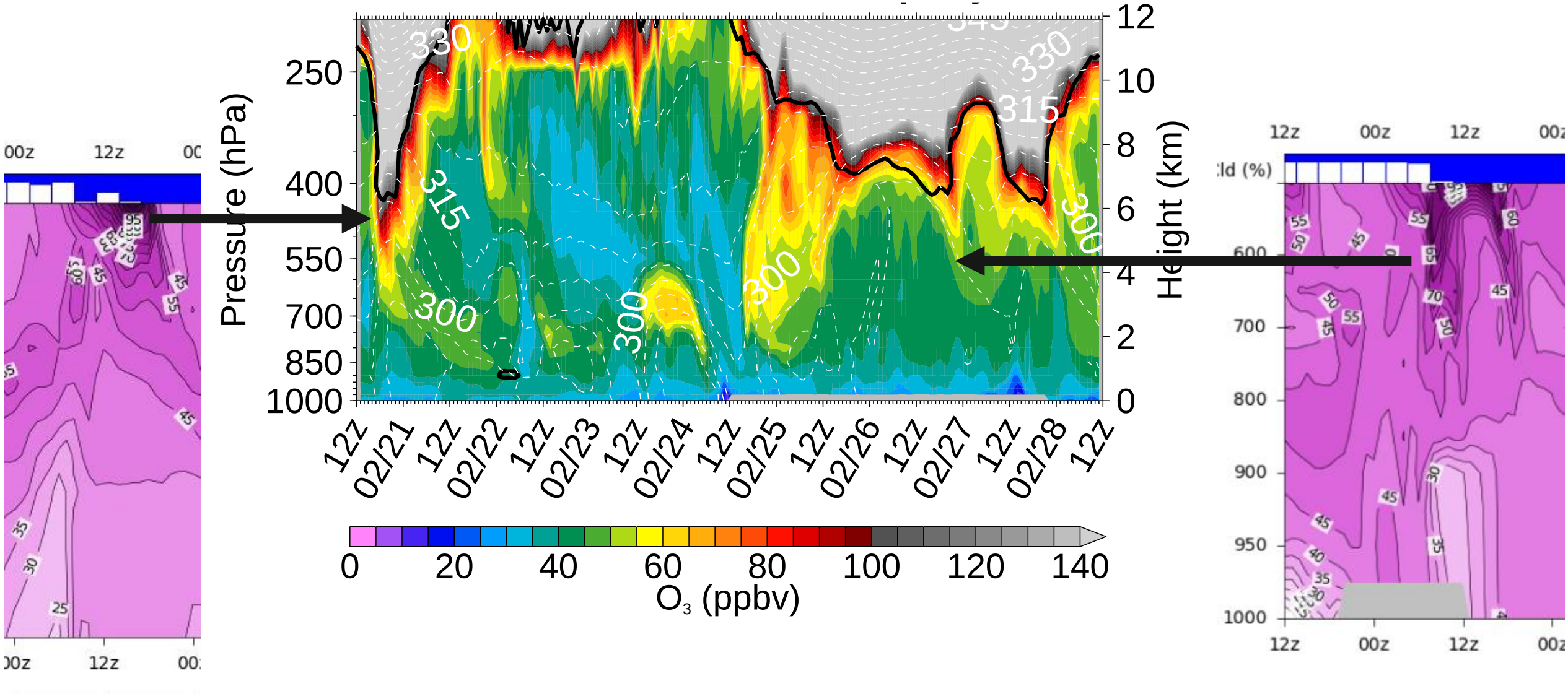
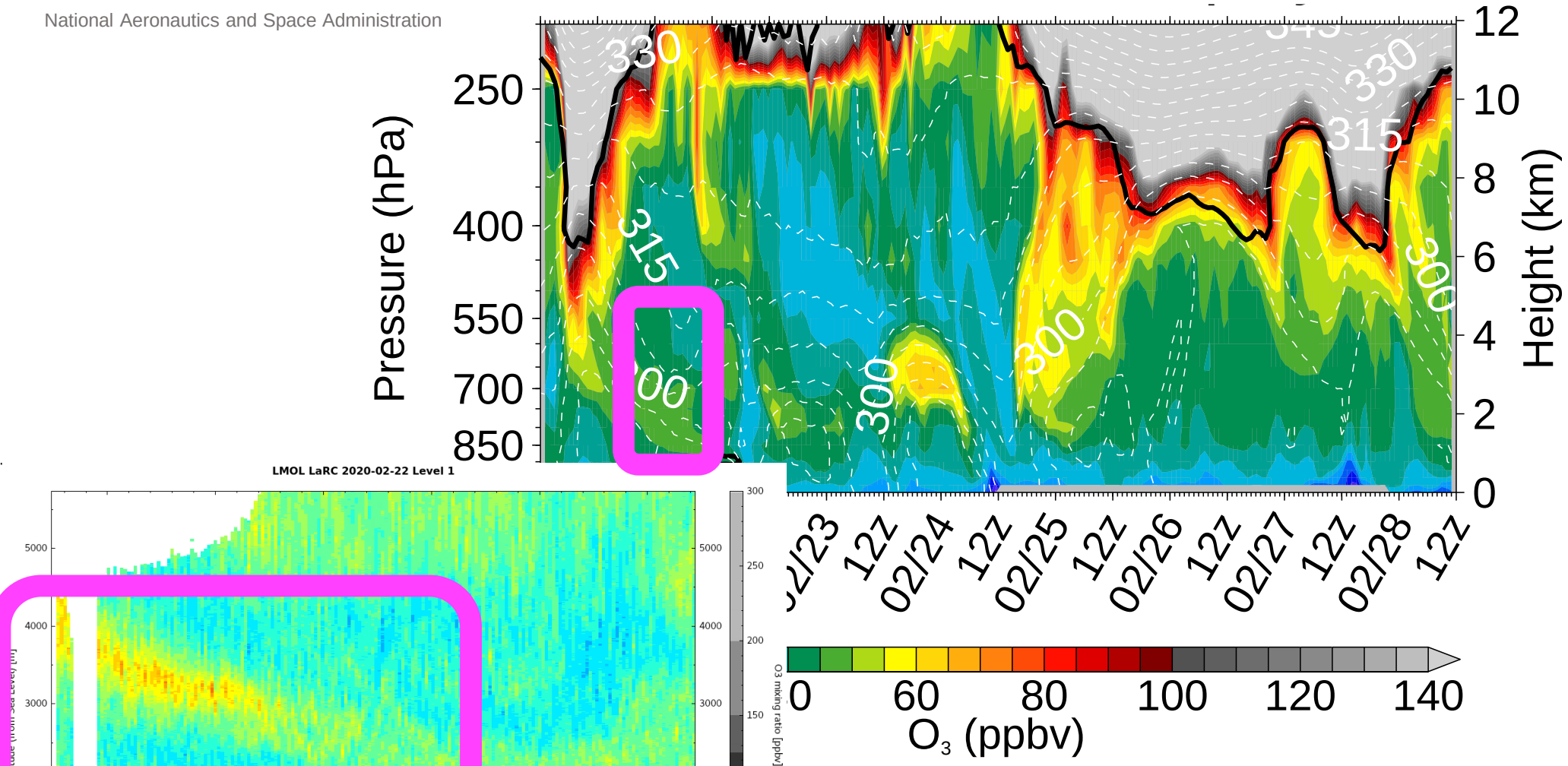
GEOS-CF Forecasts for NASA Langley: "LMOL"



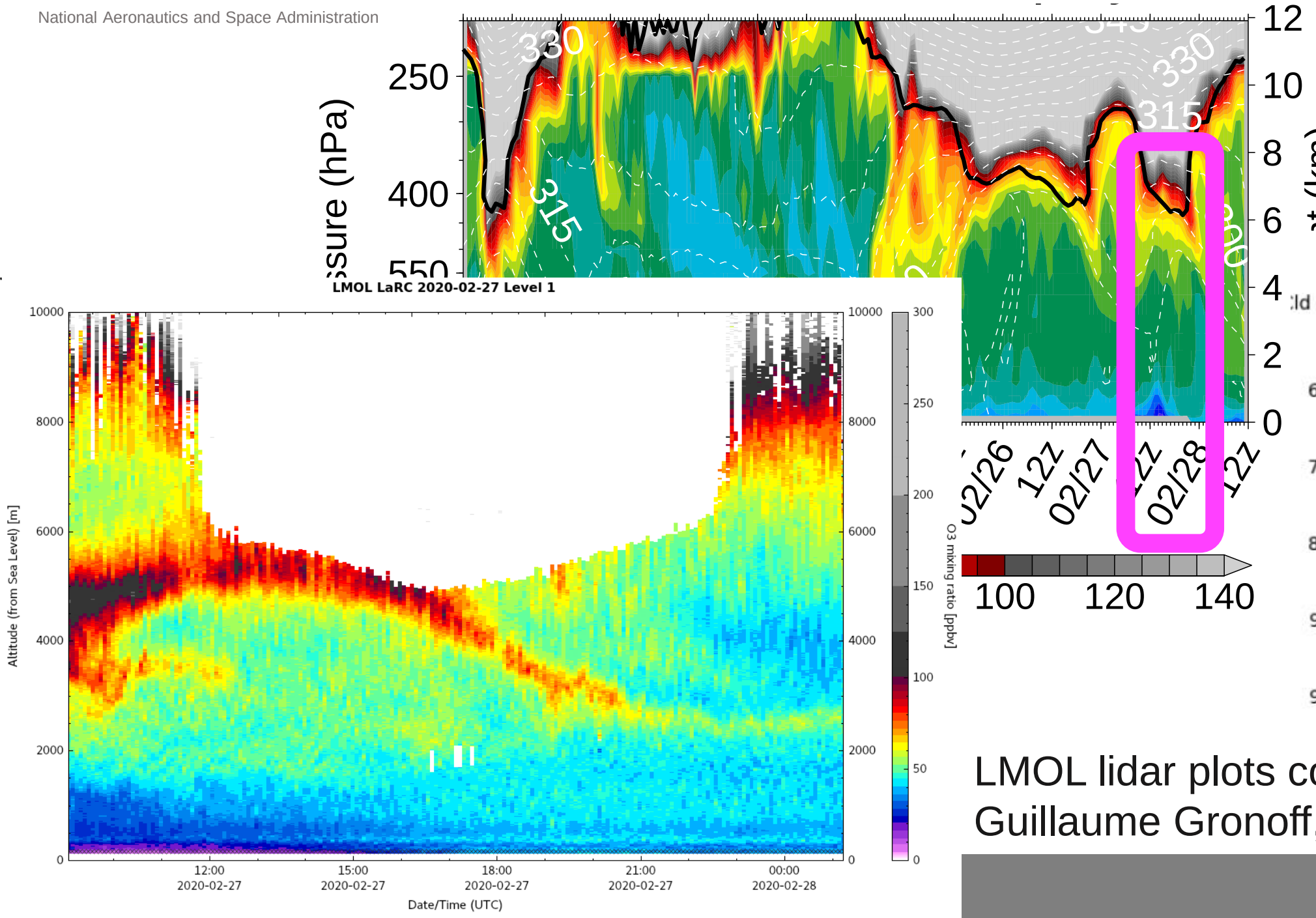


GEOS-CF ‘analysis’ at Langley (12z Feb 20 – 12z Feb 28, 2020)





LMOL lidar plots courtesy of Guillaume Gronoff, LaRC



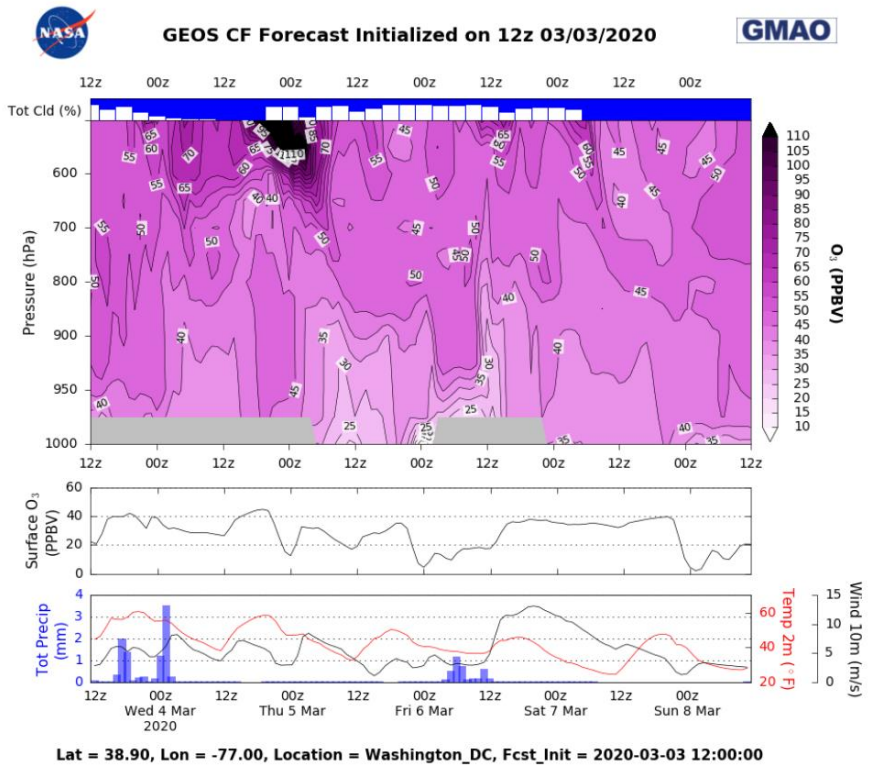
LMOL lidar plots courtesy of Guillaume Gronoff, LaRC

John Sullivan (GSFC) and Guillaume Gronoff (LaRC) are set to measure today ☺

GMAO GEOS CF Datagrams

O3 at Washington DC (38.90, -77.00)

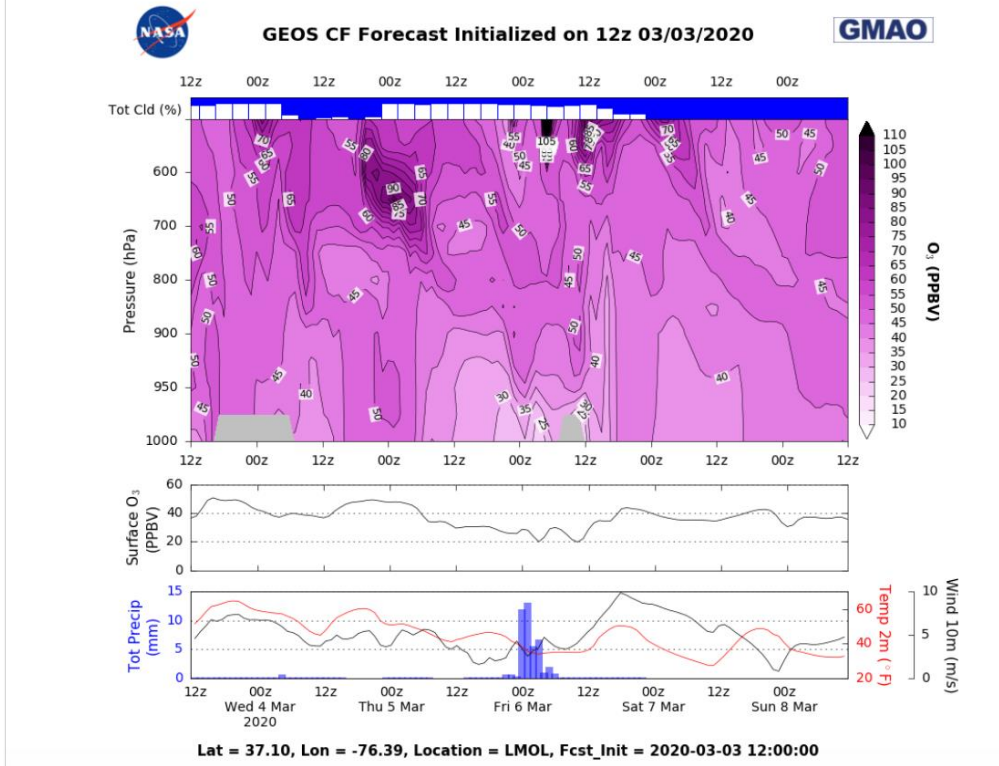
CO | NO_2 | O_3 | PM 2.5 | SO_2



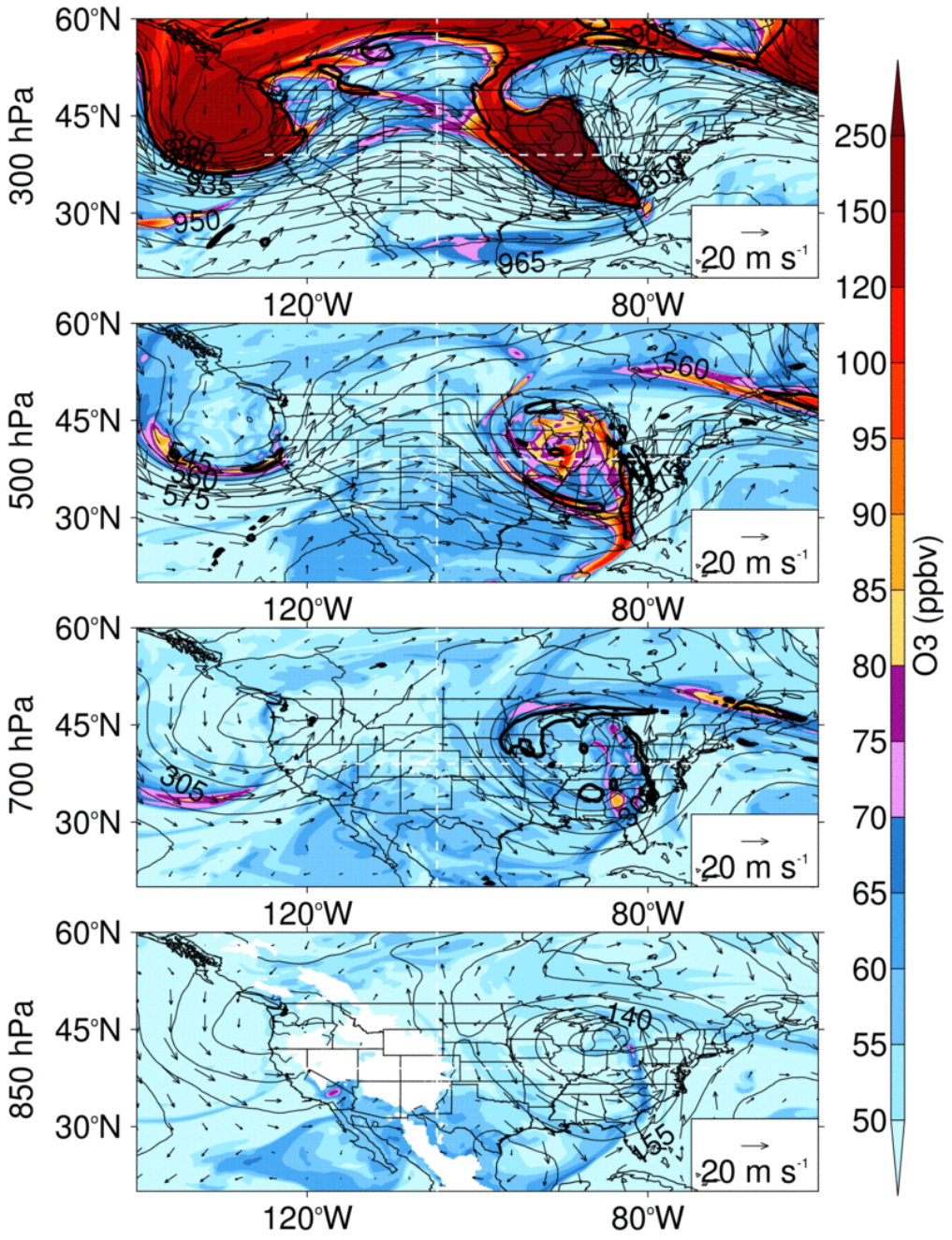
GMAO GEOS CF Datagrams

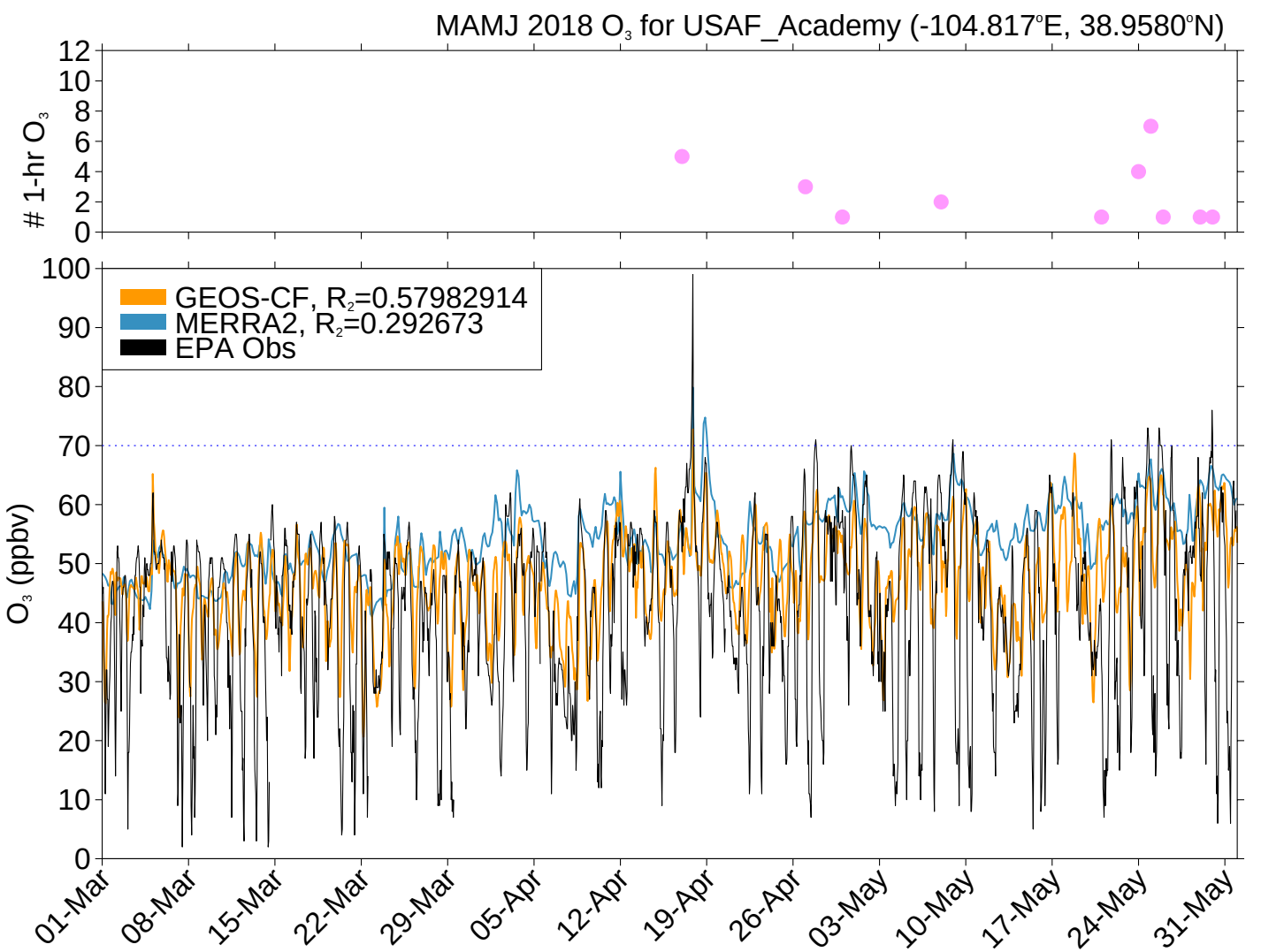
O3 at LMOL (37.10, -76.39)

CO | NO_2 | O_3 | PM 2.5 | SO_2



17 April 2018 SI event





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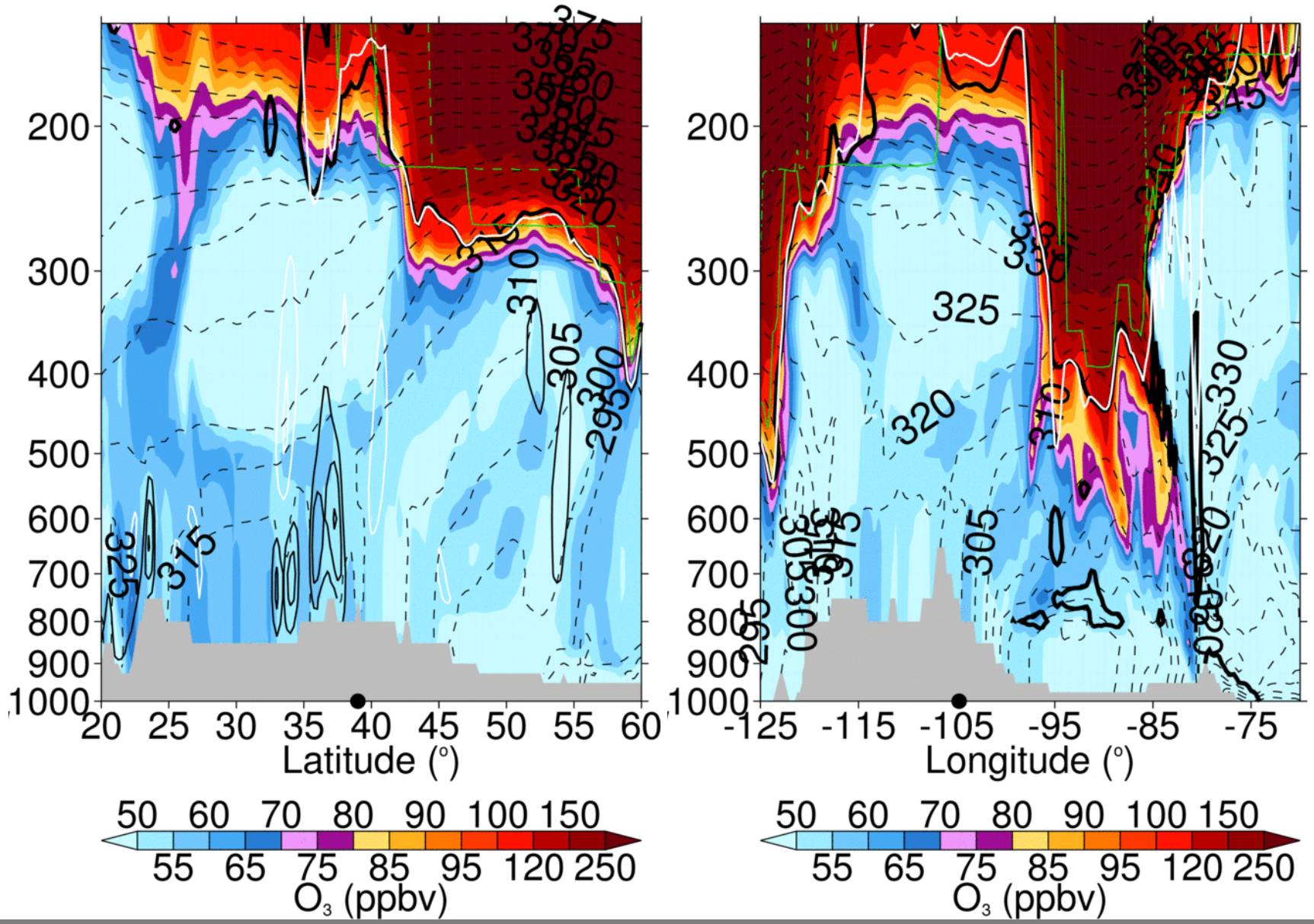
Interpolated tropopause height: TROPPI (by Larry Coy)

TROPPB: Higher pressure level for 3 PVU and thermal tropopause.

TROPPI:
Tropopause pressure using 380 K near equator
Vertically sums up the weight of the atmosphere from top towards the surface for model levels with PV > 2 PVU elsewhere

For columns with multiple 2PVU levels, weight model layer pressure thickness by how much of the PV > 2PVU.

Figure caption:
2 PVU (black contour)
TROPPI (white contour)
TROPPB (solid green)
TROPPV (dashed green)
TROPPT (dashed dot green)



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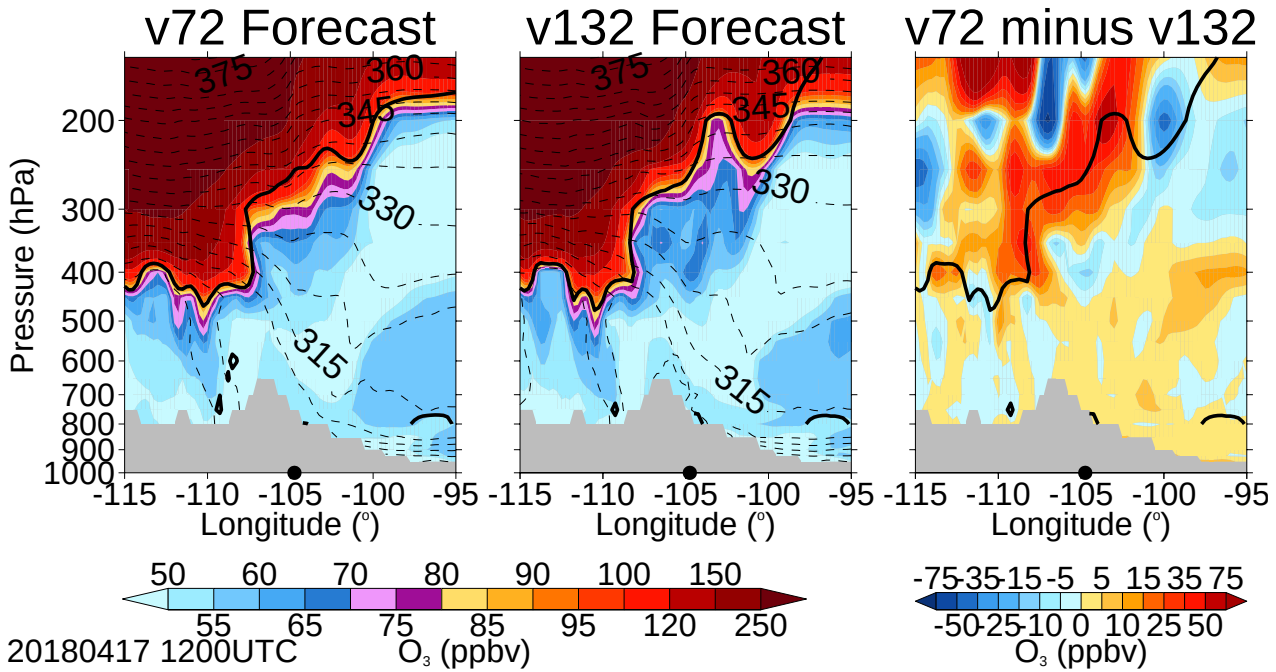
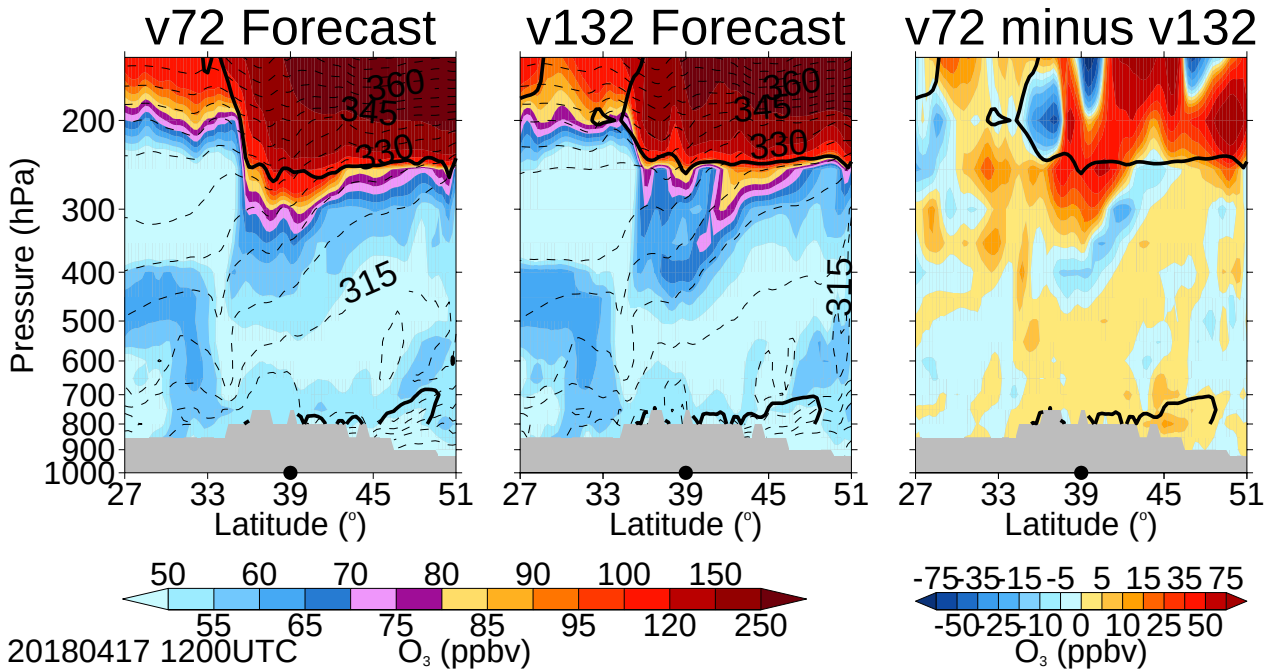
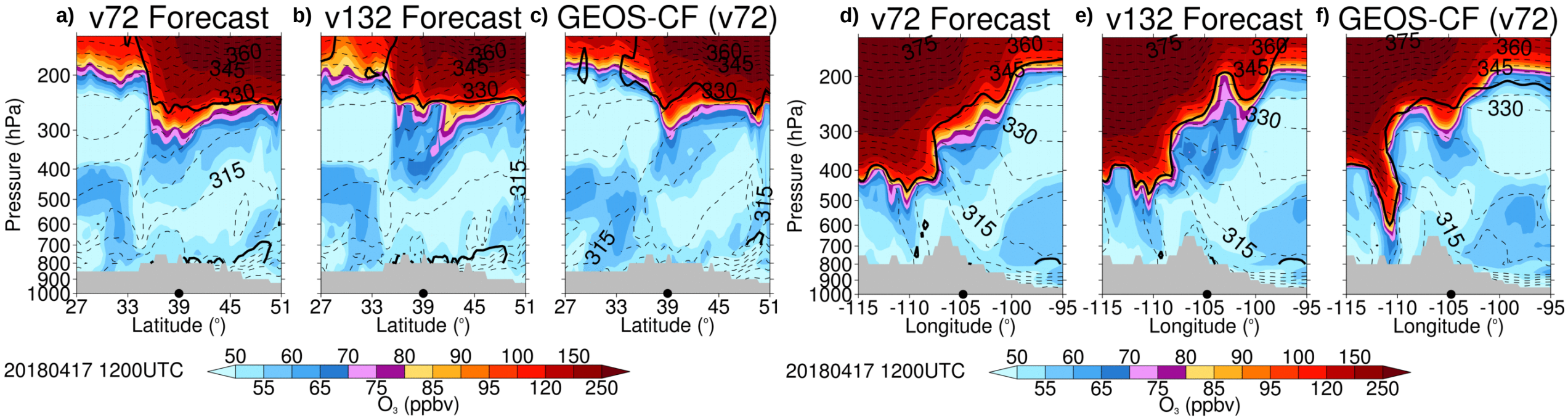
Increased vertical resolution in GEOS

- The purpose of these experiments was to investigate how increasing the model's vertical resolution would affect transfer of constituents in and between the troposphere and stratosphere.
- GEOS-CF forecast simulation of April 2018 SI event.
    1. Current GEOS grid: 72 model layers
    2. Future GEOS grid: 132 model layers
- Both simulations were initialized with the GEOS-CF one day before the event (runs performed by Elliot Sherman).



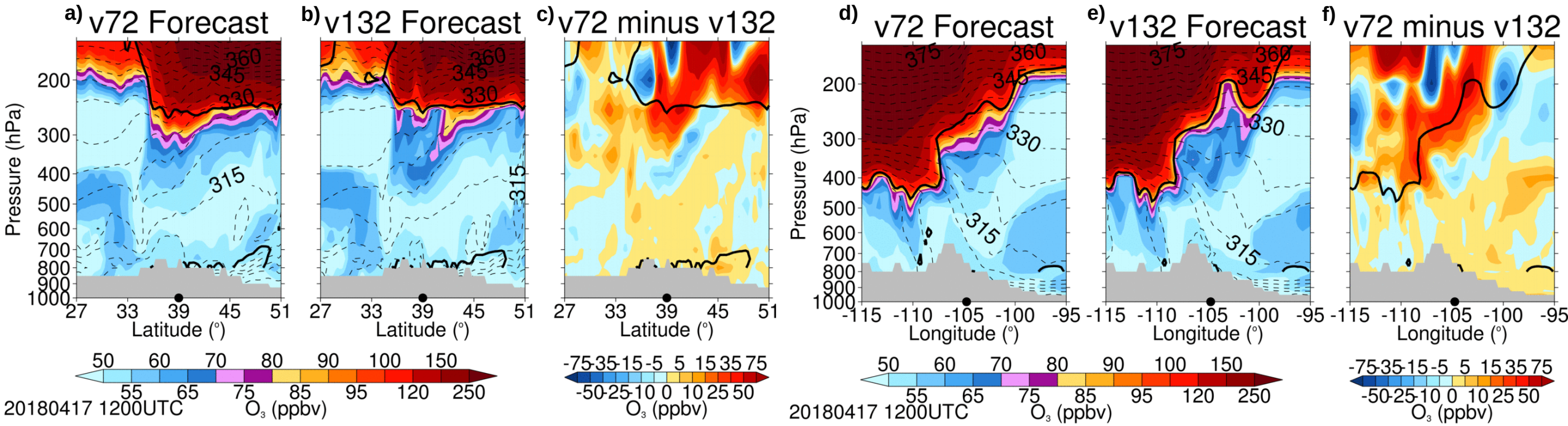


Increased vertical resolution in GEOS



The high concentration of ozone in the v72 Forecast descends to lower pressure levels (a) than in the v132 Forecast (b), however the tropopause in the v132 Forecast remains near 550 hPa, similar to the GEOS-CF replay, for longer.

Increased vertical resolution in GEOS



The 132-level simulation appears to lag the 72-level simulation on the order of a few hours. The lag is most visible in the difference plots where high negative values follow positive values.

Summary

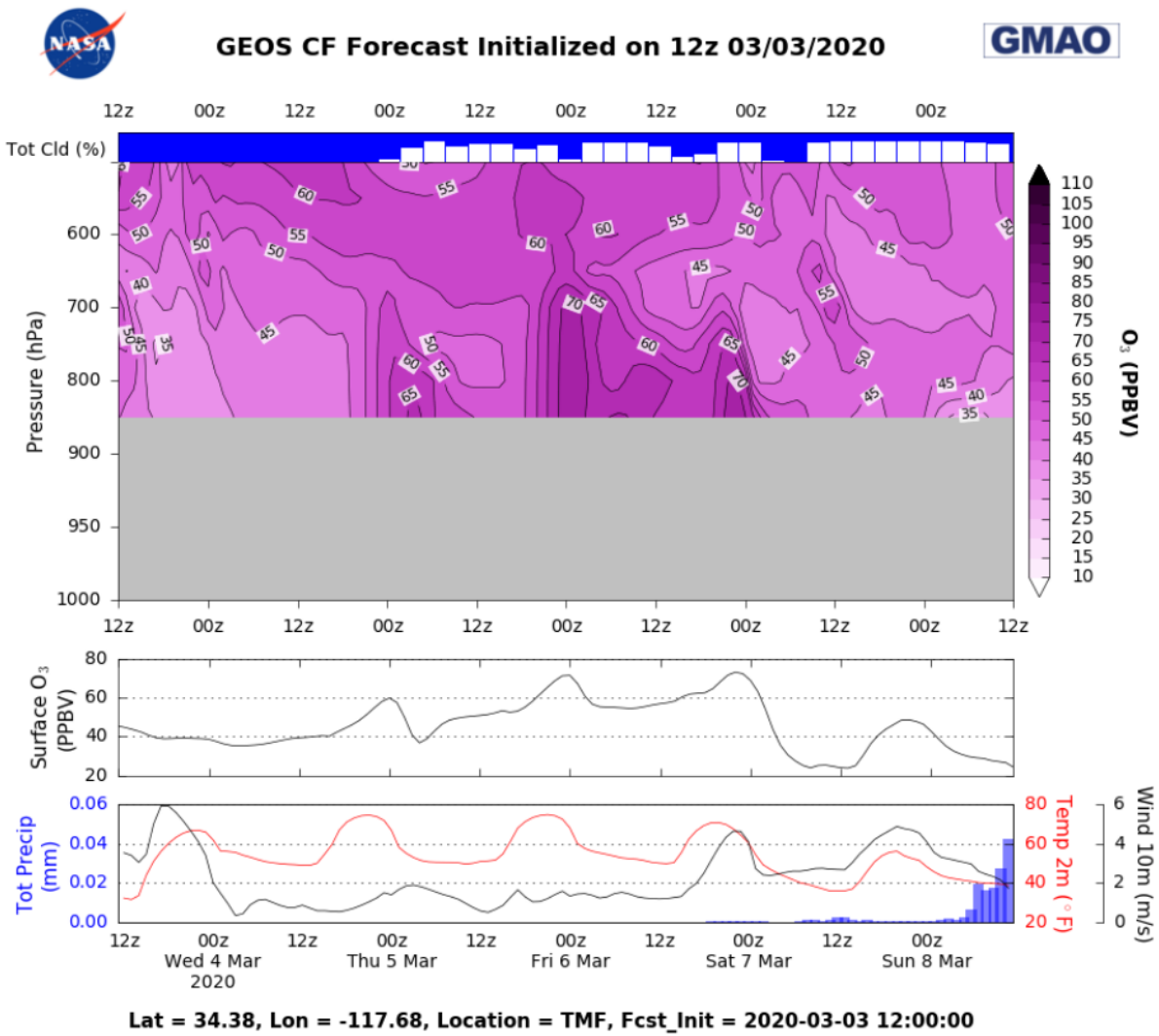
- ✓ MERRA-2 is a high-resolution global reanalysis which can used in scientific studies to identify SIs by both atmospheric dynamics and O_3
- ✓ GEOS-CF is suitable to support instrument teams measuring tropospheric and lower stratosphere composition
- ➢ Working on best approach to communicate SI potential to interested end-user groups.

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

GMAO GEOS CF Datagrams

O3 at TMF (34.38, -117.68)

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



Thank you for listening!

Ready for the ozonesonde launch?!?!?

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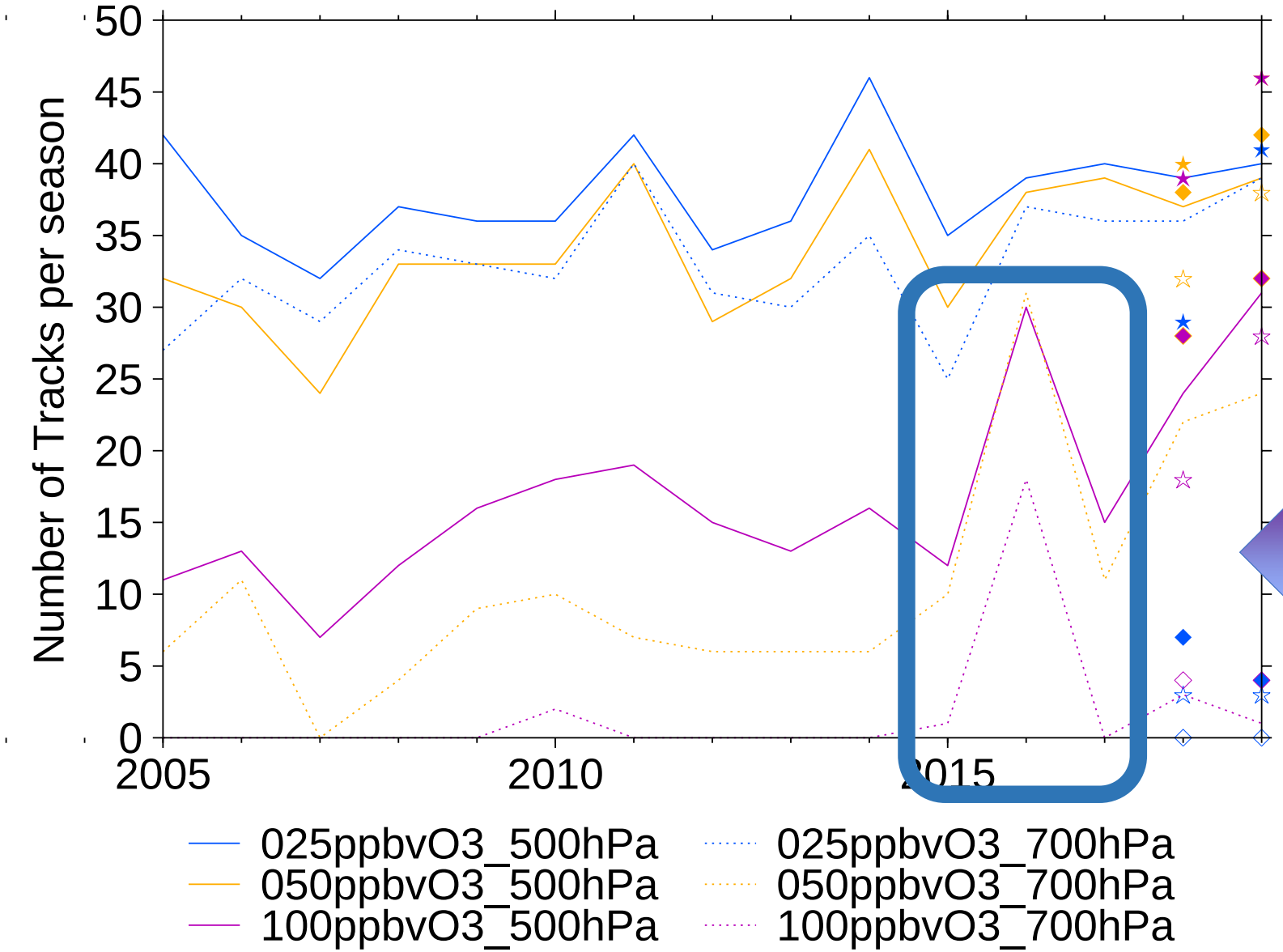
NASA

MAM USA SI Frequency



MERRA-2 (solid lines)

GEOS-FP (500 hPa 700 hPa)

GEOS-CF (500 hPa 700 hPa)

Expected spike in frequency of high O3 events with MLS v 4.2 prior to removal of 261 hPa MLS level

MERRA2 vs GEOS-FP vs GEOS-CF