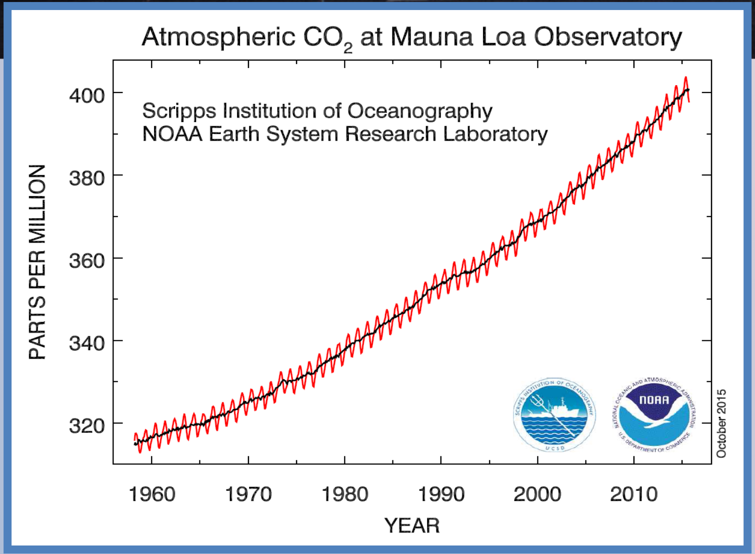
On the Role of Space-Based Observations in Understanding Atmospheric Carbon



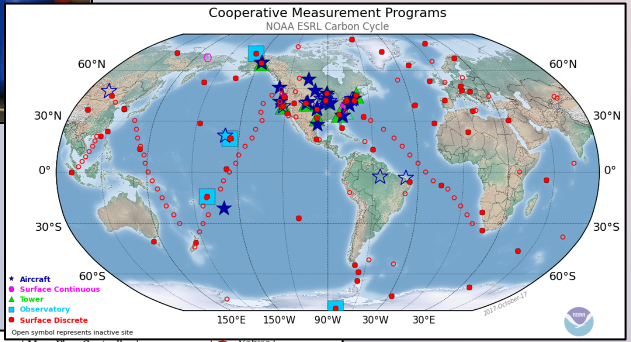
Lori M. Bruhwiler

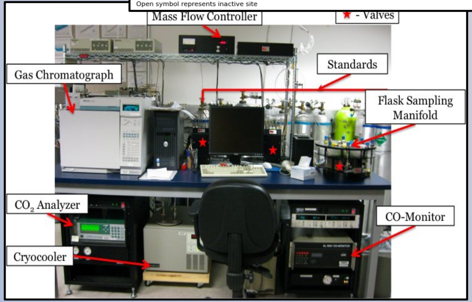
NOAA Earth System Research Laboratory,

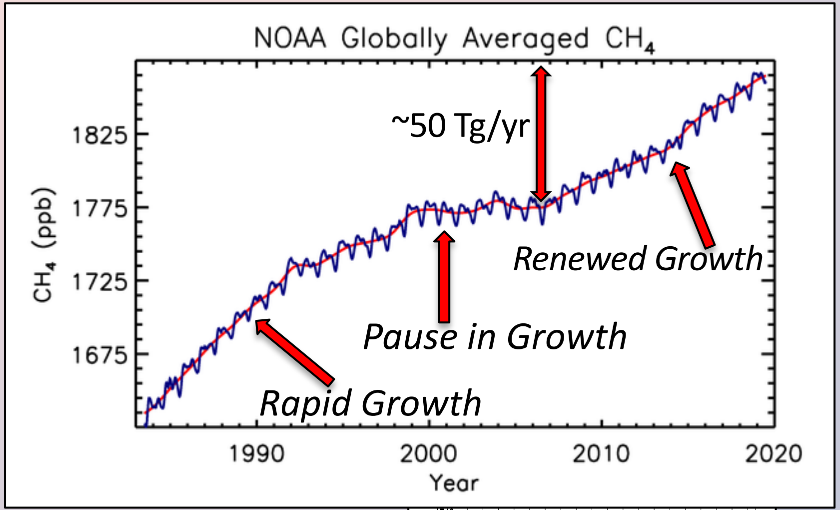
Global Monitoring Division

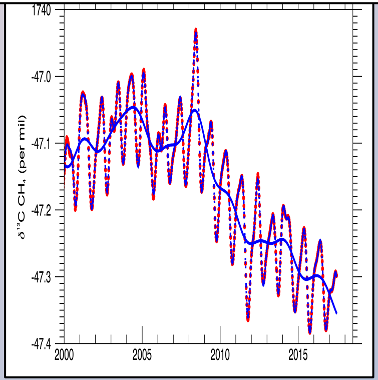
Carbon Cycle and Greenhouse Gas Group

The NOAA Cooperative Air Sampling Network: Long-Term Observations are Essential









Globally Averaged $\delta^{13}CH_4$
(Strong Hints that Growth is due to Microbial Sources, and mostly at low latitudes)

Methane's Importance in the Climate System

Methane is the 2nd largest contributor to radiative forcing* after CO_2.

It is about ~25x more powerful a greenhouse gas than CO_2 (over 100 years)

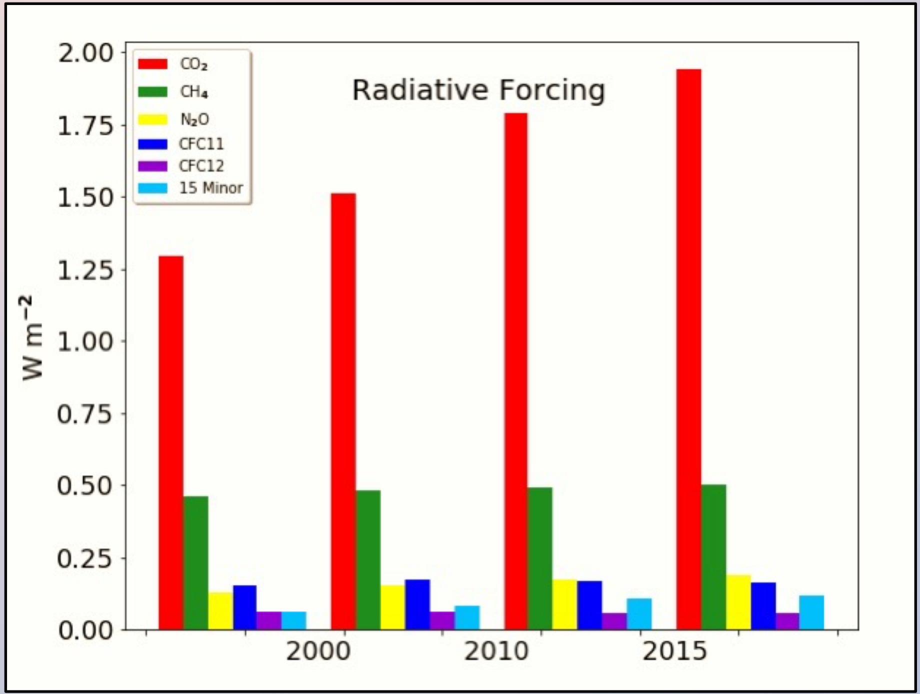
There could be CH_4-climate feedbacks.

CO_2 is the dominant component of radiative forcing, and its contribution is rapidly increasing.

We need to understand GHG sources and sinks. Are there feedbacks between GHG budgets and emissions?

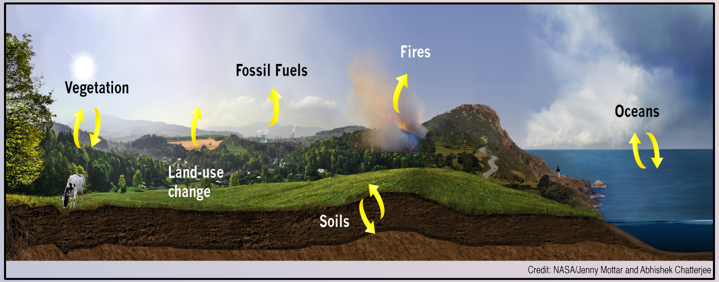
We cannot solve the climate problem by reducing only methane emissions!

GMD Annual Greenhouse Gas Index

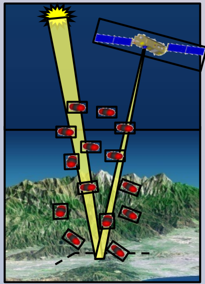


CarbonTracker NGGPS (funded by NOAA CPO AC4)

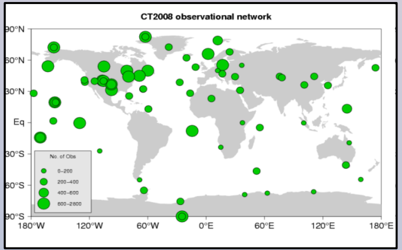
Carbon Flux Models



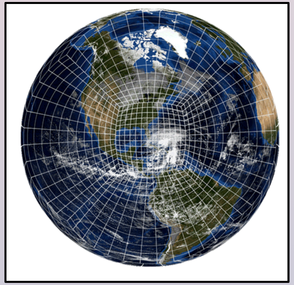
Remotely- Sensed Column Data



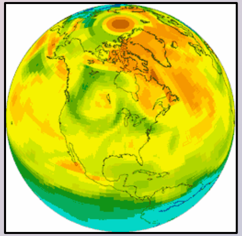
In Situ Surface Network Data

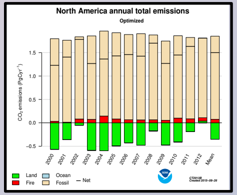


Earth System Model
With Data Assimilation
Now: TM5
Future: NGGPS, UFS, FV3-GFS



GHG Analyses

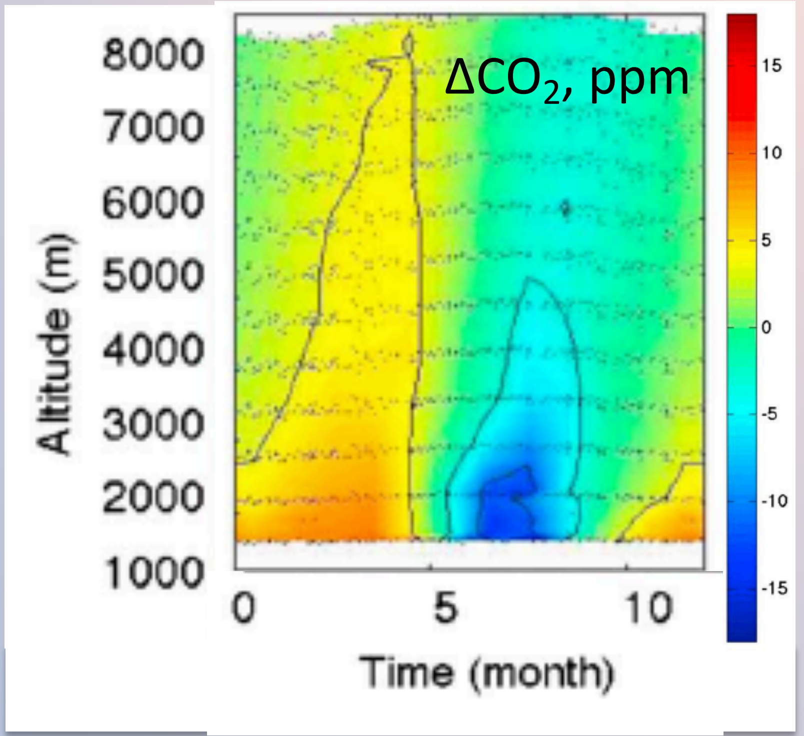




Estimated Fluxes

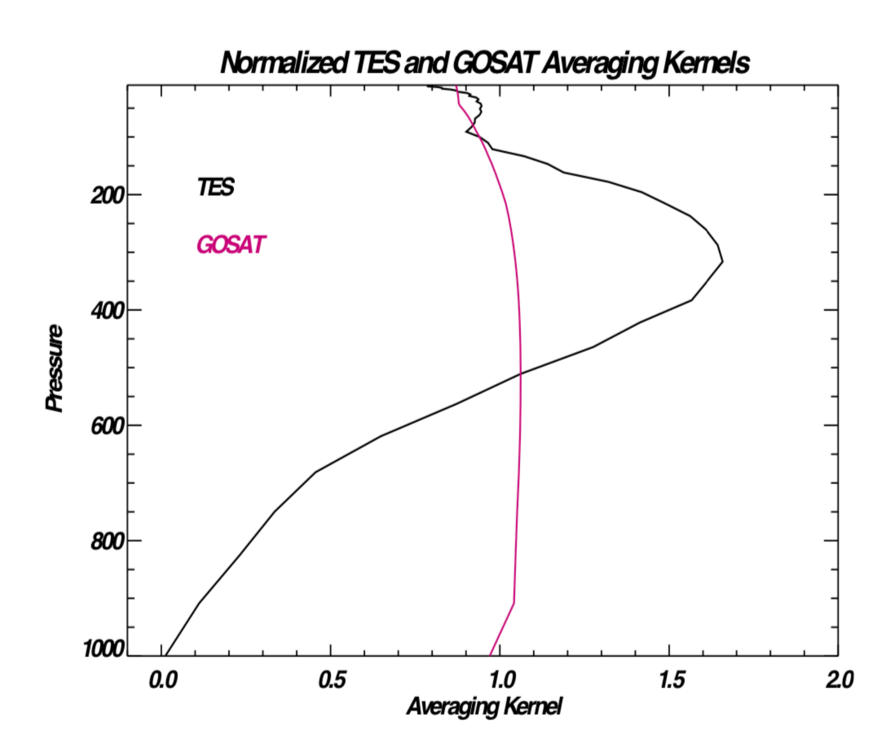
www.esrl.noaa.gov/gmd/ccgg/carbontracker/
www.esrl.noaa.gov/gmd/ccgg/carbontracker-ch4/

Vertical Information Can Help Us to Constrain Sources and Sinks of GHGs



Average Seasonal Cycle, Homer, IL

Sweeney et al., JGR, 2015



(Figure: Worden et al., 2015)

Reduced Information about Surface Sources/Sinks in Column Average Observations

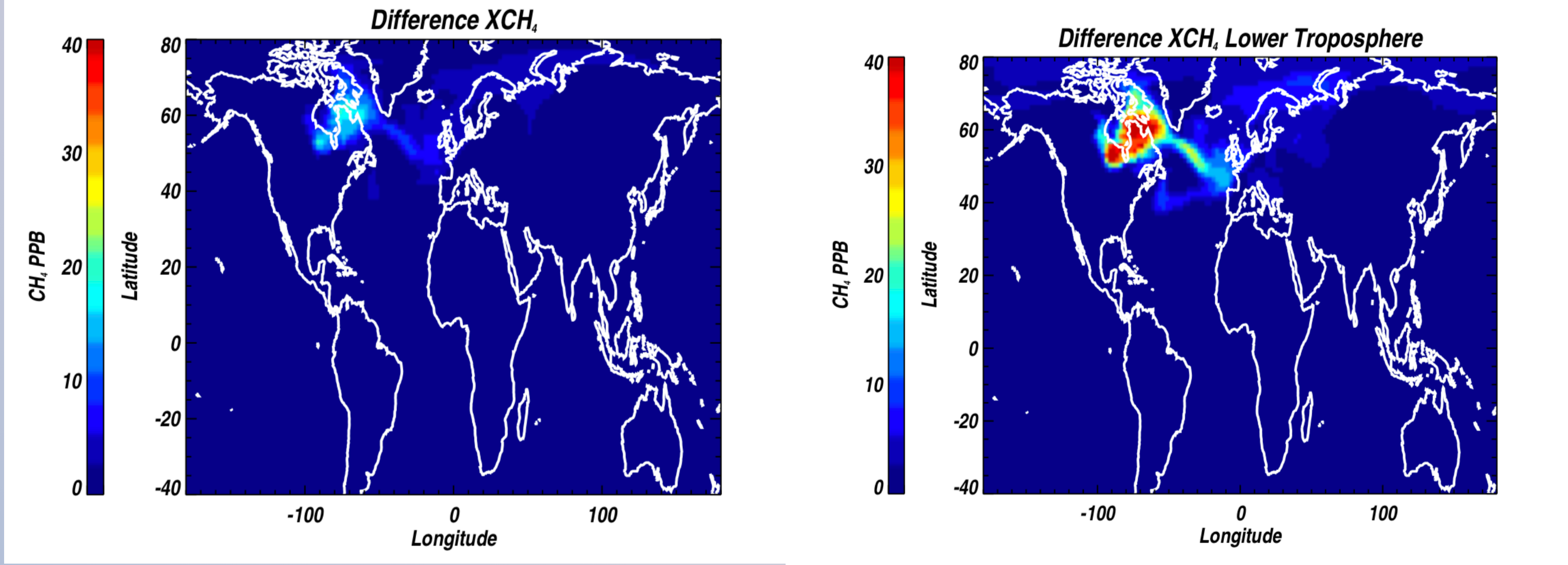
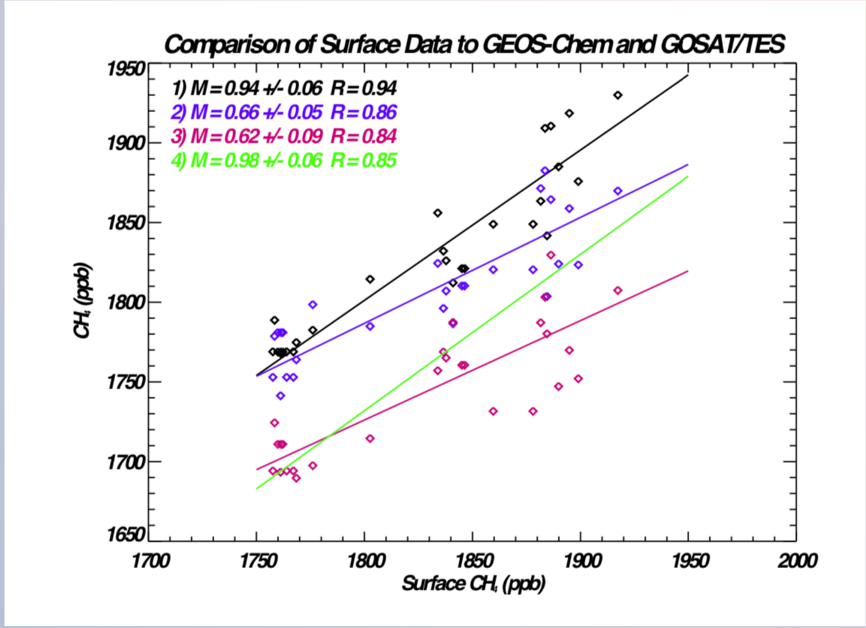
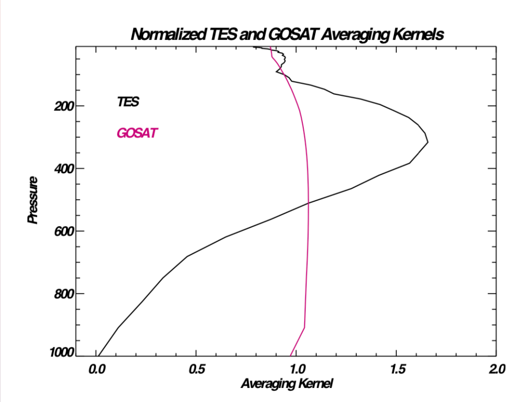


Figure 4. Top: difference in XCH_4 between a reference GEOS-Chem run and another in which the Hudson Bay lowland flux (48 to 66° N and 100 to 70° W) has been reduced by half. Bottom: same as in top panel but for the lower troposphere.

Zhang et al., 2018

Multi-Spectral Approach for Retrieving Lower Tropospheric CH_4





Precision: 10-30 ppb (monthly averages)

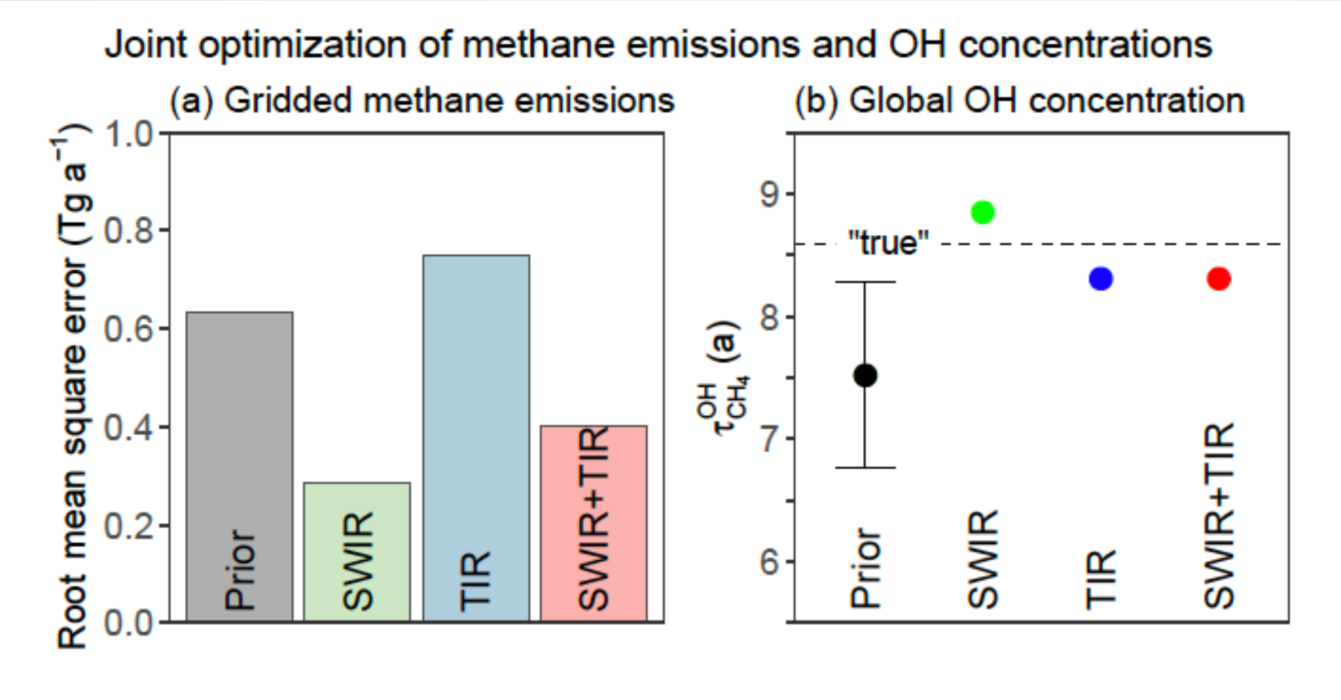
Bias vs. Model: 65 ppb

Accuracy: 6 ppb (after bias removal)

Worden et al., 2015

Satellite observations could be useful in the tropics where *in situ* observations are especially scarce.

Can we use TIR and SWIR soundings to jointly constrain CH_4 emissions and the CH_4 lifetime?

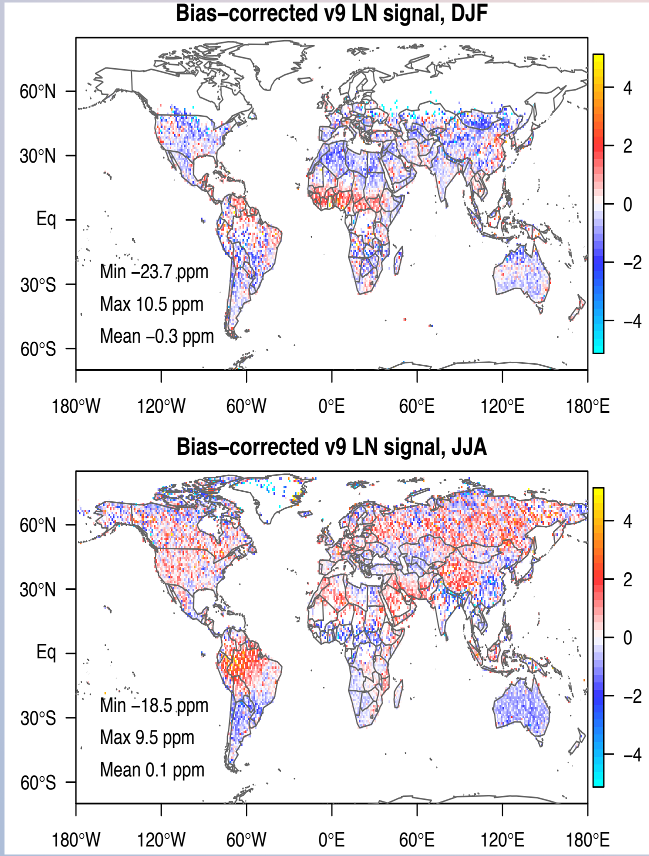


Zhang et al., 2018

Resolution of Emissions – 4x5

Error bars very small

Steps Towards Including TIR (and SWIR) retrievals in Carbon Data Assimilation Systems

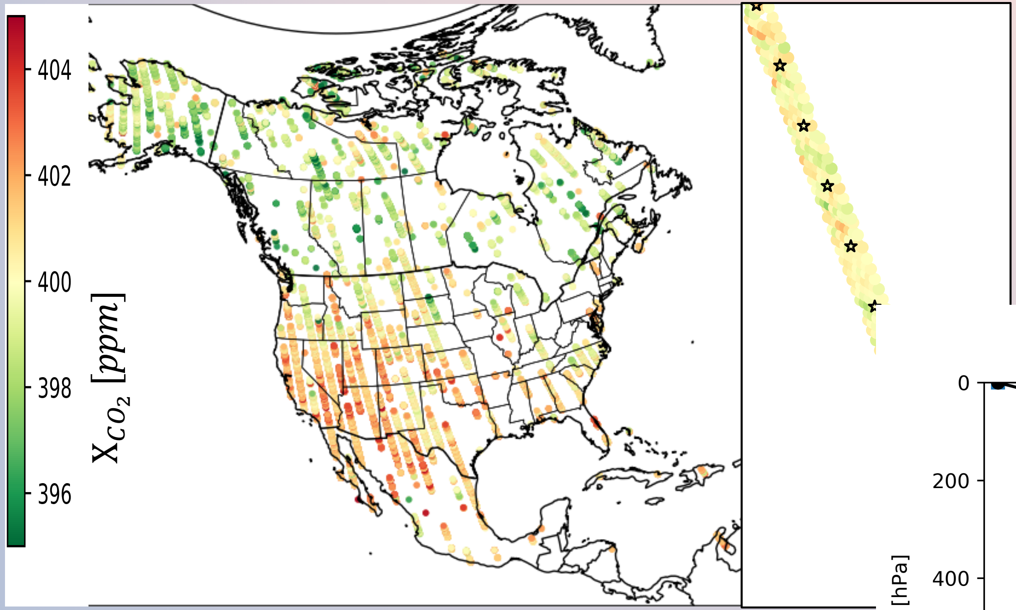


1: Evaluation against available observations:

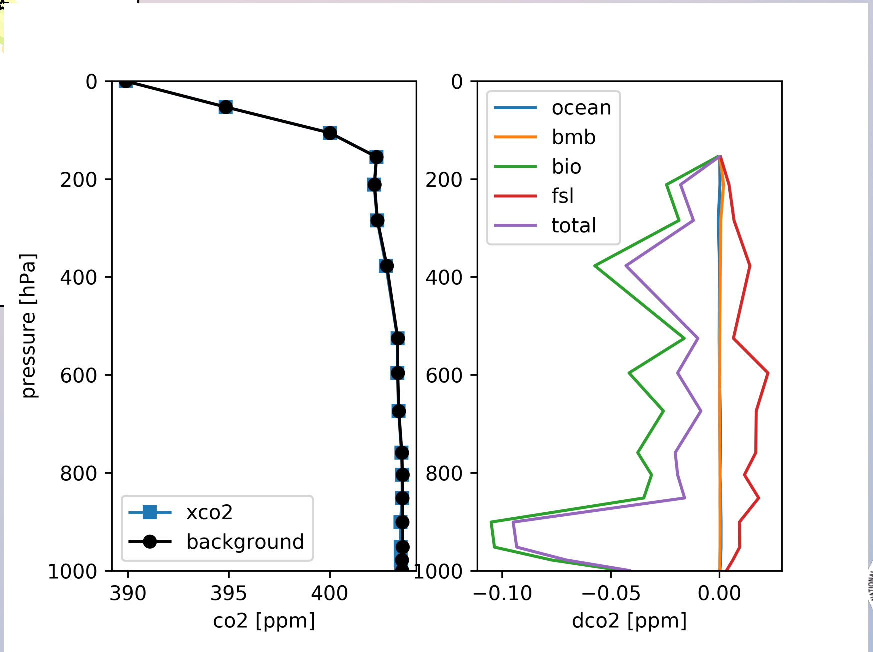
- *TCCON (Total Carbon Column Observing Network) XCO_2, XCH_4, XCO*
- *NOAA GMD Aircraft Monitoring Profiles*
- *ATom (Atmospheric Tomography Campaign) observations*
- *NOAA GMD profiles*

2: Comparisons with carbon data assimilation systems that don't assimilate satellite data – how would such data revise flux estimates?

Regional scale bias identification



- Compare OCO-2 retrieved columns to XCO_2 simulated using CT-Lagrange posterior fluxes constrained by *in situ* observations.
- Stratospheric CO_2 constrained by aircore measurements.
- Background from multiple global inverse models.



Most of the signal in XCO_2 is due to the background

[1]Hu, Lei, et al. "Enhanced North American carbon uptake associated with El Niño." *Science advances* 5.6 (2019).

Other Types of Satellite Observations that Can Help Constrain Carbon Budgets

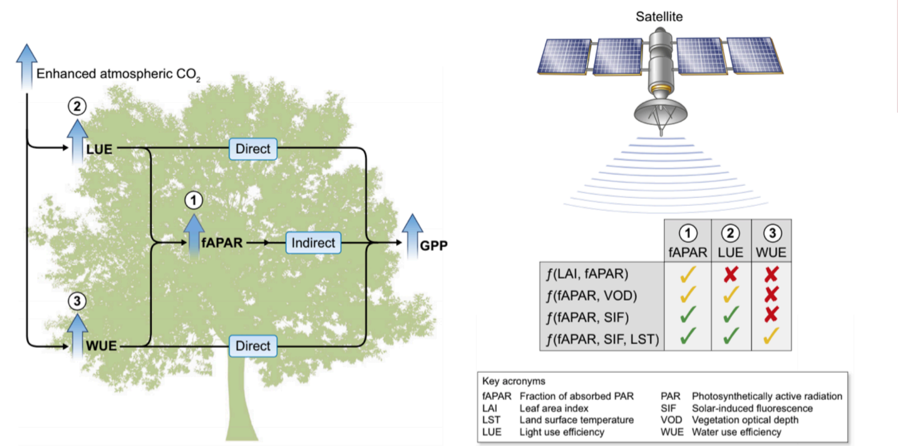


Fig. 1 Schematic of the pathways by which CO_2 fertilization effects (CFE) can increase gross primary productivity (GPP) and the potential ways satellite observations could be combined to constrain the CFE pathways. We define CFE pathways to include increases in light use efficiency (LUE), increases in water use efficiency (WUE), and increases in the fraction of photosynthetically active radiation (fAPAR). Satellite indices include leaf area index (LAI) and fAPAR, land surface temperature (LST), vegetation optical depth (VOD) and solar-induced Chl fluorescence (SIF). We show different combinations of these satellite records and indicate their potential to globally constrain (green ticks), regionally constrain (yellow ticks) or fail to constrain (red crosses) a given CFE pathway. Regional constraints (yellow ticks) are most often limited by atmospheric effects and/or signal saturation in dense canopies, such as tropical forest ecosystems.

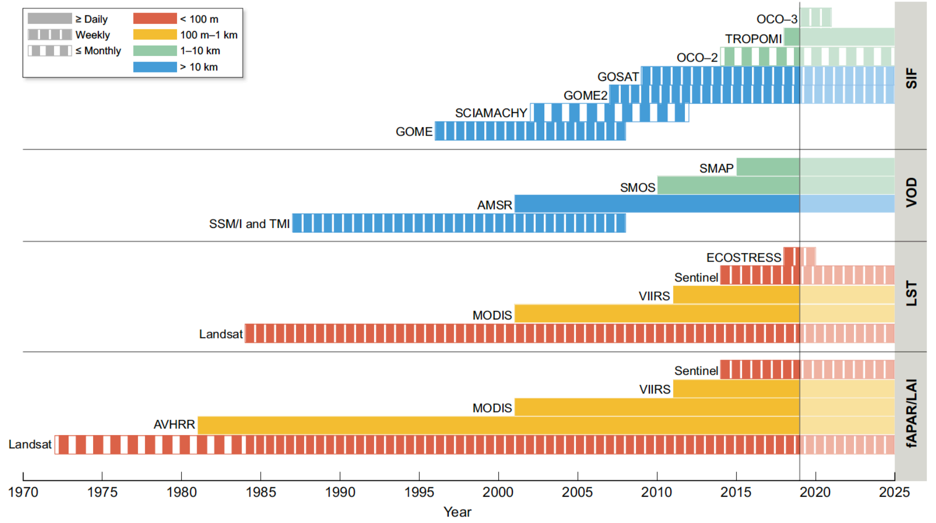


Fig. 2 A timeline of satellite observations of leaf area index (LAI) and fraction of photosynthetically active radiation (fAPAR), land surface temperature (LST), vegetation optical depth (VOD) and solar-induced fluorescence (SIF). Observation timelines are provided for context and are not meant to provide a comprehensive overview of all available sensors. This timeline clearly demonstrates the availability of diverse, multidecadal satellite observation records that are rapidly increasing in spatiotemporal resolution.

Smith et al., 2019
Can we learn about carbon fertilization using space-based data records?

Some User Needs

- User friendly data files containing only information essential for use in carbon modeling (e.g. like "OCO-2 Lite" files).
- Averaging kernels and prior profiles are essential.
- Data on pressure levels rather than altitude.
- Only give independent information, not 100-layers. (This can also reduce misuse of data).

CrIS NH_3 and CO Retrievals: From Idea to Applications

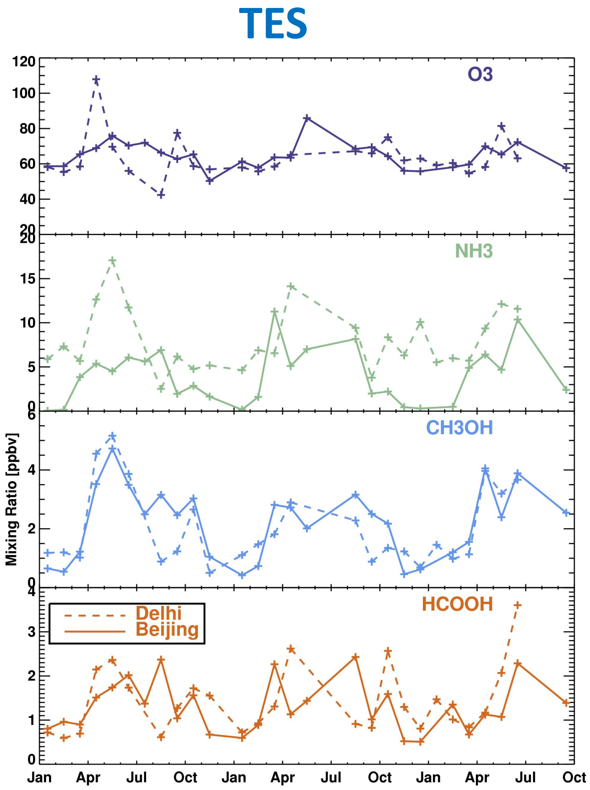
Matthew J. Alvarado[1], Karen Cady-Pereira[1], Jeana Mascio[1], Chantelle R. Lonsdale[1], Mark W. Shephard[2], Enrico Dammers[2], Shailesh K. Kharol[2], Daven Henze[3], Hansen Cao[3], Helen Worden[4], Gene Francis[4], Sara Martinez-Alonso[4], Dejian Fu[5], Kevin Bowman[5], Vivienne Payne[5]
And Many Others!

[1]Atmospheric and Environmental Research (AER) [2]Environment and Climate Change Canada
[3]University of Colorado Boulder [4]NCAR [5]JPL

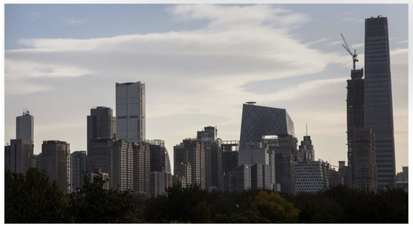
Acknowledgements: NOAA AC4 Grants NA13OAR4310060 & NA14OAR4310129
NASA S-NPP Science Team Grants NNH15CM65C and 80NSSC18K1562
NASA Applied Science Grant #80NSSC19K0190

JPSS/GOES-R Proving Ground / Risk Reduction Summit
24-28 February 2020

Using (TIR) Satellites to Study Atm. Composition



Beijing

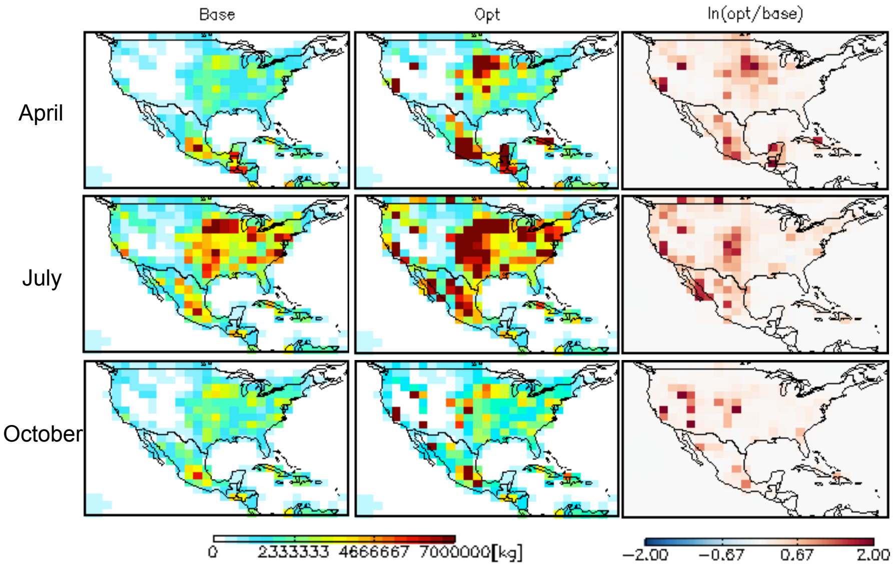


Delhi

Cady-Pereira et al., 2017

Moving from TES to CrIS

Using TES to Optimize NH_3 Emissions



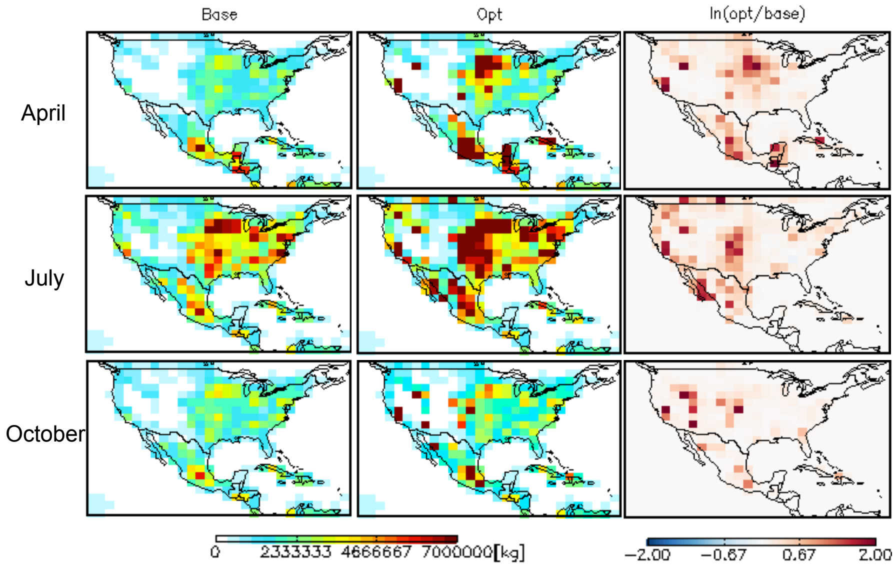
Zhu et al., 2013, JGR

TES and CrIS Comparison

	TES	CrIS
Satellite	AURA	S-NPP and JPSS-1
Dates	2004 - 2019	2011-present
Resolution	0.06 cm^{-1}	0.625 cm^{-1}
Repeat cycle	16 days	Daily
Noise in NH_3 window	0.09 – 0.12 K	0.03 – 0.06 K

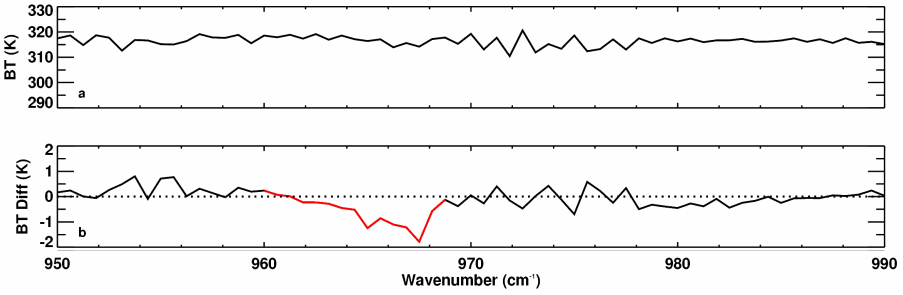
Moving from TES to CrIS

Using TES to Optimize NH_3 Emissions



Zhu et al., 2013, JGR

Original Proof of Concept for CrIS NH_3 Retrieval from NOAA AC4 proposal

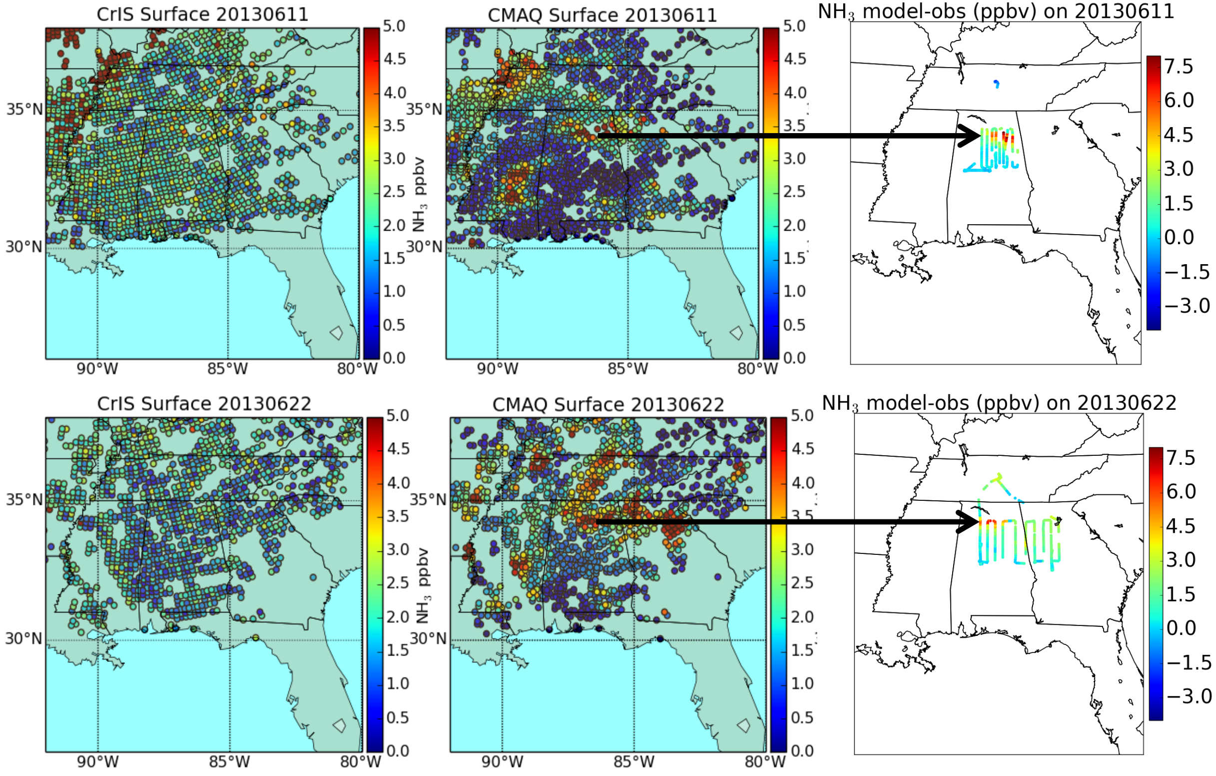


First Application in NOAA SENEX Campaign

CrIS Surface NH_3 | CMAQ Surface NH_3 | CMAQ – NOAA P3 NH_3

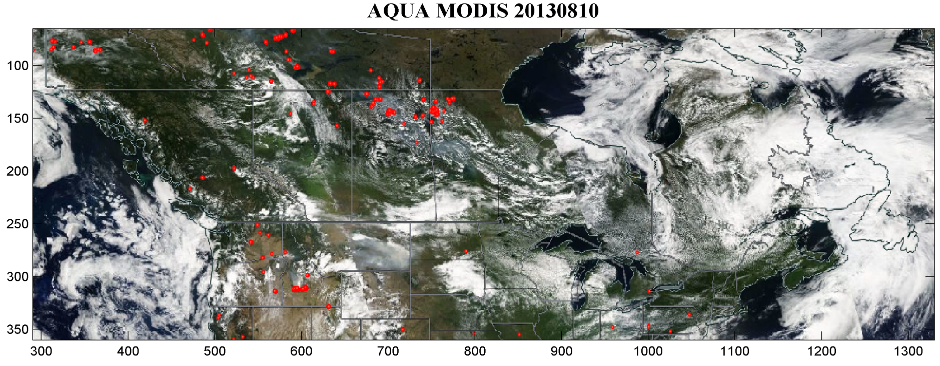
06/11/13
(Tuesday)

06/22/13
(Saturday)

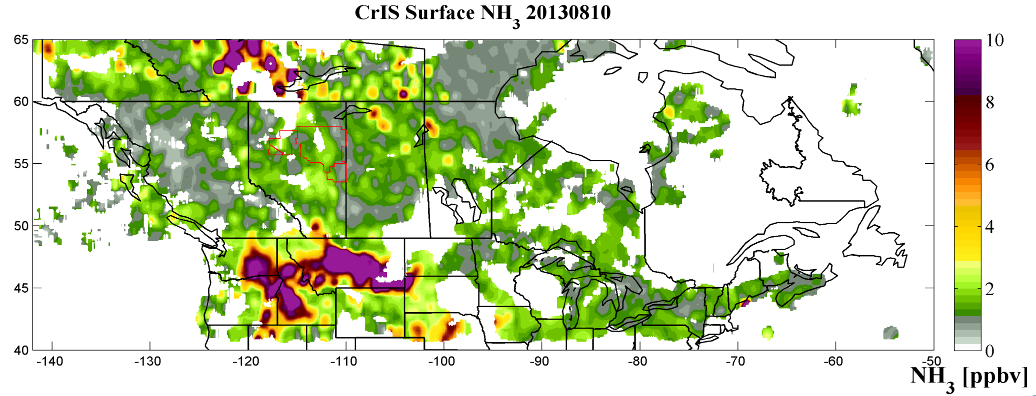


CrIS NH_3: Example of Fire Impacts

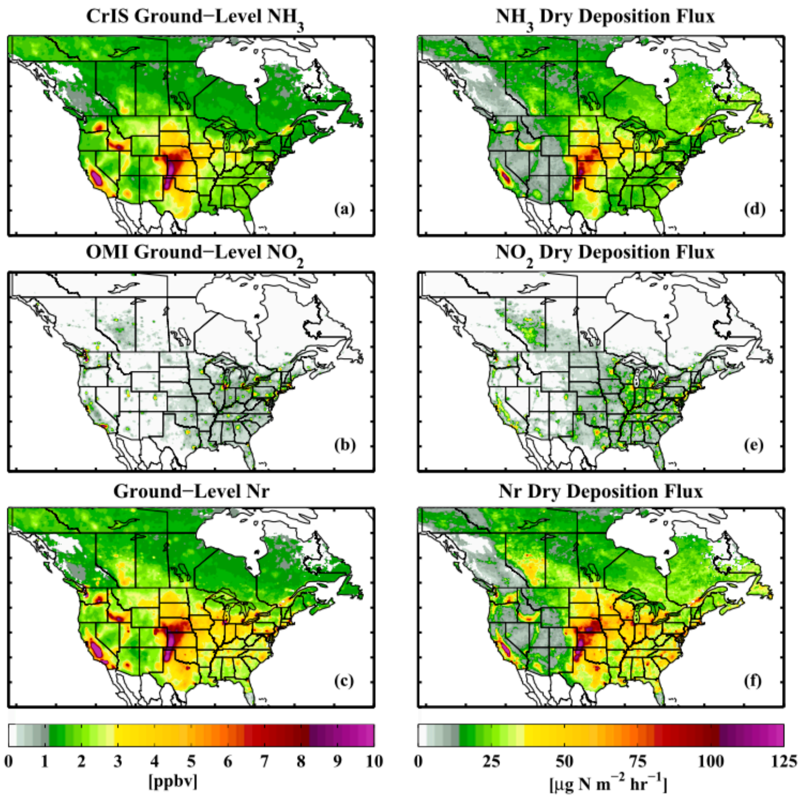
MODIS
Infrared:
Fire Detection (red)
Visible:
Cloud (White)
Smoke (blue/gray)



CrIS
Infrared:
NH_3



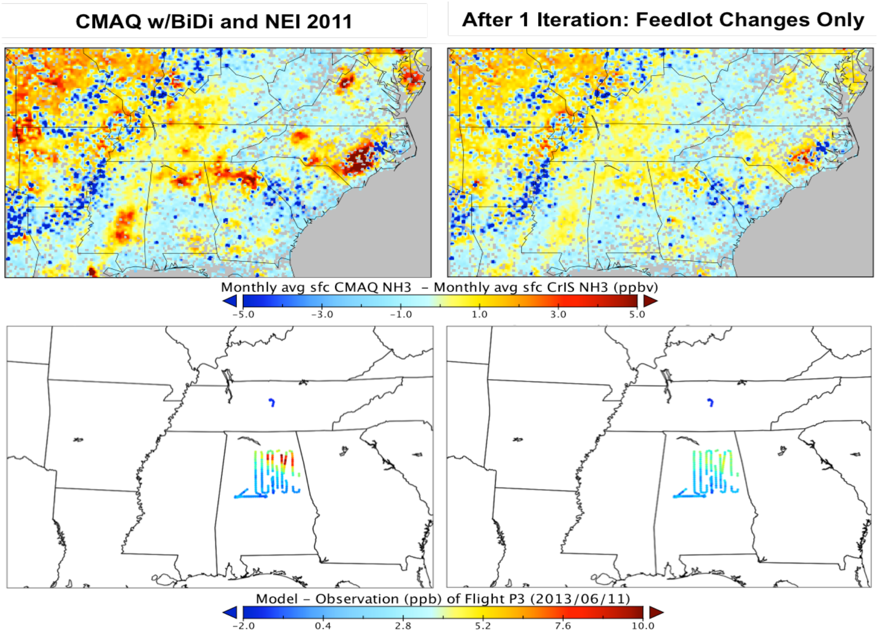
Using CrIS and OMI to Quantify Reactive N Deposition



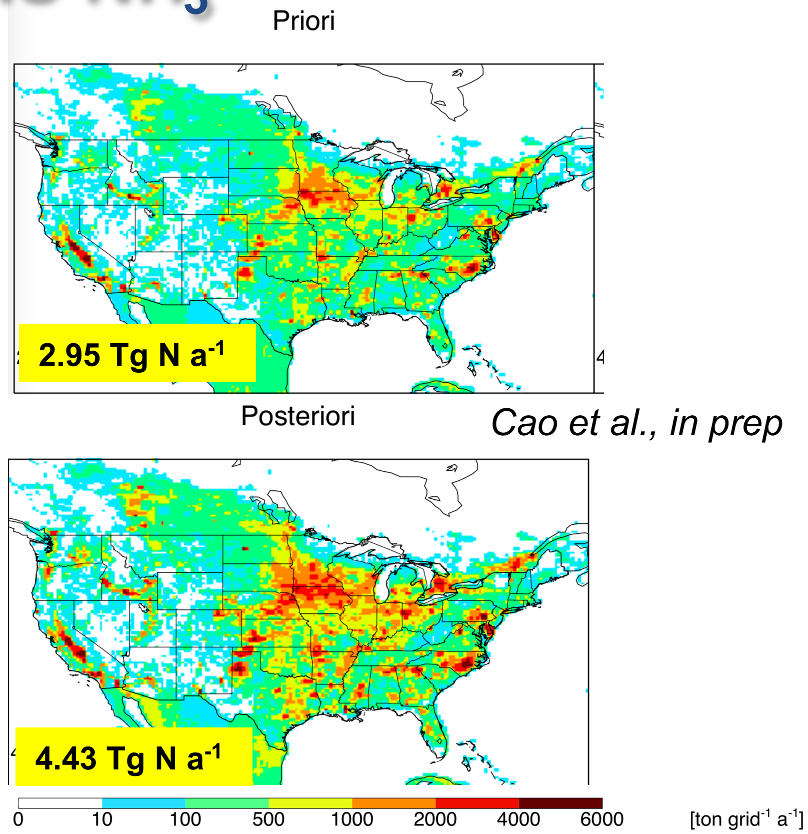
- GEM-MACH model used to estimate diurnal cycles and deposition velocities
- NH_3 dry dep is lower in Intermountain West due to lower deposition velocities
- NO_2 dry dep hot spots are mainly located over urban and industrial regions (e.g., oil and gas development in Alberta).

Kharol et al., GRL, 2018.

Optimizing Emissions with CrIS NH_3



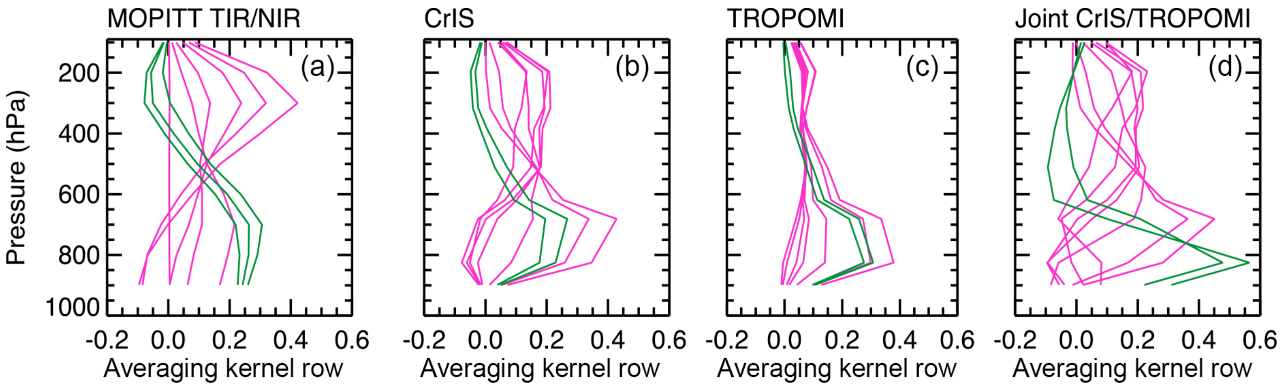
Lonsdale et al., in prep



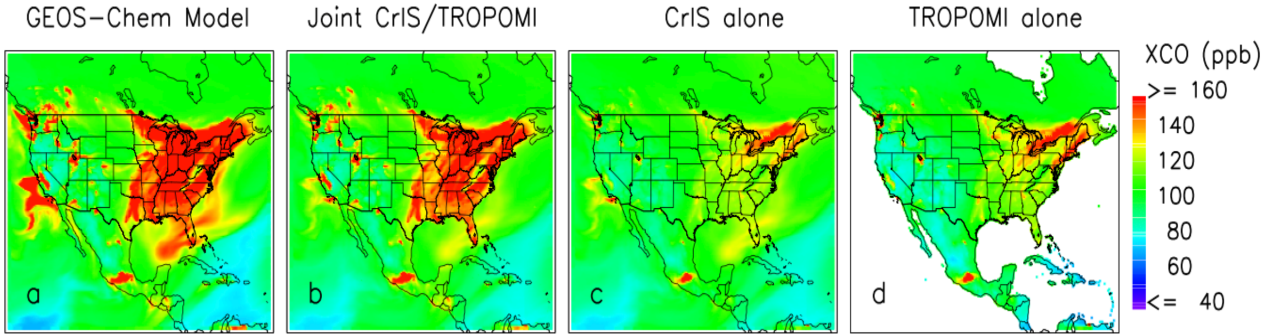
Cao et al., in prep

Extending the MOPITT CO record with CrIS and TROPOMI

Averaging Kernels From Fu et al., AMT, 2016 – Using MUSES Algorithm for single pixel, OE retreivals



Simulated retrievals of surface layer CO (0-2km)



Where Should We Go From Here?

More Species More Often

- Get as complete spectral coverage as possible
- Geostationary TIR
- Seed funding before full product?

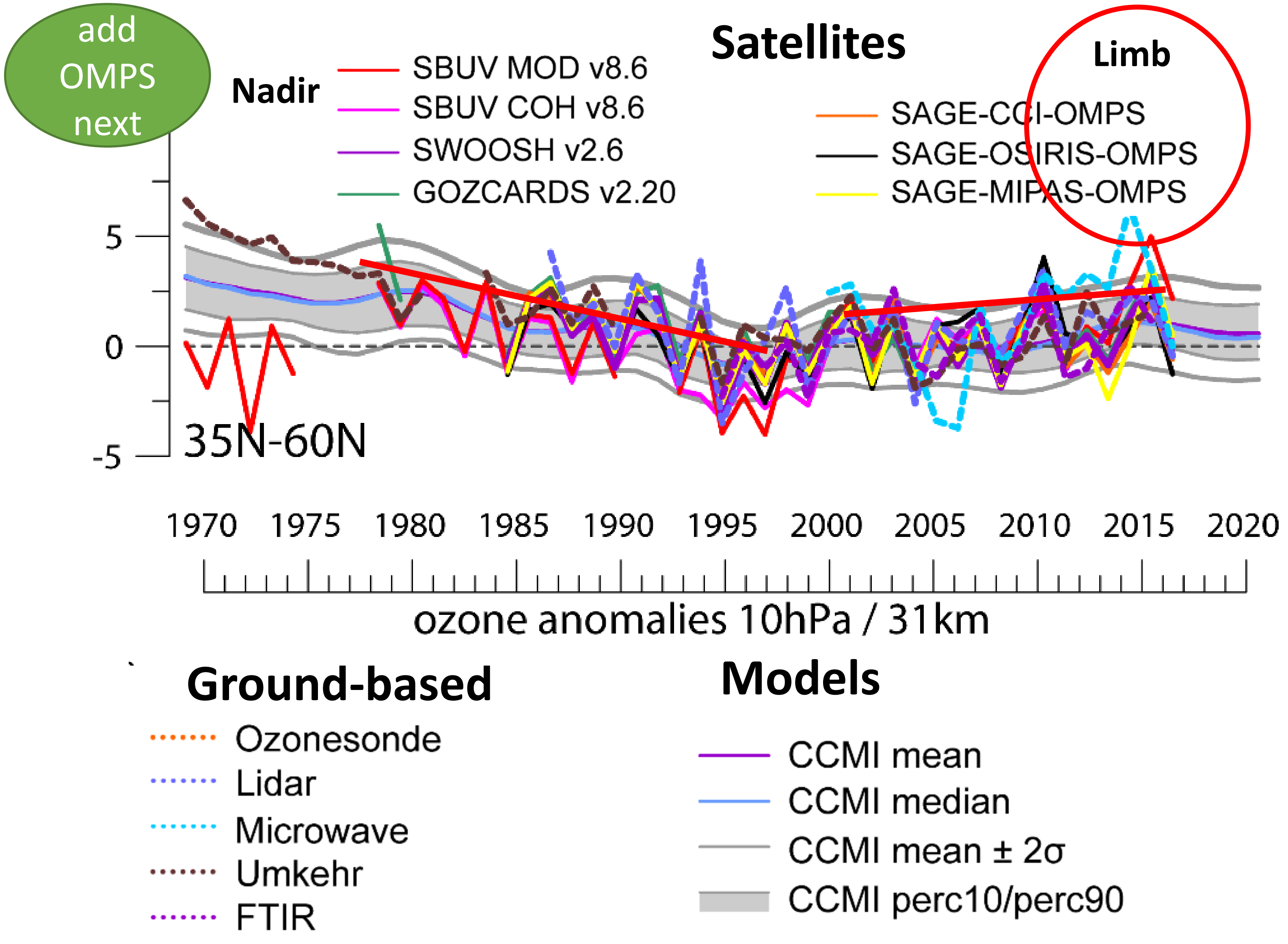
Nitrogen cycle studies

- NH_3, NO_x, PAN, and N_2O are all part of a larger N cycle that includes soil and ocean biology and chemistry
- *Use GOES/JPSS observations as part of a more comprehensive satellite picture of N cycle*

Use and applications for the JPSS and ground-based ozone products

U. Of Colorado, CIRES: I. Petropavlovskikh, A. McClure, G. McConville
NOAA/ESRL/GMD: B. Johnson, K. Miyagawa (visitor)
U. Of Maryland, ESSIC: J. Wild
NESDIS/STAR: L. Flynn
NOAA/STAR/IMSG: E. Beach
NOAA Science Center: C. Long

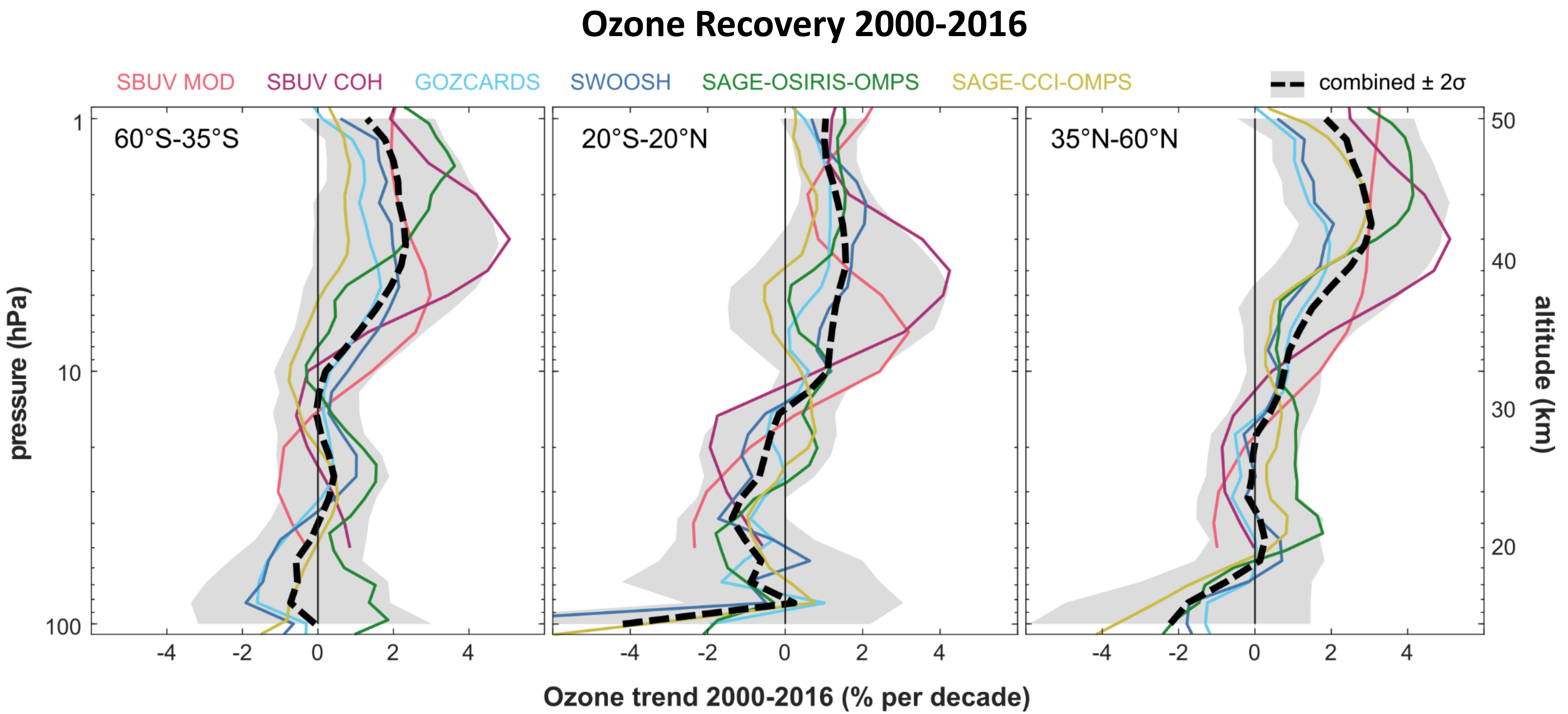
Satellite and ground-based (GB) data for tracking stratospheric ozone recovery under the Montreal Protocol and US Clean Air act compliance

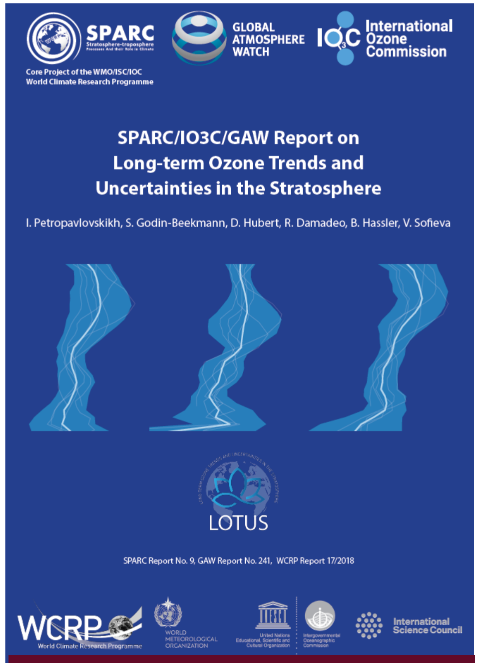


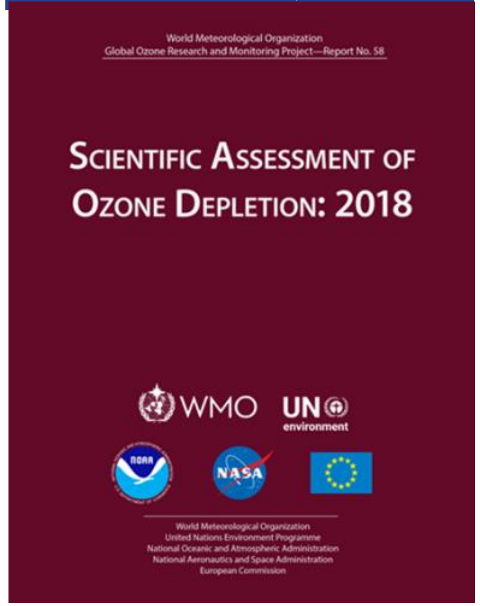
Ozone assessment requires:

1) Collect observations (satellites, GB, in-situ)
2) Create common formats (i.e. monthly averages, deseasonalized, zonal averages, overpass)
3) Common statistical model (i.e attribution to natural and anthropogenic atmospheric changes)
4) Global Climate Models (scenarios to separate Climate vs Ozone depleting substances impacts)

SPARC/IO3C/GAW LOTUS Report 2018: trends and uncertainties





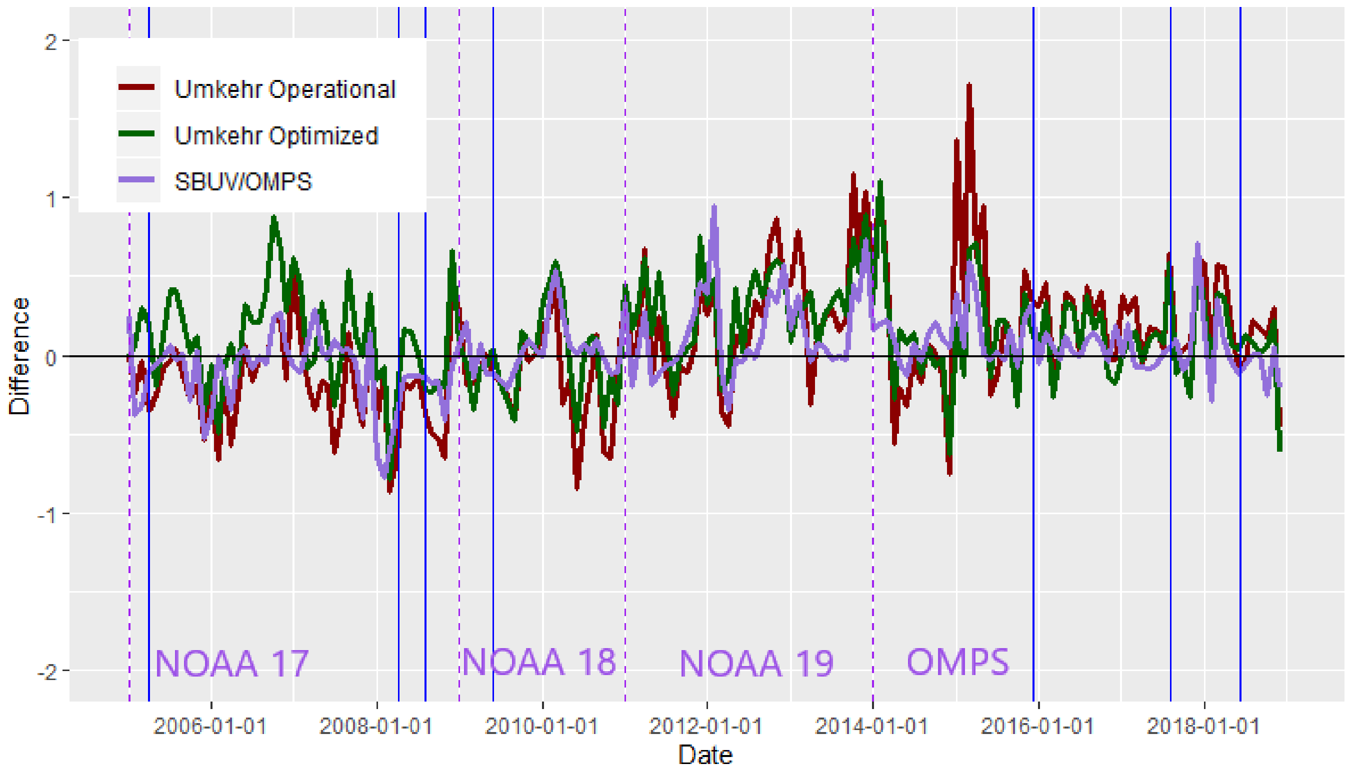


- Different trends from combined satellite records
- Merging of trends and defining uncertainty
- Need for homogenization and reduced uncertainties

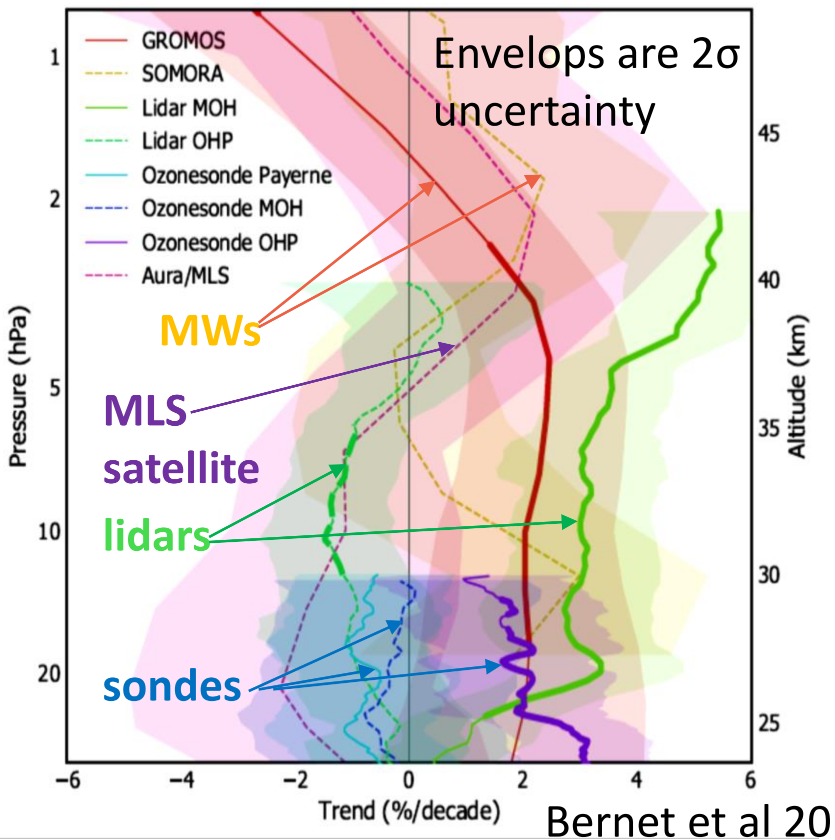
NOAA/AC4 and SPARC LOTUS phase 2:

- Improve the long-term combined satellite (i.e. NOAA/SBUV + JPSS OMPS) and GB ozone records (i.e. Dobson Umkehr)
- Compare ozone variability in regional (i.e. station) and zonal domains
- Analyze data for trends in time for the WMO/UNEP Ozone assessment 2022.
- LOTUS 3 Workshop, Helsinki, Finland, May 26-27, 2020
- QOS 2020 in Seoul, S. Korea, Oct 4-10, 2020

Boulder, De-seasonalized, MM Ozone anomalies, 3 hPa, %

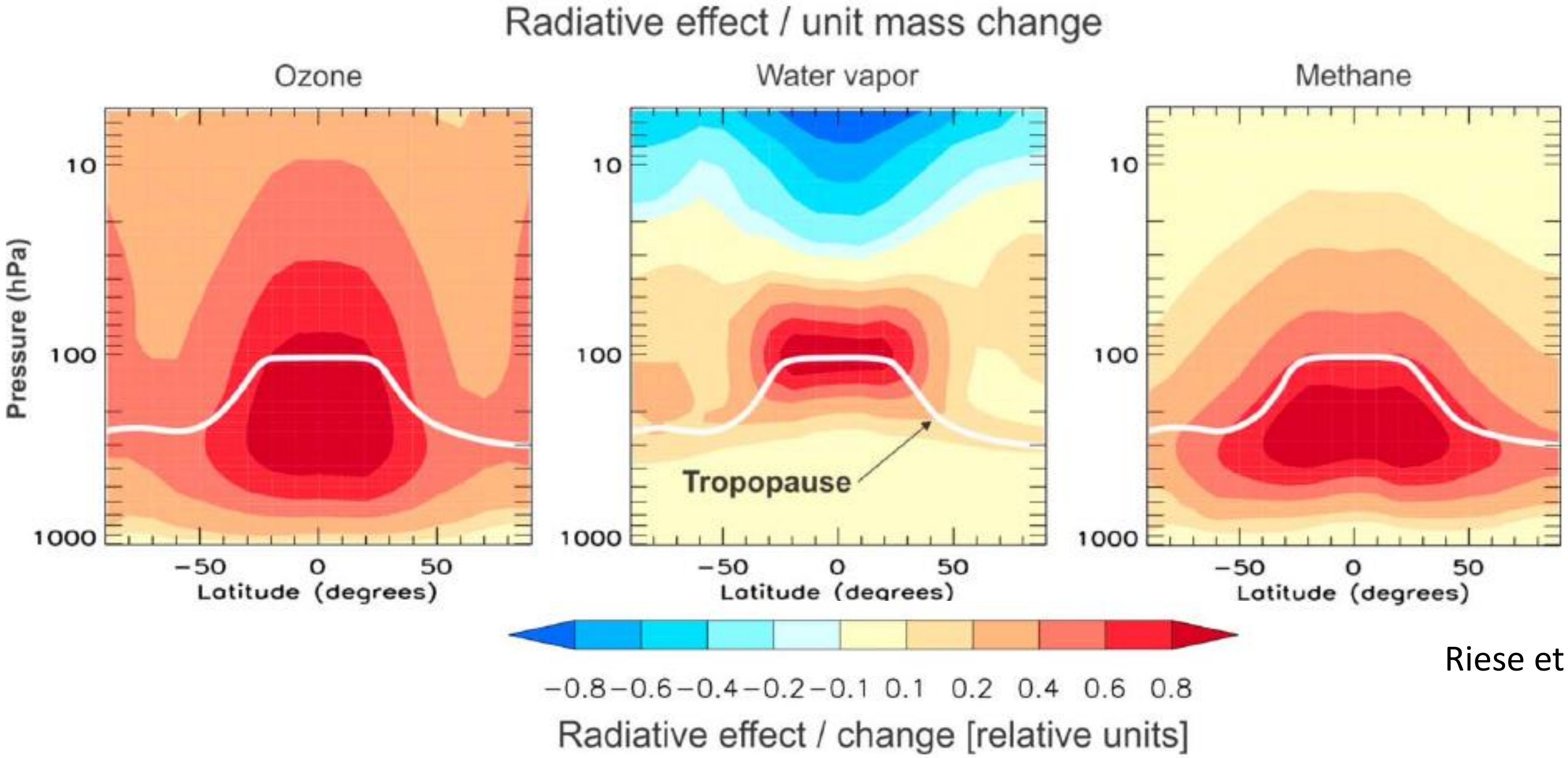


Trends, 1997-2017



Bernet et al 2018

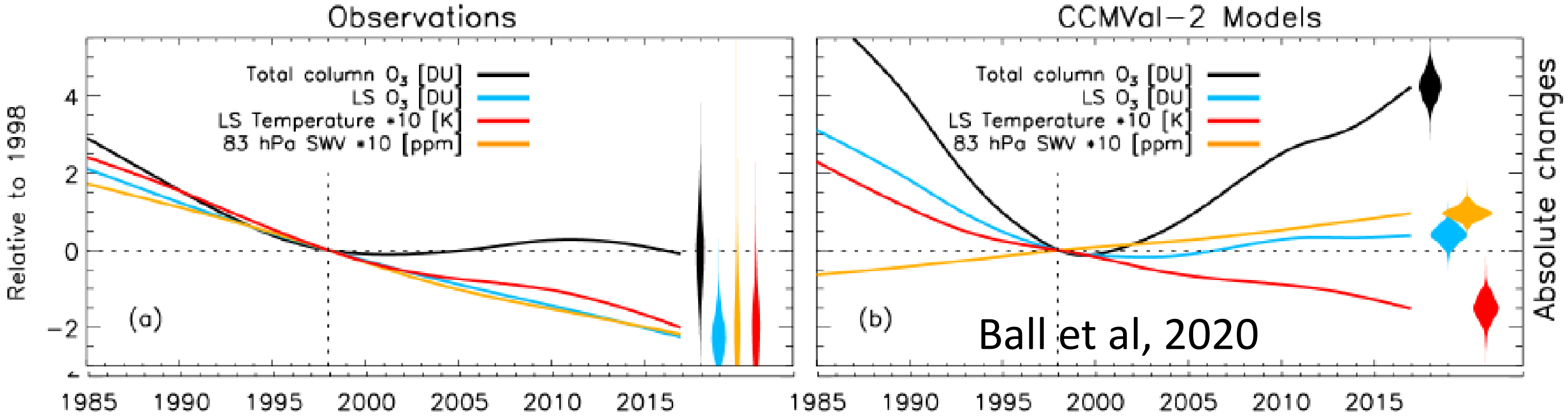
SPARC Observing Composition Trends and Variability in the UTLS (OCTAV-UTLS)

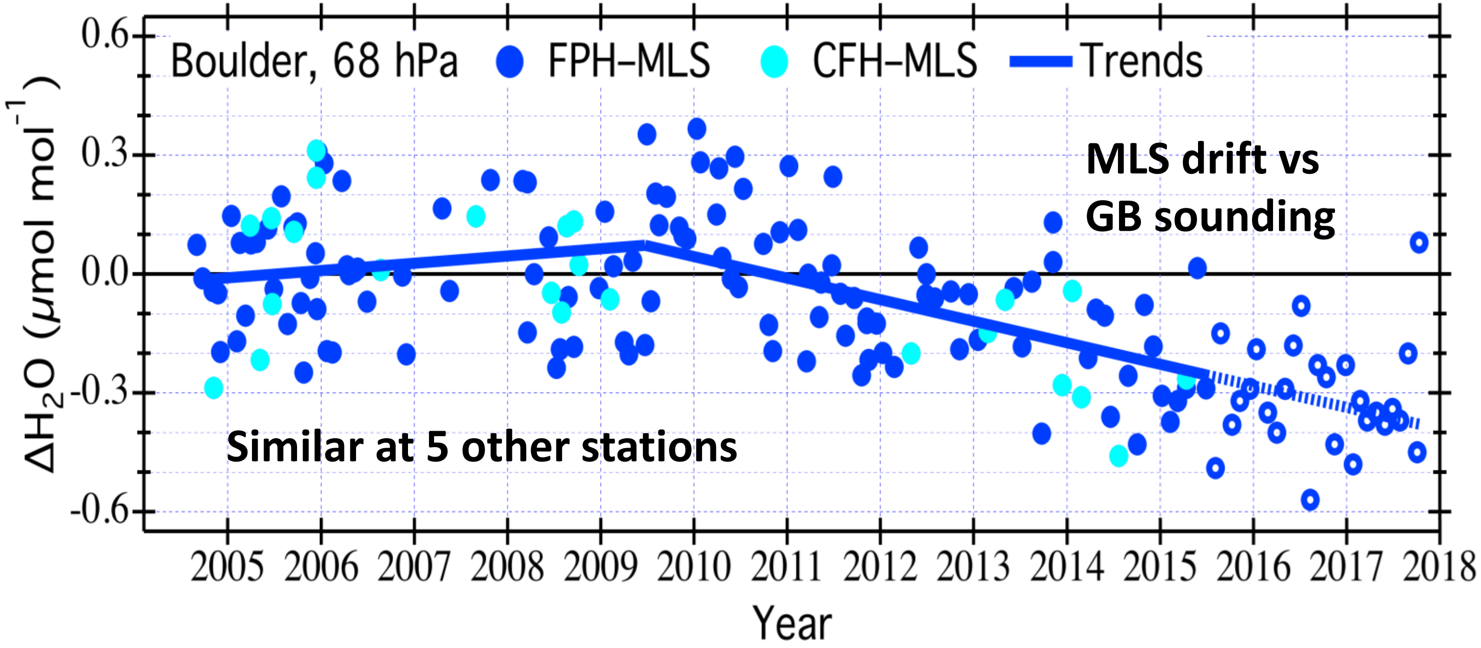


Riese et al., 2012

Why? Strong sensitivity of surface temperature to changes of radiatively active trace gases in the UTLS

SPARC activity OCTAV – UTLS,
Observing Composition Trends and Variability in the UTLS

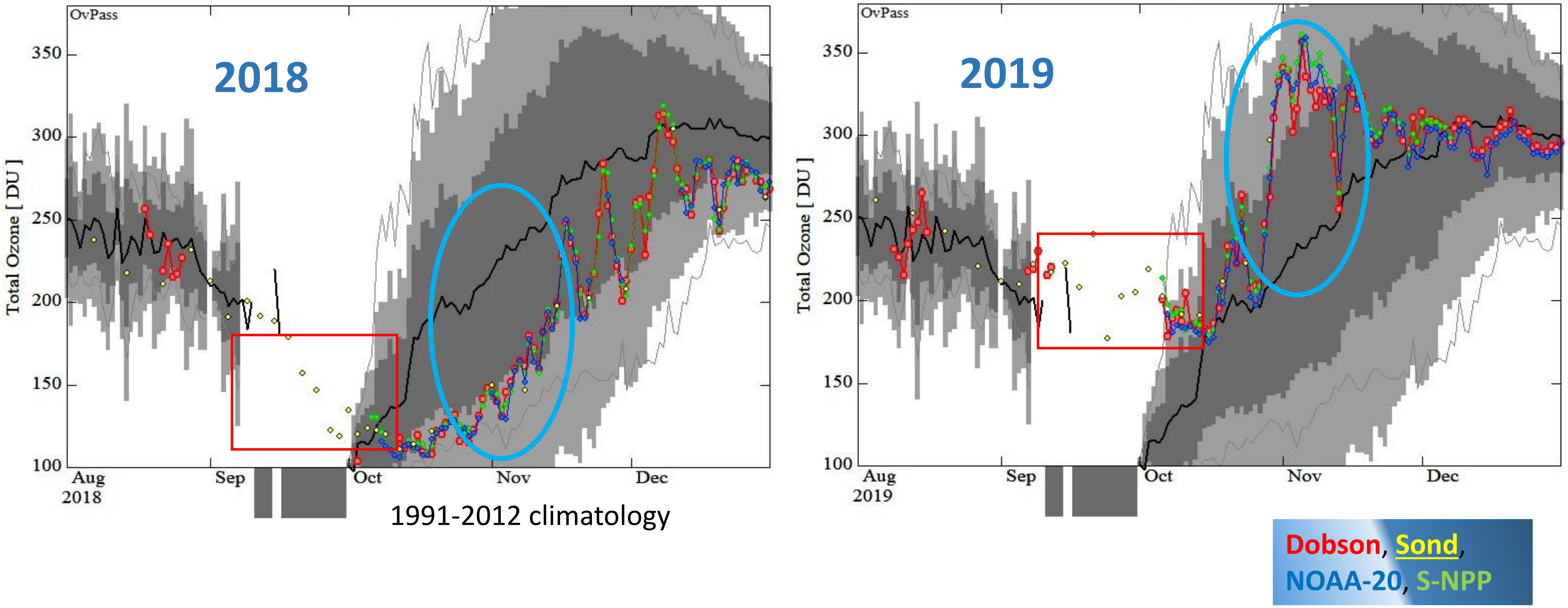




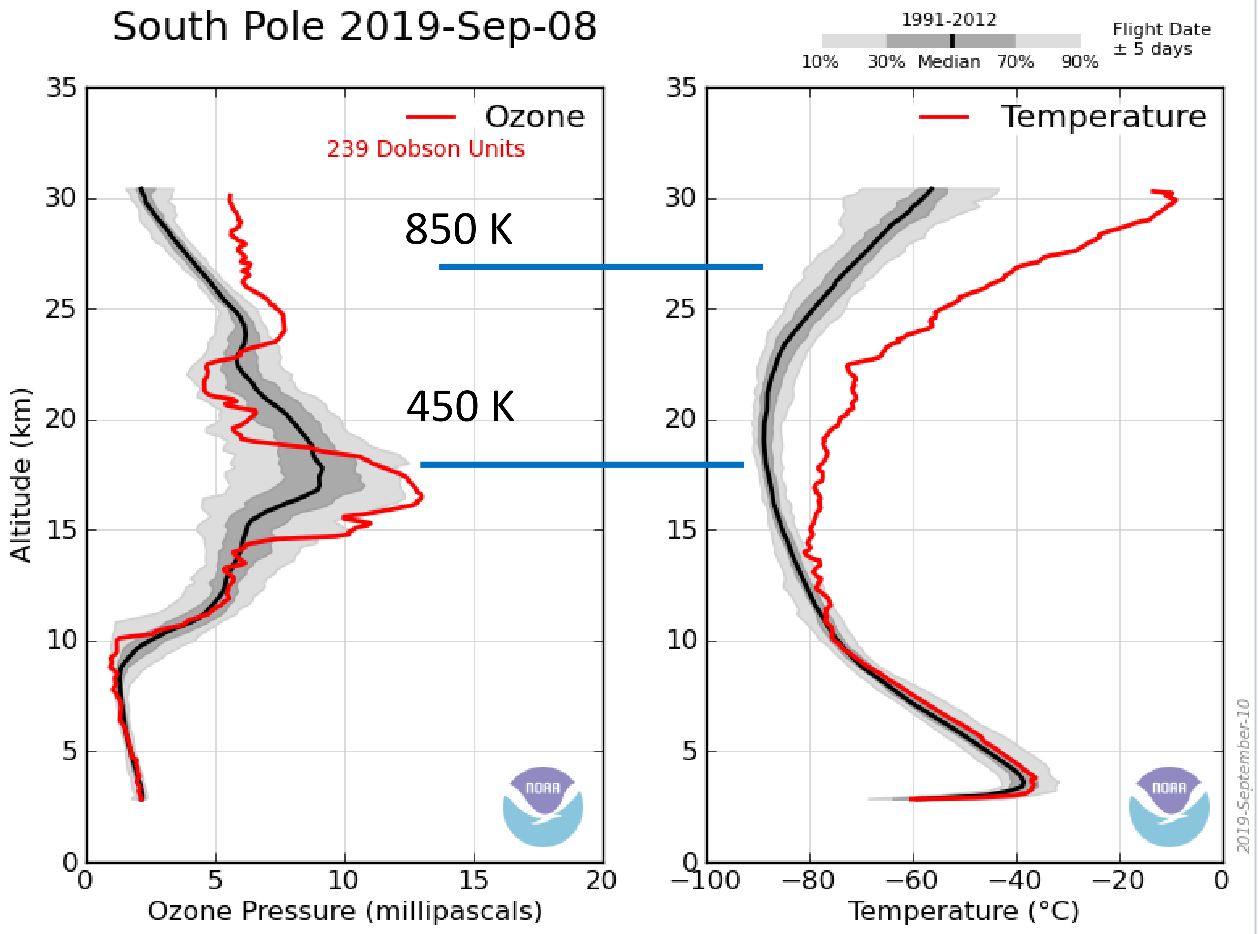
OCTAV-UTLS goals

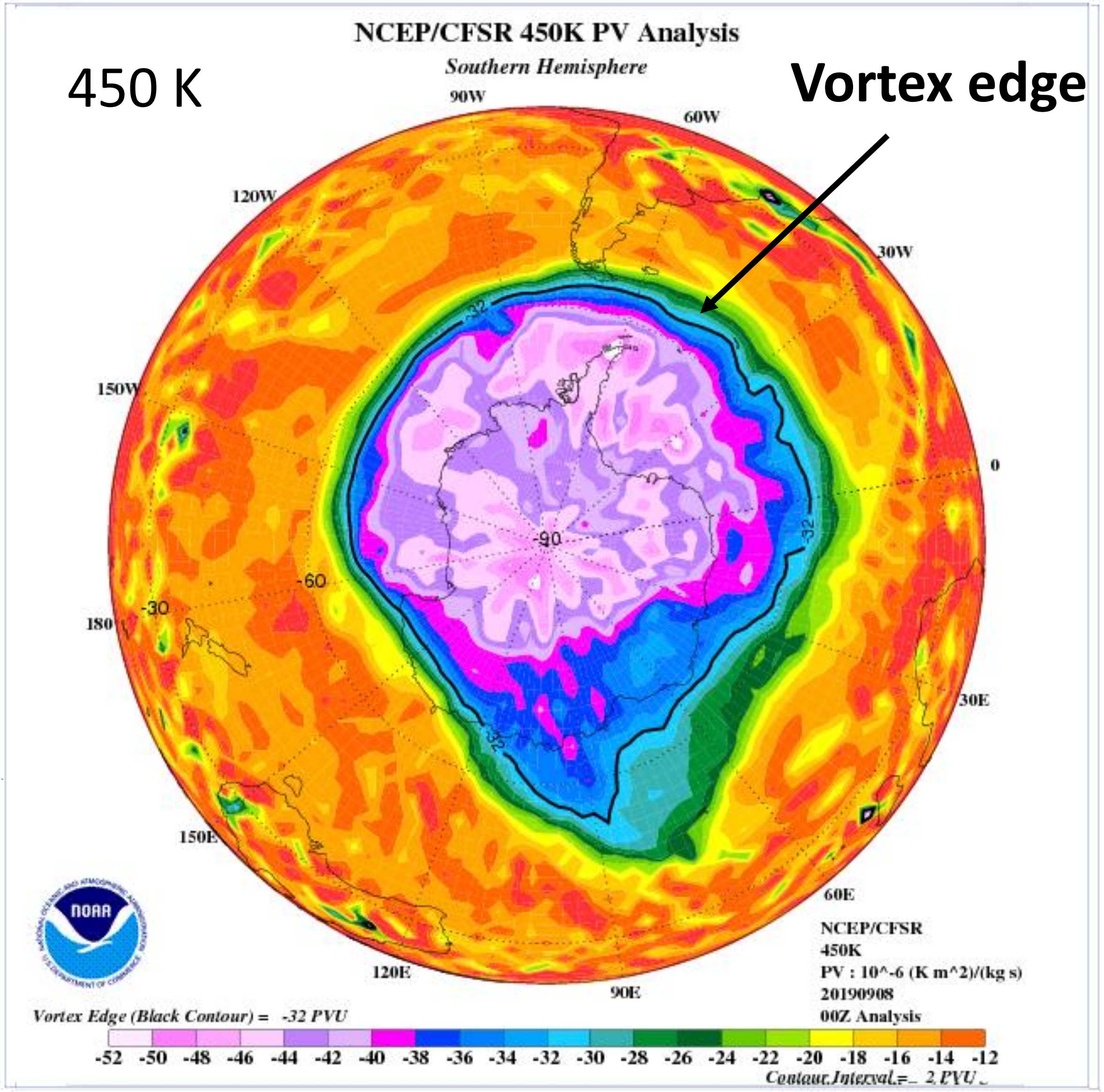
- account for dynamically induced variability of tracers and trends
- quantify trends and variability in UTLS composition by applying consistent analysis methods using cross platform observations

NOAA-20 Total ozone, South Pole
2018 vs 2019 season



2019 was a special year when vortex was shifted from South Pole: Satellite provides interpretation and explanation of the event



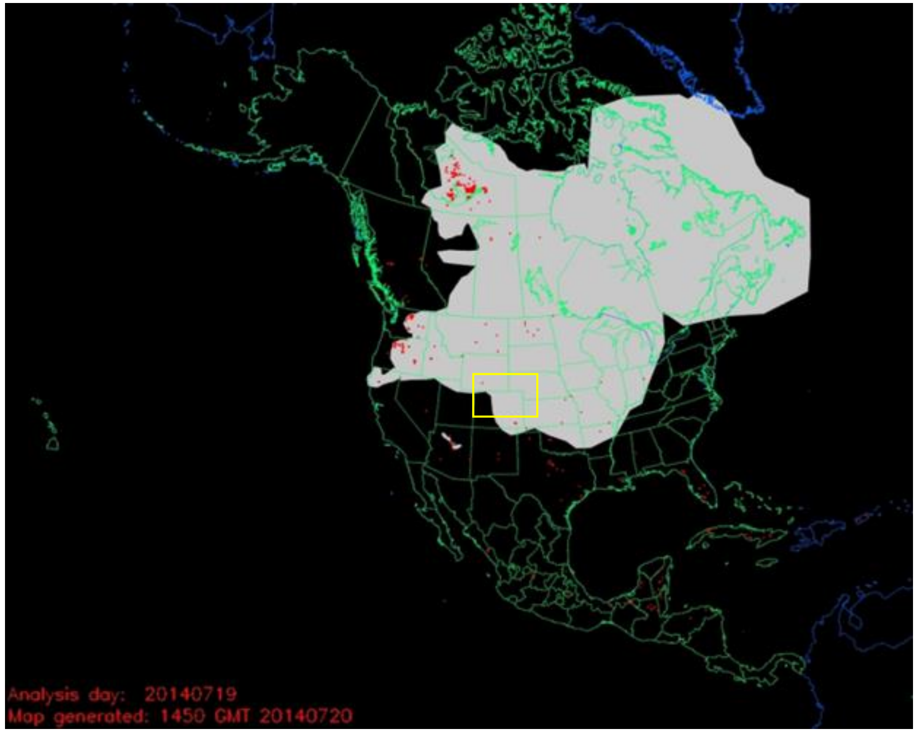


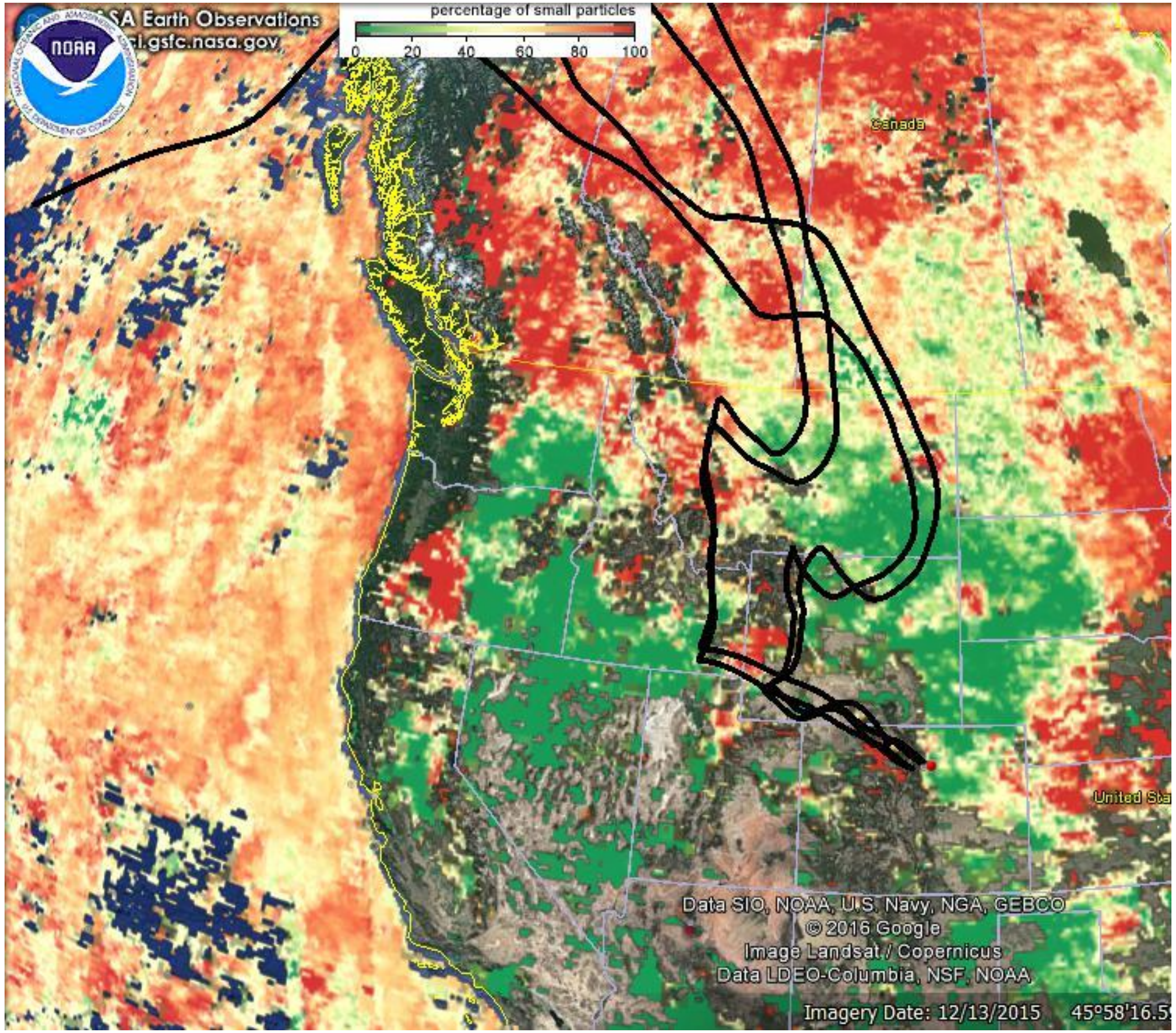
Future topics: research, applications and development.

- Regional vs zonal vs global stratospheric ozone recovery –gridded records
- Tropospheric ozone changes (geostationary satellites) – regional processes and attribution to the sources
- UTLS composition changes - surface temperature and precipitation patterns – seasonal to inter-annual impacts – verify models
- Atmospheric composition (assimilation and chemistry) in NOAA weather forecast models - attribution
- New products: aerosol (OD and SSA), volcanic SO_2 height, cloud cover/height, hourly/daily temperatures, vertical moisture; diurnal ozone, HCHO and NO2 changes for air pollution studies
- Data for GB station overpass criteria, NRT format.

Extra slides

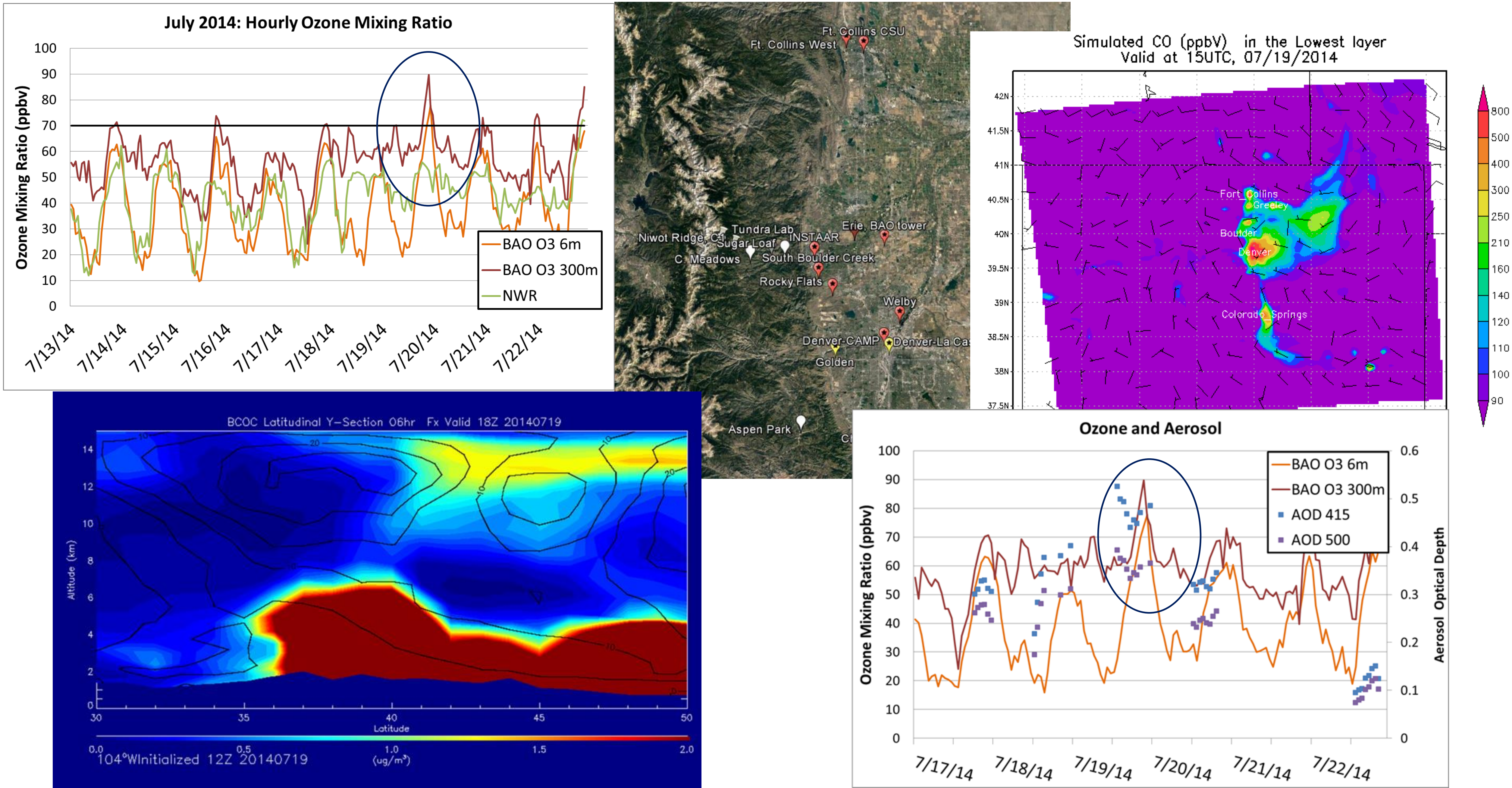
July 19, 2014 – Wildfire airmass Identification Method





Long range transport of wildfire plumes from boreal regions has been detected previously and can impact ozone production at intercontinental distances.
(Val Martin et. al, 2006)

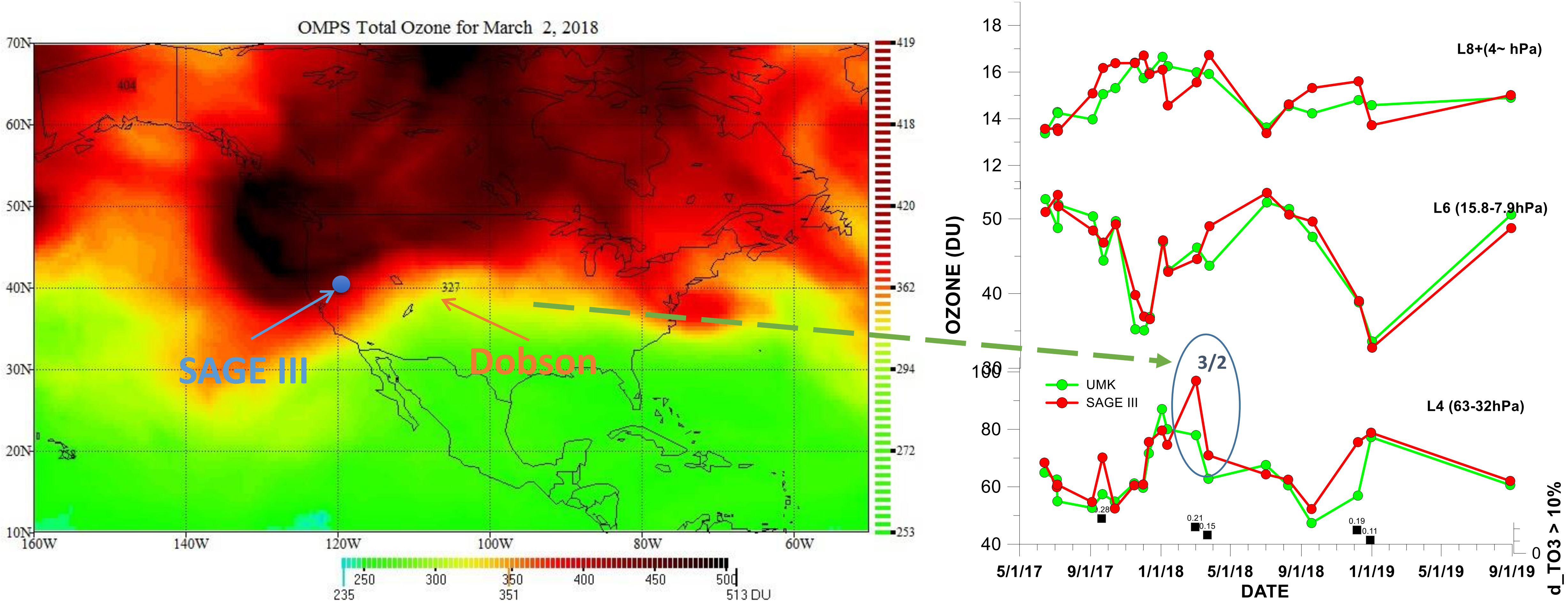
FRAPPE campaign in CO, July 2014 – biomass burning episode



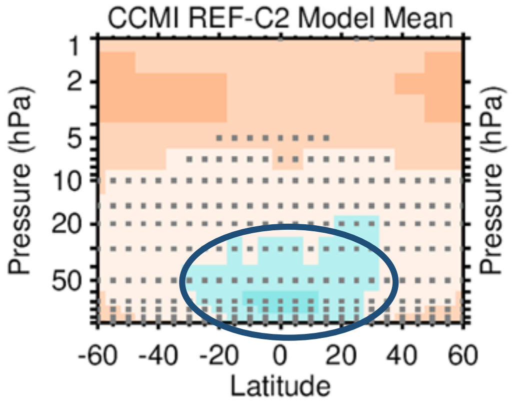
Data location

- Ozonesondes: ftp://aftp.cmdl.noaa.gov/data/ozwv/Ozonesonde/SouthPole,Antartica/100MeterAverageFiles/
- PV plots: https://www.cpc.ncep.noaa.gov/products/stratosphere/

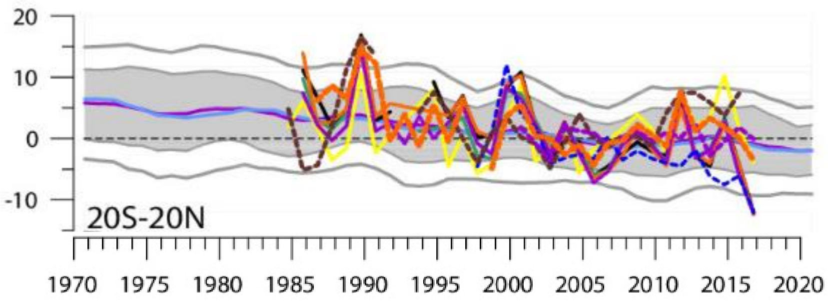
Total ozone OMPS fields align along the PV gradient. Ozone maps help to interpret ozone variability at GB station vs satellite overpass (i.e. SAGE III ISS)



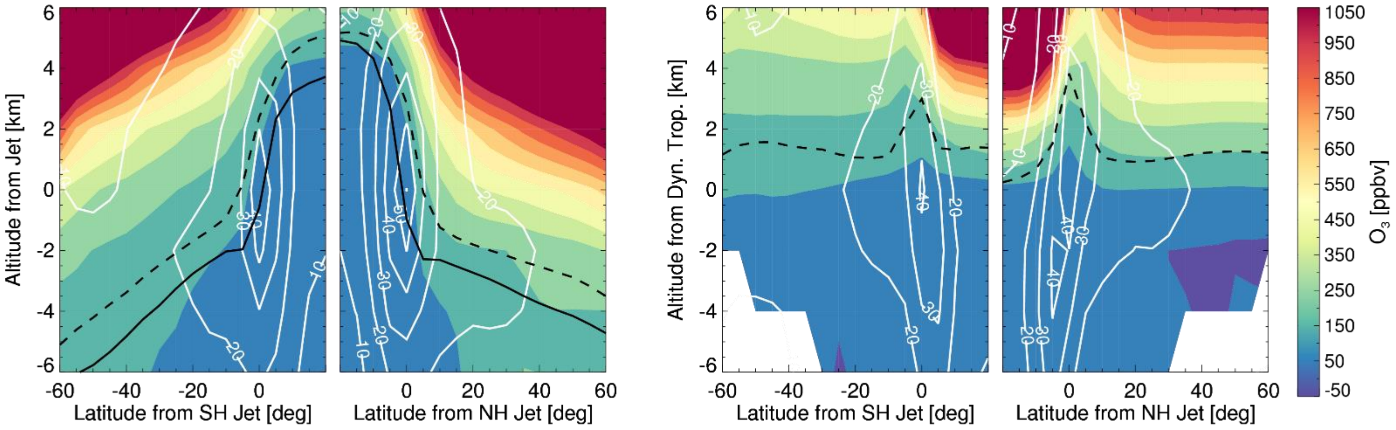
OCTAV – UTLS
Observing Composition Trends and Variability in the UTLS



Lower stratosphere (70 hPa)



MLS, DJF 2011-2013, 2 PVU tropopause, Subtropical Jet

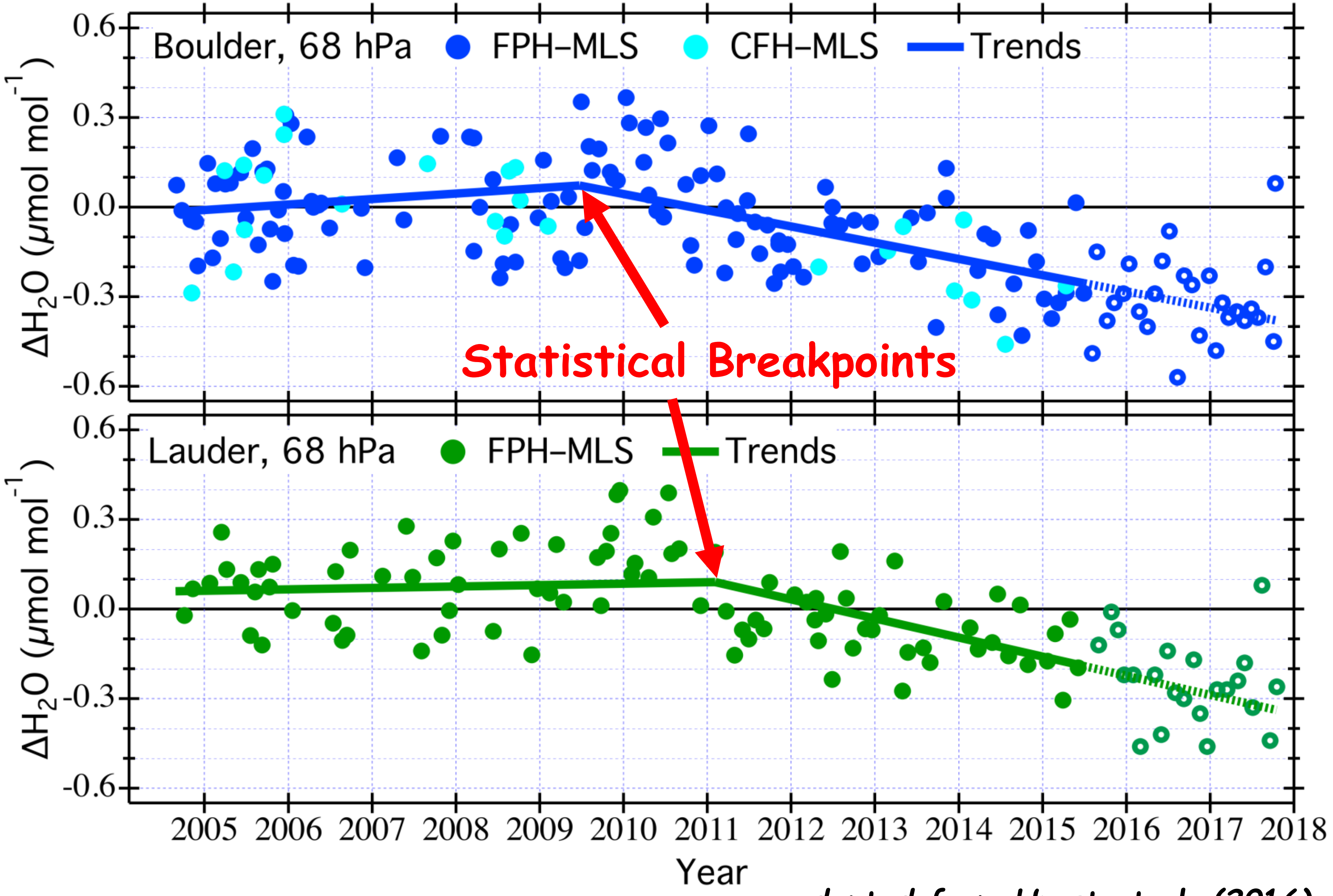


OCTAV-UTLS

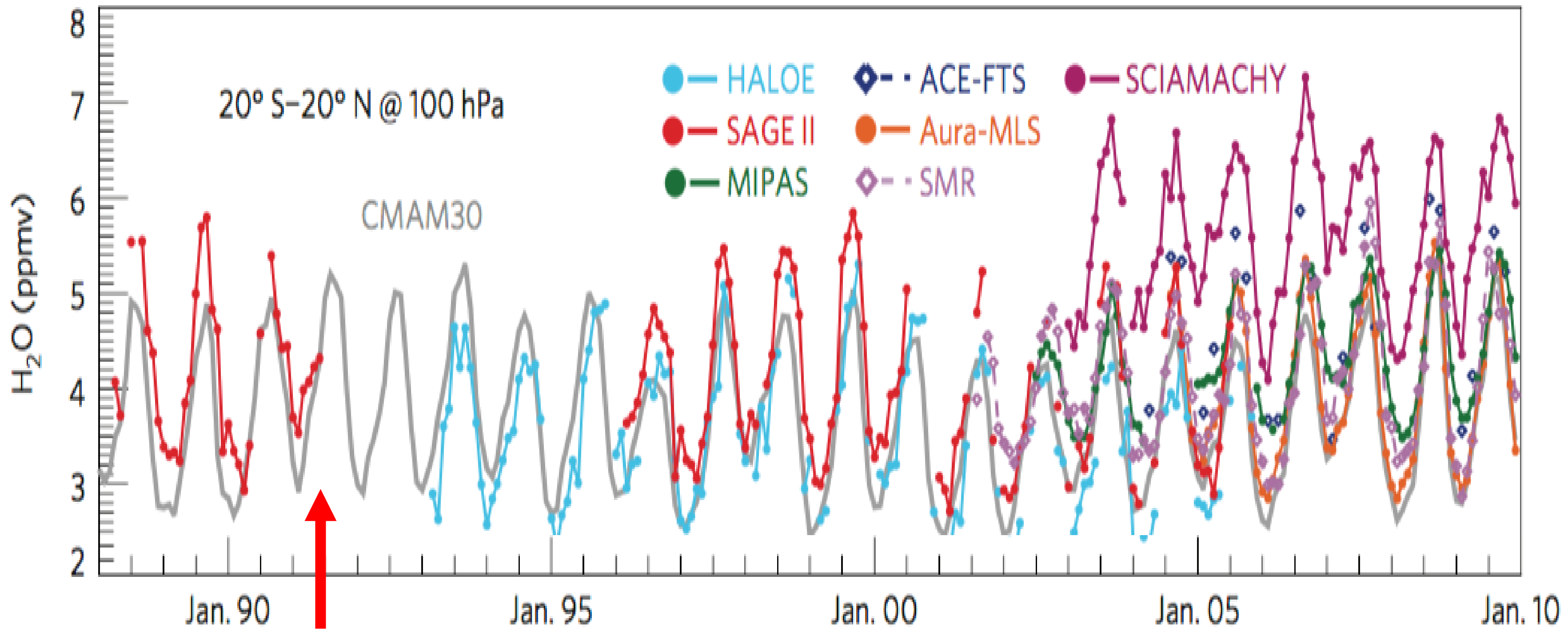
- account for dynamically induced variability of tracers and trends
- quantify trends and variability in UTLS composition by applying consistent analysis methods using cross platform observations

FP vs Satellite Drifts

FPH – MLS



adapted from Hurst et al. (2016)



20° S–20° N @ 100 hPa
HALOE
ACE-FTS
SCIAMACHY
SAGE II
Aura-MLS
MIPAS
SMR
CMAM30
H_2O (ppmv)
Jan. 90
Jan. 95
Jan. 00
Jan. 05
Jan. 10

Composition Products from Hyperspectral Thermal Sounders

Chris Barnet

Science and Technology Corporation, STC

At the

2020 JPSS/GOES Proving Ground / Risk Reduction (PGRR) Summit

Feb. 27, 2020

STC Team: Nadia Smith, Rebekah Esmaili

Other Developers: STAR NUCAPS Team, NASA JPL, and NASA GSFC

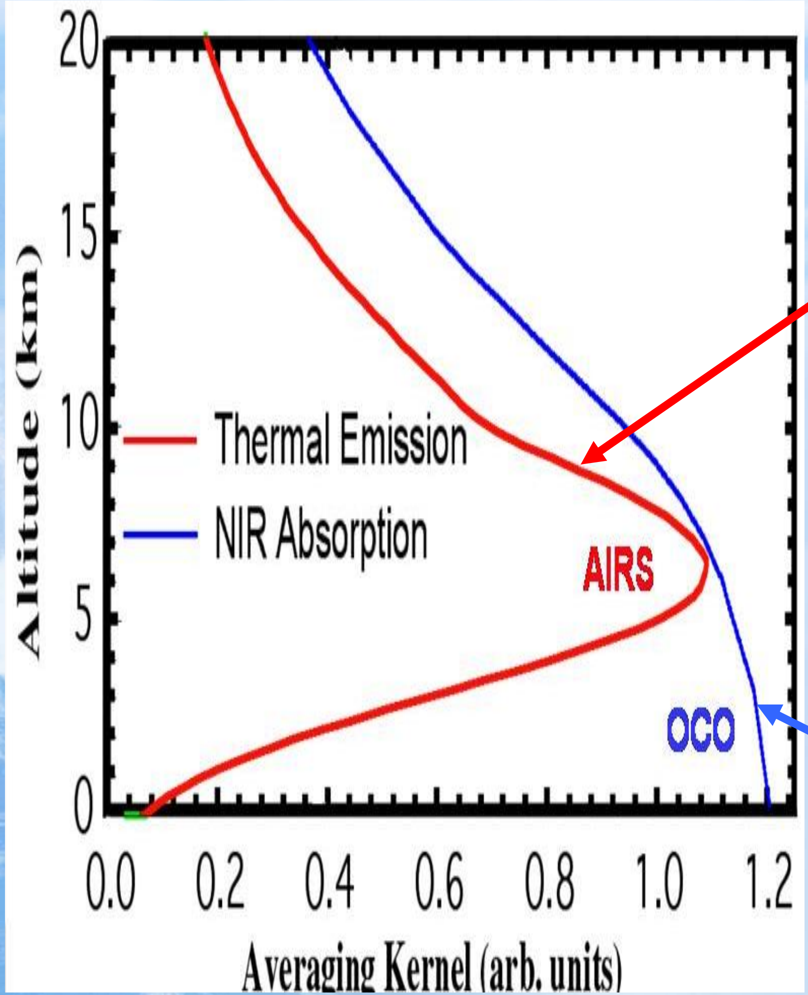
Past Developers: Wallace McMillan, Eric Maddy, Antonia Gambacorta …

Measurement Approaches

	Passive-Thermal	Passive-Solar	Active
Source Function	Planck Function	Sun	LASER
Measures	Mid-trop column	Total Column	Total Column/Profile
Sampling	Global, Day & Night	Global, Daytime	TBD
Interference	Strong interaction with T(p), q(p)	Weak interaction with T(p), q(p)	Very weak interference
Data availability	20+ years, launch almost guaranteed	Research grade, 2-3 mission, no follow-on	Future missions

- An excellent overview of instruments, methods, and status by Dave Crisp et al. “A constellation architecture for monitoring carbon dioxide and methane from space”
- http://ceos.org/document_management/Virtual_Constellations/ACC/Documents/CEOS_AC-VC_GHG_White_Paper_Version_1_20181009.pdf

Utilization of thermal product requires knowledge of vertical averaging



- Thermal instruments measure mid-tropospheric column
  - Peak of vertical weighting is a function of clouds, lapse rate and water and ozone content.
  - Age of air is on the order of weeks or months.
  - Significant horizontal and vertical displacements of the trace gases from the sources and sinks.
- Solar/Passive instruments (*e.g.*, SCIA, OCO) & laser approaches measure a total column average.
  - Mixture of surface and near-surface atmospheric contribution
  - Age of air varies vertically.

Space-borne operational hyperspectral *thermal sounders* to be discussed today

- We have 5 operational thermal sounder suites at this time

Satellite	Instruments	Overpass	Launch dates
Aqua	AIRS, AMSU	1:30 **	2002
Metop	IASI, AMSU, MHS	9:30	2008, 2012, …
S-NPP, JPSS	CrIS, ATMS	1:30	2011, 2017, …

- There are numerous differences in these sounding suites
  - **Instruments are different**
    - Spectra resolution, sampling and noise
    - Spatial sampling
    - Degradation over time
  - **Algorithm differences**
    - NOAA algorithms became operational ~1-2 year after launch and have asynchronous maintenance schedules (e.g., training datasets are different)
    - 9:30/1:30 orbits co-location w/ in-situ is different (affects tuning/regression training and makes validation more difficult)
  - **Sensitivity to a-priori assumptions**
    - Sensitivity to meteorology (e.g., clouds at 9:30 vs 1:30 am/pm)
    - Sensitivity to seasonal and climate changes (e.g., 8% increase in CO_2, 2002-2017)

Trace Gas products were not the primary design criteria of the modern satellite sounding suite

** in early 2022 Aqua will drop out of A-train // begins a 6 year drift to 5:30

At STC, we are attempting to bridge NASA and NOAA sounding development efforts

- Operational products are not as much fun as you think.
  - With limited funding we are attempting to satisfy all users with "one" algorithm.
- What we are doing: NASA AIRS v5.9 → R2O → NUCAPS → O2R → CLIMCAPS → R2O ?? → *NECAPS(GFS or HRRR)*

	NASA/CLIMCAPS	NOAA/NUCAPS
A-priori	Merra-2	Global regression (i.e.,model independent)
Error propagation	2-D covariance	Diagonal
Supported systems	S-NPP NSR & FSR running (4.5 years are done) NOAA-20 has begun Aqua begins this summer	Metop –A, -B, -C S-NPP, NOAA-2x Aqua (non-op, post A-train proposal by NASA/NOAA)
Latency	~1 month f/ MERRA	Real time (~30 minutes)
Averaging Kernels?	YES – fully supported	Not operational, but can provide via science code

Operational and experimental retrieval products

Supported profile products

Retrieval Product	Spectral Region(s)
Lower stratosphere / Upper Trop Ozone, O_3(p)	990 – 1070 cm^{-1}
Mid-tropospheric Carbon Monoxide, CO(p)	2155 – 2220 cm^{-1}
Mid-troposphere Methane, CH_4(p)	1220 – 1350 cm^{-1}
Mid-troposphere Carbon Dioxide, CO_2(p)	660 – 760, 980, 2200 – 2400 cm^{-1}

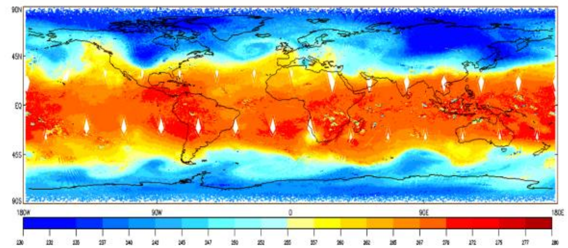
Experimental profile products

Mid-troposphere Nitric Acid, HNO_3(p)	760 – 1320 cm^{-1}
Lower-stratosphere Nitrous Oxide, N_2O(p)	1290 – 1300 cm^{-1} 2190 – 2240 cm^{-1}
Volcanic mid-tropospheric Sulfur Dioxide, SO_2(p)	1343 – 1383 cm^{-1}

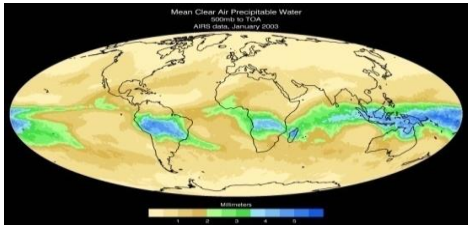
Noise filtered S-FOV detection flags

Isoprene (C5H8)	893.8 cm^{-1}
Ethane (C2H6)	822.5 cm^{-1}
Propylene (C3H6)	911.9 cm^{-1}
Ammonia (NH3)	966.25 + 928.75 cm^{-1}

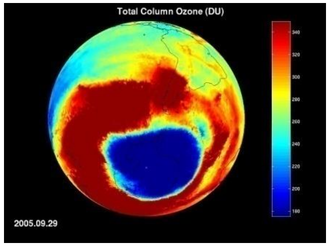
500 hPa Temperature



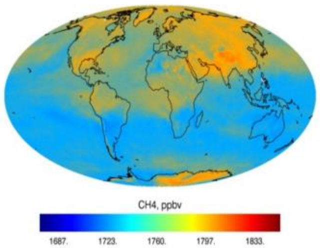
500 hPa Water Vapor



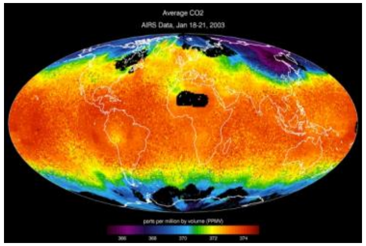
Ozone



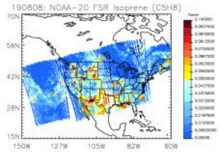
Methane



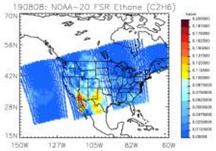
Carbon Dioxide



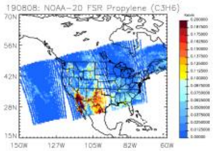
Isoprene



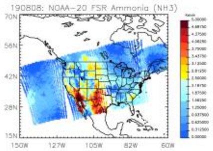
Ethane



Propylene



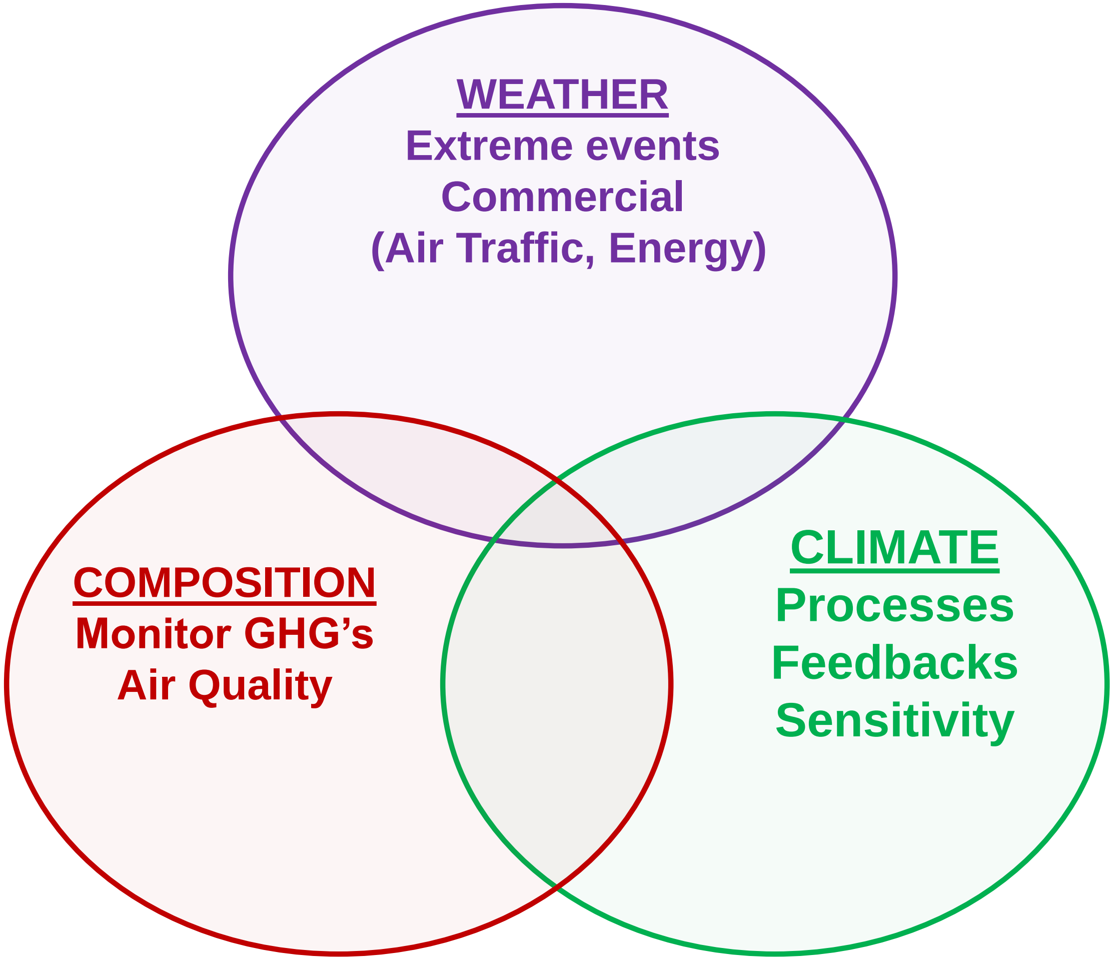
Ammonia



Relevant ROSES-TASNPP funded research activities at NASA – began 1.5y ago

- Larrabee Strow (UMBC) Climate anomalies of CO2, CH4, N2O, etc. from CrIS and AIRS
- Helen Worden (UCAR): Extend MOPITT Carbon Monoxide from CrIS + TROPOMI
- Karen Cady-Pereira (AER) and David Henze (U.Colorado): Ammonia retrieval and inverse modeling from CrIS
- Vivienne Payne: Peroxyacetyl Nitrate (PAN) retrievals from CrIS

Together these algorithms can ***contribute*** to the needs of three communities



Applications we are NOT targeting with NUCAPS & CLIMCAPS.

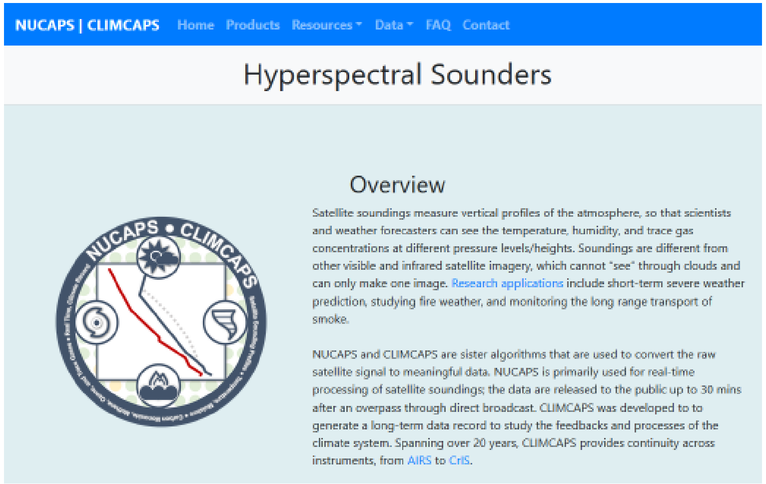
Topic	Potential applications for thermal sounding products
Long term trends	For GHG-relevant gases we have very low information content. We relax to a-priori assumptions so we only see ~50% of the signal. Large cross-talk between CO2/T, N2O/T, CH4/q, etc. Recommend using Larrabee Strow's radiance anomaly product for trends
GHG Monitoring	We have very low (and variable) sensitivity in the boundary layer. Need passive solar or active sensors to
High spatial resolution approaches	Clouds are still a major obstacle for infrared sounding. NU/CLIMCAPS are intended as global quick look products NU/CLIMCAPS can be used as "triggers" for more advanced algorithms could launch algorithms that are computationally expensive (e.g., NASA TASNPP or AC4 funded algorithms, MUSES, etc.)

Applications we are targeting with NUCAPS & CLIMCAPS.

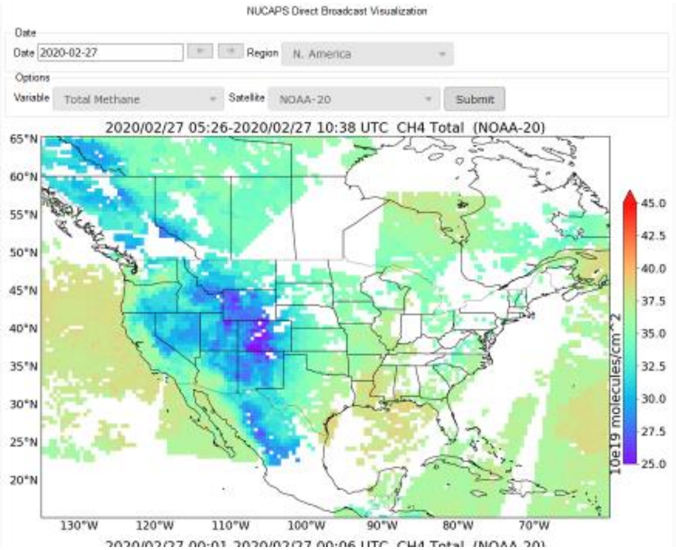
Topic	Potential applications for thermal sounding products
T(p), q(p) sounding and data assimilation	We require knowledge of CO2, O3, HNO3, N2O etc. to derive T(p) We require knowledge of CH4 to derive q(p)
GHG Monitoring	We enhance the boundary layer sensitivity of passive solar or active methods.
Ozone	Ozone hole; Intrusions and mid-trop O3 (Langford 2018 Atmos. Env); LS O3 trends (Ball 2018 ACP, Wargan 2018 GRL); CO/O3 ratio (Anderson 2016 Nat.Comm)
Carbon Dioxide (CO2)	Contribute to discussion of seasonal cycle amplitude (Barnes 2016 JGR), clear bias and diurnal “rectifier” effects (Corbin 2008 JGR), and stratospheric/troposphere CO2 gradient. Evaluation of transport models (mixing into mid-trop, etc.). Note that separability of T/CO2 is significantly improved with use of Merra-2 a-priori and with AMSU/ATMS O2 bands for T(p)
Carbon Monoxide	Long-term trends of CO (Worden 2013 ACP). Impact on OH (Gaubert 2017 GRL), Seasonal cycle (Park 2015 JGR) and CO/CO2 emission factors (Wang 2009 ACP)
Methane (CH4)	Monitoring of Amazon CH4 (Bloom 2016 ACP), Changes to Arctic emissions (Shakhova 2010 Science, Thornton 2016 GRL)
Other trace gases	Nitric Acid, Nitrous Oxide, Sulfur Dioxide, Isoprene, PAN, Acetylene, Methanol, etc Potentially useful as tracer-tracer correlations, emission ratios (errors tend to cancel), source type identification, etc.

More information

- Rebekah Esmaili and Emily Berndt (NASA/SPoRT) created a NUCAPS & CLIMCAPS landing site: https://weather.msfc.nasa.gov/nucaps
  - Product descriptions, data access, FAQ's and more



- Rebekah created a direct broadcast (real time) visualization page for selected NUCAPS products from CSPP: http://sigma.umd.edu/resmaili/nucaps.html
  - T, q, O3, CO, CH4, d.o.f., etc.

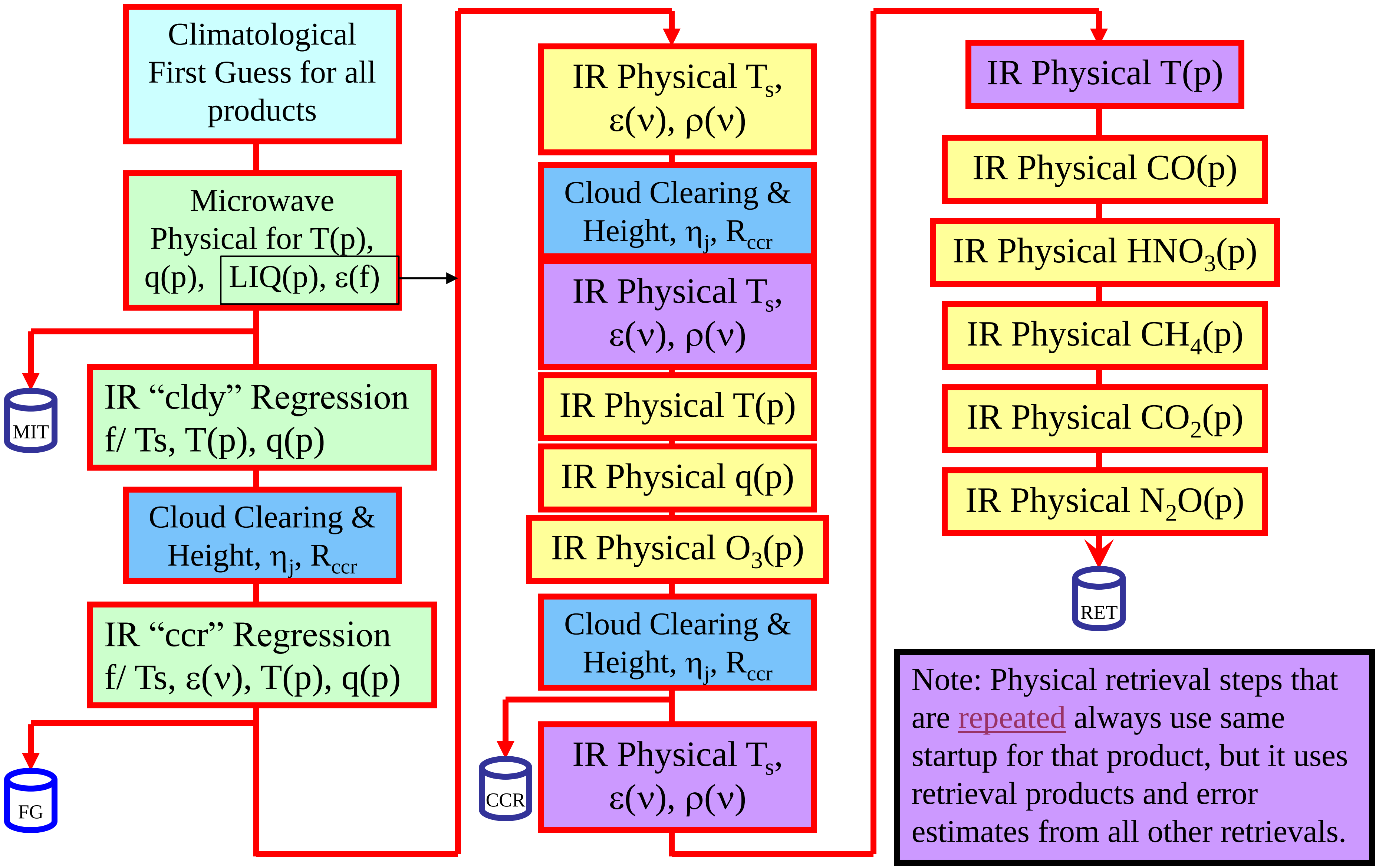


HOW WE TRY TO ADVANCE COMPOSITION PRODUCTS

- **We have actively sought out partners to help us explore and characterize the value (or lack of value) of specific products (e.g., O_3, CO, CH_4)**
  - **Need user feedback on a-priori choices**
- **JPSS funds a project to characterize all NUCAPS trace gases (PI: Frost)**
- **I personally find scientific field campaigns the most valuable:**
  - **We learn about user-specific needs.**
  - **Users gain experience of our products and caveats.**
  - **Burst of development.**
  - **We can tailor our products to application needs.**

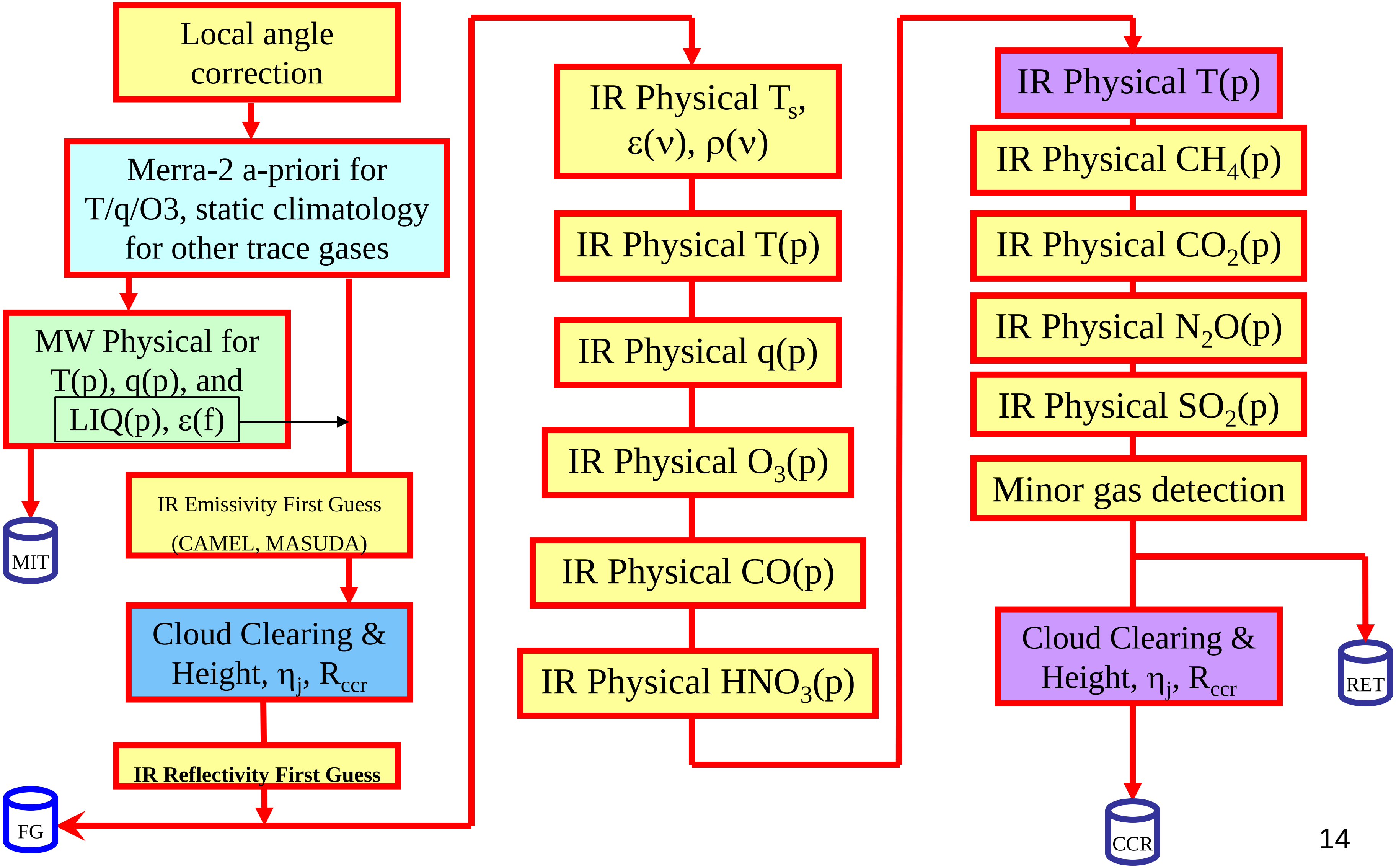
Link to CLIMCAPS algorithm paper: **https://www.mdpi.com/2072-4292/11/10/1227**

Simplified Flow Diagram of the NUCAPS Algorithm (based on AIRS v5.9)

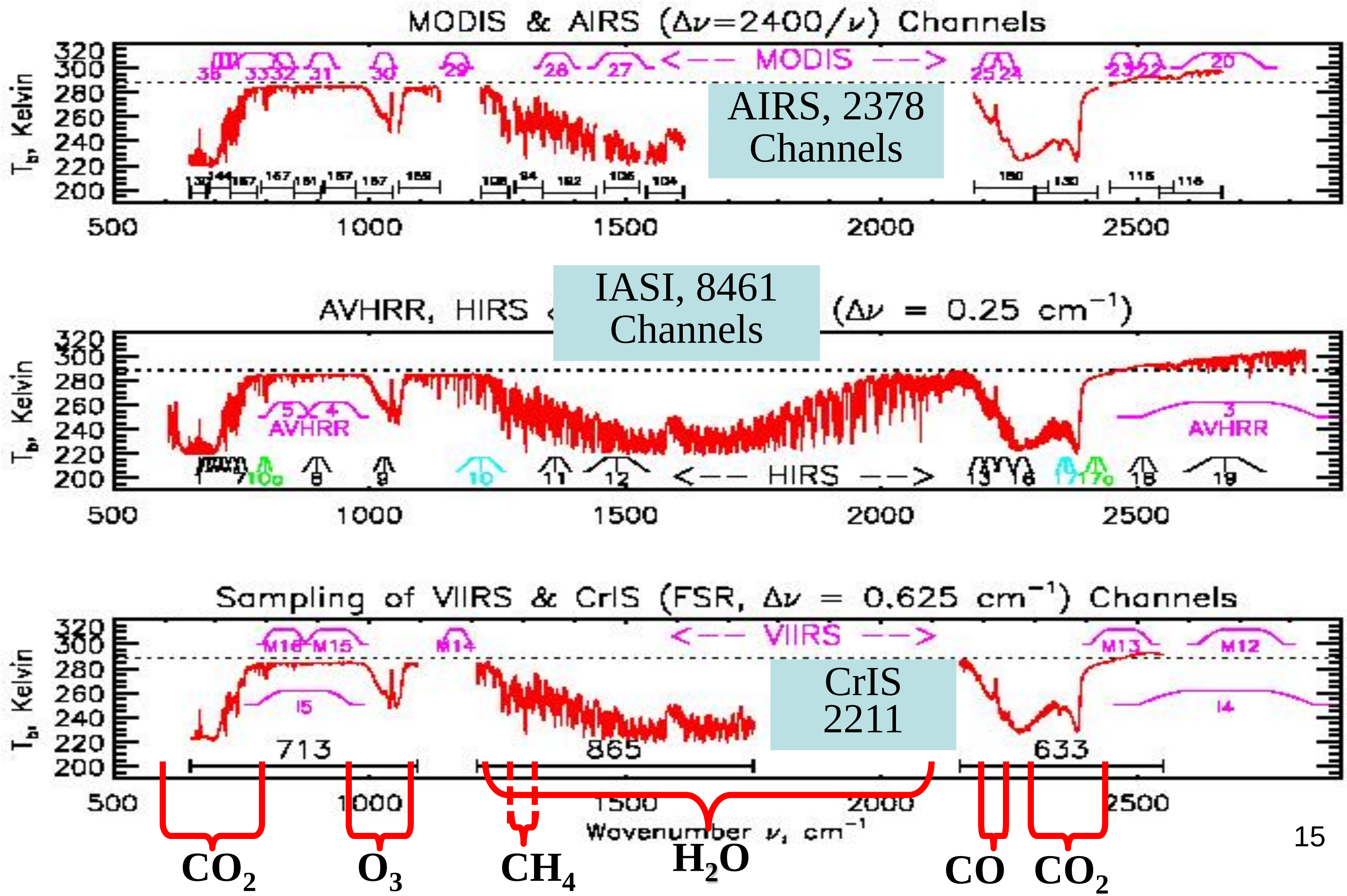


Simplified Flow Diagram of the CLIMCAPS Algorithm

Note: Repeated steps use same a-priori, w/ updated error estimates from other steps.

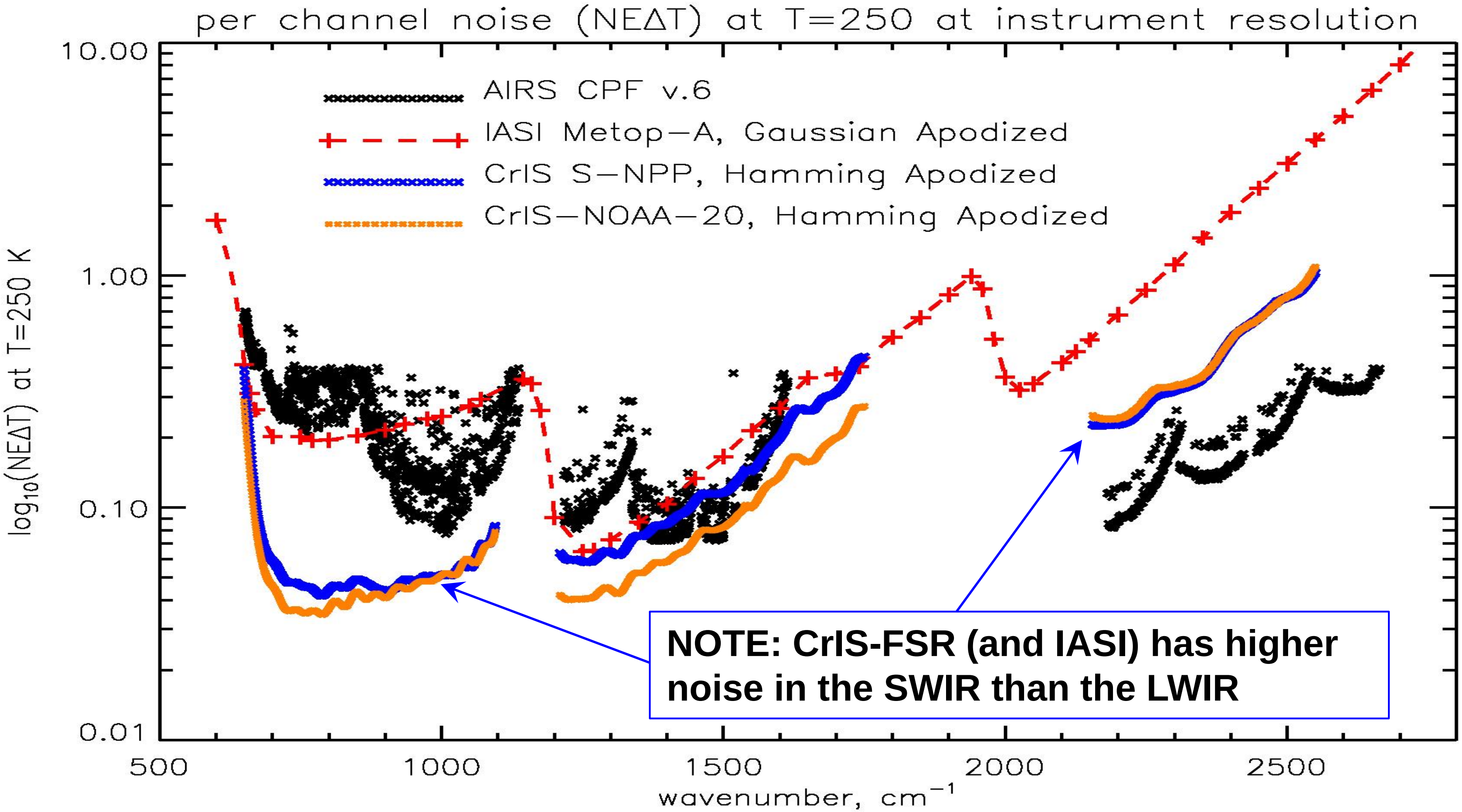


Spectral Coverage of Thermal Sounders & Imagers (Aqua, Metop-A,B,C, Suomi-NPP, NOAA-20+)



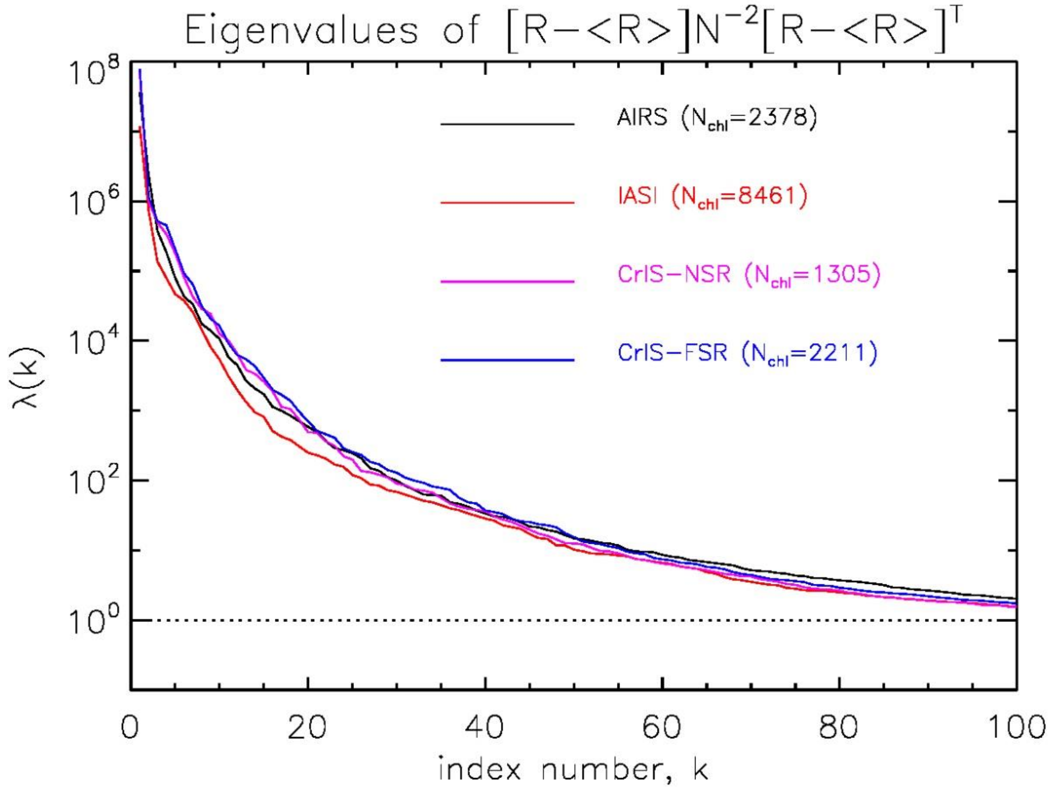
What is important for sounding is signal to noise

Per channel noise is shown as noise equivalent delta temperature (NEΔT) at a cold scene temperature (T=250 K)



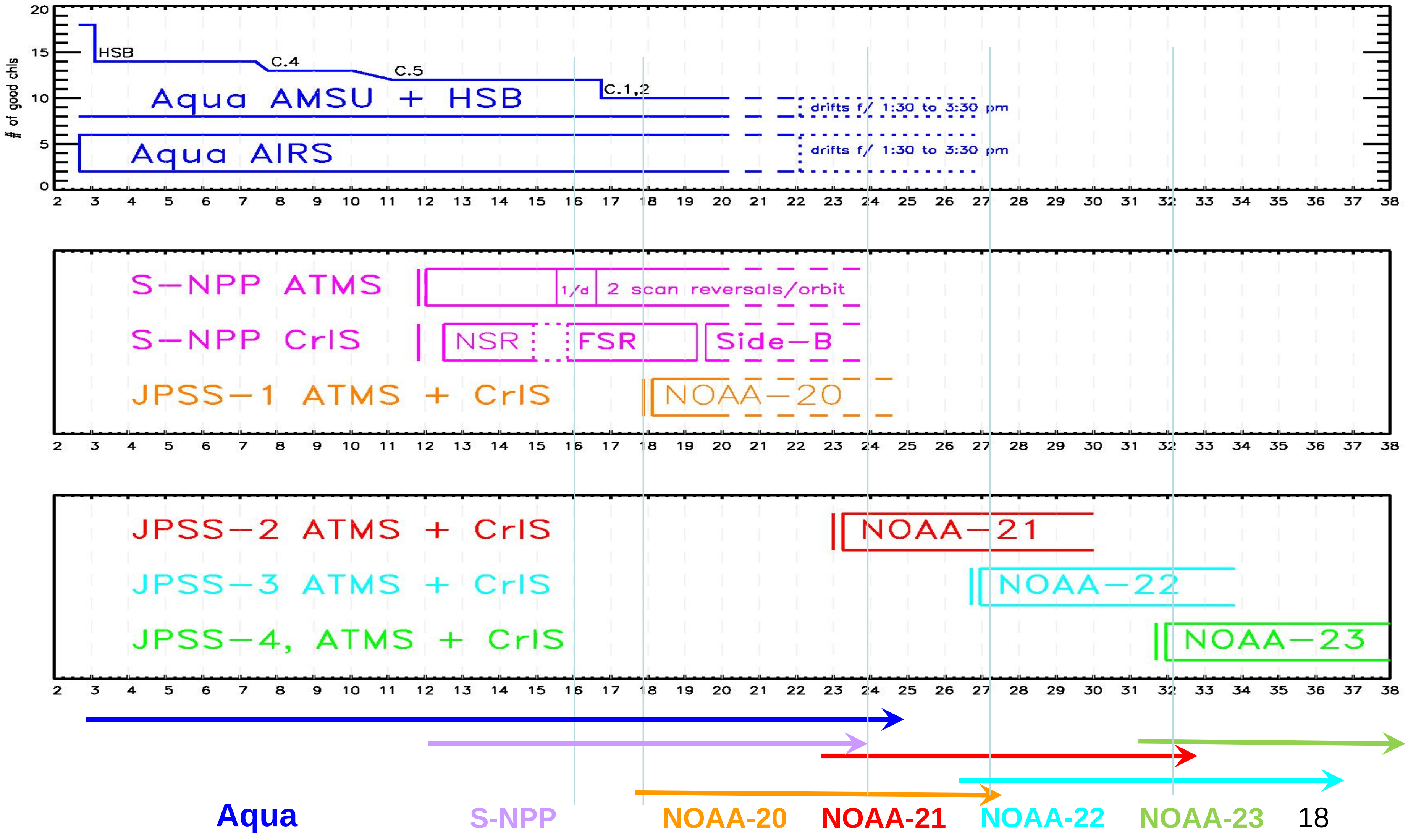
The information content of modern sounding instruments is ***amazingly*** similar

- AIRS, IASI, and CrIS each have ~100 degrees of freedom
- Even though AIRS, IASI, and CrIS have different number of channels, ILS, noise, etc.



The 1st 100 significant eigenvectors of radiance covariance for a set of focus days normalized at λ(k=200)

Choosing the cross-over points for Aqua, S-NPP, NOAA-20 and beyond



NUCAPS Trace Gas Recent Updates

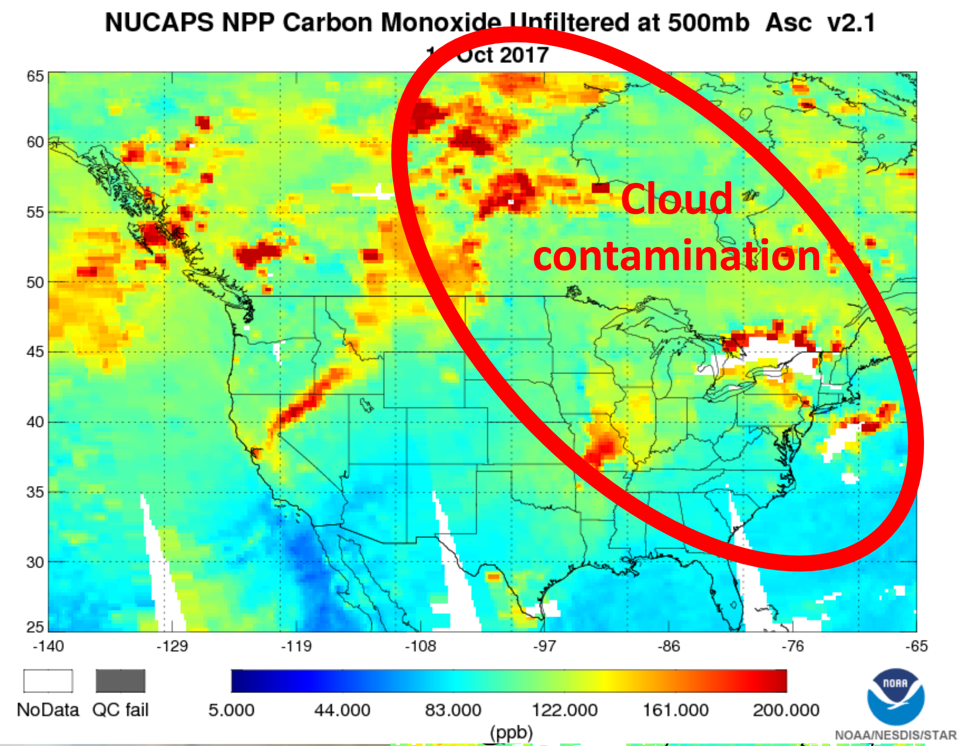
Juying Warner and Zigang Wei, AOSC/UMD

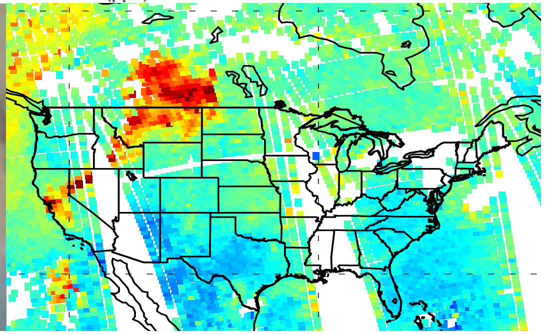
NOAA/STAR NUCAPS: Murty Divakaria,
Ken Pryor, Michael Wilson, Nick Nalli,
Changyi Tan, Tong Zhu, Tianyuan Wang

*Supported through CICS-MD and CISESS, University of Maryland

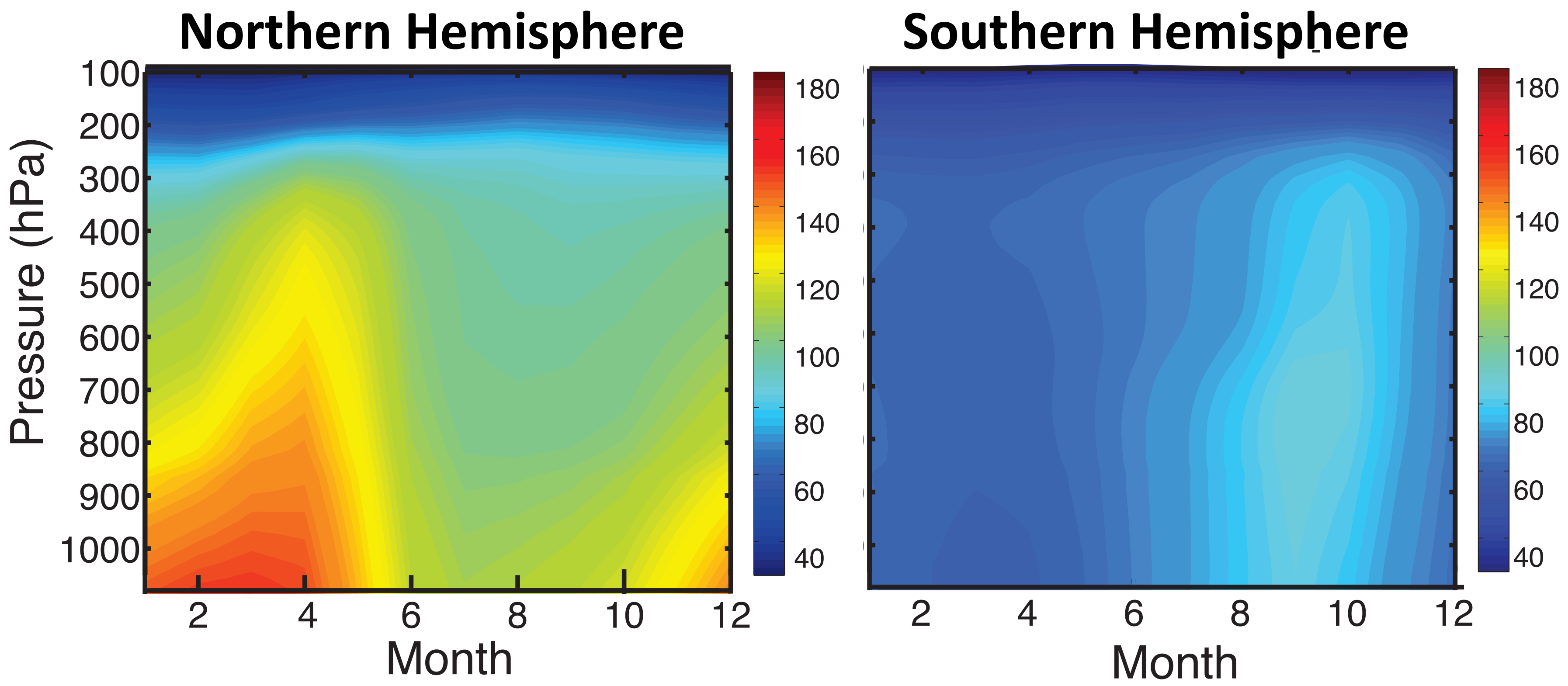
NUCAPS CO

JPSS NUCAPS Carbon Monoxide of Santa Rosa Fire 20171011





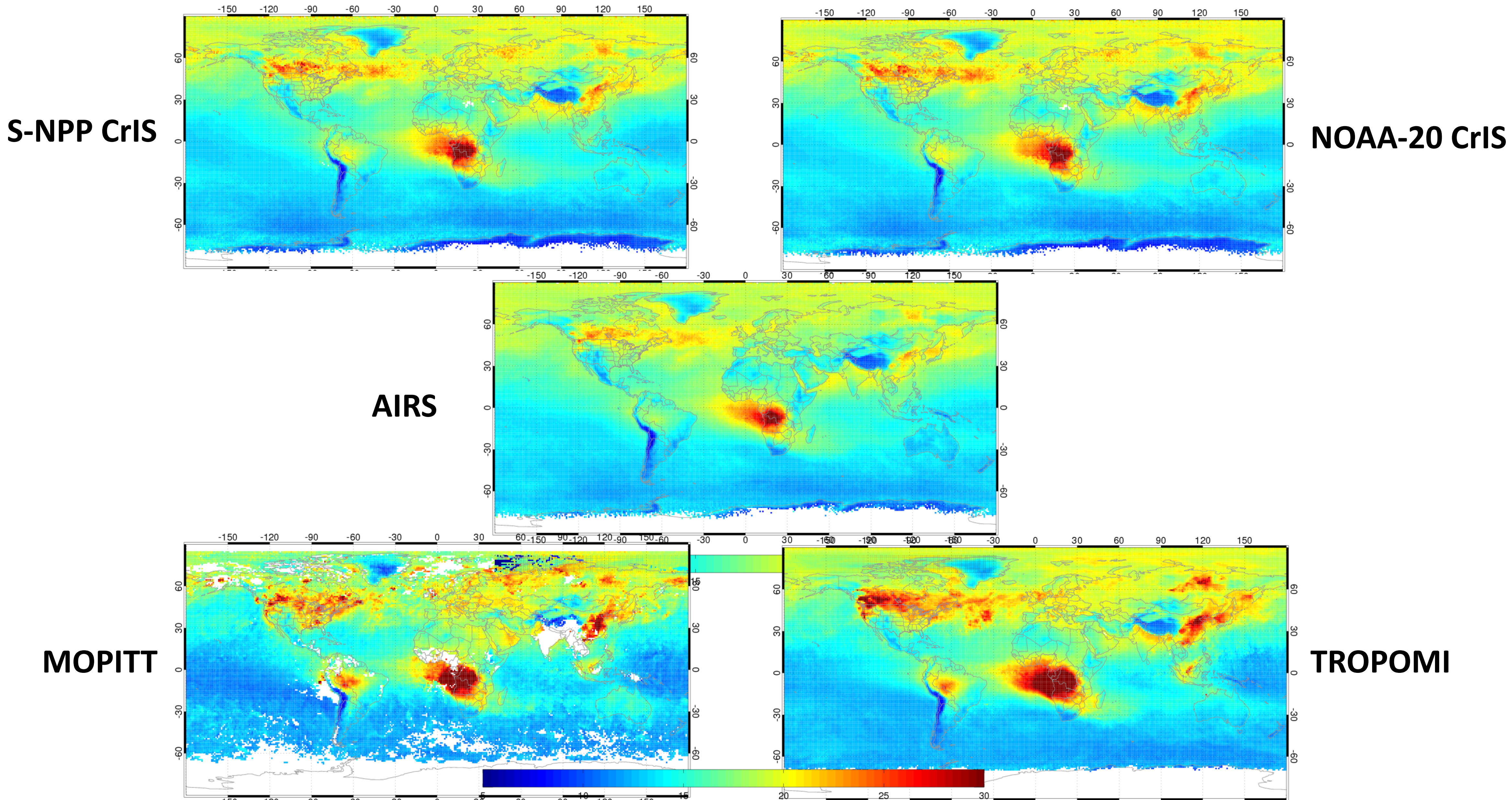
S-NPP & NOAA-20 NUCAPS CO a priori
for Operational and V2.5.2.2



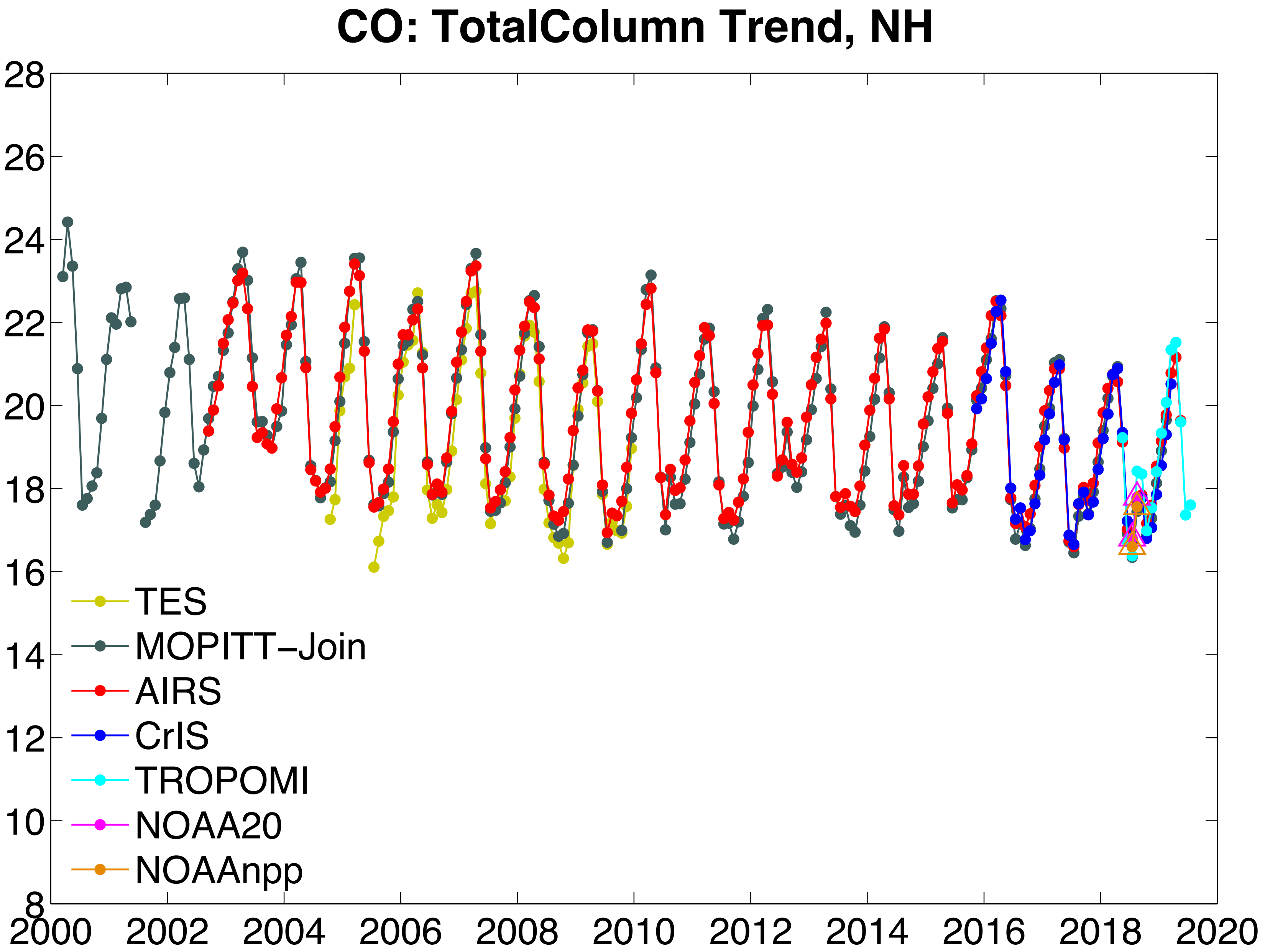
- Two hemispheric CO profiles (ppbv) developed from NCAR MOZART-GEOS5 model;
- Linearly transition between 15N and 15S;
- Monthly varying, but no year-to-year variations;
- Same approach as for AIRS, but updated to current values for NUCAPS.

Comparisons of CO Column

($x10^{17}$ mols/cm^2) 201808

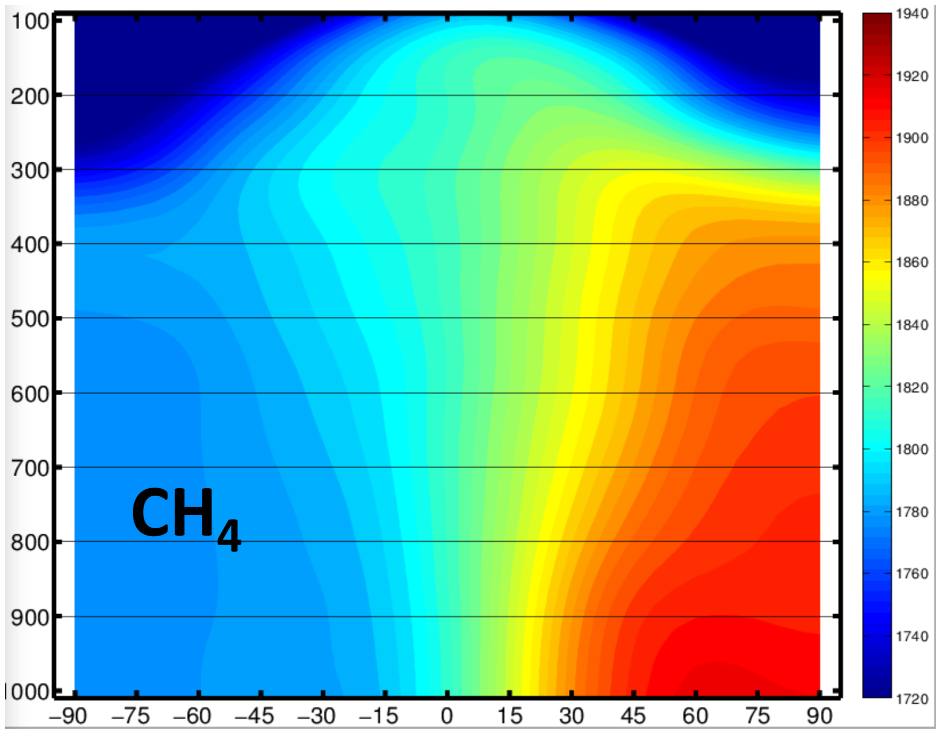


CO Trend Comparison

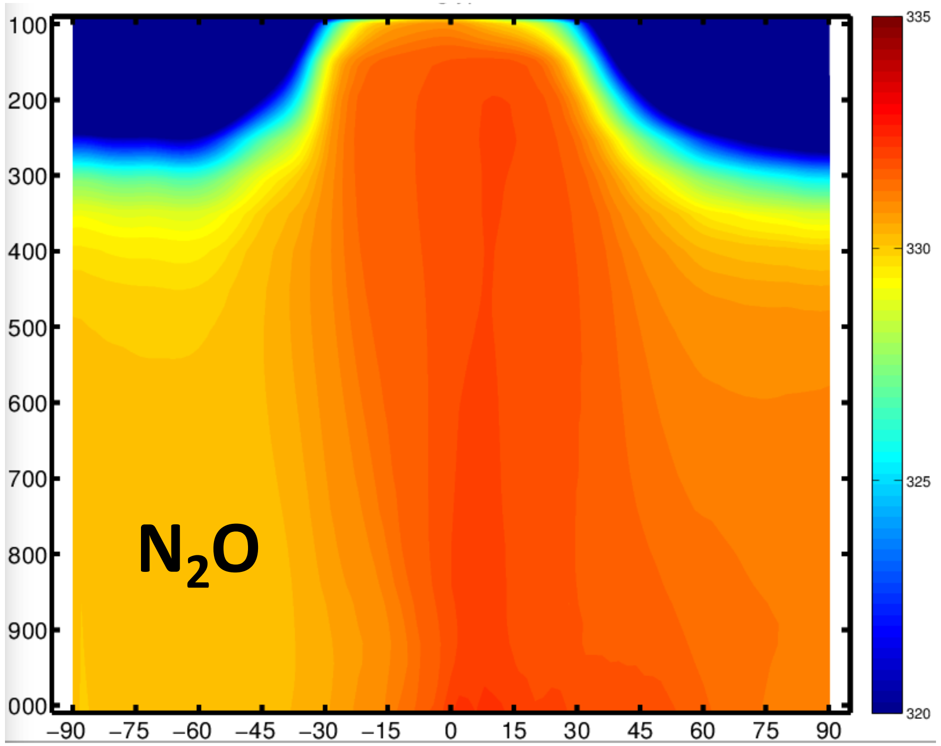


NUCAPS CH_4

CH_4 a priori/first guess - CH4fgtype=9



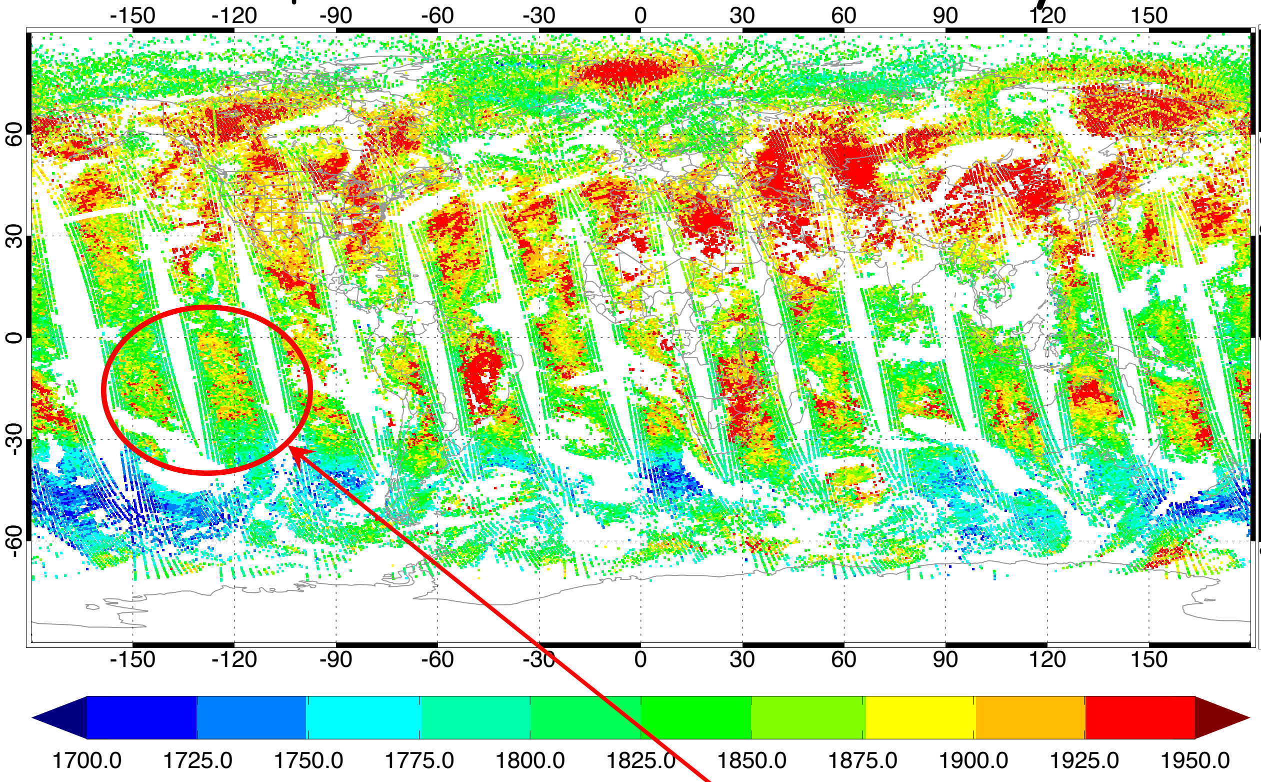
N_2O a priori/first guess - N2Ofgtype=5



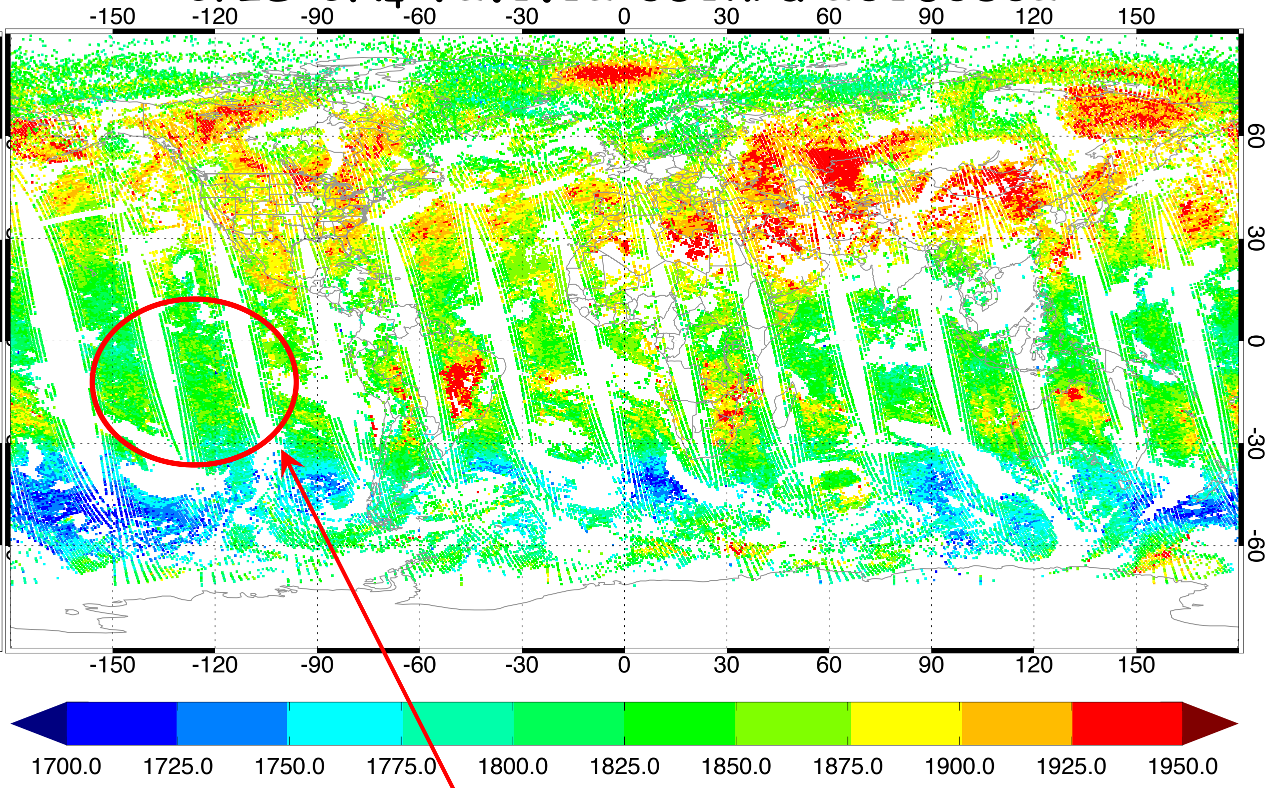
- N_2O AP are based on CTM from NASA/GSFC, with yearly change, so not for N_2O retrievals;
- CH_4 AP are based on in situ measurement;
- N_2O AP are used to improve CH_4 retrievals;
- V2.5.2.2 validation include these upgrades

Significant Improvements Lowered Biases!

CrIS CH_4 V2.1.12 351hPa 20160802 daytime



CrIS CH_4 V2.1.12 351hPa 20160802

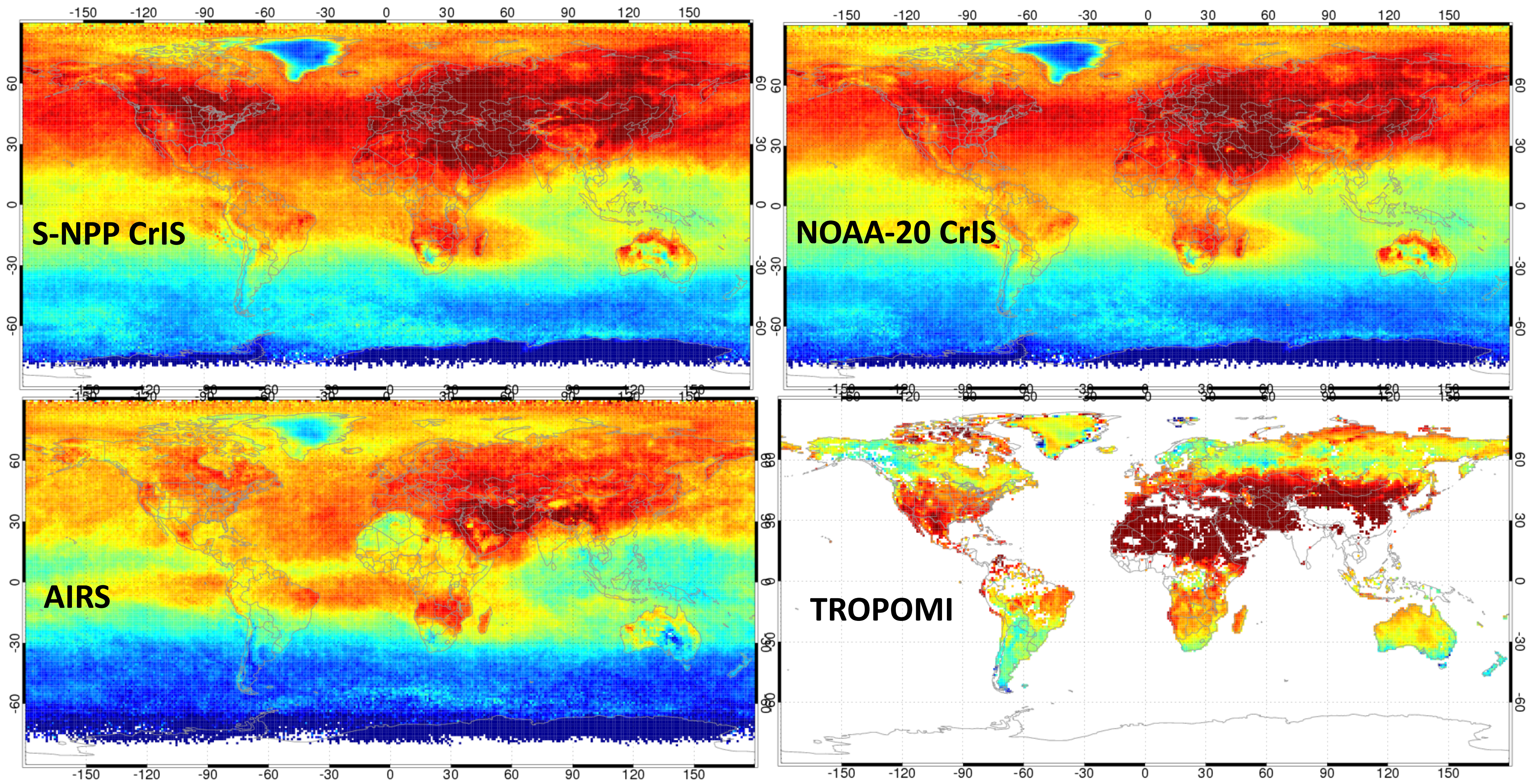


Edges lower!

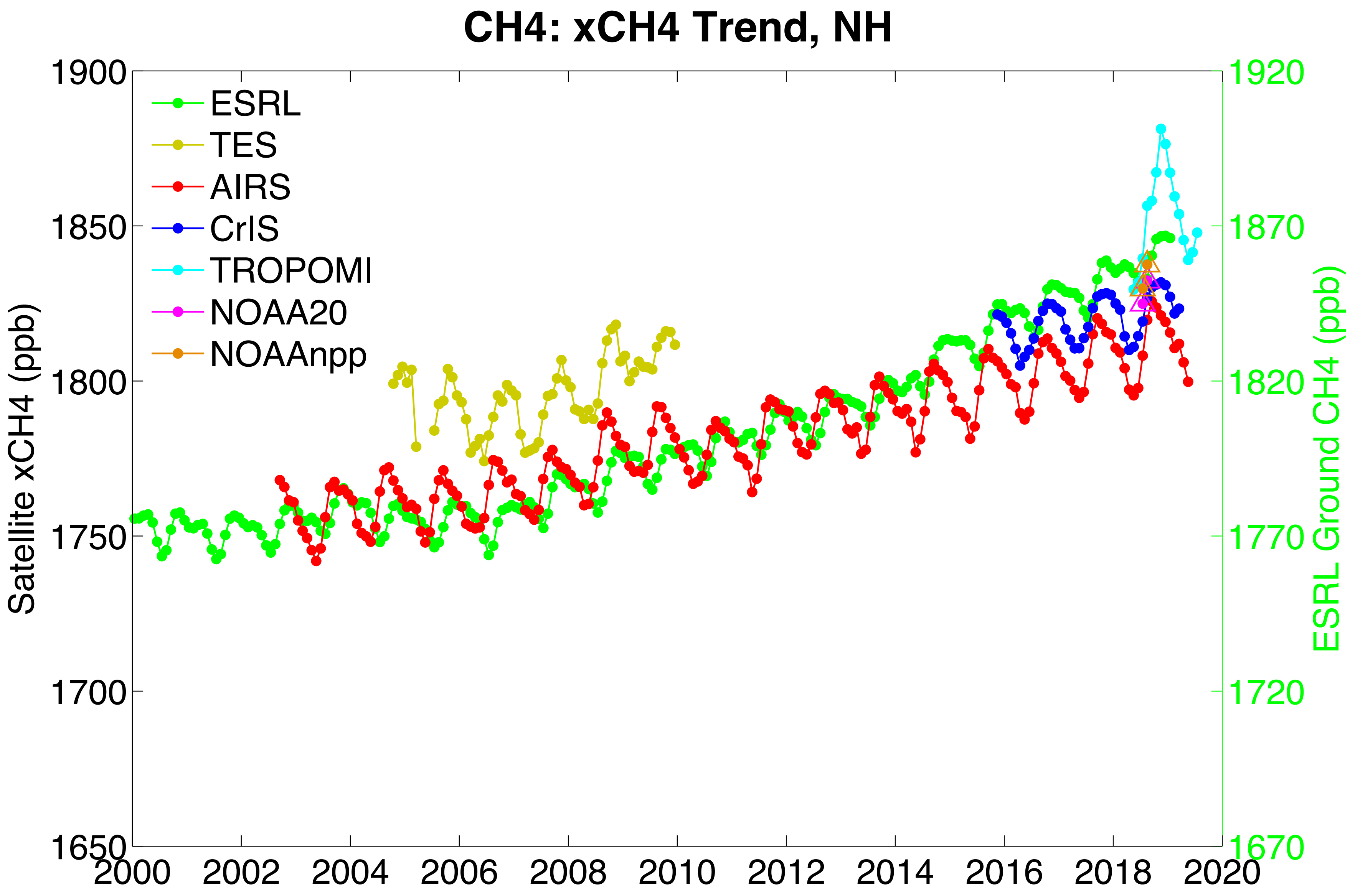
NO Edges!

- Removed cross-track biases and provided realistic values based on validations
- Delivered CH4 and N2O a priori; channel selection, and quality control.

xCH_4 Comparisons

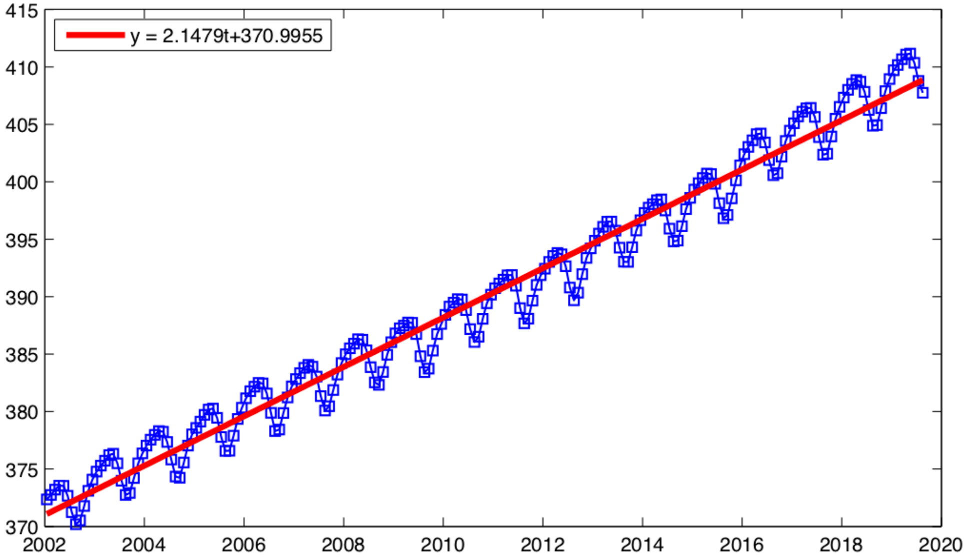


xCH_4 Trend Comparison



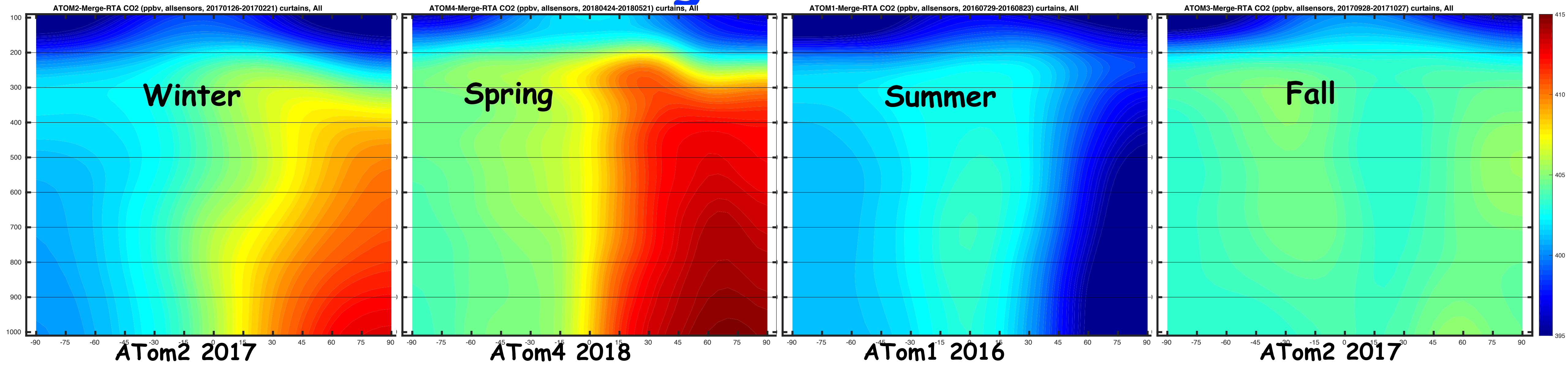
NUCAPS CO_2

A priori Using Carbon Tracker and ESRL Trends



1. Latitudinal variation from curtains;
2. Seasonality from Carbon Tracker;
3. Linear trend from ESRL surface measurements;
4. Climatology uses anomaly from ESRL data.

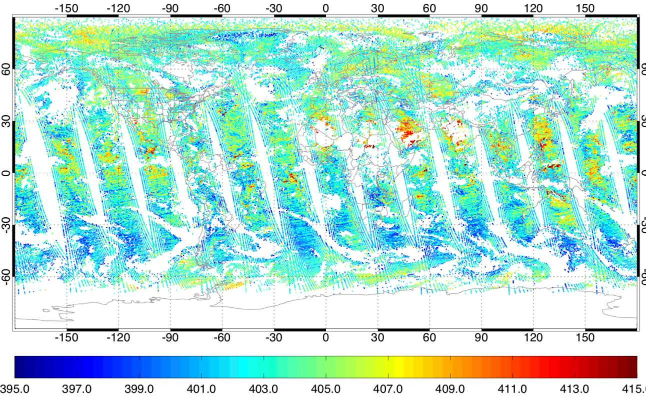
Validate Against ATom1-4



V2.5.2.2 CO2 VMR 2018/5/15

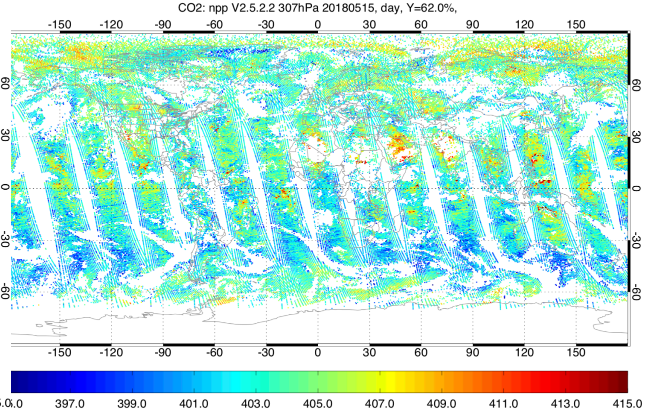
217hPa

CO2: npp V2.5.2.2 217hPa 20180515, day, Y=62.0%,



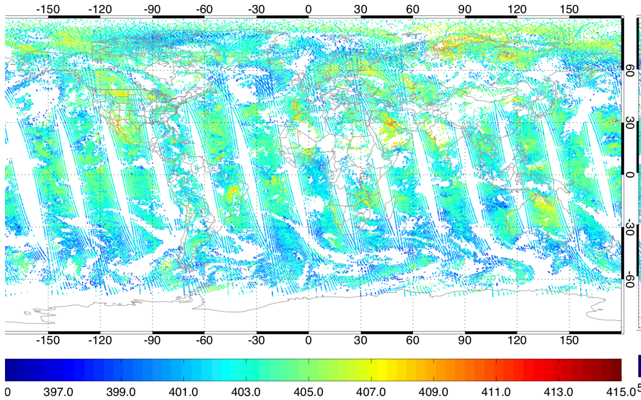
307hPa

CO2: npp V2.5.2.2 307hPa 20180515, day, Y=62.0%,



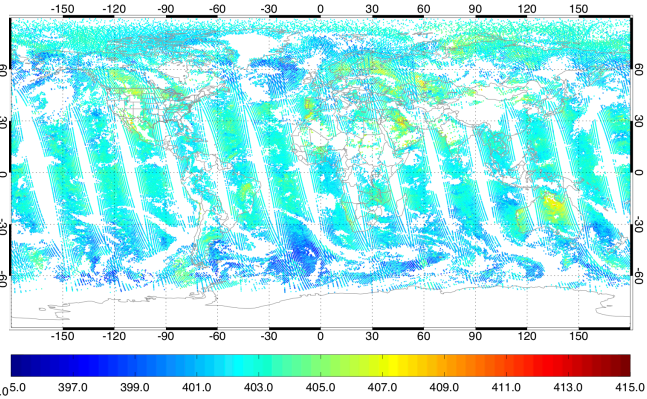
506hPa

CO2: npp V2.5.2.2 506hPa 20180515, day, Y=62.0%,



841hPa

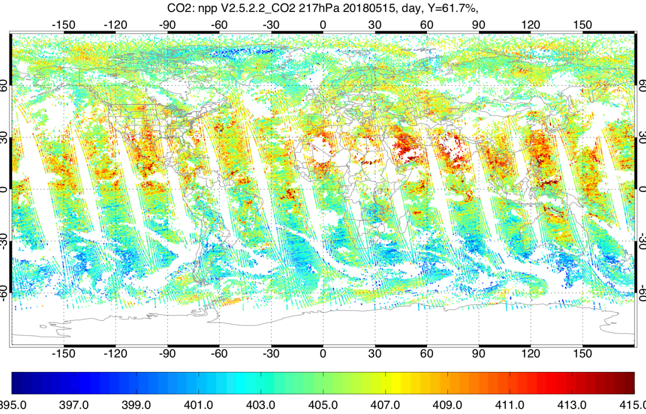
CO2: npp V2.5.2.2 840hPa 20180515, day, Y=60.5%,



V2.5.2.2 CO2 VMR Updated 2018/5/15

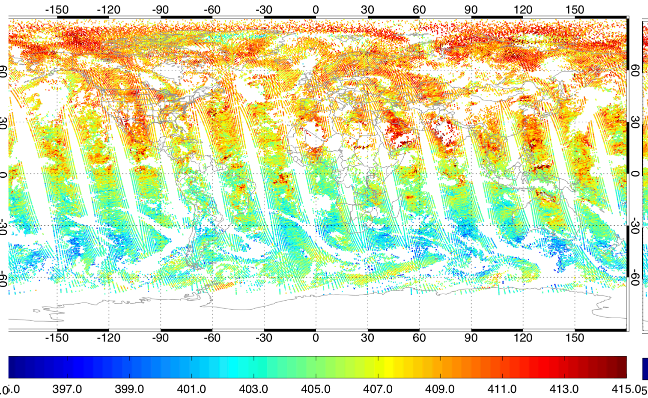
217hPa

CO2: npp V2.5.2.2_CO2 217hPa 20180515, day, Y=61.7%,



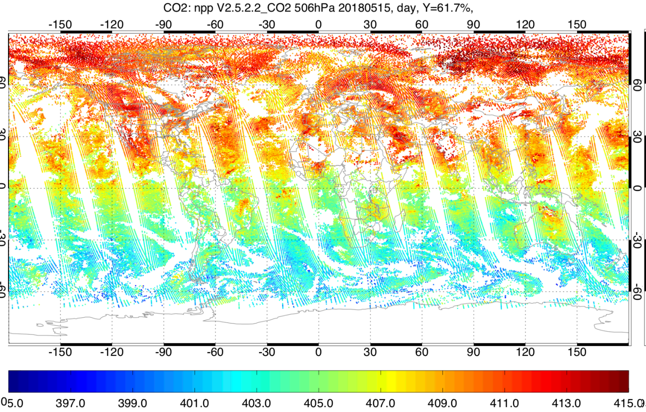
307hPa

CO2: npp V2.5.2.2_CO2 307hPa 20180515, day, Y=61.7%,



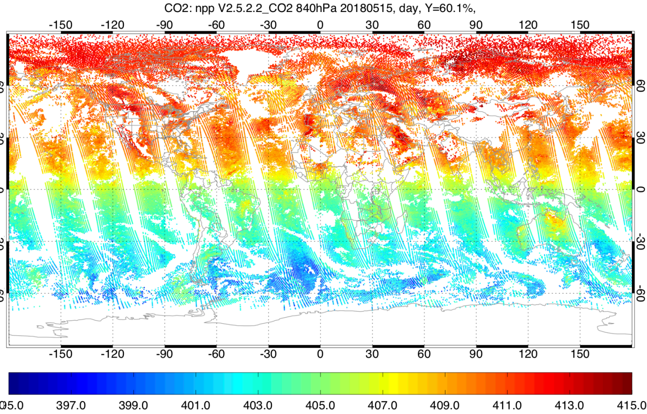
506hPa

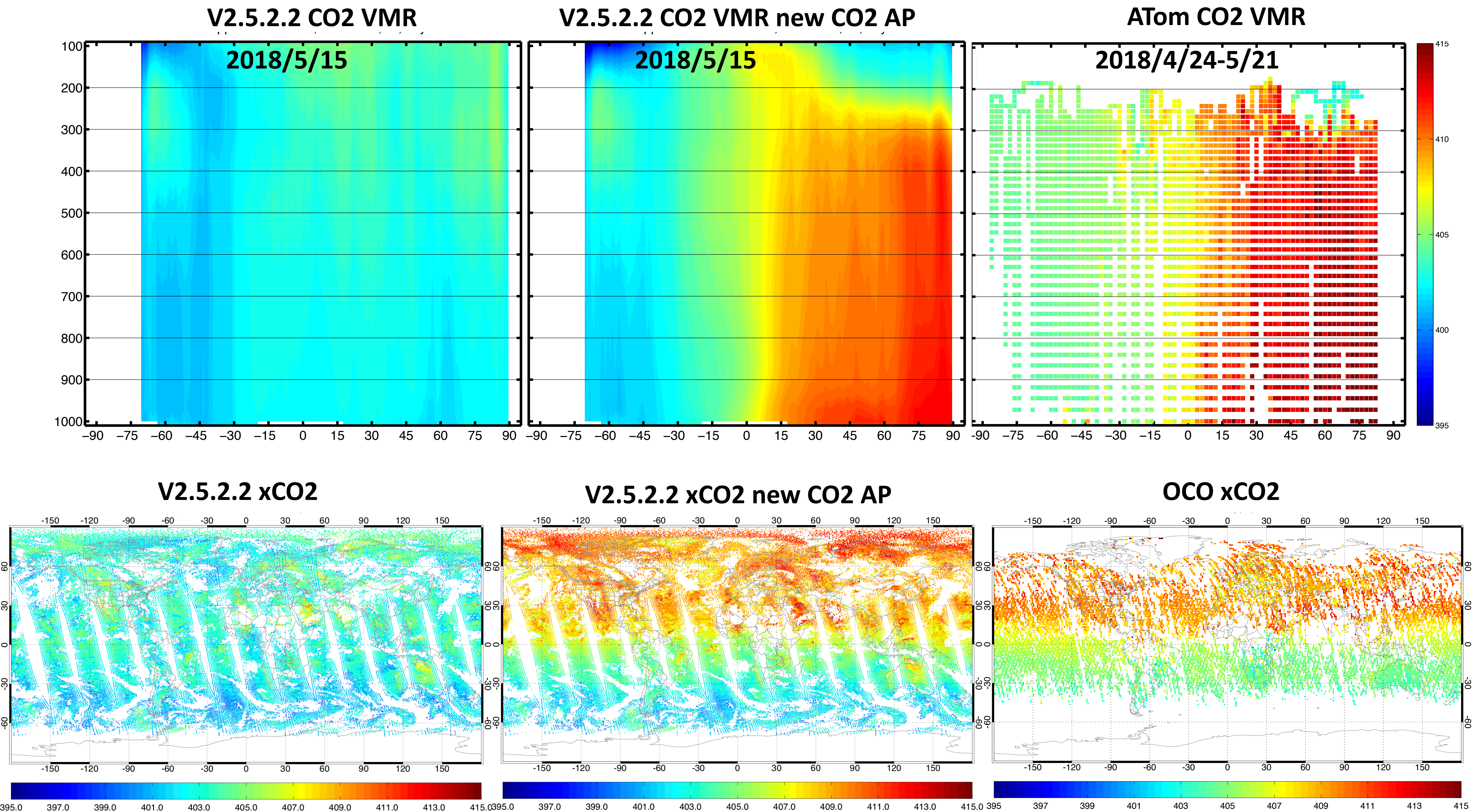
CO2: npp V2.5.2.2_CO2 506hPa 20180515, day, Y=61.7%,



841hPa

CO2: npp V2.5.2.2_CO2 840hPa 20180515, day, Y=60.1%,




V2.5.2.2 CO2 VMR
2018/5/15
V2.5.2.2 CO2 VMR new CO2 AP
2018/5/15
ATom CO2 VMR
2018/4/24-5/21
100
200
300
400
500
600
700
800
900
1000
−90 −75 −60 −45 −30 −15 0 15 30 45 60 75 90
415
410
405
400
395
V2.5.2.2 xCO2
V2.5.2.2 xCO2 new CO2 AP
OCO xCO2
-150 -120 -90 -60 -30 0 30 60 90 120 150
395.0 397.0 399.0 401.0 403.0 405.0 407.0 409.0 411.0 413.0 415.0
395 397 399 401 403 405 407 409 411 413 415

Summary and Thoughts

- NUCAPS trace gas products have been significantly improved;
- Continued refinements are needed;
- More in situ measurements for validation are needed;
- Capability to reprocess for the duration of records are needed.

- Better coordination from other NOAA resources to fund algorithms that can be directly delivered to operational products and/or to directly evaluate NOAA operational trace gas products.

Atmospheric composition products from space-based hyperspectral scattered solar measurements

***Lawrence Flynn**, NOAA*

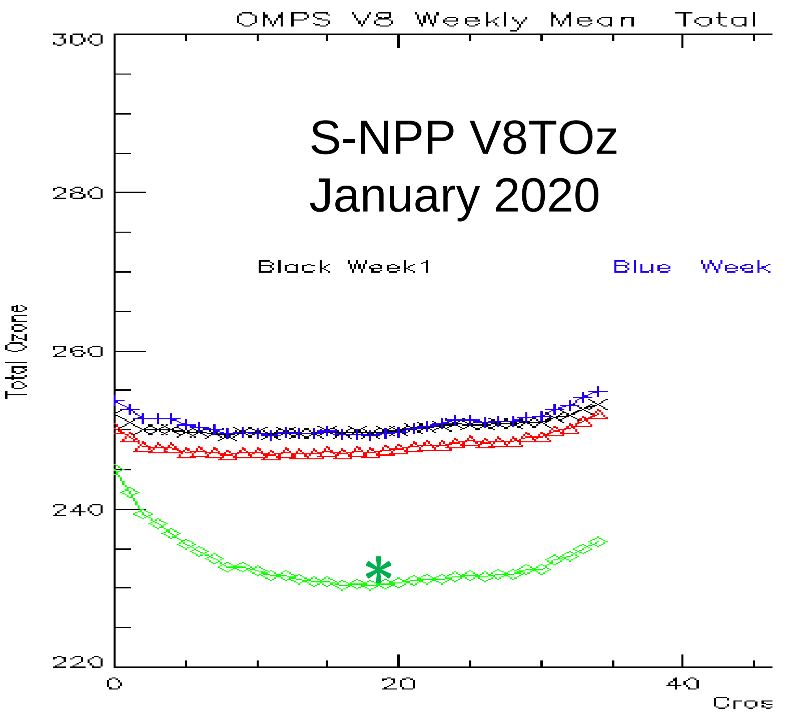
and members of the SBUV/2, OMI, OMPS and GOME-2 Teams working with NOAA, NASA, EUMETSAT and DLR

Disclaimer

"The contents of this presentation are those of the authors and do not necessarily reflect any position of the US Government or the National Oceanic and Atmospheric Administration."

Total Column Ozone

- Total Ozone – OMPS V8TOz: Operational NetCDF and BUFR from NDE, Daily Maps, Long-term CDRs.
  - The OMPS NM sensors have been very stable. We use soft calibration adjustments to force agreement between S-NPP and NOAA-20. BUFR files contain layer retrieval efficiencies. Products can be used in Tropospheric Residual calculations.
  - Reprocessed SDRs are used to create consistent CDRs. The S-NPP V8TOz operational processing since 1/1/2019 can be used to continue the CDRs. *Note 1/16/2020 and 1/17/2020 need to be reprocessed – poor notification.
  - JPSS-2 V8TOz products will be at 10x10 km^2.
- Ozone products from Metop A/B/C GOME-2: NOAA V8TOz operational products.
  - Additional operational and reprocessed GOME-2 ozone products are available from EUMETSAT / DLR / ACSAF and others.
- There are other satellite total ozone products from OMI, GOME-2, TropoMI, TOU, EMI, etc.



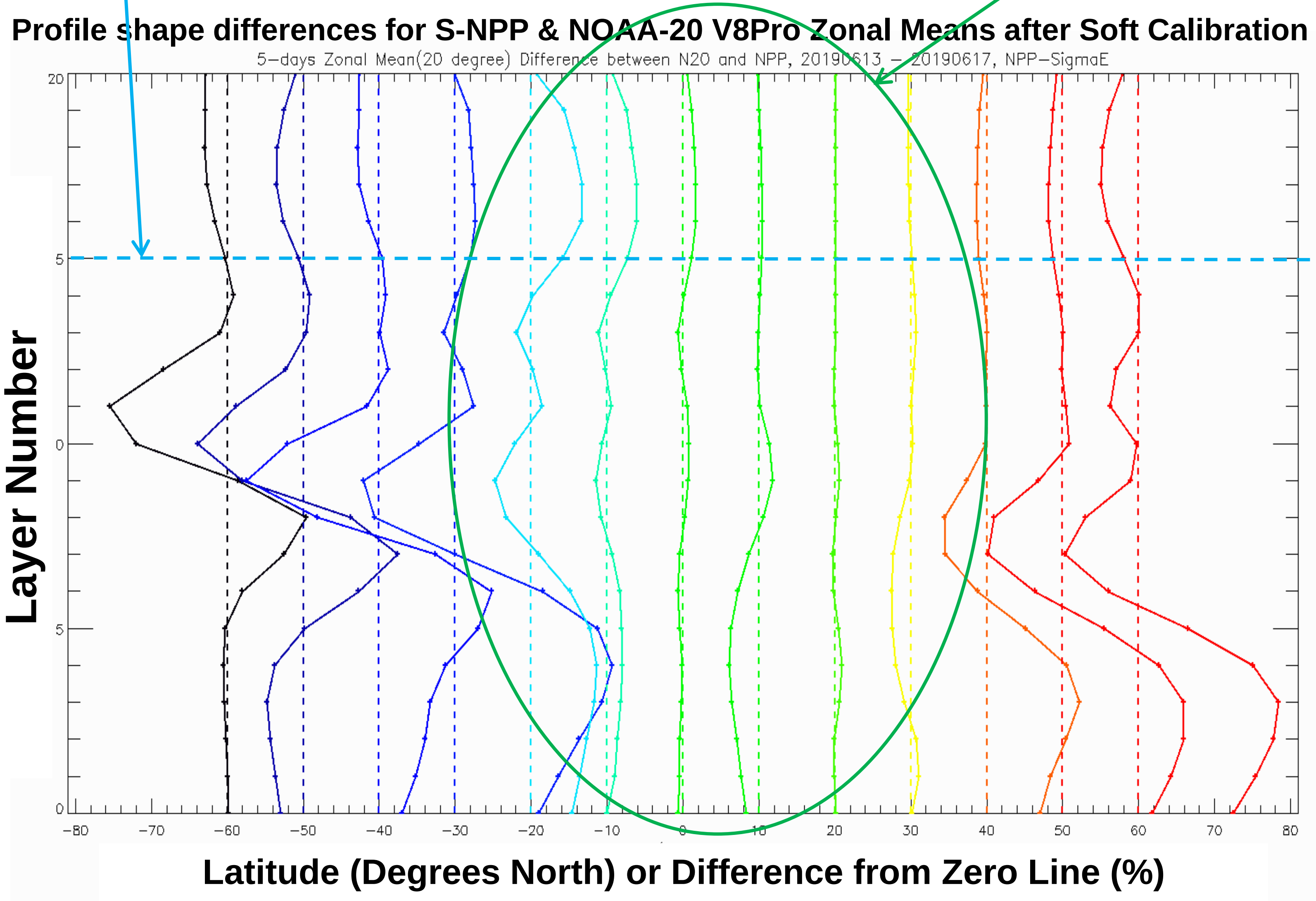
Nadir Profile Ozone

- Nadir Ozone Profile – OMPS V8Pro: Operational NetCDF and BUFR products from NDE, Long-term CDRs from STAR.
  - Users expect that our products from similar instruments with the same algorithm should be consistent.
  - We use soft calibration adjustments to account for instrument throughput degradation and to force agreement between V8Pro products removing measurement biases. This did not work, because …
  - The S-NPP and NOAA-20 OMPS NP have significant differences in their bandpass FWHMs. We are modifying the V8Pro to improve our bandpass model fidelity.
  - BUFR products contain averaging kernels.

Good Agreement for Layer 15

Good Agreement in the Tropics

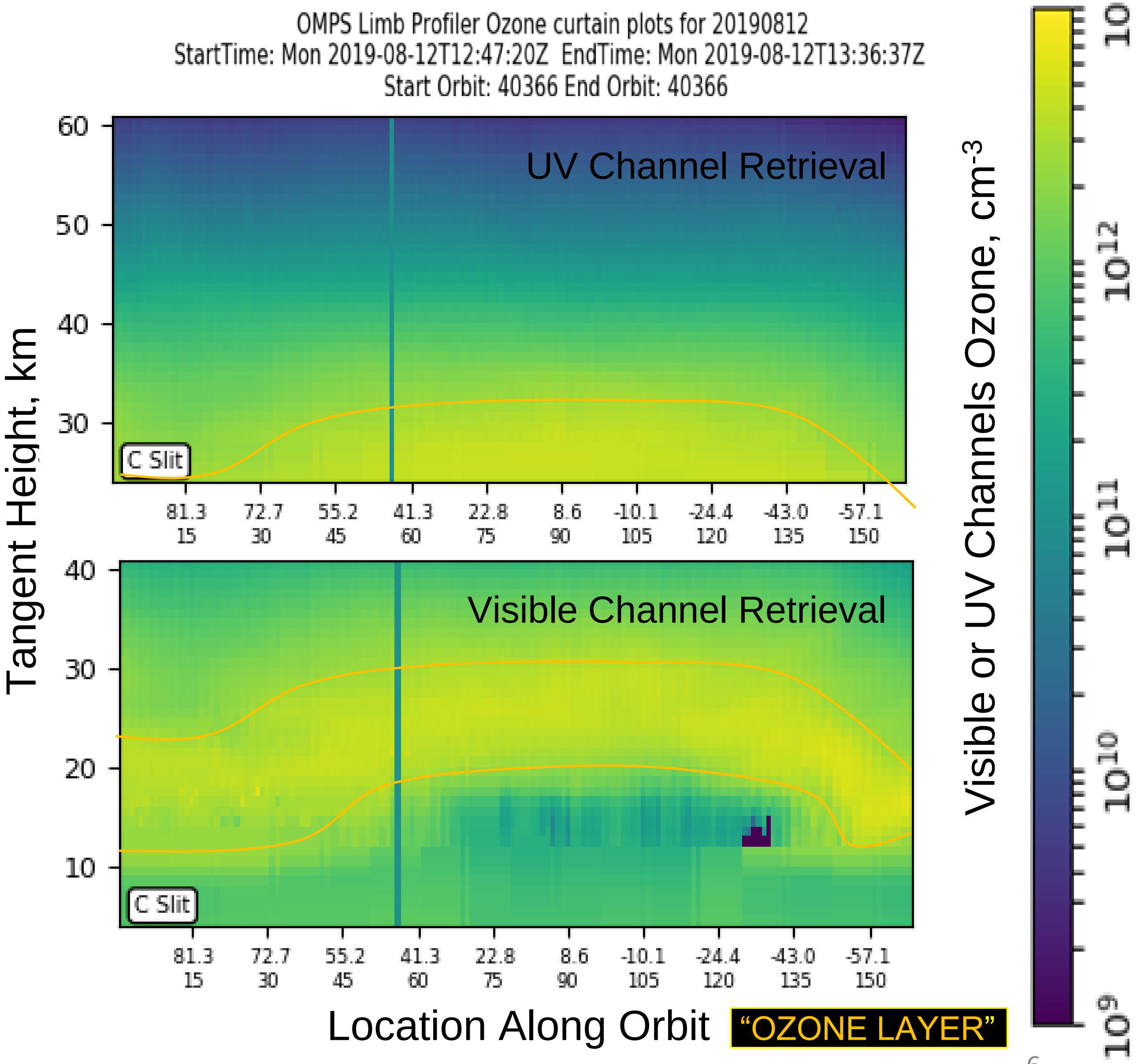
Failure to Obtain Agreement between NOAA-20 V8Pro and S-NPP V8Pro with Soft Calibration Adjustments



Limb Profile Ozone

- Limb Ozone – OMPS V2Limb: operational (soon) NetCDF and BUFR from NDE.
  - Long-term records to continue SAGE are available from NASA GSFC and USask.
  - Product has good vertical resolution, ~3-km.
  - Need to check agreement of averaging-kernel-adjusted Limb Profiles with Nadir Profiles.
  - Disagreement between Limb UV and Vis profiles retrievals.
  - Project to create A Priori for NUCAPS ozone profiles from the Limb retrievals.

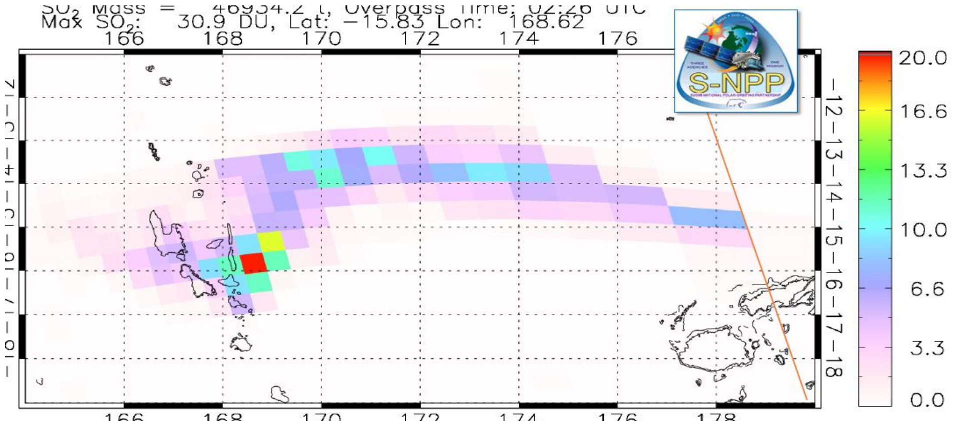
Orbital Curtain Plots for OMPS Limb Ozone Profile Retrievals



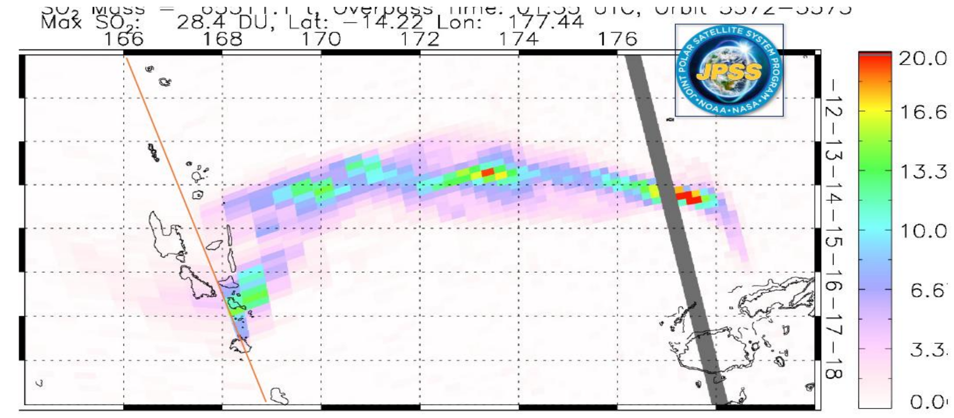
Trace Gases – SO_2

- We make near-real-time estimates of total column SO_2 – LFSO2/V8TOS: Operational NetCDF from NDE.
- The OSPO follow on to OMI Alert pages is in final stages.
- There is a major project led by Mike Pavolonis (See Wed PM.) fusing all sources (IR, VIS, UV; GEO & LEO) to create Volcanic Alerts based on SO_2 and ash products.
- Other SO_2 products are available from operational (GOME-2) and research (OMI and TropoMI) processing. Note, GOME-2 is in a 9:30 AM orbit.

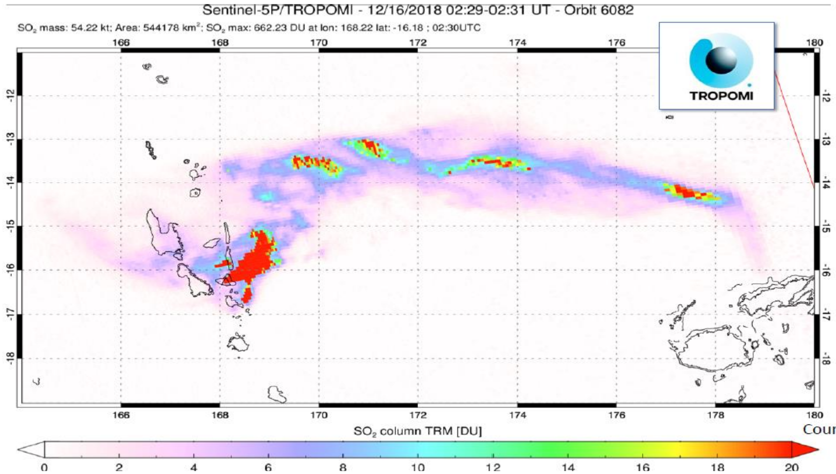
Ambrym, Vanuatu 12/16/2018 →



Courtesy: Can Li



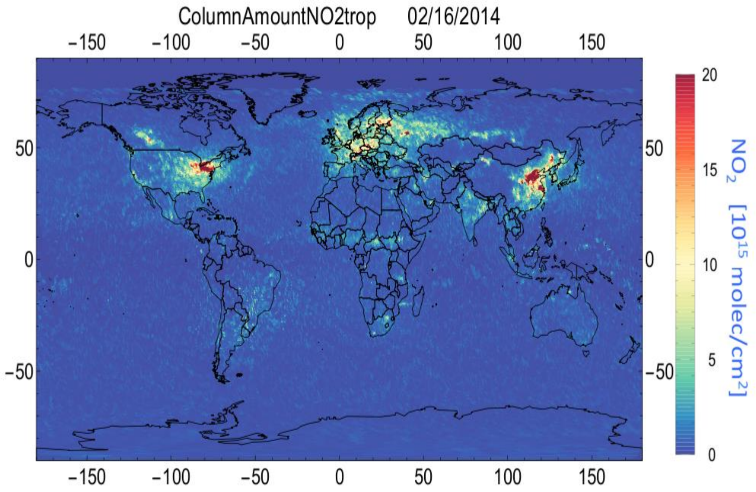
Courtesy: Can Li



Courtesy: Simon Carn

Trace Gases: Formaldehyde (HCHO) and Nitrogen Dioxide (NO_2)

- Retrievals of HCHO* and NO_2^ column amounts have been produced from OMPS Nadir Mapper measurements.
- Paths to operational or other processing at NESDIS require user requests.
- Should we be going to the cloud or to direct broadcast implementation?
- Products from GOME-2, OMI and TropoMI are available with a range of latency times from various operational and research centers.



Nitrogen dioxide tropospheric column amounts for 16 February 2014. From K. Yang UMD. See also https://agupubs.onlinelibrary.wiley.com/doi/full/10.1002/2014GL060136

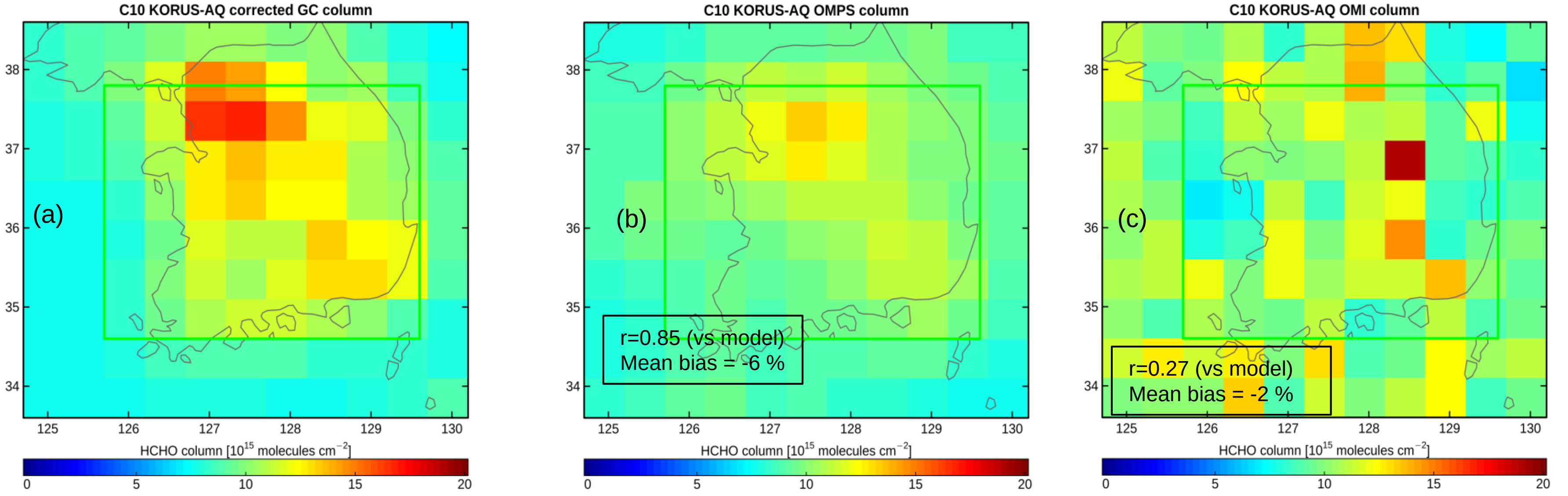


Figure 6: Mean vertical column HCHO during KORUS-AQ at satellite overpass time on a 0.5°x0.5° grid from a) GEOS-Chem scaled to match mean in situ observations (above); b) OMPS/Suomi-NPP; and c) OMI. OMPS shows a much better spatial correlation than OMI with the model, due partly to OMI instrument degradation over time. From Poster by Caroline Nowlan, Harvard.

*https://www.atmos-meas-tech.net/12/3551/2019/

^https://snpp-omps.gesdisc.eosdis.nasa.gov/data/SNPP_OMPS_Level2/OMPS_NPP_NMNO2_L2.2/doc/README.OMPS_NPP_NMNO2_L2.2.pdf

Outside the Box – or maybe not

- EUMETSAT/DLR/AC-SAF make a full suite of trace gas products in Near-Real-Time from Metop-A/B/C GOME-2 measurement. These are available to NOAA – The J(oint) in IJPS.
- TropoMI is flying in formation with S-NPP and making high spatial resolution trace gas products (including methane and carbon monoxide). These will continue with the follow-on Sentinel-5 replacing GOME-2.
- UV sensors on GEO are here: GEMS just launched, TEMPO in 2022, Sentinel-4 UVN in 2023. They will provide frequent refresh of trace gas products at good spatial resolution over limit regions of the disks, mainly in the Northern Hemisphere. (EPIC is at L1)

https://www.weathernationtv.com/news/first-satellite-in-global-air-quality-constellation-launches/

Backup Slides

- Not Covered
  - Solar activity products, e.g., Mg II Index.
  - UV Absorbing Aerosols at the same resolution as the total ozone products.
  - TOAST Combined UV/IR ozone products.

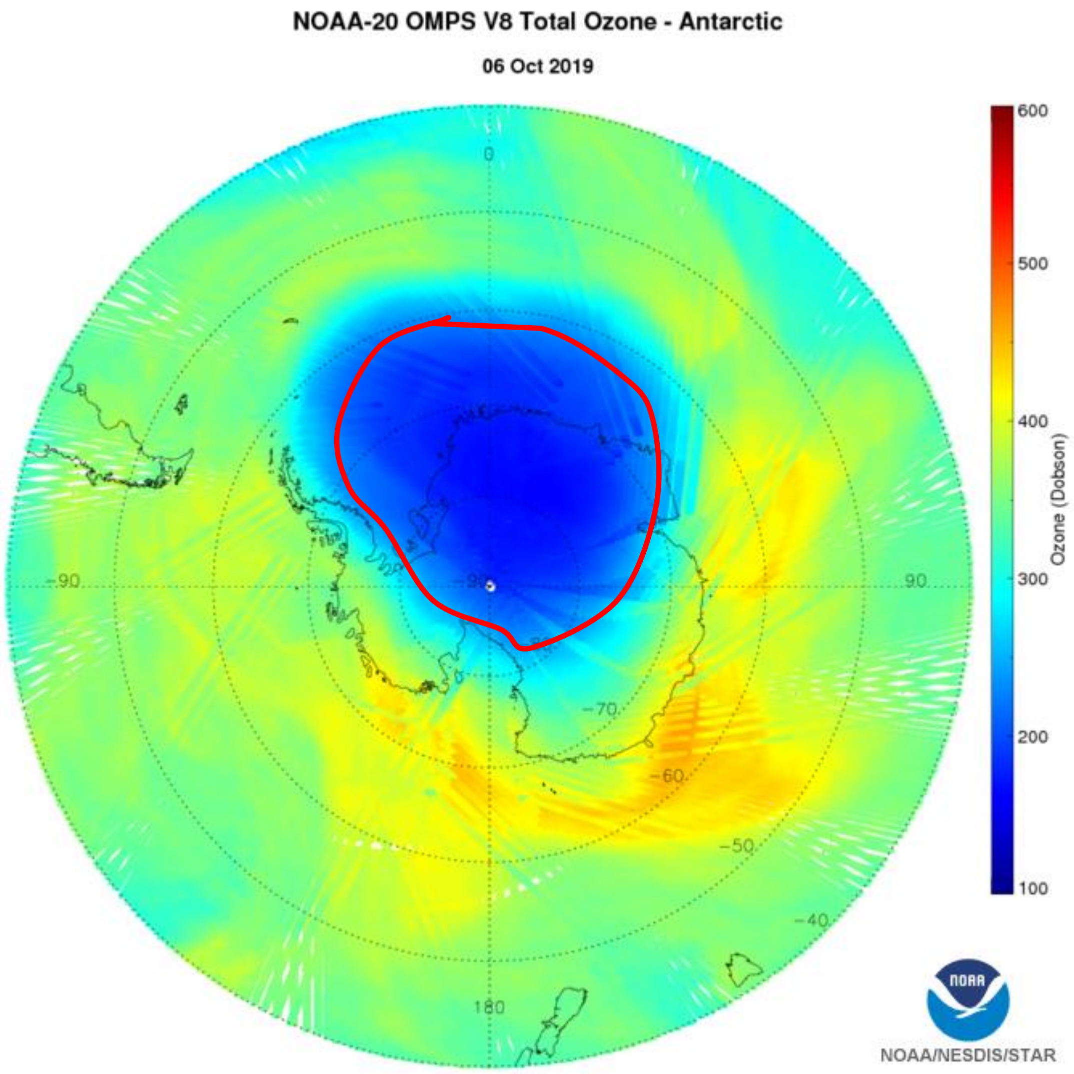
GOME-2 Products from EUMETSAT

https://wdc.dlr.de/sensors/gome2/
https://acsaf.org/products/nto_no2.html
https://acsaf.org/product_list.html

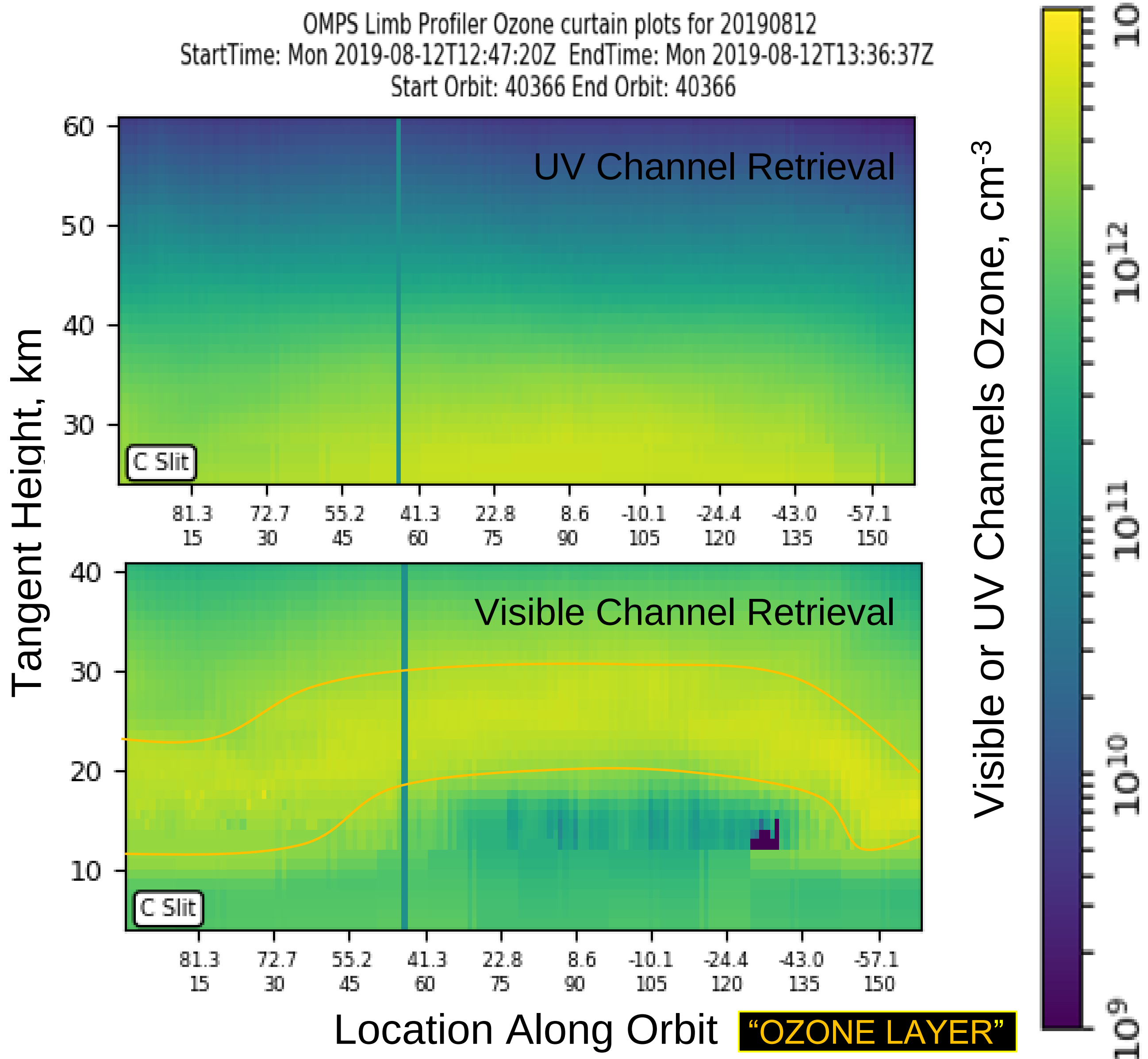
GOME-2 level 2 total columns products of ozone, minor trace gases and cloud properties are generated at DLR in the framework of the Satellite Application Facility on Ozone and Atmospheric Chemistry Monitoring (O3M SAF). Near-real-time products are disseminated via EUMETCast and internet.
GOME-2 Level 2 off-line products can be order on-line via EOWEB or UMARF (Unified Metereological ARchive Facility).
The GOME-2 level 3 (composites) and level 4 (assimilated products) are generated at DLR in the framework of WDC.

2019 Ozone Hole

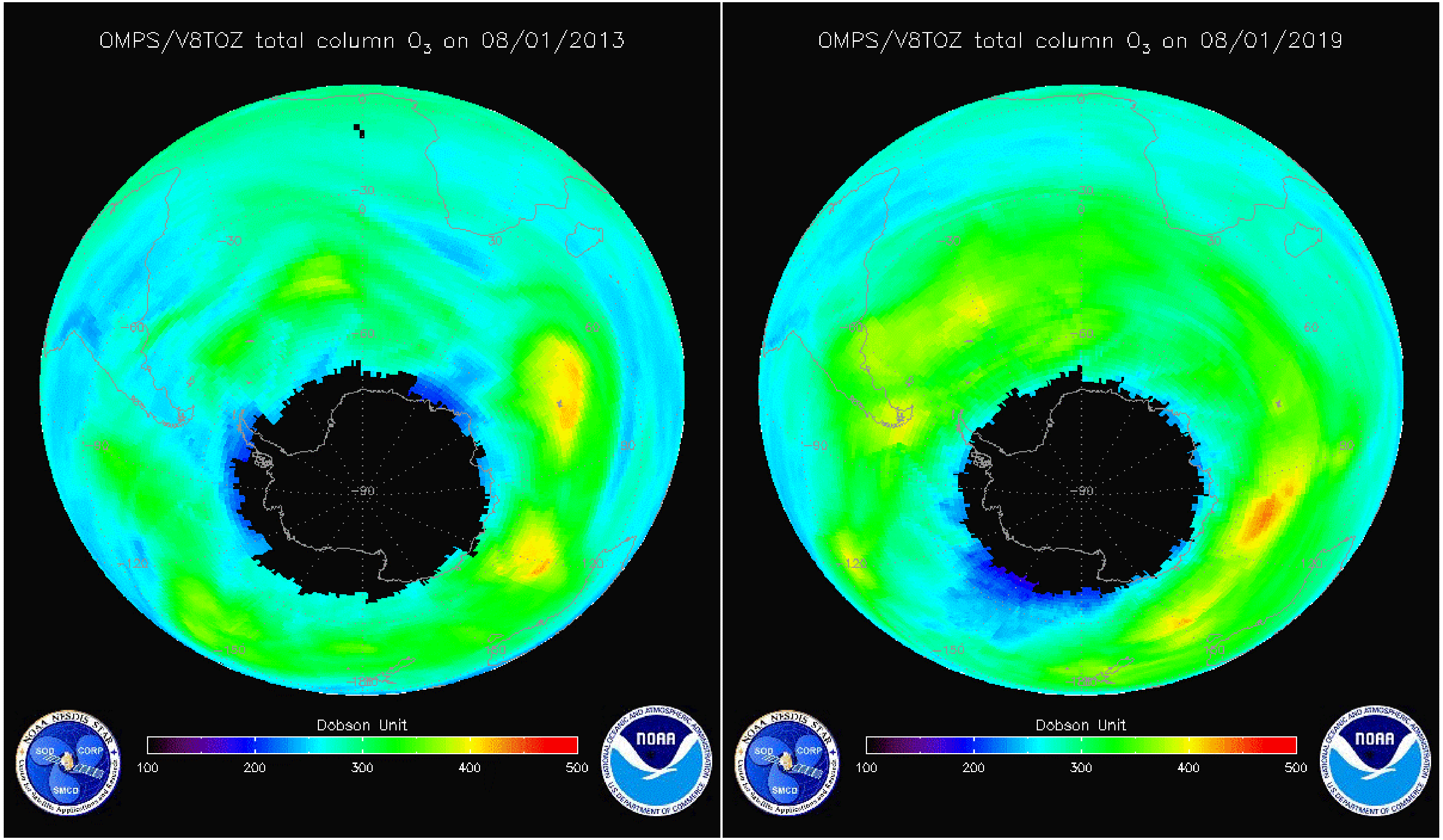
Warmth in the polar stratosphere limited ozone depletion. Abnormal weather patterns in the upper atmosphere over Antarctica dramatically limited ozone depletion in September and October, resulting in the smallest ***"Ozone Hole"*** observed since the onset of the phenomenon in 1984.



Orbital Curtain Plots for OMPS Limb Ozone Profile Retrievals



S-NPP Total Column Ozone Hole Movies for 2013 and 2019



Outline

- OMPS Nadir Mapper V8TOz Total Column Ozone
  - Ground-based Comparisons
  - Reprocessed S-NPP (uniform calibration)
  - S-NPP versus NOAA-20 and Monitoring
- OMPS Limb Profiler V2Limb Ozone Profile
  - Operational processing differences with NASA
- OMPS Nadir Profiler V8Pro Ozone Profile
  - Ground-based comparisons
  - S-NPP versus NOAA-19 Disagreement
- Summary and Conclusions

Helpful Links

Additional information is available in the OMPS V8TOz and V8Pro algorithm theoretical basis documents (ATBDs) and the SDR maturity review briefing, which can be accessed at:

https://www.star.nesdis.noaa.gov/jpss/Docs.php

and

https://www.star.nesdis.noaa.gov/jpss/AlgorithmMaturity.php

OMPS SDR near-real-time status and performance monitoring web page are available at:

https://www.star.nesdis.noaa.gov/icvs/status_N20_OMPS_NM.php

and associated pages.

NOAA-20 OMPS EDR near-real-time status and performance monitoring are available at

- Archives

https://www.bou.class.noaa.gov/saa/products/search?sub_id=0&datatype_family=JPSS_OZONE

- Operations

https://www.ospo.noaa.gov/Products/atmosphere/index.html

- Long-term

https://www.star.nesdis.noaa.gov/smcd/spb/OMPSDemo/proOMPSbeta.php

- Daily maps

https://www.star.nesdis.noaa.gov/jpss/EDRs/products_ozone.php

- Activity

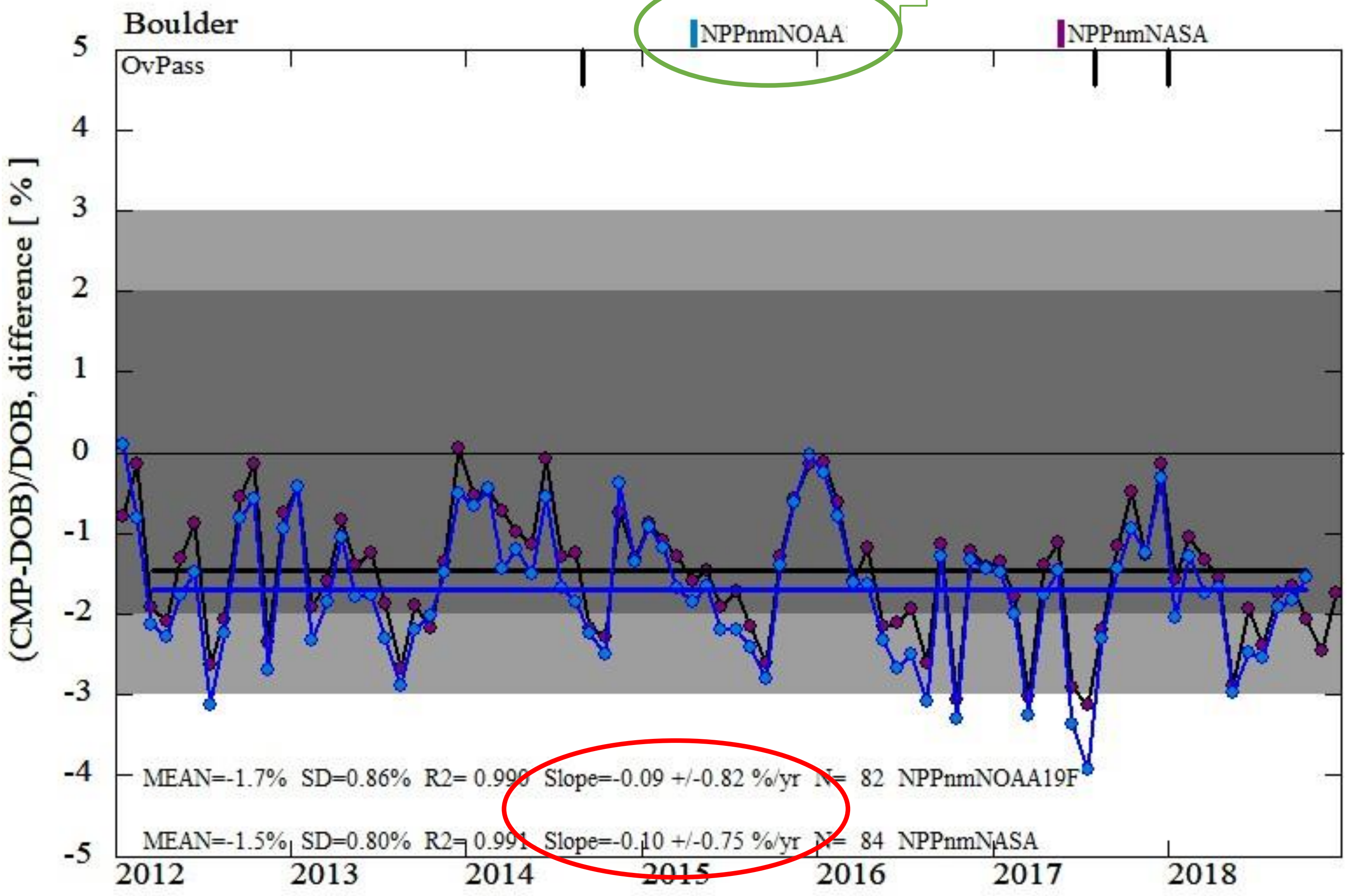
https://ozoneaq.gsfc.nasa.gov/omps/n20/activity

Dobson Overpass Data

- OMPS NOAA_NPP
  - Nadir Mapper V8TOz: Jan 2012 - Nov 2018
    - Closest_Dist < 50 km
    - ftp://ftp.star.nesdis.noaa.gov/pub/smcd/spb/ozone/irina/NPP/NM/V8/reproc_feb_2019/
- OMPS NASA_NPP
  - NM: Jan 2012 – Present
    - Closest_Dist < 50 km
    - ftp://toms.gsfc.nasa.gov/pub/omps_tc/overpass/suomi_npp_omps_l2ovp_nmto3_v02_boulder.co_067.txt
- Dobson Total Column Ozone Product
  - Temperature adjustment based on McPeters and Labow (2011) seasonal climatology for 40-50N.
  - B&P Ozone Cross Sections

Boulder Dobson versus S-NPP
Monthly Mean Total Column Ozone

NOAA OMPS, Revised Feb 2019



Product Overview/Requirements NOAA-20 OMPS V8TOz performance

- Product performance requirements from JPSS L1RD supplement (threshold) versus observed/validated/JERD Vol. II

Attribute	Threshold	Observed/Validated
Geographic coverage	90% Daily Global Earth	SZA < 80° (>90% coverage)
Vertical Coverage	0-60 km	0-60 km (RT tables, physics)
Vertical Cell Size	NA	NA
Horizontal Cell Size	50x50 km^2 at nadir	50x17 km^2 at nadir (12x17 future)
Mapping Uncertainty	5 km at nadir	3 km at nadir (SDR Team)
Measurement Range	50 – 650 DU	90-700 DU (SDR range and past algorithm performance)
Measurement Accuracy		
X < 250 DU	9.5 DU	-5 to 5 DU vs. NPP (-2 DU avg.)
250 DU < X < 450 DU	13.0 DU	-5 to 5 DU vs. NPP (-2 DU avg.)
X > 450 DU	16.0 DU	-5 to 5 DU vs. NPP (-2 DU avg.)
Measurement Precision	for 50x50 km^2 products	for 50x17 km^2 products
X < 250 DU	6.0 DU	2 DU RMSDD, 5.0 DU NPPMU
250 DU < X < 450 DU	7.7 DU	3 DU RMSDD, 6.0 DU NPPMU
X > 450 DU	2.8 DU + 1.1%	4 DU RMSDD, 9.0 DU NPPMU

Product Overview/Requirements
NOAA-20 OMPS V8Pro Performance

- Product performance requirements from JPSS L1RD supplement (threshold) versus observed/validated/JERD Vol. II

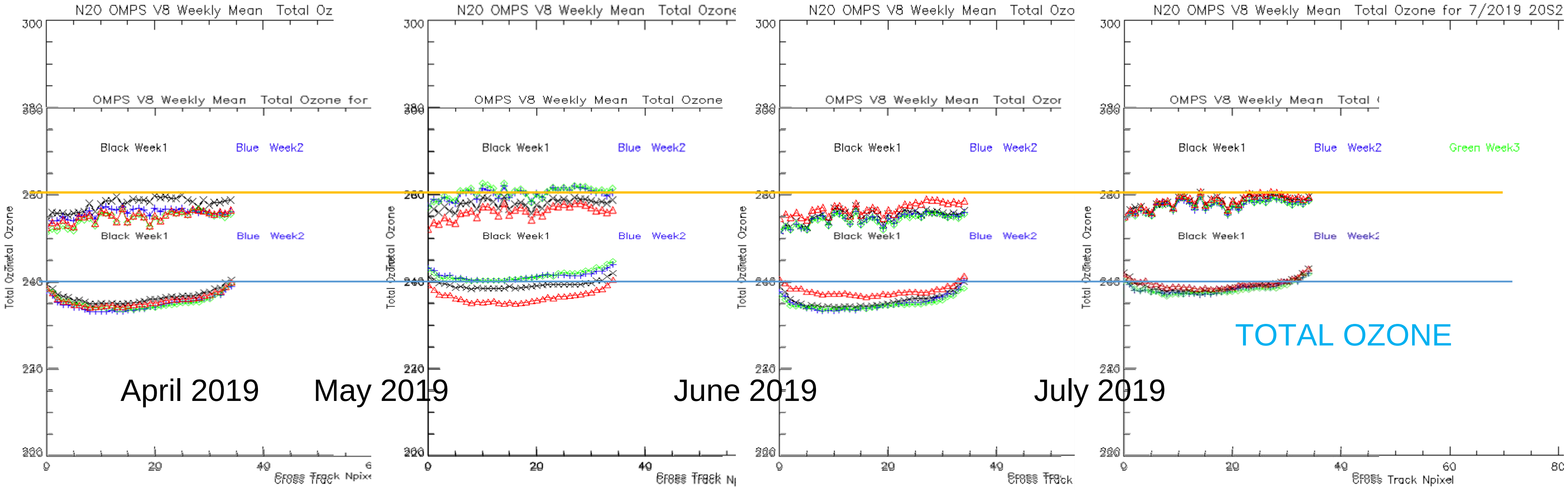
Attribute	Threshold	Observed/validated
Geographic coverage	60% Global Earth 7 days	SZA < 86°, orbital track
Vertical Coverage	0-60 km	0-60 km
Vertical Cell Size	3-km reporting, 7-20 km	21 layers, averaging kernel
Horizontal Cell Size	250x250 km^2	250x50 km^2
Mapping Uncertainty	25 km	5 km
Measurement Range	0.1-15 ppmv	0.1-15 ppmv
Measurement Accuracy		
h < 25 km	10%	<5% versus S-NPP in the tropics
25 km < h < 50 km	5-10%	<5% versus S-NPP in the tropics
h > 50 km	10%	<5% versus S-NPP in the tropics
Measurement Precision		
h < 25 km	20%	Measurement noise and initial and final residuals have been evaluated. The values are consistent with the expected performance and the SDR improvements.
25 km < h < 50 km	5-10%	
h > 50 km	10%	

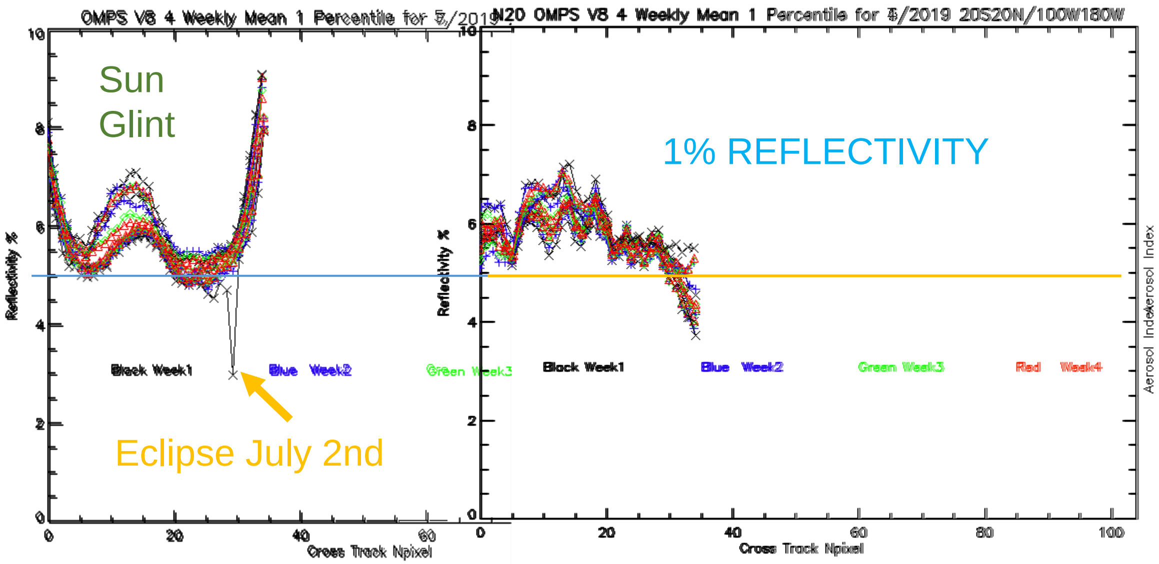
OMPS Limb Profile EDR Requirements

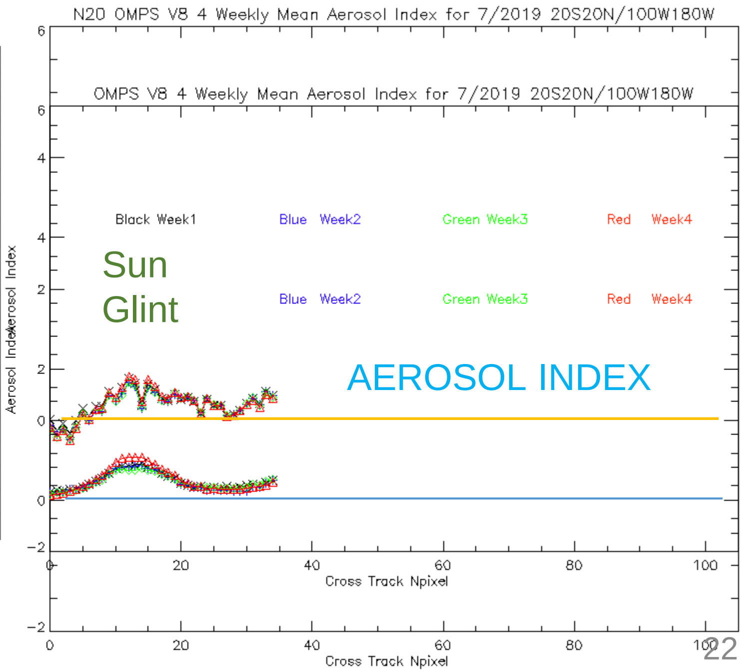
Table X.X. Ozone Limb Profile (OMPS-L)		
Attribute	**Threshold**	**Objective**
Ozone LP Applicable Conditions	SZA < 80 degrees	SZA < 88 degrees
a. Horizontal Attributes		
1. Horizontal Cell Size	250 km	125 km
2. Horizontal Reporting	125 km	50 km
b. Vertical Attributes		
1. Vertical Coverage	TH to 60 km	0 km to 60 km
2. Vertical Reporting	1 km	1 km
3. Vertical Resolution		
i. 0 to TH (1)	N/A	3 km
ii. TH to 25	5 km	1 km
iii. 25 km to 60 km	5 km	3 km
c. Mapping Uncertainty, 1 Sigma	< 25 km	< 5 km
d. Measurement Range		
1. 0 to TH (1)	N/A	0.01 to 3 ppmv
2. TH - 60 km	0.1 to 15 ppmv	0.1 to 15 ppmv
e. Measurement Precision		
1. 0 to TH (1)	N/A	10%
2. TH to 15 km	Greater of 10 % or 0.1 ppmv	3%
3. 15 to 50 km	Greater of 3 % or 0.05 ppmv	1%
4. 50 to 60 km	Greater of 10% or 0.1 ppmv	3%
f. Measurement Accuracy		
1. 0 to TH (1)	N/A	10%
2. TH to 15 km	Greater of 20 % or 0.1 ppmv	10%
3. 15 to 60 km	Greater of 10 % or 0.1 ppmv	5%
g. Refresh	At least 75% coverage of the globe every 4 days (monthly average) (2)	24 hrs (2)
h. Long-term Stability	2% over 7 years	1% over 7 years

Notes:		
1. TH is Tropopause Height or 8 km, whichever is greater as determined by ancillary data.		
2. All OMPS measurements require sunlight, so there is no coverage in polar night areas. With three limb curtains (each with a Vertical FOV of ~ 1.85°) positioned at Nadir and 250 km (+/- 4.3 degrees) on each side, the measurements are taken to give a good representation of the ozone profile in the central 750 Km of the orbital track. With a 4-day repeat cycle in the orbital tracks, this will yield a 4-day revisit time (approximately) for 30,000 km out of 40,000 km equator.		

Four Months of Pacific Box Monitoring
V8TOz NOAA-20 Versus S-NPP

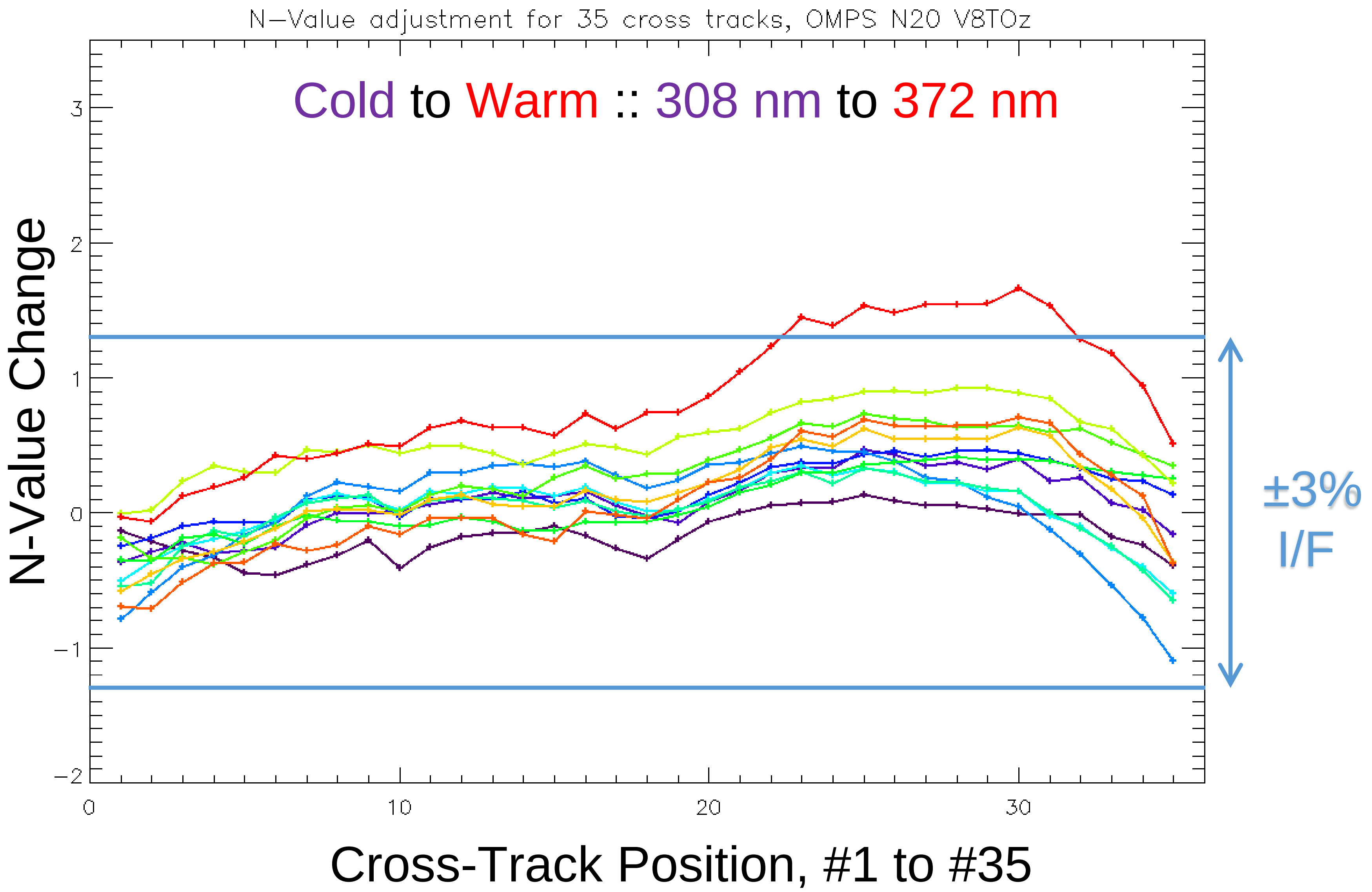






Cross Track Positions 0 to 34

N-Value Adjustments for NOAA-20 OMPS V8TOz to force agreement with S-NPP OMPS V8TOz



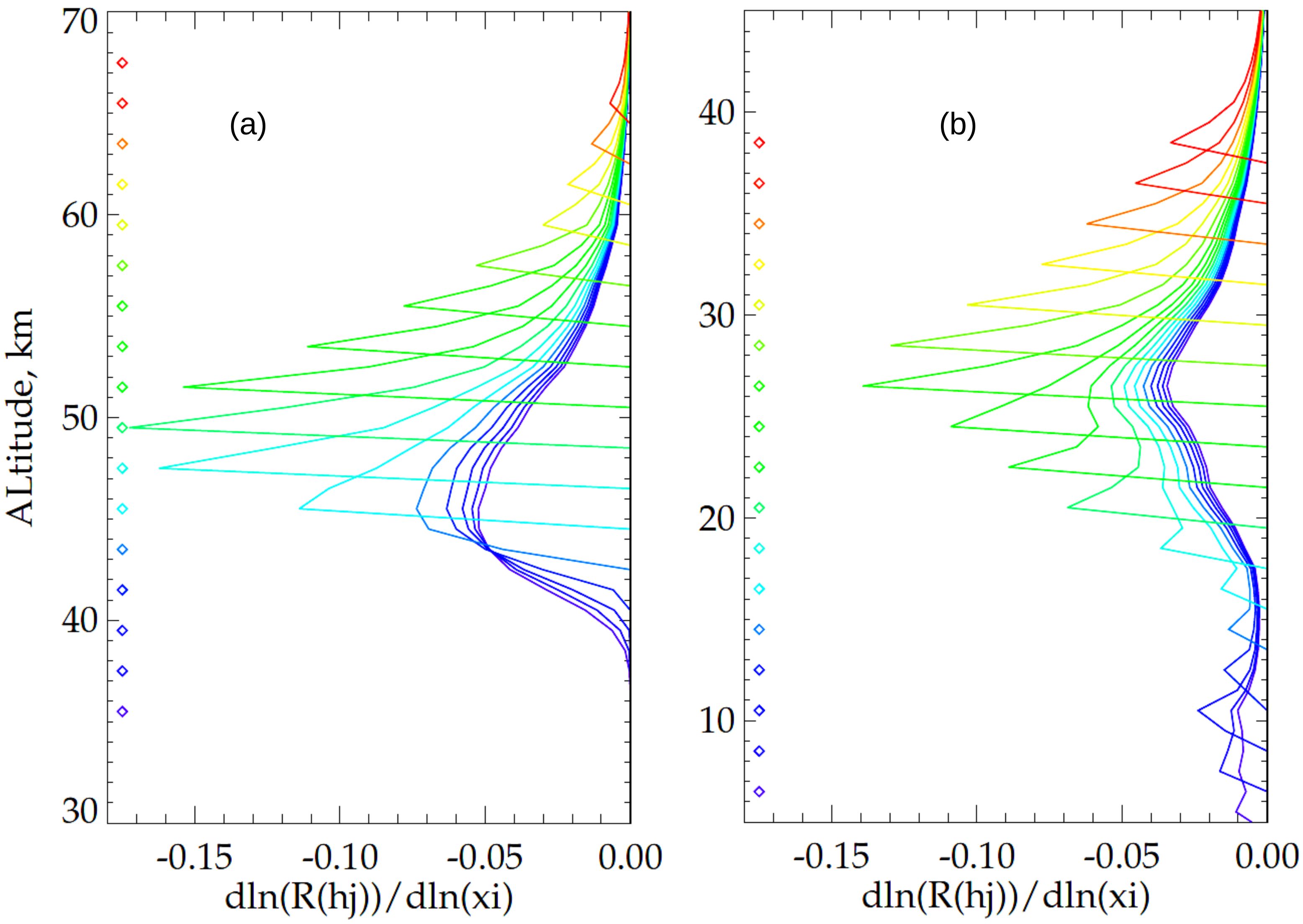
OMPS Limb Ozone Profiles

- NOAA is implementing the NASA OMPS Limb Retrieval algorithm in operations to provide near-real-time access to high-vertical-resolution products in NetCDF and BUFR files.
- The OMPS Limb Profiler is on S-NPP OMPS and will be on JPSS-2 (NOAA-21) OMPS but is not present on NOAA-20 OMPS.
- The performance of the instrument and validation of the products are reported in

https://doi.org/10.1002/2013JD020482

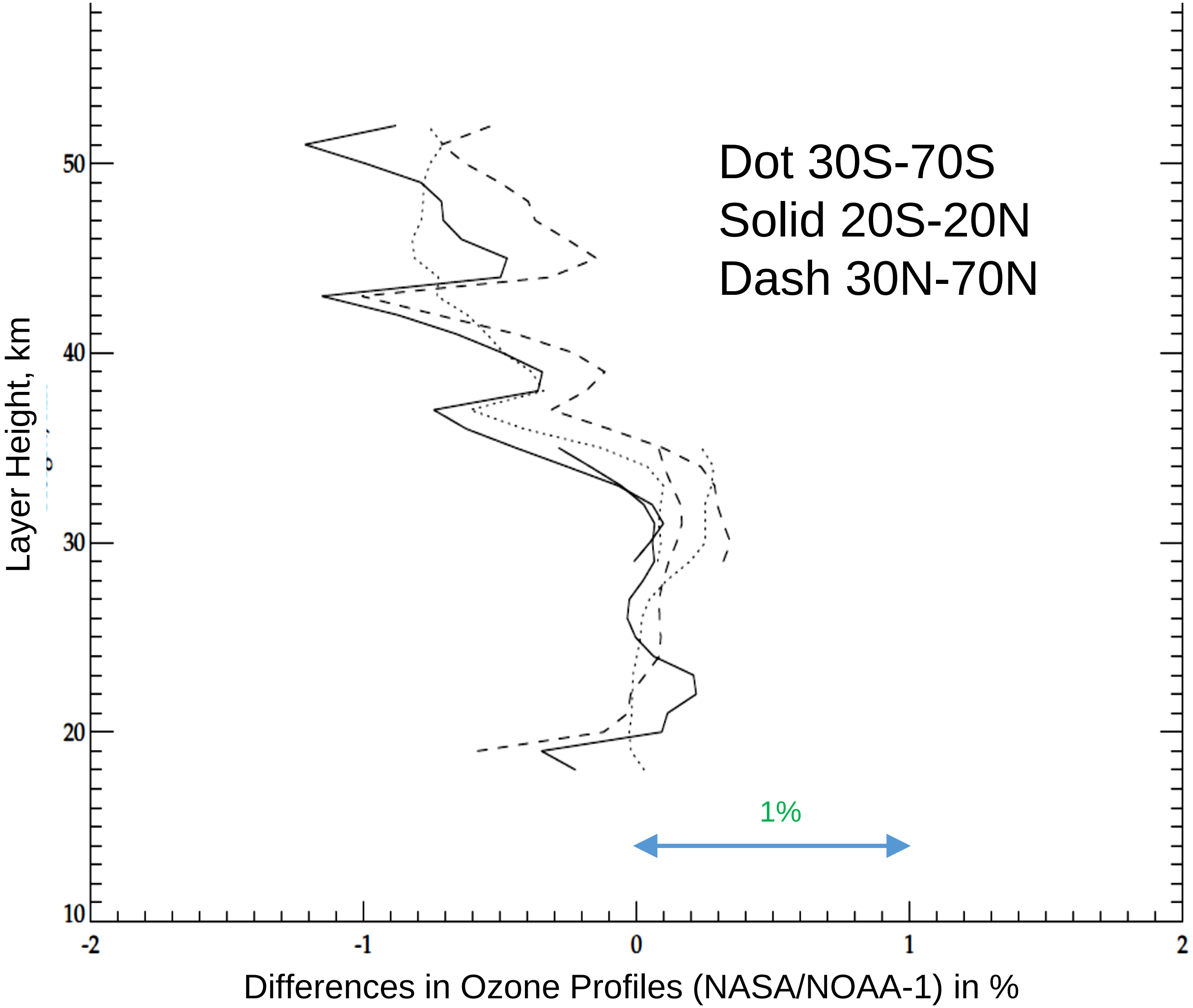
https://doi.org/10.5194/amt-11-2837-2018

https://doi.org/10.5194/amt-11-2135-2018



Jacobians for OMPS Limb Profiler for 1-km layers: (a) 296 nm and (b) 601 nm channels for orbit #24119, Earth View #52, 45° SZA. Diamond symbols are color keyed to give Tangent Height altitudes of corresponding lines.

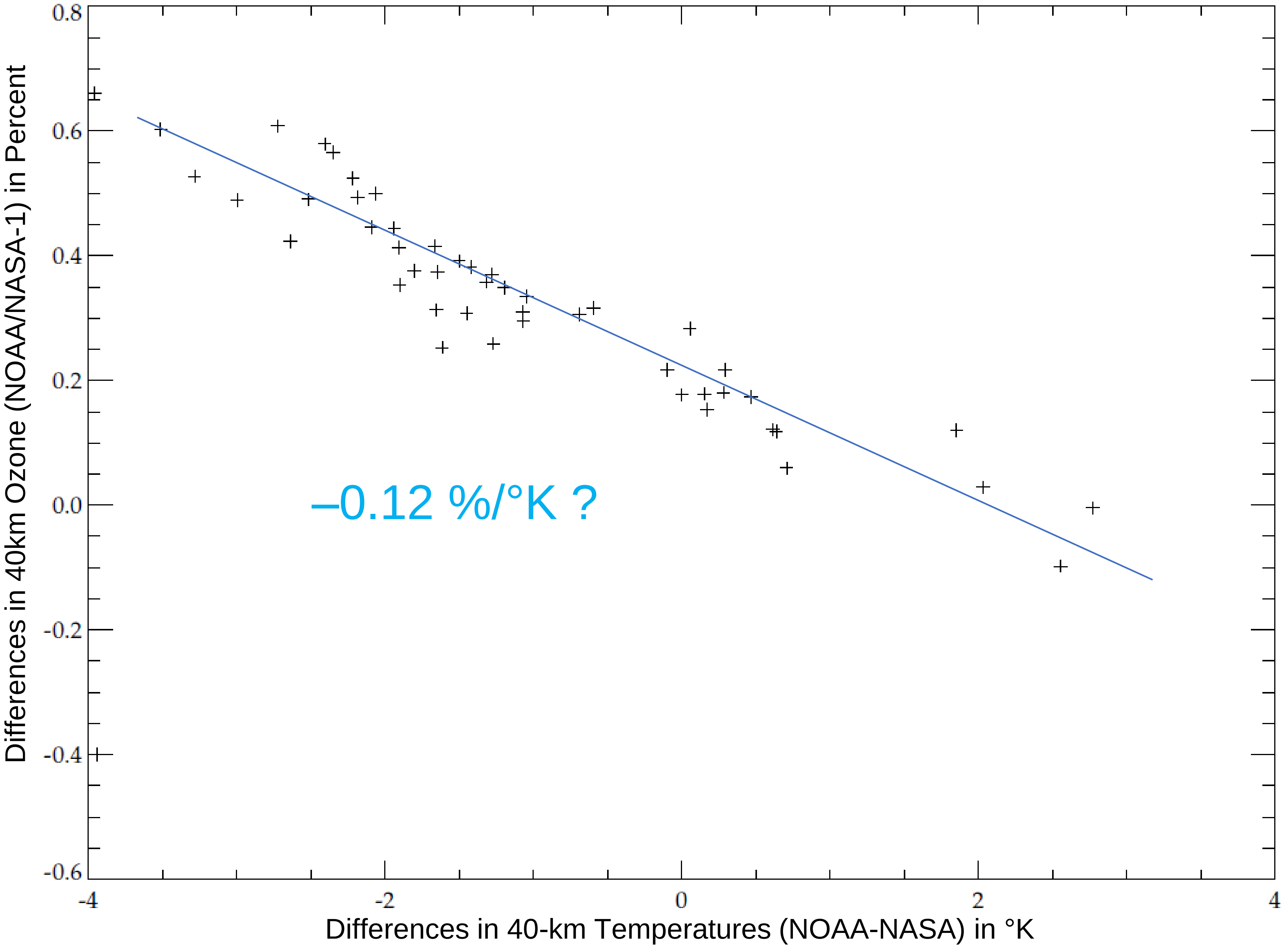
OMPS Limb Profile Zonal Mean Retrieval Differences, NASA versus STAR for August 10, 2019



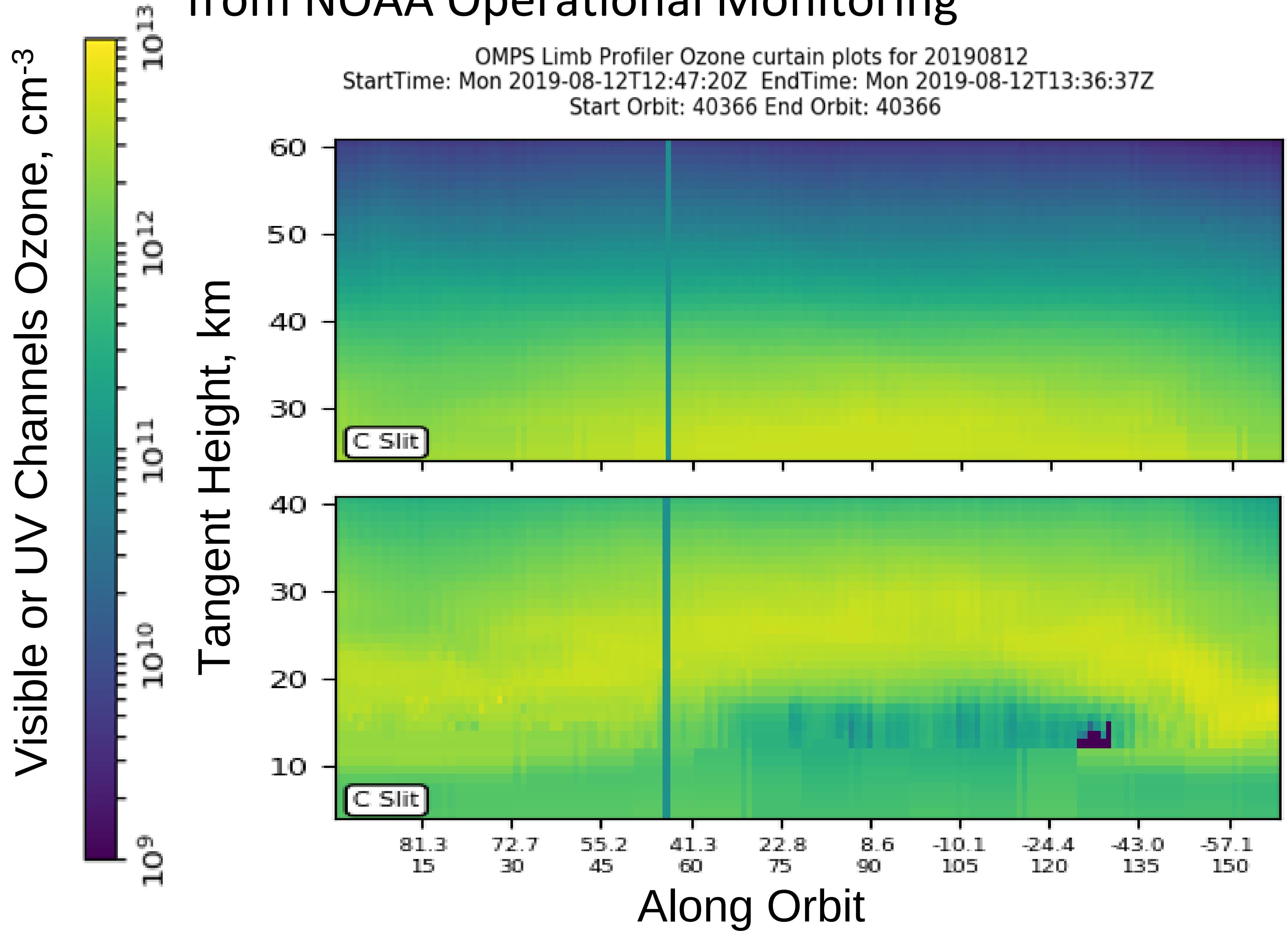
Comparisons of zonal mean ozone profiles from NASA forward processing and NOAA NDE I&T processing for V2.5Limb ozone products.

Different ancillary temperature files are responsible for most of the biases and variations between the retrievals.

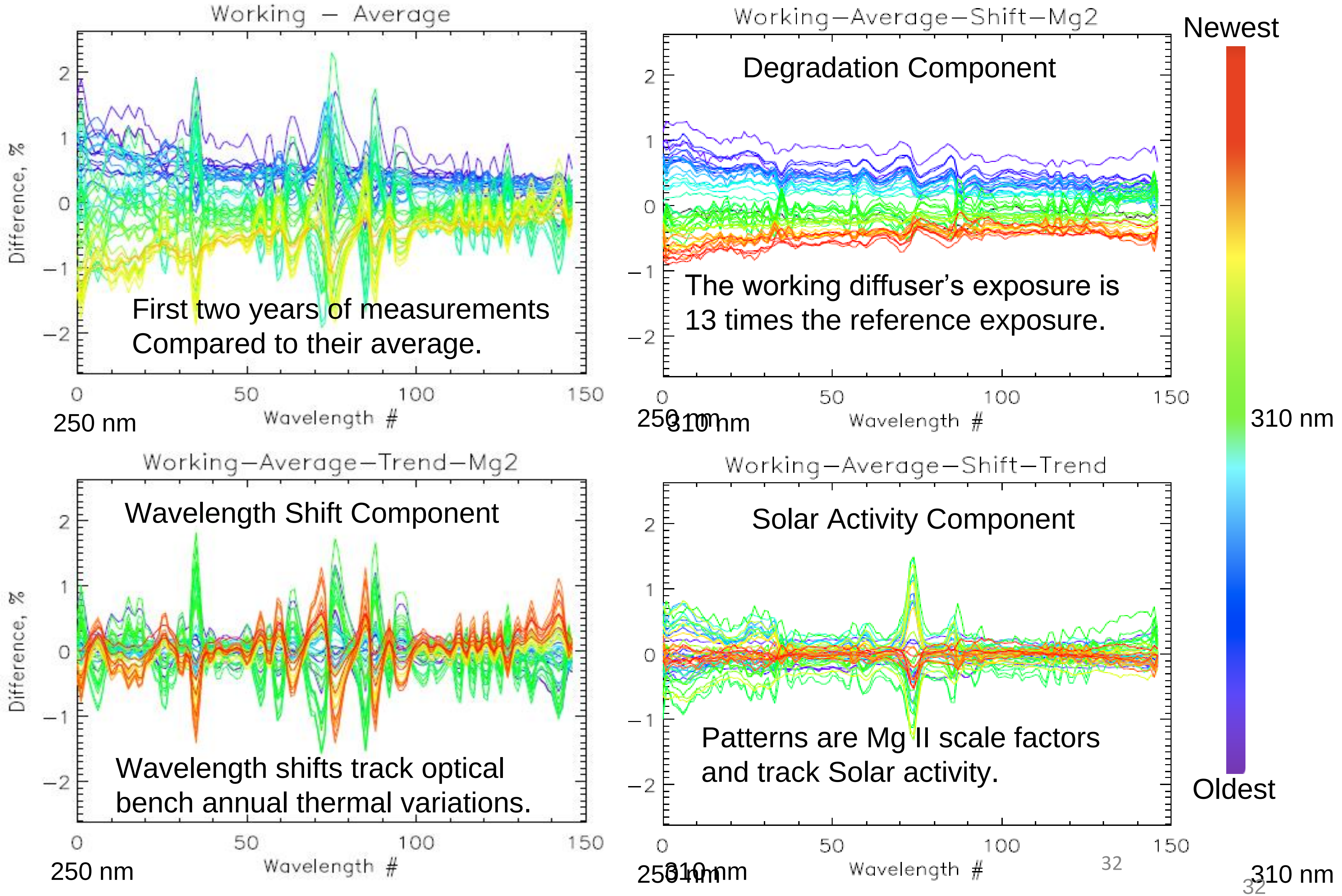
Ancillary Temperature Forecast Differences versus Limb Ozone Profile Retrievals for one Orbit



Curtain Plots for Orbital Retrievals from NOAA Operational Monitoring

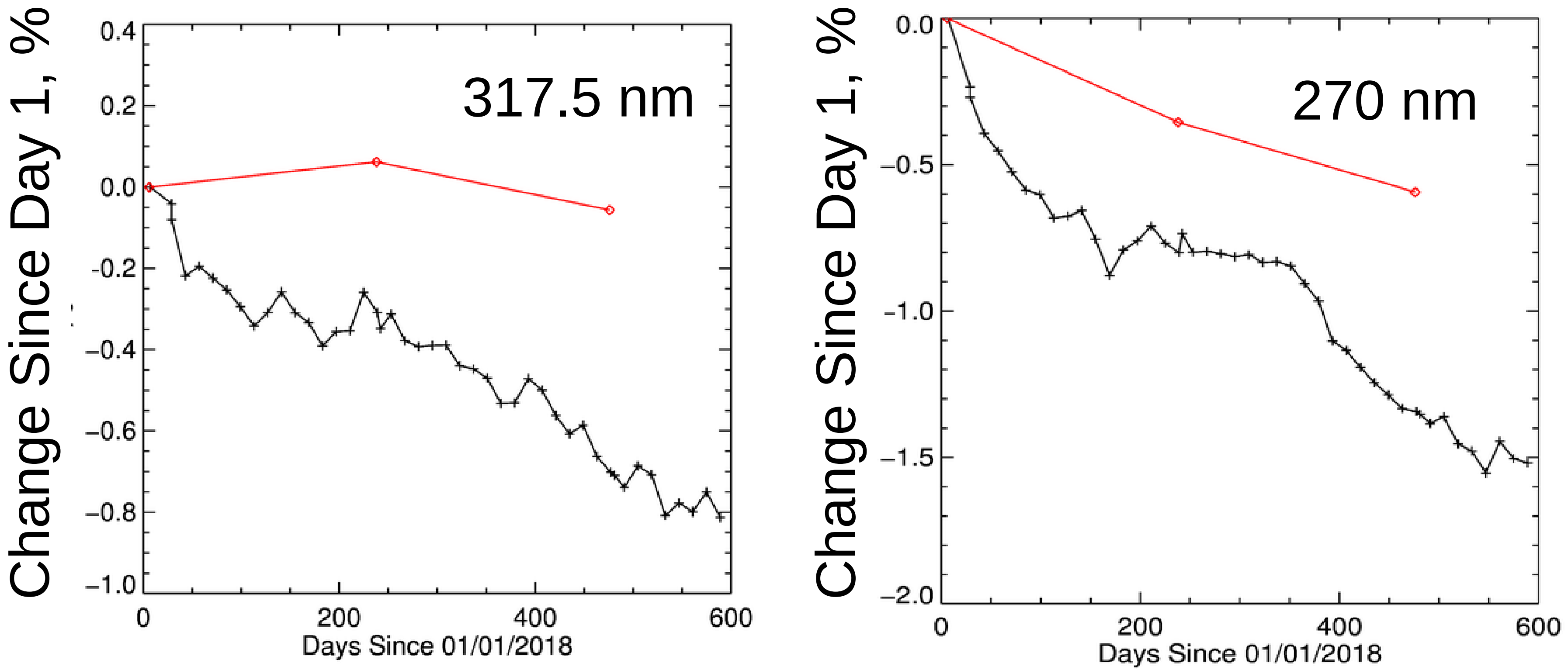


S-NPP OMPS Nadir Profiler Solar Measurements



NOAA-20 OMPS Sensor and Diffuser Degradation since Launch

The Reference solar diffuser measurements track sensor throughput changes.
The Working solar diffuser is exposed 13 times as often as the Reference is.



- No degradation surprises – rates are slightly greater than SNPP OMPS.
- 0.6% correction adjustment currently accumulated at 270 nm.
- Reprocessing uses daily estimates of throughput changes and solar activity levels.

V8Pro v3r3 Refinements

A. Dual Adjustment Tables
- Provides Old (Current) and New (Updated) soft calibration tables with the option to interpolate between them to smooth the transition for operational degradation updates at the request of data assimilation applications.

B. Metadata improvements.
- Additional fields are added to metadata to be consistent with NDE requirements and to provide better information. These include the NDE production site, NDE production environment, and the adjustment table's file name.

C. Area-Weighted FOV Averages
- When the NOAA-20 OMPS NM goes to [10,10,10,10, 5, 10, 5, 10, 10, 10, 10] pixel aggregation, we will want to have area-weighted values computed in the Glueware. This refinement provides the code to calculate and use the relative sizes of the FOVs.

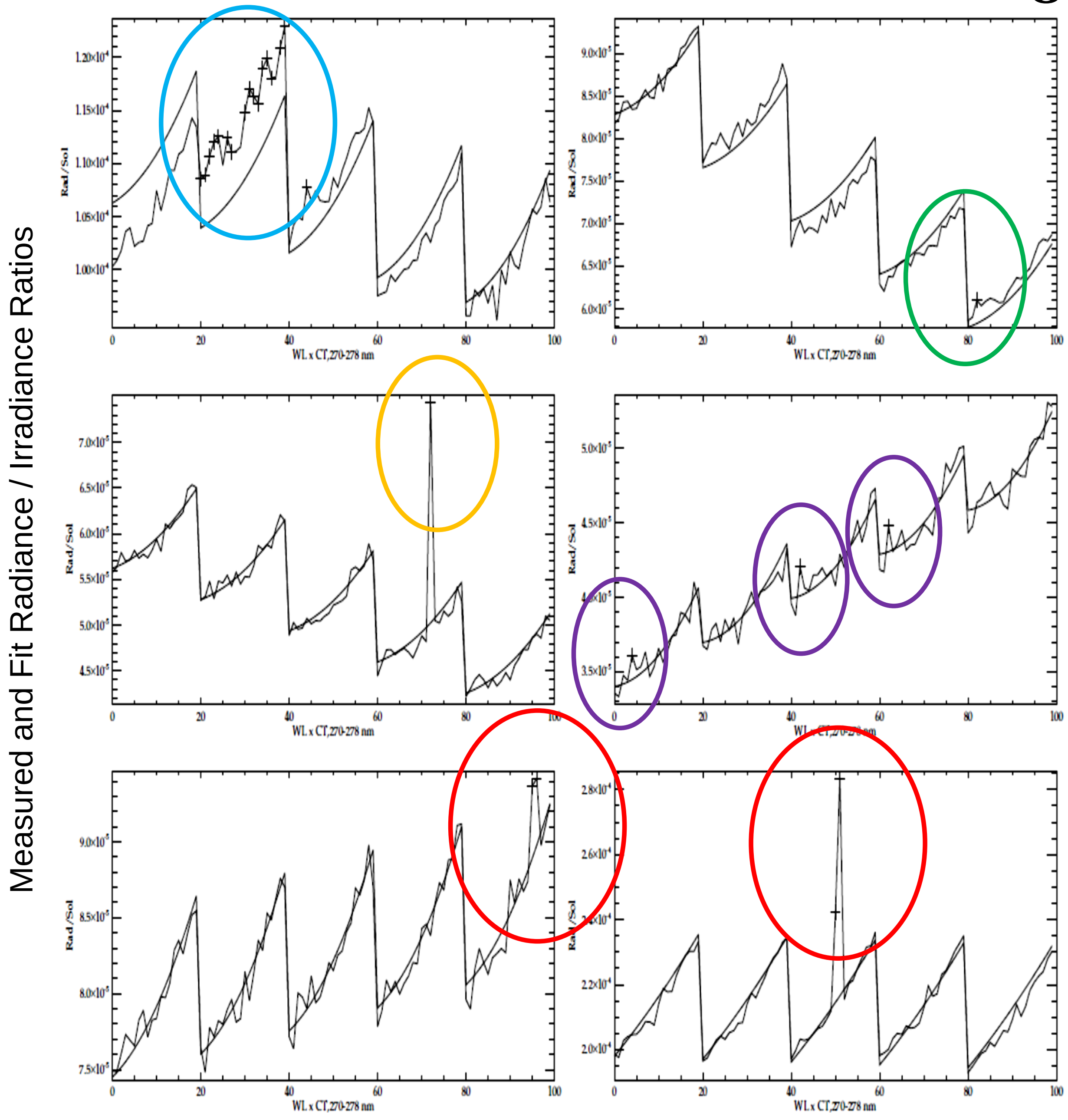
D. Remove the use of 340 nm channel for reflectivity.
- Code updates to switch from 340 nm channel to 331 nm channel for some reflectivity calculations for consistency with the NASA V8Pro implementation.

E. Code Fixes
- Averaging Kernels: Change OMPS V8Pro product configuration for the averaging kernels to agree with the SBUV/2 relative response ones.
- Mixing ratio inconsistency in amount and pressure order.
- Terrain Pressure maximum and minimum extended to include Dead Sea and Mt. Everest.
- Descending orbit data are not processed – fixed by changing corner order in Glueware.

F. Changes to handle OMPS NM SDR sizes up to 30 scans x 140 cross-track FOVs per granule.

G. Outlier Detection Filter and Information Concentration (F&IC) for smaller FOV
- Implements a combination of median filter and 10- to 12-wavelength polynomial fits of the radiance / irradiance ratios for the shorter ozone profile channels to reduce measurement noise, remove outliers and identify PMCs.

Outlier Detection & Filtering for NOAA-20 OMPS NP

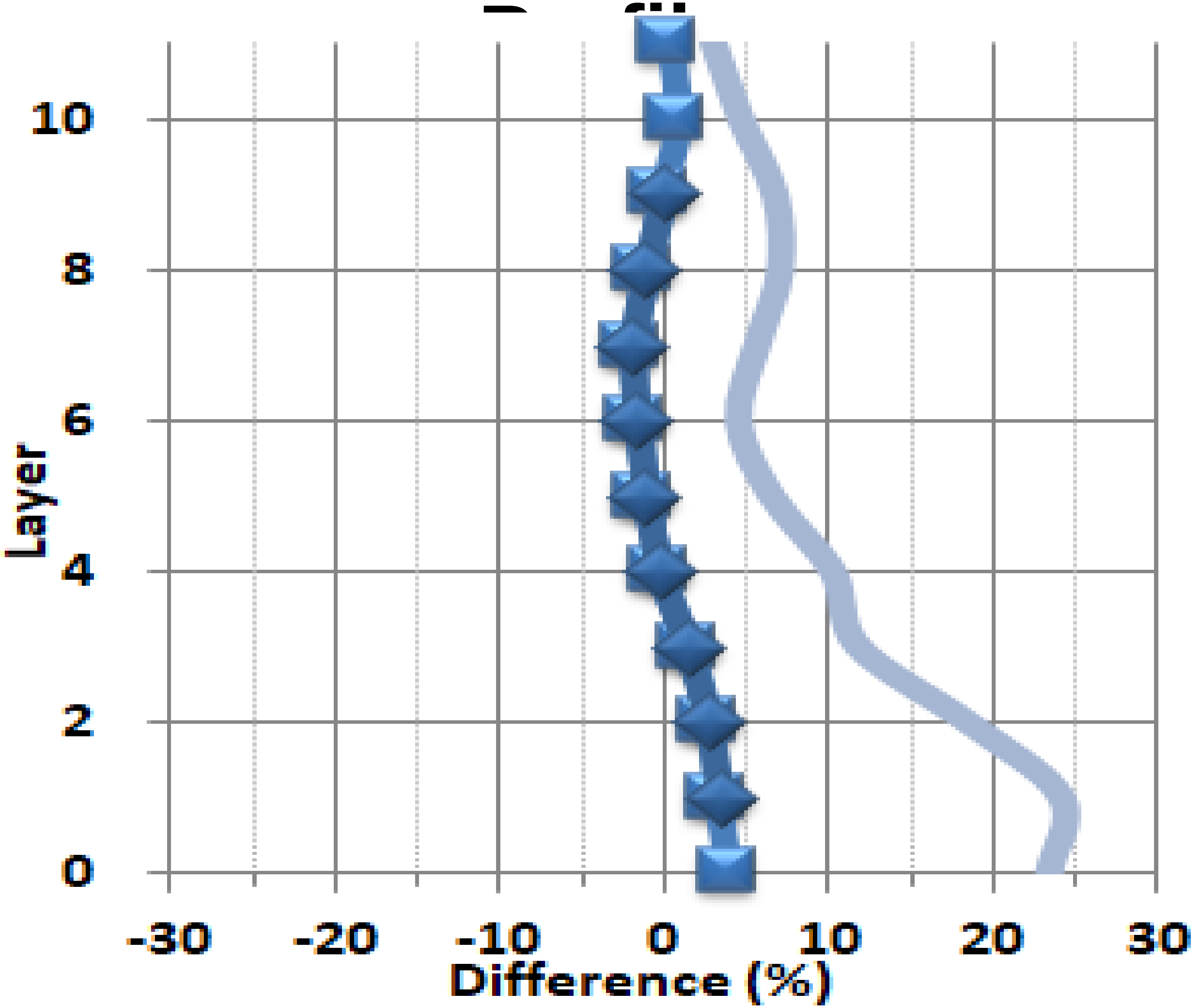


12 Spectral by 5 Cross-track

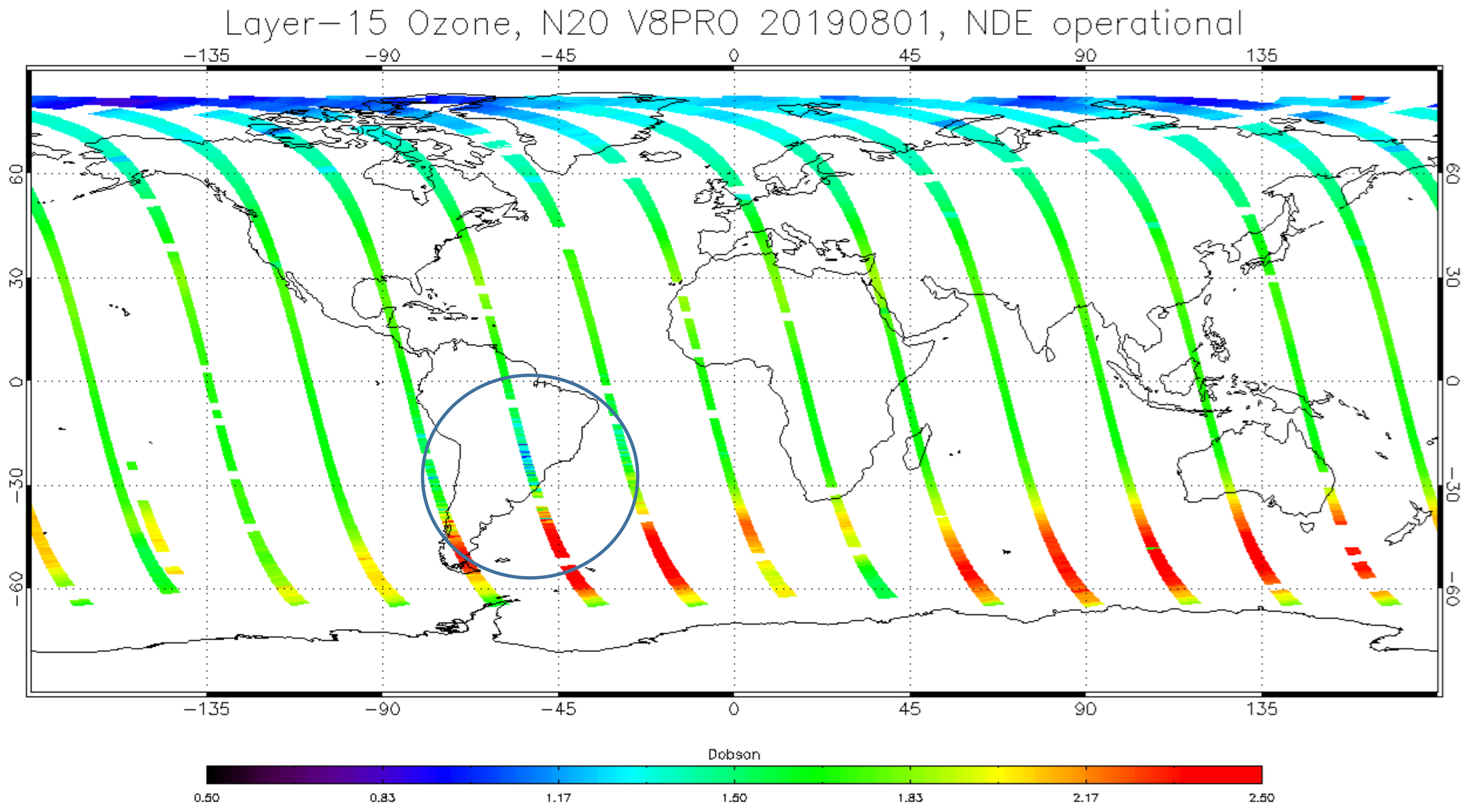
12 Spectral by 5 Cross-track

Filter with a 4% threshold. A "+" indicates a bad value. Orange - a single spike. Red - two spikes. Purple - three spikes for the same spectral row. These all occurred in the SAA. Blue - high latitude, summer hemisphere, Polar Mesospheric Clouds (PMCs) are present in at least one FOVs. Green - marginal case due to PMCs, or noise, or a charged particle hit in the auroral oval.

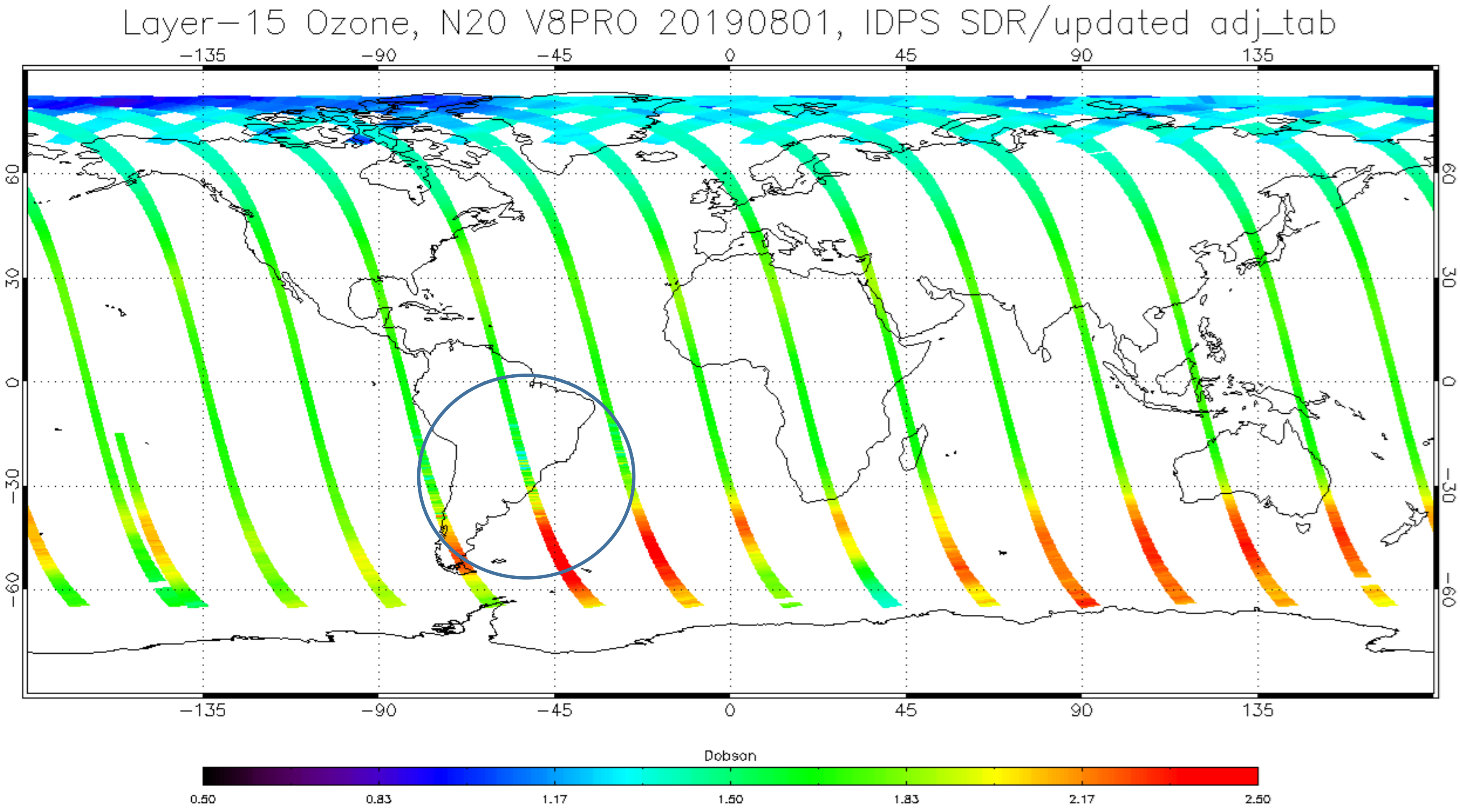
S-NPP V8Pro Ozone Profile versus Boulder CO Umkehr Ozone Profile



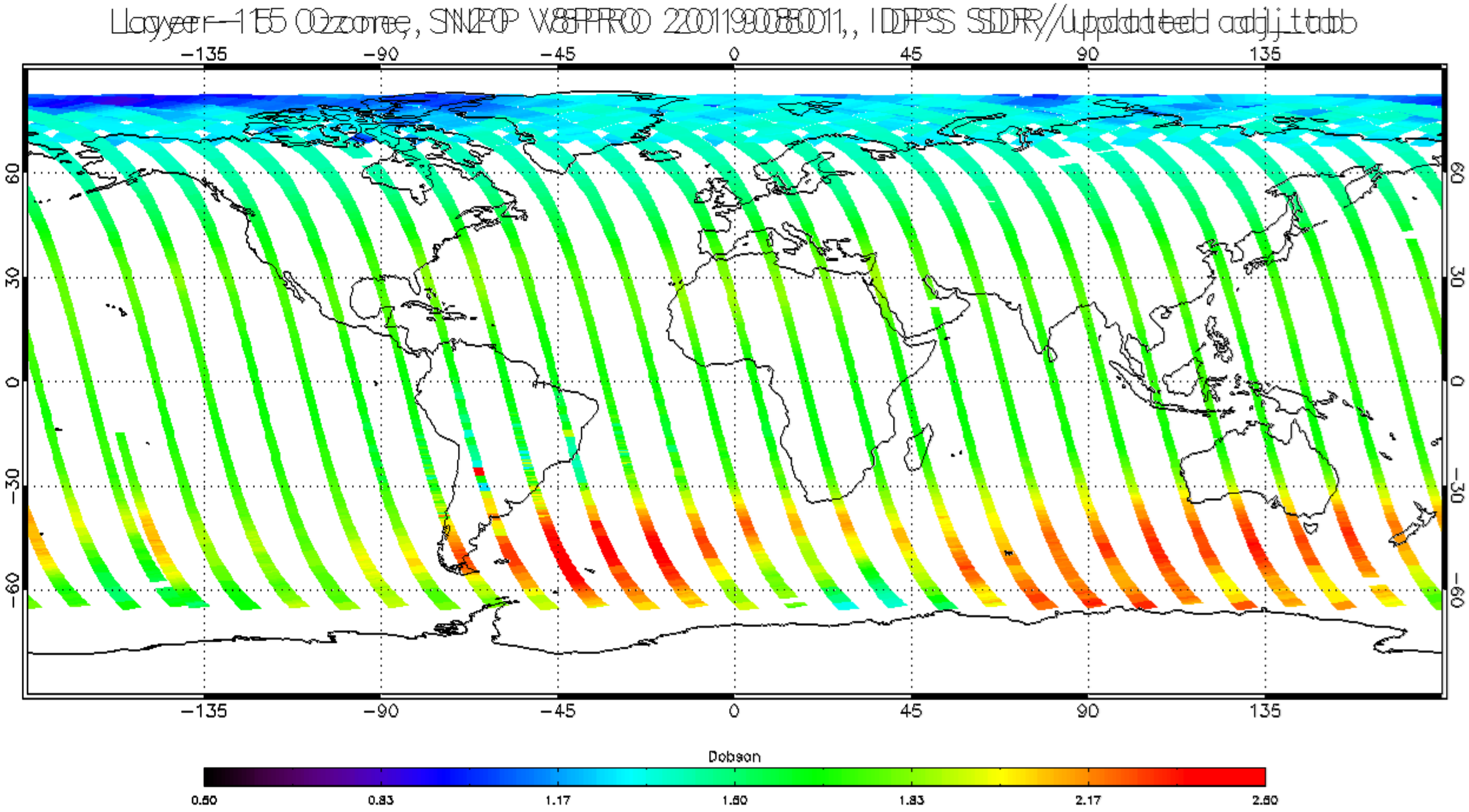
Layer 15 (1.6 hPa to 1 hPa)
NOAA Operational Integration & Testing



Layer 15 (1.6 hPa to 1 hPa)
NOAA Offline with Code Improvements



Layer 15 (1.6 hPa to 1 hPa)
NOAA Offline N20 versus Offline NPP



Summary and Conclusions

- The OMPS Nadir Mapper V8TOz Total Column Ozone products are fulfilling their roles in continuing Climate Data Records and monitoring the Ozone Hole and Ozone Layer recovery.
- The OMPS Limb Profiler V2Limb high-vertical-resolution Ozone and Aerosol Profile products will soon be available for operational users.
- The OMPS Nadir Profiler V8Pro Ozone Profile products are tracking the changes in the ozone layer but inconsistencies between the NOAA-20 and S-NPP results disclose a need for improved characterization of the wavelength registration.