

**This document is a pdf of a slide show that has several animations. The original Powerpoint file is over 100 mb, so this file is offered as a transportable alternative. If you would like any of the animations, please contact Mke Fromm.**

**If you have any questions, comments, suggestions, or requests, please conatct one of the authors.**

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**24 September 2019**

# Sulfate Rising: Observational Analysis of Dramatic Diabatic Lofting of the Raikoke Volcanic Cloud



Mike Fromm<sup>1</sup>, Pat Kablick<sup>1</sup>, Isabelle Taylor<sup>2</sup>, Don Grainger<sup>2</sup>

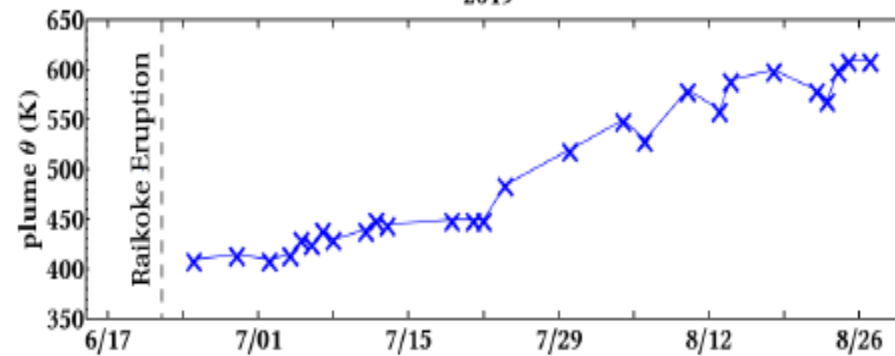
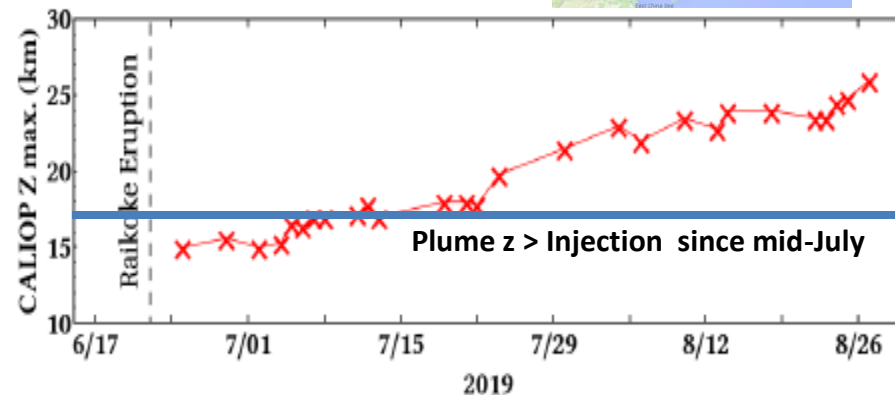
1. Naval Research Lab, Washington, D.C.

2. University of Oxford



21-Jun-2019 17:40:34 UTC  
GOES-17 ABI / Visible / 0.64 um / Band 2

Injection z max:  
15-17 km



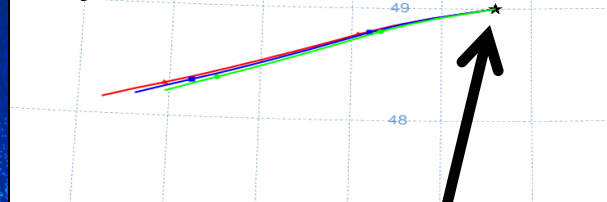
Credit: Scott Bachmeier, SSEC

## Raikoke Volcanic Cloud (VC) on 22 June

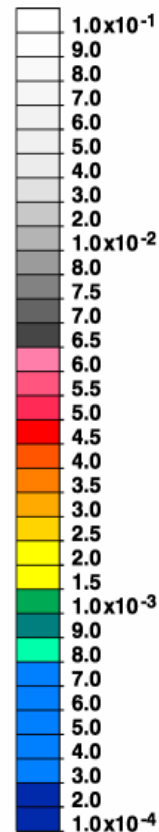
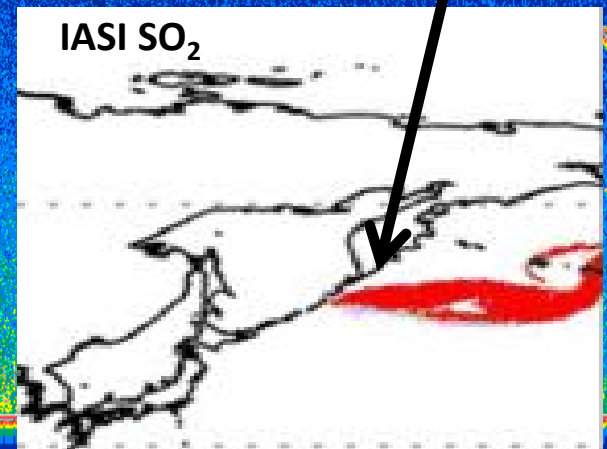
VC @ 16.5 km



Back  
Trajectories



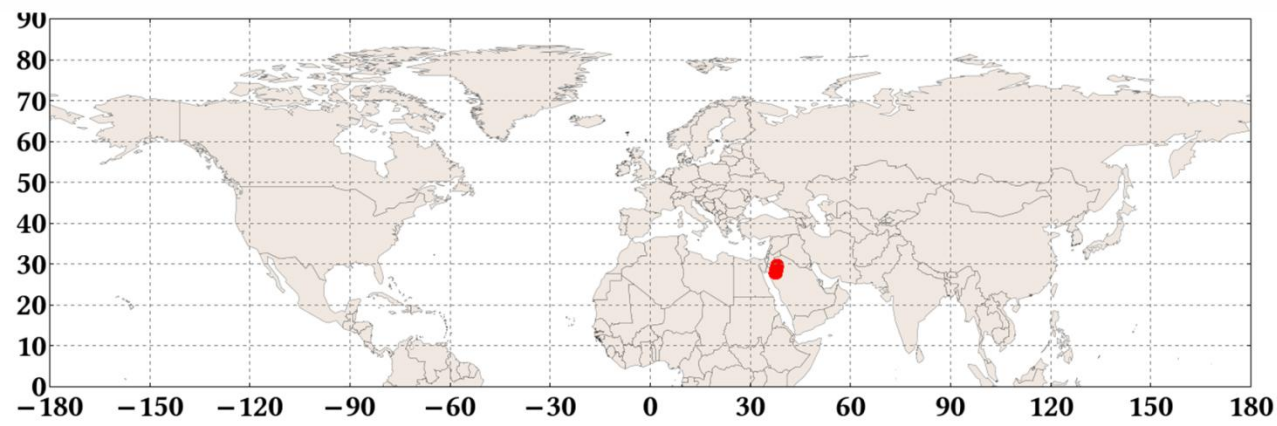
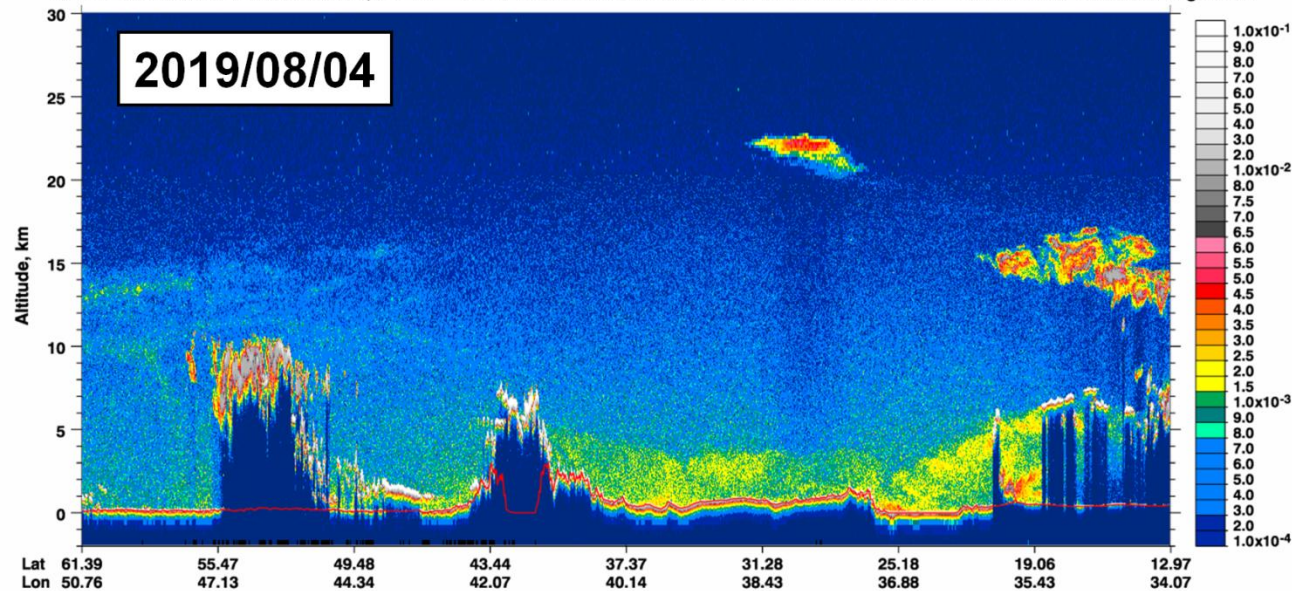
IASI SO<sub>2</sub>



Altitude, km

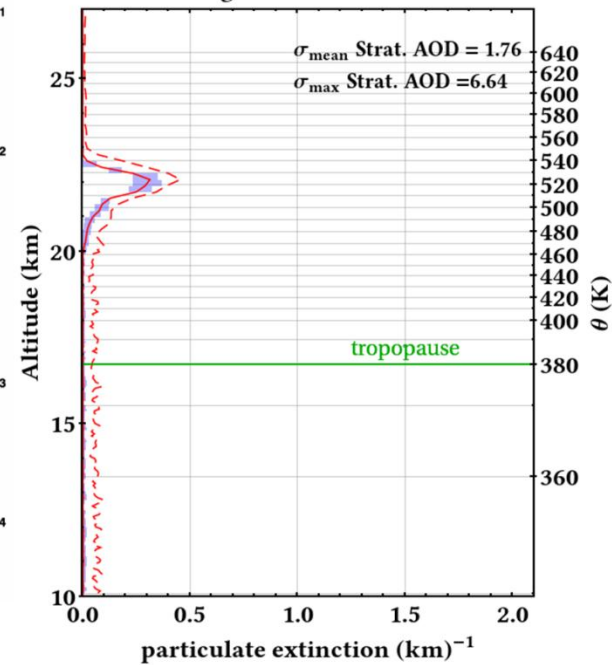
Lat 54.96 48.97 42.93 36.86 30.77 24.66 18.53 12.40 6.31  
Lon 159.34 156.61 154.37 152.46 150.77 149.23 147.79 146.42 145.10

532 nm Total Attenuated Backscatter,  $\text{km}^{-1} \text{sr}^{-1}$  UTC: 2019-08-04 23:28:27.6 to 2019-08-04 23:41:56.3 Version: 3.40 Standard Nighttime



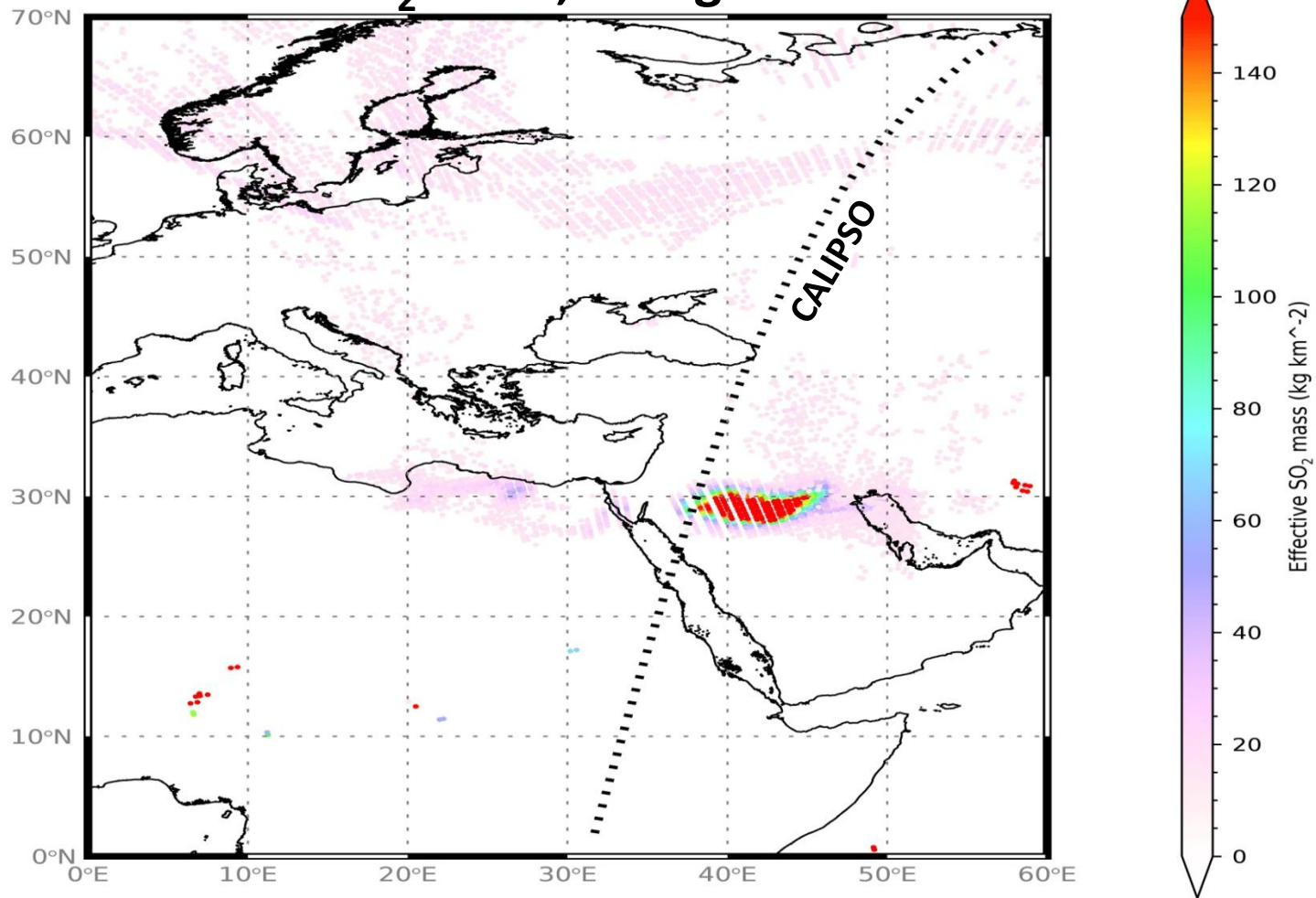
Smoothed over latitudes: 28.0 to 30.0,

longitudes: 38.1 to 37.6



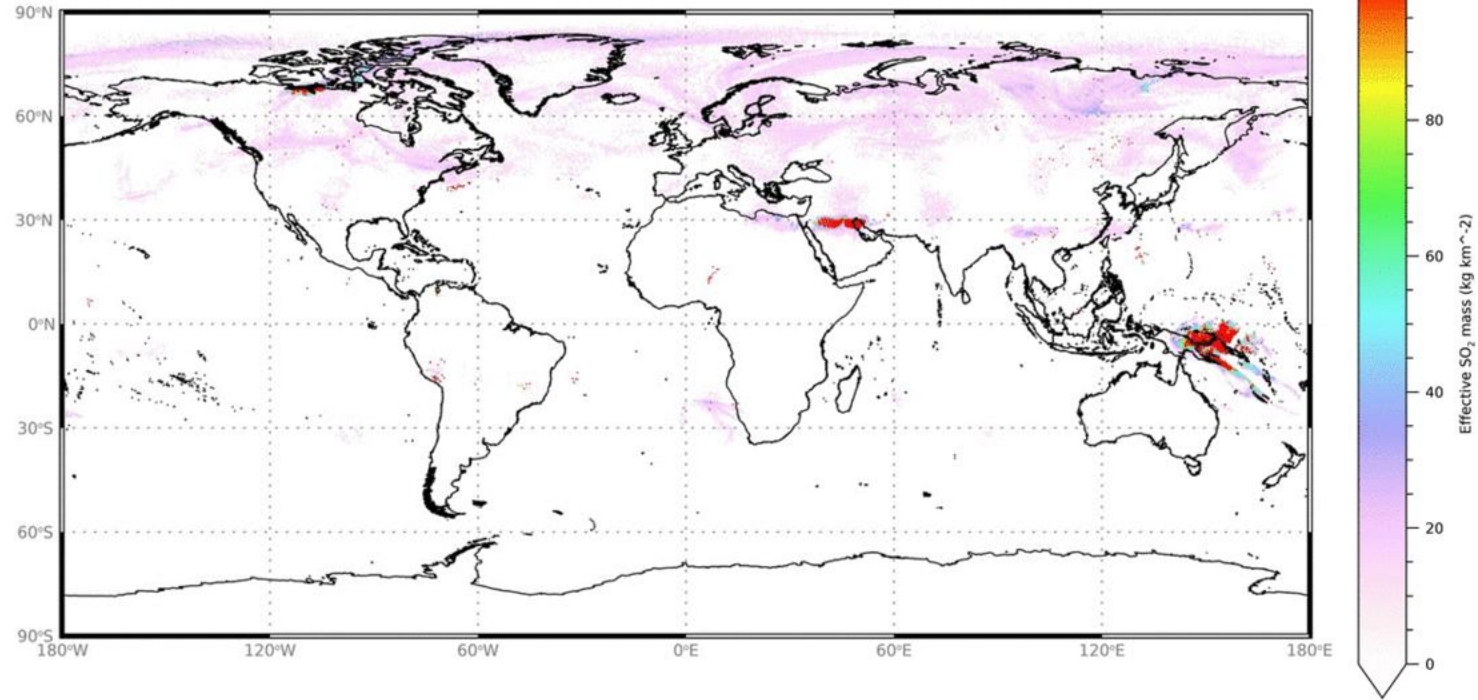


# IASI SO<sub>2</sub> Mass, 4 August 2019

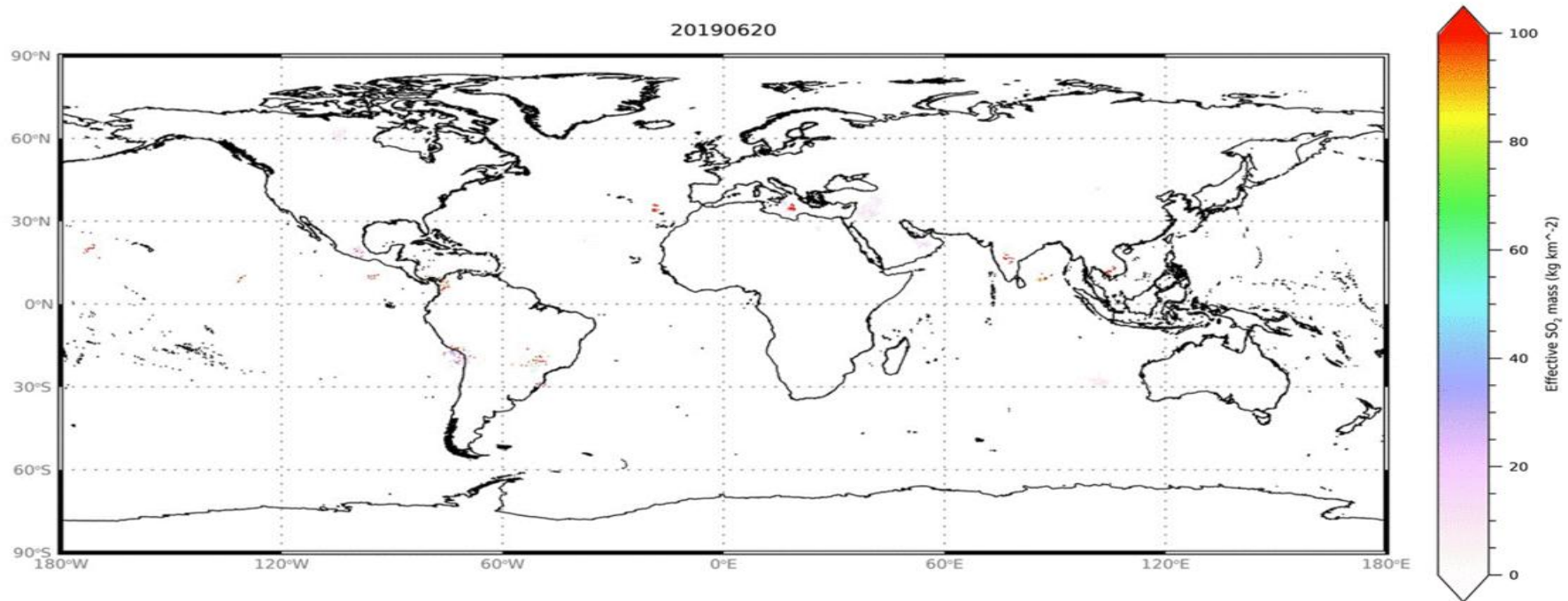


# IASI SO<sub>2</sub> Mass (Day and Night), Backward animation 4 August – 20 June

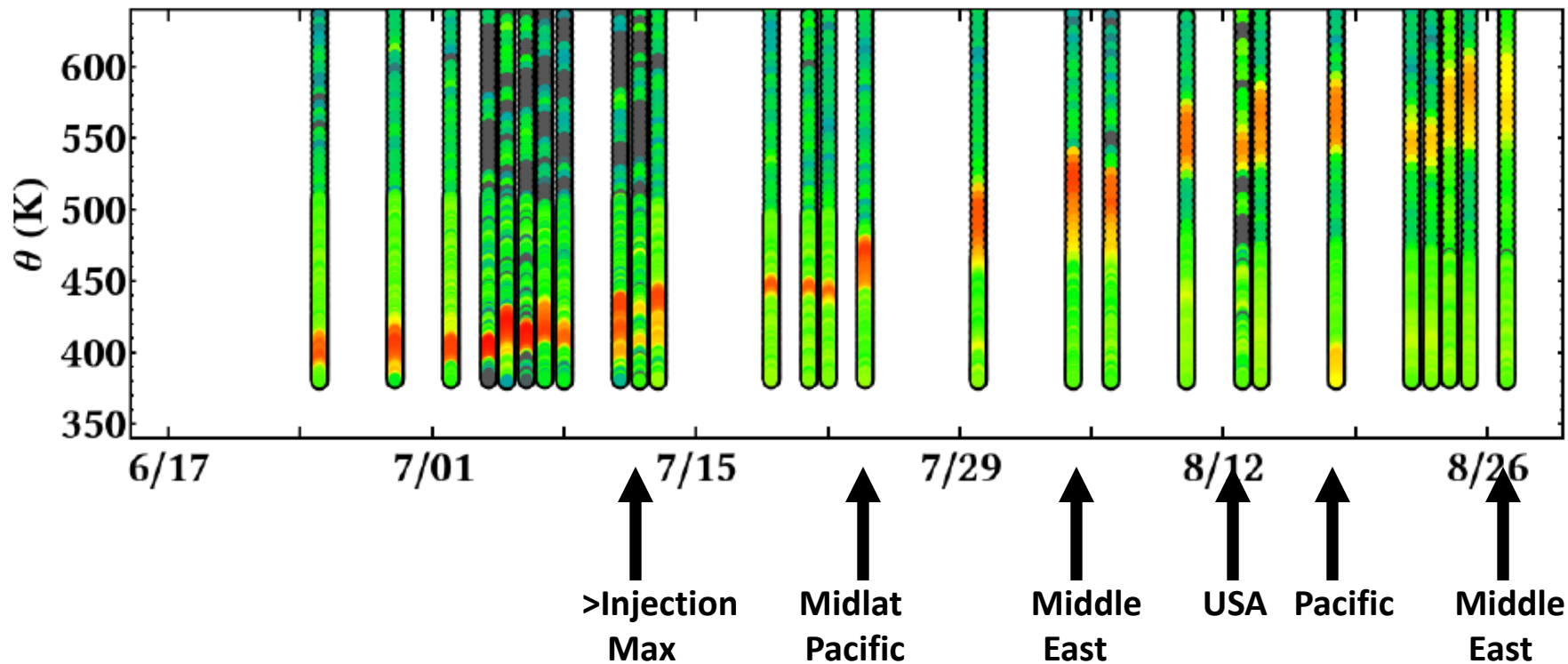
20190804



# IASI SO<sub>2</sub> Mass (Day and Night), Forward Animation 20 June – 29 August

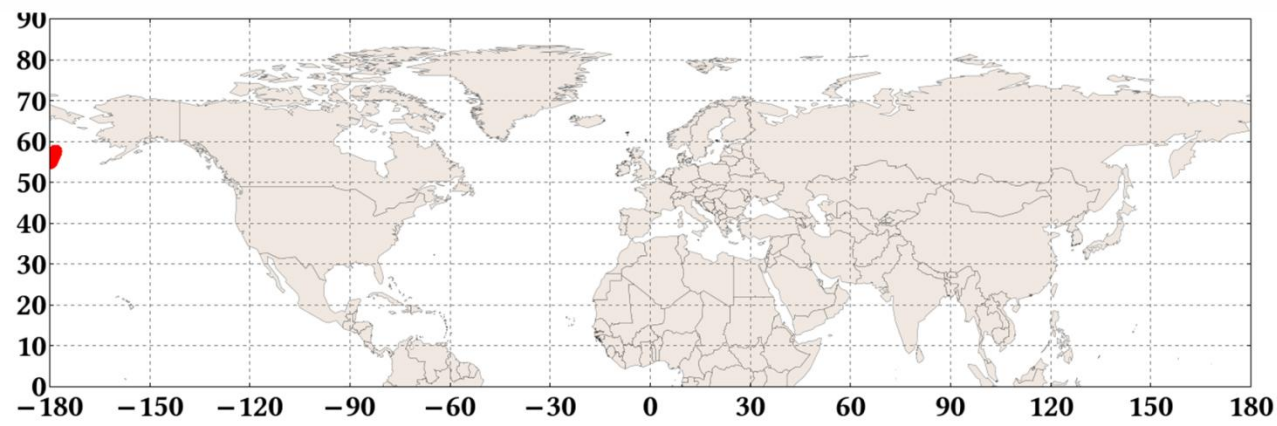
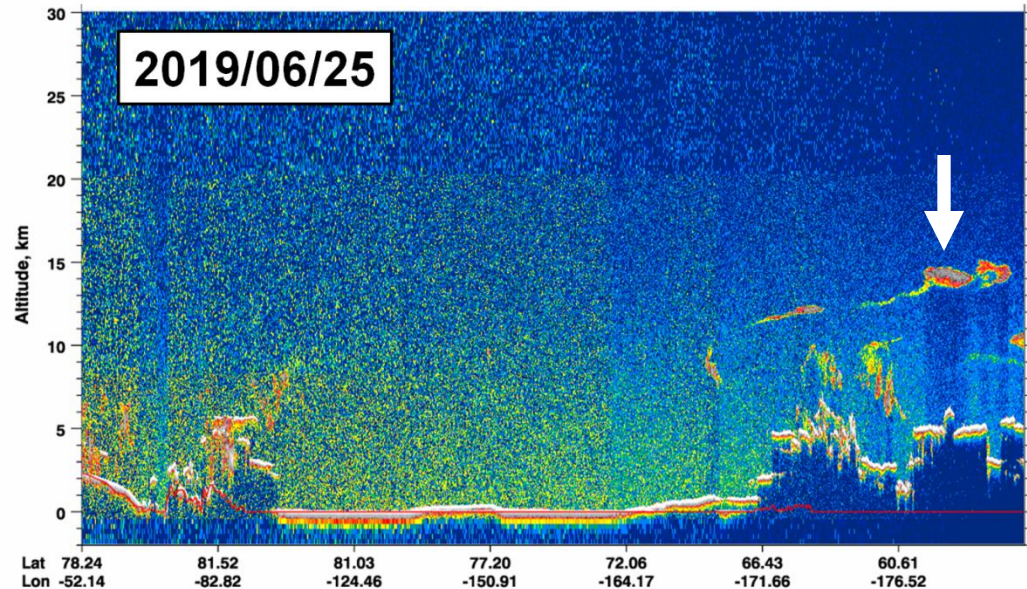


Progression of CALIOP extinction profiles w.r.t  
to potential temperature following the plume.



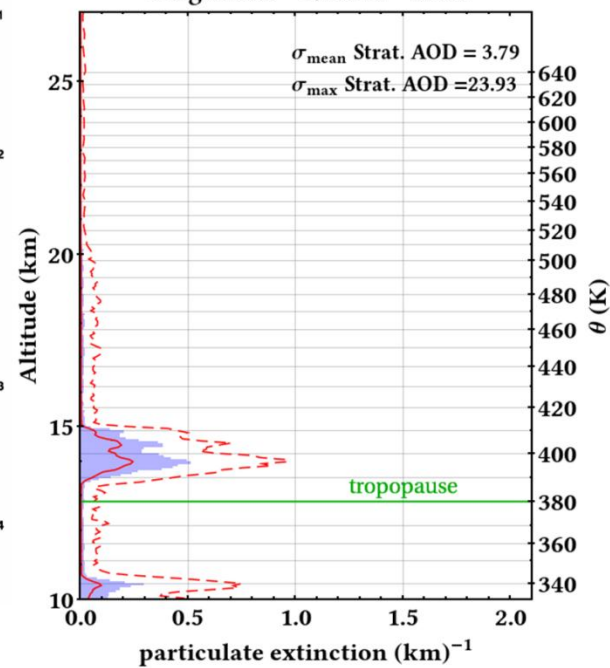


532 nm Total Attenuated Backscatter,  $\text{km}^{-1} \text{sr}^{-1}$  UTC: 2019-06-25 14:24:33.7 to 2019-06-25 14:36:13.8 Version: 3.40 Standard Daytime

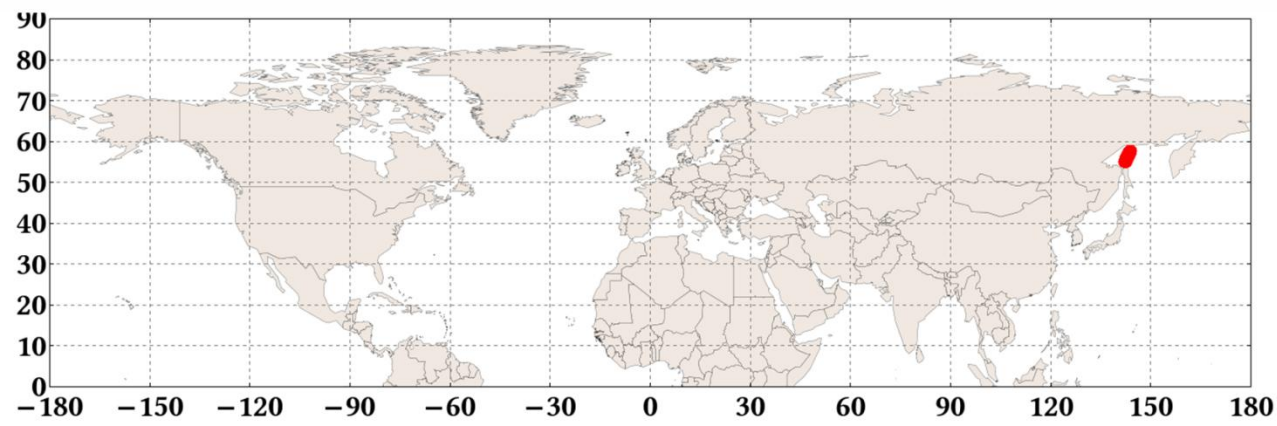
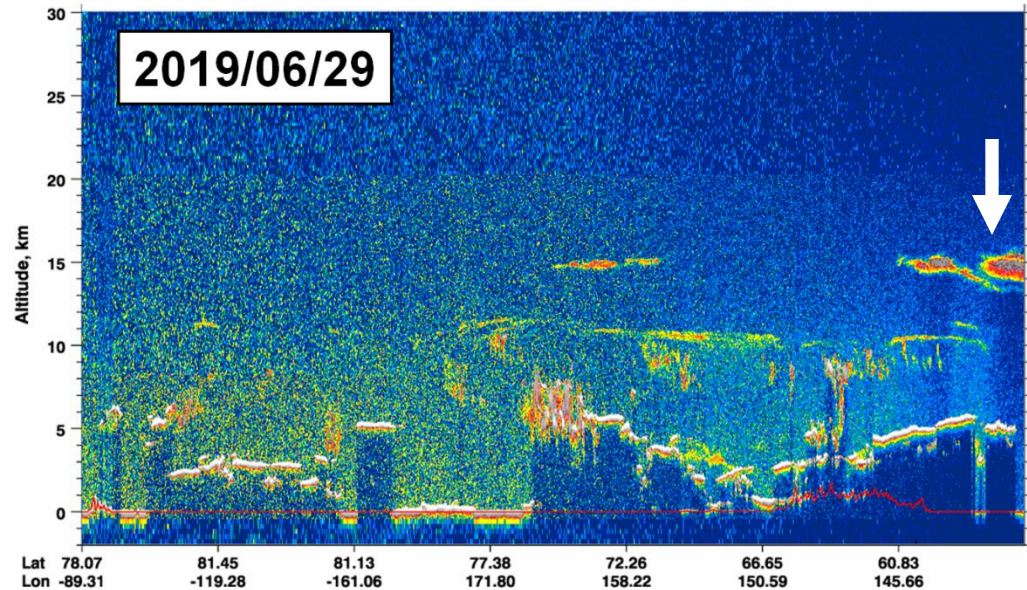


Smoothed over latitudes: 55.0 to 58.0,

longitudes: -178.0 to -180.0

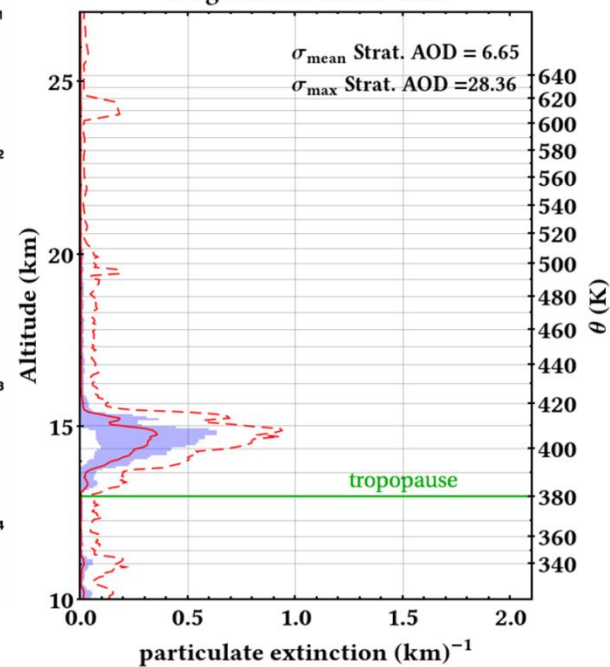


532 nm Total Attenuated Backscatter,  $\text{km}^{-1} \text{sr}^{-1}$  UTC: 2019-06-29 16:56:26.8 to 2019-06-29 17:08:06.8 Version: 3.40 Standard Daytime



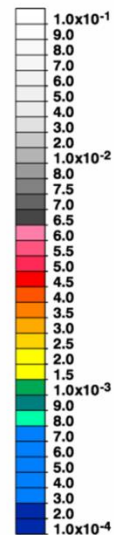
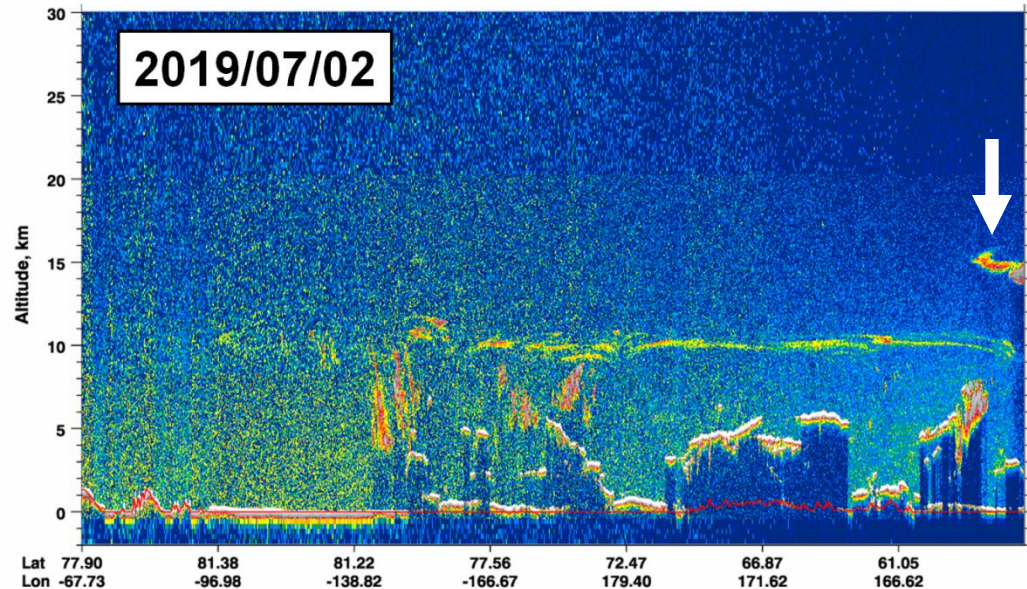
Smoothed over latitudes: 54.0 to 58.0,

longitudes: 144.0 to 142.0



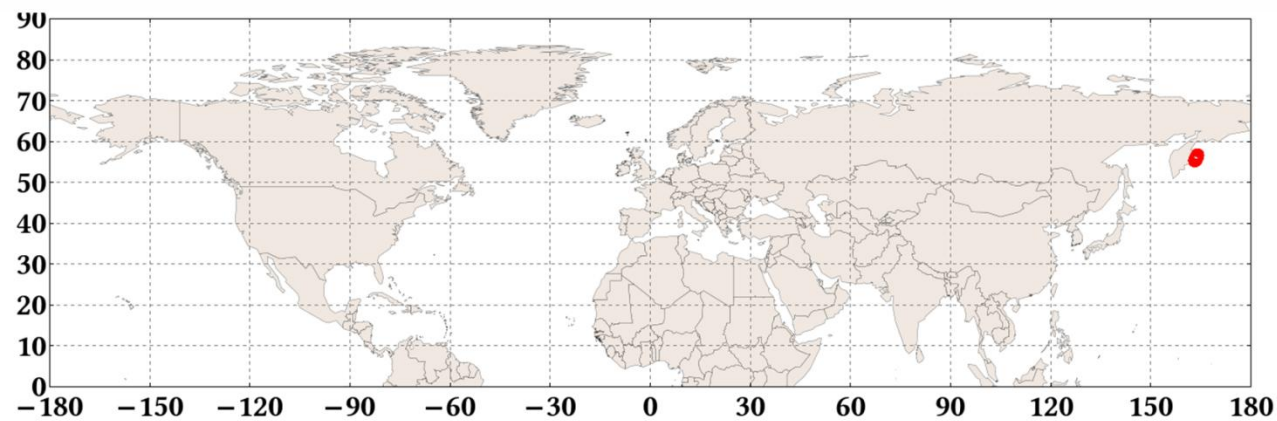
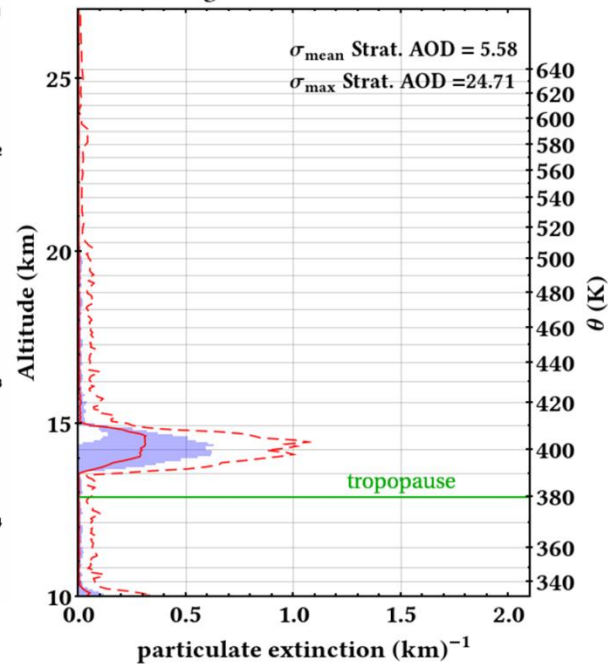


532 nm Total Attenuated Backscatter,  $\text{km}^{-1} \text{sr}^{-1}$  UTC: 2019-07-02 15:33:16.6 to 2019-07-02 15:44:56.7 Version: 3.40 Standard Daytime



Smoothed over latitudes: 54.0 to 57.0,

longitudes: 164.0 to 163.0



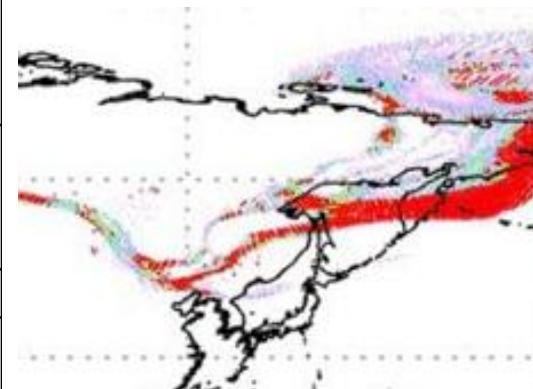
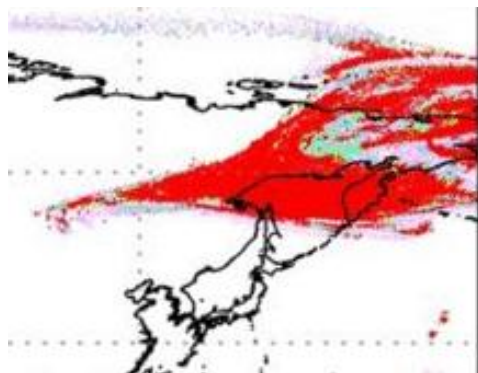
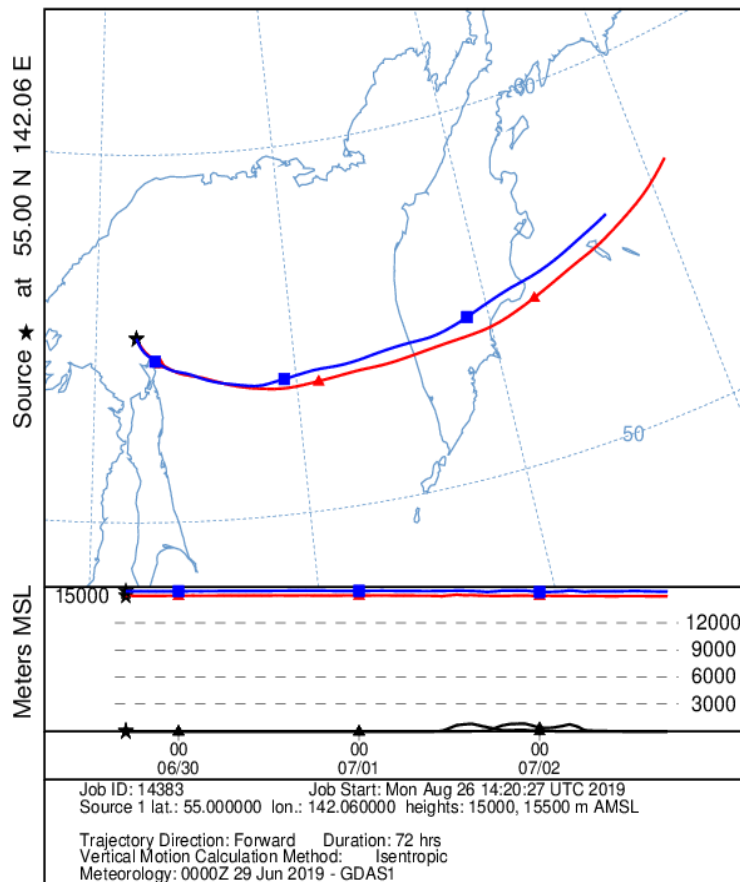
# Lagrangian Connection

3-day forward trajectories

29 June



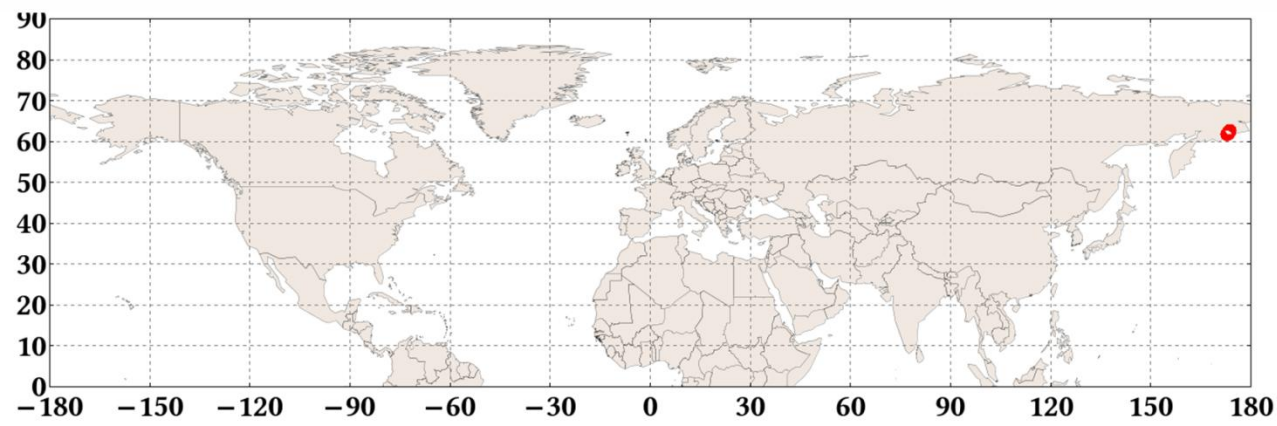
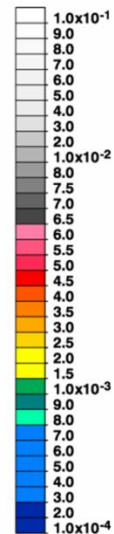
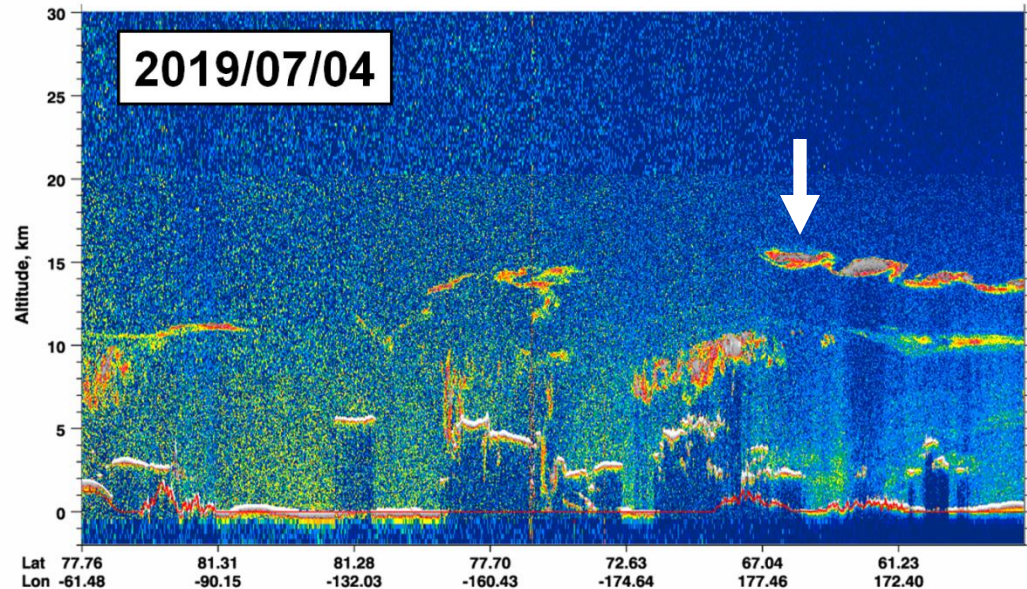
2 July





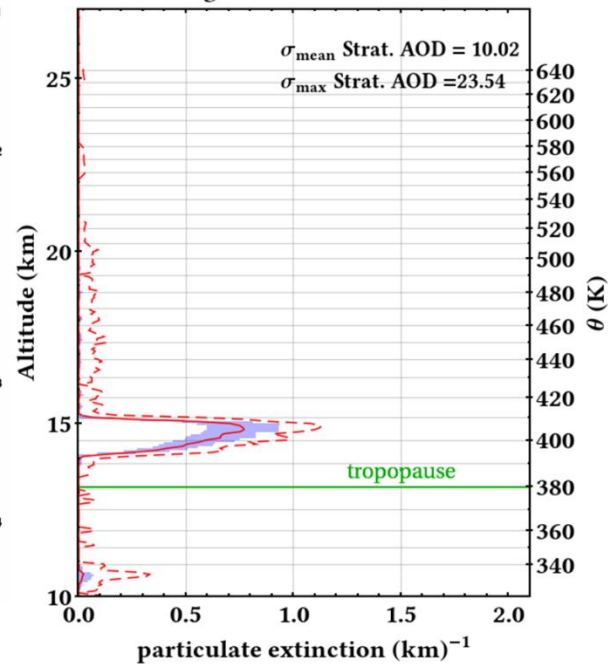
532 nm Total Attenuated Backscatter,  $\text{km}^{-1} \text{sr}^{-1}$  UTC: 2019-07-04 15:10:39.9 to 2019-07-04 15:22:20.0 Version: 3.40 Standard Daytime

2019/07/04

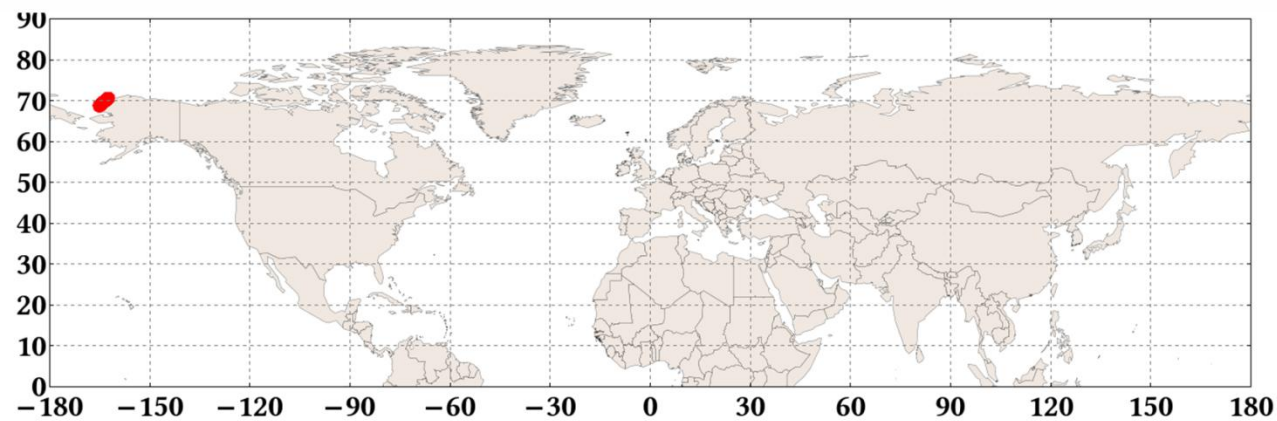
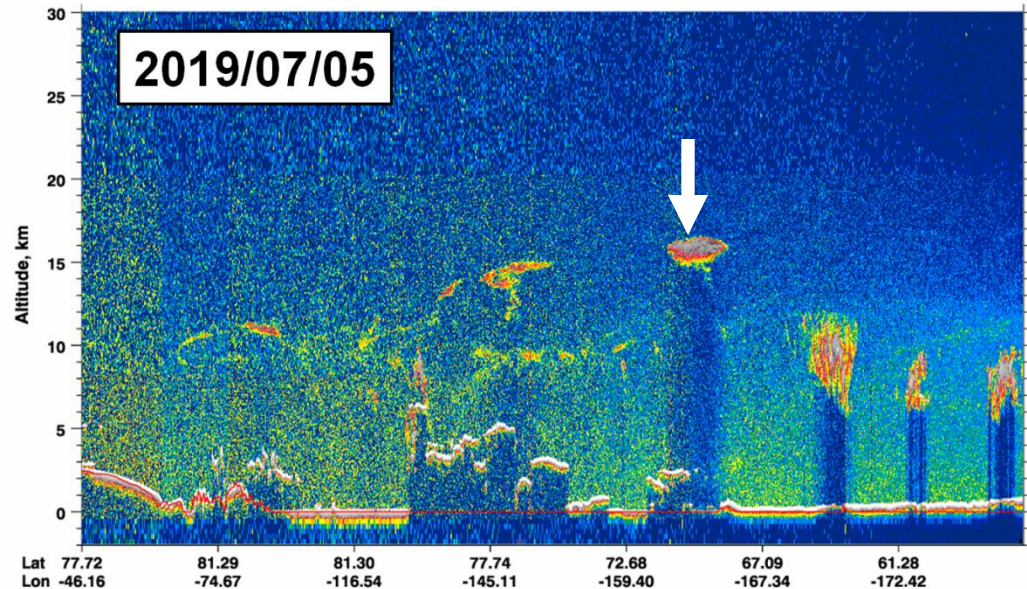


Smoothed over latitudes: 62.0 to 63.0,

longitudes: 174.0 to 173.0

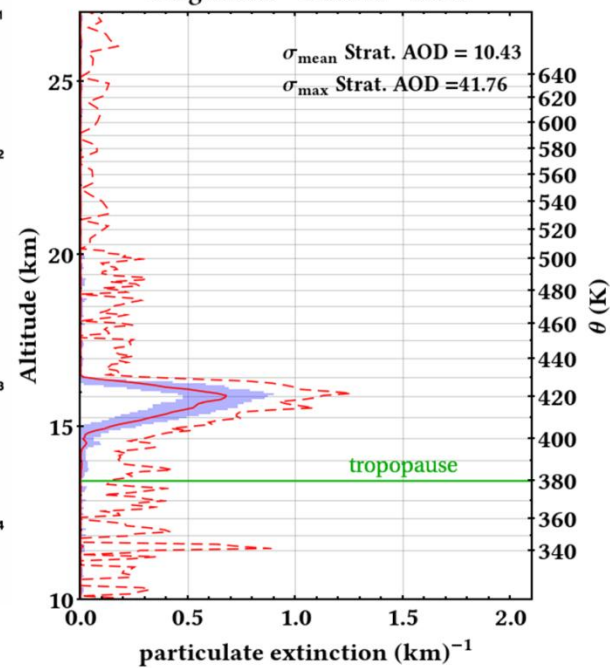


532 nm Total Attenuated Backscatter,  $\text{km}^{-1} \text{sr}^{-1}$  UTC: 2019-07-05 14:10:06.2 to 2019-07-05 14:21:45.6 Version: 3.40 Standard Daytime



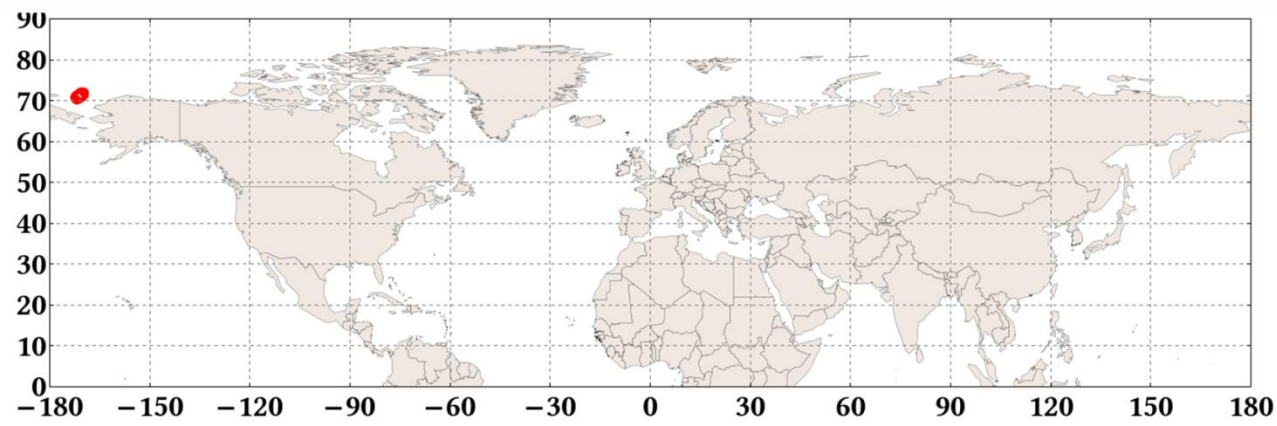
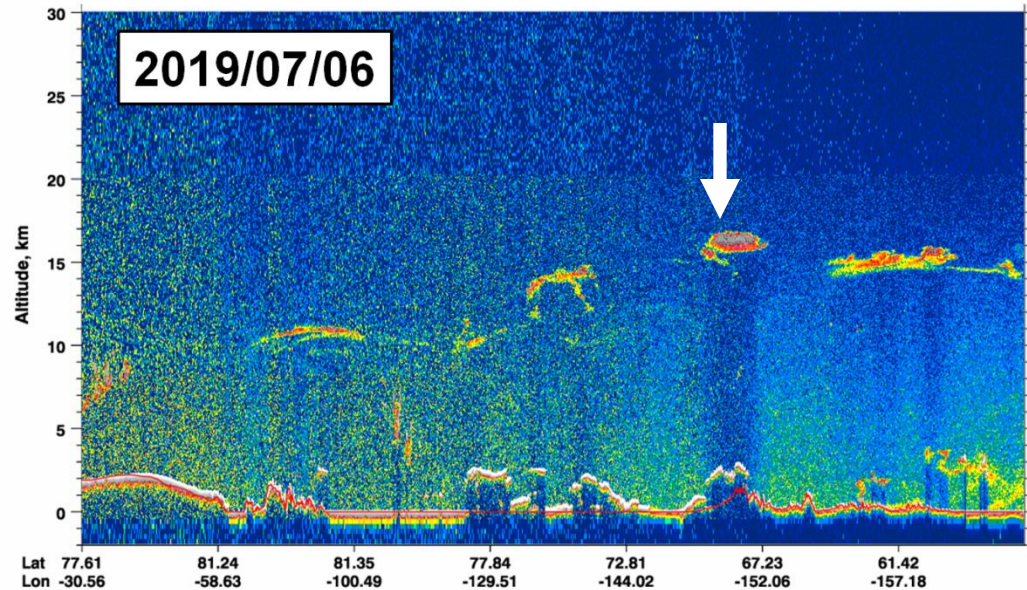
Smoothed over latitudes: 69.0 to 71.0,

longitudes: -162.0 to -165.0



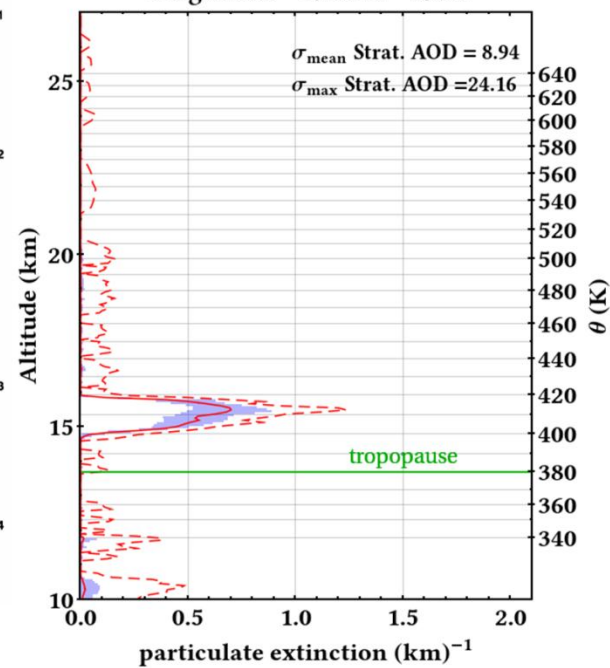


532 nm Total Attenuated Backscatter,  $\text{km}^{-1} \text{sr}^{-1}$  UTC: 2019-07-06 13:09:31.1 to 2019-07-06 13:21:11.2 Version: 3.40 Standard Daytime

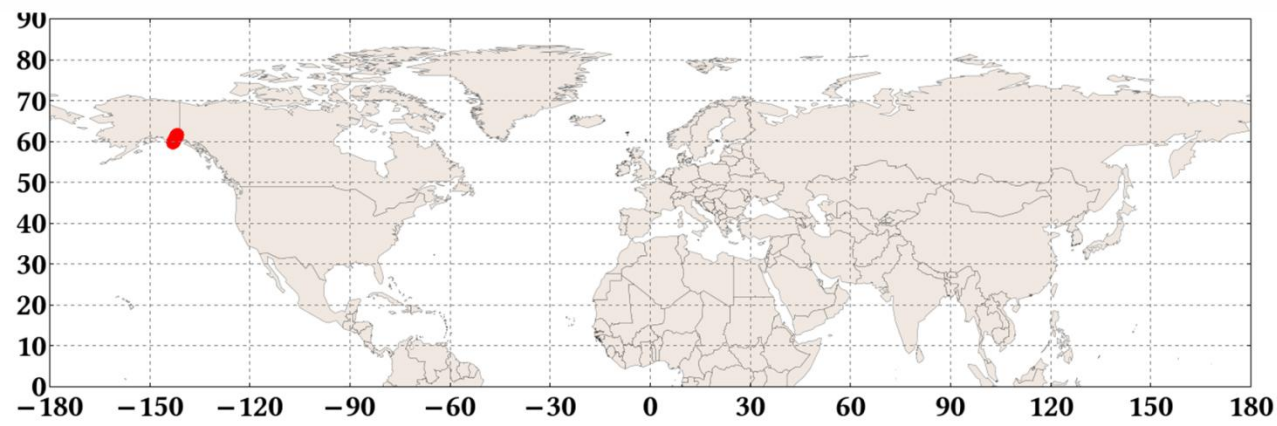
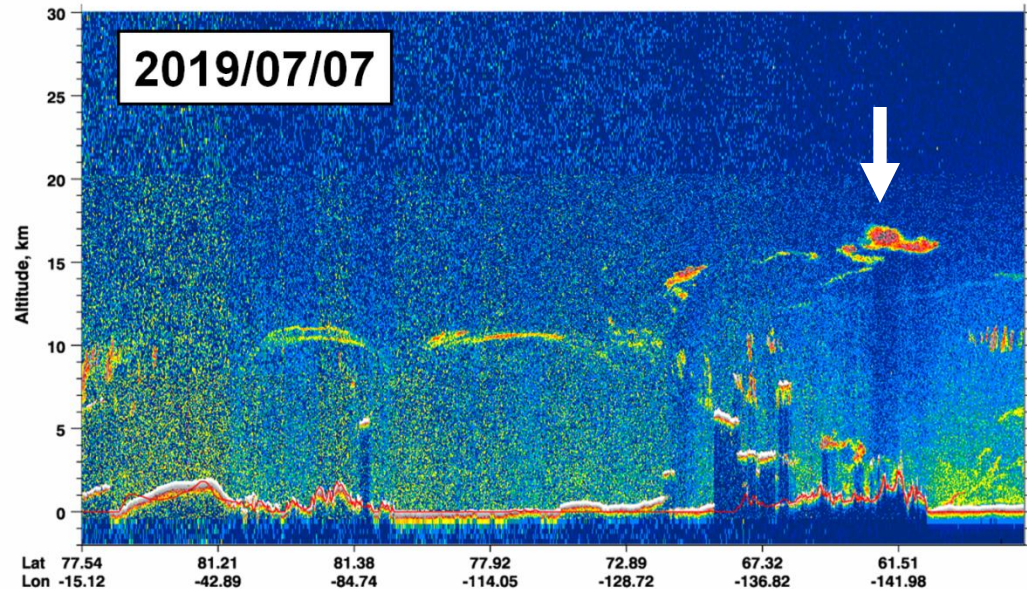


Smoothed over latitudes: 71.0 to 72.0,

longitudes: -170.0 to -172.0

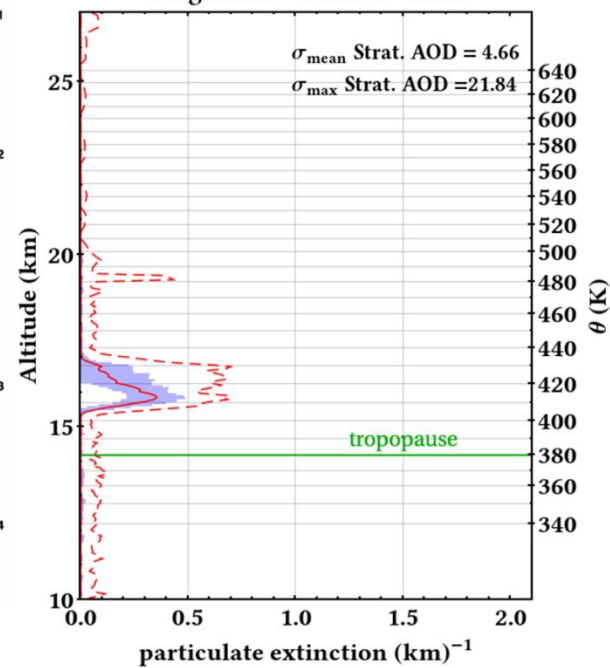


532 nm Total Attenuated Backscatter,  $\text{km}^{-1} \text{sr}^{-1}$  UTC: 2019-07-07 12:08:56.7 to 2019-07-07 12:20:36.8 Version: 3.40 Standard Daytime



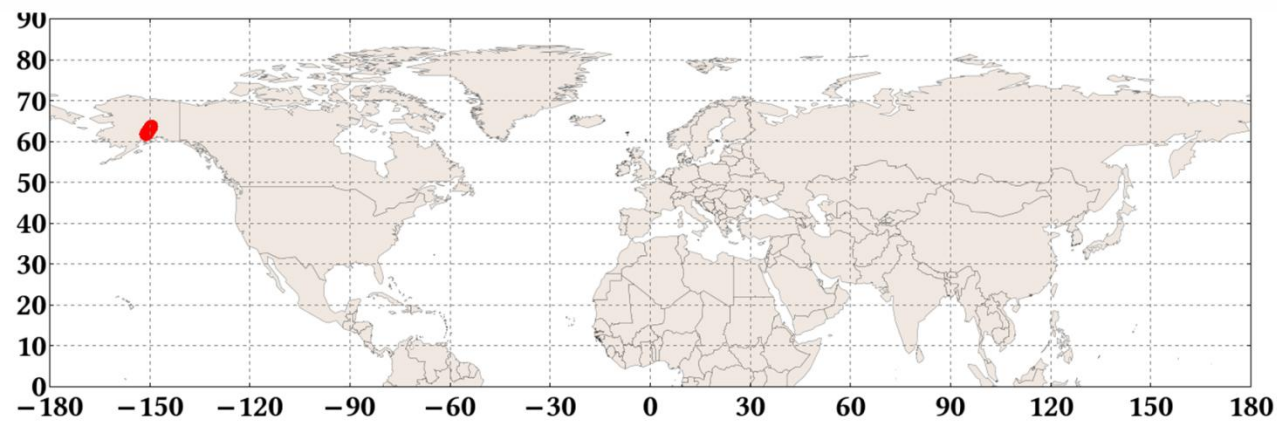
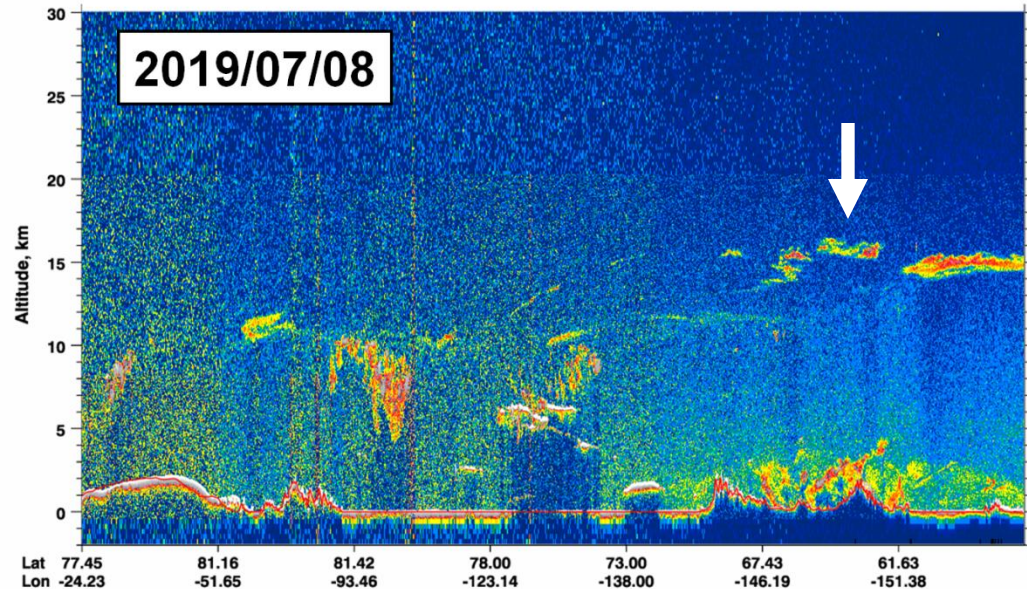
Smoothed over latitudes: 60.0 to 62.0,

longitudes: -142.0 to -143.0



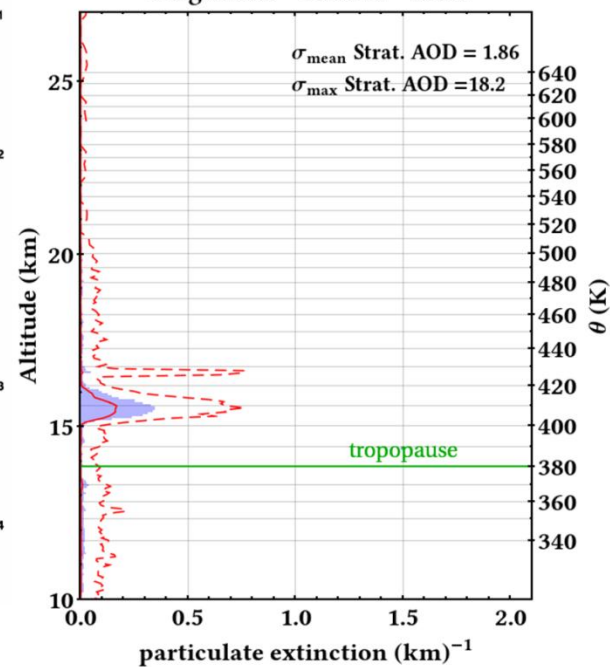


532 nm Total Attenuated Backscatter,  $\text{km}^{-1} \text{sr}^{-1}$  UTC: 2019-07-08 12:46:53.8 to 2019-07-08 12:58:33.9 Version: 3.40 Standard Daytime

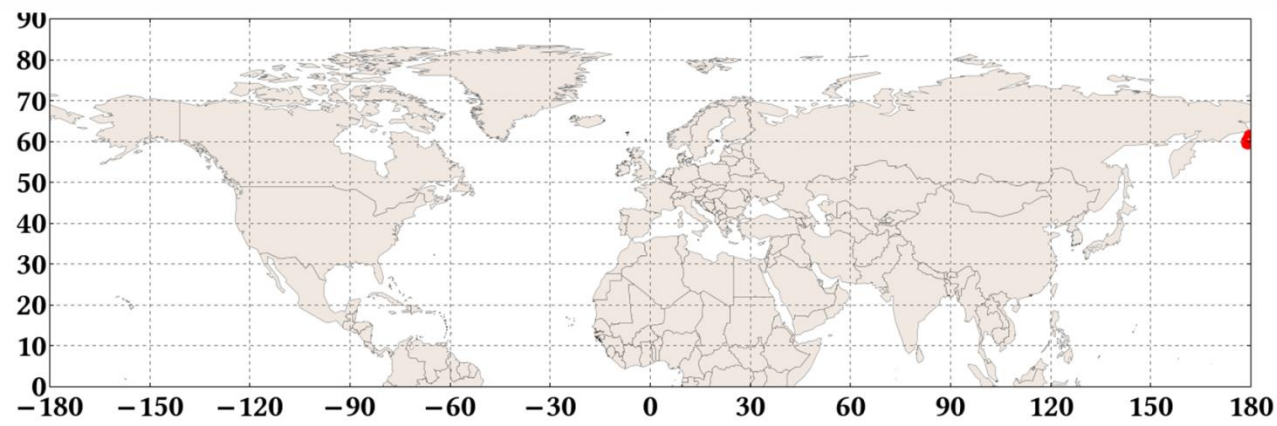
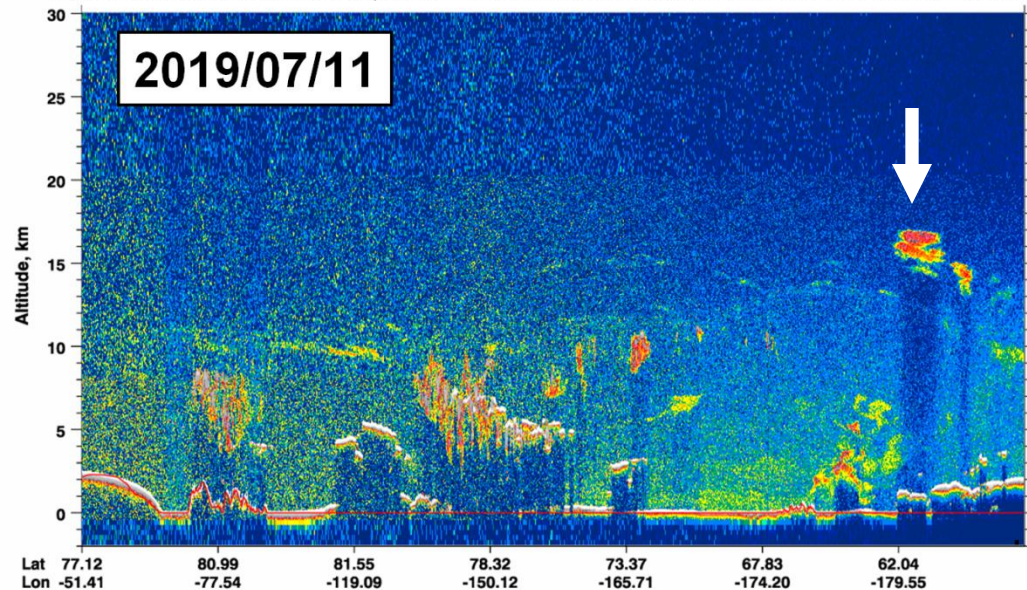


Smoothed over latitudes: 62.0 to 64.0,

longitudes: -150.0 to -151.0

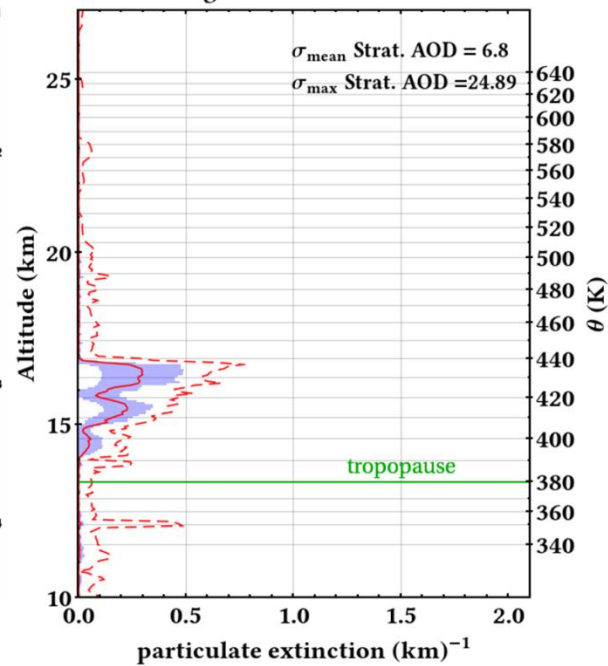


532 nm Total Attenuated Backscatter,  $\text{km}^{-1} \text{sr}^{-1}$  UTC: 2019-07-11 14:40:43.8 to 2019-07-11 14:52:23.8 Version: 3.40 Standard Daytime



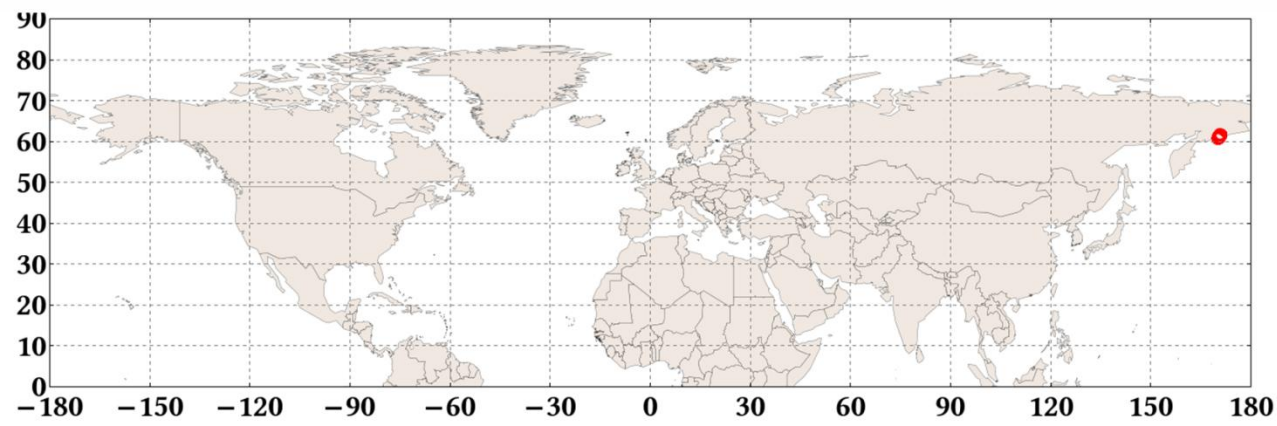
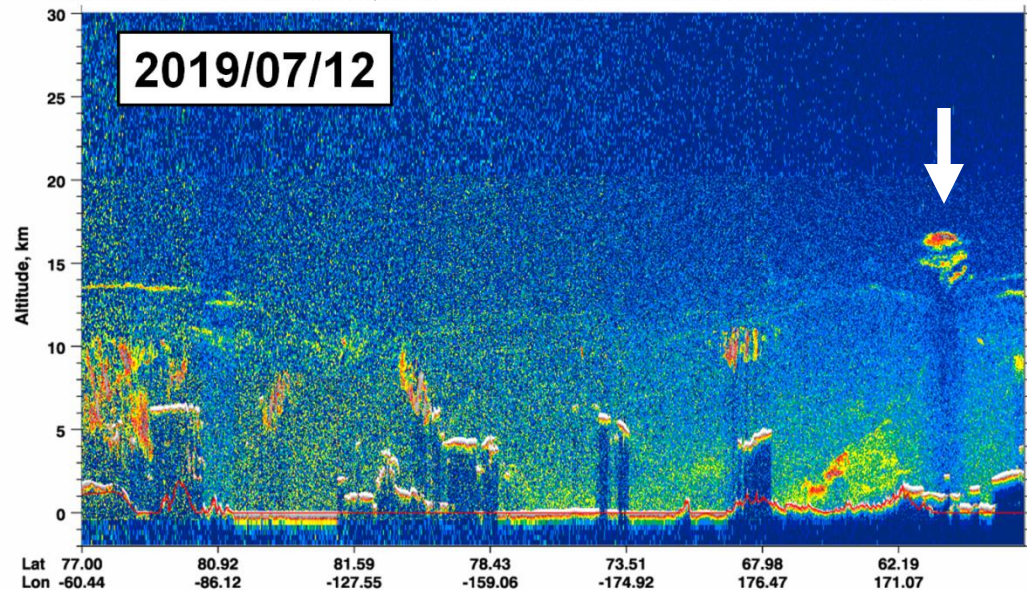
Smoothed over latitudes: 60.0 to 62.0,

longitudes: 180.0 to 179.0



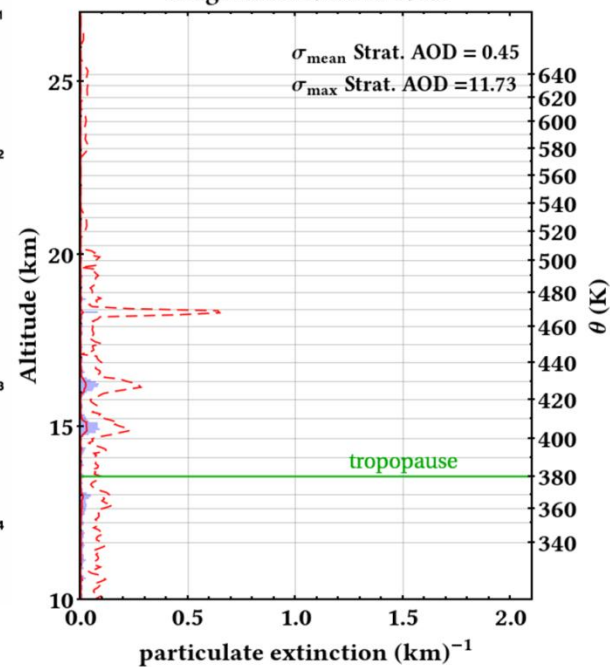


532 nm Total Attenuated Backscatter,  $\text{km}^{-1} \text{sr}^{-1}$  UTC: 2019-07-12 15:18:40.2 to 2019-07-12 15:30:20.2 Version: 3.40 Standard Daytime

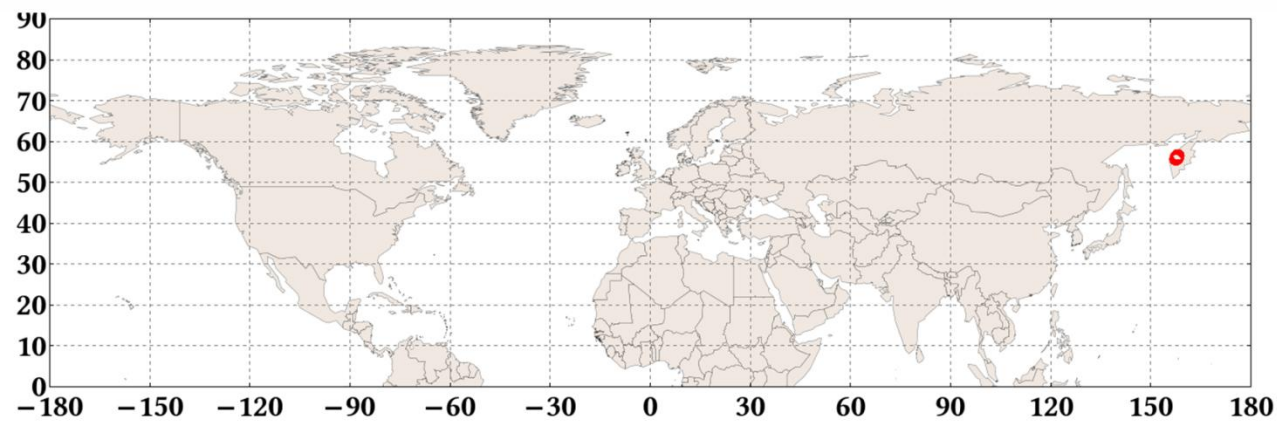
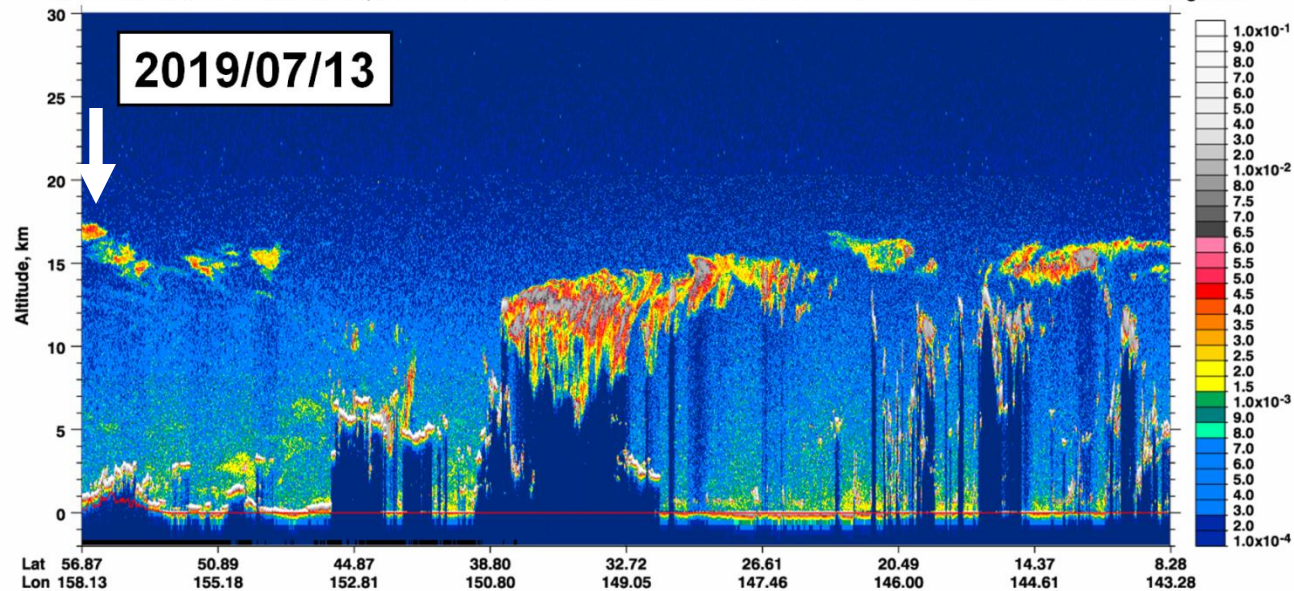


Smoothed over latitudes: 61.0 to 62.0,

longitudes: 171.0 to 170.0

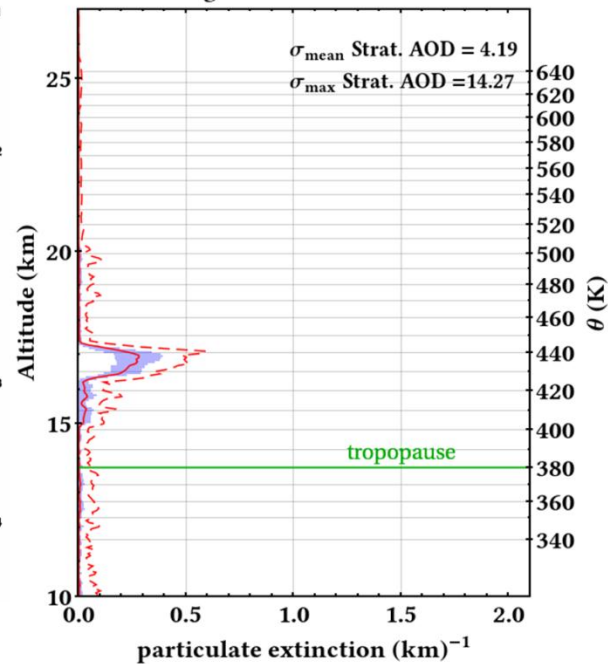


532 nm Total Attenuated Backscatter,  $\text{km}^{-1} \text{sr}^{-1}$  UTC: 2019-07-13 16:08:17.4 to 2019-07-13 16:21:46.1 Version: 3.40 Standard Nighttime



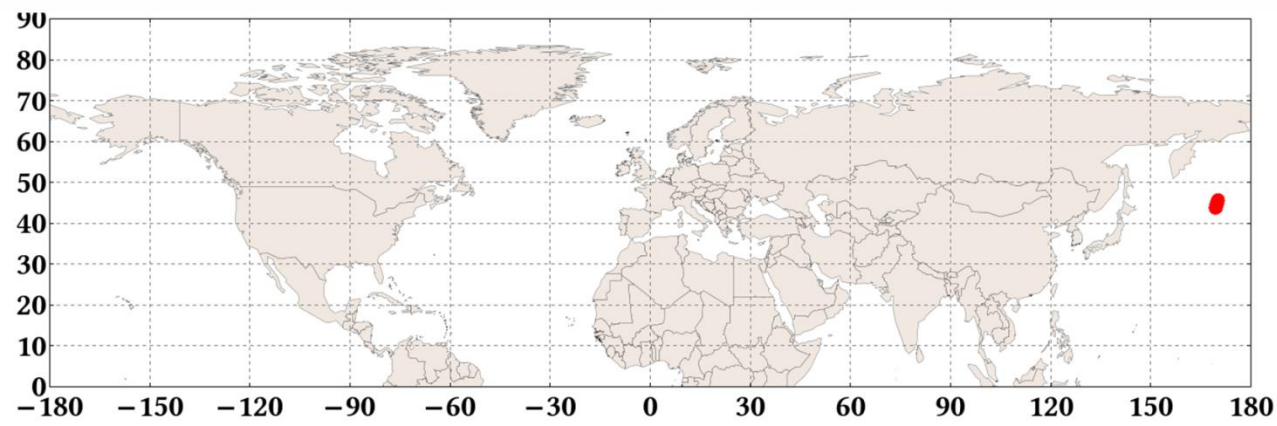
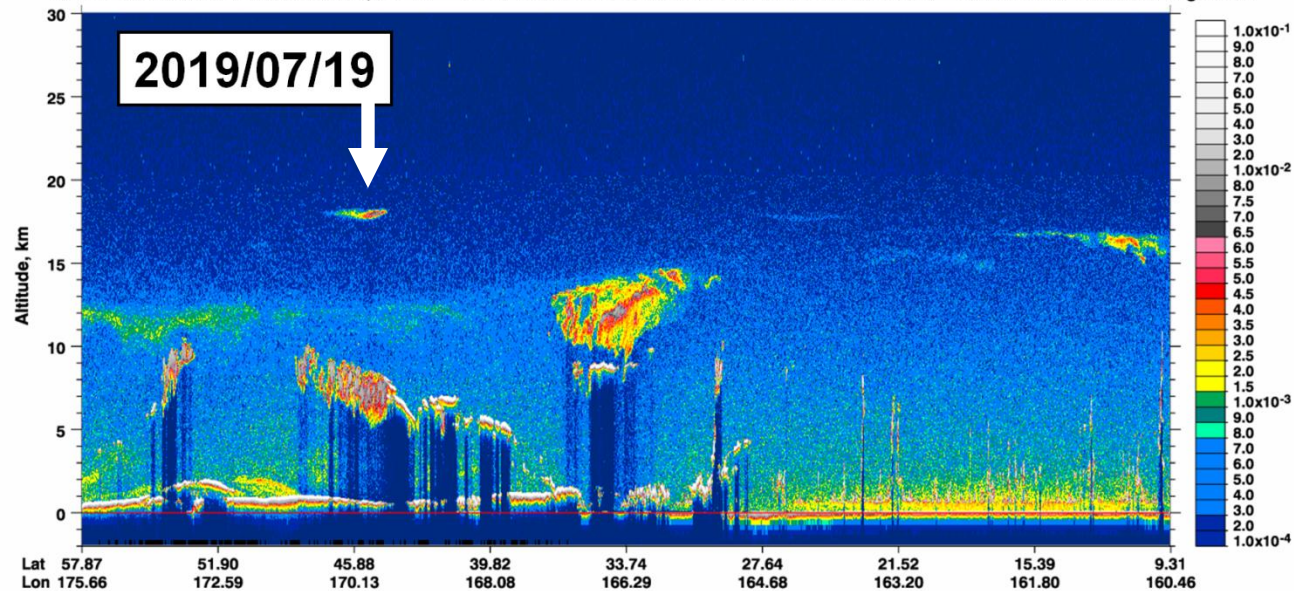
Smoothed over latitudes: 56.0 to 58.0,

longitudes: 158.0 to 158.0



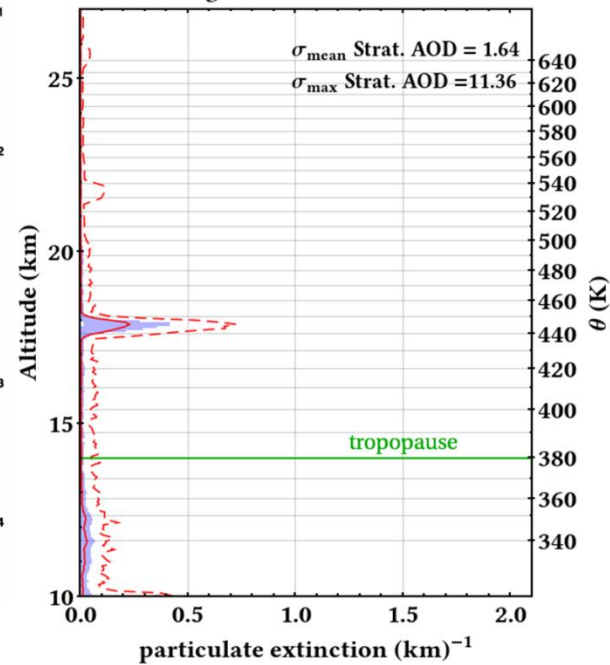


532 nm Total Attenuated Backscatter,  $\text{km}^{-1} \text{sr}^{-1}$  UTC: 2019-07-19 15:00:18.5 to 2019-07-19 15:13:47.2 Version: 3.40 Standard Nighttime

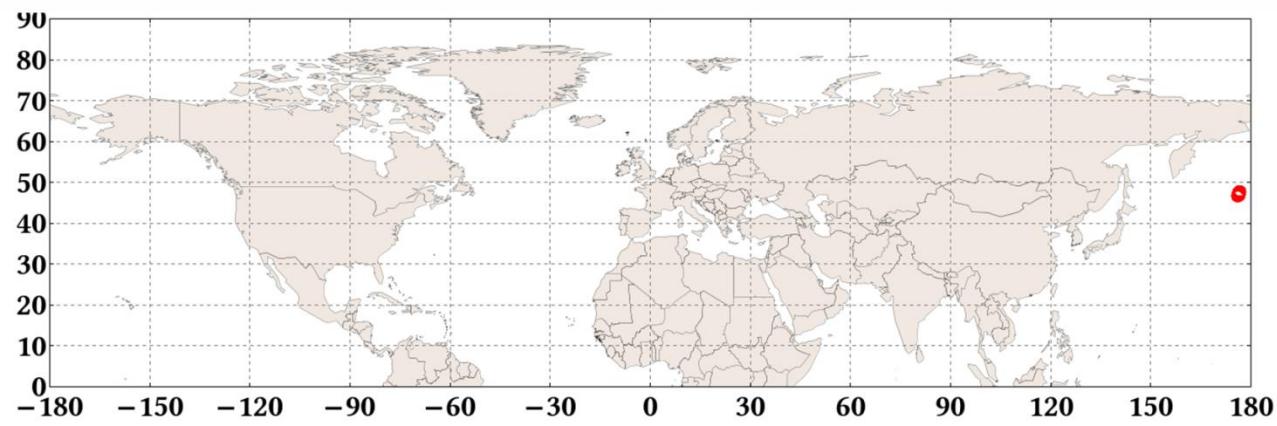
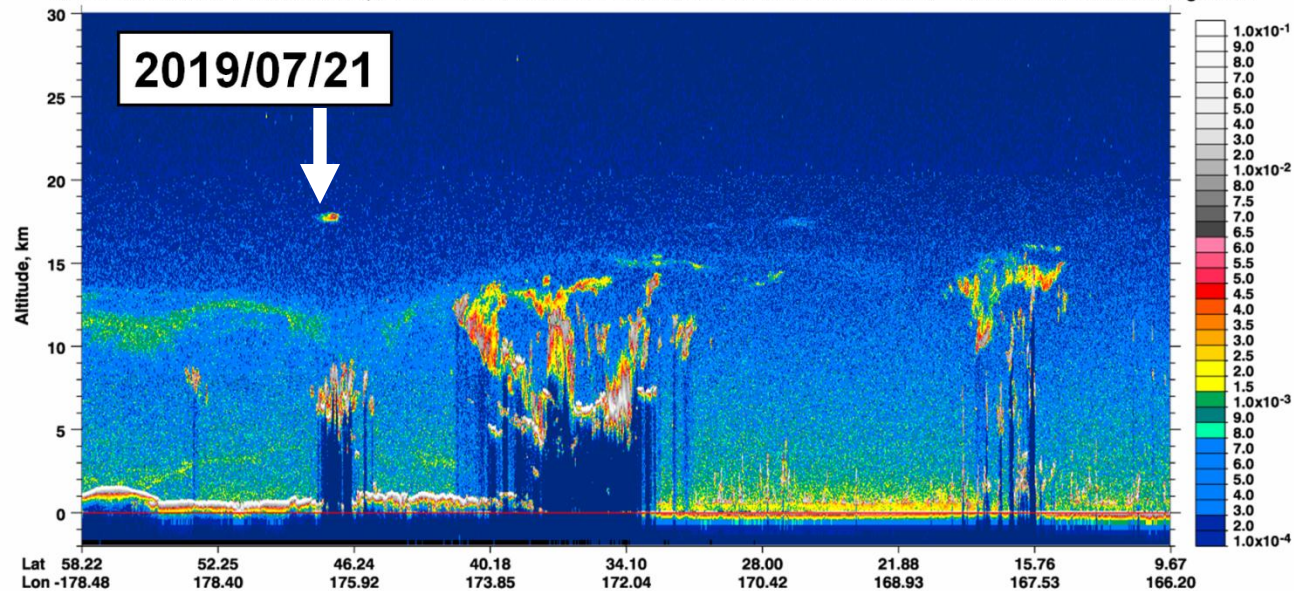


Smoothed over latitudes: 44.0 to 46.0,

longitudes: 170.0 to 170.0

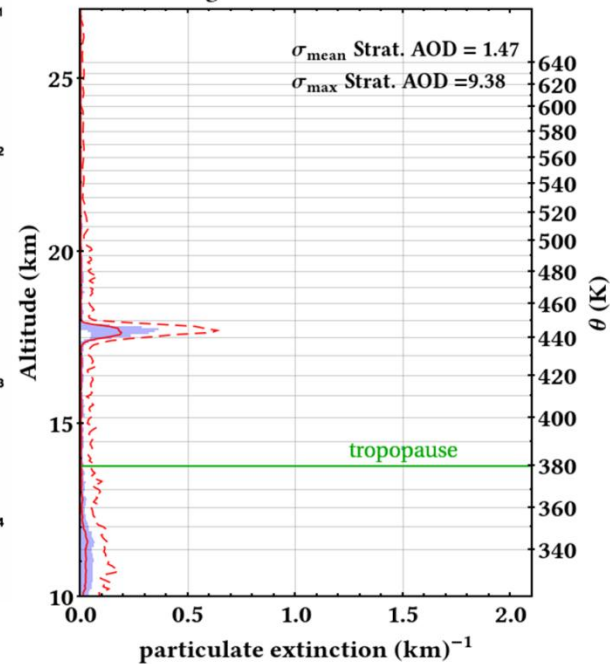


532 nm Total Attenuated Backscatter,  $\text{km}^{-1} \text{sr}^{-1}$  UTC: 2019-07-21 14:37:38.5 to 2019-07-21 14:51:07.2 Version: 3.40 Standard Nighttime



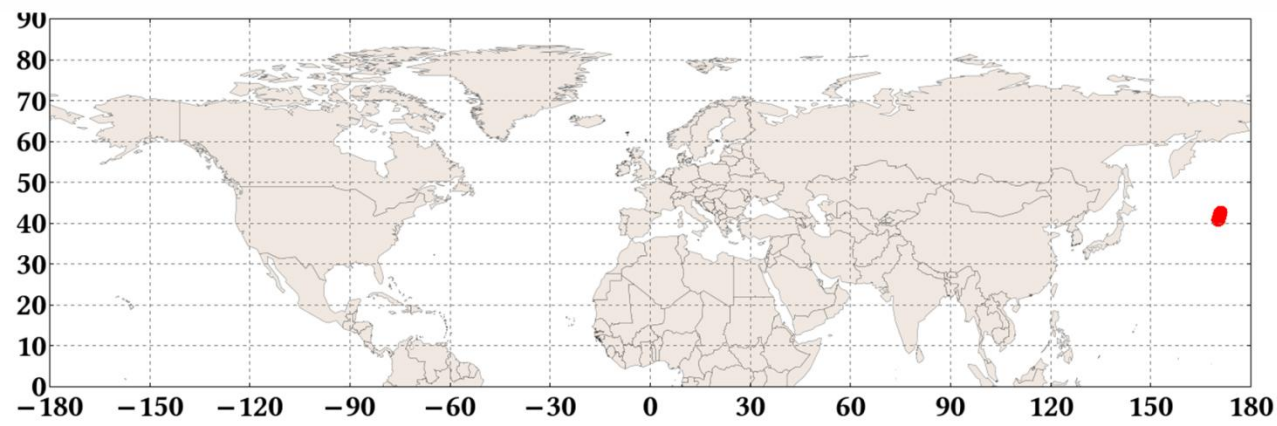
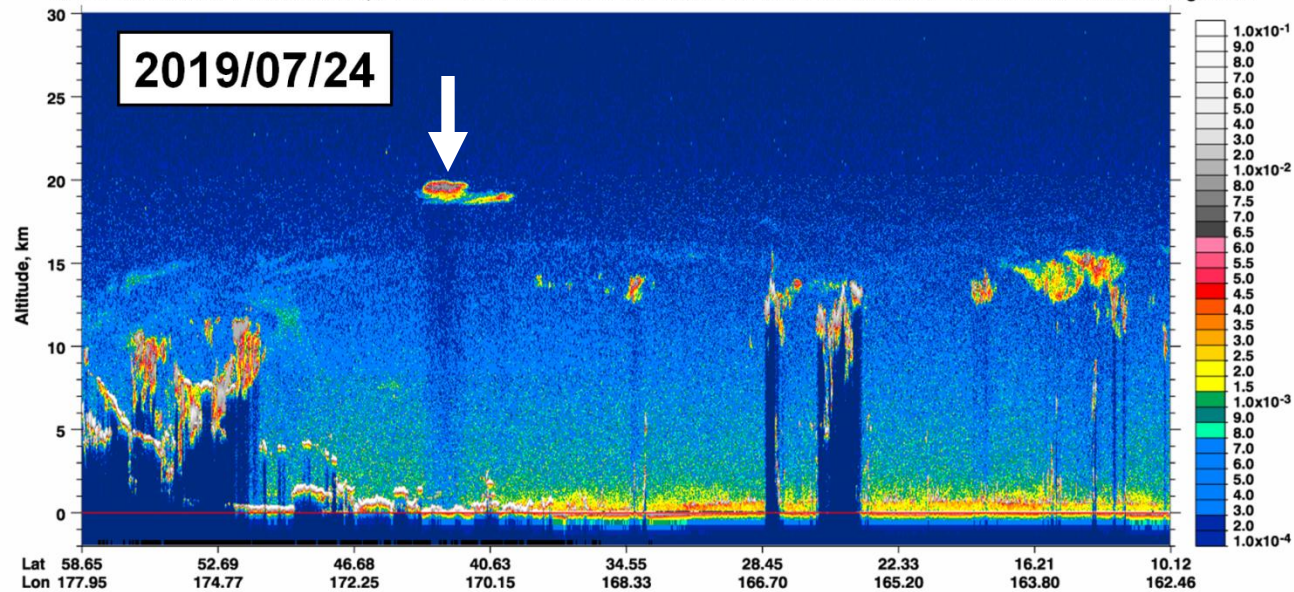
Smoothed over latitudes: 47.0 to 48.0,

longitudes: 177.0 to 176.0



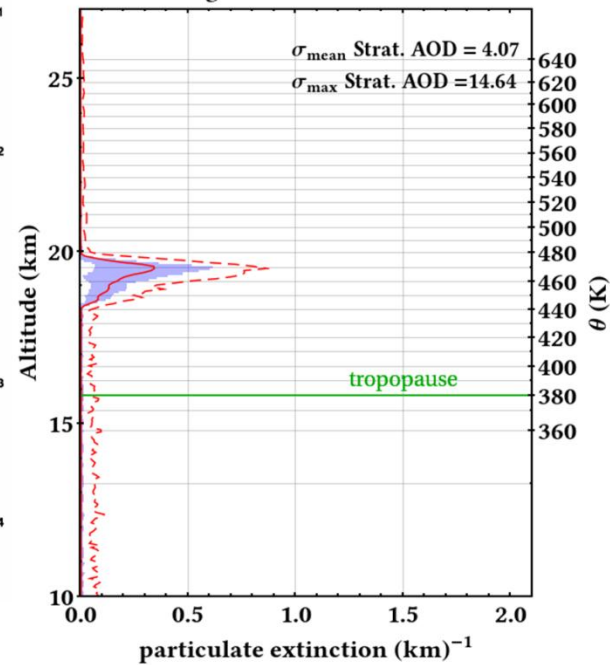


532 nm Total Attenuated Backscatter,  $\text{km}^{-1} \text{sr}^{-1}$  UTC: 2019-07-24 14:52:55.8 to 2019-07-24 15:06:24.5 Version: 3.40 Standard Nighttime



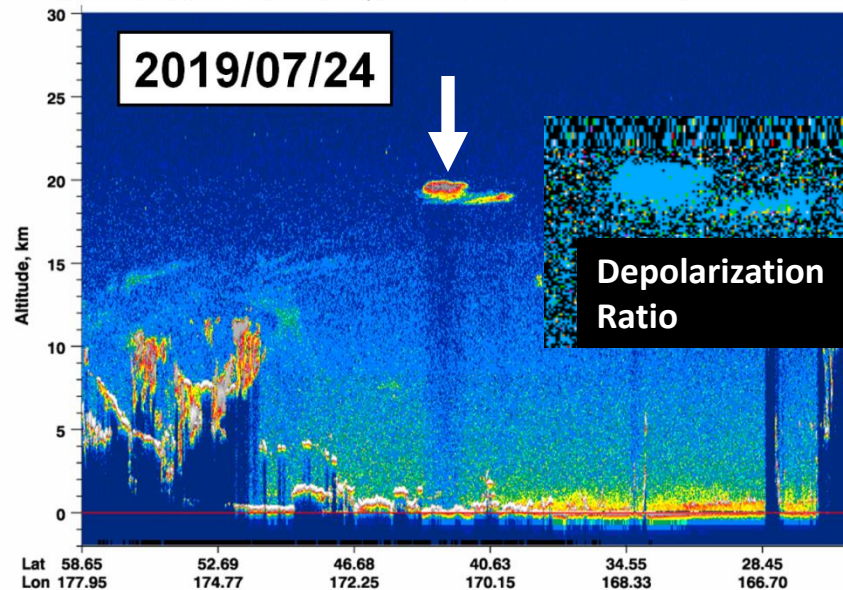
Smoothed over latitudes: 41.0 to 43.0,

longitudes: 171.0 to 170.0

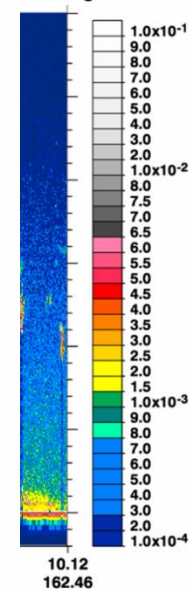




532 nm Total Attenuated Backscatter,  $\text{km}^{-1} \text{sr}^{-1}$  UTC: 2019-07-24 14:52:55.8 to 2019-07-24

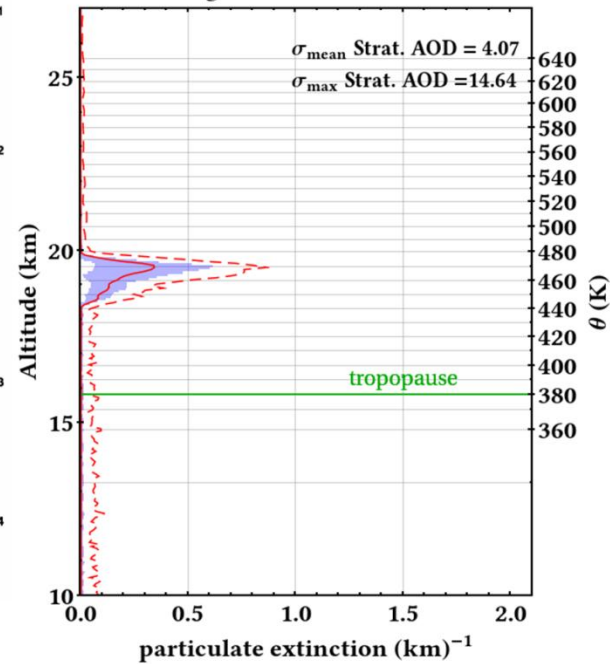


1012 Nighttime

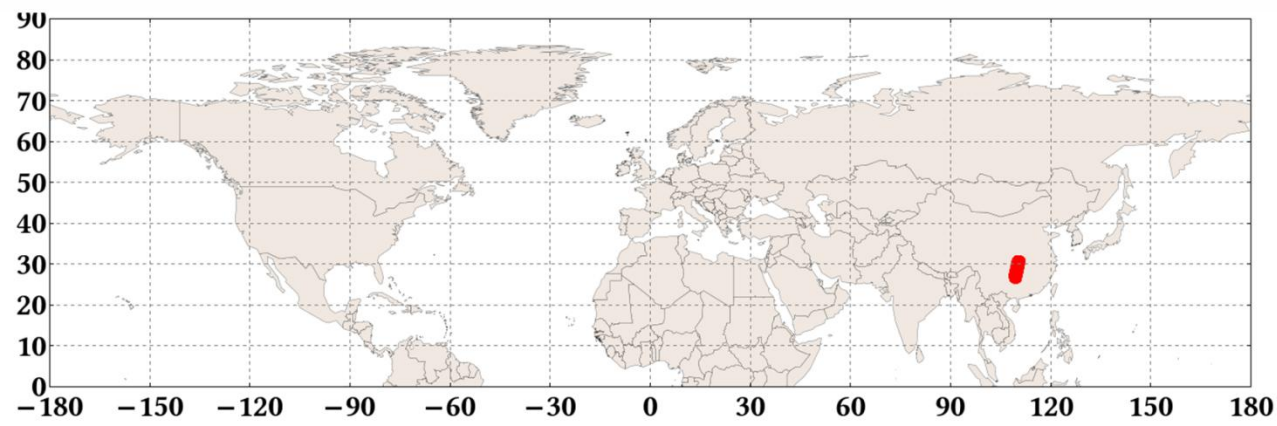
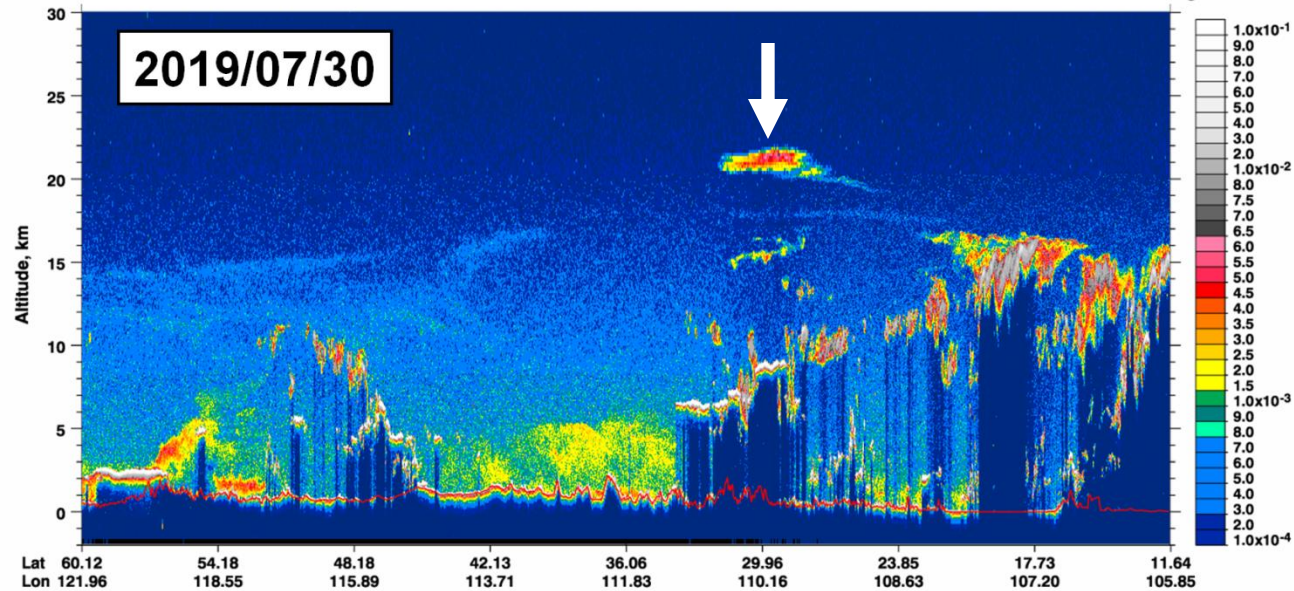


Smoothed over latitudes: 41.0 to 43.0,

longitudes: 171.0 to 170.0

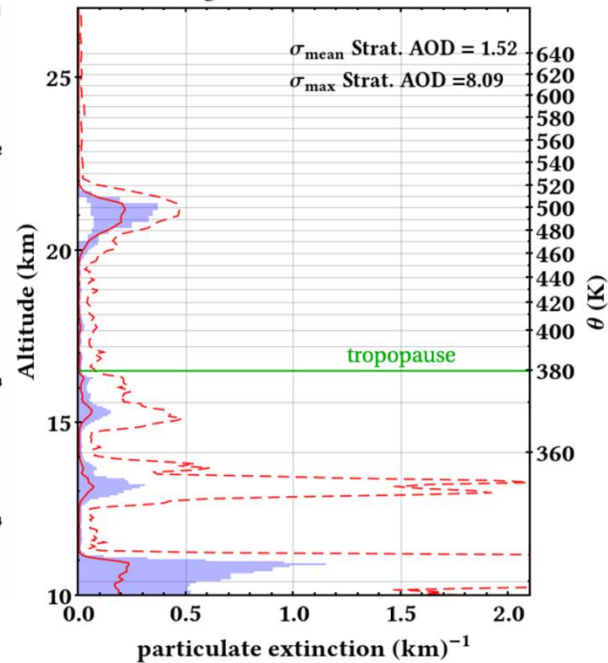


532 nm Total Attenuated Backscatter,  $\text{km}^{-1} \text{sr}^{-1}$  UTC: 2019-07-30 18:40:23.6 to 2019-07-30 18:53:52.3 Version: 3.40 Standard Nighttime



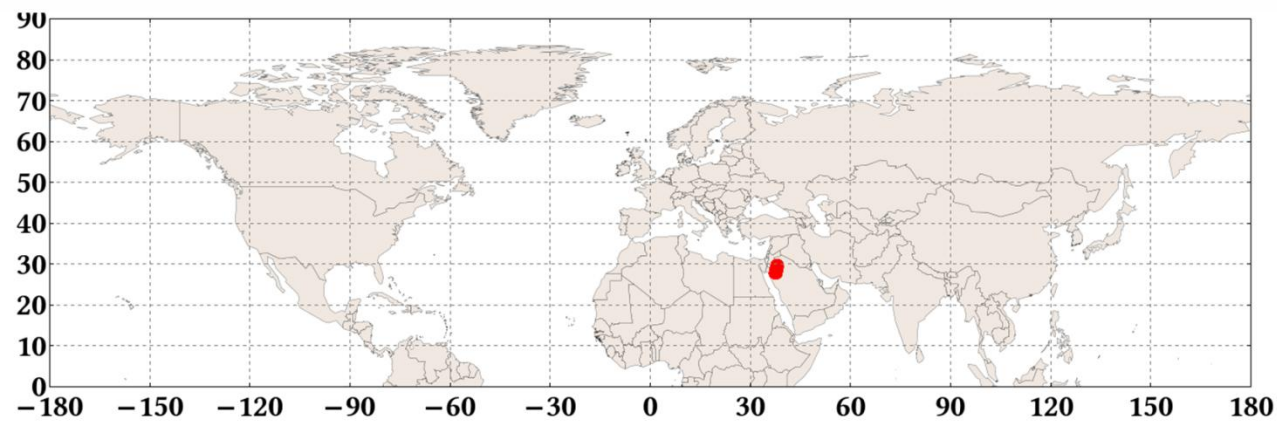
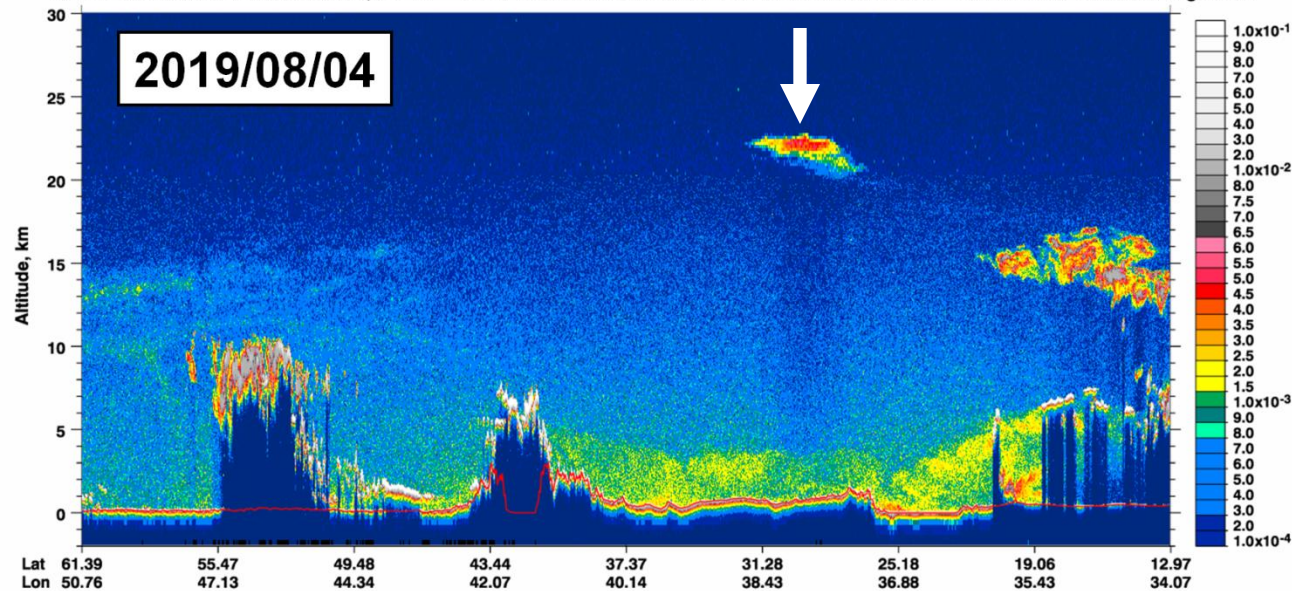
Smoothed over latitudes: 27.0 to 31.0,

longitudes: 110.0 to 109.0



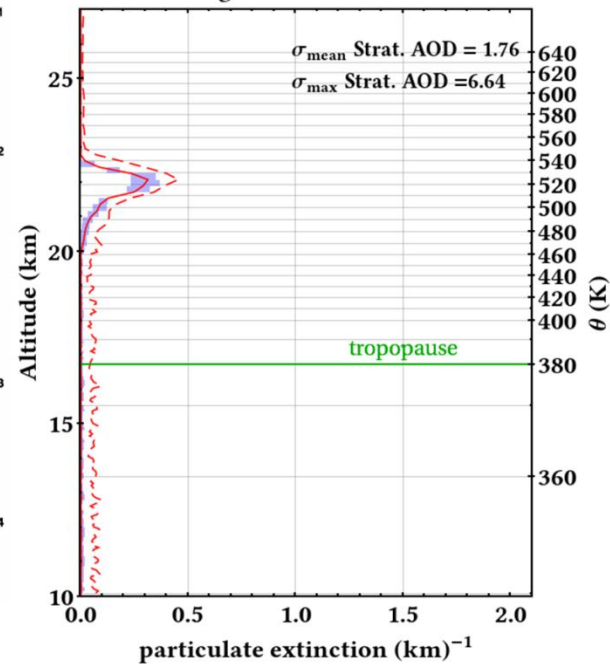


532 nm Total Attenuated Backscatter,  $\text{km}^{-1} \text{sr}^{-1}$  UTC: 2019-08-04 23:28:27.6 to 2019-08-04 23:41:56.3 Version: 3.40 Standard Nighttime



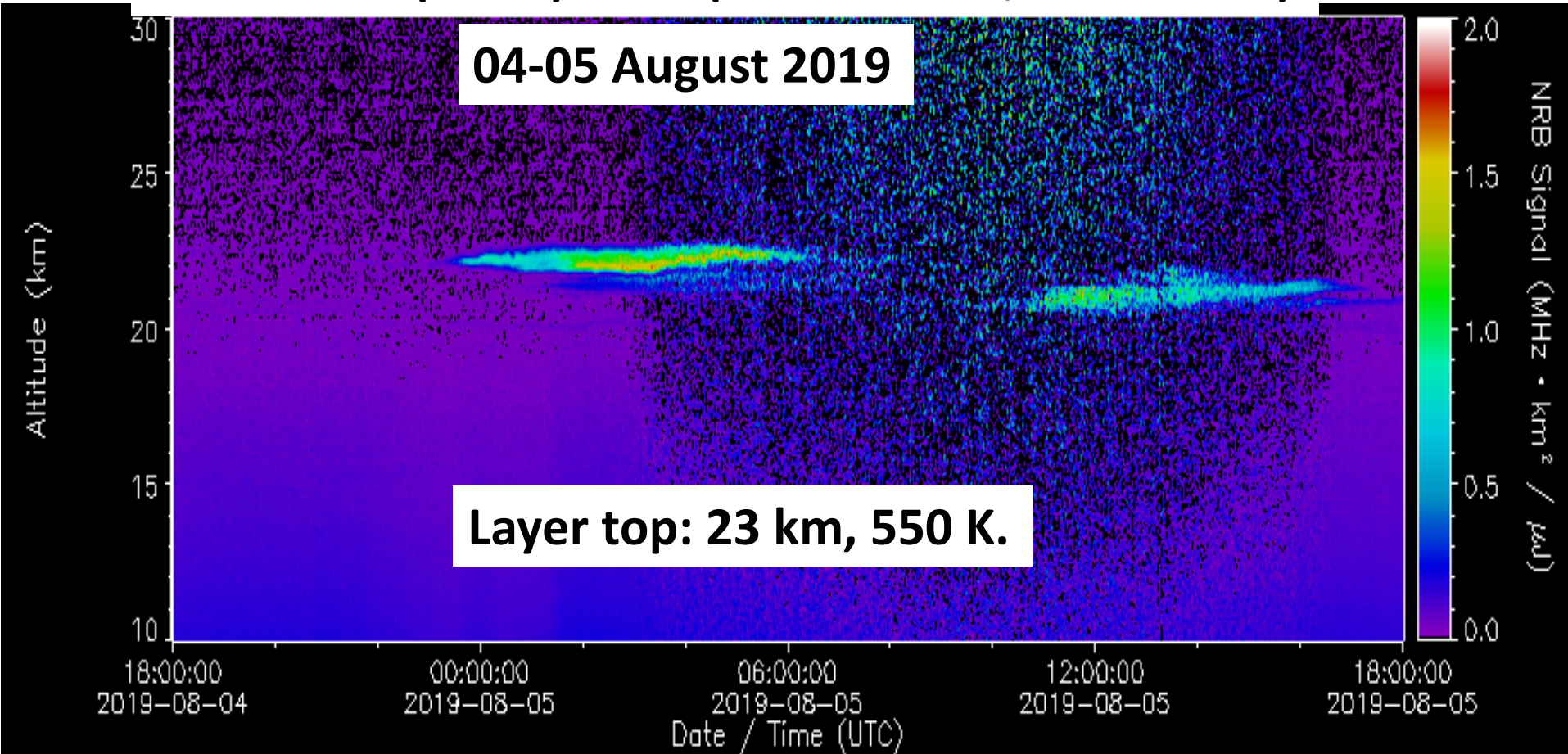
Smoothed over latitudes: 28.0 to 30.0,

longitudes: 38.1 to 37.6





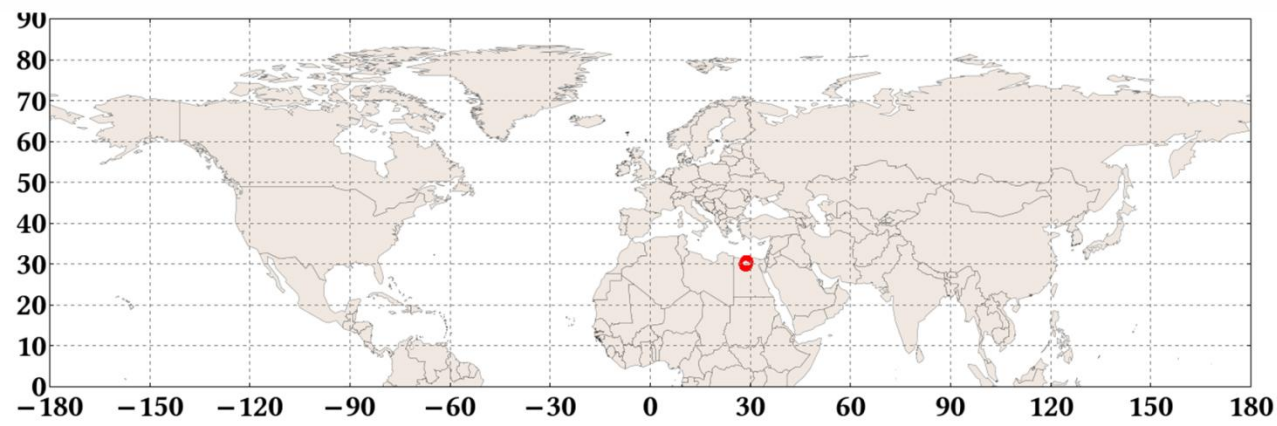
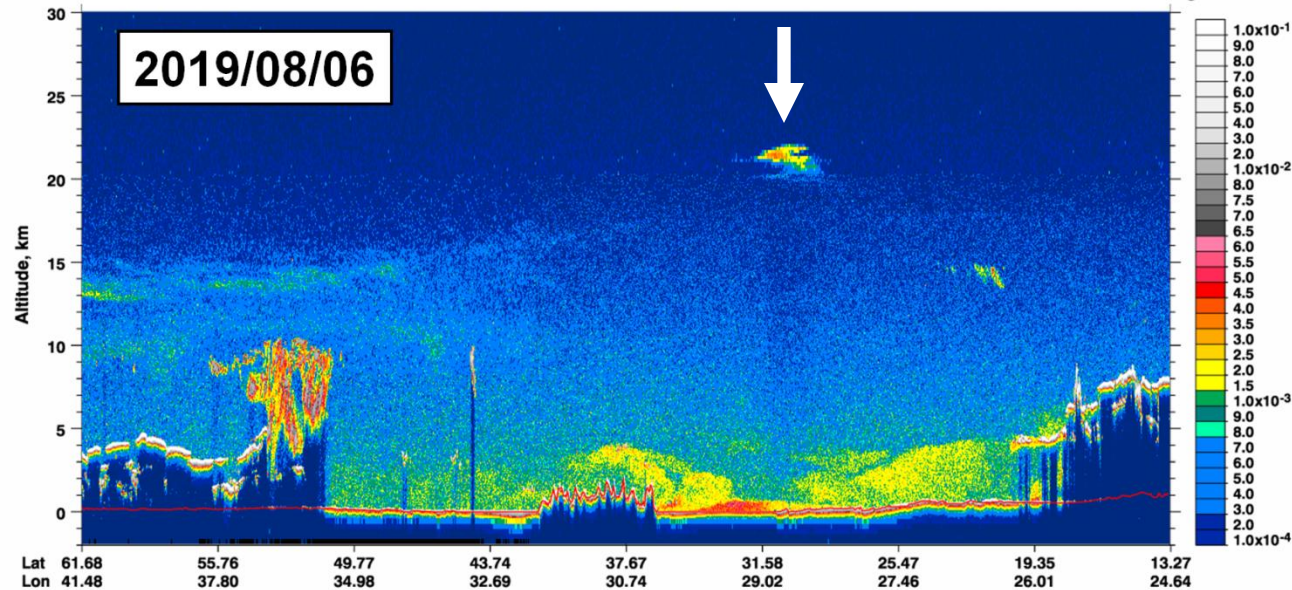
# Sede Boker (Israel) MPL (Judd Welton, MPLNET PI)



No overlap calibration.  
No pol calibration.

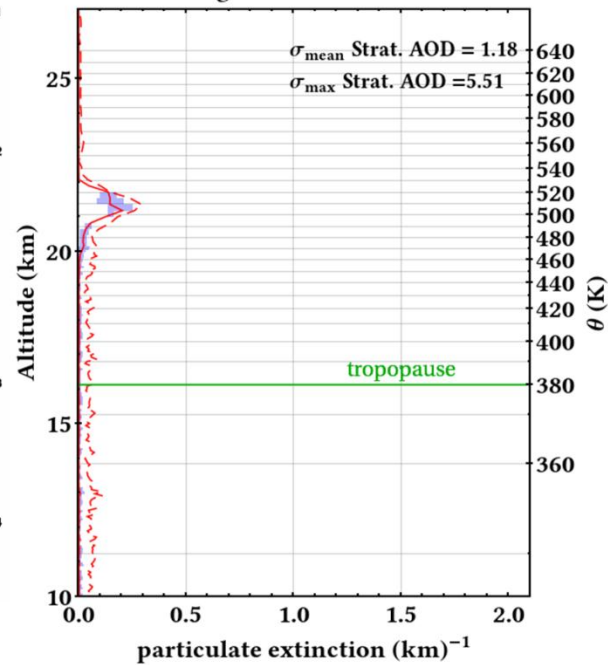
PRELIMINARY CALS

532 nm Total Attenuated Backscatter,  $\text{km}^{-1} \text{sr}^{-1}$  UTC: 2019-08-06 00:06:21.4 to 2019-08-06 00:19:50.1 Version: 3.40 Standard Nighttime



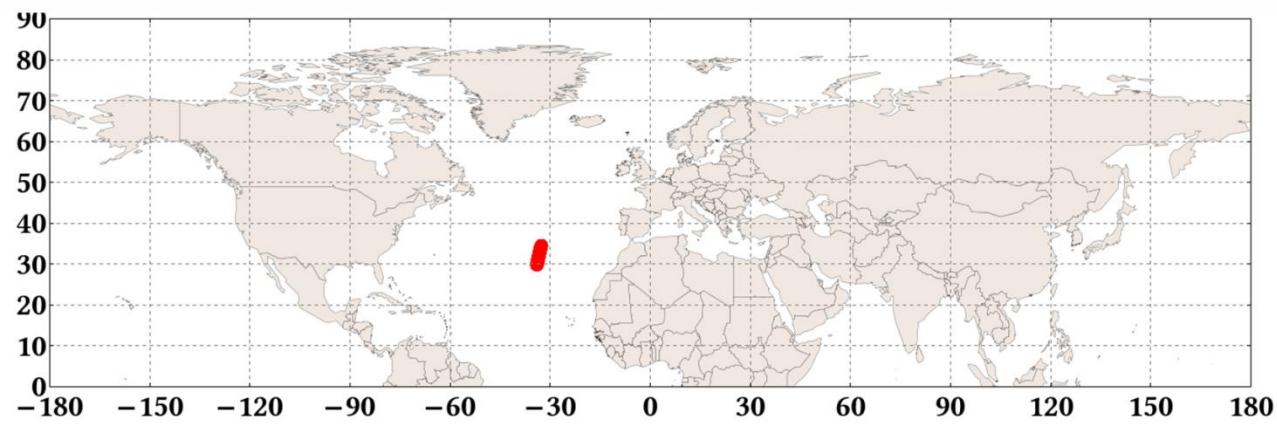
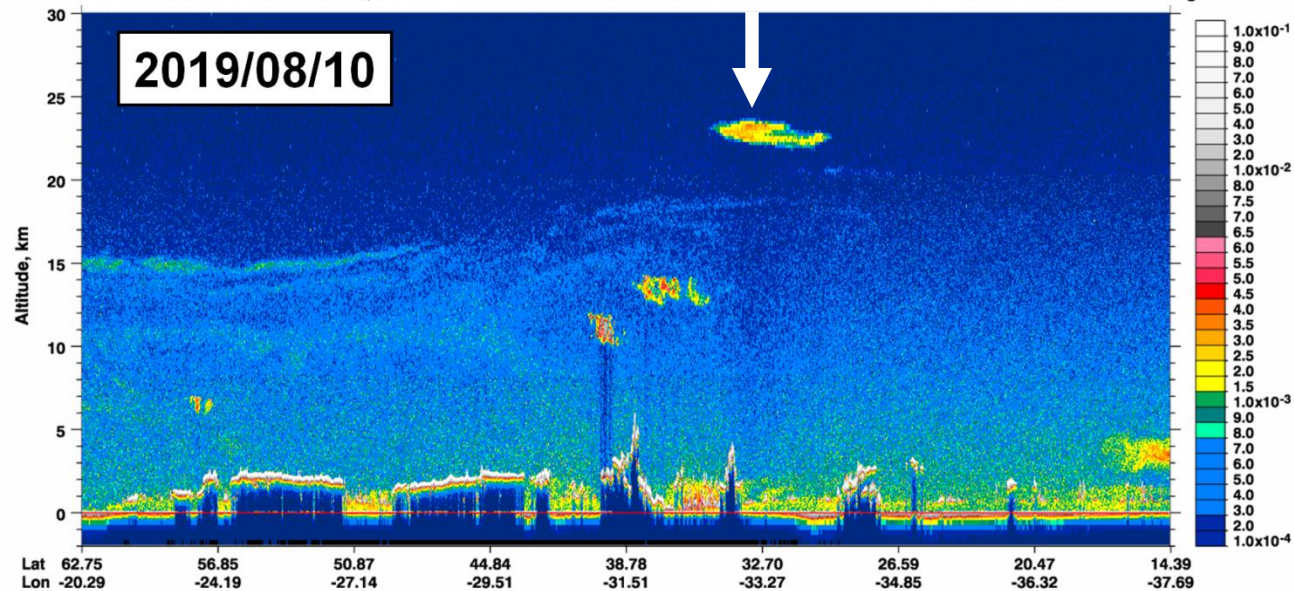
Smoothed over latitudes: 30.0 to 31.0,

longitudes: 28.9 to 28.6



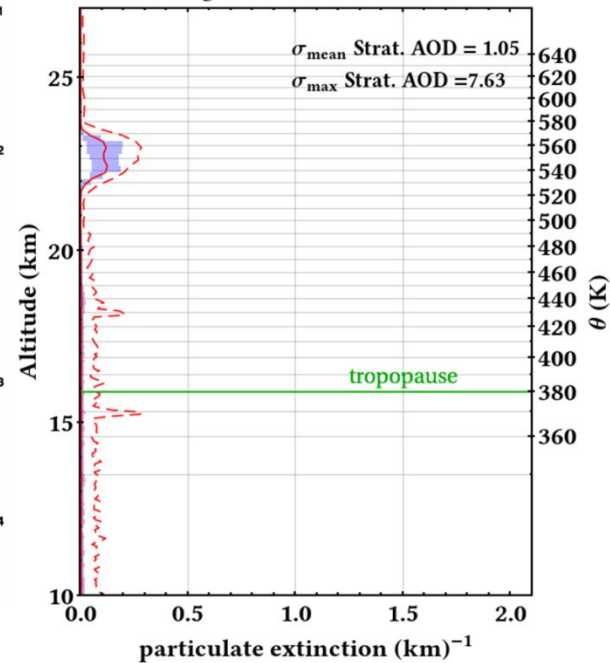


532 nm Total Attenuated Backscatter,  $\text{km}^{-1} \text{sr}^{-1}$  UTC: 2019-08-10 04:16:29.4 to 2019-08-10 04:29:58.1 Version: 3.40 Standard Nighttime

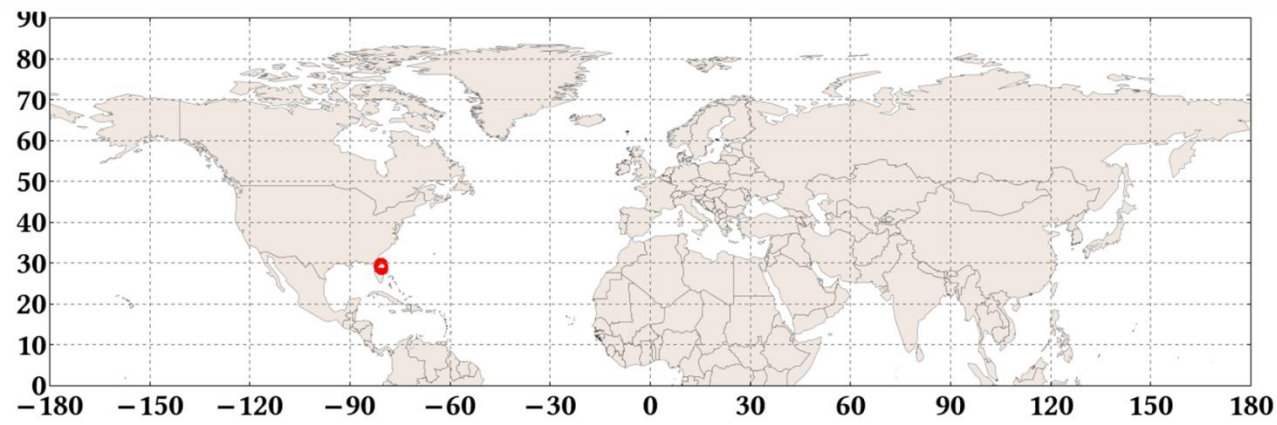
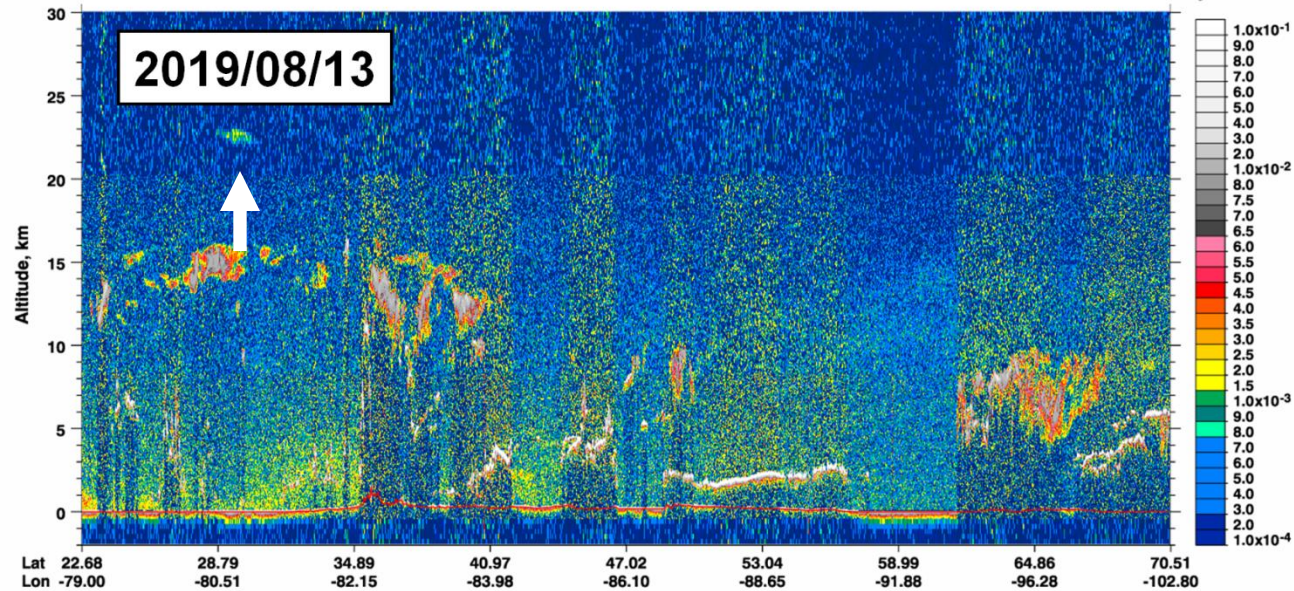


Smoothed over latitudes: 30.0 to 35.0,

longitudes: -32.6 to -34.0

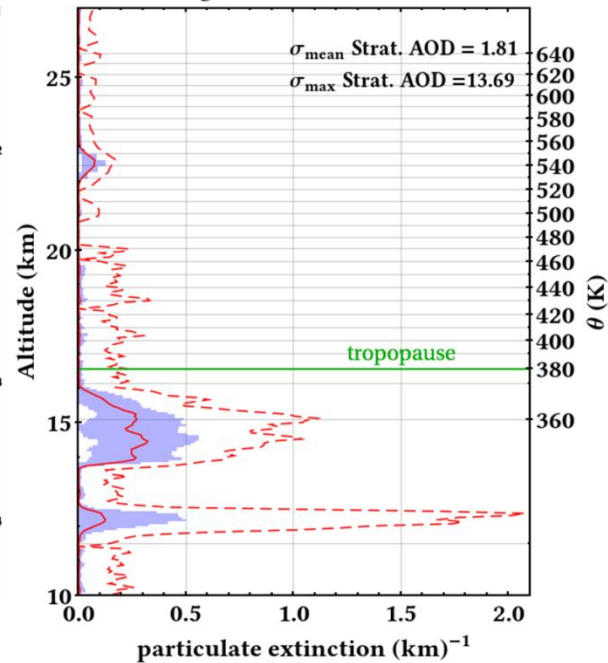


532 nm Total Attenuated Backscatter,  $\text{km}^{-1} \text{sr}^{-1}$  UTC: 2019-08-13 18:53:09.3 to 2019-08-13 19:06:38.0 Version: 3.40 Standard Daytime



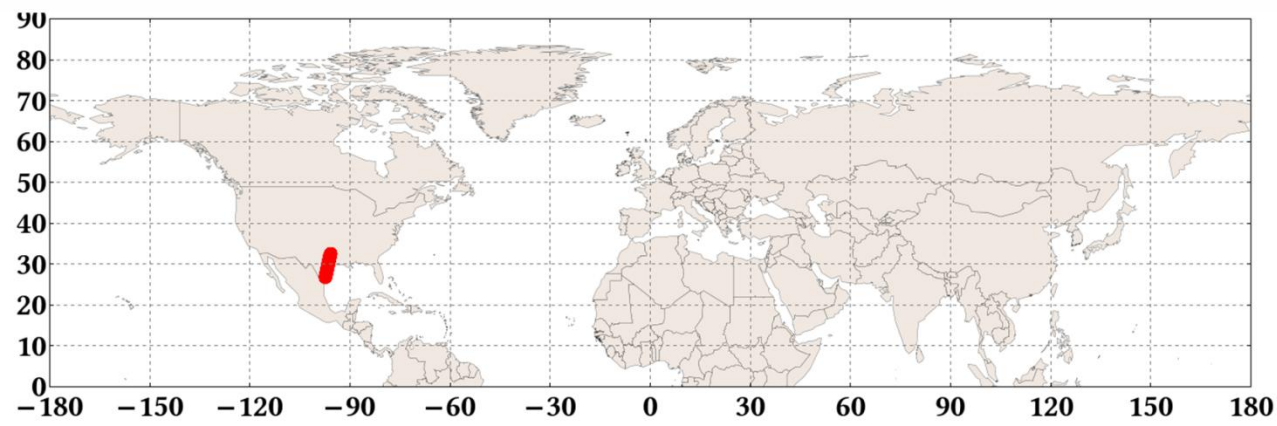
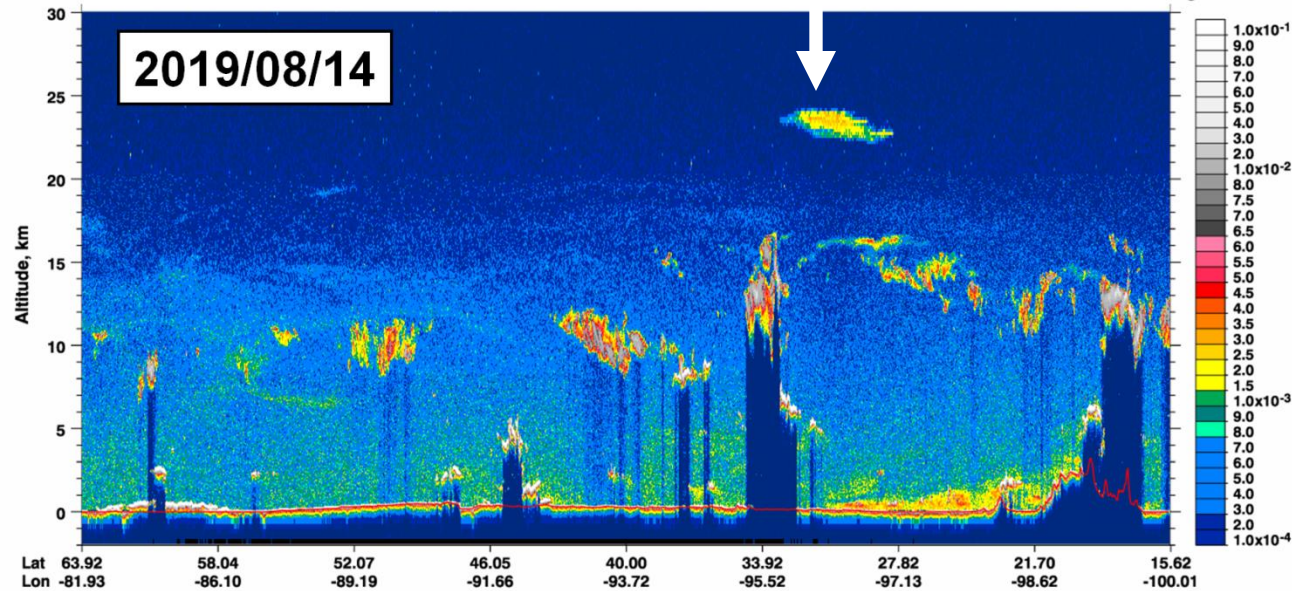
Smoothed over latitudes: 29.0 to 30.0,

longitudes: -80.6 to -80.8



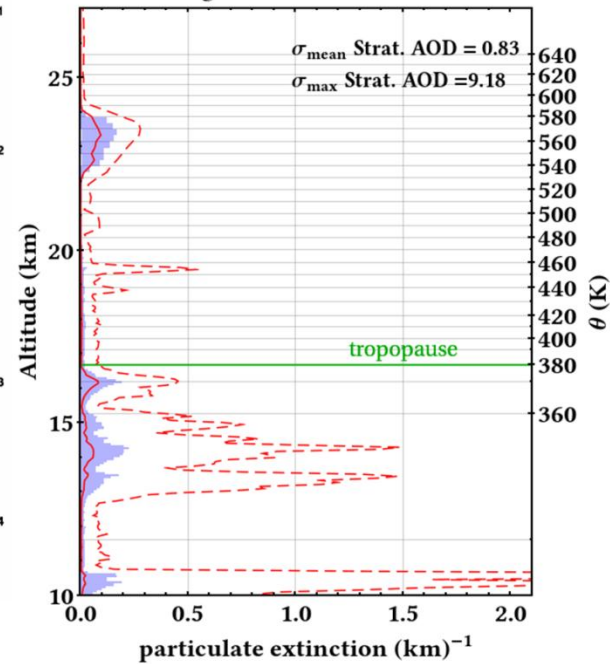


532 nm Total Attenuated Backscatter,  $\text{km}^{-1} \text{sr}^{-1}$  UTC: 2019-08-14 08:26:35.8 to 2019-08-14 08:40:04.5 Version: 3.40 Standard Nighttime

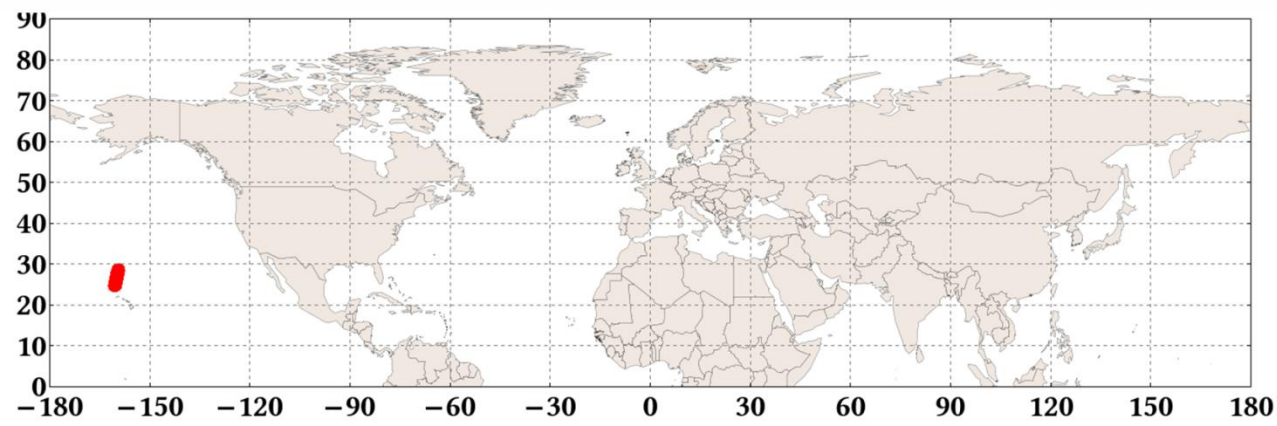
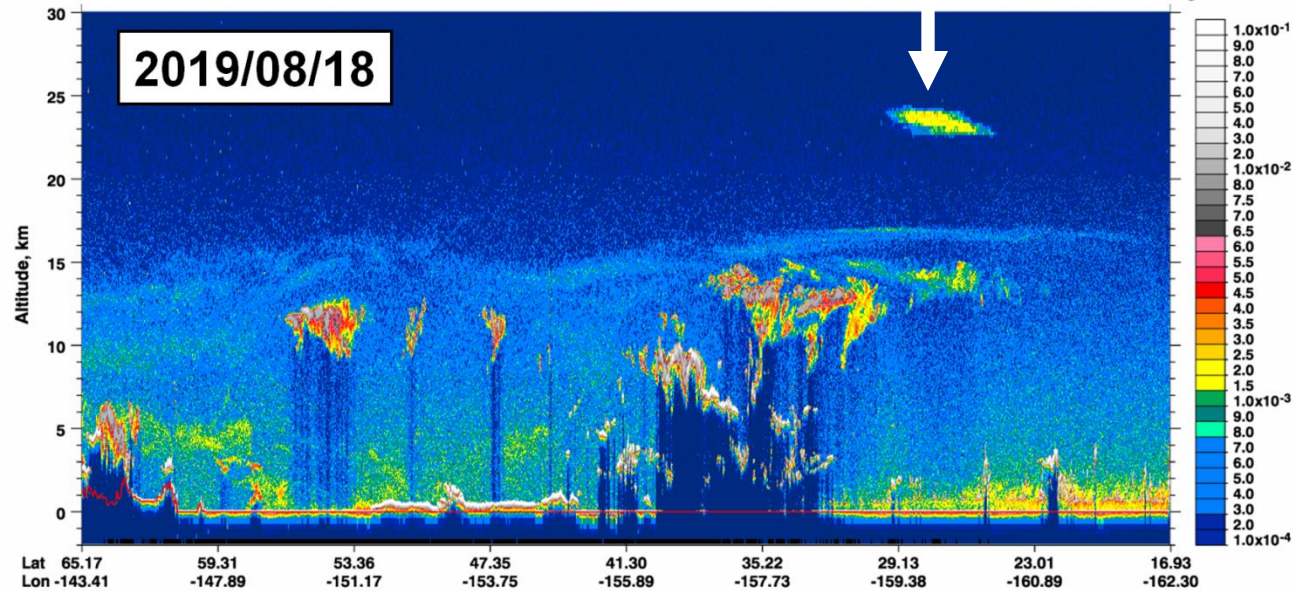


Smoothed over latitudes: 27.0 to 33.0,

longitudes: -95.8 to -97.3

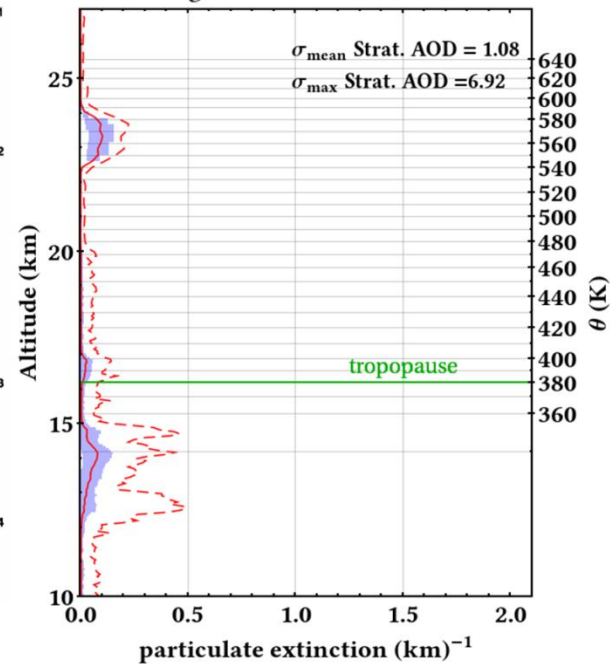


532 nm Total Attenuated Backscatter,  $\text{km}^{-1} \text{sr}^{-1}$  UTC: 2019-08-18 12:36:40.3 to 2019-08-18 12:50:09.0 Version: 3.40 Standard Nighttime



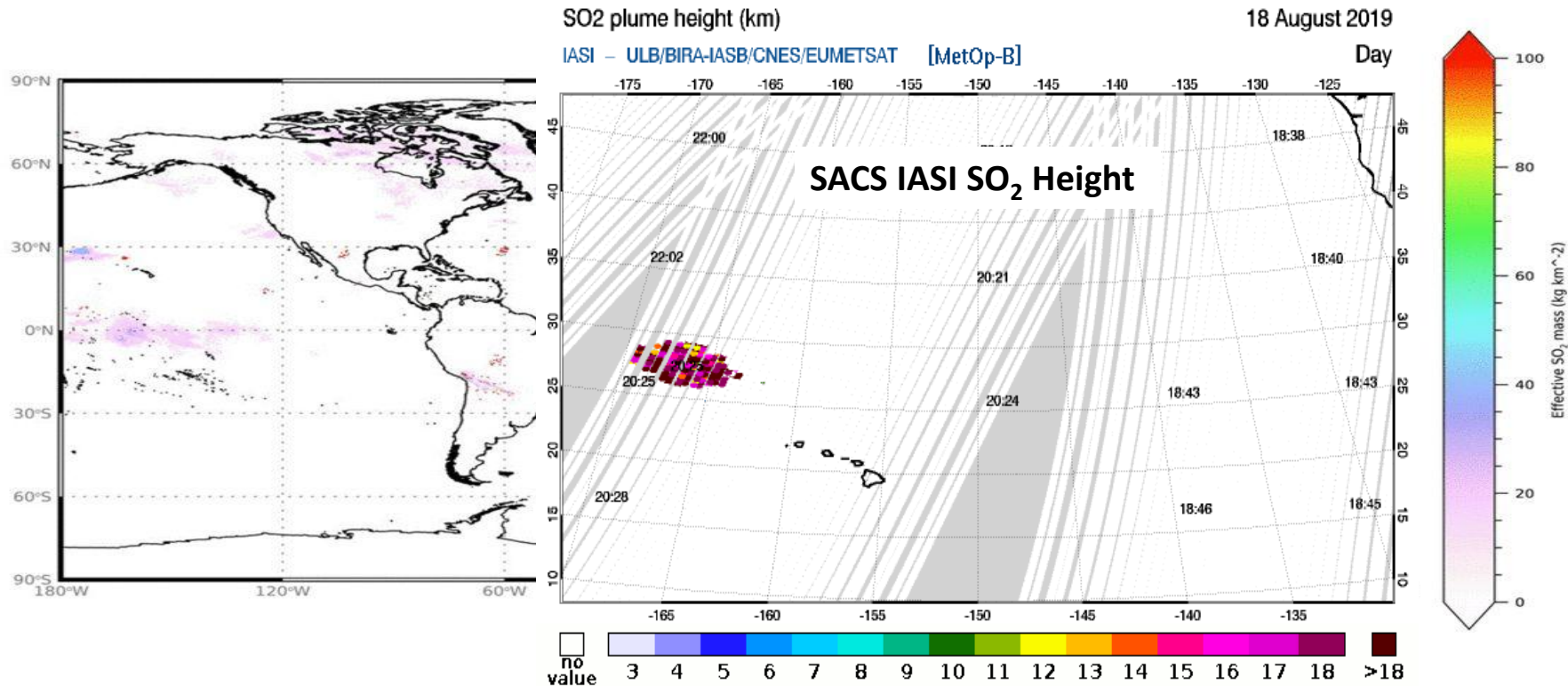
Smoothed over latitudes: 25.0 to 29.0,

longitudes: -159.0 to -160.0



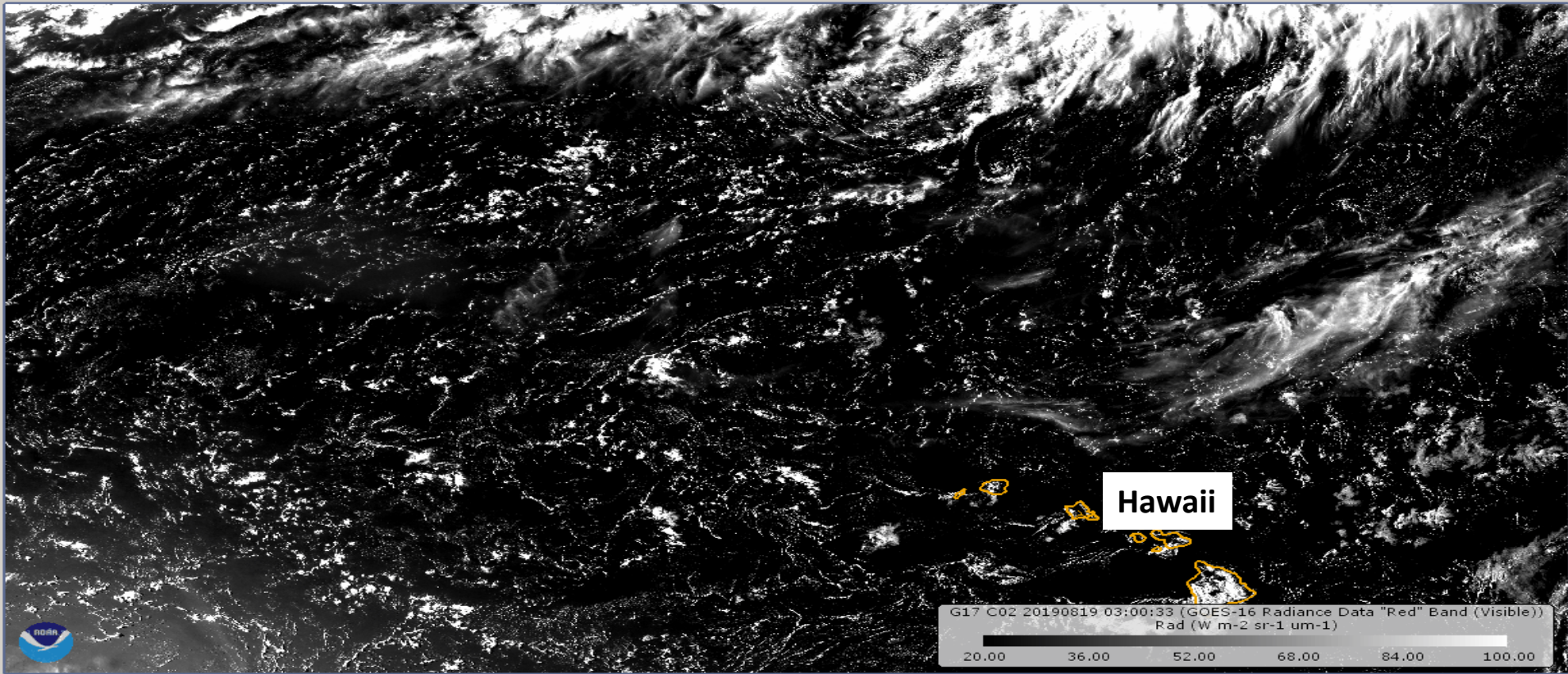


# IASI SO<sub>2</sub>, Subtropical Pacific Ocean , 19 August 2019



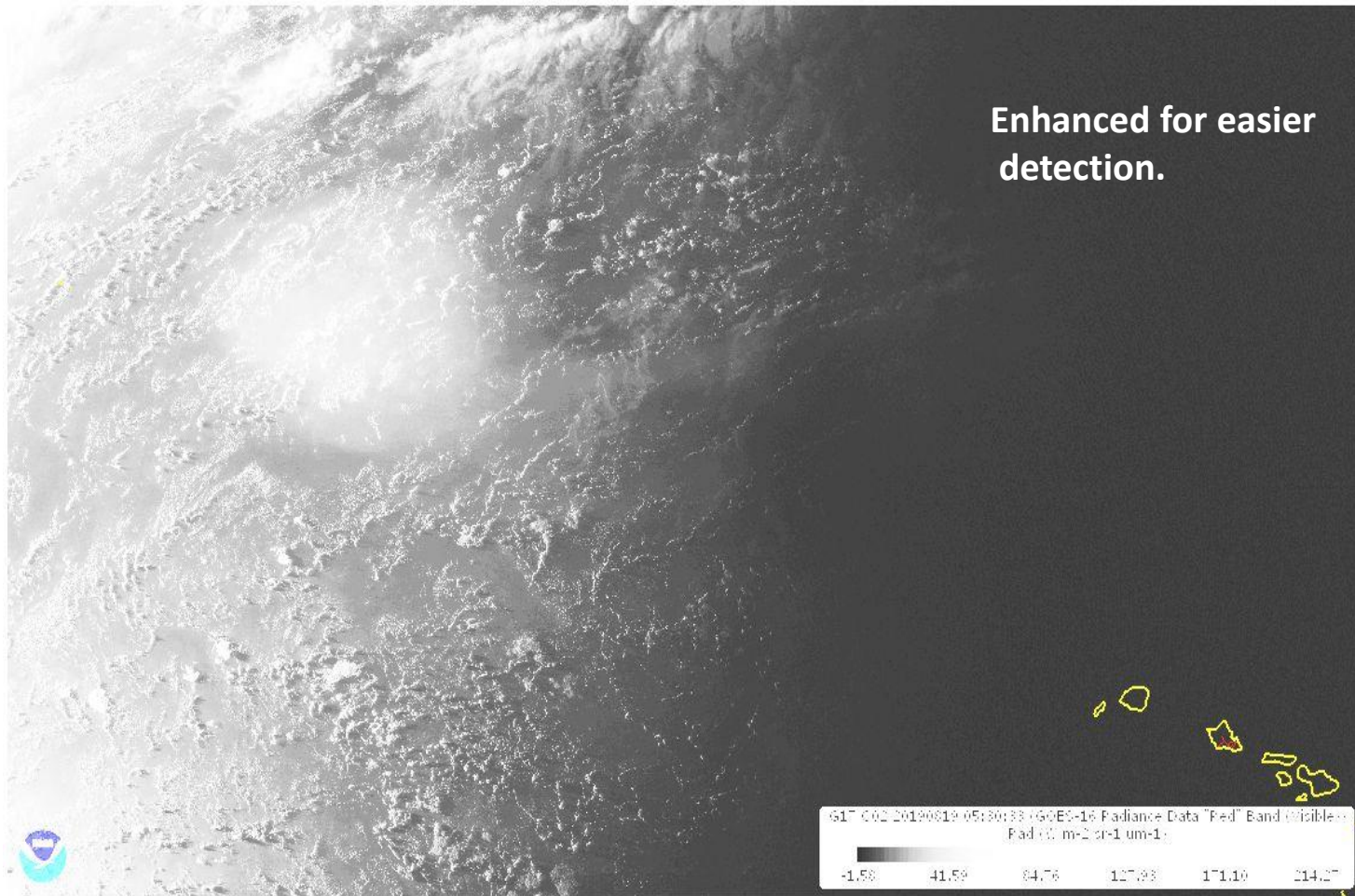
# GOES 17 Visible, Subtropical Pacific Ocean , 19 August 2019

## Twilight animation illuminates Raikoke VC



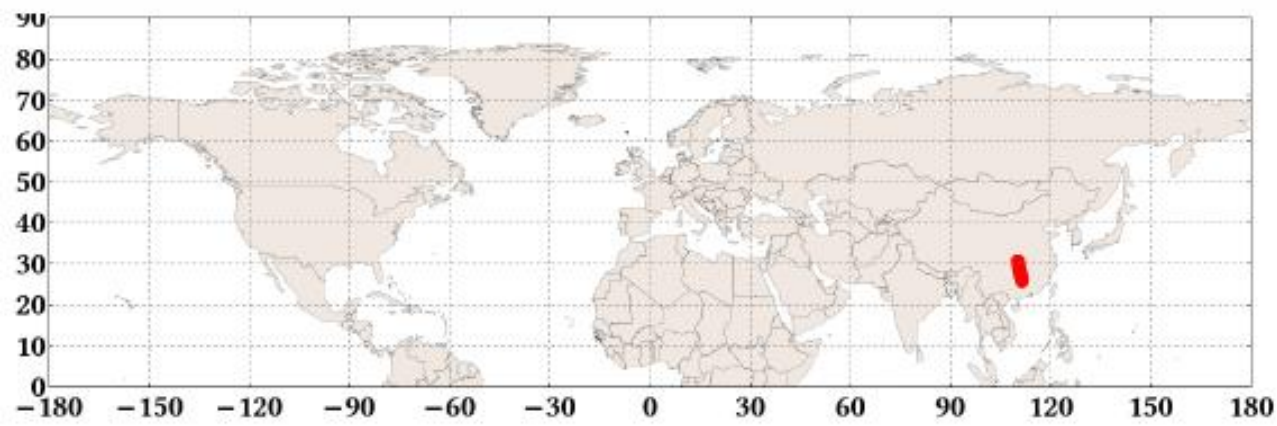
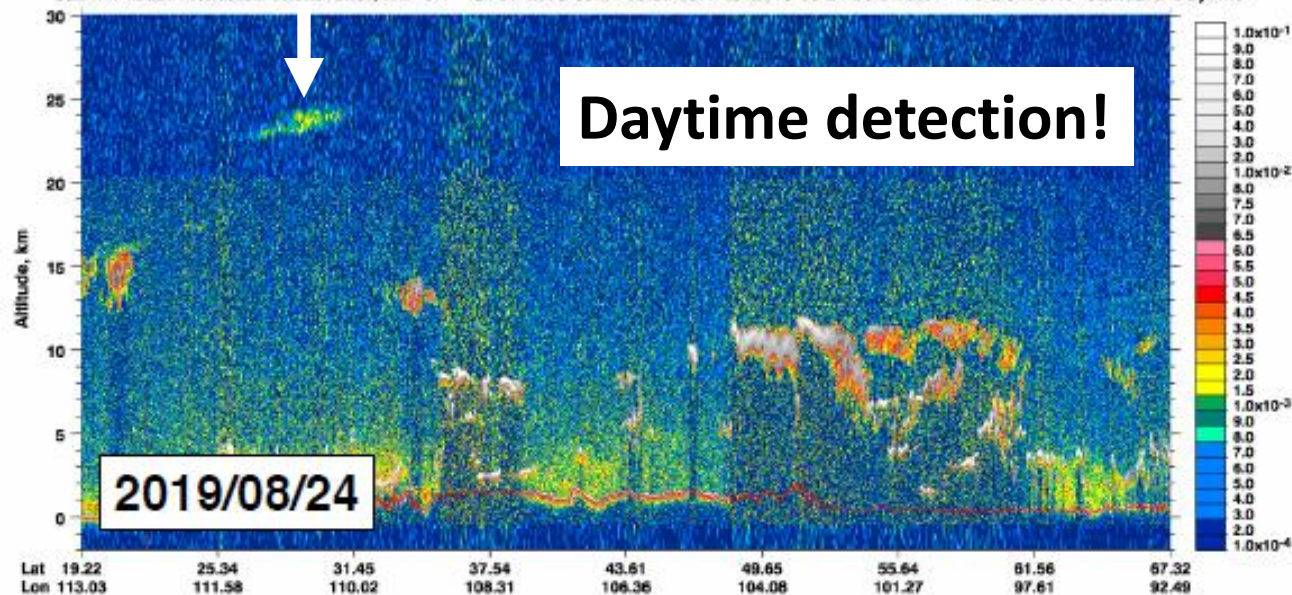
**Optical depth: Raikoke sulfate plume is *VISIBLE* after ~2 months.**





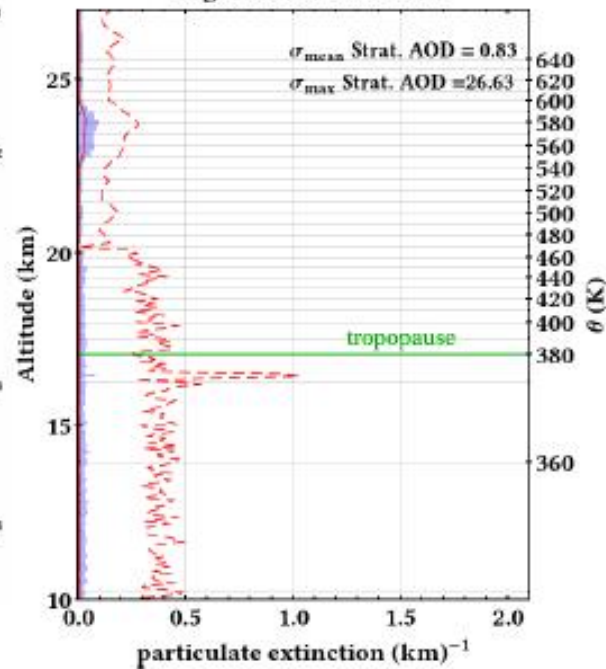
**Optical depth: Raikoke sulfate plume is *VISIBLE* after ~2 months.**

532 nm Total Attenuated Backscatter,  $\text{km}^{-1} \text{sr}^{-1}$  UTC: 2019-08-24 06:07:33.4 to 2019-08-24 06:21:02.1 Version: 3.40 Standard Daytime



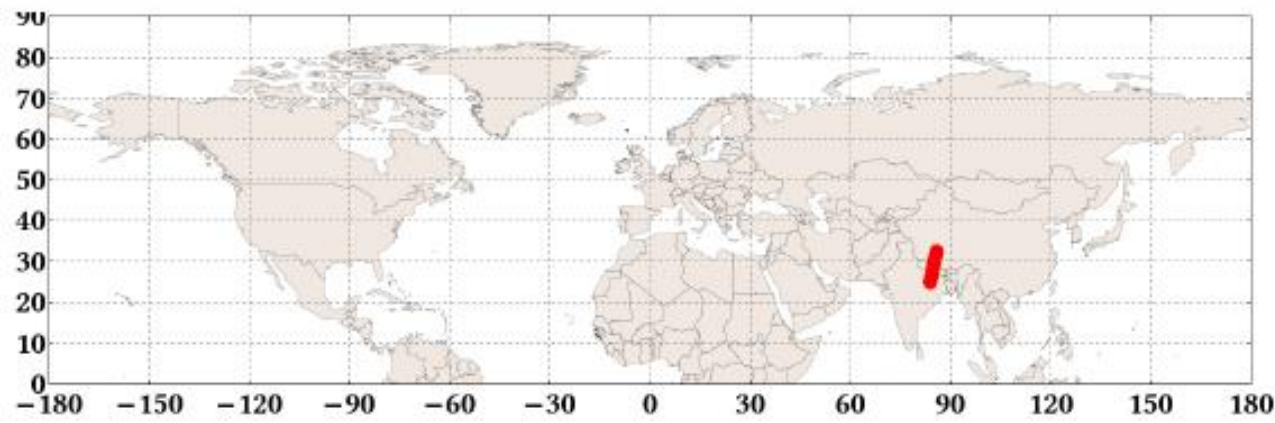
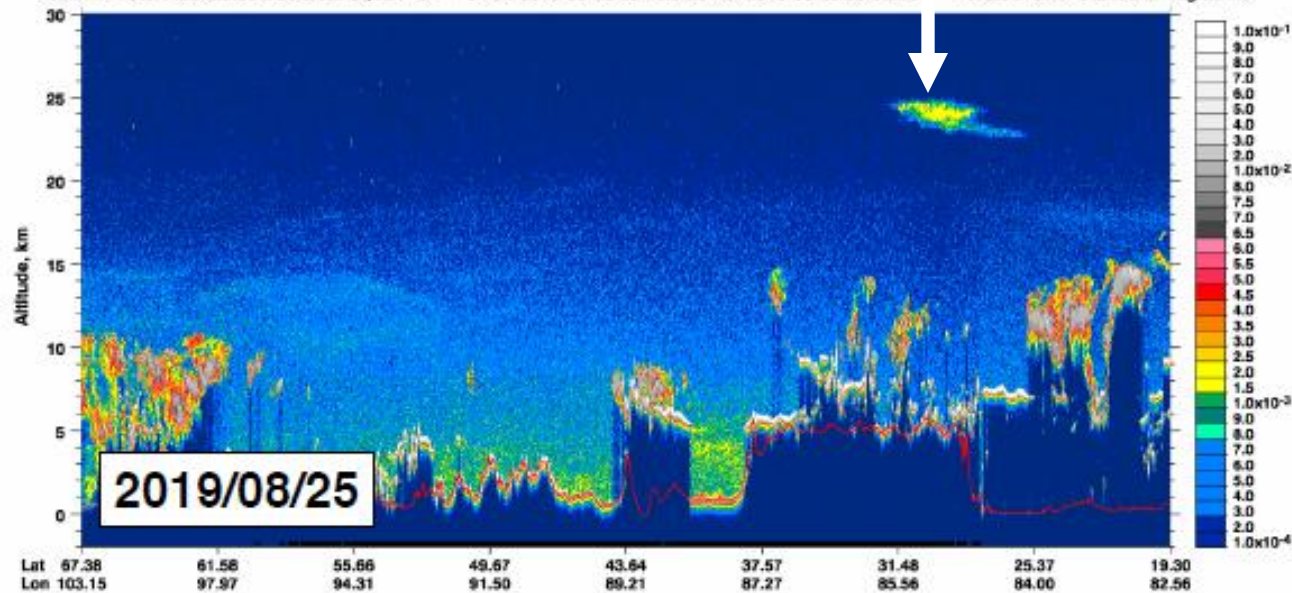
Smoothed over latitudes: 26.0 to 31.0,

longitudes: 111.0 to 110.0



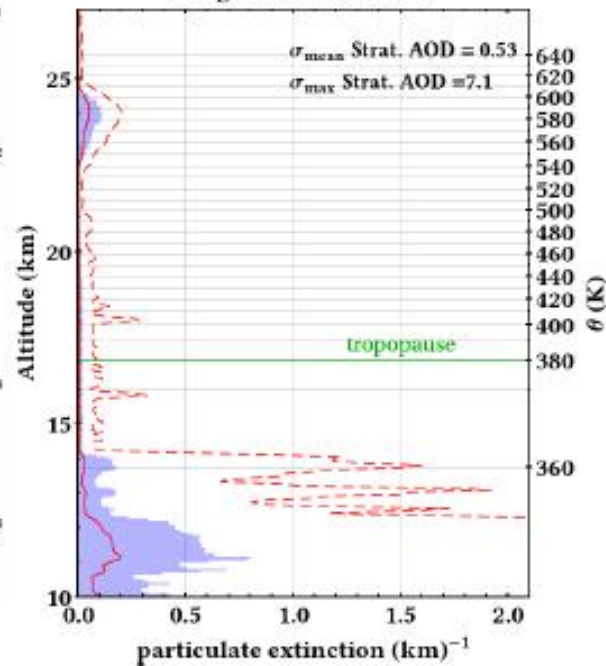


532 nm Total Attenuated Backscatter,  $\text{km}^{-1} \text{sr}^{-1}$  UTC: 2019-08-25 20:18:54.6 to 2019-08-25 20:32:23.3 Version: 3.40 Standard Nighttime

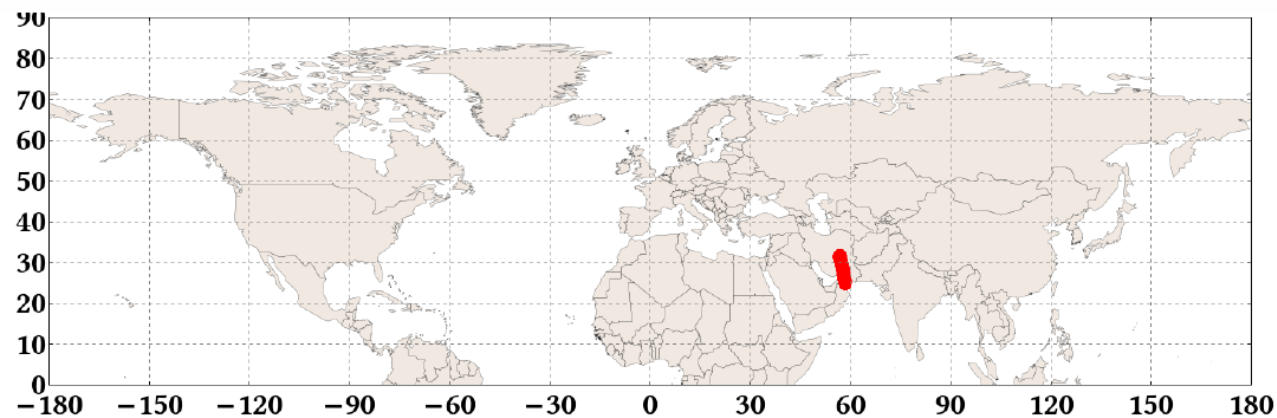
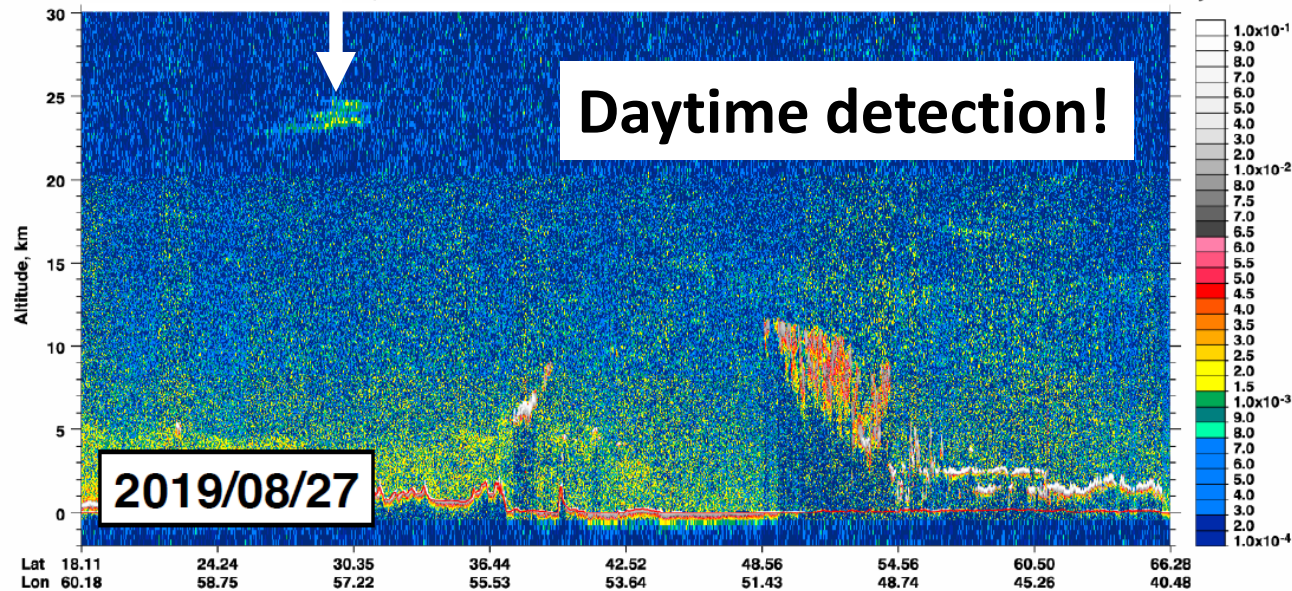


Smoothed over latitudes: 25.0 to 33.0,

longitudes: 86.0 to 83.9

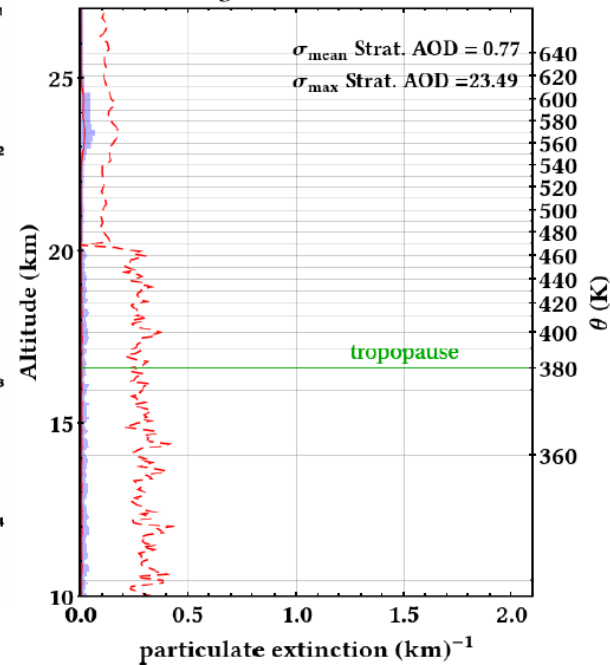


532 nm Total Attenuated Backscatter,  $\text{km}^{-1} \text{sr}^{-1}$  UTC: 2019-08-27 09:39:42.6 to 2019-08-27 09:53:11.3 Version: 3.40 Standard Daytime



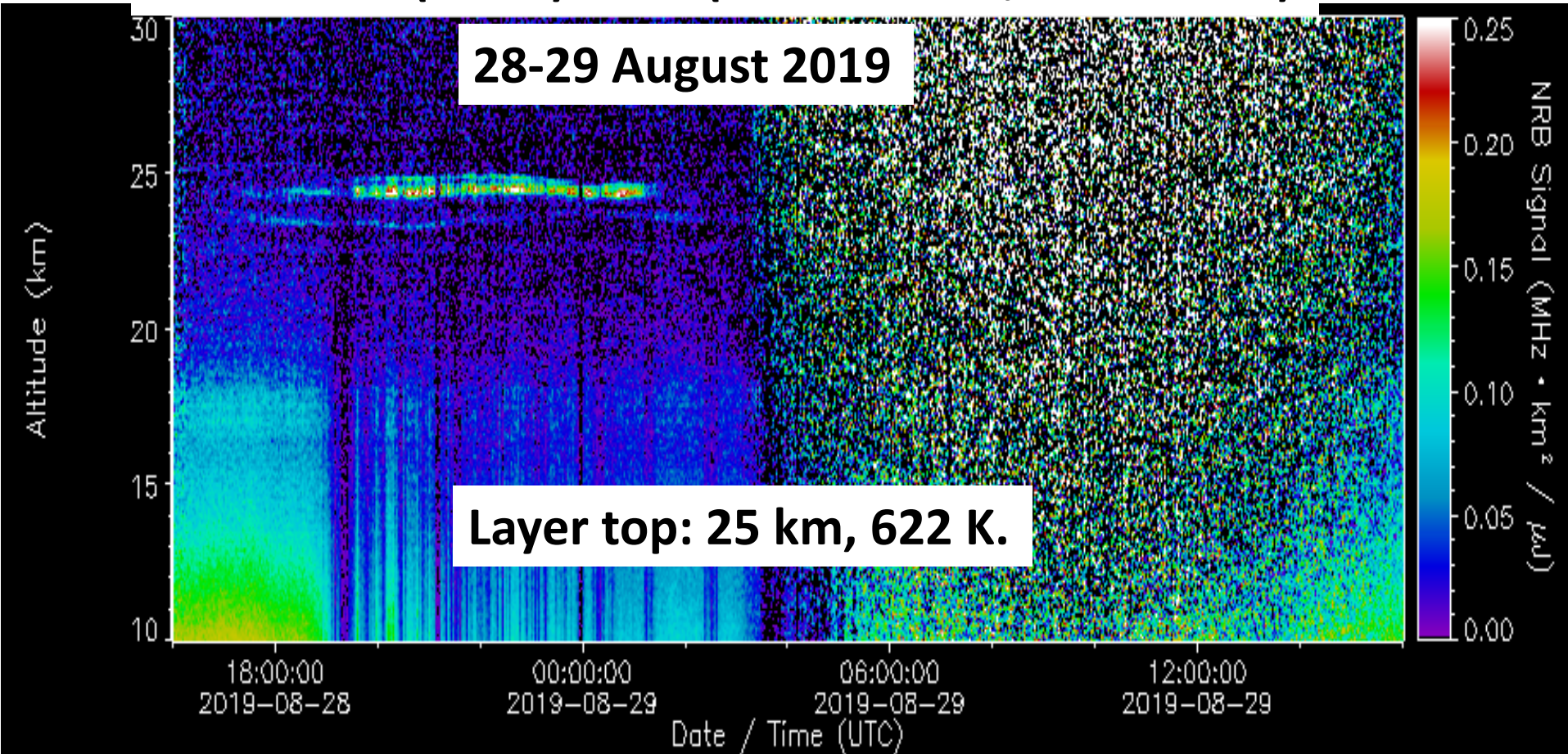
Smoothed over latitudes: 25.0 to 32.0,

longitudes: 58.6 to 56.8





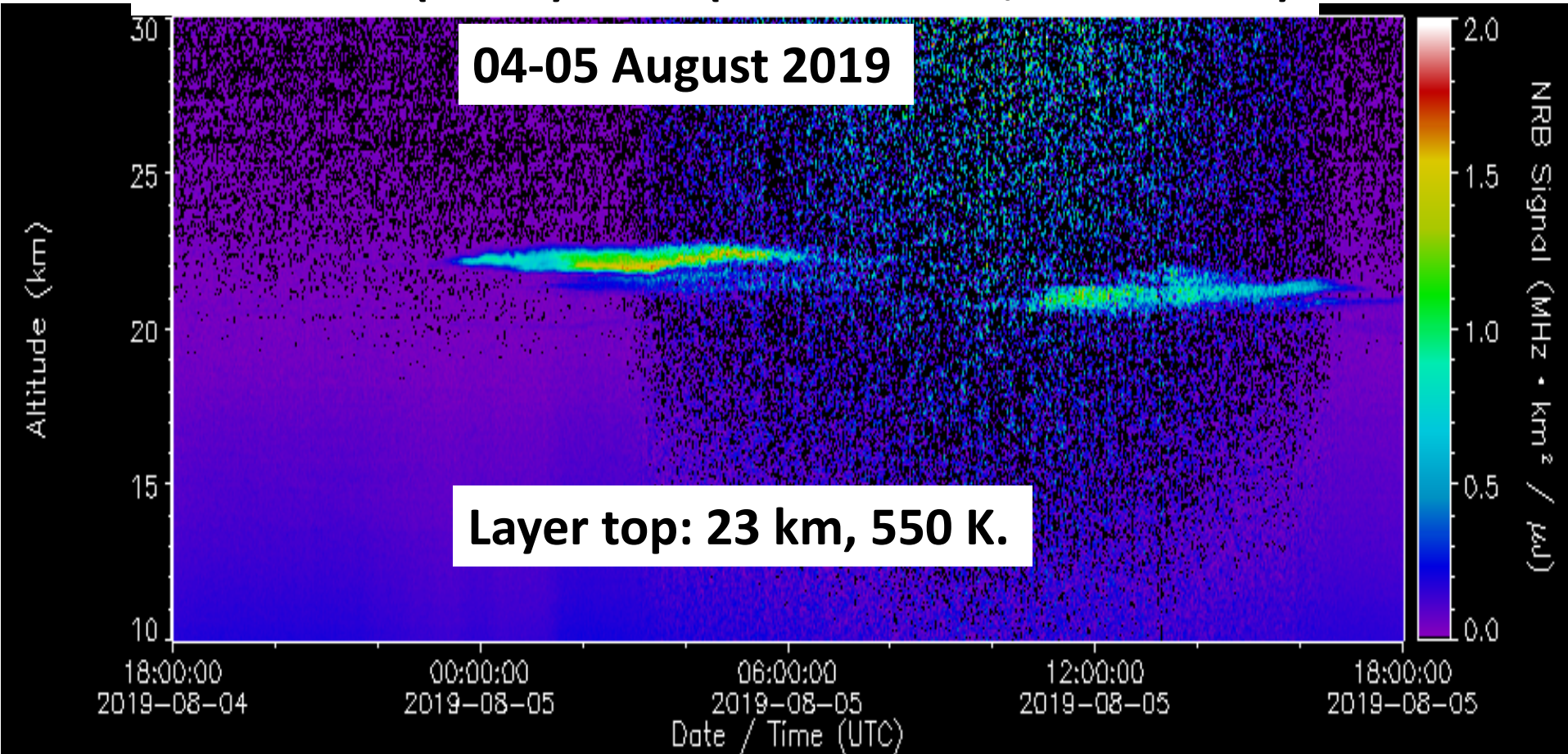
# Sede Boker (Israel) MPL (Judd Welton, MPLNET PI)



No overlap calibration.  
No pol calibration.

PRELIMINARY CALS

# Sede Boker (Israel) MPL (Judd Welton, MPLNET PI)

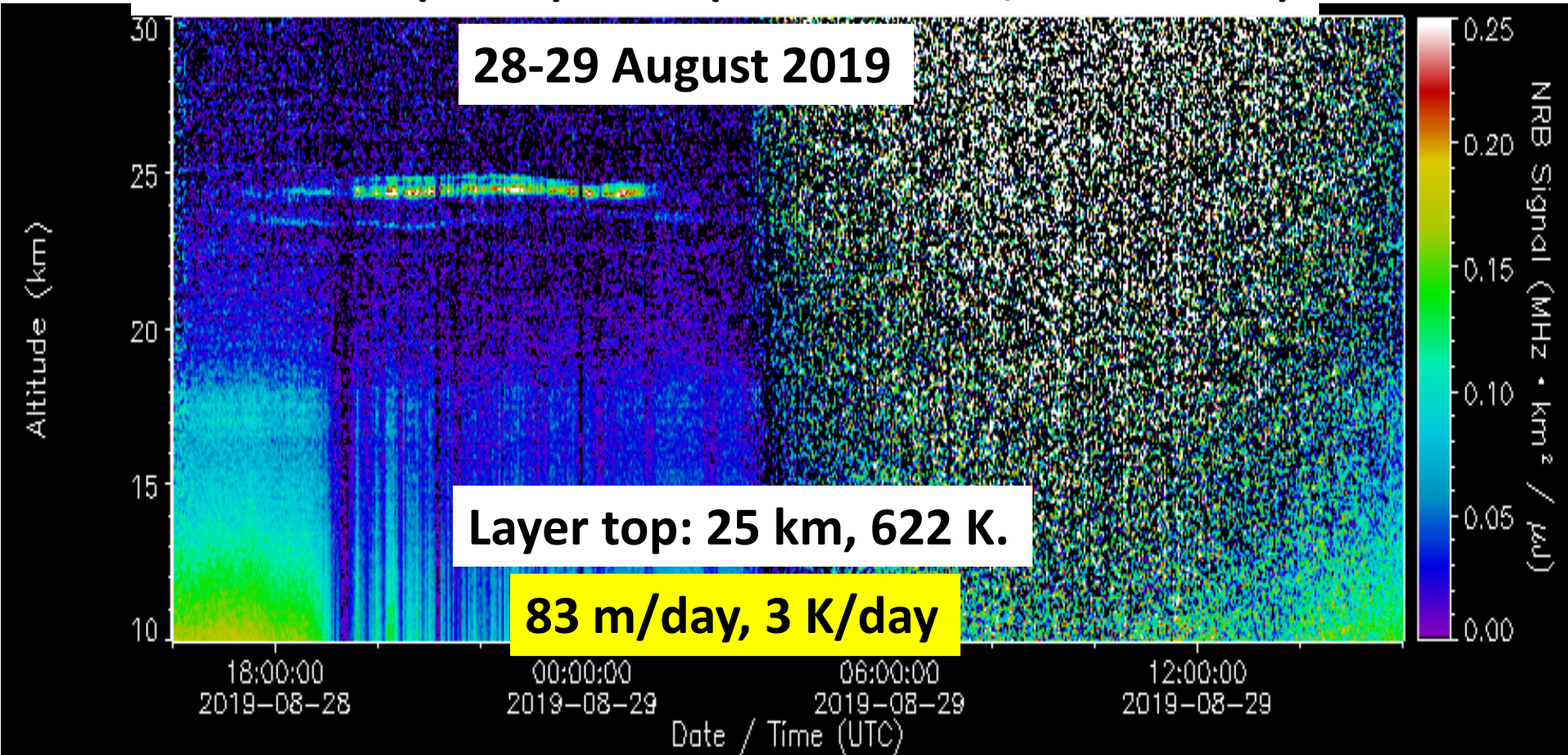


No overlap calibration.  
No pol calibration.

PRELIMINARY CALS



# Sede Boker (Israel) MPL (Judd Welton, MPLNET PI)



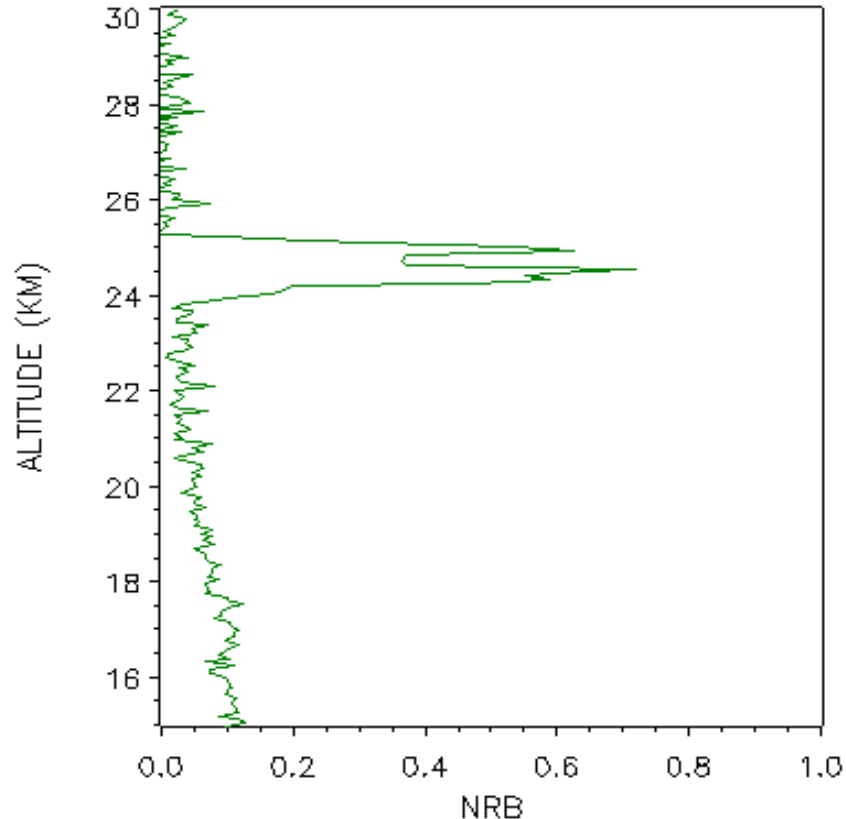
No overlap calibration.  
No pol calibration.

PRELIMINARY CALS

# Raikoke VC on 31 August 2019. MPL detection at Tenerife.

## - Layer to 25 km (627 K).

MPLNET Santa\_Cruz\_Tenerife 2019-08-31 22:12:30



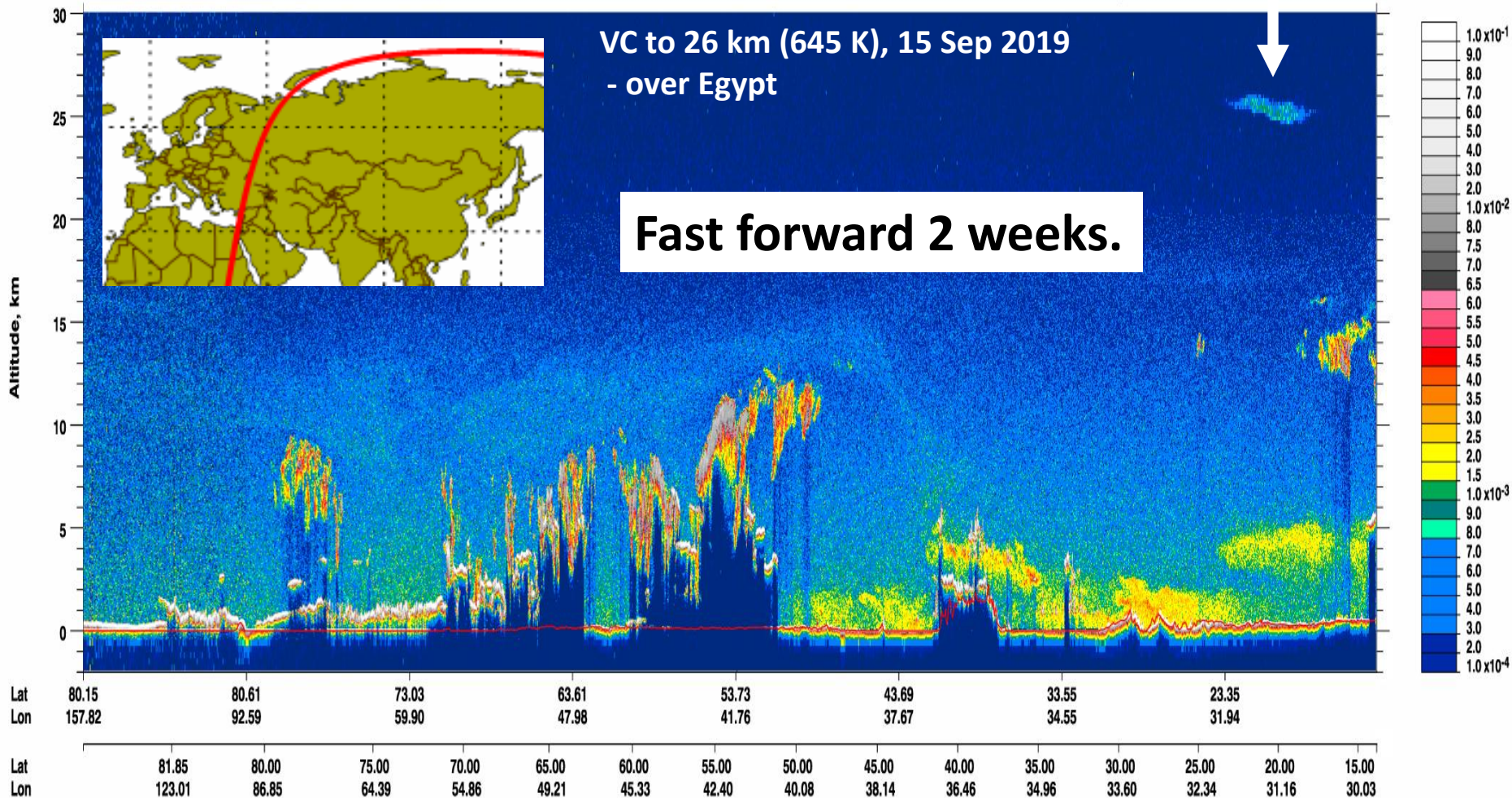
[28.4720° N](#)

[16.2470° W](#)



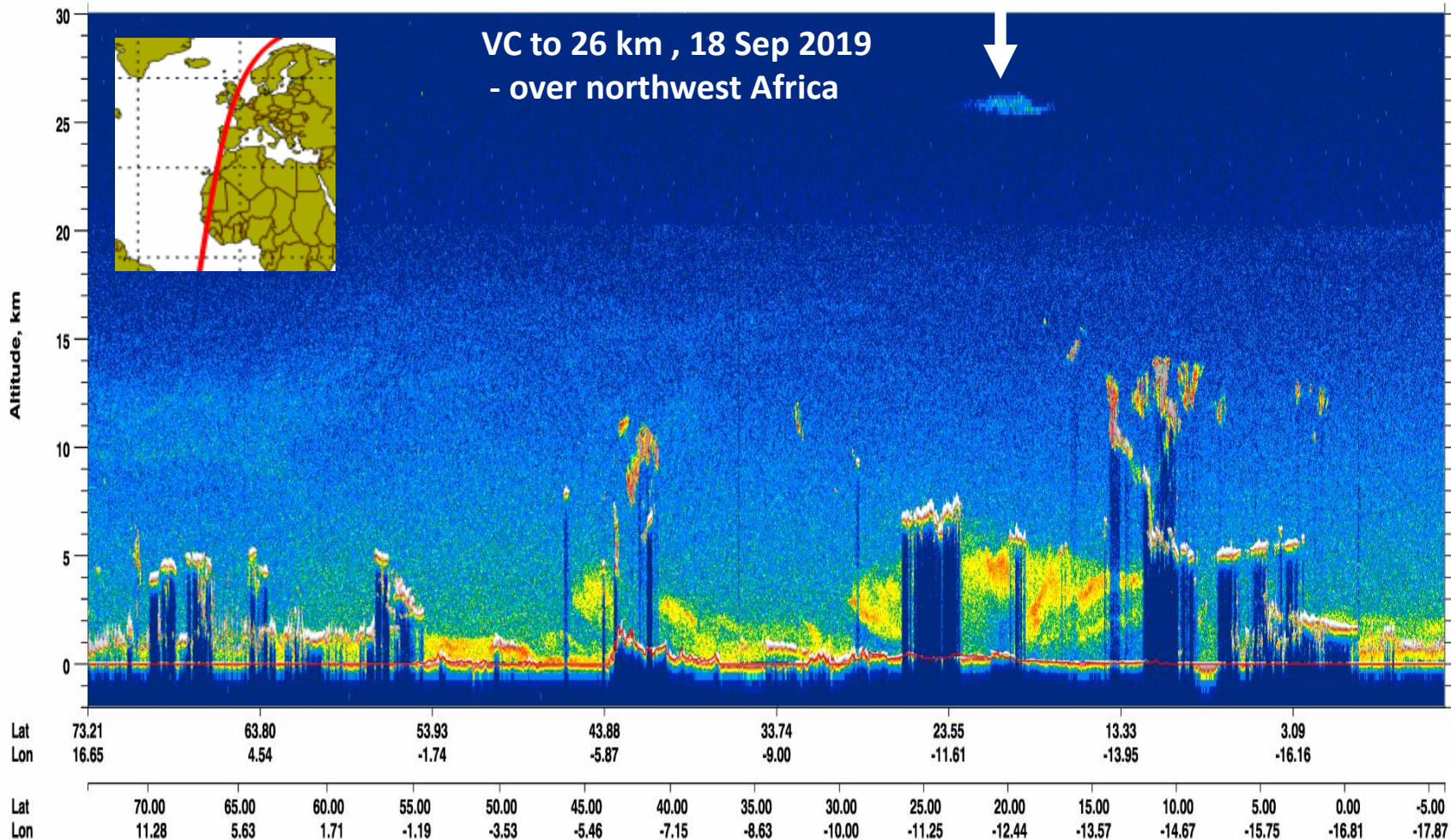
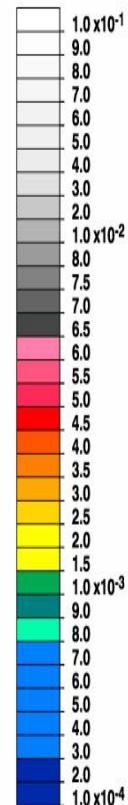
VC to 26 km (645 K), 15 Sep 2019  
- over Egypt

Fast forward 2 weeks.





VC to 26 km , 18 Sep 2019  
- over northwest Africa





# El Chichon VC, October 1982.

- McCormick and Swissler (GRL, 1983).

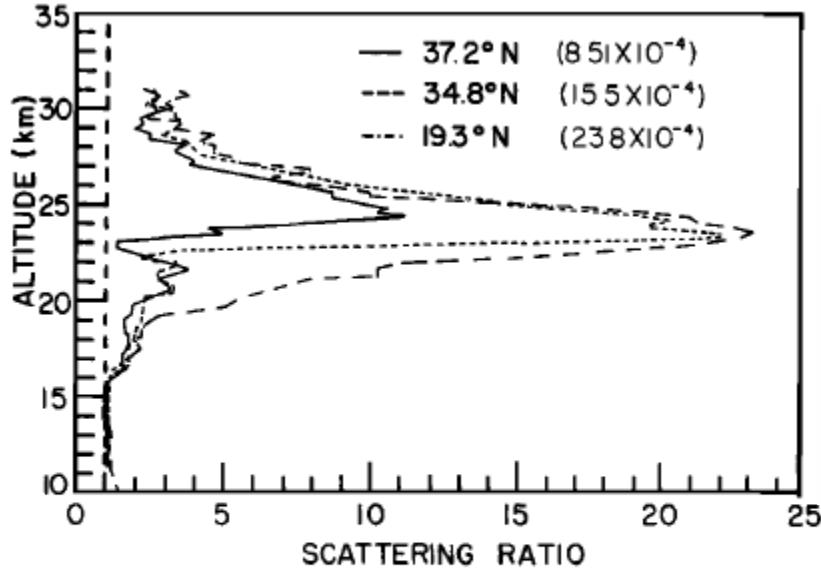
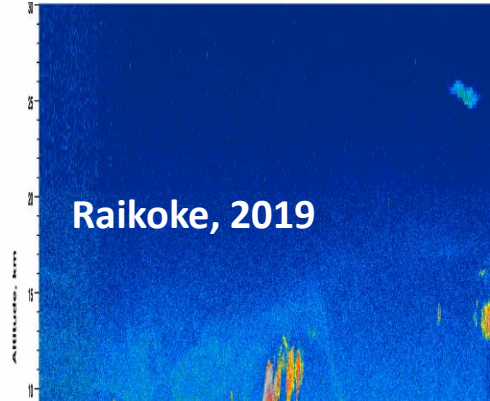


Fig. 2 Representative vertical profiles of lidar scattering ratio at  $\lambda = 0.6943 \mu\text{m}$ , for the northern latitudes shown on the first two flight legs in Figure 1, October 19-20, 1982. Integrated backscatter function, from the tropopause through the layer, is given in parenthesis.



**Raikoke VC  
in El Chichon  
height class.**

# Conclusions and Questions

- Raikoke sulfate VC rose diabatically from 15-26 km (>250K)
- VC AOD, compactness and meteorology conspired to permit tracking
- Rise was quasi-continuous from outset
- Rise occurred over oceans and continents
- Rise occurred over mid-latitudes and subtropics
- Approx. due west trajectory over 2+global circuits
- No apparent influence of pyroCb smoke

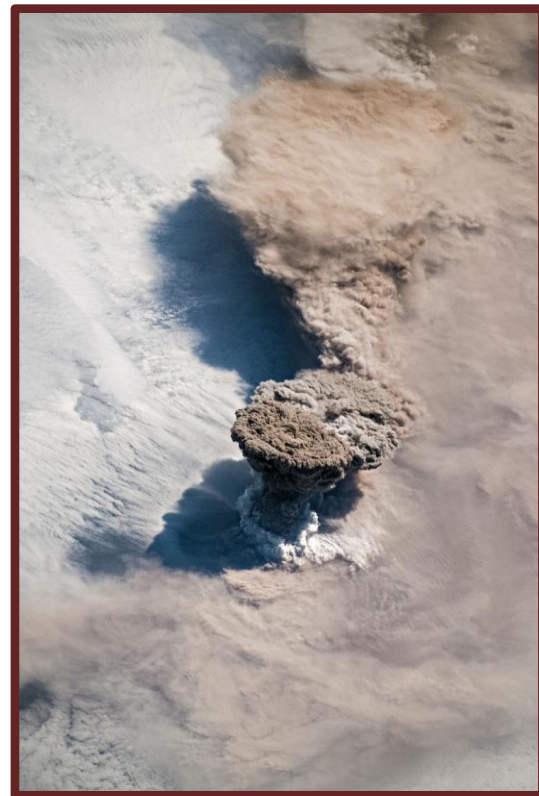
? First time such a diabatic excursion observed ?

? How much did the rest of Raikoke VC rise ?

? How does this comport with historical VC ?

? How well can models simulate Raikoke transport ?

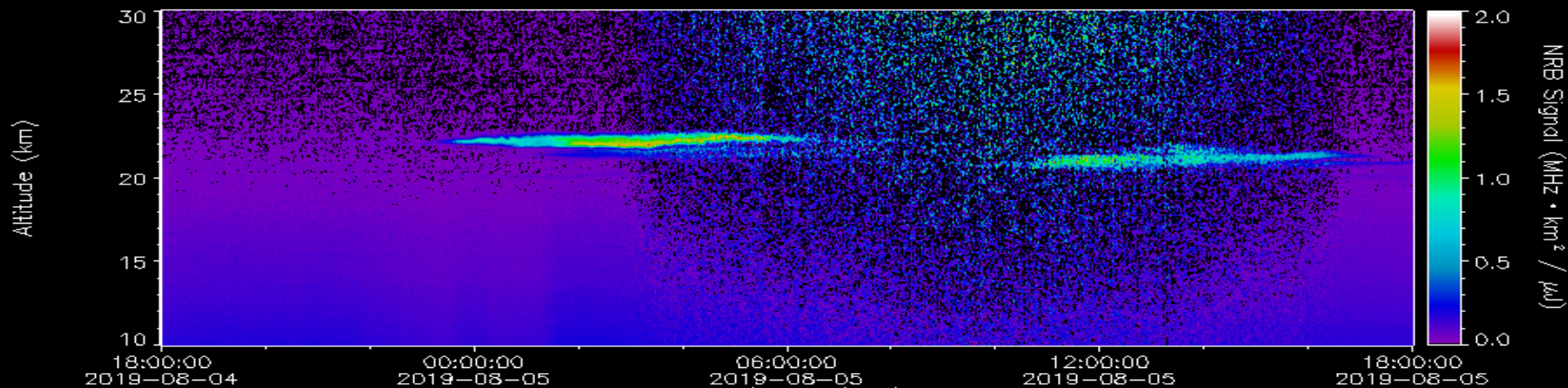
? What did we get wrong or miss?



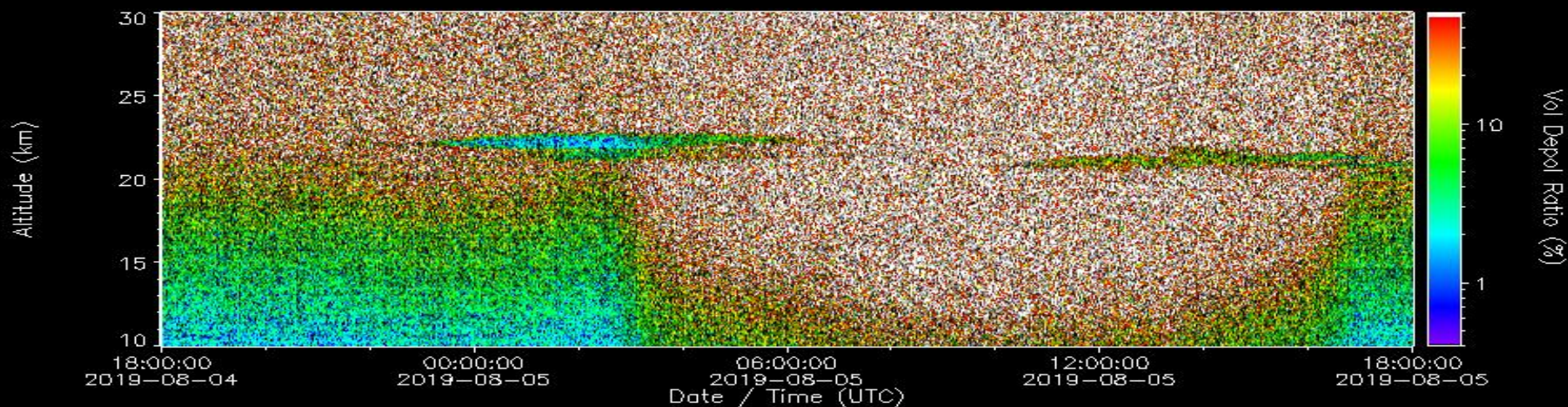


Extras

MPLNET SEDE\_BOKER 2019-08-04...2019-08-05: V3\_L1\_NRB (MPL44241, 532.00 nm)



MPLNET SEDE\_BOKER 2019-08-04...2019-08-05: V3\_L1\_NRB (MPL44241, 532.00 nm)



No overlap calibration.  
No pol calibration.

PRELIMINARY CALS



# VC to 26.5 km , 21 Sep 2019 - Gulf of Mexico

