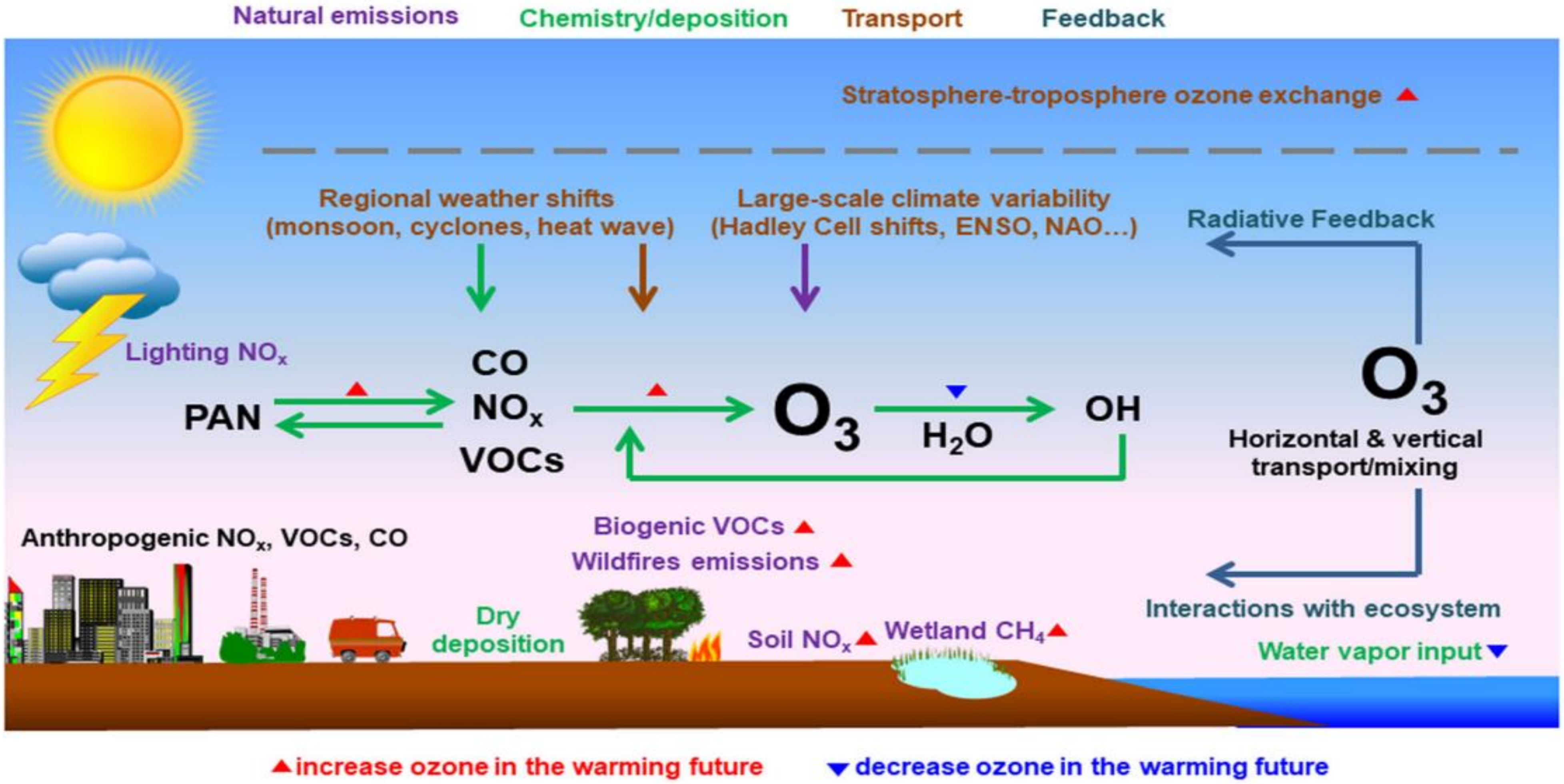
Analysis of a Mid-Atlantic Ozone Episode

Maurice E. D. Roots

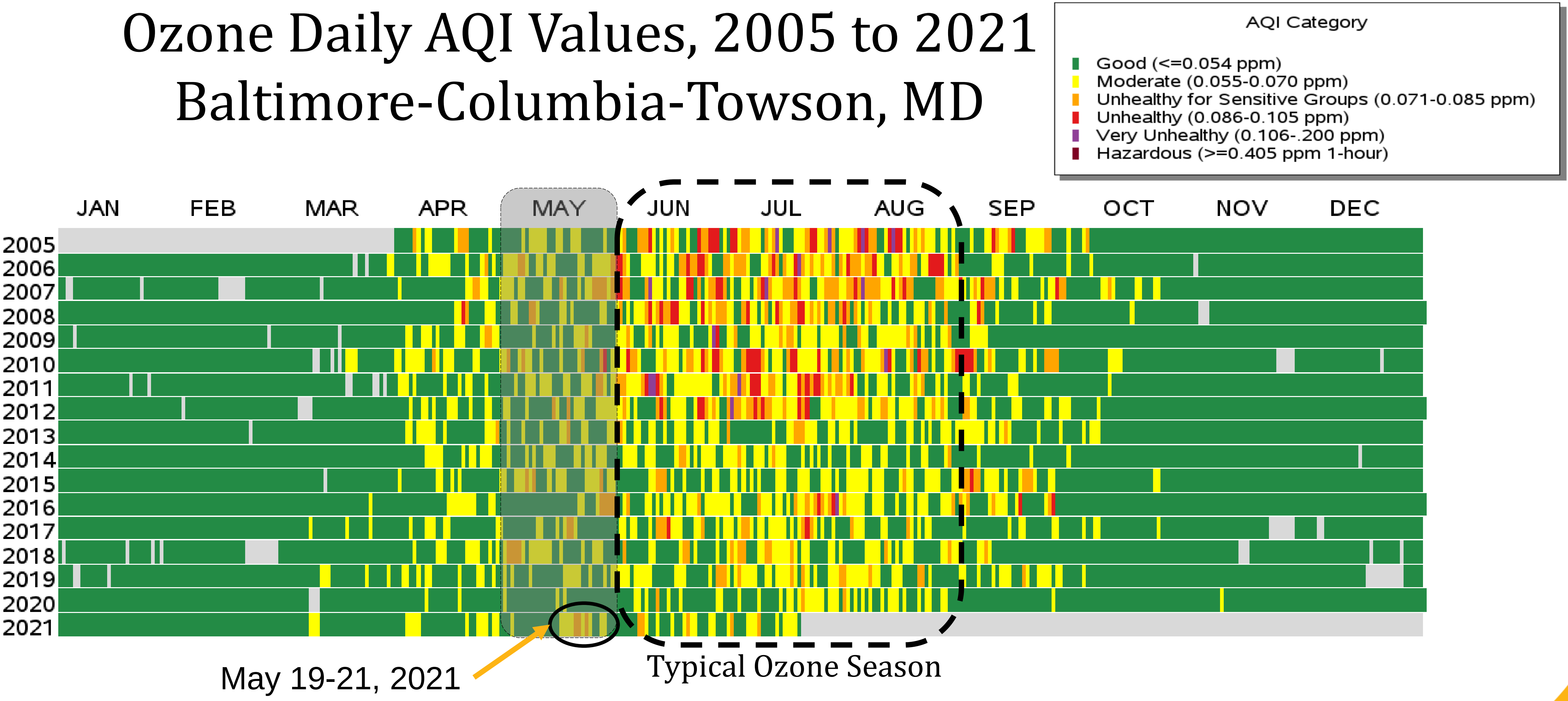
PHYS 650: Atmospheric Measurement

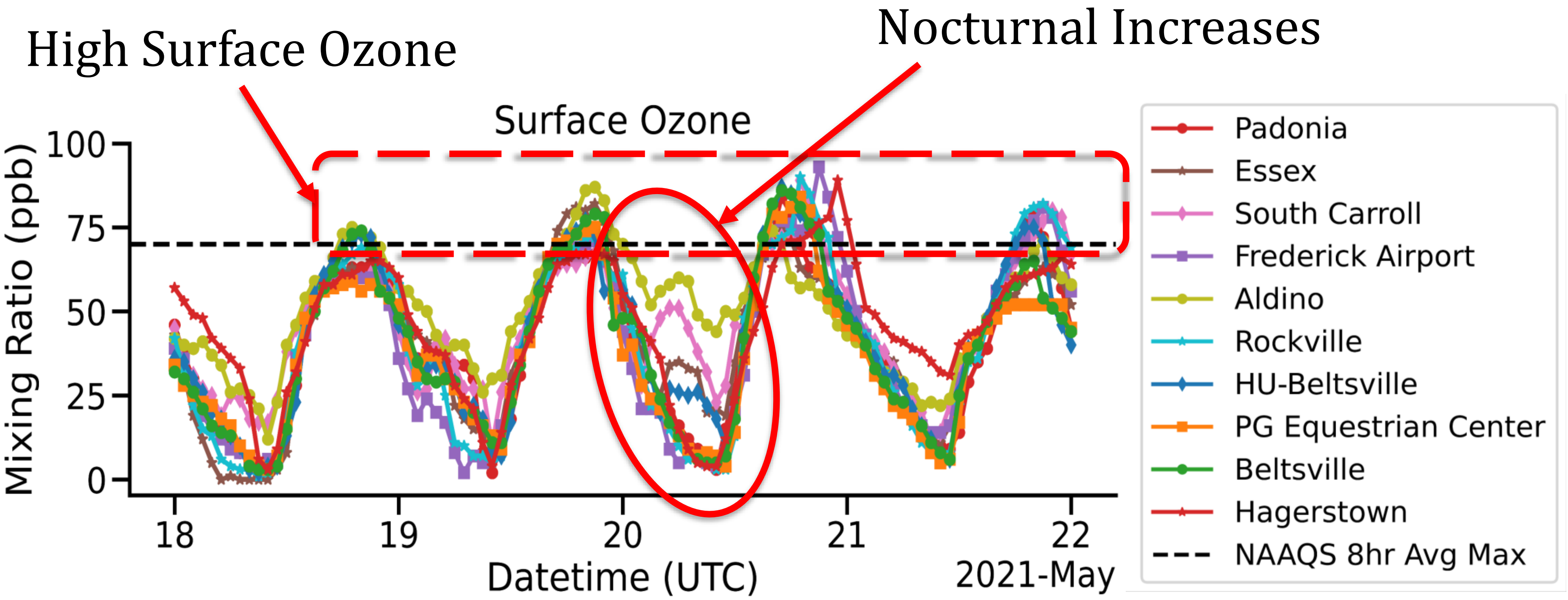
What is Ozone?



Lu et al., 2019

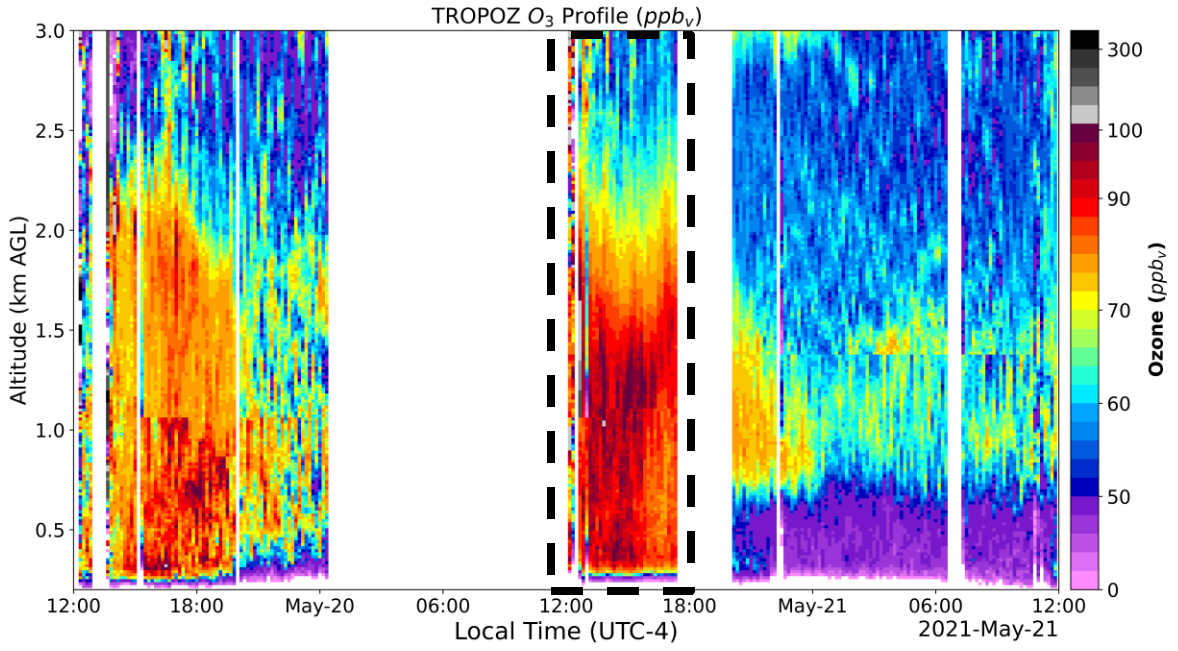
Ozone Daily AQI Values, 2005 to 2021
Baltimore-Columbia-Towson, MD

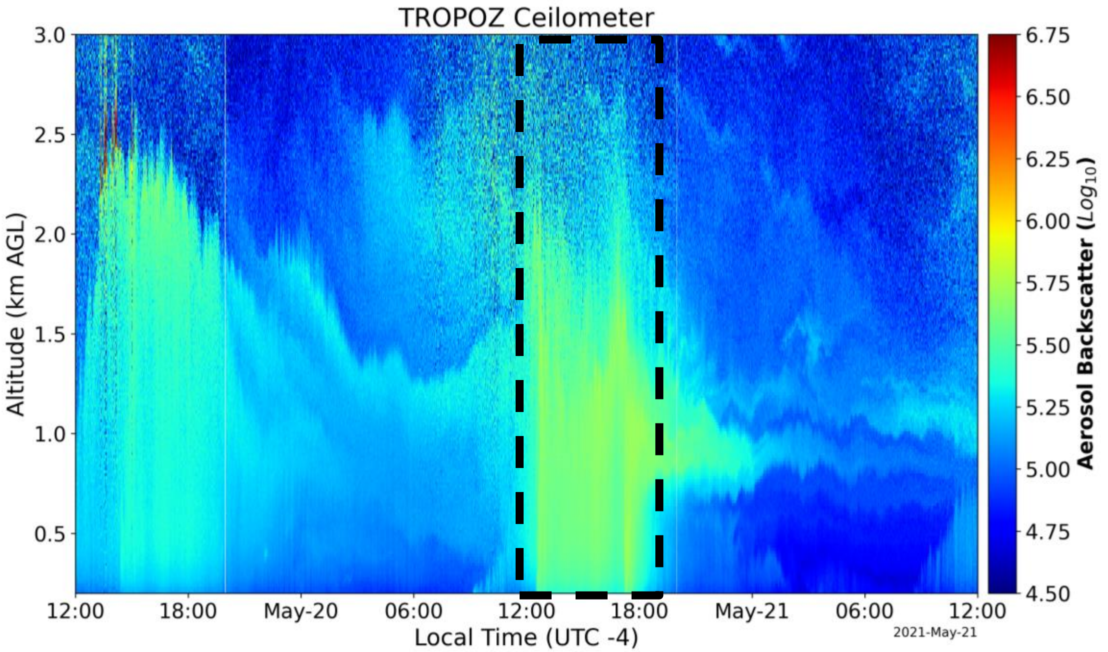




High Surface Ozone
Nocturnal Increases
Surface Ozone
Mixing Ratio (ppb)
100
75
50
25
0
18
19
20
21
22
2021-May
Datetime (UTC)
Padonia
Essex
South Carroll
Frederick Airport
Aldino
Rockville
HU-Beltsville
PG Equestrian Center
Beltsville
Hagerstown
NAAQS 8hr Avg Max

Lidar Profiles

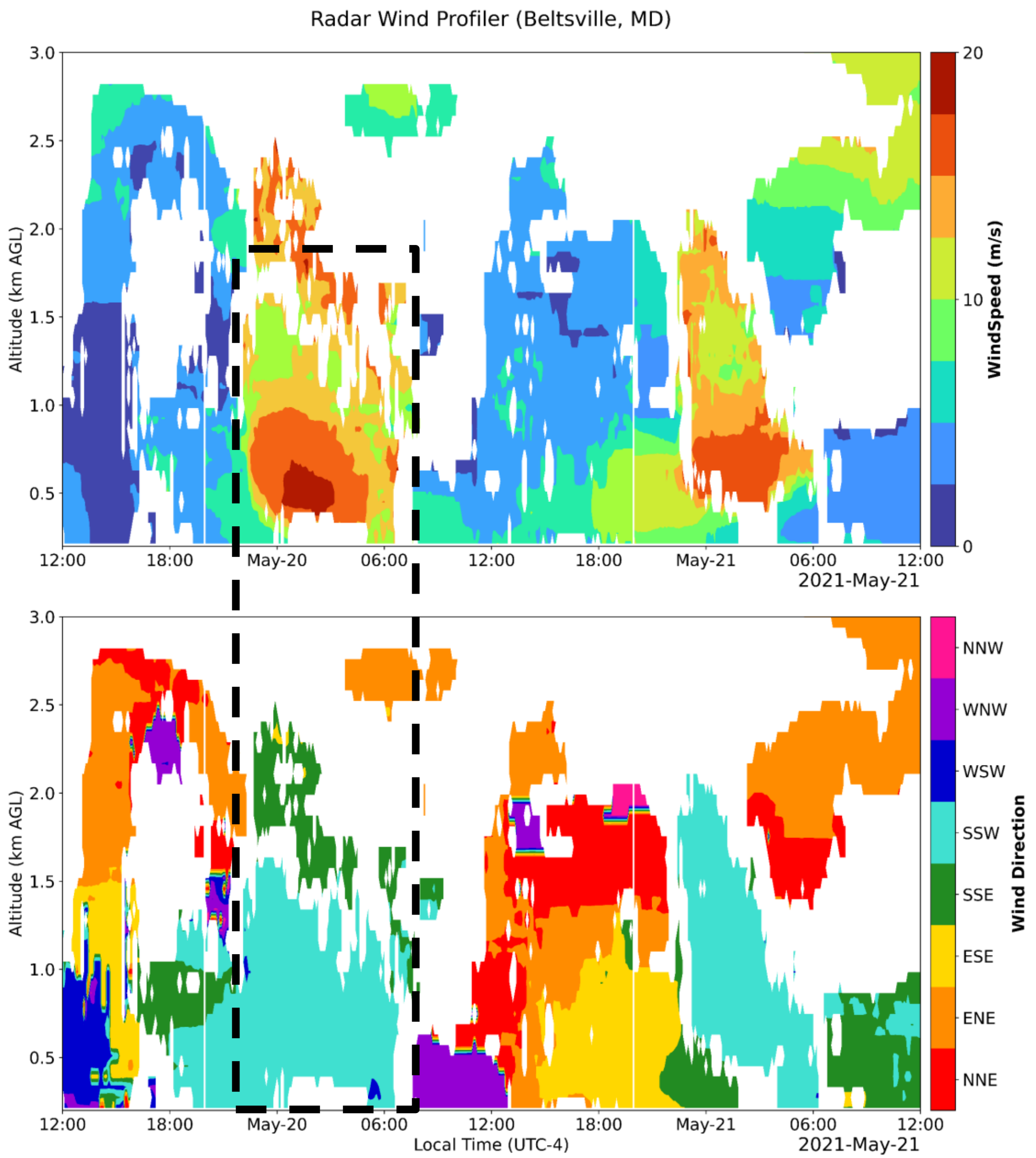




- Well-mixed polluted PBL seen from TROPOZ, Ceilometer, Sonde and surface
- Arrival of polluted air-mass marked by wind profile with
- Sonde observes over 10 m/s wind speeds at 02 LT (06 UTC) on 20th
- Wind, ceilometer, and ozone profiles indicate an air mass change occurring near 14 LT in the Beltsville, MD area marking the arrival well-mixed from the northeast.

The GSFC TROPOZ DIAL deployed at Ft. Collins, CO for the 2014 DISCOVER-AQ campaign. [Source: TOLNet - Tropospheric Ozone Lidar Network (nasa.gov), Photo Credit: L. Twigg.]

Wind Profile

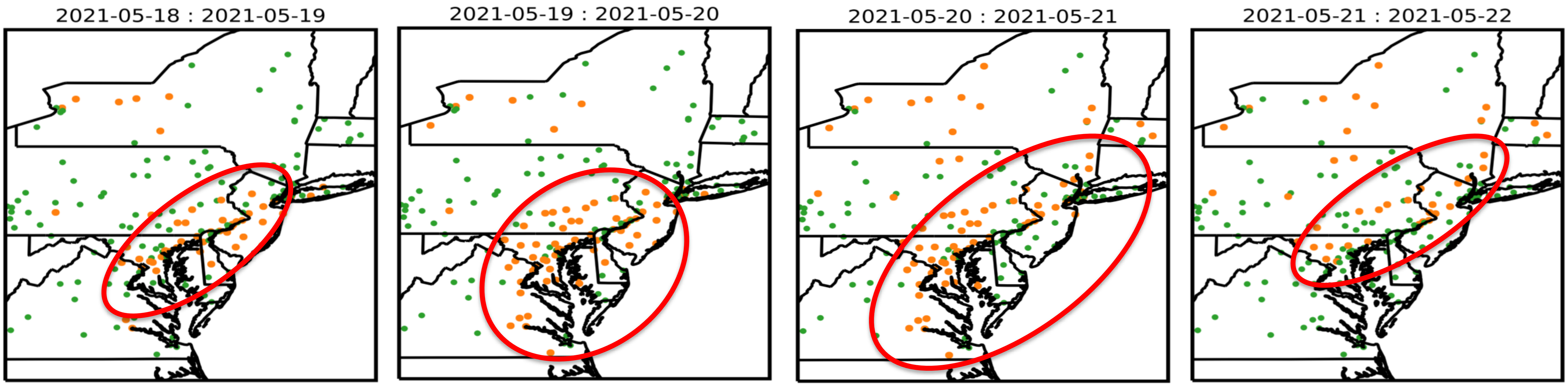


•HU-Beltsville RWP shows wind direction and magnitude change at time of polluted air-mass and cleaning it out.

•NLLJ at 0 - 6 LT on the 20th which preceding DSW and clean-out leading to next-day entrainment and transport

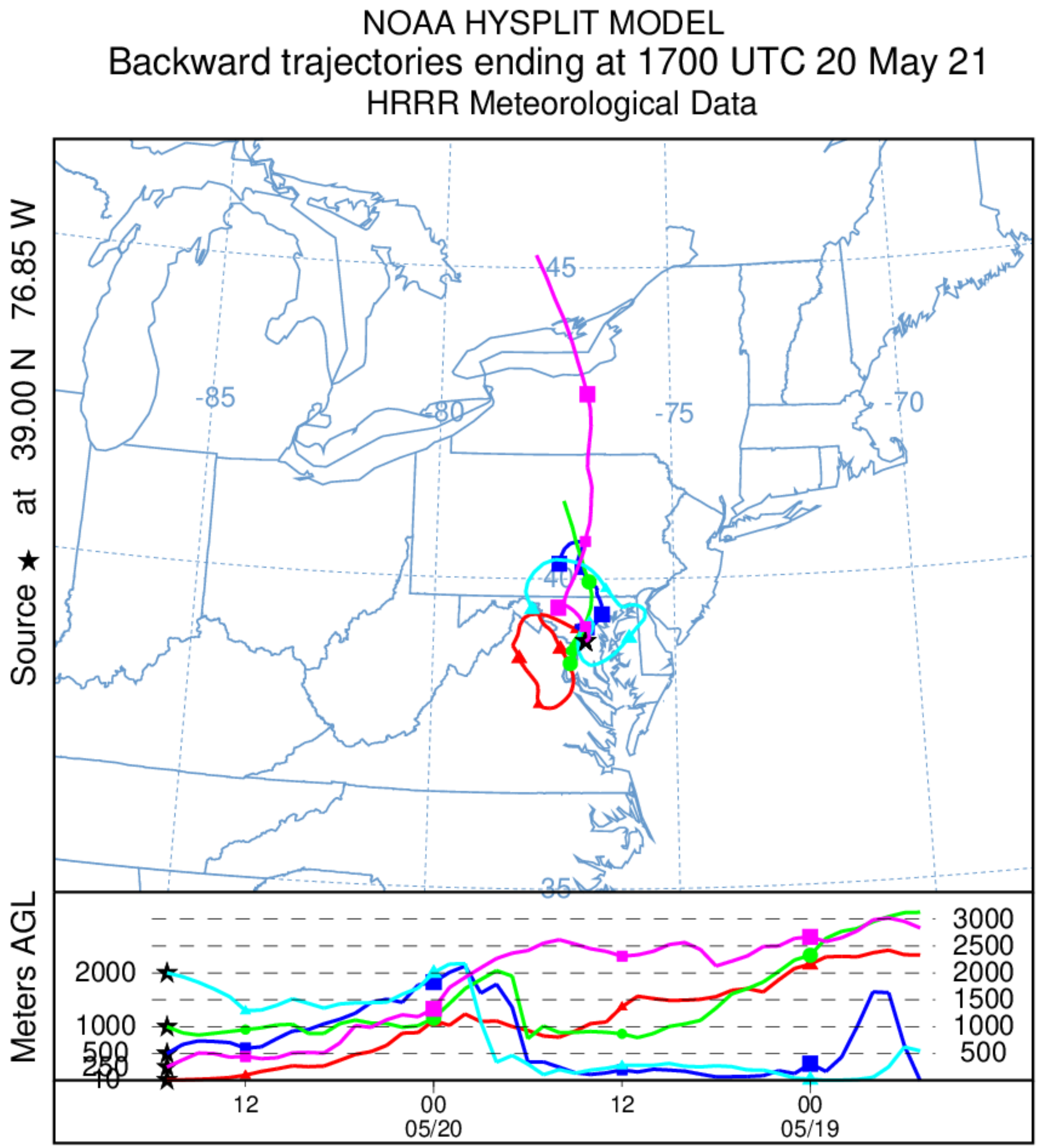
HU-Beltsville Wind Profiler

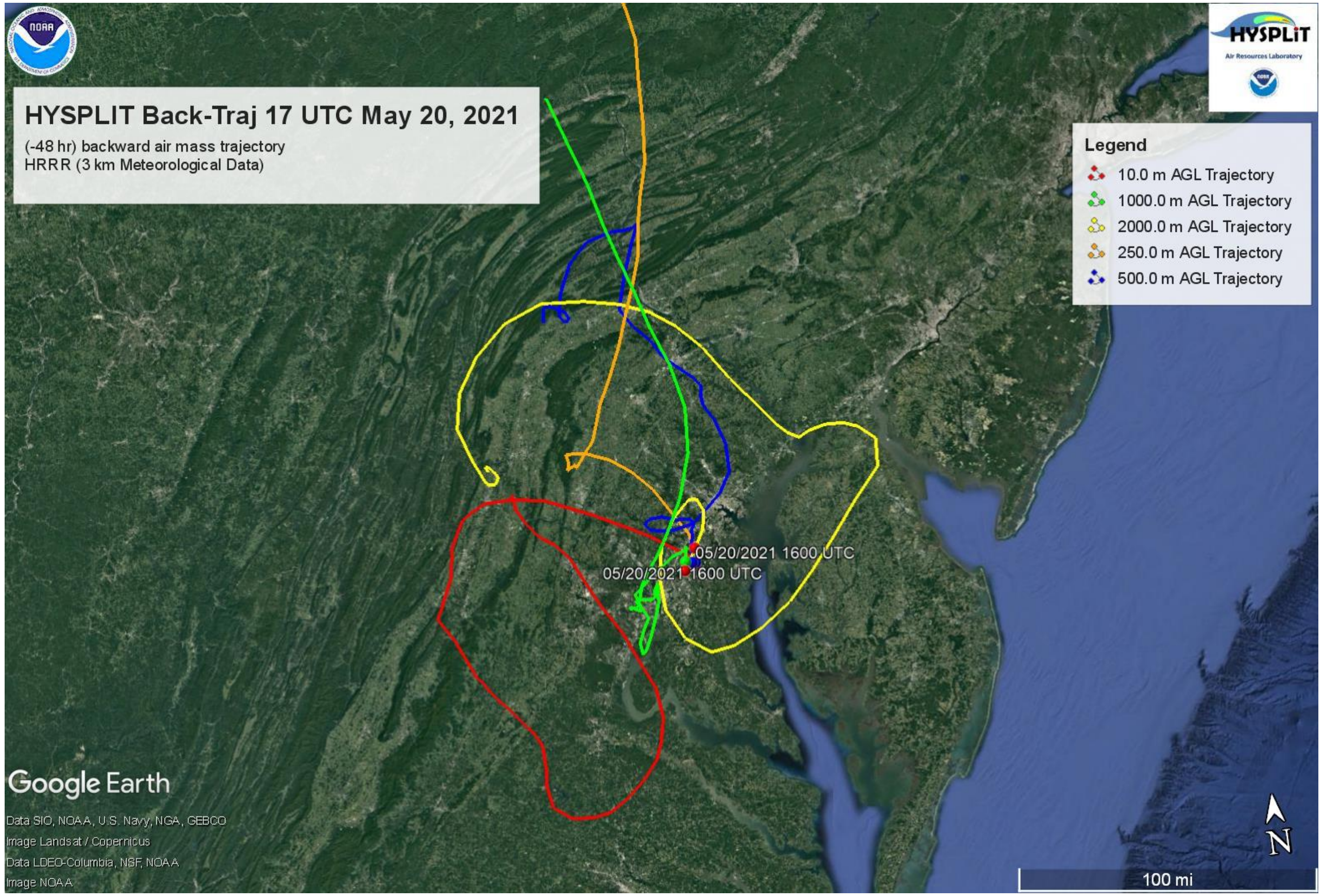
In-situ Surface Observations



Orange circles are sites with >70 ppb surface ozone at **least once** in the time period. Green circles are <70ppb during the time period.

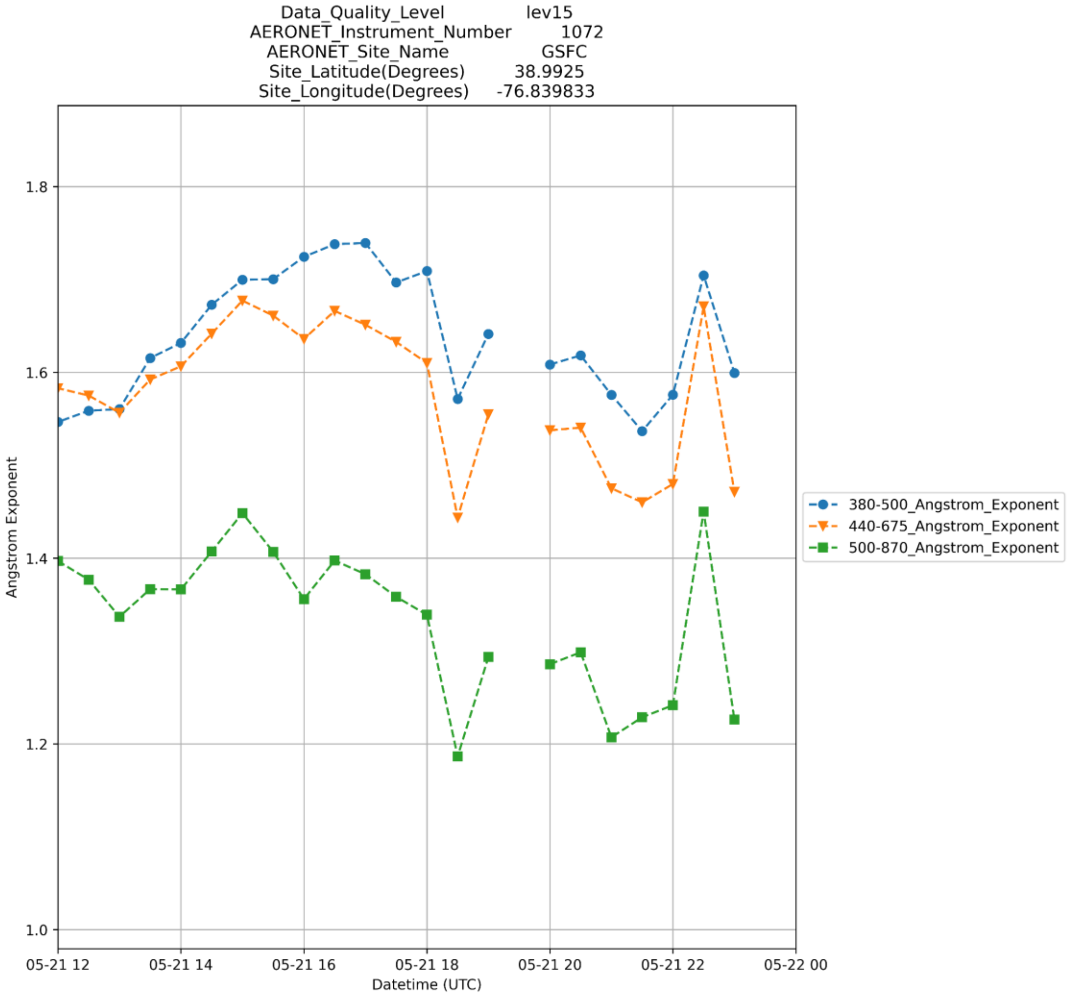
HYSPLIT Transport

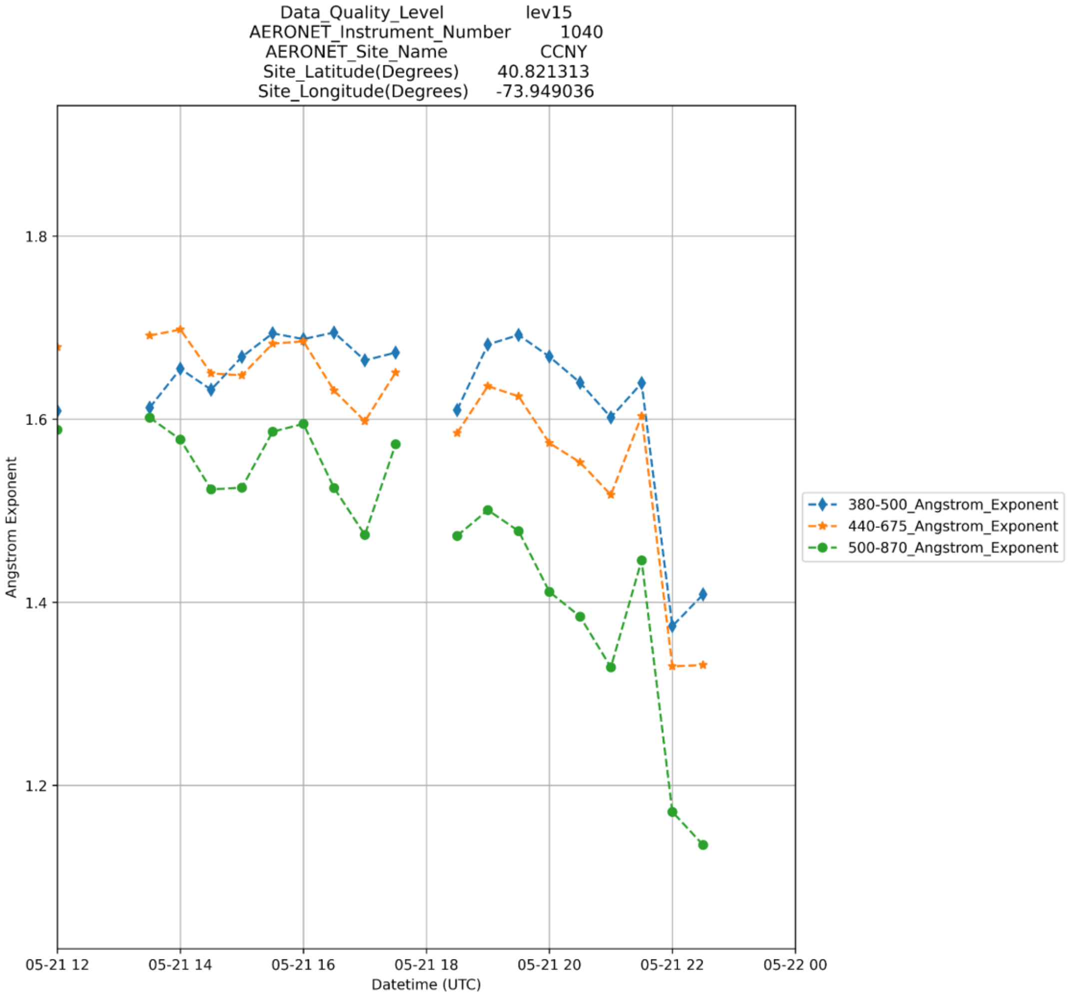




- Hybrid Sing Particle Lagranian Transport Model
  - Shows the air mass transport forwards or backwards

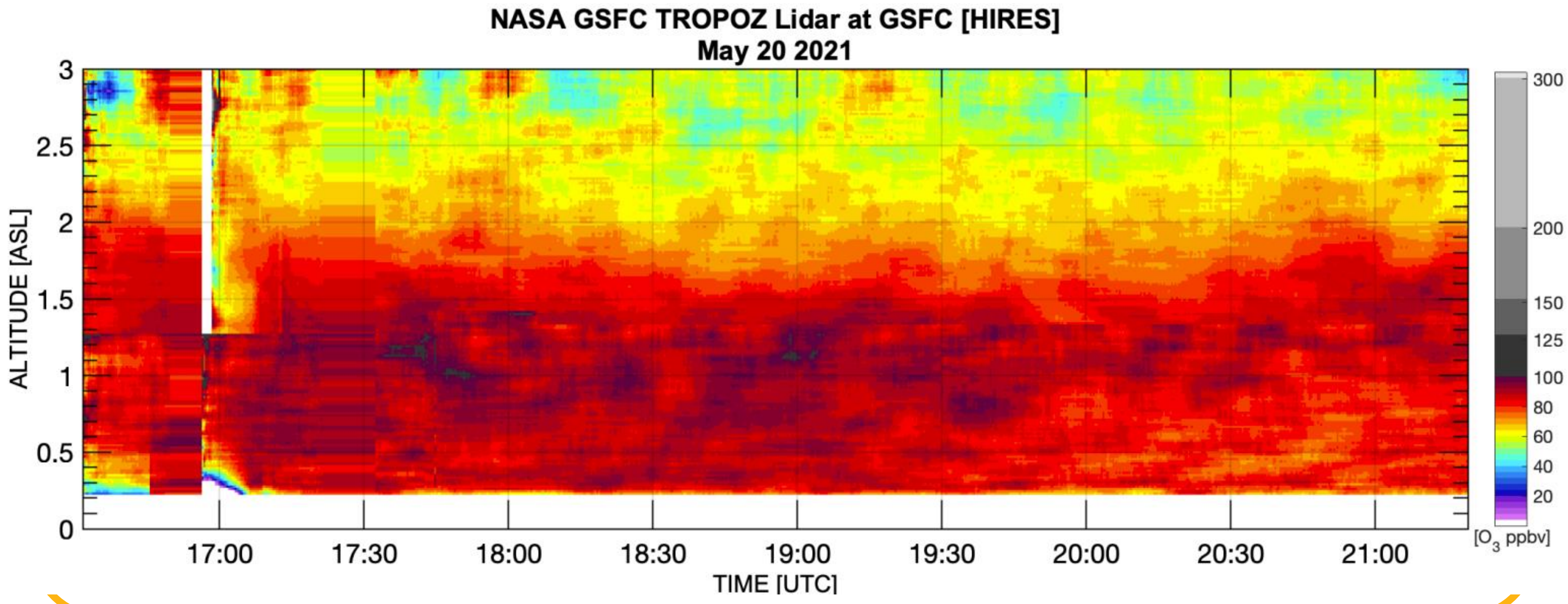
AERONET Angstrom Exponent





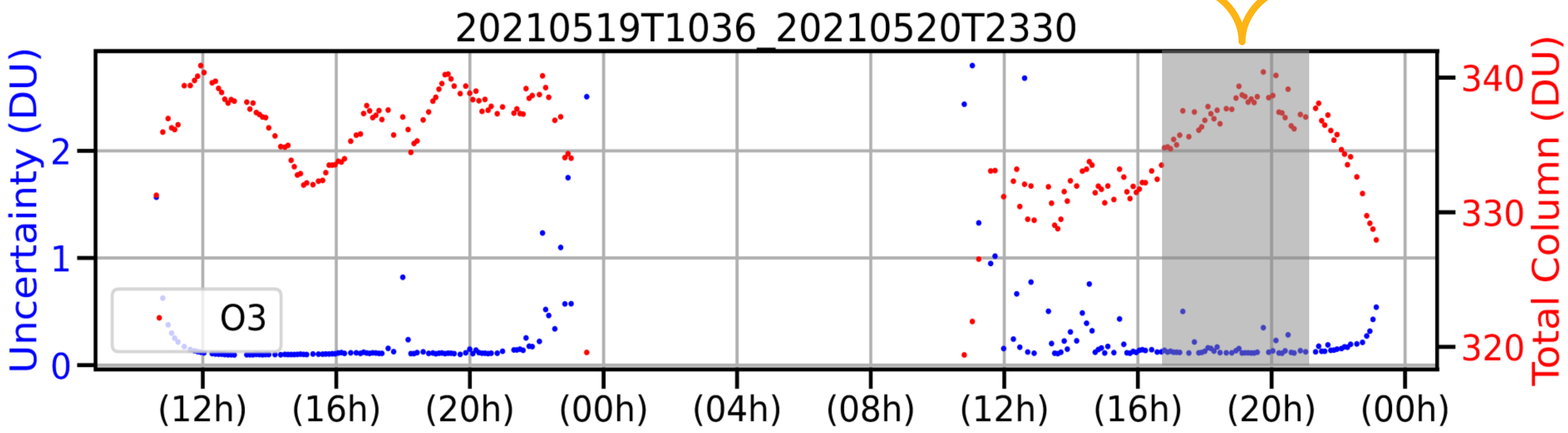
Note that the temporal evolution is led by CCNY and followed by GSFC indicated North to South transport of aerosols. Using Russel et al 2010 scheme for Aerosols classification by Angstrom Exponents we see that this is an influx of biomass burning aerosol (1 > AAE < 2) from the North transported into the Baltimore, MD - Washington, DC region.

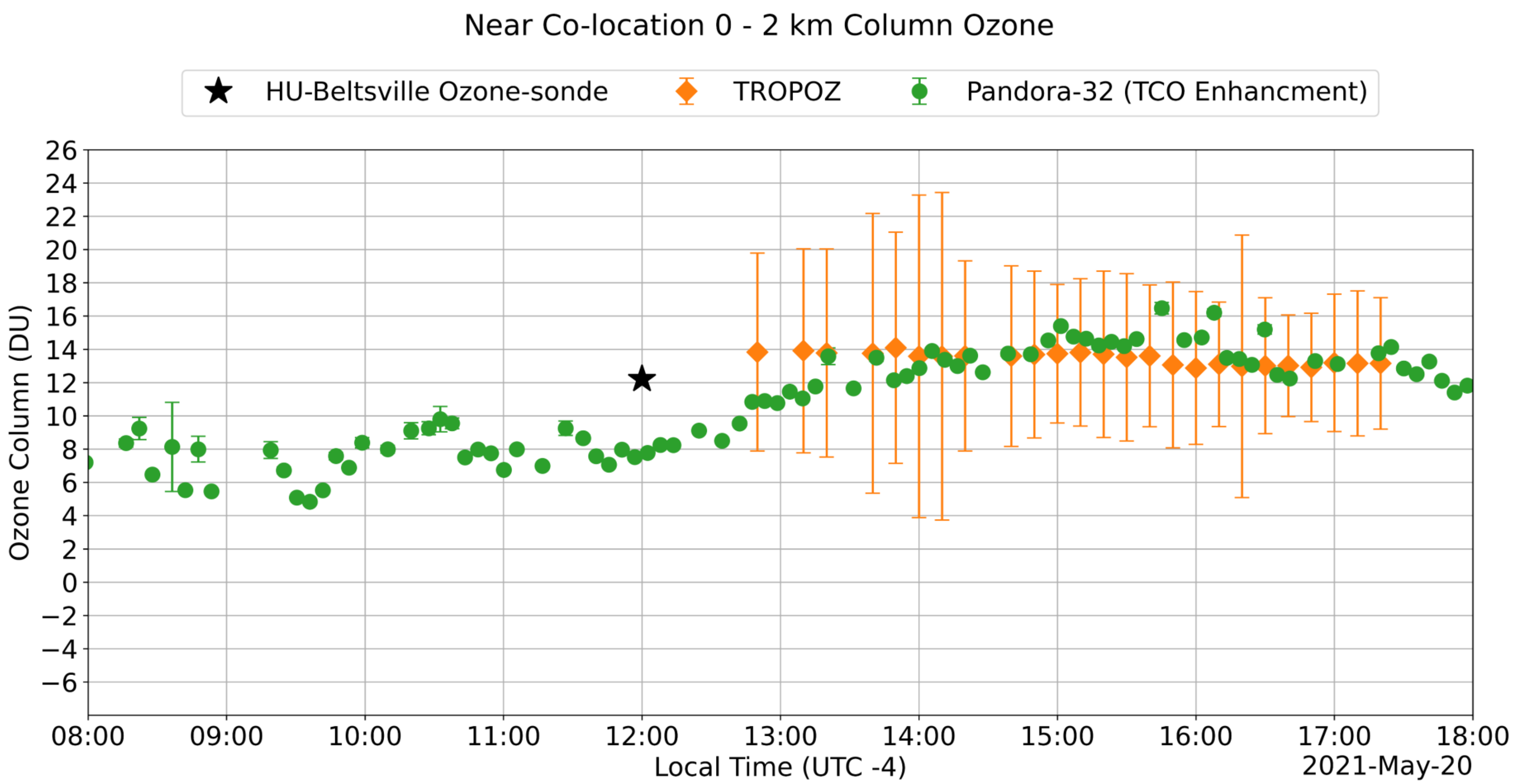
Pandora with Ozone Lidar



TCO_3 increase known in Pandora ~7 DU with Ozone lidar 0-2km ~14DU.

No known case study relating the Pandora (NASA Ground Based Dataset) TCO_3 with O3 Lidar





Near Co-location 0 - 2 km Column Ozone
HU-Beltsville Ozone-sonde
TROPOZ
Pandora-32 (TCO Enhancment)
Ozone Column (DU)
26
24
22
20
18
16
14
12
10
8
6
4
2
0
−2
−4
−6
08:00
09:00
10:00
11:00
12:00
13:00
14:00
15:00
16:00
17:00
18:00
Local Time (UTC -4)
2021-May-20

Summary

Ozone episode May is out of the norm for this location. The episode evolved from entrainment of a transported polluted air-mass then recirculation in the mid-atlantic on May 19 & 20, 2021 followed by quick lofting by DSW (as shown by ceilometer and wind) resulting in next-day entrainment.

- High resolution observations from active and passive remote sensors captured the evolution of the ozone episode.

- Pandora agrees with 0-2 km TROPOZ profile (TEMPO Ozone product)
  - This shows a potential for further usage in AQ event characterization

- The evolution of the PBL height from May 19 - 21 shows a clear relation to the 3-Stage Diurnal Boundary Model model[3].
  - Increased surface ozone as result of local transport by dynamics
  - Decreasing height of the PBL each day -> Evidence of sinking layers

- This work also serves to demonstrate the usefulness of multi-instrument perspectives in air quality event analysis and study of spatio-temporal variability.

Further Work

- Spatial Distribution:
    - Forward dispersion & trajectory from GSFC at time of polluted air-mass
    - Comparison of Surface, Pandora, and AERONET throughout the Mid-Atlantic
- Aerosol Analysis:
    - Analysis of speciated surface PM

Acknowledgements and Reference

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1. Dreessen, J., Sullivan, J., and Delgado, R.: Observations and impacts of transported Canadian wildfire smoke on ozone and aerosol air quality in the Maryland region on June 9–12, 2015, Journal of the Air & Waste Management Association, 66, 842–862, https://doi.org/10.1080/10962247.2016.1161674, 2016.

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3.Rabenhorst, S., Whiteman, D. N., Zhang, D.-L., and Demoz, B.: A Case Study of Mid-Atlantic Nocturnal Boundary Layer Events during WAVES 2006, 53, 2627–2648, https://doi.org/10.1175/JAMC-D-13-0350.1, 2014.

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5.Sullivan, J. T., Rabenhorst, S. D., Dreessen, J., McGee, T. J., Delgado, R., Twigg, L., and Sumnicht, G.: Lidar observations revealing transport of O3 in the presence of a nocturnal low-level jet: Regional implications for “next-day” pollution, Atmospheric Environment, 158, 160–171, https://doi.org/10.1016/j.atmosenv.2017.03.039, 2017.

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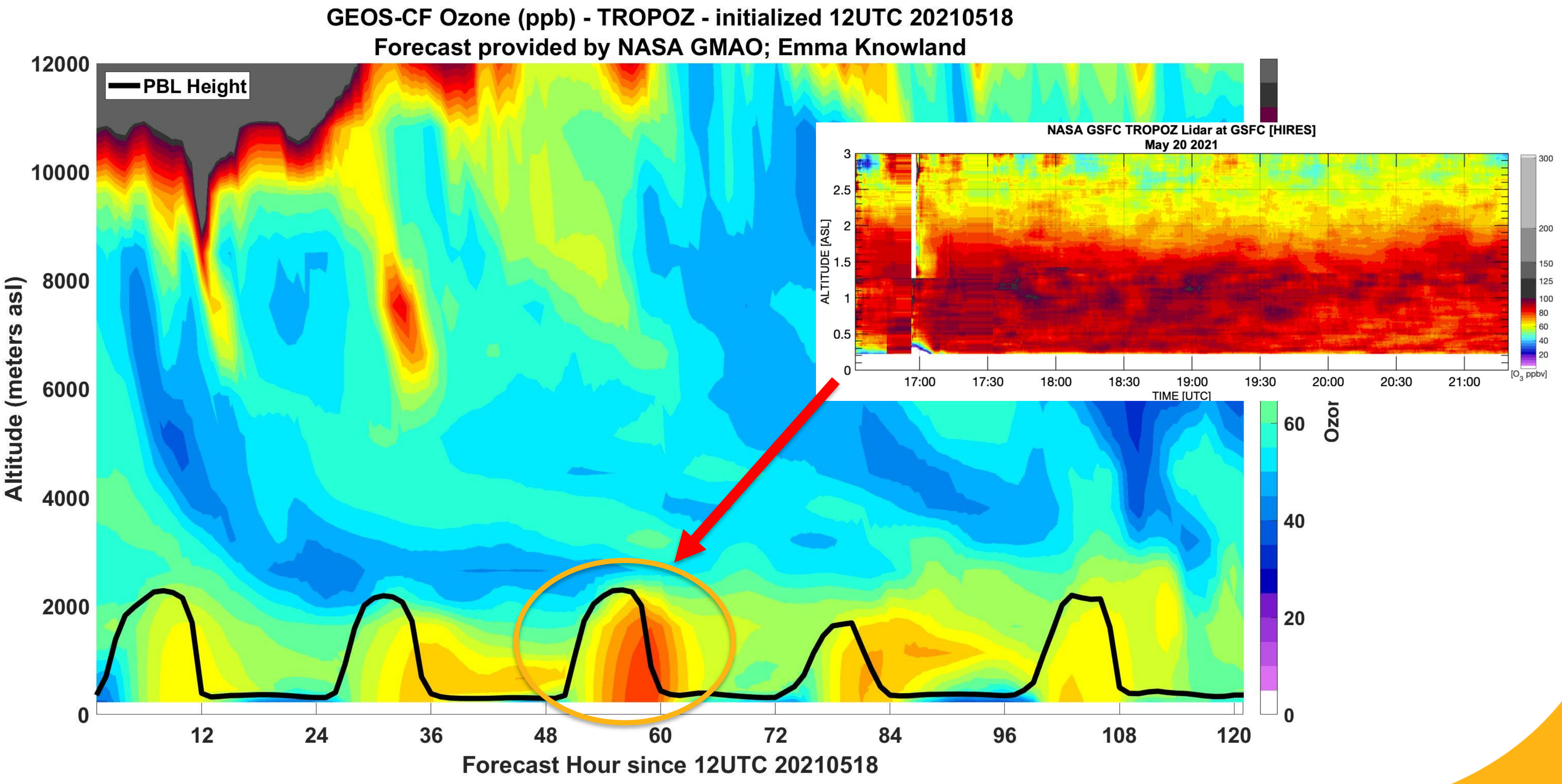
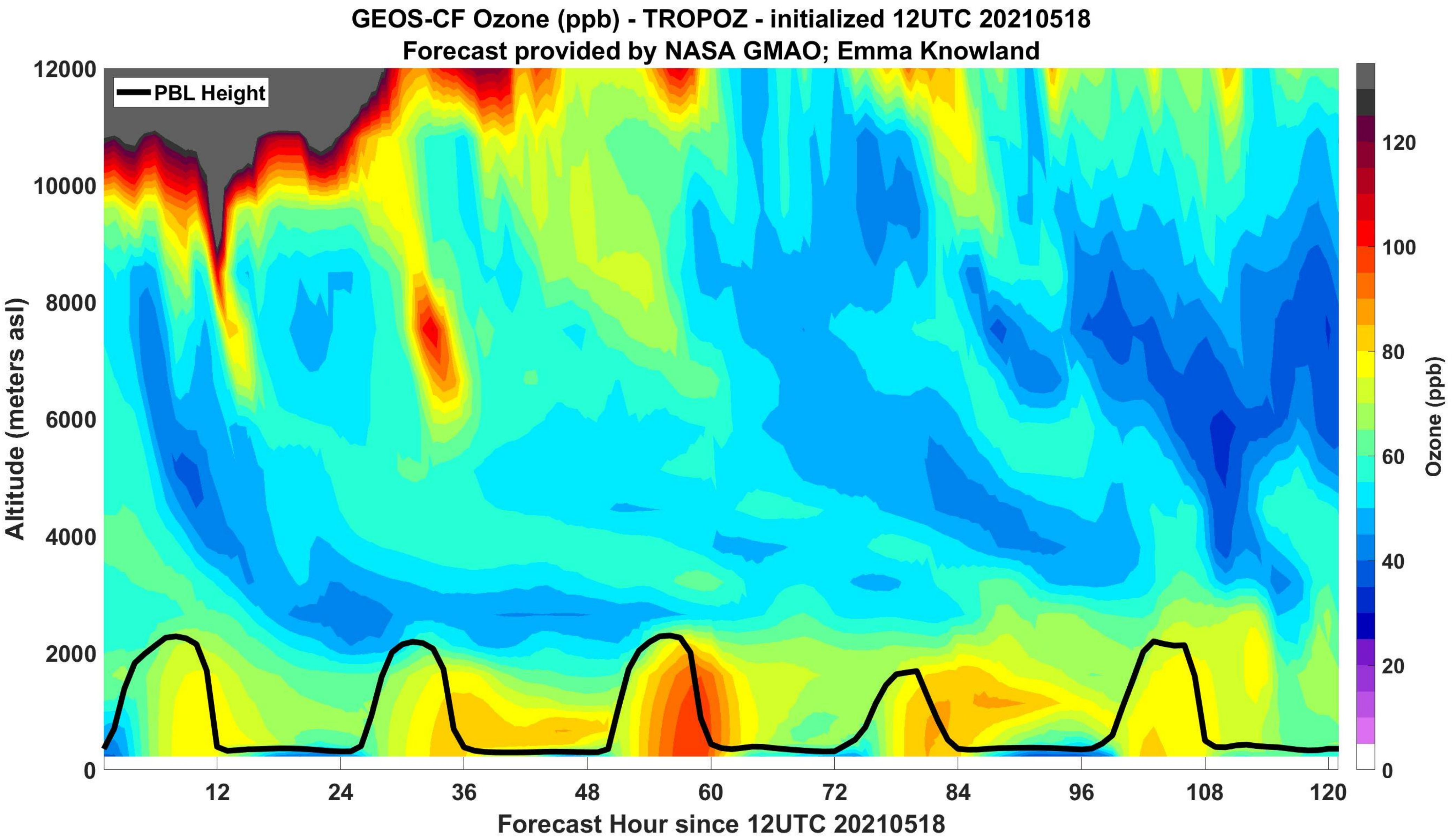
Supplemental Slides

NASA GEOS-CF



GEOS-CF Ozone (ppb) - TROPOZ - initialized 12UTC 20210518
Forecast provided by NASA GMAO; Emma Knowland
PBL Height
Altitude (meters asl)
Forecast Hour since 12UTC 20210518
NASA GSFC TROPOZ Lidar at GSFC [HIRES]
May 20 2021
ALTITUDE [ASL]
TIME [UTC]
Ozon

NASA GEOS-CF



GEOS-CF Ozone (ppb) - TROPOZ - initialized 12UTC 20210518
Forecast provided by NASA GMAO; Emma Knowland
PBL Height
Altitude (meters asl)
12000
10000
8000
6000
4000
2000
0
12
24
36
48
60
72
84
96
108
120
Forecast Hour since 12UTC 20210518
Ozone (ppb)
120
100
80
60
40
20
0

The Pandora Spectrometer System

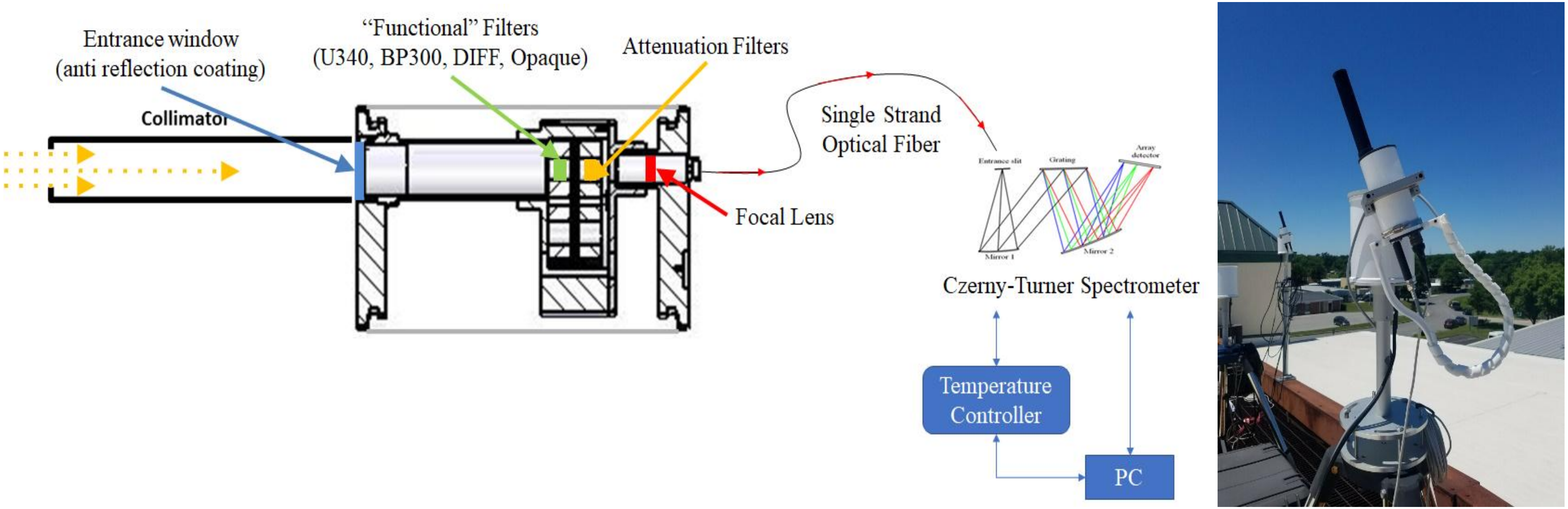


Figure 6: (a) Schematic view of Pandora version two (V2) and three (V3) sensor head configuration. (b) The Pandora-1S V3, equipped with; AvaSpec-ULS CCD spectrometer (Czerny-Turner optical design) with 2048 x 64 effective pixels, SciGlob-NASA tracker with 0.01° steps, and Cincoze DC-1100 R10 computer. Source NASA Pandora project.

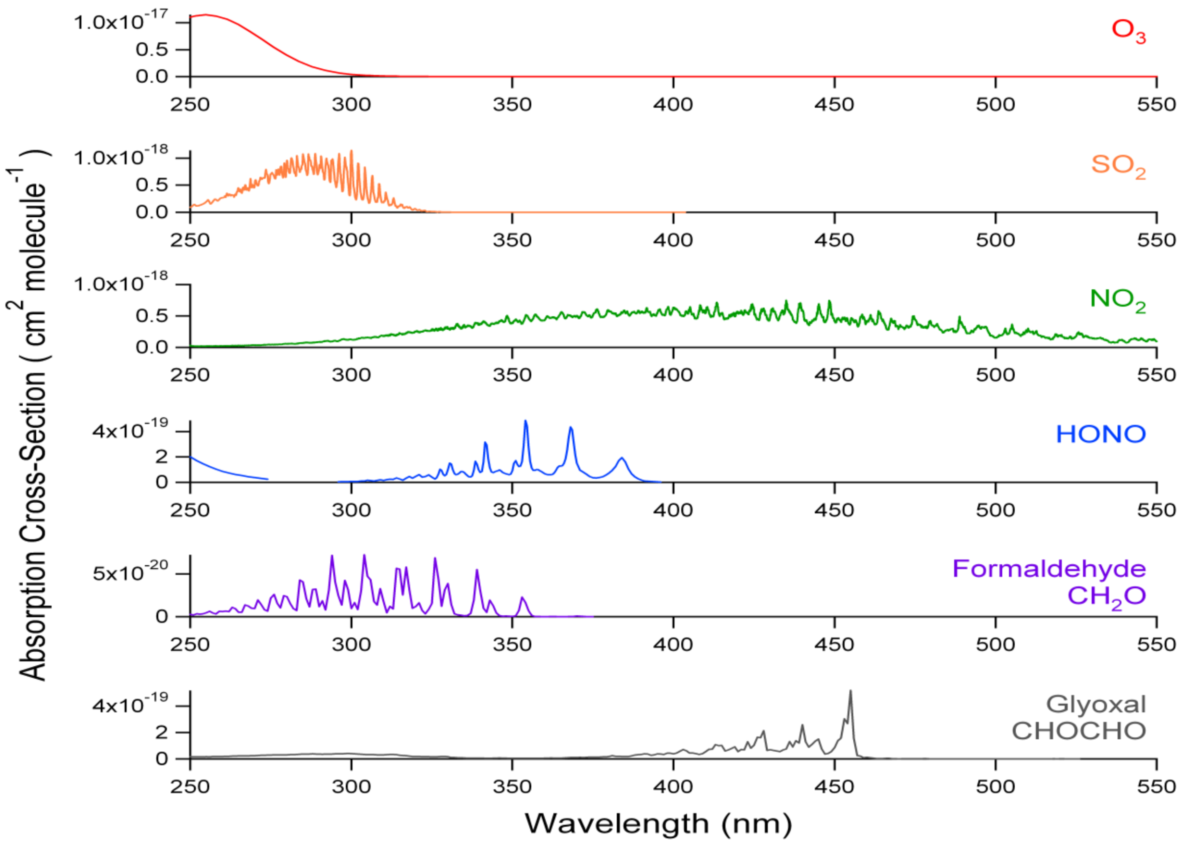
Total Column Concentrations | Vertical Profiles in PBL | Tropospheric & Stratospheric Column | Near Surface Concentrations

The Pandora System

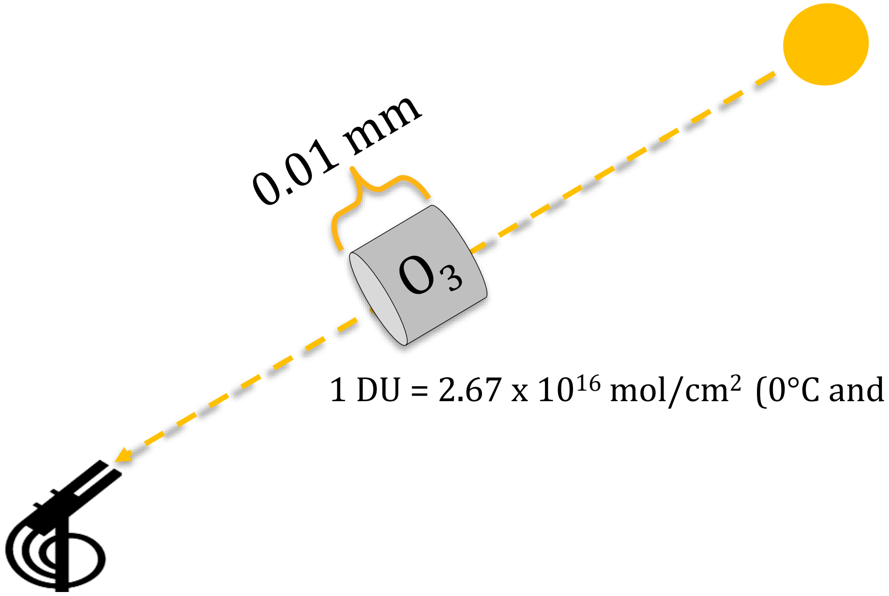
Direct Sun Differential Optical Absorption Spectroscopy (DS-DOAS)

Multiple attenuators in columnar of incoming solar radiation.

Full spectrum fit with all known absorption cross-sections.



Pandora's default is Dobson Units (DU)



1 DU = 2.67×10^{16} mol/cm^2 (0°C and 1 atm)

Average 300 DU of Ozone = 300 x 0.01 mm thick

Total Colum	NO_2	O_3
Precision (DU)	0.002	0.6
Accuracy (DU)	0.05	15

Research Quality
SO_2, HCHO, BrO, H_2O

Differential Optical Absorption Spectroscopy

$$I(\lambda) = I_0(\lambda)\exp\left\{-L\left(\sum_{j=1}^{J}\sigma_j(\lambda)C_j + \sigma_M(\lambda)C_M + \sigma_R(\lambda)C_R\right)\right\},$$

j – Species | M – Mie | R – Rayleigh

$$\sigma_j(\lambda) = \sigma_{j0}(\lambda) + \sigma'_j(\lambda),$$

$$\tau(\lambda) = \ln\left(\frac{I_0(\lambda)}{I(\lambda)}\right) = \left\{L\left(\sum_{j=1}^{J}\sigma_j(\lambda)C_j + \sigma_M(\lambda)C_M + \sigma_R(\lambda)C_R\right)\right\}.$$

$$I(\lambda) = I_0(\lambda)\exp\left\{-L\sum_{j=1}^{J}\sigma'_j(\lambda)C_j + \sum_p b_p\lambda^p\right\},$$

$$\ln(I(\lambda)/I_0(\lambda)) = -L\sum_{j=1}^{J}\sigma'_j(\lambda)C_j + \sum_p b_p\lambda^p.$$

$$S_k = \ln(I(\lambda_k)/I_0(\lambda_k)) = -L\sum_{j=1}^{J}\sigma'_j(\lambda_k)C_j + \sum_p b_p\lambda_k{}^p, \quad k = 1, n.$$

Geiko et al, 2015

Planned Activities

Summer 2021: June-September IOP

⇢ DOE Tracking Aerosol Convection interactions ExpeRiment

comprehensive in situ and remote sensing observations of clouds, aerosols, precipitation, radiation and meteorology

TRACER-AQ: September 2021

⇢ Coordinated Ground Instruments

- 3 TOLNet O_3 lidars
- 8 Pandora Spectrometers (O_3, NO2, HCHO)
- Routine regulatory monitoring measurements
- 70 ozonesondes
- Boat measurements
- Mobile labs both supported by TRACER mission (July-August) and another pending NSF Support

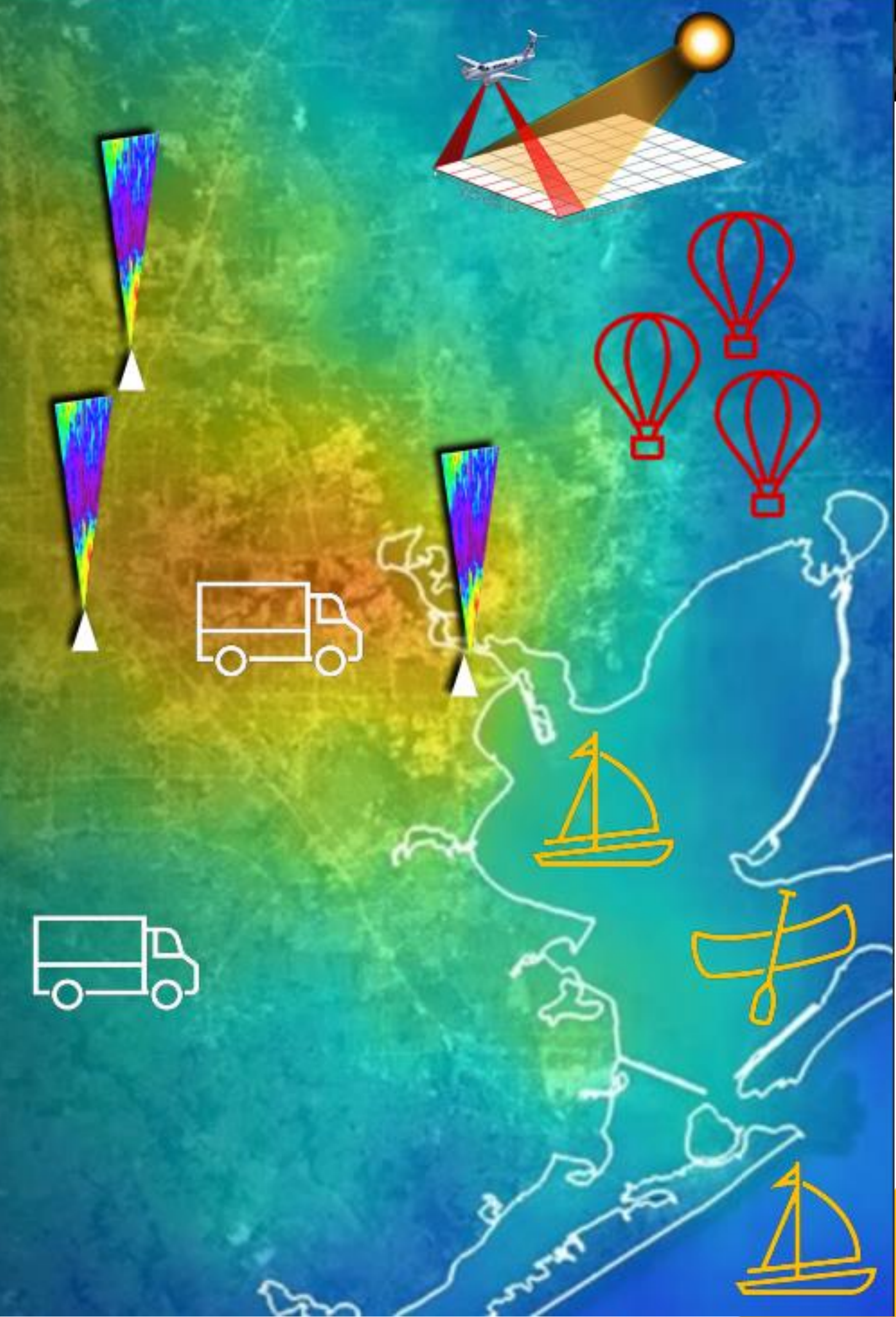
⇢ NASA JSC G-V Aircraft (77 flight hours)

- GCAS+HSRL2-DIAL (O_3, NO_2, HCHO, aerosols)

Science Plan Document will be available soon:

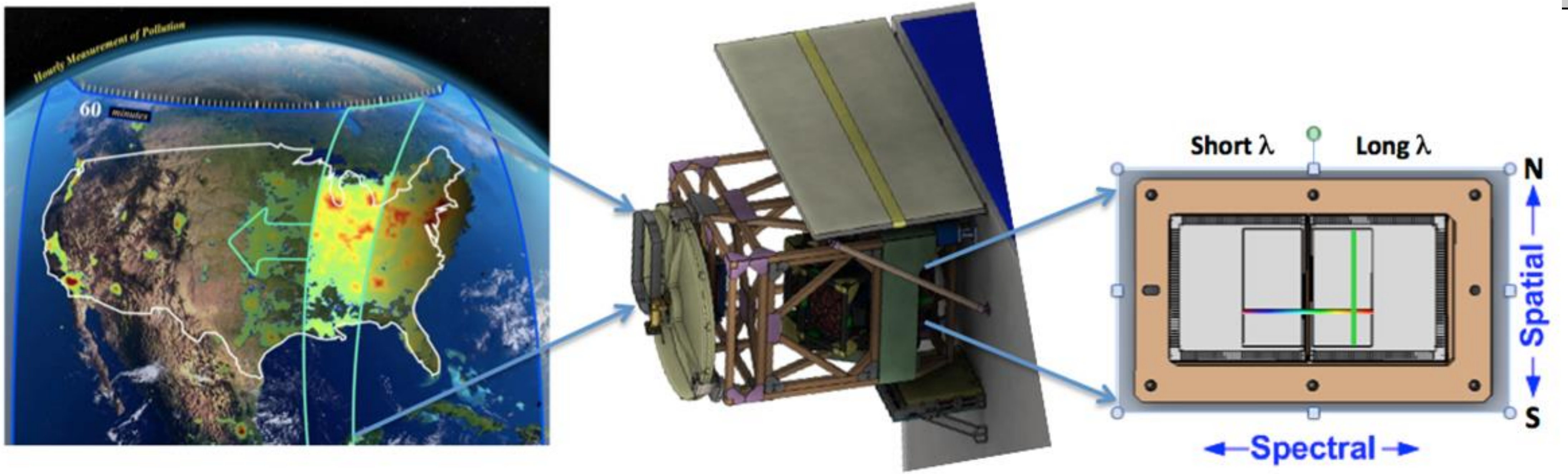
https://www-air.larc.nasa.gov/missions/tracer-aq/index.html

Study has room to grow in anyone has the support and desire to join!

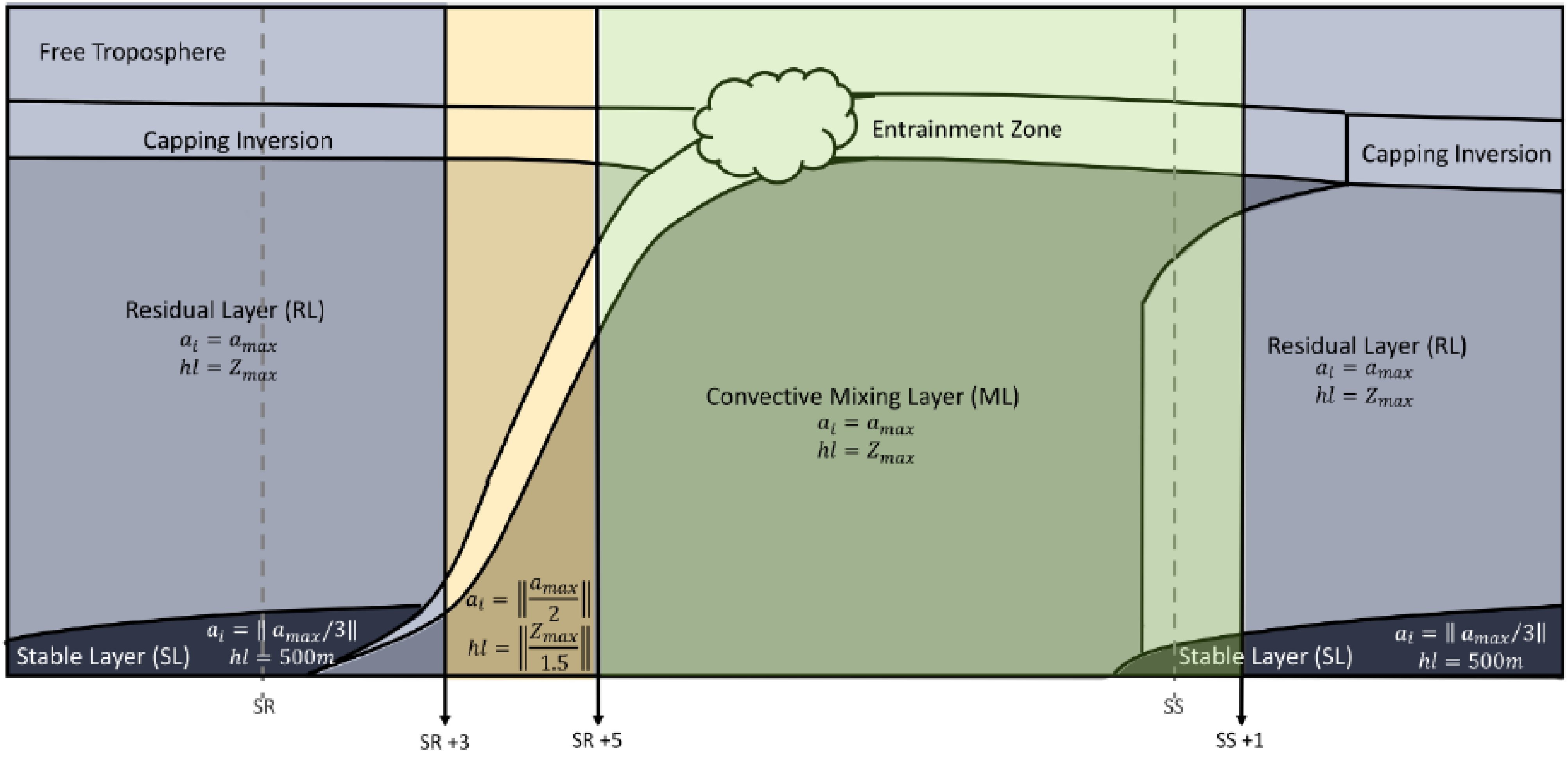


UV / Vis Spectrometer & Radiometers

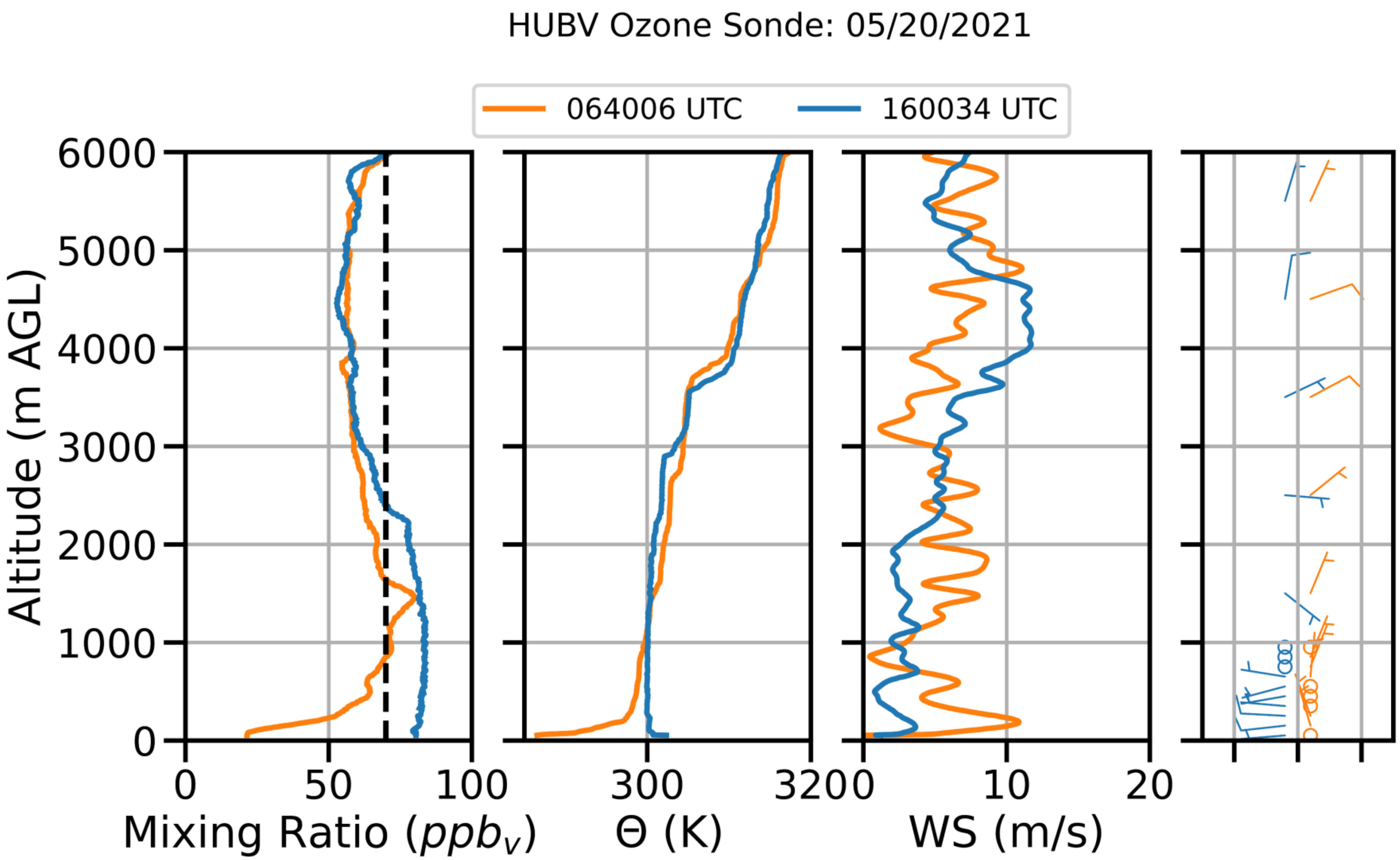
Tropospheric Emissions Monitoring of POllution		
Spectral range: 290–740 nm (UV, VIS)	spectral sampling: 0.2 nm	spectral resolution: 0.6 nm
Spatial resolution: 2 km/pixel in the north-south direction, 4.5 km /pixel in the east-west direction at the center of the FOR (Field of Regard) which is desired to be 36.5° N, 100° W. Co-add/cloud clear as needed for specific data products		
Two 2D detectors (2 k x 1 k pixels) images the full spectral range except for a gap from 490–540 nm for each geospatial scene		



PBL Evolution (Adapted from Stull)

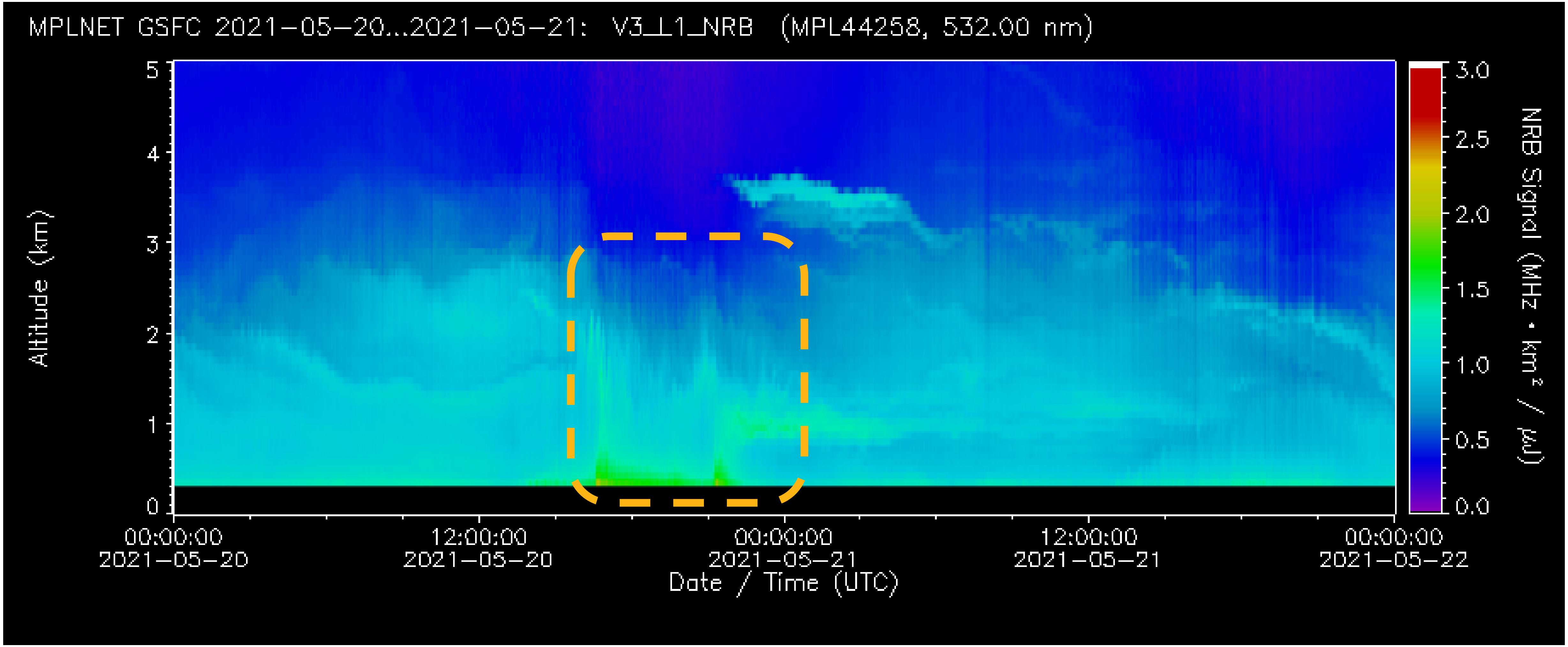


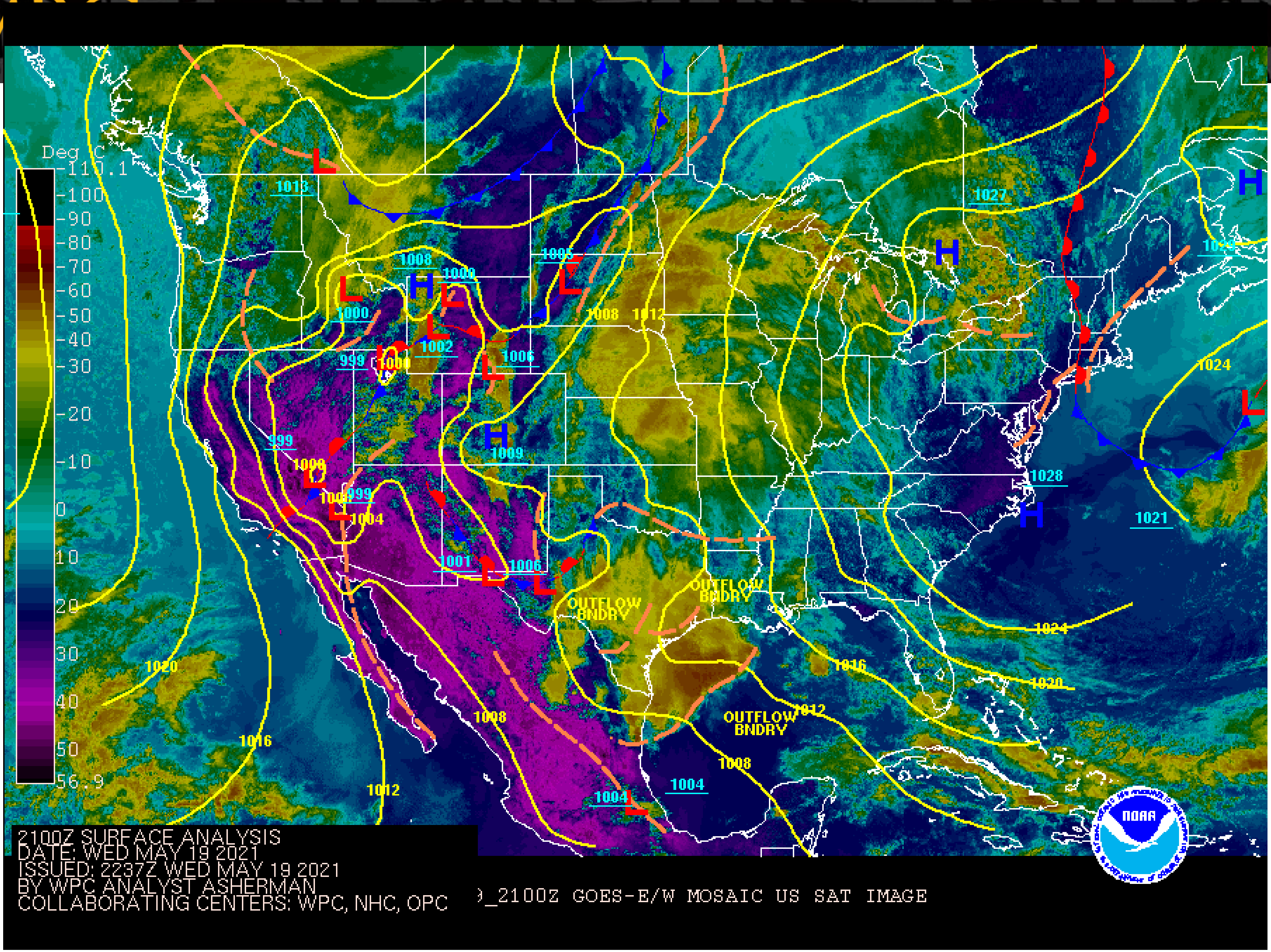
V. Caecedo et al (2017)



HUBV Ozone Sonde: 05/20/2021
064006 UTC
160034 UTC
Altitude (m AGL)
6000
5000
4000
3000
2000
1000
0
0
50
100
Mixing Ratio (ppb_v)
300
320
Θ (K)
0
10
20
WS (m/s)

GSFC Micro-Pulse Lidar





Deg C
OUTFLOW BNDRY
OUTFLOW BNDRY
OUTFLOW BNDRY
2100Z SURFACE ANALYSIS
DATE: WED MAY 19 2021
ISSUED: 2237Z WED MAY 19 2021
BY WPC ANALYST ASHERMAN
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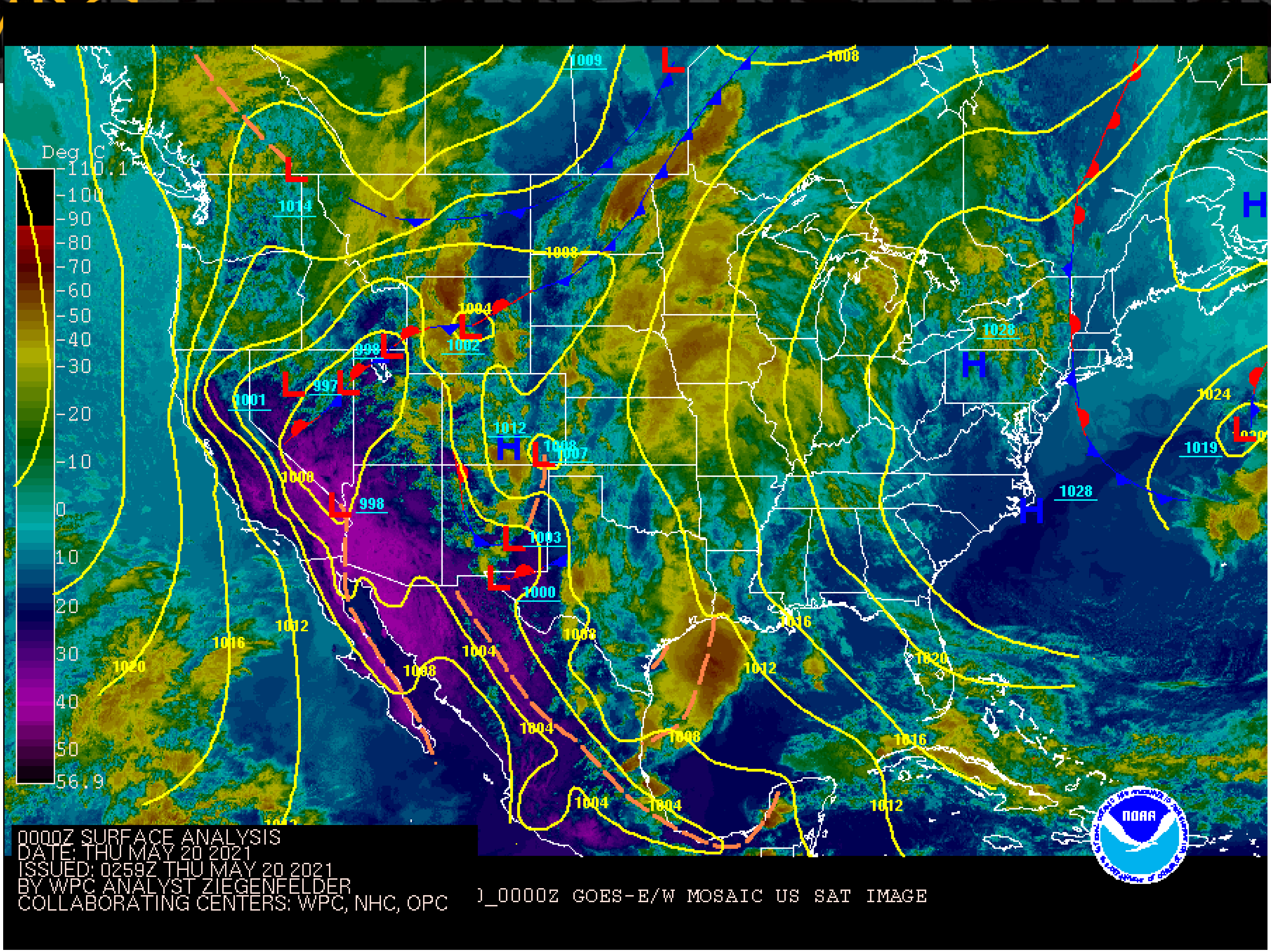
_2100Z GOES-E/W MOSAIC US SAT IMAGE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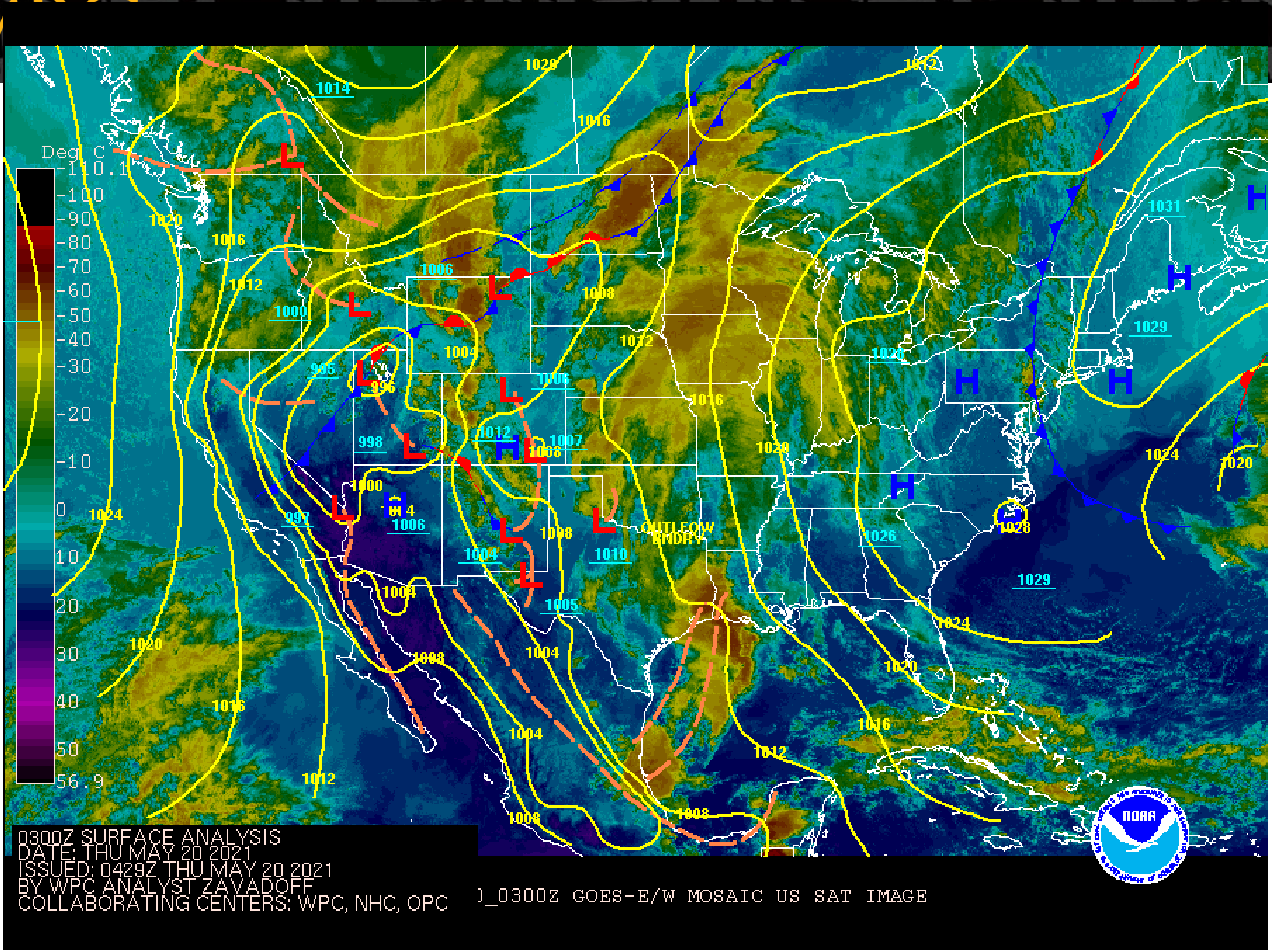
NOAA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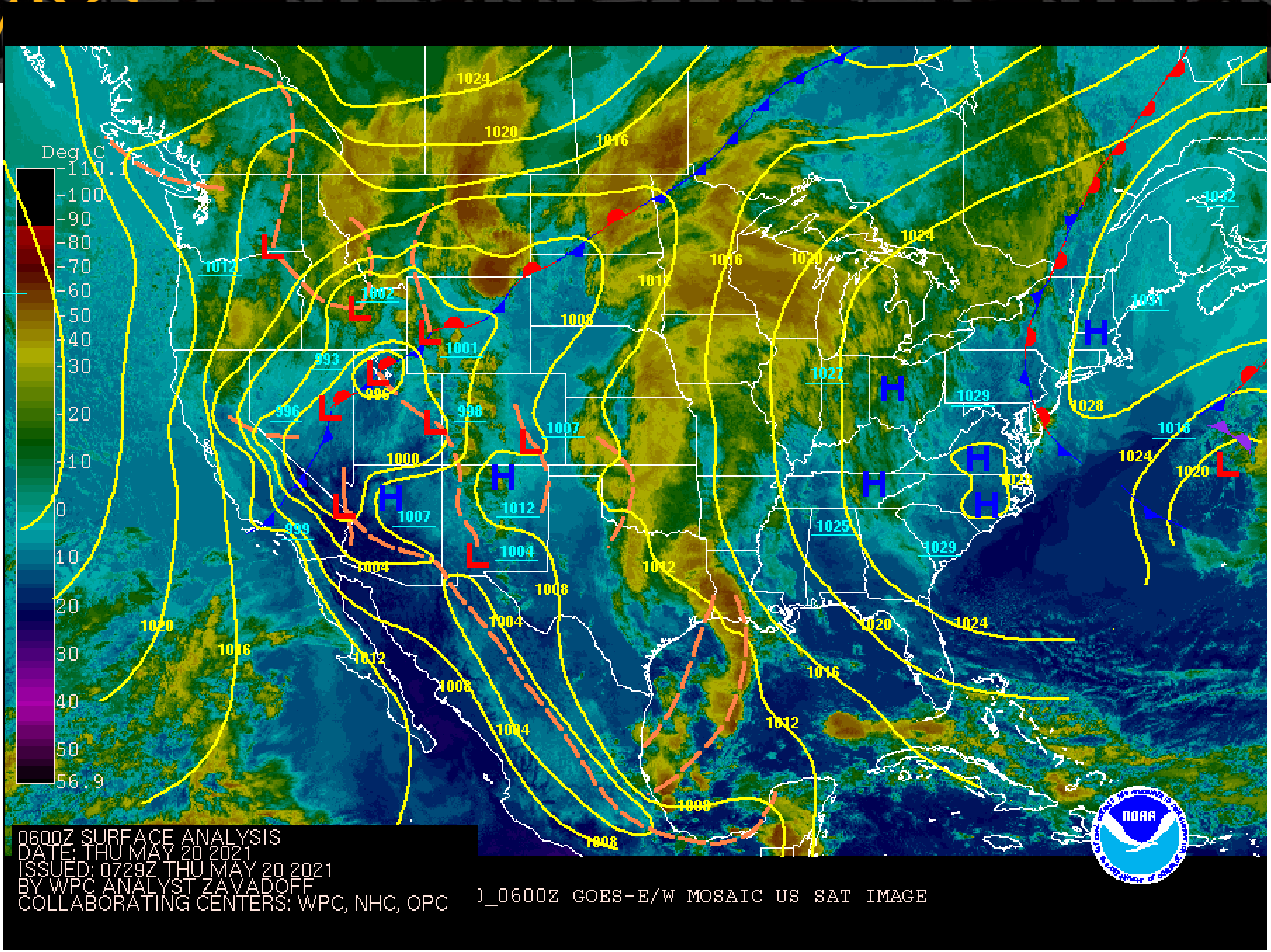
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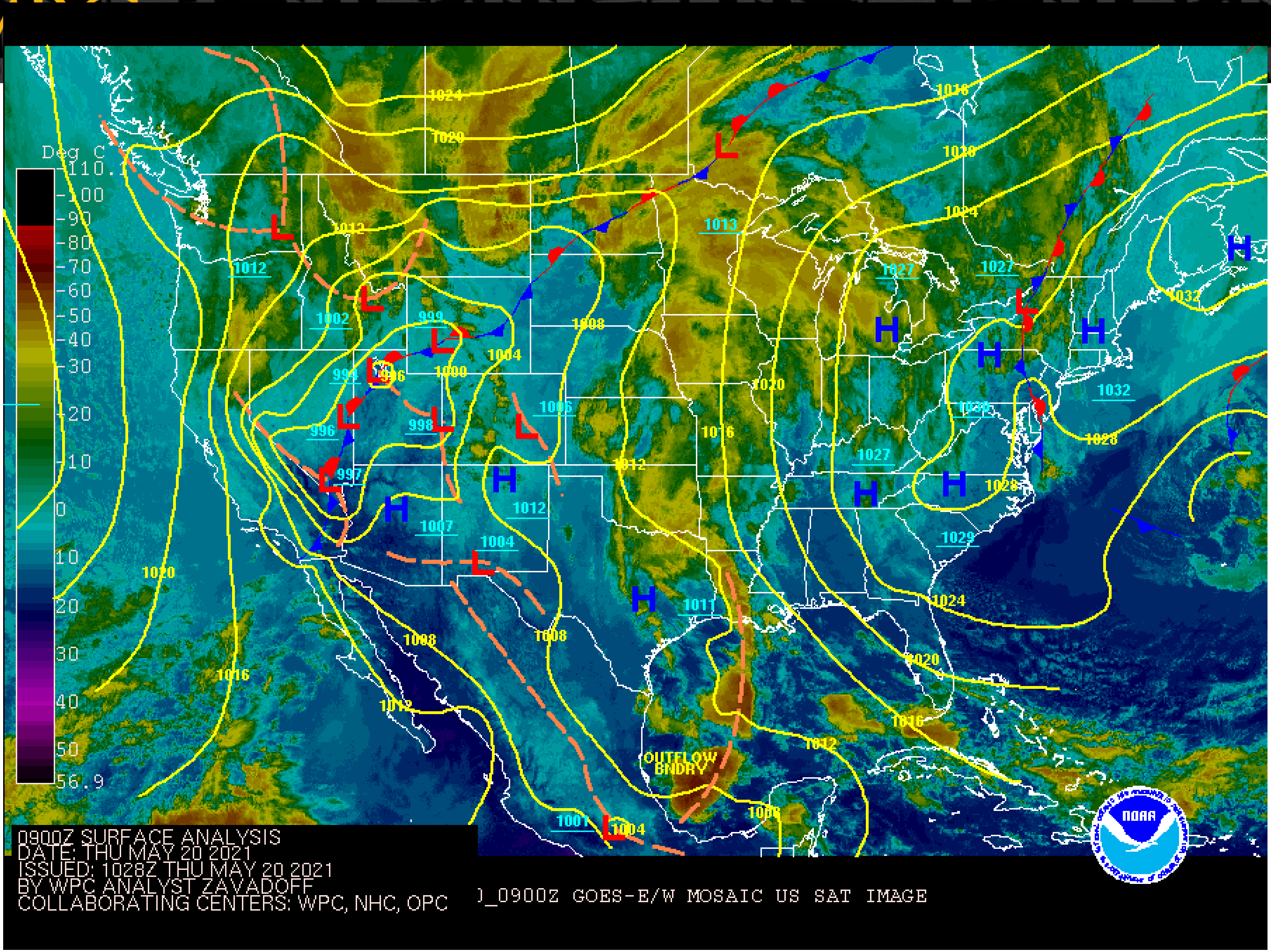
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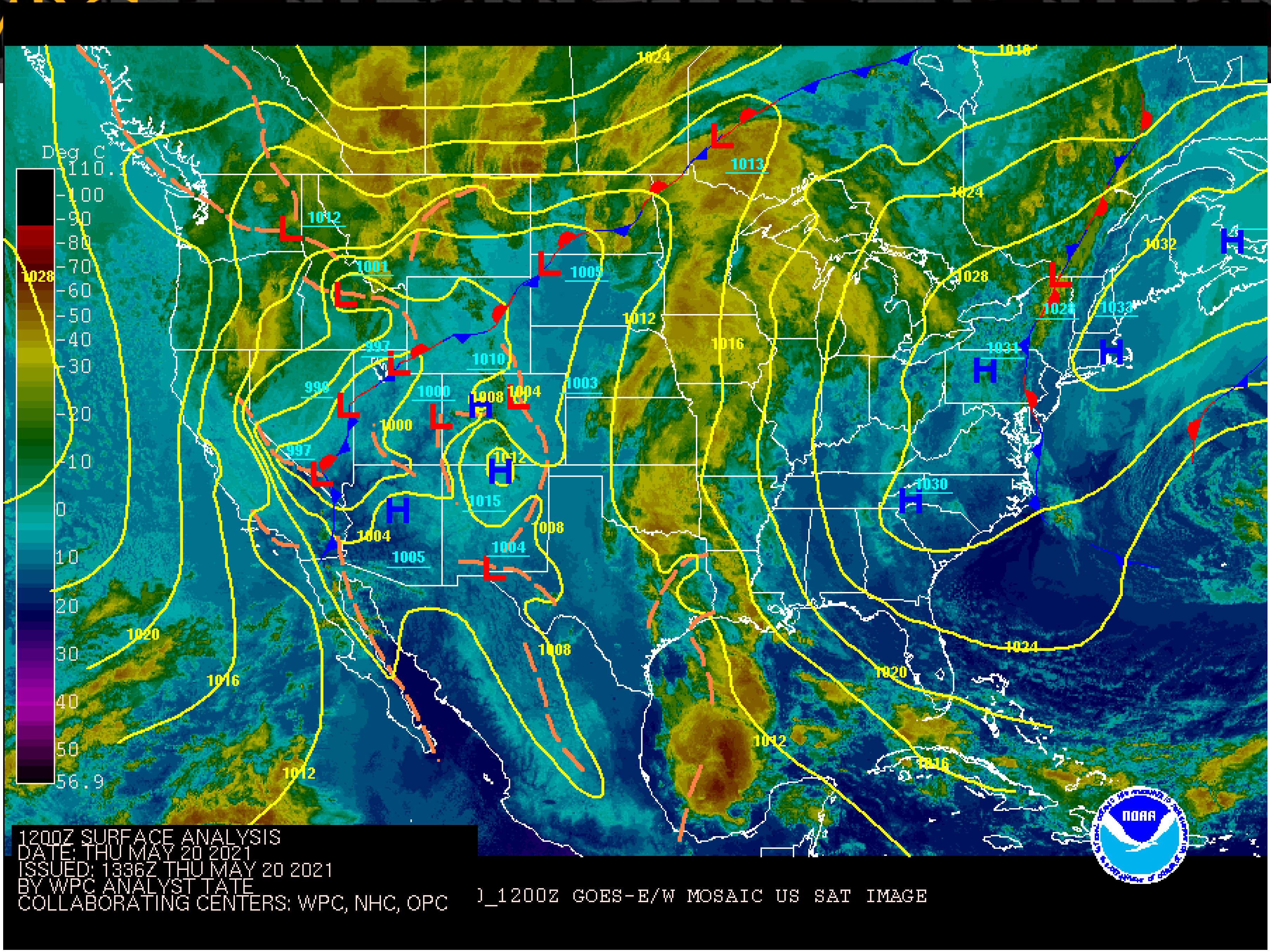
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ISSUED: 1336Z THU MAY 20 2021
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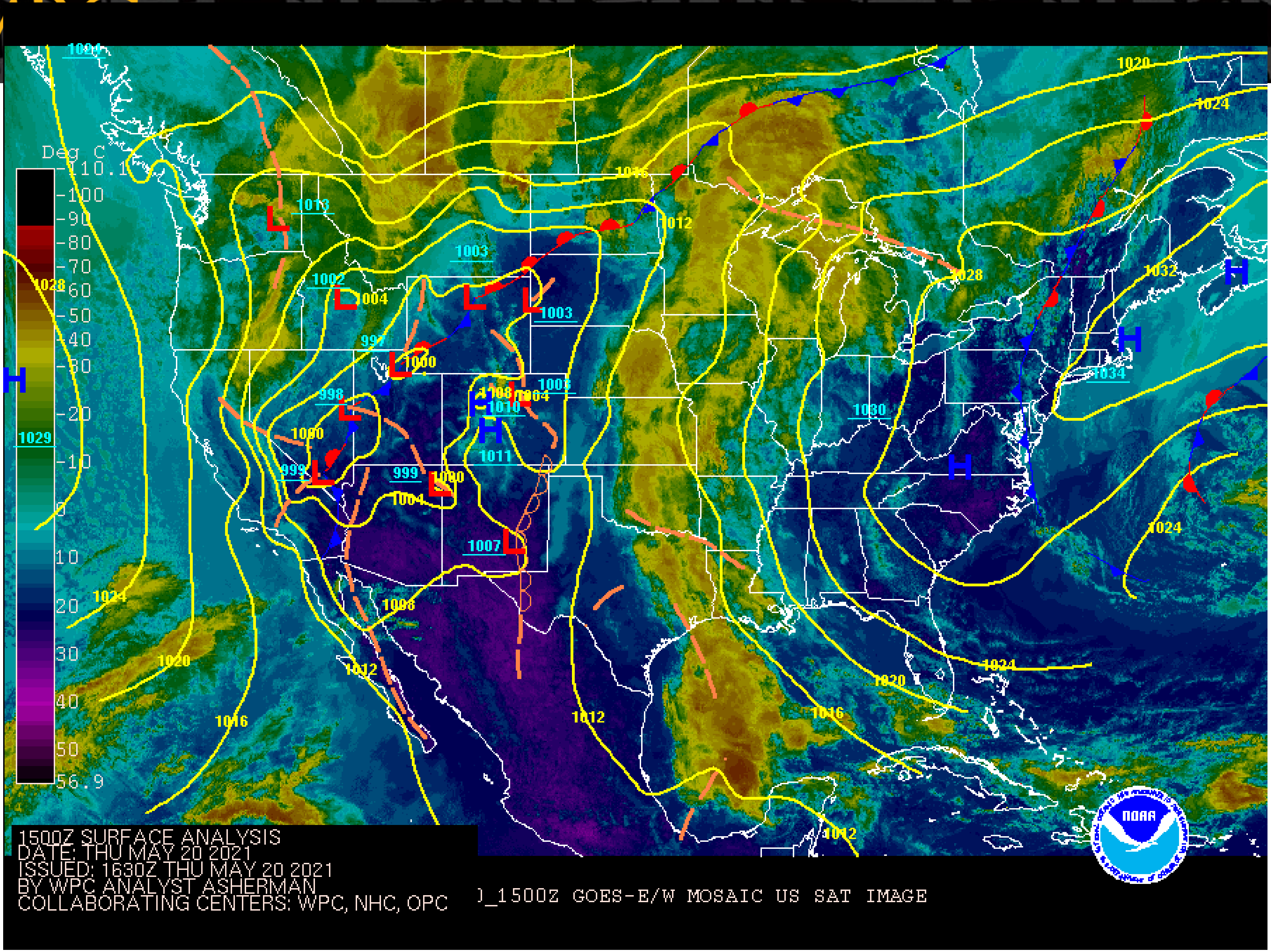
Deg C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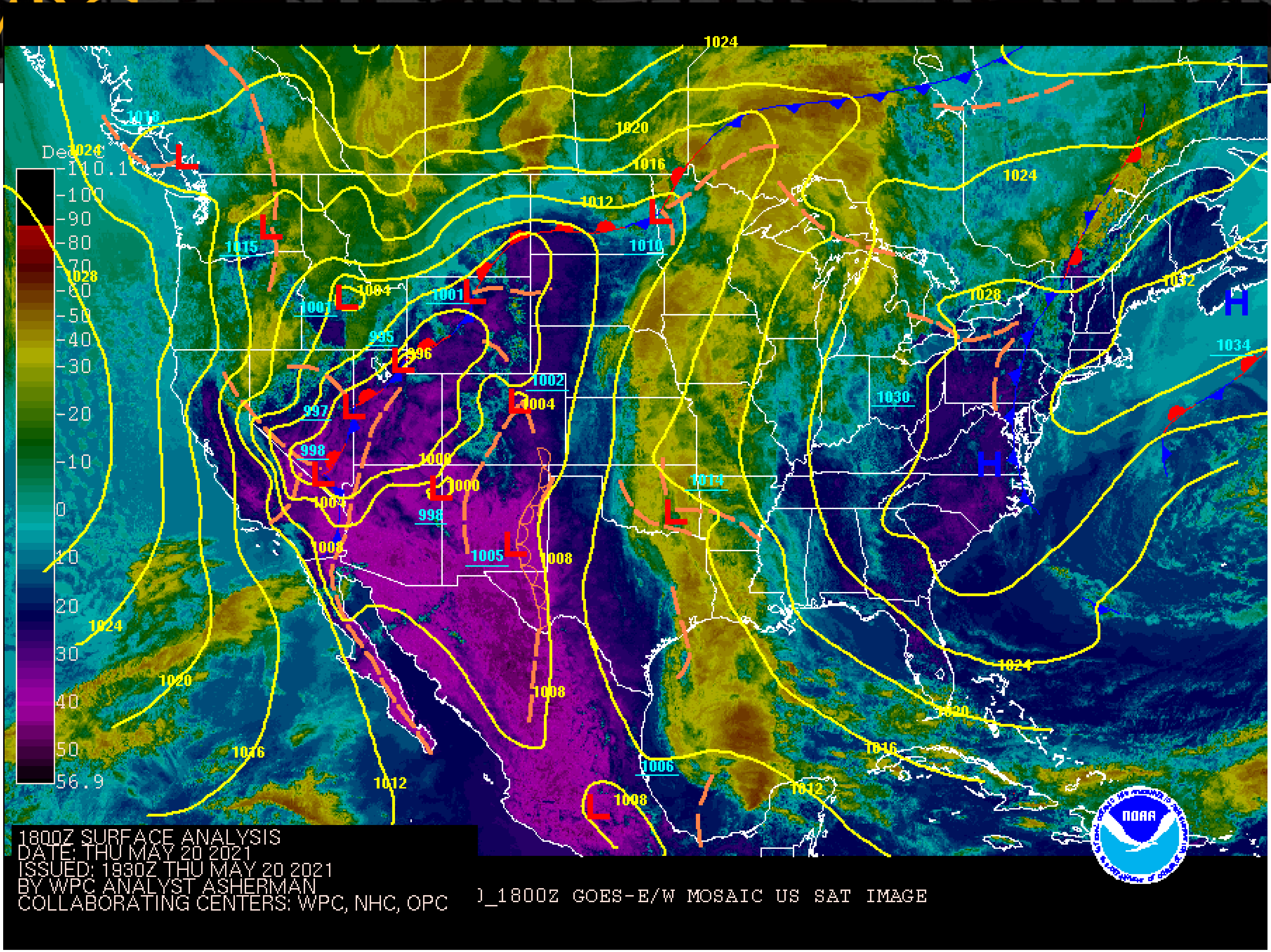
Deg C
NOAA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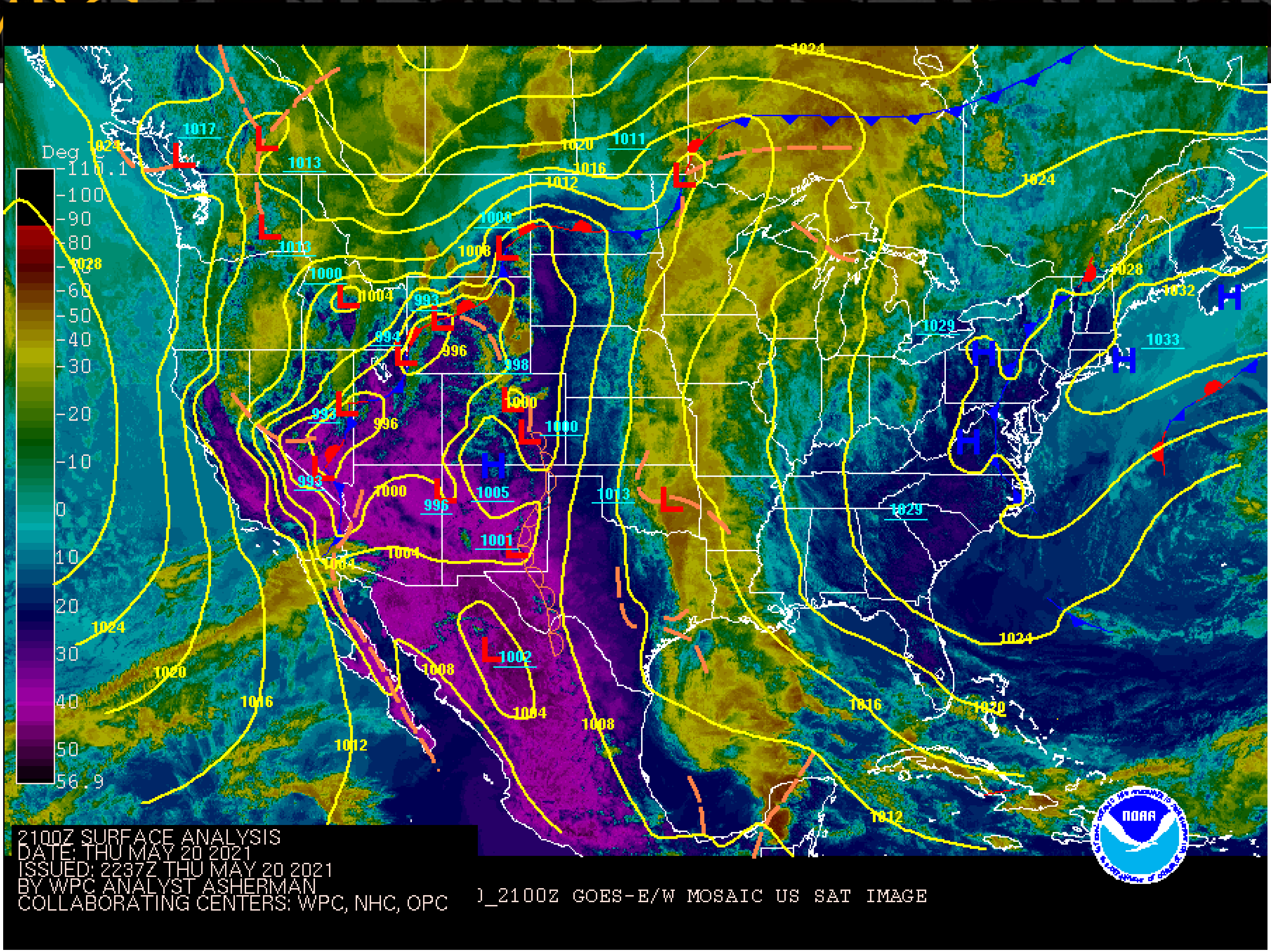
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Deg
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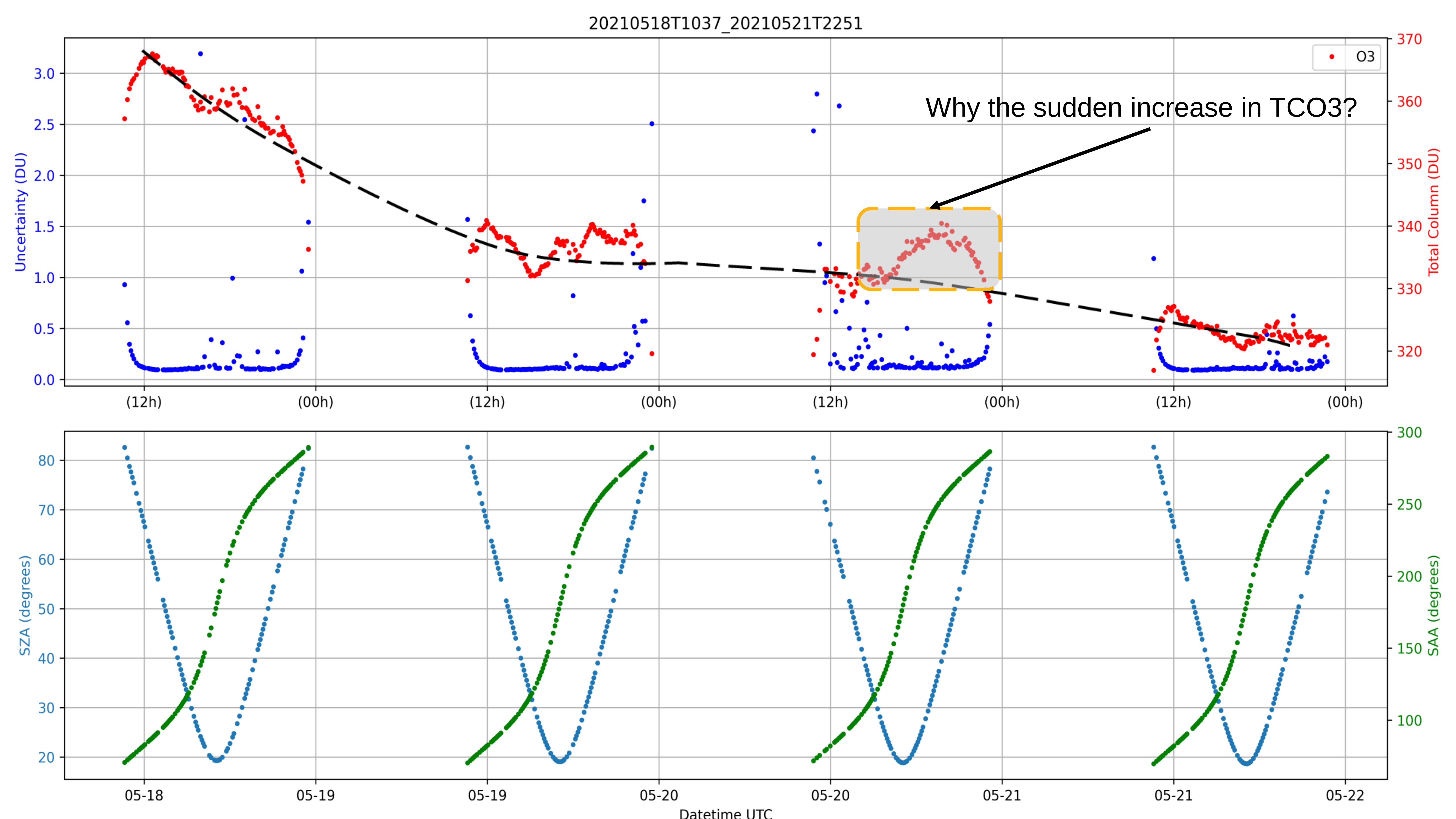

20210518T1037_20210521T2251
Why the sudden increase in TCO3?
O3
Uncertainty (DU)
Total Column (DU)
3.0
2.5
2.0
1.5
1.0
0.5
0.0
370
360
350
340
330
320
(12h)
(00h)
SZA (degrees)
SAA (degrees)
80
70
60
50
40
30
20
300
250
200
150
100
05-18
05-19
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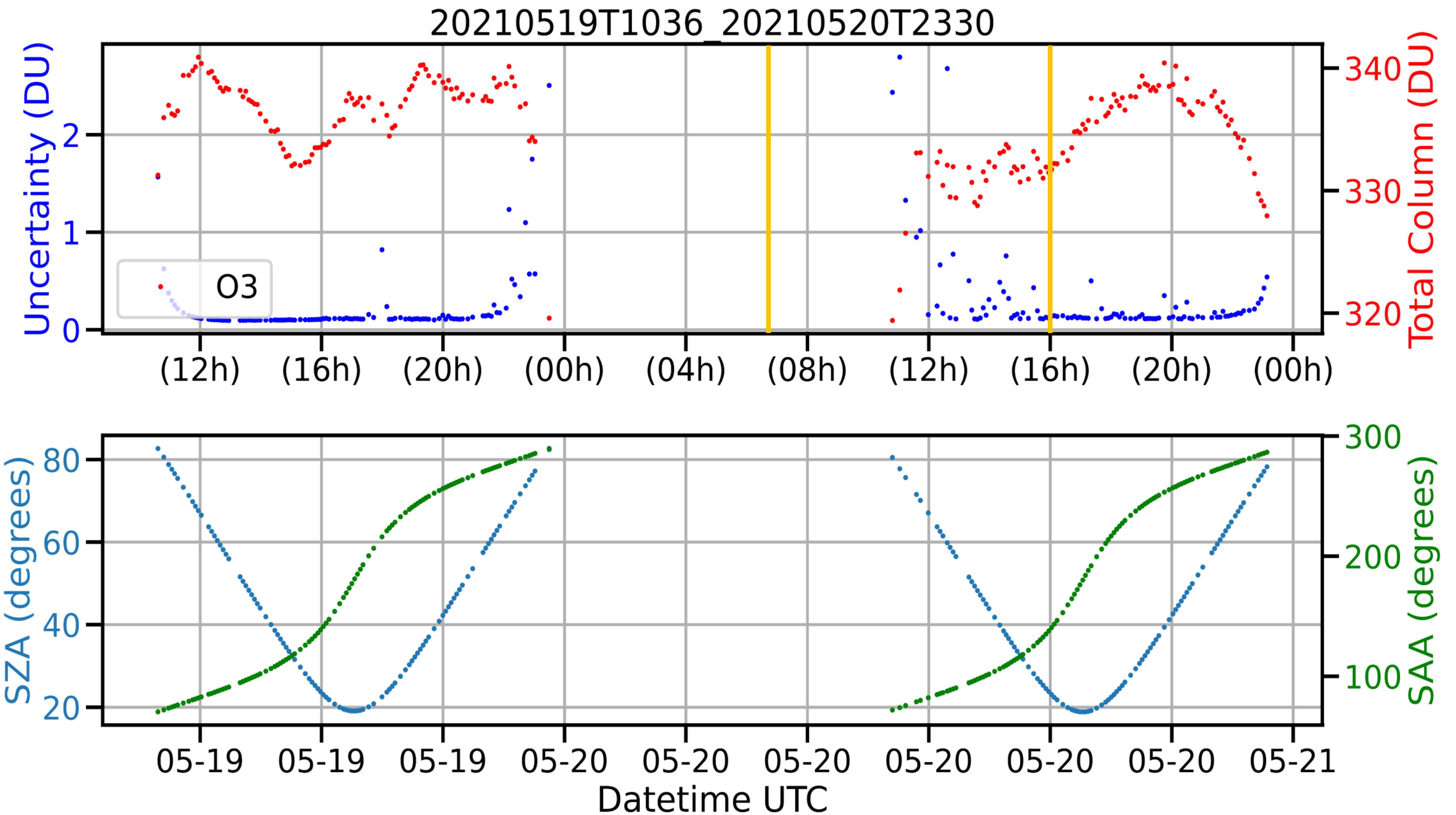
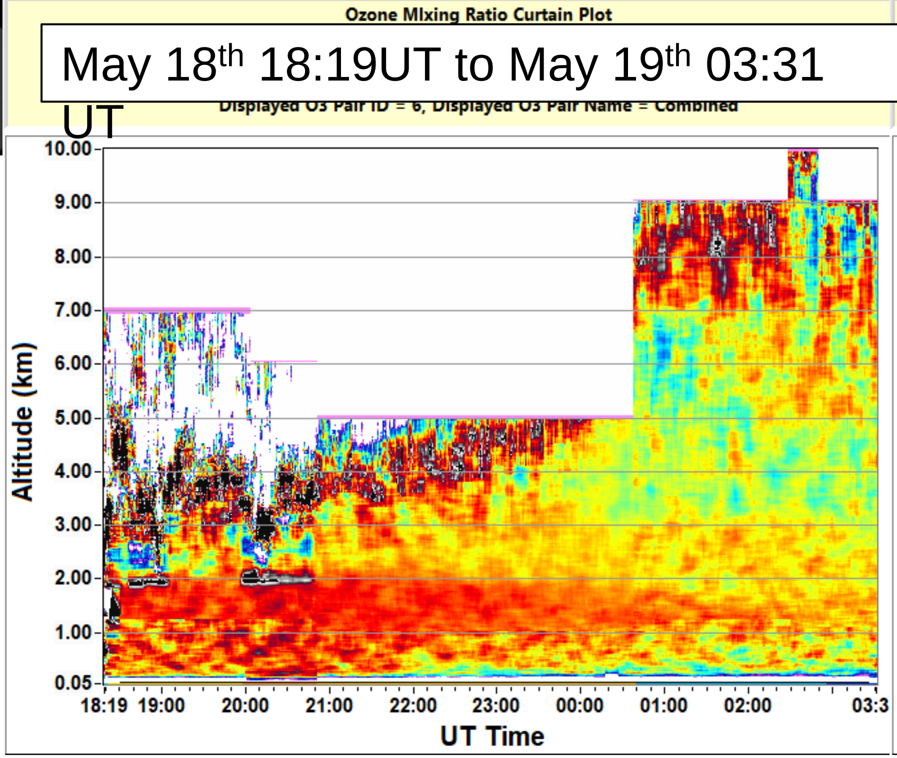
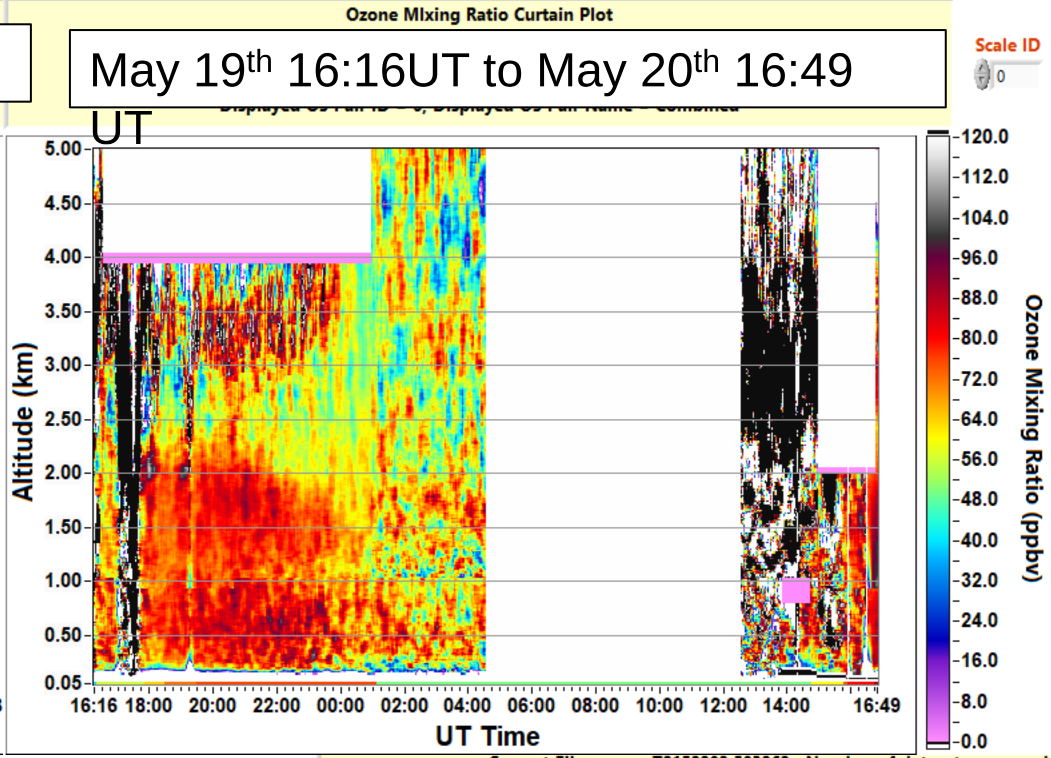
05-21
05-22
Datetime UTC


20210519T1036_20210520T2330
Uncertainty (DU)
Total Column (DU)
O3
0
1
2
320
330
340
(12h)
(16h)
(20h)
(00h)
(04h)
(08h)
(12h)
(16h)
(20h)
(00h)
SZA (degrees)
SAA (degrees)
20
40
60
80
100
200
300
05-19
05-19
05-19
05-20
05-20
05-20
05-20
05-20
05-20
05-21
Datetime UTC

May 18th 18:19UT to May 19th 03:31 UT

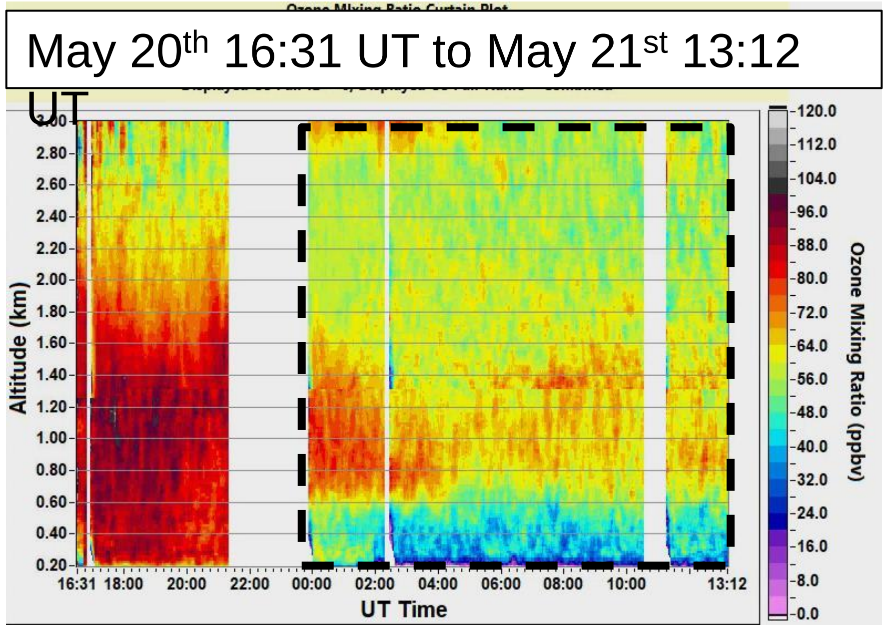


May 19th 16:16UT to May 20th 16:49 UT

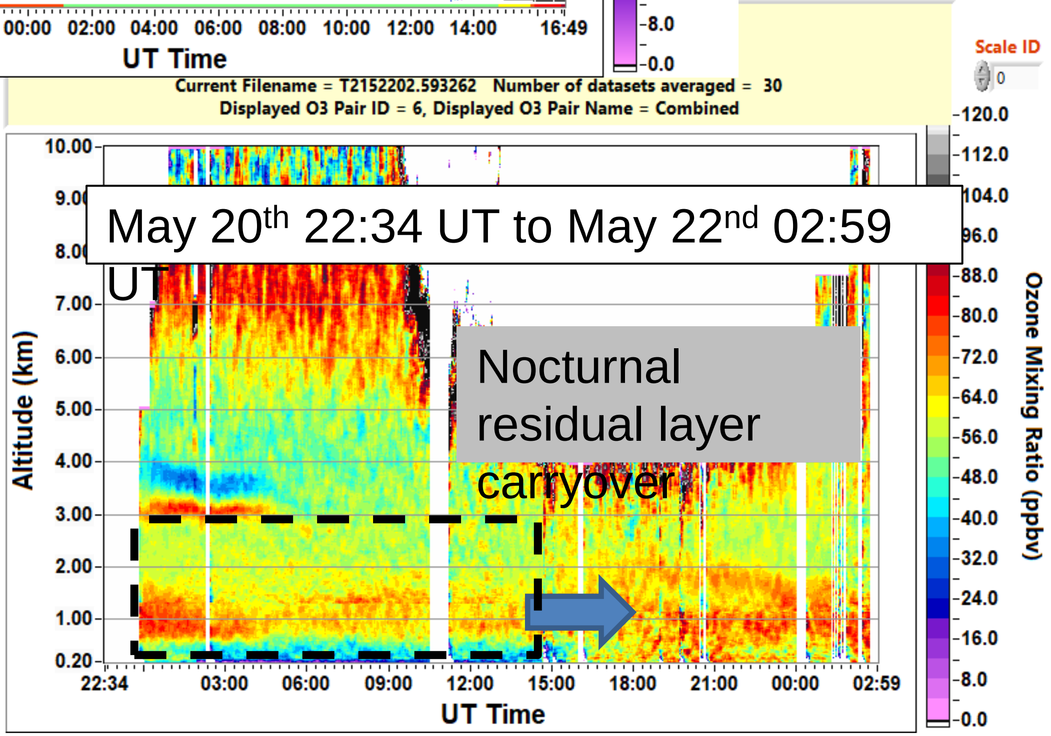


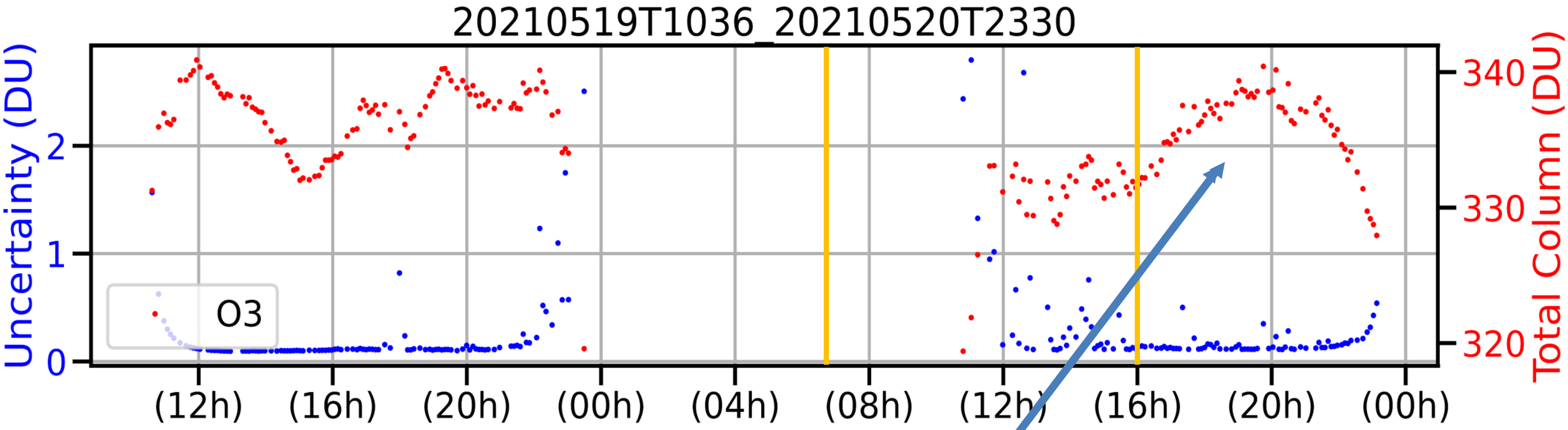
UT – LT+4hrs

May 20th 16:31 UT to May 21st 13:12 UT



May 20th 22:34 UT to May 22nd 02:59 UT





Is the high density of O3 the causation for this spike?