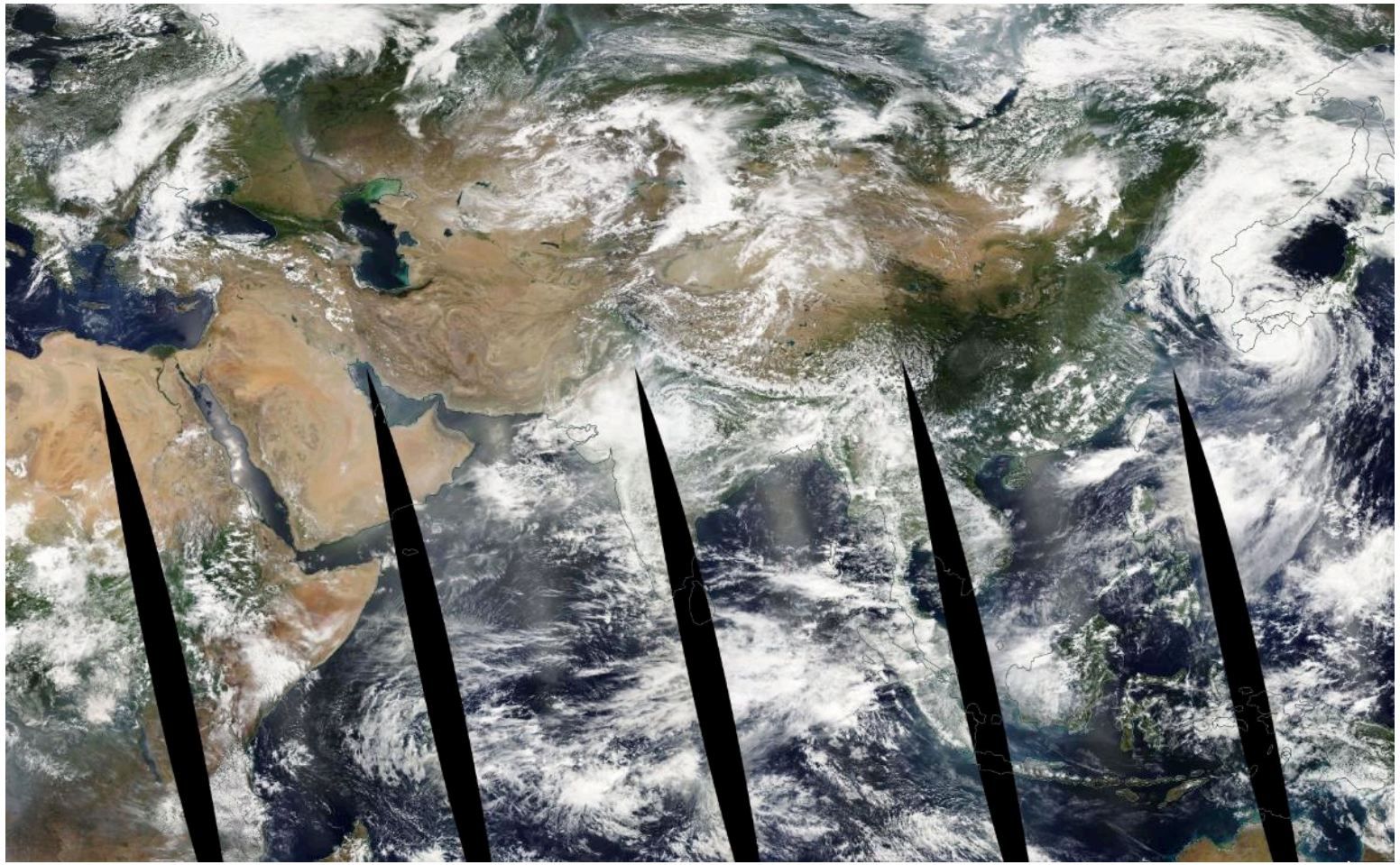
Aerosol Discrimination in the Asian Monsoon Region: Is it a cloud? Depolarizing Aerosol? Non-depolarizing aerosol?



Melody Avery, NASA Langley; With a whole lot of help from colleagues and friends:

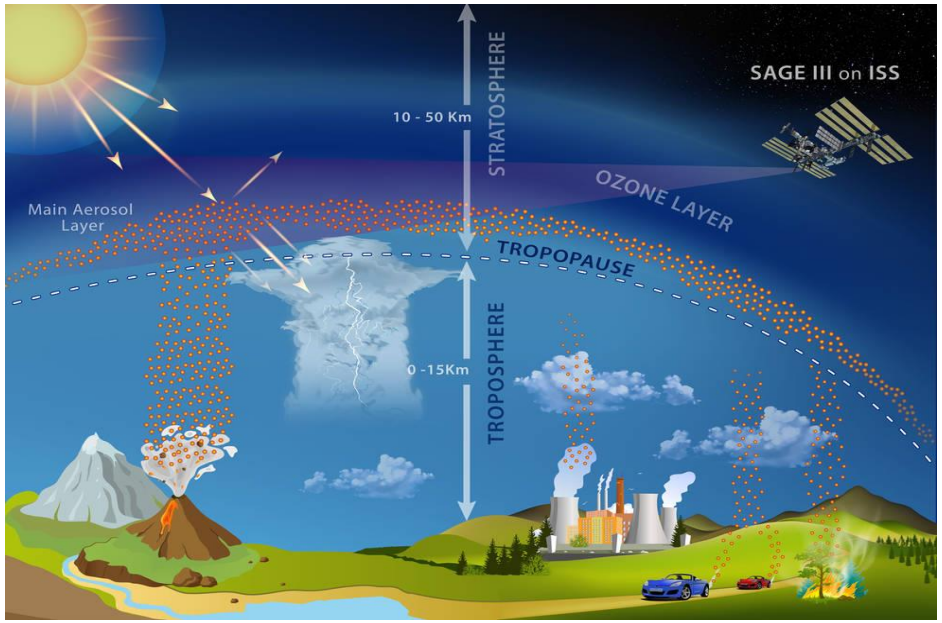
John Kummer, Mark Schoeberl, Kris Bedka, Jean-Paul Vernier, Hongyu Liu, Duncan Fairlie, Bo Zhang, Amit Pandit, Karen Rosenlof, Sean Davis, Jason Tackett, Jayanta Kar, Zhaoyan Liu, Mark Vaughan

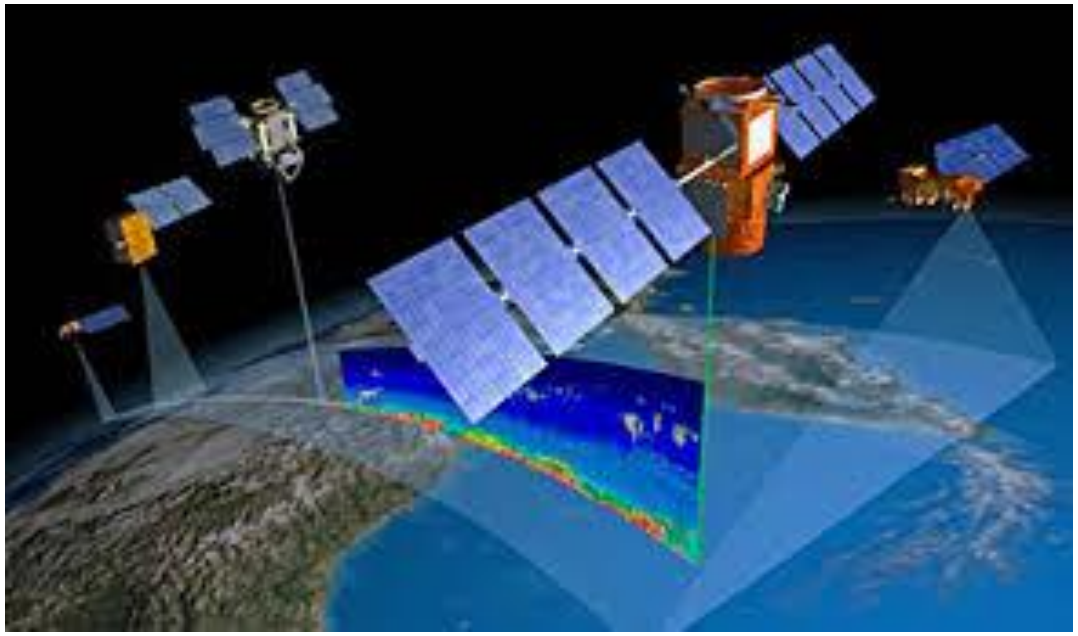
Science questions/Talk Outline

- Top of Aerosol layers > top of convective parameterization in models. What happens to loft aerosols in the ATAL?
- Hypotheses:
  - Modeled convection is too low.
  - Intermittent very deep convective events contribute long-lasting aerosols by injection.
  - Cloud radiative effects create lofting that elevates small particles.
  - All of these things could be true.
- Measurement Challenges:
  - Imperfect data, always missing something in space or in time.
  - Particles are detected. Aerosols or Clouds? Or both!
  - Where is the local tropopause?
- This talk:
  - Focus on observations by CALIOP, SAGE-III/ISS and some geostationary for context.

Goal: A regional comparison of cloud/aerosol discrimination in CALIOP and SAGE-III data, with an atmospheric process context.

SAGE-III vs CALIOP Cloud and Aerosol Detection

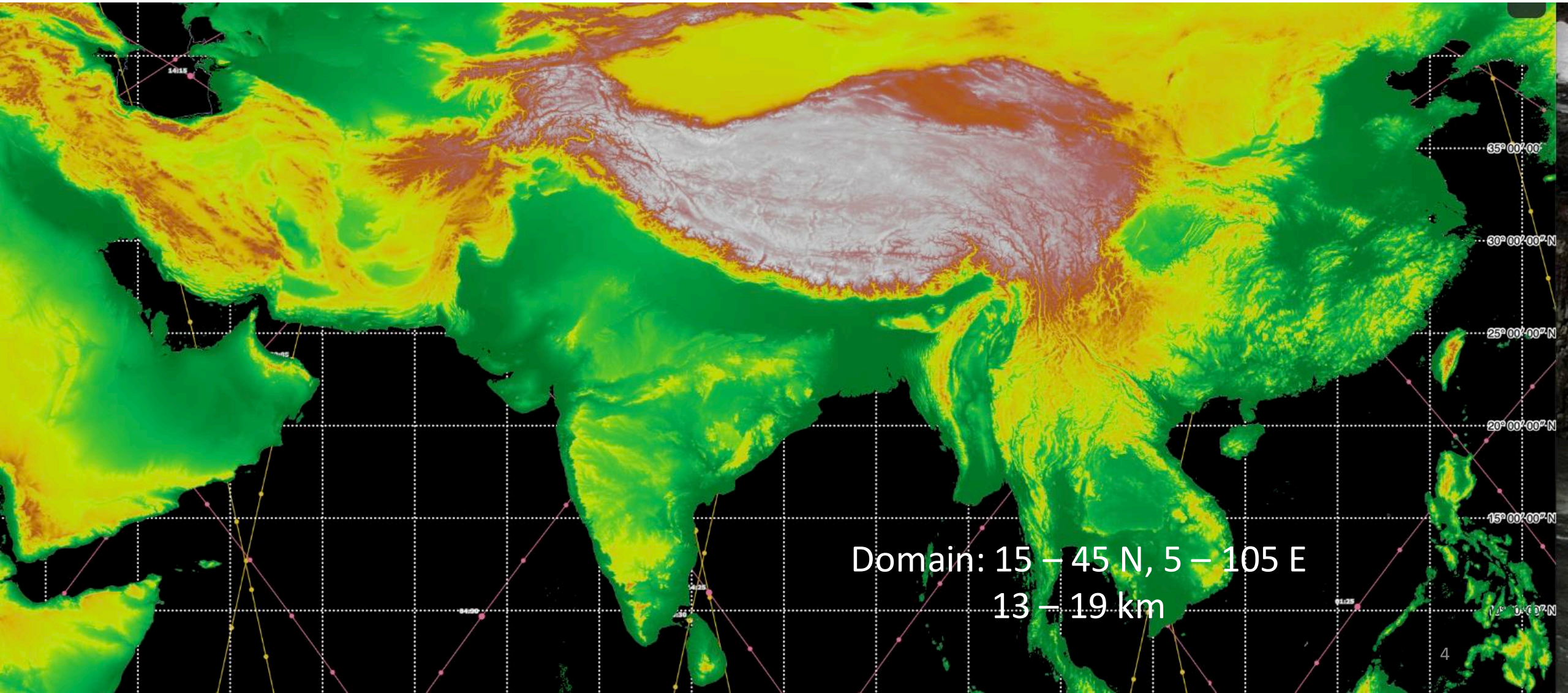




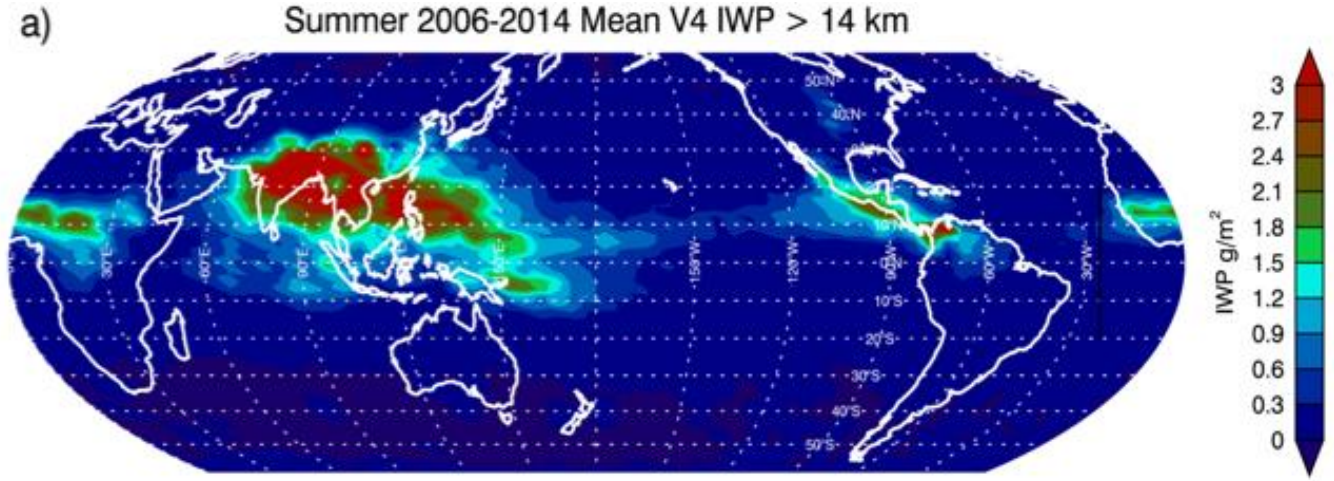
- 200 km path, 500 m vertical resolution
- 9 wavelengths (nm): 384, 449, 521, 602, 676, 756, 869, 1022, 1544
- Extinction observations at solar occultations
- Chemical observations as well
- *Detects cumulative extinction by aerosols and cloud ice particles along the sample path.*

- Features detected at 5, 20, 80 km
- Mode of transparent layer thickness distribution in the tropopause region is ~ 500 m, like SAGE bins
- Two 532 nm Channels with linear polarization plus 1064 nm
- Continuous measurements but no swath
- *Detects atmospheric features in a profile that have elevated backscatter and sorts them into aerosols and clouds.*

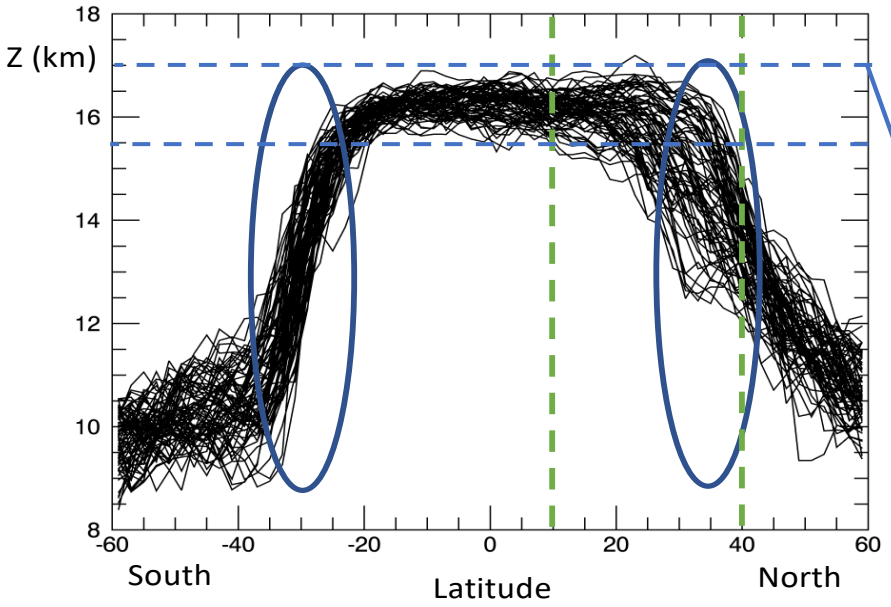
Domain: Asian Monsoon, Tropopause Region
Peak Monsoon Season; July and August 2017-2018



In the NH Summertime UT/LS, the Asian Monsoon is the biggest, baddest game in town.



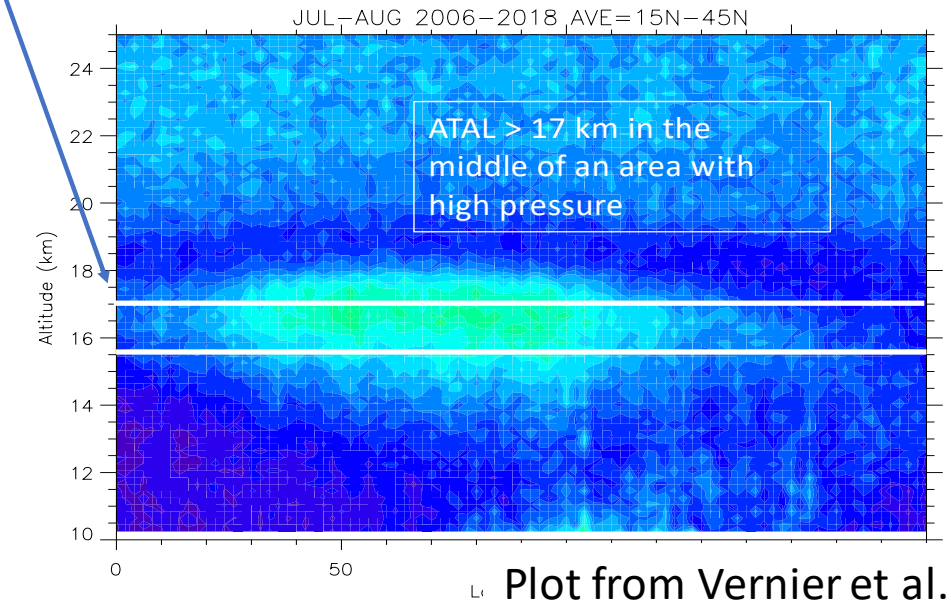
MERRA-2 tropopause height vs latitude



Hemispheric asymmetry in the Boreal Summer due to the Asian Monsoon in the Northern Hemisphere.
The NH tropopause break at the subtropical jet is much less well-defined due to deep convection.

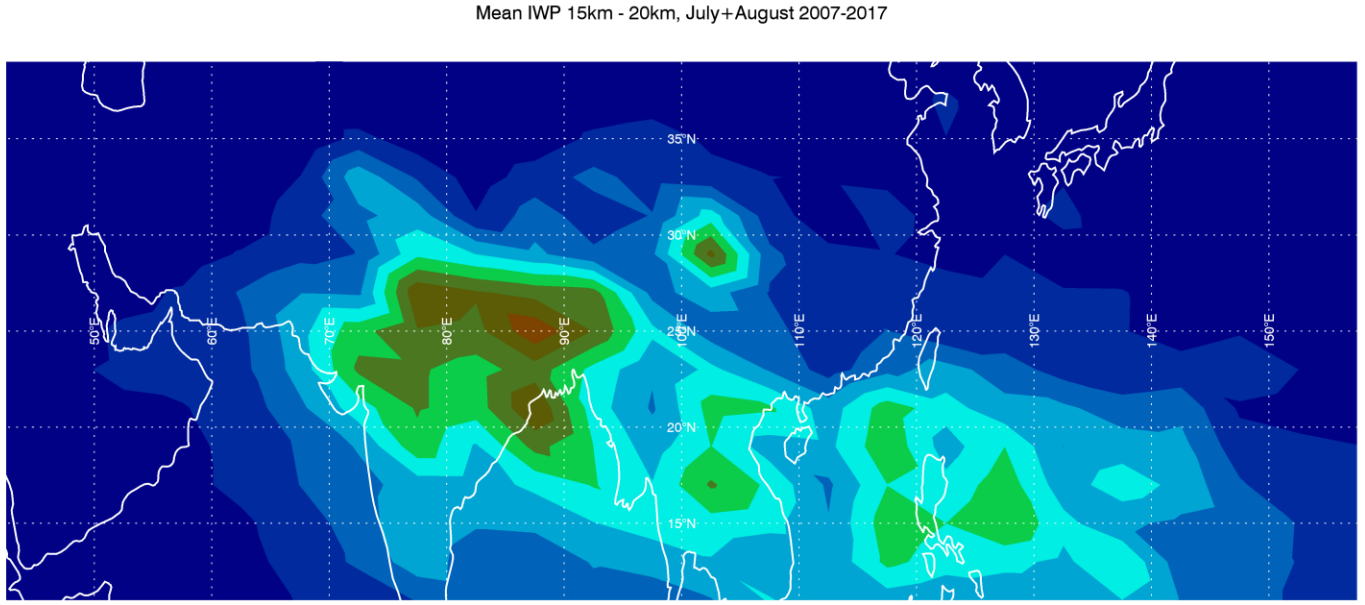
Asian Monsoon:

1 – Convective transport of tropospheric chemicals to the Stratosphere.
2 – More Subtropical, overshooting convection more likely to contribute water vapor to the Stratosphere (Schoeberl et al., 2019)
3 – Asian Tropopause Aerosol Layer (ATAL – Vernier et al.)

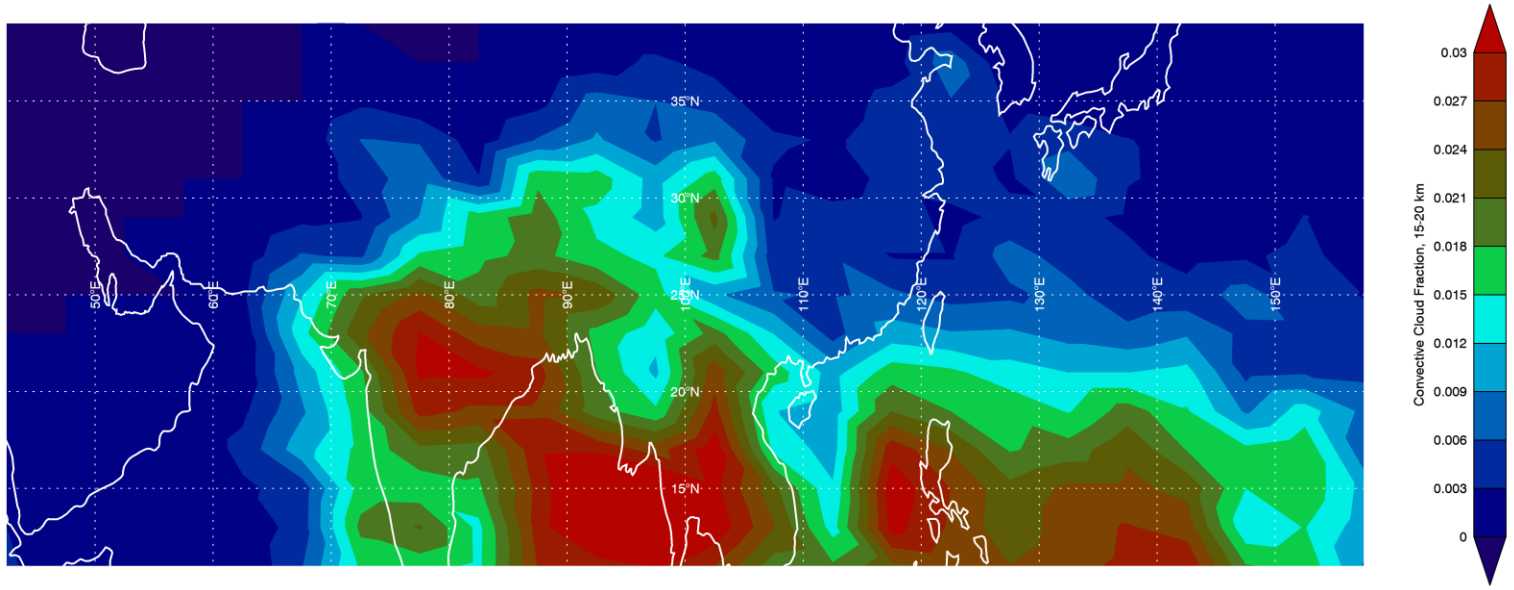


Plot from Vernier et al., 2020

CALIOP Nighttime Cloud Distribution “Climatology”

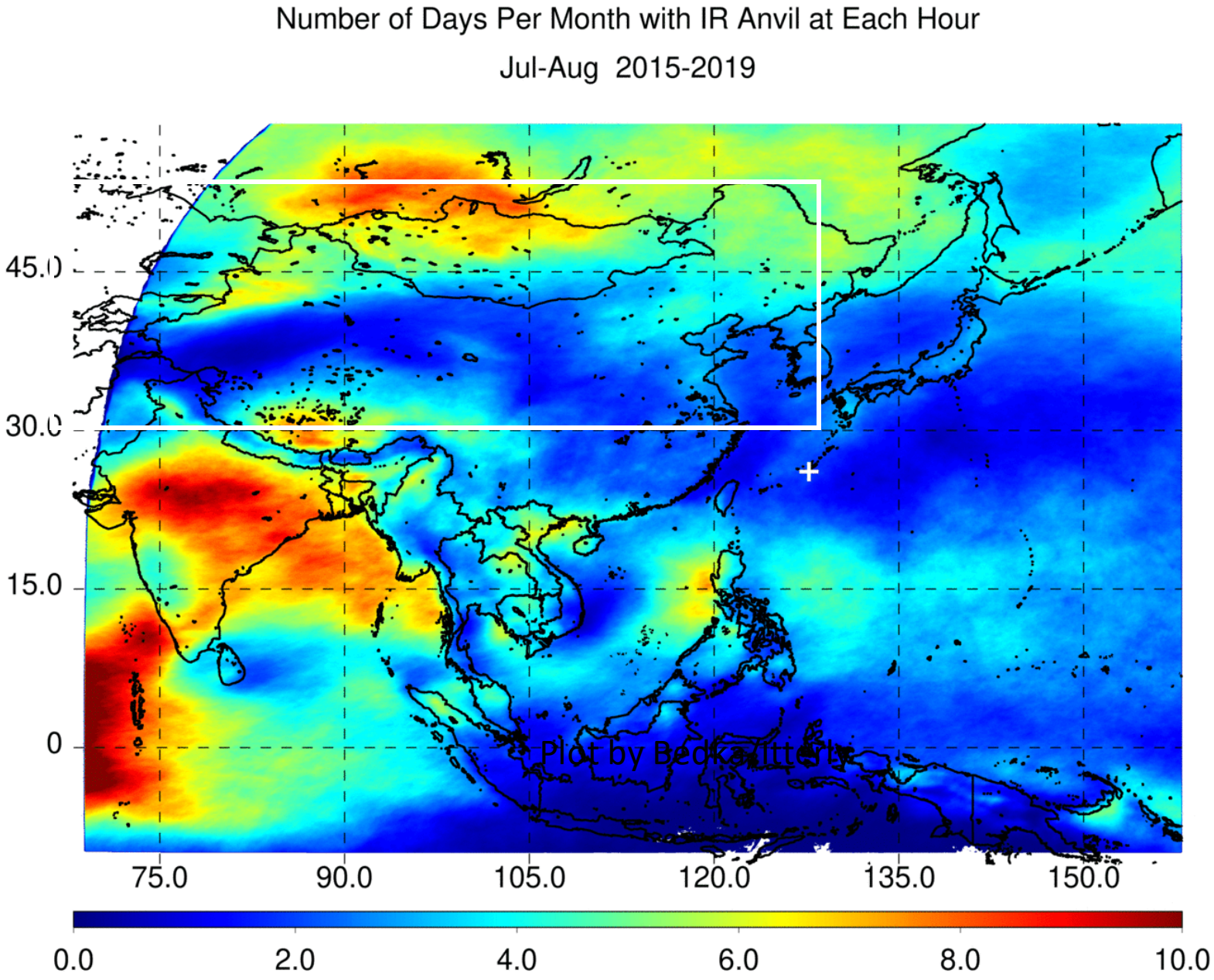


Cloud Ice Water Path, 15-20 km July and August 2007 - 2017 CALIOP Nighttime



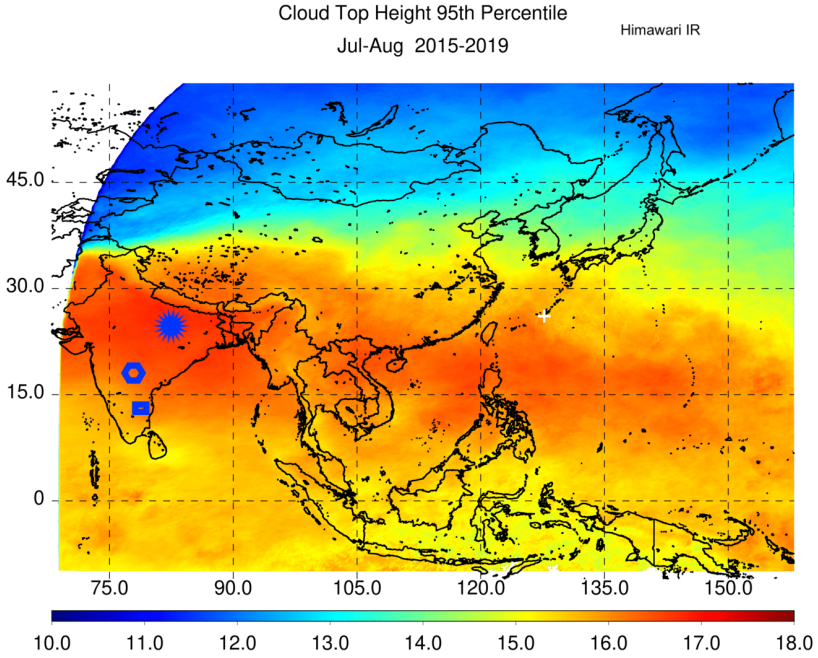
Convective Cloud Fraction > 15 km July and August 2007 - 2017 – CALIOP Nighttime

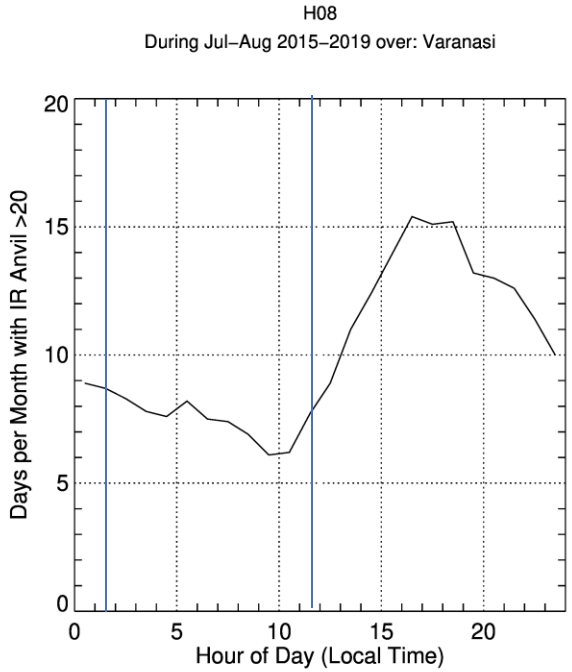
Compare Geostationary (IR) with LIDAR (vis) – “All-Times” vs Nighttime



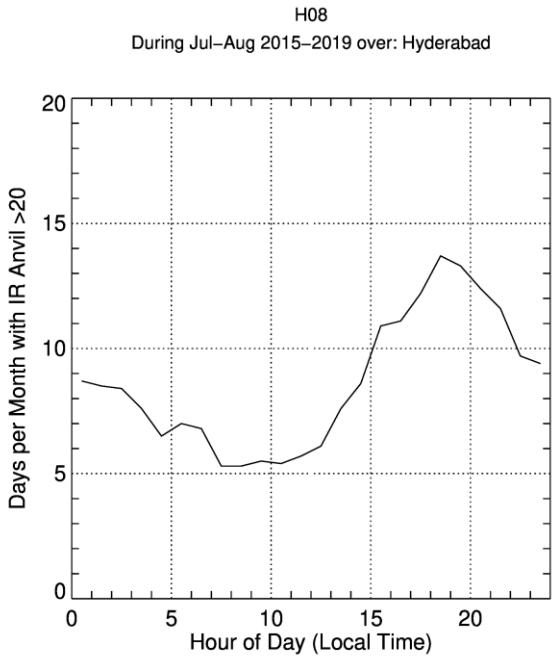
From Himawari IR, Anvil counts using the method of Scarino et al. (2020, in preparation) on a 4x4 degree grid.
Mean for Julys and Augusts, 2015 - 2019

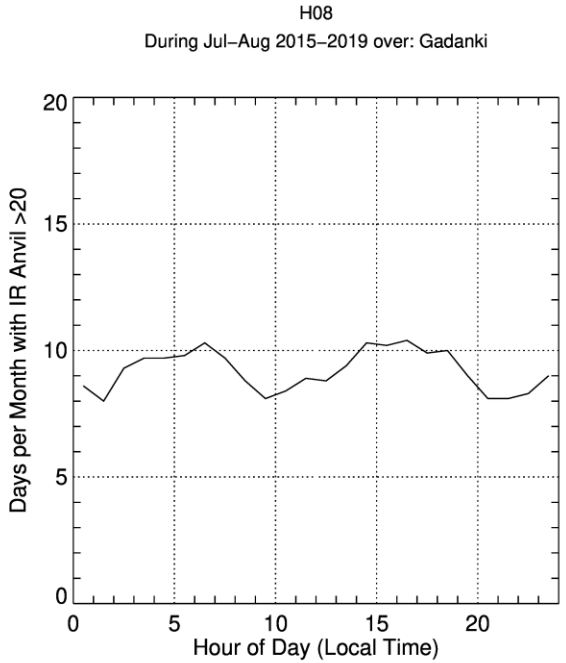
Plot by Bedka/Itterly





For land convection, apparently A-Train crossing times would be about the same.





Plots by Bedka, Itterly

SAGE-III Cloud/Aerosol Categorization

SAGE-II

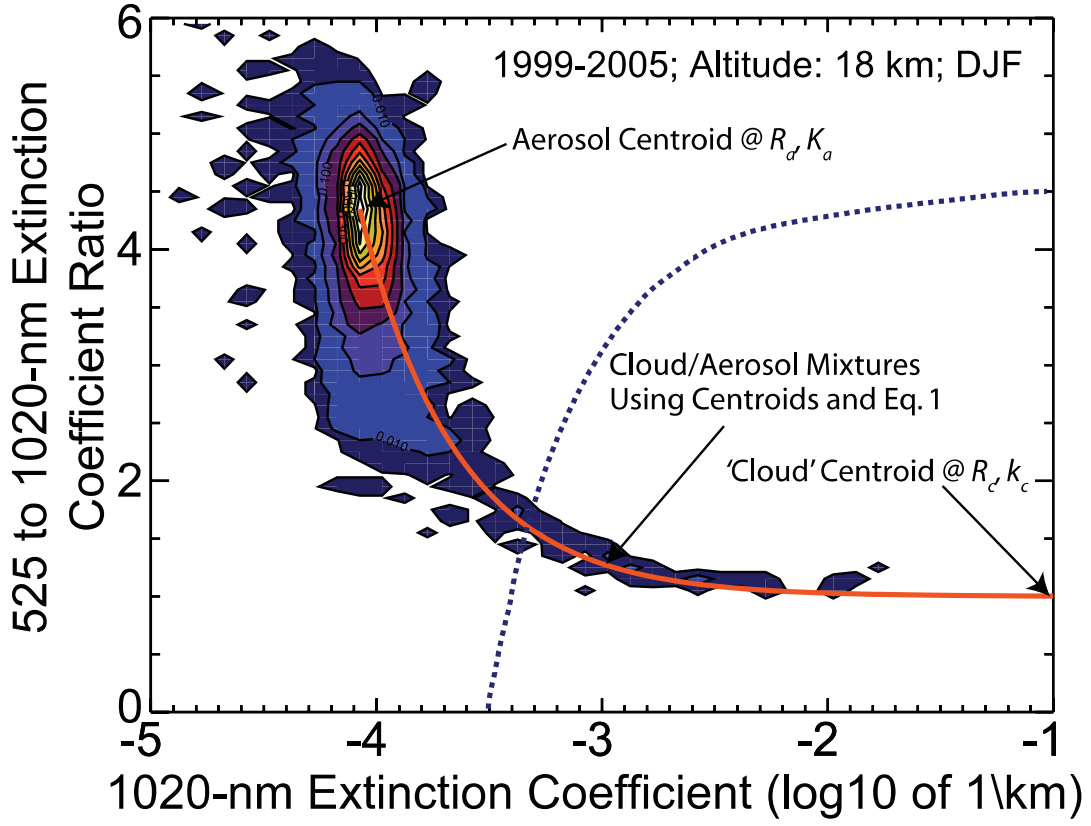
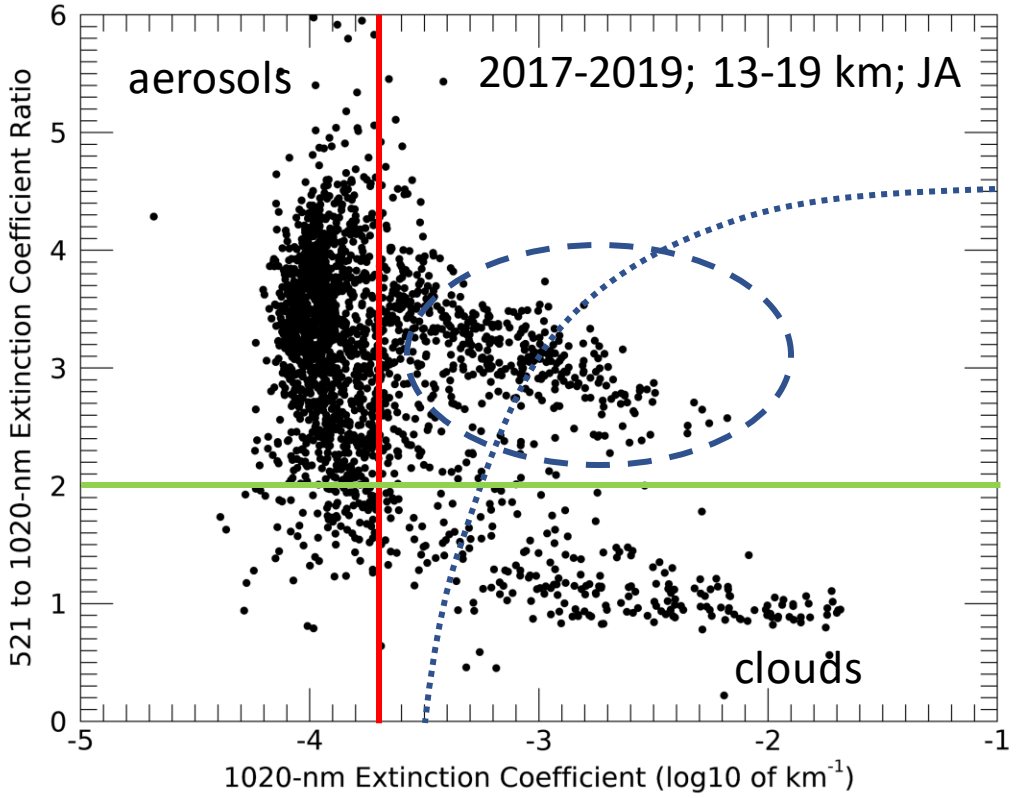


Figure 4, Thomason and Vernier, ACP 2013

SAGE-III/ISS

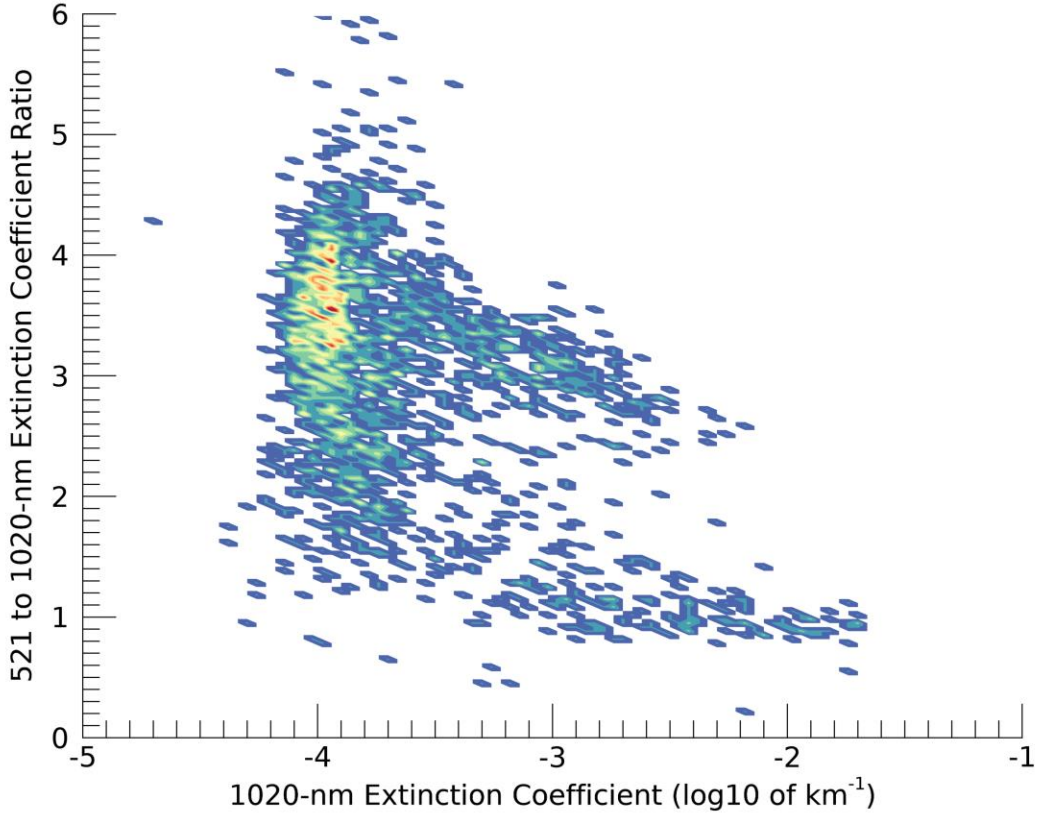


Solar (sunrise, sunset), 179 events, 500 m bins

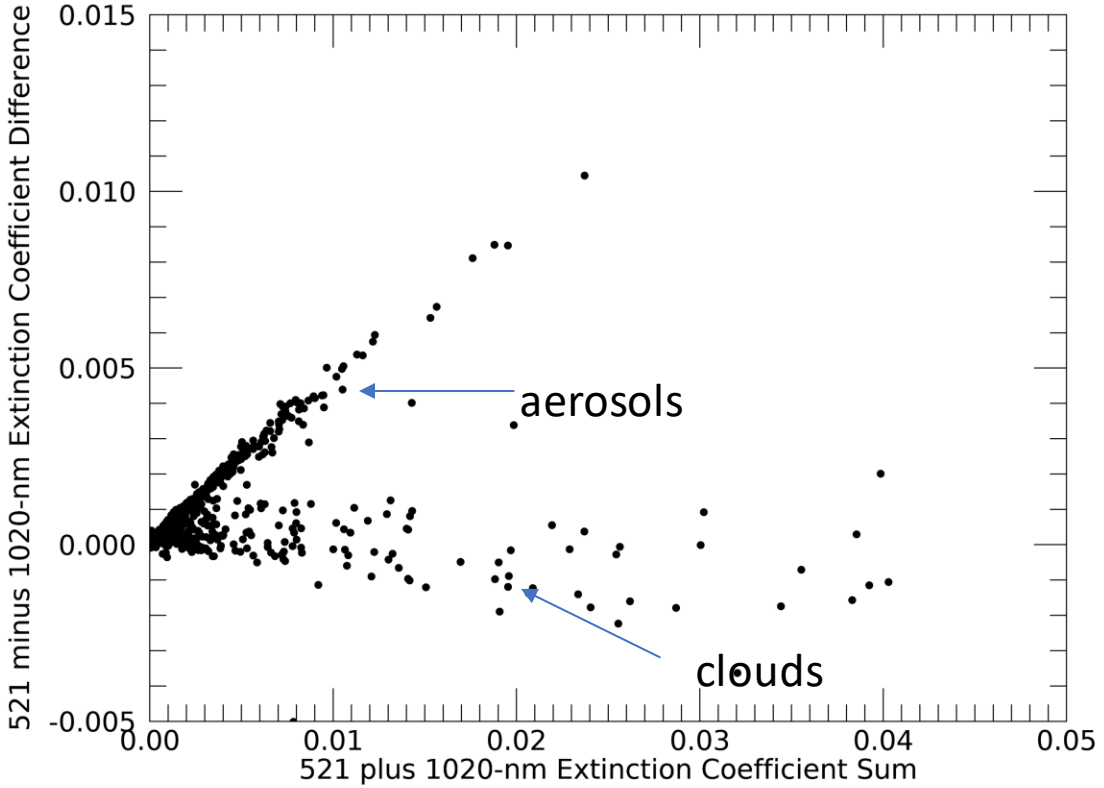
2-λ (Thomason algorithm) – red and green lines

Alternative View: Spectral Radiative Signature (SRS) algorithm

521/1020 Ratio vs log10 of 1020 – same as last plot with some distribution information

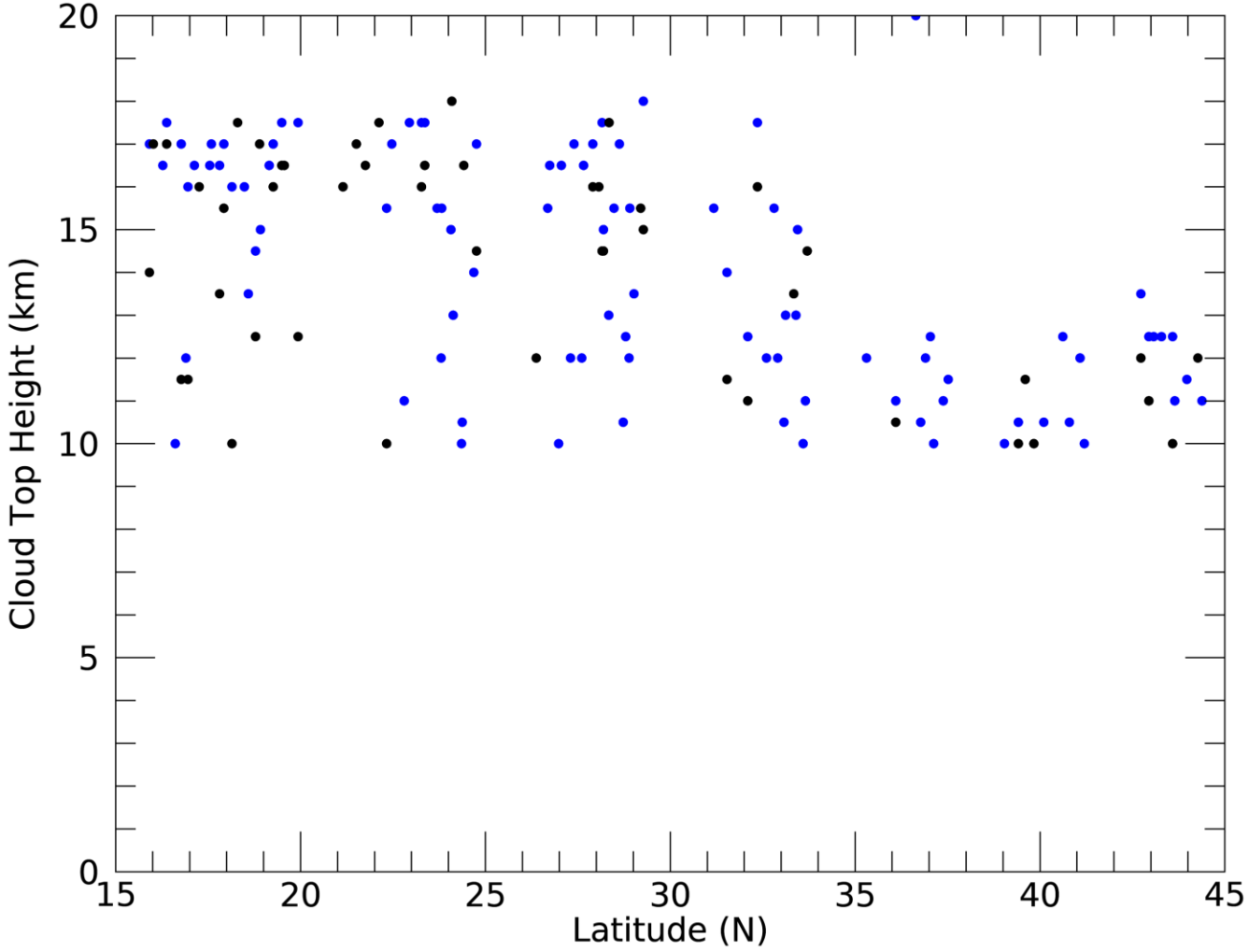


521 - 1020 nm Extinction Coefficient Difference vs 521 + 1020 nm Extinction Coefficient Sum



SRS technique from Chiu et al. (2009)

SAGEIII-ISS Cloud Tops –July, August 2017-2019

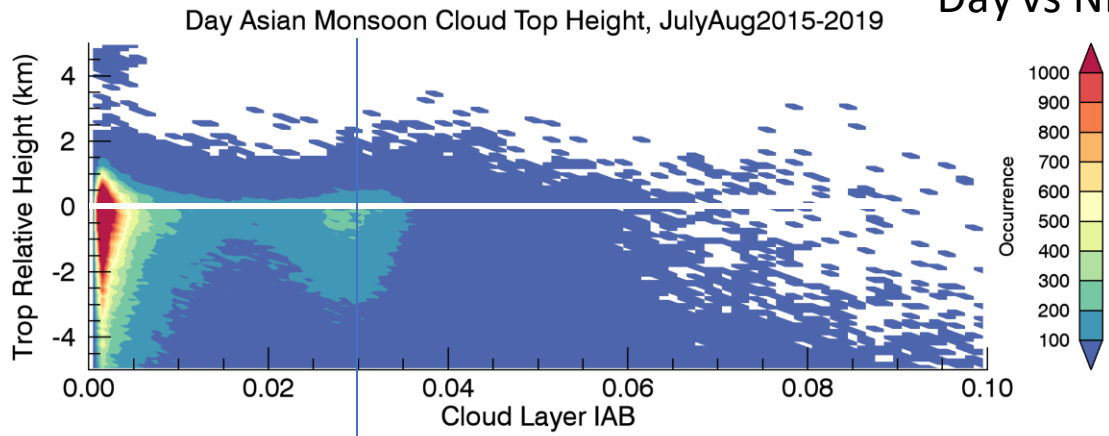


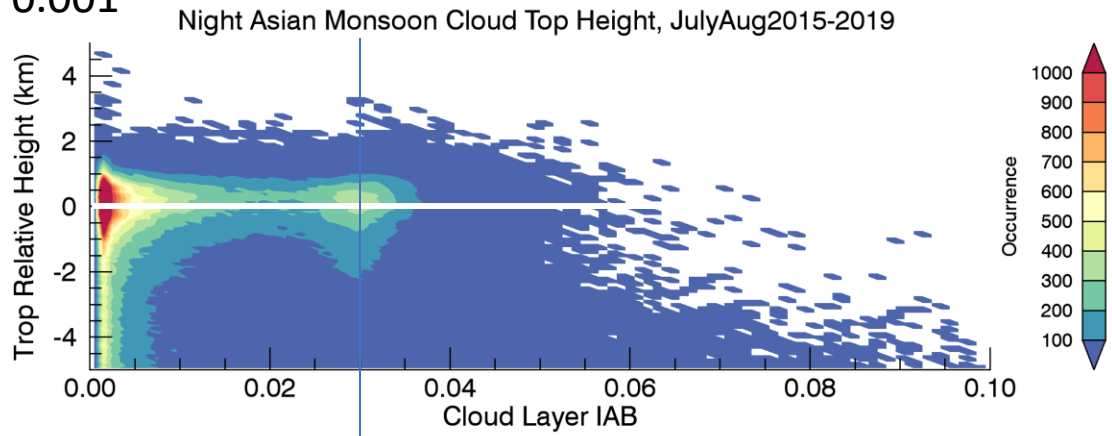
Clouds Detected by John Kummer using the 2-wavelength method of Thomason and Vernier (2013).

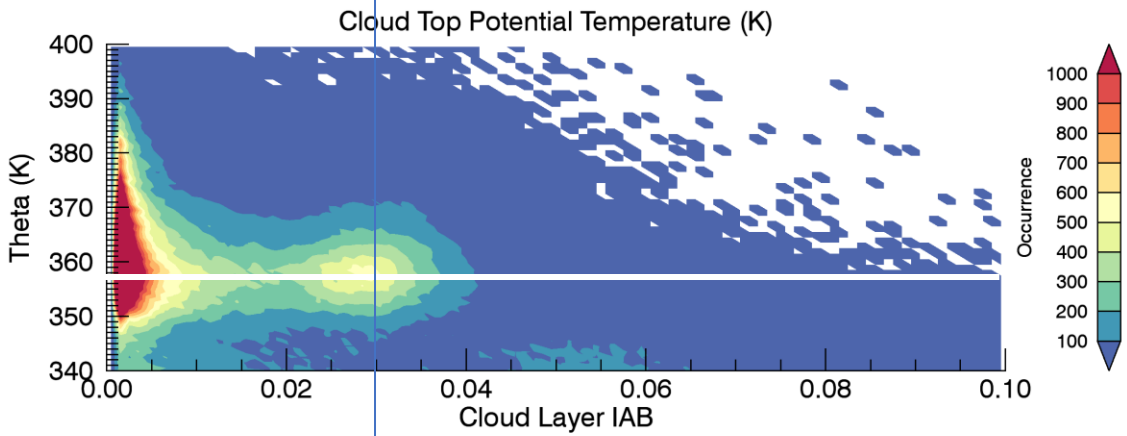
SAGE-III Clouds

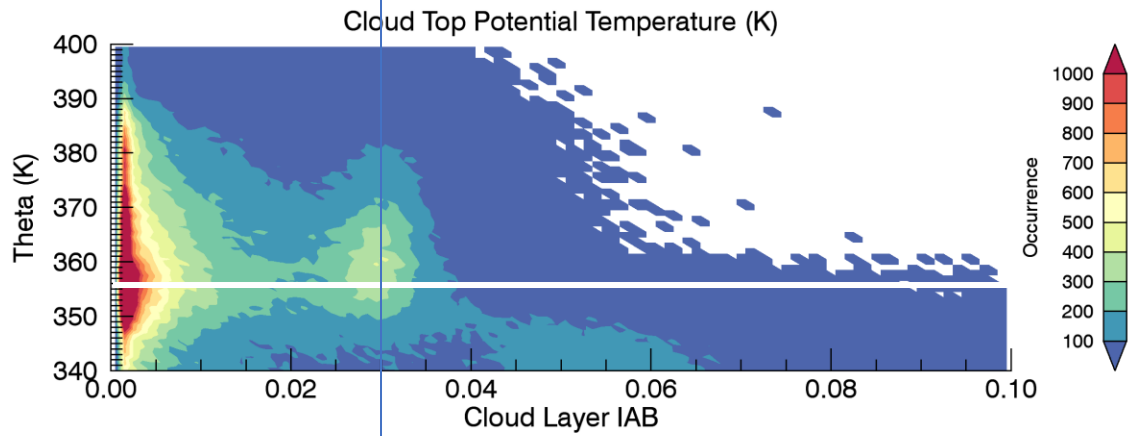
Opaque to SAGE-III at 1020 nm

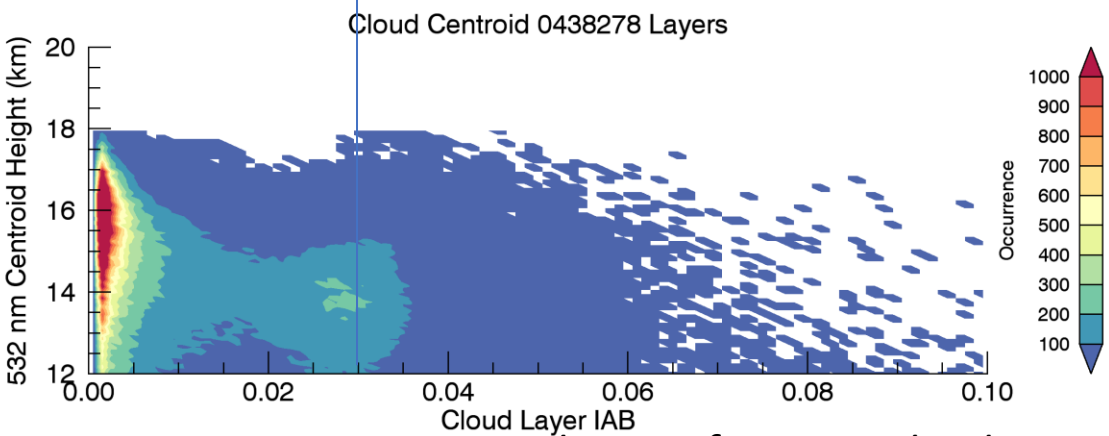
Day vs Night, IAB > 0.001

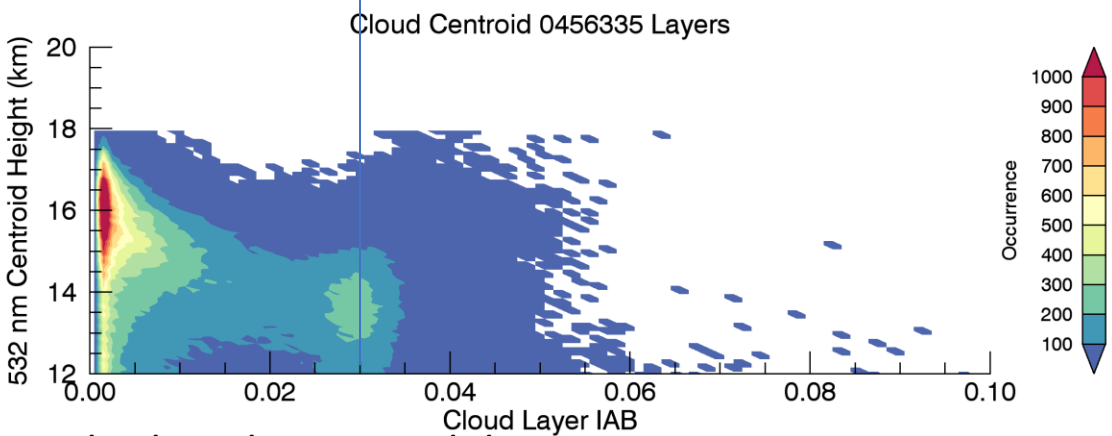








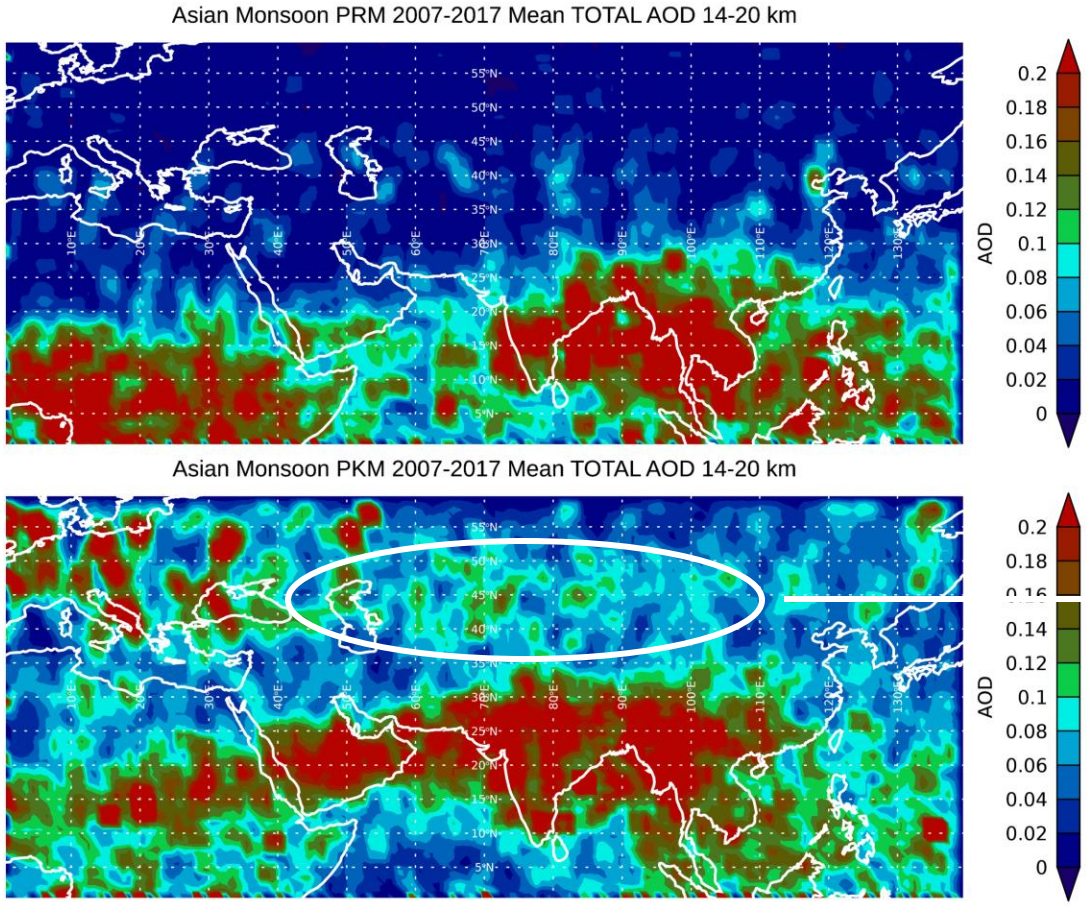




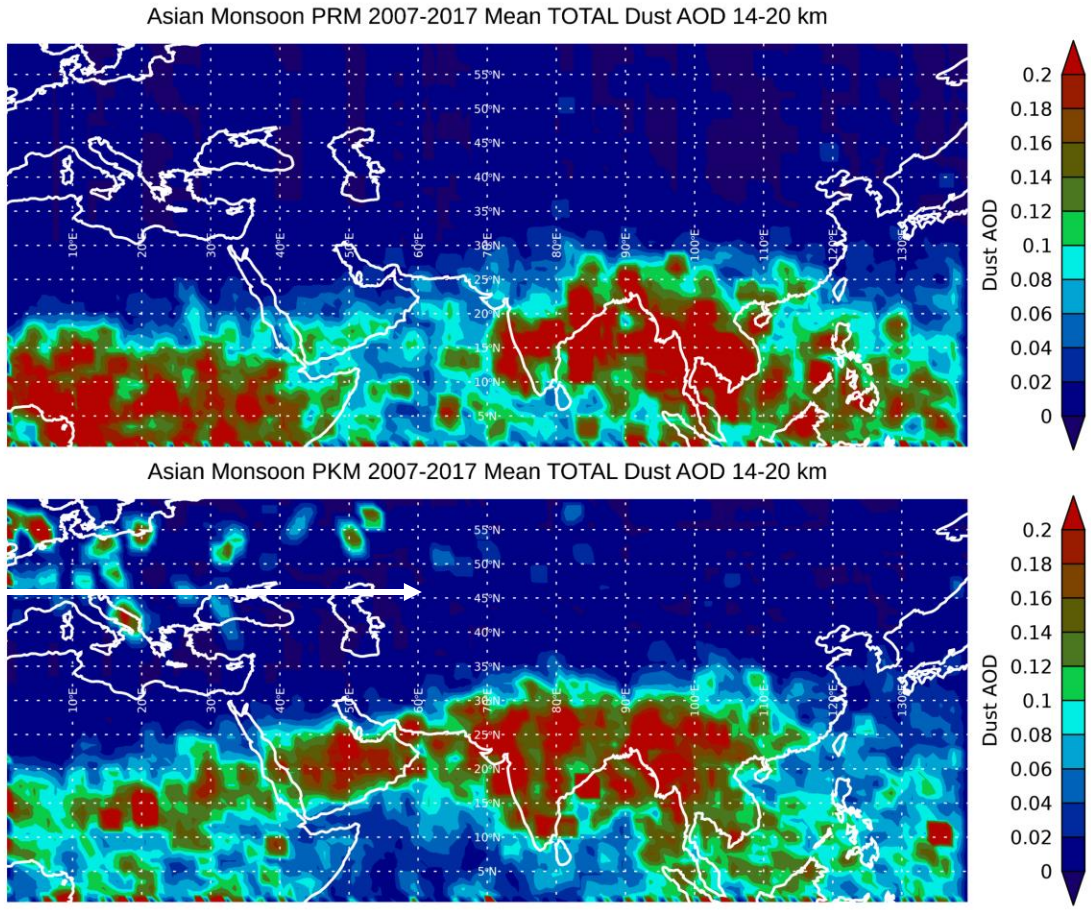
Population of opaque clouds maximizes at 0.03 both nighttime and daytime

CALIOP Aerosols – Total AOD vs Dust AOD

Total AOD: Top = May, June
Bottom = July, August



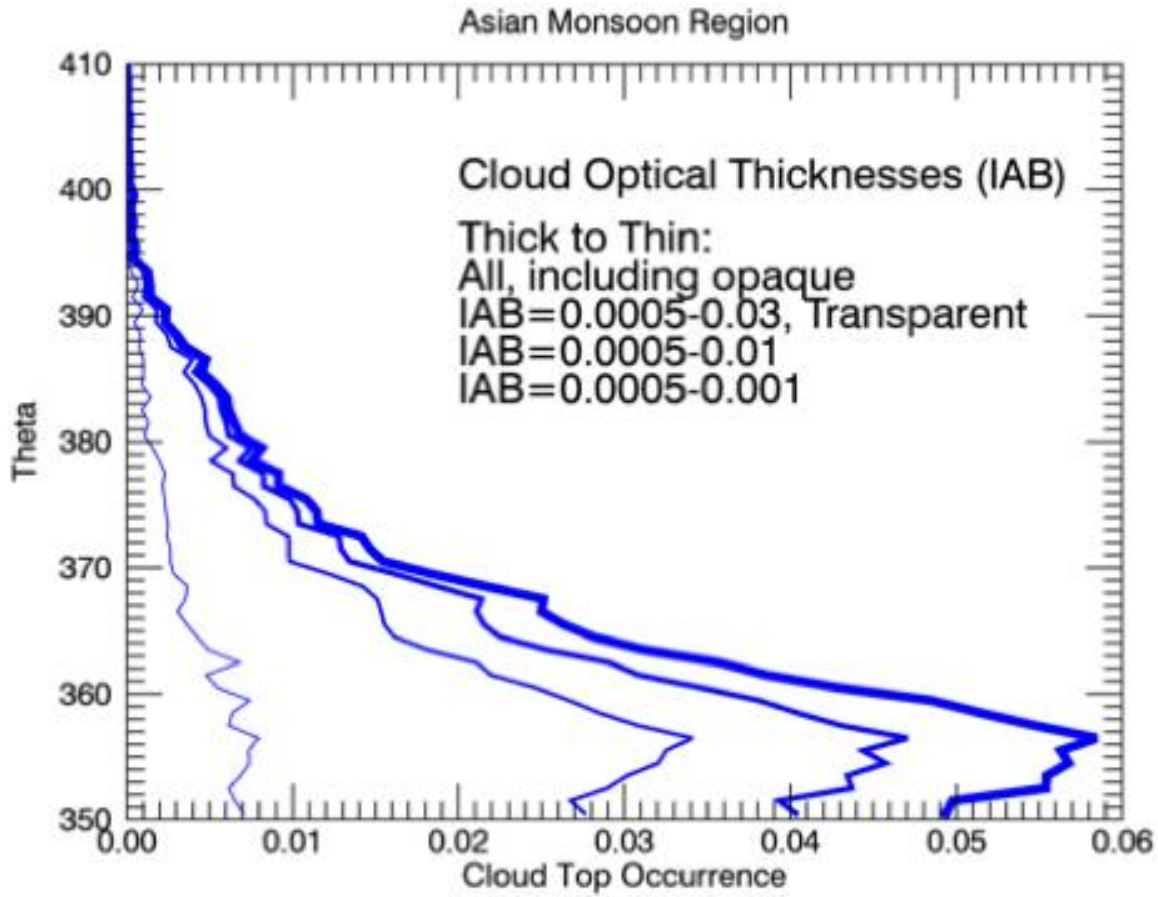
Dust AOD: Top = May, June
Bottom = July, August



Take-Away Messages

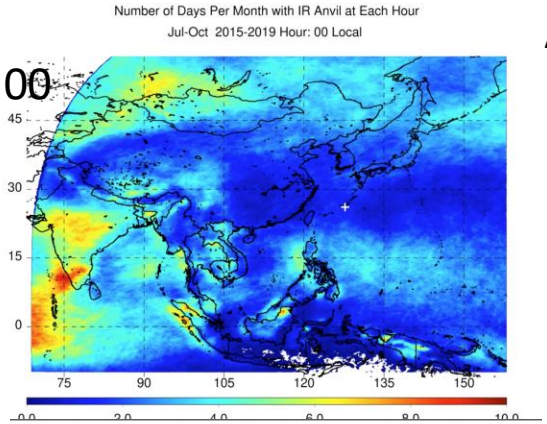
- In the UT/LS, detecting polarizing aerosol layers is complicated.
- There is ample evidence of mixed cloud and aerosol sampling in the Asian Monsoon UT/LS.
- While SAGE-III cloud tops might be expected to be lower than CALIOP cloud tops due to the tangent height location (Kent et al., 1997), they appear to be comparable, or higher.
- Cloud top heights might be higher partly due to real diurnal variability and a different sampling time.
- More work to do: CALIOP thin cloud layers and depolarizing layers can be compared with SAGE-III – more to come!
- Finding 1:1 sampling isn't likely to produce much.

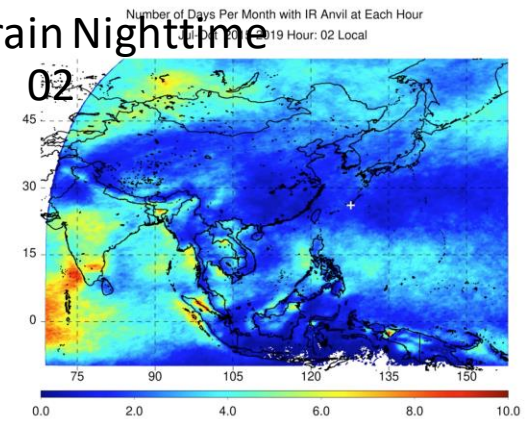
Extras

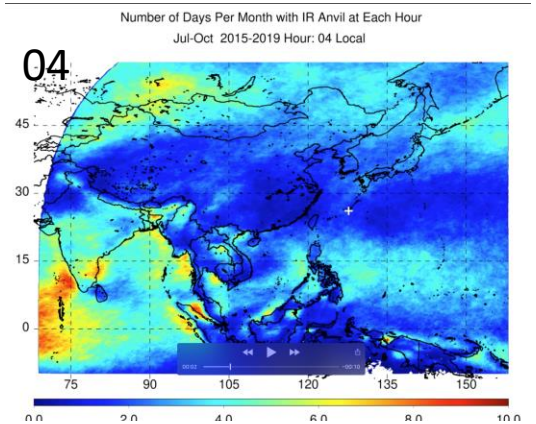

Asian Monsoon Region
Cloud Optical Thicknesses (IAB)
Thick to Thin:
All, including opaque
IAB=0.0005-0.03, Transparent
IAB=0.0005-0.01
IAB=0.0005-0.001
Theta
410
400
390
380
370
360
350
0.00
0.01
0.02
0.03
0.04
0.05
0.06
Cloud Top Occurrence

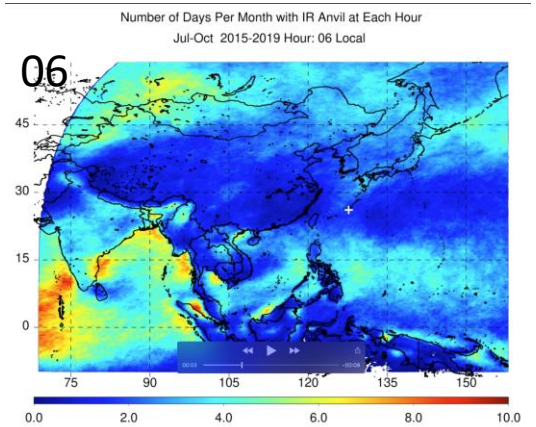
Mean Anvil Counts by Local Time from Himawari IR, Scarino et al., 2020 in prep.; July – Oct. 2015 - 2019

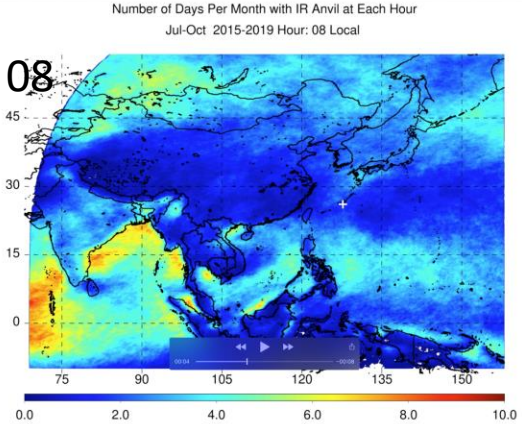
A-Train Nighttime

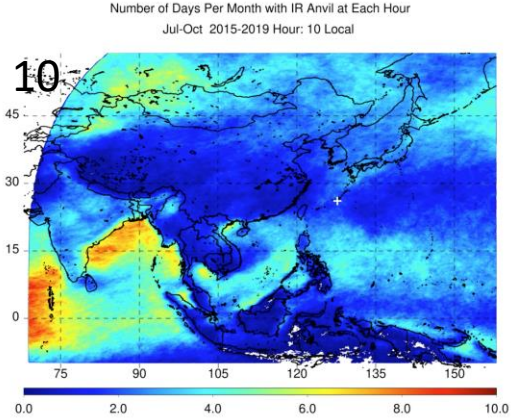


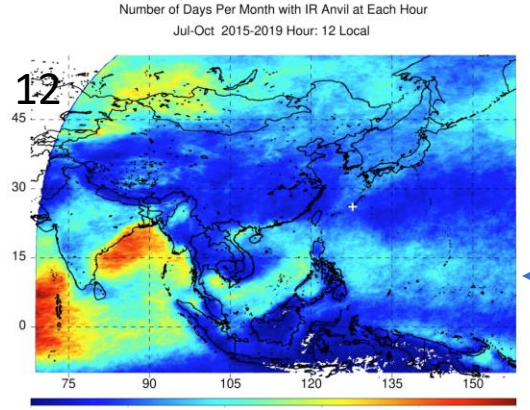




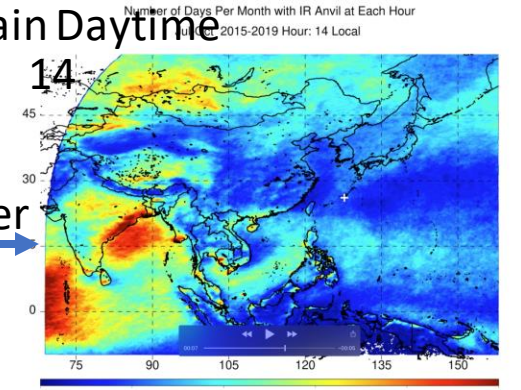




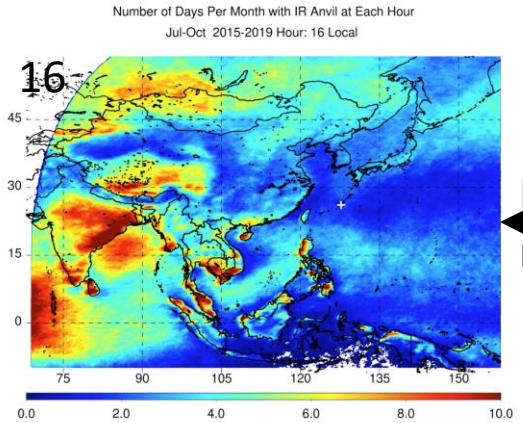




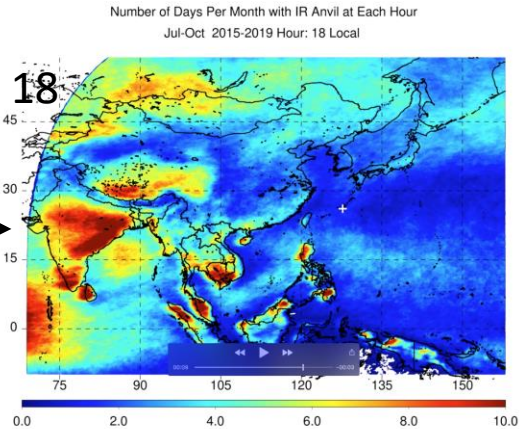
A-Train Daytime

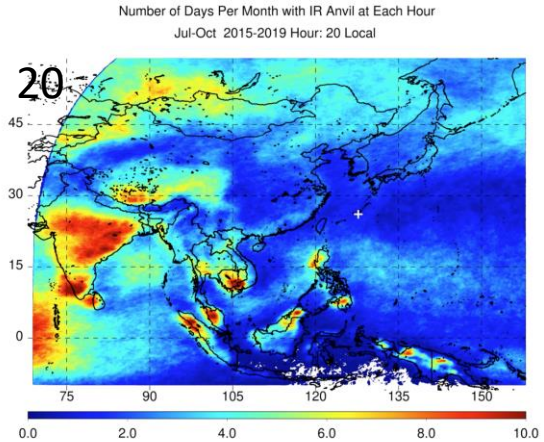


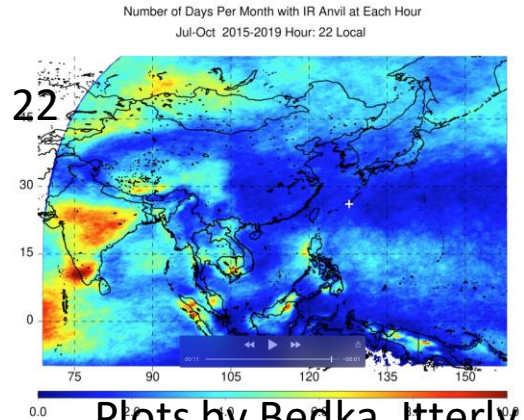
Water max



Land max

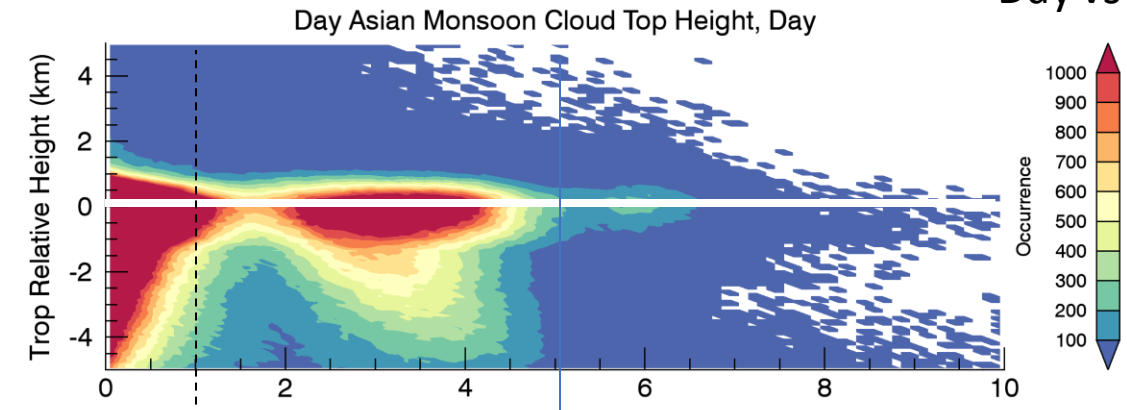


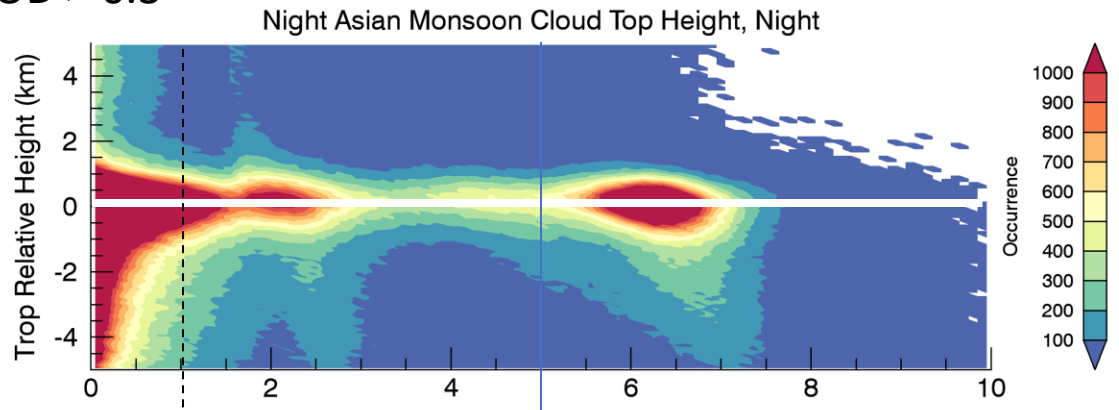


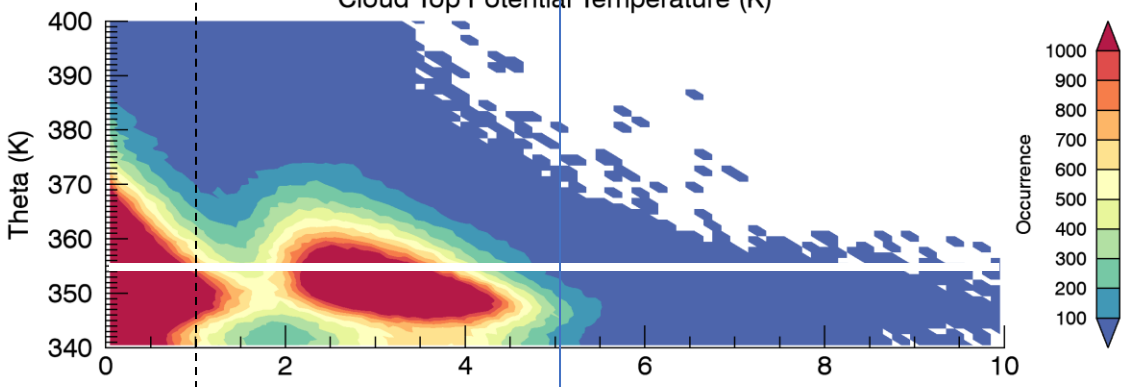


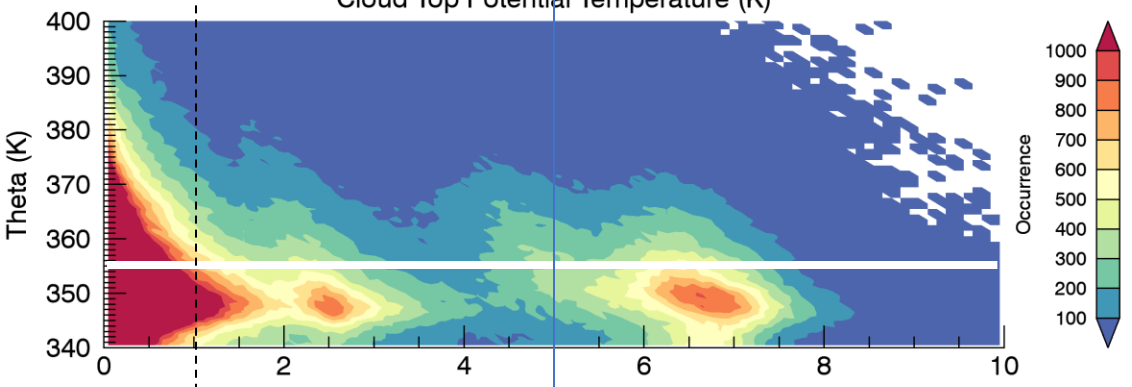
Plots by Bedka, Itterly

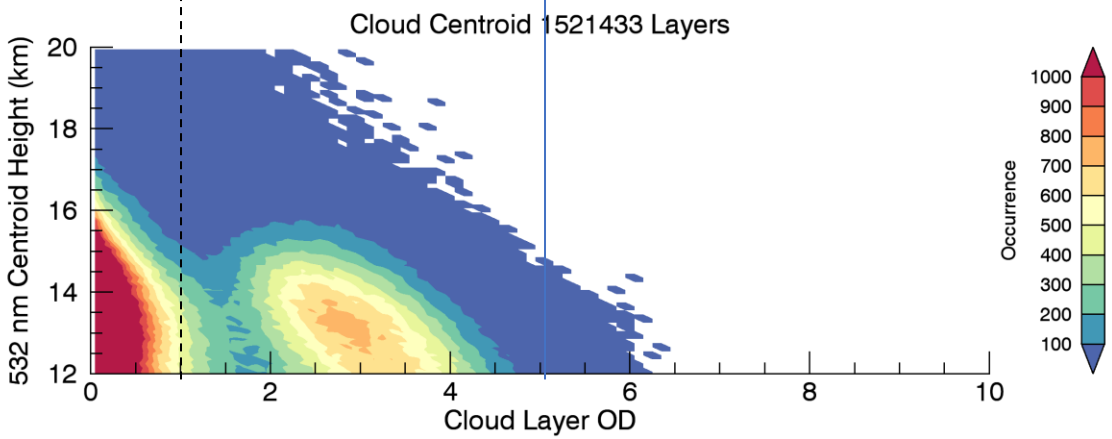
Day vs Night, OD > 0.3

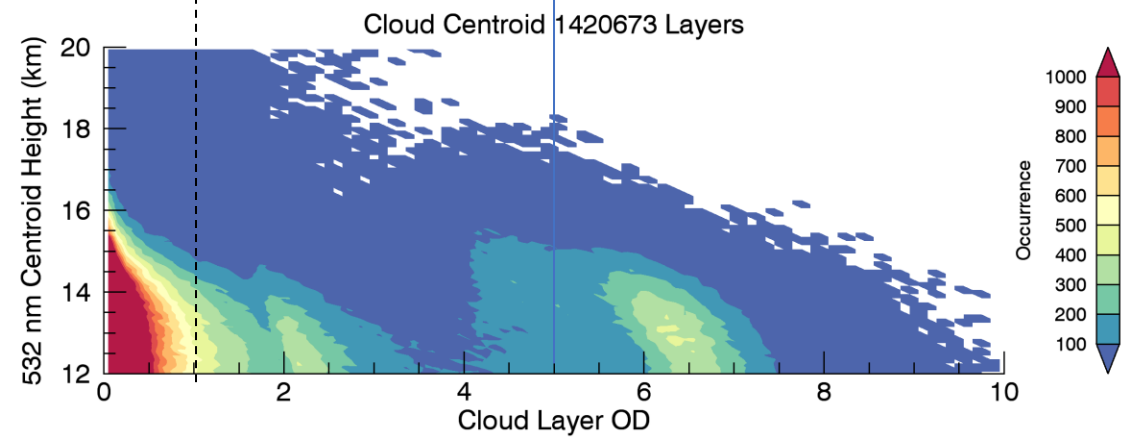












Validation of SAGE III/ISS solar water vapor data with correlative satellite and balloon-borne measurements

Sean Davis
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NOAA Chemical Sciences Laboratory, Boulder, CO

Rob Damadeo, Dave Flittner, Karen Rosenlof, Mijeong Park, Bill Randel, Emrys Hall, Dave Huber, Dale Hurst, Allen Jordan, Susan Kizer, Luis Millan, Rennie Selkirk, Ghassan Taha, Kaley Walker, Holger Vömel

Overview

- This talk will summarize the recent SAGE III/ISS WV validation paper:

  Davis, S. M., et al.: Validation of SAGE III/ISS solar water vapor data with correlative satellite and balloon-borne measurements. JGR-Atmos, in revision

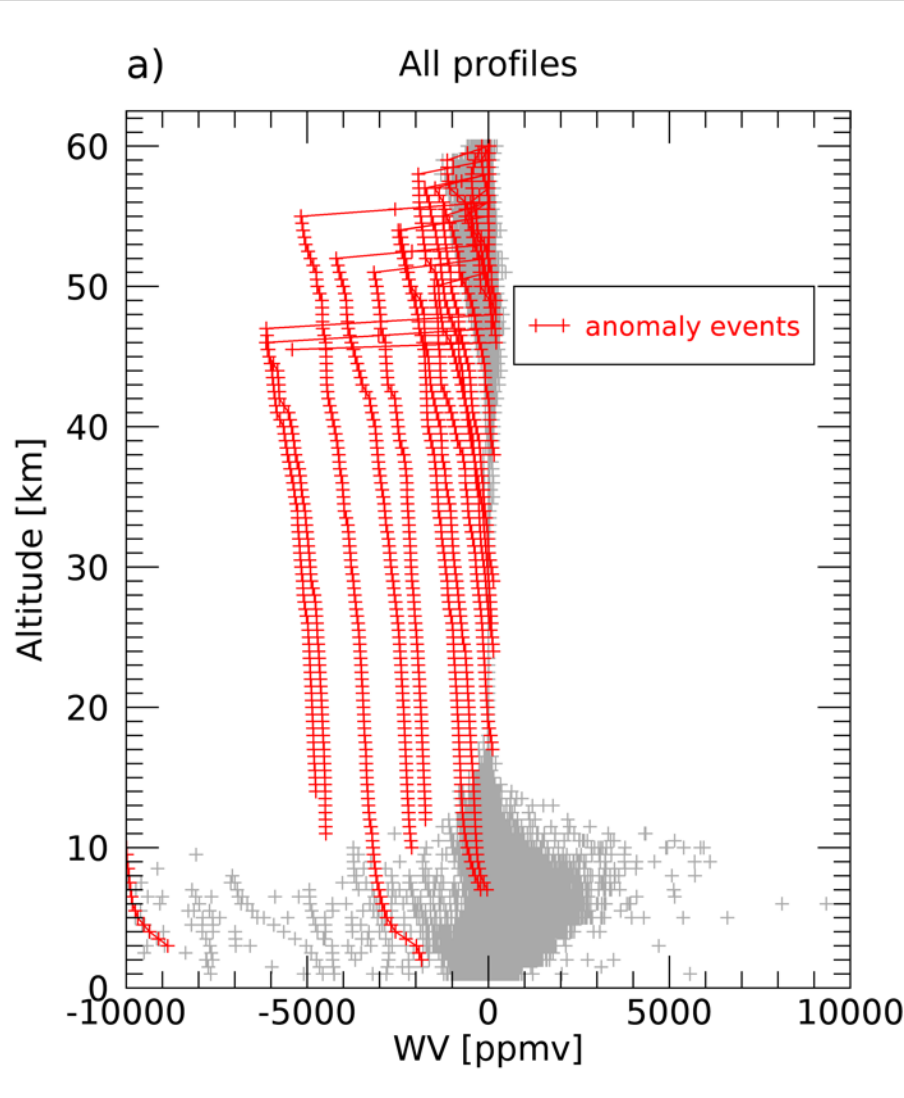
Overall goals: Establish SAGE III/ISS WV data quality and provide data user guidance

- Basic QC screening of v5.1 WV data
- Quantify agreement with other instruments
  - MLS, ACE-FTS, and balloon frostpoint coincident profile comparisons

QC screening

- Extreme outliers are manually identified for removal

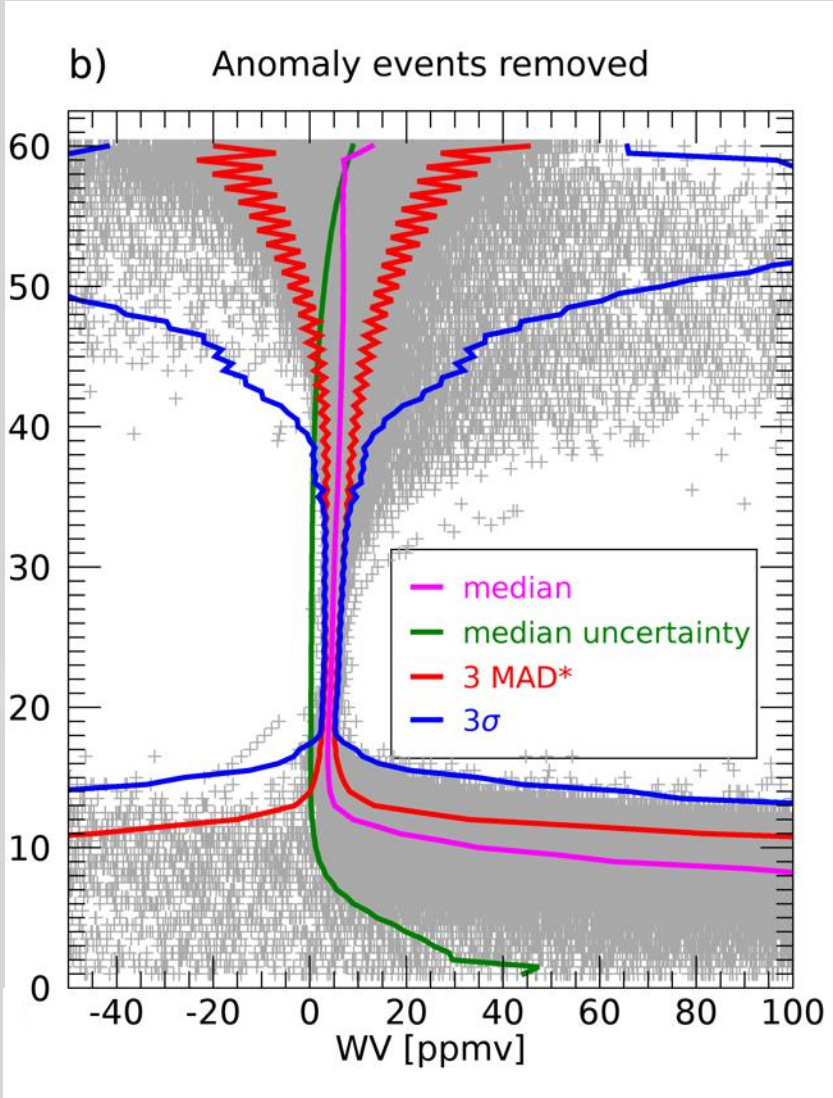
Event number	Date	Time	Latitude	Longitude	Reason
1128120	2018-05-11	12:51:54	-39.97	60.35	anomaly
1495410	2019-01-02	16:59:41	43.92	-139.92	anomaly
1587720	2019-03-03	3:01:49	-54.70	-122.50	anomaly
1587920	2019-03-03	6:07:17	-54.45	-169.04	anomaly
1589520	2019-03-04	6:50:56	-52.29	178.72	anomaly
1592220	2019-03-06	0:34:43	-48.09	-89.27	anomaly
1596720	2019-03-08	22:08:09	-39.07	-55.50	anomaly
1630910	2019-03-30	22:05:22	-43.44	123.49	anomaly
1632310	2019-03-31	19:44:11	-45.70	159.39	anomaly
1683520	2019-05-03	18:50:00	-46.95	-30.86	anomaly
1739820	2019-06-09	0:20:16	33.84	-78.85	anomaly
1756710	2019-06-19	22:29:33	-1.39	113.57	anomaly
1762620	2019-06-23	17:13:27	-32.26	-3.68	anomaly
1766110	2019-06-25	22:25:57	28.04	100.89	anomaly
719620	2017-08-21	20:23:56	-6.69	-36.65	eclipse



QC screening

- Median absolute deviation (MAD) – outlier resistant dispersion metric
  - Gaussian distribution: MAD* ~ σ

MAD* and σ diverge below ~17 km and above ~40 km
→ Large outliers

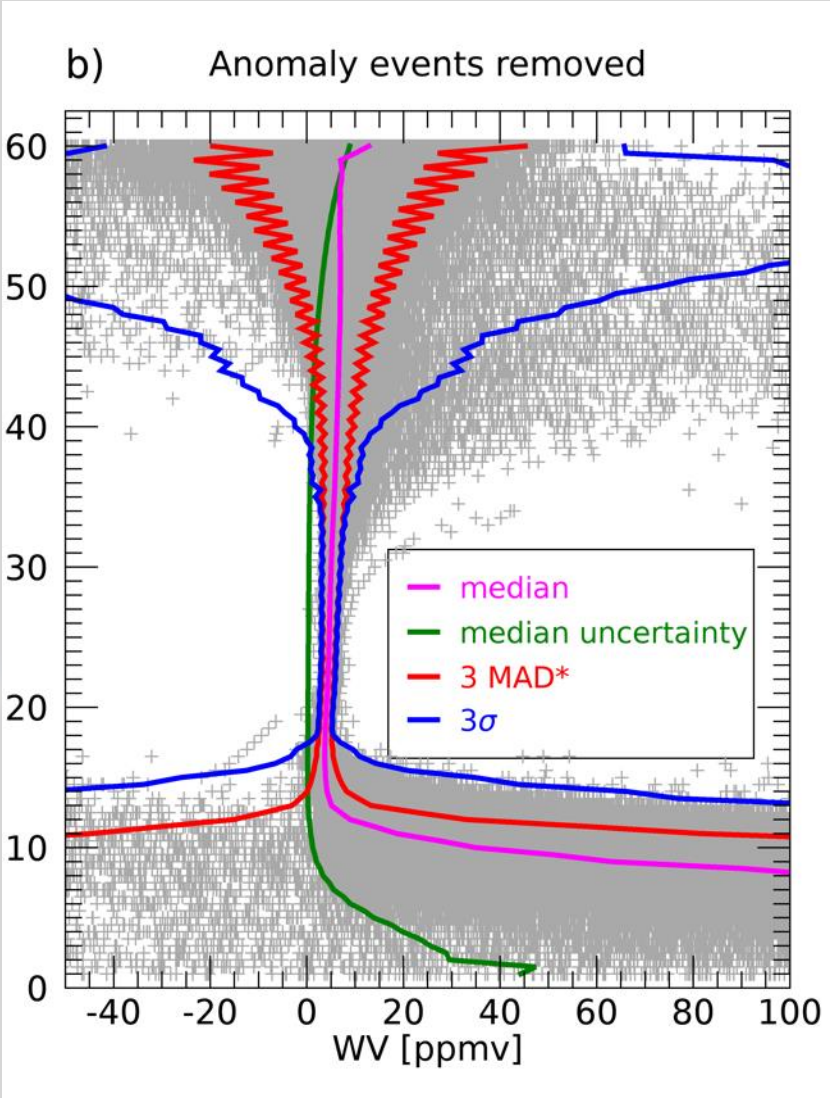


QC screening

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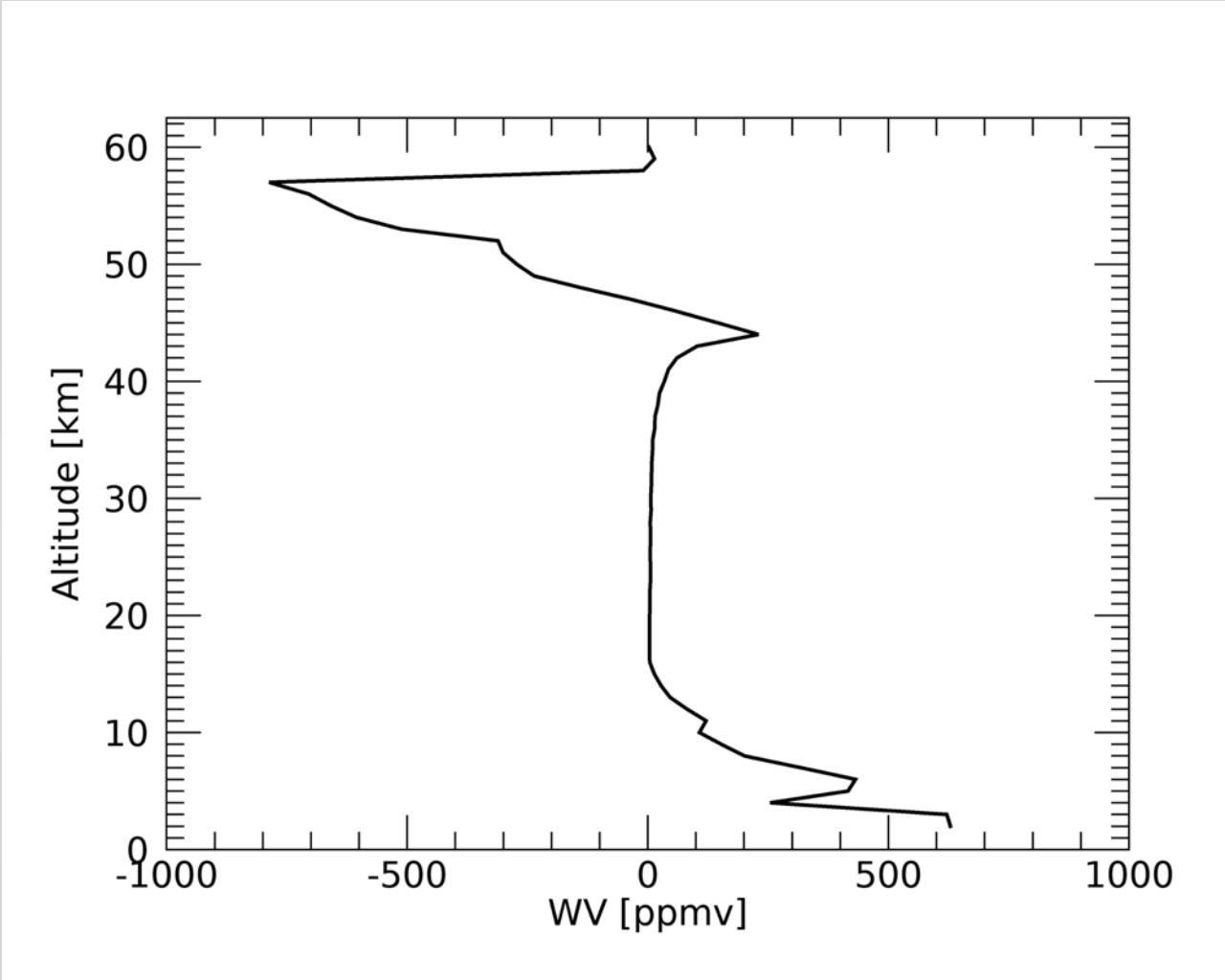
MAD* and σ diverge below ~17 km and above ~40 km
→ Large outliers

- Above 35 km, we remove “keel over” profiles
- Below 20 km, we remove cloud-impacted profiles



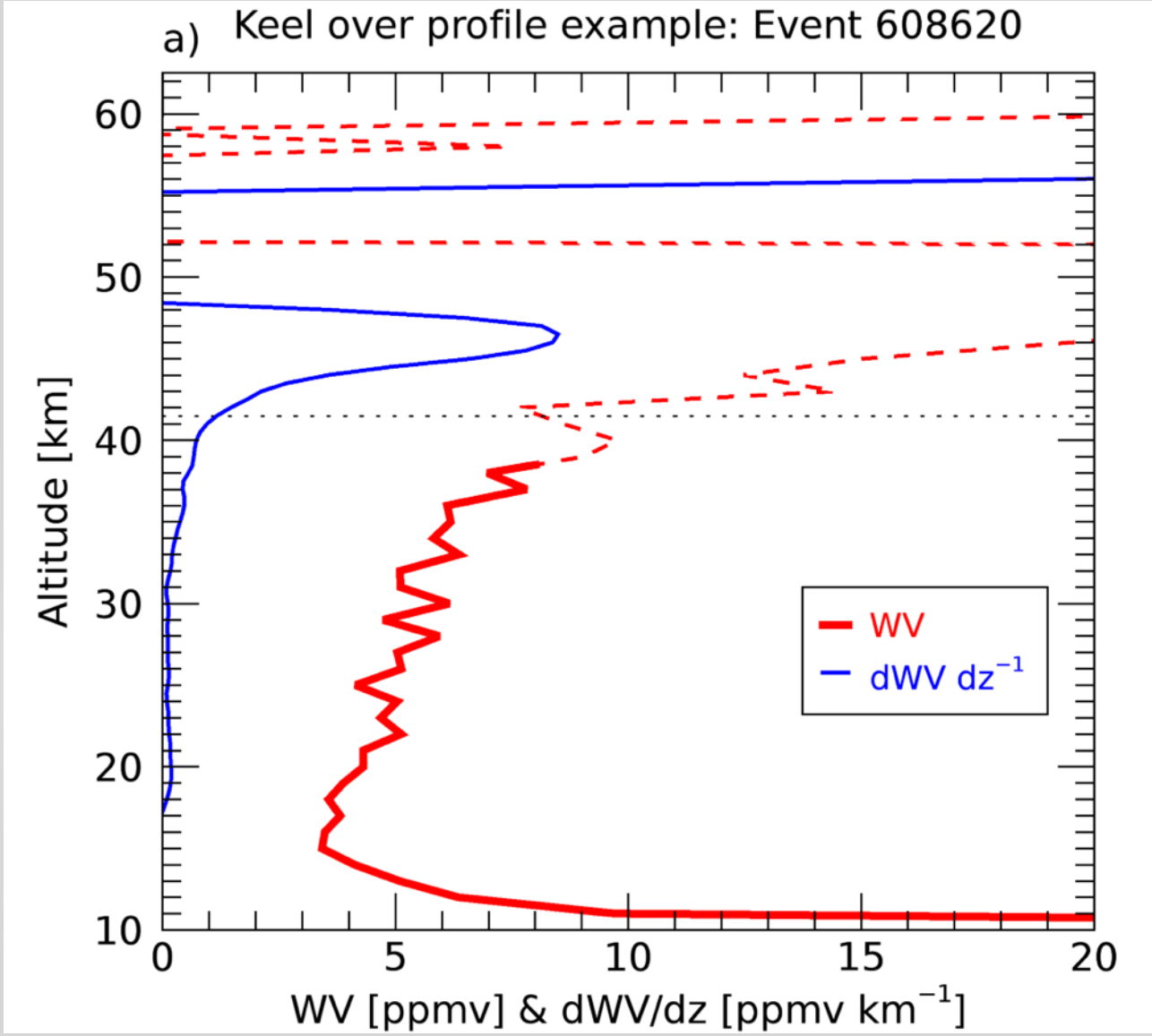
Keel over profiles

- Profiles with abrupt jumps



Keel over profiles

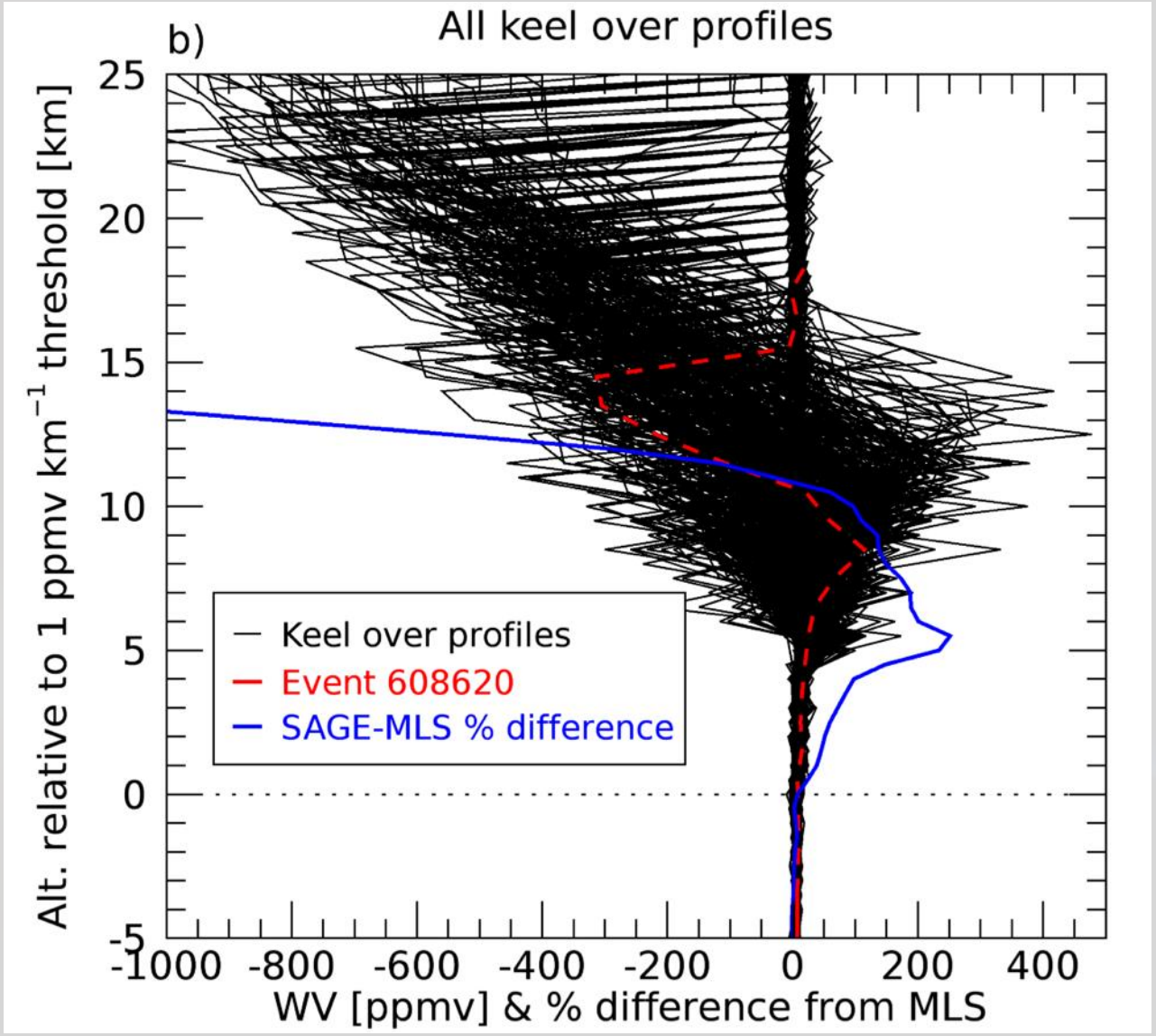
- Filtering based on vertical derivative
  - Remove points from 5 km below where derivative exceeds 1 ppmv km^{-1}



Keel over profiles

- Keelovers have a similar profiles

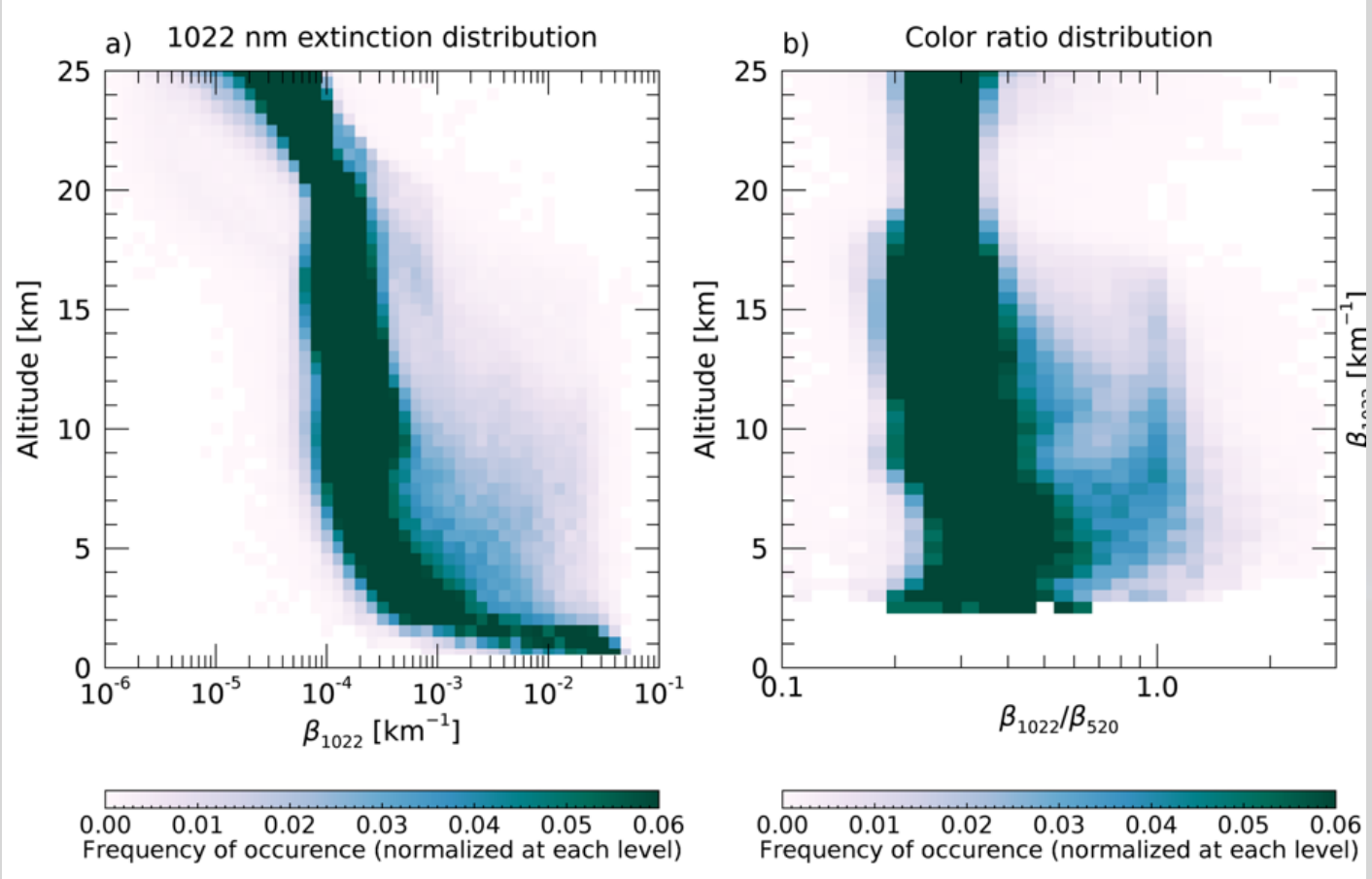
- Below keelover point SAGE and MLS agreement is normal for keel over events
  → Bottom part of keelover is OK



Cloud filtering

- Basic idea
  - clouds mess up WV retrieval
  - identify highest cloud occurrence and truncate profile below this point

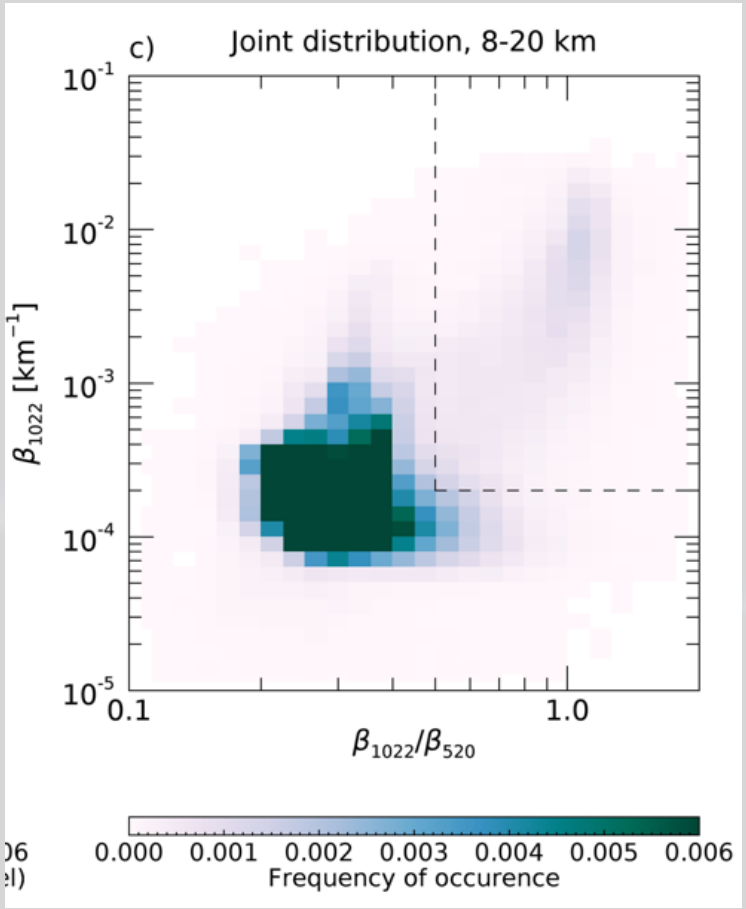
- Cloud identification
  - Large extinction & color ratio
  - Color ratio ≡ $\beta_{1020\,nm}$ / $\beta_{520\,nm}$



Cloud filtering

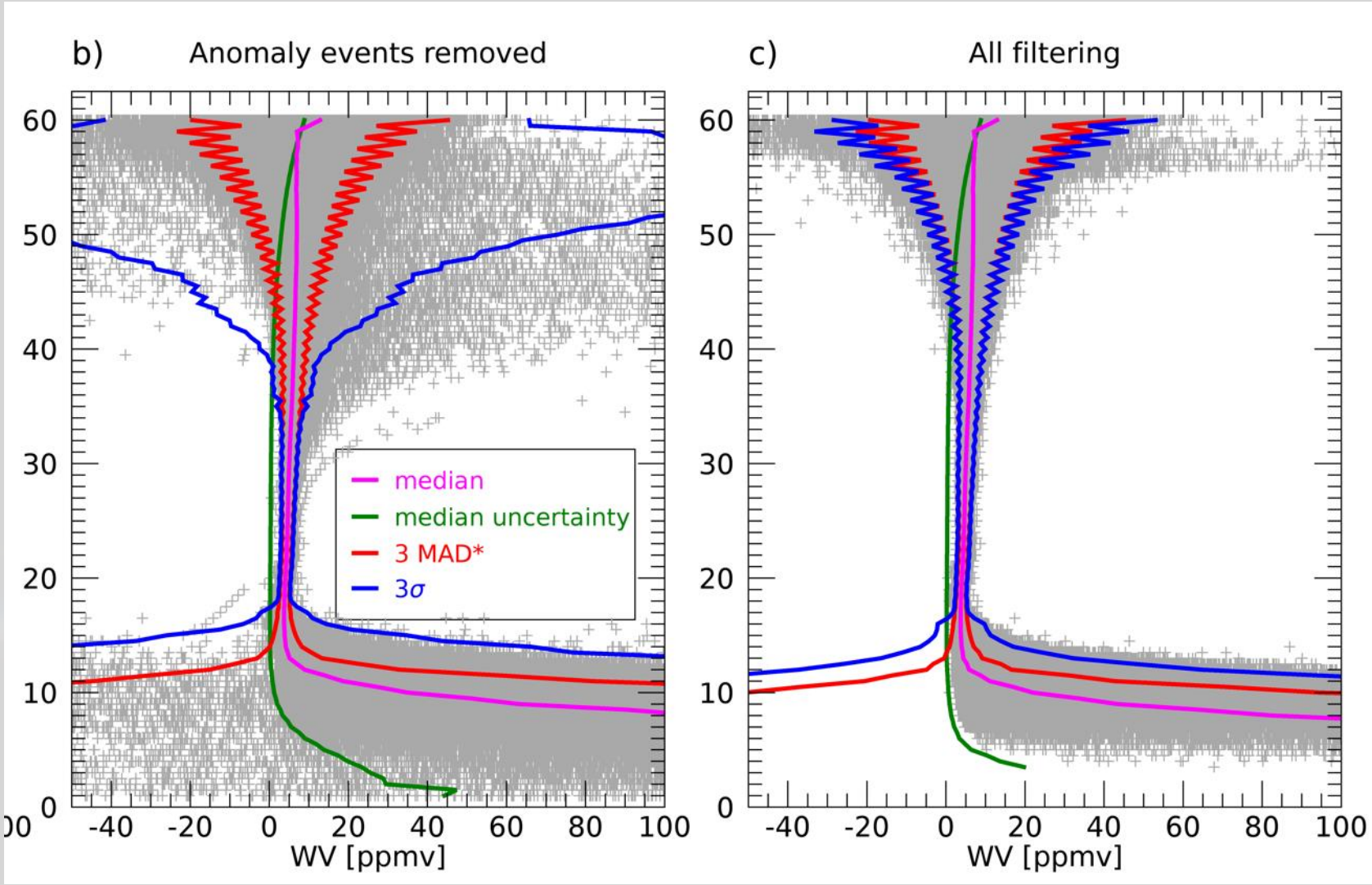
- Basic idea
  - clouds mess up WV retrieval
  - identify highest cloud occurrence and truncate profile below this point
- Cloud identification
  - Large extinction & color ratio
  - Color ratio ≡ $\beta_{1020\,nm}$ / $\beta_{520\,nm}$
- Joint distribution of $\beta_{1020\,nm}$ and CR is bimodal

Truncate profile below where CR > 0.5 & $\beta_{1020\,nm} > 2 \times 10^{-4}$ km^{-1}
or
When extinction fill value is reported



Application of cloud/keel over filtering

- These two screenings remove most outliers (upper strat) and negative values (upper trop)
- No other screening recommended
- Large uncertainty events reflect events that are, well, uncertain



Coincident profile comparison

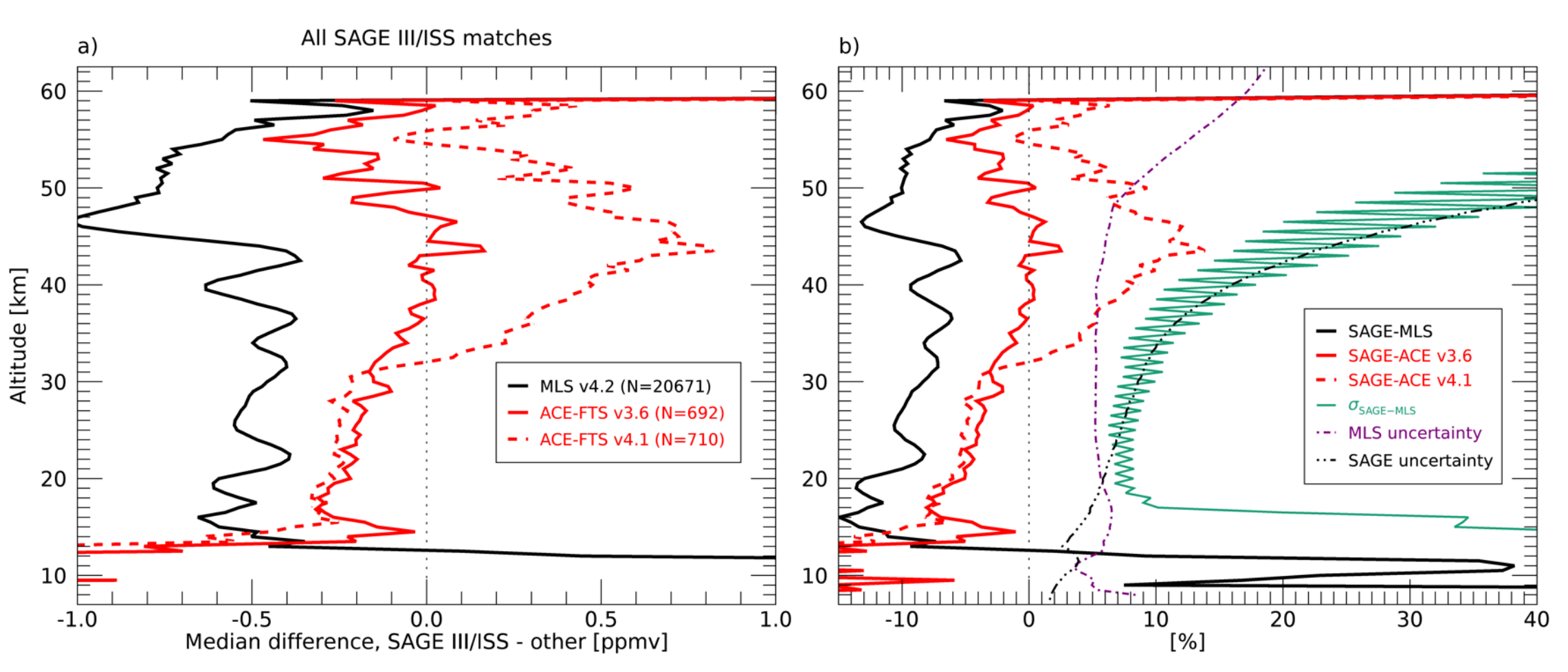
- Comparisons are with MLS, ACE-FTS, and balloon frostpoints
- For each SAGE III profile, look for MLS and ACE-FTS within
  ± 1 day, ± 10° longitude, ± 2° latitude
- For frostpoint comparison, use
  ± 2 days, ± 20° longitude, ± 4° latitude

→ Take closest profile in space if > 1 profile match

- MLS WV mixing ratio interpolated to SAGE altitude grid using MERRA2

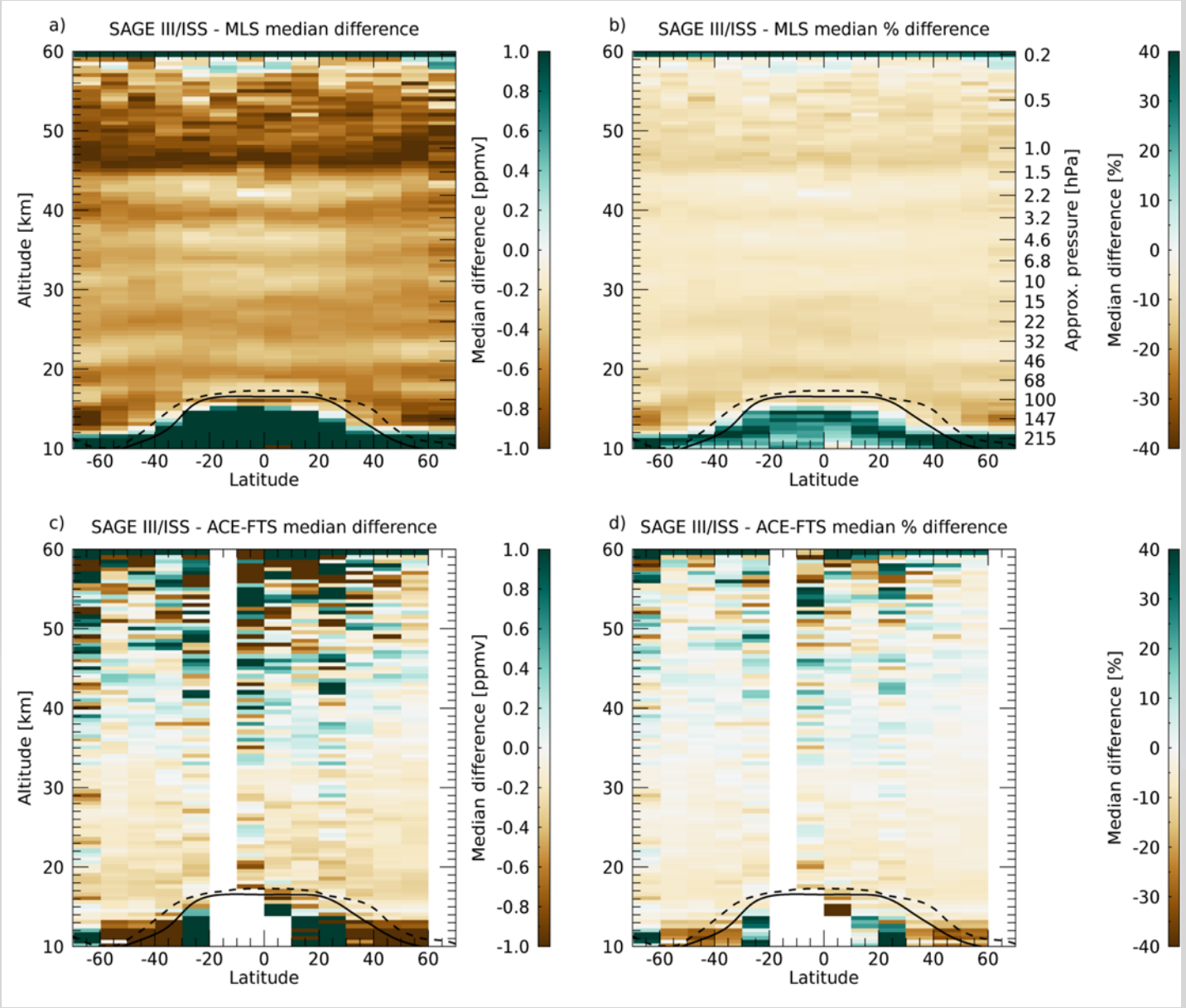
SAGE / MLS / ACE-FTS comparison

- SAGE is ~0.5 ppmv (10%) drier than MLS through most of the stratosphere
- Closer agreement with ACE-FTS, but version dependent



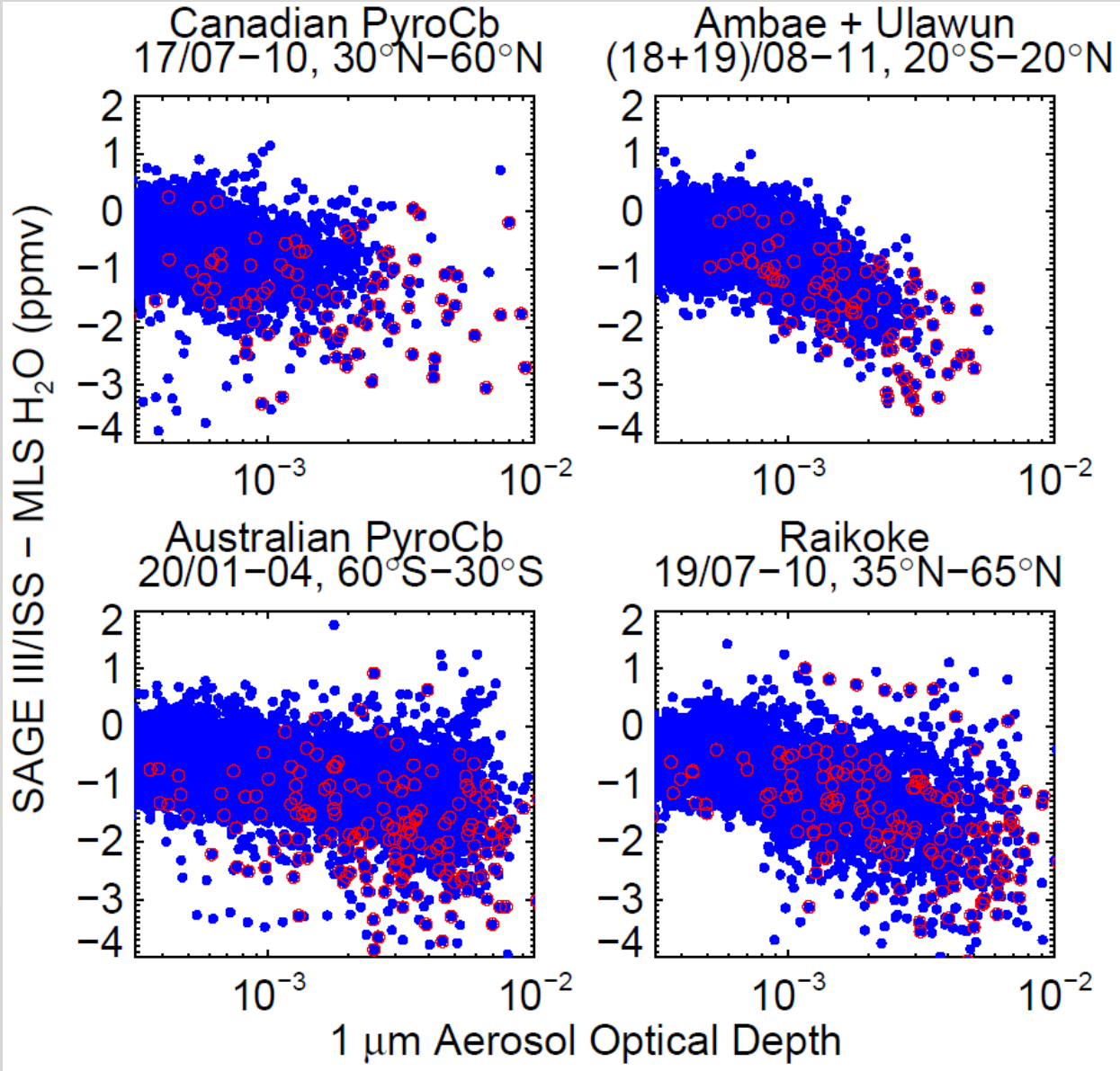
SAGE / MLS / ACE-FTS (v3.6) comparison

- No strong lat dependence with MLS
- Hint of a lat-dependence with ACE-FTS
  - But poor sampling in tropics



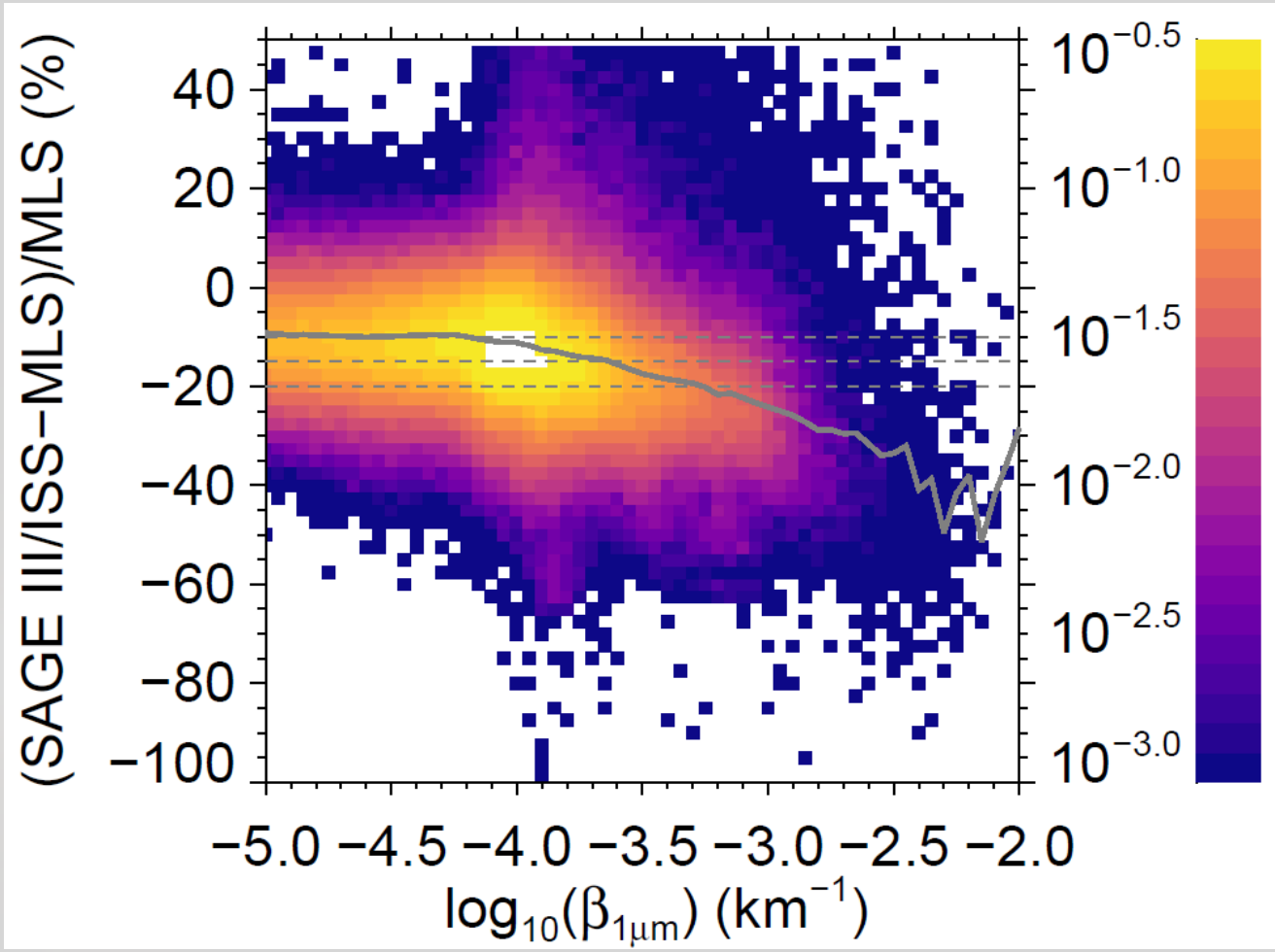
Aerosol sensitivity: pyrocbs and eruptions

- Negative bias increases w/ OD
- Eruptions show steeper slope
- Increased uncertainty (red points) at higher OD



Aerosol sensitivity: pyrocbs and eruptions

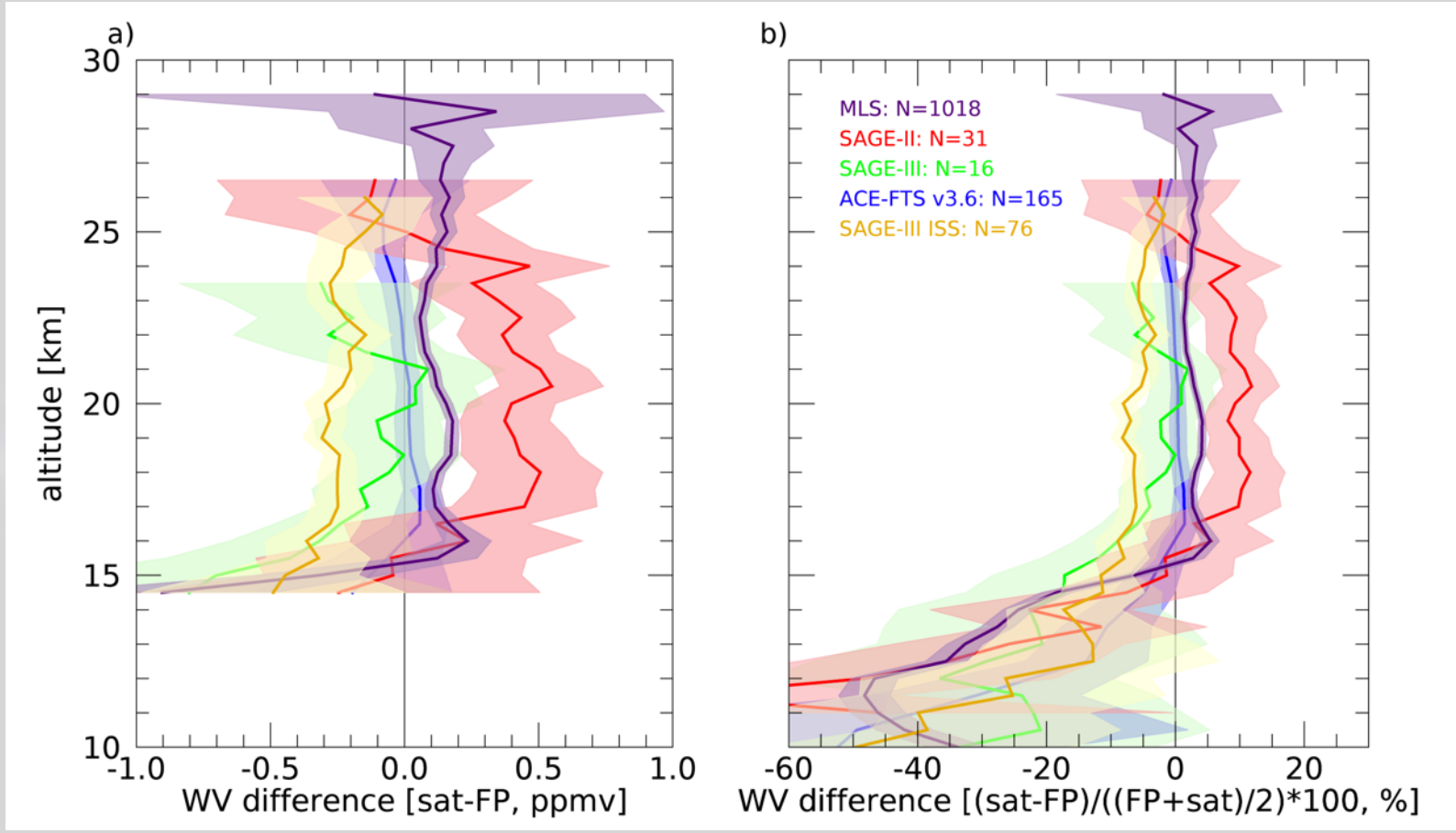
- Negative bias increases w/ OD
- Eruptions show steeper slope
- Increased uncertainty (red points) at higher OD



SAGE III/ISS – frostpoint coincident profile comparison

- SAGE dry bias ~0.1-0.3 ppmv

- SAGE III/ISS has smaller magnitude bias, and more consistent vertical structure, than SAGE II.

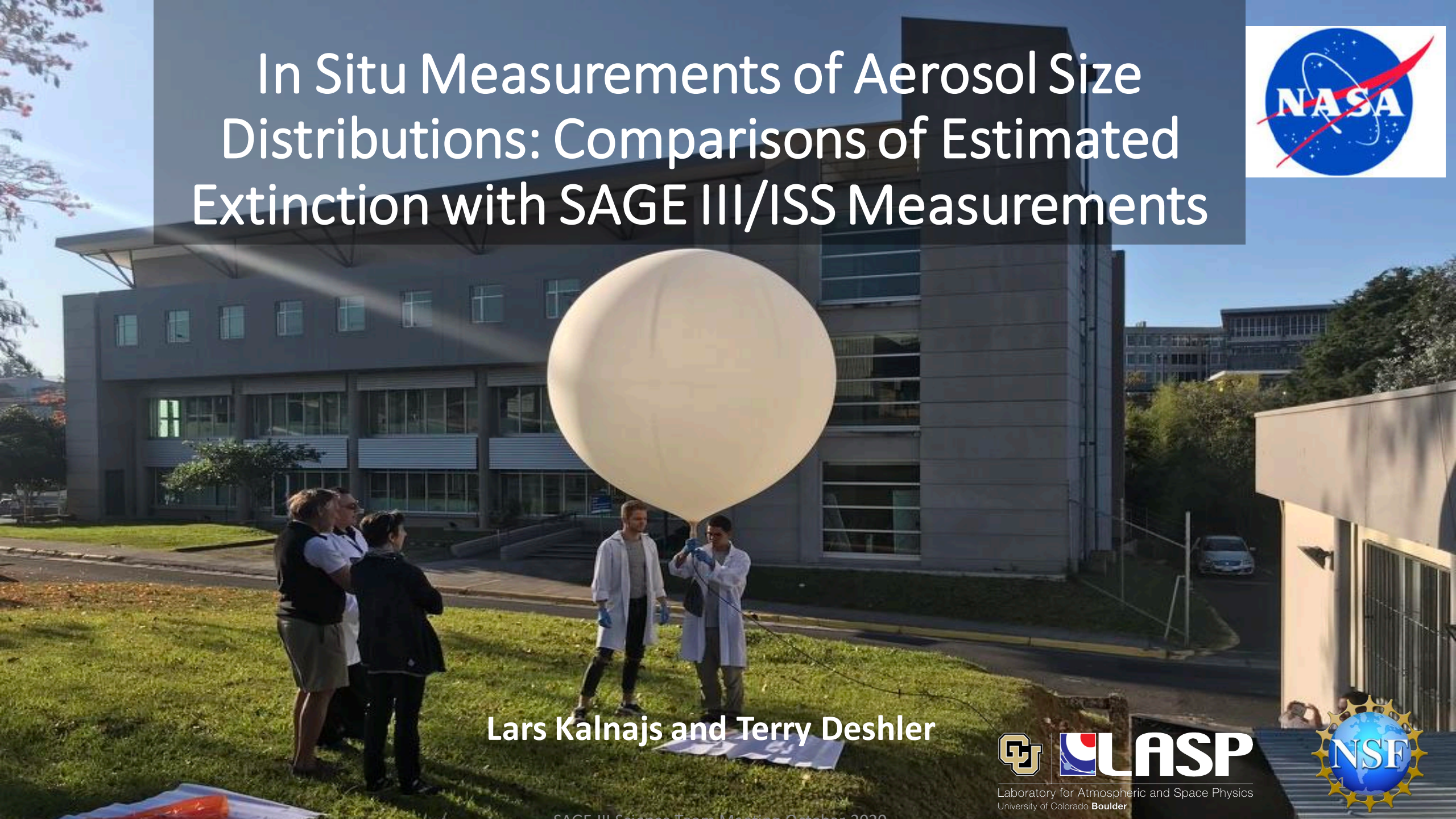


Conclusions

- Overall, SAGE III/ISS v5.1 data provides high quality water vapor measurements
- SAGE III / ISS WV data require significant filtering, but we have a decent set of criteria to QC the data
  - Keel-over profile filtering removes most large outliers in upper stratosphere
  - Extinction + Color ratio filtering to remove clouds in upper troposphere

- From ~20 – 40 km, SAGE III/ISS WV shows a < ~10% (0.0 - 0.5 ppmv) dry bias relative to MLS, ACE-FTS, and FP balloon measurements

In Situ Measurements of Aerosol Size Distributions: Comparisons of Estimated Extinction with SAGE III/ISS Measurements

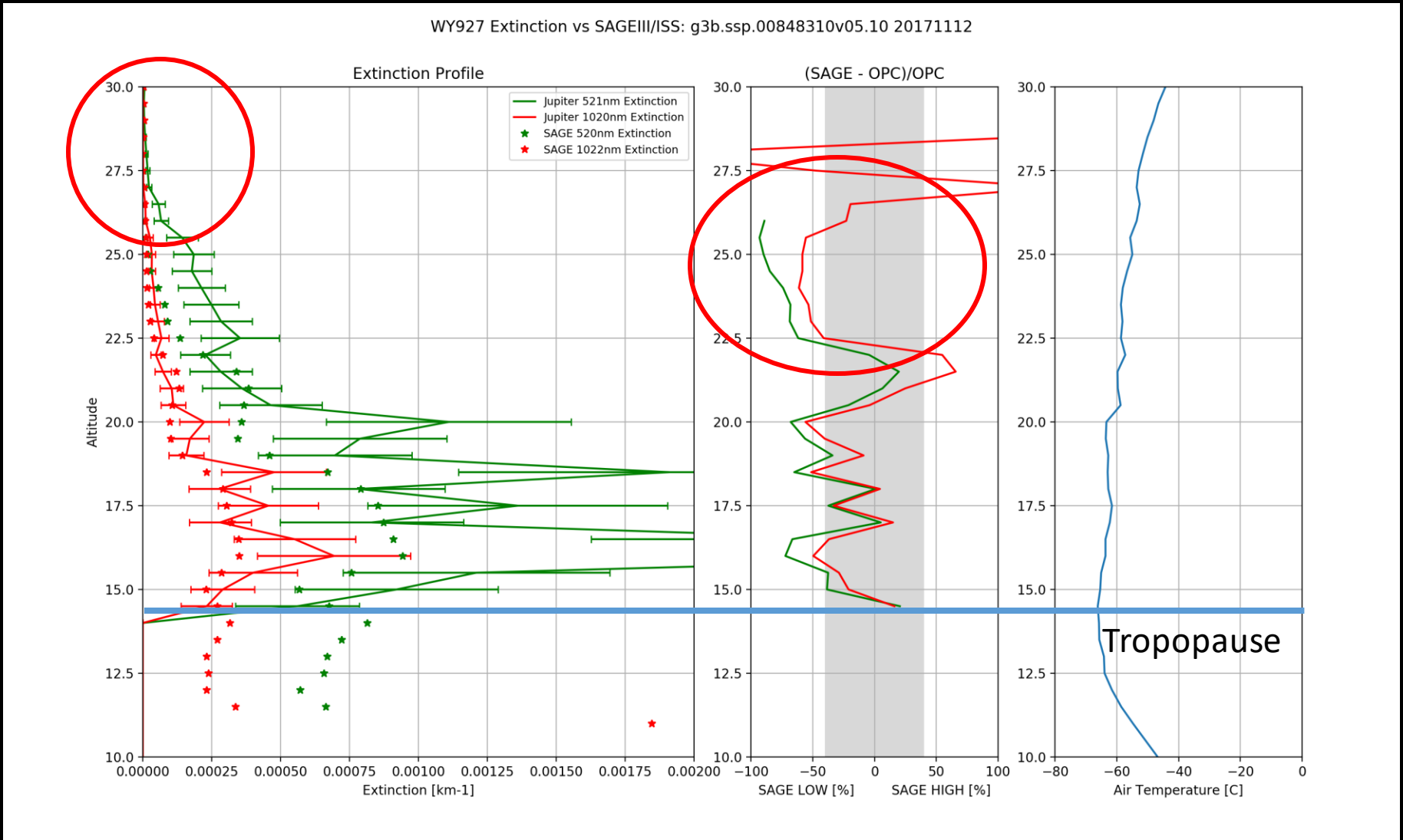


Lars Kalnajs and Terry Deshler

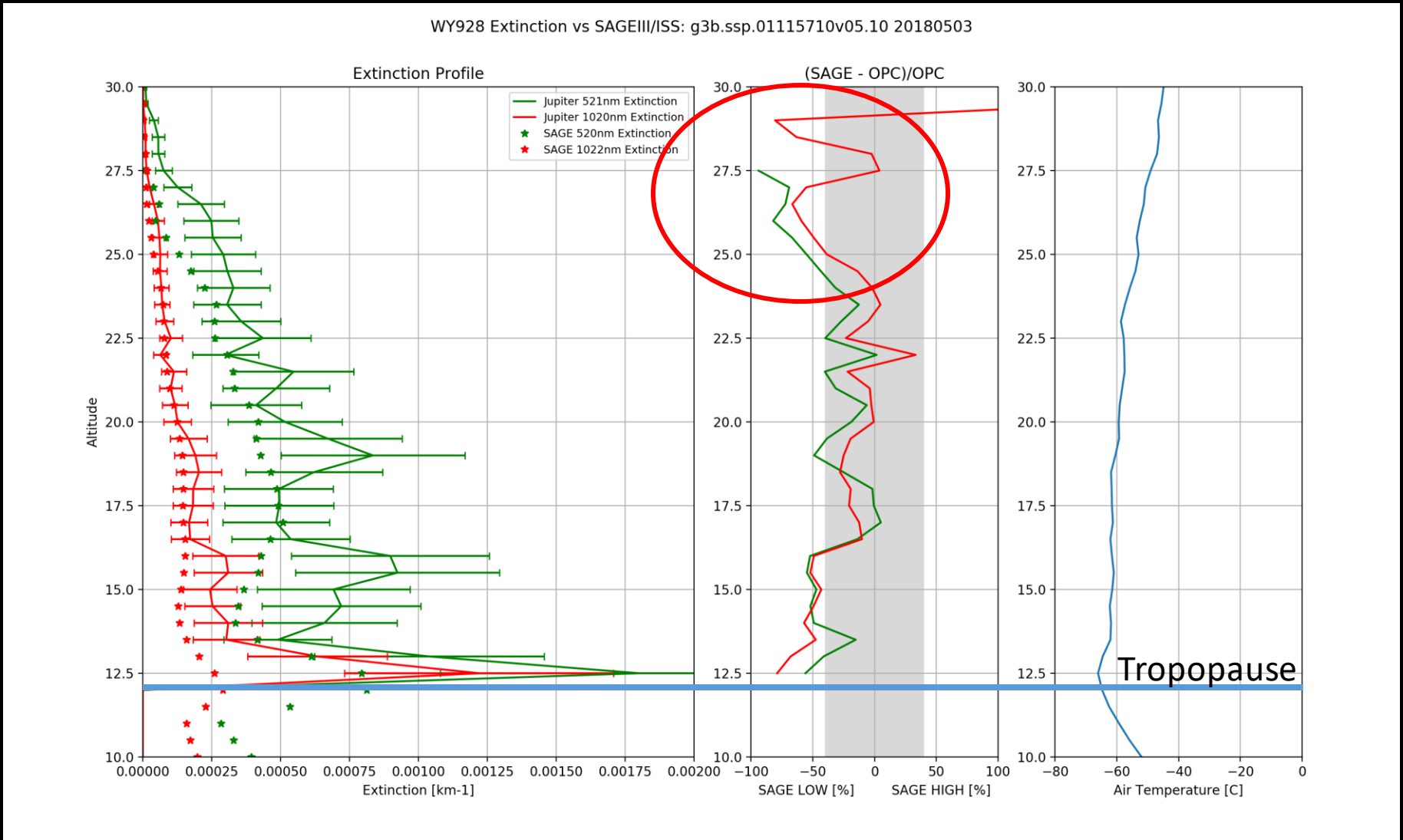
Laboratory for Atmospheric and Space Physics
University of Colorado **Boulder**

1. Current OPC vs SAGE III-ISS comparisons
2. OPC vs OPC vs OPC vs CPC (vs SAGE III/ISS)
3. Comparisons in the Tropical Tropopause Layer from long duration balloons

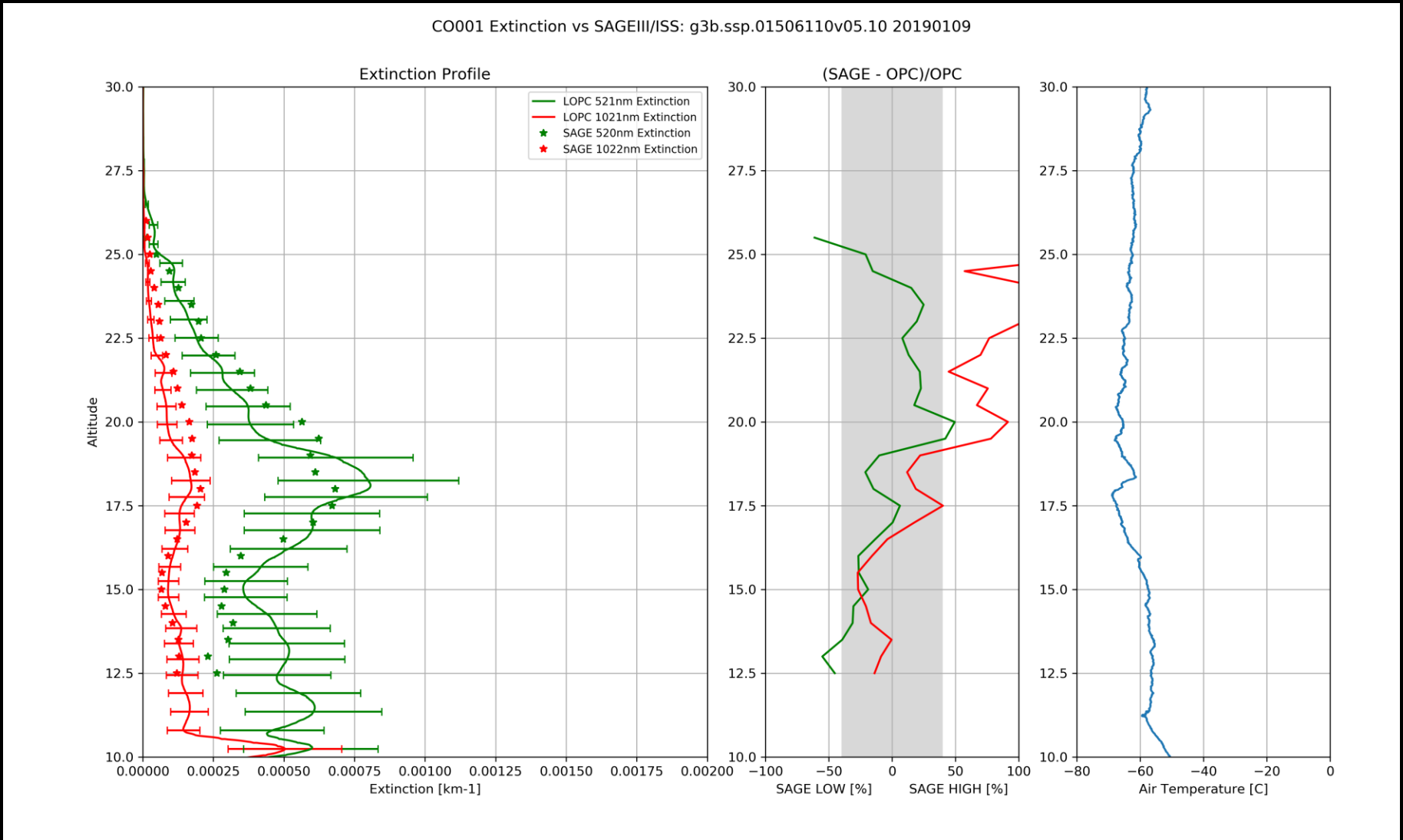
1. SAGE III/ISS vs OPC



1. SAGE III/ISS vs OPC

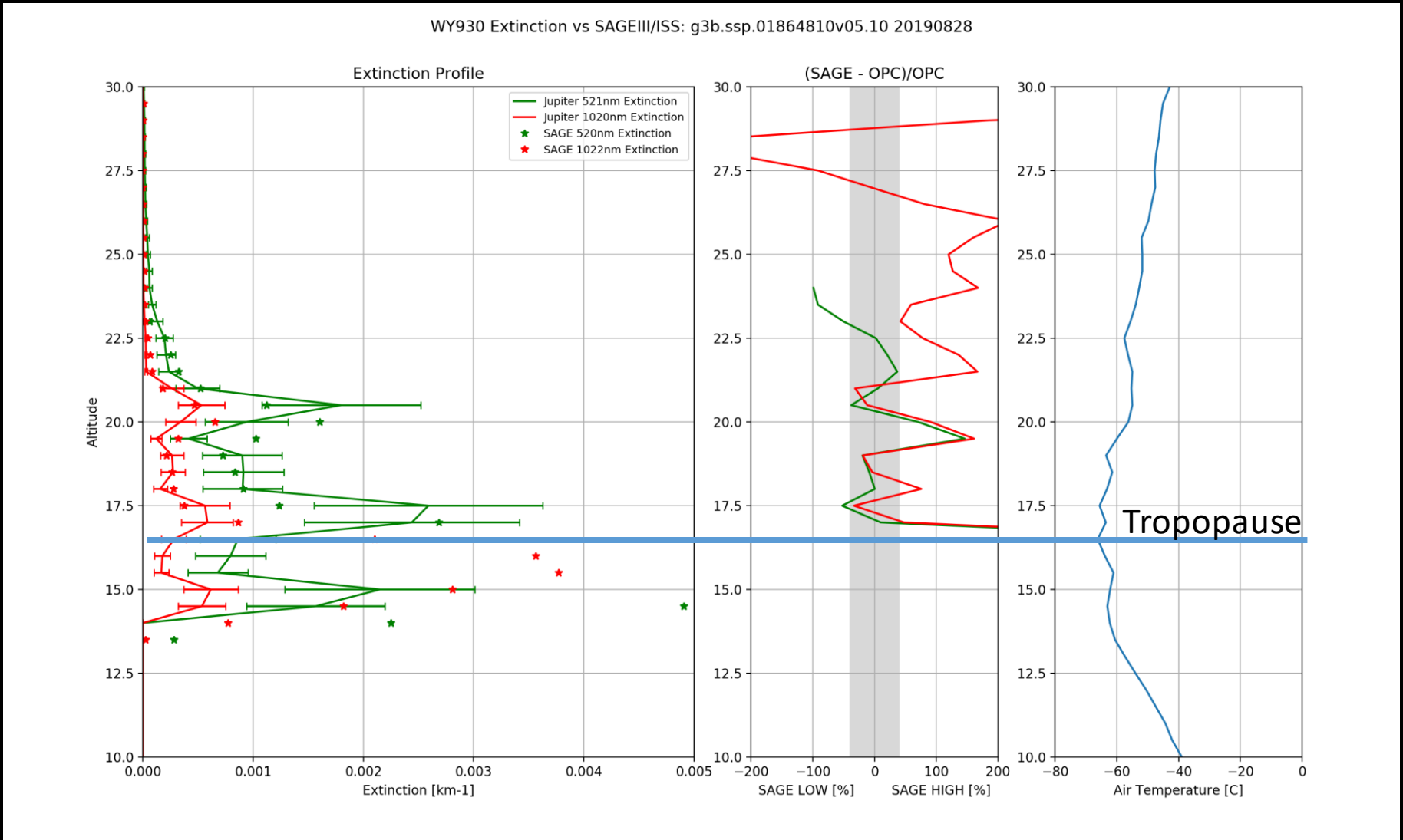


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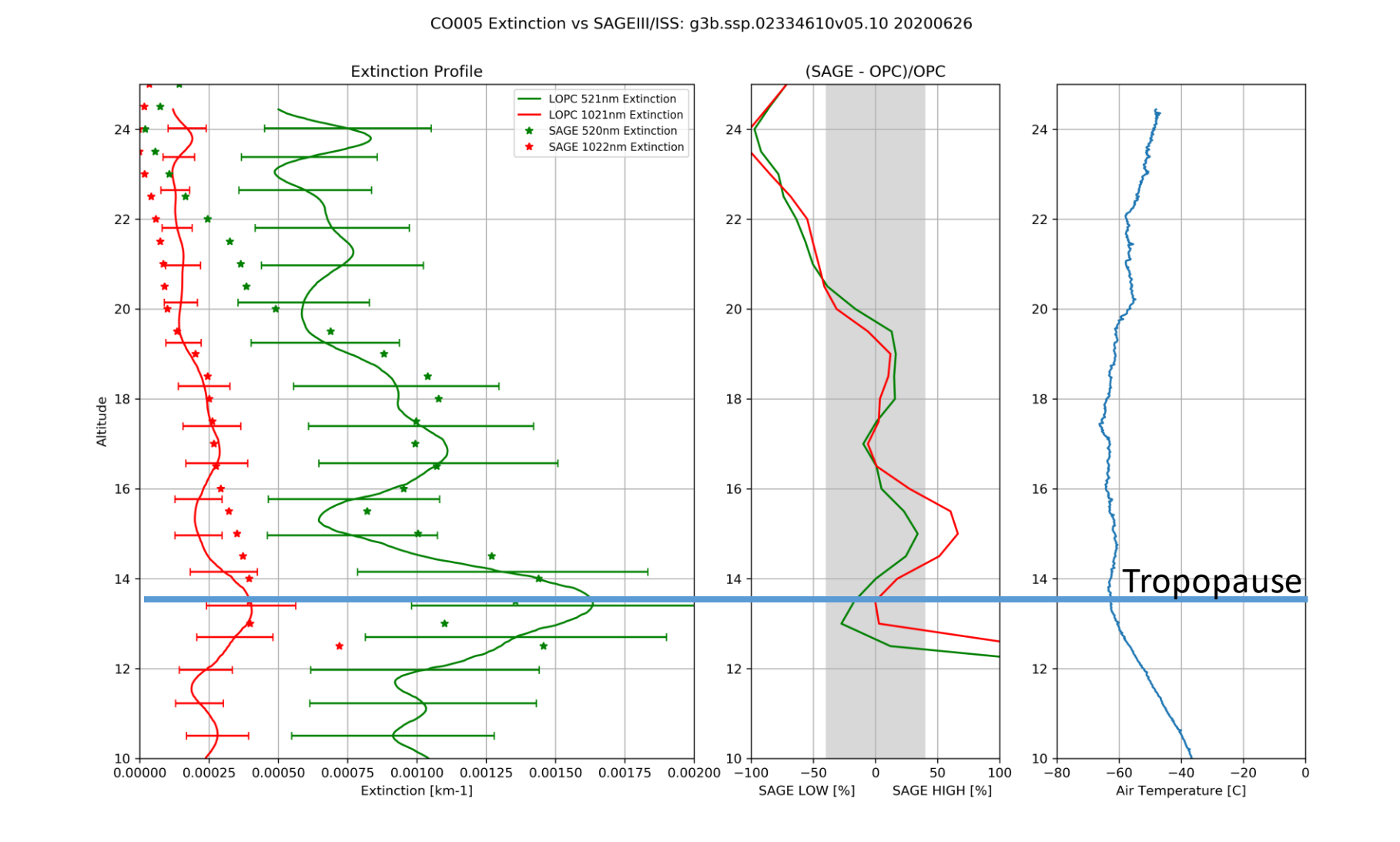


1. SAGE III/ISS vs OPC

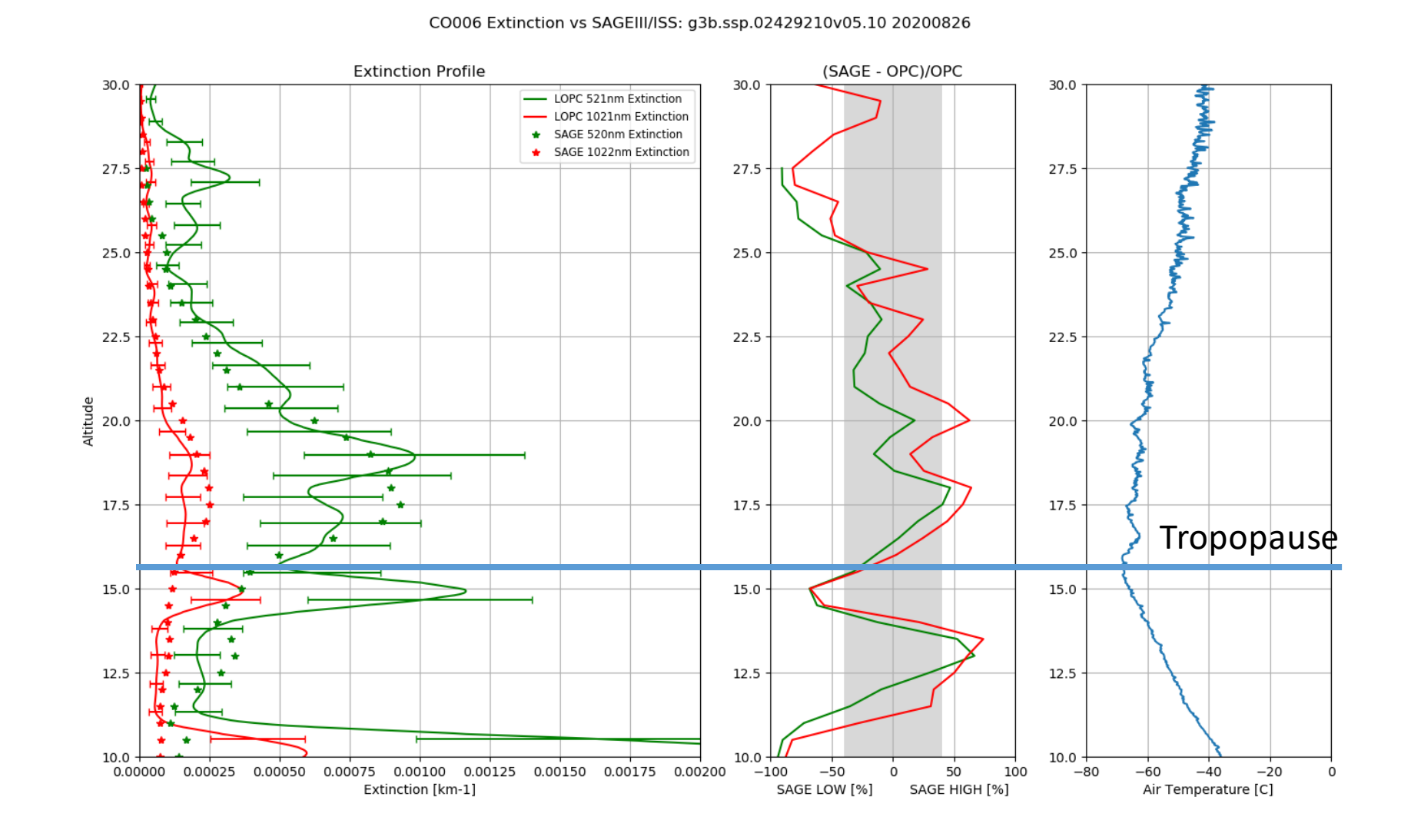
Raikoke Eruption - Note Scale Change!



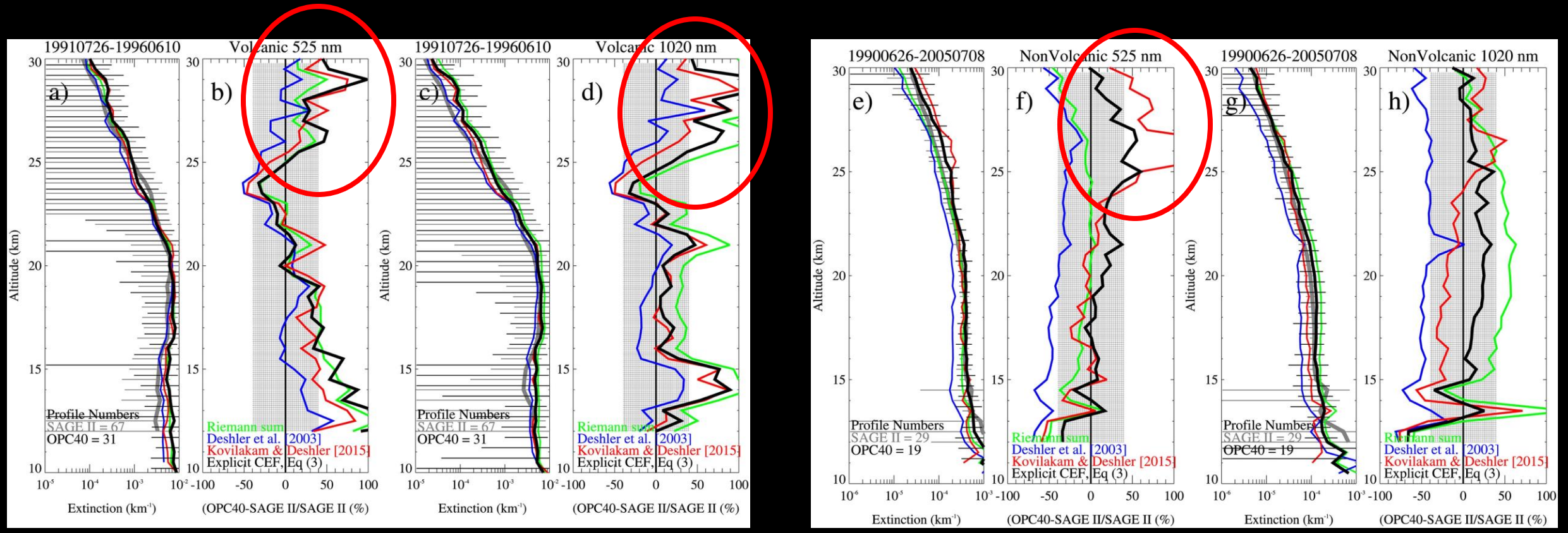
1. SAGE III/ISS vs OPC



1. SAGE III/ISS vs OPC



1. SAGE II vs OPC

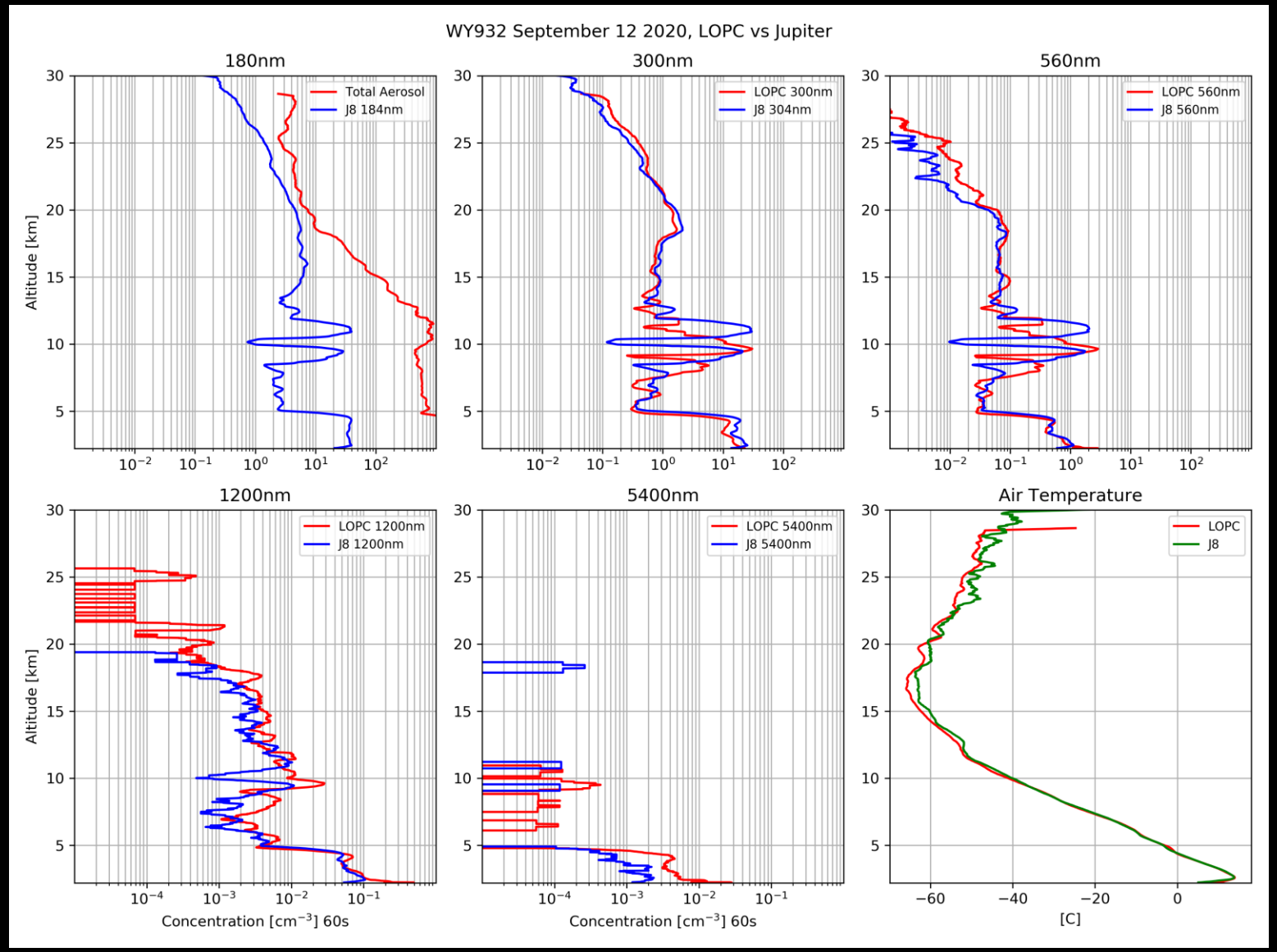


Deshler, T., Luo, B., Kovilakam, M., Peter, T., & Kalnajs, L. E. (2019). Retrieval of aerosol size distributions from in situ particle counter measurements: Instrument counting efficiency and comparisons with satellite measurements. *Journal of Geophysical Research: Atmospheres*, 124, 5058–5087. https://doi.org/10.1029/2018JD029558

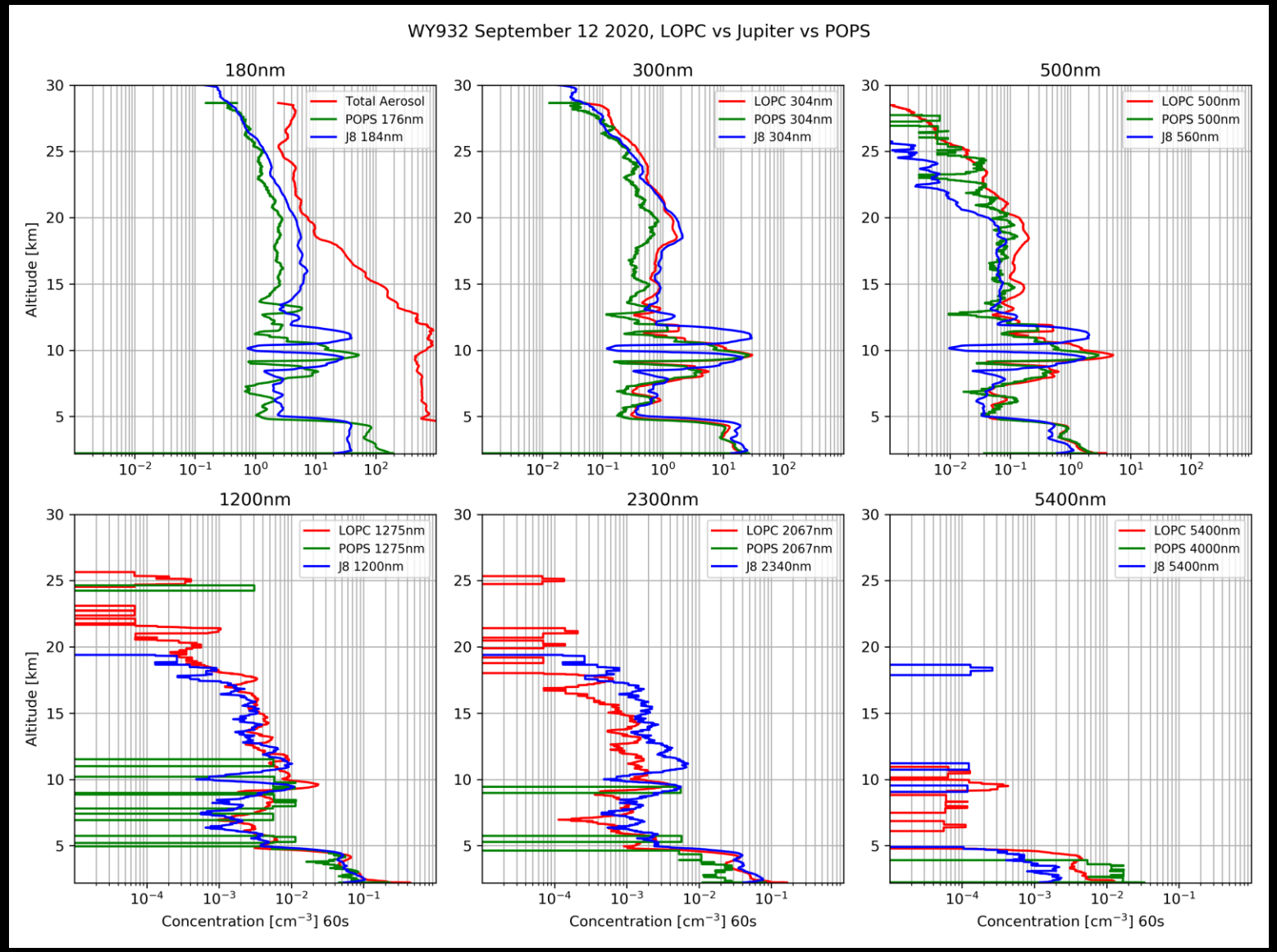
1. SAGE III/ISS OPC Conclusions

- **From the tropopause up to 25km SAGE III/ISS Extinctions agree with OPC measurements**
- Above 22-25km SAGE III/ISS is underestimating extinction
- This was also observed with SAGE II
- During anomalous events (i.e. Raikoke eruption and smoke plumes) with fine vertical structures, significant differences between SAGE III/ISS and OPC are observed

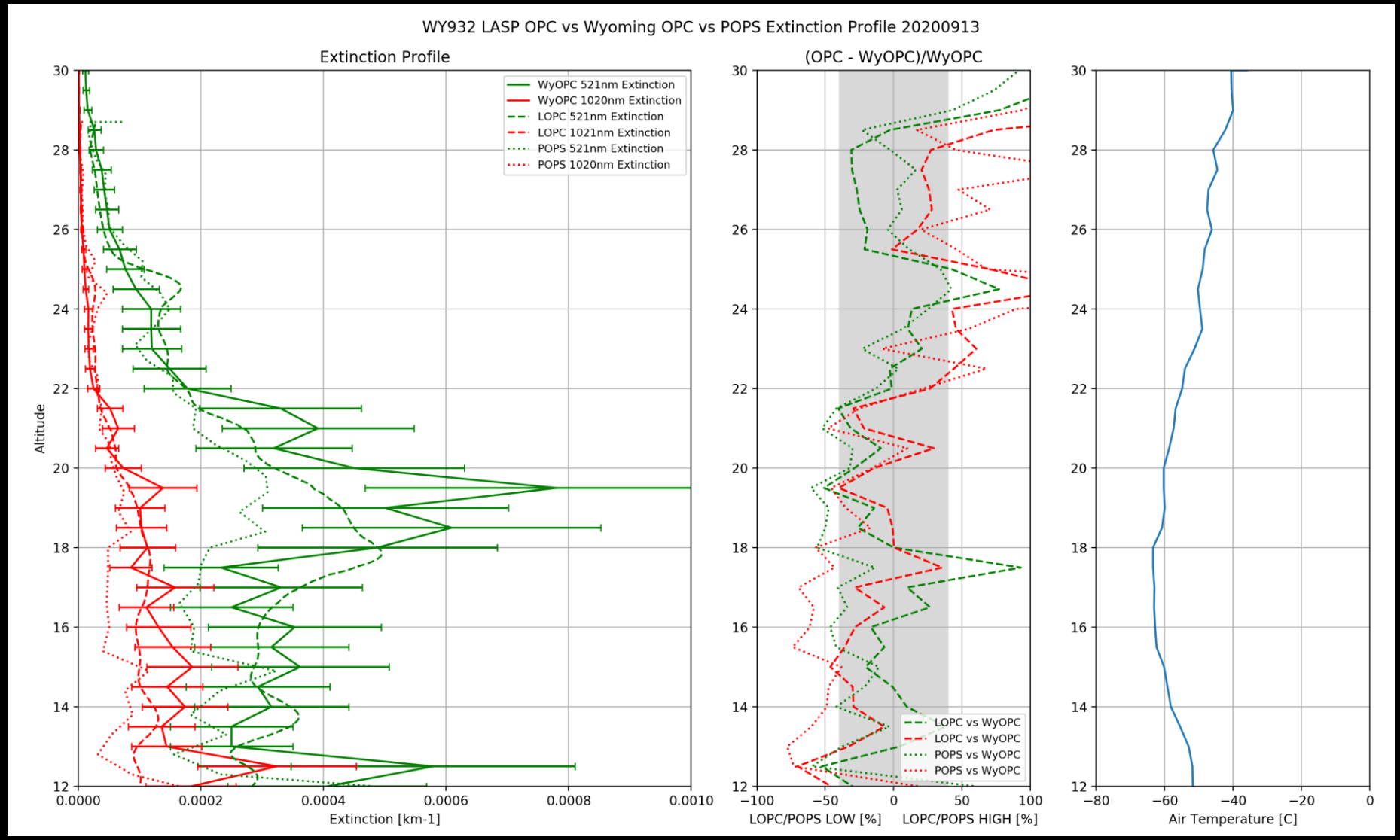
2. OPC vs OPC vs OPC vs CPC (vs SAGE III/ISS)



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2. OPC vs OPC vs OPC vs CPC (vs SAGE III/ISS)



2. OPC vs OPC Conclusions

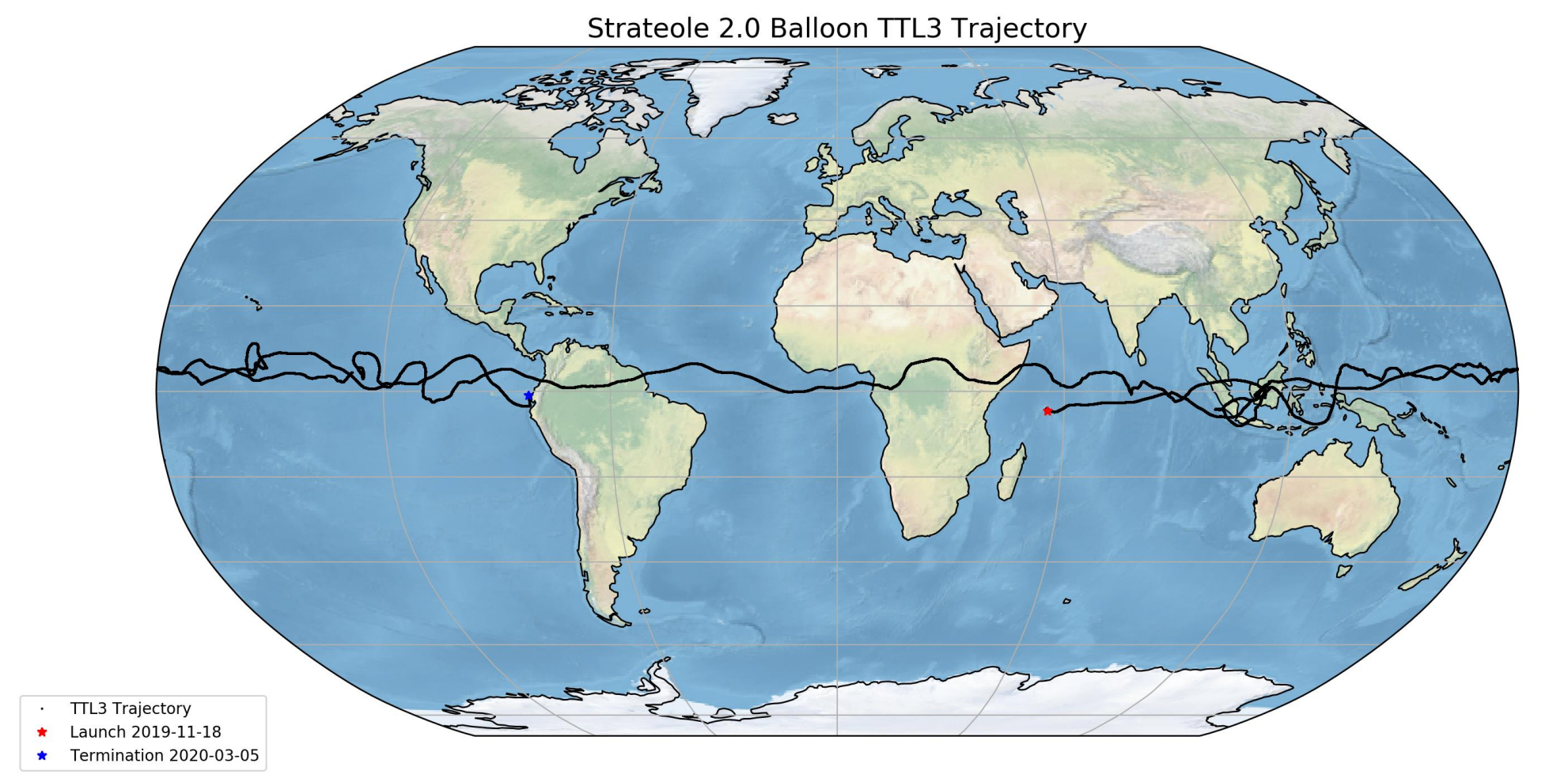
- New LASP OPC (LOPC) aerosol concentrations agree well with heritage Wyoming OPC measurements (Jupiter)
- Comparison of extinction profiles using different instruments and different/independent extinction algorithms agree to within instrument and algorithmic uncertainty

3. Long duration TTL measurements to validate SAGE III/ISS

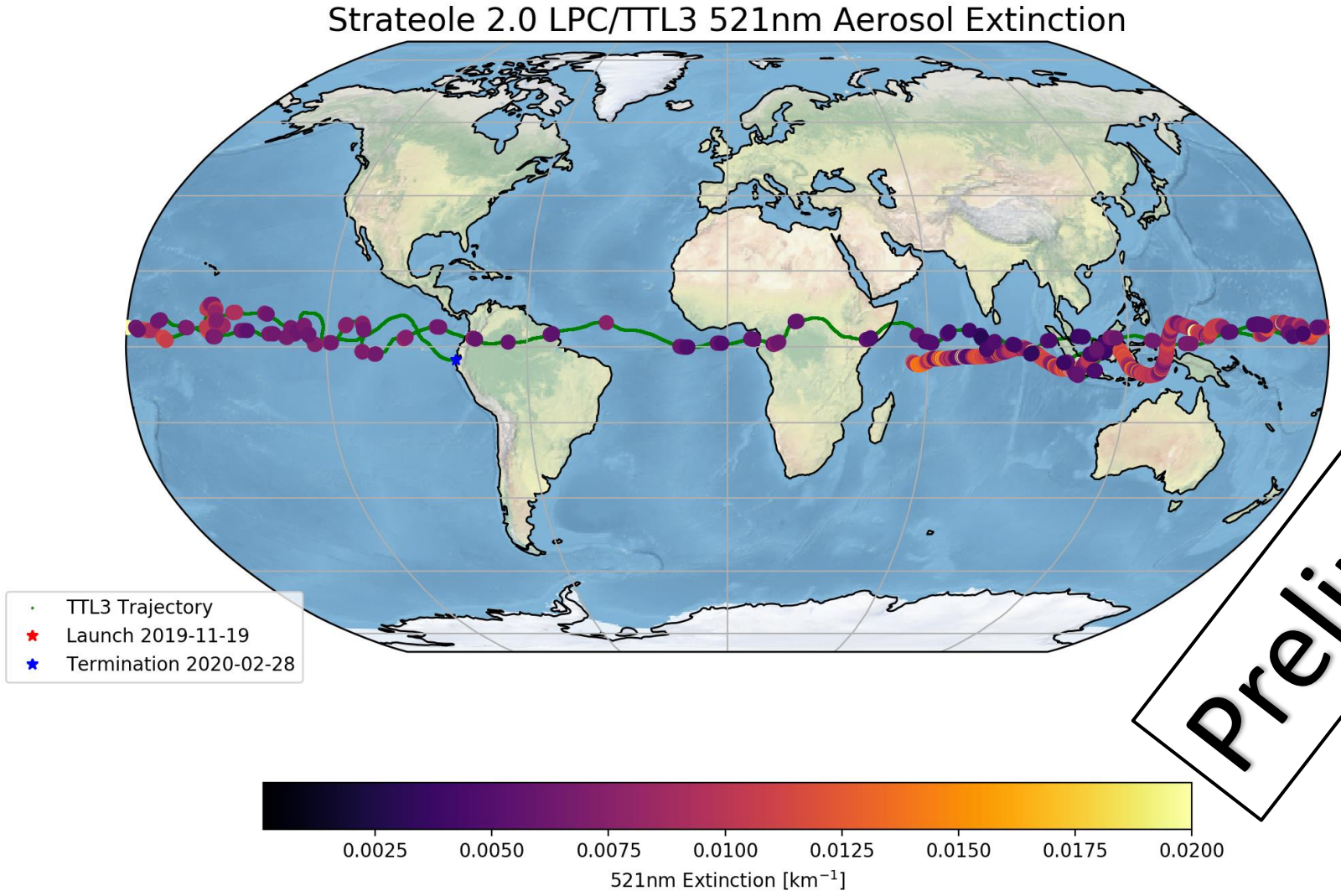


- Series of long duration super pressure balloon missions to study the Tropical Tropopause Layer
- Three balloon missions with a total of 50 balloons flying at ~19 – 21km in the tropics for 3-4 months each
- LASP built instruments for measuring aerosol (LOPC), and profiles of aerosol and water vapor
- Test mission complete in 2019/2020, main missions in 2021 and 2024
- Many opportunities to validate SAGE III aerosol, water vapor and ozone in the tropics

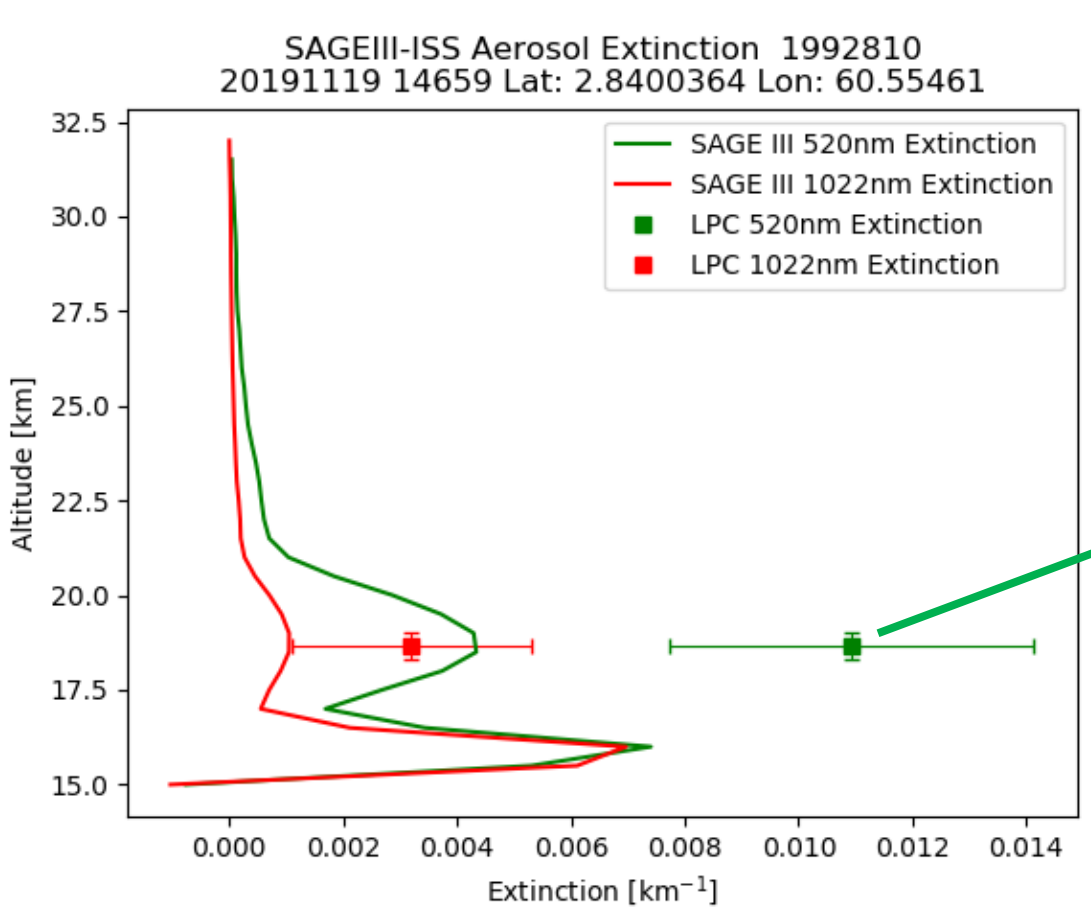
3. Long duration TTL measurements to validate SAGE III/ISS

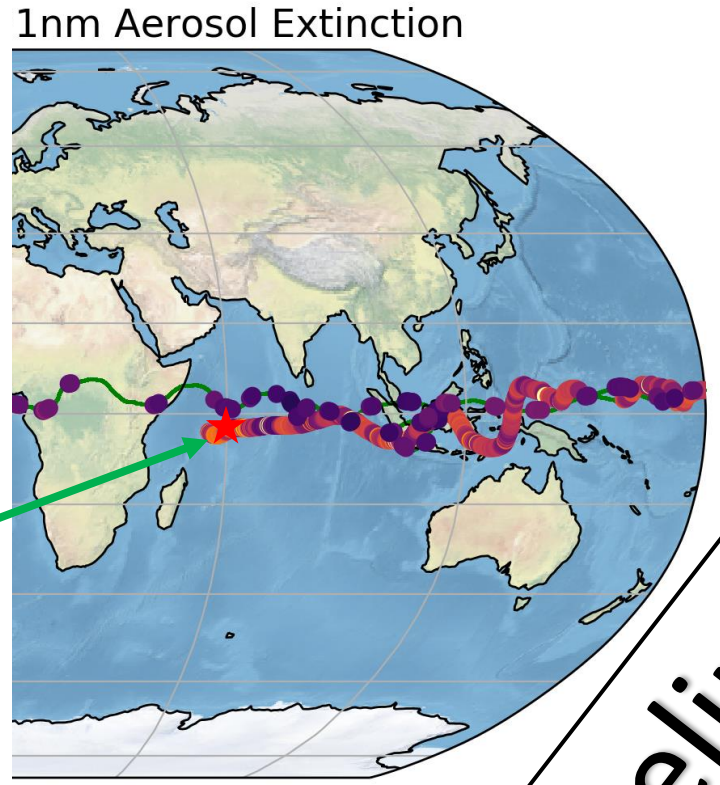


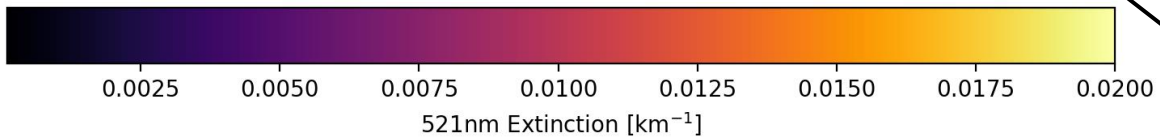
3. Long duration TTL measurements to validate SAGE III/ISS



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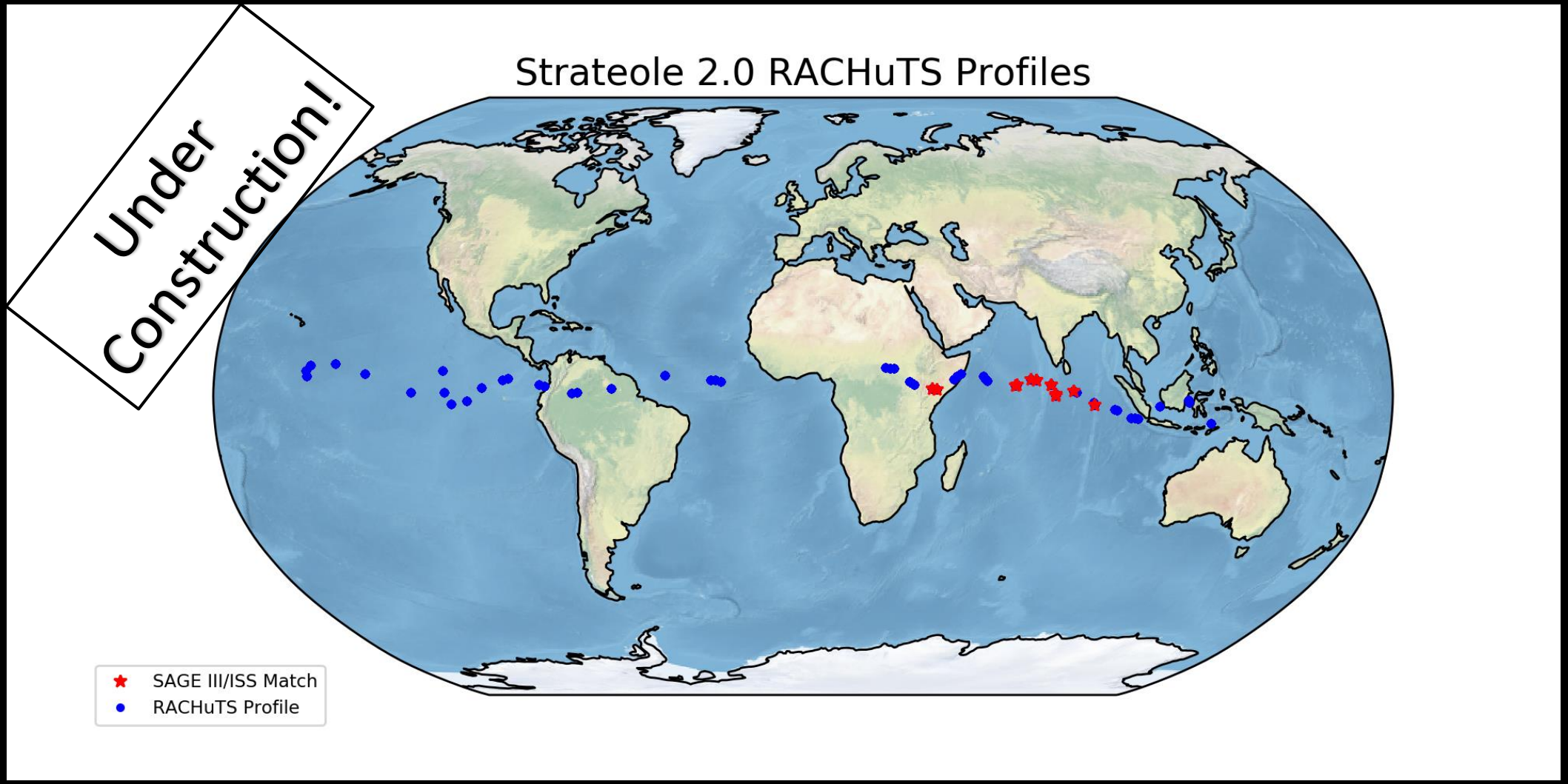






Preliminary!

3. Long duration TTL measurements to validate SAGE III/ISS



RACHuTS Provides vertical profiles (16.5 – 18.5km) of Aerosol, Water Vapor and Temperature

3. Strateole 2 for comparisons near the TTL

- Flight level and reel down profile measurements of aerosol from Strateole 2 campaigns will provide numerous tropical comparisons to SAGE III/ISS
- The TTL and lower Tropical Stratosphere are a particularly interesting region, but pose unique challenges for satellite retrievals
- Future campaigns (2021, 2024) will fly ~ 50 balloons and provide many more measurements including profiles of aerosol and water vapor as well as flight level aerosol, water vapor and ozone

Conclusions

- SAGE III/ISS agrees within uncertainty with In Situ measurements below 25km
- New Colorado OPC agrees with Wyoming OPCs within uncertainty
- Stratéole 2 Campaigns will provide many opportunities for tropical validation



Accounting for the photochemical variation of NO_2 in the SAGE III/ISS retrieval

Kimberlee Dubé, Adam Bourassa, Daniel Zawada, Doug Degenstein, Robert Damadeo, David Flittner, William Randel

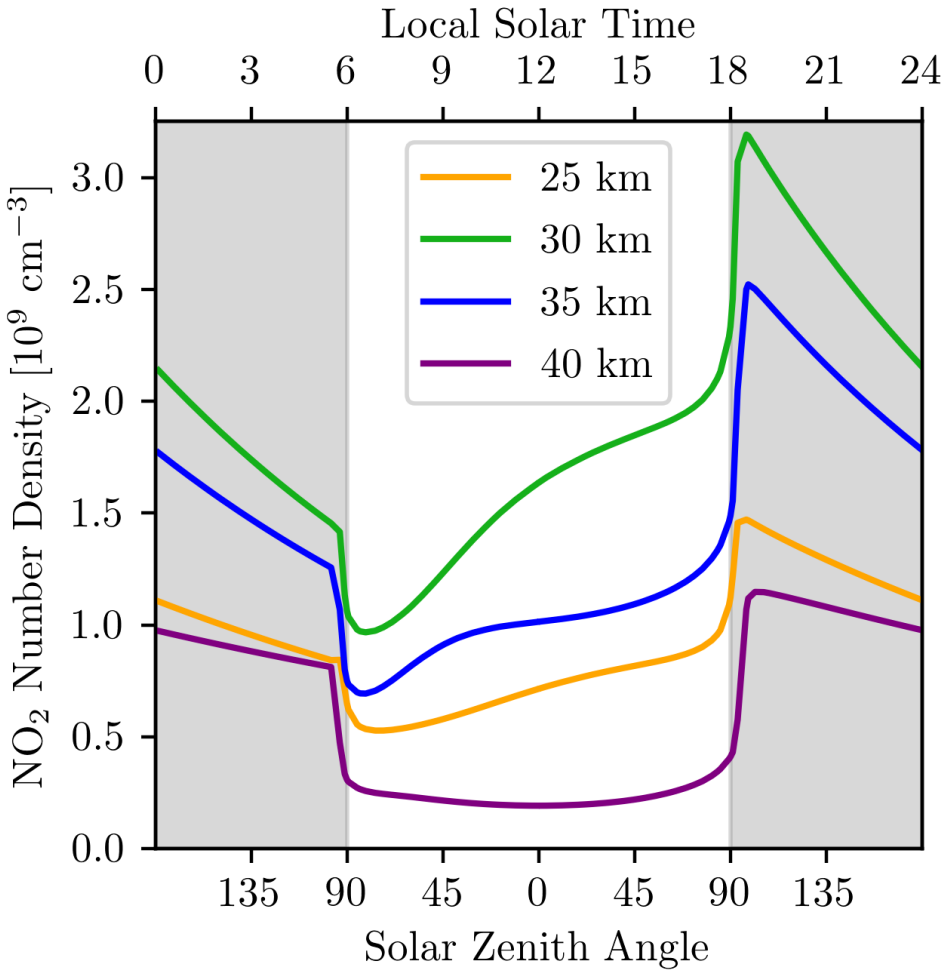
University of Saskatchewan

Introduction

- Photochemistry causes the stratospheric NO_2 concentration to vary with solar zenith angle (SZA).
- The SAGE III/ISS retrieval assumes that NO_2 number density has a constant gradient within each layer of the atmosphere.
- This assumption results in a retrieval bias in the SAGE III/ISS NO_2.
- Purpose of this work is to account for diurnal variations in SAGE III/ISS NO_2 retrievals and assess the impact on the resulting number densities.

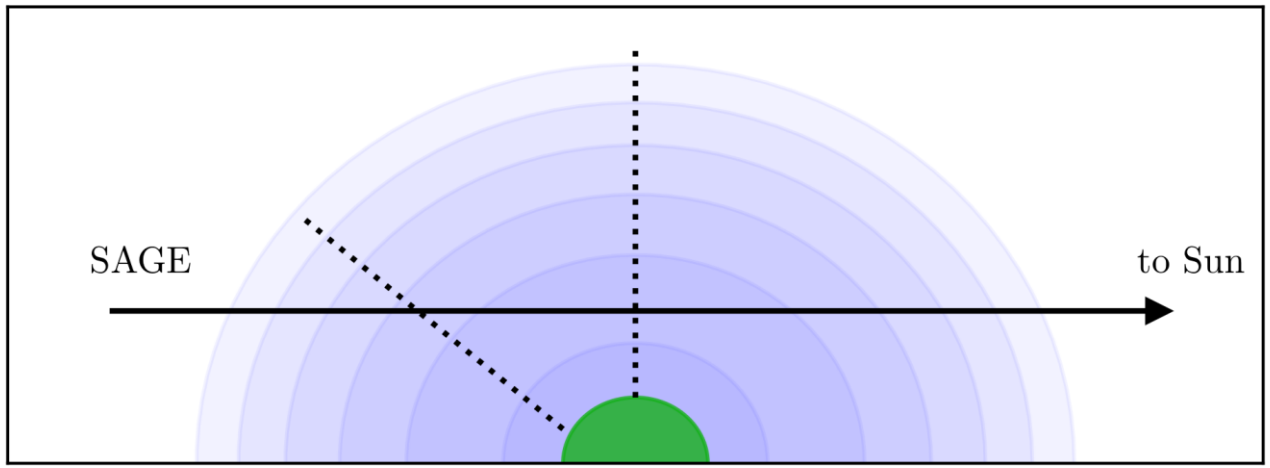
NO_2 Photochemistry

- Decrease in NO_2 at sunrise as it is photolyzed to NO.
- Increase at sunset as NO production ceases.
- Decrease at night from conversion to reservoir species.
- Modelled with PRATMO photochemical box model.



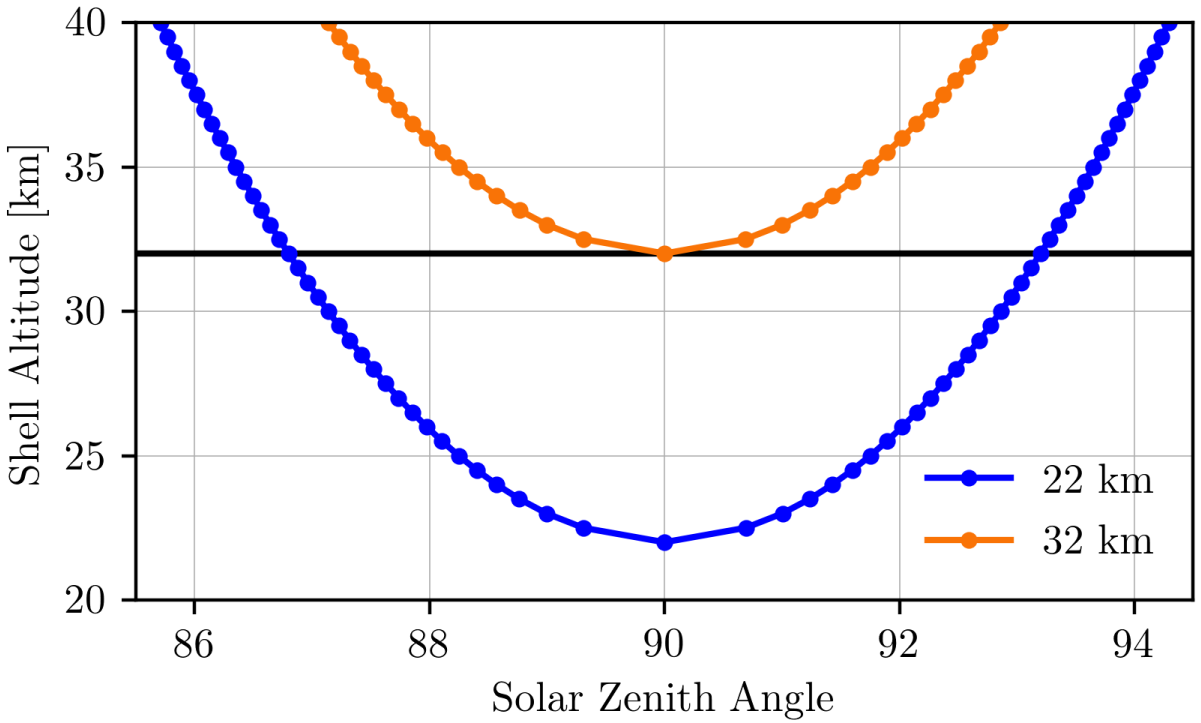
SAGE III/ISS Measurements

- During each occultation SAGE III/ISS looks through multiple layers of the atmosphere.

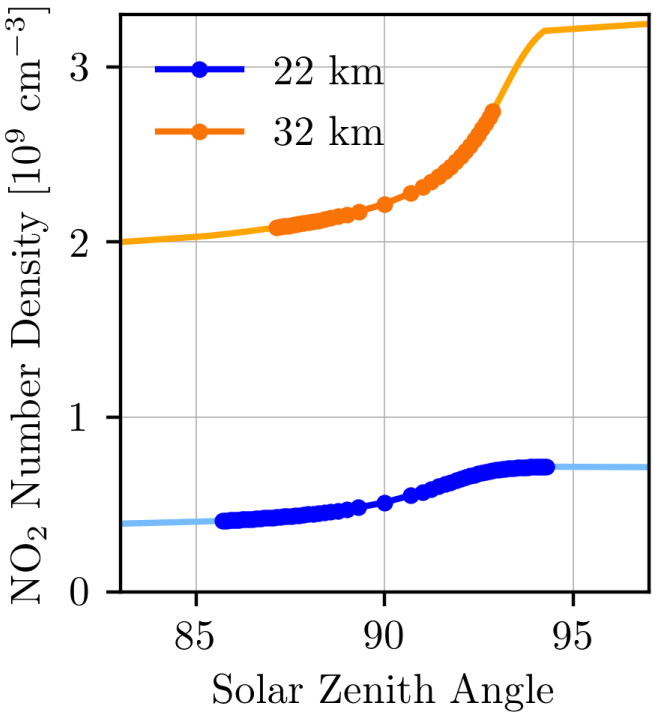


- Retrieval assumes that the number density of each constituent has a constant gradient within each layer (shell).

NO_2 along the SAGE III/ISS Line of Sight (LOS)



Change in SZA with shell altitude along two lines of sight for a simulated sunset occultation.



Change in NO_2 at tangent altitudes of 22 km and 32 km for the same simulated sunset occultation.

Scaling the NO_2 – Part 1

- Account for diurnal variations by scaling NO_2 according to SZA at each point along the LOS.
- First "undo" the SAGE III/ISS retrieval to get the optical depths,

$$\tau = \sigma X_0 n_0$$

- X_0 is the path length matrix: each row represents a LOS for a particular tangent point altitude, and each column represents a different altitude through which the LOS passes.

Scaling the NO_2 – Part 2

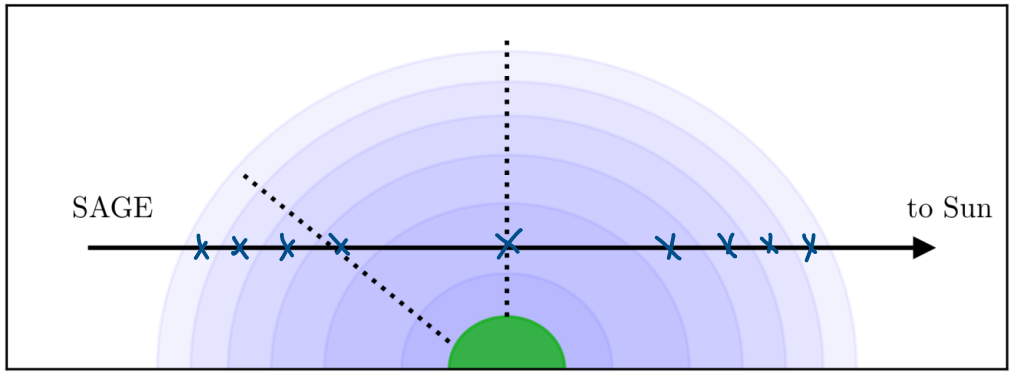
- Use optical depths, along with a new matrix X_{dv} to find the number densities accounting for diurnal variations,

$$n_{dv} = \sigma^{-1} X_{dv}^{-1} \tau$$

- Here each element in the path length matrix is multiplied by a scale factor that depends on solar zenith angle.

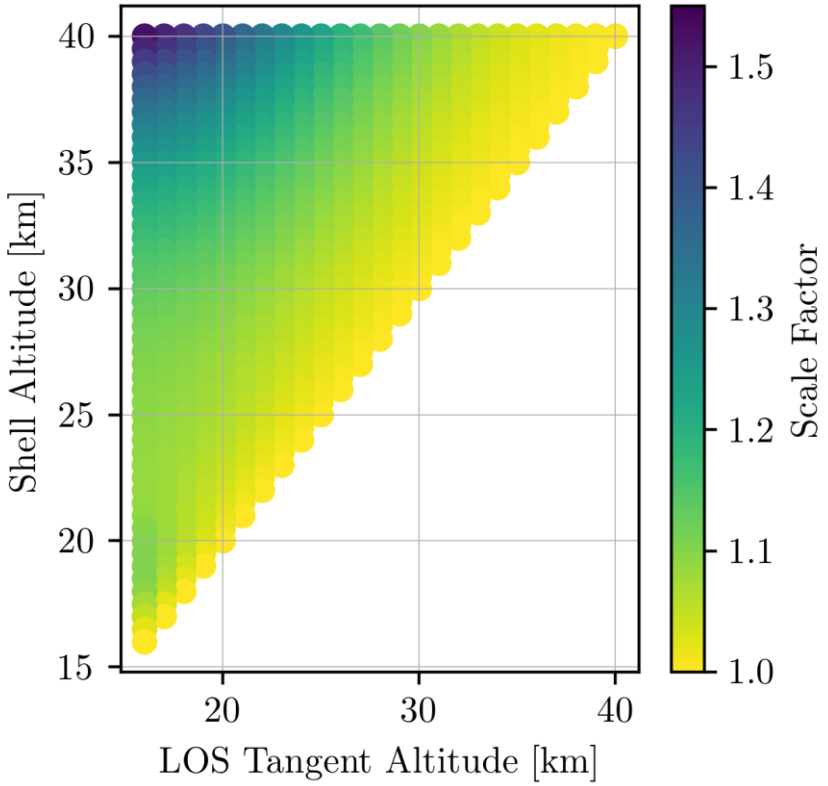
The Scale Factors – Part 1

- LOS for a tangent altitude intersects all the shells above it,

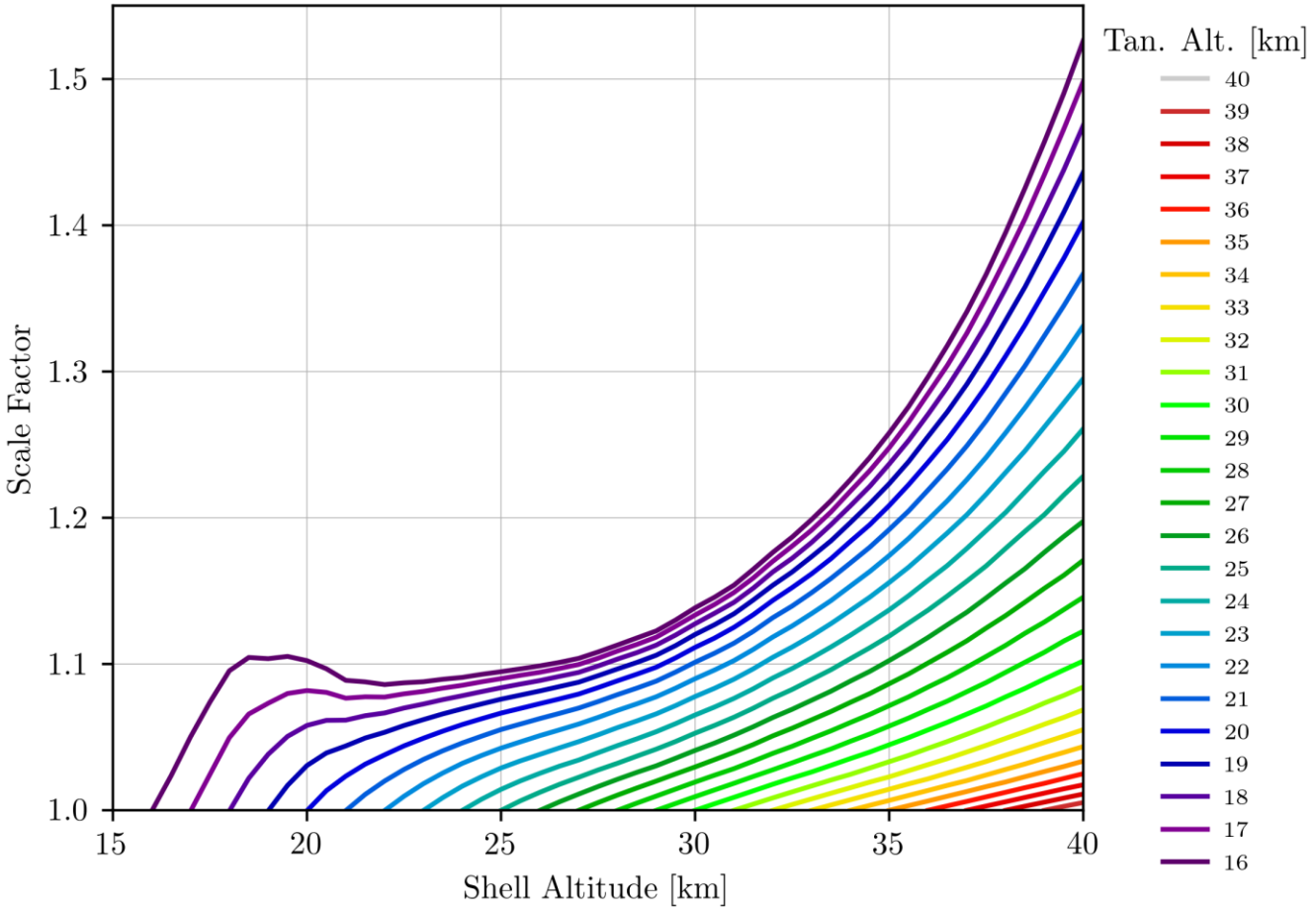


- Use PRATMO to calculate the NO_2 at the solar time corresponding to the midpoint of each intersection.
- For each shell along the LOS, the scale factor is the PRATMO NO_2 at that altitude divided by the PRATMO NO_2 at the tangent point altitude for that LOS.

The Scale Factors – Part 2



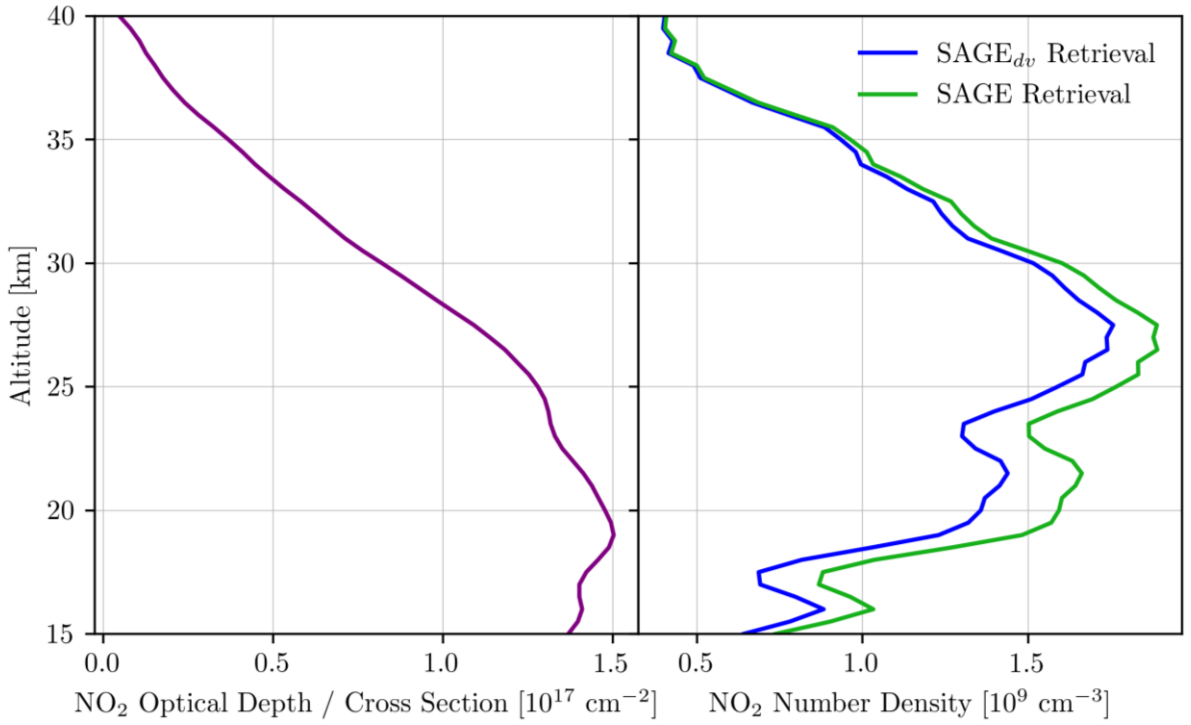
Scale factor matrix for a simulated sunset occultation.



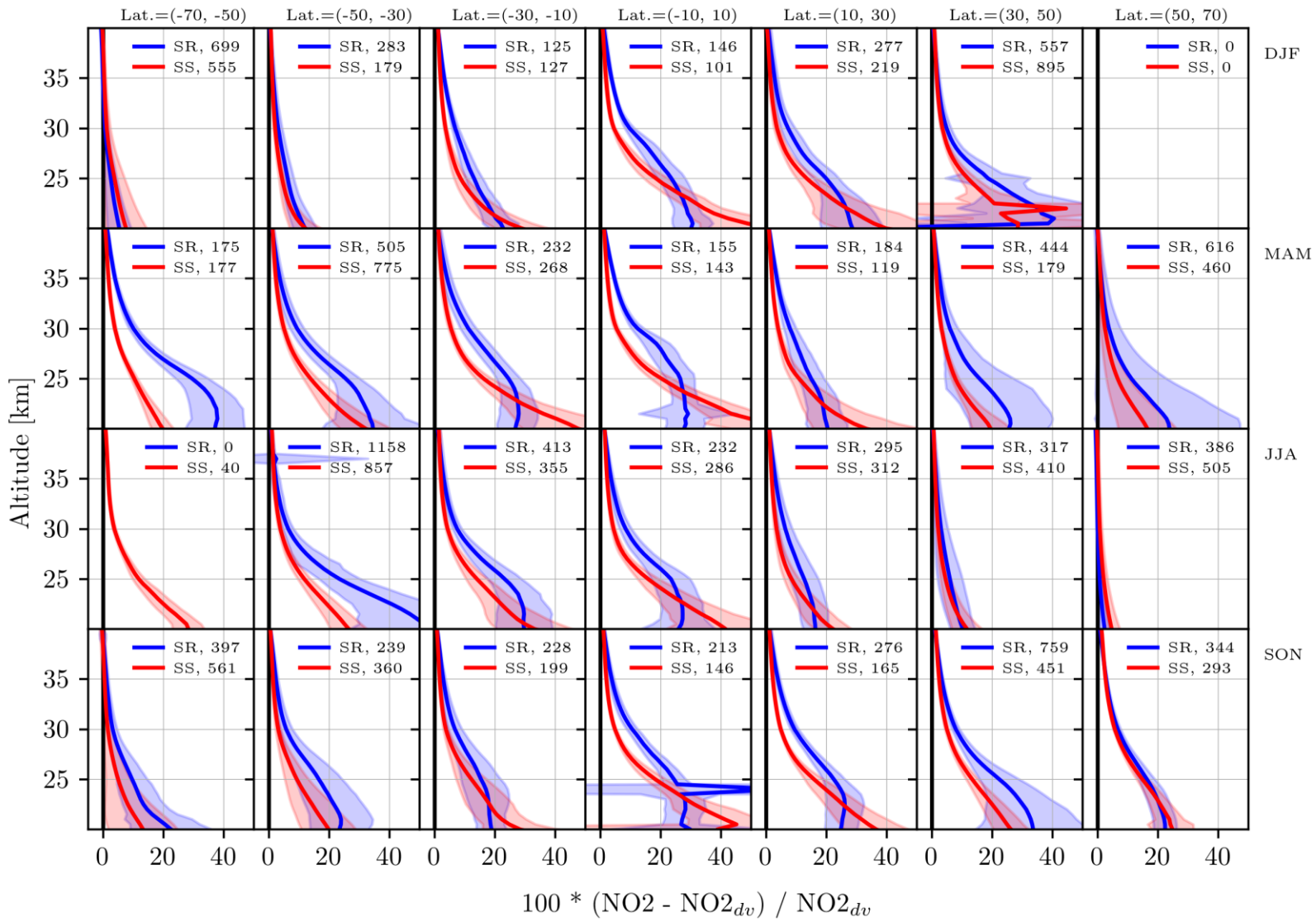
Scale factor along each LOS for a simulated sunset occultation.

Scaling the NO_2 – Part 3

- Use the scale factors along with the optical depths to find the NO_2 number density that accounts for diurnal variations.
- Number density from diurnally varying retrieval is always lower.

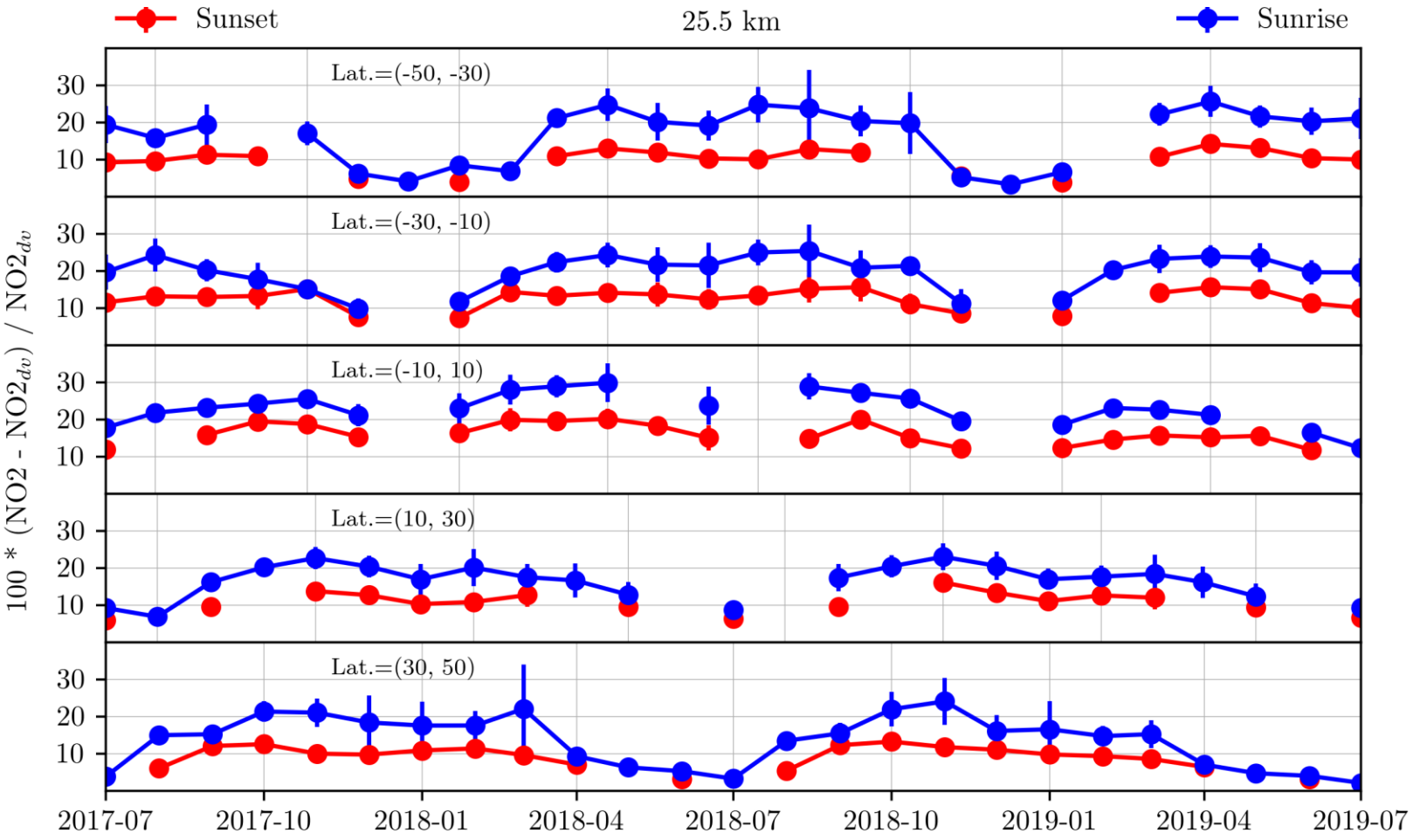


Results – Part 1



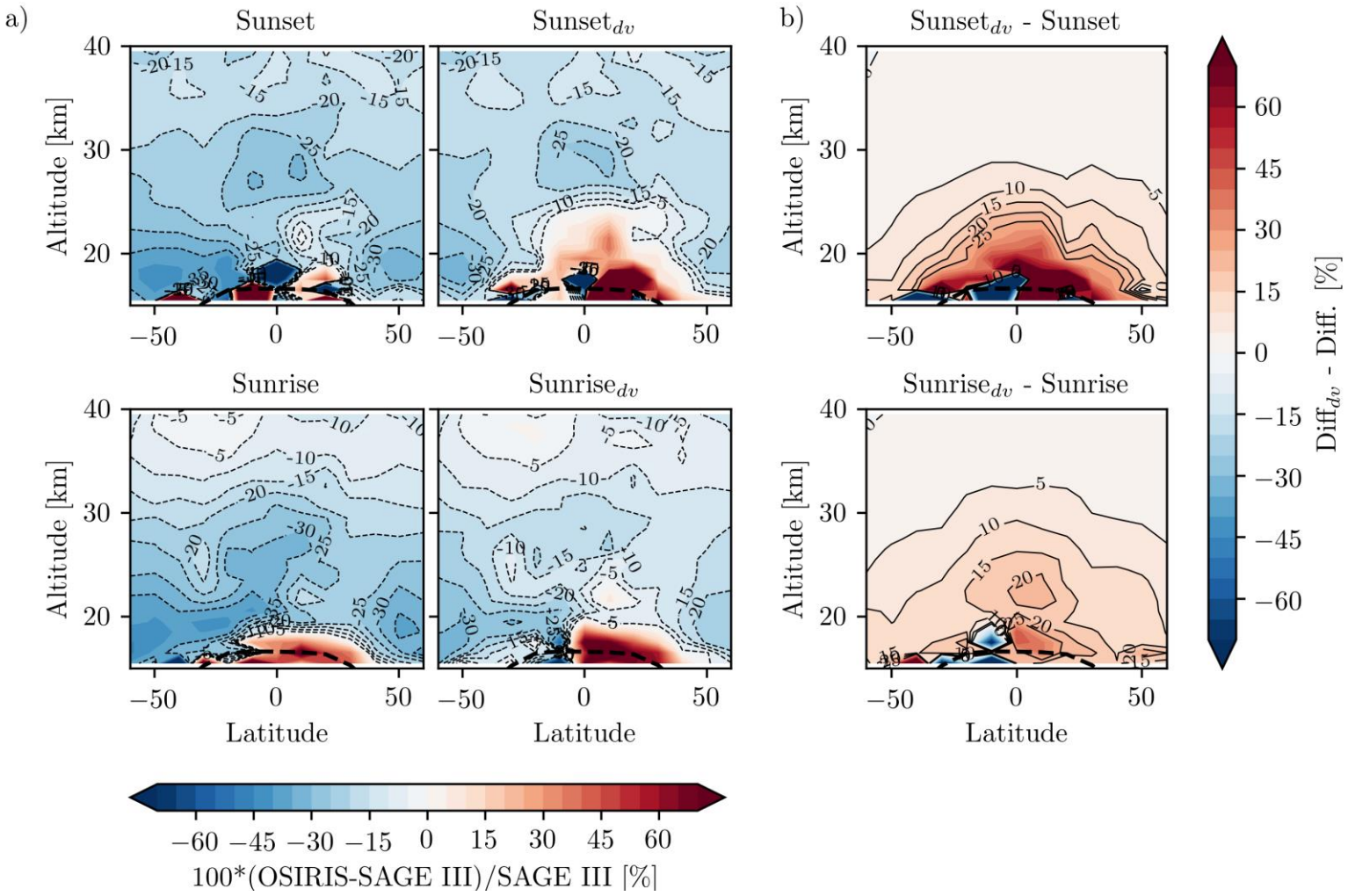
- Difference between SAGE v5.1 retrieval and diurnally varying retrieval.
- Difference becomes greater than 10% below 30 km.
- Greatest difference at high latitudes in winter.

Results – Part 2



- Difference between SAGE v5.1 retrieval and diurnally varying retrieval in the time series at 25.5 km.
- Sunset decrease ranges from 5-20%, sunrise decrease ranges from 5-30%.

Comparison with OSIRIS



- Difference between coincident OSIRIS and SAGE III NO_2 measurements for both SAGE retrievals.
- SAGE NO_2 biased high, better agreement after including diurnal variations.

Conclusions

- We developed a new retrieval that uses publicly available SAGE III/ISS NO_2 data that accounts for photochemical variations along the LOS.
- Neglecting diurnal variations always biases the resulting NO_2 number density high.
- The diurnal effect is most important below 30 km where it becomes greater than 10%.
- The effect is more important at sunrise than sunset and at high winter latitudes.
- Accounting for diurnal variations improves agreement between SAGE III/ISS and OSIRIS NO_2 by up to 20% at lower altitudes.
- Preprint available: https://amt.copernicus.org/preprints/amt-2020-331/

Dynamical Diagnostics for SAGE III/ISS: Progress Report & Dynamical Coordinate Investigations

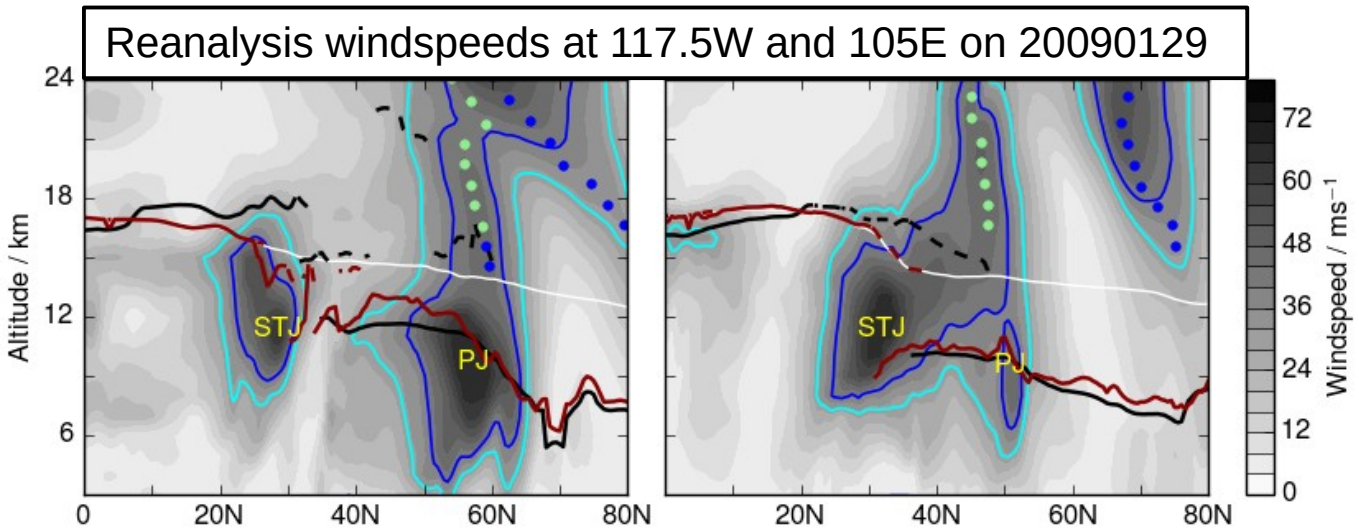
Gloria L Manney (NWRA, NMT) & Luis F Millán Valle (JPL/Caltech)



SAGE III/ISS Science Team Meeting, 19–20 October 2020

Dynamical Diagnostics from JETPAC

JEt and Tropopause Products for Analysis and Characterization



JETPAC diagnostics have been calculated at multi-instrument measurement locations, including SAGE III/ISS (preliminary calculations have also been done for SAGE II)

Jet Cores: windspeed maxima >40m/s Jet region edges: 30m/s windspeed

Subtropical jet (STJ): Lowest latitude westerly jet with tropopause altitude > 13km at its equatorward edge and a drop >2km between equatorward & poleward edge

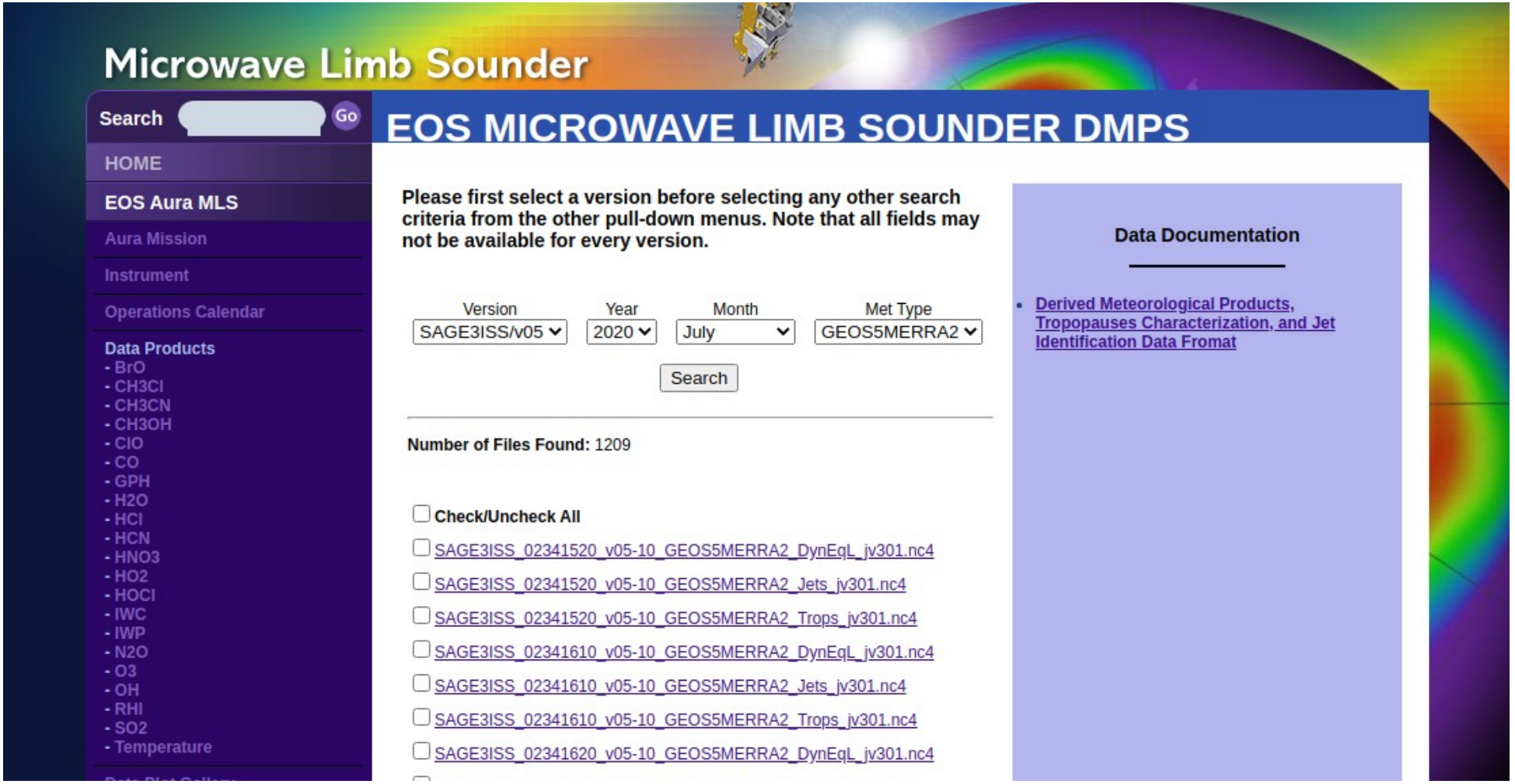
Polar Jet (PJ): Strongest westerly jet poleward of STJ (or of 40° if no STJ)

Characterization of WMO (Temperature gradient) and dynamical (PV-based) tropopauses

Characterization of stratospheric subvortex (blue and green dots; two offspring from split SSW shown here)

JETPAC tropopause and UTLS jet analysis: Manney et al, 2011, 2014, 2017; Manney & Hegglin, 2018

SAGE III/ISS JETPAC Diagnostics



https://mls.jpl.nasa.gov/dmp/data/dmp locator.php

Contact Luis (lmillan@jpl.nasa.gov) if you want a zip file for full mission

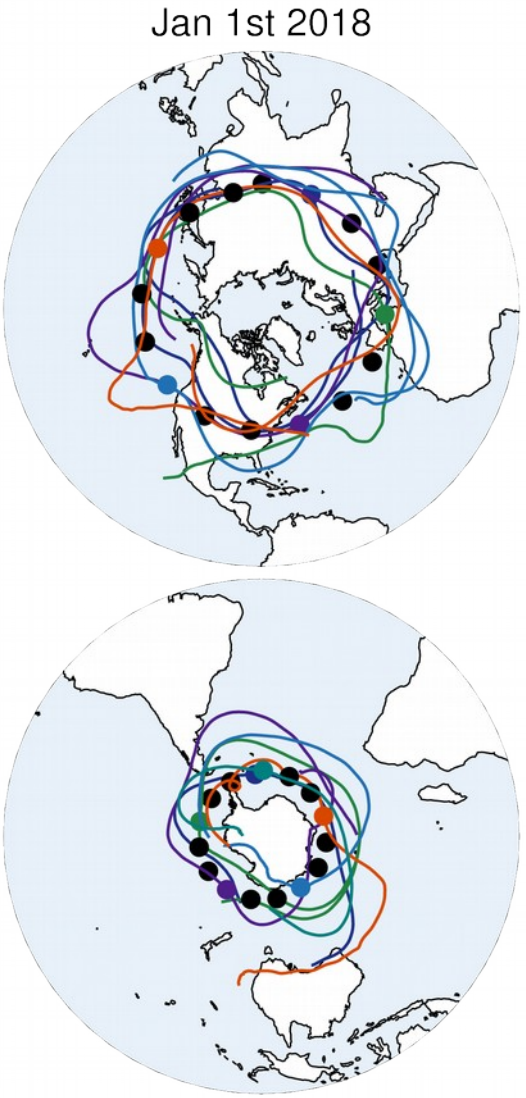
SAGE III/ISS Trajectory Diagnostics

We have launched trajectories from the SAGEIII/ ISS measurement locations (10 day forward/backward).

- Currently available until May 2019; will re-run and update to present with v5.2
- MERRA-2 winds and heating rates are used in a 4th order Runge-Kutta integration with 5 minute timesteps
- Parcel locations are saved every 20 minutes
- Flanking trajectories added to quantify dispersion / mixing
- Trajectories are stored in nc4 format

Work in progress: Use the trajectory hunting technique to validate SAGEIII/ISS versus other satellite instruments.

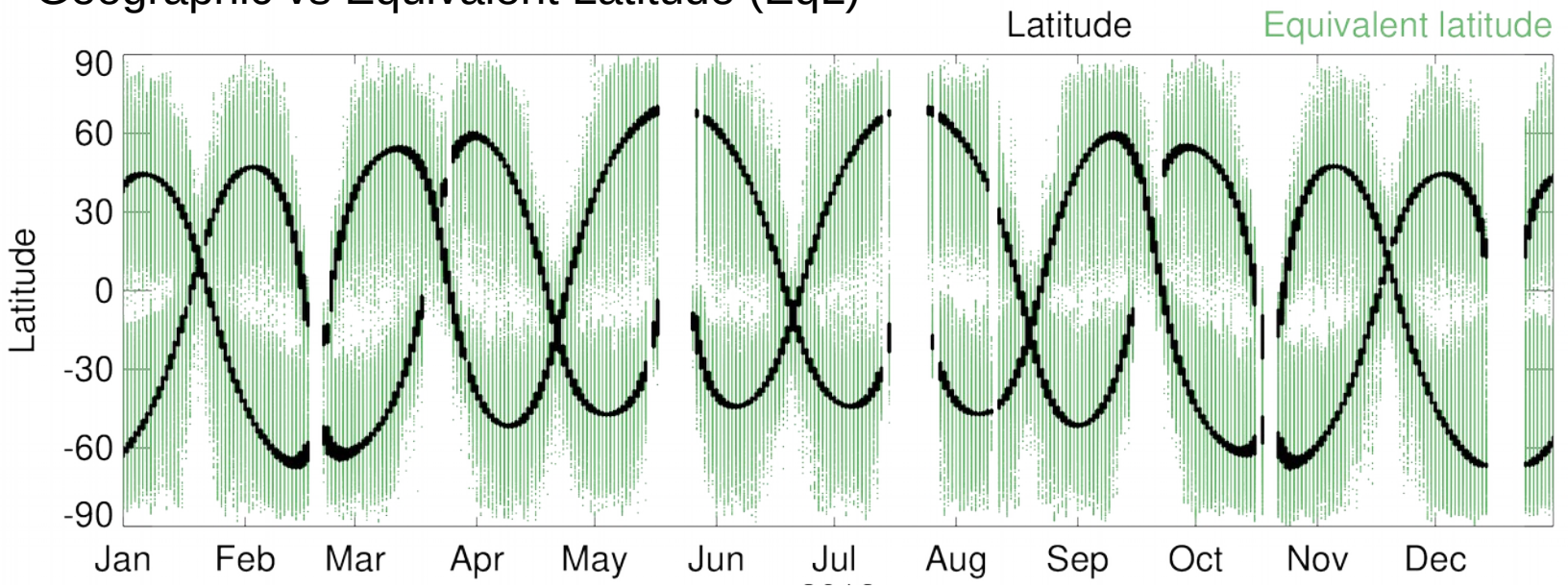
Please contact lmillan@jpl.nasa.gov if you want to get a hold of these trajectories



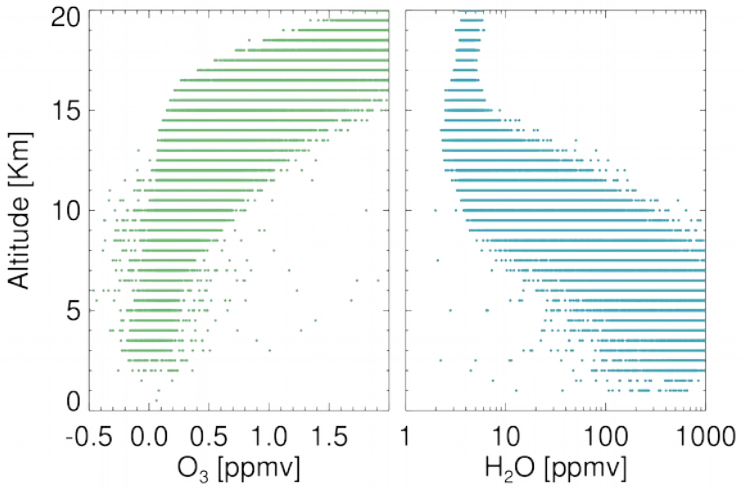
Parcels started at 15km

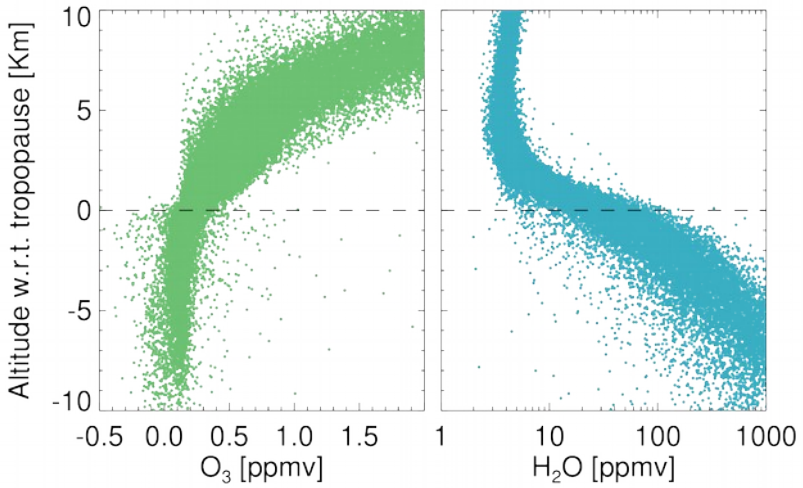
Dynamical Coordinate Motivation

Geographic vs Equivalent Latitude (EqL)



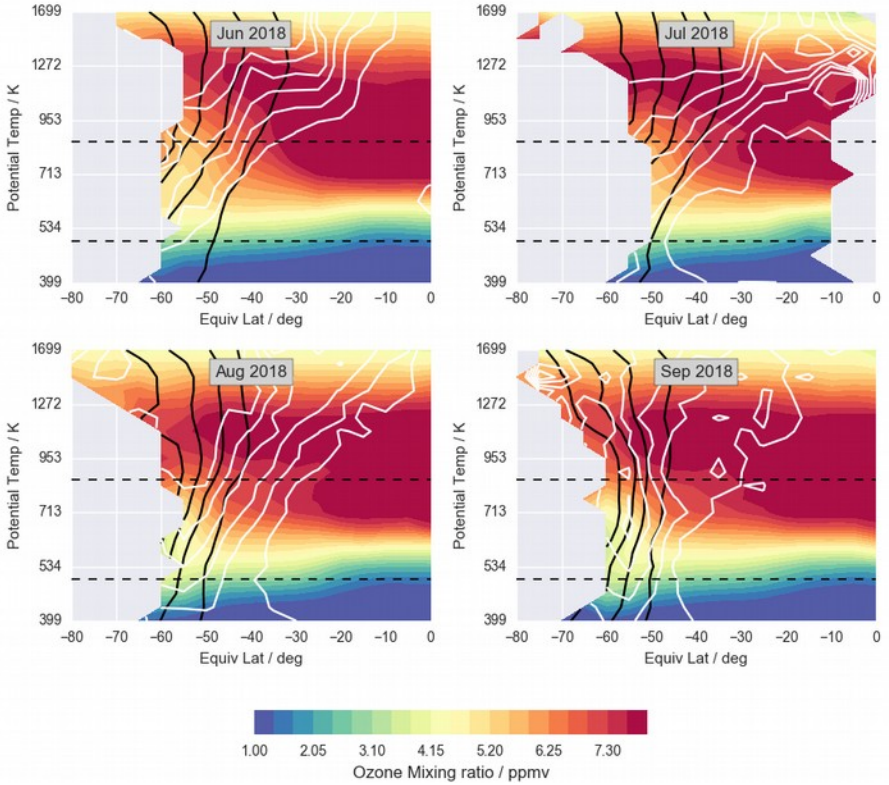
Altitude vs Tropopause Relative Vertical Coordinate



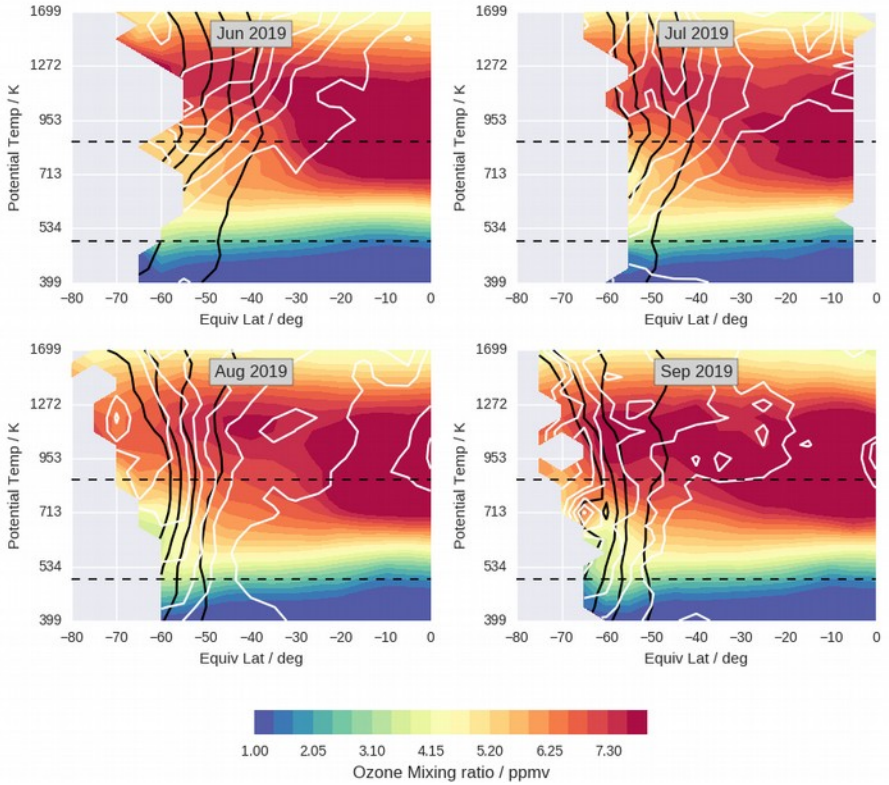


EqL/θ SH Stratospheric Polar Ozone

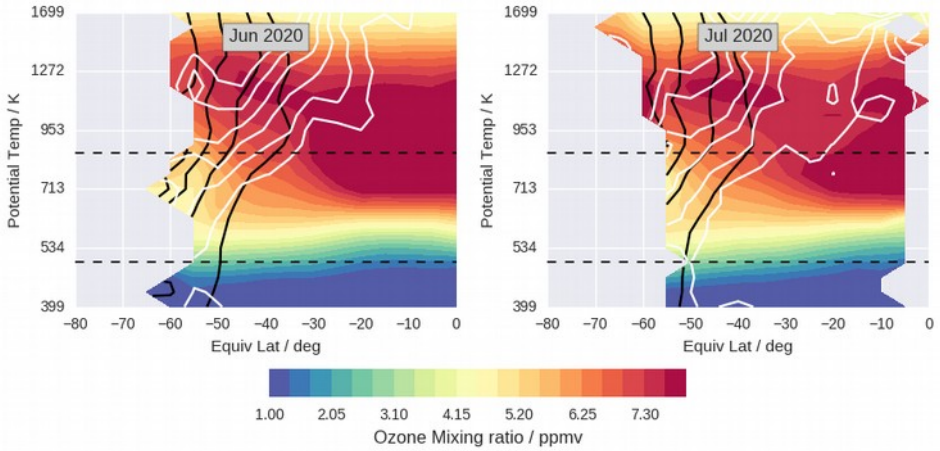
SAGE III/ISS SH Winter 2018



SAGE III/ISS SH Winter 2019

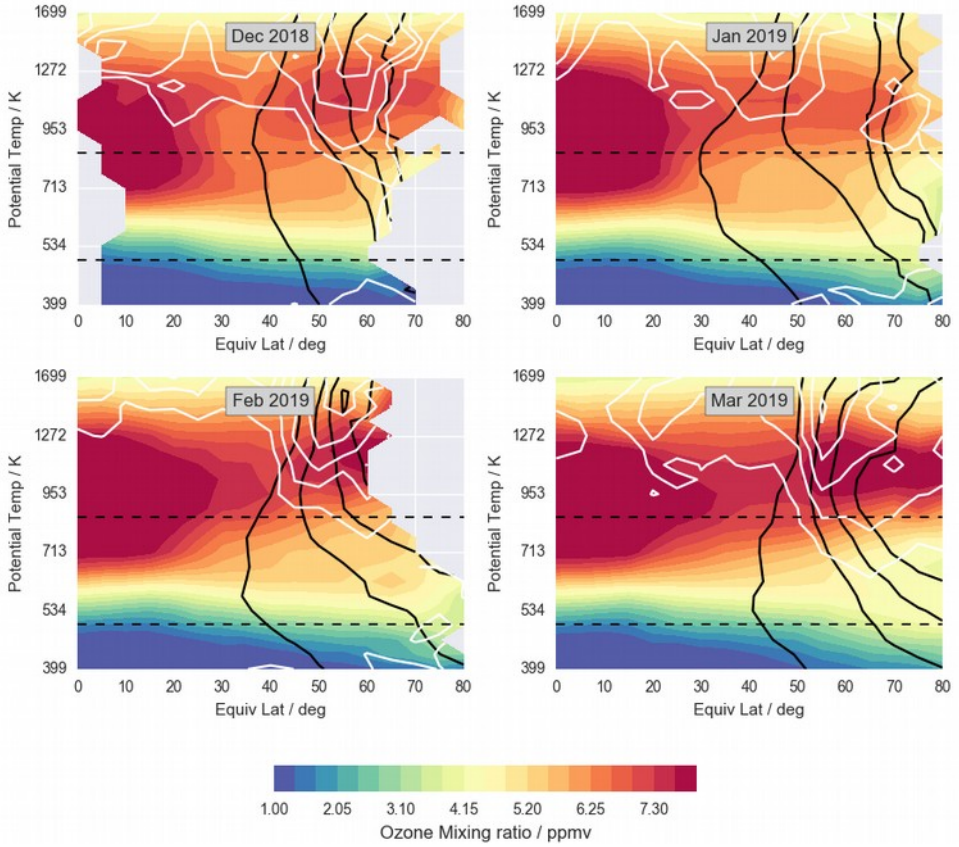


SAGE III/ISS SH Winter 2020

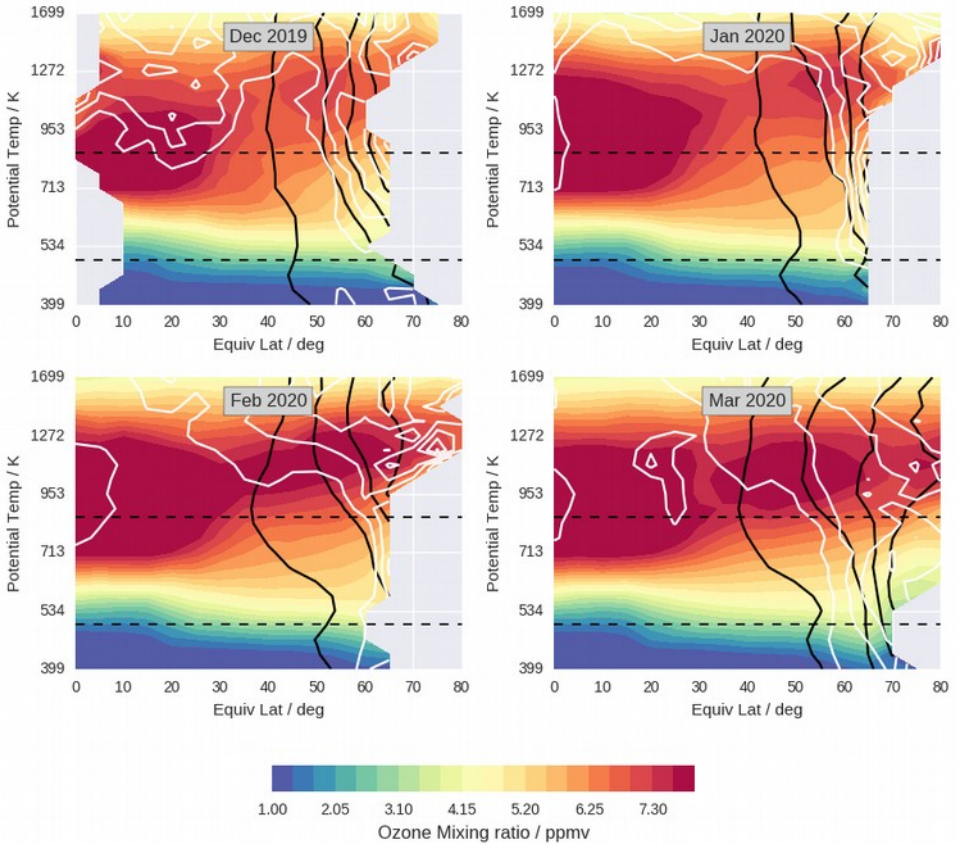


EqL/θ NH Stratospheric Polar Ozone

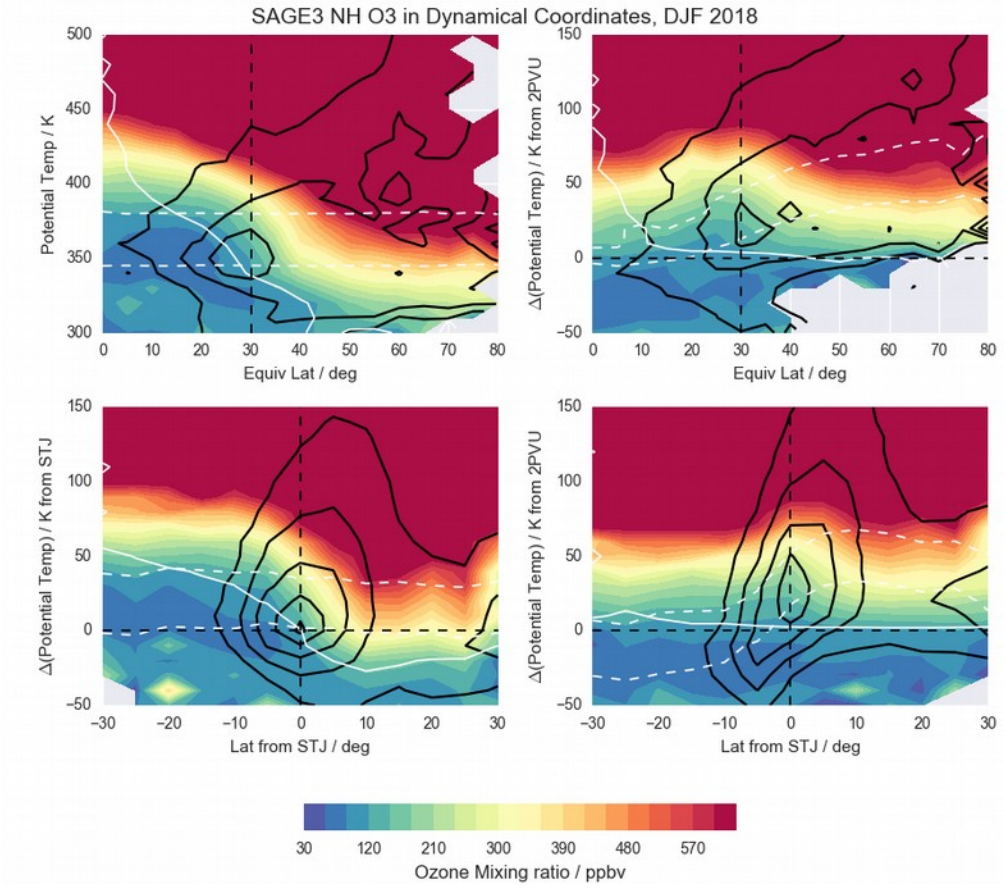
SAGE III/ISS NH Winter 2018/2019



SAGE III/ISS NH Winter 2019/2020

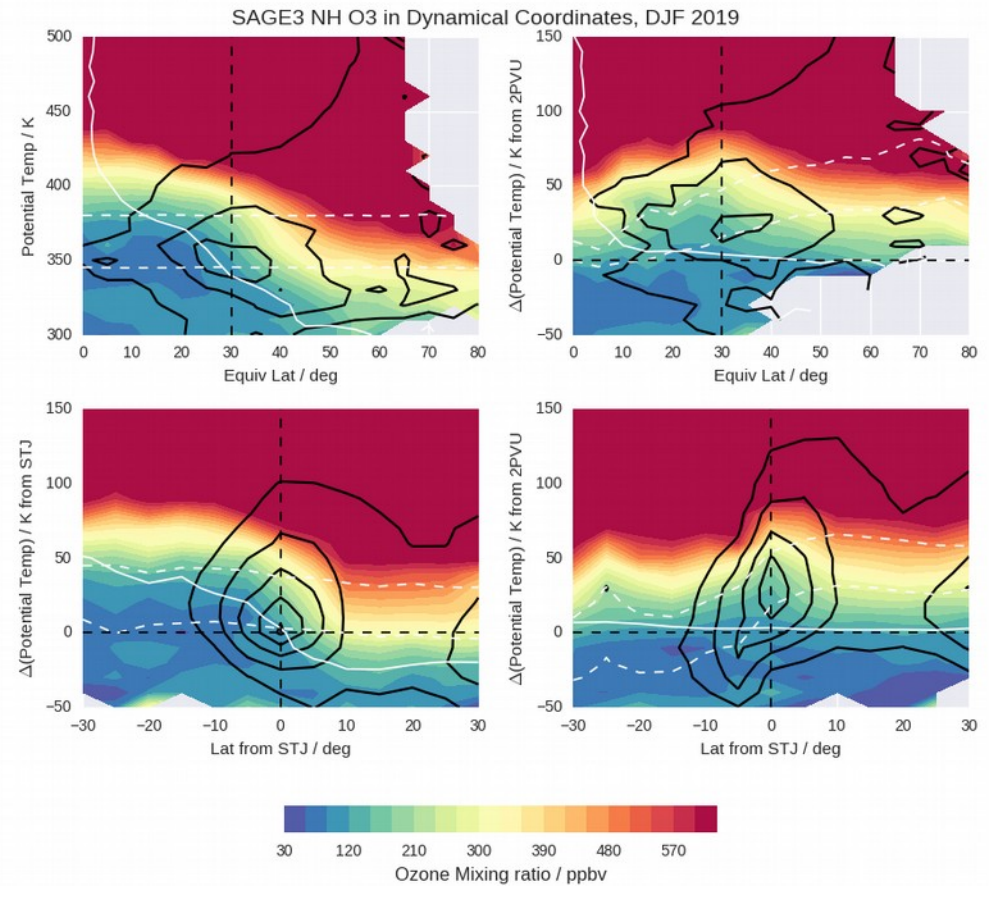


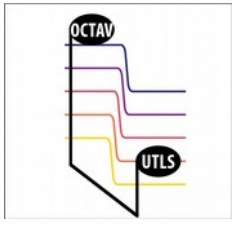
SAGE III/ISS NH UTLS Ozone in Dynamical Coordinates



(black = windspeeds, solid white 2PVU, dashed white 345 and 380 K potential temperature)

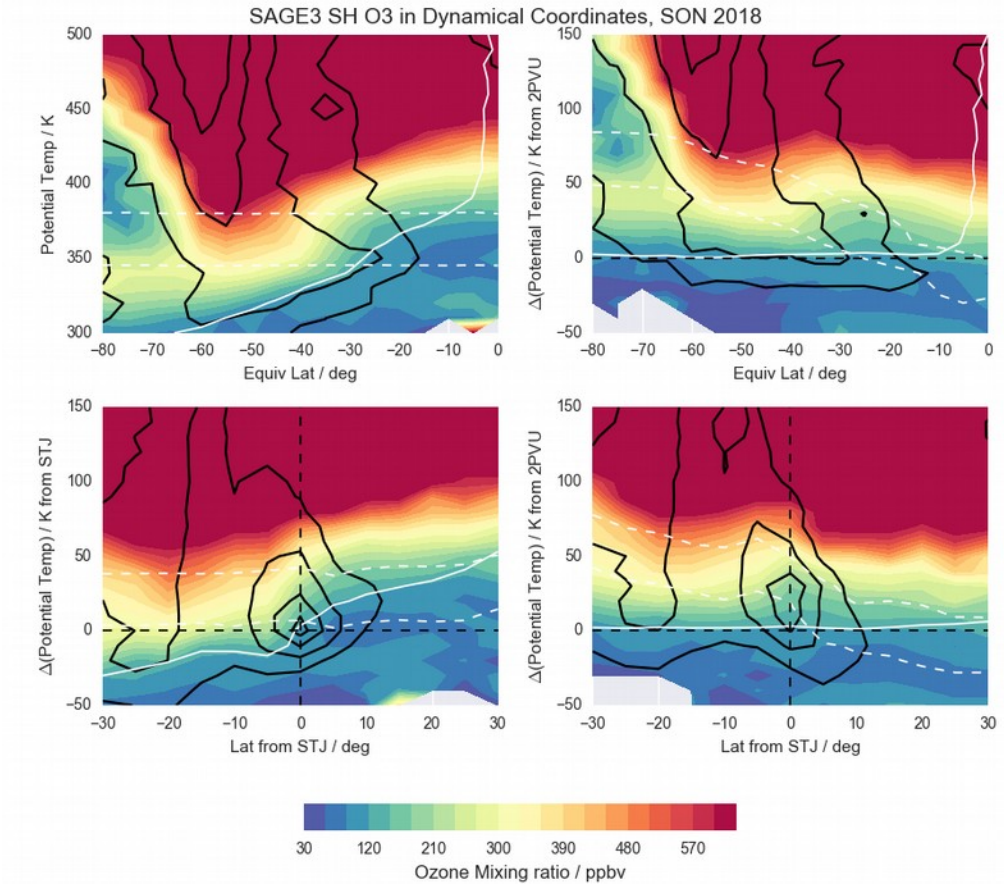
SAGE III/ISS NH DJF 2018/2019 (left) & 2019/2020 (below) in various dynamical coordinates





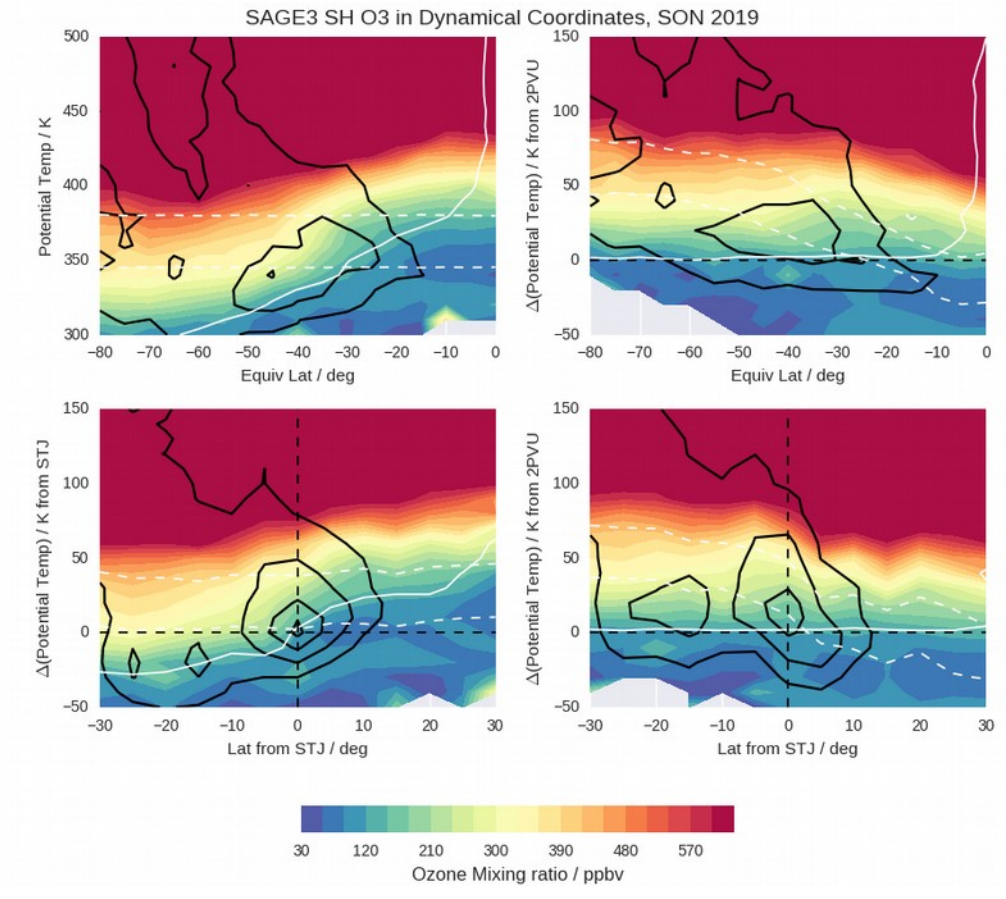


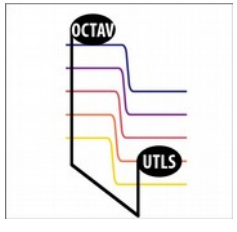
SAGE III/ISS SH UTLS Ozone in Dynamical Coordinates



(black = windspeeds, solid white 2PVU, dashed white 345 and 380 K potential temperature)

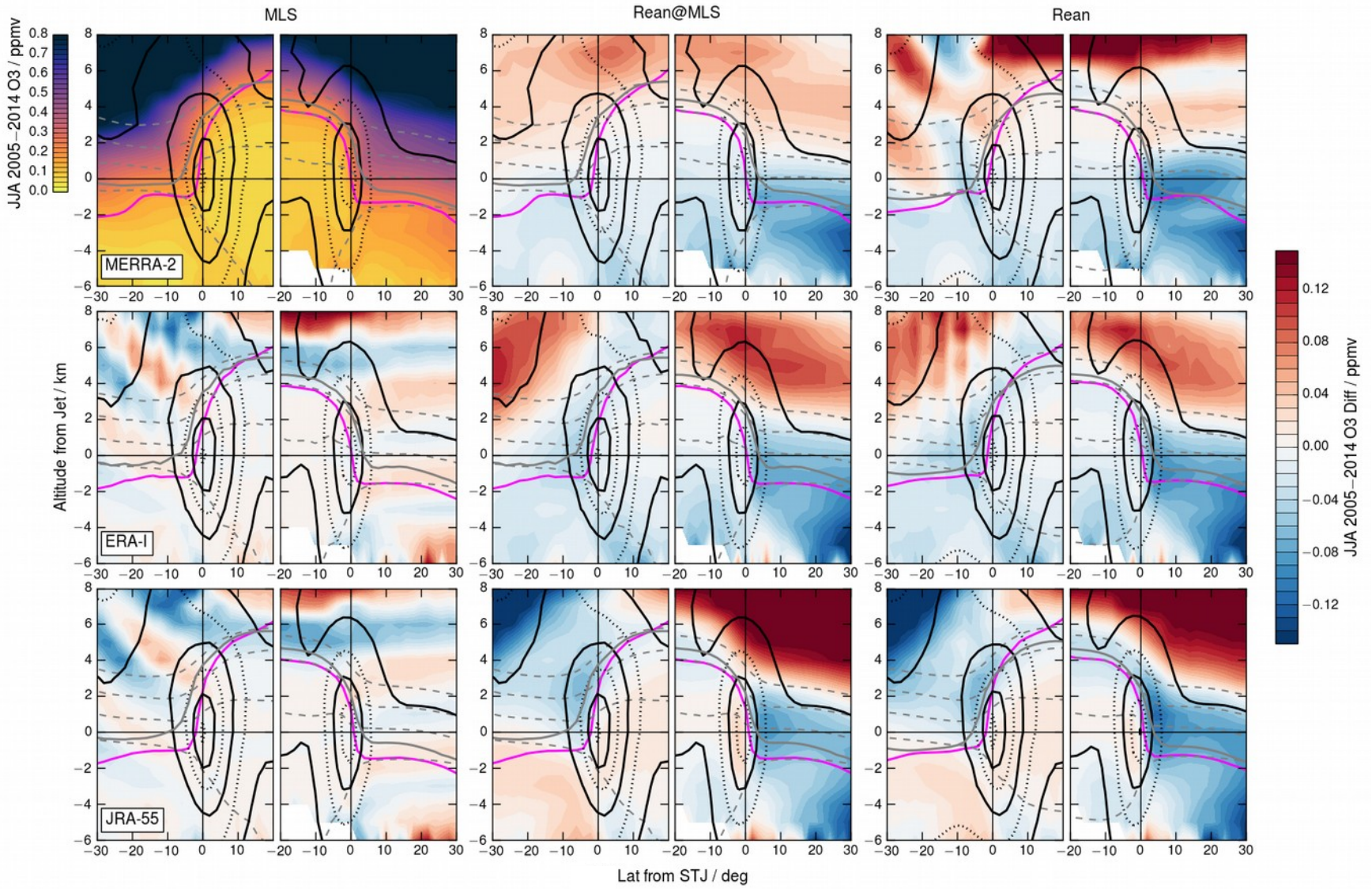
SAGE III/ISS SH SON 2018 (left) & 2019 (below) in various dynamical coordinates







Future work: Sampling Matters!



MLS O3 mapped with each reanalyses' dynamical fields

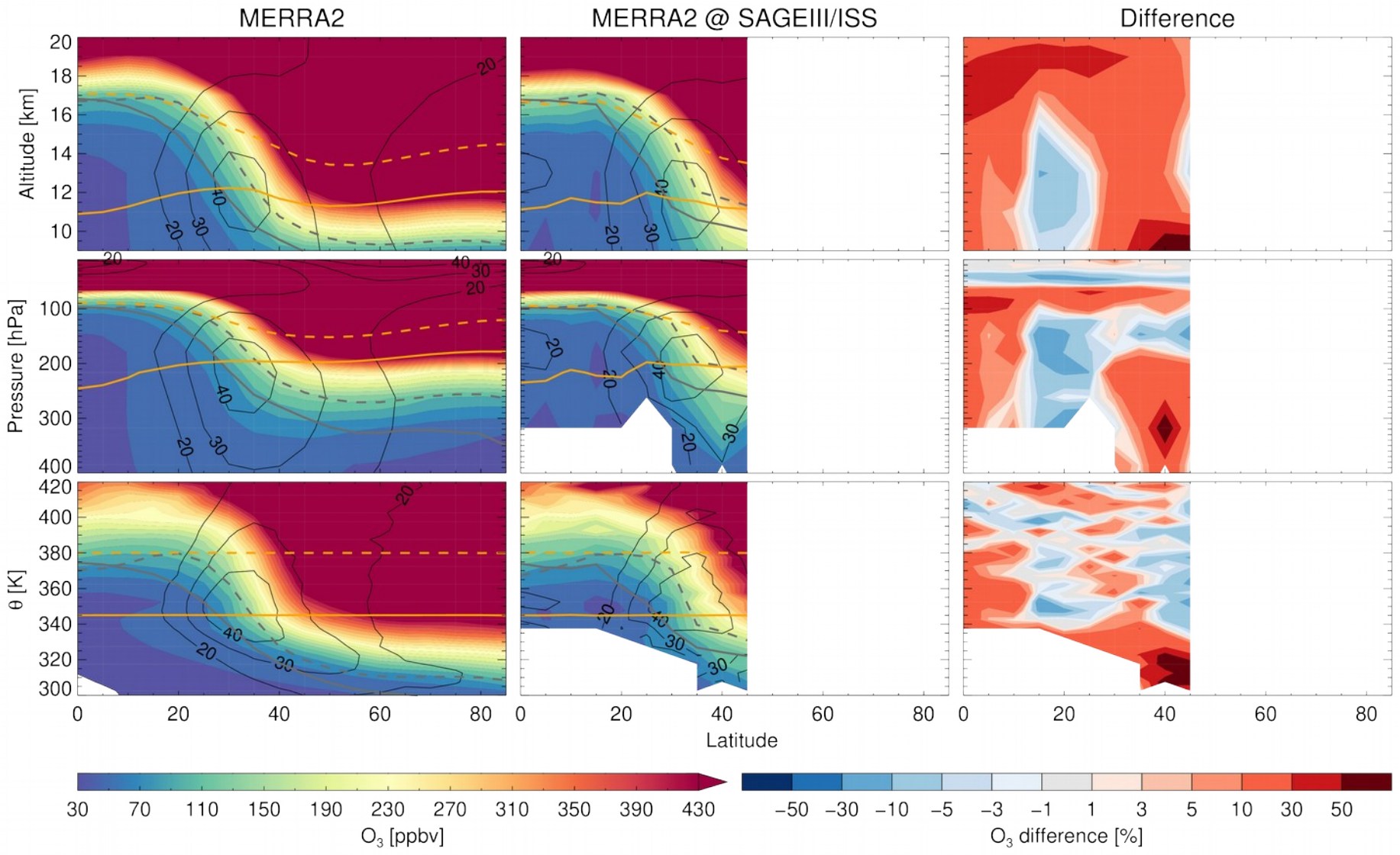
Each reanalyses' O3 interpolated to MLS locations before mapping

Each reanalyses' O3 mapped from its native grid

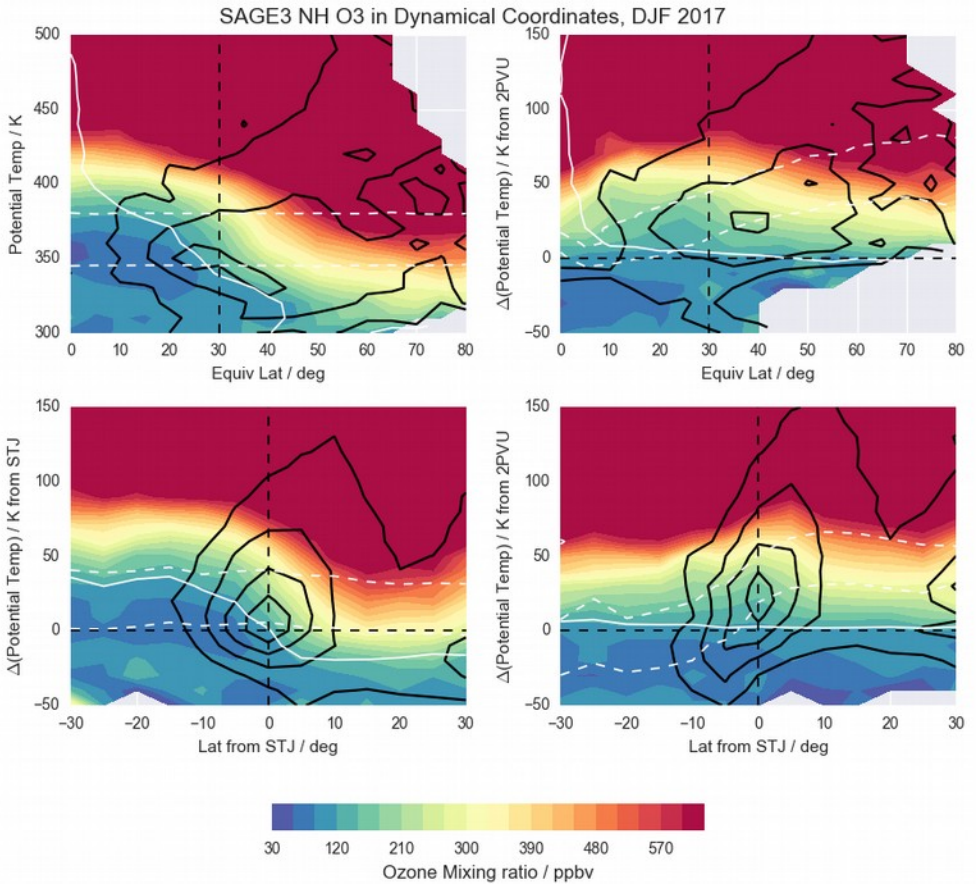
Chapter 7

S·RIP SPARC Reanalysis Intercomparison Project

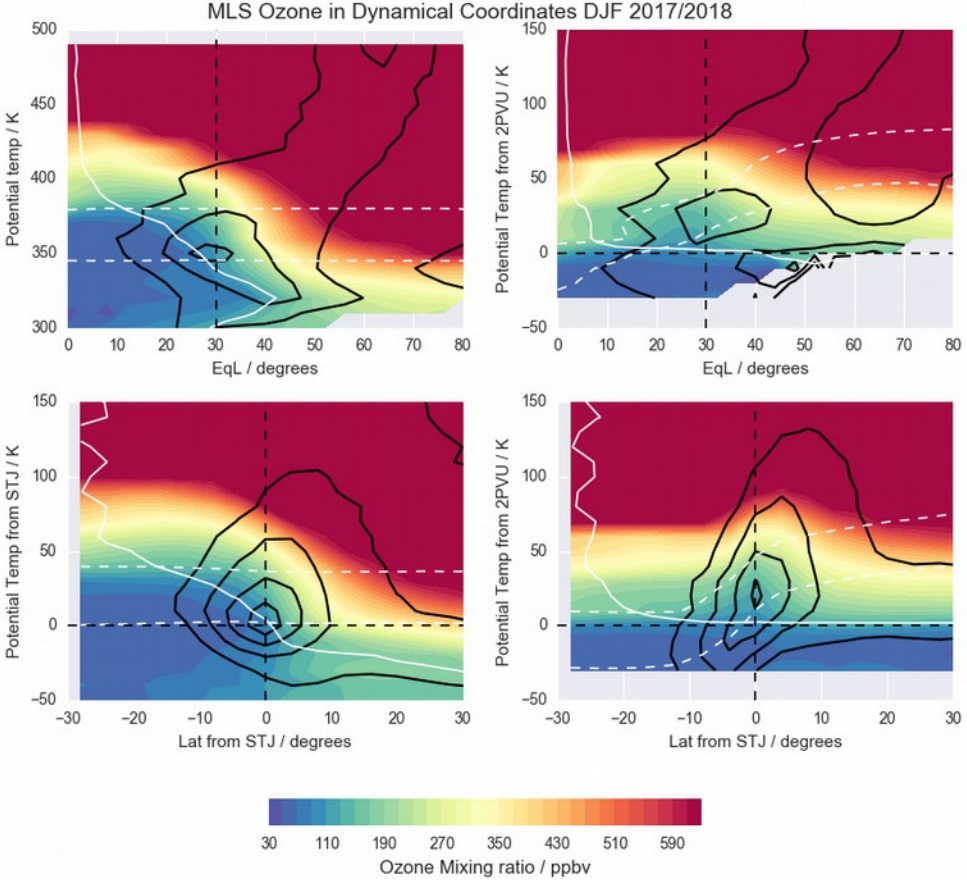
Future work: SAGE III Sampling Assessment



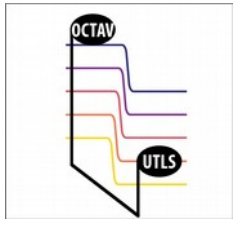
Future work: SAGE & MLS Comparison / Bias Assessment



SAGE III/ISS (left) and MLS (below) Ozone in dynamical coordinates for DJF 2017/2018



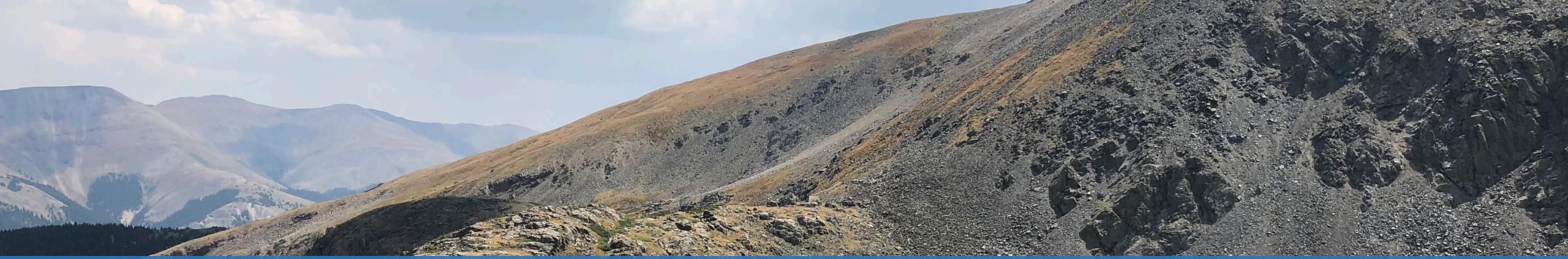
(black = windspeeds, solid white 2PVU, dashed white 345 and 380 K potential temperature)





Future work: Immediate Plans

- Continue to update and provide dynamical diagnostics for SAGE-III/ISS
- Eagerly awaiting v5.2, and will promptly reprocess dynamical diagnostics (including trajectory analysis)
- With v5.2, will do non-coincident validation of SAGE-III/ISS ozone with ACE-FTS, OSIRIS, and Aura MLS, using a variety of dynamical coordinates as per the above examples, as well as with MLS using trajectory-hunting methods
- With v5.2, will apply the tools we have been developing to assess sampling and instrument biases
- Description of SAGE-III/ISS dynamical diagnostics, and results of initial non-coincident validation in dynamical coordinates will be part of a planned paper for ESSD on dynamical diagnostics / coordinate mapping developed using JETPAC for the SPARC OCTAV-UTLS Activity
- Submit a proposal to the current SAGE-III/ISS call to continue this work and extend it to analysis of UTLS ozone variability and trends in dynamical coordinates



Near-global Variability of Stratospheric Water Vapor observed by SAGE III/ISS

Mijeong Park, Bill Randel, Robert Damedeo, David Flittner, Sean Davis and Karen Rosenlof

SAGE III/ISS Science Team Meeting, October 19-20, 2020

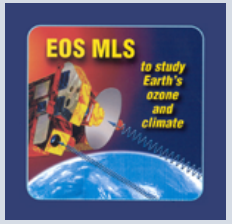
Mohawk lake, Colorado

SAGE III/ISS and MLS H_2O

1. H_2O Tape Recorder in the Tropical Stratosphere
2. Data Screening and Aerosol Sensitivity
3. Relative Humidity (RH)
4. Seasonal Variability

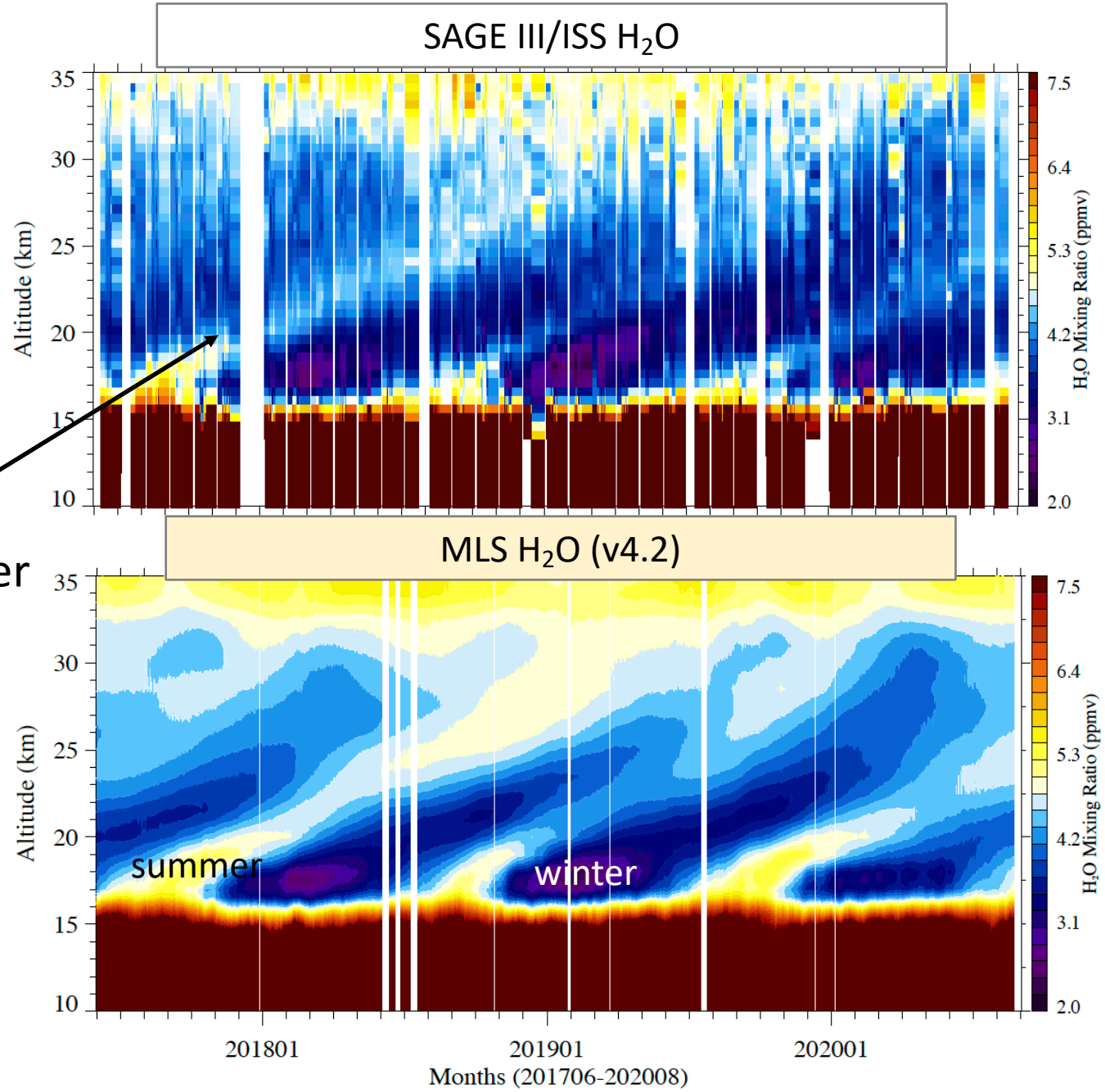
Data - SAGE III/ISS v5.1 H_2O (Jun 2017-May 2020)

MLS H_2O v4.2 and v5.0 (interpolated to an altitude grid)





H_2O tape recorder (15S-15N) Jun 2017-Aug 2020



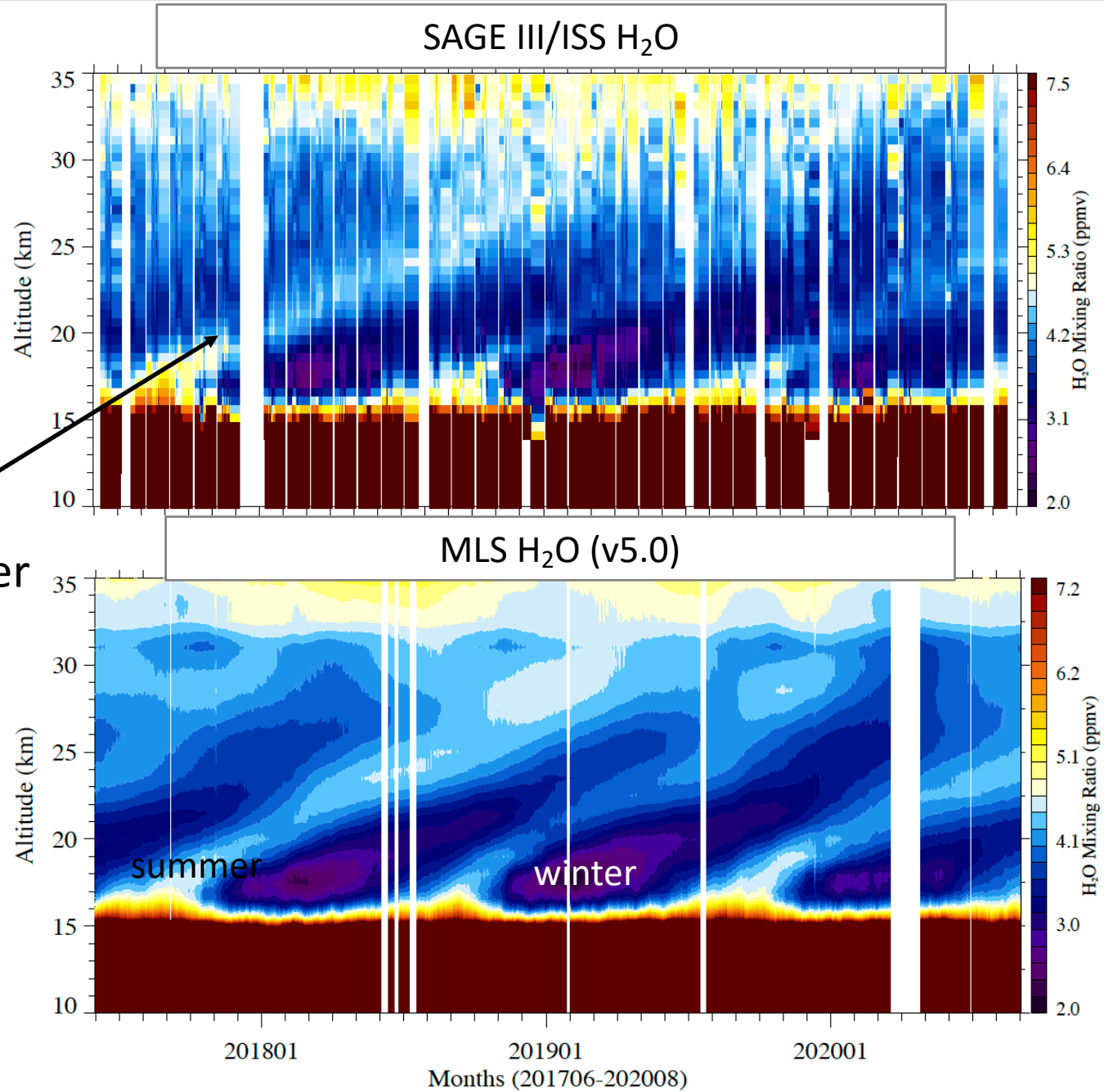
H_2O tape recorder (wet phase/ dry phase)

SAGE III/ISS and MLS H_2O agree in phase and amplitude (16-30 km).

SAGE III/ISS ~ 10 % drier than MLS v4.2 H_2O in the stratosphere (Davis et al., 2020).

H_2O tape recorder (15S-15N) Jun 2017-Aug 2020

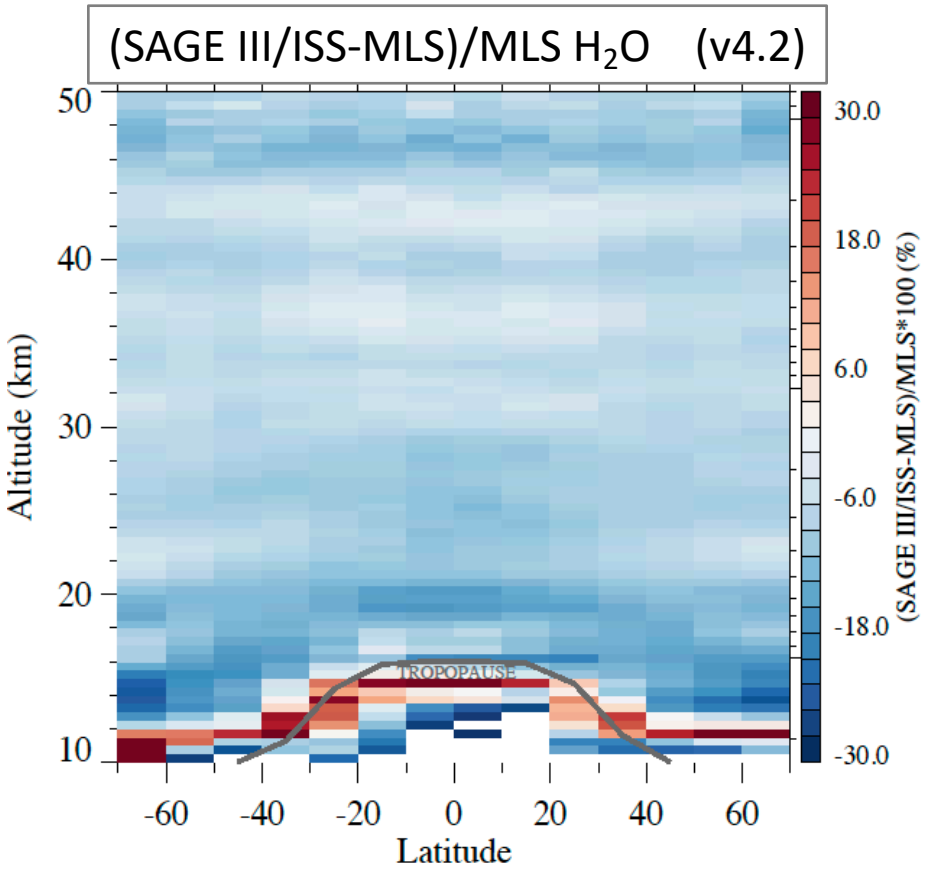
H_2O tape recorder (wet phase/ dry phase)



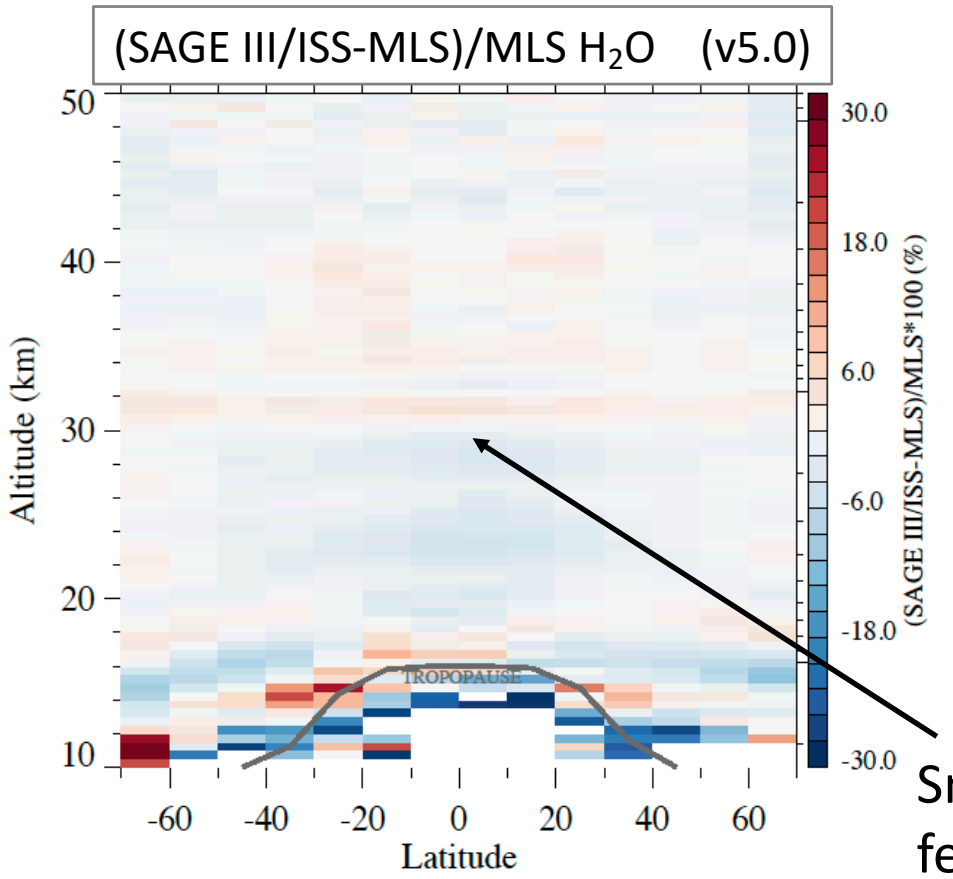
SAGE III/ISS agrees with MLS v5.0 H_2O in the stratosphere.

MLS v5.0 is ~5-10 drier than v4.2 (instrument drift issues).

SAGE III/ISS & MLS H_2O Differences (v4.2 & v5.0)



SAGE III/ISS ~ 10 % drier than MLS v4.2 H_2O in the stratosphere.

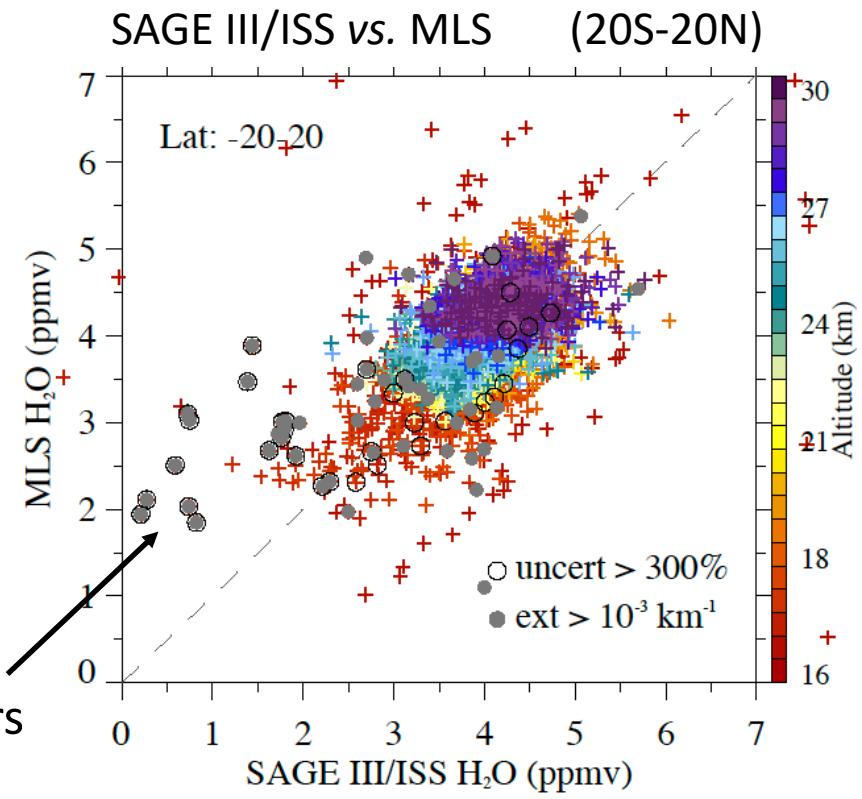


Small scale features remain.

SAGE III/ISS agrees with MLS v5.0 H_2O in the stratosphere.

SAGE III/ISS – H_2O Screening (example - Nov. 2017)

Before Screening

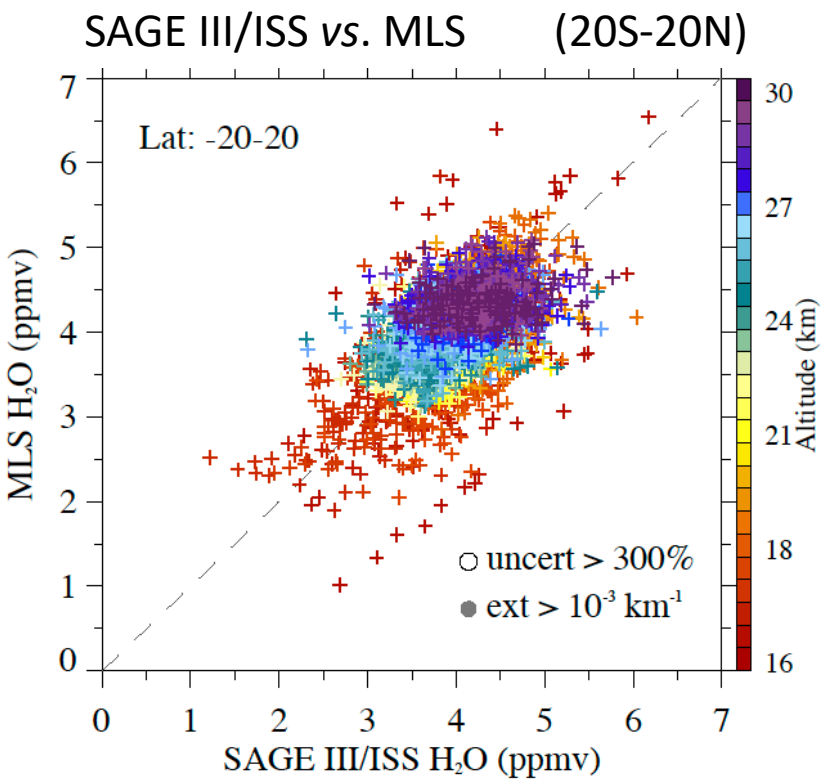


outliers

Uncertainty (300 %)

Aerosol Ext. at 1022 nm (10^{-3} km^{-1})

After Screening



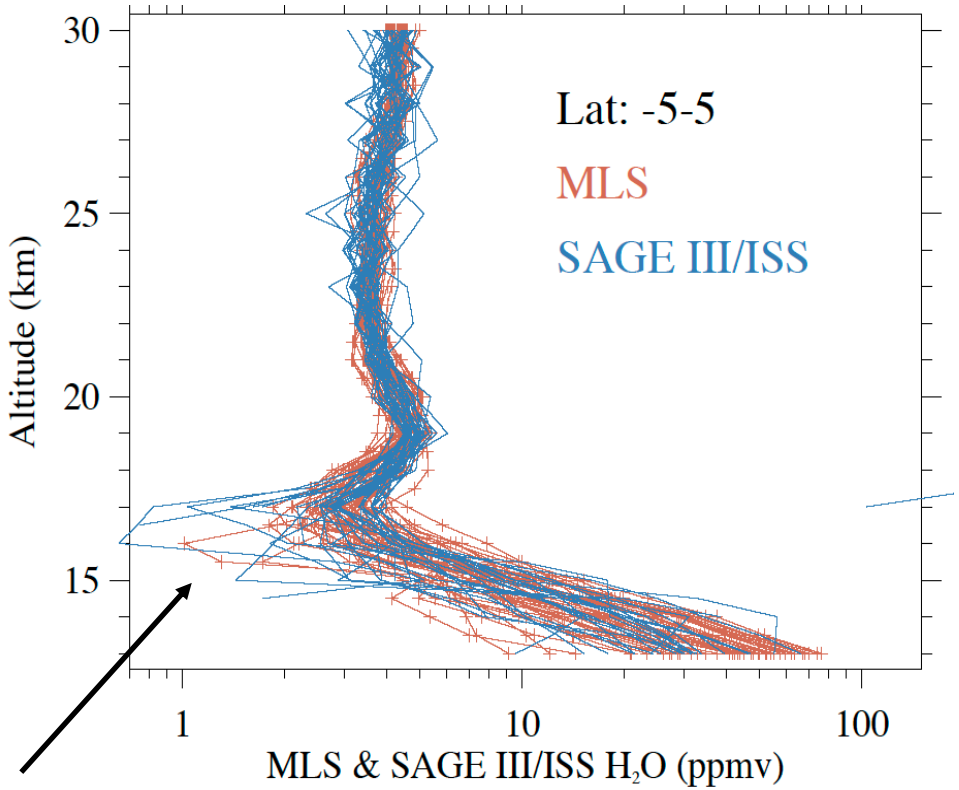
The screening filters out obvious outliers but not all (~1.2 % of total profiles).

<u>Screening Criteria</u>
(Davis et al. 2020)

Anomalous events
Keel over
Color ratio (B1022/B520)

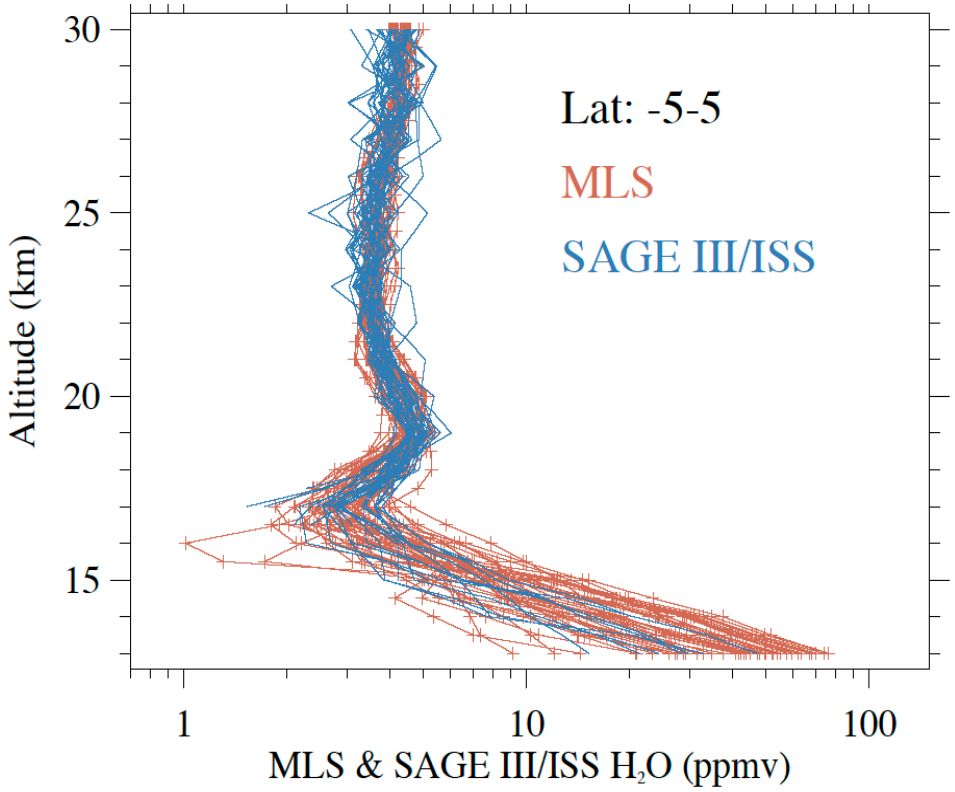
SAGE III/ISS – H_2O Screening 5S-5N (example - Nov. 2017)

Before Screening



outliers & very low H_2O

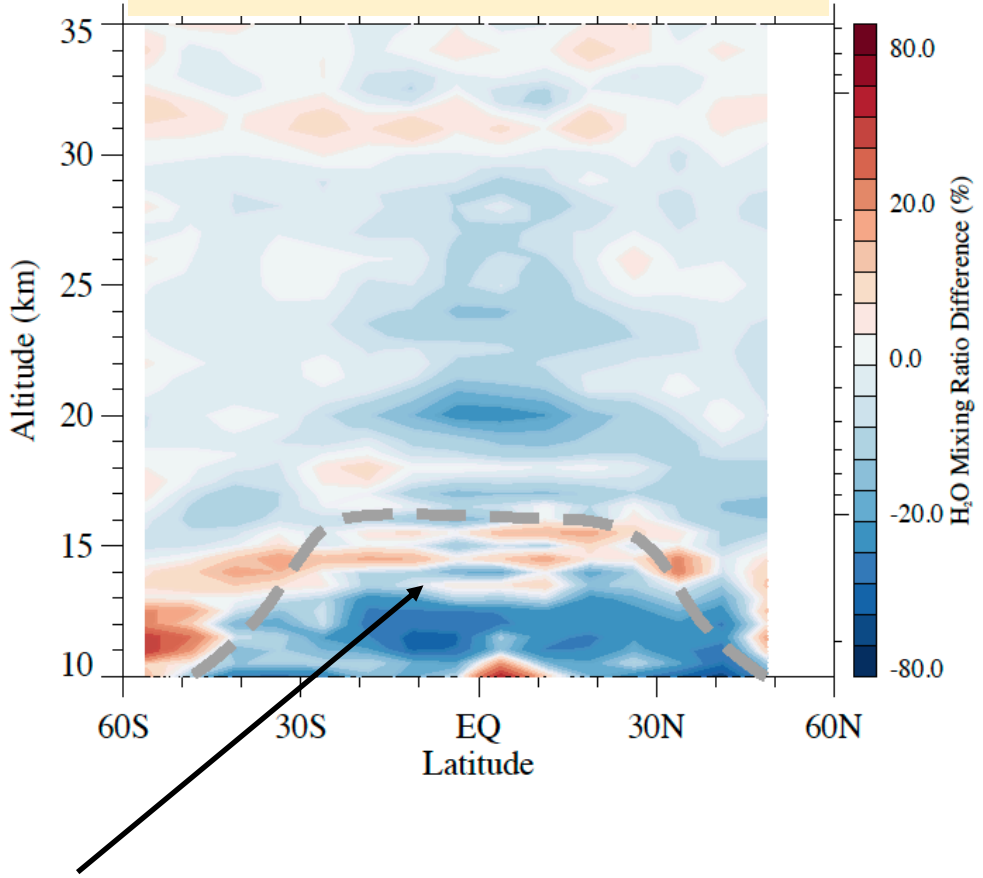
After Screening



SAGE III/ISS *vs*. MLS H_2O + Aerosol Sensitivity (Nov 2019)

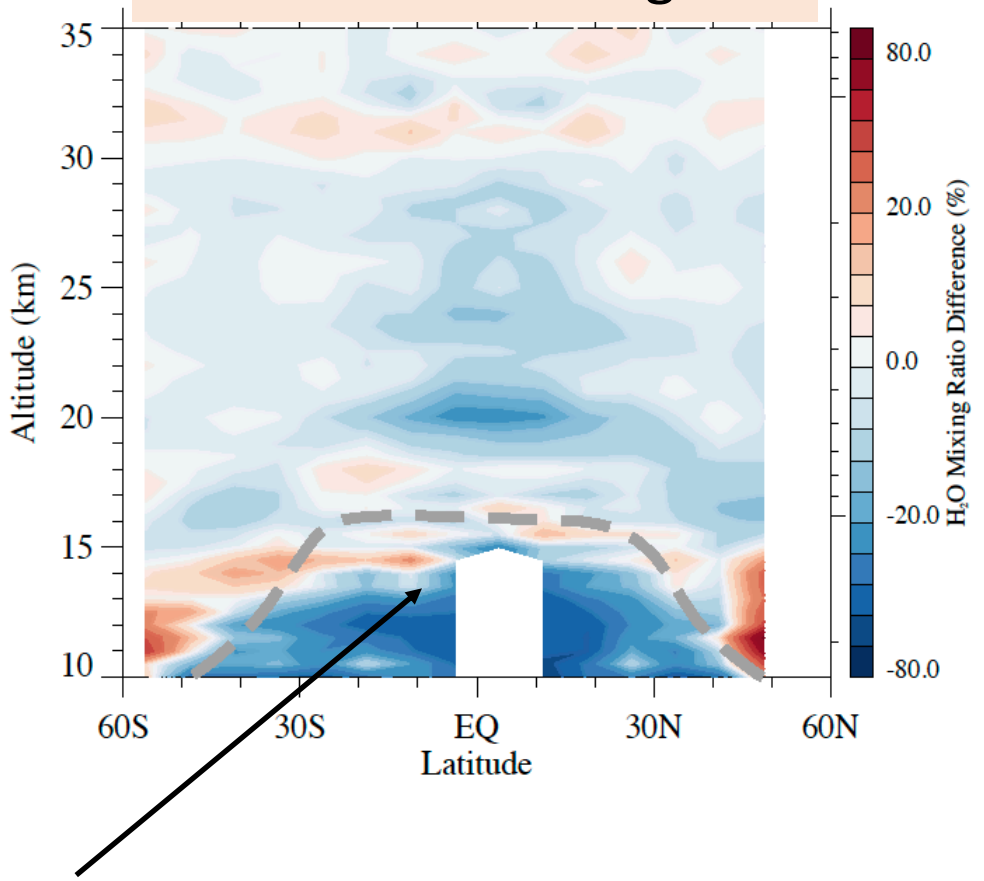
(SAGE III/ISS-MLS)/MLS

Before Screening



Noise

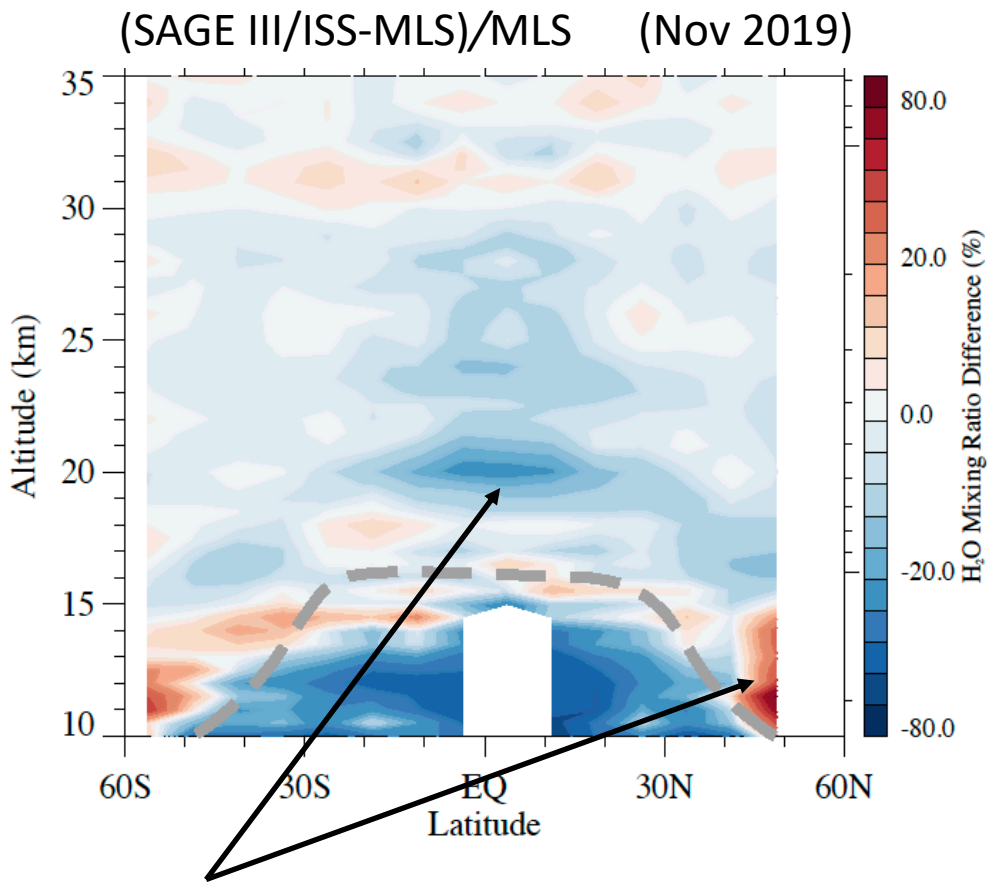
After Screening



Filtered

Filtering affects low altitudes.

SAGE III/ISS *vs*. MLS H_2O + Aerosol Sensitivity (Nov 2019)



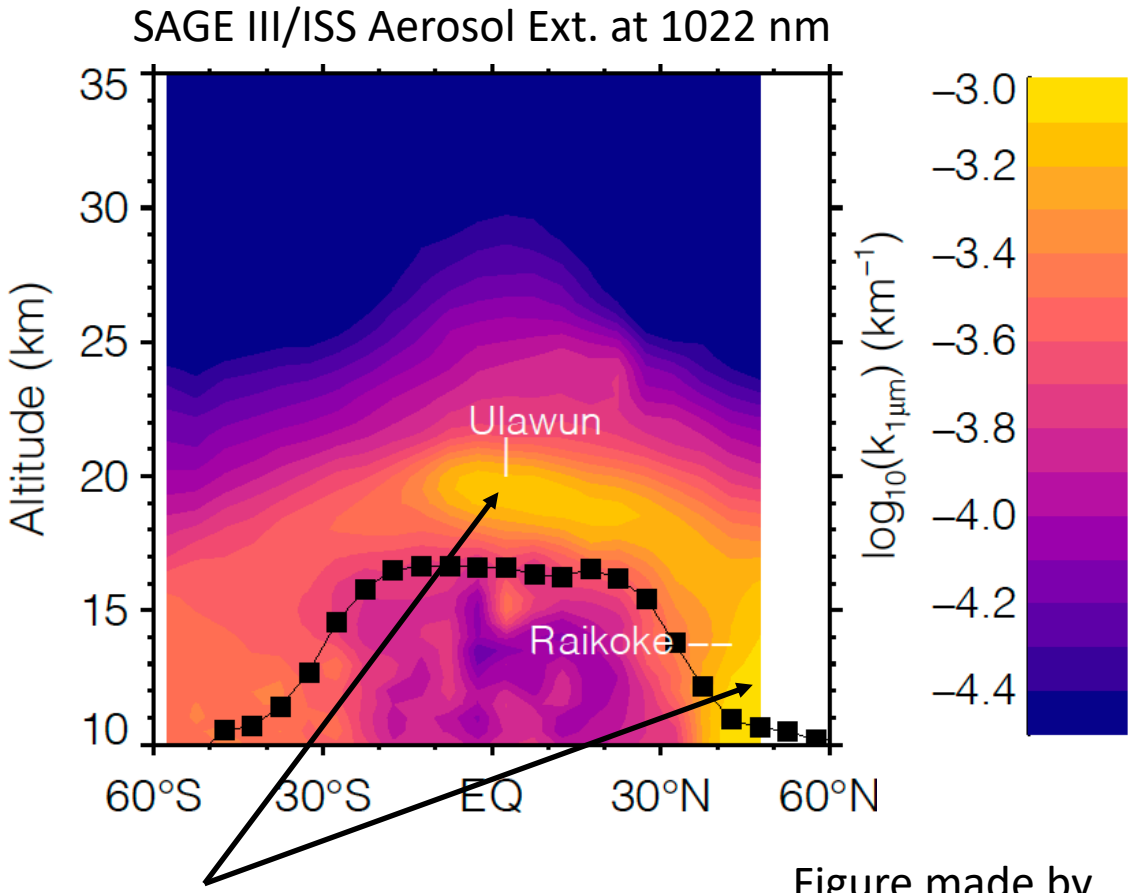
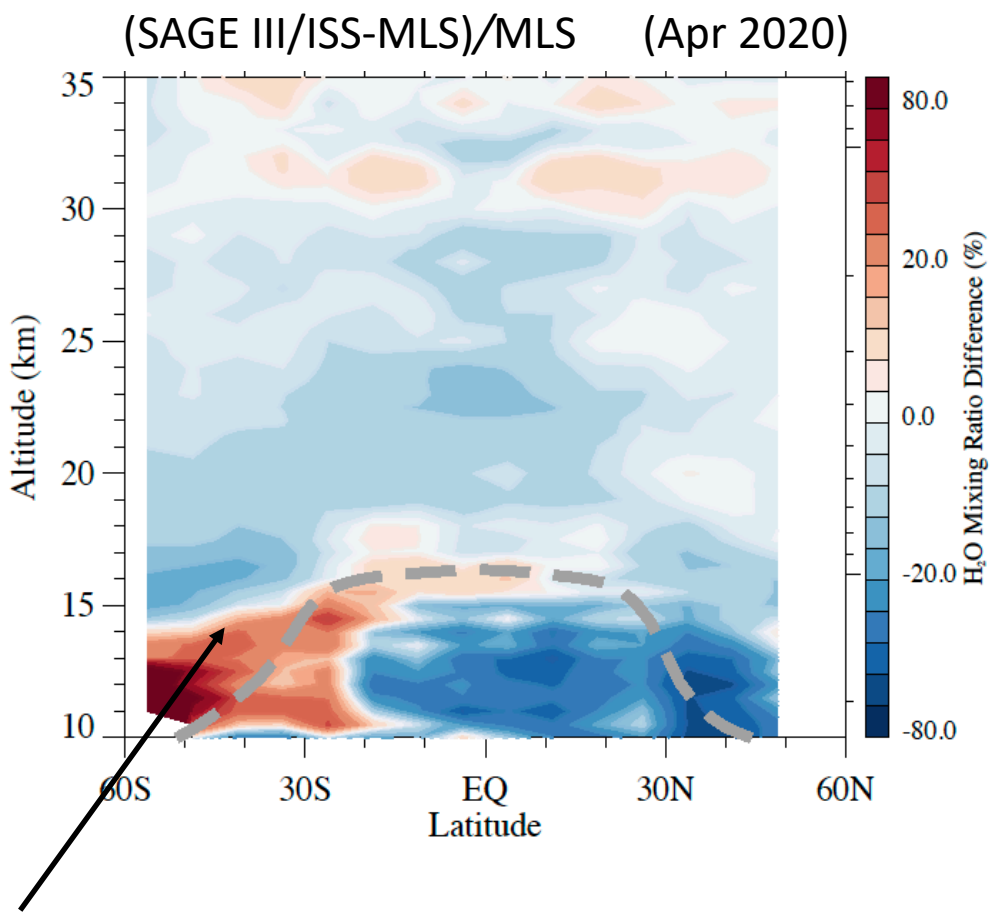


Figure made by Rob Damadeo

Larger difference coincides with high aerosol loadings related to volcanic eruptions.

SAGE III/ISS *vs*. MLS H_2O + Aerosol Sensitivity (Apr 2020)



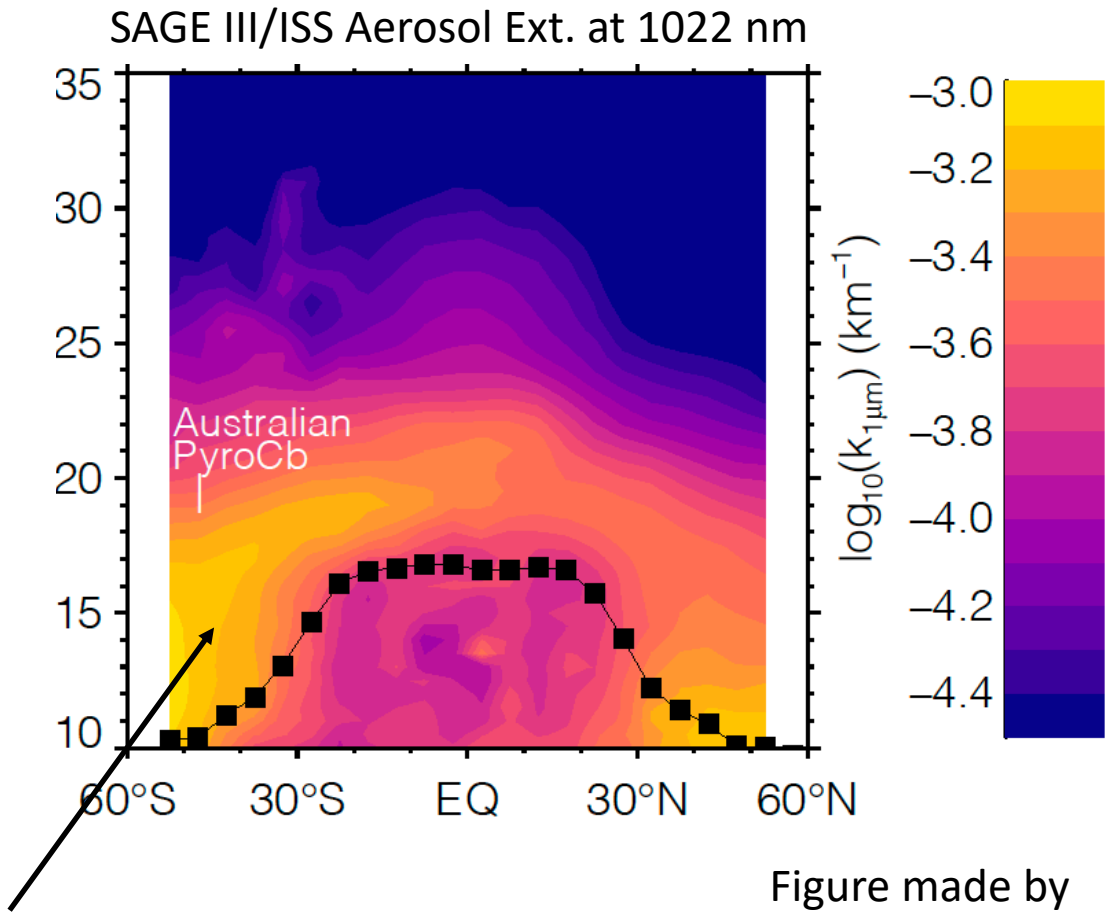
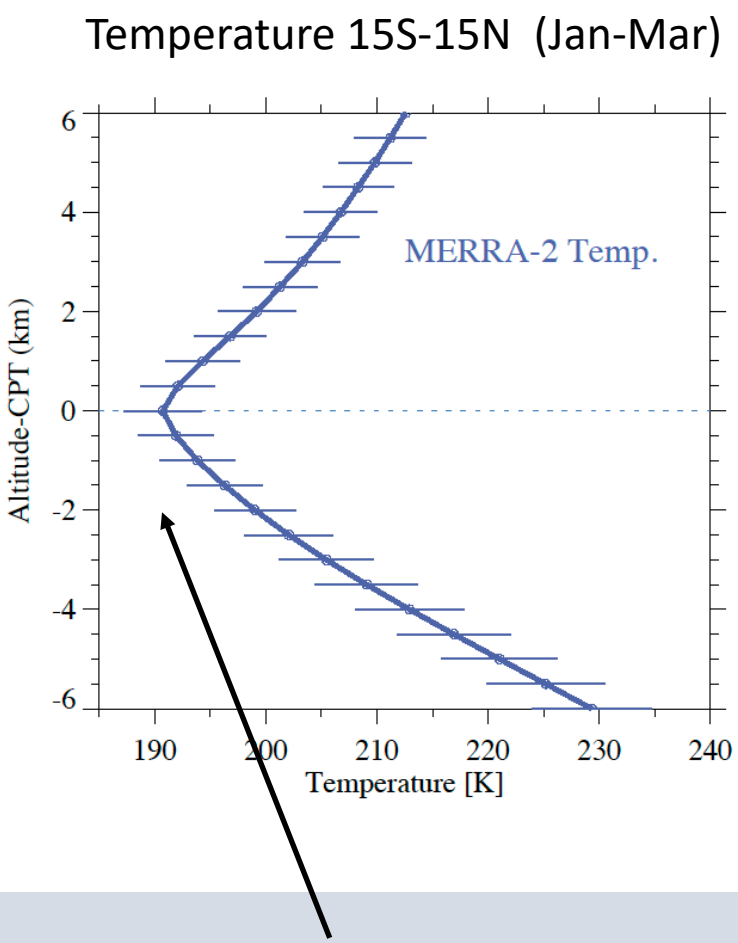
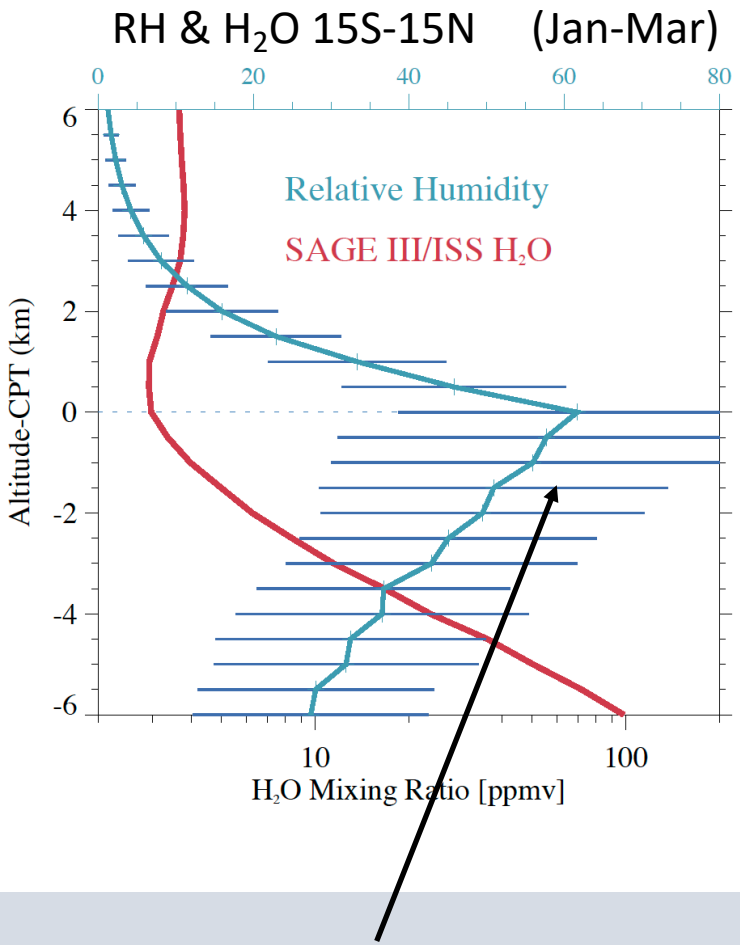


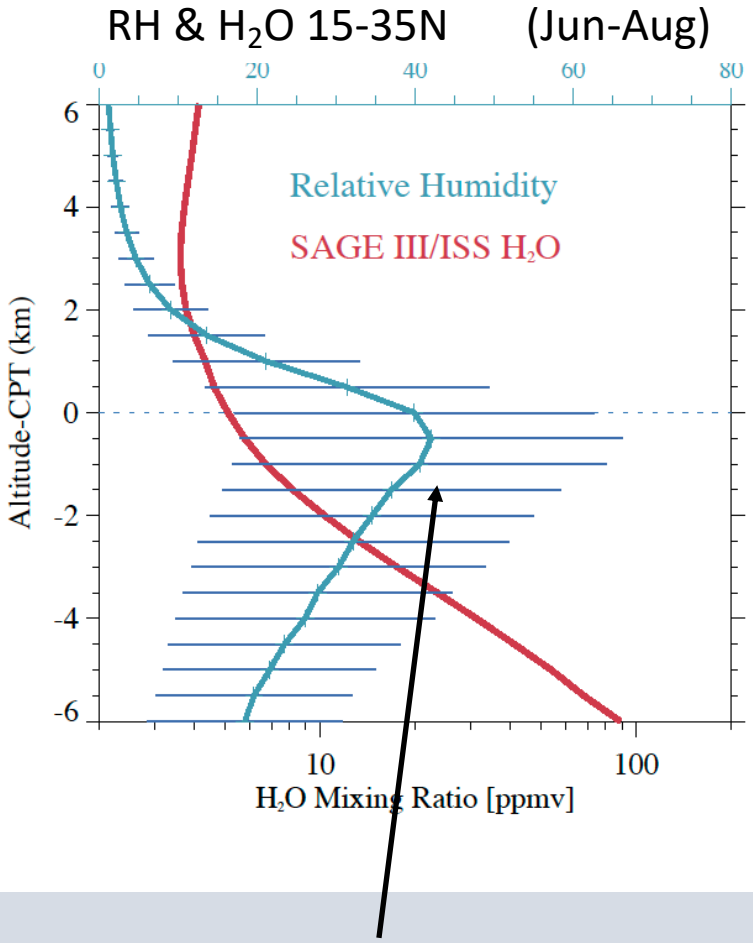
Figure made by
Rob Damadeo

Larger difference coincides with high aerosol loadings related to volcanic eruptions.

SAGE III/ISS H_2O – Temperature - Relative Humidity (RH)





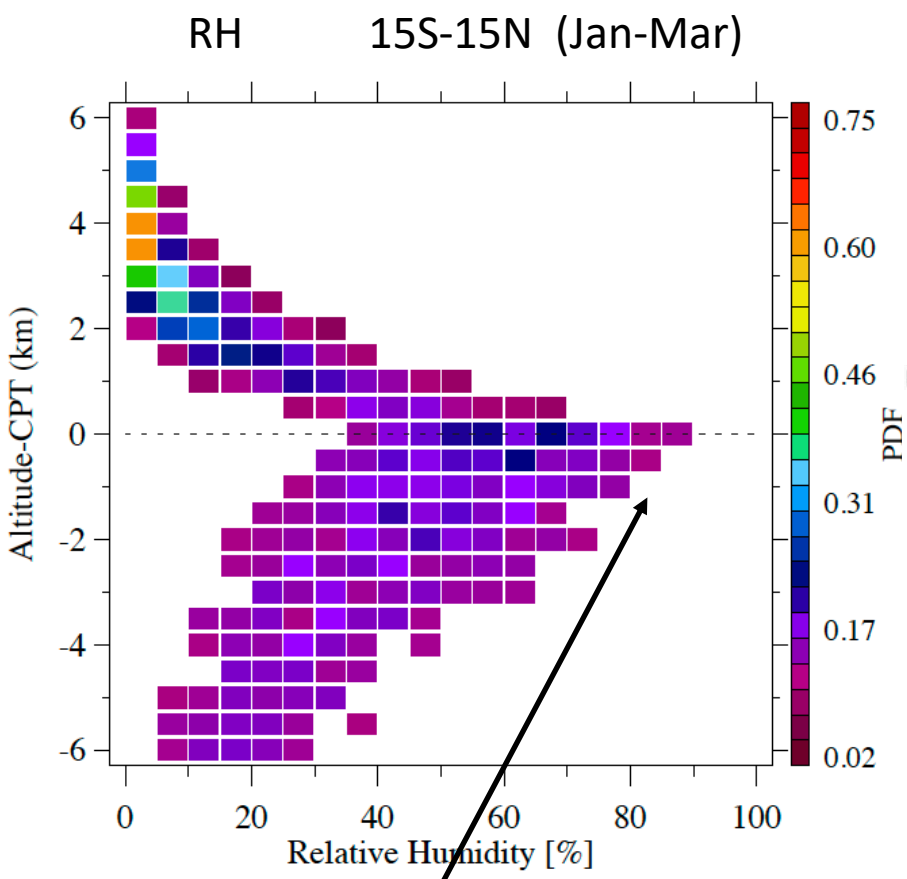


CPT
(Tropics, winter)

High RH
(Tropics, winter)

Drier
(Subtropics, summer)

SAGE III/ISS RH PDF (Winter vs. Summer)



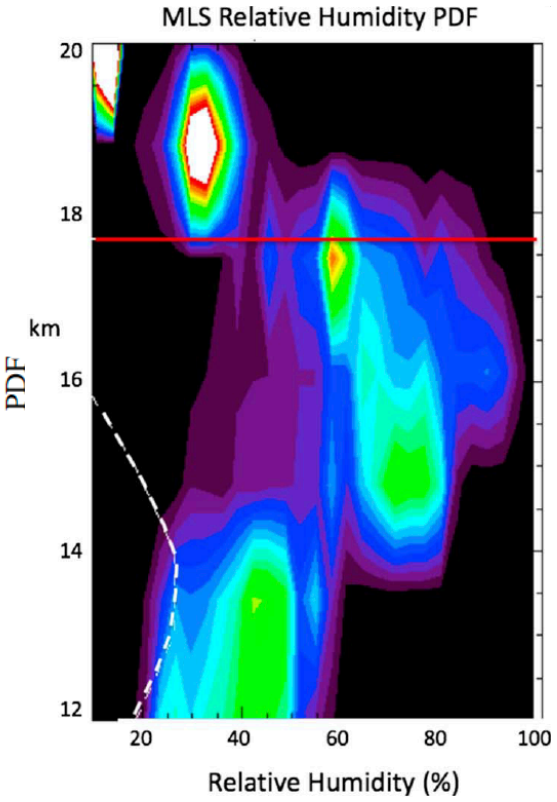
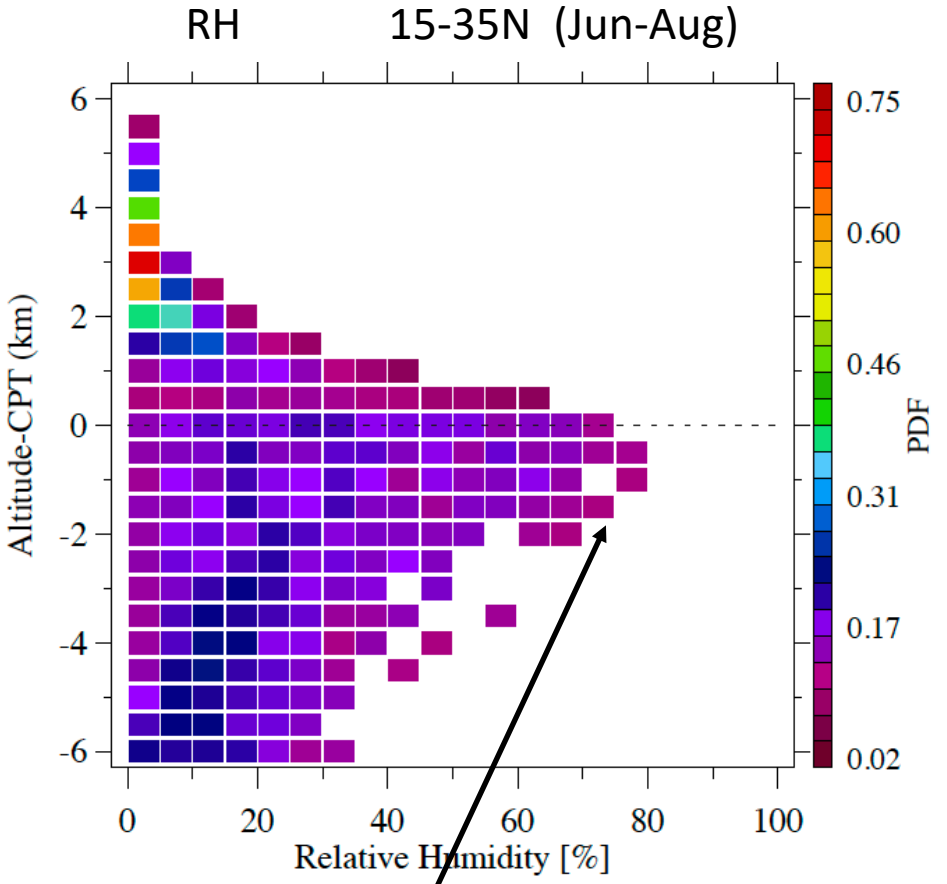


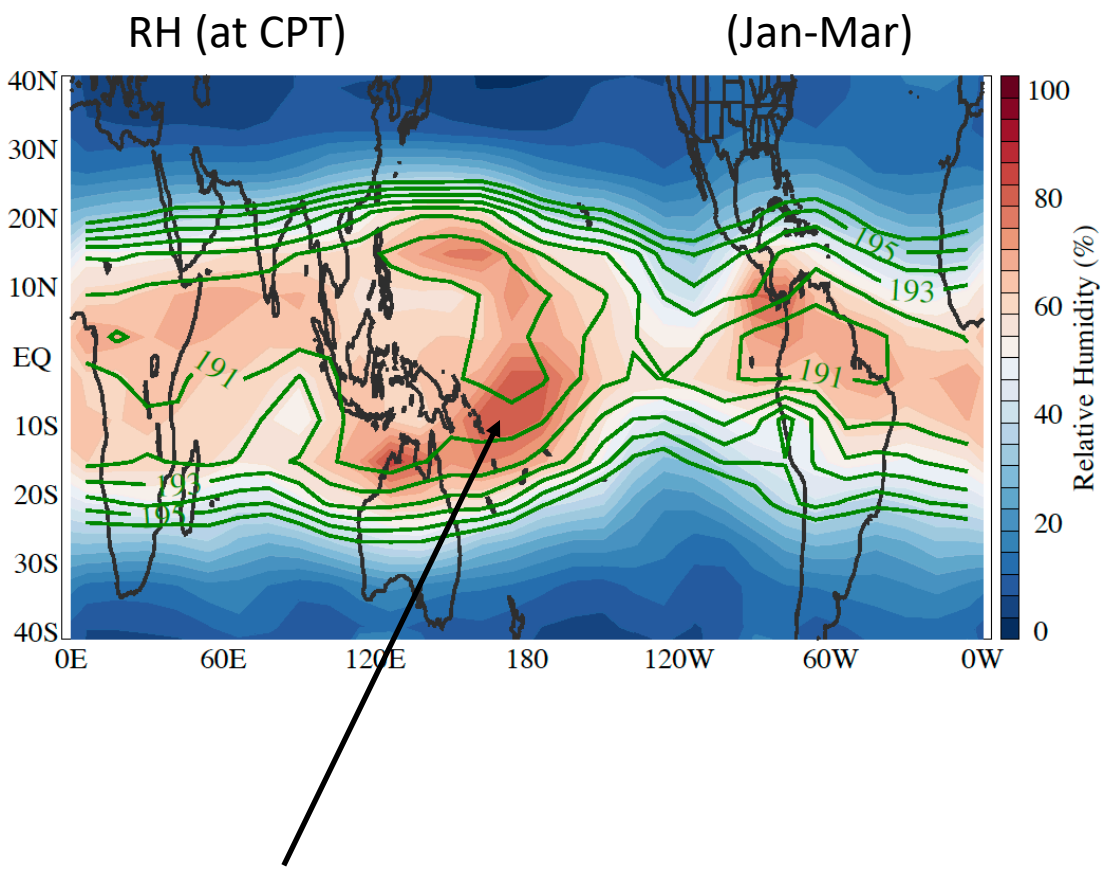
Fig. 4 - Schoeberl et al. (2019)

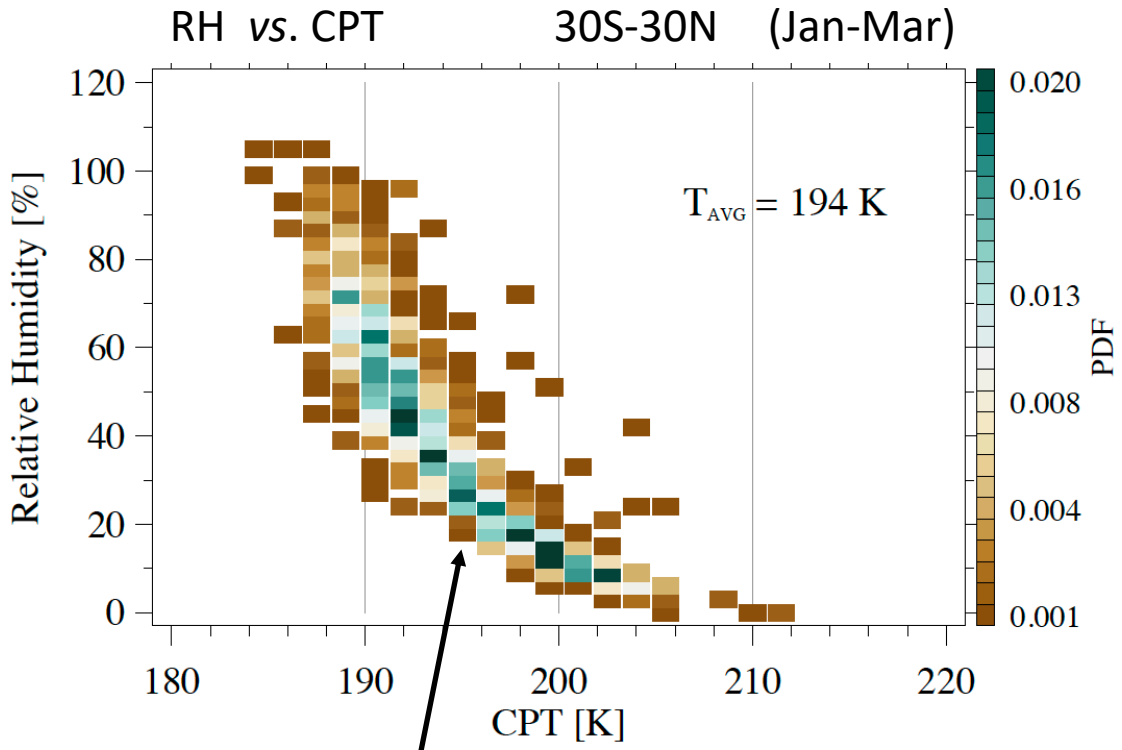


Max RH at CPT then sharp decrease above the CPT.

Drier than tropics. Max RH below the CPT. CPT is not well defined.

SAGE III/ISS RH PDF (at CPT) (Jan-Mar)

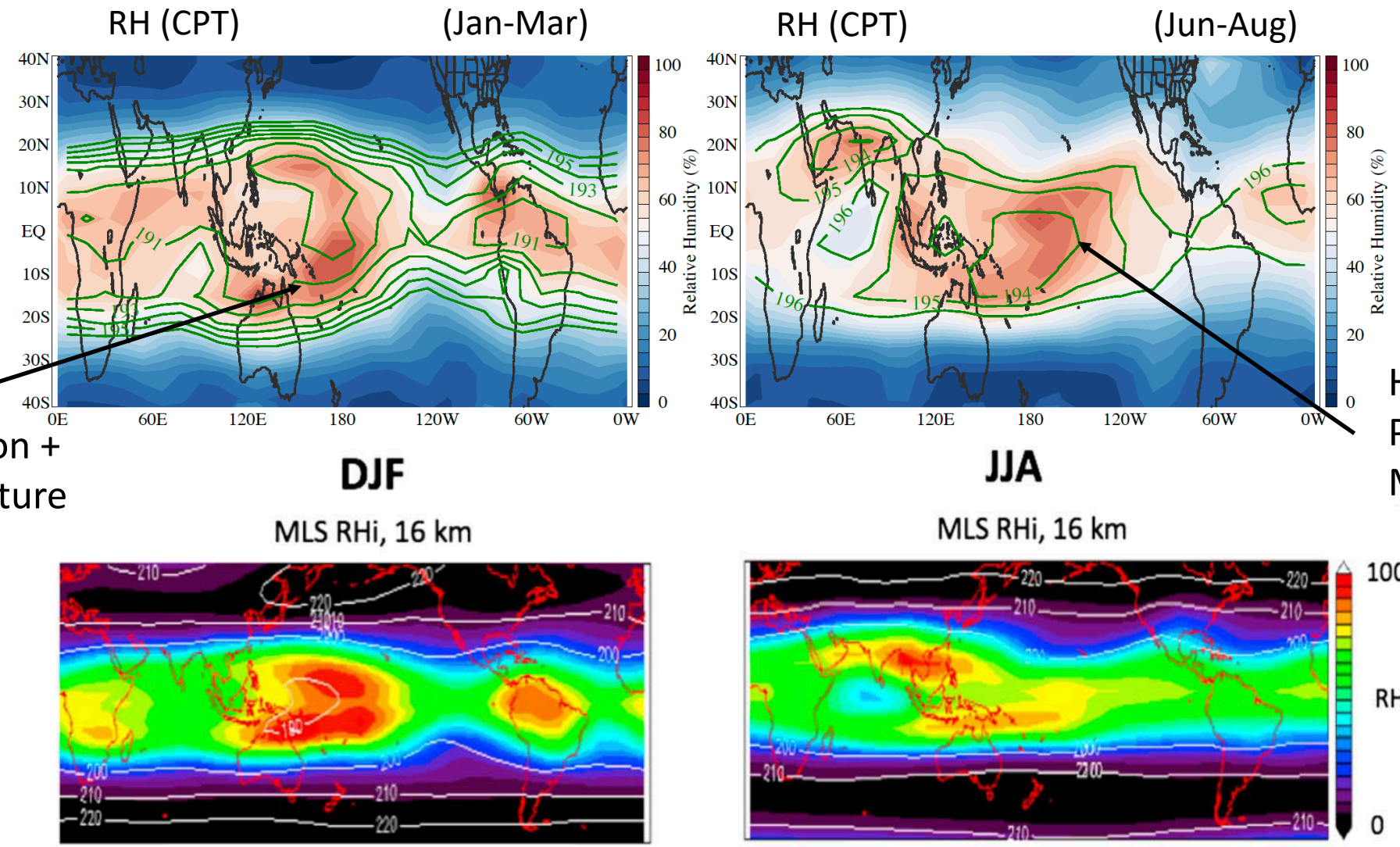




Max RH over Western Pacific, South America and Africa where CPT is cold.

CPT – 190-200 K (average=194K)
RH – 0-60 %

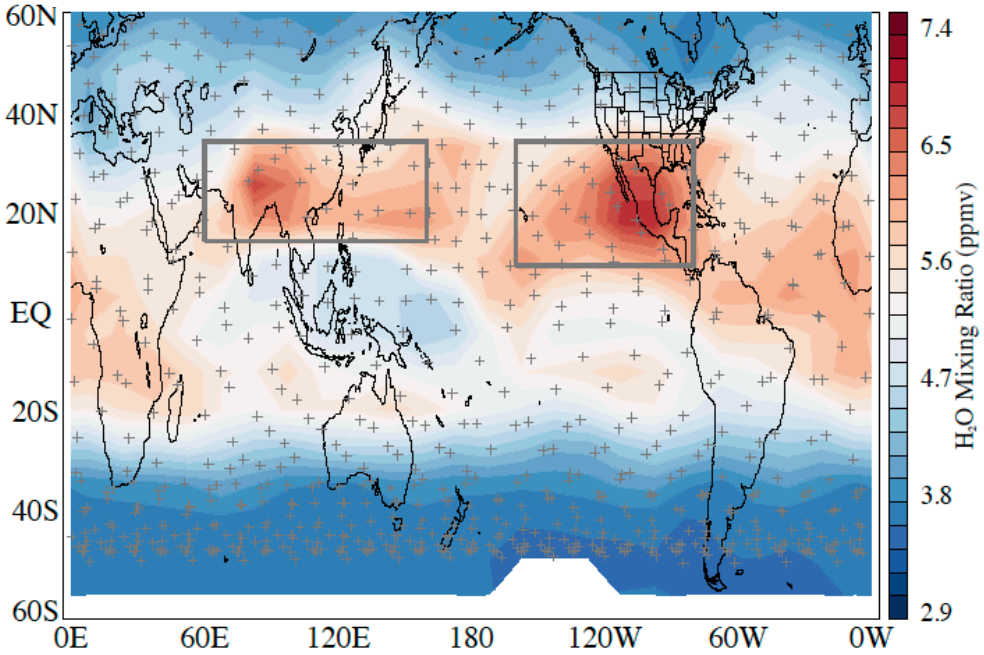
SAGE III/ISS RH PDF (at CPT) Winter/Summer



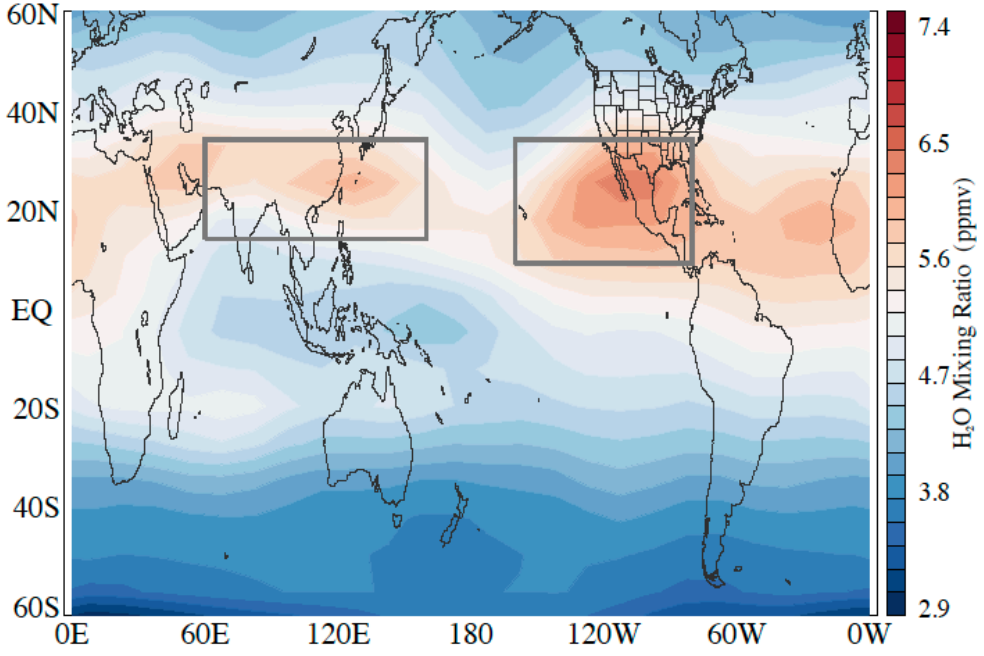
Schoeberl et al. (2019) – Figure 2 (8-year average RHI from MLS H_2O + MERRA-2 Temperature)

SAGE III/ISS and MLS H_2O 16.5 km August 2017

SAGE III/ISS H_2O 16 .5 km (Aug 2017)



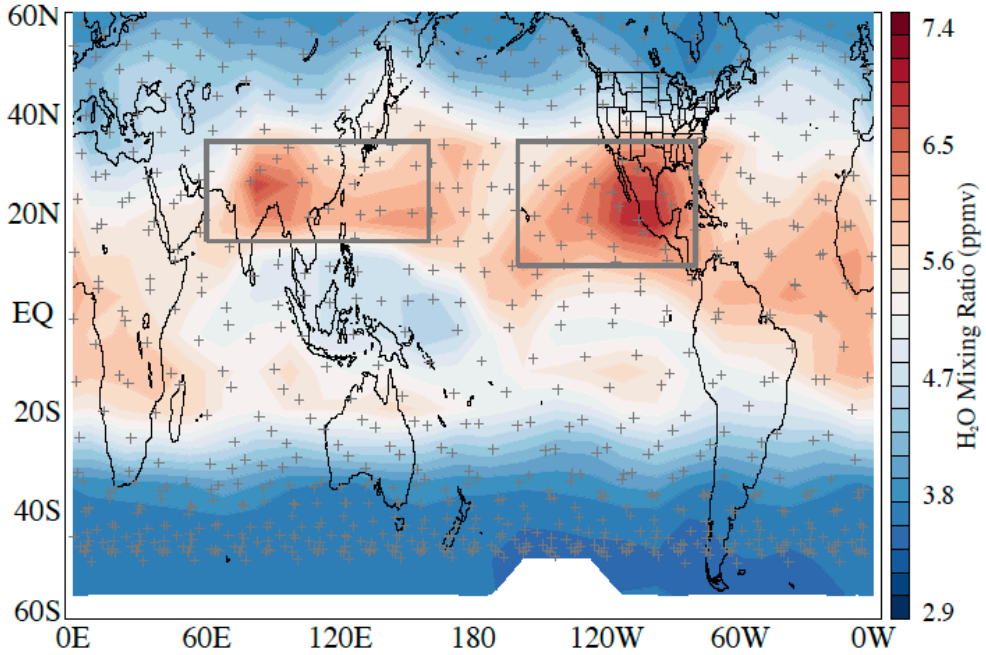
MLS H_2O 16 .5 km (Aug 2017)



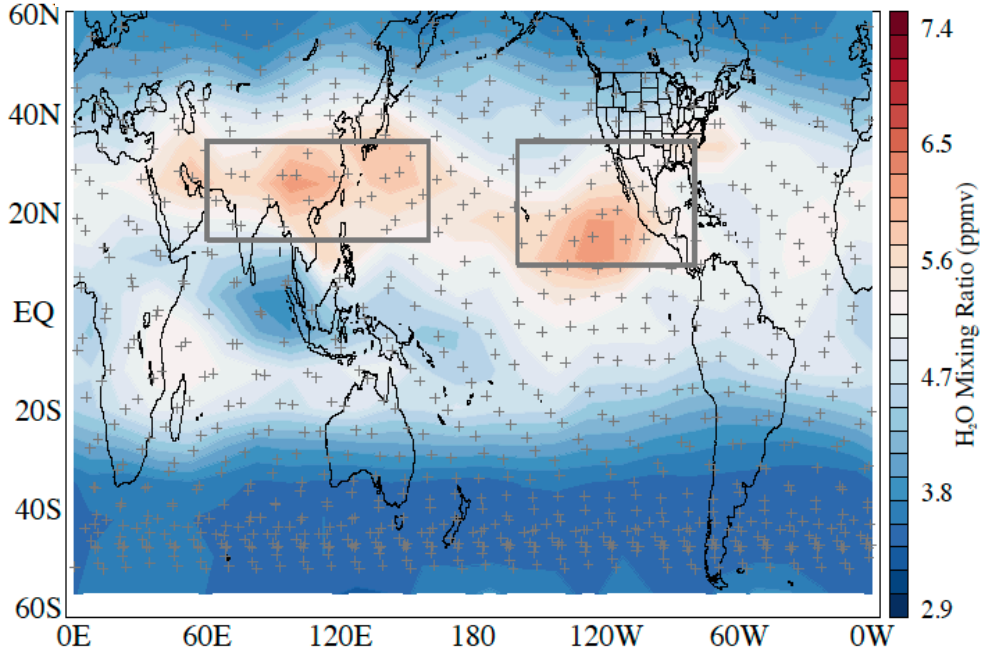
Max H_2O over Asian and North American monsoons.
Max over N. America is larger than one over Asia (SAGE III/ISS and MLS).

SAGE III/ISS H_2O 16.5 km August 2017/2018

SAGE III/ISS H_2O 16 .5 km (Aug 2017)

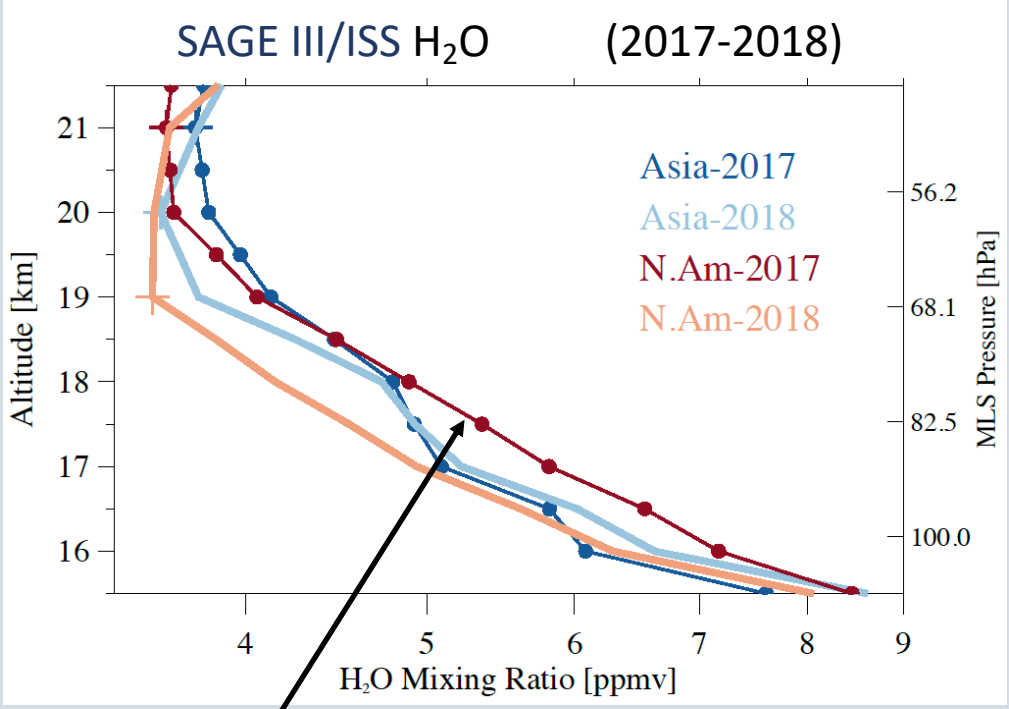


SAGE III/ISS H_2O 16 .5 km (Aug 2018)

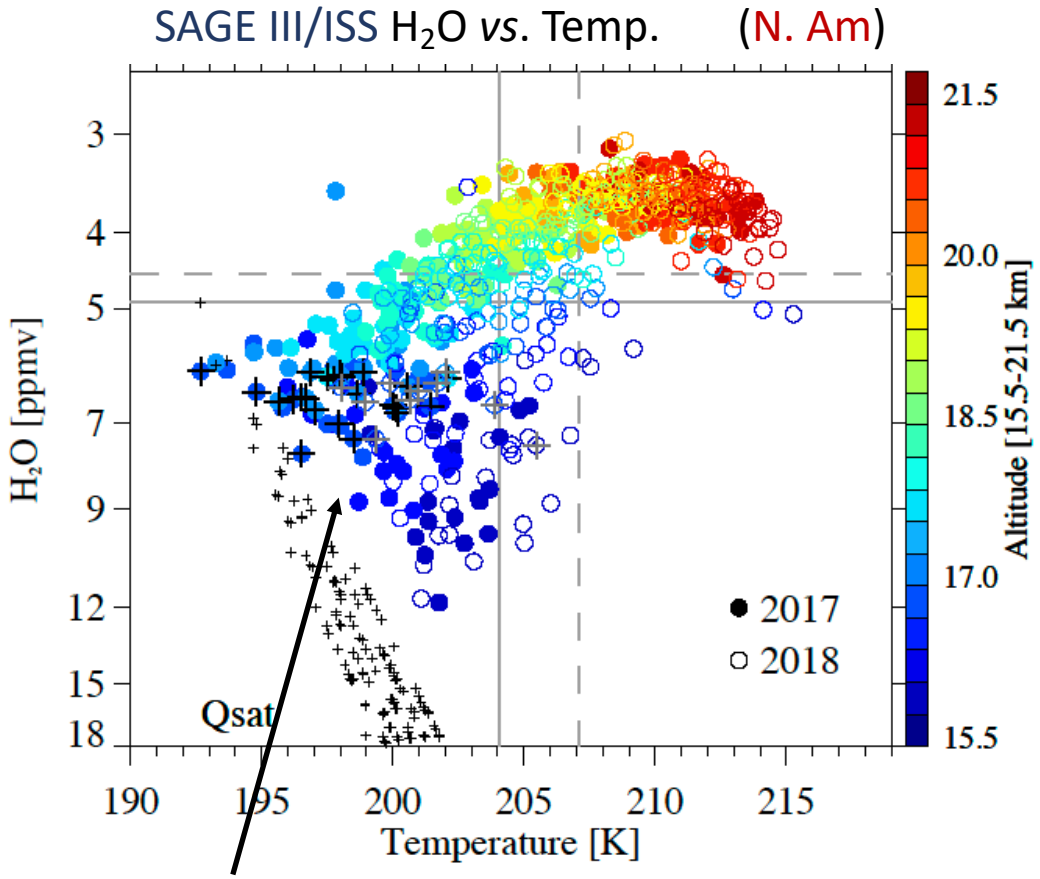


Max H_2O over Asian and North American monsoons.
Max over North America is larger in 2017 than 2018.

SAGE III/ISS H_2O N. America August 2017/2018

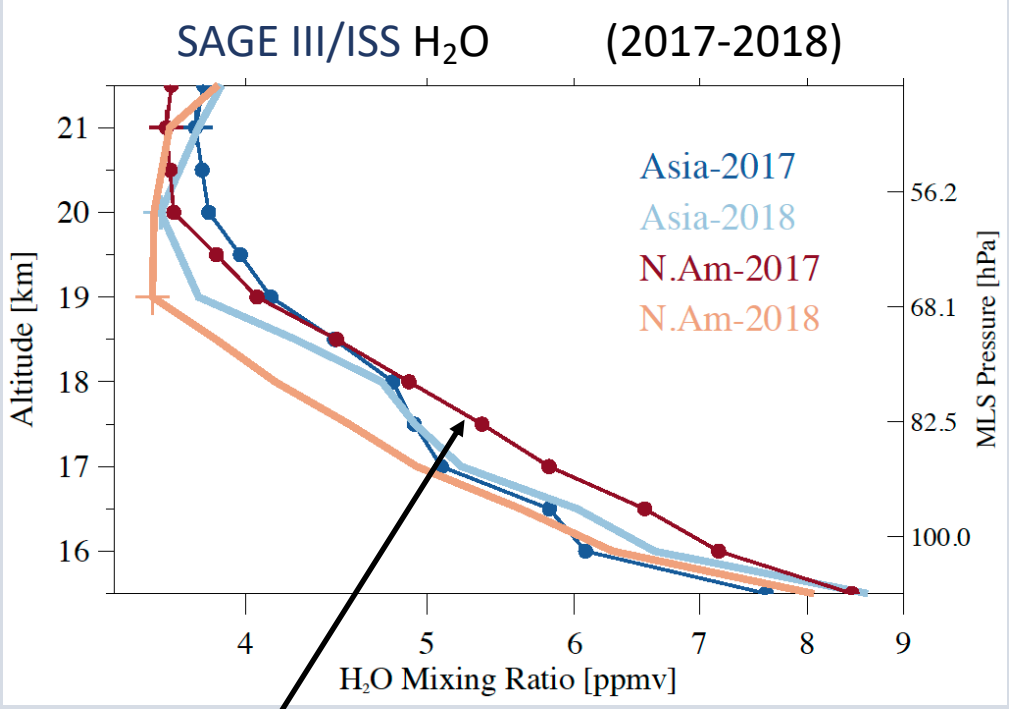


N. America (2017) – Highest H_2O (16-18.5 km)

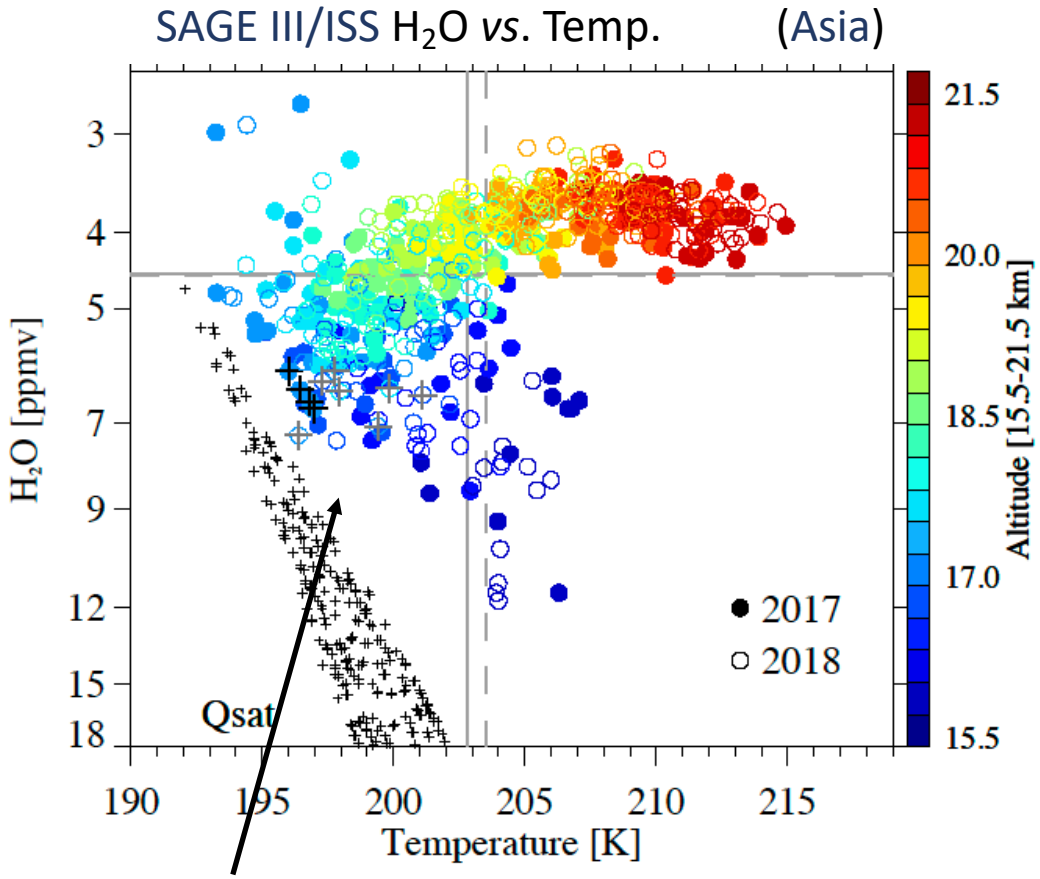


North America (2017)
- High H_2O & Low Temperature
- H_2O > 6 ppm (above CPT)

SAGE III/ISS H_2O Asia August 2017/2018



N. America (2017) – Highest H_2O (16-18.5 km)



Asia (2017 & 2018)

- Low H_2O & Low Temperature
- Very few H_2O > 6 ppm exists above CPT

Summary

- SAGE III/ISS agrees with MLS H_2O version 5 in terms of spatial and temporal variability in the stratosphere for June 2017-May 2020.

- Relative humidity (RH) calculated from SAGE III/ISS H_2O at CPT show seasonal maxima over the Western Pacific and Africa in NH winter and central Pacific and Asian monsoon region in NH summer.

- SAGE III/ISS H_2O retrieval sensitivity to stratospheric aerosol loadings needs further evaluation. Looking forward to version 5.2 release!



Jet Propulsion Laboratory
California Institute of Technology

Ground-Based Diurnal Measurements of NO_2 and NO_3 in Support of SAGE-III/ISS Validation

Thomas J. Pongetti[1], King-Fai Li[2], Yuk L. Yung[3], Steven S. Brown[4],
Stanley P. Sander[1,2] and the SAGE-III/ISS Algorithm Team[5]
[1]JPL/Caltech, [2]Caltech, [3]UC Riverside, [4]NOAA, [5]NASA/Langley

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Objectives

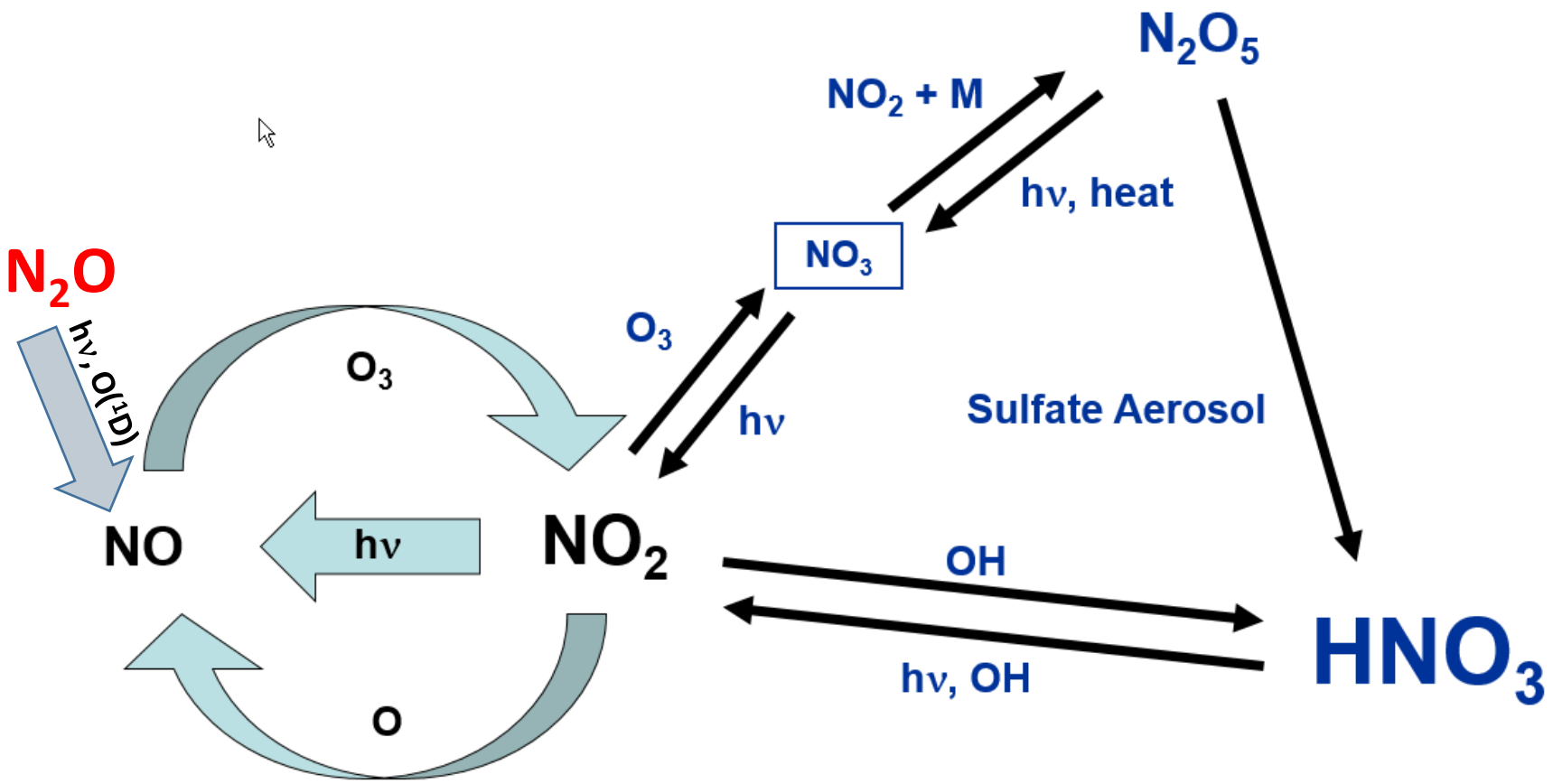
Objective 1: Obtain direct solar/lunar measurements of NO_3 and NO_2 from Table Mountain Facility in support of SAGE III/ISS validation.

Objective 2: Analyze comparisons with coincident SAGE III/ISS measurements and work with the algorithm and science teams to interpret the comparisons and incorporate improvements into retrieval algorithms.

Objective 3: Utilize in-situ measurements of NO_3 and N_2O_5 and chemical modeling to separate stratospheric and tropospheric partial columns.

Co-Investigators	
Thomas J. Pongetti, JPL	Data Acquisition/Analysis
King-Fai Li, UCR	1-D Modeling
Yuk L. Yung, Caltech	1-D Modeling
Steven S. Brown, NOAA	In-situ measurements

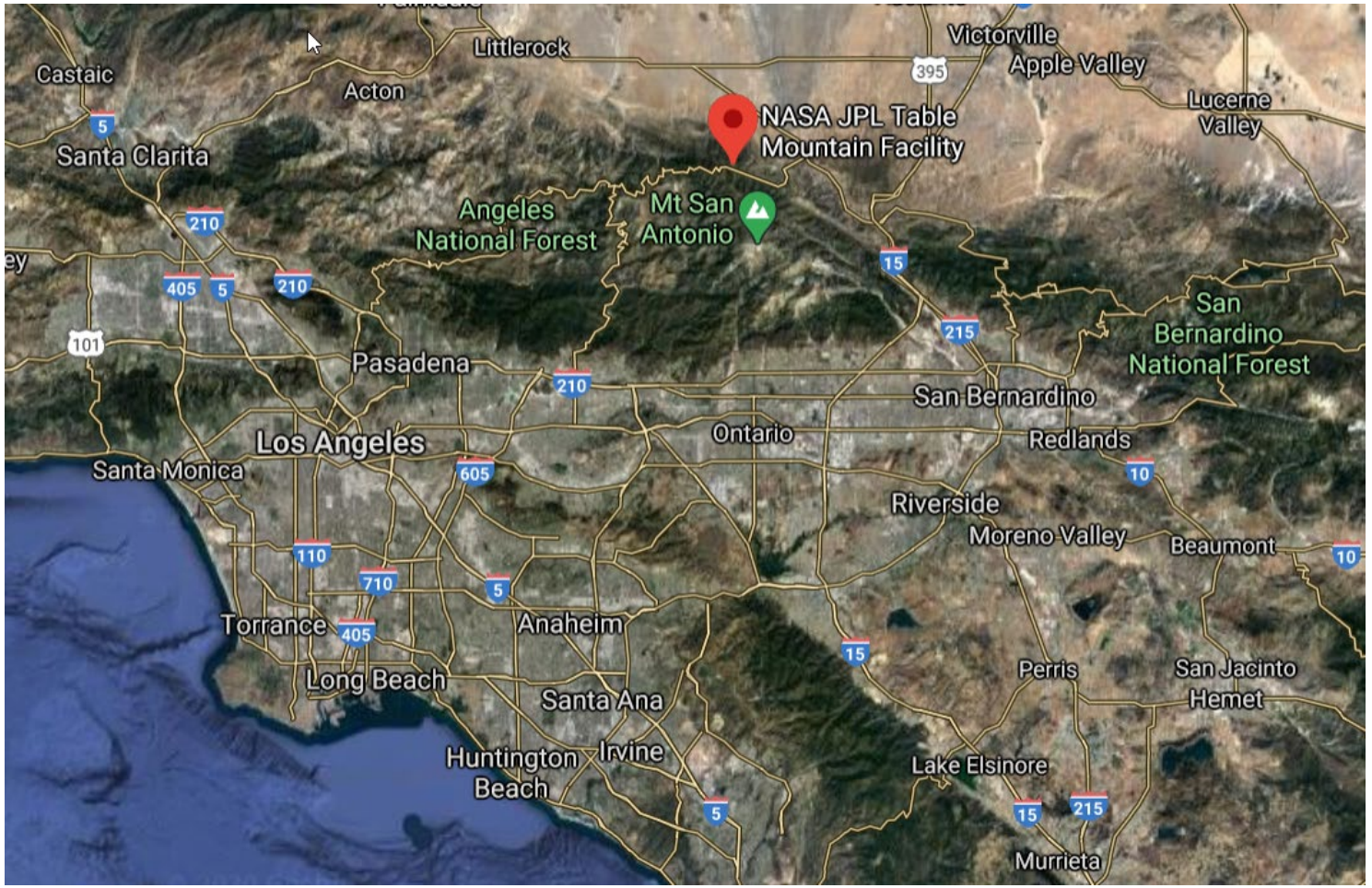
Key Processes in Stratospheric NO_x-NO_y Photochemistry



- Two pathways to HNO_3 formation:
  - Daytime (through OH + NO_2 + M reaction)
  - Nighttime (through N_2O_5 + sulfate aerosol reaction, NO_3-mediated

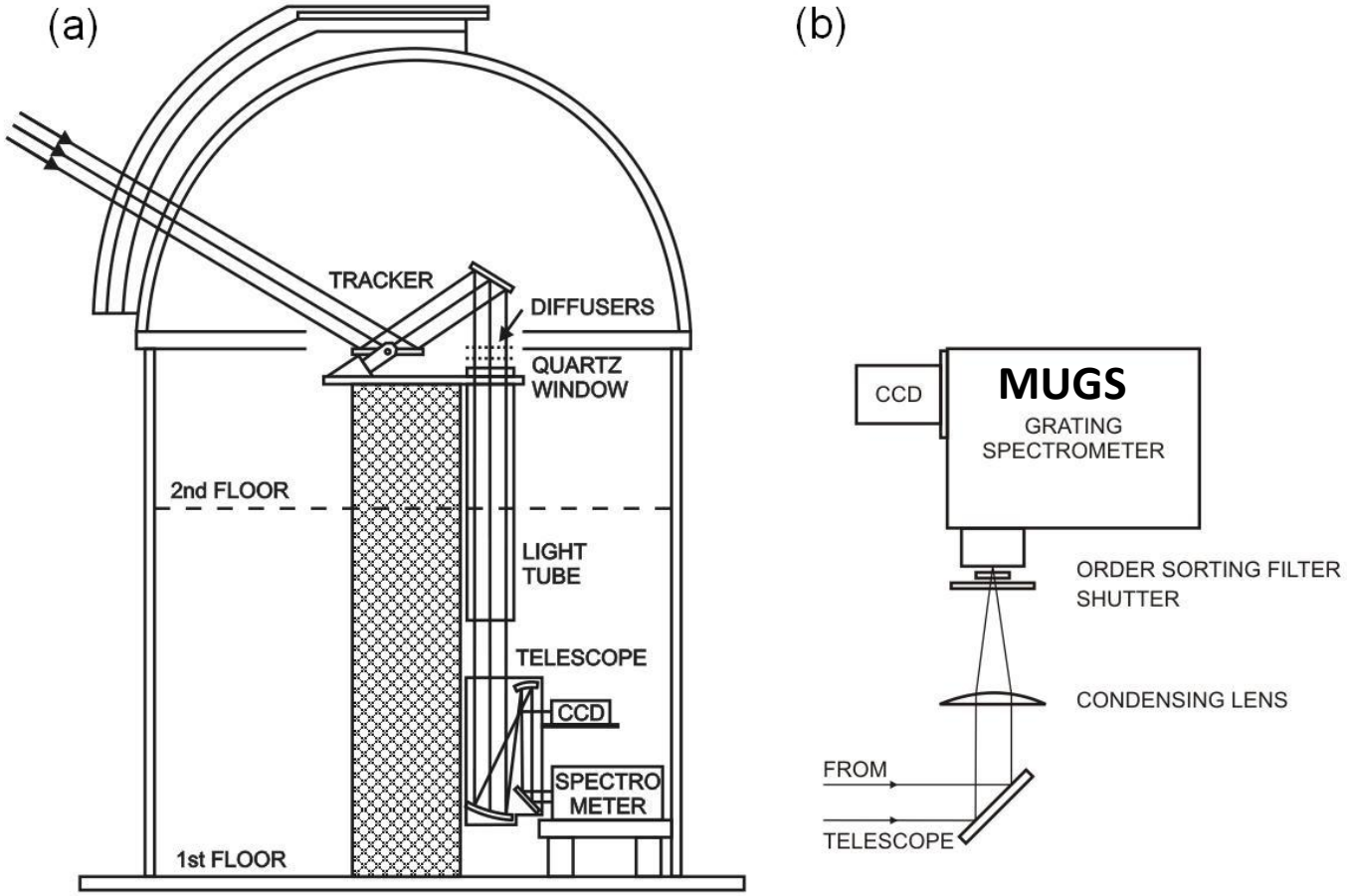
Ground-Based Measurements

Direct Solar and Lunar Spectroscopy at JPL Table Mountain Facility



Jet Propulsion Laboratory
California Institute of Technology

UV-Visible Grating Spectrograph (MUGS) at JPL/Table Mountain Facility



Schematic of the instrument light path. (a) Light is collected by the primary of the heliostat (tracker) then through an off-axis telescope which also serves as a fine guider for the pointing system. (b) The light is directed through a condensing lens, shutter, order-sorting filter, and then into the spectrometer where it is dispersed and recorded by a CCD camera.

Correcting for Trace Gas Absorption in the NO_2 Reference Spectrum

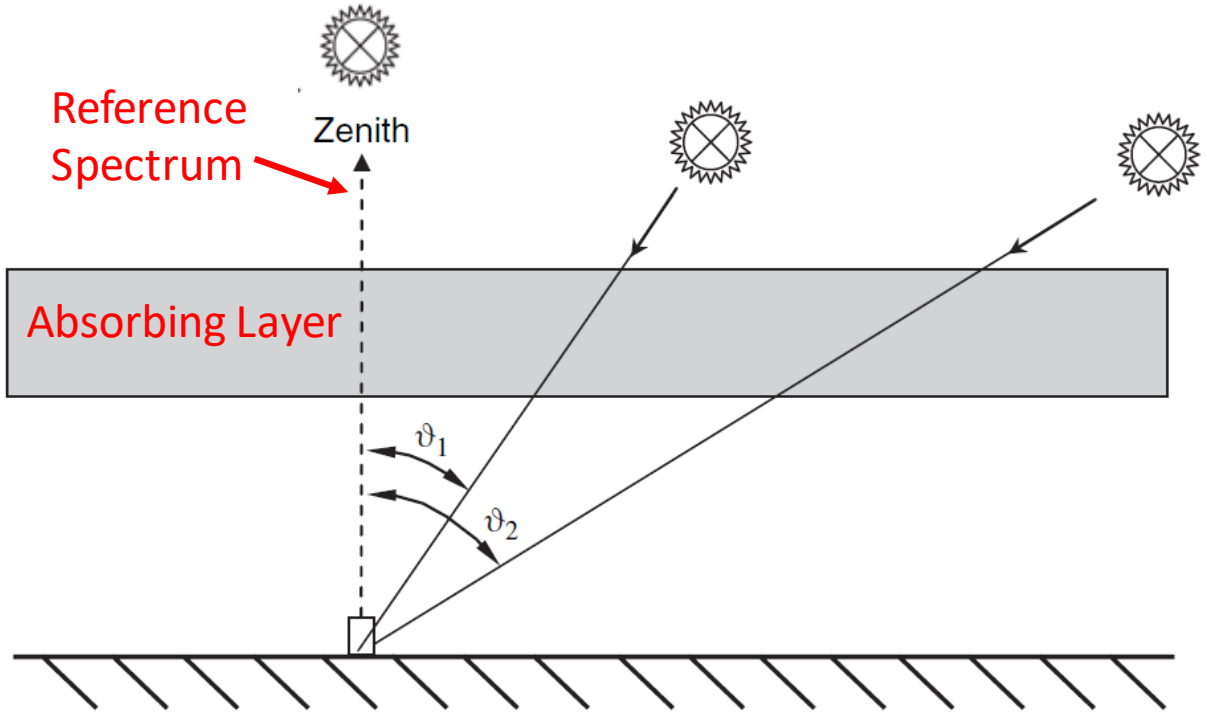
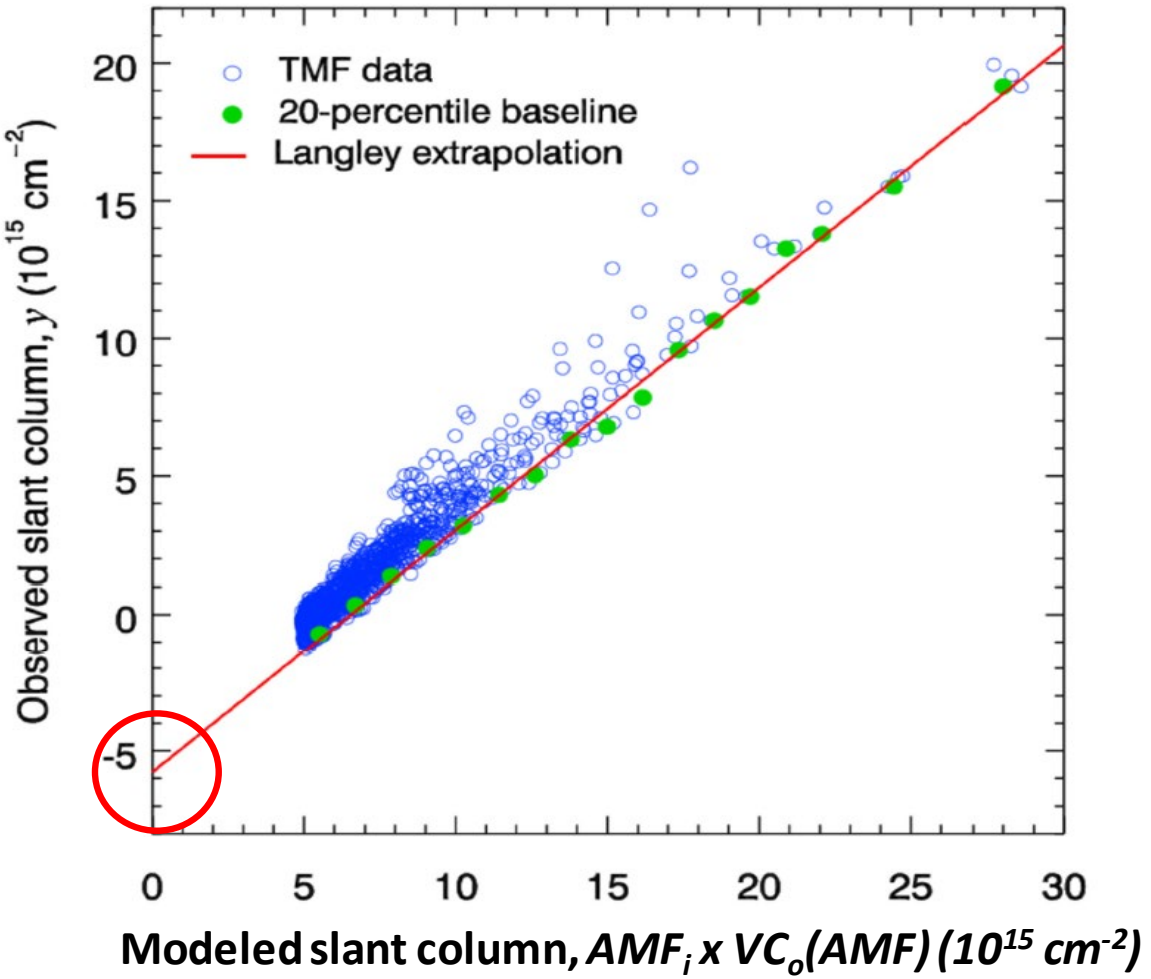


Fig. 9.1. Sketch of direct light observation geometries. In first approximation, the light path through a trace gas layer varies with $1/\cos\vartheta$ (ϑ = zenith angle of celestial body observed) From Stutz and Platt, *Differential Optical Absorption Spectroscopy* (2008)

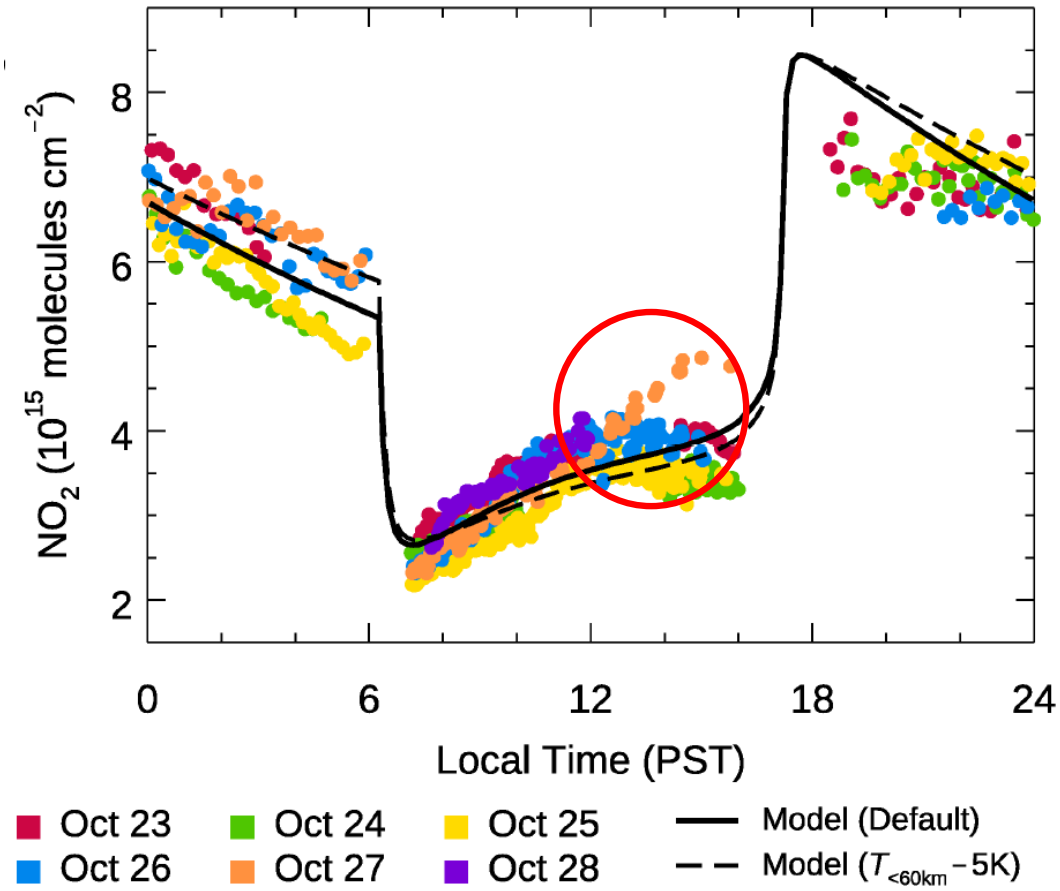
- A *reference spectrum* is acquired near zenith to obtain a background solar spectrum
- The reference spectrum contains absorption(s) from the molecule(s) of interest.
- A *Langley Plot* is constructed to determine the slant column density in the reference spectrum.

Modified Langley Extrapolation



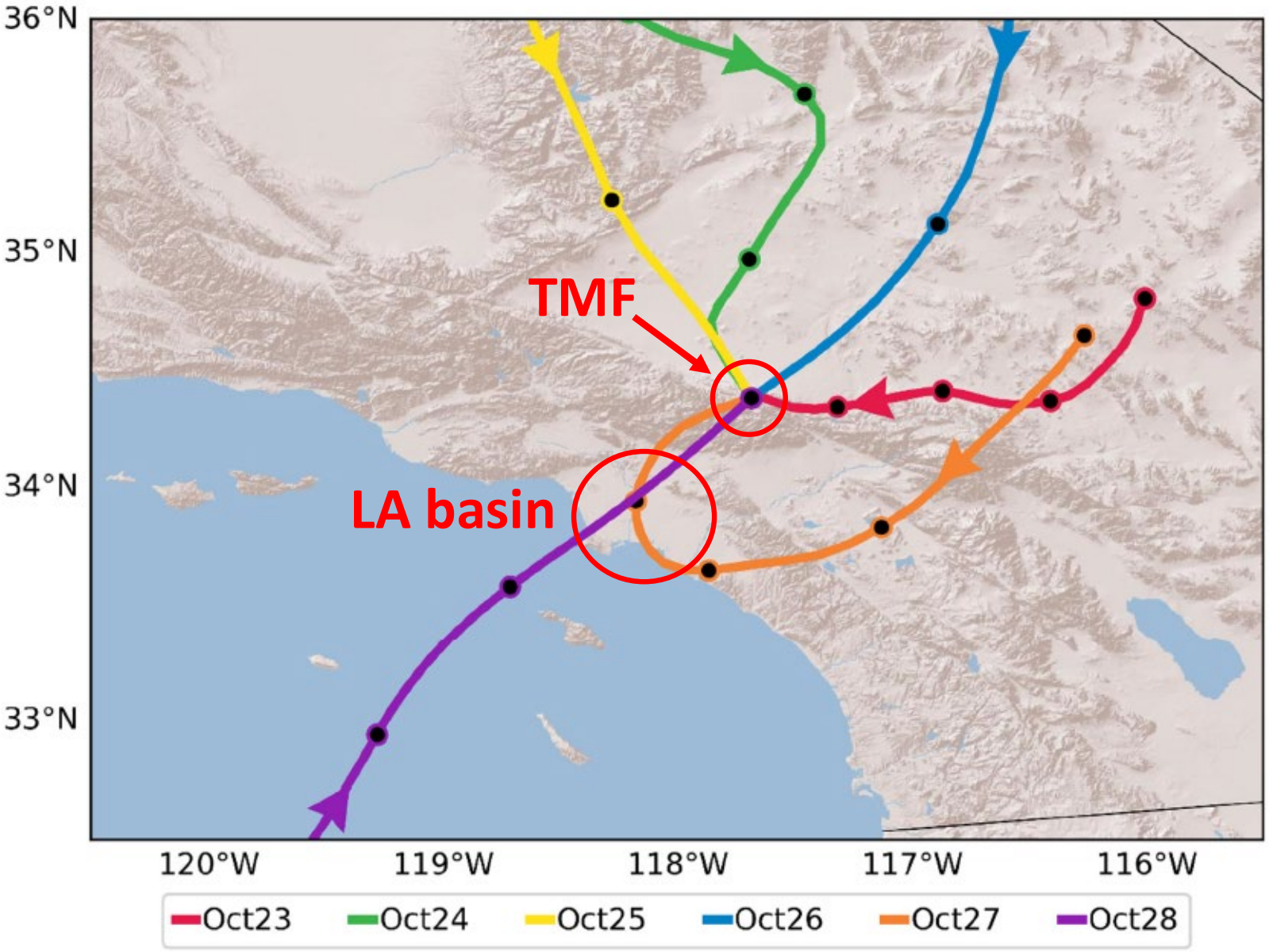
- X-axis is transformed from AMF_i to AMF_i x VC_o(AMF) where the function VC_o(AMF) is derived from the model's *a* priori time-dependence of NO_2
- This transformation results in the correct value of the reference column abundance as determined from the y-intercept

NO_2 Column Model-Measurement Comparison



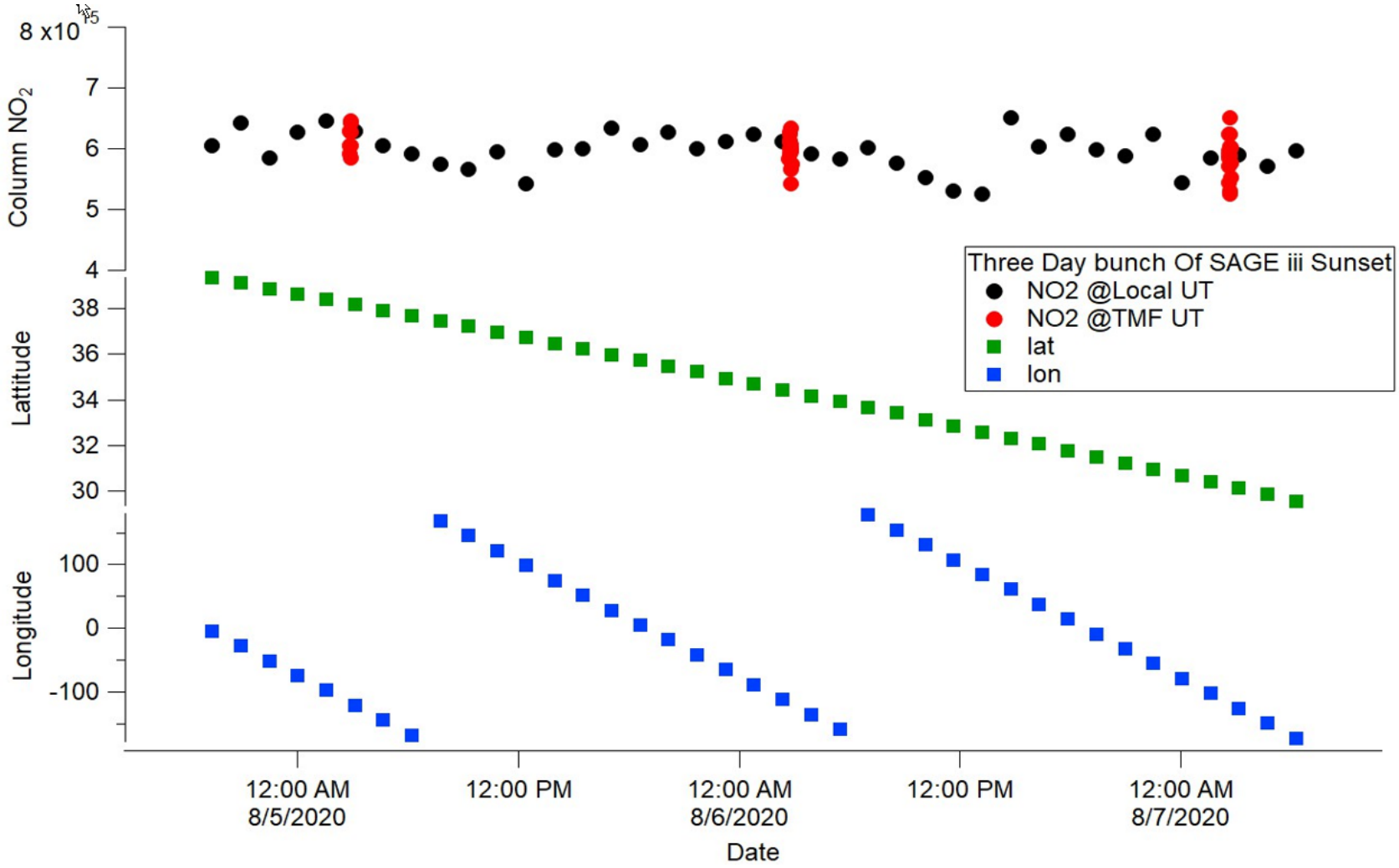
- NO_2 reference column using modified Langley method
- Overall agreement is excellent; First continuous night/day record
- MUGS cannot measure at the exact time of sunrise or sunset due to obstructions
- October 27 daytime data show influence of a polluted air mass

24 Hour Back-Trajectories Reaching TMF at 1500



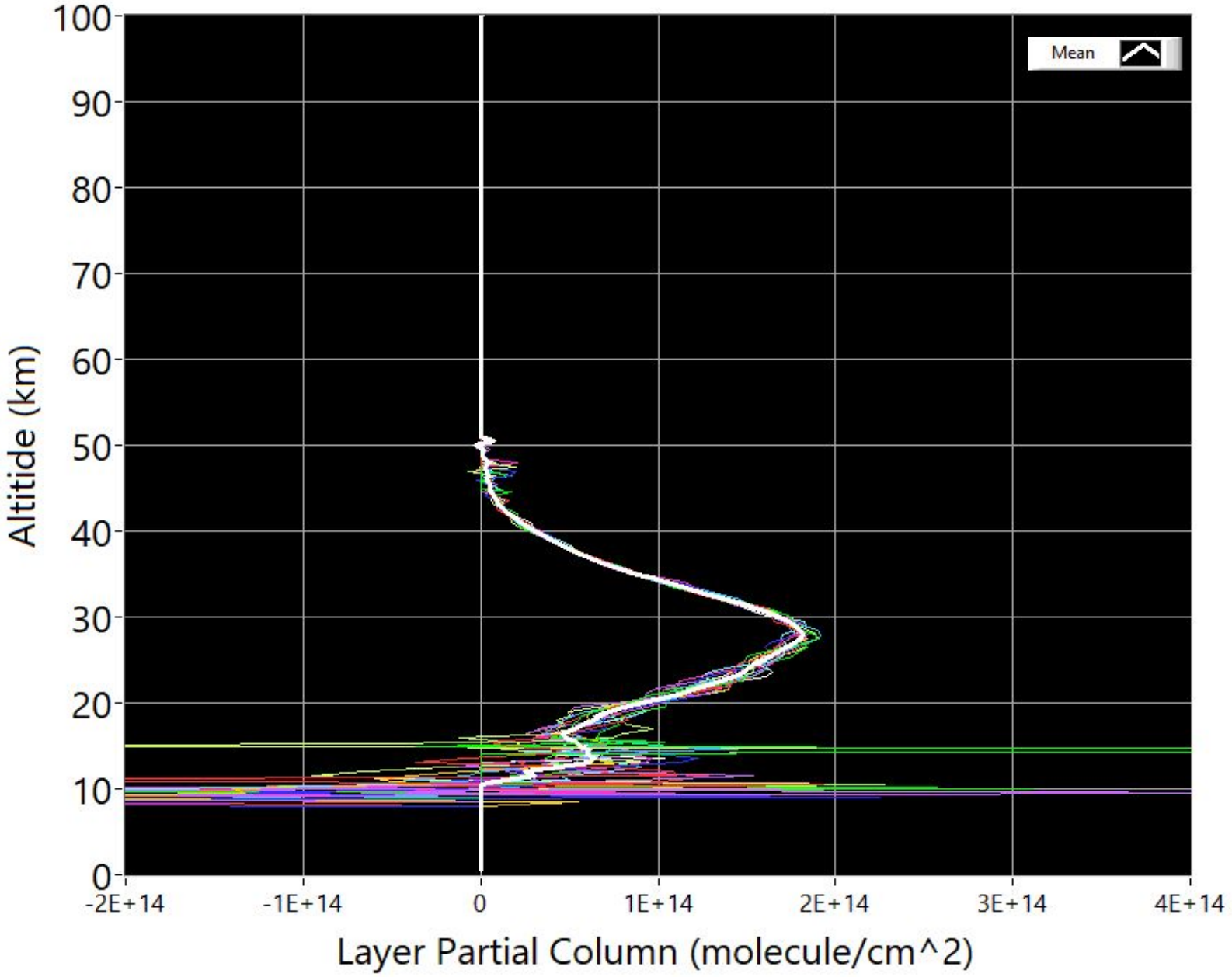
MUGS Comparisons with SAGE-III/ISS

SAGE-III/TMF Coincidences

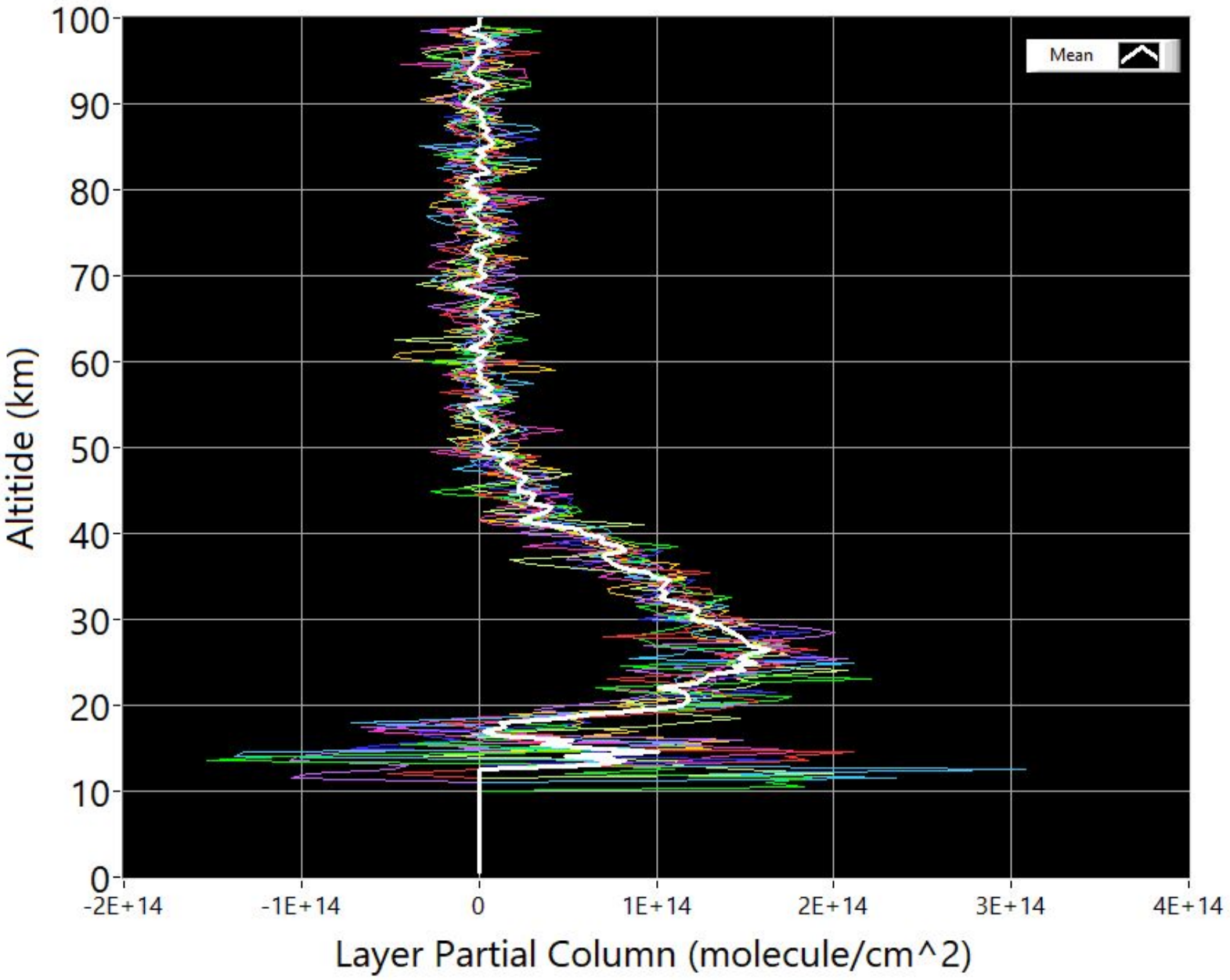


- Exact coincidences between SAGE-III and TMF are exceedingly rare
- We consider coincidences within a global zonal belt $\pm 5°$ latitude from TMF (34.4 °N)
- SAGE occultations at other longitudes are converted to TMF local time

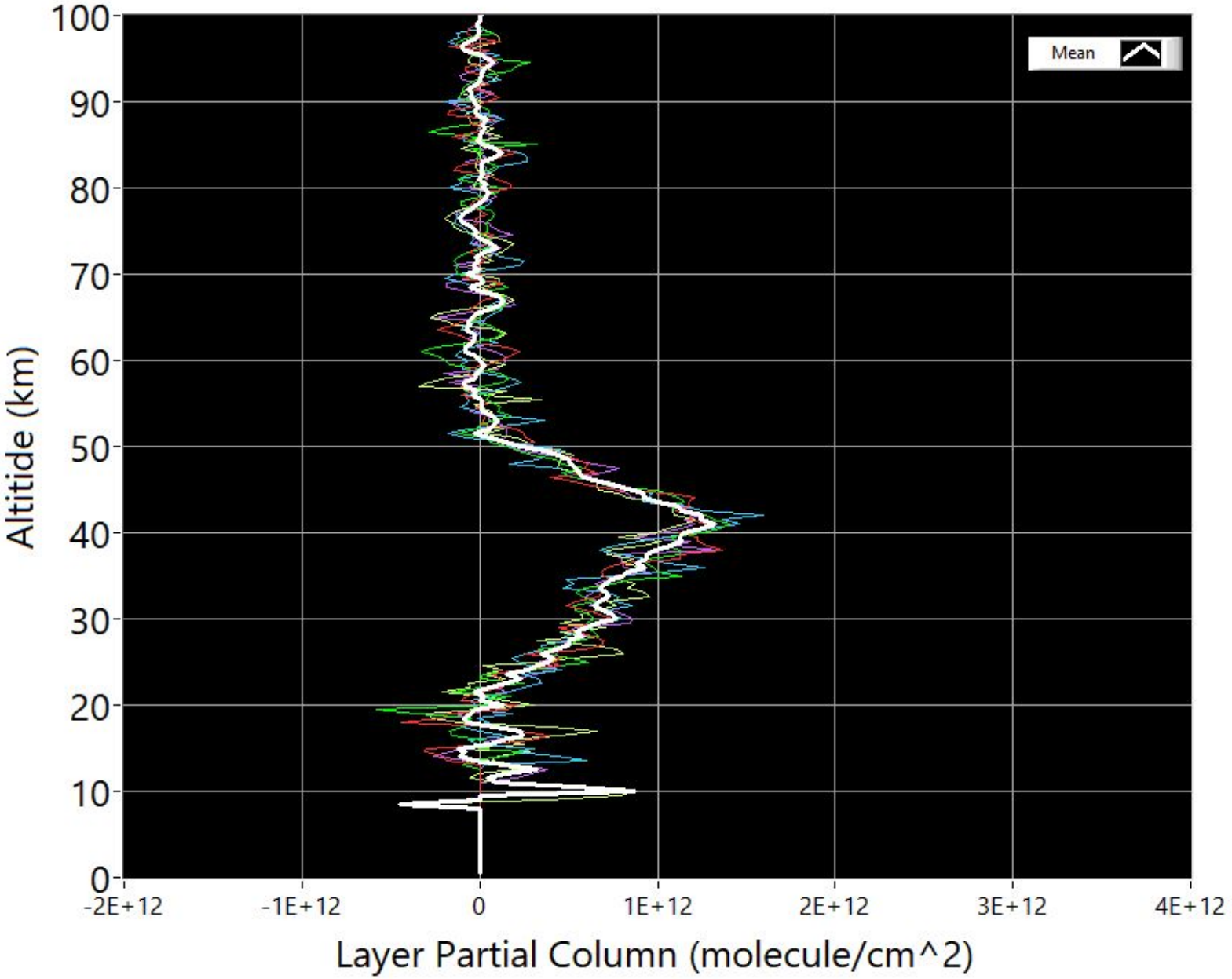
Typical SAGE-III Sunrise NO_2 Profiles (zonal average)



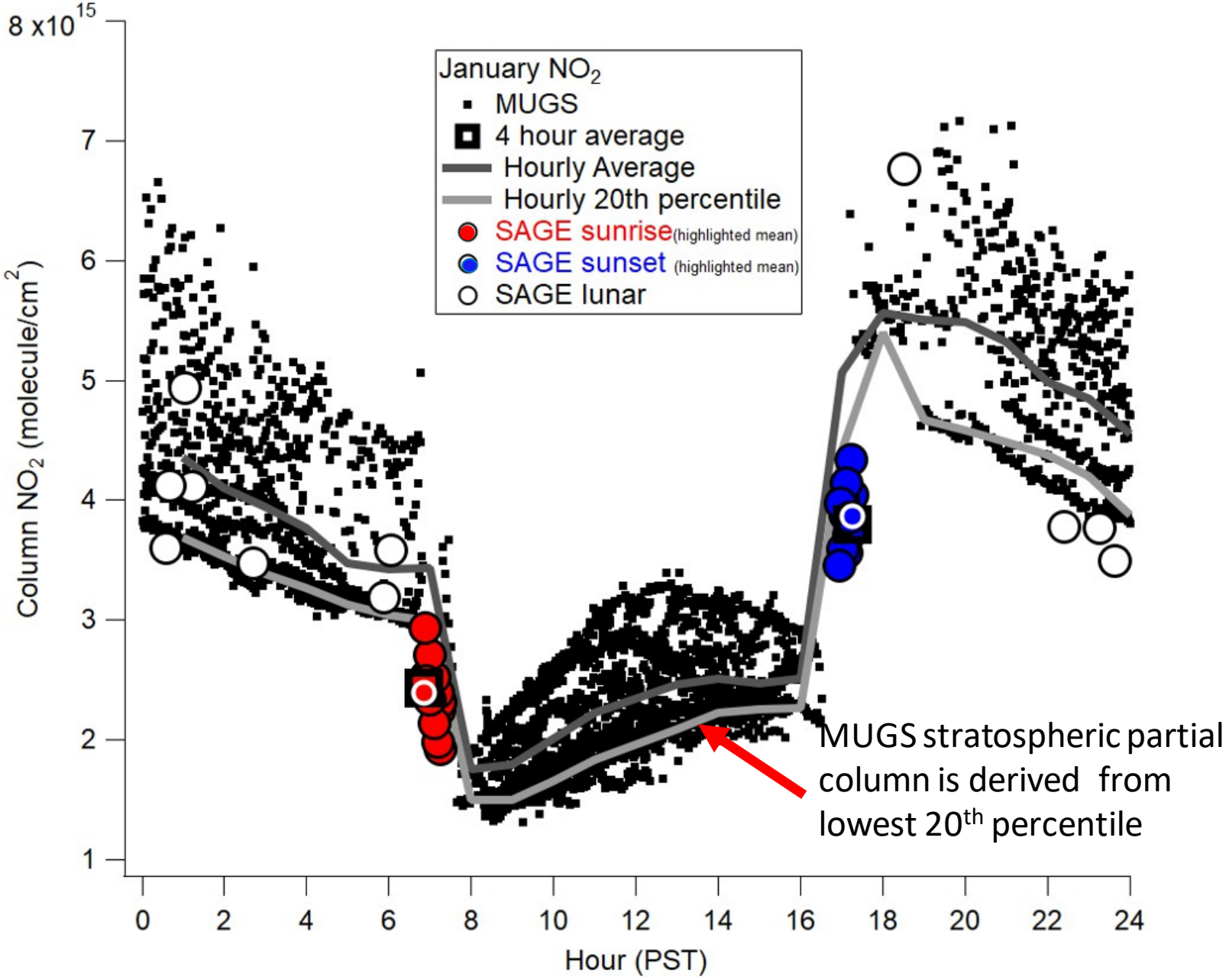
Typical SAGE-III Lunar NO_2 Profiles (zonal average)



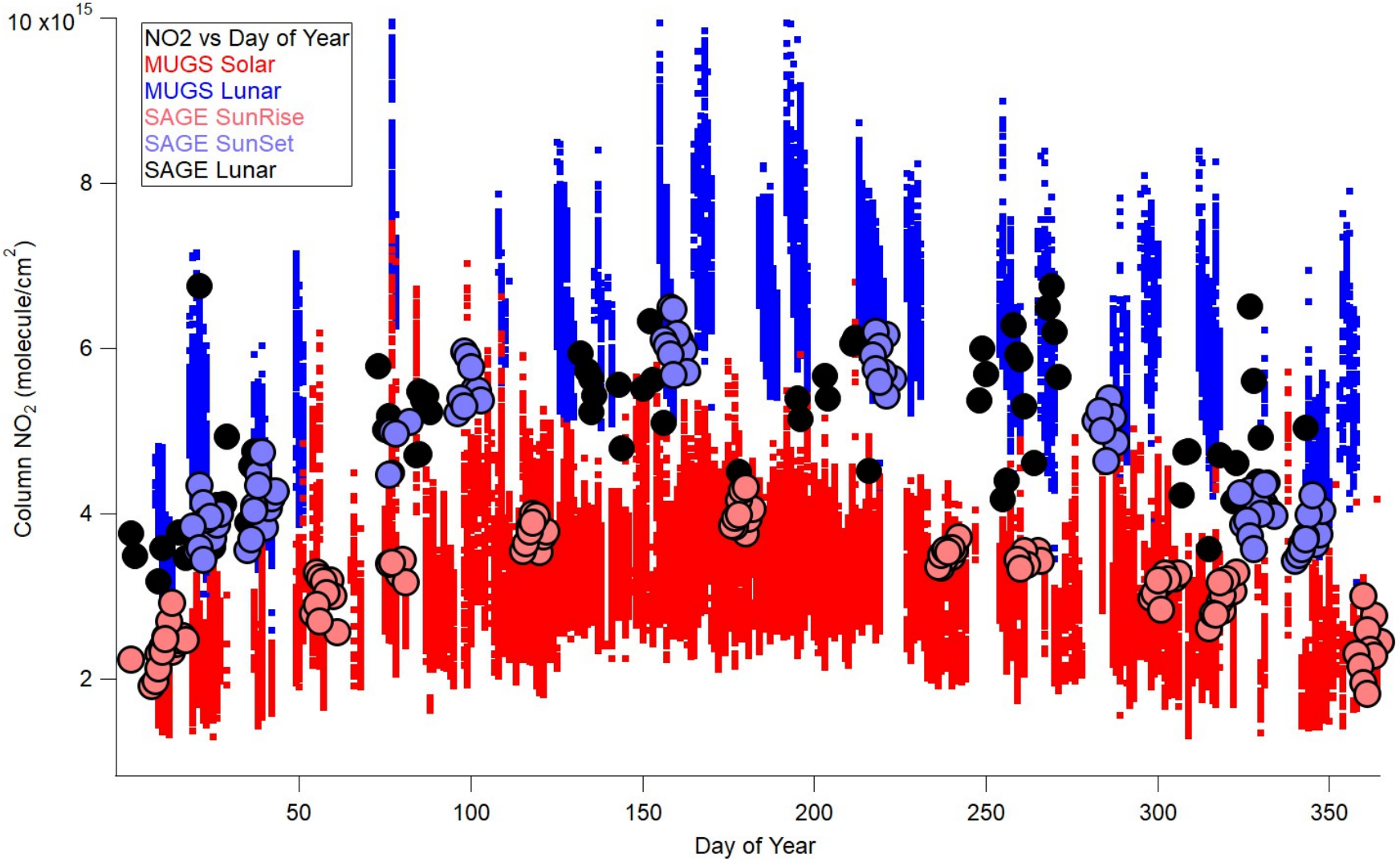
Typical SAGE-III Lunar NO_3 Profiles (zonal average)



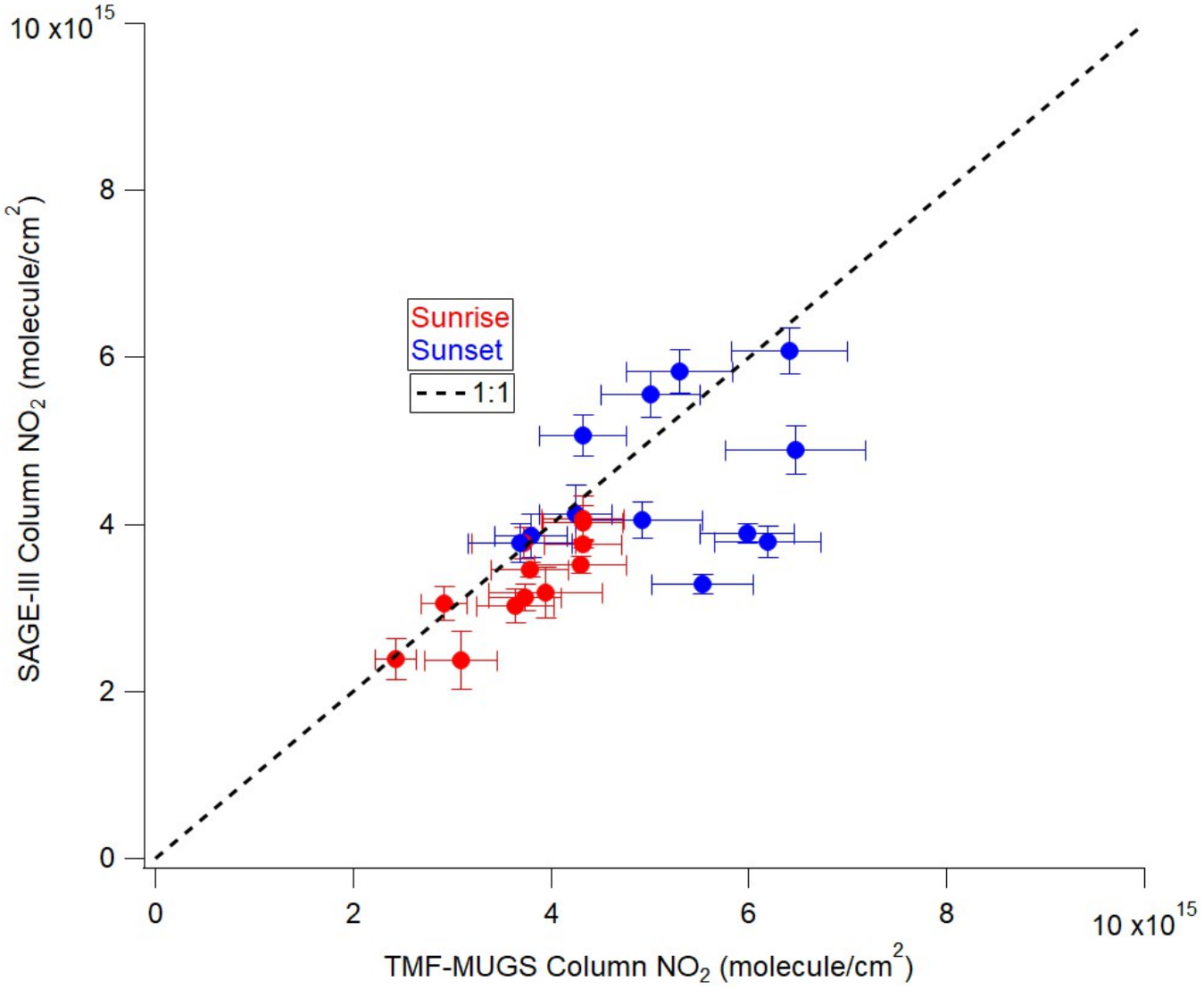
Example SAGE-MUGS NO_2 Comparison: January



SAGE-MUGS NO_2 Comparison: year-over-year



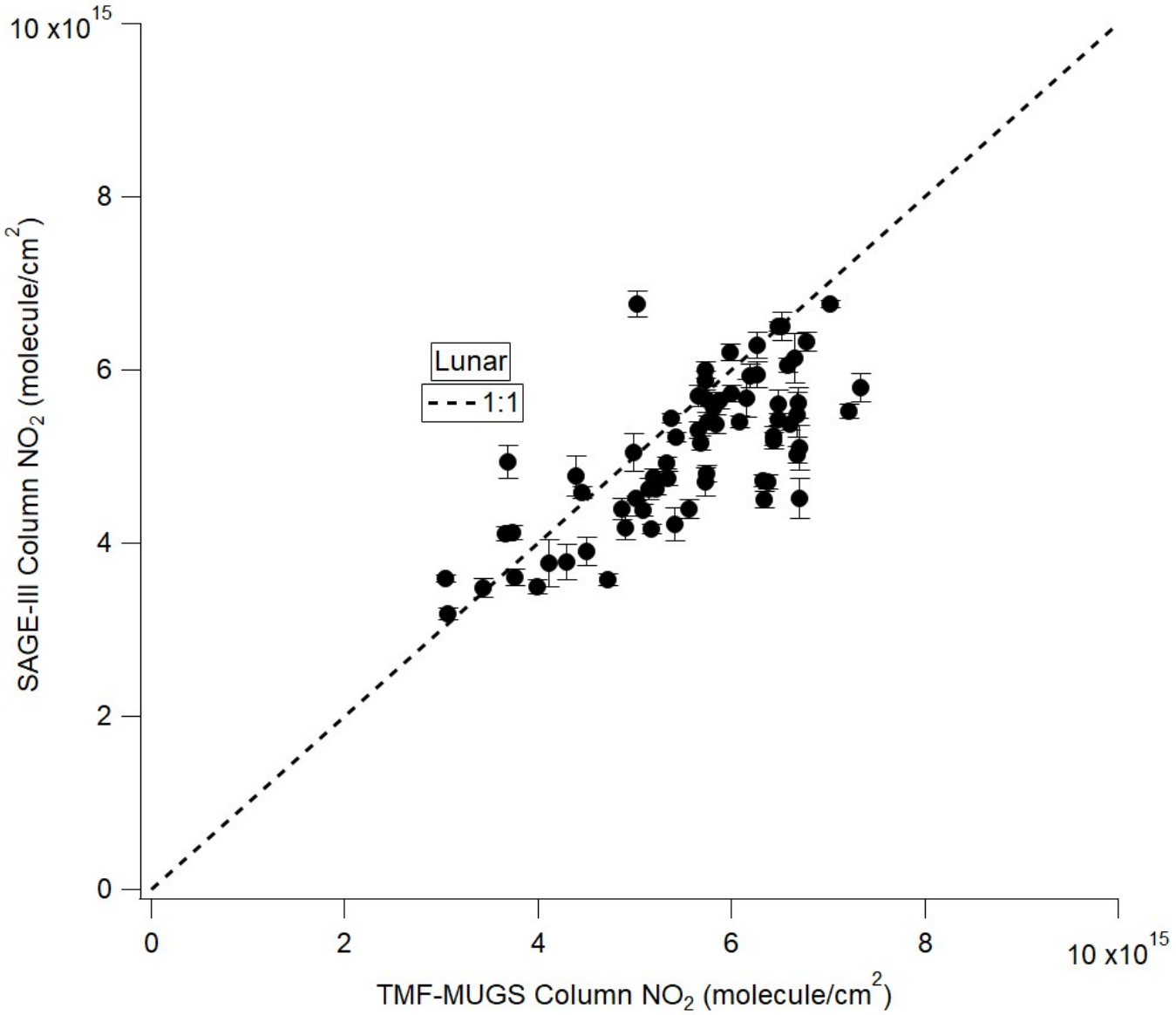
SAGE-MUGS NO_2 Correlation (Solar)



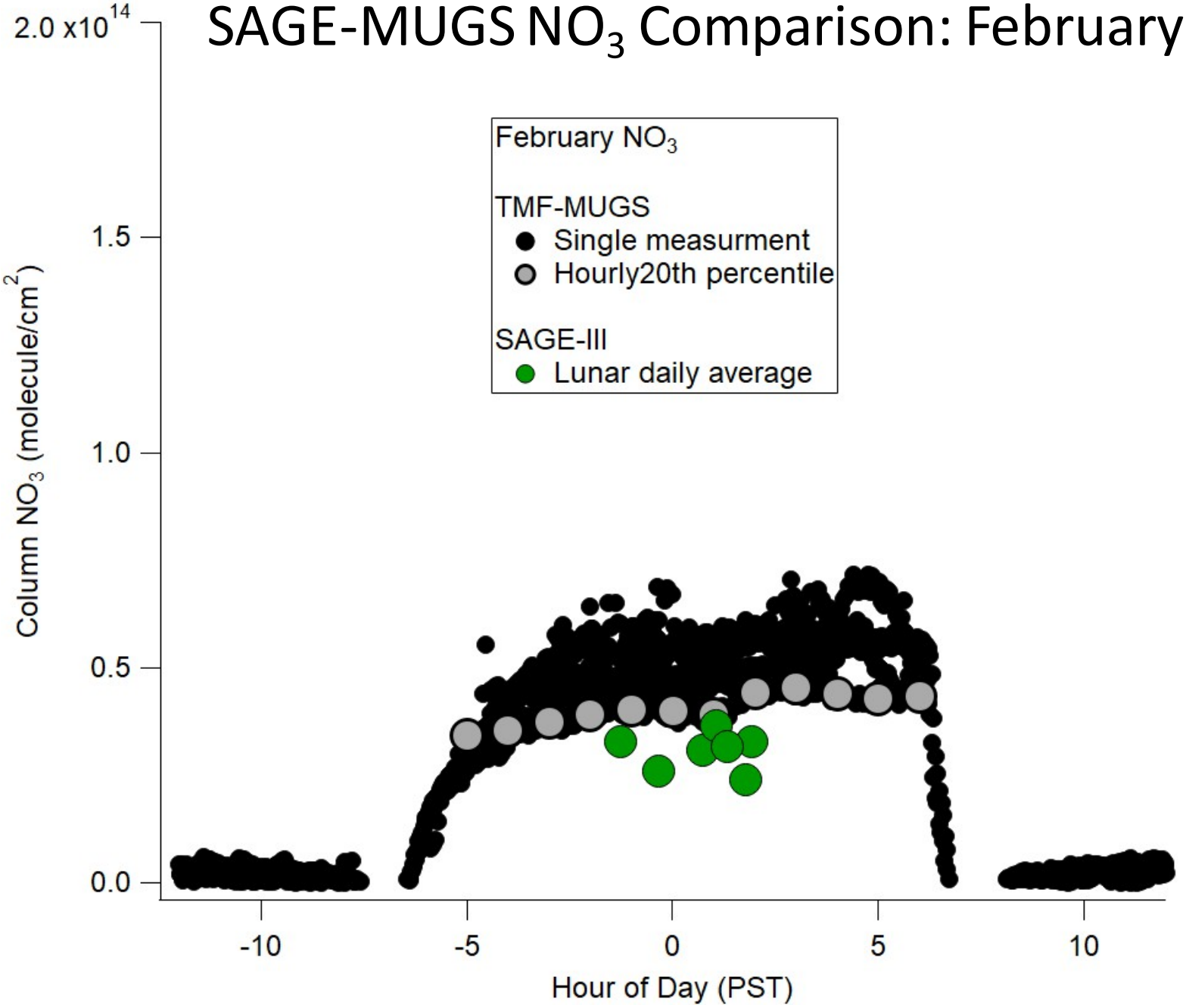
- Scatter plot between monthly averages of SAGE-III columns (z>15 km) and MUGS total columns ($\pm$ 2 hours from sunset or sunrise, 20th percentile)

SAGE-MUGS NO_2 Correlation (Lunar)

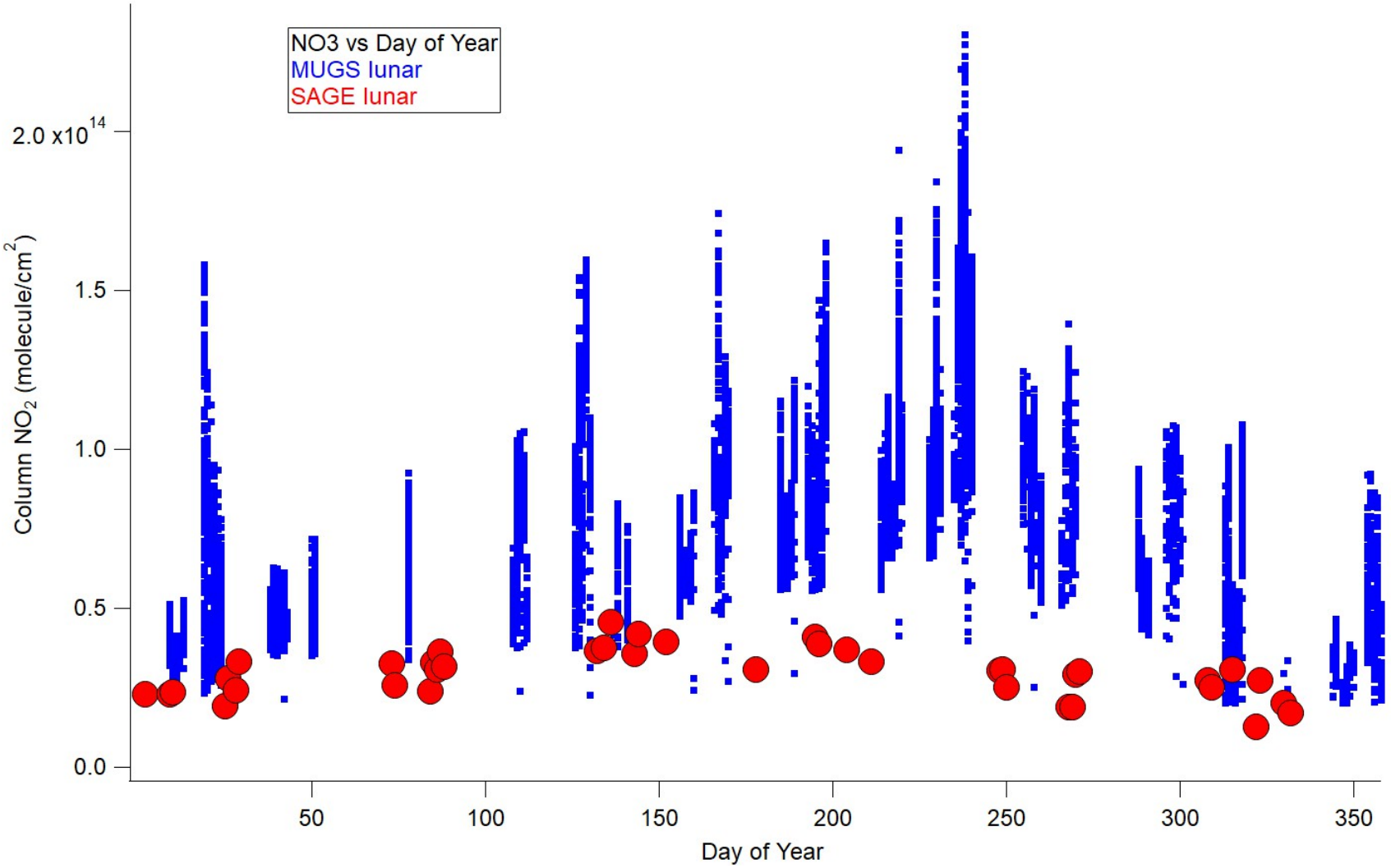
Note: Lunar NO_2 is a research product – not formally released



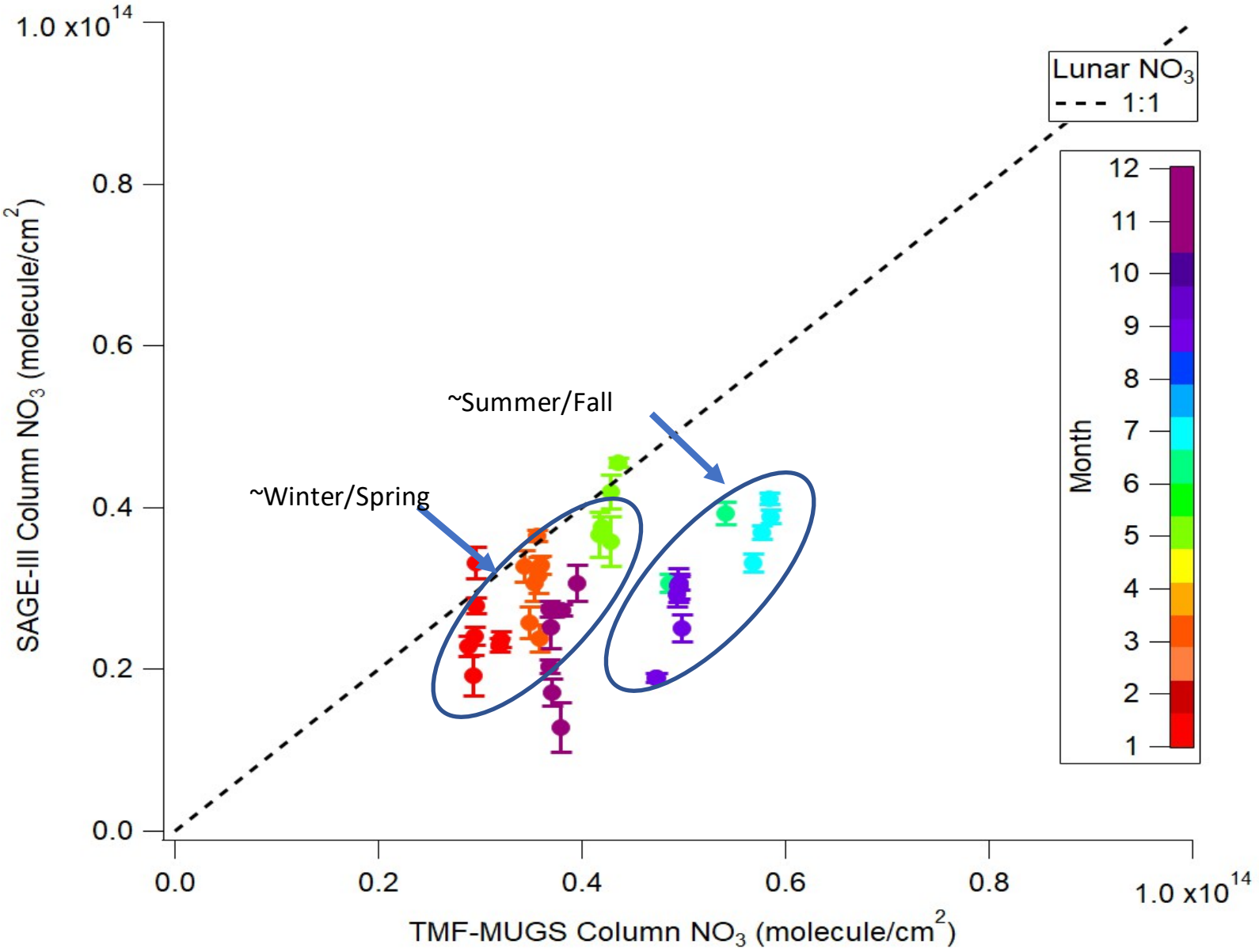
SAGE-MUGS NO_3 Comparison: February



SAGE-MUGS NO_3 Comparison: year-over-year



SAGE-MUGS NO_3 Correlation (Lunar)



Take-Home Points

- Ground-based TMF direct sun/moon total column measurements provide very good comparisons with SAGE-III/ISS stratospheric partial columns because:
  - High altitude (2.3 km) and remote location of TMF minimize PBL pollution contributions to the total column
  - Sorting methods are available to identify measurements (NO_2, NO_3) that contain significant tropospheric contributions.
  - 1-D model provides the nominal tropospheric partial column contributions
- *Preliminary* comparisons between MUGS and SAGE show good correlations for NO_2. NO_3 agrees well in winter/spring, less well in summer/fall
- *Future work* will focus on extending the ground-based climatologies, using the 1-D model for diurnal corrections, working with algorithm team on lunar NO_2 product including cross sections.



Sonde observations from Boulder & Lauder

Emrys Hall[1,2], Dale Hurst[1,2], Allen Jordan[1,2], Patrick Cullis[1,2], Troy Thornberry[1,3], Elizabeth Asher[1,3], Steve Ciciora[3], Betsy Andrews[1,2], Susan Kizer[4,5], Marilee Roell[4], Carrie Roller[4,5], Richard Querel[6], Penny Smale[6], Wills Dobson[6]

1: University of Colorado, CIRES
2: NOAA, Global Monitoring Laboratory
3: NOAA, Chemical Sciences Laboratory
4: NASA, Langley Research Center
5: Science Systems and Apllications, Inc
6: NIWA Lauder

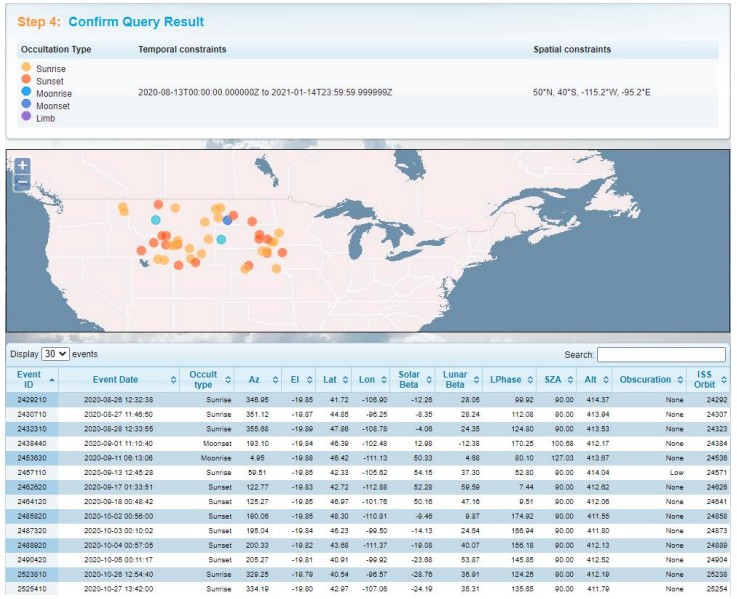


SAGE III/ISS STM - October 19-20, 2020

Satellite / Balloon Coincident Overpasses



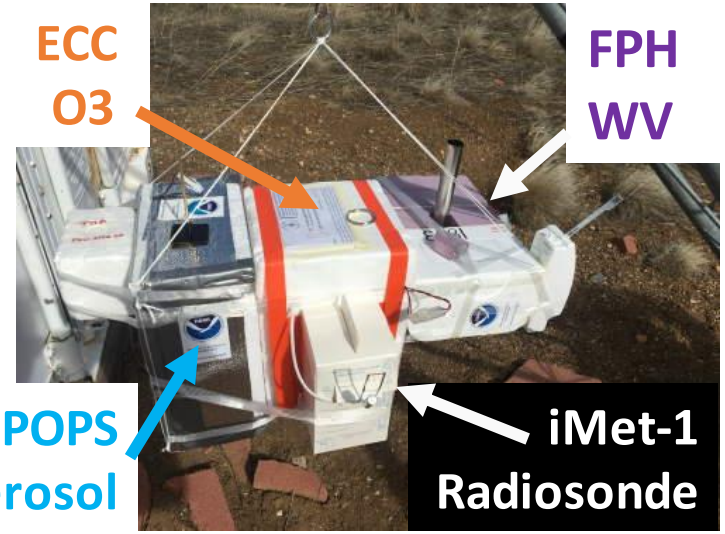
Boulder, Colorado





Lauder, New Zealand

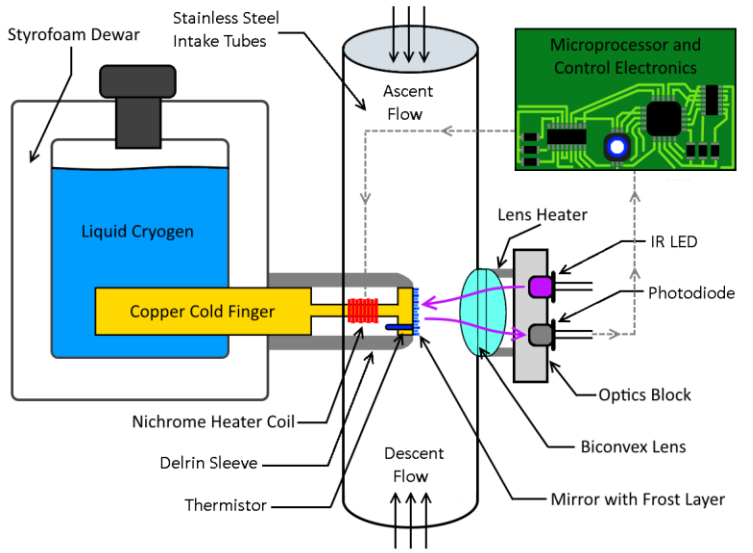
- 58 coordinated balloon flights
- 33 with a NOAA FPH water vapor sonde
- 57 with an En-Sci ECC ozonesonde
- 19 with a NOAA CSL POPS aerosol sonde
- Average difference in time, Lat, Long
  - 10.9 hours, 2.5° Lat, 5.0° Long

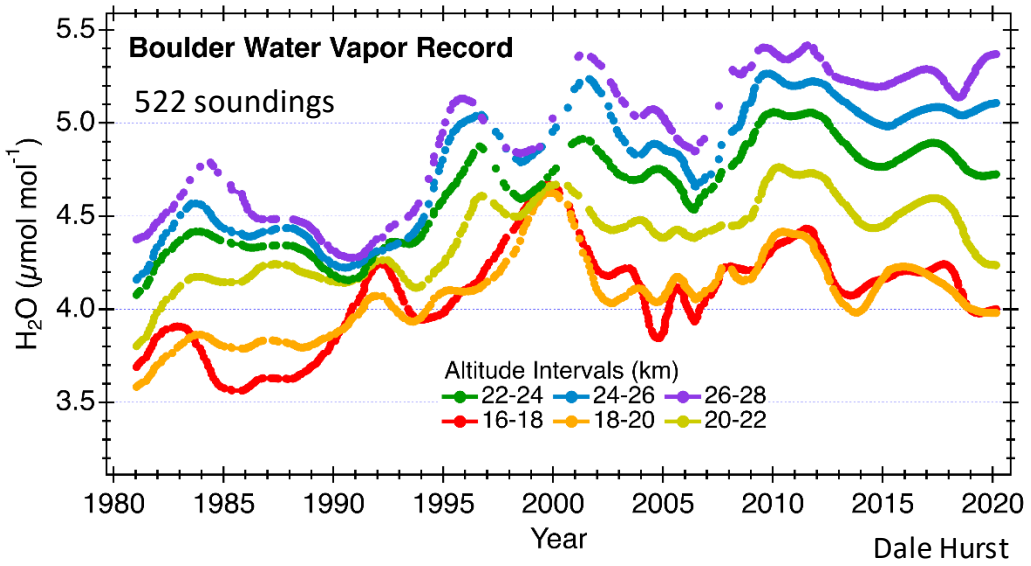


- 17 coordinated balloon flights
- 17 with a NOAA FPH water vapor sonde
- 17 with an En-Sci ECC ozonesonde
- 7 with a NOAA CSL POPS aerosol sonde
- Average difference in time, Lat, Long
  - 11.3 hours, 1.8° Lat, 5.6° Long

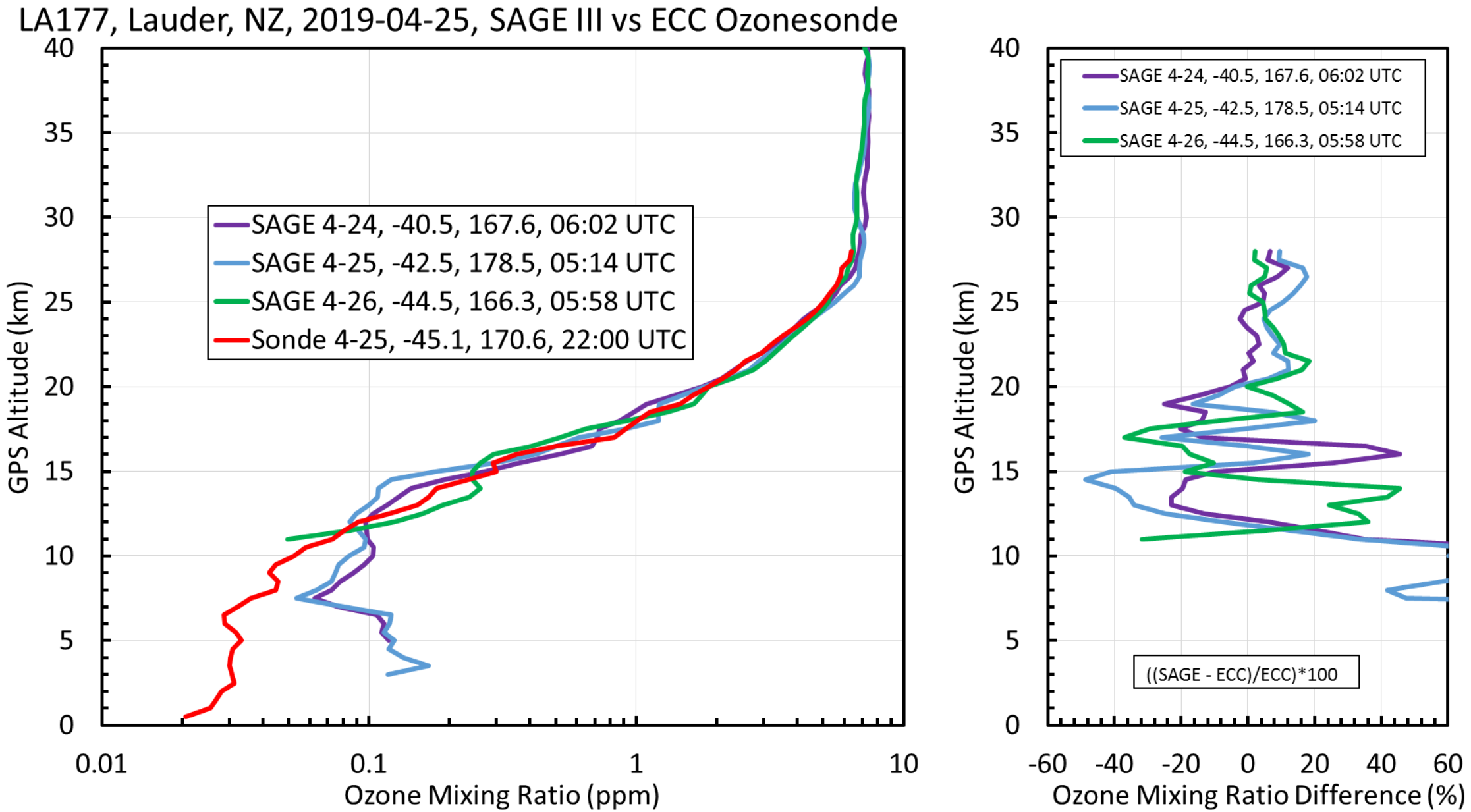
NOAA Frost Point Hygrometer (FPH)

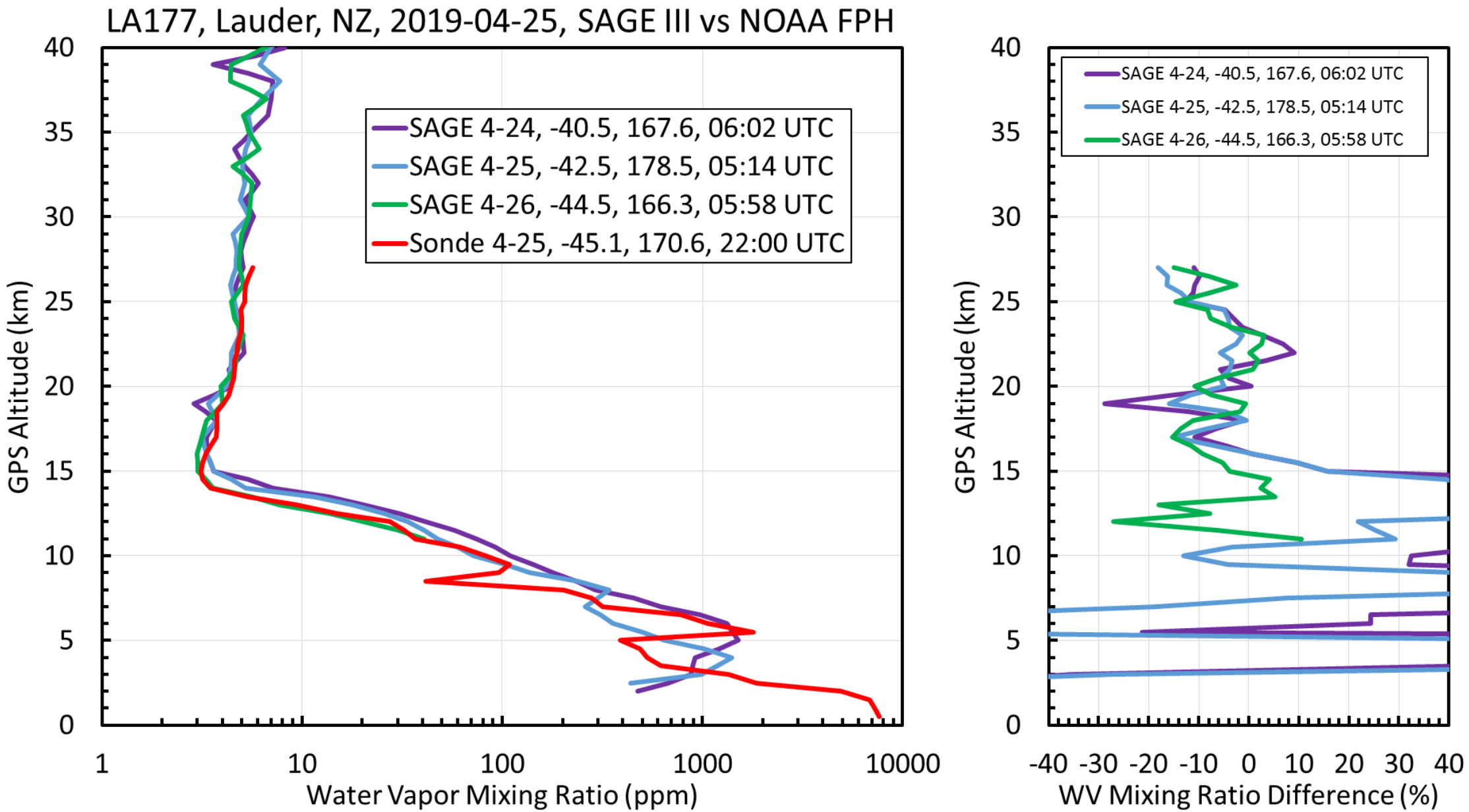






- Boulder has the longest continuous water vapor record
  - 1980 – present
- Lauder: 2004 – present
- Hilo: 2010 – present
- Weight = **850 g** (cryo + batts)
- Surface to ~ 28 km
- Vertical resolution ~ 10 m
- **< 6 % uncertainty** in stratosphere (2σ)

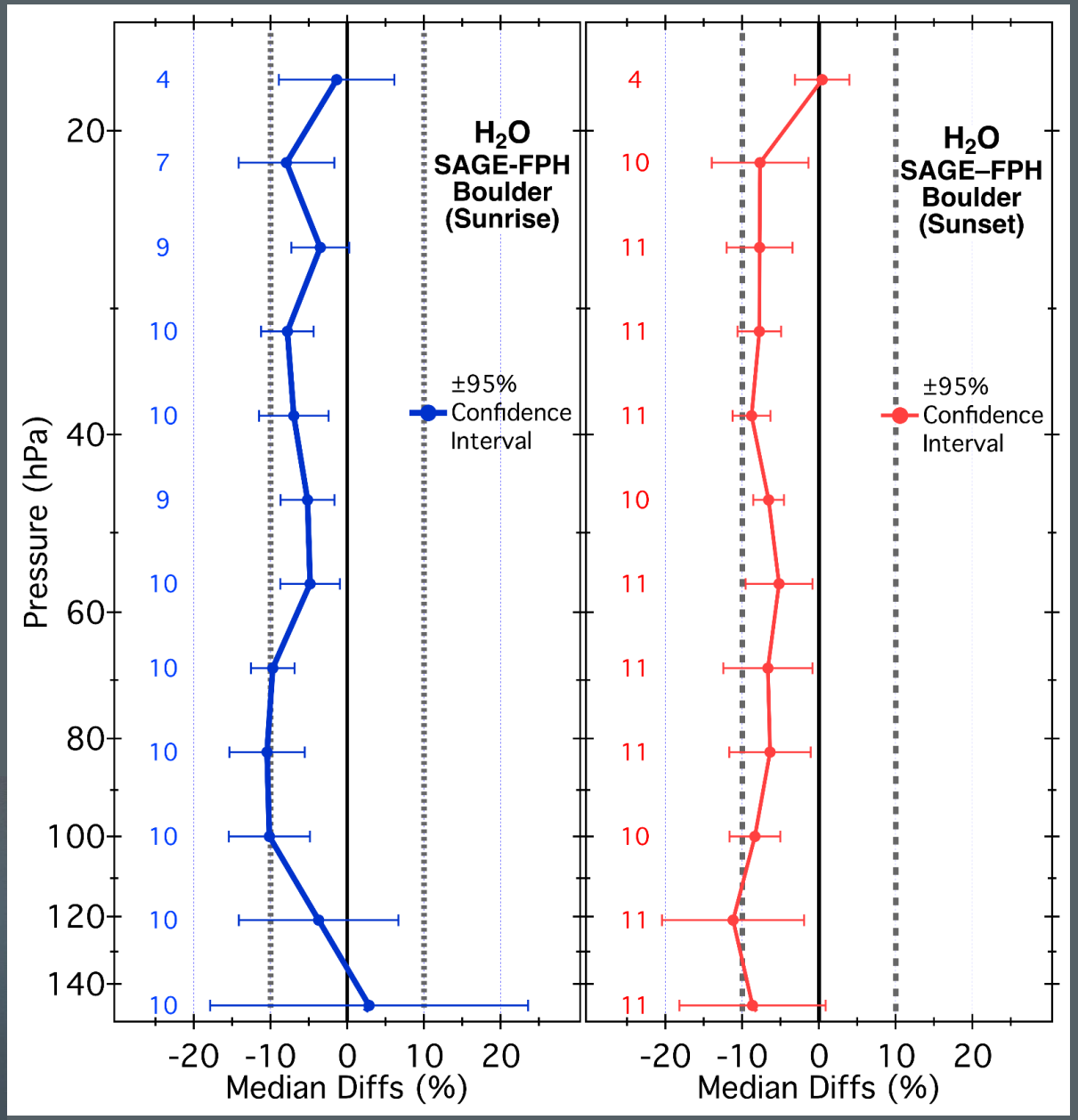

LA177, Lauder, NZ, 2019-04-25, SAGE III vs ECC Ozonesonde
SAGE 4-24, -40.5, 167.6, 06:02 UTC
SAGE 4-25, -42.5, 178.5, 05:14 UTC
SAGE 4-26, -44.5, 166.3, 05:58 UTC
Sonde 4-25, -45.1, 170.6, 22:00 UTC
GPS Altitude (km)
Ozone Mixing Ratio (ppm)
0.01
0.1
1
10
0
5
10
15
20
25
30
35
40
SAGE 4-24, -40.5, 167.6, 06:02 UTC
SAGE 4-25, -42.5, 178.5, 05:14 UTC
SAGE 4-26, -44.5, 166.3, 05:58 UTC
((SAGE - ECC)/ECC)*100
GPS Altitude (km)
Ozone Mixing Ratio Difference (%)
-60
-40
-20
0
20
40
60


LA177, Lauder, NZ, 2019-04-25, SAGE III vs NOAA FPH
SAGE 4-24, -40.5, 167.6, 06:02 UTC
SAGE 4-25, -42.5, 178.5, 05:14 UTC
SAGE 4-26, -44.5, 166.3, 05:58 UTC
Sonde 4-25, -45.1, 170.6, 22:00 UTC
GPS Altitude (km)
Water Vapor Mixing Ratio (ppm)
1
10
100
1000
10000
0
5
10
15
20
25
30
35
40
SAGE 4-24, -40.5, 167.6, 06:02 UTC
SAGE 4-25, -42.5, 178.5, 05:14 UTC
SAGE 4-26, -44.5, 166.3, 05:58 UTC
GPS Altitude (km)
WV Mixing Ratio Difference (%)
-40
-30
-20
-10
0
10
20
30
40

Water Vapor

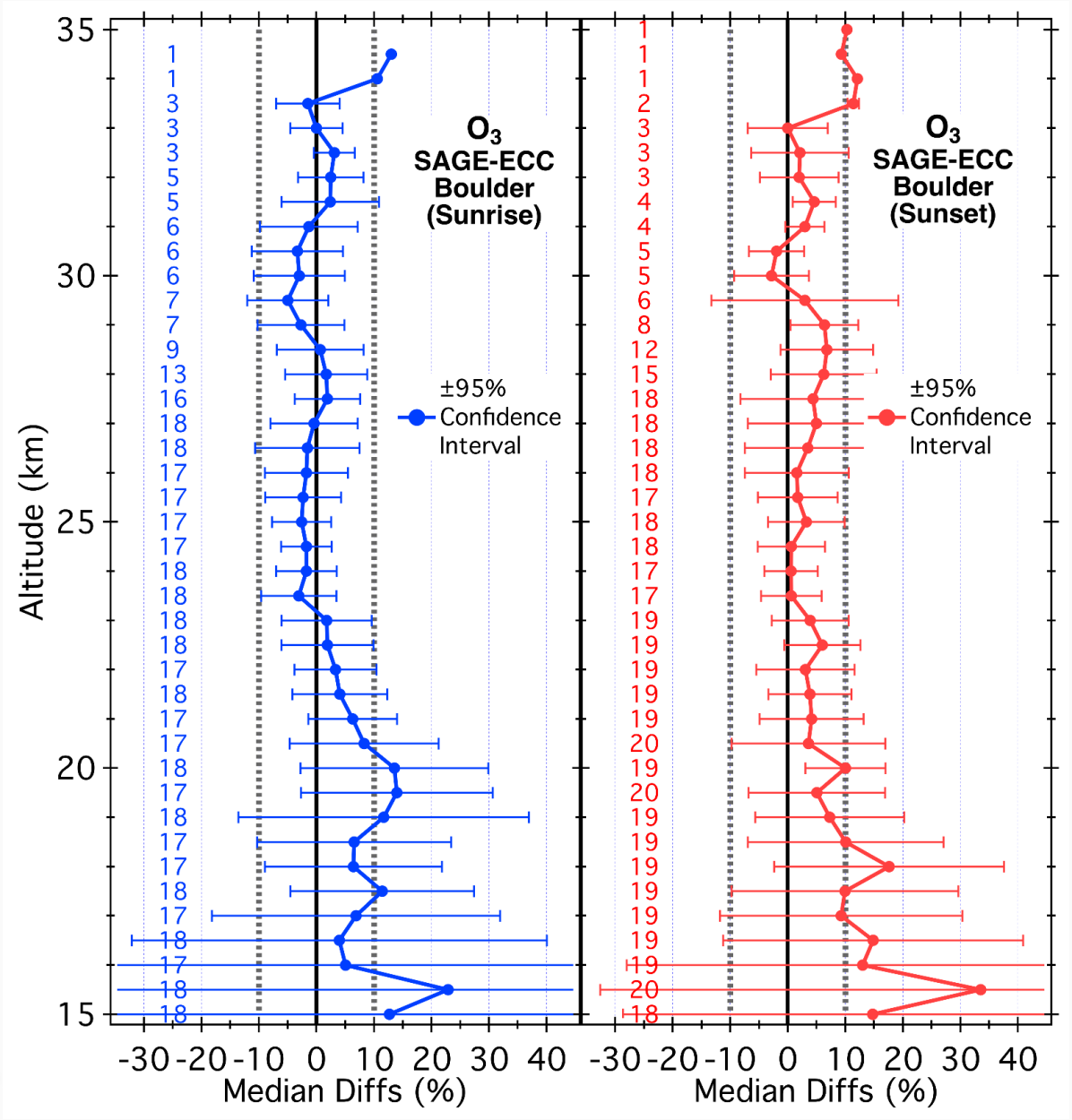
- Statistically significant bias between SAGE III and NOAA FPH
- 5 – 10 % (0.2 – 0.5 ppm)
  - 100 – 20 hPa (sunrise)
  - 120 – 20 hPa (sunset)





Dale Hurst





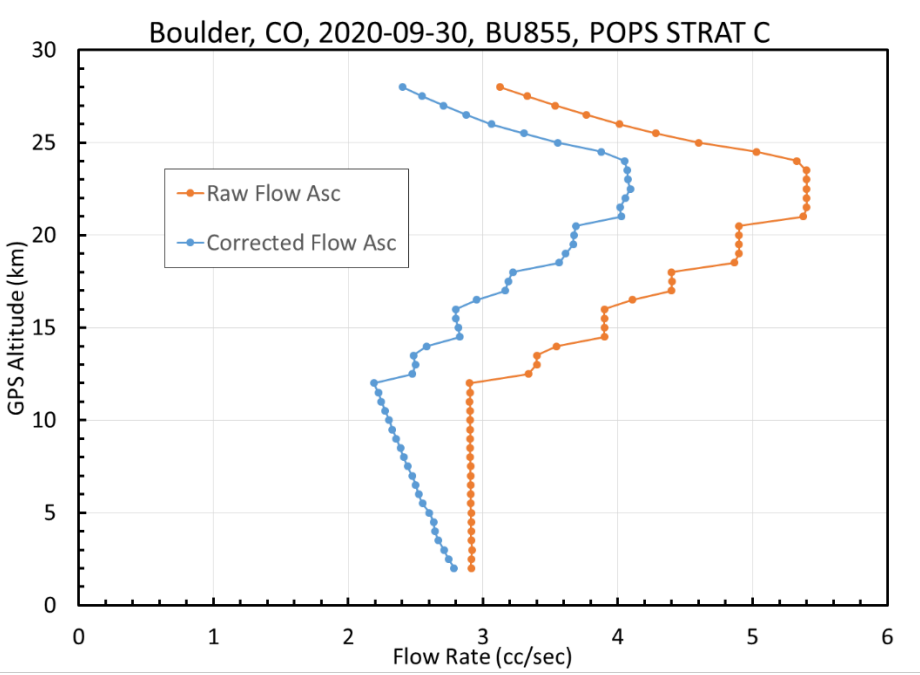
Dale Hurst

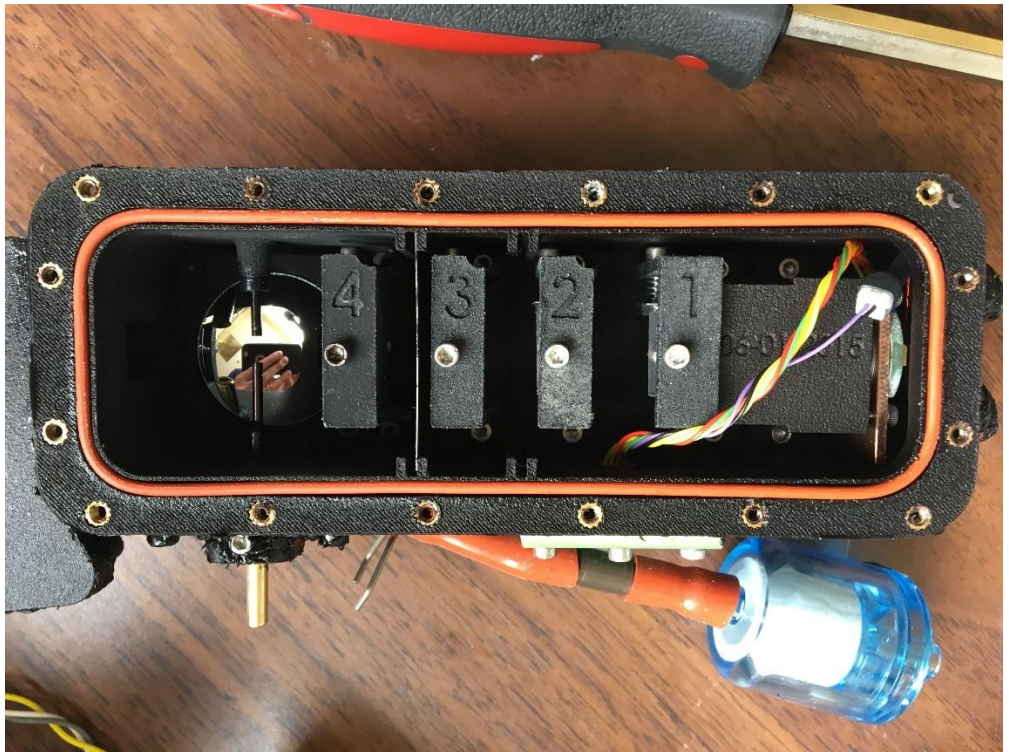
Ozone

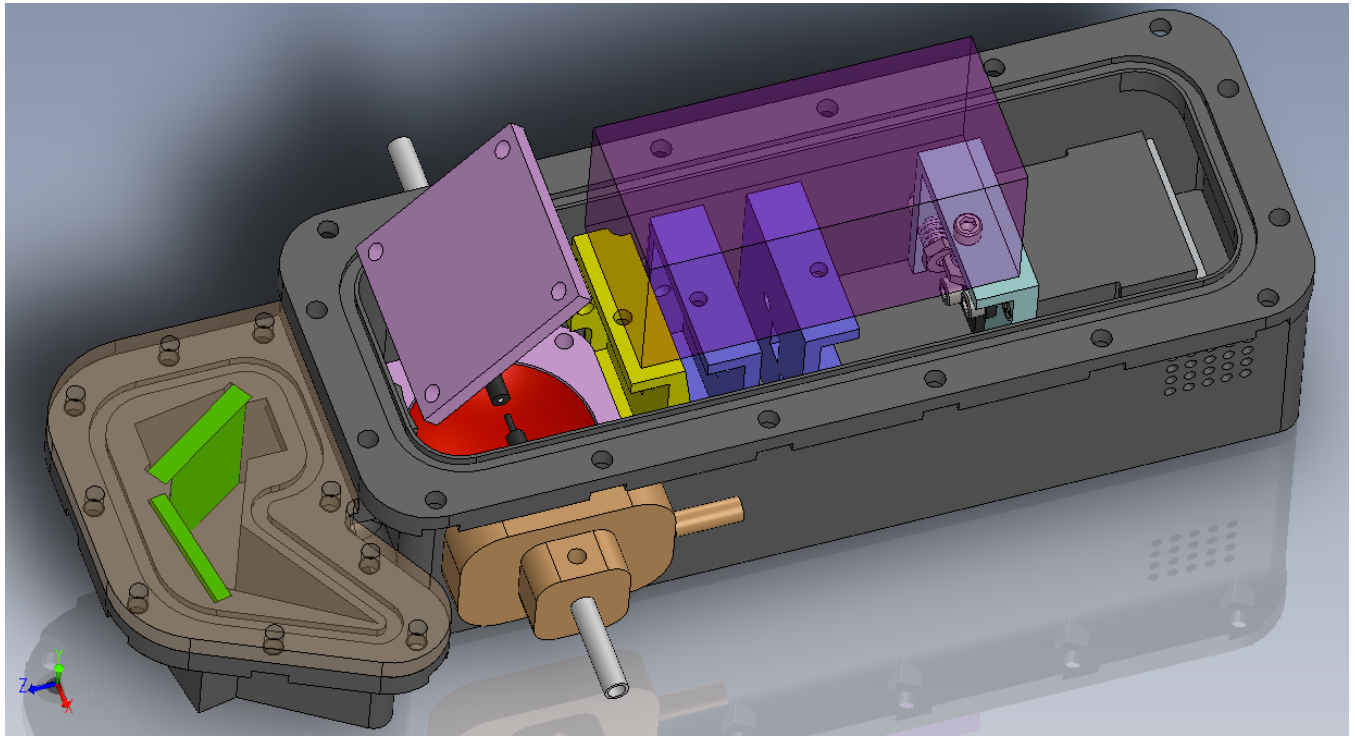
- No significant biases between SAGE III and ECC ozonesondes in the stratosphere
- Spatial and temporal variability of ozone increases in lowermost stratosphere

POPS Optical Particle Counter

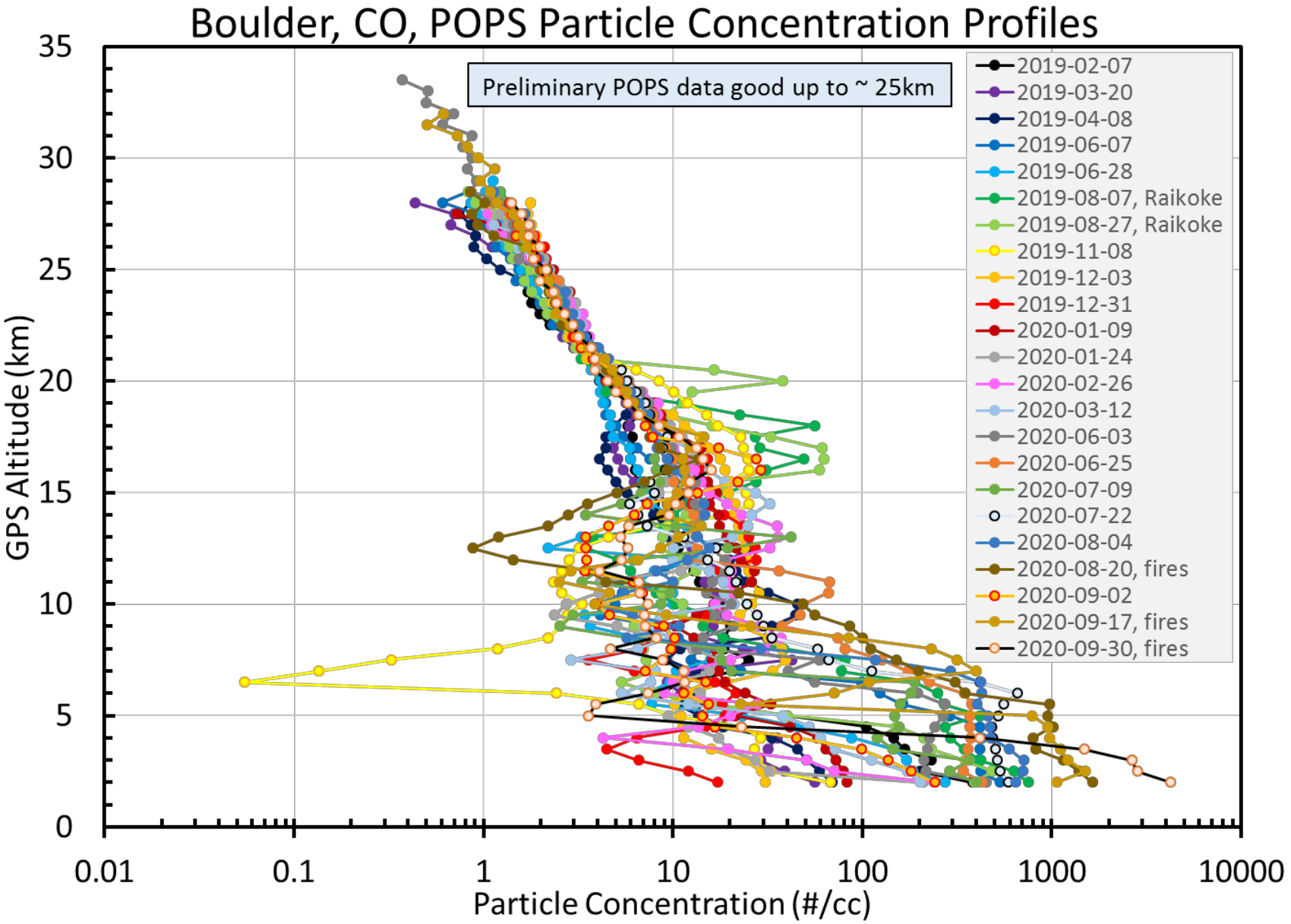
- Optical particle counter
  - Particle size distribution (140 – 2500 nm)
  - Bin sizes changed from being evenly spaced in log detector signal space to evenly spaced in log Dp (nm) Aug 15, 2019 (BLD) and Jan 1, 2020 (LDR)
- Weight ~ 1 kg (with foam and battery)
- Power < 5 W
- 15 size bins transmitted at 1 Hz with iMet radiosonde
- Flow rate ~ 2.0 – 4.5 cc/sec (altitude dependent)







POPS Balloon Launches in Boulder, CO

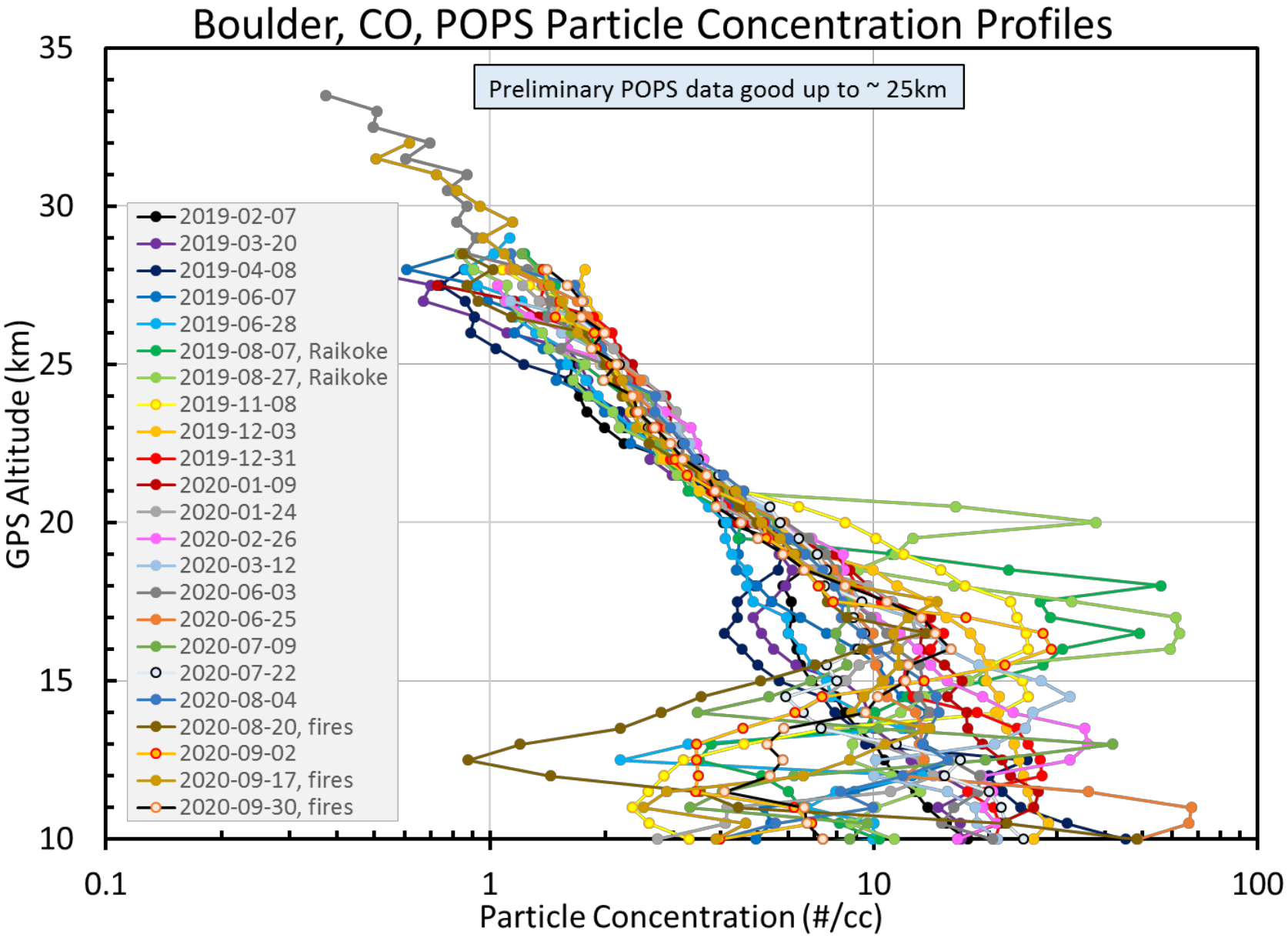


- 23 balloon launches with POPS in Boulder



Photo credit: Jim Elkins

POPS Balloon Launches in Boulder, CO

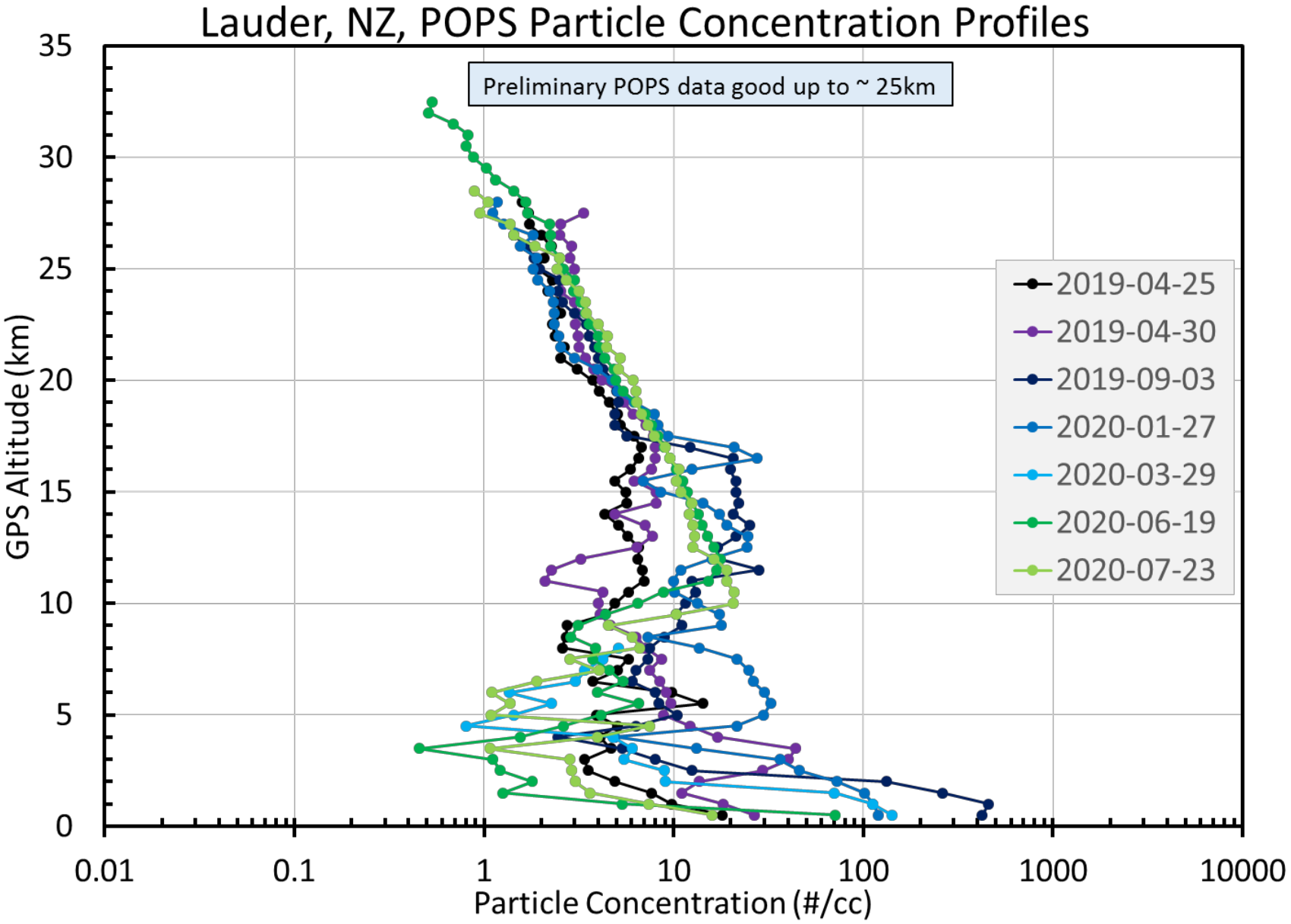


- Less variability above 20 km
  - Starting to see the stratospheric baseline



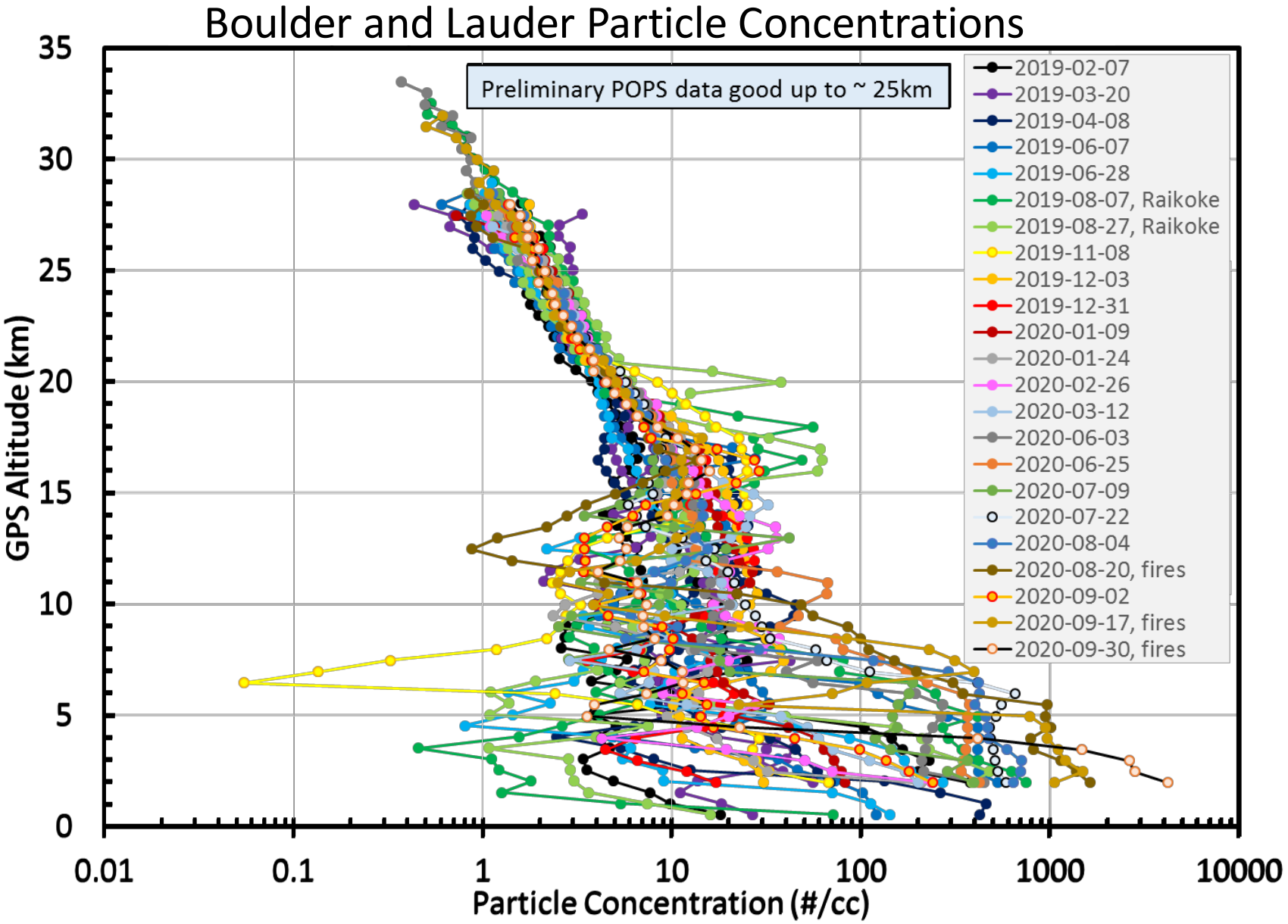
Photo credit: Jim Elkins

POPS Balloon Launches in Lauder, NZ



- 7 balloon launches with POPS in Lauder
- Particle concentrations > 40 #/cc were rarely observed, even in the lower troposphere

Boulder and Lauder POPS Comparison

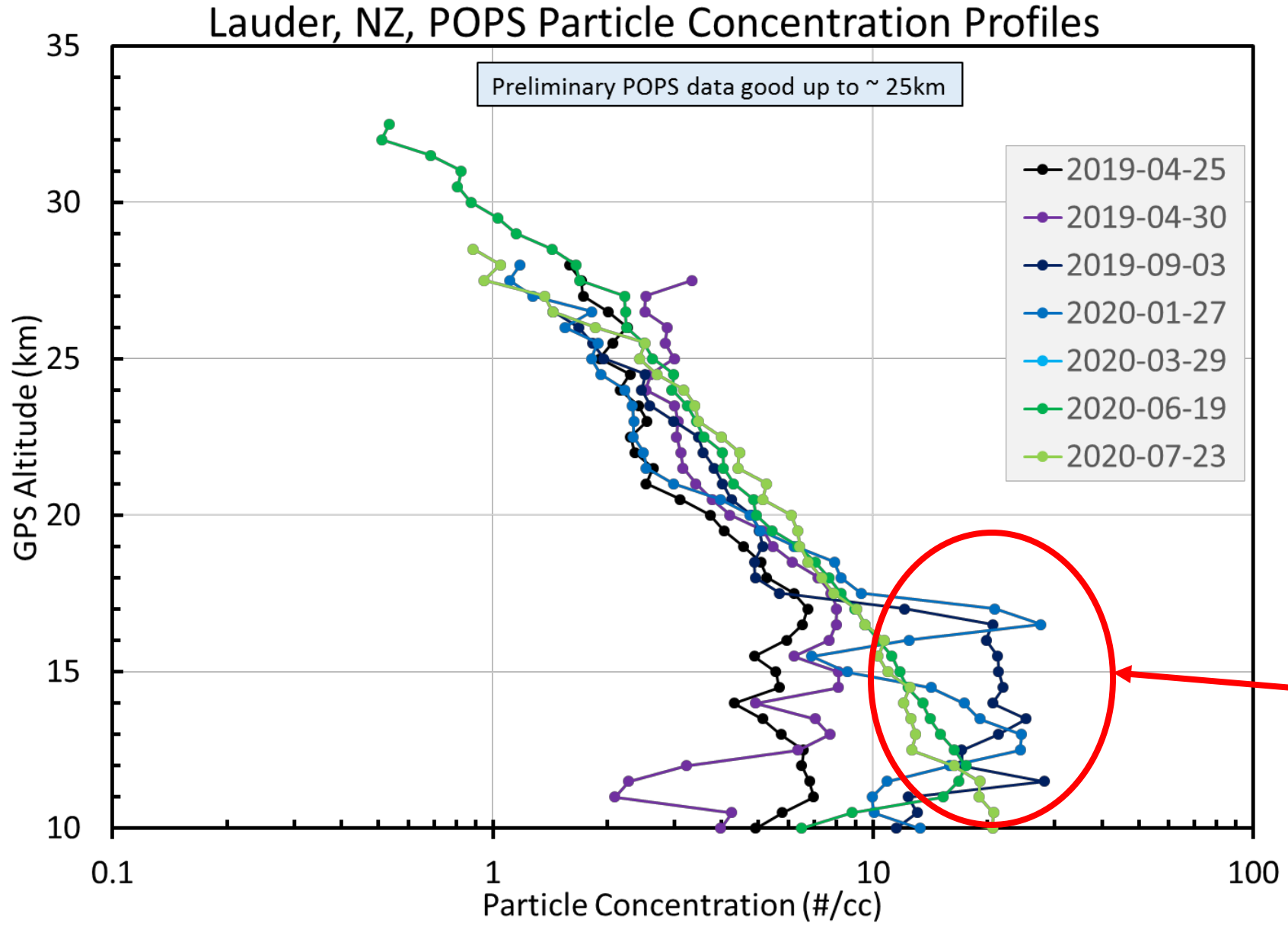


Boulder (40 N) and Lauder (45 S)

- Similar stratospheric aerosol profiles > 20 km
- Lauder shows lower aerosol particle concentrations < 10 km
- Boulder has much higher tropospheric concentrations
  - Concentrations > 100 #/cc were frequently measured up to 9 km in Boulder
  - Partially due to ongoing wildfires in the western US



POPS Balloon Launches in Lauder, NZ



Ulawun Eruption June 26, 2019



- Papua New Guinea
- Elevation = 2334 m
- 5° S, 151° E
- Eruption up to 19 km

Raikoke Eruption

- 22 June 2019
- Kuril Islands
- Latitude 48.3° N
- Tropopause height ~ 11 km
- Ash plume ejected up to ~ **13-17** km

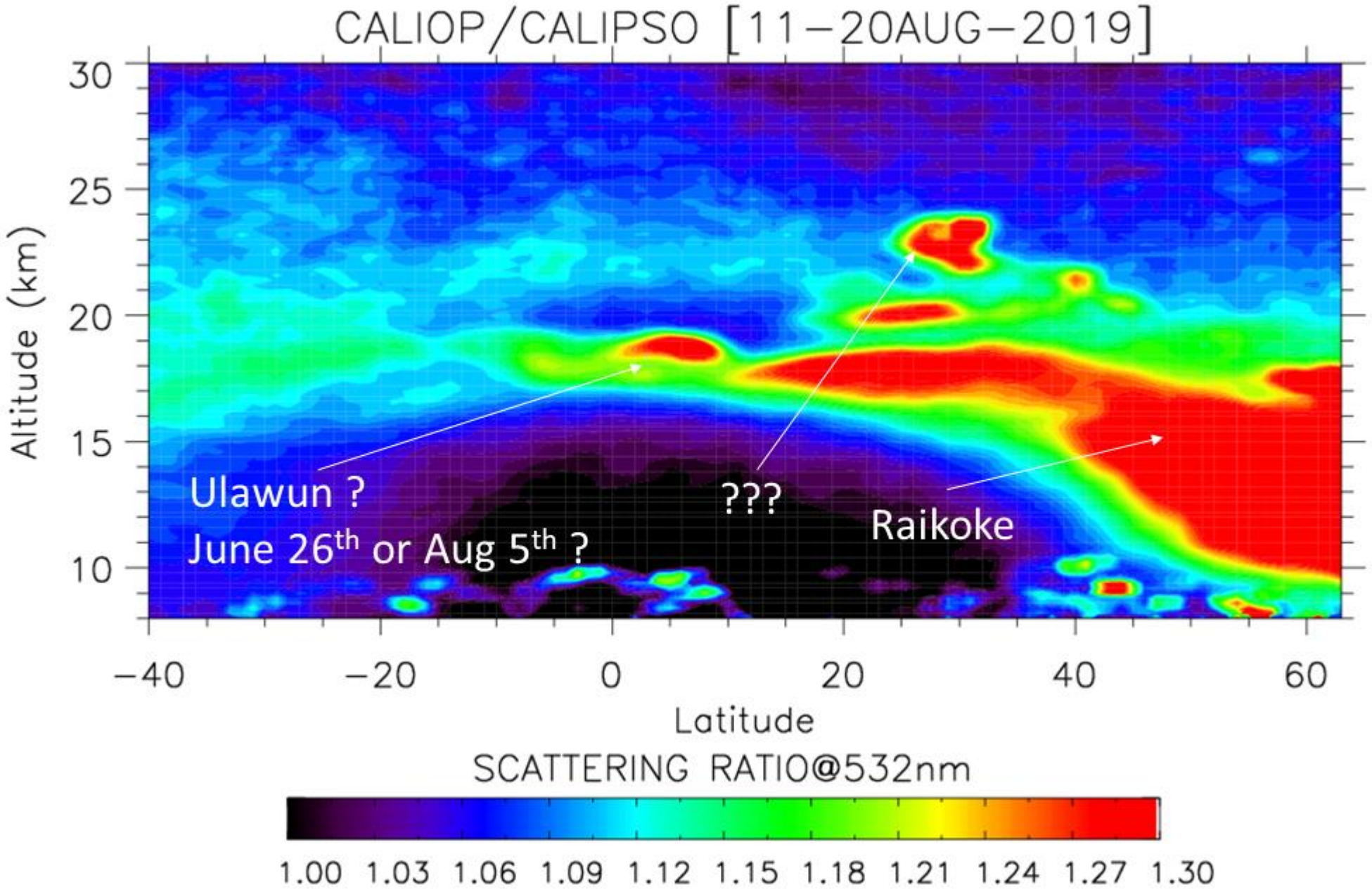
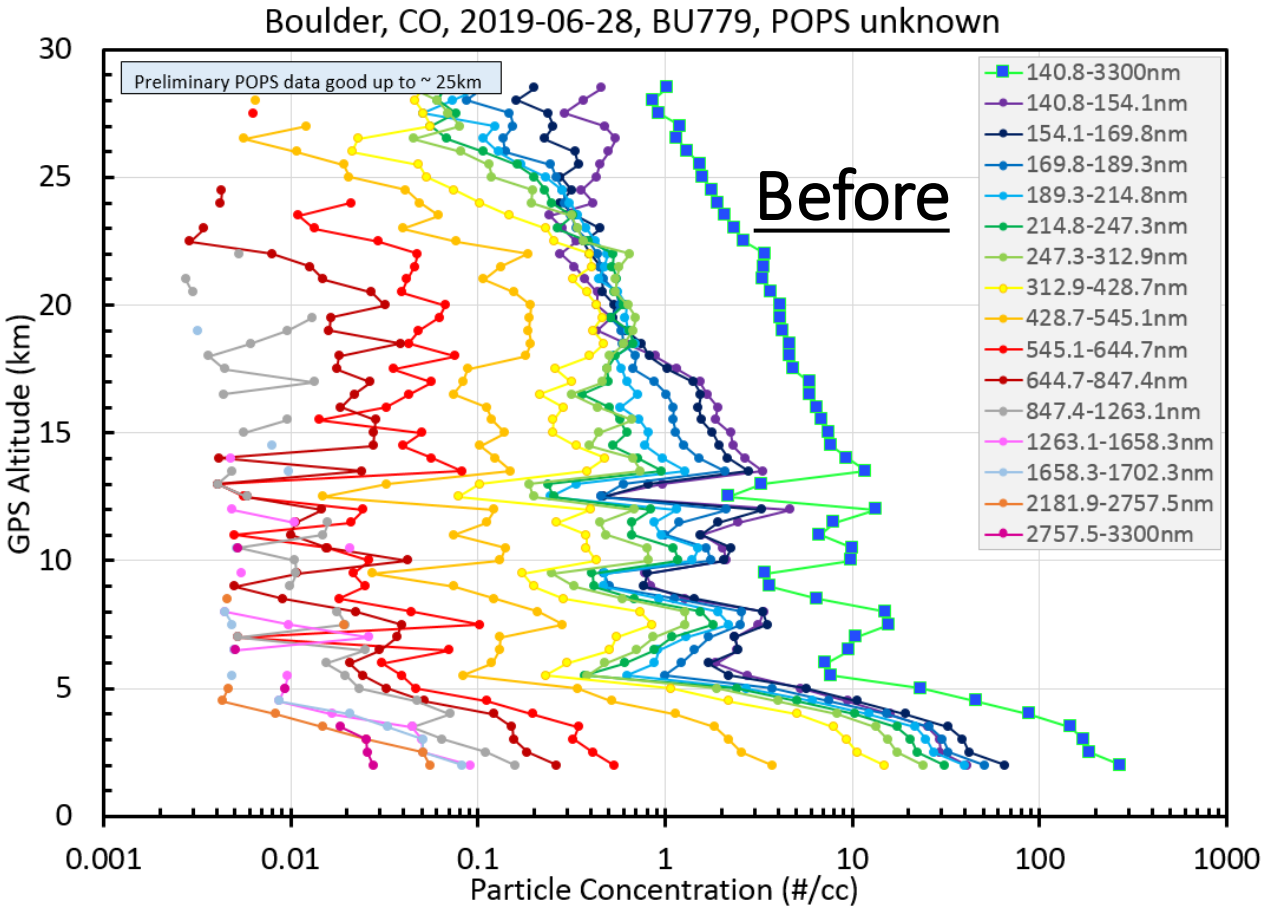
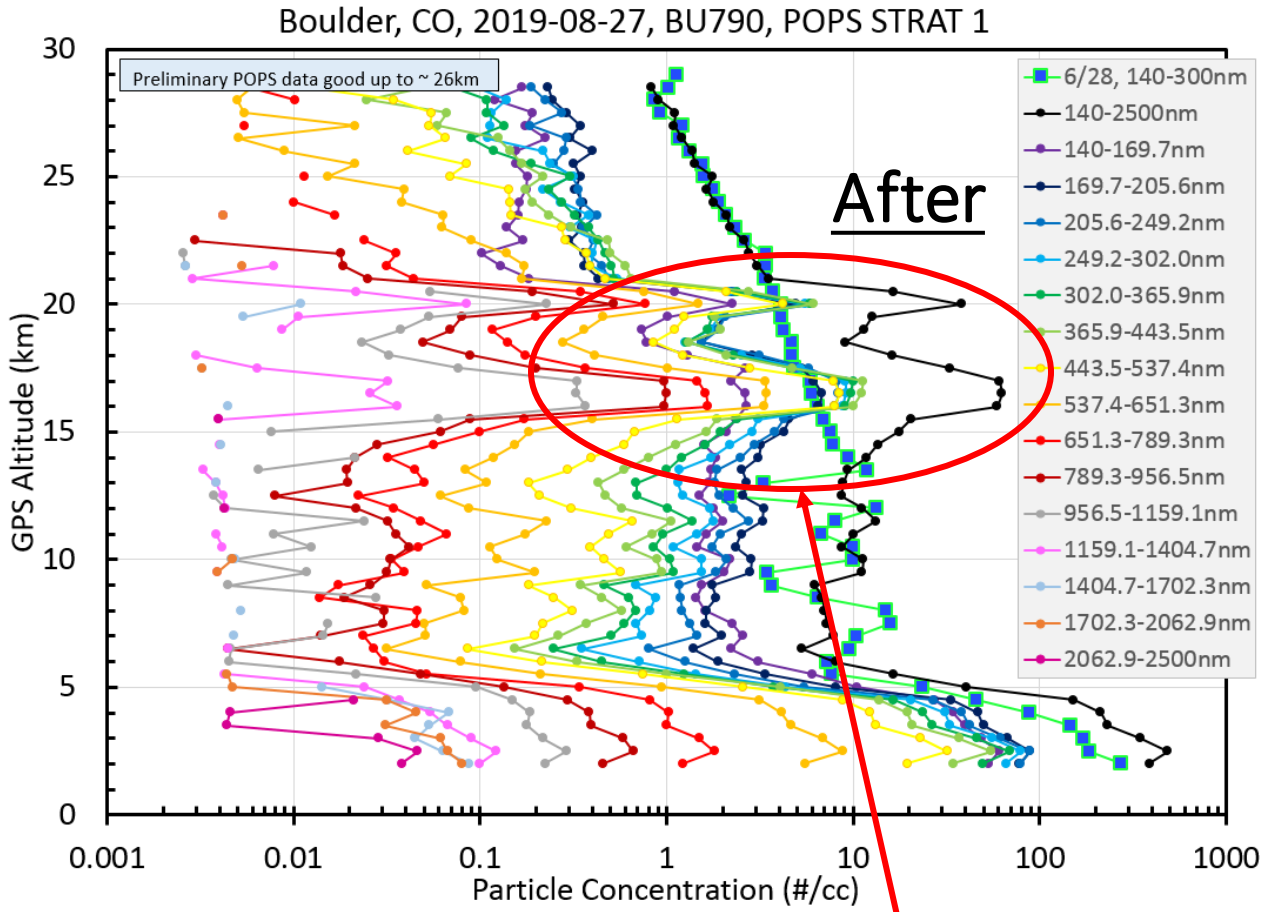


Figure: Jean-Paul Vernier





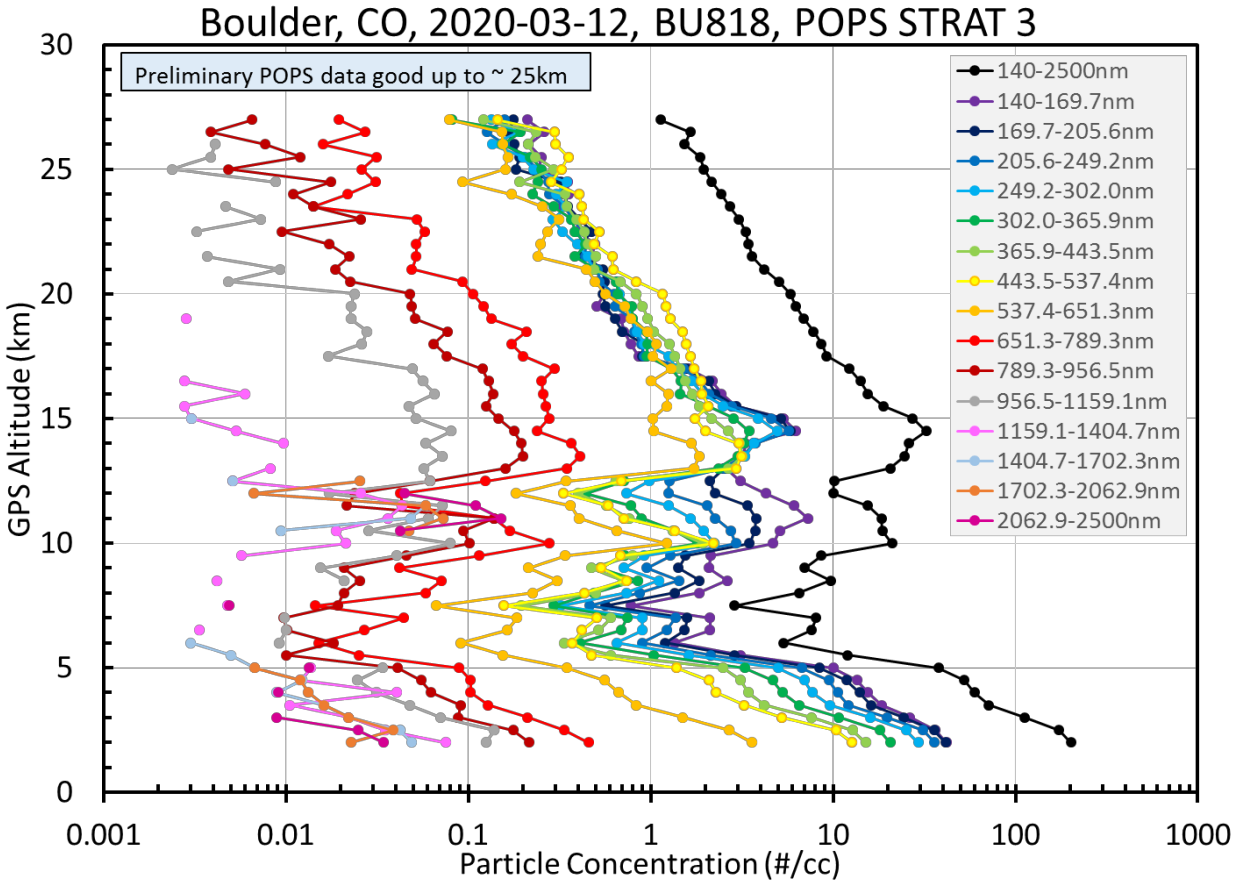


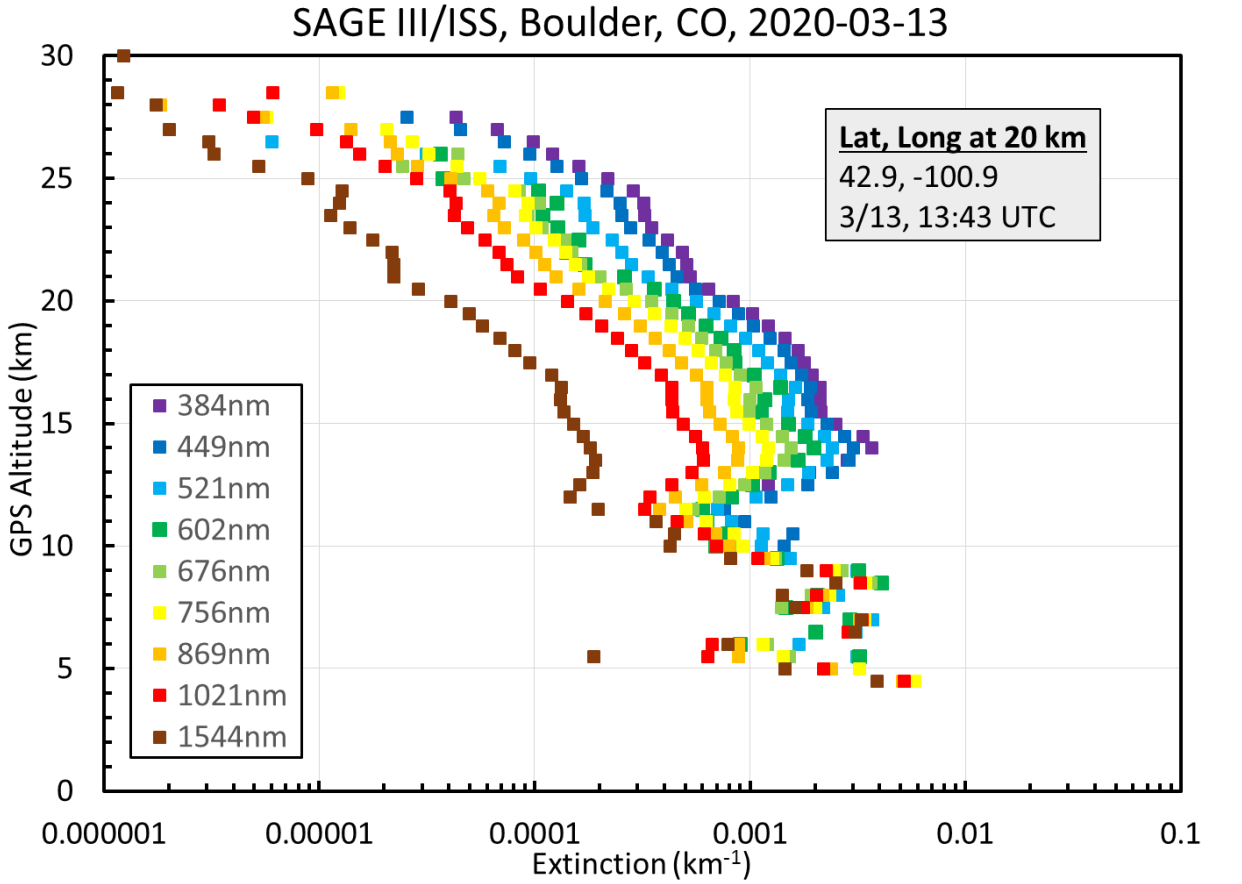




- Distinct plumes observed at 16-18 and ~20 km above Boulder on 27 Aug 2019
- x10 increase in concentration at 17 km in August (61 cm^{-3}) compared to June (6 cm^{-3})
- Size distribution peak near 300 nm

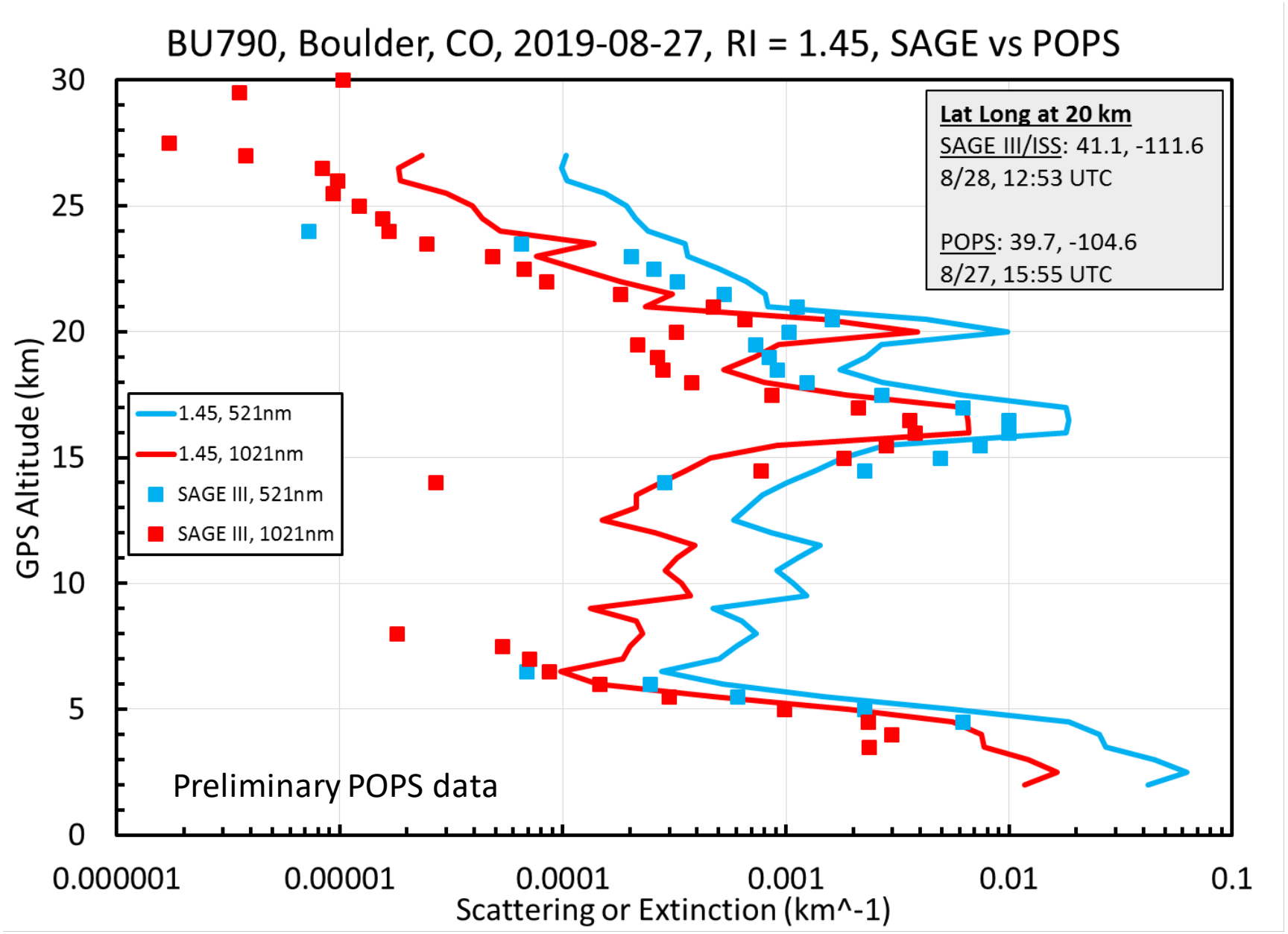
Comparing Particle Concentration to Extinction





Calculating POPS Scattering

- Ran Mie scattering code for the 9 different SAGE III wavelengths between 384 – 1544 nm
  - Used 3 different refractive indices = **1.33, 1.45, and 1.55 (pure water, sulfate, dust/sea salt)**
  - Calculated scattering coefficient (Qscat)
- Calculated POPS scattering at each of the 9 different SAGE III wavelengths:
  - Scattering = (π/4) * Qscat * (particle size(nm)^2) * (particle concencentration (#/cc))


BU790, Boulder, CO, 2019-08-27, RI = 1.45, SAGE vs POPS
Lat Long at 20 km
SAGE III/ISS: 41.1, -111.6
8/28, 12:53 UTC
POPS: 39.7, -104.6
8/27, 15:55 UTC
1.45, 521nm
1.45, 1021nm
SAGE III, 521nm
SAGE III, 1021nm
Preliminary POPS data
GPS Altitude (km)
30
25
20
15
10
5
0
0.000001
0.00001
0.0001
0.001
0.01
0.1
Scattering or Extinction (km^-1)

Smoky Boulder POPS Flight

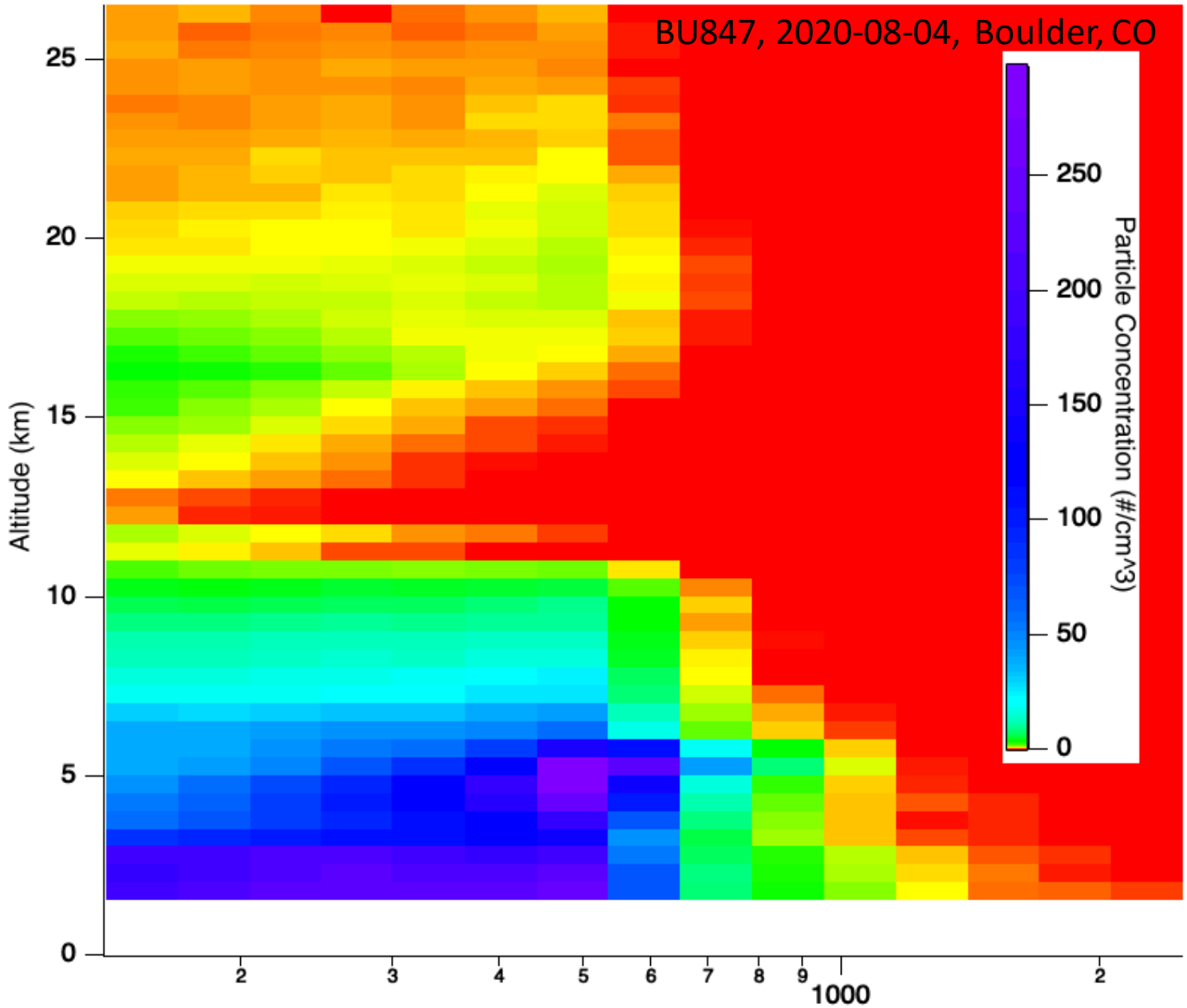


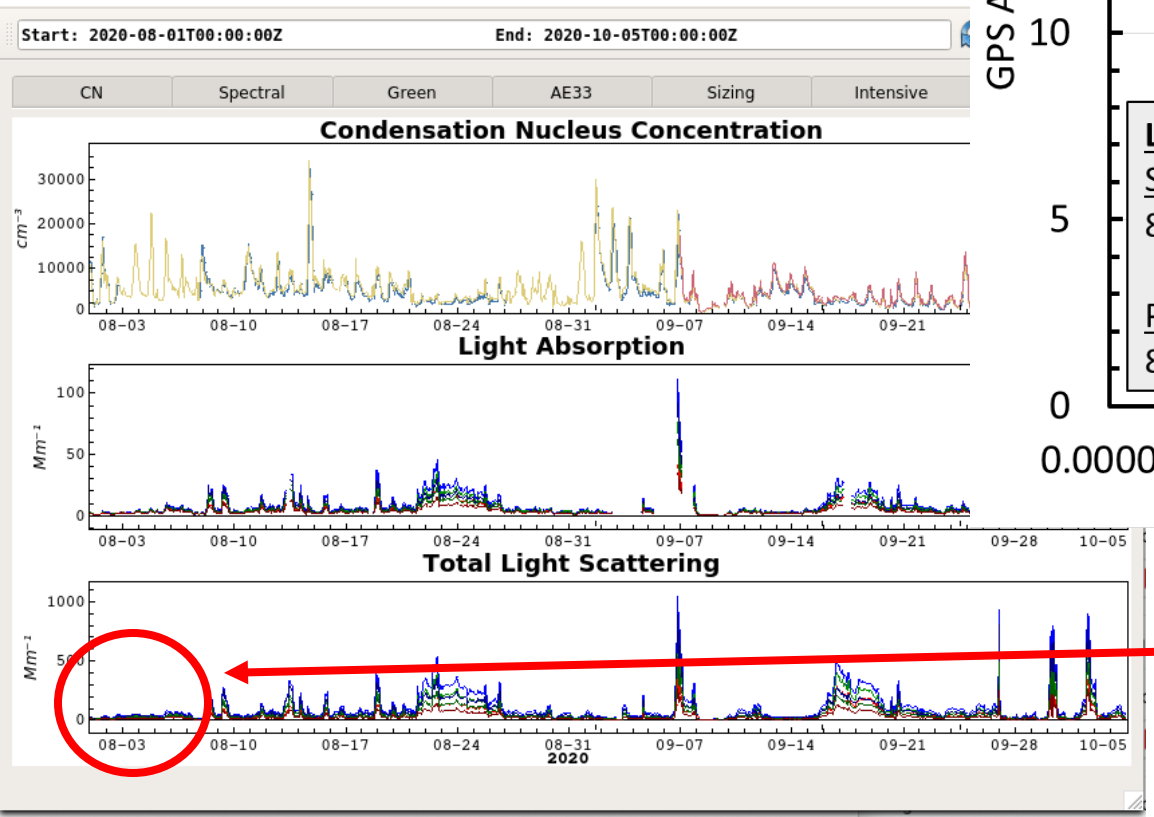
Figure: Lizzy Asher

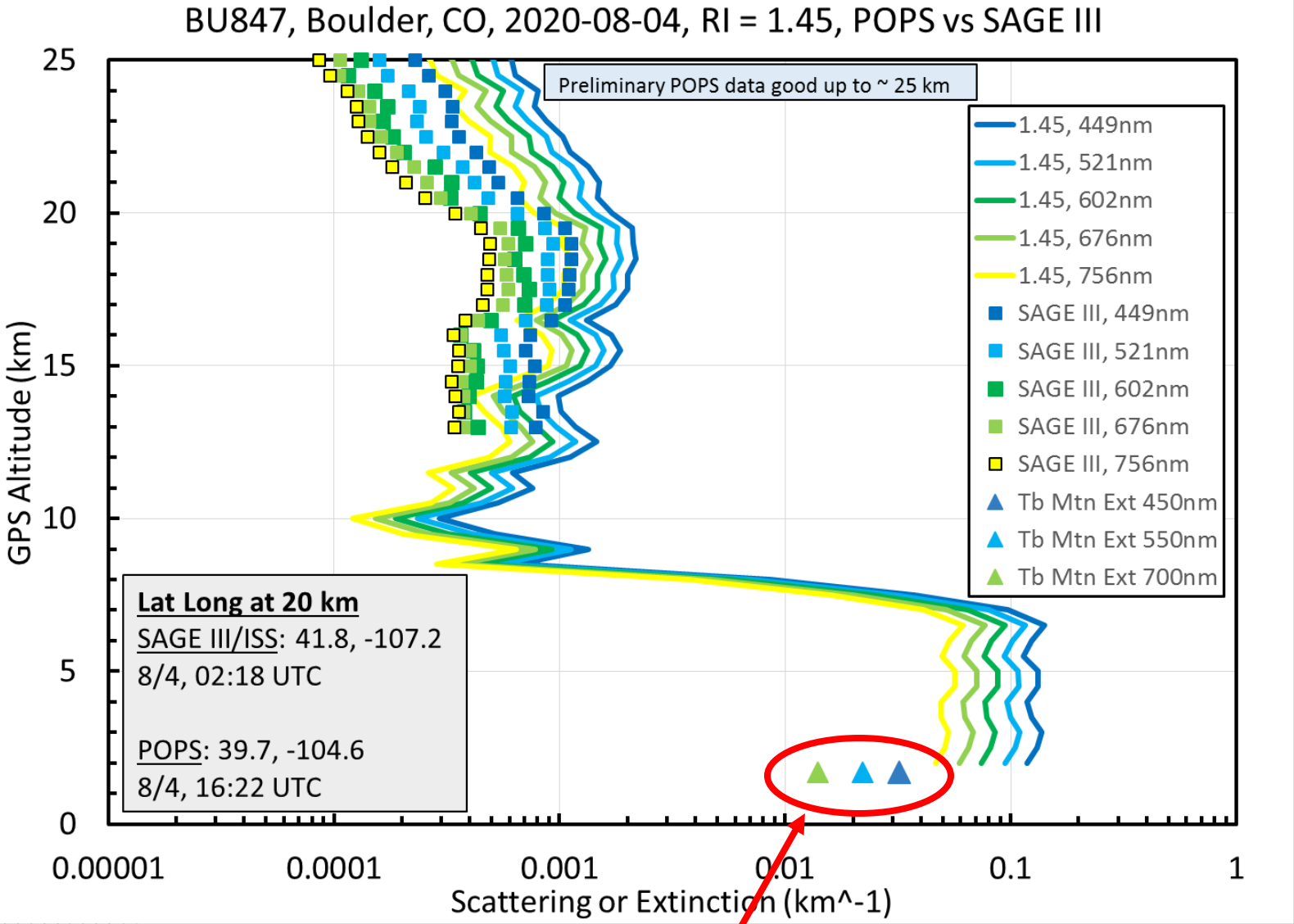
Preliminary POPS data

Aug 4th, 2020

- West coast fires + local Colorado fires
- **200 – 550 nm** peak particle diameter near the surface
- Maximum particle concentration
  - between **4 - 5.5 km**
  - Particle diameter near **440 – 540 nm**
- Clean air layer at 11 km







- Table Mountain Surface Aerosol site shows much lower scattering values just 12 miles north of balloon launch facility

What a balloon launch looks like in Boulder, CO



https://www.youtube.com/watch?v=_fdE0dexw2A&feature=youtu.be

A one minute video showing what a balloon launch looks like in Boulder

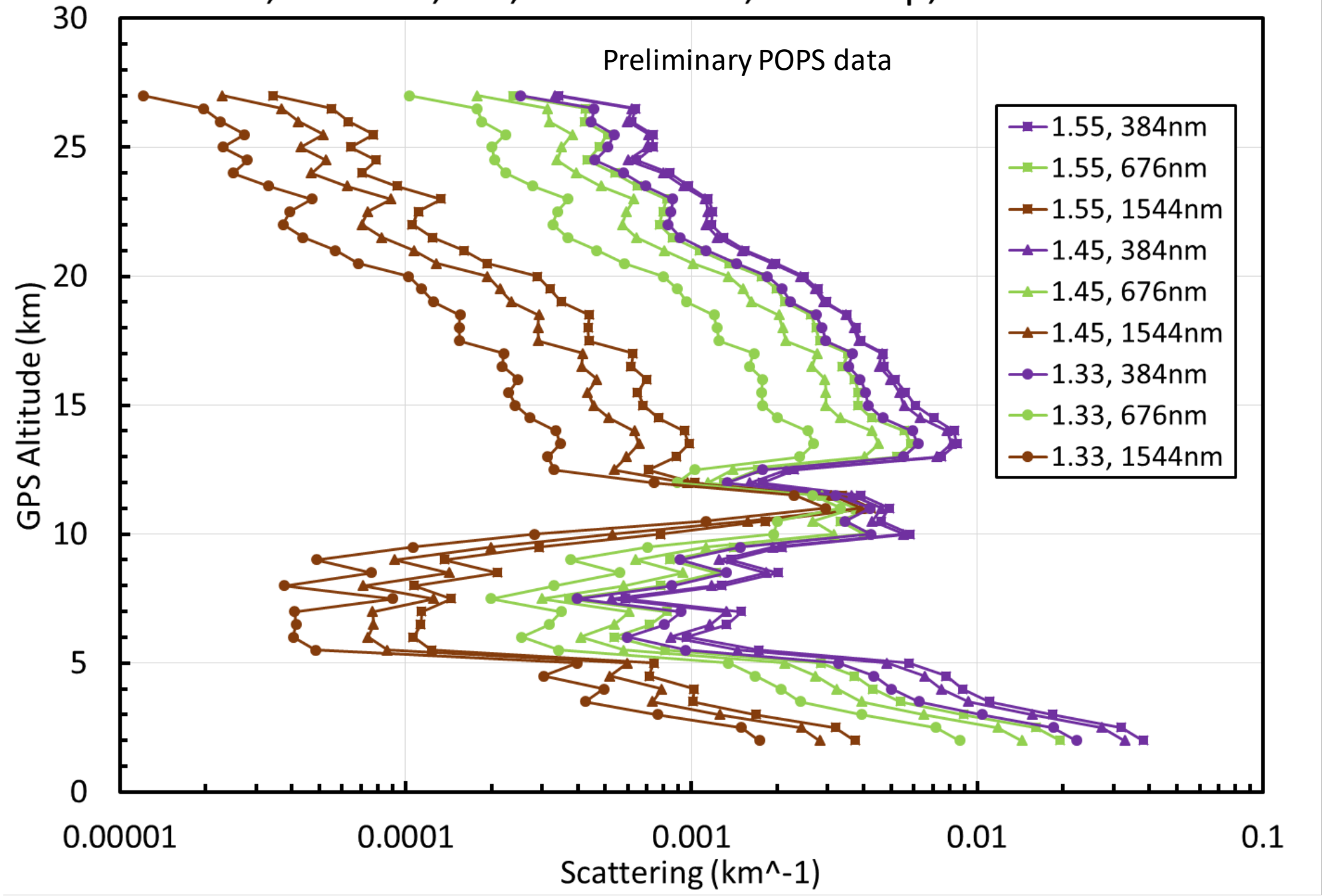
Video: Patrick Cullis

Summary

- We have many successful coincident balloon flights since 2017
  - 58 flights from Boulder
  - 17 flights from Lauder
- Significant stratospheric water vapor biases between SAGE III vs NOAA FPH
  - 0.2 – 0.5 ppm (5-10%)
- No significant biases in SAGE III stratospheric ozone vs balloon
- POPS aerosol instruments attached to the water vapor and ozonesonde package provides a nice set of data on each validation overpass flight
  - Feb 2019 – Boulder
  - April 2019 – Lauder

Thank you for your attention
Any questions?

Extra


BU818, Boulder, CO, 2020-03-12, RI Comp, POPS Strat 3
Preliminary POPS data
GPS Altitude (km)
Scattering (km^-1)
0
5
10
15
20
25
30
0.00001
0.0001
0.001
0.01
0.1
1.55, 384nm
1.55, 676nm
1.55, 1544nm
1.45, 384nm
1.45, 676nm
1.45, 1544nm
1.33, 384nm
1.33, 676nm
1.33, 1544nm

TRENDS IN TROPICAL LMS OZONE (1998-2019) FROM SHADOZ V06 PROFILES: REFERENCE FOR SAGE-BASED SATELLITE PRODUCTS

Anne Thompson (anne.m.thompson@nasa.gov)
with Ryan Stauffer, J. C. Witte,* D. E. Kollonige,
K. Wargan, J. R. Ziemke

*@ NCAR/EOL; all others at NASA-Goddard, Greenbelt, MD

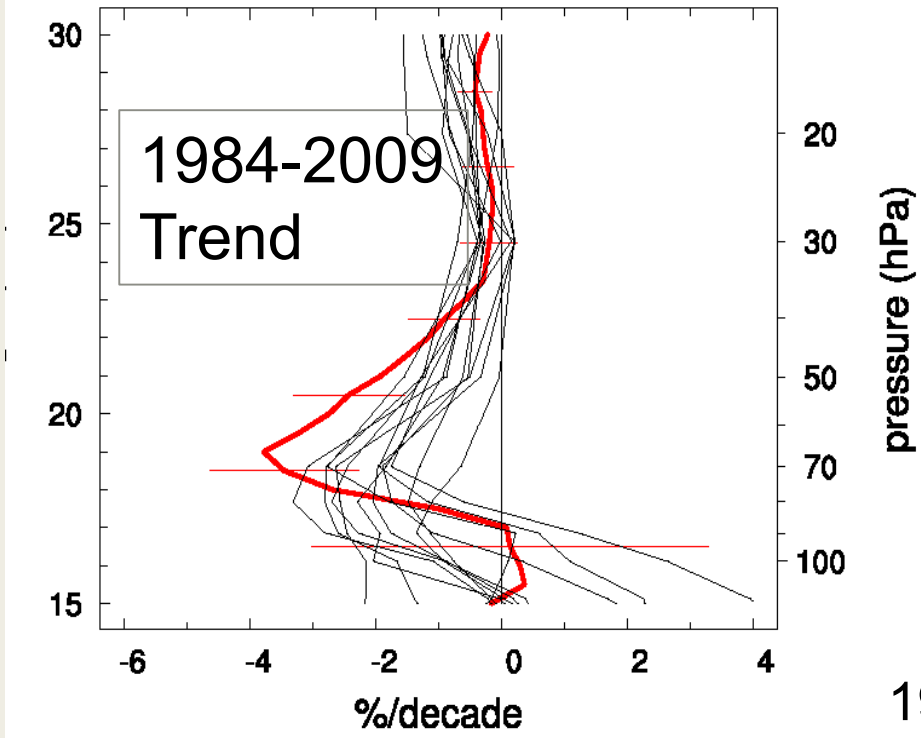
ISS/SAGE III Science Team, 20-Oct-2020

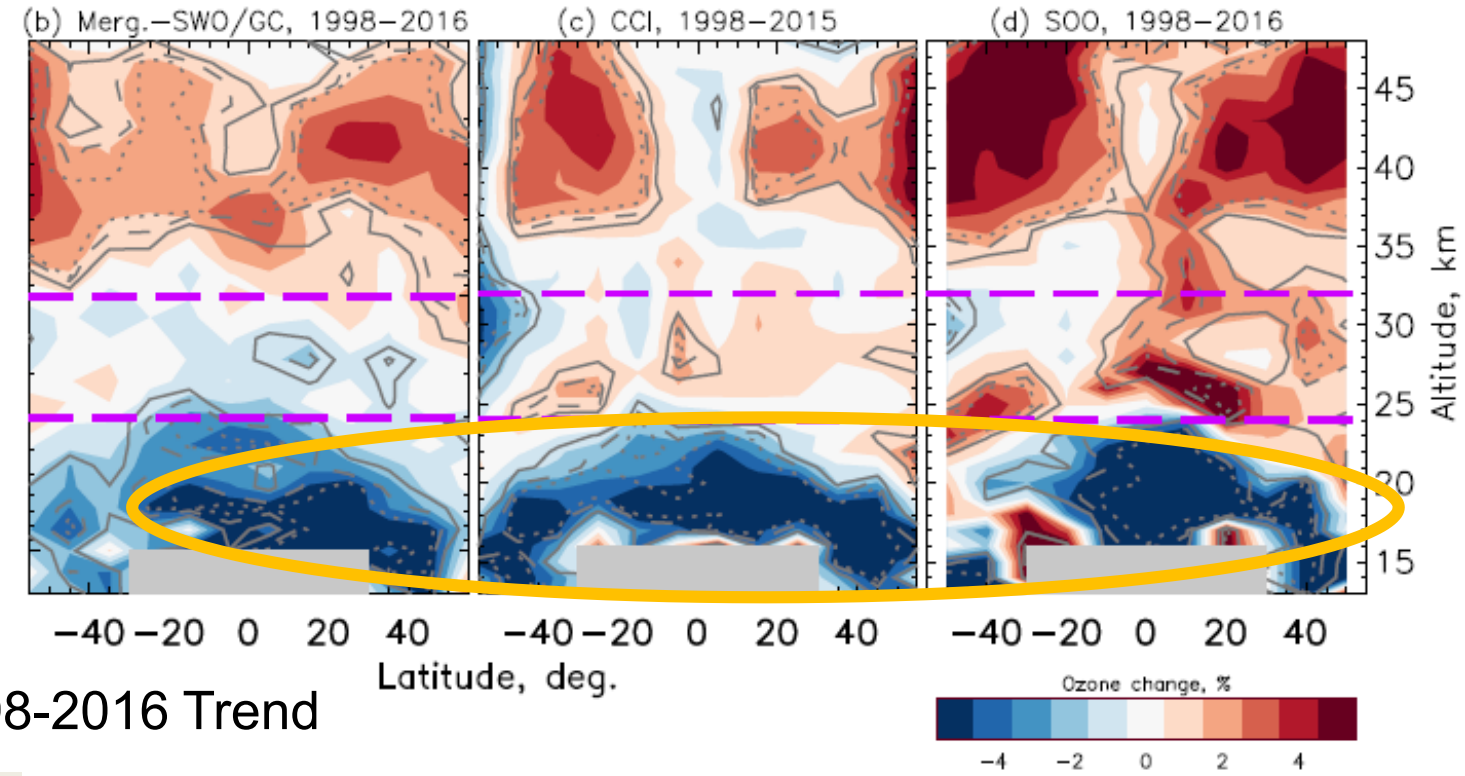
PAPER IN REVISION https://www.essoar.org/doi/10.1002/essoar.10503415.1

OUTLINE

- Background: Tropical LMS (lowermost stratosphere, 15-20 km) ozone trends are important! Context from Pre-ISS/SAGEIII studies
- Climatology of FT (free tropospheric) & LMS O_3 at 5 SHADOZ sites
  - Tropopause Height ("TH," 380K level) from SHADOZ radiosonde
  - "Convective Proxy" = Gravity-wave (GWI) from in O_3, PT laminae
- Trends (1998-2019) in O_3, GWI, Tropopause Height computed with MLR. Assume QBO, ENSO, IOD oscillations, annual & seasonal cycles
- Results: <u>Regional and seasonally</u> dependent LMS O_3 trends that can be compared to models and satellite "products."

Background: LMS Ozone Trends with SHADOZ and SAGE-based Merged Satellite Products





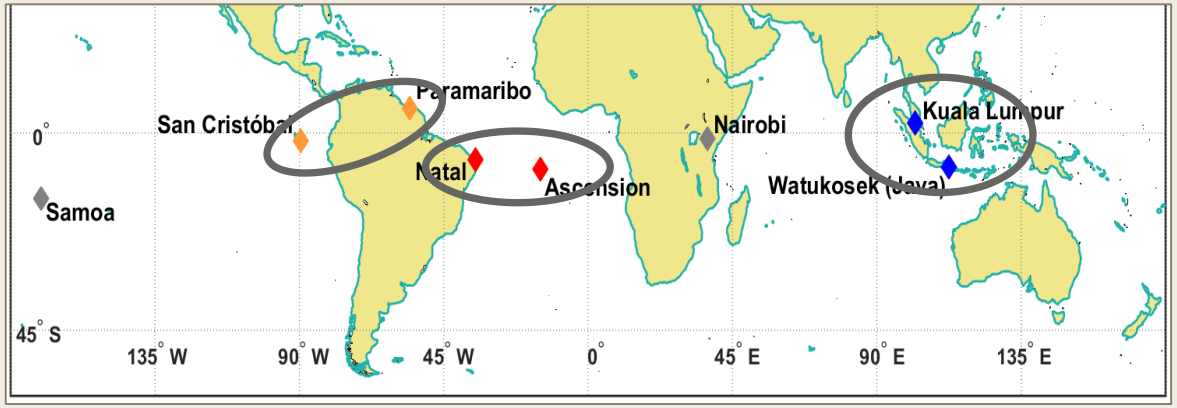
1998-2016 Trend

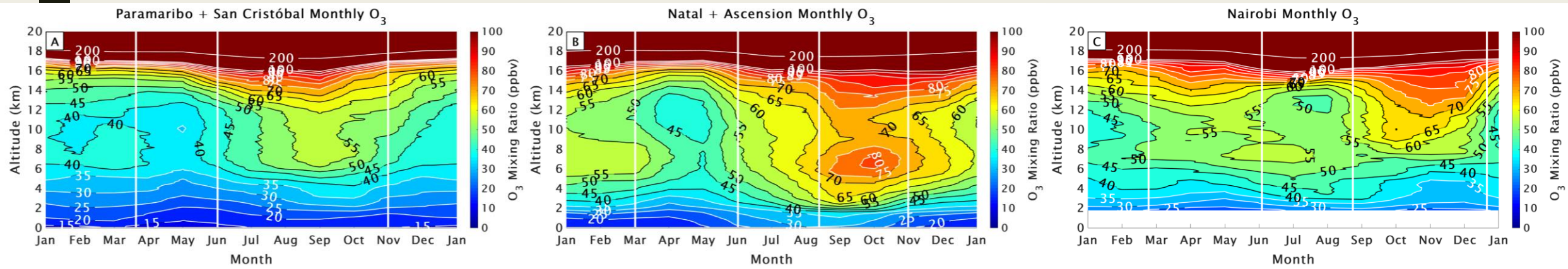
- **LEFT.** Merged SAGE II-SHADOZ profiles with 1998-2009 from SHADOZ. MLR with MEI for ENSO variability, Randel & Thompson (2011) yields a negative trend, ***~-4%/decade*** at 18 km
- **RIGHT.** Tropical strat. O_3 "merged products," three with SAGE II => ***-(2-4)%/dec,*** 1998-2016 (Ball et al., 2018). Compare MERRA trend, ***+~5%/decade*** (Wargan et al., 2018, not shown)

SHADOZ Climatology: O_3 Seasonal & Regional Variability

- **Use 22-yr SHADOZ data (1998-2019) to** determine trends in O_3 and 2 dynamical indicators derived from radiosondes.
- **Sonde advantages over satellite data**
  (1) More precise O_3 than satellite data in LMS
  (2) Regular fixed site sampling at ~100-150 m resolution gives Free Tropos. (FT) and LMS trends
  (3) In-situ profile data, full zonal coverage
- **Data presented from 5 "sites" (Right)**
- **Seasonal O_3 to 20 km (Below)**

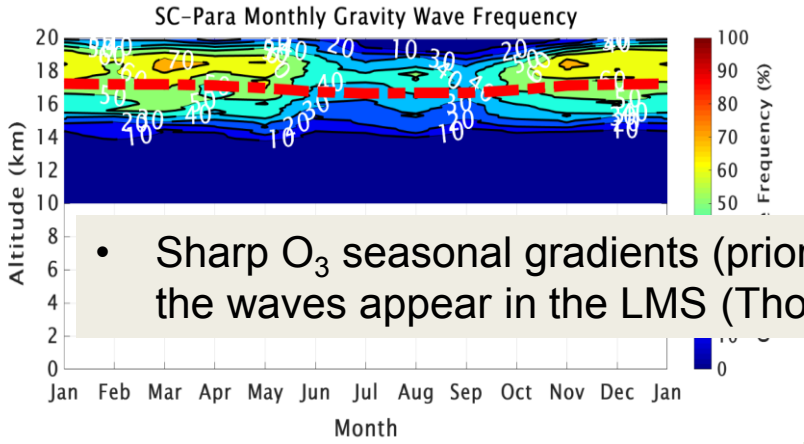
SC-Para Nat-Asc KL-Java

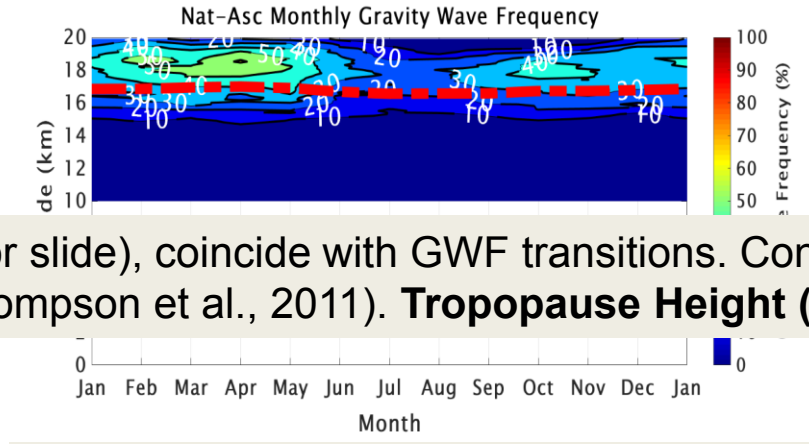


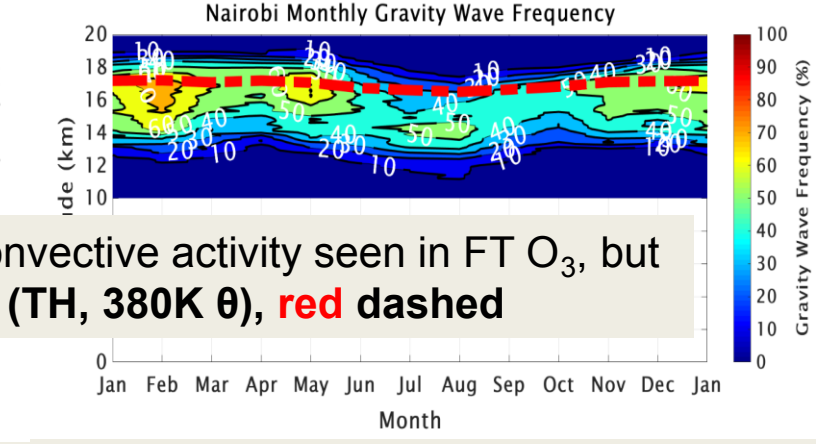


"Seasonal" transitions, marked by sharp O_3 gradients (white vertical lines), represent alternations in dominant dynamic influences, ie convection vs advected pollution (Thompson et al., 2012)

Seasonal Transitions in FT O_3 & Convective Proxy (GWF) Align. TH Annual Cycles Vary Annually (16.5 – 17.3 km)





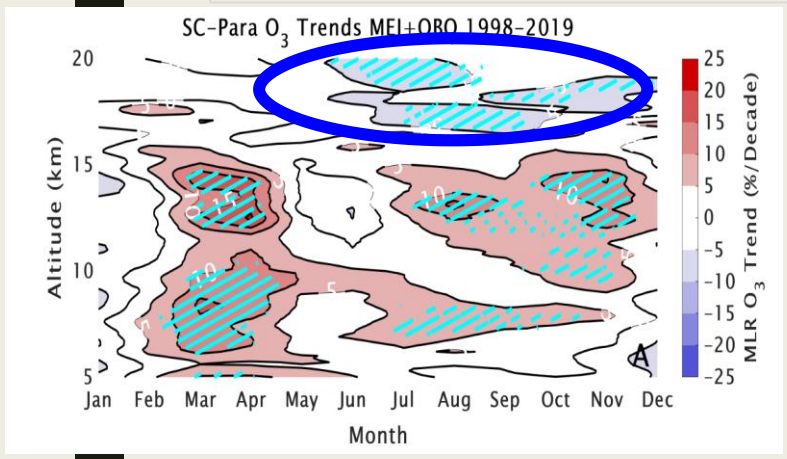


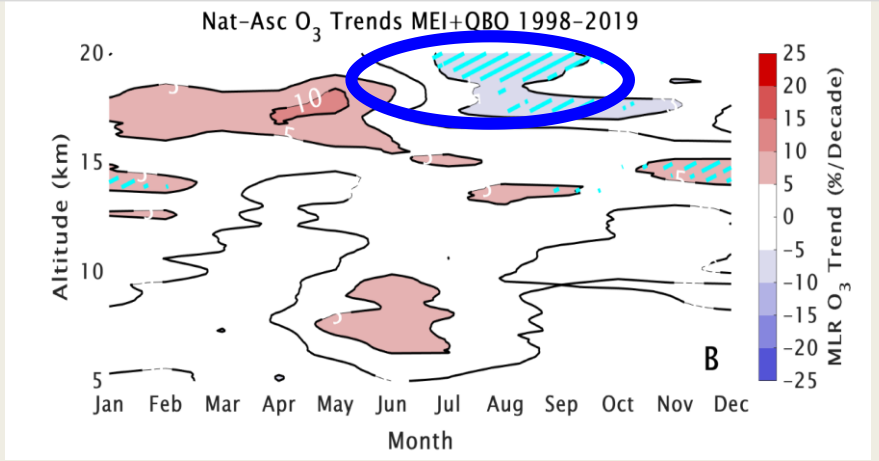
- Sharp O_3 seasonal gradients (prior slide), coincide with GWF transitions. Convective activity seen in FT O_3, but the waves appear in the LMS (Thompson et al., 2011). **Tropopause Height (TH, 380K θ), red dashed**

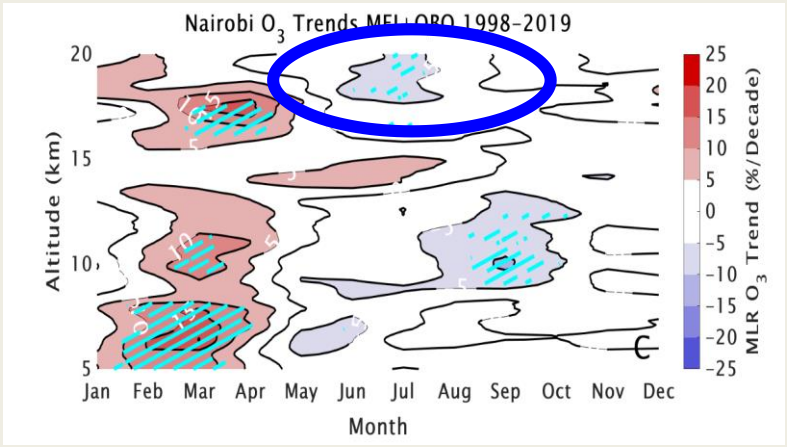
- **Compute Trends in monthly mean O_3, GWF (0.1 km intervals) and TH using GSFC MLR model with typical QBO, ENSO, IOD terms.**
- **Table (Right) lists 5 station locations, profile #, and terms for best model fit. Last column is annually averaged trend**
- **One station displays significant annual trend**

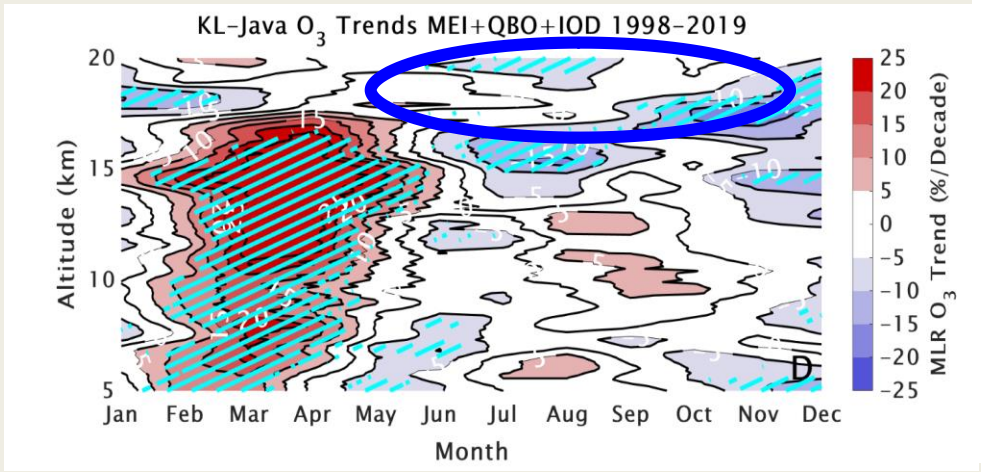
Site	Lat, Lon (°)	Profiles	MLR Terms	Ann
SC+Para	5.8, -55.21/-0.92, -89.62	1227	ENSO+QBO	
15-20 km			%/dec	-2.6
Natal+Ascen	-5.42, -35.38/-7.58, 14.24	1436	ENSO+QBO	
15-20 km				0.9
Nairobi	-1.27, 36.8	941	ENSO+QBO	
15-20 km				1.2
KL+Java	2.73, 101.27/-7.5, 112.6	786	ENSO+QBO+IOD	
15-20 km				-2.7
Samoa	-14.23, -170.56	795	ENSO+QBO	
15-20 km				-2.9

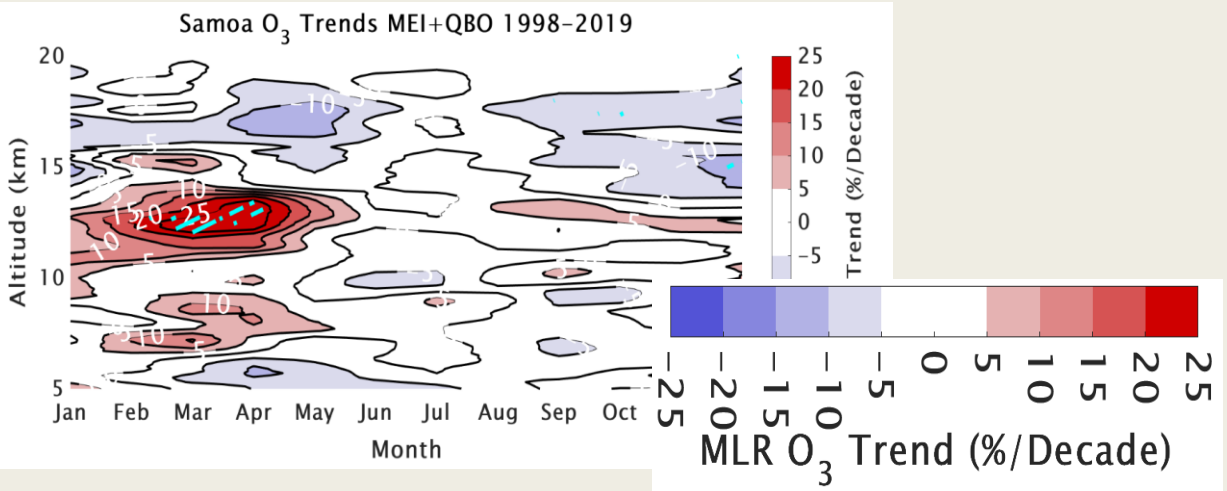
LMS Ozone Trends (%/decade; cyan significant)





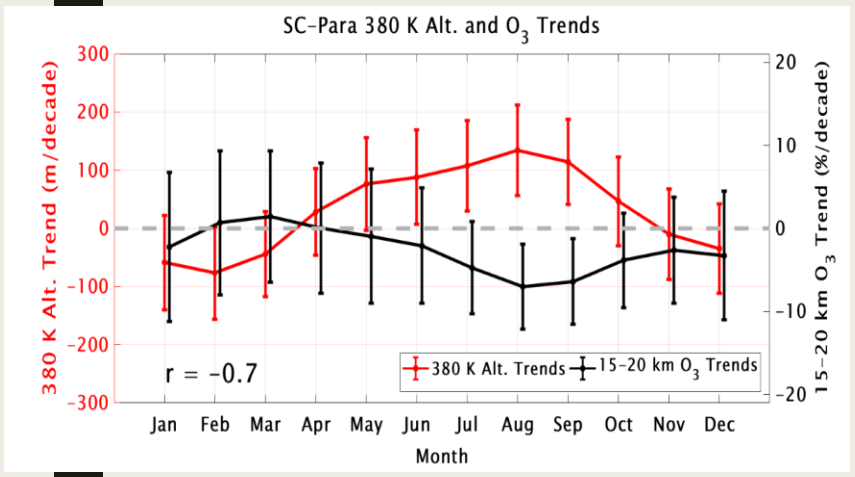


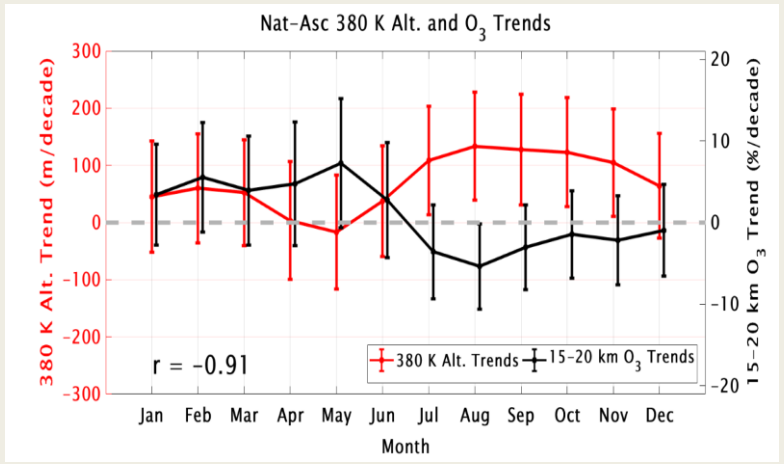


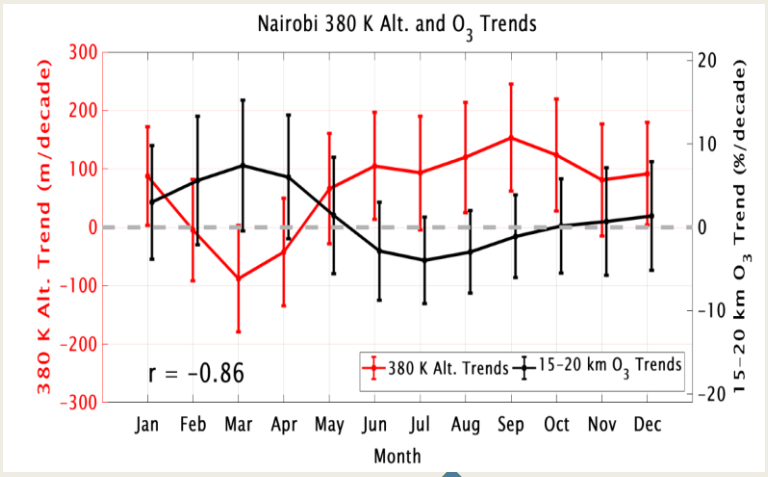


- LMS ozone displays a negative trend but mostly during latter part of year
- Magnitude of LMS ozone losses (blue circles) is 5-10%/decade

Positive Trends in Tropopause Height Coincide with LMS Ozone Loss







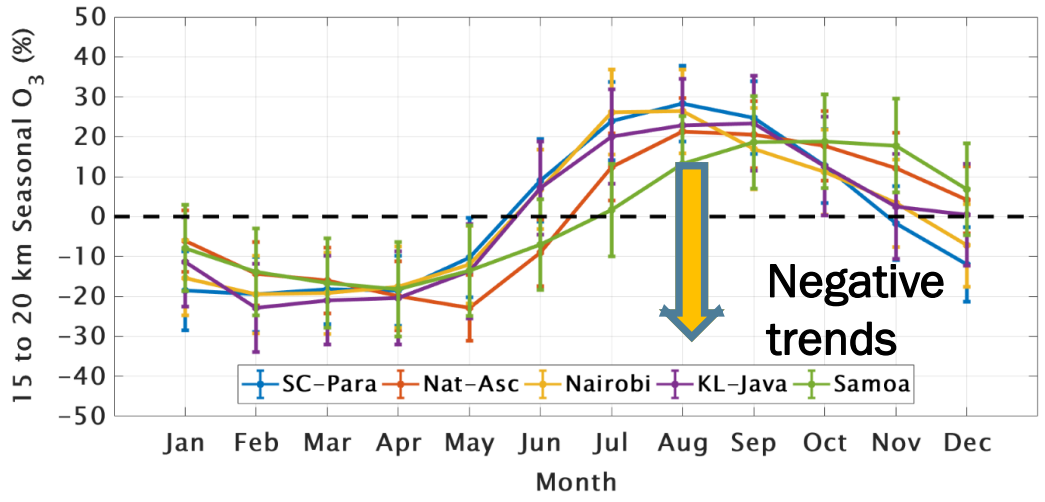
LMS O_3 trend

TH (380K) trend

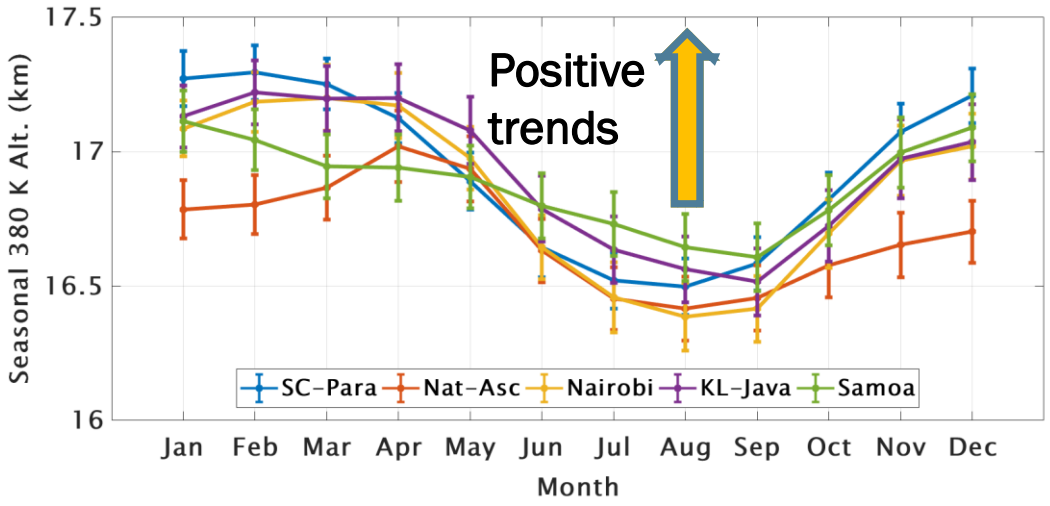
- **Mid-late year**: Tropopause Height (380K altitude) increases, ~150-175 m, occur when LMS O_3 decreases ~5%/dec. LMS O_3-TH anti-correlated (0.7-0.9)
- Connection to GW change (not shown) less clear
- **Next:** Examine other data, re-analyses for evidence of TH & convective trends

SIGNIFICANCE OF SHADOZ TRENDS. Context from LMS Ozone & TH Cycles (Anomaly from Means)

Monthly LMS Ozone Anomaly



Tropopause Height Anomaly



- **Significant LMS O_3 losses coincide with O_3 maximum, July – Sept/Oct.** A decreasing maximum with little change in Jan-May O_3 minimum signifies a "flattening" of the annual cycle (due to BDC, Randel et al. 2007)
- **Tropopause Height increase coincides with LMS O_3 loss.** Small decrease in TH Jan.-May (TH max) means that mean TH is increasing and the annual cycle will flatten out

Summary: SHADOZ LMS Trends

- **Ozone Trends:** Only 1 of 5 SHADOZ stations exhibits "robust" annual change, ~3%/dec **LMS O_3 loss at SC-Para** during 1998-2019. *From Jun/Jul to Nov/Dec, 3 stations display significant O_3 losses in isolated months*
  - Our results do not readily "match up" with zonally averaged satellite trends. The trends of Szelag et al. (2020) with 4 merged products using SAGE II (one with SAGE III) show maximum LMS O_3 losses in M-A-M, not J-J-A as in sondes
  - SHADOZ O_3, TH data & model fits over 22 yrs will be available for satellite and model comparisons – ***Reference*** for ongoing Assessments (LOTUS, etc)?
- **Dynamical Influences on LMS Ozone Trends?**
  - LMS O_3 losses are strongly correlated with TH increases (mid-late year)
  - In both cases, LMS O_3 (maximum) and TH (minimum), the direction of change during this time flattens the annual cycle
  - More study of links among LMS O_3 TH, convective activity is needed. Look at independent data, re-analyses and output from suitable Chem-Climate models.

THANK YOU FOR ATTENTION!

- **NASA SUPPORT:** Upper Atmospheric Composition Observations Program (Ken Jucks, HQ) for SHADOZ support. **ISS/SAGE III to AMT (R. Eckman).** Additional funding from USRA/NPP to RMS, GMAO to KW

- **ISS/SAGE III PARTNERS:** H-J. Ray Wang, Ga Tech, PI; S. Strahan, USRA/GSFC, Co-I. Also Co-I with L. Kalnajs & T. Deshler (CU-Boulder)

- **COMMENTS:** W. Randel (NCAR); O. Cooper/A. Gaudel (NOAA/CSD)

BIBLIOGRAPHY

EARLY SAGE & SHADOZ ARTICLES

Randel & Thompson (2011) *J. Geophys. Res.* https://doi.org/10.1029/2010JD015195

Randel, W. J. et al (2007) *J. Atmos. Sci.* https://doi.org/10.1175/2007JAS2409.1

Thompson, A. M. et al. (2011) *J. Geophys. Res.* https://doi:10.1029/2009JD013429

Thompson, A. M. et al. (2012) *J. Geophys. Res.* https://doi: 10.1029/2010JD016911

RECENT SATELLITE PRODUCT TRENDS

Ball, W. T. et al. (2018) *Atmos. Chem. Phys.* https://doi.org/10.5194/acp-18-1379-2018

Ball, W. T. et al. (2020) *Atmos. Chem. Phys.* https://doi.org/10.5194/acp-20-9737-2020

Szelag, M. et al. (2020) *Atmos. Chem. Phys.* https://doi.org/10.5194/acp-20-7035-2020

Wargan, K. et al. (2018) *Geophys. Res. Lett.* https://doi.org/10.1029/2018GL077406

SHADOZ V06 OZONE ARTICLES

Stauffer, R. M. et al. (2020) *Geophys. Res. Lett.* e2019GL086791. https://doi.org/10.1029/2019GL086791

Thompson, A. M., et al. (2017) *J. Geophys. Res.* https://doi.org/10.1002/2017JD027406

Witte, J. C. et al. (2017) *J. Geophys. Res.* https://doi:10.1002/2016JD026403

Witte, J. C. et al. (2018) *J. Geophys. Res.* https:// doi:10.1002/2017JD027791

Comparisons with Stratospheric Aerosol and Gas Experiment-III (SAGE III-ISS) Ozone Profiles and Umkehr

by Irina Petropavlovskikh, Koji Miyagawa, Jeannette Wild, Sean Davis and Karen Rosenlof

OCTOBER 20, 2020, SAGE III/ISS ST MEETING

Data

SAGE III (v5.1)

- SAGE II (1985-2005), SAGE III (2017.06-2020.06)
- Matched time +/- 24 hrs
- Latitude +/- 2 degree ~200 km
- Longitude +/- 20 degree ~2000 km
- Binary conversion using IDL program for SAGE II
- HDF conversion by Allen program for SAGE III
- Individual profile applied Aks
- https://asdc.larc.nasa.gov/project/SAGE%20III-ISS

Aura MLS (MLS) V4

- Station overpass data from AVDC archive

https://avdc.gsfc.nasa.gov/pub/data/satellite/Aura/MLS/V04/L2GPOVP_Prof/O3

UMKEHR (UMK)

- UMK applied Stray light correction and Optimized
- Umkehr 61 layers pressure interpolation

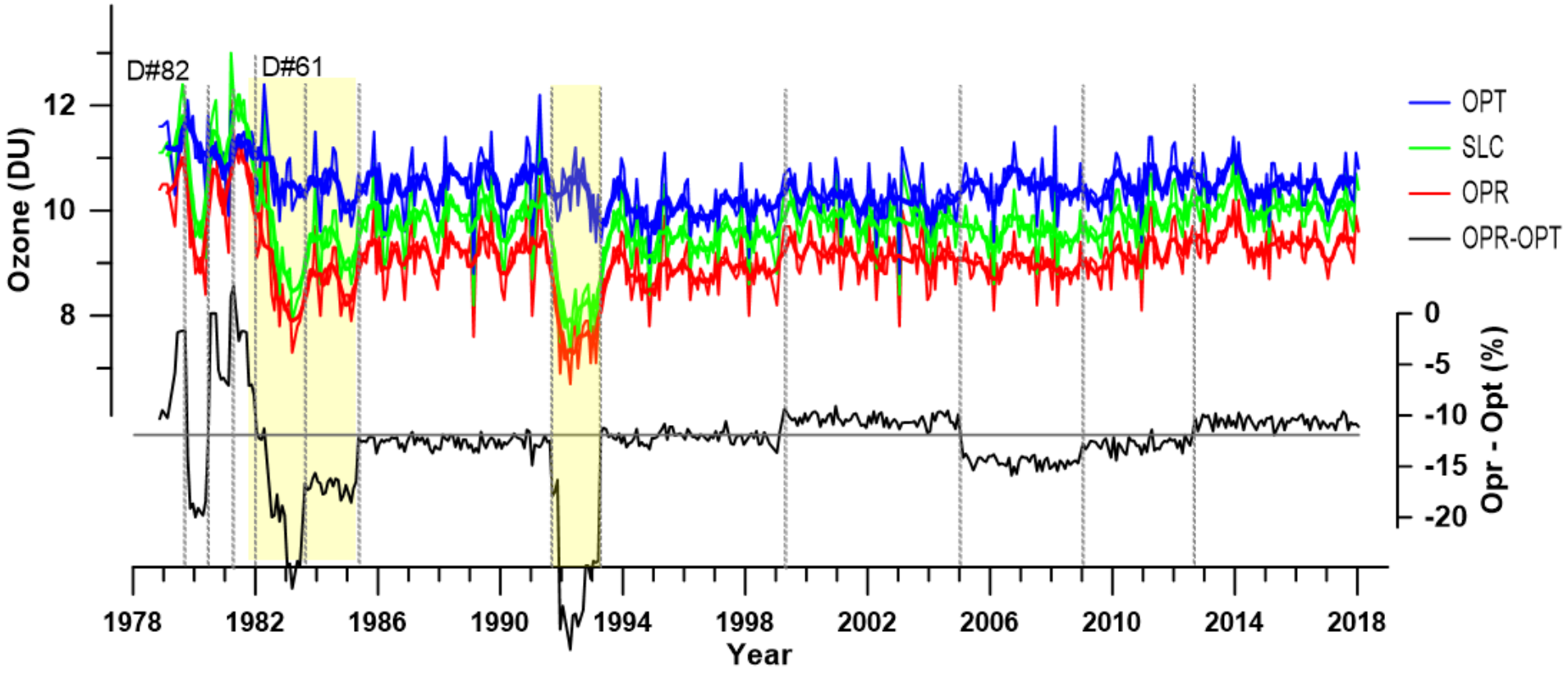
Ozonesonde (SND)

- NOAA GML processing
- With Umkehr AK smoothing

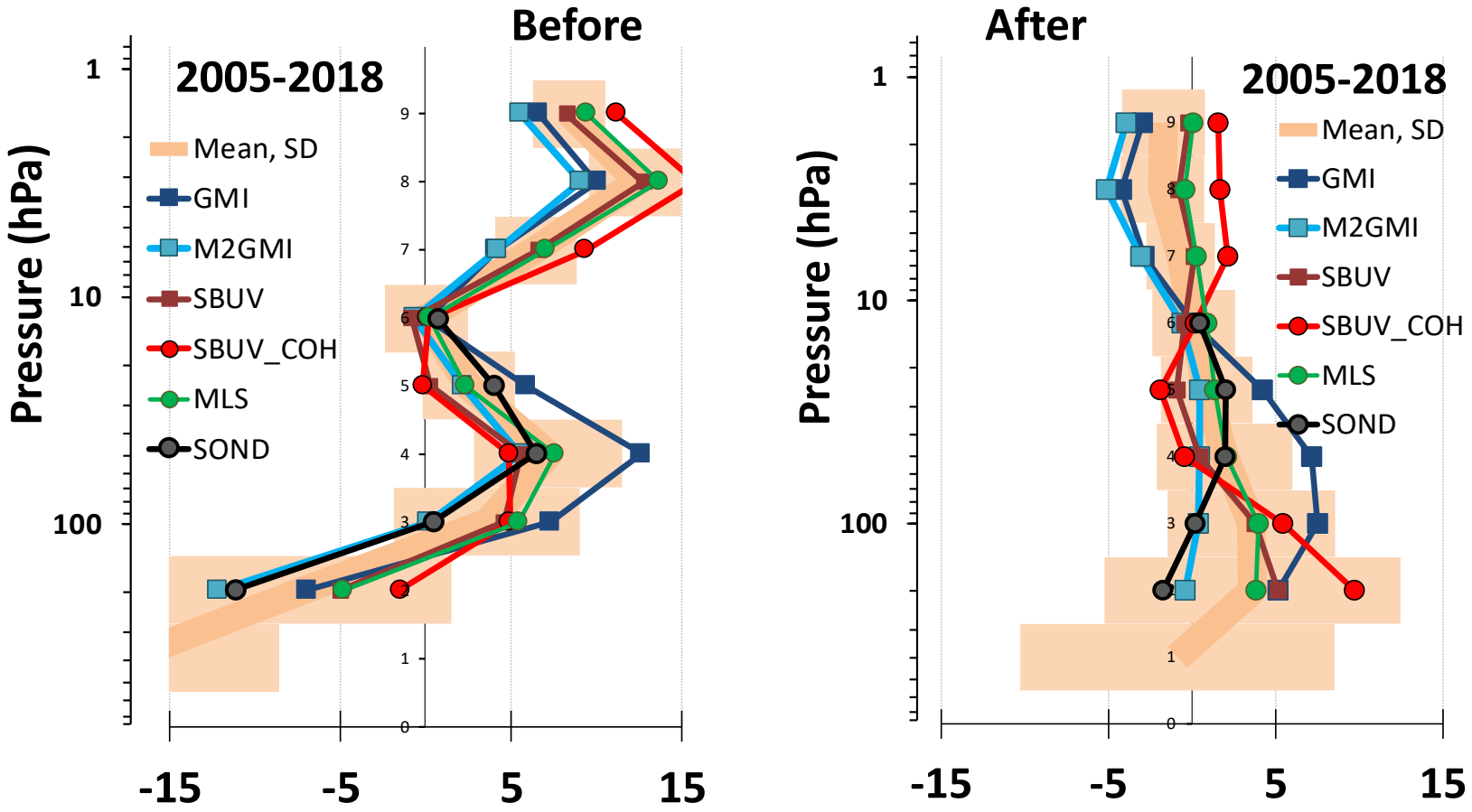
GMI model (GMI)

- NDACC station dataset – hourly ozone, temperature, PV etc.

Umkehr O3 optimization and homogenization (SAGE III/ISS and AC4)



Verificaton of Umkehr optimization (Boulder)

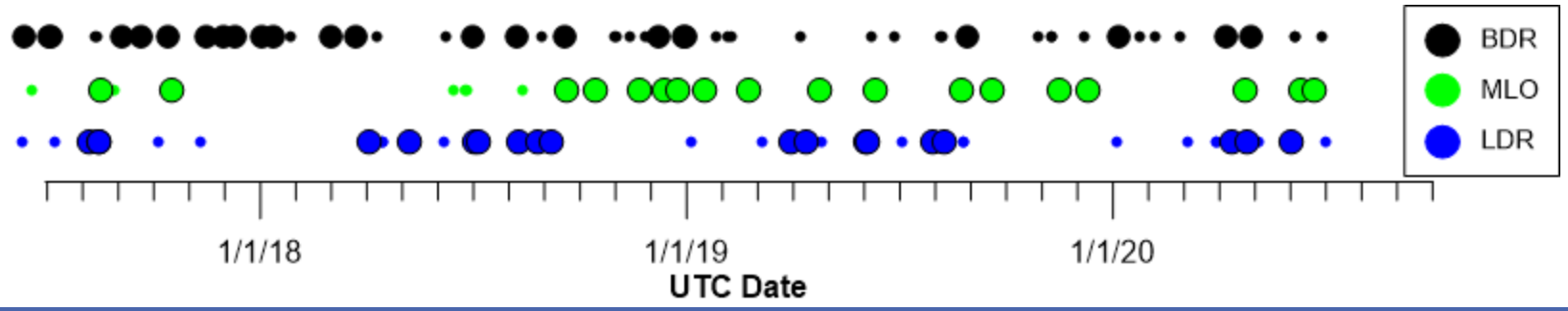


SAGE III/ISS and Umkehr, matched date +/- 3 hrs

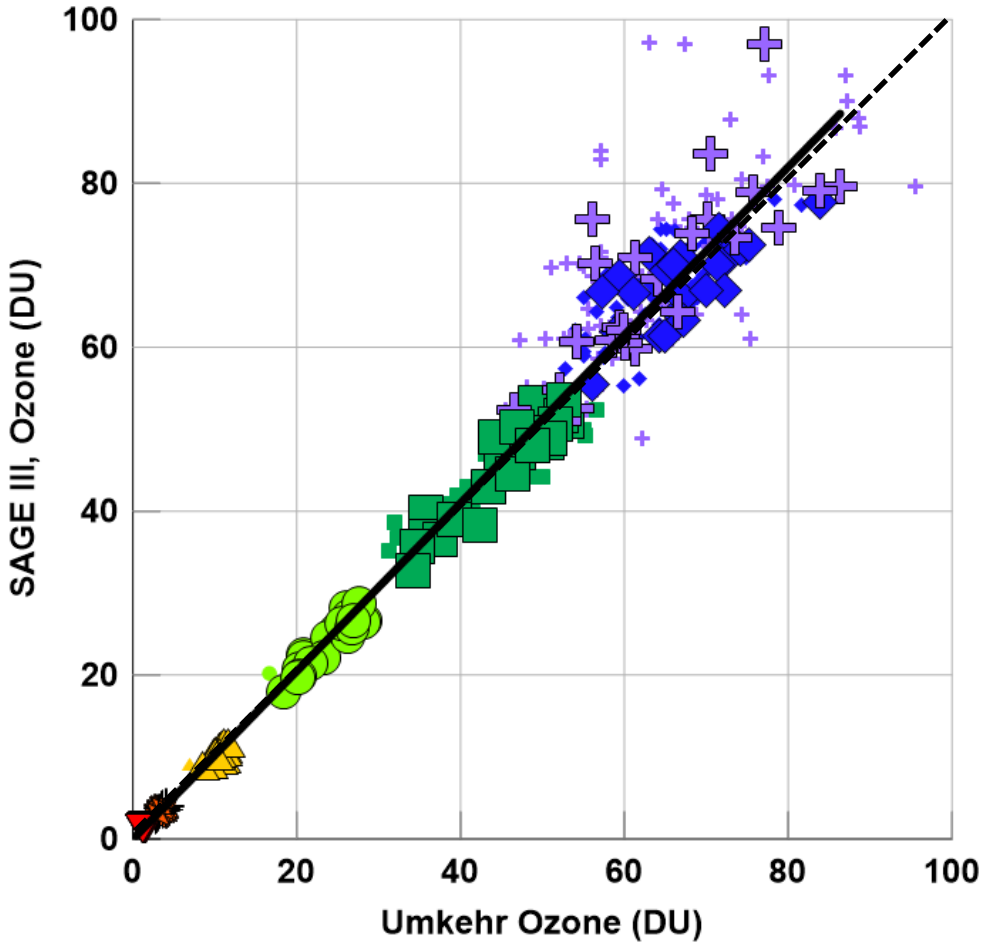
utc_umk	utc_sageIII	d_hrs	sage_lat	sage_lon	stn
06/13/2017 01:28	06/13/2017 01:46	0	41.22	-94.65	BDR
07/04/2017 12:38	07/04/2017 12:47	0	38.23	-120.04	BDR
07/05/2017 12:39	07/05/2017 11:57	-1	41.59	-109.95	BDR
09/03/2017 13:27	09/03/2017 13:20	-1	41.64	-116.98	BDR
09/21/2017 13:45	09/21/2017 13:48	0	38.09	-119.34	BDR
10/12/2017 23:25	10/12/2017 23:40	0	40.49	-95.26	BDR
11/15/2017 14:56	11/15/2017 14:44	-1	39.53	-118.76	BDR
11/30/2017 22:21	11/30/2017 23:21	0	39.73	-102.48	BDR
12/10/2017 22:17	12/10/2017 22:43	0	41.4	-94.63	BDR
01/02/2018 15:40	01/02/2018 15:20	-1	41.5	-117.1	BDR
01/11/2018 15:37	01/11/2018 15:31	-1	41.2	-120.3	BDR
03/02/2018 14:32	03/02/2018 14:23	-1	40.8	-116.6	BDR
03/24/2018 00:18	03/24/2018 00:14	-1	39.9	-91	BDR
07/01/2018 12:37	07/01/2018 11:33	-2	38.8	-102.5	BDR
08/09/2018 01:07	08/09/2018 02:04	0	41.7	-105	BDR
09/18/2018 13:41	09/18/2018 12:55	-1	38.1	-106.8	BDR
12/07/2018 22:18	12/07/2018 22:10	-1	41	-86.2	BDR
12/29/2018 15:40	12/29/2018 14:07	-2	39.9	-100.4	BDR
12/30/2018 15:40	12/30/2018 14:50	-1	41.5	-109.8	BDR
08/28/2019 13:21	08/28/2019 12:53	-1	41.1	-111.6	BDR
01/05/2020 15:40	01/05/2020 15:29	-1	41.9	-119.0	BDR
04/06/2020 00:32	04/06/2020 01:22	0	38.6	-104.7	BDR
04/27/2020 13:02	04/27/2020 12:36	-1	41.8	-112.6	BDR

utc_umk	utc_sageIII	d_hrs	sage_lat	sage_lon	stn
08/17/2017 04:02	08/17/2017 03:36	-1	21.5	-137.7	MLO
10/17/2017 03:10	10/17/2017 04:05	0	21.3	-158.8	MLO
09/20/2018 16:56	09/20/2018 17:30	0	20.8	-174.5	MLO
10/14/2018 03:12	10/14/2018 03:21	0	20.5	-146.9	MLO
11/21/2018 02:51	11/21/2018 03:03	0	20.2	-147.0	MLO
12/13/2018 02:52	12/13/2018 04:53	2	20.9	-174.2	MLO
12/24/2018 17:46	12/24/2018 18:12	0	18.9	-174.8	MLO
01/15/2019 17:50	01/15/2019 17:03	-1	21.3	-154.8	MLO
02/22/2019 17:34	02/22/2019 17:07	-1	19.0	-159.9	MLO
04/24/2019 16:44	04/24/2019 15:54	-1	18.7	-153.5	MLO
06/12/2019 04:10	06/12/2019 04:10	0	20.1	-143.6	MLO
08/23/2019 16:51	08/23/2019 16:45	-1	19.8	-164.8	MLO
09/18/2019 16:55	09/18/2019 15:14	-2	18.3	-140.7	MLO
11/15/2019 17:20	11/15/2019 17:13	-1	20.9	-164.8	MLO
12/11/2019 02:51	12/11/2019 02:51	0	21.3	-144.0	MLO
04/22/2020 16:45	04/22/2020 16:23	-1	21.2	-161.3	MLO
06/10/2020 04:10	06/10/2020 03:34	-1	18.9	-135.4	MLO
06/21/2020 16:34	06/21/2020 15:59	-1	18.9	-157.8	MLO

utc_umk	utc_sageIII	d_hrs	sage_lat	sage_lon	stn
07/09/2017 03:39	07/09/2017 04:55	1	-44.0	174.1	LDR
08/06/2017 21:07	08/06/2017 21:06	-1	-45.4	152.3	LDR
08/14/2017 20:52	08/14/2017 20:35	-1	-45.8	157.3	LDR
08/15/2017 20:49	08/15/2017 19:45	-2	-44.6	168.9	LDR
04/03/2018 20:06	04/03/2018 20:20	0	-45.4	151.4	LDR
05/09/2018 04:10	05/09/2018 05:16	1	-44.2	172.4	LDR
07/03/2018 03:31	07/03/2018 04:39	1	-43.3	177.5	LDR
07/07/2018 03:36	07/07/2018 05:57	2	-43.4	158.6	LDR
08/09/2018 21:02	08/09/2018 21:12	0	-46.5	150.4	LDR
08/26/2018 04:56	08/26/2018 06:39	1	-44.1	160.3	LDR
09/07/2018 05:14	09/07/2018 05:57	0	-45.4	173.9	LDR
03/31/2019 20:01	03/31/2019 19:44	-1	-45.7	159.4	LDR
04/12/2019 20:19	04/12/2019 19:18	-2	-45.5	169.8	LDR
06/02/2019 21:44	06/02/2019 20:23	-2	-44.1	166.8	LDR
06/04/2019 21:47	06/04/2019 20:21	-2	-44.0	167.7	LDR
07/30/2019 21:21	07/30/2019 19:59	-2	-43.6	170.3	LDR
08/08/2019 21:04	08/08/2019 20:37	-1	-44.4	158.5	LDR
04/10/2020 20:18	04/10/2020 19:06	-2	-44.9	172.0	LDR
04/25/2020 04:37	04/25/2020 05:47	1	-46.8	168.0	LDR
05/31/2020 21:43	05/31/2020 21:05	-1	-43.1	178.5	LDR



Boulder

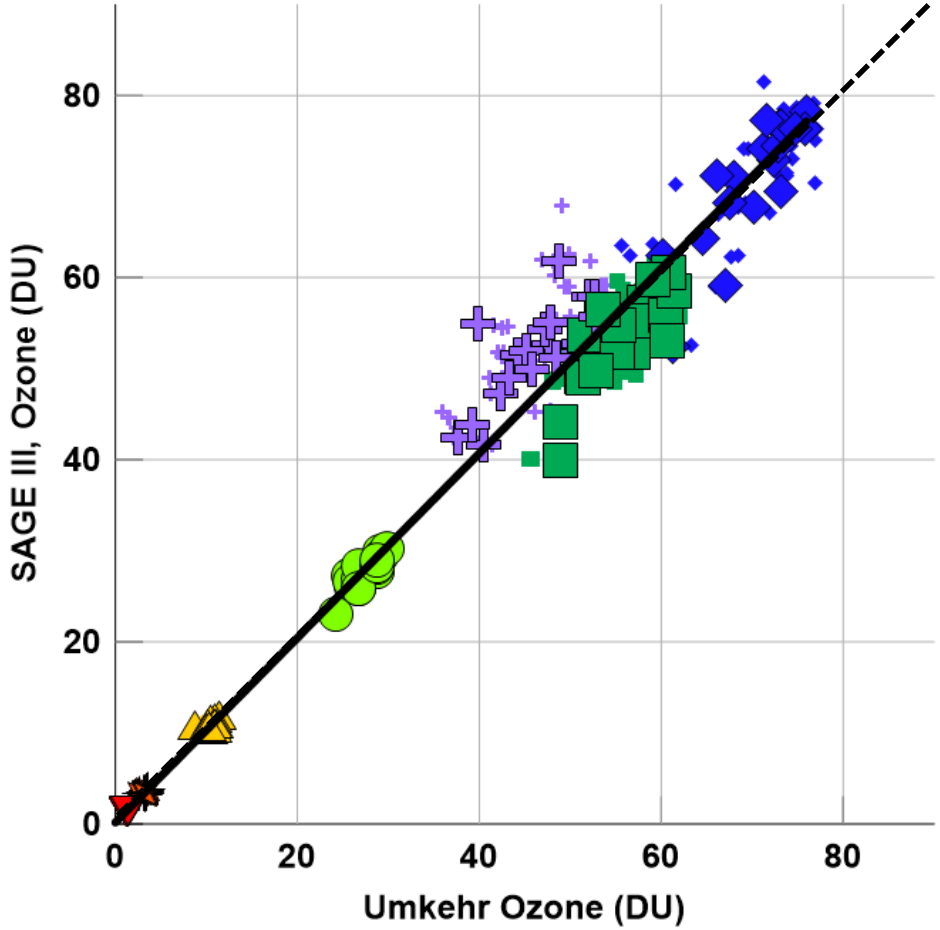


Matched time +/- 3 hrs
Linear
Equation Y = 1.025556488 * X - 0.04322525547
Number of data points used = 276
Average X = 18.0824
Average Y = 18.5013
Residual sum of squares = 1985.38
Regression sum of squares = 187383
Coef of determination, R-squared = 0.989516
Residual mean square, sigma-hat-sq'd = 7.24589

Umkehr Layer Bins	B_Pres (hPa)
4 to <5	63.33
5 to <6	31.66
6 to <7	15.83
7 to <8	7.916
8 to <9	3.958
9 to <10	1.979
10 to <10.01	0.99

A big symbol is within 3 hours, and a small symbol is +/-24 hours.

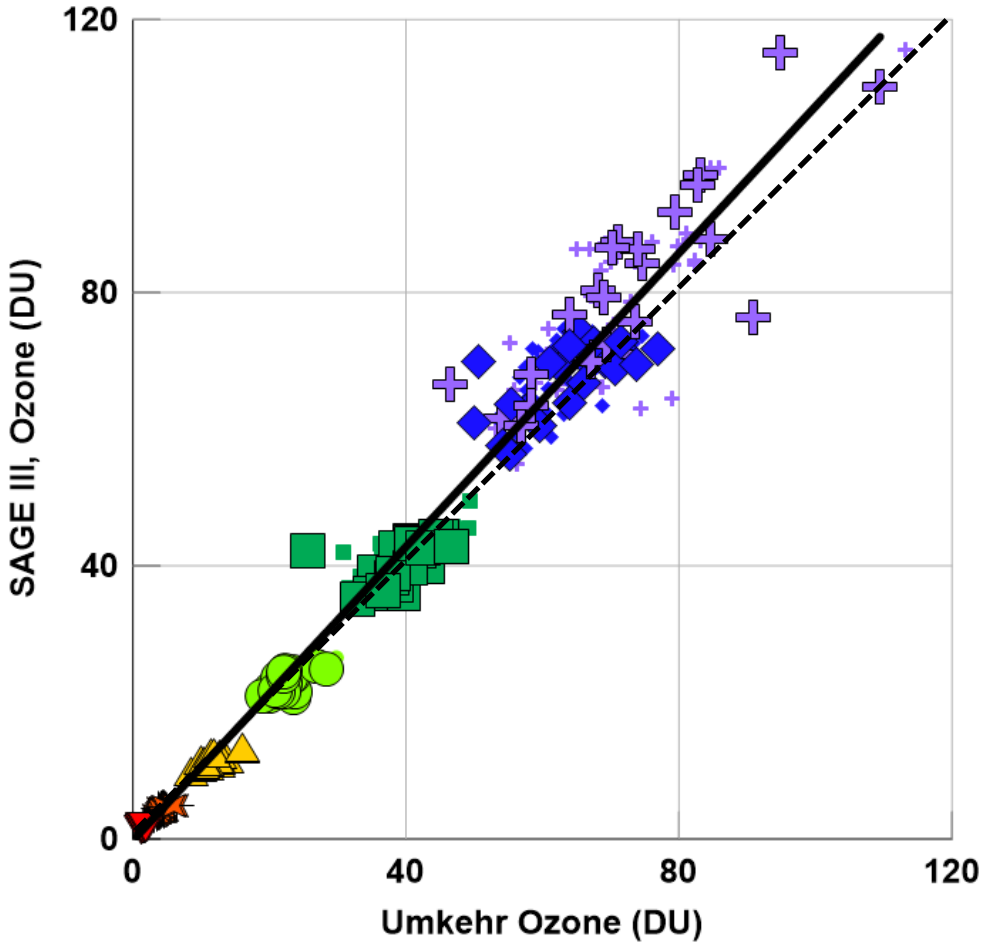
MLO



Matched time +/- 3 hrs
Linear
Equation Y = 1.014114085 * X + 0.1434920742
Number of data points used = 216
Average X = 17.8272
Average Y = 18.2223
Residual sum of squares = 1331.52
Regression sum of squares = 133233
Coef of determination, R-squared = 0.990105
Residual mean square, sigma-hat-sq'd = 6.22204

Umkehr Layer Bins	B_Pres (hPa)
4 to <5	63.33
5 to <6	31.66
6 to <7	15.83
7 to <8	7.916
8 to <9	3.958
9 to <10	1.979
10 to <10.01	0.99

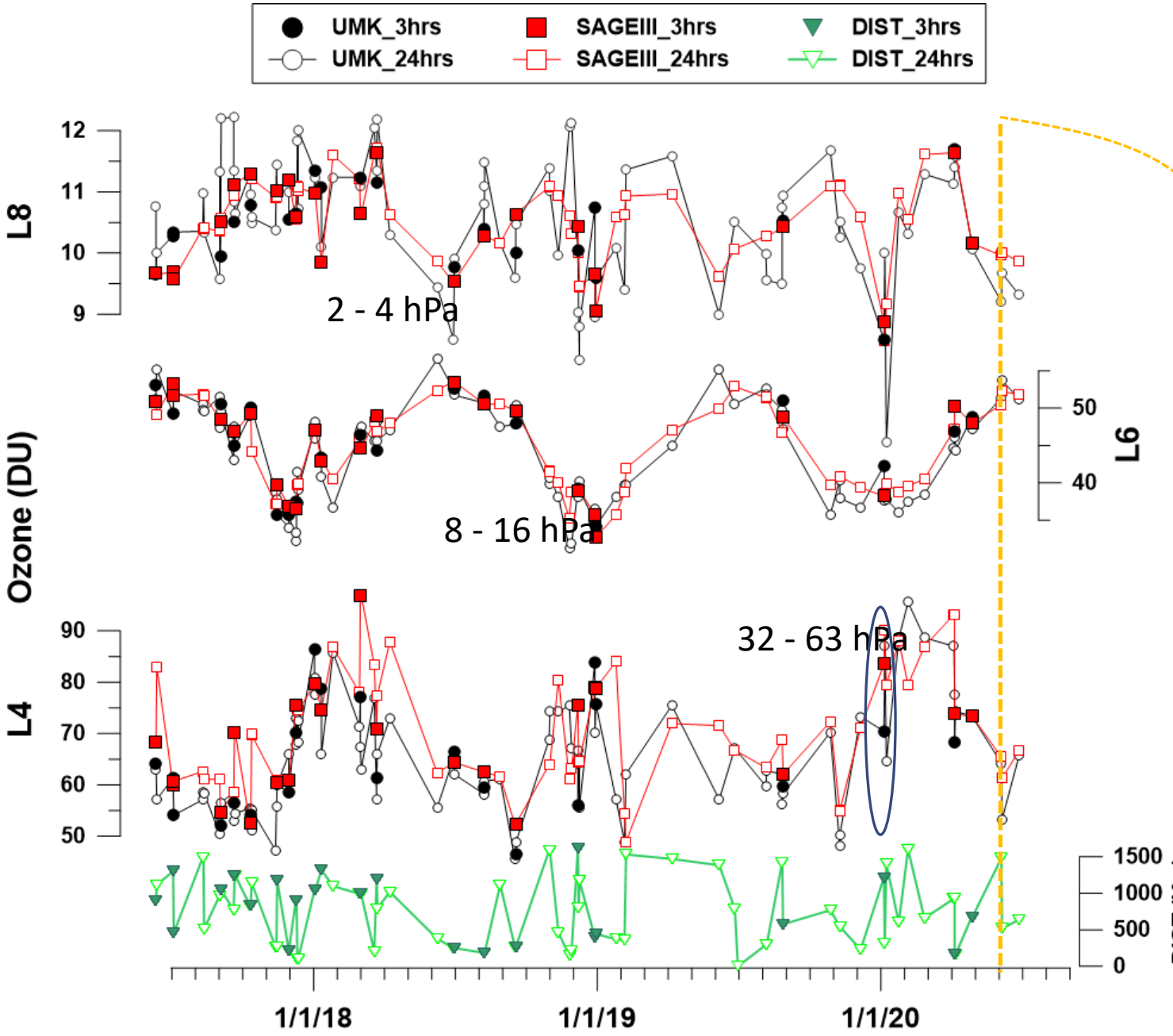
Lauder

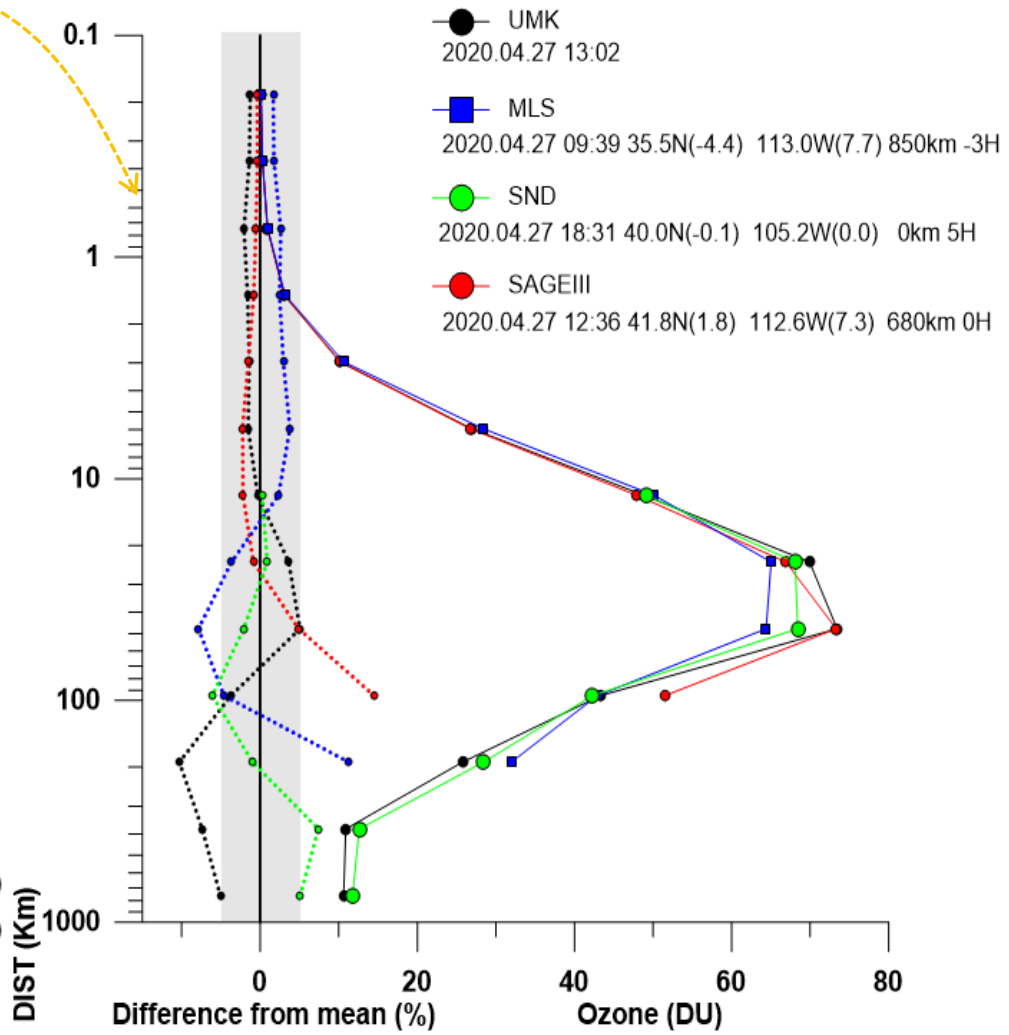


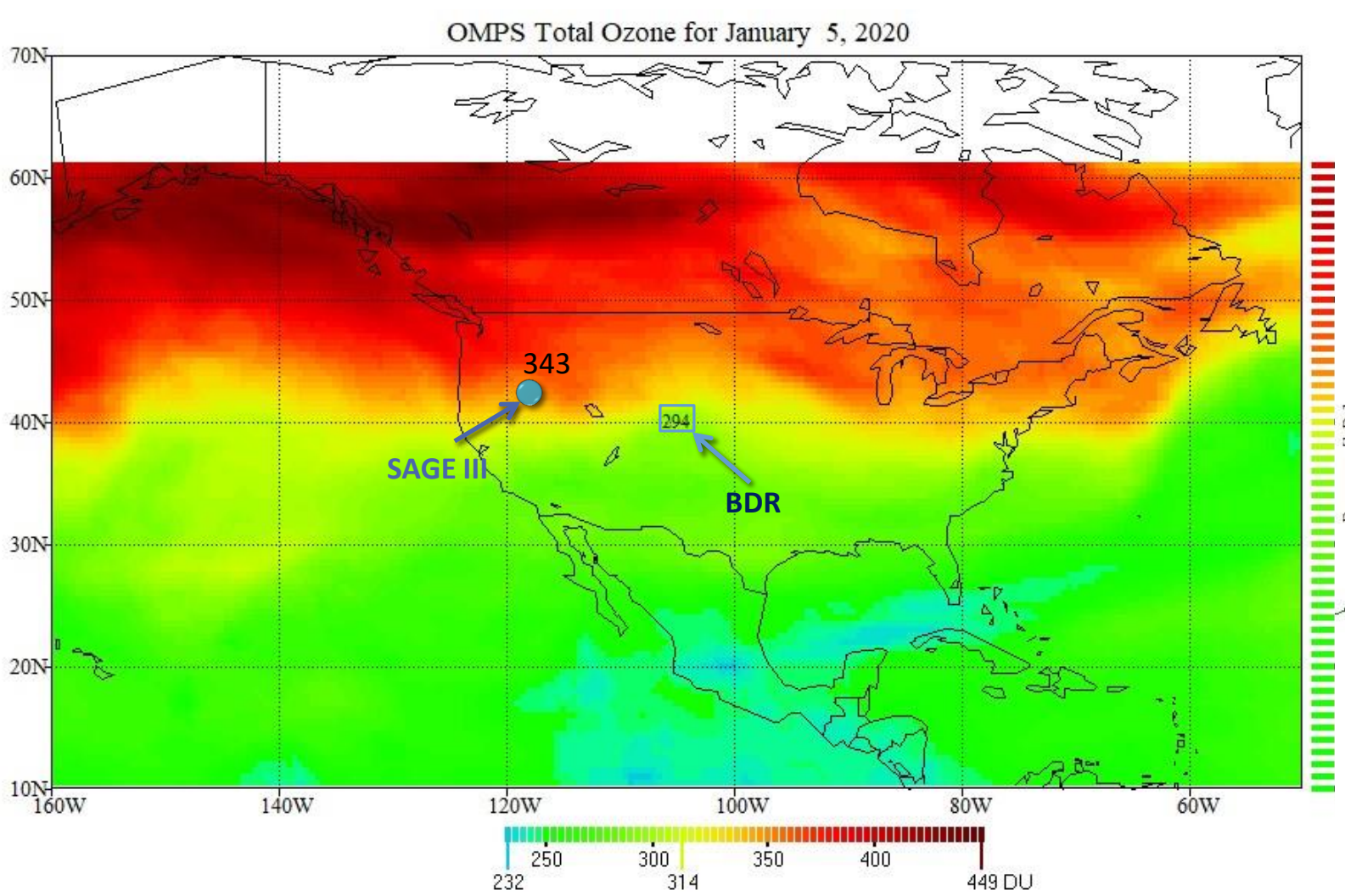
Matched time +/- 3 hrs
Linear
Equation Y = 1.075239236 * X - 0.2233470974
Number of data points used = 276
Average X = 17.9701
Average Y = 19.0988
Residual sum of squares = 3092.14
Regression sum of squares = 211095
Coef of determination, R-squared = 0.985563
Residual mean square, sigma-hat-sq'd = 11.2852

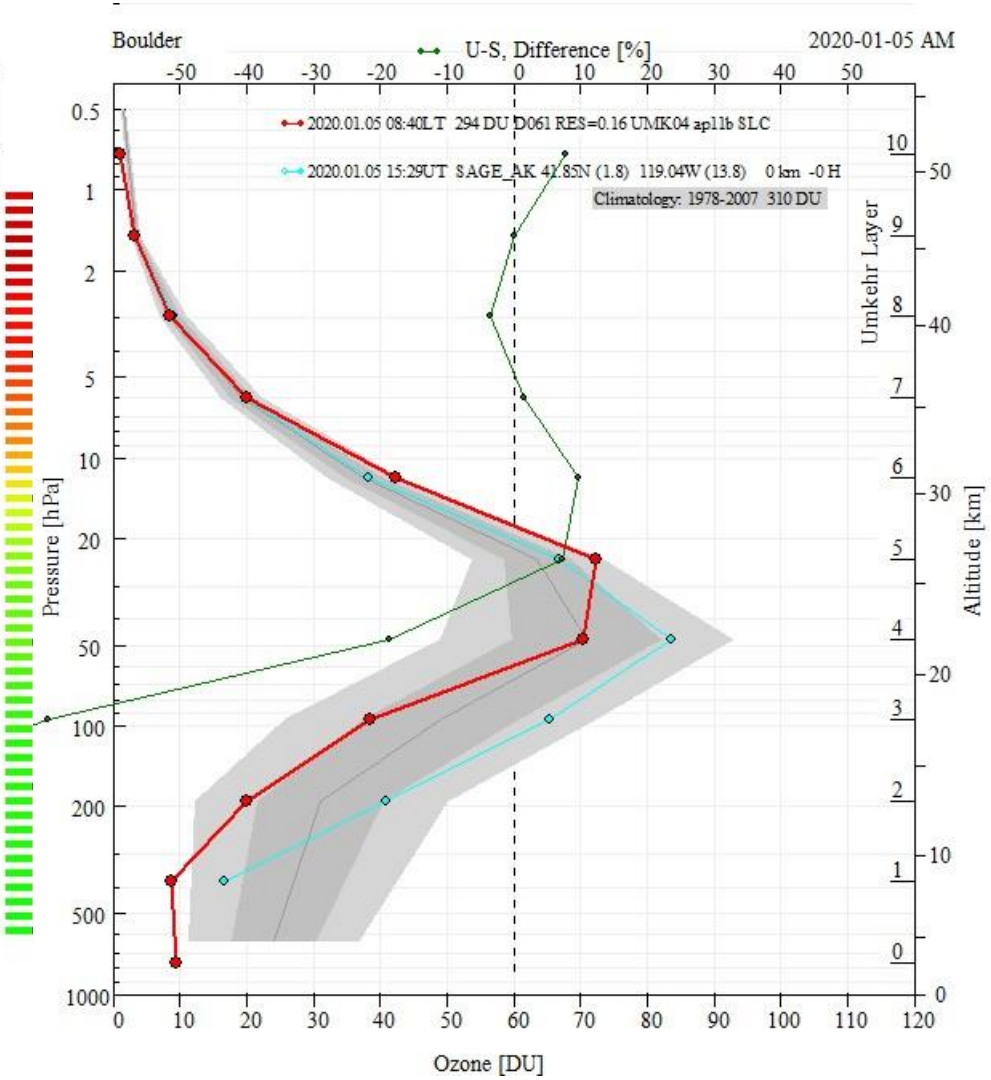
Umkehr Layer Bins	B_Pres (hPa)
4 to <5	63.33
5 to <6	31.66
6 to <7	15.83
7 to <8	7.916
8 to <9	3.958
9 to <10	1.979
10 to <10.01	0.99

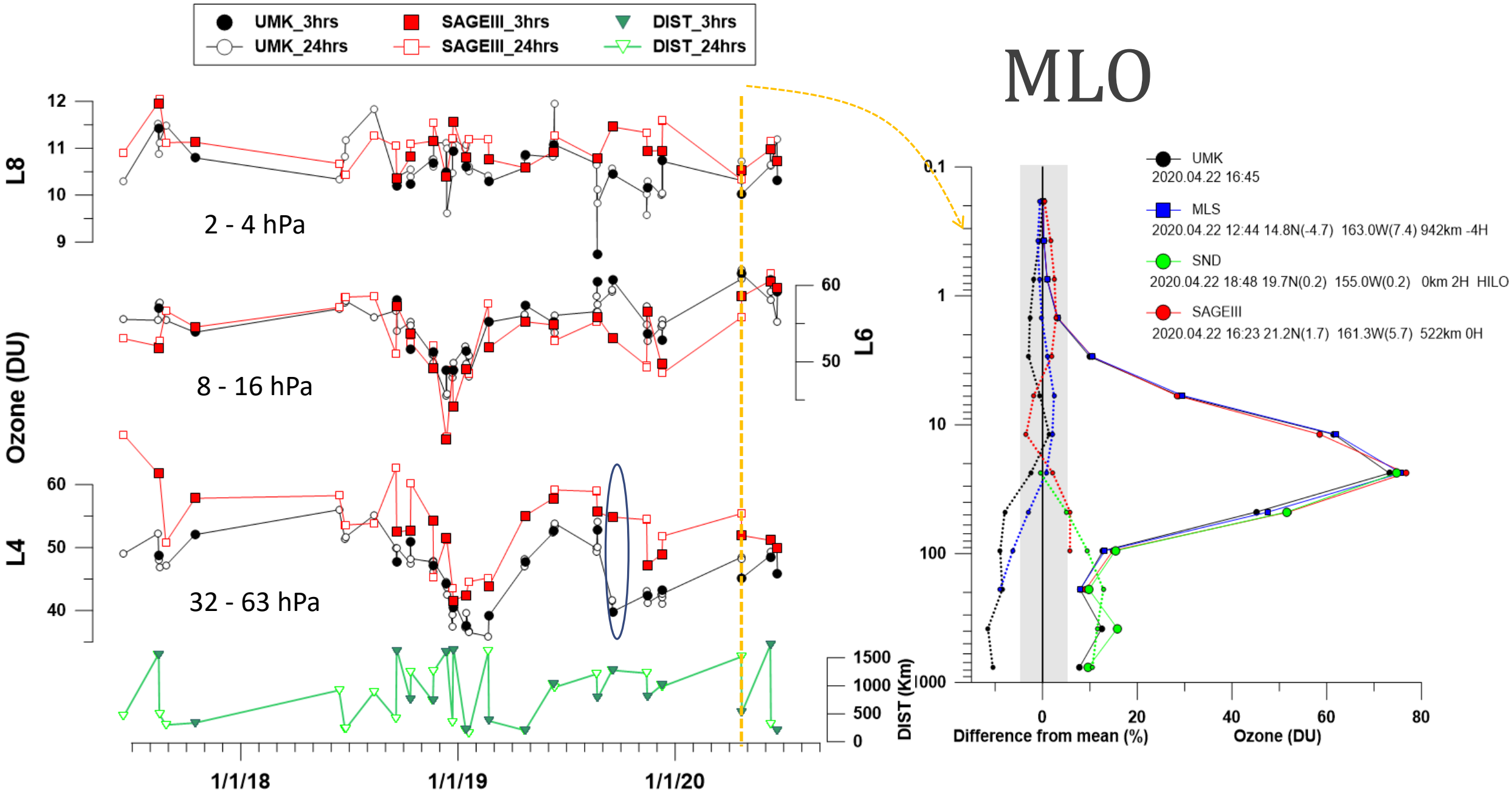
Boulder

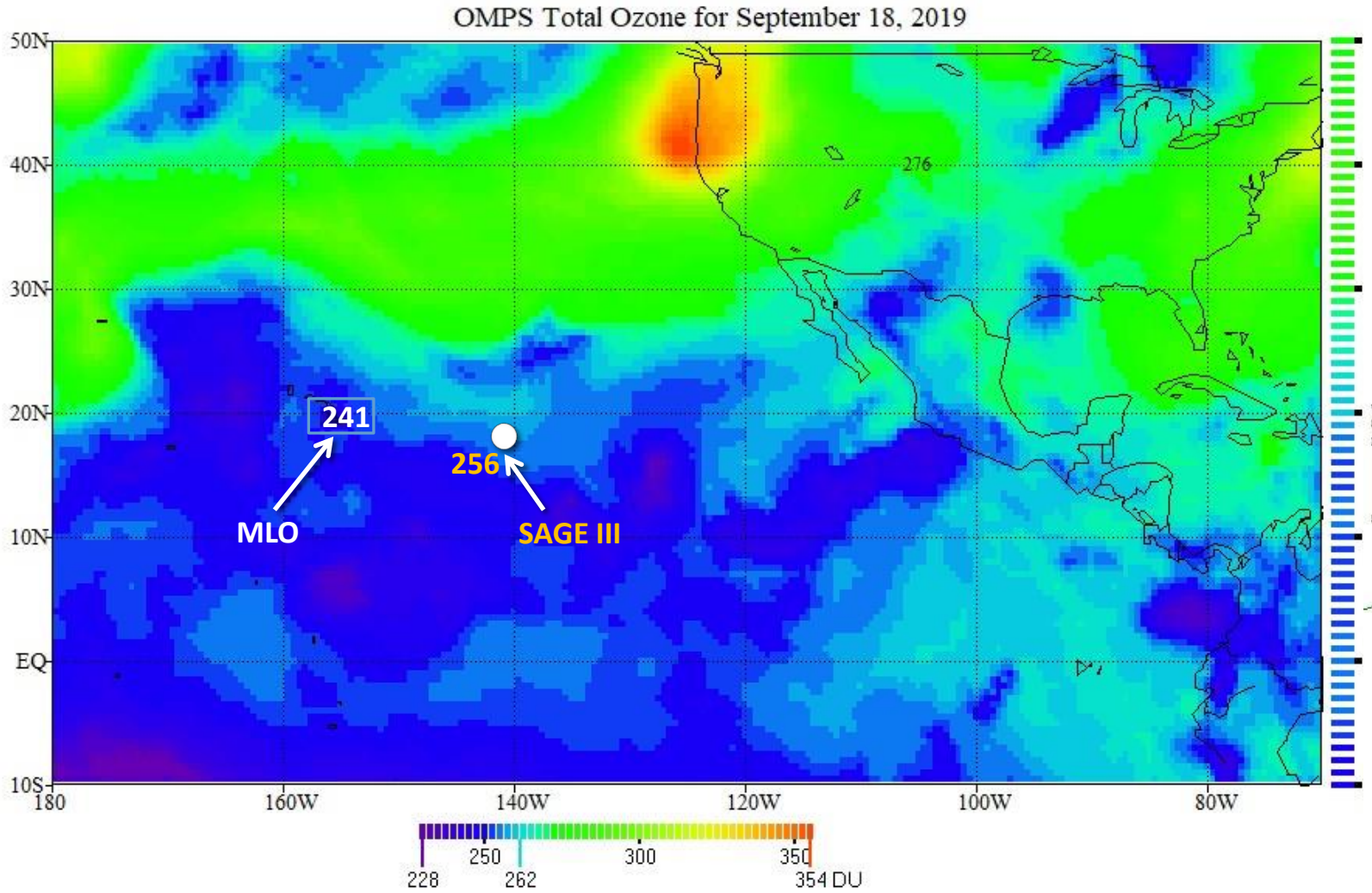

UMK_3hrs
UMK_24hrs
SAGEIII_3hrs
SAGEIII_24hrs
DIST_3hrs
DIST_24hrs
L8
L6
L4
Ozone (DU)
DIST (Km)
2 - 4 hPa
8 - 16 hPa
32 - 63 hPa
1/1/18
1/1/19
1/1/20

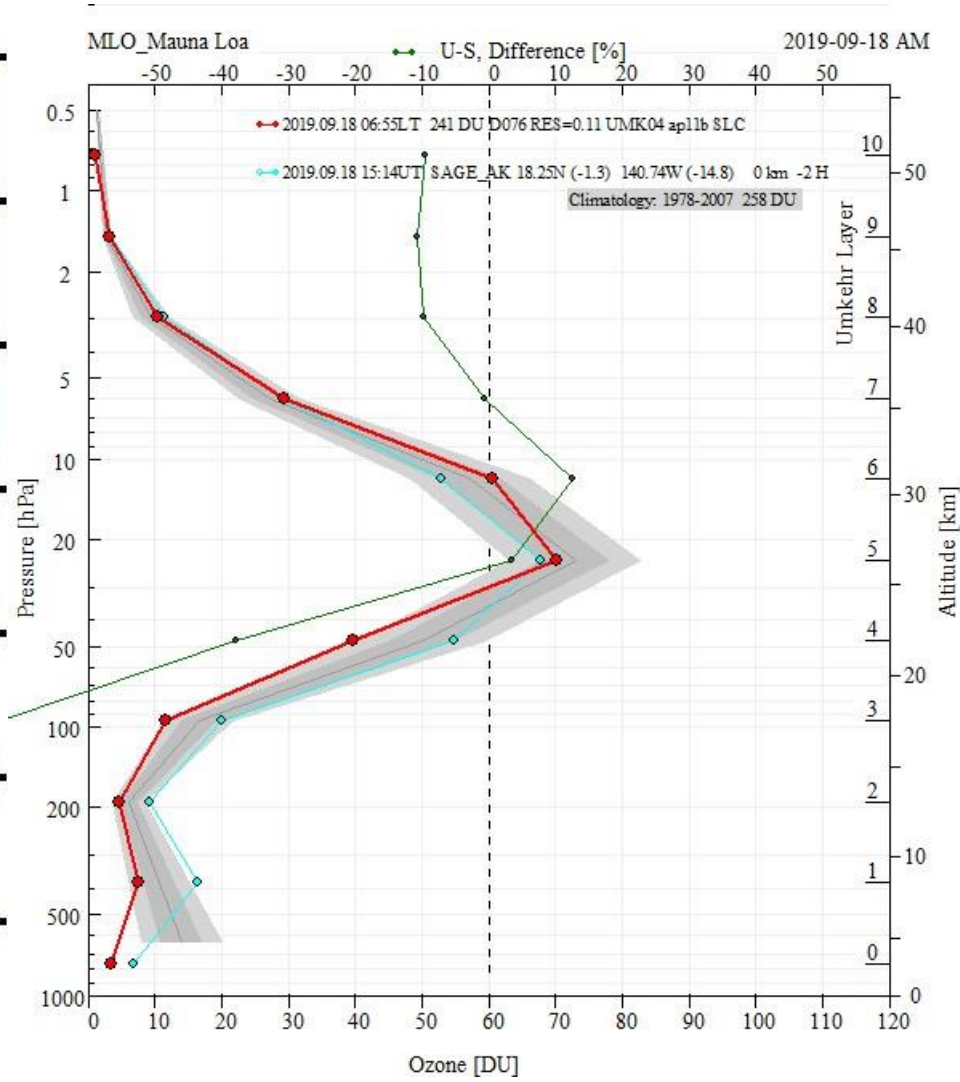

UMK
2020.04.27 13:02
MLS
2020.04.27 09:39 35.5N(-4.4) 113.0W(7.7) 850km -3H
SND
2020.04.27 18:31 40.0N(-0.1) 105.2W(0.0) 0km 5H
SAGEIII
2020.04.27 12:36 41.8N(1.8) 112.6W(7.3) 680km 0H
Difference from mean (%)
Ozone (DU)


OMPS Total Ozone for January 5, 2020
70N
60N
50N
40N
30N
20N
10N
160W
140W
120W
100W
80W
60W
343
294
SAGE III
BDR
250
300
350
400
232
314
449 DU

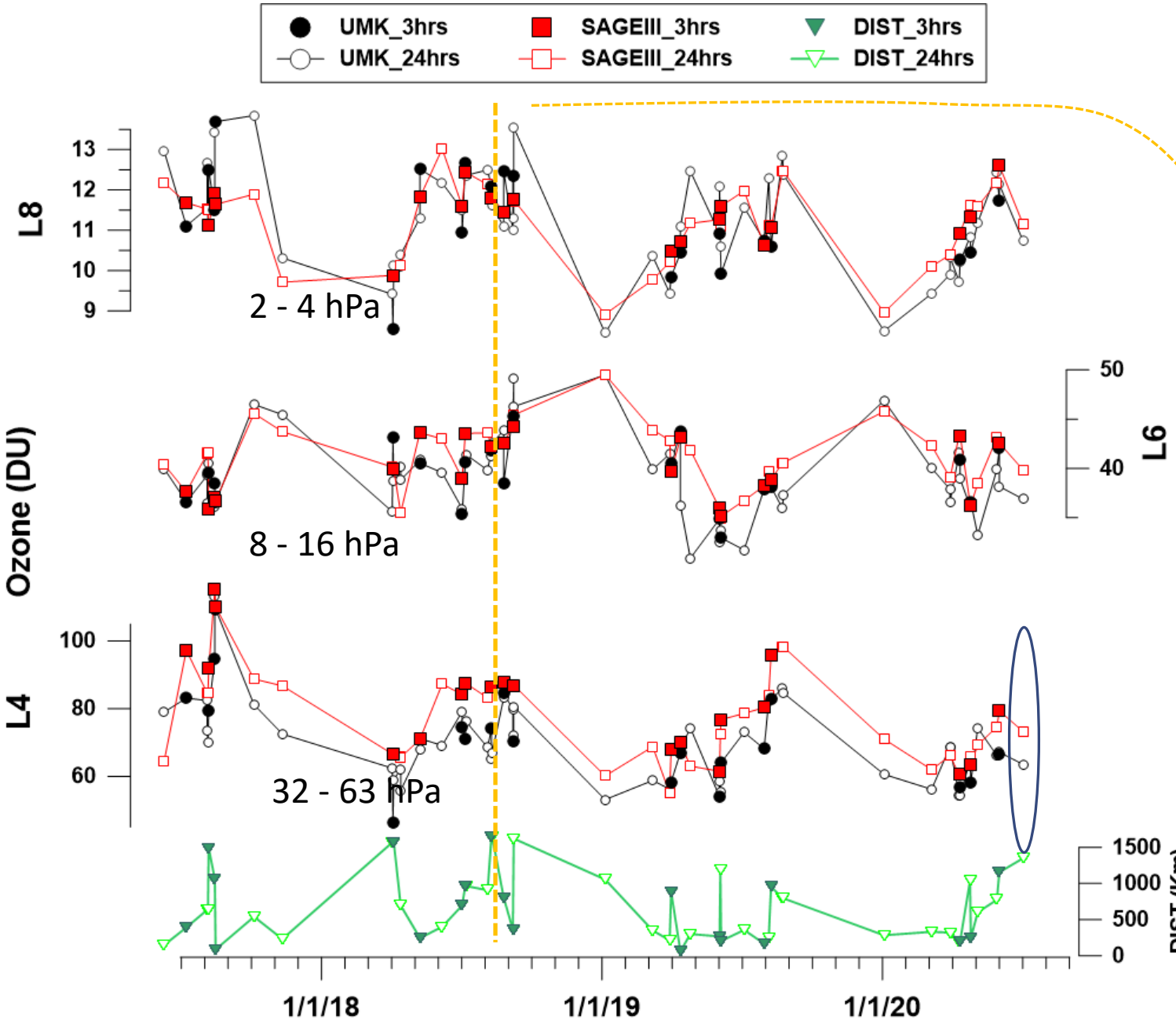

Boulder
U-S, Difference [%]
2020-01-05 AM
2020.01.05 08:40LT 294 DU D061 RES=0.16 UMK04 ap11b SLC
2020.01.05 15:29UT SAGE_AK 41.85N (1.8) 119.04W (13.8) 0 km -0 H
Climatology: 1978-2007 310 DU
Pressure [hPa]
Umkehr Layer
Altitude [km]
Ozone [DU]

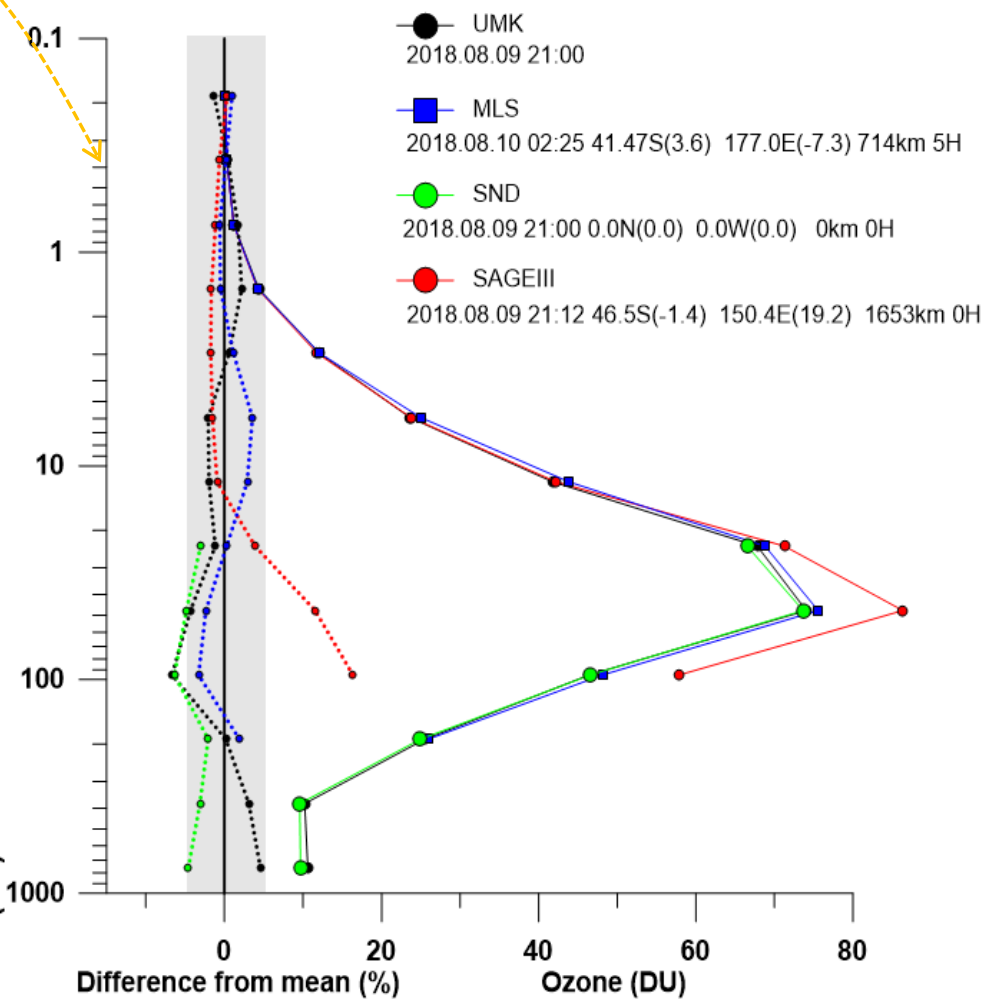

UMK_3hrs
UMK_24hrs
SAGEIII_3hrs
SAGEIII_24hrs
DIST_3hrs
DIST_24hrs
L8
L6
L4
Ozone (DU)
2 - 4 hPa
8 - 16 hPa
32 - 63 hPa
DIST (Km)
1/1/18
1/1/19
1/1/20
MLO
UMK
2020.04.22 16:45
MLS
2020.04.22 12:44 14.8N(-4.7) 163.0W(7.4) 942km -4H
SND
2020.04.22 18:48 19.7N(0.2) 155.0W(0.2) 0km 2H HILO
SAGEIII
2020.04.22 16:23 21.2N(1.7) 161.3W(5.7) 522km 0H
Difference from mean (%)
Ozone (DU)

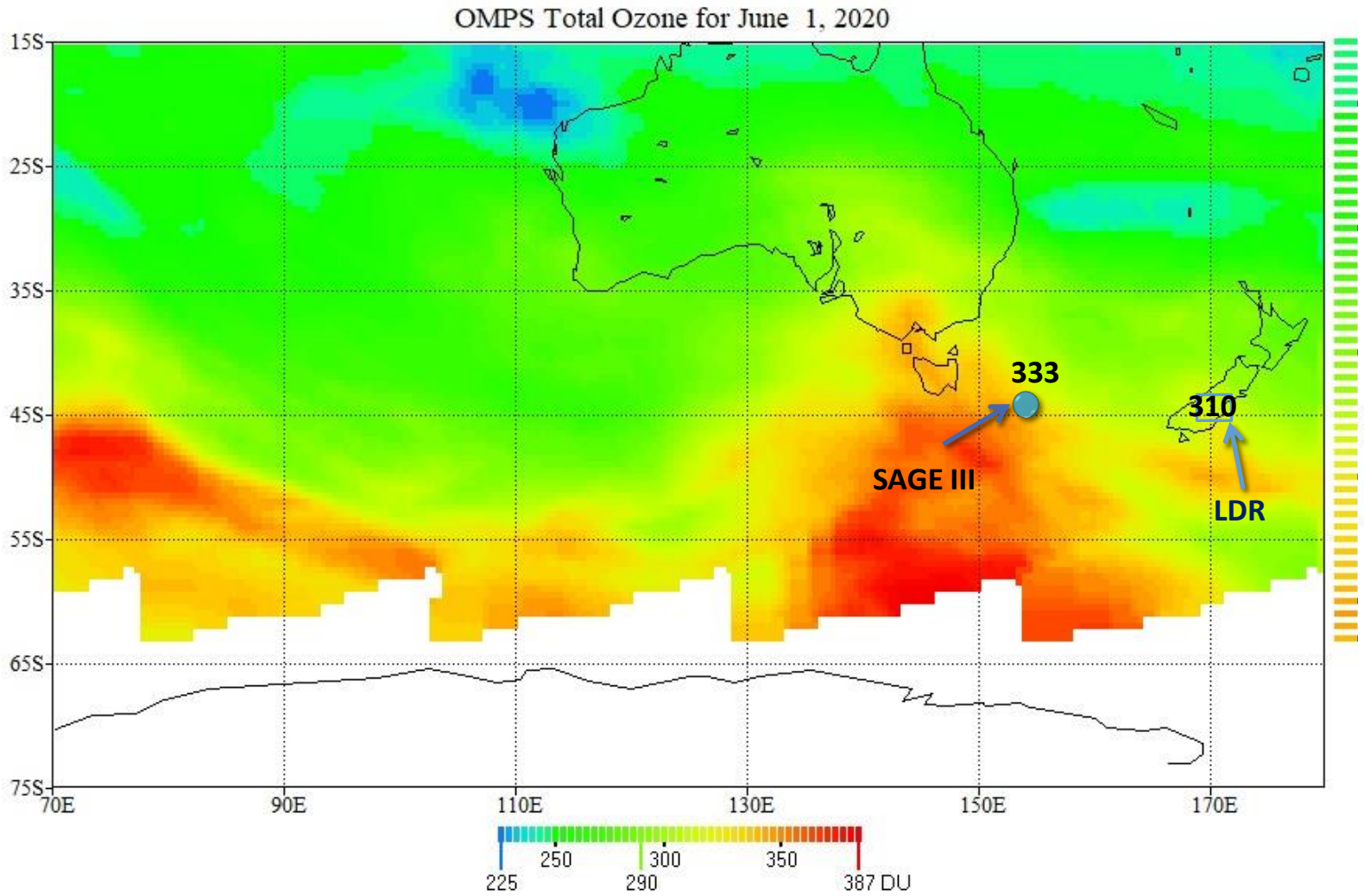

OMPS Total Ozone for September 18, 2019
50N
40N
30N
20N
10N
EQ
10S
180
160W
140W
120W
100W
80W
276
241
256
MLO
SAGE III
228
250
262
300
350
354 DU

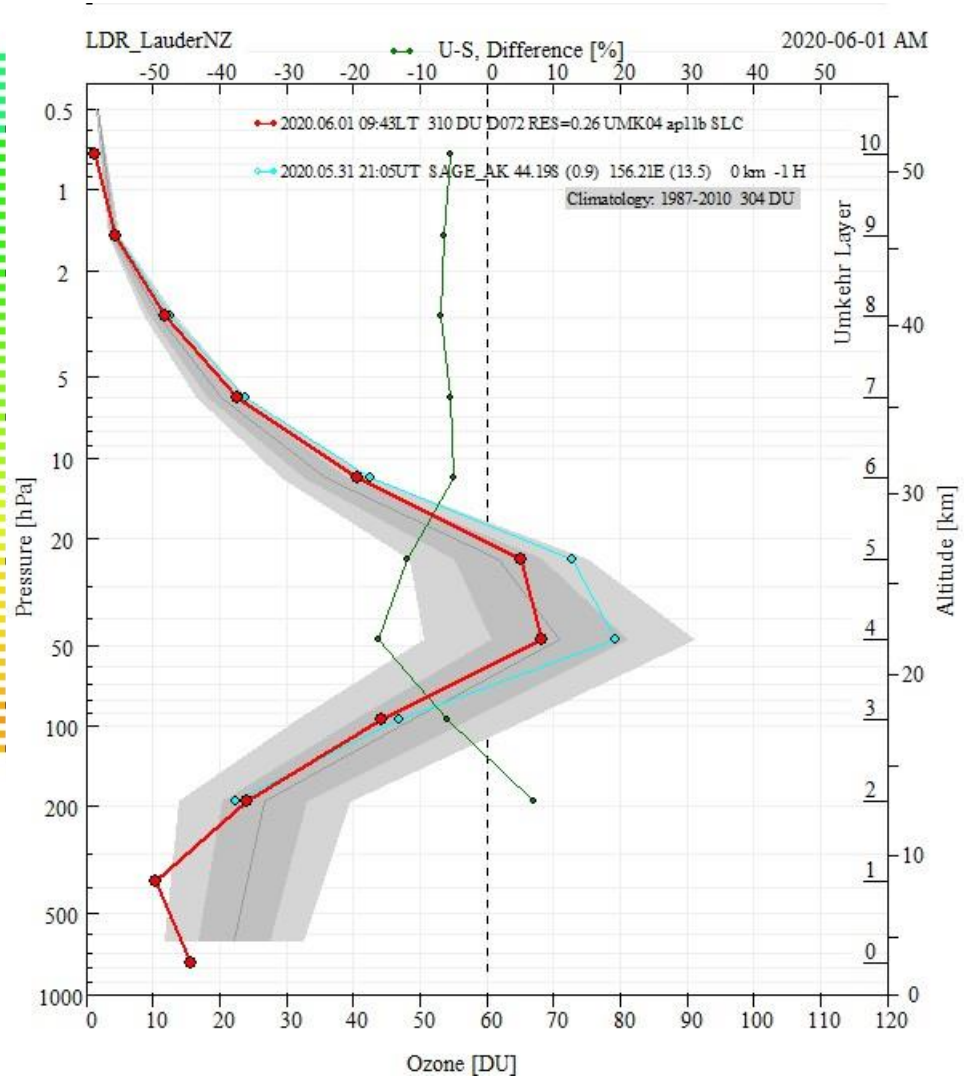

MLO_Mauna Loa
U-S, Difference [%]
2019-09-18 AM
2019.09.18 06:55LT 241 DU D076 RES=0.11 UMK04 ap11b SLC
2019.09.18 15:14UT SAGE_AK 18.25N (-1.3) 140.74W (-14.8) 0 km -2 H
Climatology: 1978-2007 258 DU
Pressure [hPa]
Umkehr Layer
Altitude [km]
Ozone [DU]

Lauder

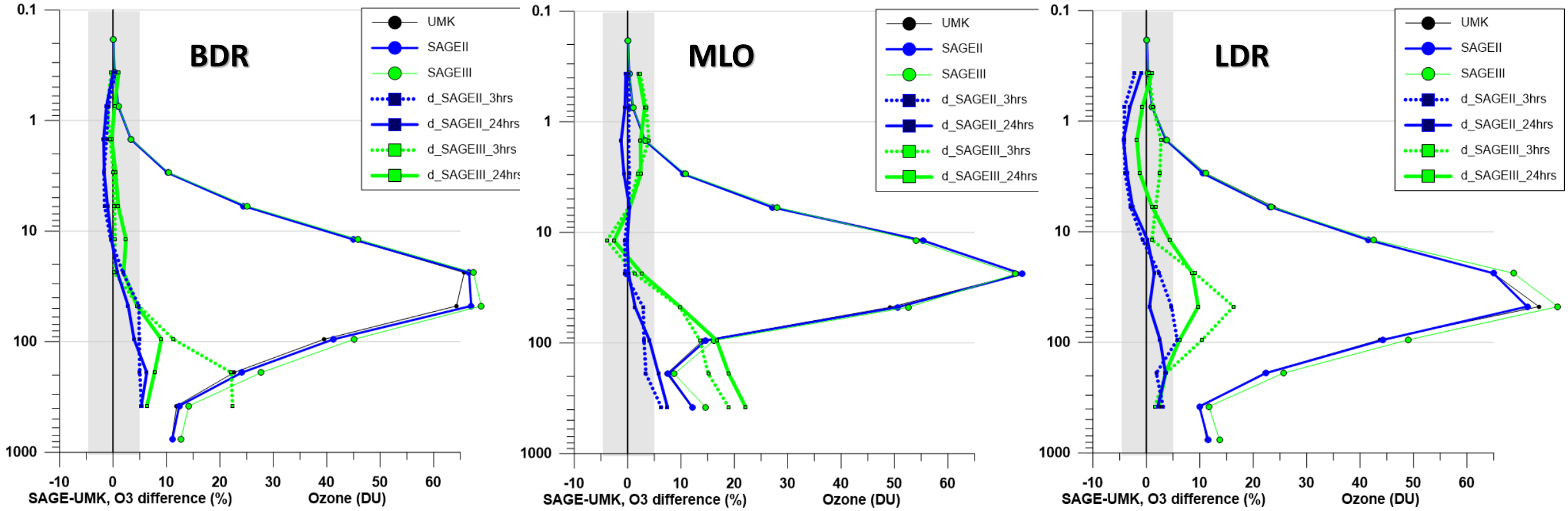

UMK_3hrs
UMK_24hrs
SAGEIII_3hrs
SAGEIII_24hrs
DIST_3hrs
DIST_24hrs
L8
L6
L4
Ozone (DU)
DIST (Km)
2 - 4 hPa
8 - 16 hPa
32 - 63 hPa
1/1/18
1/1/19
1/1/20

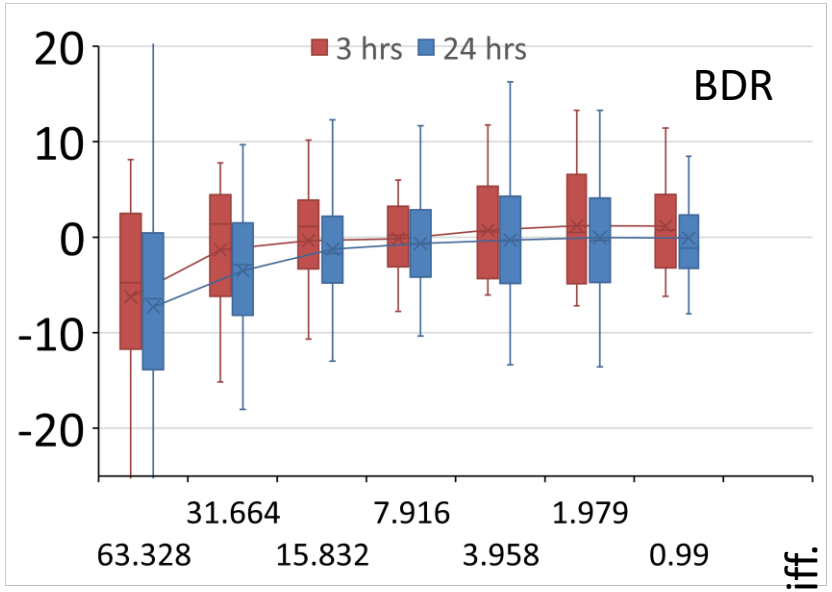

UMK
2018.08.09 21:00
MLS
2018.08.10 02:25 41.47S(3.6) 177.0E(-7.3) 714km 5H
SND
2018.08.09 21:00 0.0N(0.0) 0.0W(0.0) 0km 0H
SAGEIII
2018.08.09 21:12 46.5S(-1.4) 150.4E(19.2) 1653km 0H
Difference from mean (%)
Ozone (DU)

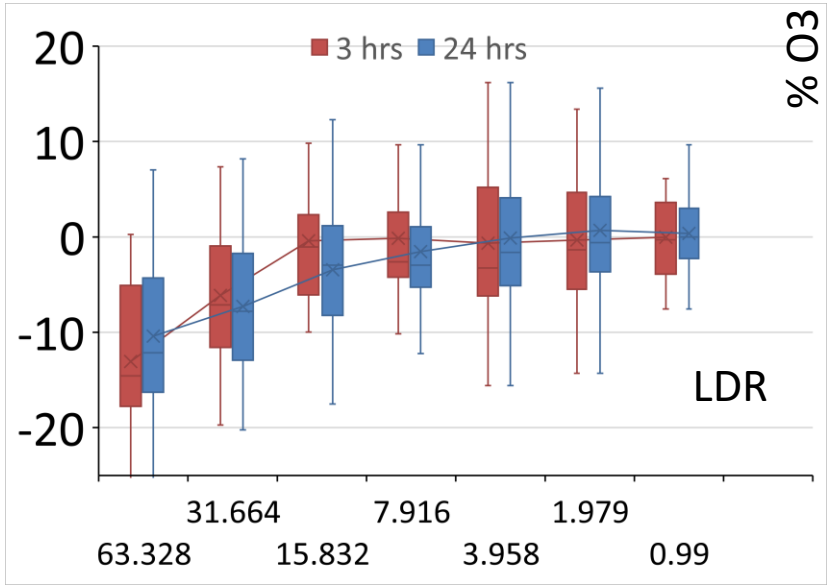

OMPS Total Ozone for June 1, 2020
15S
25S
35S
45S
55S
65S
75S
70E
90E
110E
130E
150E
170E
333
310
SAGE III
LDR
225
250
290
300
350
387 DU


LDR_LauderNZ
U-S, Difference [%]
2020-06-01 AM
2020.06.01 09:43LT 310 DU D072 RES=0.26 UMK04 ap11b SLC
2020.05.31 21:05UT SAGE_AK 44.19S (0.9) 156.21E (13.5) 0 km -1 H
Climatology: 1987-2010 304 DU
Pressure [hPa]
Umkehr Layer
Altitude [km]
Ozone [DU]

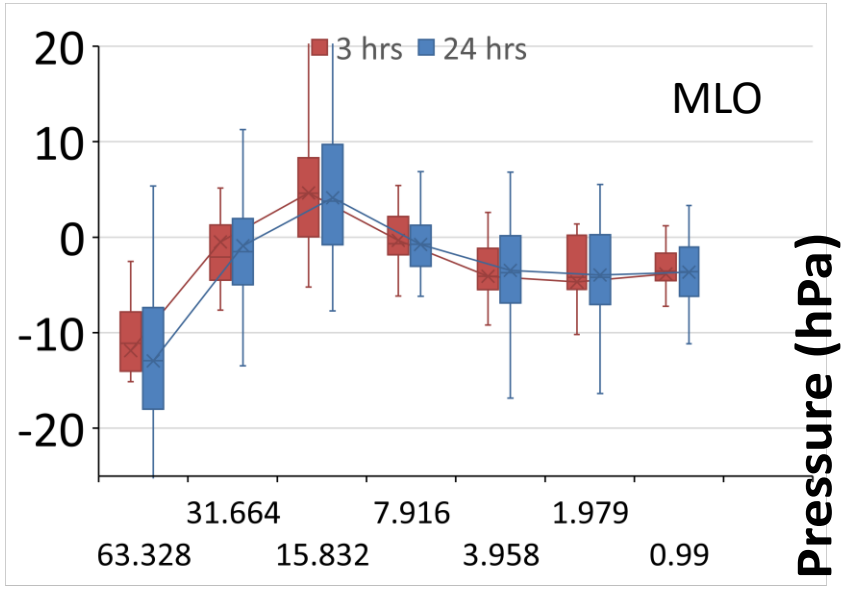
SAGE II (1985-2005) and SAGE III (2017-2020.08)



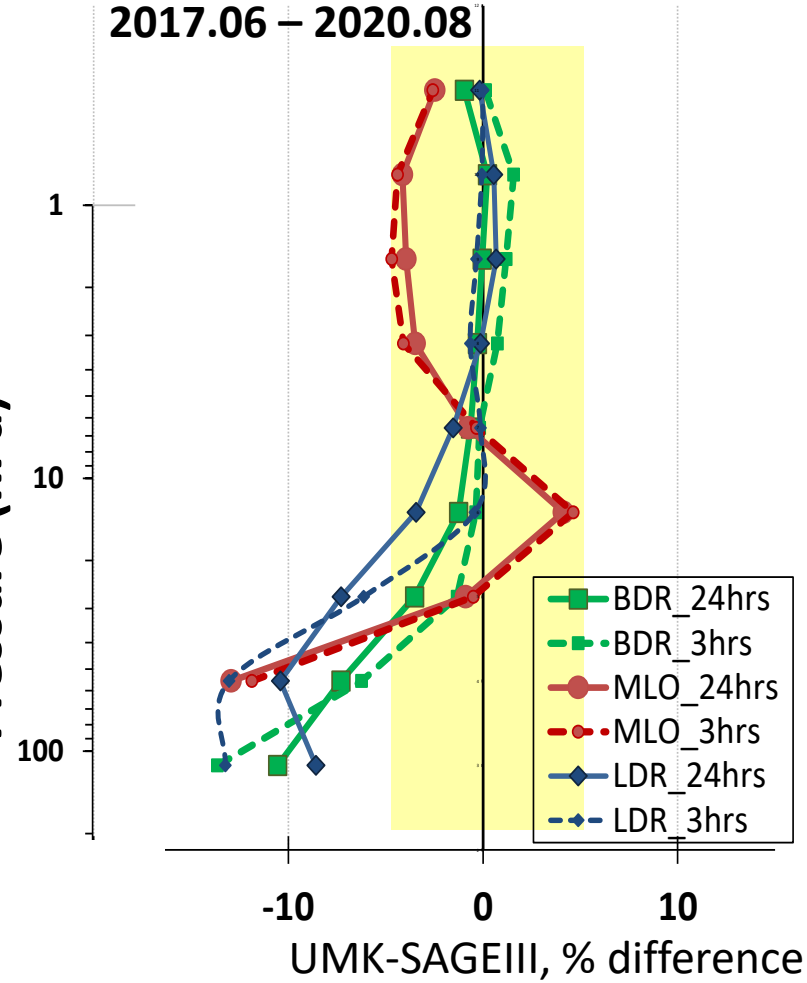




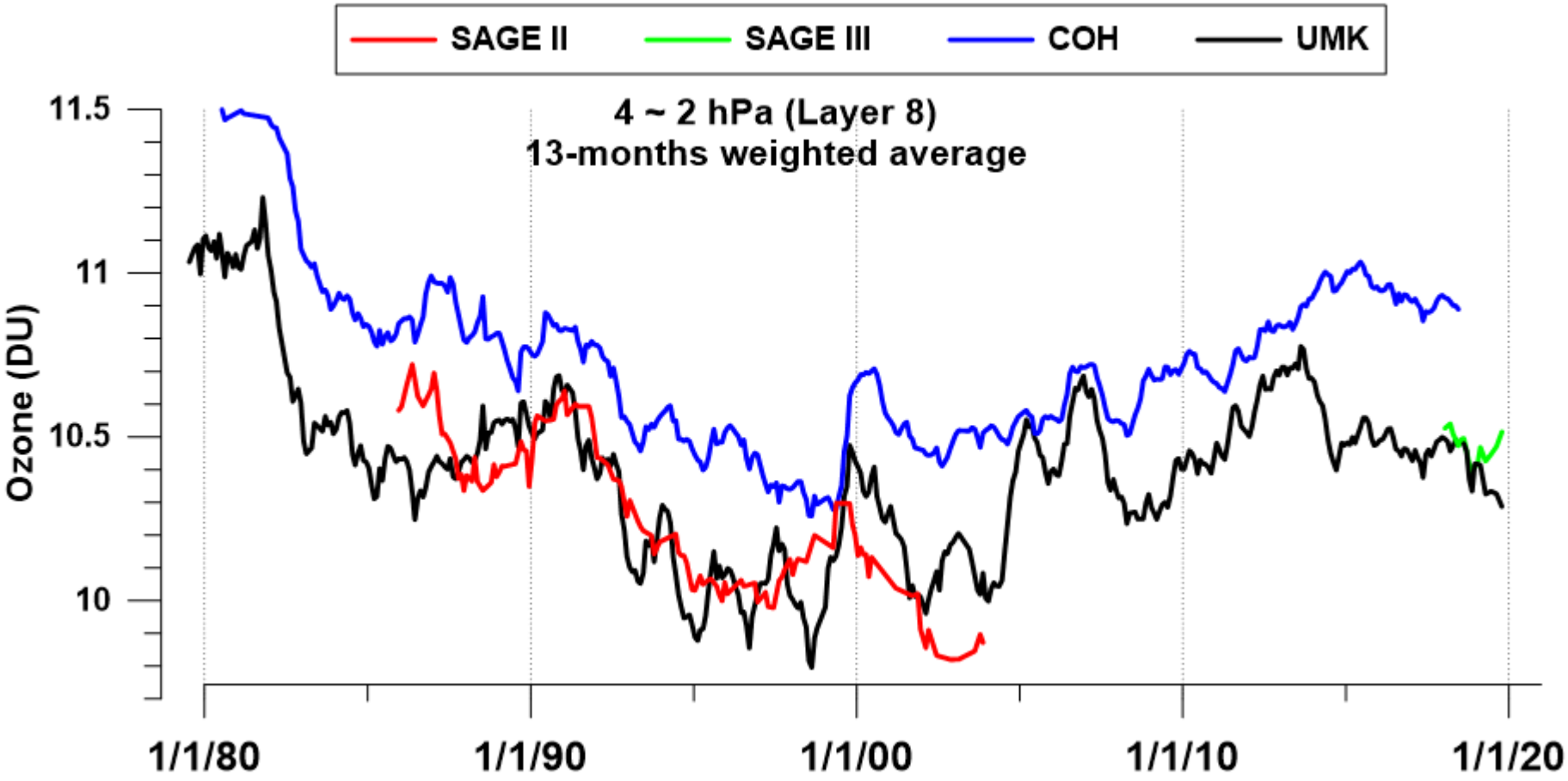
% O3 Diff.



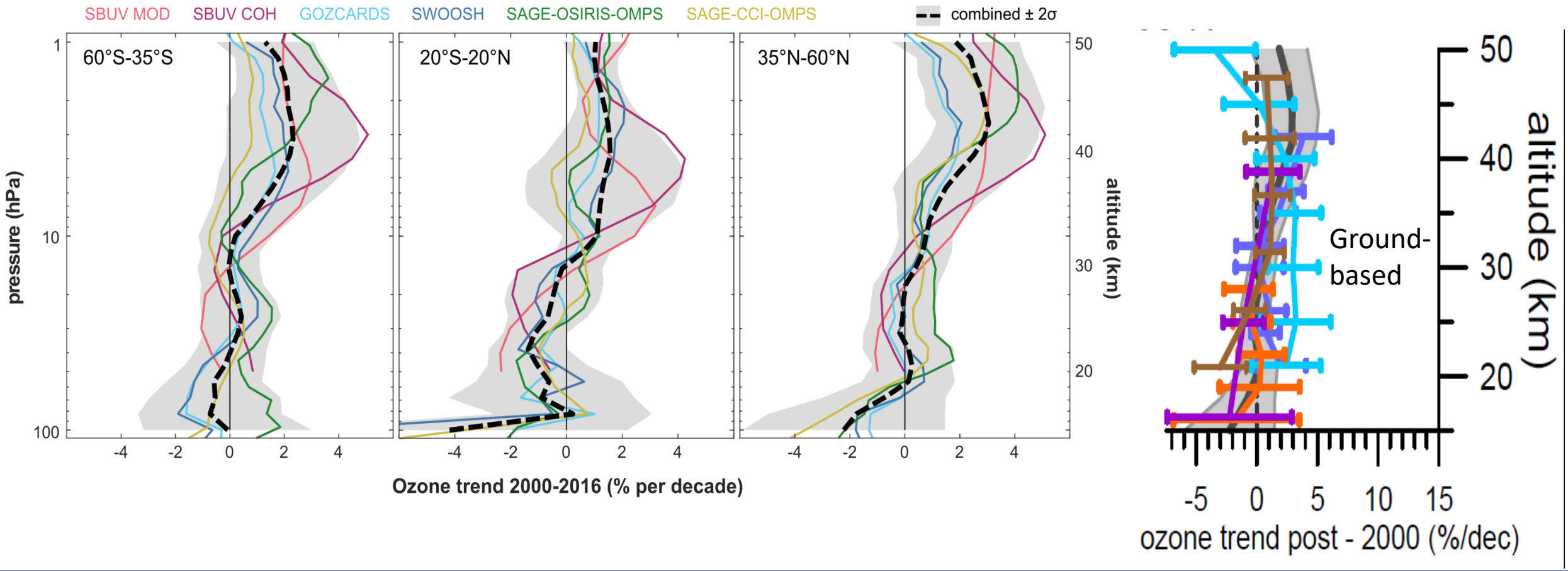
Layer bottom Pressure (hPa)



Time series of Umkehr data (MM), SAGE II and SAGE III, and COH (6-2hPa) in Boulder



Ozone assessment and SPARC LOTUS-1 New LOTUS-2 – updated data needs








Thank you very much!






Portable Optical Particle Spectrometer measurements in support of SAGE III-ISS aerosol retrieval

Elizabeth (Lizzy) Asher[1,2], Troy Thornberry[2]

Emrys Hall[1,3], Allen Jordan[1,3], Patrick Cullis[1,3], Dale Hurst[1,3]

Penny Smale[4], Richard Querel[4]

SAGE III-ISS Science Team Meeting 2020

Monday, October 19, 2020

[1] *Cooperative Institute for Research in Environmental Sciences, University of Colorado Boulder*

[2] *NOAA Chemical Sciences Laboratory, Boulder*

[3] *NOAA Global Monitoring Laboratory, Boulder*

[4] *National Institute of Water and Atmospheric Research, Lauder, New Zealand*

Outline

- POPS instrument and measurement
- Timeline of POPS stratospheric measurements
- SAGE III-ISS Boulder sondes
- SAGE III-ISS Lauder sondes
- Status and plans



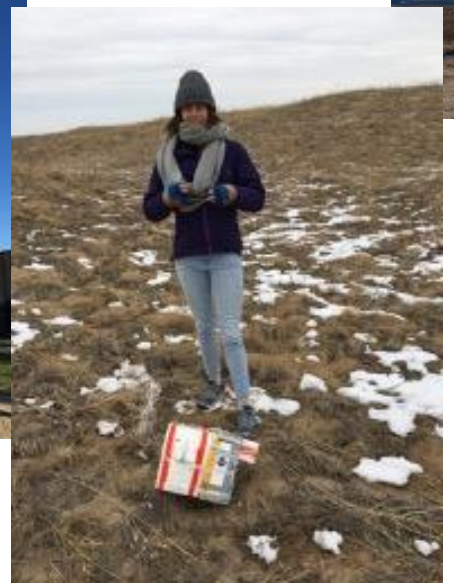
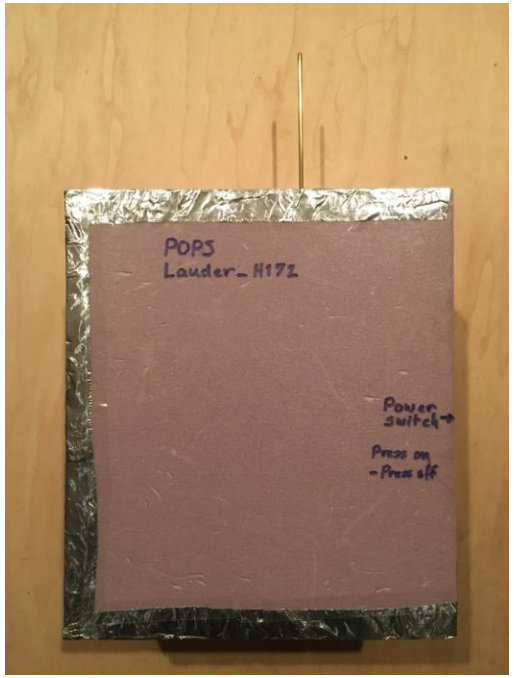
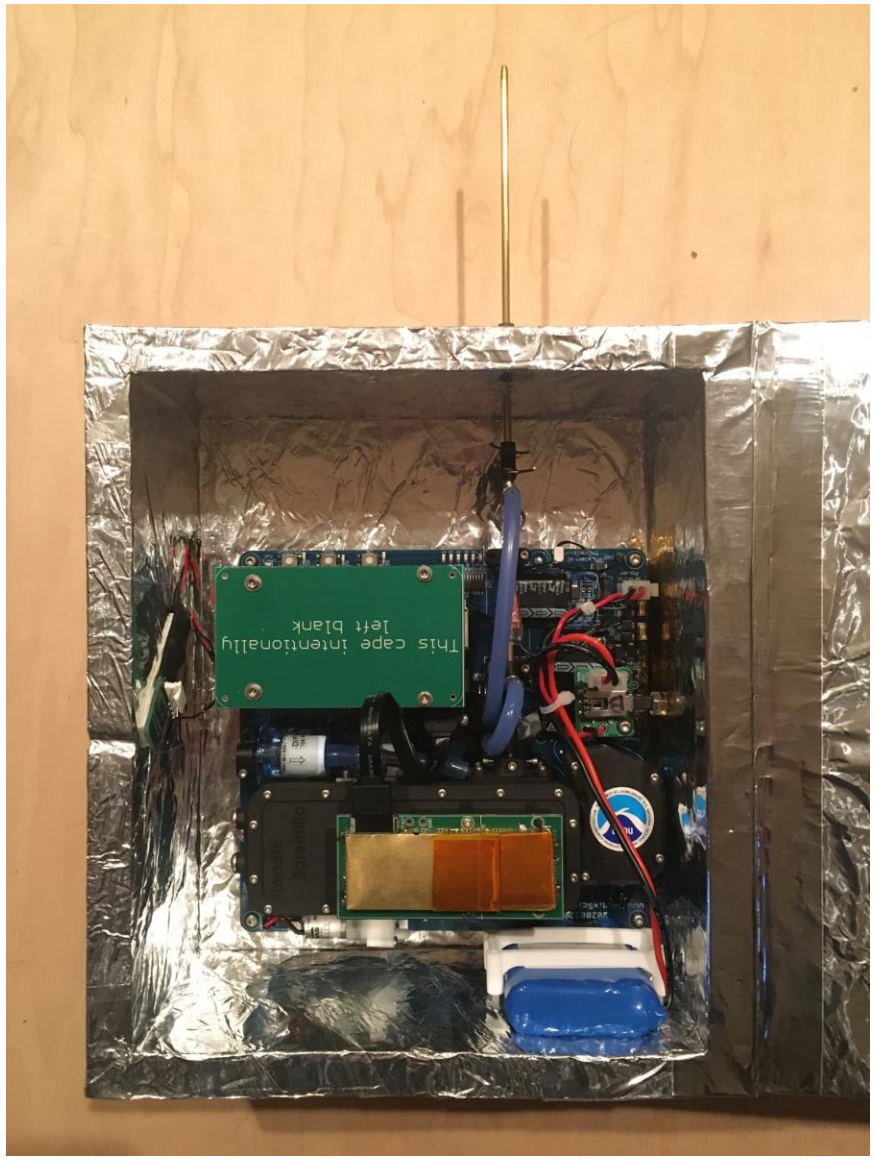




Photo credit:
Jim Elkins

Portable Optical Particle Spectrometer



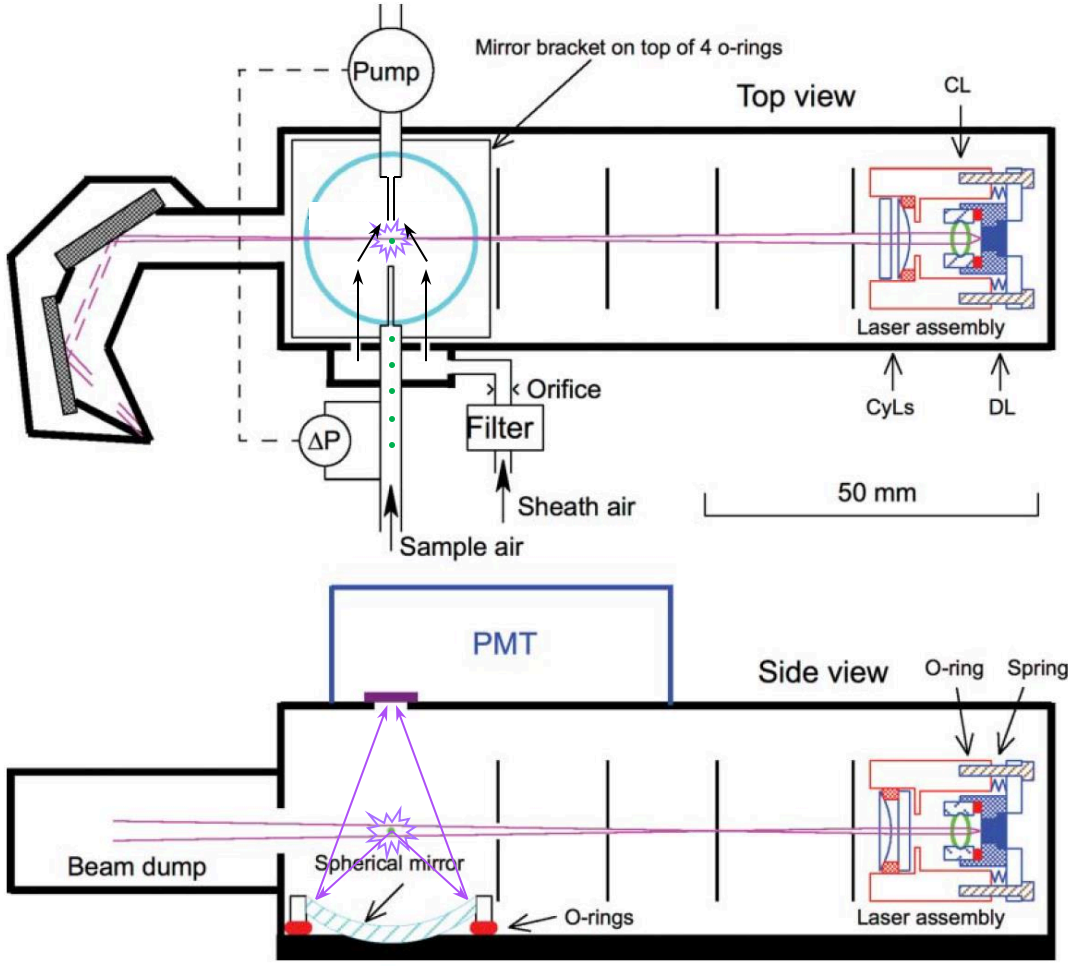


POPS specifications:

- 950 g
- 5 Watts
- Single-particle detection
- 140 – 2500 nm diameter range
- 3 - 5.5 cm^3 s^{-1} sample flow
- Measurements to > 28 km

Gao et al., AS&T 2016

POPS Measurement is Simple and Robust



adapted from Gao et al., AS&T 2016

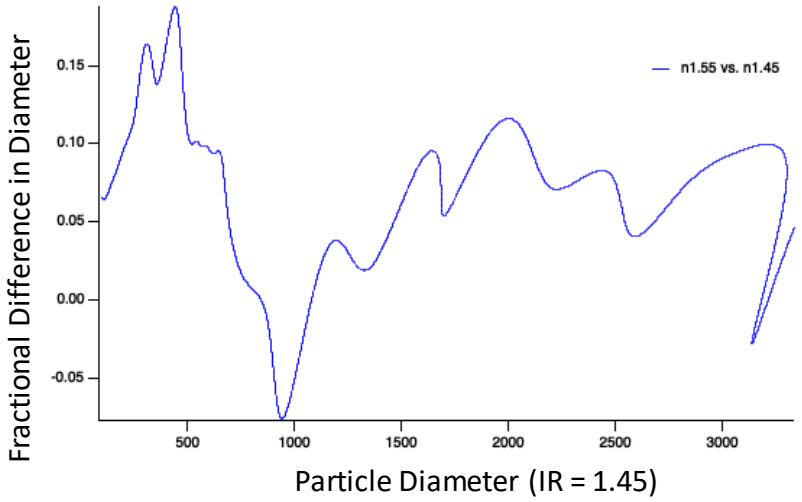
- Measures light scattered from a 405 nm (Blu-Ray) laser when a particle passes through the beam
- The intensity of the scattered light is a function of the particle size
- Peak height and width are recorded for each individual particle
- Particle counts within preselected size bins are reported each second
- Calibrated Mie theory calculation used to determine particle geometric size from the measured signal
  - Requires assuming an index of refraction and spherical shape (a requirement for all optical particle sizing instruments)

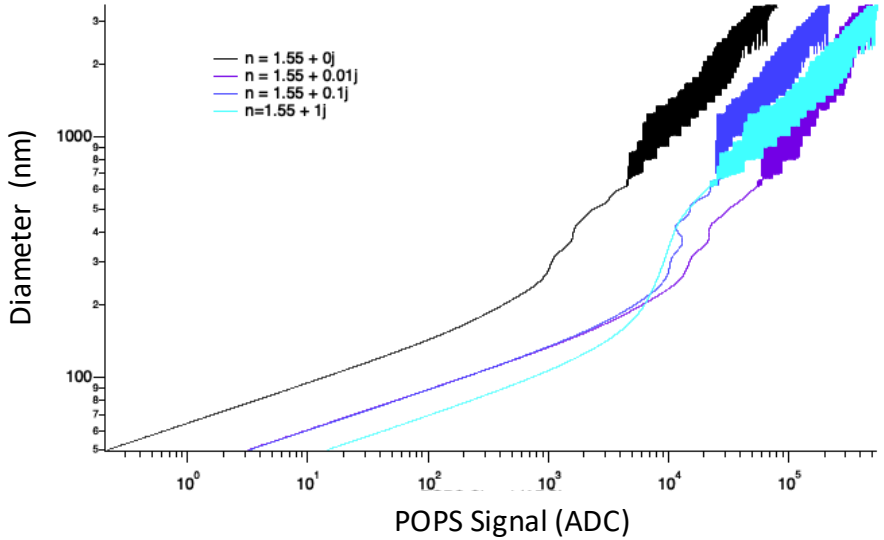
Sizing aerosol can be a bit like using a rear-view mirror- objects may be larger (or smaller than they appear).

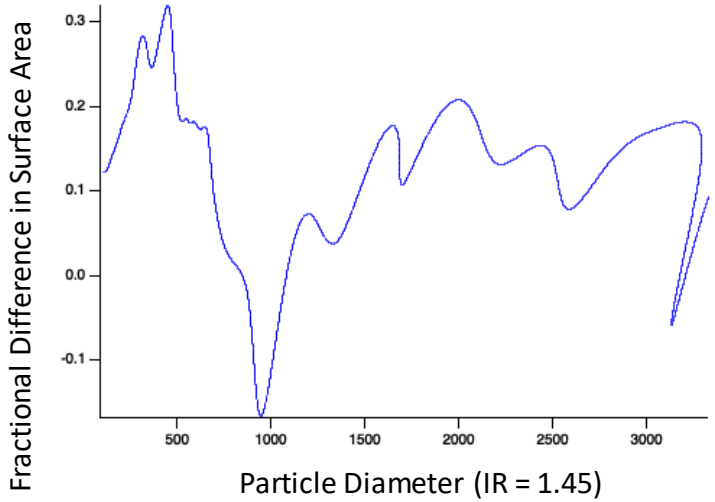


- It may depend on aerosol composition and the bulk index of refraction!

Refractive Index Effects on Aerosol Size Determination







- Assuming the "wrong" bulk index of refraction, can lead to noticeable differences in aerosol sizing and large differences in aerosol surface area
- BB aerosols from very large fires, such as over Australia, may have a substantially higher uncertainty related to aerosol size distributions

A brief timeline of POPS in the stratosphere

POPS measurements of stratospheric aerosol size and abundance have been made from a number of different high altitude platforms since 2015

2015
First POPS balloon flights:
Houston, TX
and Kunming, China (ATAL)

2016
WB-57 POSIDON
Gao et al. POPS paper published

2017
Global Hawk HOPE-EPOCH
Réunion sonde
U Wyoming Large Balloon

2018
First SAGE III-ISS validation flight from Boulder
Handix Scientific scales up production

2019
11 SAGE III-ISS coincident POPS sondes
First POPS sondes from Lauder, NZ

2020 (so far)
10 SAGE III-ISS coincident POPS sondes from Boulder
3 from Lauder



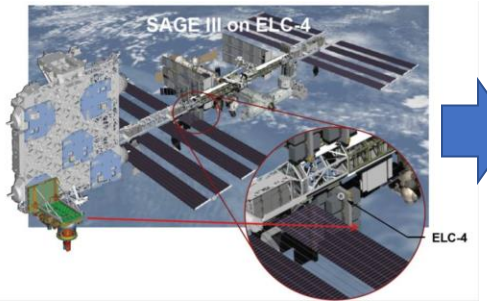


NEW GENERATION OF AEROSOL INSTRUMENTATION FOR DISTRIBUTED OR PERSONAL SAMPLING

A light-weight, high-sensitivity particle spectrometer for PM2.5 aerosol measurements



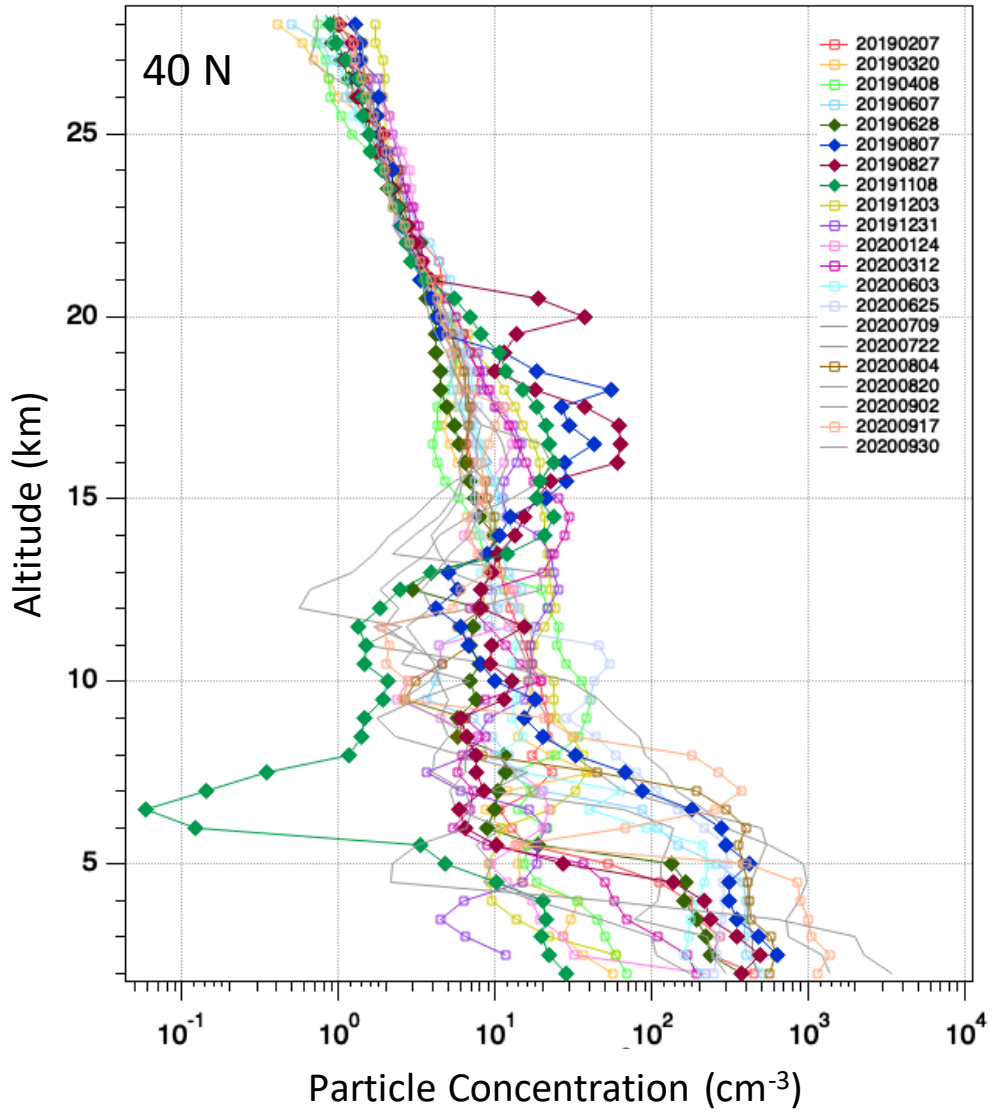






Figures courtesy of RuShan Gao, NASA, and Handix Scientific

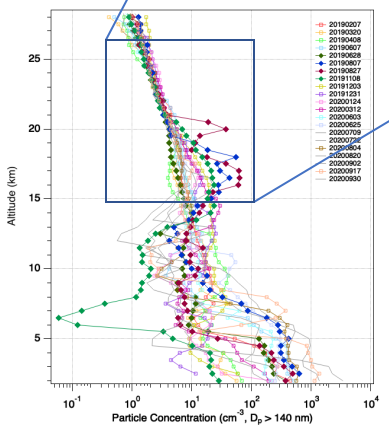
Approaching two years of POPS Sondes in Boulder, CO

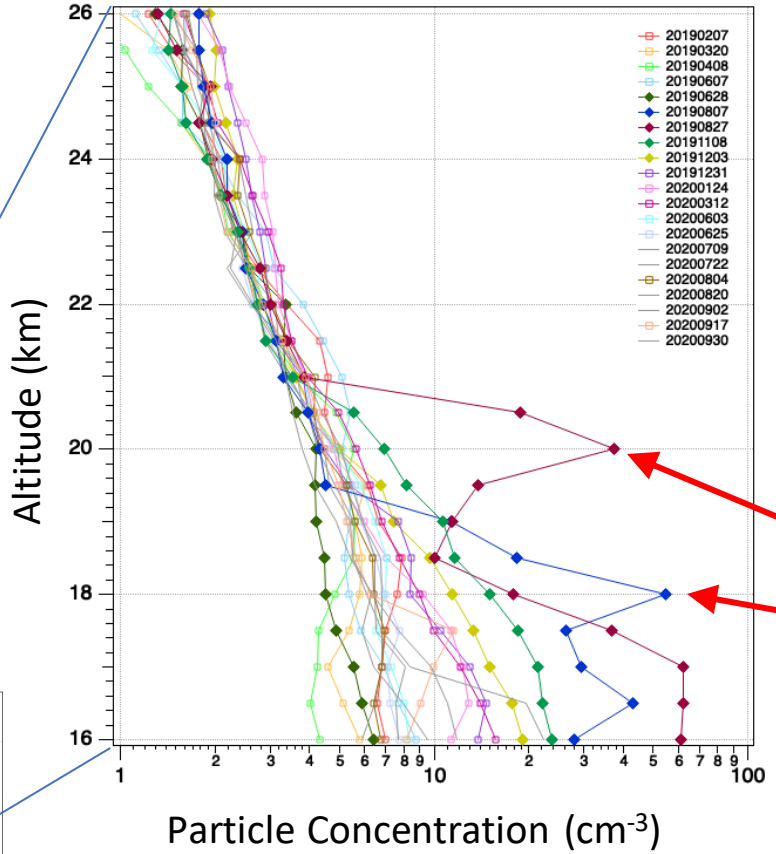


- NASA supported POPS measurements of stratospheric aerosols for SAGE III-ISS aerosol retrieval validation began in December 2018
- POPS sonde launches from Boulder (12/year), timed to match SAGE III-ISS observations (21 shown here)
- 0.5 km average particle concentration vs altitude
- Current iMet telemetry provides 15 size bins log-spaced over D_p 140 nm to 2.5 µm

Thornberry and Asher unpublished data

POPS observations in the NH stratosphere





SD between 21 – 25 km: 0.24 – 0.38 particles cm^{-3}

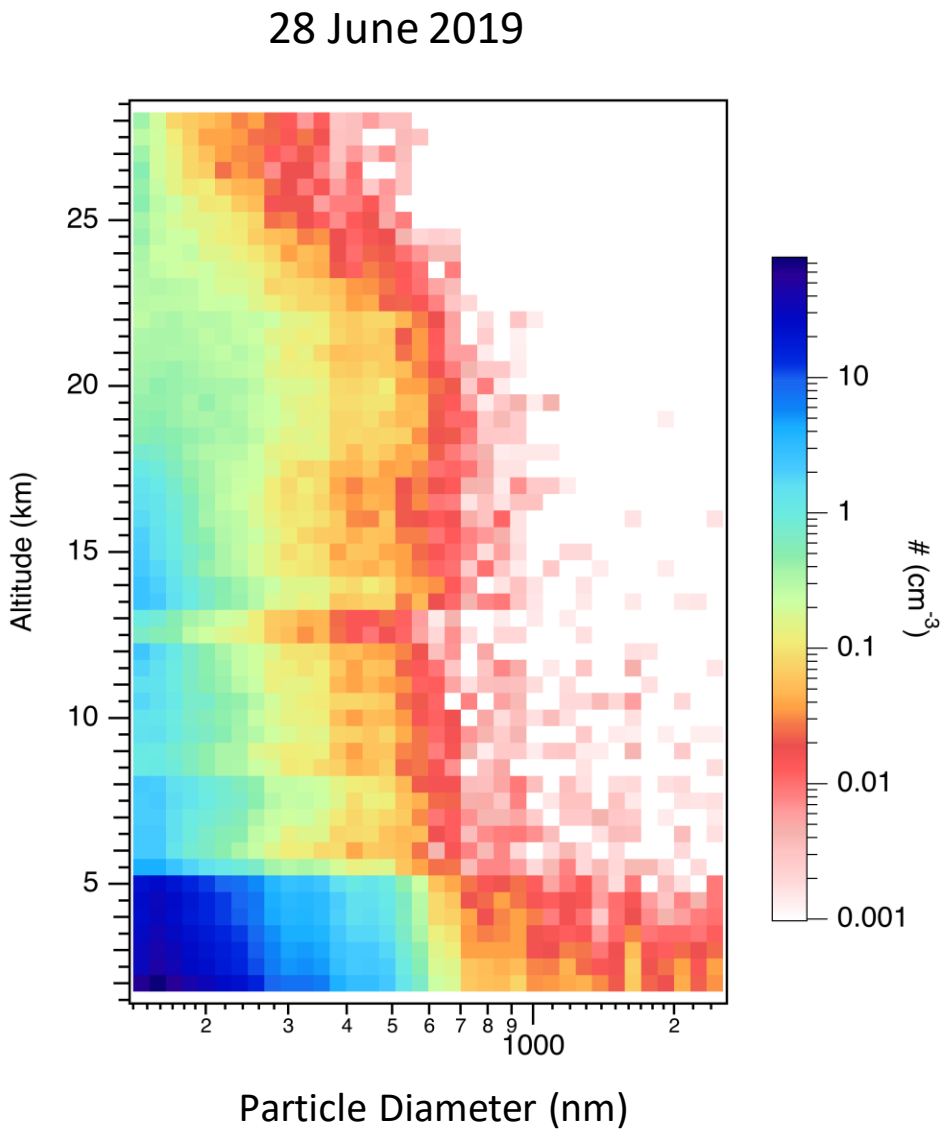
SD between 17 – 21 km: 0.76 – 9.9 particles cm^{-3}

- June 22, 2019 Raikoke erupted
- 10x particle concentration increase observed in layers in August relative to June
- Return to ~ baseline by Dec. 31



June 22, 2019
Source: NASA

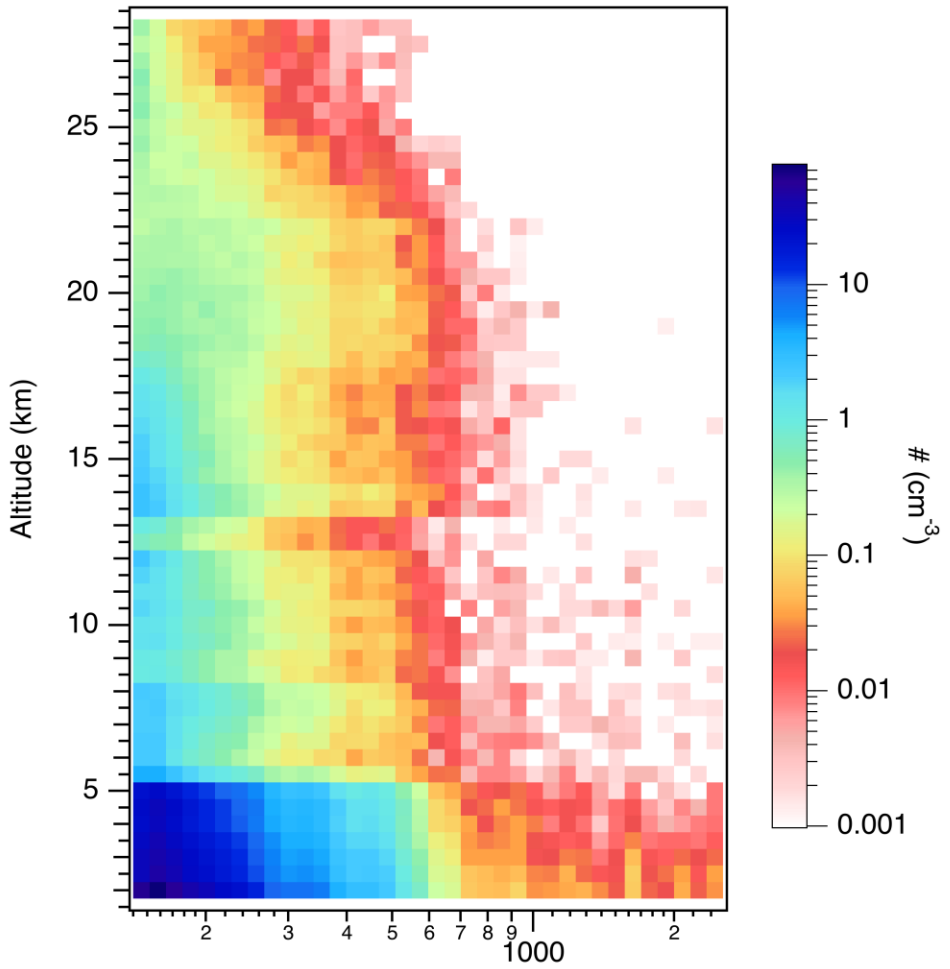
Stratospheric Aerosol Structure in Summer 2019



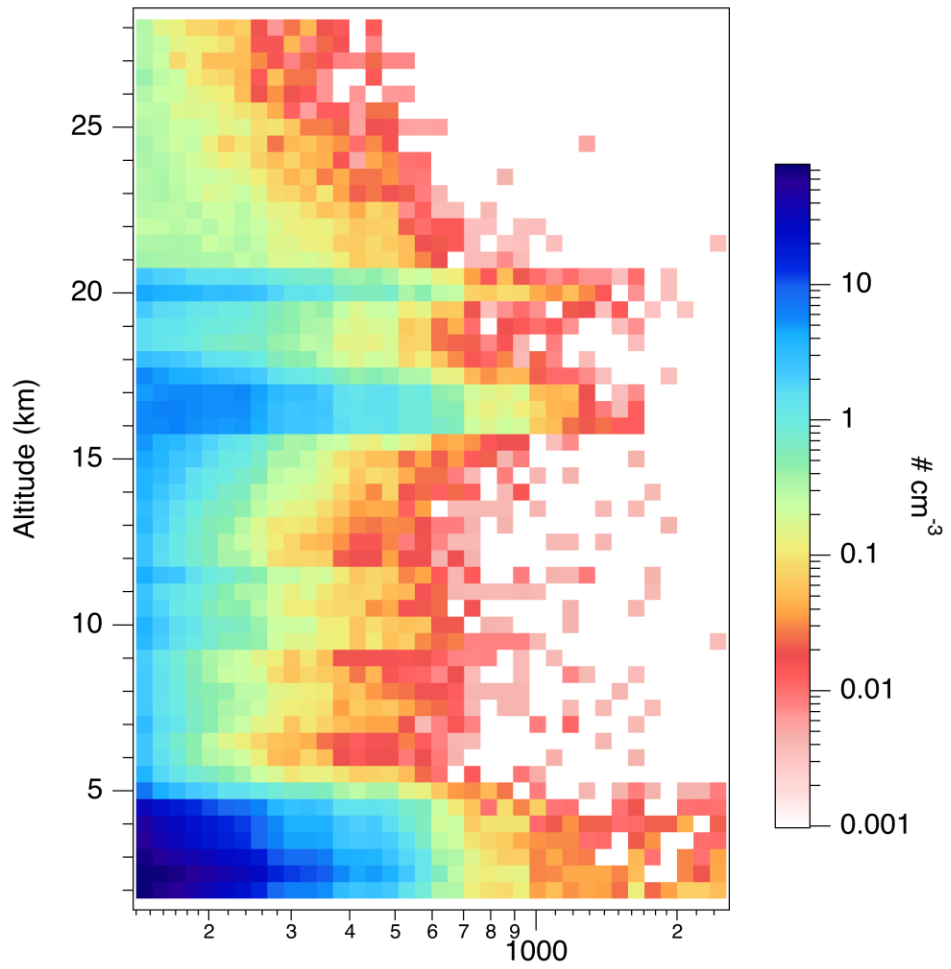
- Raikoke (48° N, 153° E) erupted on 21-22 June, sending a plume of ash and SO_2 into the stratosphere (to 13 km, local tropopause 11 km)
- The plume was transported around the northern hemisphere and rose through self-lofting due to heating by aerosol absorption
- In August, stratified layers of the plume at 16-17 km and 20 km are sampled by POPS in soundings from Boulder (40° N, 105° W)

Stratospheric Aerosol Structure in Summer 2019

28 June 2019

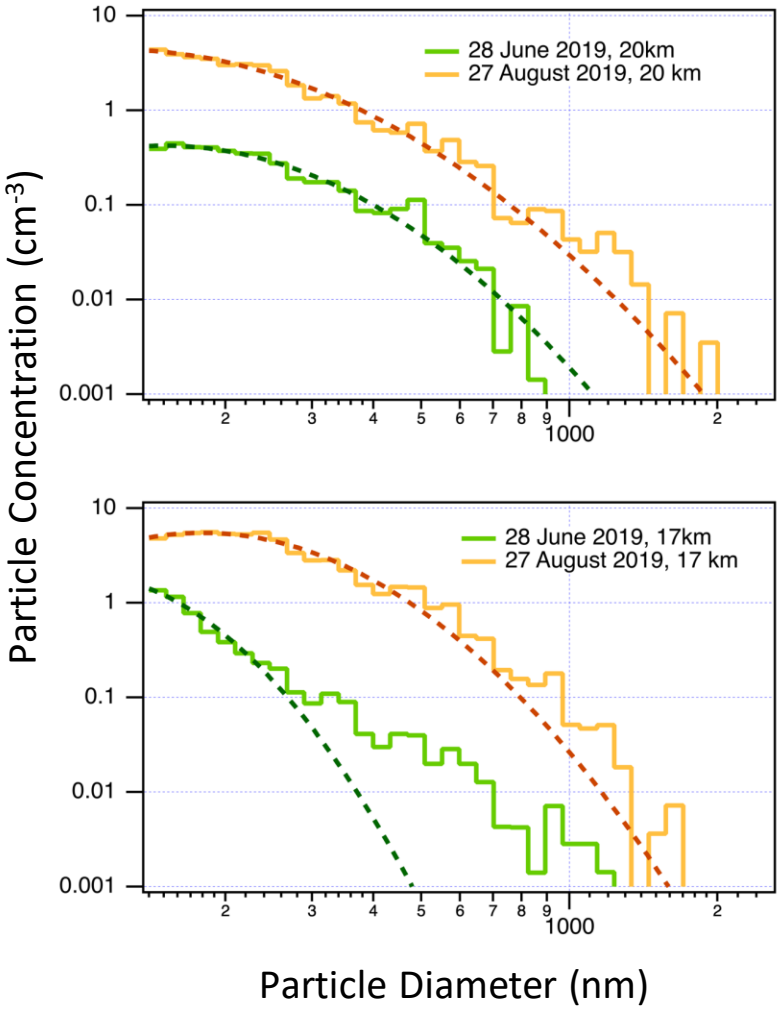


27 August 2019

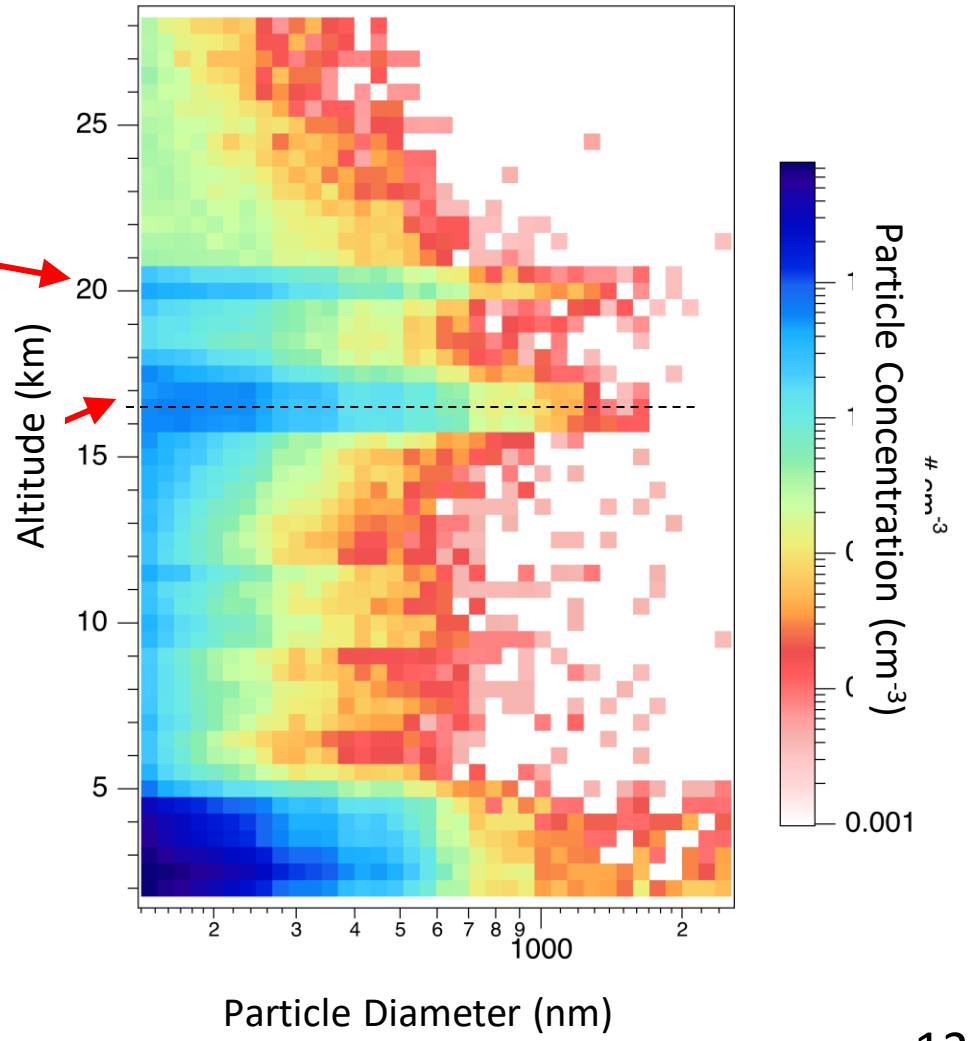


A Closer Look at Stratospheric Aerosol Structure

Aerosol size distributions

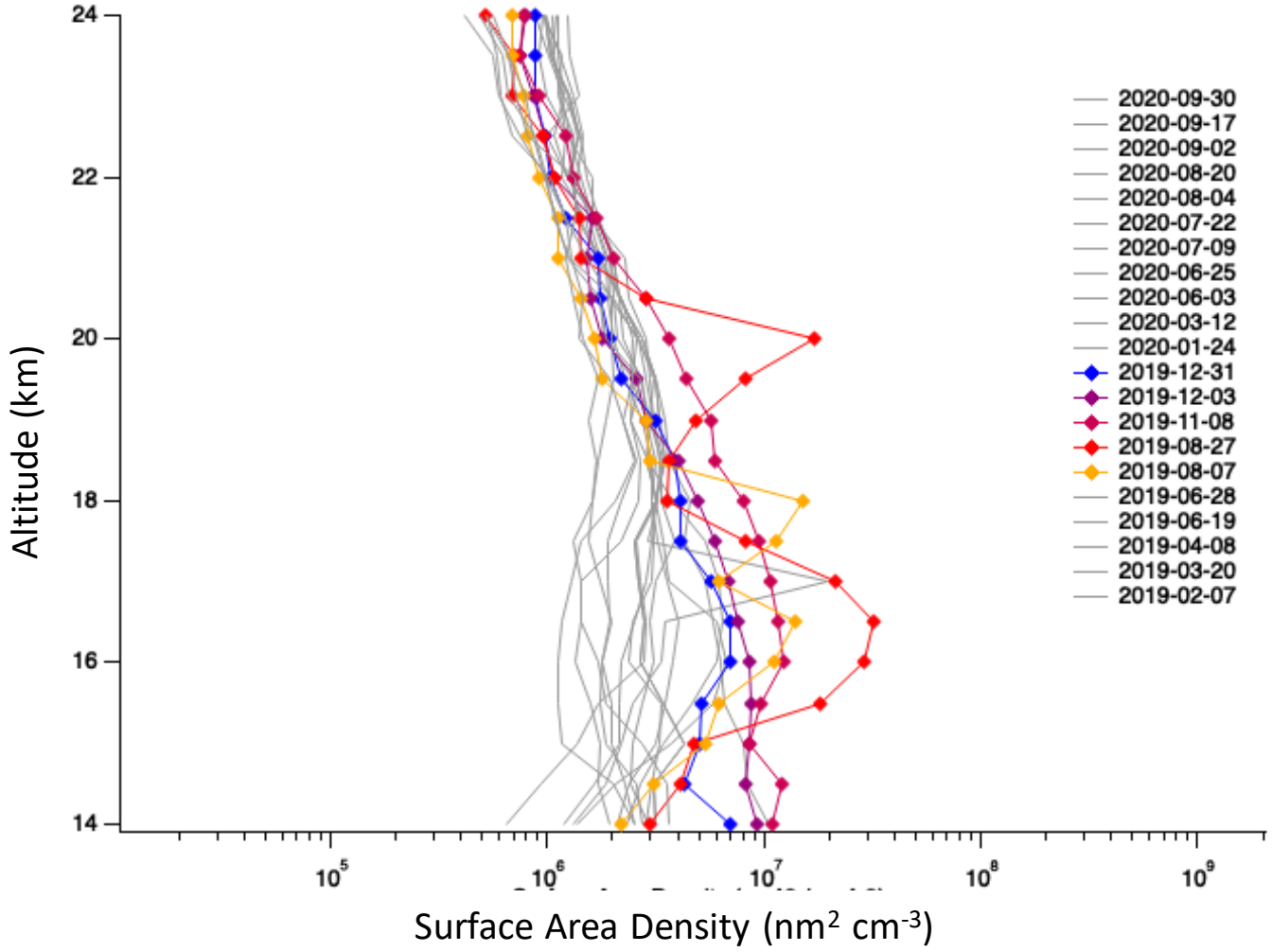


27 August 2019



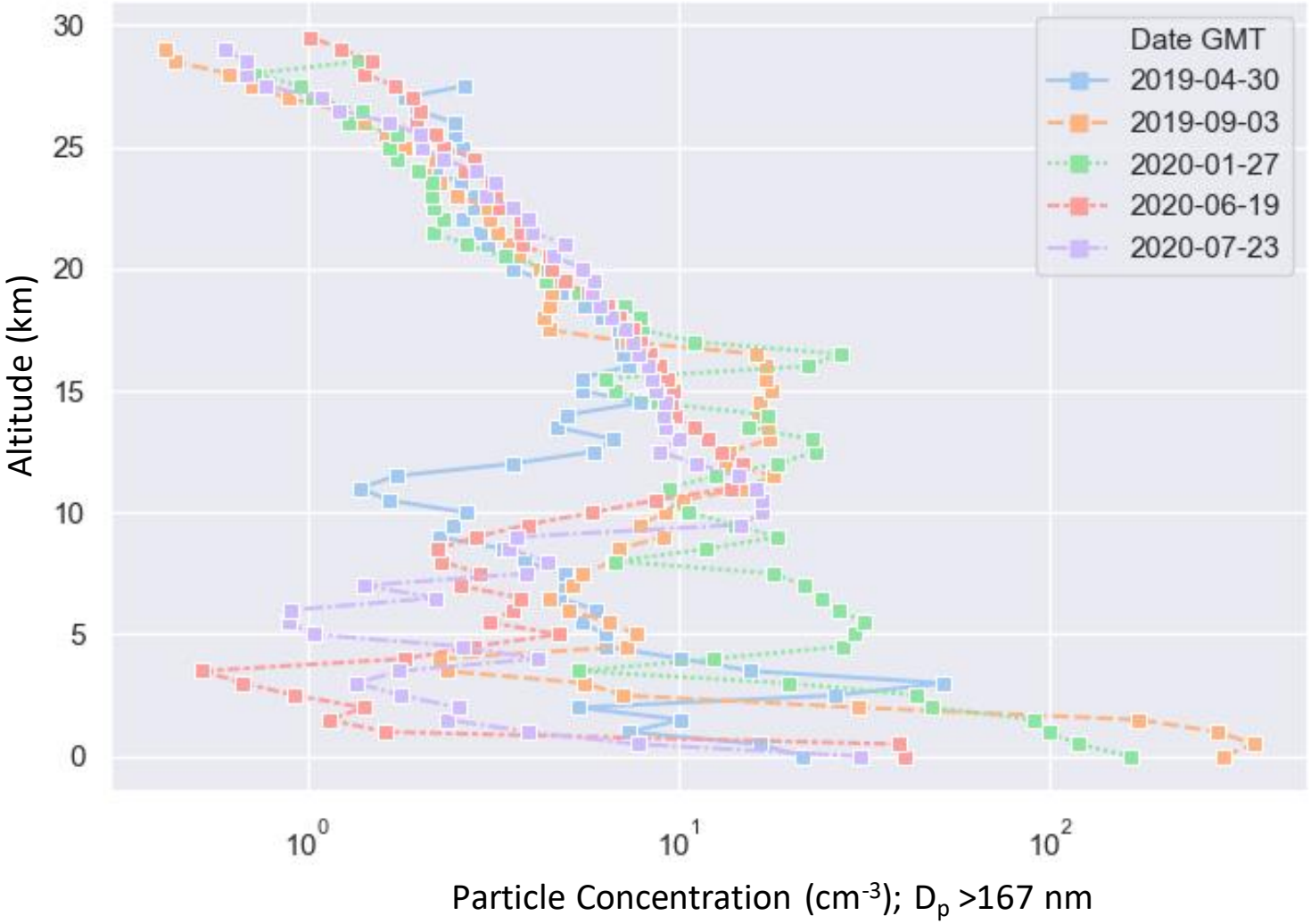
Thornberry and Asher unpublished data

Vertical Distribution of Aerosol Surface Area Density



- Aerosol surface area density has a more direct relationship to aerosol radiative effects than aerosol number concentration
- Surface area is also the important aerosol parameter in heterogenous chemistry (e.g. $N_2O_5 \rightarrow HNO_3$ on aerosol surfaces which has implications for O_3 chemistry)
- SAD in the lowermost stratosphere varied by more than an order of magnitude between profiles
- At higher altitudes (> 21 km), SAD was more consistent, though still varied by a factor of 3 between profiles

POPS sondes from Lauder, NZ (45° S)



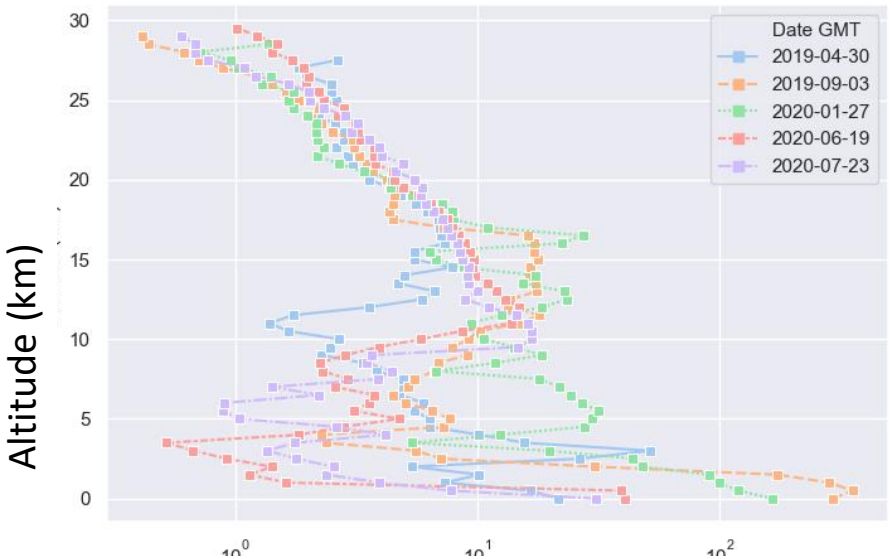
- POPS sonde launches from Lauder, NZ started in April 2019
- Good data from 5 out of 8 launches so far
- 0.5 km altitude bins
- Data currently limited to 15 size bins transmitted via iMET telemetry



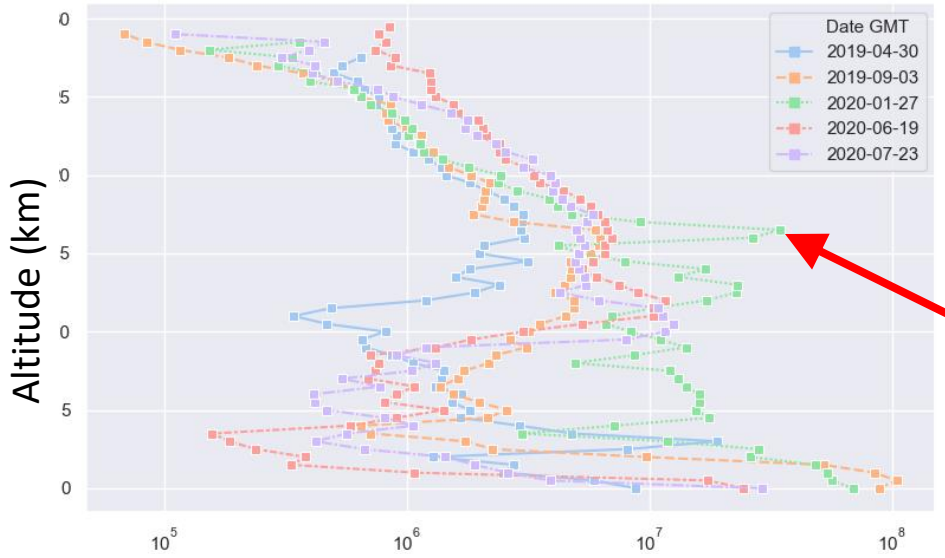
Photo credit: Emrys Hall

Thornberry and Asher unpublished data

Similar number concentration 2019-09-03 and 2020-01-27 but a large disparity in total surface area density



Number Concentration (cm^{-3});
D_p >167 nm



Surface Area Density (nm^2 cm^{-3});
D_p >167 nm

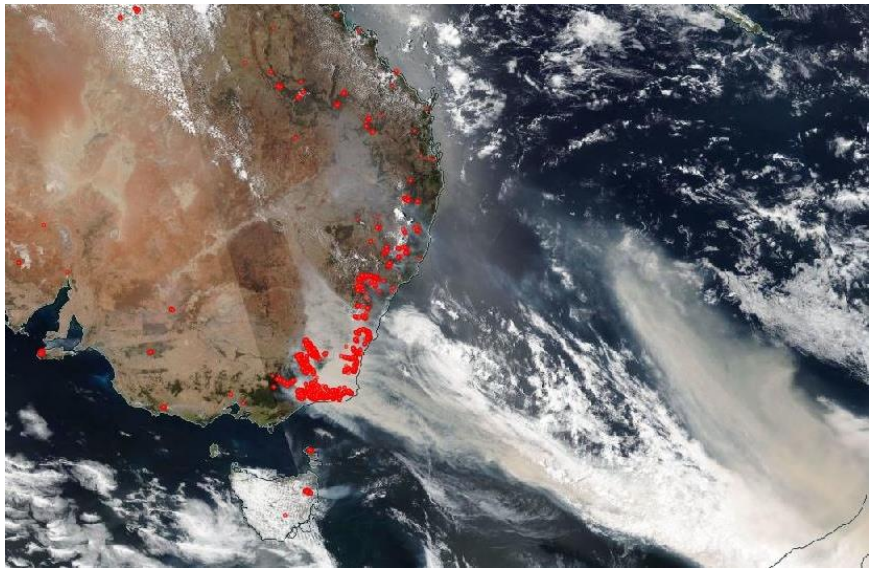
- 72,000 square miles burned
- 306 million tons CO_2 emitted
- Potential extinction of several endangered species



Source: The New York Times

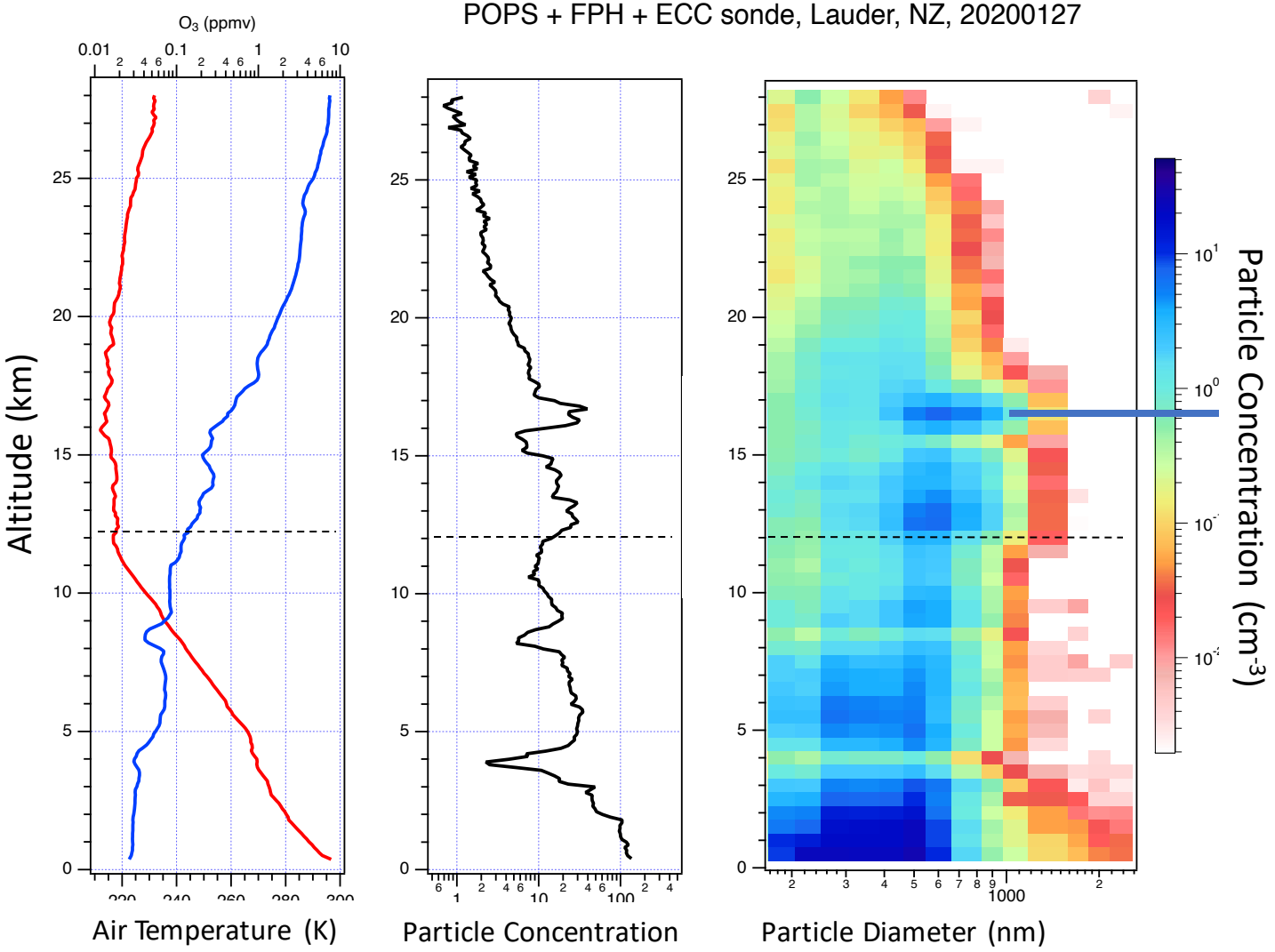
Source: NASA January 1, 2020

Stratospheric aerosol from Australian bushfires

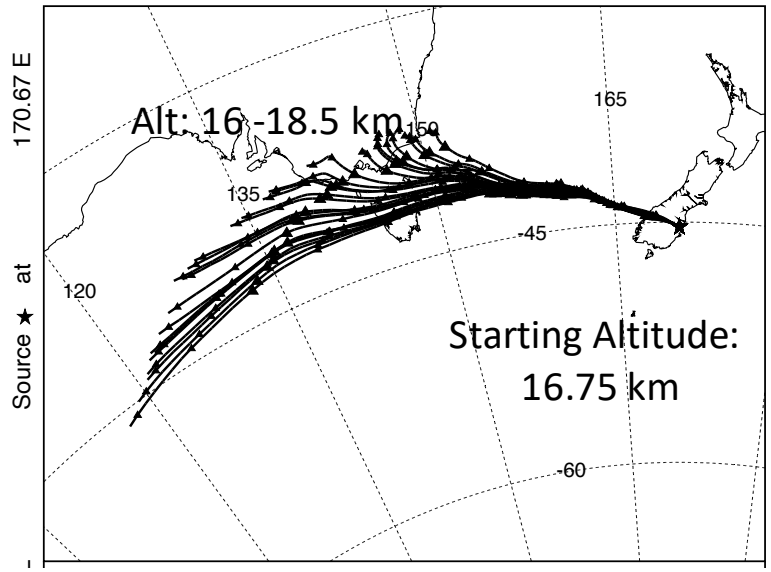


January 27, 2020

POPS + FPH + ECC sonde, Lauder, NZ, 20200127



NOAA HYSPLIT MODEL
Backward trajectories ending at 2300 UTC 27 Jan 20
GFSQ Meteorological Data

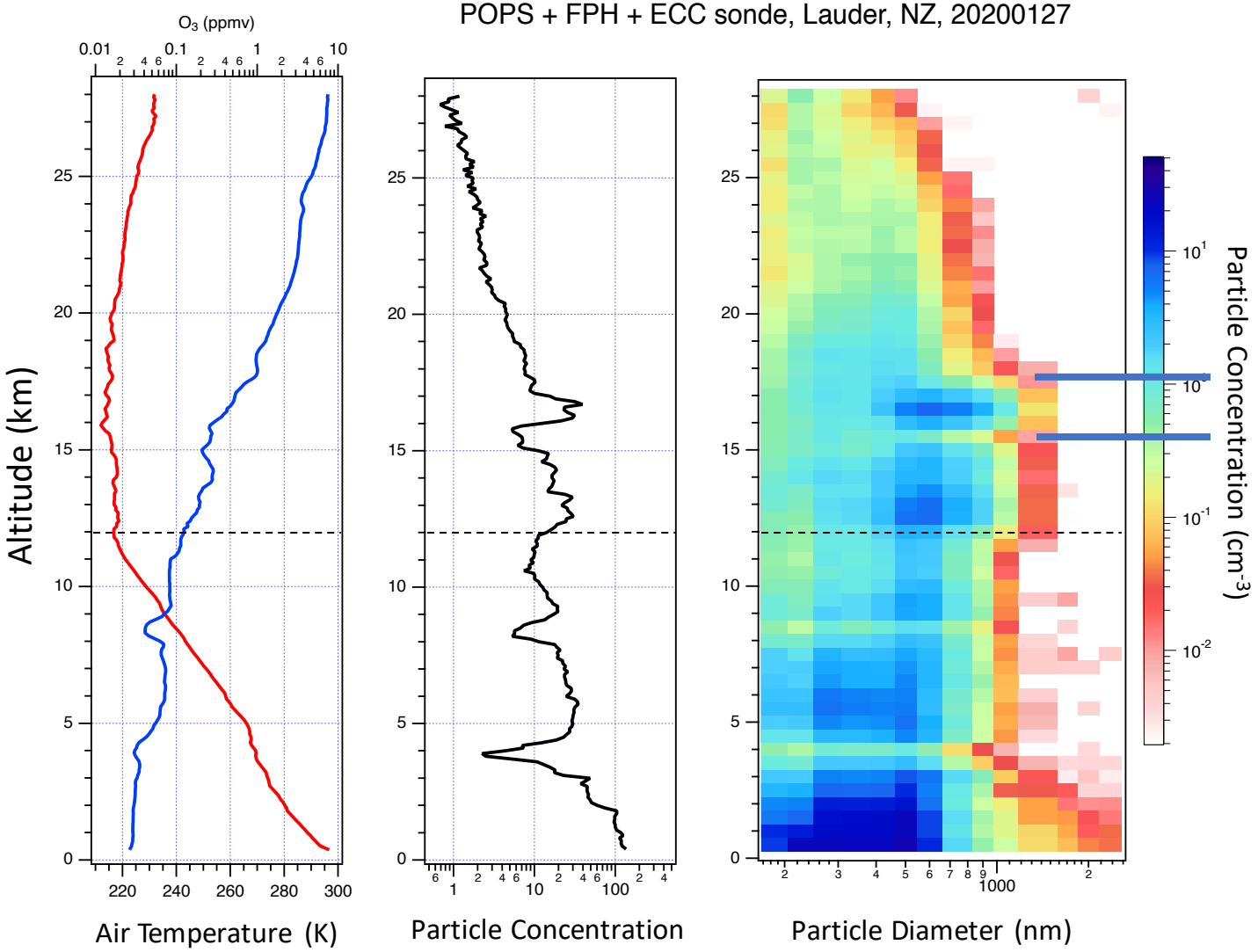


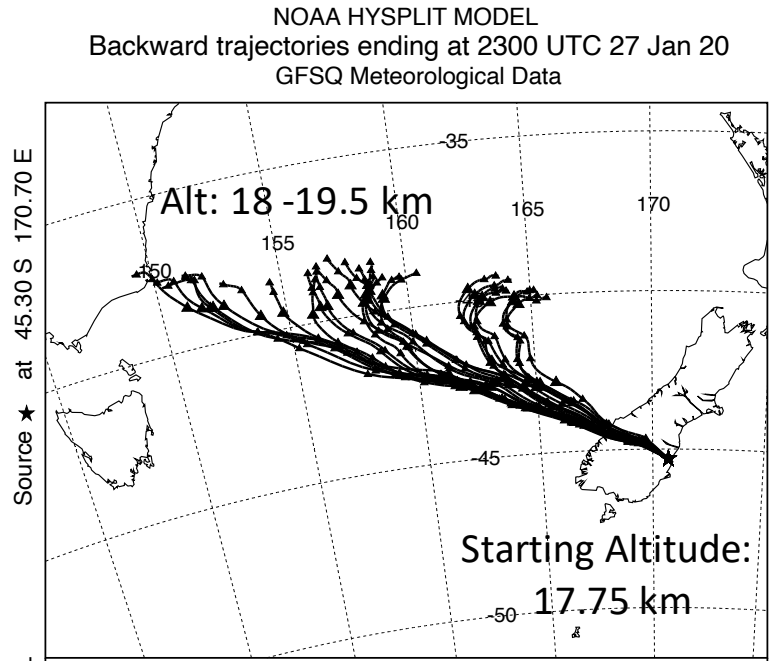
Thornberry and Asher unpublished data

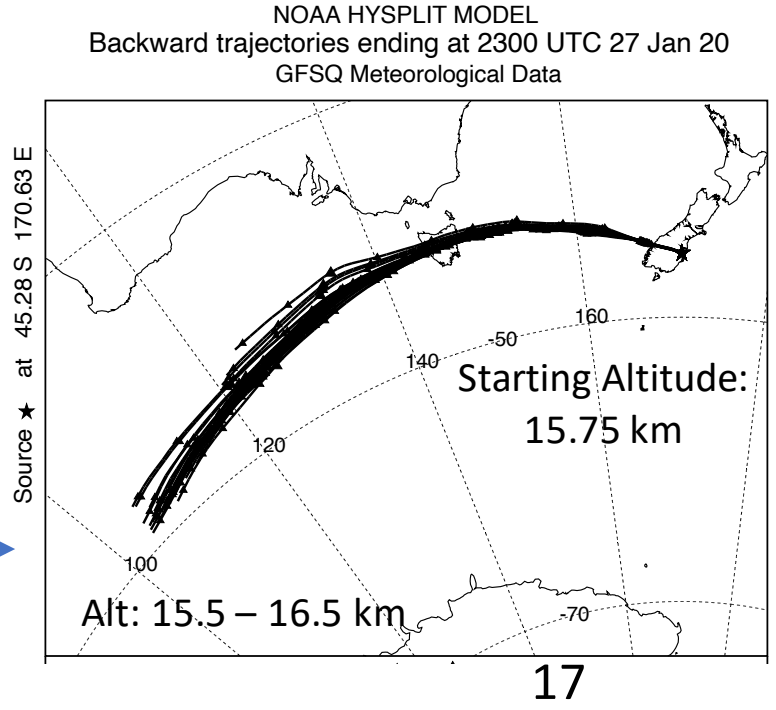
Stratospheric aerosol from Australian bushfires

January 27, 2020

POPS + FPH + ECC sonde, Lauder, NZ, 20200127



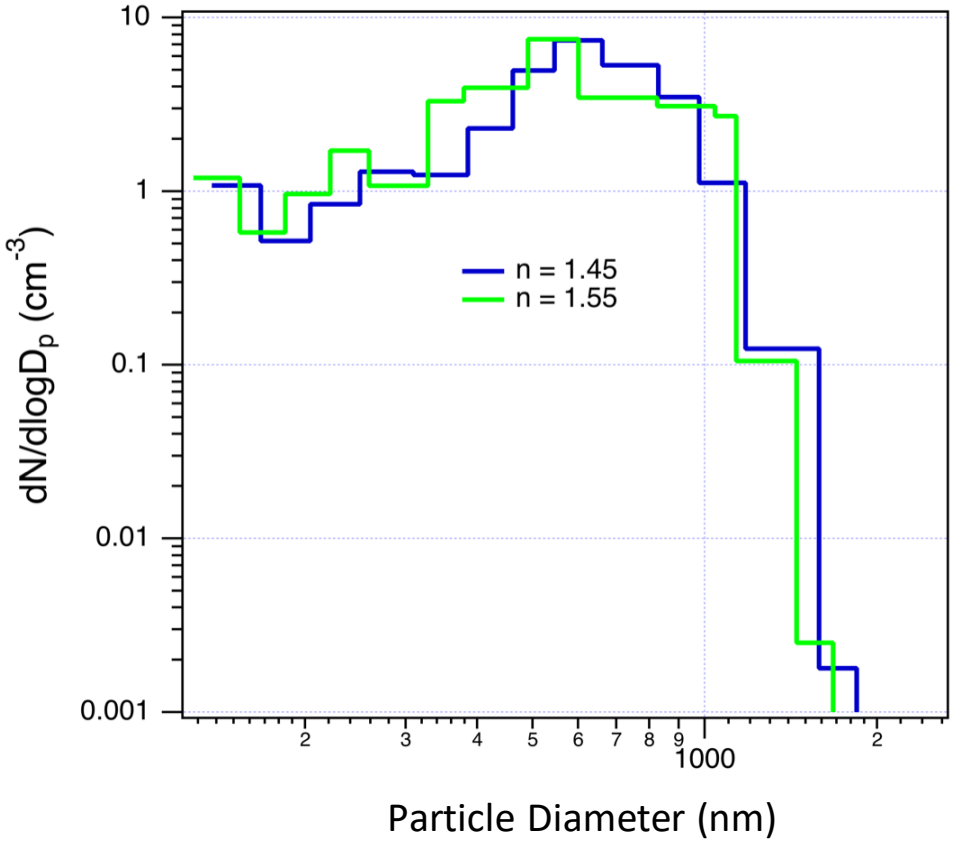




Thornberry and Asher unpublished data

Impact of Refractive Index Uncertainty on Derived Surface Area Density

Particle Size Distribution for different assumed indices of refraction



- SAD calculated for BB plume sampled at 16.5 km on Jan. 27, 2020 from Lauder, NZ
- Total SAD for n =1.45 is 35.7 µm2/cm3
- Total SAD for n =1.55 is 36.2 µm2/cm3
- This difference is well within the overall uncertainty of the POPS measurement
- The values in the pyrogenic plume fall at the upper end of SAGE II 1984 – 1994 climatology (Thomason et al. 1997)

Status and Plans

→ Since early 2019, 21 SAGE III-ISS coincidence POPS sondes from Boulder and 5 from Lauder (and continuing)

→ Within this period, these launches have captured episodes of altered stratospheric aerosol loading and size distribution from both volcanic eruption (Raikoke) and pyrogenic injection (Australian bush fires)

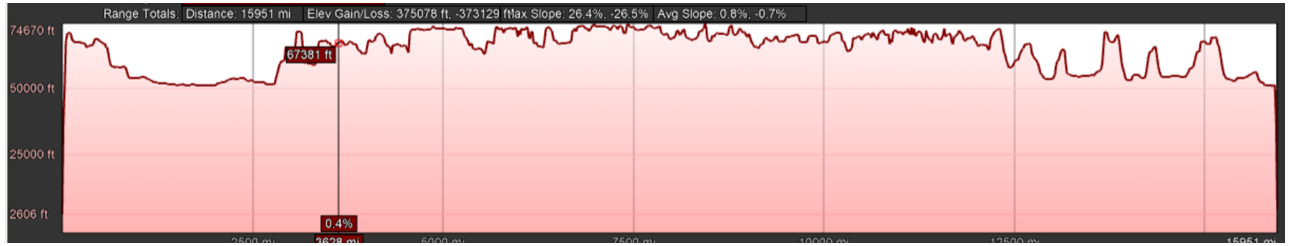
→ Currently finalizing data reprocessing with higher resolution from recovered POPS and formatting (ICARTT) for public archiving. Code and protocols will be applied immediately for processing after future launches.

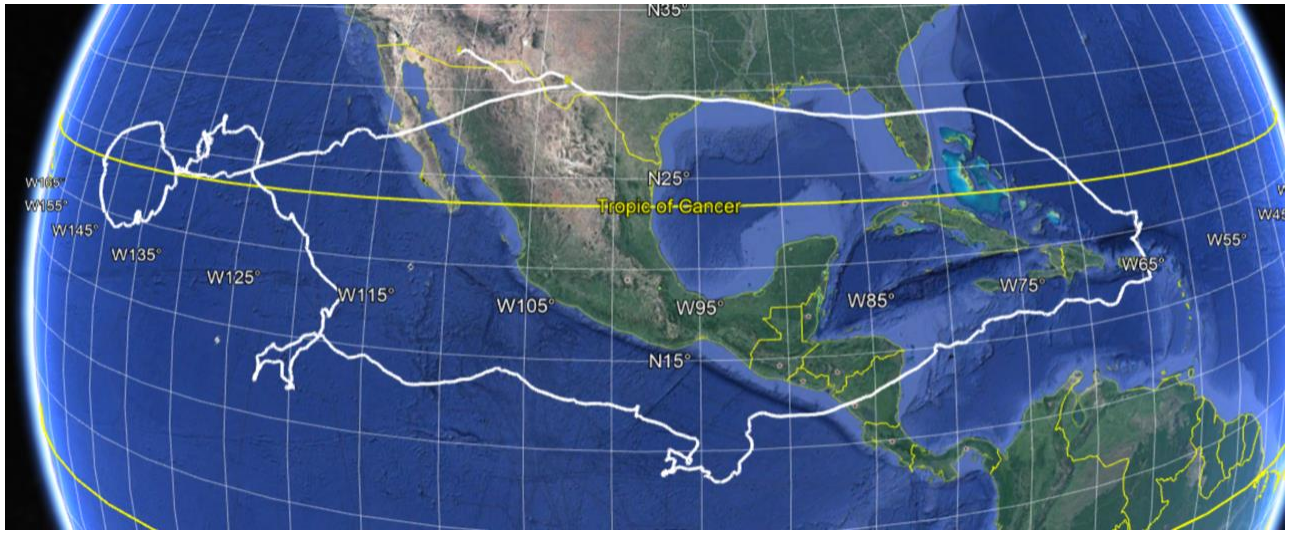
→ Anticipating a potential change in iMet to allow higher resolution size data to be telemetered along with additional engineering data to improve data QA/QC from non-recovered sondes

→ Additional POPS sondes with the NOAA B^2SAP project and multiple flights in 2021 with the WorldView Stratollite will enhance our understanding of stratospheric aerosol seasonal variability and the influence of volcanic and pyroCb events

NOAA CSL working with Worldview to fly POPS on the Stratollite in 2021

Profiling capability : 15 km (50,000 feet) - 23 km (75,000 feet)
Large geographic extent in both hemispheres
Potential for multiple flights in 2021







Source: World View

Thank You

Elizabeth (Lizzy) Asher[1,2], Troy Thornberry[2]
Emrys Hall[1,3], Allen Jordan[1,3], Patrick Cullis[1,3], Dale Hurst[1,3]

SAGE III-ISS Science Team Meeting
Monday, October 19, 2020

[1] *Cooperative Institute for Research in Environmental Sciences, University of Colorado Boulder*
[2] *NOAA Chemical Sciences Laboratory, Boulder*
[3] *NOAA Global Monitoring Laboratory, Boulder*



Ticosonde: Over 15 years of Balloon-borne Water Vapor and Ozone Profiling in Costa Rica

Ryan M. Stauffer, Anne Thompson, Rennie Selkirk, Holger Vömel, Susan Strahan (current PI), Jorge Andres Diaz and the GasLab Team, and Ticosonde Collaborators

University of Maryland and NASA/GSFC

SAGE III/ISS Science Team Meeting

20 October 2020, 330 pm

Talk Roadmap

- A Brief History of Ticosonde and Quick Facts
- Ticosonde Water Vapor and Ozone Science
- Data Caveats and Issues
  1. Ozonesonde stratospheric “dropoff”
  2. Water vapor drift relative to Aura MLS
- What’s Next for Ticosonde?

The History of Ticosonde

- Soundings began during TCSP in July 2005 under leadership of **Holger Vömel** with launches at La Universidad Nacional (Jessica Valverde; UNA)

- Monthly water vapor soundings as well as intensive campaigns in January-March 2006 in conjunction with CR-AVE, in July-August 2006, and in July-August 2007 in conjunction with TC4

- March 2011: New PI **Rennie Selkirk**, sounding program moved to Universidad de Costa Rica (UCR) GasLab under **Jorge Andres Diaz**, where it continues today

- **Current PI Susan Strahan. Launching 2-4 ozonesondes per month, and 1 CFH water vapor sonde per month**



Ticosonde workshop and visit to GasLab in March 2019

Ticosonde Quick Facts



- Ozonesonde Profiles (SHADOZ): **614**
- CFH Water Vapor Profiles (NDACC): **221**

- Only long-term *in-situ* tropical (10° N) water vapor sounding data set in existence

- Cryogenic Frostpoint Hygrometer (CFH) water vapor soundings are currently coordinated with SAGE III/ISS occultations

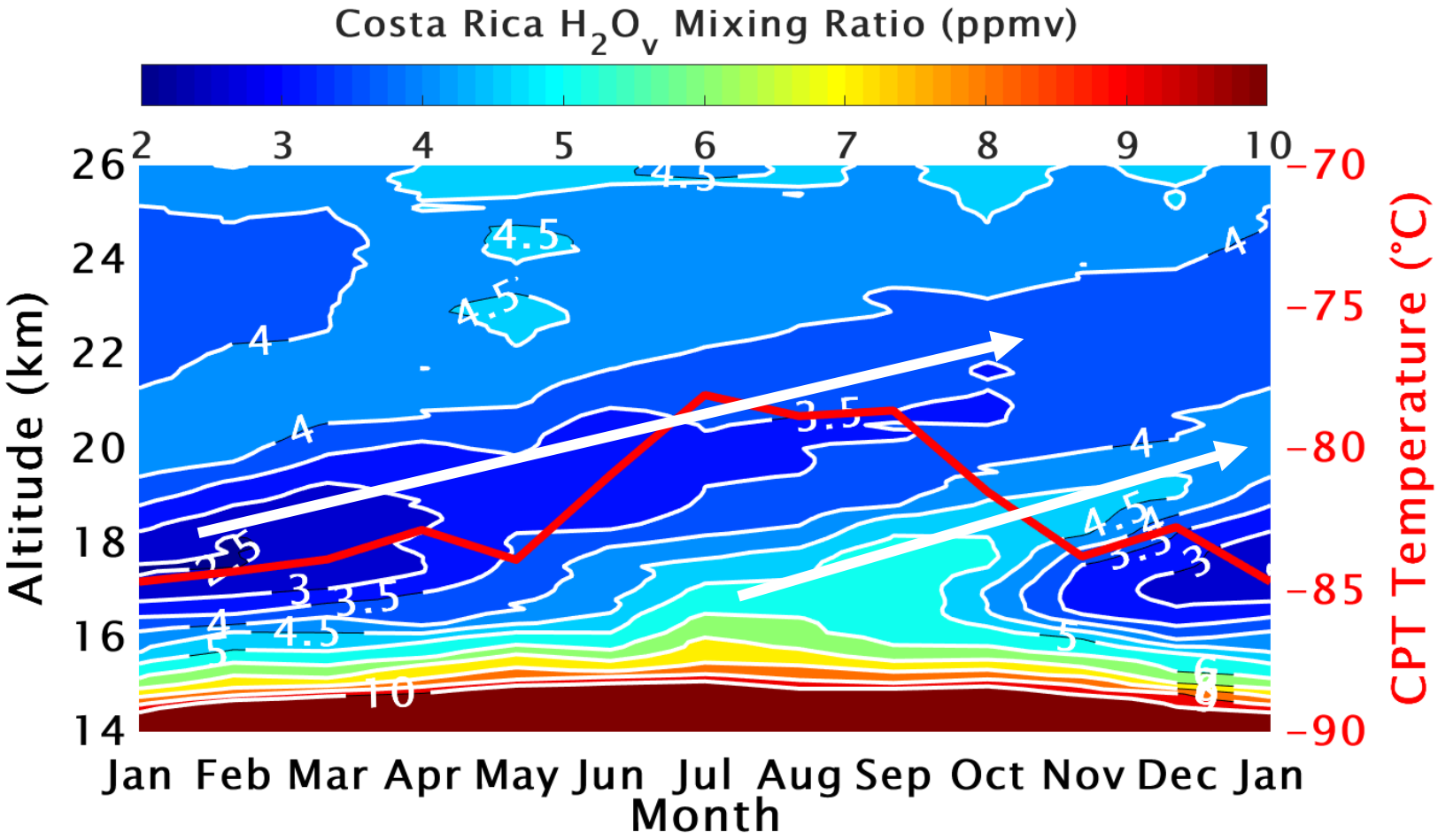
- Featured annually in the *AMS State of the Climate Report*

- Website: https://acd-ext.gsfc.nasa.gov/Projects/Ticosonde/index.html

Ticosonde Ozone and Water Vapor Science

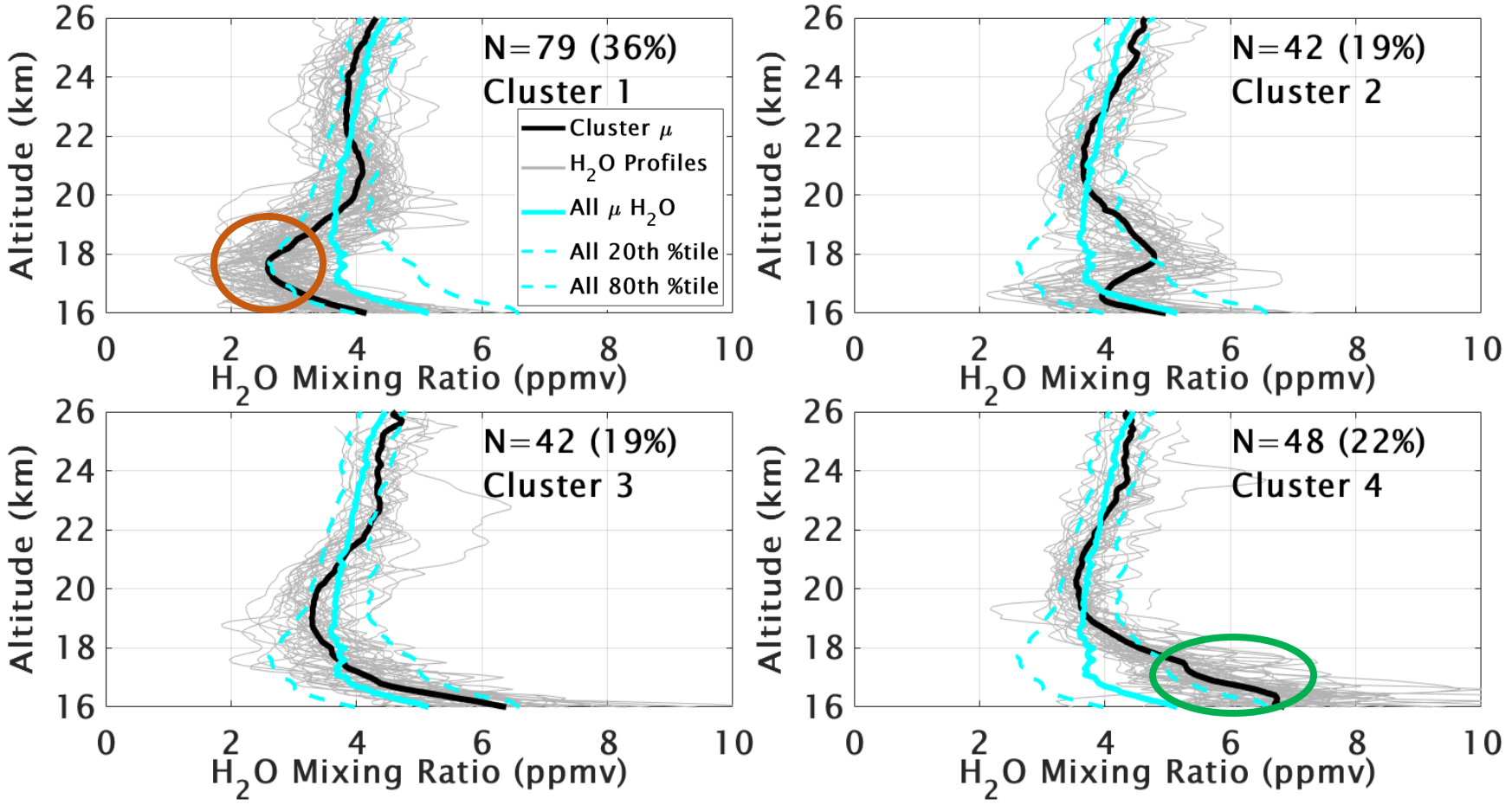
Ticosonde Water Vapor

- The *in-situ* water vapor profiles help characterize tropical dynamics with unmatched vertical resolution
- Figure on right shows monthly H_2O climatology and **cold-point tropopause** temperature
- The tropical water vapor tape recorder is prominent, which relates tropopause temperature to stratospheric water vapor content
- Slanted minima and maxima (**arrows**) quantifies the rate of ascent of stratospheric air



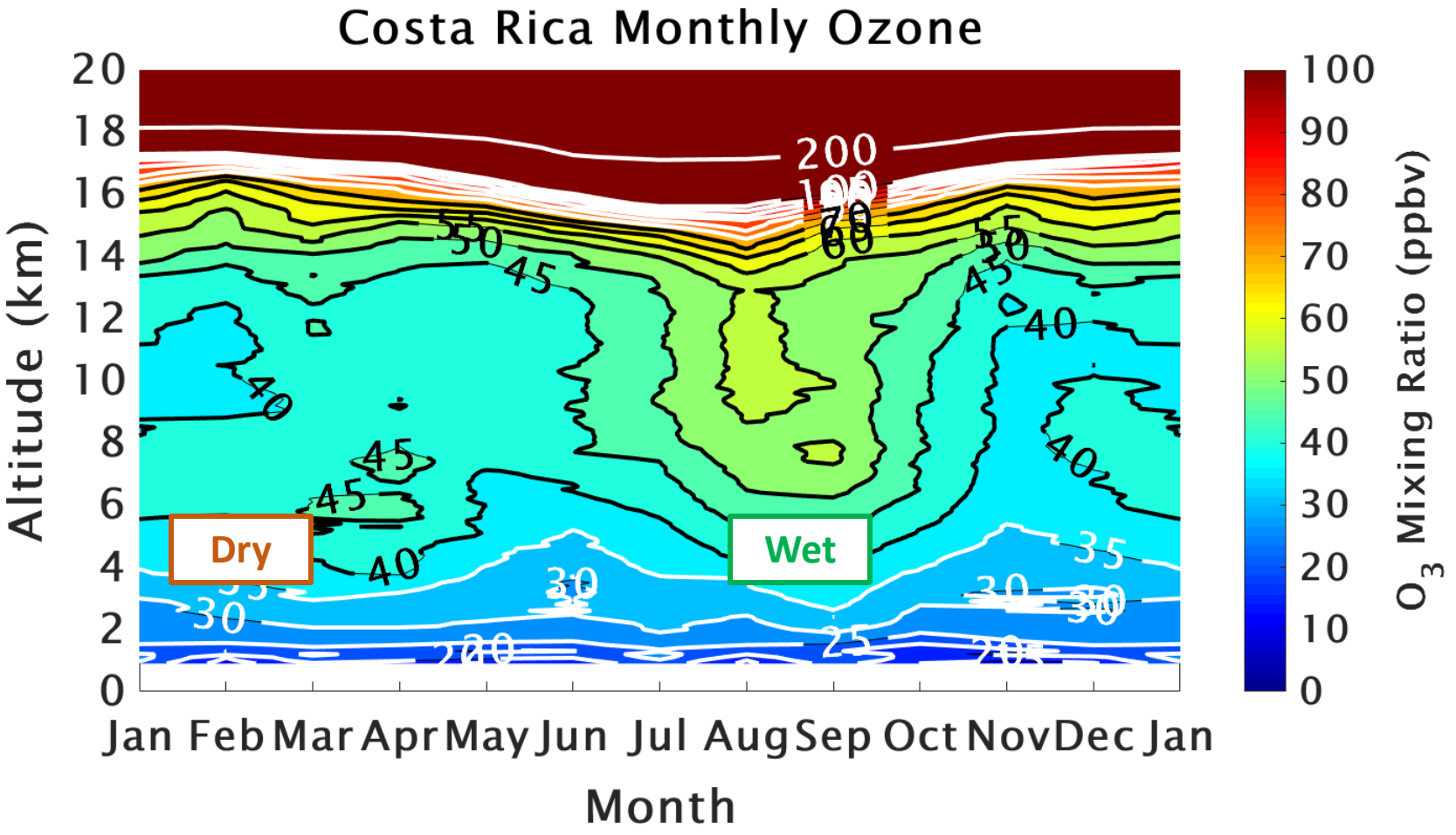
Ticosonde Water Vapor Clustering

- Taking a step beyond a simple climatology, we can use a clustering technique (self-organizing maps) to identify "prototype" water vapor profiles
- Note that clusters 1 and 4 show profiles that are particularly **dry** and **wet** and in the UT/LS
- We can use these clusters to identify how model and satellite biases are related to geophysical processes



Ticosonde Ozone

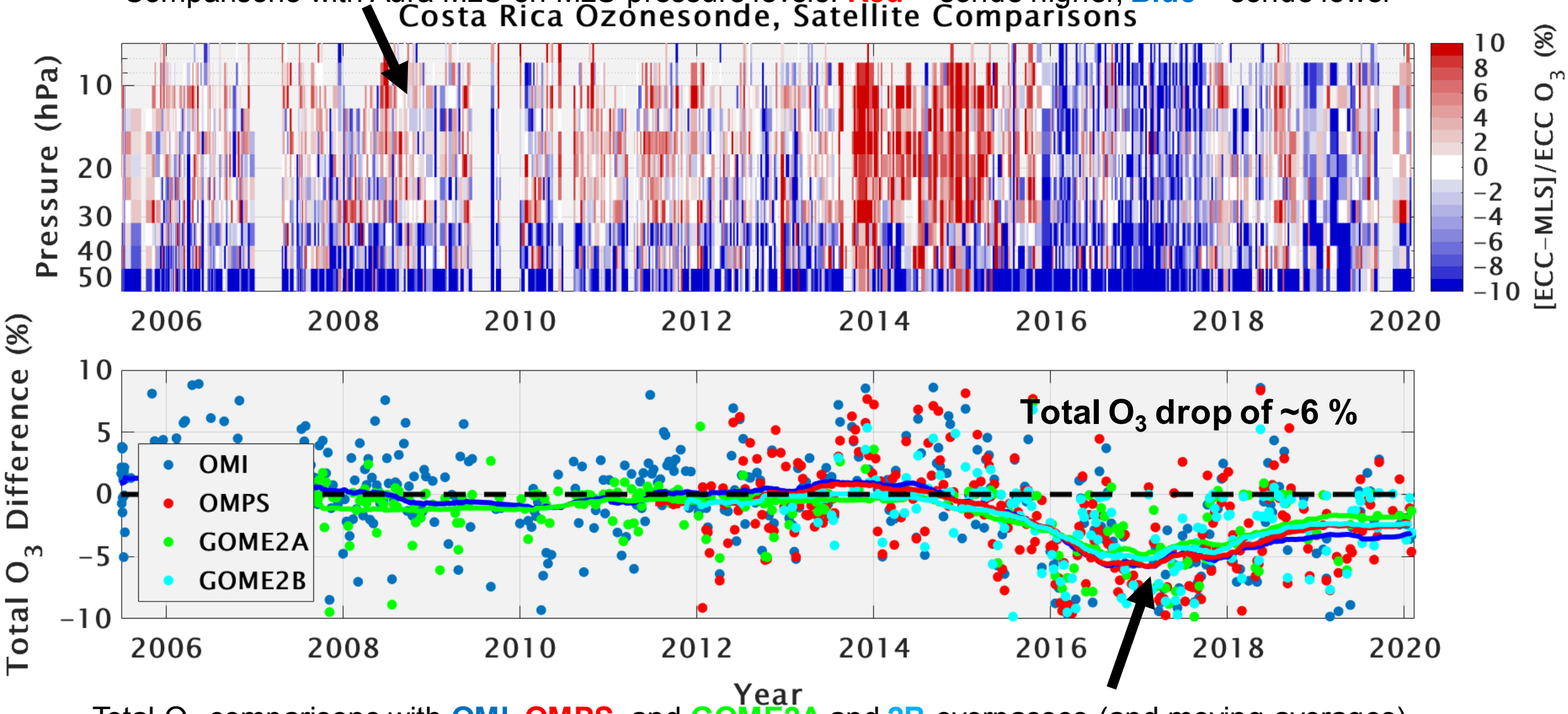
- Maximum tropospheric ozone in July to October
- Minimum tropospheric ozone in November to February
- The greatest tropospheric O_3 amounts occur during the wet season, and the lowest tropospheric O_3 occurs during the dry season
- This is atypical compared to other SHADOZ stations. Another ozone paradox??



Data Caveats and Issues

Ozonesonde "Dropoff" Problem

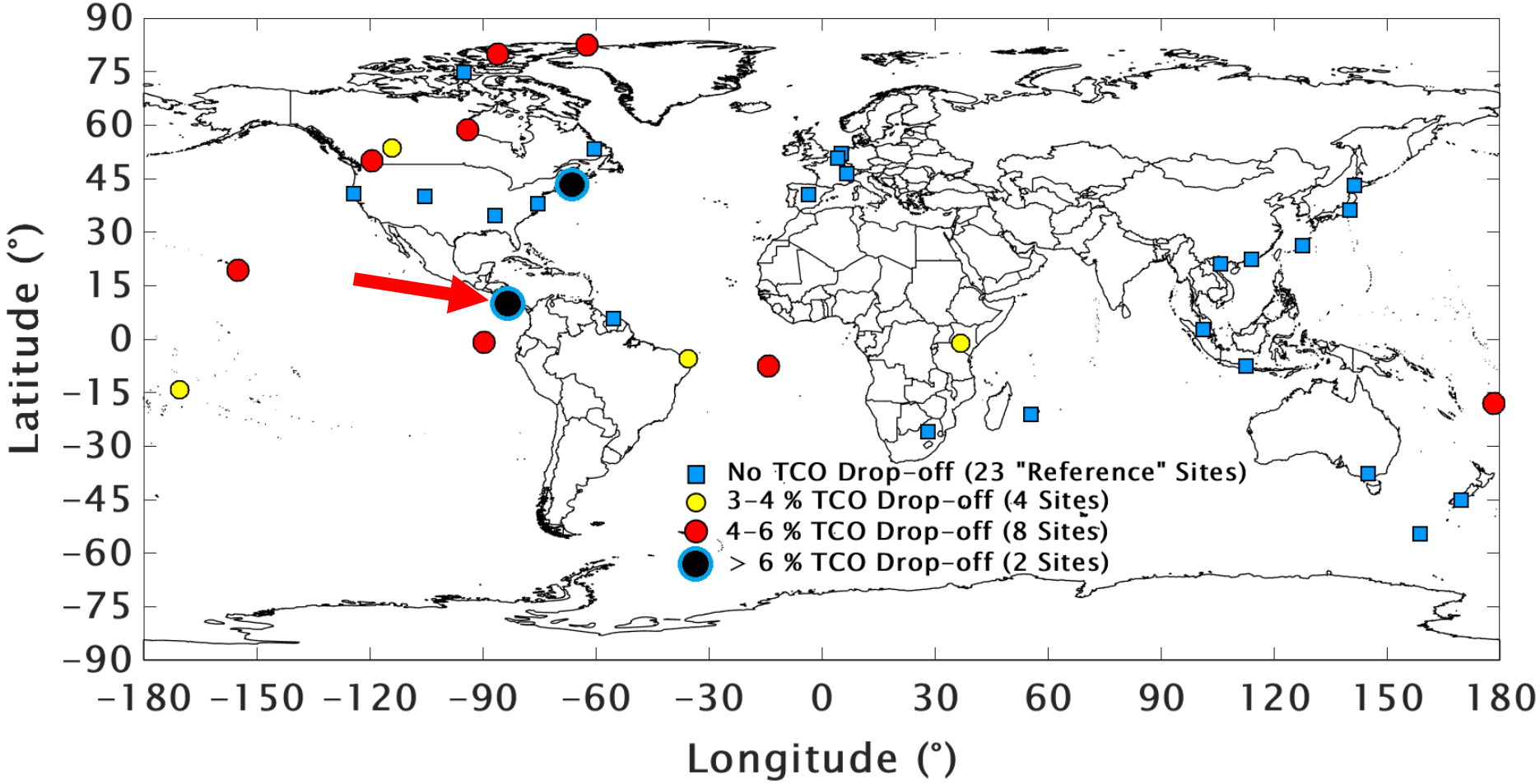
Comparisons with Aura MLS on MLS pressure levels. **Red** = sonde higher, **Blue** = sonde lower



Total O_3 comparisons with **OMI**, **OMPS**, and **GOME2A** and **2B** overpasses (and moving averages)

Global Ozonesonde "Dropoff" Problem

- The dropoff issue is not unique to Costa Rica. Over a dozen sites, which similarly use one of the two major ozonesonde manufacturers, are affected
- The largest low biases are found in the stratosphere and are 5-10% or more
- It is critical to be aware of this issue if using Ticosonde ozone to validate stratospheric satellite measurements

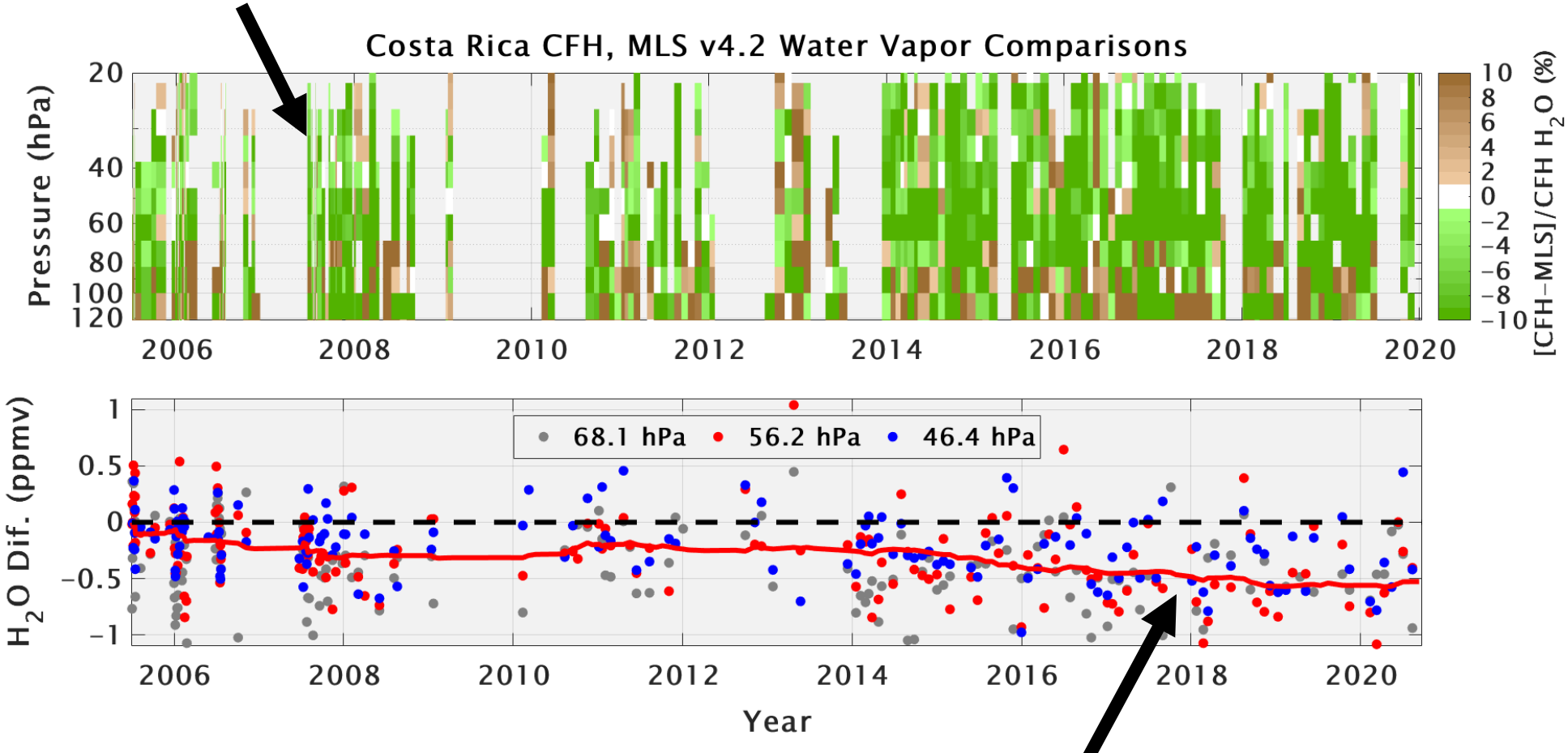


MLS H_2O Drift?

- A global survey of frost point sonde comparisons with the Aura MLS record (**Hurst et al., 2016**) showed a positive drift in MLS of ~1%/year

- The drift was less severe at Costa Rica than at mid-latitude sites…but is that changing?

Comparisons with Aura MLS on MLS pressure levels. **Green** = MLS higher, **Brown** = MLS lower



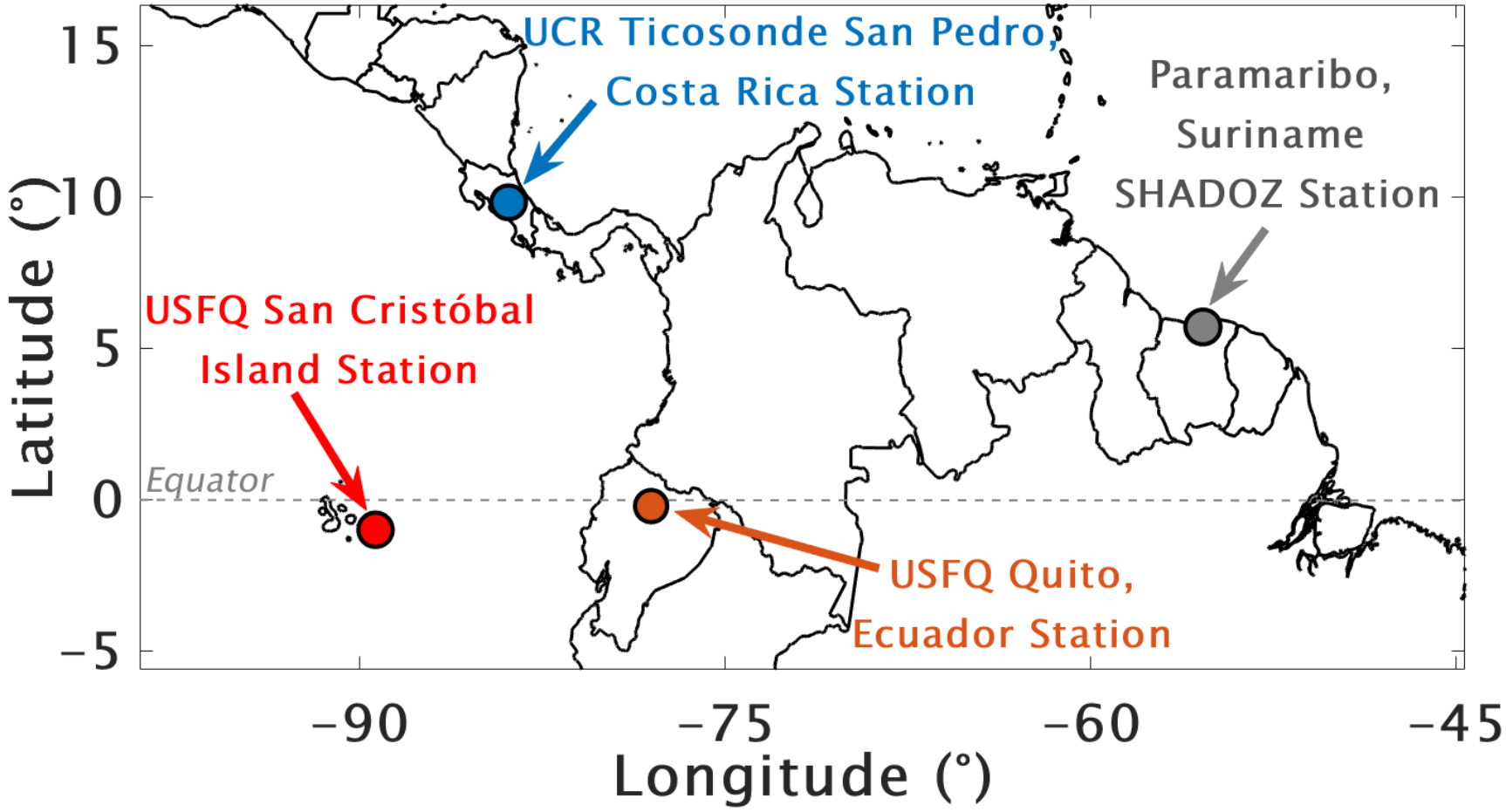
Moving average suggests that MLS wet bias may be increasing at the 56.2 hPa MLS pressure level

What's Next for Ticosonde?

- Proposal submitted to NASA ROSES UACO program for continued 2021-2024 water vapor and ozonesonde profiles

- Highlighting the Equatorial Americas, including the reactivation of the San Cristobal SHADOZ station (stoppage since 2016)

- Proposal PI/Co-I Team:
  - R. Stauffer (PI, NASA)
  - A. Thompson (Co-I, NASA)
  - A. Diaz (Co-I, UCR)
  - M. Cazorla (Co-I, USFQ)
  - H. Vömel (Co-I, NCAR)



Thanks!

Select References:

- Stauffer, R. M., et al. (2020), A post-2013 dropoff in total ozone at a third of global ozonesonde stations: Electrochemical concentration cell instrument artifacts? Geophysical Research Letters, 47, e2019GL086791. https://doi.org/10.1029/2019GL086791.
- Vömel, H., et al. (2020), A new method to correct the ECC ozone sonde time response and its implications for "background current" and pump efficiency, accepted for Atmos. Meas. Tech. (discussion: https://amt.copernicus.org/preprints/amt-2020-62/).
- Vömel, H., Naebert, T., Dirksen, R., and Sommer, M. (2016), An update on the uncertainties of water vapor measurements using cryogenic frost point hygrometers, Atmos. Meas. Tech., 9, 3755–3768, https://doi.org/10.5194/amt-9-3755-2016.

Data:

- SHADOZ Ozone: https://tropo.gsfc.nasa.gov/shadoz/CostaRica.html
- NDACC H_2O: ftp://ftp.cpc.ncep.noaa.gov/ndacc/station/costa_rica/ames/wvsonde/
- AVDC SO_2: https://avdc.gsfc.nasa.gov/pub/tmp/TICOSONDE_SO2_archive/data/

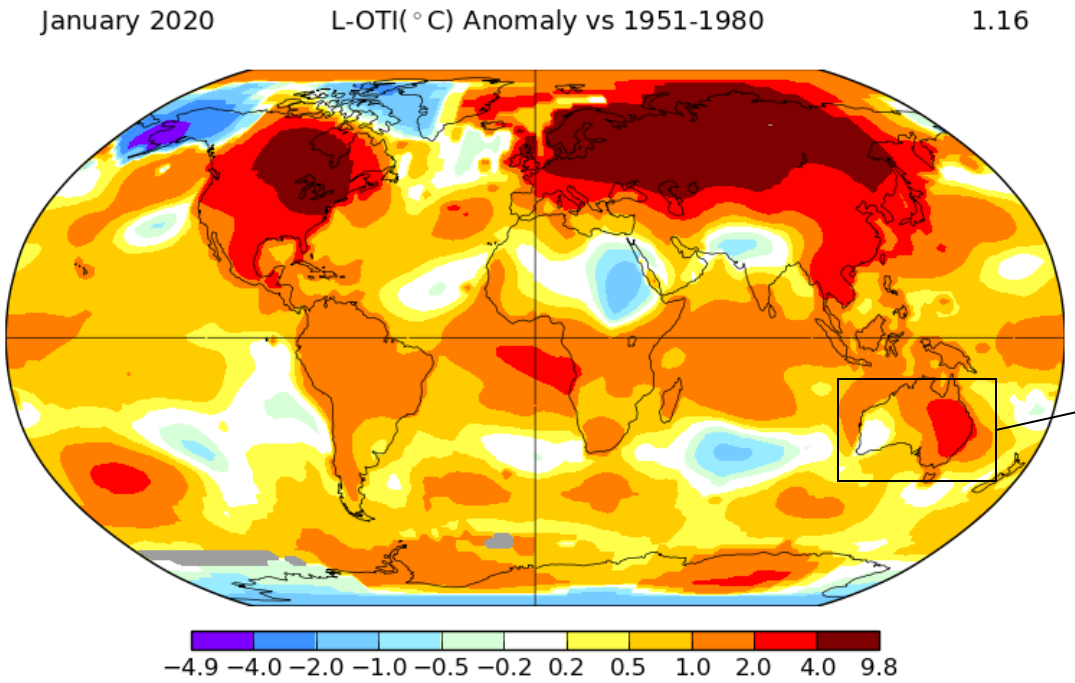


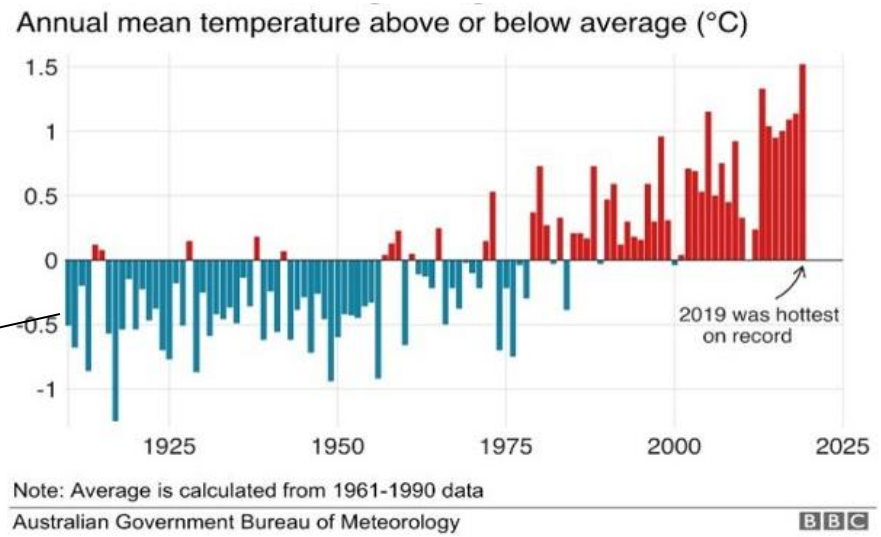
NATIONAL INSTITUTE OF AEROSPACE

The impacts of the 2019/2020 Australian Mega Fires on the stratosphere

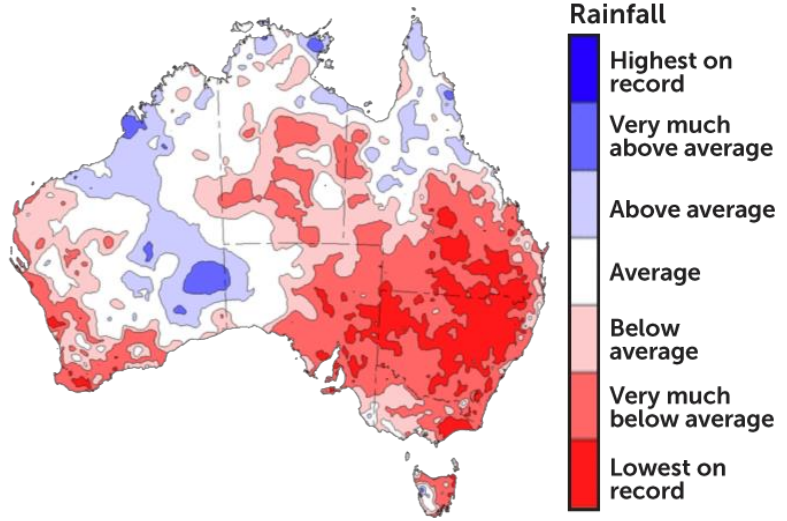
J.-P. Vernier; National Institute of Aerospace, NASA LaRC

Heat Waves and Long drought leading to the fires

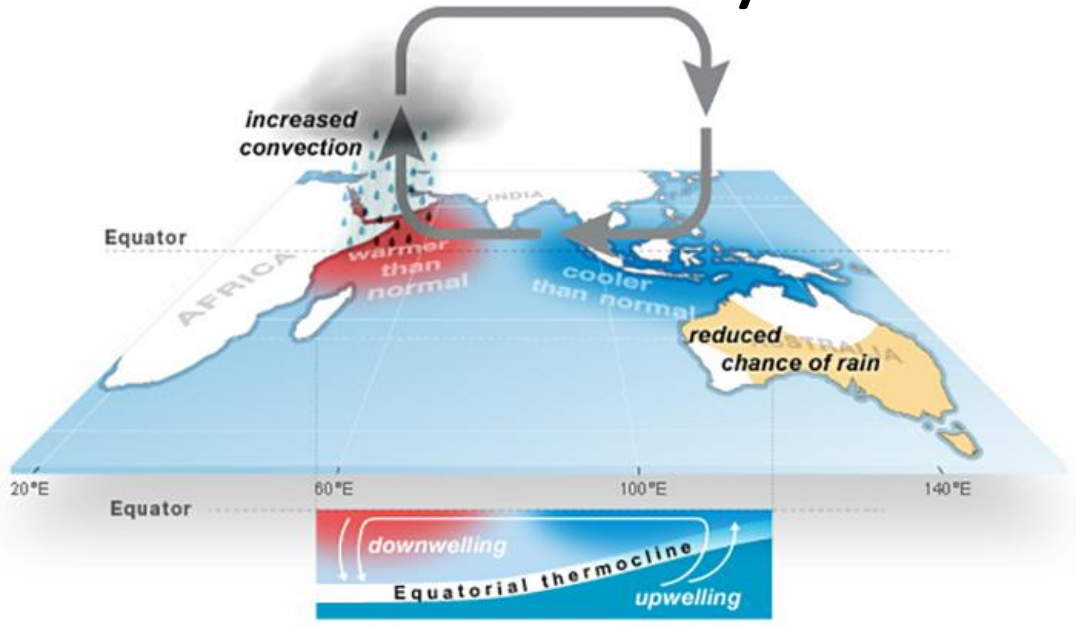




- ✓ Australia has been getting warmer (2019 hottest on record)
- ✓ Heat Waves are more severe; Canberra/Australia; 43°C 01/03/2020
- ✓ Drought exacerbated by heat and rainfall deficit for the past three years.

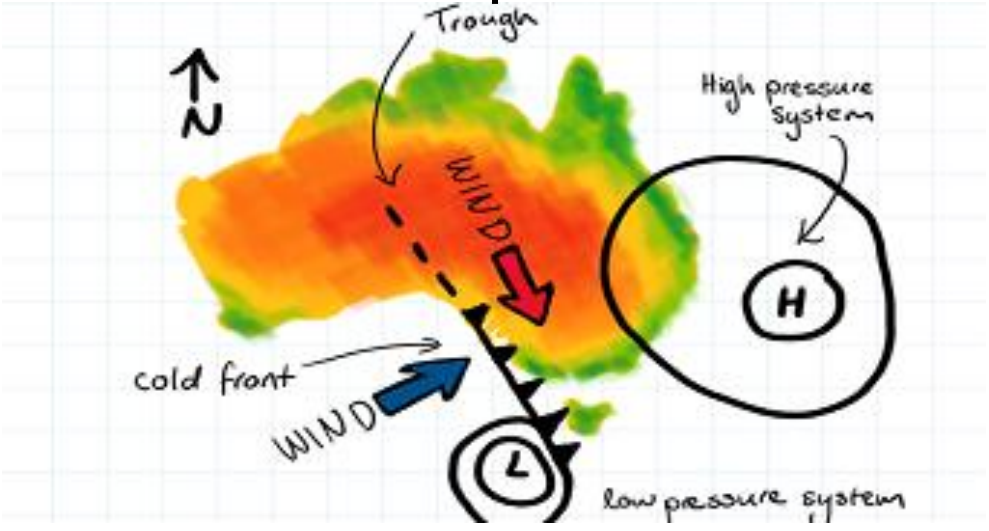


PyroCb development

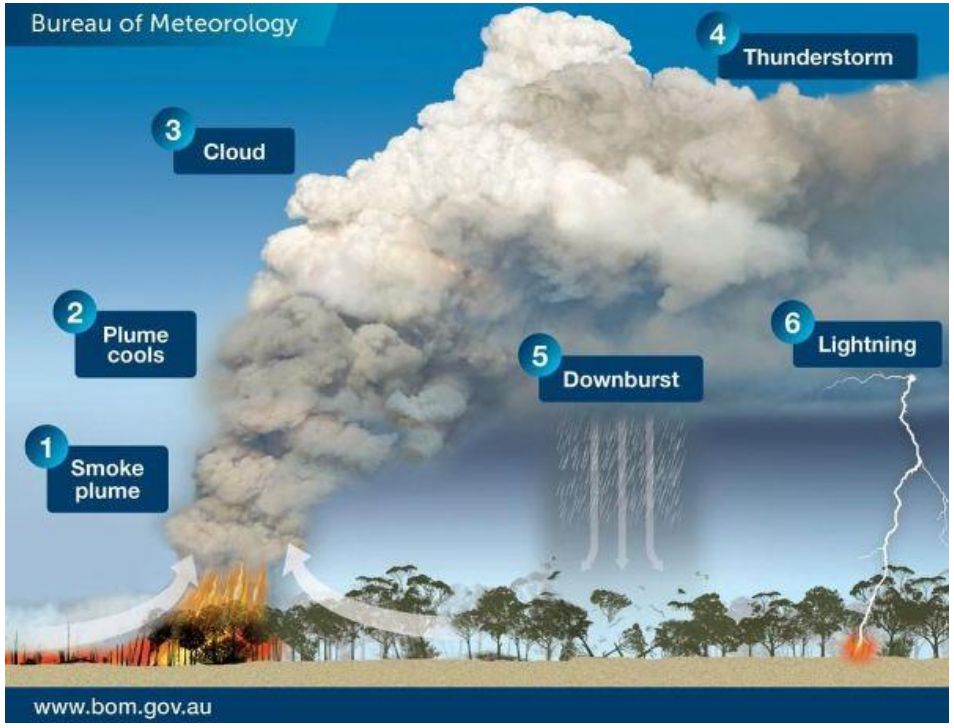


Indian Ocean Dipole (IOD): **Positive phase**

+



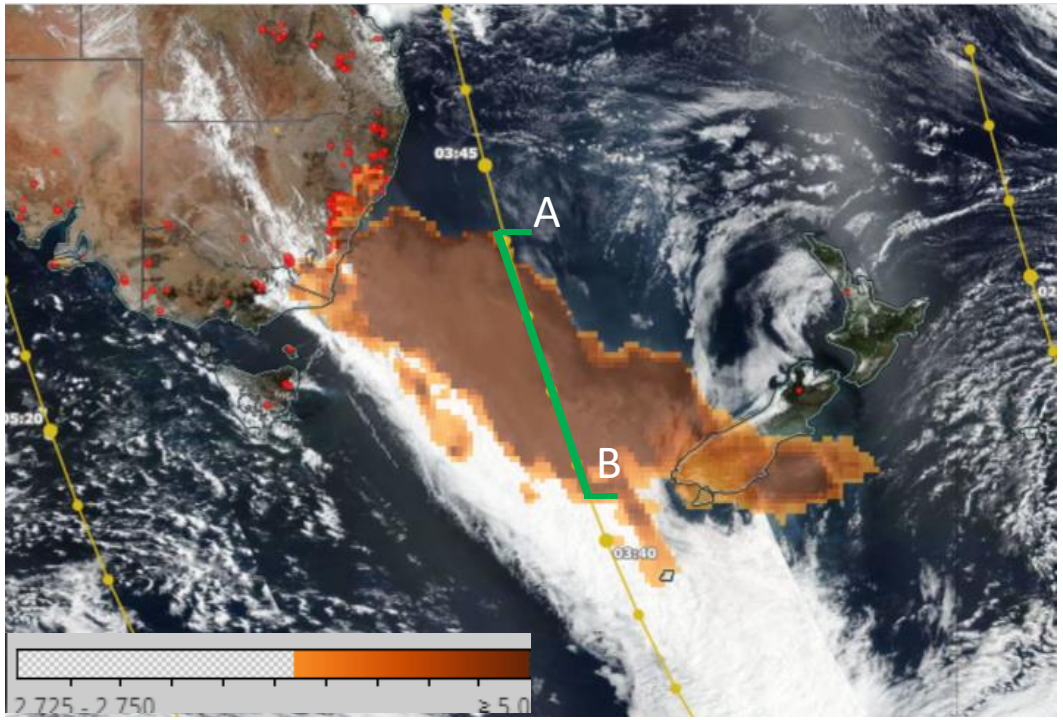
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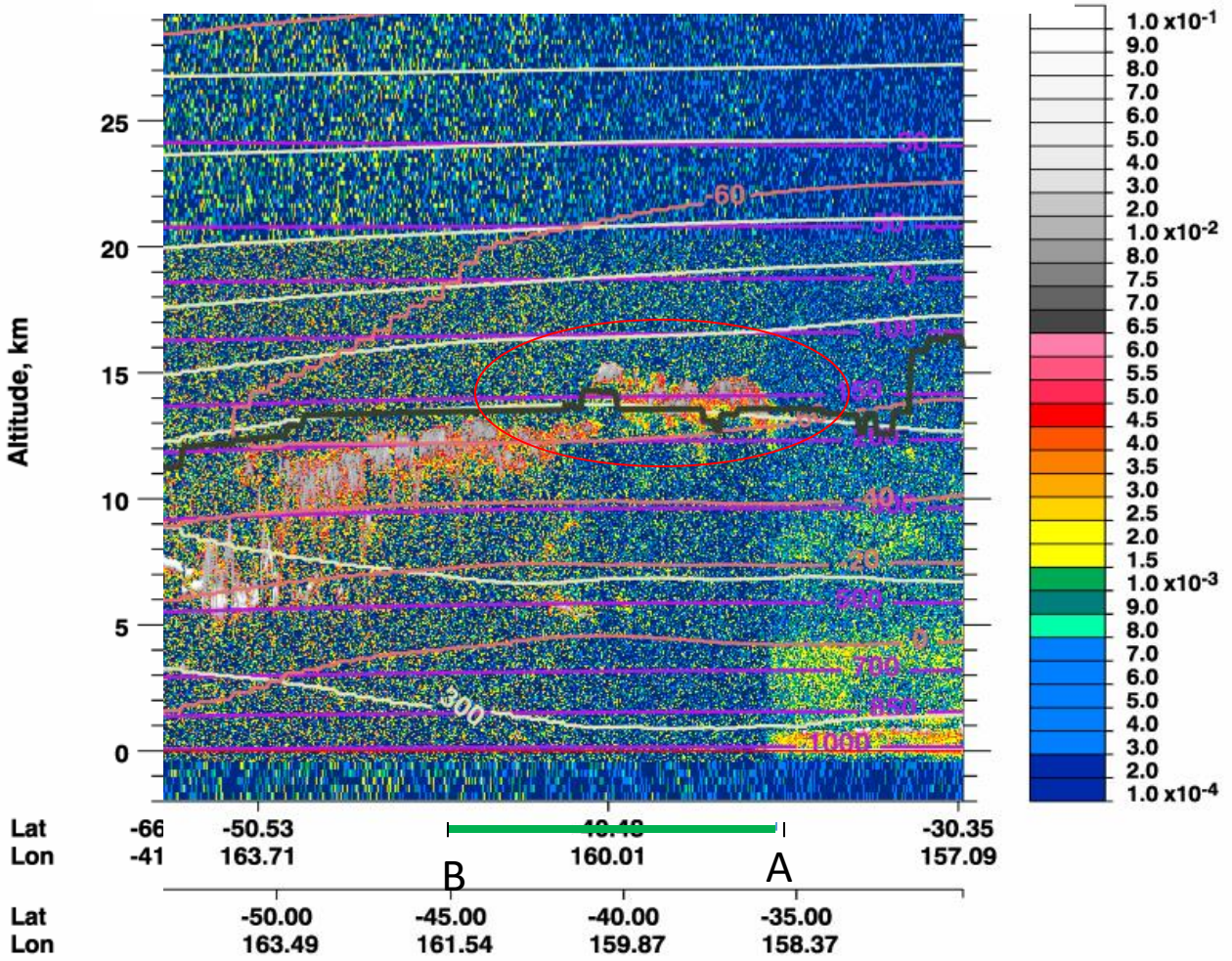
- ✓Indian Ocean Dipole also exacerbates droughts in SE Australia
- ✓Moving cold front with mid-level moisture can lead to PyroCb
- ✓ PyroCb transport smoke into the UTLS

First episode PyroCb activities
31 Dec 2019

OMPS Aerosol Index+VIIRS RGB 31 December 2019

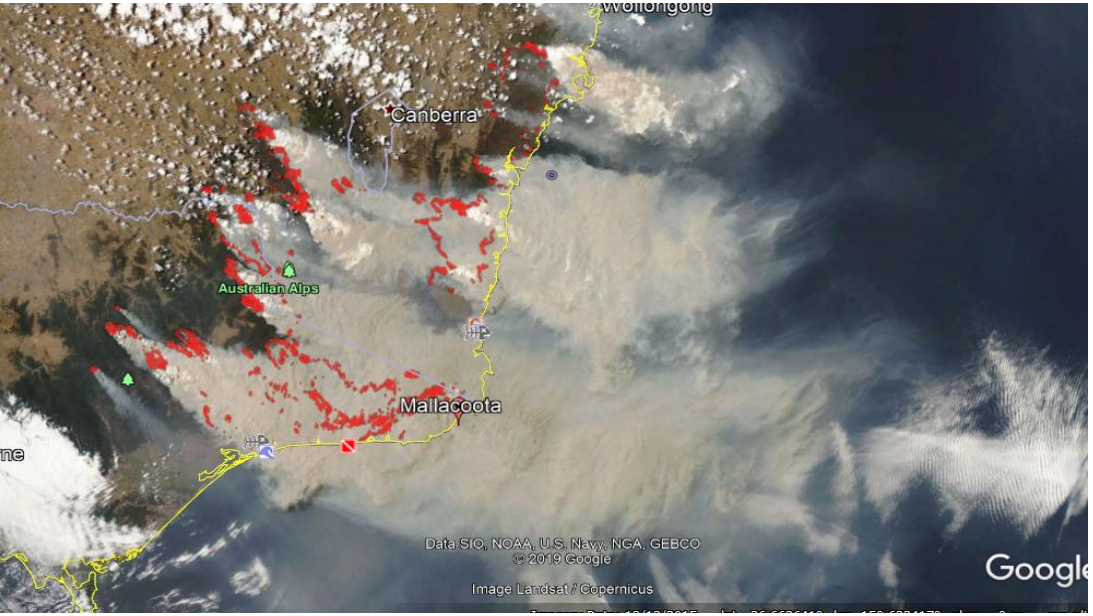


CALIOP/CALIPSO 31-12-2019 3:22



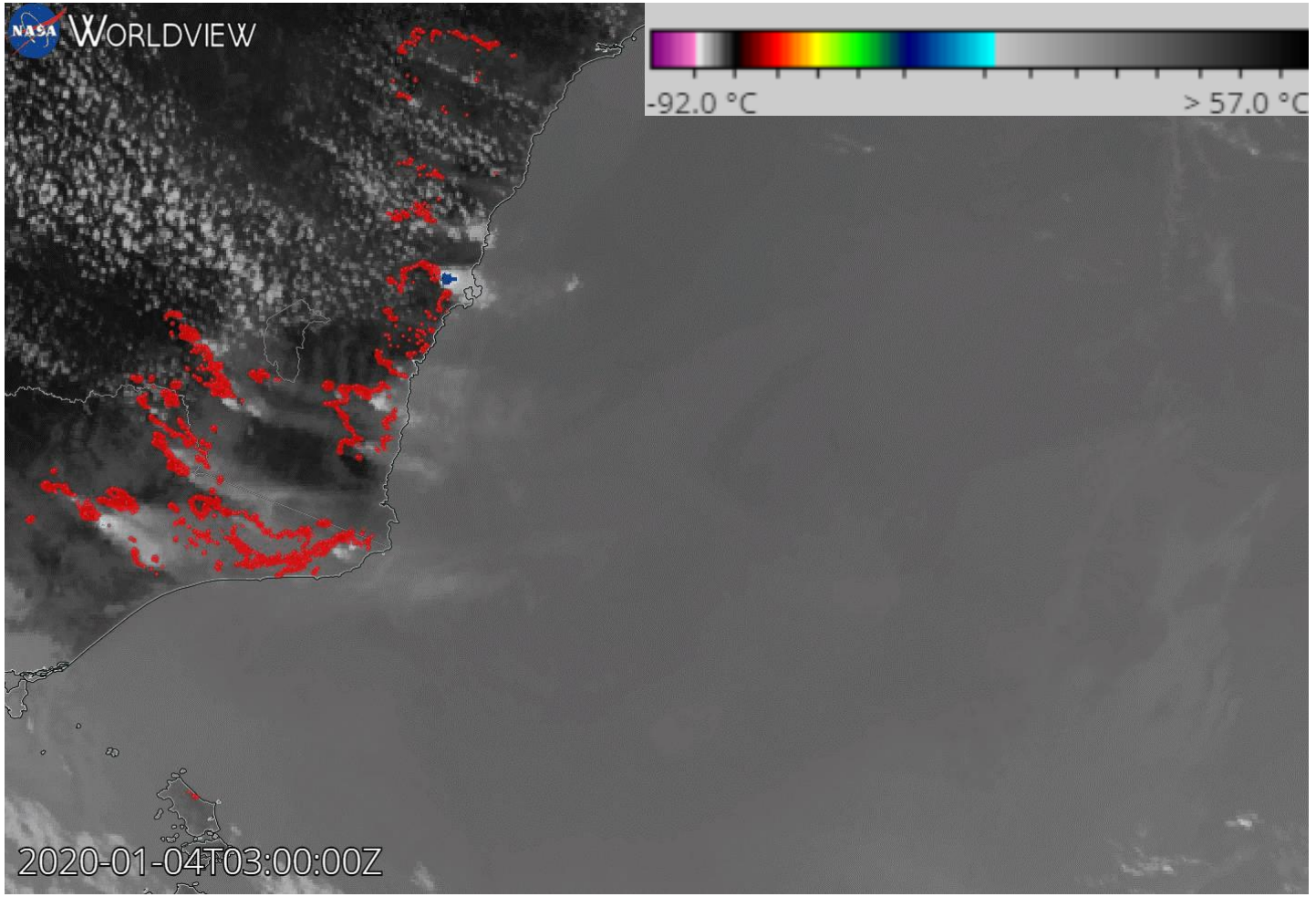
https://worldview.earthdata.nasa.gov/

Second Episode of PyroCb activities



MODIS/Aqua RGB image+ hot spots
January 4th, 2020

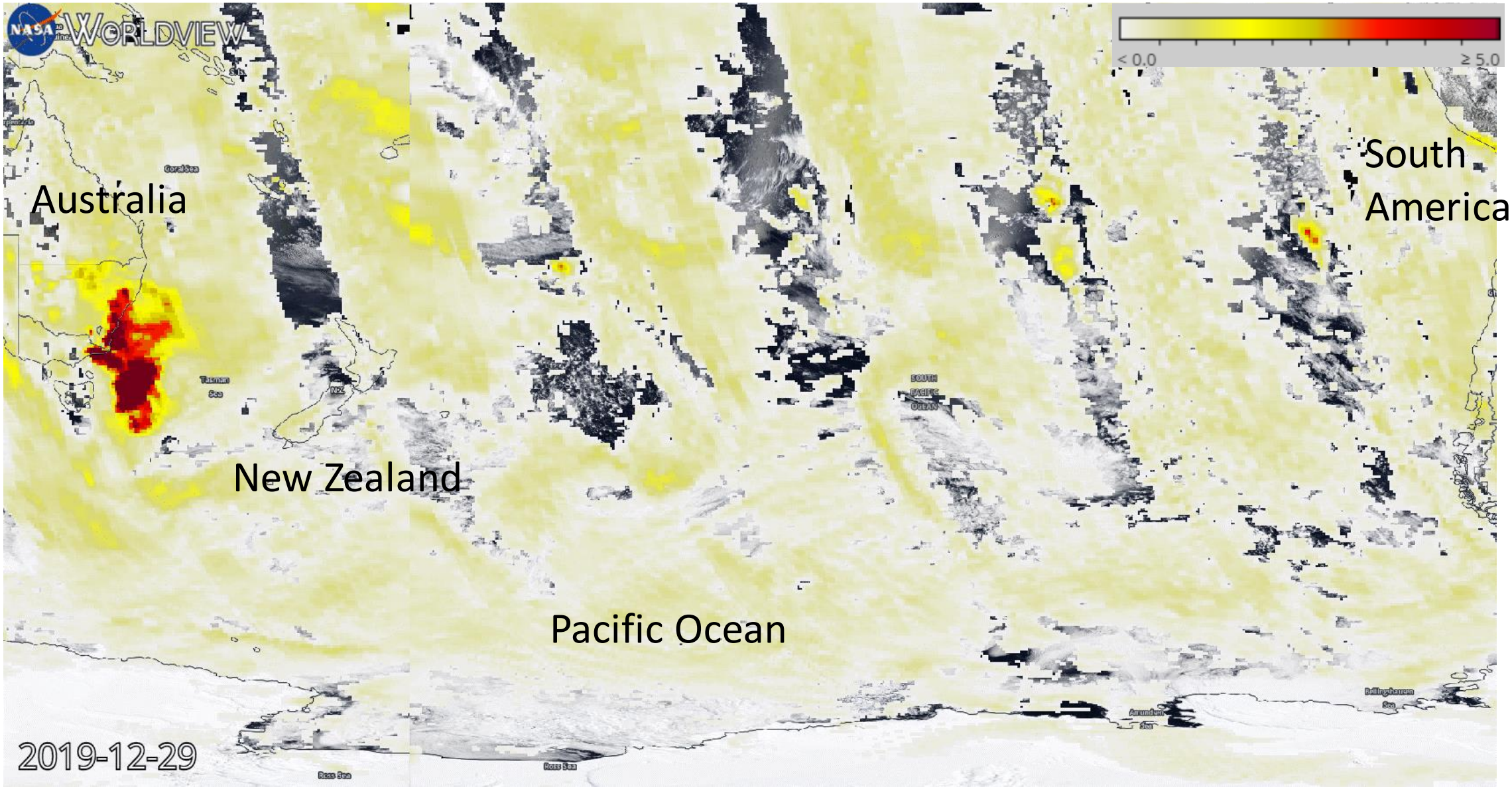
Minimum Cloud Top ~-70 °C (14-15 km]



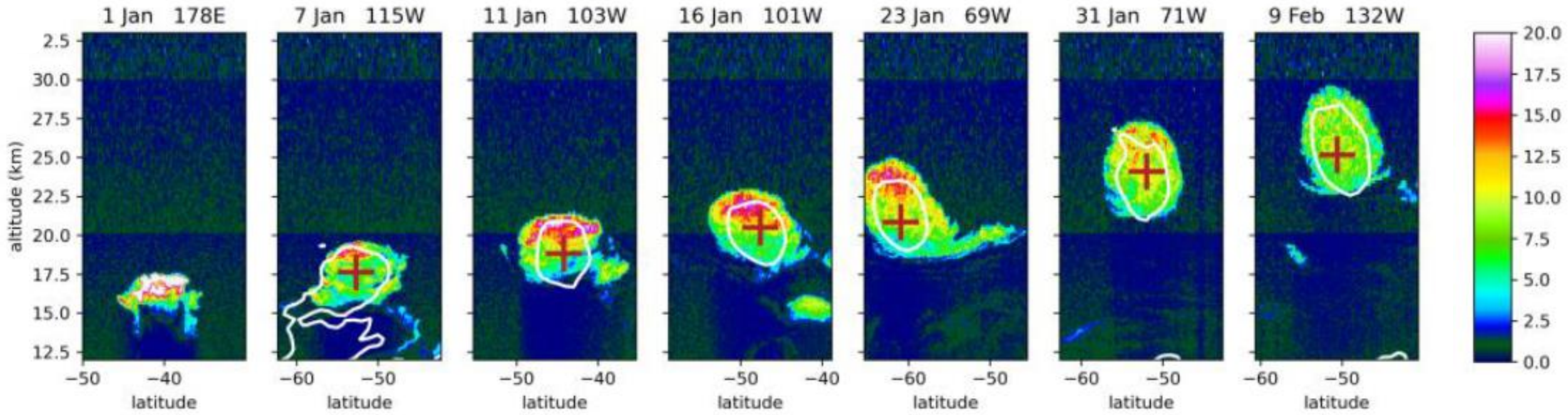
HIMAWARI-8 Cloud Top Temperature (10.3 micron)

https://disasters.nasa.gov/australia-fires-2020/satellites-provide-multiple-views-australia-fires-same-day

Early Transport of Smoke



Smoke rising into the stratosphere after the 2019/2020 Australian Bushfires

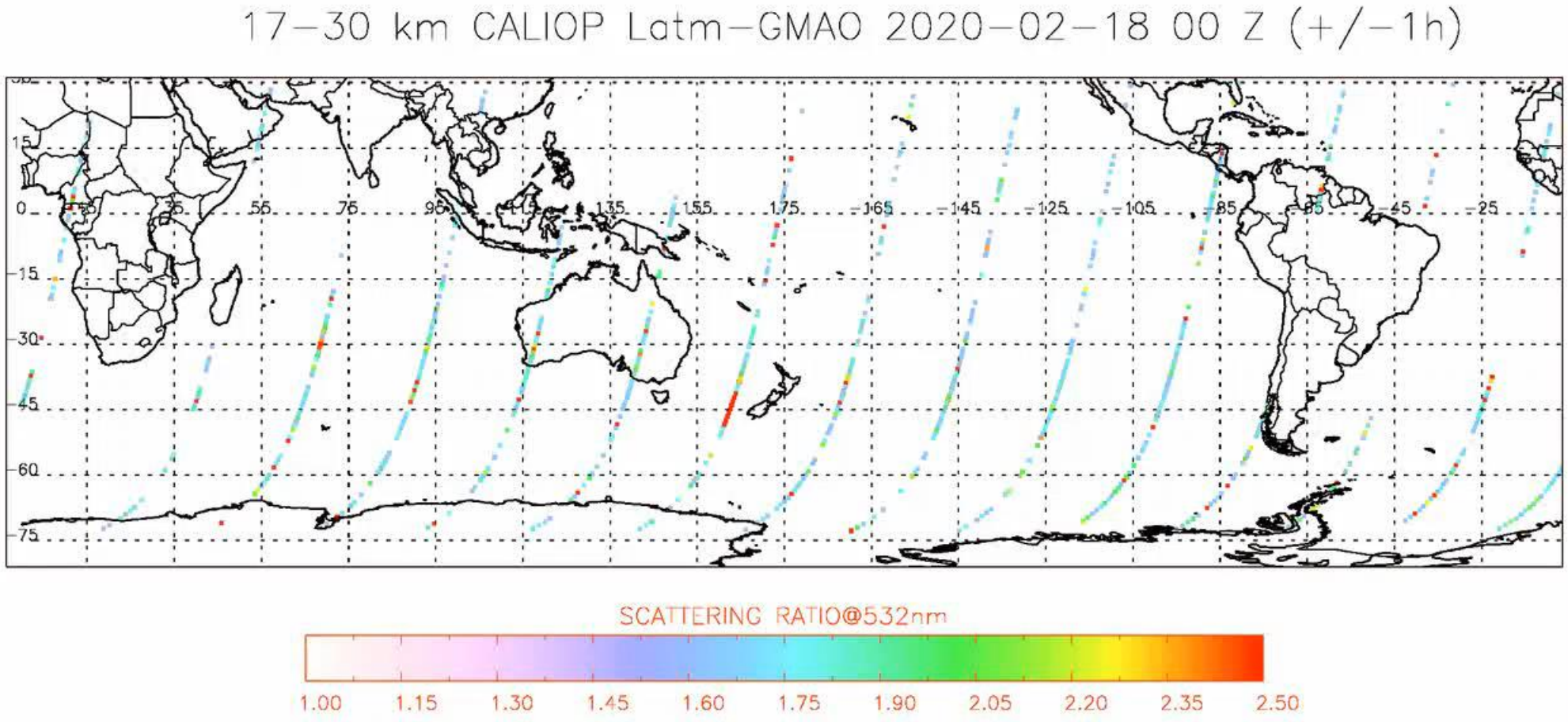


Khaykin et al., 2020

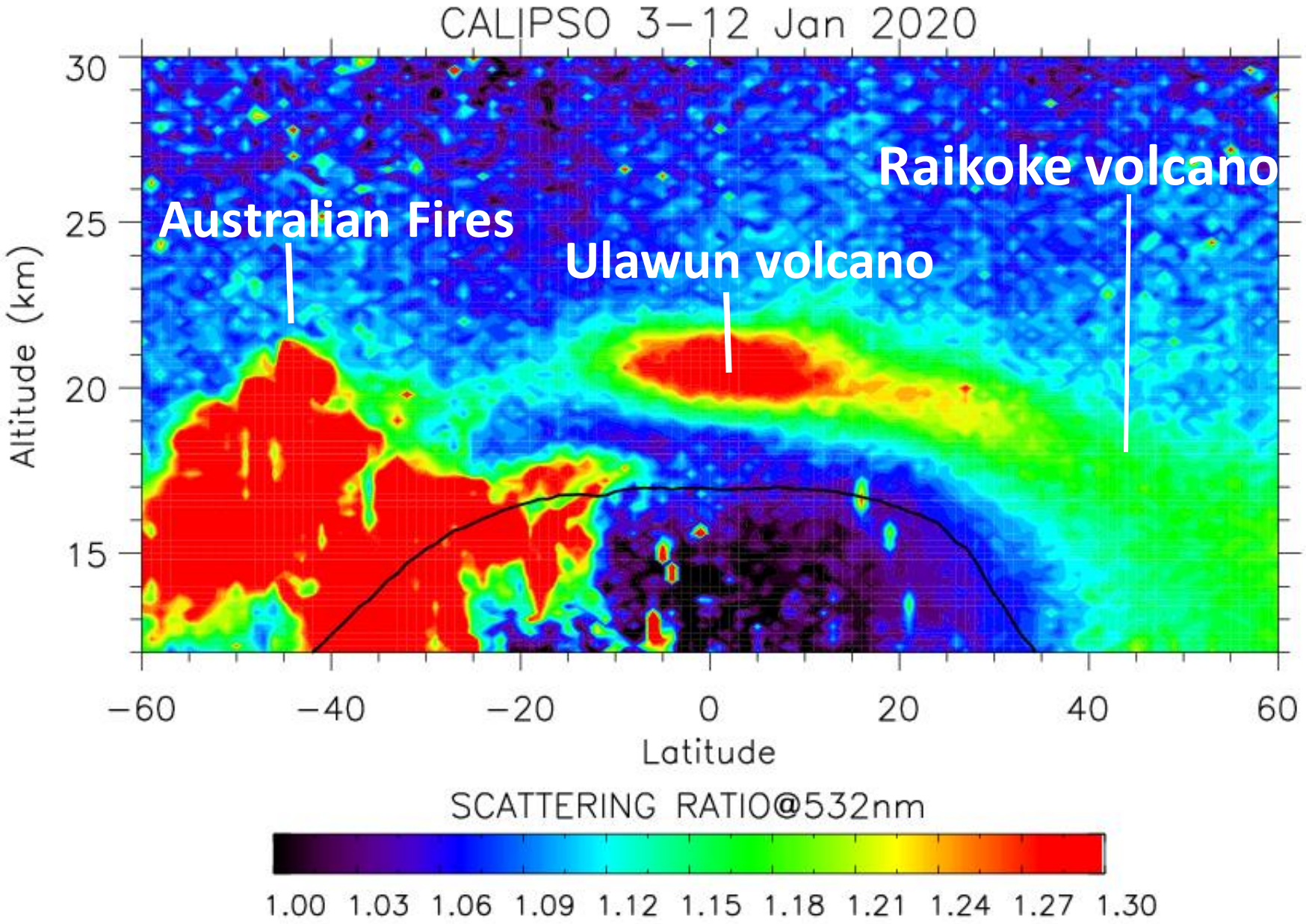
- ✓ 1000 km ellipsoid anticyclone
- ✓ Ascent rate 0.45 km/month and 0.2 km/month

A self-sustained smoky anticyclone

Trajectory mapping of CALIOP 18-23 Feb 2020

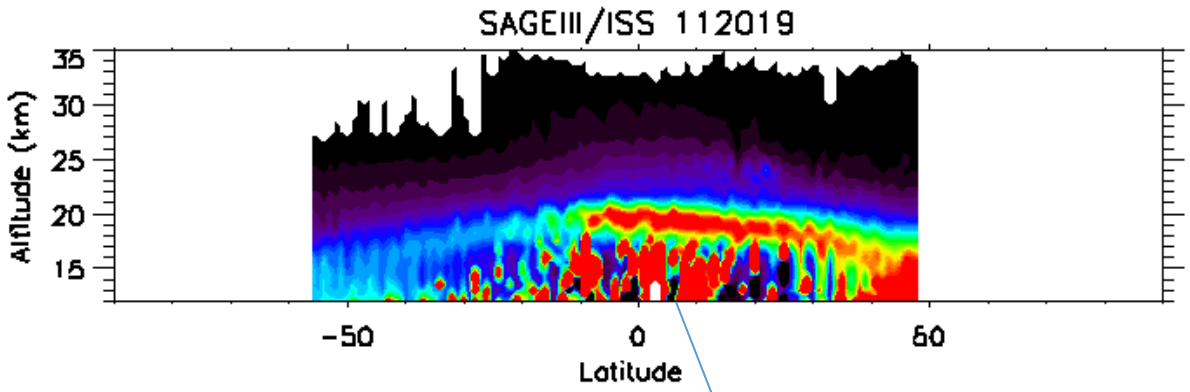


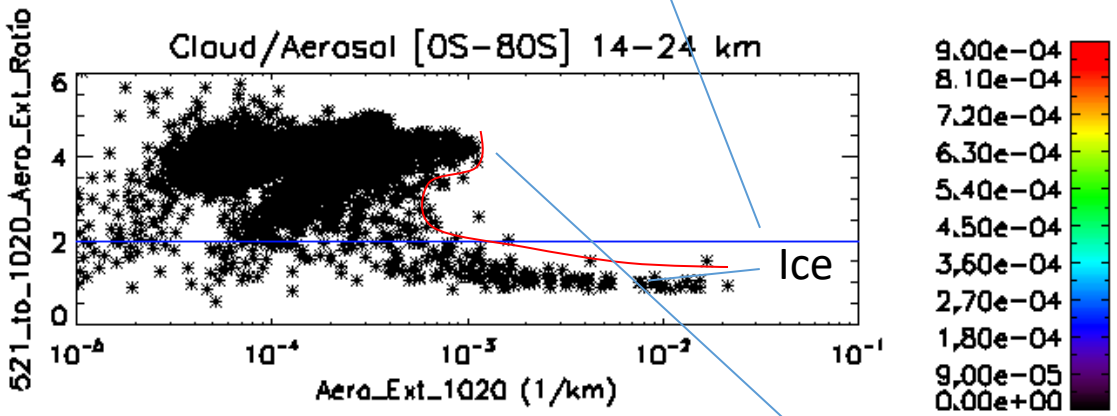
The Complexity of Stratosphere Aerosols

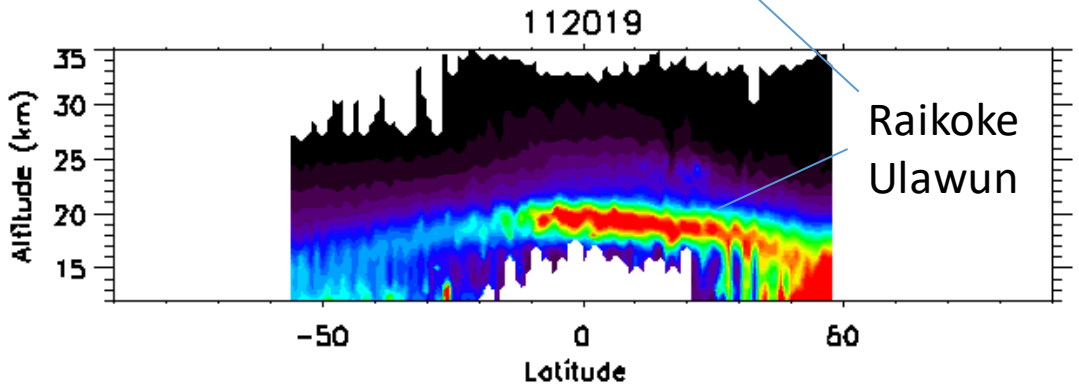


SAGE III/ISS Smoke detection/cloud filtering

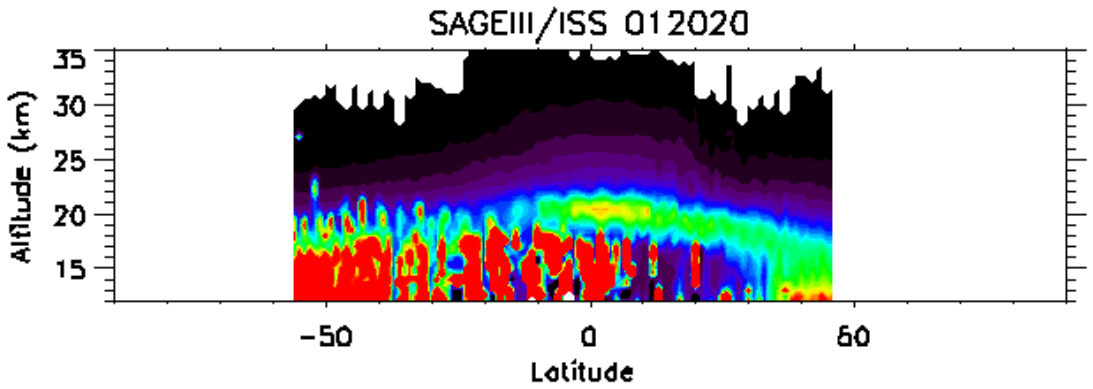
BEFORE

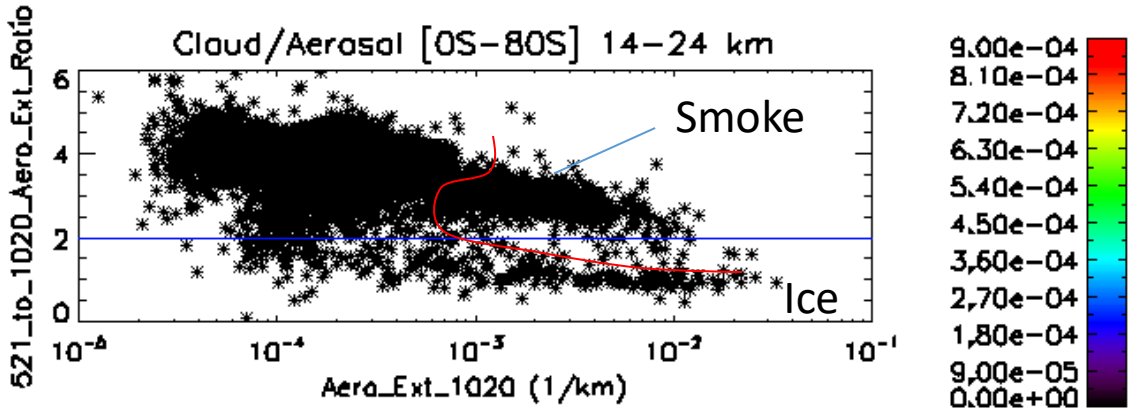


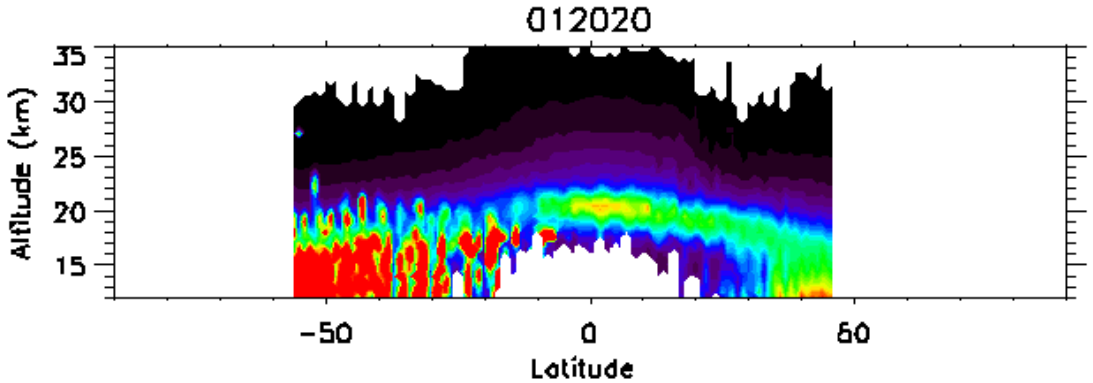




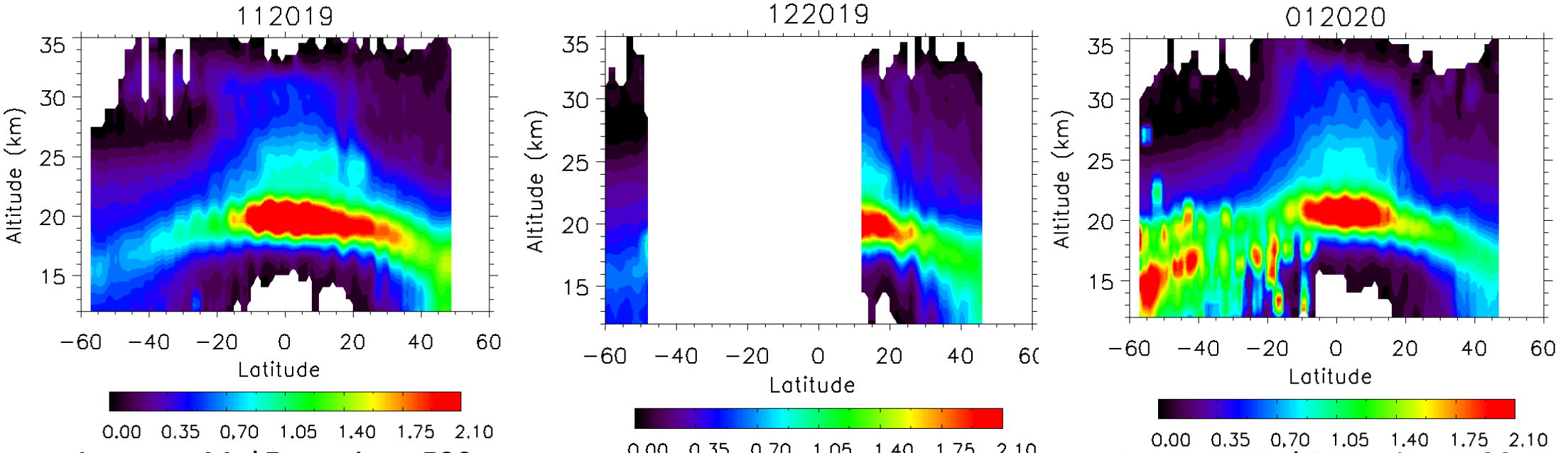
AFTER

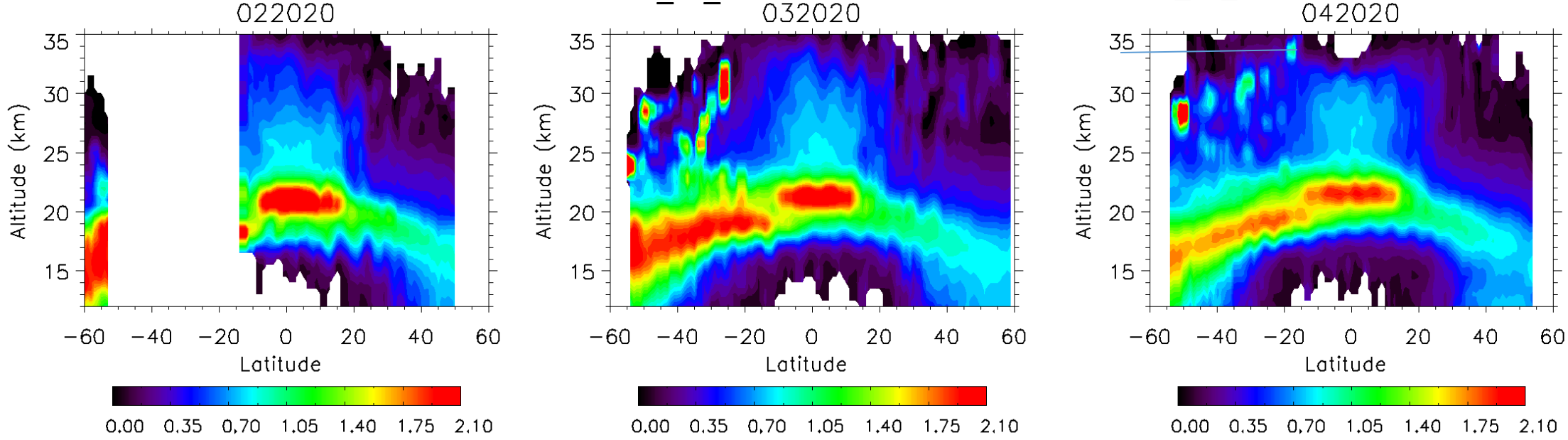




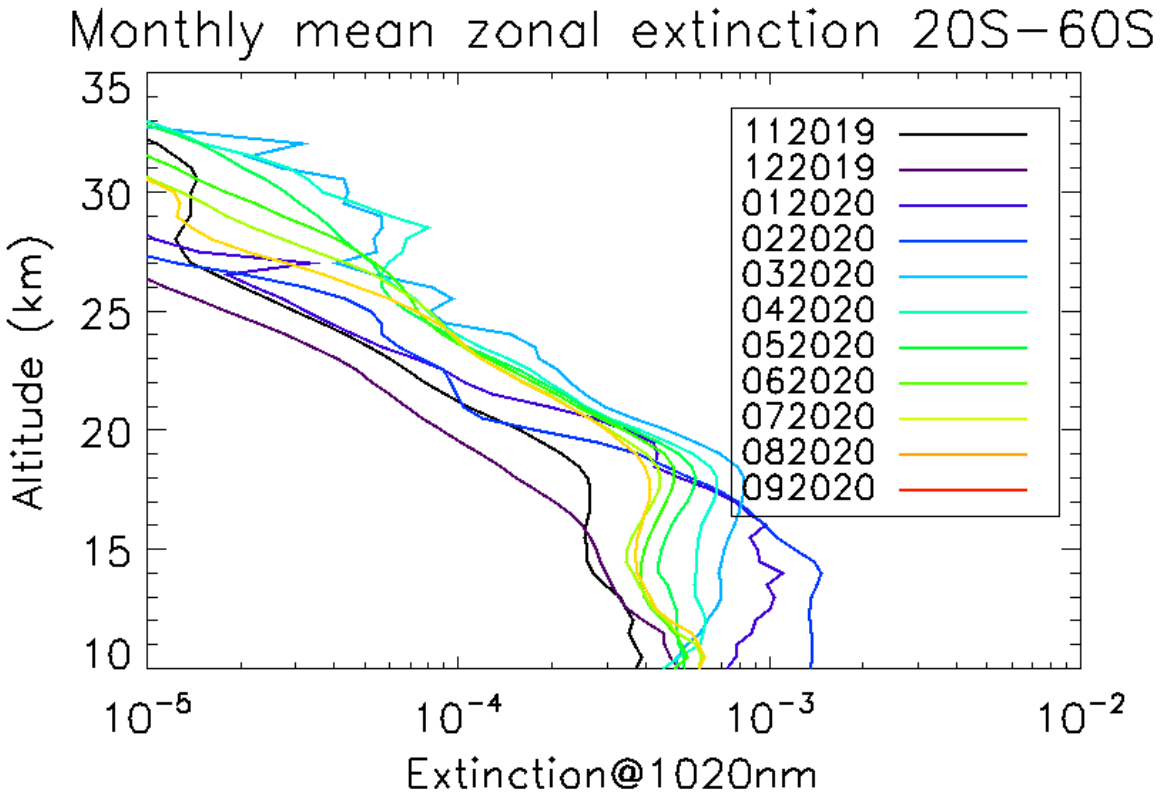


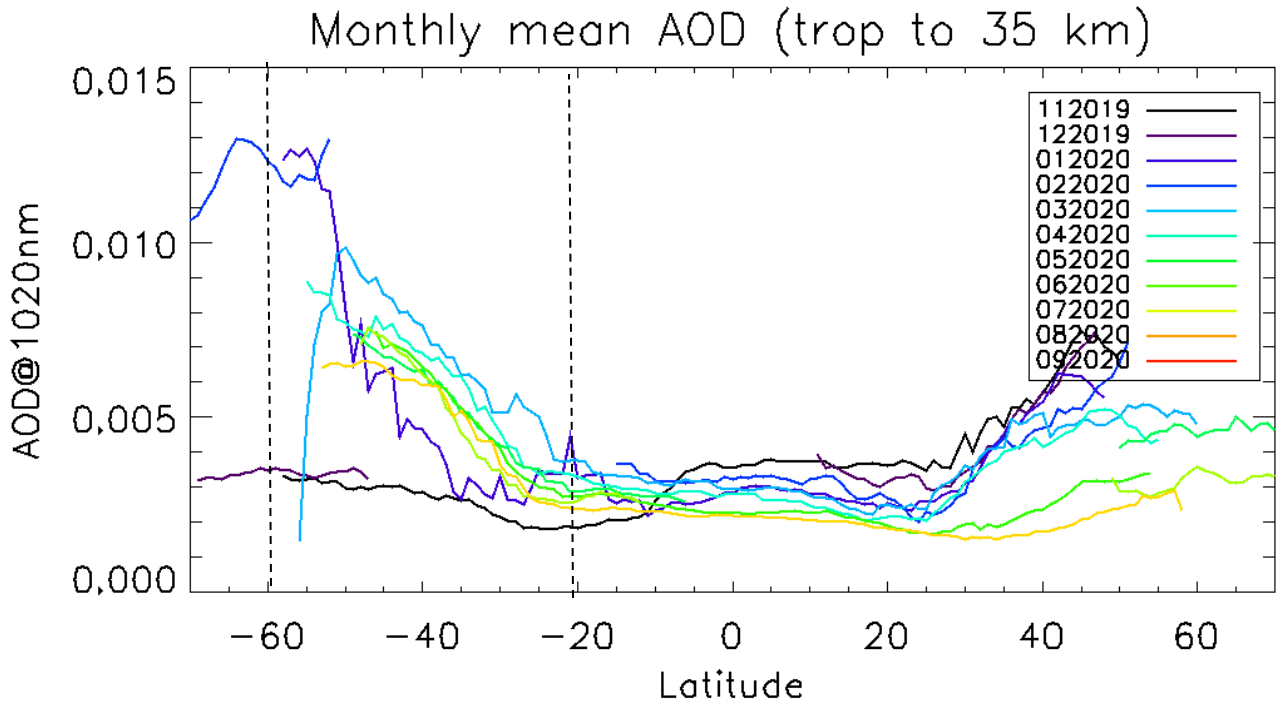
Smoke Evolution seen by SAGE III





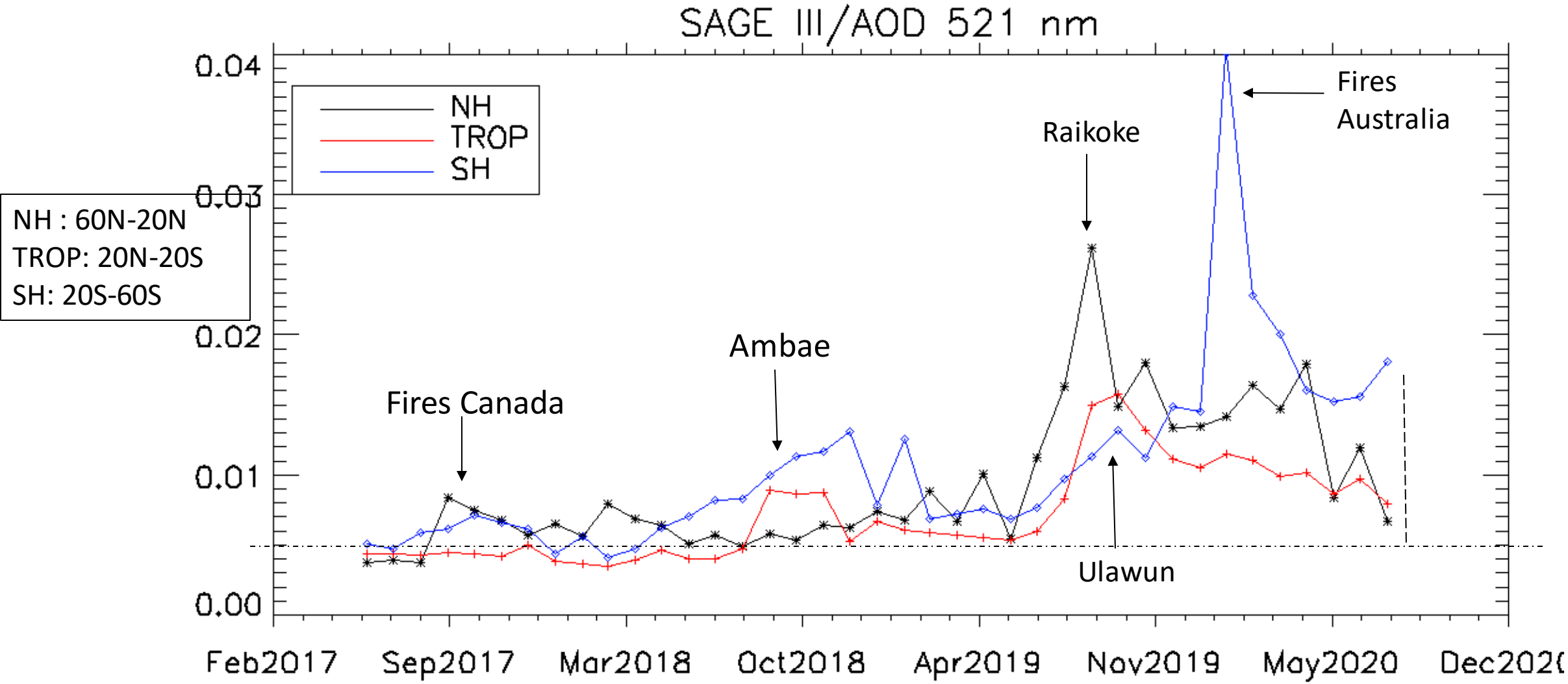
Impacts on the stratospheric aerosol layer





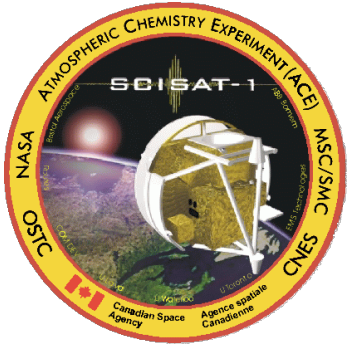
- ✓ Perturbation of the stratosphere up to 34 km (Never seen since Mt Pinatubo)
- ✓ Lon-lasting impact on stratospheric AOD (still two times higher than before the event)

Largest stratospheric aerosol perturbation on the SAGE III/ISS



Conclusion

- ✓ 2019/2020 was the worst fire season in Australian History
- ✓ Intense PyroCb activities led to smoke initial injection in the UTLS
- ✓ Diabatic heating resulted in the transport of smoke in the upper stratosphere (34 km)
- ✓ Largest AOD observed in the SAGE III record
- ✓ Increasing contribution from Mega Fires to stratospheric composition



Update on ACE: Mission Status and Recent Validation Results

Kaley A. Walker[1], Patrick E. Sheese[1], Jiansheng Zou[1], Chris D. Boone[2]

[1]Department of Physics, University of Toronto, Toronto, Canada
[2]Department of Chemistry, University of Waterloo, Waterloo, Canada

SAGE III/ISS Science Team Meeting – Online – 19 October 2020



SCISAT/ACE Mission Status

- Now into 18th year in orbit – designed for 2 year lifetime
  - Starting to see some degradation in ACE-FTS performance and ACE-MAESTRO continues to "age gracefully"

- Since launch, satellite and instrument operations nominal
  - Routine operations began on 21 February 2004
  - ~50% of occultations occur in polar regions (> 60 degrees)

- Operation of SCISAT has been approved until end of March 2021
  - Mission level review by CSA for 3-year extension is underway now



ACE Data Products

- ACE-FTS profiles (new version 4.1; validated version 3.5/3.6; previous v2.2+updates):
  - Tracers: H_2O, O_3, N_2O, NO, NO_2, HNO_3, N_2O_5, H_2O_2, HO_2NO_2, N_2, SO_2
  - Halogen-containing gases: HCl, HF, $ClONO_2$, CFC-11, CFC-12, CFC-113, COF_2, $COCl_2$, COFCl, ClO, CF_4, SF_6, CH_3Cl, CCl_4, HCFC-22, HCFC-141b, HCFC-142b, HFC134a, HFC-23
  - Carbon-containing gases: CO, CH_4, CH_3OH, H_2CO, HCOOH, C_2H_2, C_2H_4, C_2H_6, OCS, HCN acetone, CH_3CN, peroxyacetyl nitrate (PAN), CO_2 (5-18 km and >60 km), pressure / temperature from CO_2 lines
  - Isotopologues: Minor species of H_2O, CO_2, O_3, N_2O CO, CH_4, OCS, NO_2, HNO_3
- MAESTRO profiles (current version 3.13; validated version 1.2):
  - O_3, NO_2, optical depth, aerosol and water vapor (v31)
- IMAGERS profiles (current version 4.1; validated versions 3.5 and 2.2):
  - Atmospheric extinction & aerosol extinction at 0.5 and 1.02 microns

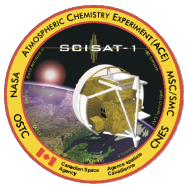
Comparison of ACE-FTS v4.1 to other data sets

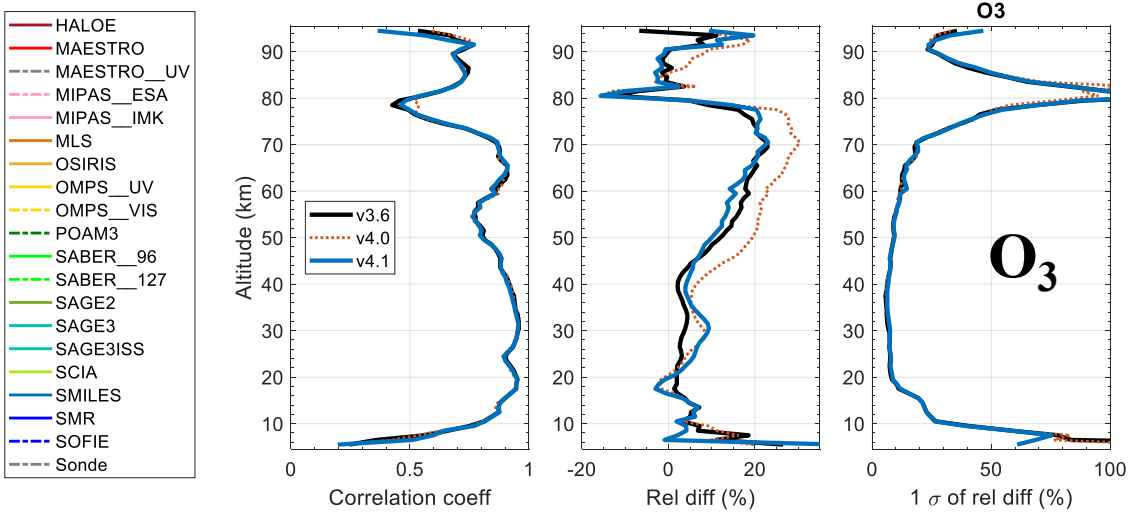
Methodology for difference calculations in satellite instrument comparison:

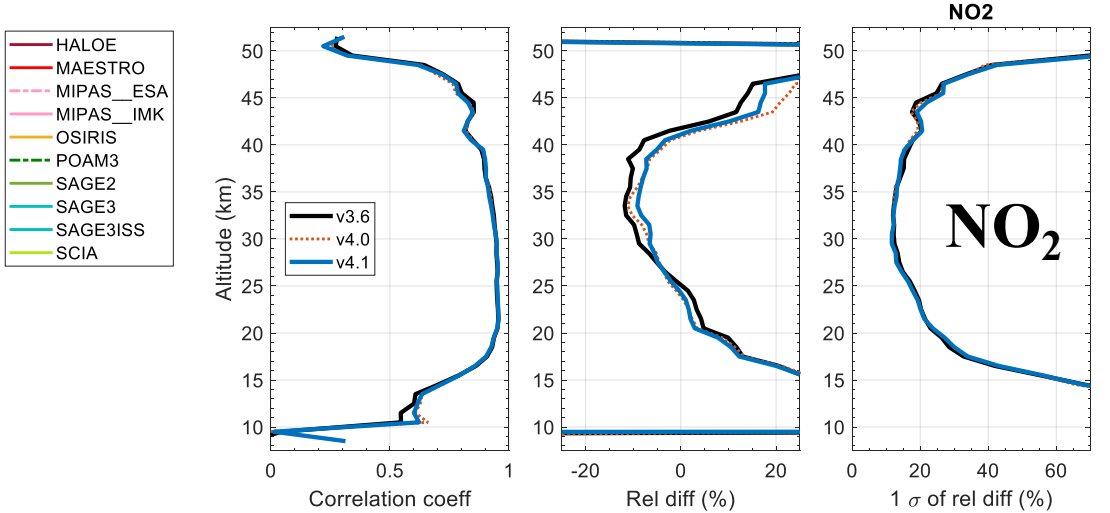
- ACE – INST for versions 3.6, 4.0, and 4.1 (used same occultations between versions)
- INST – One of suite of limb viewing remote sensing instruments used (UV, VIS, IR, MW)
  - Coincidence criteria used: ±5h, 500 km
  - All comparisons are global for plots shown
- Relative differences calculated with respect to mean of two measurements
- Mean and 1-σ of relative differences shown along with correlation coefficient

Selection of 74 species/isotopologues measured by ACE-FTS shown:

- O_3, NO_2, H_2O, T, HCl, and HNO_3 will be shown
- Looked at species measured by more than one other limb sounder

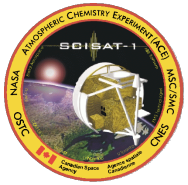


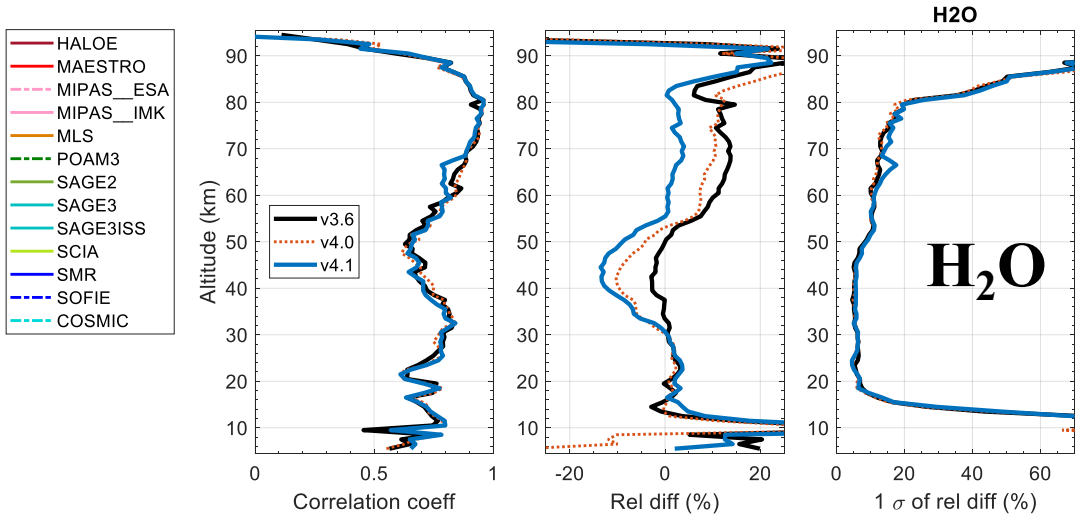


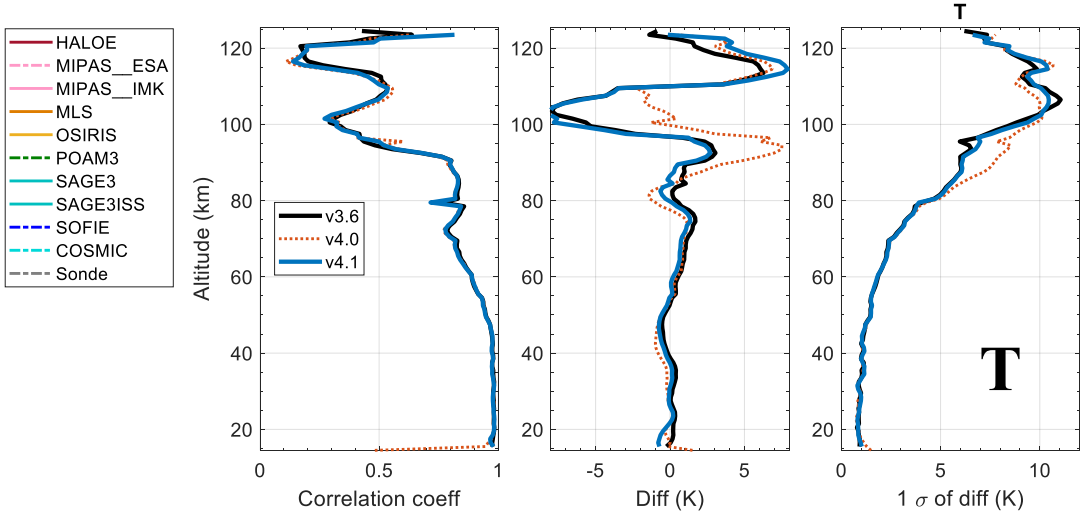


Note, these have not been scaled diurnally for comparison.

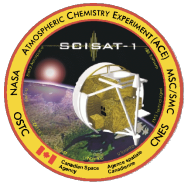
Patrick Sheese

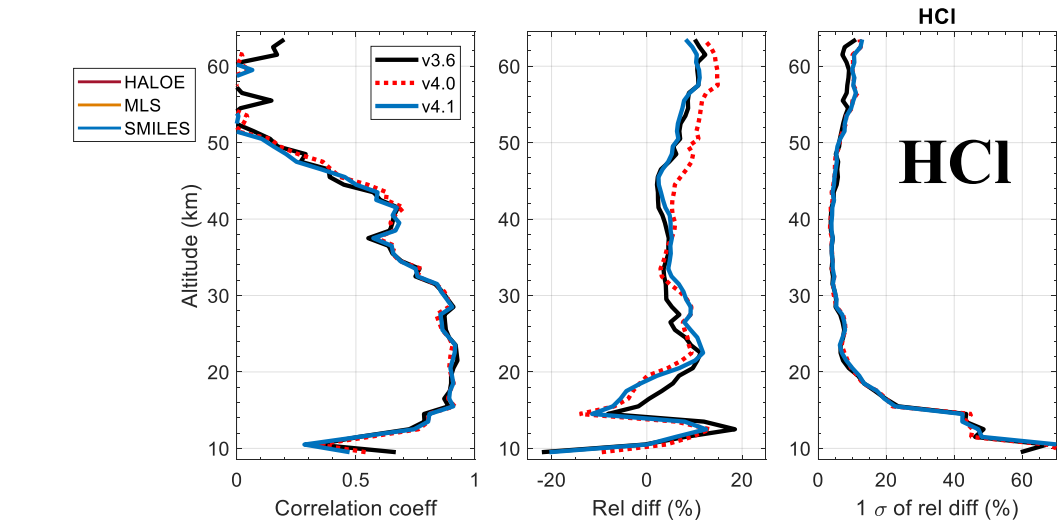


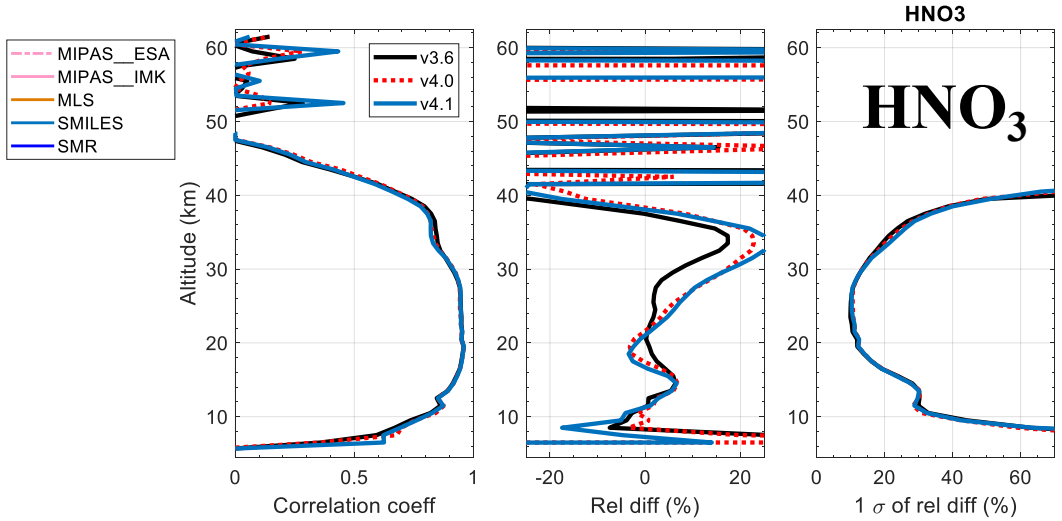




Patrick Sheese



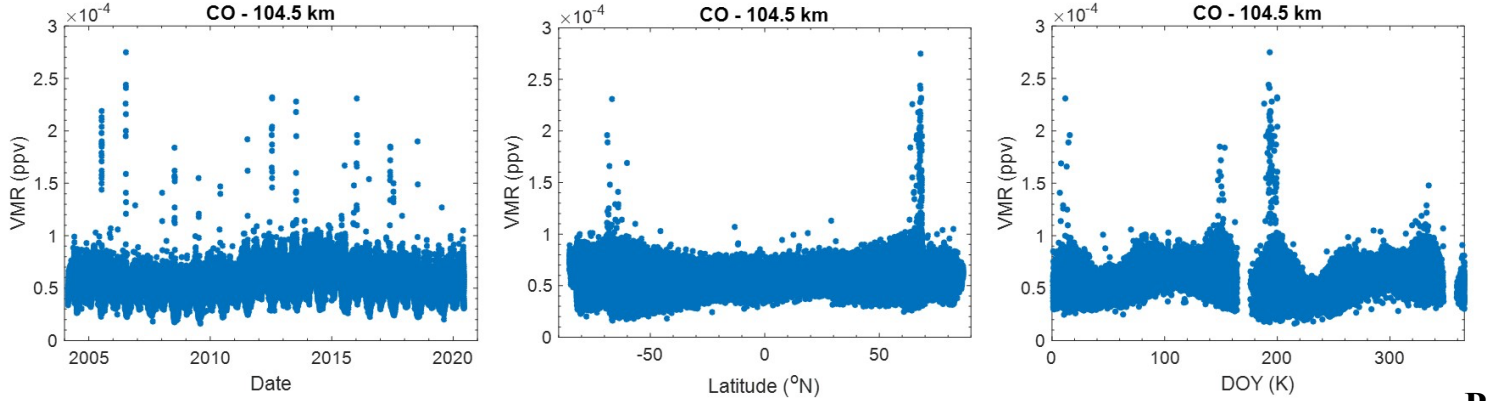




Patrick Sheese

Version 4.1 data issues at high altitudes

- Issue in MLT polar summer, more so in NH (not seen for these in previous versions)
- CO has enhancements in lower thermosphere ~95-110 km
  - Similar issue also seen in H_2O and O_3 near 95 km
  - T has cold spikes around mesopause
- Related to using temperature sensitive CO_2 lines for this altitude region, become too weak at very low temperatures – will be fixed in v5.0



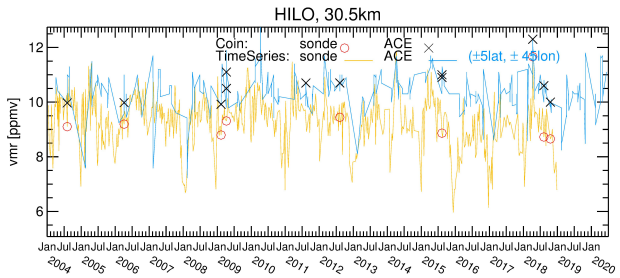
Patrick Sheese

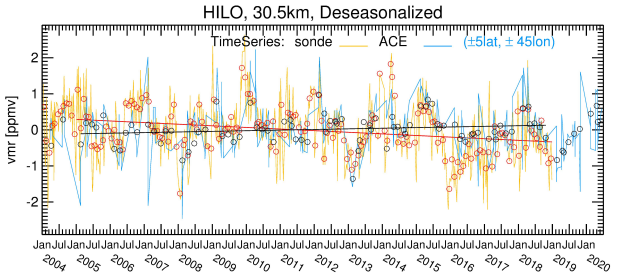
Validation comparisons for ACE-FTS v4.1

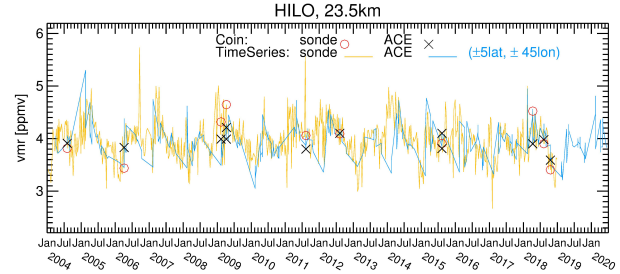
- Overall impression: biases have mostly improved over v4.0
  - The only region where v4.1 is significantly worse than both v3.6 and v4.0 is H_2O in upper stratosphere (but mesospheric H_2O greatly improved)
- Drifts seen in v3.5/3.6 are no longer present in v4
  - For trend analysis, ACE-FTS v4.1 should be used

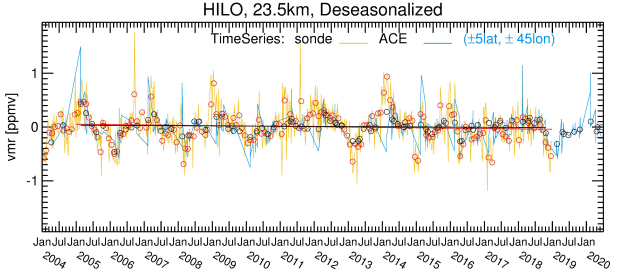
Comparison of v4.1 ACE-FTS with ozonesondes

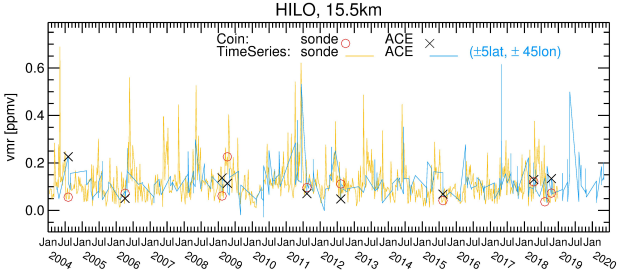
- Comparison of biases and linear trends in ozone
- Coincident pairs found for each station
- ±5 degree latitude range with wide longitude ranges
- Deseasonalized monthly means used for analysis
- Hilo example (19.7 N)

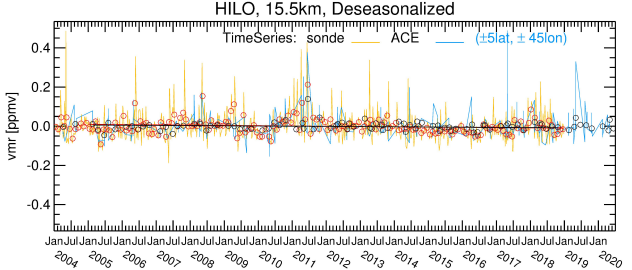








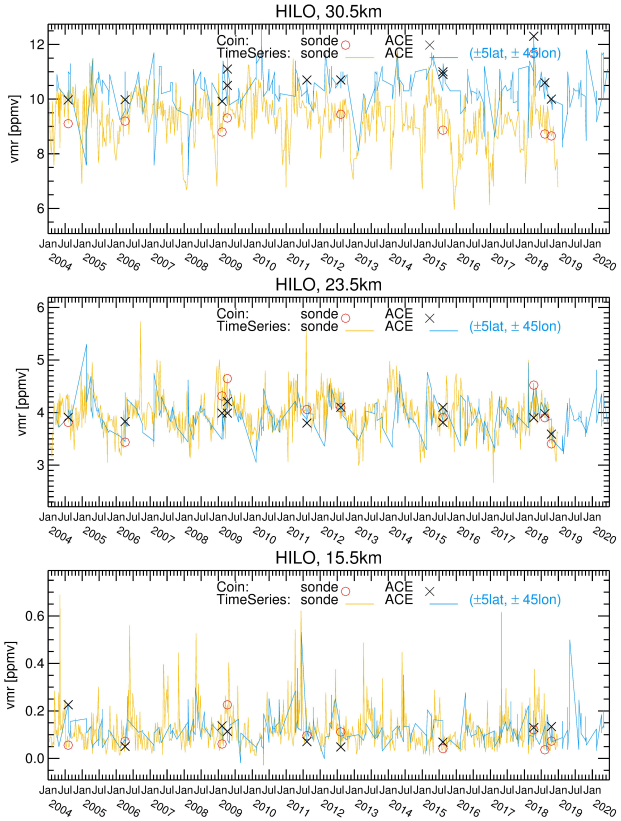


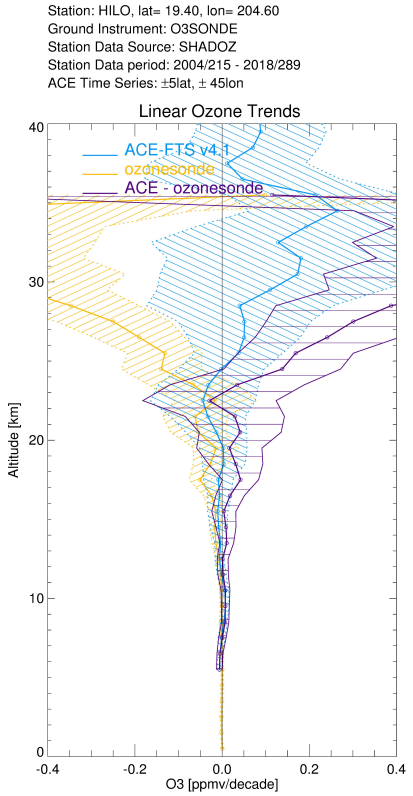


Jiansheng (Jason) Zou

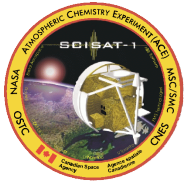
Comparison of v4.1 ACE-FTS with ozonesondes

- Comparison of biases and linear trends in ozone
- Coincident pairs found for each station
- ±5 degree latitude range with wide longitude ranges
- Deseasonalized monthly means used for analysis
- Hilo example (19.7 N)





Jiansheng (Jason) Zou

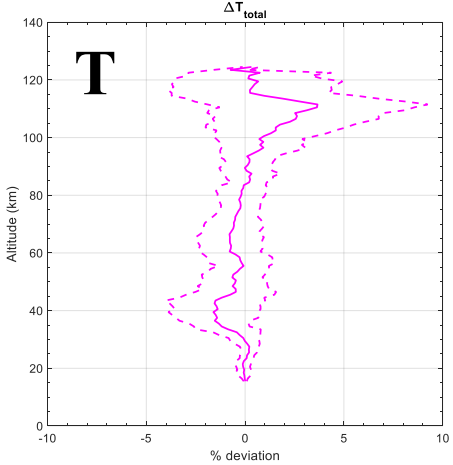


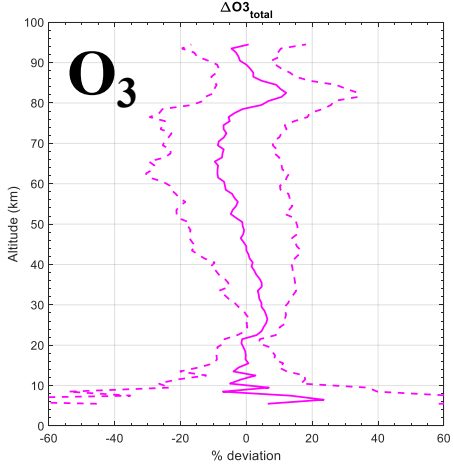
Assessment of ACE-FTS uncertainty budget

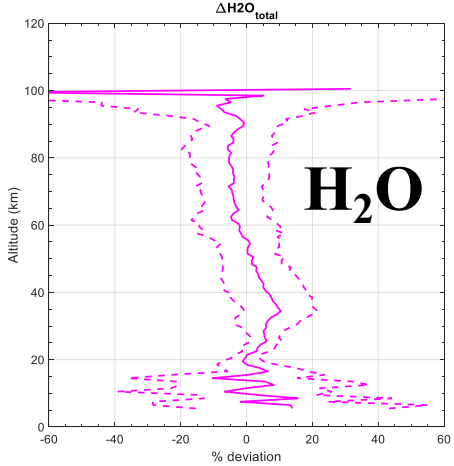
- To support SPARC TUNER activity, uncertainty budget being done for ACE-FTS
  - Using v3.6 retrievals as development platform
- Selecting 100 random occultations from full ACE-FTS data set, re-retrieving profiles with perturbation of one of the uncertainty components
  - Uncertainty is the MAD of differences between standard and perturbed retrievals
  - The median of the differences would give estimate of bias
  - Sources considered include: FOV modelling, ILS modelling, altitude registration, measurement noise, temperature measurement noise, convergence tolerance, derivative recycling – spectroscopic uncertainty in progress

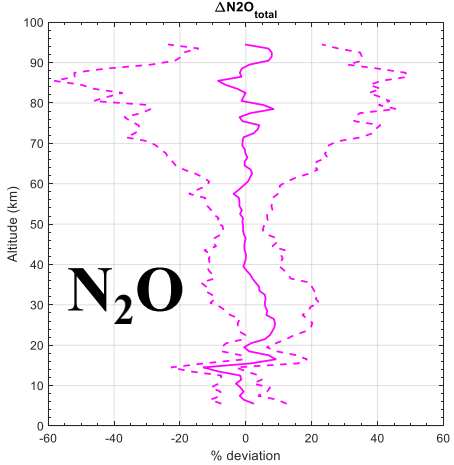
Total uncertainties (no spectroscopic uncertainty)

- Total uncertainty is calculated as the root sum square of the uncertainty components
- Total bias is sum of biases from the different bias components
- Dominated by FOV modelling uncertainty, then altitude registration uncertainty







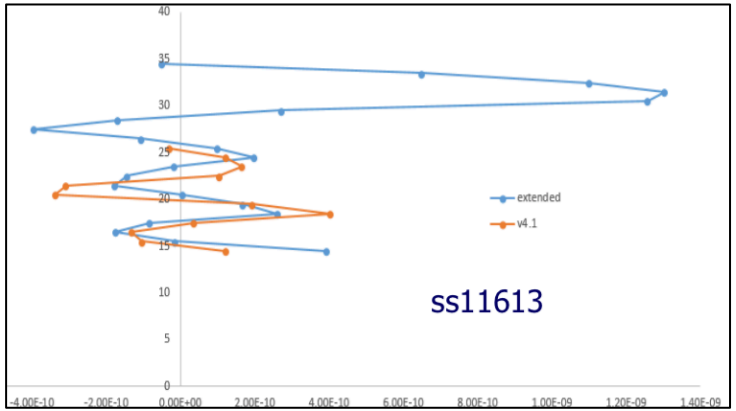


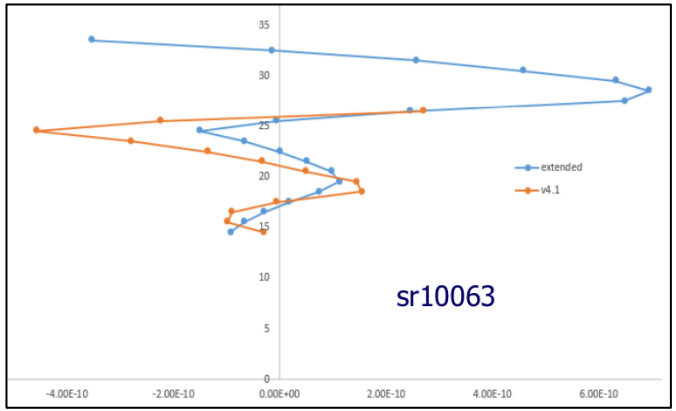
NOTE: different scale for T

Patrick Sheese

ClO improvements for v5.0

- It was originally anticipated that ClO results would only be good during enhanced polar spring conditions
- v4.1 results for background conditions seem viable (with sufficient averaging)
  - Here examples of pushing the retrievals higher to capture the secondary peak
- This new upper altitude limit to be used in v5.0 processing



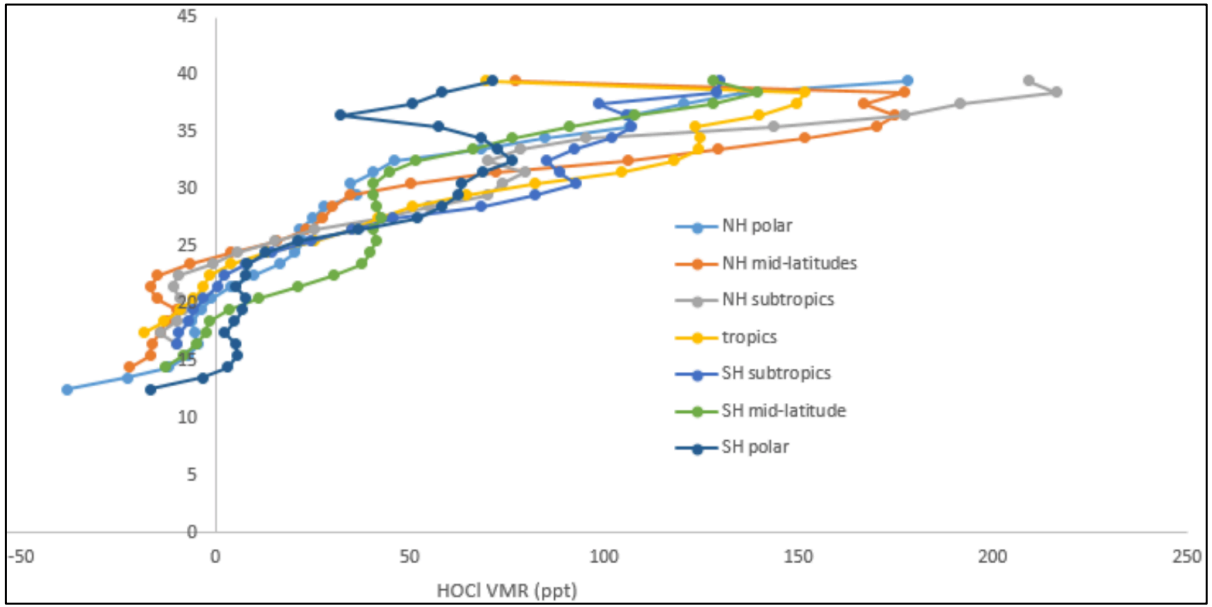


Chris Boone

New molecule for v5.0 – HOCl

- HOCl a new molecule for ACE-FTS – very weak absorber
- Preliminary test results show a significant Hemispheric difference, with higher levels in the North.

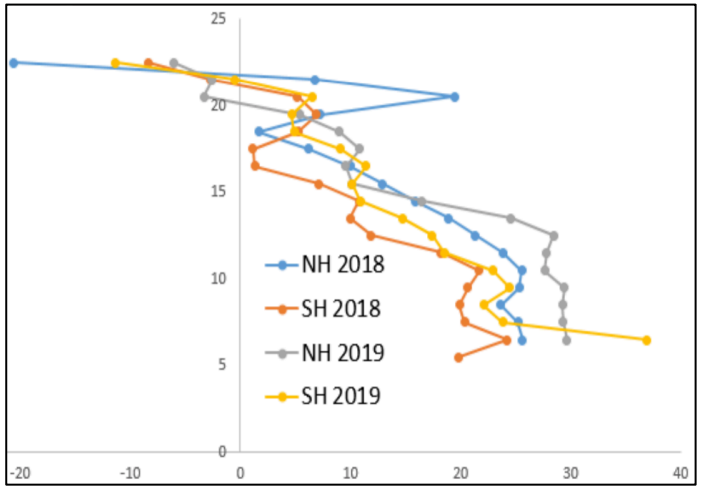
Each profile is an average from 5-10 occultations (2019)

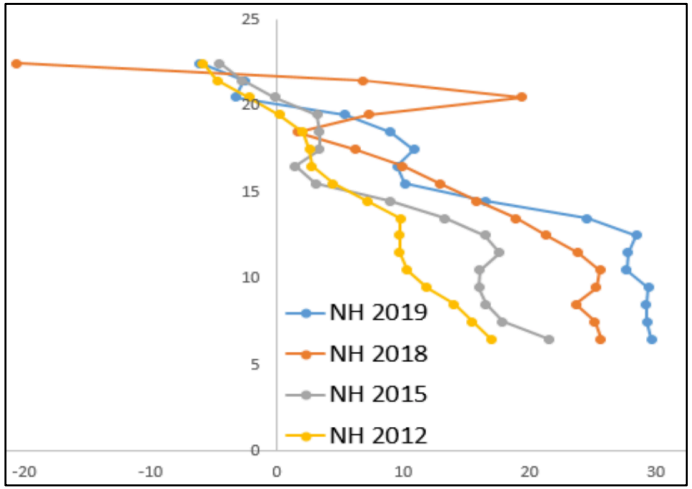


Chris Boone

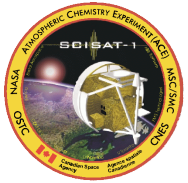
New HFC for v5.0 – HCF-32 - CH_2F_2

- Being used in refrigeration in some countries, will be controlled under Kigali Amendment
- Results are showing Hemispheric differences, as expected, and are varying strongly with time, which is expected for this molecule with a rapidly increasing concentration.
- New retrieval will be included in v5.0.





Chris Boone



Summary

- New data version available for ACE-FTS (v4.1) since July 2020
  - Download from https://databace.scisat.ca/level2 (registration required)
  - Data quality flags are being produced separately doi:10.5683/SP2/BC4ATC
- Validation work continuing for ACE-FTS and ACE-MAESTRO
  - Version 4.1 shows improvement over v4.0 for ACE-FTS and drift has been improved in this version

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- Natural Sciences and Engineering Research Council of Canada

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