NOAA JPSS Science Team Meeting

Trace gas session

Antonia Gambacorta and Monika Kopacz

Co-conveners

August 18, 2017

Auditorium: Trace Gases

Time	Presentations / Topics	Speaker	Affiliation
0830 - 0900	***Night Vision: Illuminating the Capabilities of the VIIRS Day/Night Band*** ***Auditorium***	Curtis Seaman	CIRA
0915 - 1700	***Trace Gases*** ***Chairs: Antonia Gambacorta and Monika Kopacz*** ***Auditorium***		
0915 - 0930	*Opening Remarks*	Antonia Gambacorta; Monika Kopacz	STC;CPO
0930 - 0950	*Status of the NUCAPS Full Spectral Resolution trace gas products*	Antonia Gambacorta	SGT
0950 - 1010	*Status of NUCAPS Full Spectral Resolution Trace Gas EDR Validation*	Nick Nalli	IMSG
1010 - 1030	*Forward Model Improvements: Present and Future*	Larrabee Strow	UMBC
1030 - 1100	***Break***		
1100 - 1120	*What are NUCAPS trace gas retrievals good for?*	Nadia Smith	
1120 - 1140	*Evaluating NUCAPS CH4 and CO*	Greg Frost	NOAA/ESRL
1140 - 1200	*Recent Improvements in NUCAPS CH4 retrievals using CrIS FSR data*	Xiaozhen Xiong	
1200 - 1330	***Lunch***		
1330 - 1350	*Using Ammonia Retrievals from the Cross-track Infrared Sounder to Improve Emission Inventories and Models.*	Matt Alvarado	AER, Inc.
1350 - 1410	*Increased atmospheric ammonia over the worldâ€™s major agricultural areas detected from space*	Juying Warner	UMD
1410 - 1430	*Multi-species, Multi-Spectral, Multi-Satellite retrievals of trace gases*	Vivienne Payne	JPL
1430 - 1450	*Full-chemistry Vog Forecasting over Hawaii*	Youhua Tang	ARL
1450 - 1500	***Break***		
1500 - 1520	*Smithsonian Astrophysical Observatory OMPS Nadir Mapper formaldehyde retrievals*	Gonzalo Gonzalez Abad	Harvard
1520 - 1540	*Monitoring Atmospheric NO2 and SO2 from Space: Half a Decade of Suomi NPP OMPS Global Observation*	Kai Yang	NASA
1540 - 1600	*Development of Multi-sensor JPSS SO2 Products for Volcanic Cloud Monitoring*	Mike Pavolonis	STAR
1600 - 1610	*Closing Remarks*	Monika Kopacz; Antonia Gambacorta	CPO; STC

NOAA (OAR/CPO/AC4) effort so far

- **2013**: FY13 FFO funded ammonia product development and validation
- **2014**: FY14 FFO funded further development of ammonia product; CrIS workshop gathers potential (research) users
- **2015**: FY15 FFO funded ammonia product application in GFDL Earth System Model; CrIS workshop report released
- **2016-17**: FY16 FFO funded CrIS/OMPS ozone product development
- **2017**: FY18 FFO solicits for new (BVOC) product development – 5 relevant proposals

How did we contribute? Mostly through FFO…

More progress: CrIS workshop recommendations (2015)

Scientific community uses TIR satellite observation, so far provided by NASA and EUMETSAT from **MOPITT, TES, AIRS and IASI**. All are past expiration and there are no plans to replace them.

Recommendation 1: Need data

- Provide calibrated radiances Level 1b data at full spectral resolution.

Recommendation 2: Special needs for atmospheric chemistry

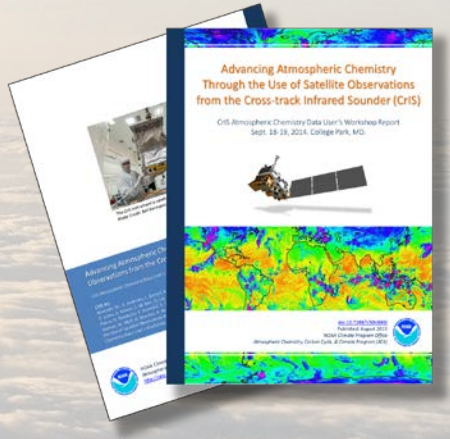
A. Provide reduced file size (like TES "lite) with retrievals for individual trace gases and their observation operators at a reduced vertical resolution.
B. Provide essential information: a priori, averaging kernels, estimated retrieval error.
C. Allow rapid multi-file download from CLASS

Recommendation 3: Validation

A. Coordinate validation with upcoming field campaigns (e.g. FIREX)
B. More frequent ESRL flights to validate trace gases
C. Plan additional field campaigns with retrieval and user communities

Recommendation 4: Future

A. Explore the possibility of new species/products
B. Close spectral gap
C. Reduce noise and increase resolution for future instruments



Most apply to all of JPSS!

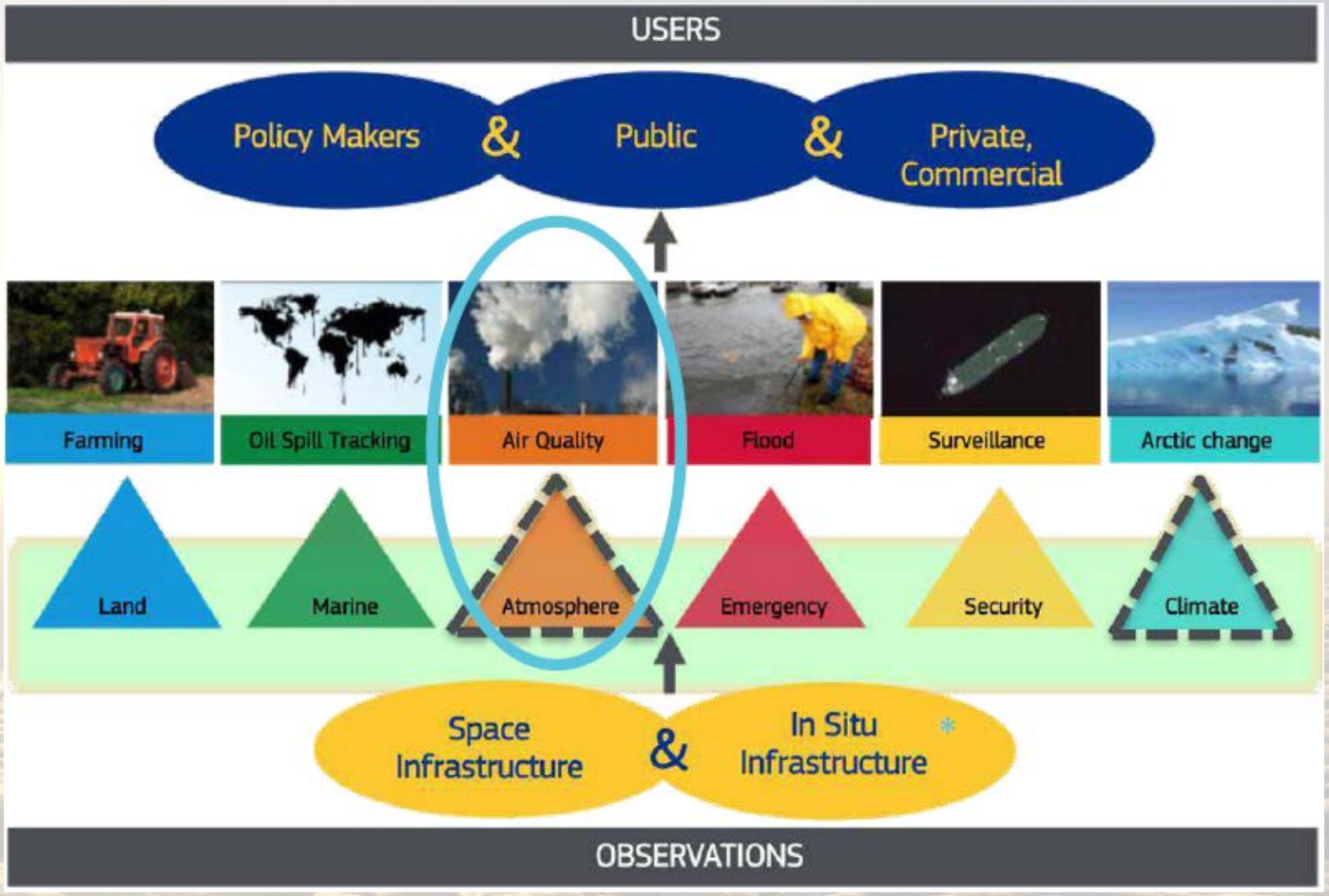
What are the applications?

- Improved understanding of atmospheric composition
- NOAA Climate/Earth System Model (GFDL) development and validation
- Air quality forecasting
- NGGPS
- Monitoring of air pollution and greenhouse gases

Priorities??? Workshops needed??

Air quality services: Can we keep up with Copernicus?





"The service provides near-real-time analysis and 4-day forecasts, as well as reanalysis, of the **European air quality**, thus enabling a permanent assessment of the air we breathe."

http://atmosphere.copernicus.eu/services/air-quality-atmospheric-composition

Figure courtesy of Mark Parrington and Vincent-Henri Peuch, ECMWF

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Status of the NOAA Unique Combined Atmospheric Processing System (NUCAPS) Trace Gas products

Antonia Gambacorta [1], Nick Nalli [2], Flavio Iturbide-Sanchez[2], Changyi Tan[2], Kexin Zhang[2], Xiaozhen Xiong[2], Bomin Sun[2], Mike Wilson[2], Tish Suillard[2], Tom King[2], Chris Barnet[1], Ahsley Wheleer[1], Nadia Smith[1], Larrabee Strow[4],Tony Reale[3], Mark Liu[3], Lihang Zhou[3], AK Sharma[3], Walter Wolf[3], Mitch Goldberg[5]

2017 JPSS Annual Meeting – Trace Gas Session

[1]STC; [2] IMSG; [3] NOAA/NESDIS/STAR; [4]UMBC; [5]NOAA JPSS

Outline of this talk

Part I.

Introduction on the NUCAPS system

Part II.

Overview of the NUCAPS Full Spectral Resolution (FSR) upgrades relevant to trace gas retrievals

- SARTA RTA upgrades and bias corrections
- CrIS FSR trace gases channel selection

Part III.

Current activities, future plans

N as in NUCAPS

NOAA	NOAA's mandate: ensuring highest computational efficiency and state of art inversion methods to maximize utilization of large volumes of data for a weather ready nation
Unique	A mathematically sound, globally applicable (land/ocean, day/night, all season, all sky, TOA-surface) hyperspectral retrieval code
Combined	… that can fully exploit all available satellite assets: infrared, microwave, visible
Atmospheric	… to generate a full suite of retrieval products: cloud cleared radiances, skin temperature, vertical profiles of temperature, water vapor, O3, CO, CH4, HNO3, N2O, SO2, CO2 (future: HN3)
Processing	… by the use of a modular design compatible with multiple platforms: Aqua, MetOp, SNPP, JPSS, EPS-SG
System	NUCAPS has been running operationally at NOAA since 2004. it is now in AWIPS II. It has been installed in CSPP DB.

Nominal vs Full Spectral Resolution CrIS

- **The Cross-Track Infrared Sounder (CrIS)** is a Fourier spectrometer covering the longwave (655-1095 cm^{-1}, "LW"), midwave (1210-1750 cm^{-1}, "MW"), and shortwave (2155-2550 cm^{-1}, "SW") infrared spectral regions.

- **Past operations (NUCAPS Phase 1-3):**
  - Maximum geometrical path *L* of 0.8 cm (LW), 0.4 cm (MW) and 0.2 cm (SW)
  - Nyquist spectral sampling (*1/2L*): 0.625 cm^{-1}, 1.25 cm^{-1} and 2.5 cm^{-1}

- **Experimental since 2013 – Operational in August 2017 (NUCAPS Phase 4):**
  - Maximum geometrical path *L* of 0.8 cm in all three bands
  - Nyquist spectral sampling (*1/2L*): 0.625 cm^{-1} in all three bands

CrIS Full Spectral Resolution (FSR) SARTA Rapid Transmittance Algorithm (RTA)

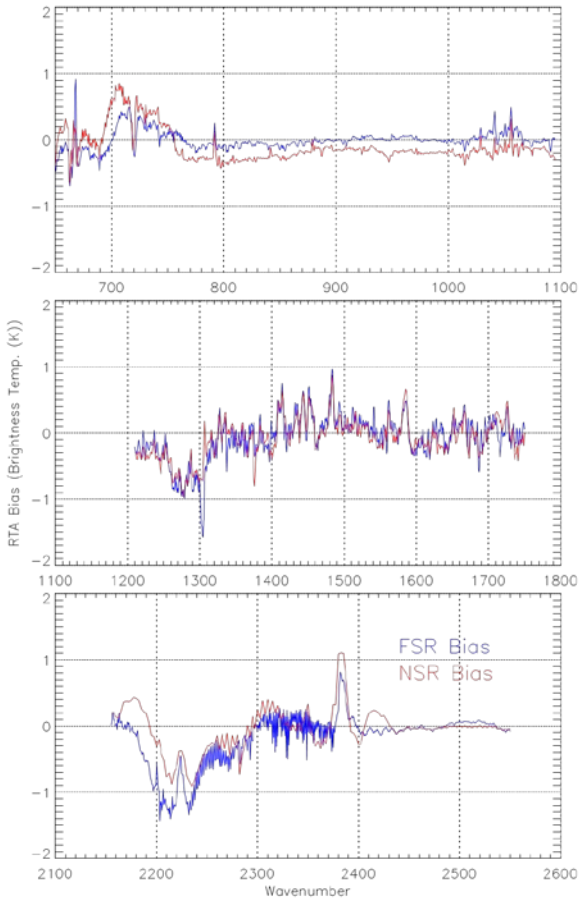
Upgrades in the CrIS FSR SARTA RTA (L. Strow's talk in the today's session)

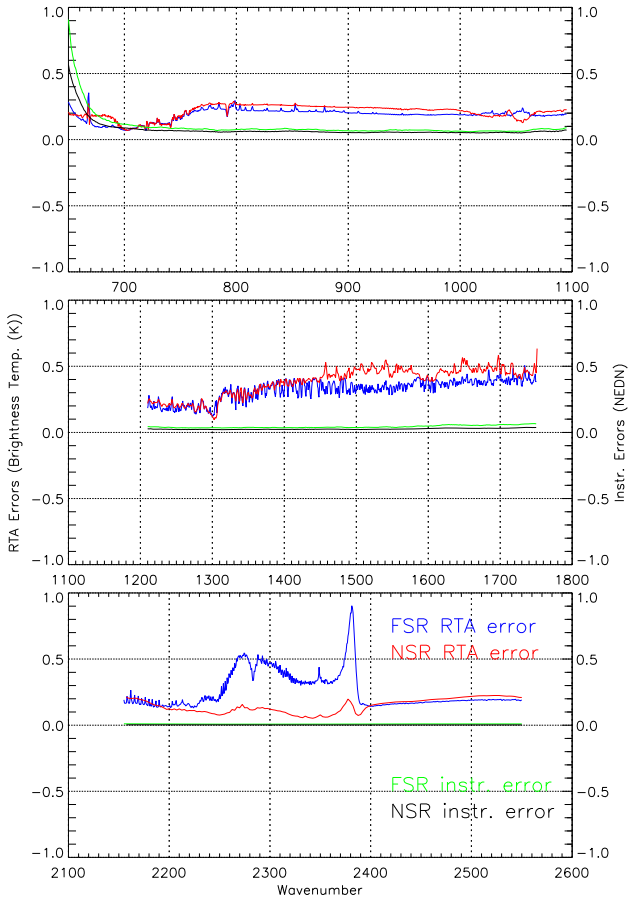
- CrIS high-resolution ILS
- HITRAN 2012 (vs 2008 in original CrIS RTA)
- LBLRTM Line Mixing for CO2 and CH4, H2O continuum
- UMBC line-by-line for water vapor
- Improved reflected thermal component for high secant angles
- Tested on 750+ profiles (from ECMWF selected subset), regressed on 49 profiles
- Error covariance estimates available from 750+ profile testing

CrIS FSR SARTA bias tuning and sdev

Bias

Standard deviation





CH4 and CO2 profiles from JAMSTEC atmospheric chemistry-transport model (ACTM) as truth.
CO profiles from MOPITT retrieval as truth. Selection of clear CrIS FOVs was performed using collocated VIIRS cloud mask IPs. (1) only confident clear pixels; (2) satellite view angle less than +/-30 degrees; (3) set multi-thresholds to screen out outliners.

Channel Selection Methods: two schools of thoughts

Jacobians method aka "Physical Approach"

- Selection methodology metrics:
  - Channel spectral purity

- Current operational users (to cite a few)
  - AIRS science team (1,3)
  - NOAA (AIRS, IASI, CrIS) (1,2)
  - ECMWF (IASI) (4)
  - Meteo UK (IASI) (4)
  - Meteo France (IASI) (4)
  - LATMOS (AIRS, IASI, CrIS) (5)
  - ULB (AIRS, IASI, CrIS)(5)

- List of references
  - (1) Susskind, Barnet, Blaisdell, IEEE 2003
  - (2) Gambacorta and Barnet, IEEE 2013;
  - (3) Susskind, Blaisdell, Iredell, JARS, 2014
  - (4) Martinet, Levananat, Fourrie, Gambacorta, 2014
  - (5) Crevoisier, Chedin, Scott, QJRM, 2003

Rodgers Method

- Selection methodology metrics:
  - Channel information content

- Current operational users (to cite a few)
  - ECMWF (1,2,3,4)
  - Meteo UK (1,2,3,4)
  - Meteo France (1,2,3,4)

- List of references
  - (1) Rodgers, 1997
  - (2) Fourrie *et al*. 2002;
  - (3) Rabier *et al*., 2002
  - (4) Collard and McNally, 2007

Physical Method vs Rodgers Method

Jacobians or Physical method

- A physically-based methodology where channels are selected upon their spectral properties.
- For each atmospheric species, we perform a spectral sensitivity analysis and retain the spectrally purest channels and reject channels carrying confounding signals.
- Other than spectral purity, priority is given to vertical sensitivity properties, low instrumental noise and RTA errors.
- The method is algorithm independent in that both simultaneous and sequential inversion algorithms benefit from channels that can discriminate between atmospheric species. Details to be explained ahead.

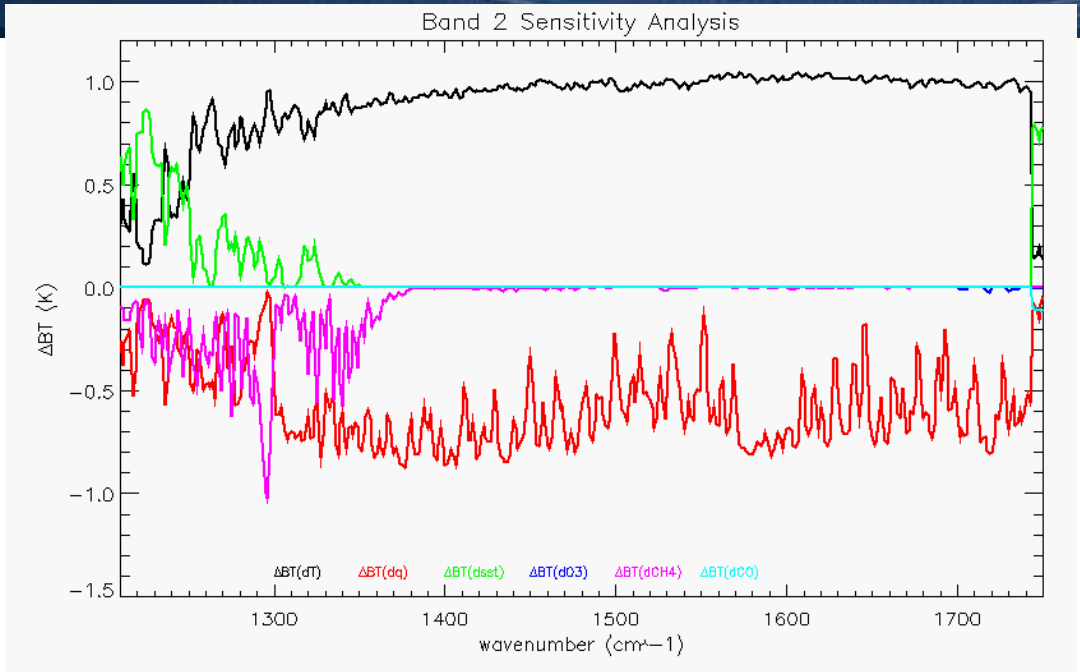
Rodgers method

- Follows a statistical iterative approach where channels are incrementally added after being tested for increased degrees of freedom.
- This methodology is more suited for simultaneous optimal estimation retrieval techniques.
- Can be automated by establishing fixed thresholds.

Both methods:

- a constant channel selection is normally used, which is derived as an average from multiple optimal selections computed over different geophysical regimes (polar, mid latitudes, tropical, land, ocean, desert).

CrIS FSR Channel Selection



Perturbation Applied

SST	1K
T	1K
H2O	10%
O3	10%
CH4	2%
CO	1%

Brightness temperature difference (ΔBT) terms represent the sensitivity of each channel to a given perturbation species and are indicative of the degree of *"spectral purity"* of each channel.

- For each atmospheric species, we select channels with:
  - **the highest degree of spectral purity** (the highest sensitivity to the species of interest and the lowest sensitivity to all other interfering species).
  - **the lowest noise sources** (NEDT, calibration & apodization corr., RTA errors)
  - **unique spectral features** (to capture atmospheric variability, maximize vertical resolution)

REF: A. Gambacorta and C. Barnet., Methodology and information content of the NOAA NESDIS operational channel selection for the Cross-Track Infrared Sounder (CrIS), IEEE, Vol. 51, Issue 6, 2013

Why do we use the Jacobian method

- NUCAPS required list of retrieval products (all sky, all seasons, all surface types)
  - Cloud cleared radiances
  - Cloud top pressure and fraction
  - Surface temperature
  - Vertical temperature
  - Water vapor
  - Trace gases: O_3, CH_4, CO, CO_2, SO_2, N_2O, HNO_3
- Future candidates:
  - NH_3 (Ammonia), HCO_2H (Formic Acid), $CH_3COOONO_2$ ("PAN")
- A "**trace gas"** is a gas which makes up less than 1% of the volume of the Earth's atmosphere.
- Trace gas radiative signals are in the range of the instrument noise.
- Most channels are largely contaminated by clouds, temperature and water vapor signals.
- Answer: *Spectral purity is essential to improve signal to noise for the retrieval of the full list of NUCAPS required products, particularly for trace gases, under all sky conditions.*
- This methodology, being *physically based*, is applicable to *ALL* retrieval schemes. It is particularly suited for sequential retrieval approaches. See next slide.

REF: A. Gambacorta and C. Barnet., Methodology and information content of the NOAA NESDIS operational channel selection for the Cross-Track Infrared Sounder (CrIS), IEEE, Vol. 51, Issue 6, 2013

Why do we use the Jacobian method

Summary of current NUCAPS retrieval products

gas	Range (cm^{-1})	Precision	d.o.f.	Interfering Gases
T	650-800 2375-2395	1K/km	6-10	H2O,O3,N2O emissivity
H_2O	1200-1600	15%	4-6	CH4, HNO3
O_3	1025-1050	10%	1+	H2O,emissivity
CO	2080-2200	15%	≈ 1	H2O,N2O
CH_4	1250-1370	1.5%	≈ 1	H2O,HNO3,N2O
CO_2	680-795 2375-2395	0.5%	≈ 1	H2O,O3 T(p)
Volcanic SO_2	1340-1380	50% ??	< 1	H2O,HNO3
HNO_3	860-920 1320-1330	50% ??	< 1	emissivity H2O,CH4,N2O
N_2O	1250-1315 2180-2250	5% ??	< 1	H2O H2O,CO
$CFCl_3$ (F11)	*830-860*	*20%*	-	*emissivity*
CF_2Cl (F12)	*900-940*	*20%*	-	*emissivity*
CCl_4	*790-805*	*50%*	-	*emissivity*

Potential additions

How do we maximize linearity?

- **Sequential OE** (solves each state variable separately) **vs simultaneous OE** (solves all parameters simultaneously) **approach**

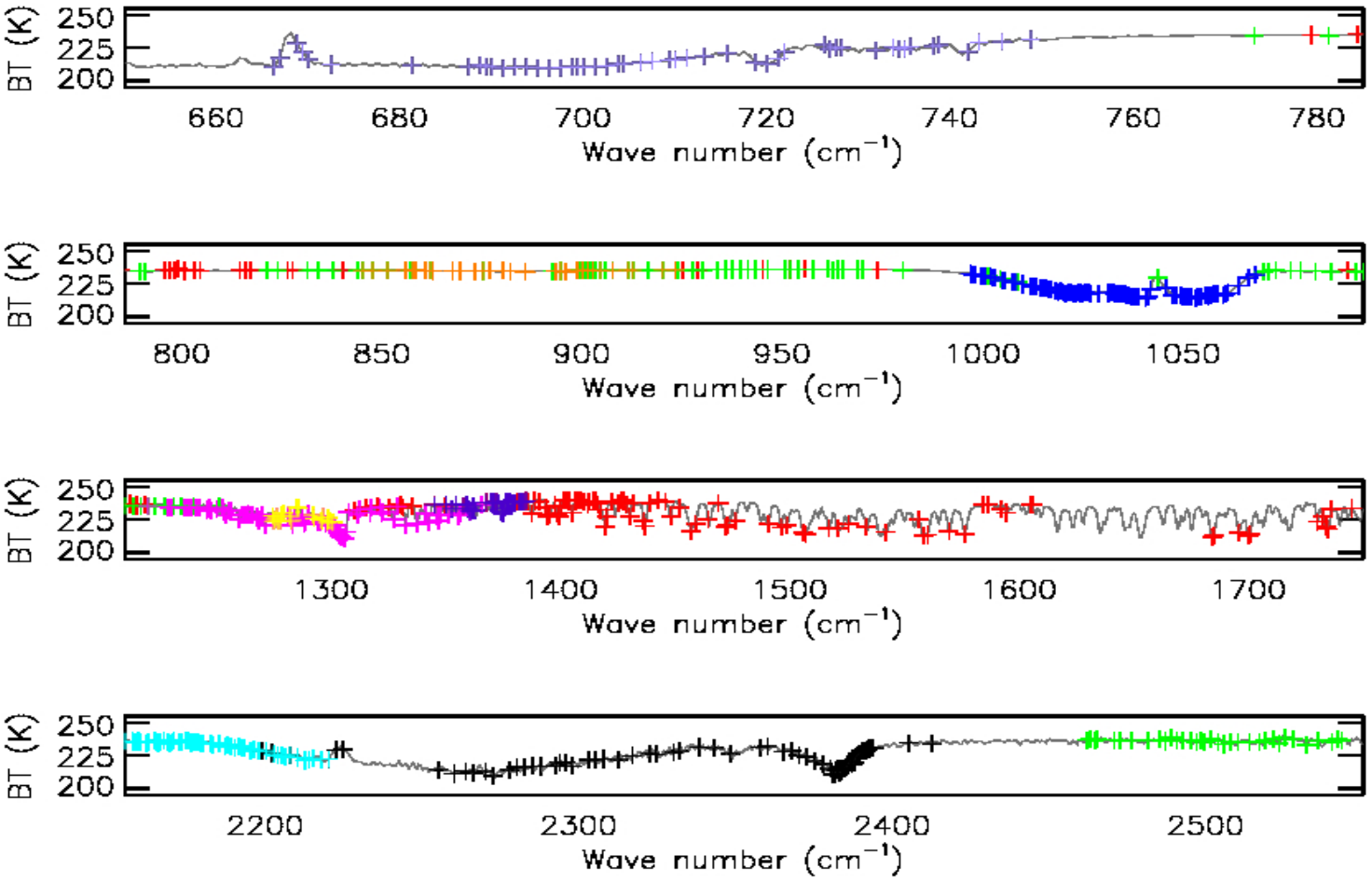
$$R_n^{obs} - R_n(\vec{X}) \simeq K_{n,i}^1 \cdot \Delta\vec{T}_i + e_n$$

$$\begin{aligned} e_n = & K_{n,i}^2 \cdot \delta\vec{q}_i \\ & + K_{n,i}^3 \cdot \delta\vec{O}_i \\ & + K_{n,i}^4 \cdot \delta\vec{C}O_i \\ & + \ldots + \epsilon_n \end{aligned}$$

- Careful analysis of the physical spectrum will show that many components are physically separable (spectral derivatives are unique).
- Select channels within each step with large K and small e_n
- This makes the solution more linear with respect to the simultaneous OE approach.
- State matrices are small and covariance matrices of the channel subsets are quite small. This has significant implications for operational execution time.

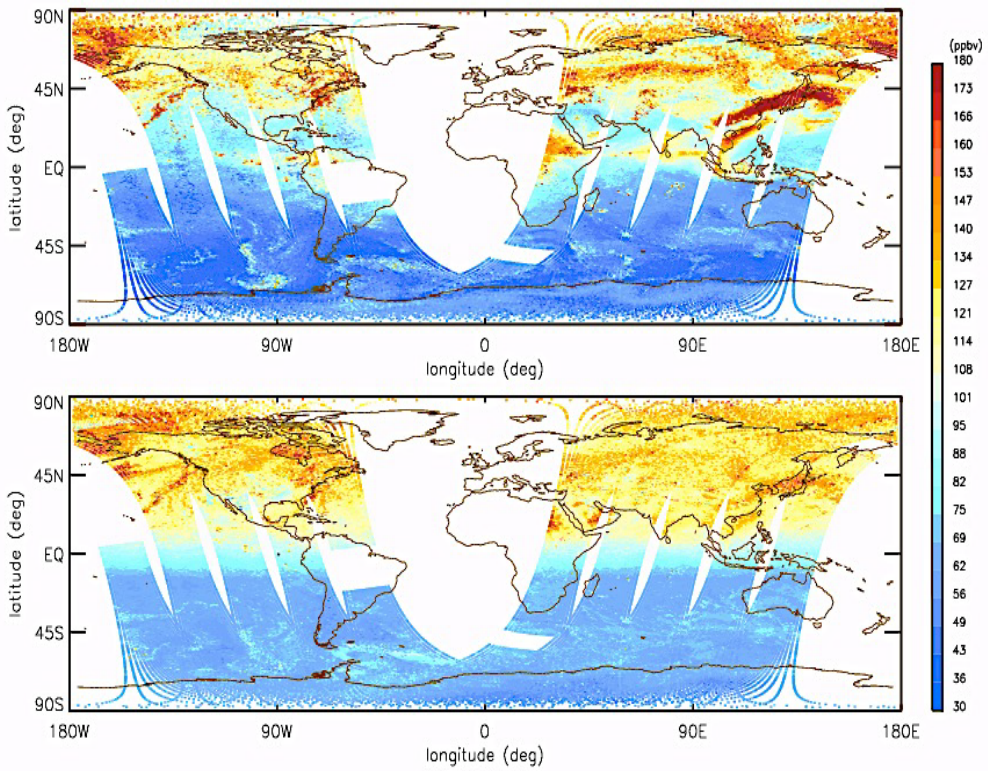
NUCAPS Operational FSR CrIS channel selection (610 channels)

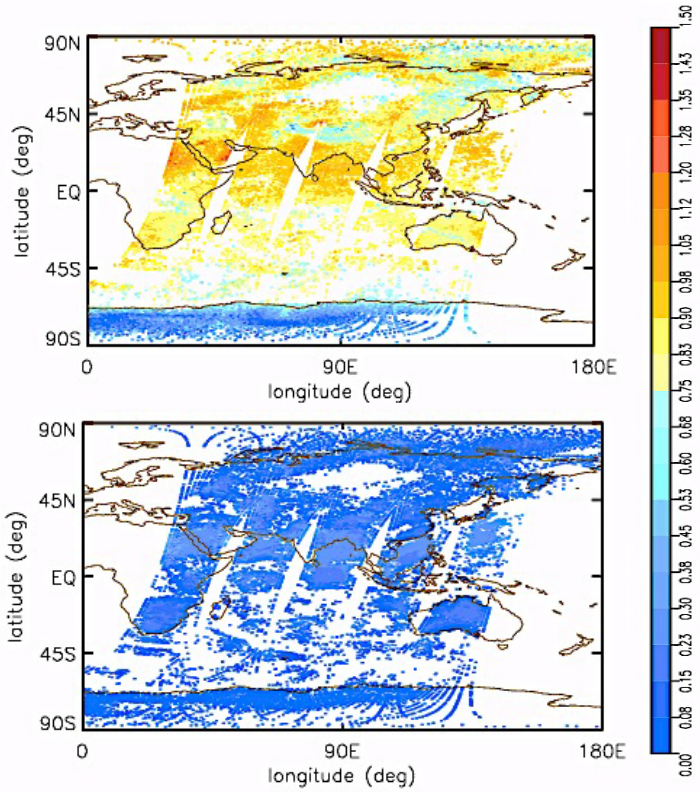
EDR	#chns
Temp	116
Surf	136 (62)
HO2	123 (62)
O3	77
CO	52
CH4	84
N2O	21
SO2	31
HNO3	30
CO2 (& Temp)	50 (T LW)



August 2013: Preliminary demonstration of FSR NUCAPS CO (top) vs NSR NUCAPS CO (bottom) using 5 test FSR orbits and ~2008 FSR RTA

NUCAPS CO retrieval (~450mb) NUCAPS CO DOF





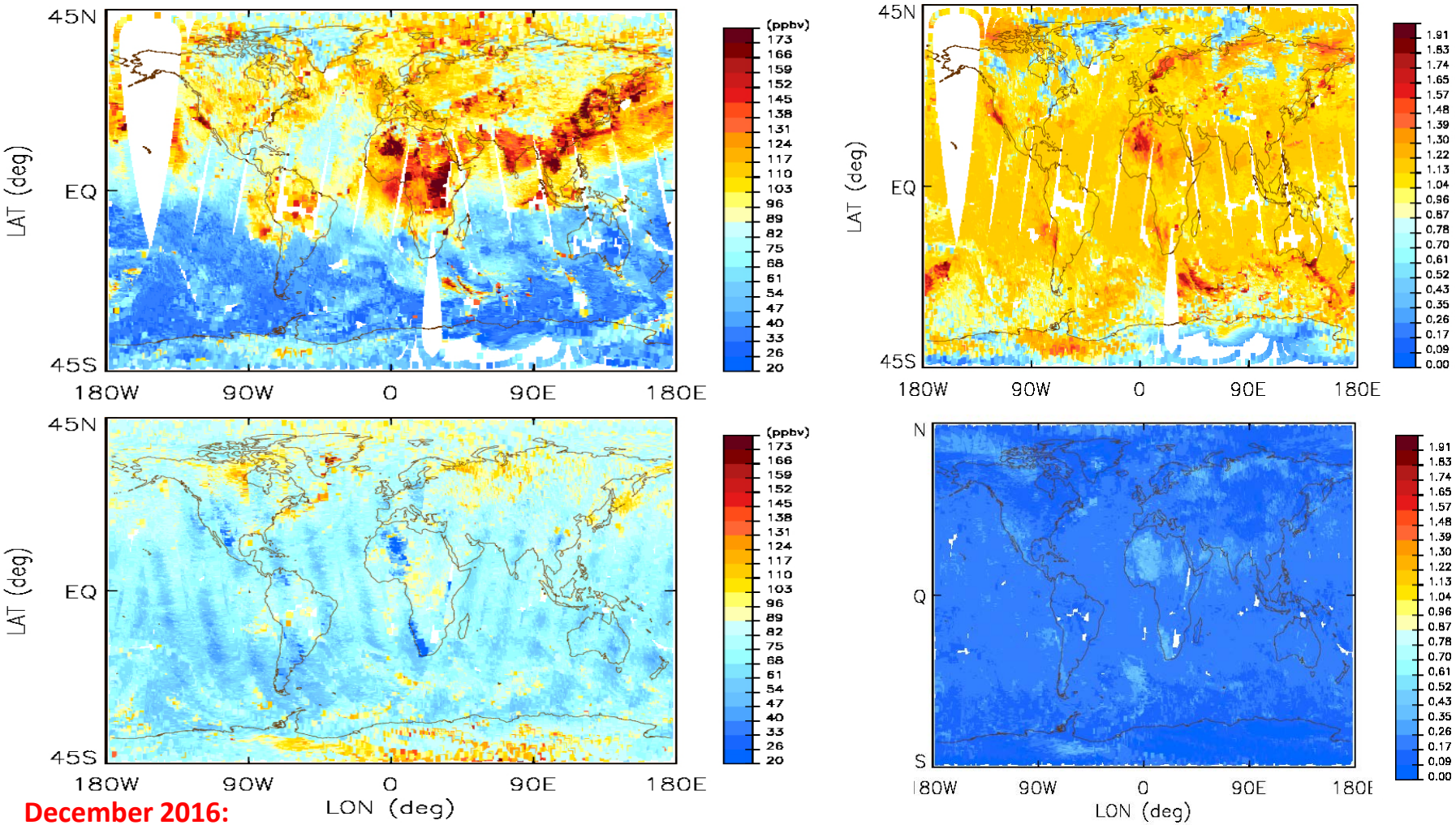
- The higher information content enables a larger departure from the a priori, hence the increased spatial variability observed in the high spectral resolution map (top left) compared to the low resolution (bottom left).
- **August 2013**: this was a demonstration experiment in support for the need of high spectral resolution CrIS measurements using 5 experimental orbits from March 2013. Top is FSR NUCAPS; Bottom is NSR NUCAPS.

Ref.: Gambacorta et al., "An experiment using CrIS high spectral resolution measurement for trace gas retrievals: CO retrieval impact study", IEEE Transactions on Geoscience and Remote Sensing Letters, 2014.

December 2016: Preliminary demonstration of FSR NUCAPS CO (top) vs NSR NUCAPS CO (bottom) using Operational FSR RTA and Chn. Selection

NUCAPS CO retrieval (~450mb)

NUCAPS CO DOF

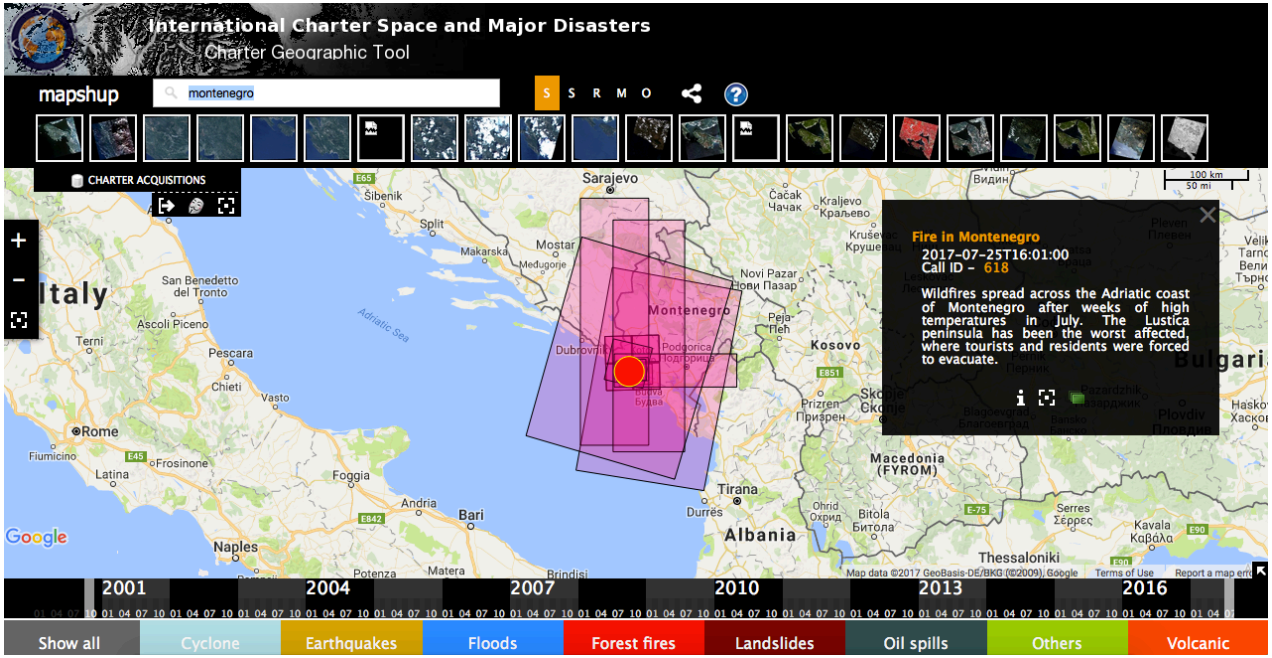


December 2016:

TOP: FSR NUCAPS/CLIMCAPS CO retrieval results (focus day 2015-02-17)

BOTTOM: NSR NUCAPS/CLIMCAPS CO retrieval results (focus day 2015-02-17)

July 2017 – Montenegro Fire



- The International Charter aims at providing a unified system of space data acquisition and delivery to those affected by natural or man-made disasters through Authorized Users.
- Each agency member has committed resources to support the provisions of the Charter and thus is helping to mitigate the effects of disasters on human life and property.
- https://disasterscharter.org/web/guest/home

July 2017 – Croatia and Montenegro Fires

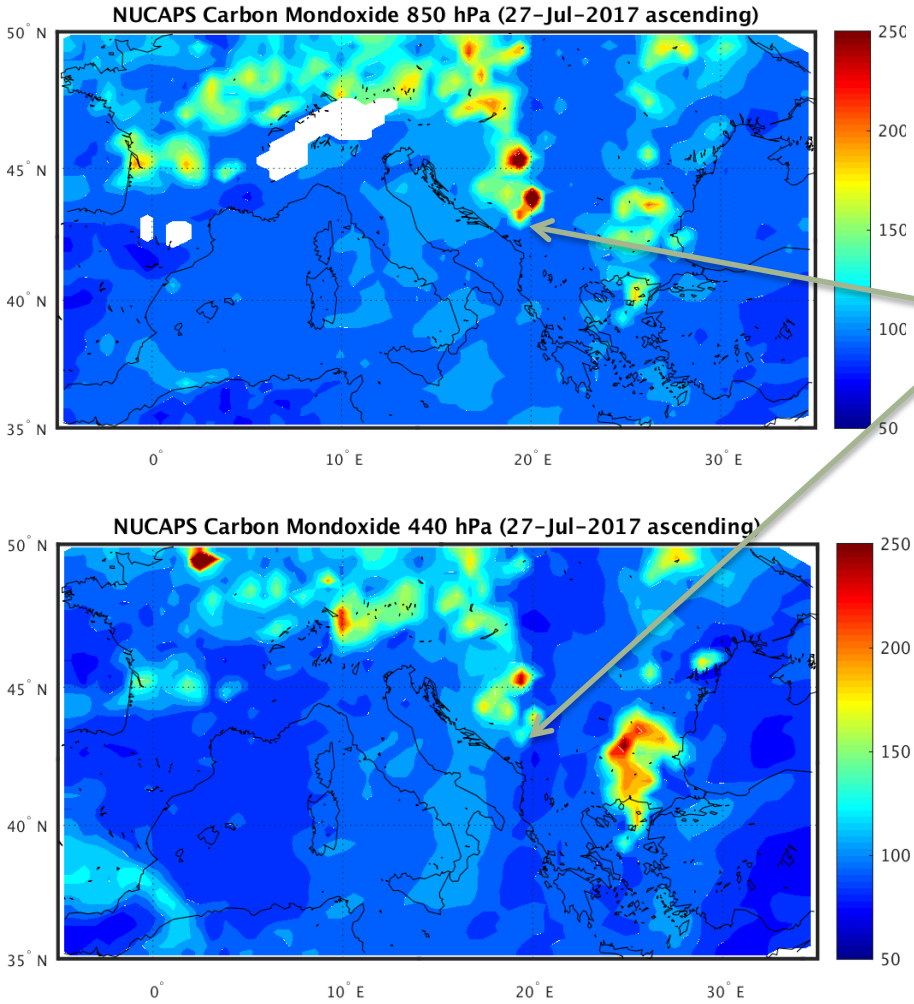


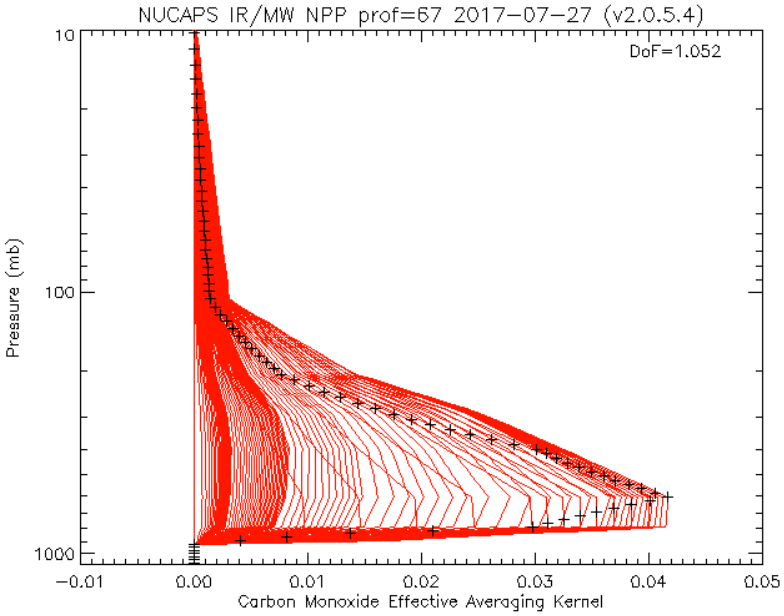


Left: Smoke and flames rise from a fire in the village of Podstrana, near the Adriatic coastal town of Split, on July 18, 2017. Montenegro asked for international help to fight wildfires on the Lustica peninsula on the country's Adriatic coast, while forest fires in neighboring Croatia spread to suburbs of the coastal city of Split.

Right: NASA image courtesy NASA MODIS Rapid Response Team
https://www.nasa.gov/image-feature/goddard/2017/nasa-sees-smoke-from-fires-in-croatia-and-montenegro

NUCAPS FSR CO retrieval skills: July 27 2017 – Croatia and Montenegro Fires





NUCAPS FSR CO Aks

Near Podgorica, LAT: 42.7583 LON: 19.1978

Current NUCAPS trace gas JPSS funded initiatives

This is not validation in the traditional sense, it is developing new users applications.

1. **Carbon Monoxide and Methane product evaluation** (NESDIS/STAR & OAR/ESRL/CSD).

Scope: Models are used to interpolate the sparse aircraft observations to the satellite temporal, spatial, and vertical sampling characteristics for detailed validation. NUCAPS (and AOD from VIIRS) will be used within IDEA (Infusing Satellite Data into Environmental Air Quality Applications)

I. PI Greg Frost: "Understanding emissions and tropospheric chemistry using NUCAPS and VIIRS"
II. PI Brad Pierce: "High Resolution Trajectory-Based Smoke Forecasts using VIIRS Aerosol Optical Depth and NUCAPS Carbon Monoxide Retrievals. "

- References:
  - Songnex: http://esrl.noaa.gov/csd/projects/songnex/
  - SENEX: http://www.esrl.noaa.gov/csd/projects/senex/
  - IDEA: http://www.star.nesdis.noaa.gov/smcd/spb/aq/

2. Use of NUCAPS Ozone in hurricane extra-tropical transition applications (SPoRT)
Scope: Migrate AIRS/SEVIRI product to NUCAPS O_3 with VIIRS RGB. To conduct a product demonstration and assessment with the NHC, WPC and OPC forecasters

I. PI Emily Berndt: "investigation of NUCAPS T(p), q(p), and O3(p) to study extra-tropical transition of hurricanes"

- Reference:
  - https://nasasport.wordpress.com/2016/10/05/nucaps-soundings-and-hurricane-matthew/

Few lessons learned on users needs in preparation for the next field campaign (FIREX 2018)

- Users need to know spatial and vertical error covariance
  - Many of the signals we see have seasonal or spatial variability in the information content.
  - Trace gas retrievals are sensitive to stratospheric-tropospheric exchange. Broad vertical weighting functions tend to mix stratospheric and upper tropospheric contributions together. Averaging kernels should become an integral part of the operationally distributed products.
  - We are working on submitting a formal user request to have NUCAPS averaging kernels operationally distributed.

- Users need reprocessing capability to study long-term stability of an algorithm.
  - All archived data ("granule" processing)
  - Global "gridded" data sub-sets (for rapid evaluation of algorithm modifications)
  - All validation datasets (including radio-sonde, aircraft match up datasets)

- Users need user-friendly data formats (netcdf4 is generally preferred)
- Users need more sophisticated QCs than what is used in current operations
  - Original QC was developed to demonstrate that we meet requirements
  - Some "green" scenes are bad, some "red" scenes are good
  - We need to develop QCs specifically tailored for trace gas applications

- Users need near real time access to NUCAPS high resolution operational products (essential for applications involving fire trajectories and air quality).
  - FSR NUCAPS soon to be installed in the NOAA DB.
  - This is in preparation of the future NOAA FIREX 2018 campaign (http://www.esrl.noaa.gov/csd/projects/firex/).

Future upgrades and conclusions remarks

Coming next

- We are working on a formal request for a NUCAPS NH_3 product.
- What defines the need for a trace gas operational product?
  - Just because we can retrieve a product, it does not mean that we should do it.
  - We need a real time, vetted, institutional user: EPA, National Forest Service, DOA, etc.
  - We need users that need archived consistent products: NUCAPS CO2 might serve as forecast climatology for the National Weather Service.

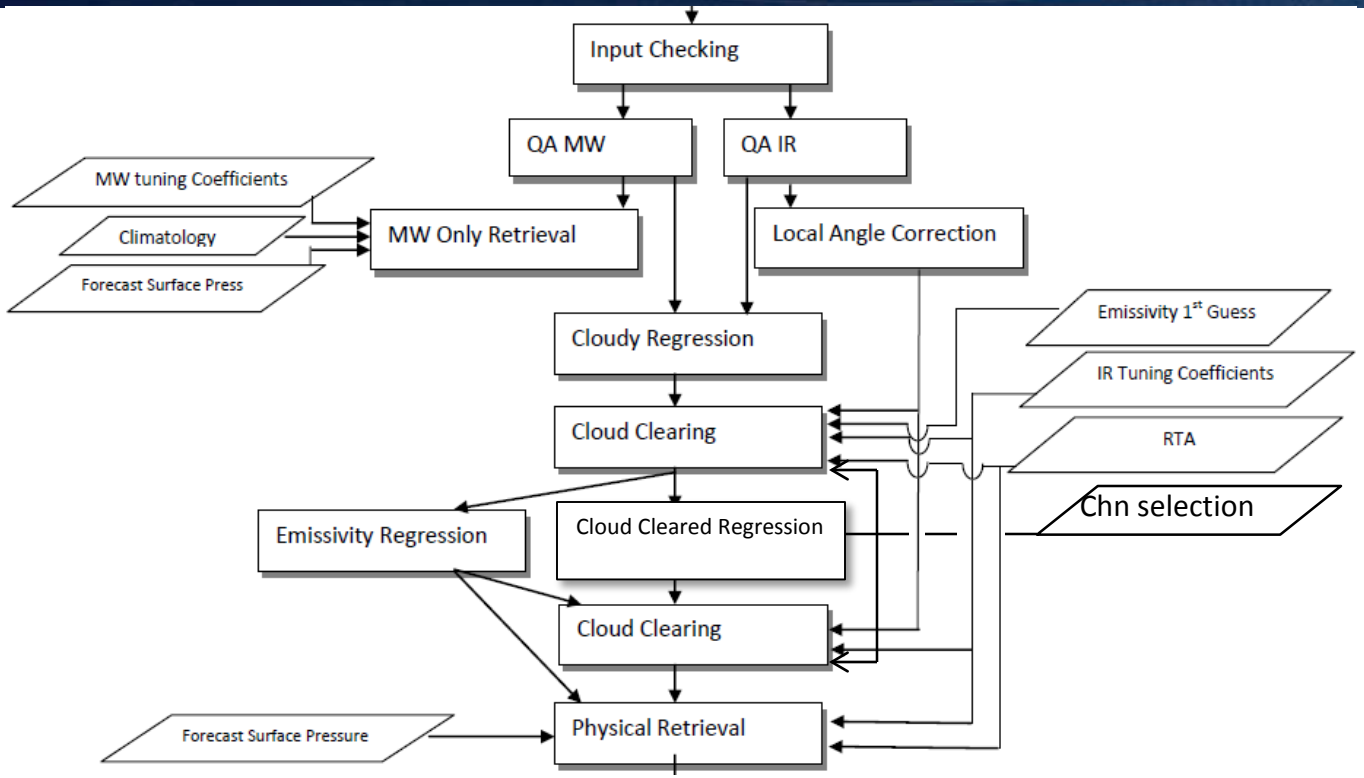
Conclusion remarks

- We would like to support any project supported by the NOAA AC4 Program to engage new potential users and gain insights on the applicability of our products.
  This will ultimately lead to a <u>user requirement</u> to justify the effort of
  - **maintaining and improving current and**
  - **developing new**

  trace gas operational products.

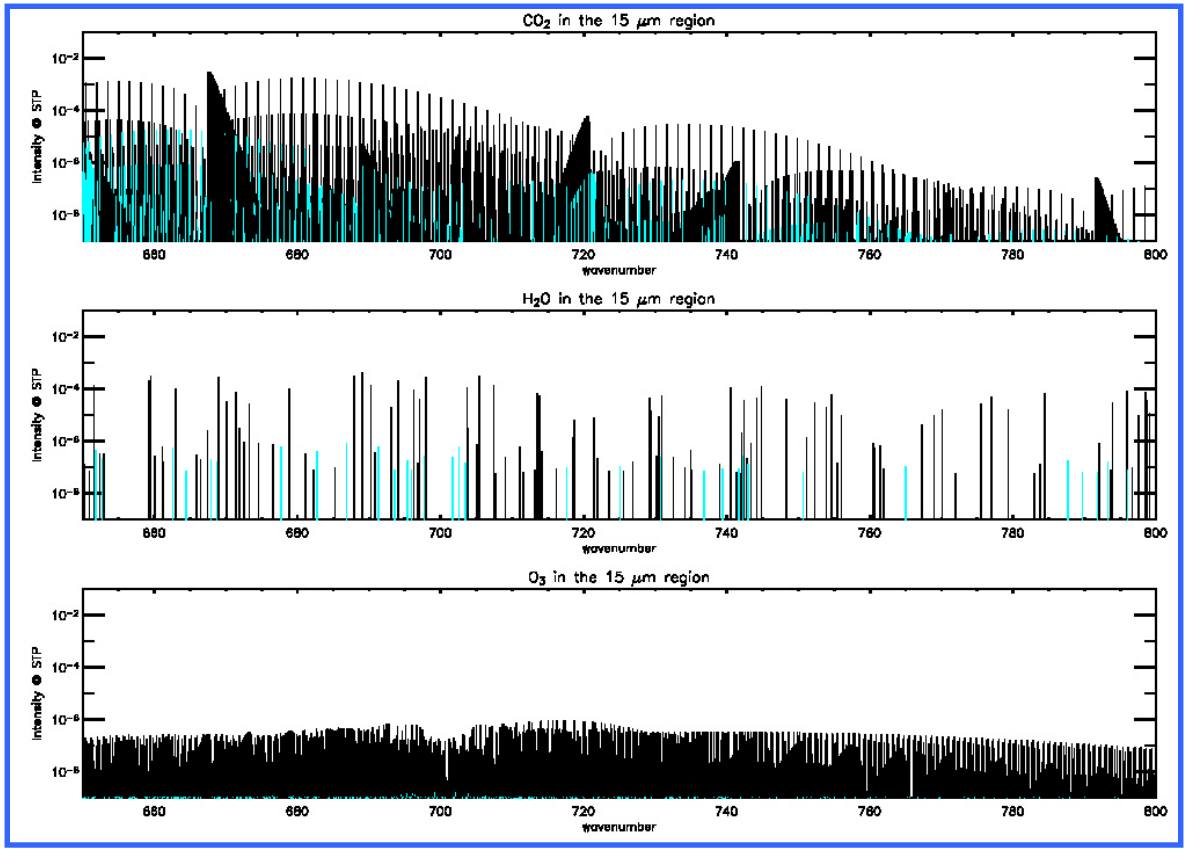
Back ups

NUCAPS Retrieval Algorithm Flow Chart



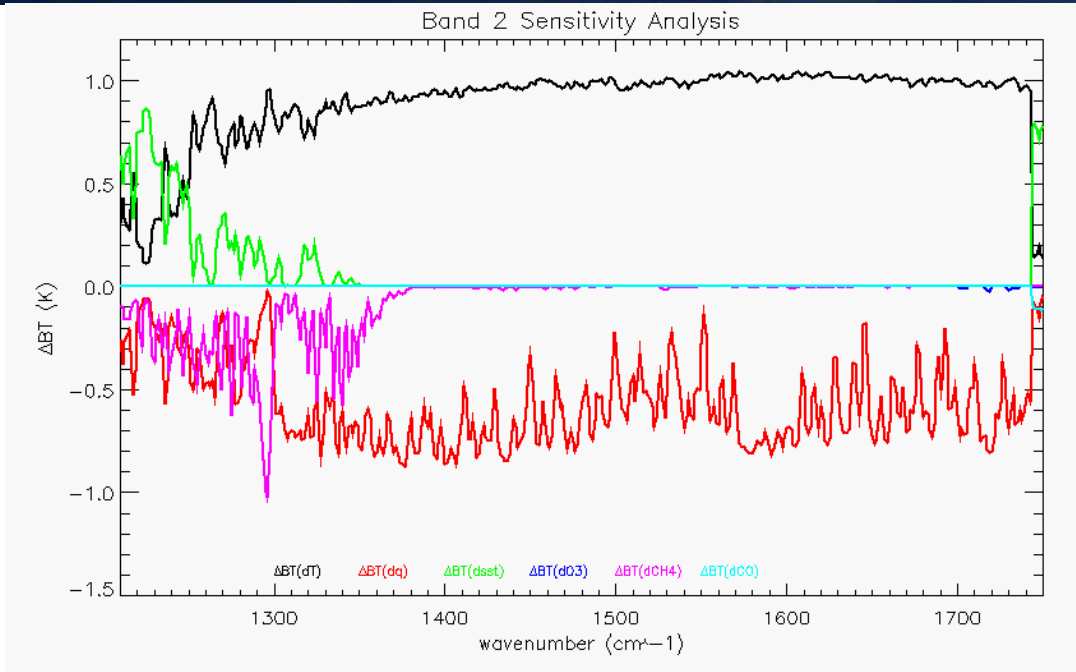
- **I. A microwave retrieval module** which computes Temperature, water vapor and cloud liquid water (Rosenkranz, 2000)
- **II. A fast eigenvector regression** retrieval that is trained against ECMWF and all sky radiances which computes temperature and water vapor (Goldberg et al., 2003)
- **III. A cloud clearing module** (Chahine, 1974)
- **IV. A second fast eigenvector regression** retrieval that is trained against ECMWF analysis and cloud cleared radiances
- **V. The final infrared physical retrieval** based on a regularized iterated least square minimization: temperature, water vapor, trace gases (O3, CO, CH4, CO2, SO2, HNO3, N2O) (Susskind, Barnet, Blaisdell, 2003)

Definition of "Spectral Purity"



- The finite spectral resolution of the instrument does not allow for *spectral purity*. Specifically, in the infrared domain, the signal associated with a given channel of nominal frequency v is, in reality, the result of multiple molecular rotovibrational transitions whose spectral range of occurrence falls in within the spectral resolution Δv of the channel.

NUCAPS: a sequential, iterated, linearized, weighted, regularized least square fit



Perturbation Applied

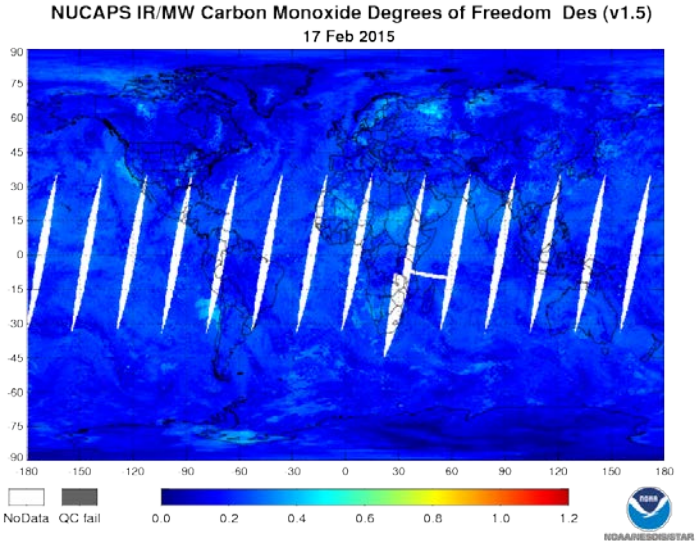
SST	1K
T	1K
H2O	10%
O3	10%
CH4	2%
CO	1%

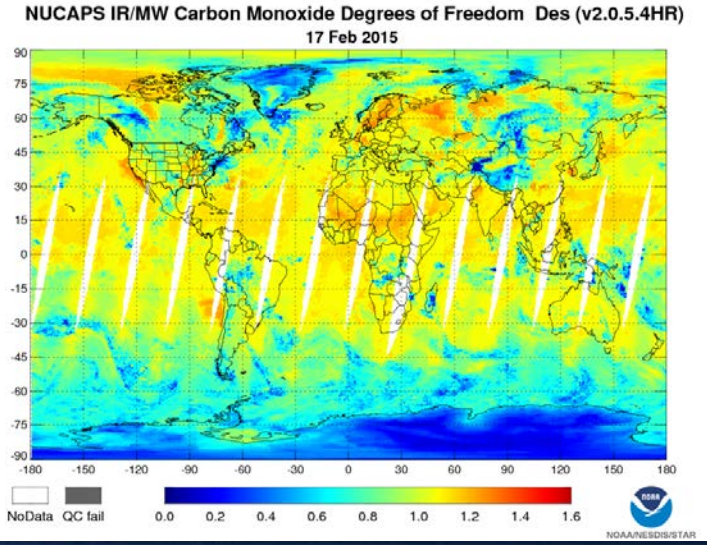
$$\Delta R_n = K^i_{n,L}\Delta X^i_{n,L} + \varepsilon_n$$

$$\varepsilon_n = NEDT_n + \delta R_{CCR} + \delta RTA_n + \sum_{j \neq i} K^j \delta X^j$$

$$X_L = X^a_L + \left[K^T_{L,n} \cdot S^{-1}_{\epsilon n,n} \cdot K_{n,L} + S^{-1}_{aL,L}\right]^{-1} \cdot K^T_{L,n} \cdot S^{-1}_{\epsilon n,n} \cdot (R_n - K_{n,L} \cdot X^a_L) \pm \delta X$$

NUCAPS FSR CO DOFs





Status of NUCAPS Full Spectral-Resolution Trace Gas EDR Validation

Nicholas R. Nalli[1,2], A. Gambacorta[3,2], C. Tan[1,2], F. Iturbide-Sanchez[1,2], C. D. Barnet[3], X. Xiong[1,2], M. Wilson[1,2], K. Zhang[1,2], *et al.*

[1]*IMSG, Rockville, Maryland, USA*
[2]*NOAA/NESDIS/STAR, College Park, Maryland, USA*
[3]*STC, Columbia, Maryland, USA*

2017 STAR JPSS Annual Meeting
College Park, Maryland, USA
August 2017

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- **SNPP Sounder Trace Gas EDR Validation Truth Dataset collection**
  - **Ozone**
    - **NOAA AEROSE:** *V. R. Morris, E. Joseph*, M. Oyola (HU/NCAS); D. Wolfe (NOAA/ESRL); NOAA PIRATA Northeast Extension (PNE); *NOAA Educational Partnership Program* (EPP) grant NA17AE1625, NOAA grant NA17AE1623
    - **CalWater/ACAPEX:** *R. Spackman* (STC); *R. Leung* (PNNL); *C. Fairall, J. Intrieri* (NOAA); *N. Hickmon, M. Ritsche, A. Haruta,* and the ARM Mobile Facility 2 (AMF2)
    - **World Ozone and Ultraviolet Radiation Data Centre (WOUDC)** data contributors (DWD-GRUAN, & INPE, & KNMI, & NASA-WFF, & SMNA. http://www.woudc.org
    - **SHADOZ: Southern Hemisphere Additional Ozonesondes** (*A. Thompson* et al.)
  - **Carbon Trace Gases**
    - **NASA Sounder Science Team:** *E. Olsen, T. Pagano, E. Fetzer* (NASA/JPL)
    - **Total Carbon Column Observing Network (TCCON)** (*D. Wunch* et al.) data were obtained from the TCCON Data Archive, hosted by the Carbon Dioxide Information Analysis Center (CDIAC), tccon.onrl.gov

- The **NOAA Joint Polar Satellite System (JPSS-STAR) Office** (*M. D. Goldberg, L. Zhou, et al.*) and the NOAA/STAR Satellite Meteorology and Climatology Division.

- **STAR soundings team**: *A.K. Sharma, Q. Liu, T. King, W. W. Wolf* (STAR)

Outline

- **JPSS Sounder Trace Gas EDR Cal/Val Overview**
  - JPSS Level 1 Requirements
  - Validation Hierarchy recap
  - NUCAPS Algorithm
    - v1.5, nominal spectral-resolution (NSR) CrIS
    - v2.0 Phase 4, full spectral-resolution (FSR) CrIS
- **NUCAPS IR Ozone Profile EDR Product Evaluation**
  - v1.5 NSR Review
    - Global ozonesonde ensemble
  - v2.0 FSR (Phase 4) Status
    - Global Focus Day ECMWF
- **NUCAPS Carbon Trace Gas EDR Product Evaluation (Preliminary)**
  - Truth Datasets and Methodology
    - AIRS Version 6
    - TCCON
  - v2.0 FSR (Phase 4) Status
    - Carbon Monoxide (CO)
    - Methane (CH_4)
    - Carbon Dioxide (CO_2)

Status of NUCAPS FSR Trace Gas EDR Validation

JPSS SOUNDER TRACE GAS EDR CAL/VAL OVERVIEW

JPSS Specification Performance Requirements
CrIS Trace Gas EDR Uncertainty (O_3, CO, CO_2, CH_4)

CrIS Infrared Trace Gases Specification Performance Requirements		
PARAMETER	**THRESHOLD**	**OBJECTIVE**
O_3 (Ozone) Profile Precision, 4–260 hPa (6 statistic layers)	20%	10%
O_3 (Ozone) Profile Precision, 260 hPa to sfc (1 statistic layer)	20%	10%
O_3 (Ozone) Profile Accuracy, 4–260 hPa (6 statistic layers)	±10%	±5%
O_3 (Ozone) Profile Accuracy, 260 hPa to sfc (1 statistic layer)	±10%	±5%
O_3 (Ozone) Profile Uncertainty, 4–260 hPa (6 statistic layers)	25%	15%
O_3 (Ozone) Profile Uncertainty, 260 hPa to sfc (1 statistic layer)	25%	15%
CO (Carbon Monoxide) Total Column Precision	35%, or full res mode 15%	3%
CO (Carbon Monoxide) Total Column Accuracy	±25%, or full res mode ±5%	±5%
CO_2 (Carbon Dioxide) Total Column Precision	0.5% (2 ppmv)	1.05 to 1.4 ppmv
CO_2 (Carbon Dioxide) Total Column Accuracy	±1% (4 ppmv)	NS
CH_4 (Methane) Total Column Precision	1% (≈20 ppbv)	NS
CH_4 (Methane) Total Column Accuracy	±4% (≈80 ppmv)	NS

Source:
(L1RD, 2014, pp. 45-49)

Validation Methodology Hierarchies

$T/H_2O/O_3$ Profiles

(e.g., *Nalli et al., JGR Special Section,* 2013)

1. **Numerical Model (e.g., ECMWF, NCEP/GFS) Global *Comparisons***
   - Large, truly global samples acquired from Focus Days
   - Useful for sanity checks, bias tuning and regression
   - Limitation: Not independent truth data
2. **Satellite Sounder EDR (e.g., AIRS, ATOVS, COSMIC) *Intercomparisons***
   - Global samples acquired from Focus Days (e.g., AIRS)
   - Limitation: Similar error characteristics
3. **Conventional PTU/O3 Sonde Matchup *Assessments***
   - WMO/GTS operational sondes or O3-sonde network (e.g., SHADOZ)
   - Representation of global zones, long-term monitoring
   - Large samples after a couple months (e.g., *Divakarla et al.,* 2006; *Reale et al.* 2012)
   - Limitations: Skewed distributions; mismatch errors; non-uniform radiosondes, assimilated into NWP
4. **Dedicated/Reference PTU/O3 Sonde Matchup *Assessments***
   - *Dedicated* for the purpose of satellite validation
   - Reference sondes: CFH, **GRUAN** corrected RS92/RS41
   - E.g., **ARM sites** (e.g., *Tobin et al.,* 2006), **AEROSE**, **CalWater/ACAPEX ,** BCCSO, PMRF
   - Limitation: Small sample sizes, geographic coverage
5. **Intensive Field Campaign *Dissections***
   - Include dedicated sondes, some *not* assimilated into NWP models
   - Include ancillary datasets, ideally funded aircraft campaign(s)
   - E.g., **SNAP, SNPP, AEROSE, CalWater**, JAIVEX, AWEX-G, EAQUATE

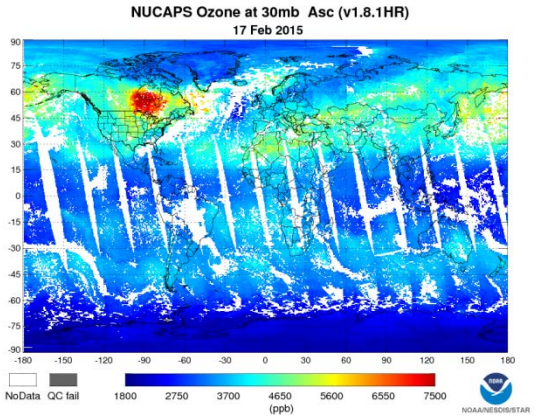
Carbon Trace Gases

1. **Numerical Model Global *Comparisons***
   - Examples: **ECMWF, NCEP/GFS**
   - Large, truly global samples acquired from Focus Days
   - Limitation: Not independent truth data
2. **Satellite Sounder EDR *Intercomparisons***
   - Examples: **AIRS, OCO-2, MLS**
   - Global samples acquired from Focus Days (e.g., AIRS)
   - Limitation: Similar error characteristics
3. **Surface-Based Spectrometer Network Matchup *Assessments***
   - **Total Carbon Column Observing Network (TCCON)**
   - Provide routine independent measurements representing global zones akin to RAOBs
   - Limitations: Small sample sizes, uncertainties in conversions to column abundances, different sensitivity to atmospheric layers
4. **Intensive Field Campaign *In Situ* Data *Assessments***
   - Include ancillary datasets, ideally funded aircraft campaign(s)
   - E.g., ATom, FIREX, HIPPO

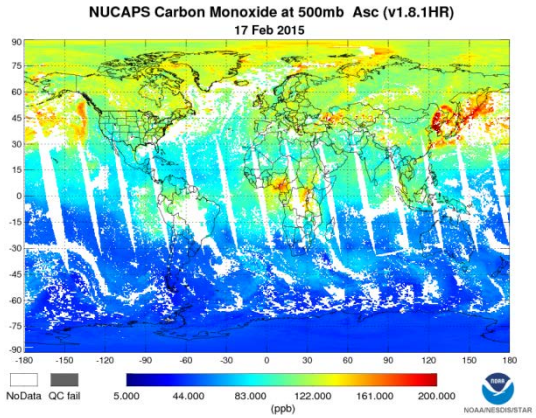
NOAA Unique Combined Atmospheric Processing System (NUCAPS) Algorithm (1/2)

- **Operational algorithm**
  - NOAA Enterprise Algorithm for CrIS/IASI/AIRS (*Susskind, Barnet and Blaisdell,* IEEE 2003; *Gambacorta et al.,* 2014)
  - Global non-precipitating conditions
  - Atmospheric Vertical Temperature, Moisture Profiles (AVTP, AVMP)
  - **Trace gas profiles (O_3, CO, CO_2, CH_4)**
- **Users**
  - Weather Forecast Offices (AWIPS)
    - Nowcasting / severe weather
    - Alaska (cold core)
  - NOAA/CPC (OLR)
  - **NOAA/ARL** (IR ozone, trace gases)
  - **NOAA TOAST** ozone product
  - Basic and applied science research (e.g., *Pagano et al.,* 2014)
    - Via NOAA Data Centers (e.g., CLASS)
    - Atmospheric chemistry research
    - Universities, peer-reviewed pubs

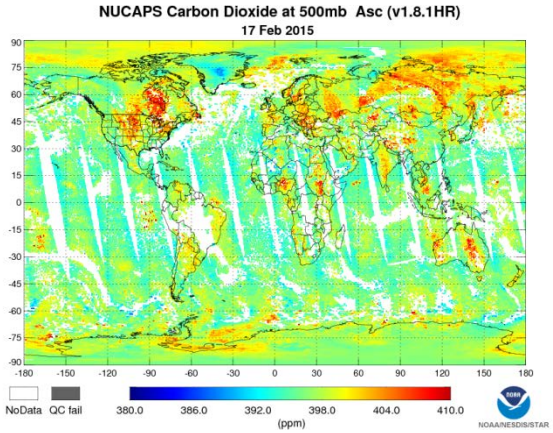
NUCAPS IR O_3



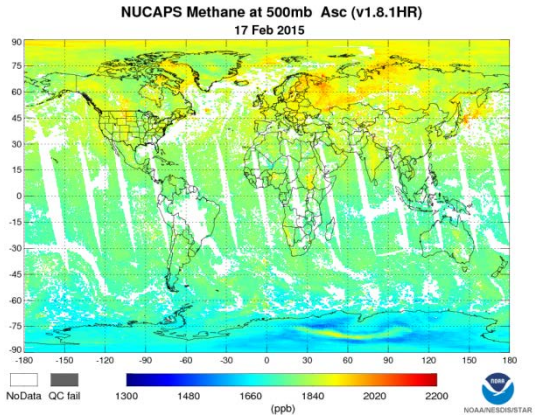
NUCAPS CO



NUCAPS CO_2



NUCAPS CH_4



NOAA Unique Combined Atmospheric Processing System (NUCAPS) Algorithm (2/2)

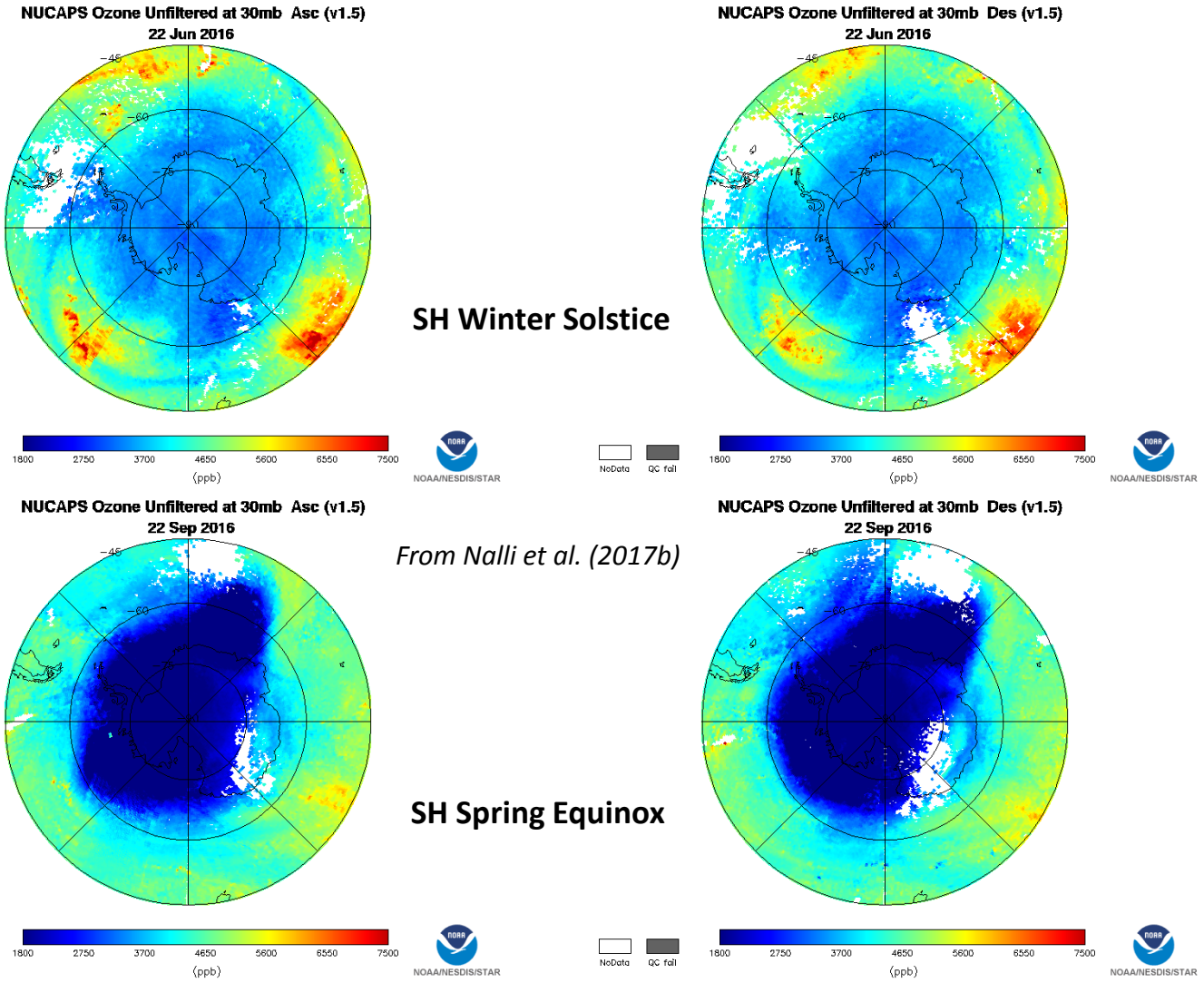
NUCAPS Offline Code Versioning

- **Version 1.5**
  - Operational system beginning in September 2013
  - Runs on CrIS nominal spectral-resolution (NSR) data
  - Validated Maturity for IR Ozone Profile EDR attained Oct 2016
  - Carbon trace gas EDR validation was not required
- **Versions 1.8.x to 1.9.x**
  - Preliminary offline experimental algorithms in preparation for CrIS full spectral-resolution (FSR) data
  - *Ad hoc* CrIS full-resolution radiative transfer algorithm (RTA) and bias correction coefficients
- **Version 2.0 (Phase 4)**
  - Uses **UMBC CrIS full-res (FSR) RTA** (L. Strow et al.)
  - Includes **IR-only version** (risk-mitigation for ATMS loss)
  - **Phase 4 Algorithm Readiness Review (ARR)** delivered on 6 July 2017
    - Draft ATBD delivered August 2017
    - Code currently being delivered and transitioned into operations

Status of NUCAPS FSR Trace Gas EDR Validation

IR OZONE PROFILE EDR

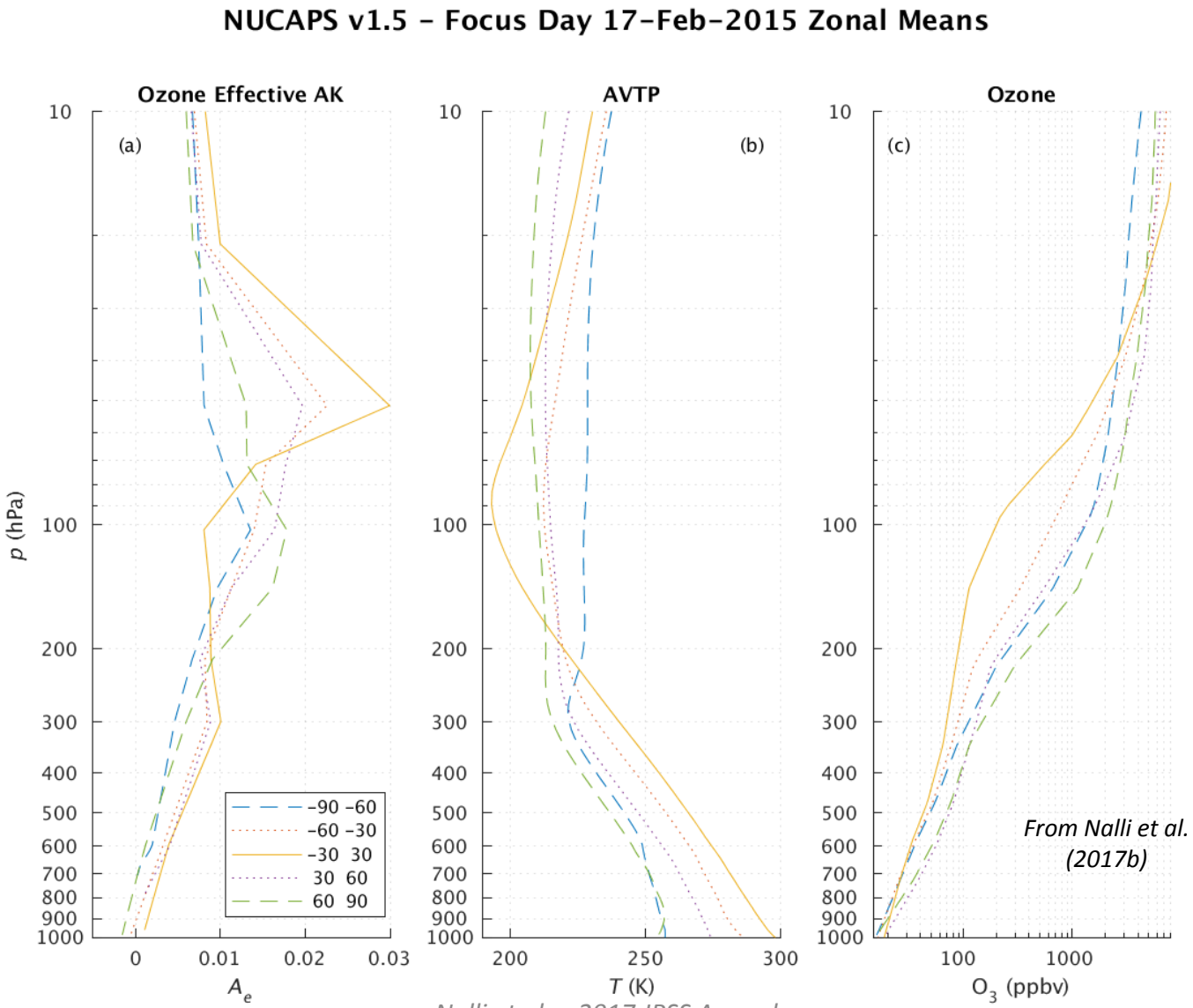
Science Application: Ozone Hole Over Antarctica



From Nalli et al. (2017b)

NUCAPS observed ozone depletion during SH springtime

NUCAPS IR Ozone and AVTP Zonal Means

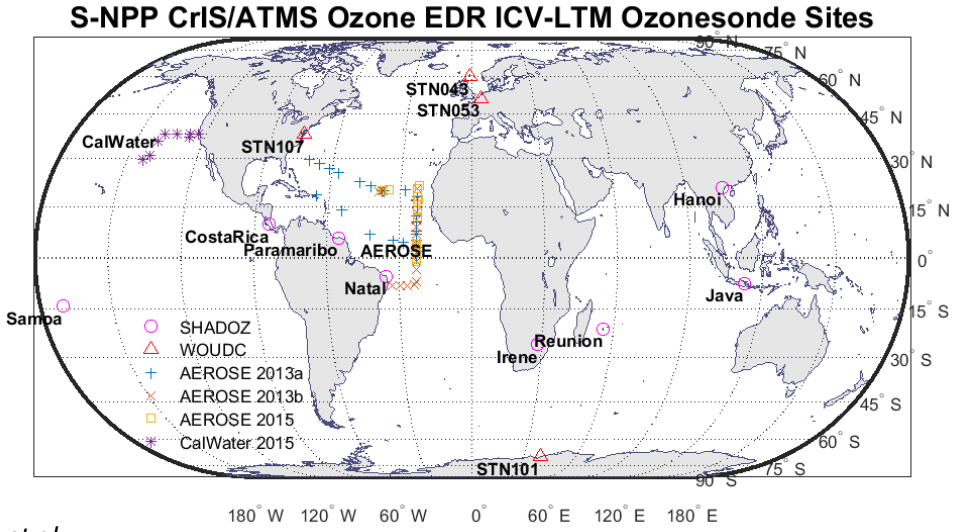


NUCAPS IR Ozone Profile EDR Validation

NSR (v1.5) *In Situ* Truth Datasets

Collocated Ozonesondes for O_3 Profile EDR

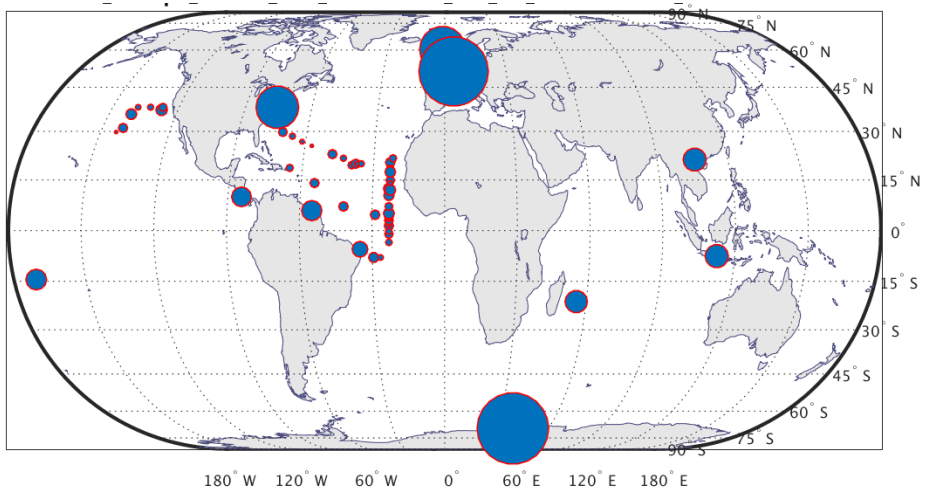
- **Dedicated Ozonesondes**
  - **NOAA AEROSE** (*Nalli et al.* 2011)
  - **CalWater/ACAPEX 2015**
- **Sites of Opportunity**
  - **SHADOZ** (*Thompson et al.* 2007)
    - Costa Rica
    - Hanoi
    - Irene
    - Java
    - Natal
    - Paramaribo
    - Reunion
    - American Samoa
  - **WOUDC**
    - STN043
    - STN053
    - STN107
    - STN101



From Nalli et al. (2017b)

Geographic Sample Histogram (Equal Area)

FOR Collocation Criteria: $\delta x \leq 125$ km, $-240 < \delta t < +120$ min

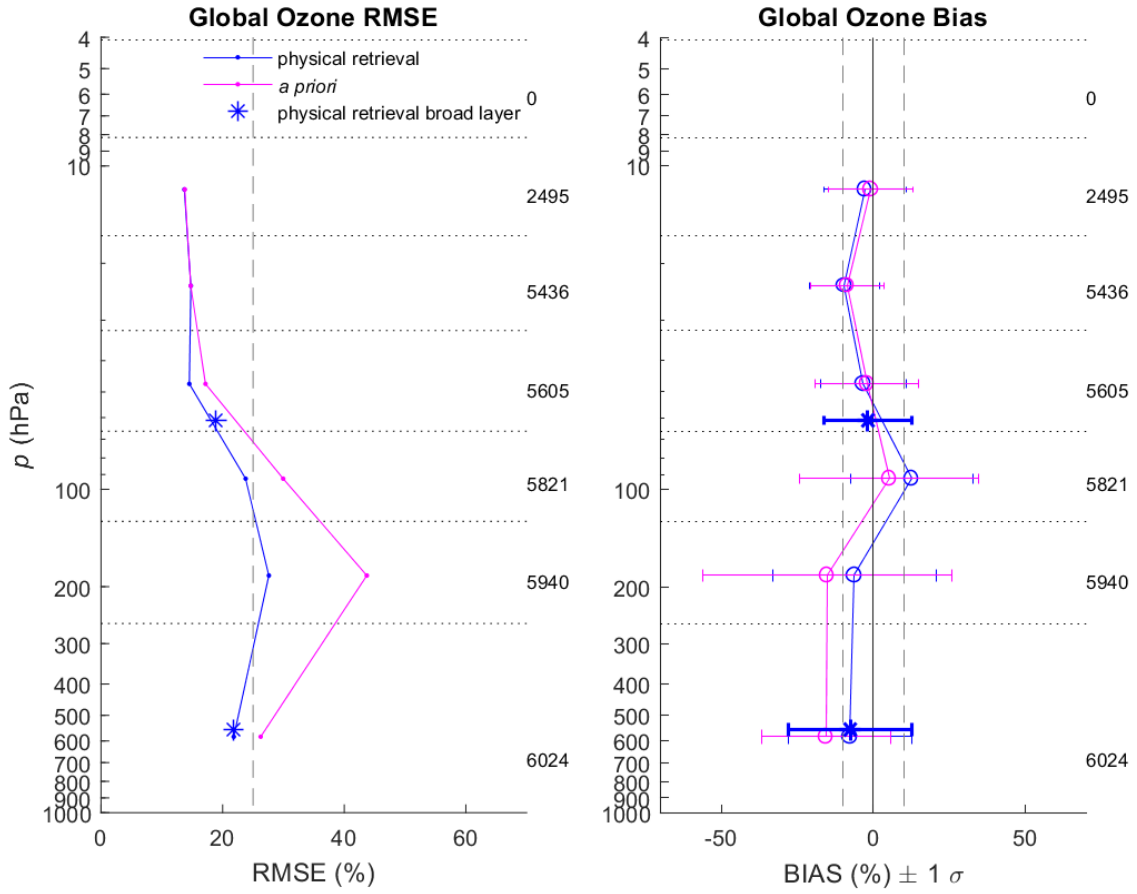


NUCAPS IR Ozone Profile Coarse-Layer Statistics

NSR (v1.5) versus Global Ozonesondes

Retrieval and ***A Priori***

IR+MW Yield = 62.2%



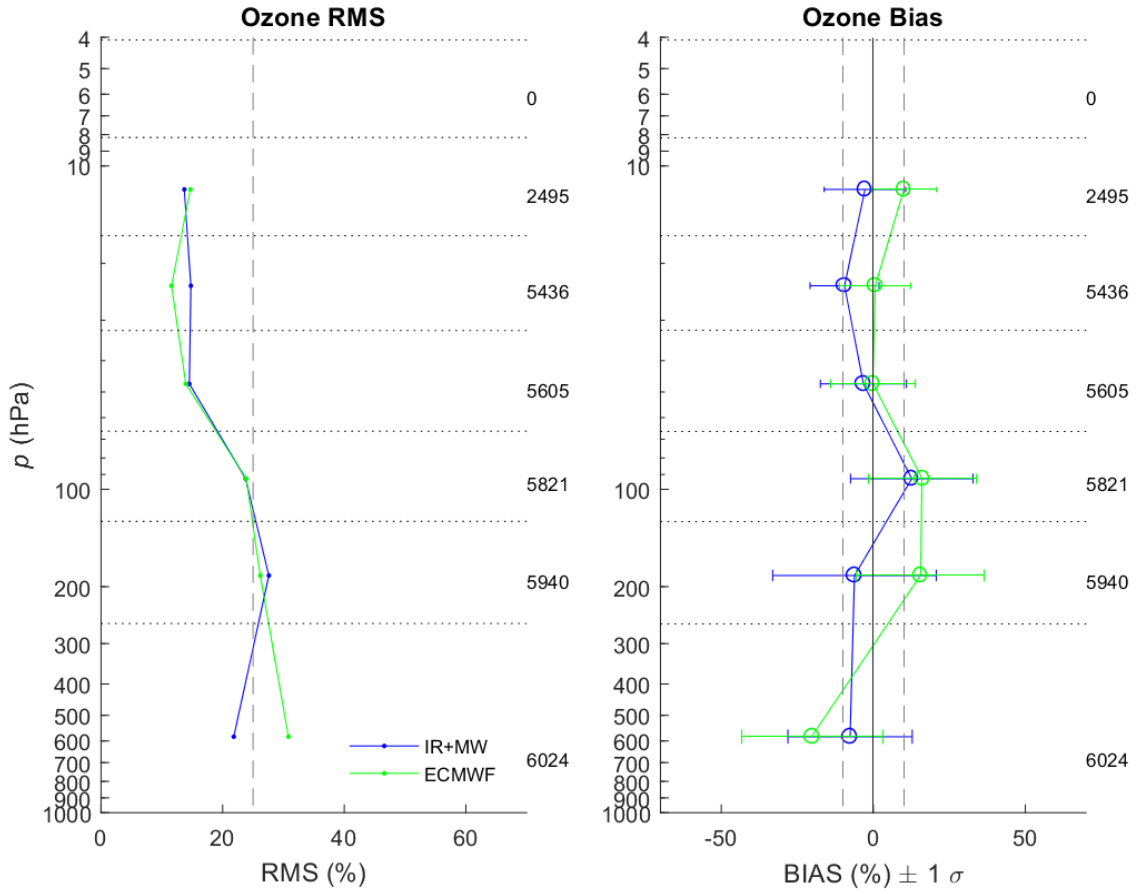
From Nalli et al. (2017)

NUCAPS IR Ozone Profile Coarse-Layer Statistics

NSR (v1.5) versus Global Ozonesondes

Retrieval and **ECMWF**

IR+MW Yield = 62.2%



NUCAPS v2.0 FSR Ozone Profile Coarse-Layer Statistics

Global Focus Day 17-Feb-2015 ECMWF

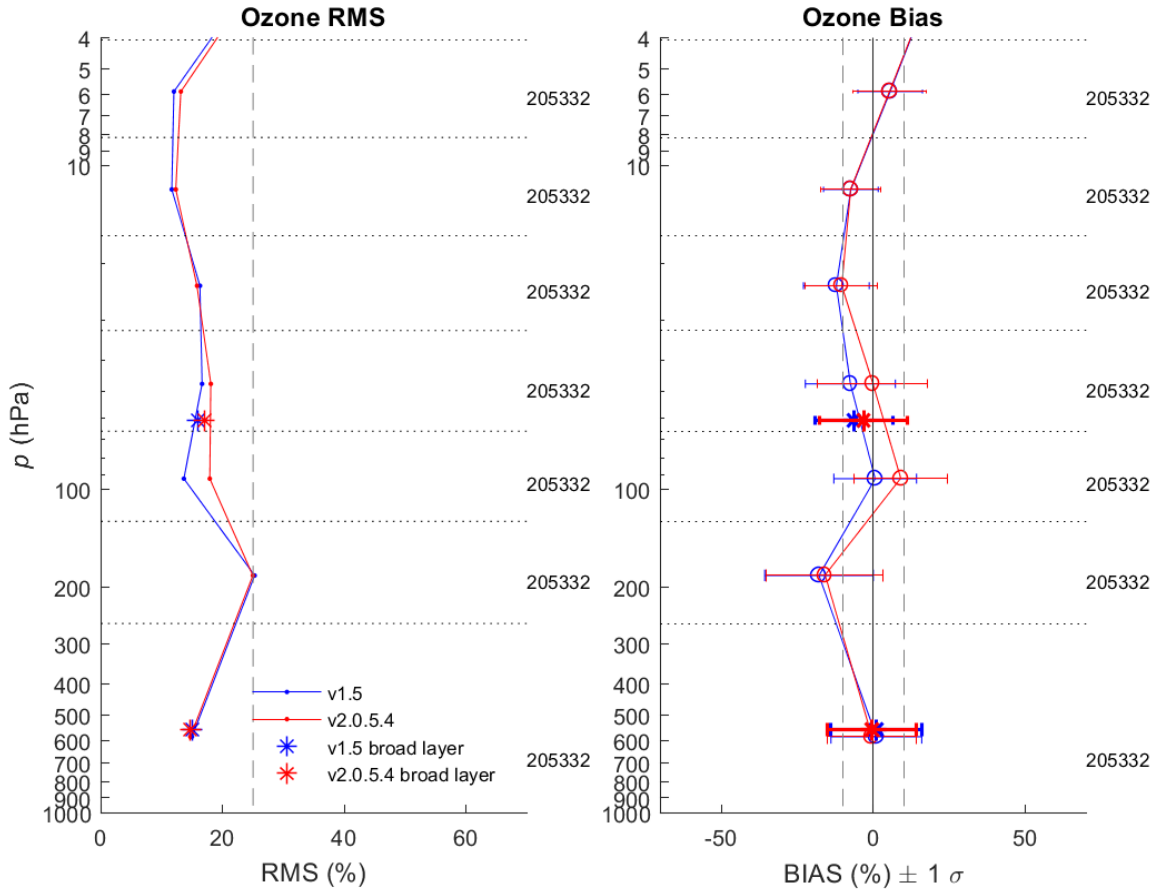
NUCAPS FSR Ozone Versus ECMWF

V1.5 IR+MW

V2.0 IR+MW

v1.5 Yield = 63.4%

v2.0 Yield = 88.5%



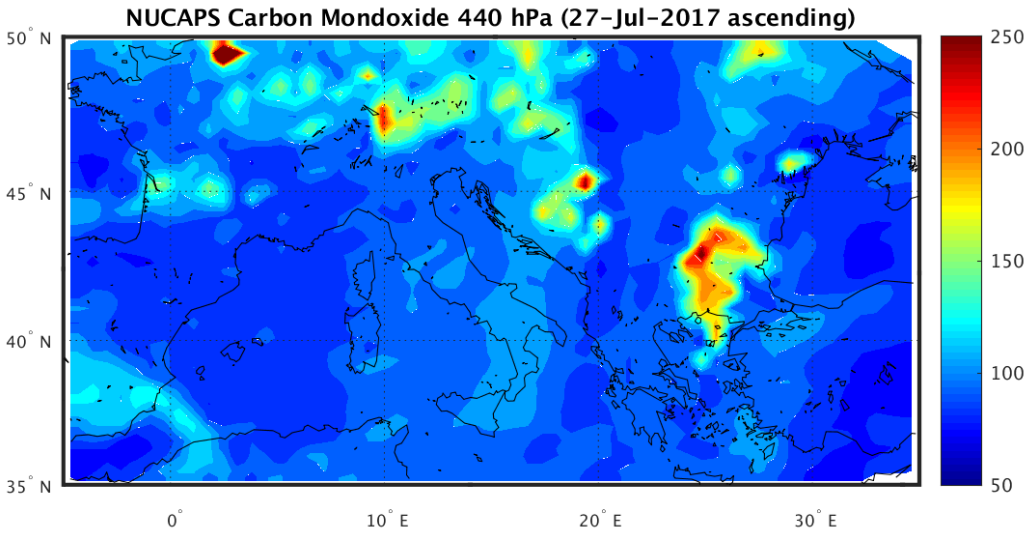
From Nalli et al. (2017)

Status of NUCAPS FSR Trace Gas EDR Validation

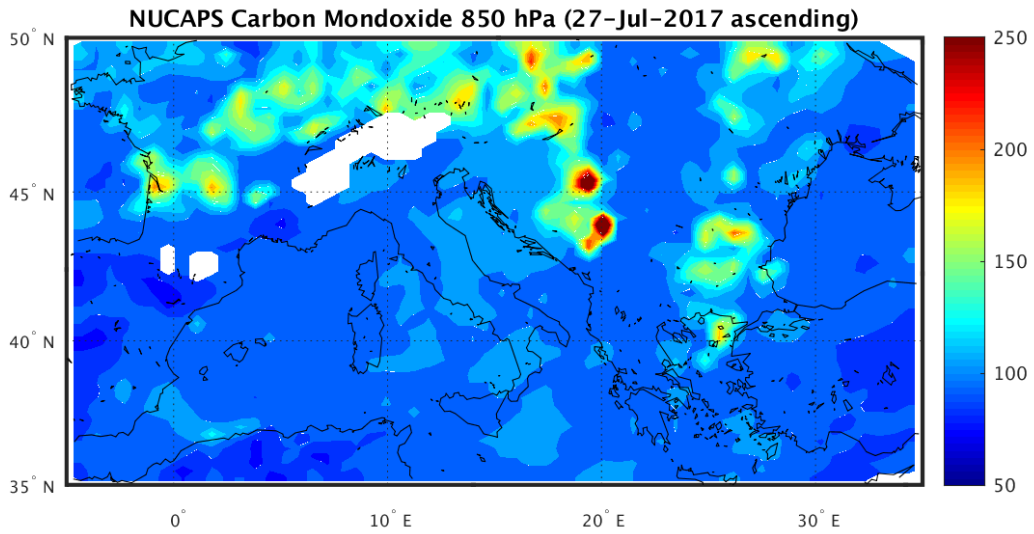
CARBON TRACE GAS EDR

Science Application:
Elevated CO From European Fires, 27 July 2017

440 hPa Layer



850 hPa Layer



Preliminary Methodology for Carbon Trace Gas Validation

- **Carbon trace gas EDR validation** versus JPSS program established uncertainty specifications is a **new sounder validation requirement** that began during the transition period to the FSR CrIS NUCAPS
- **In response to these new requirements, a validation strategy was devised** with preliminary validation of NUCAPS carbon trace gas EDRs conducted leveraging global truth datasets, including
  - **ECMWF from Global Focus Days** (Cal/Val Method #1)
  - **Satellite EDRs from Global Focus Days** (Cal/Val Method #2)
    - **Aqua AIRS v6**
      - **Ideally suited** given same orbit, retrieves the same constituents as NUCAPS, including total column CO and CH_4; offline v6 runs for CO_2 were made available courtesy of Ed Olsen
    - **OCO-2, MLS** (future plans)
    - Of high value for **inter-satellite stability**
  - **Total Carbon Column Observing Network (TCCON)** (*Wunch et al.* 2011) Cal/Val Method #3
    - Global network of ground-based FTS that accurately measure total column abundances of CO_2, CO, CH_4, N_2O trace gases
    - Provides "spot checks" for verifying NUCAPS and AIRS
- **Collocation Methodology**
  - 2-D linearly interpolated FOR – used for AIRS versus NUCAPS
  - "VALAR method" used for NUCAPS/AIRS versus TCCON
    - Include all FOR within threshold radius (150 km for 1 Focus Day; 100 km for 2 Focus Days); time window (±6 hours) versus mean TCCON
  - Quality assurance (QA)
    - NUCAPS IR+MW quality flag and AIRS trace gas quality flags
    - NUCAPS trace gas QA flags have not yet been developed, but possible criteria include DoF, Chi-Square and EDR thresholds

- **For NUCAPS CO_2,** stats are performed simply for atmospheric column averages (in PPMV)
- **For NUCAPS CO, CH_4,** profile EDRs on 100 RTA layers are integrated to obtain total column abundances (molecules/cm2) (e.g., *Nalli et al.* 2013)

$$\Sigma_x(z) \equiv \int_{z_t}^{z} N_x(z')\,\mathrm{d}z'$$

$$\Longrightarrow \quad \Sigma_x(z_s) \;\approx\; \mathcal{F}_{\mathrm{BL}}\,\overline{N}_{x,L_b}\,\delta z_{L_b} + \sum_{L}^{L_b-1} \overline{N}_{x,L}\,\delta z_L$$

- **TCCON CO, CH_4** (in dry mole fractions, ppm) are converted to total column abundance Σ_i (molecules/cm^2) using the following formula

$$\Sigma_i(z_s) = x_i\left[\frac{N_A\,p_s}{g\,M_{dry}} - \varepsilon\,\Sigma_w(z_s)\right]$$

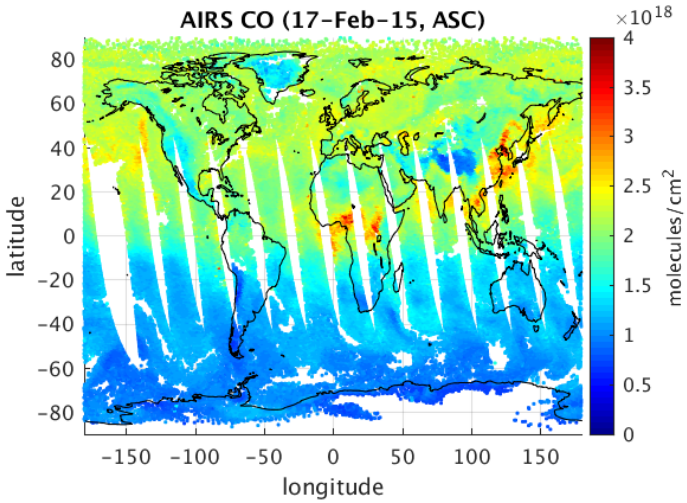
where x_i is the TCCON-measured dry mole fraction for species i, and Σ_w is the H_2O column abundance (provided by NUCAPS retrieval).

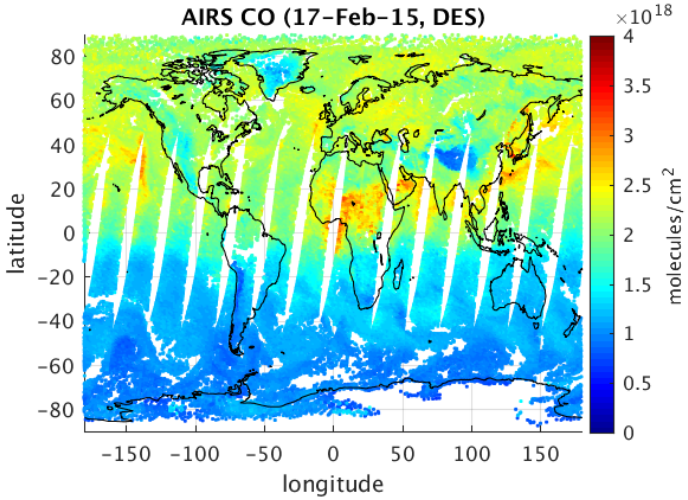
- A more rigorous methodology employing the **TCCON averaging kernels** is currently being researched and will be the subject of near-future work

Total Column Carbon Monoxide (CO) EDRs

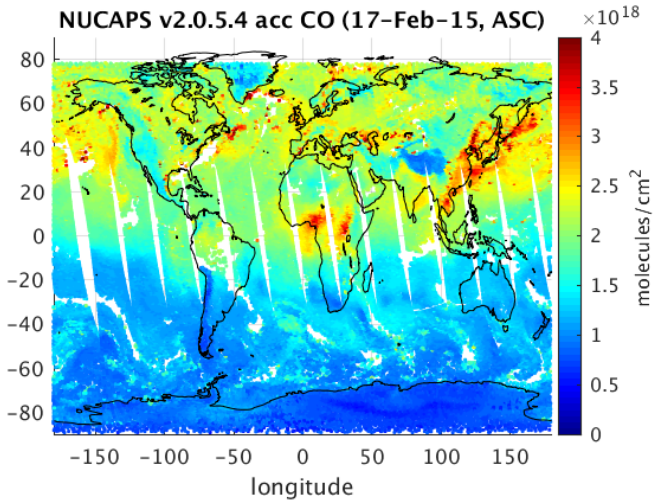
17 Feb 2015 Focus Day, All Cases

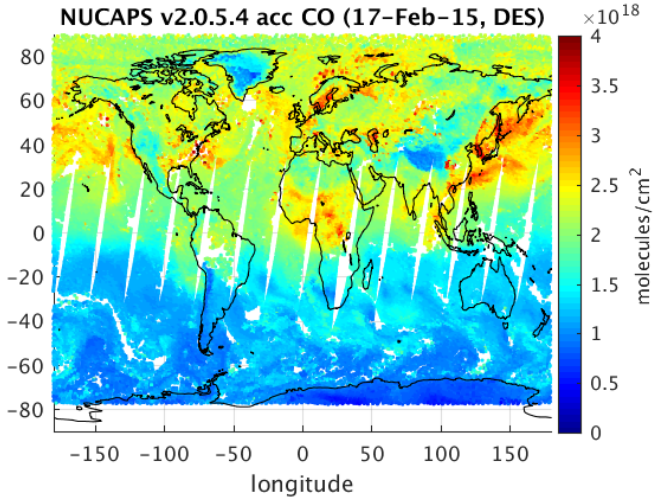
AIRS v6





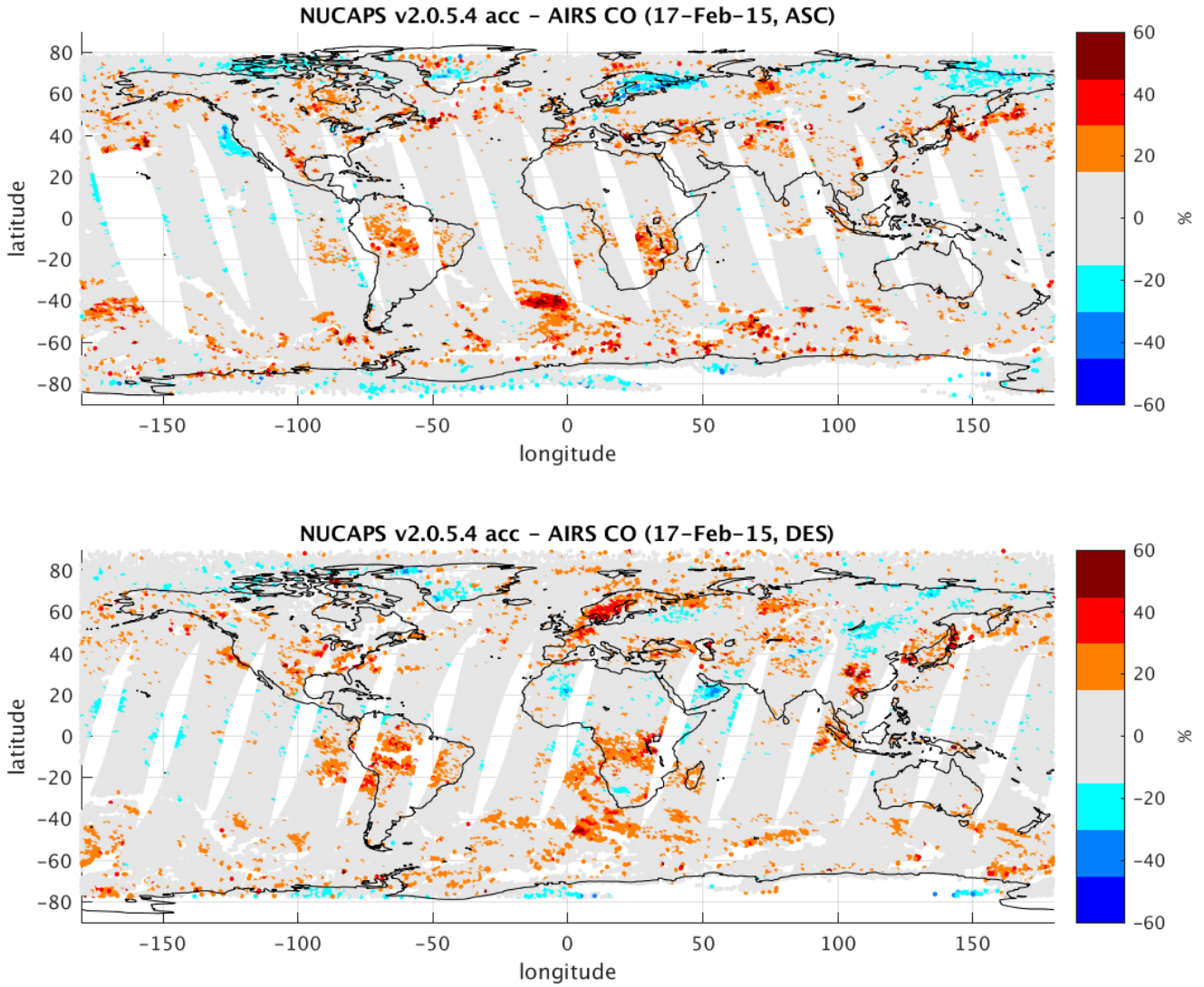
NUCAPS v2.0.5.4





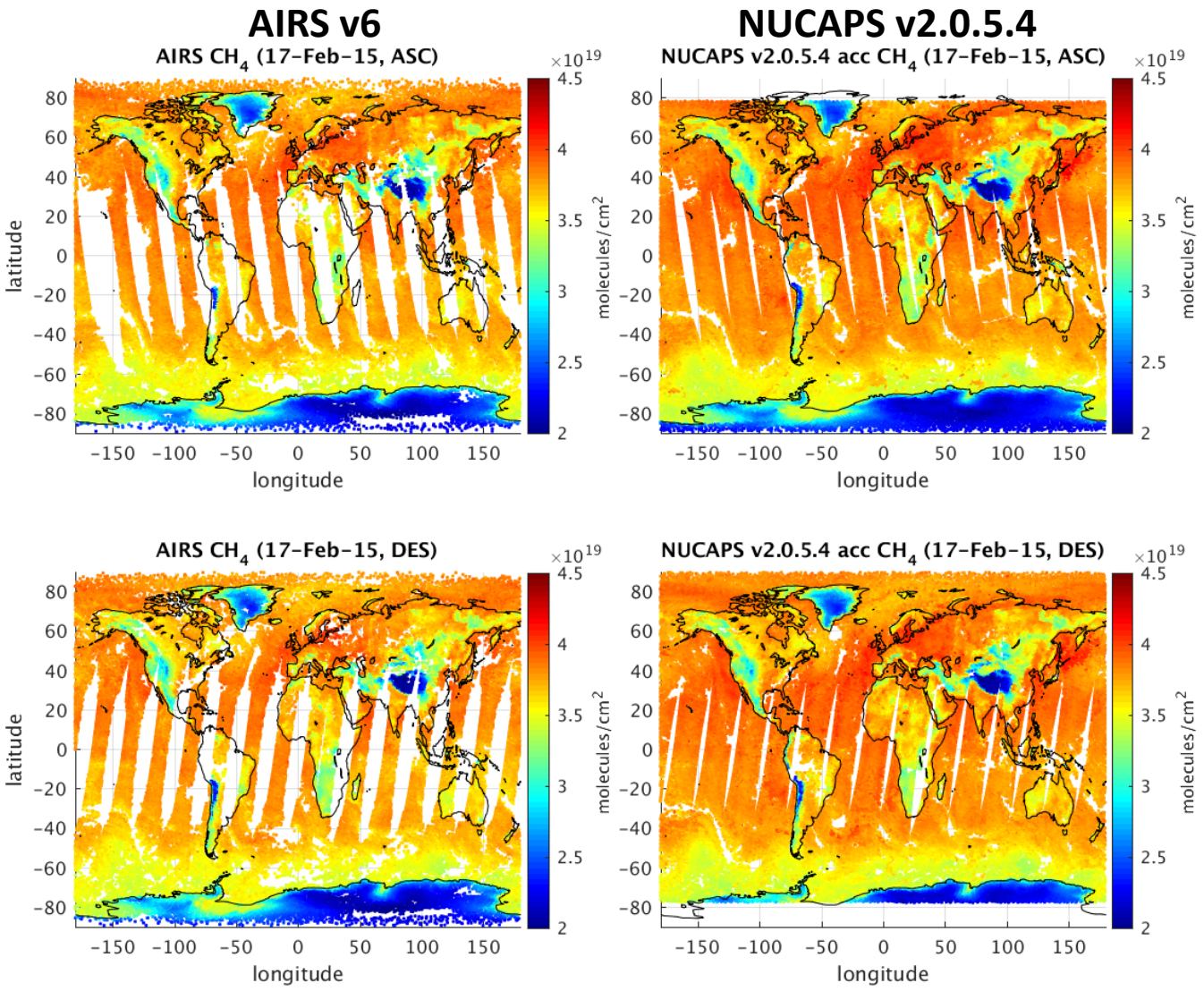
NUCAPS v2.0.5.4 CO – AIRS v6 CO

17 Feb 2015 Focus Day, Accepted Cases



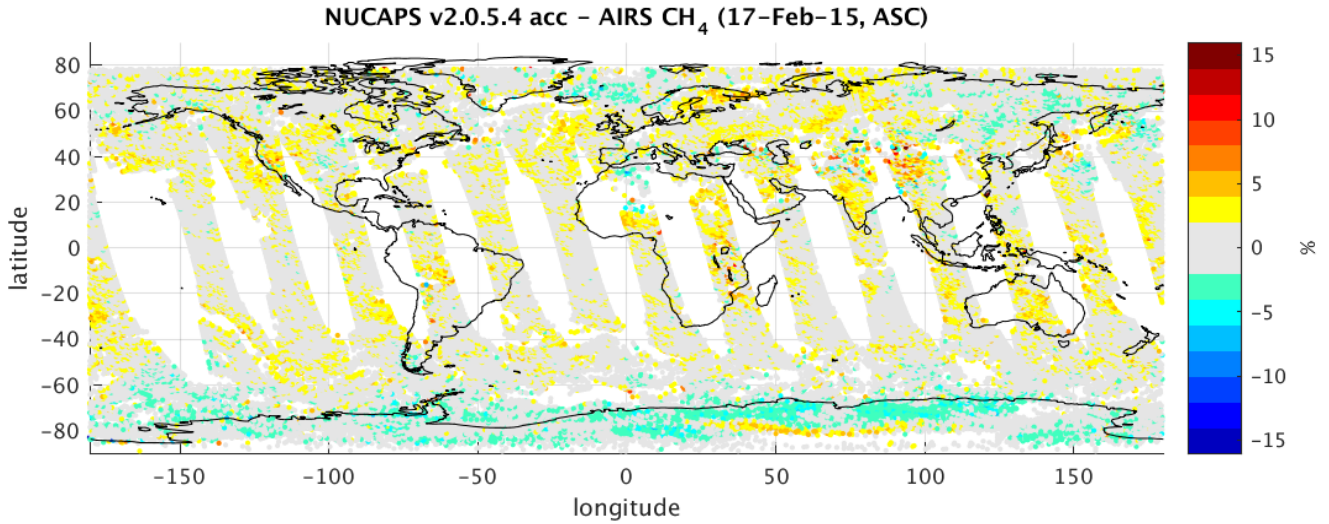
Total Column Methane (CH_4) EDRs

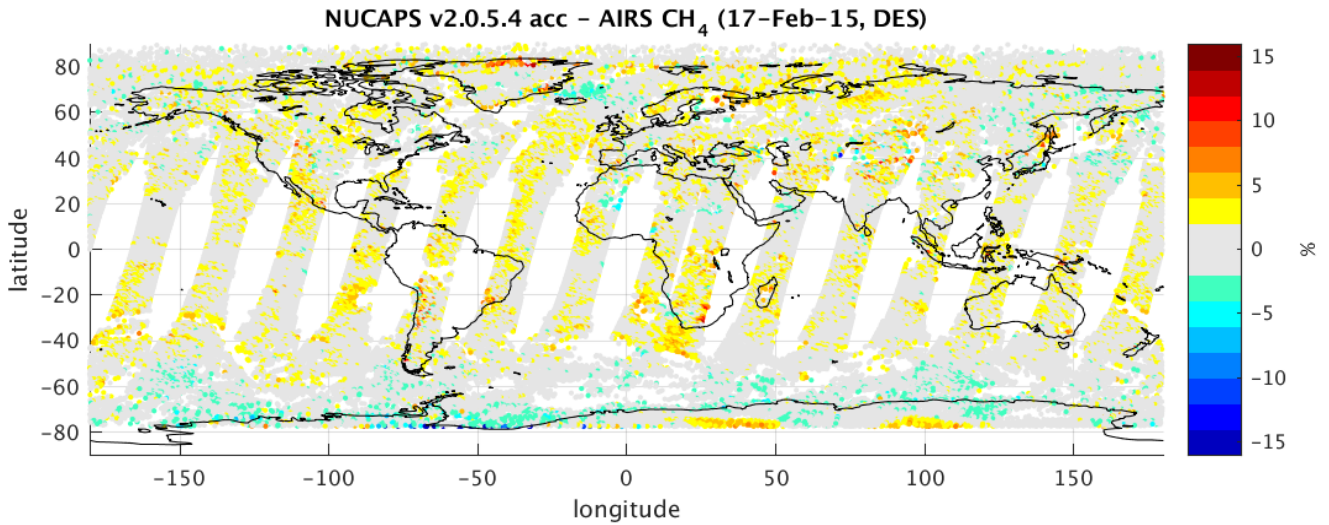
17 Feb 2015 Focus Day, All Cases



NUCAPS v2.0.5.4 CH_4 – AIRS v6 CH_4

17 Feb 2015 Focus Day, Accepted Cases

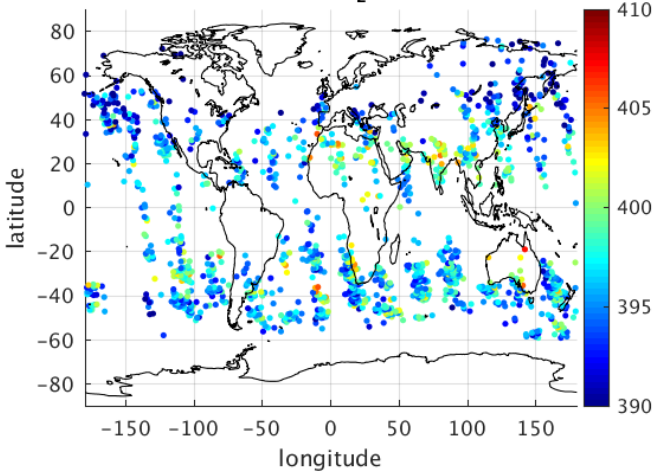




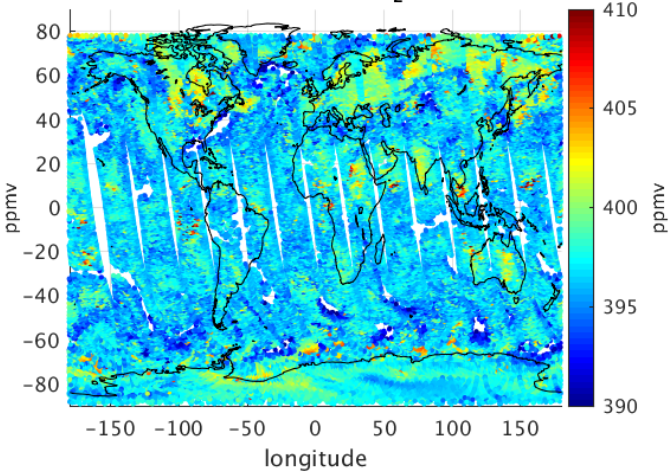
Total Column Carbon Dioxide (CH_2) EDRs

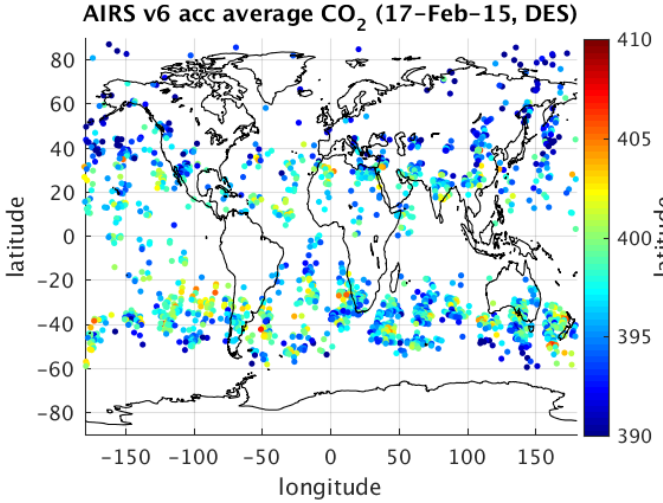
17 Feb 2015 Focus Day, All Cases

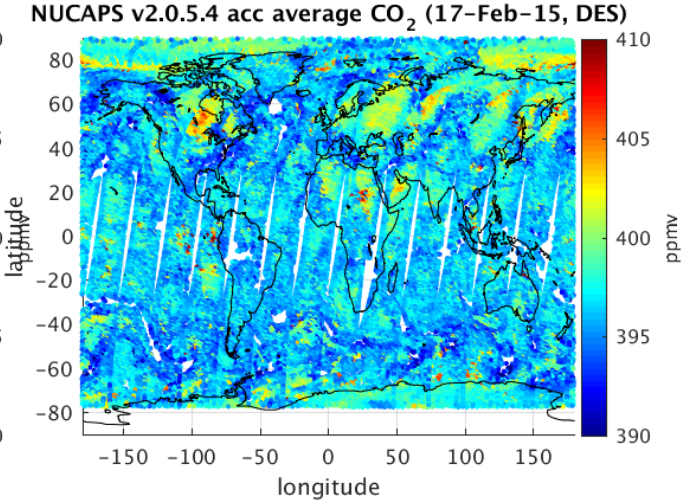
AIRS v6



NUCAPS v2.0.5.4

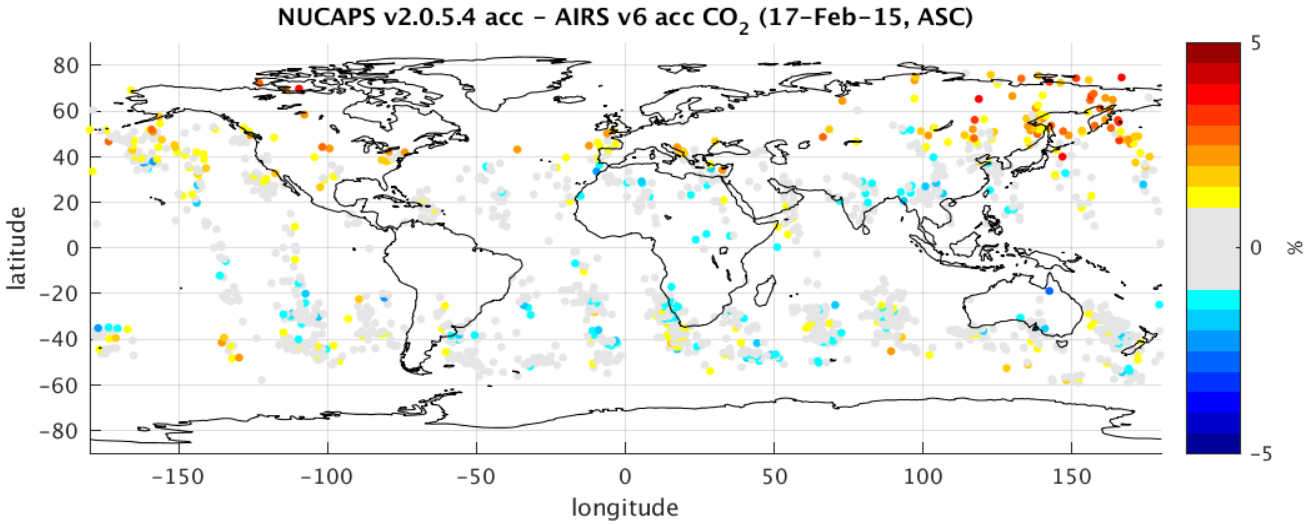


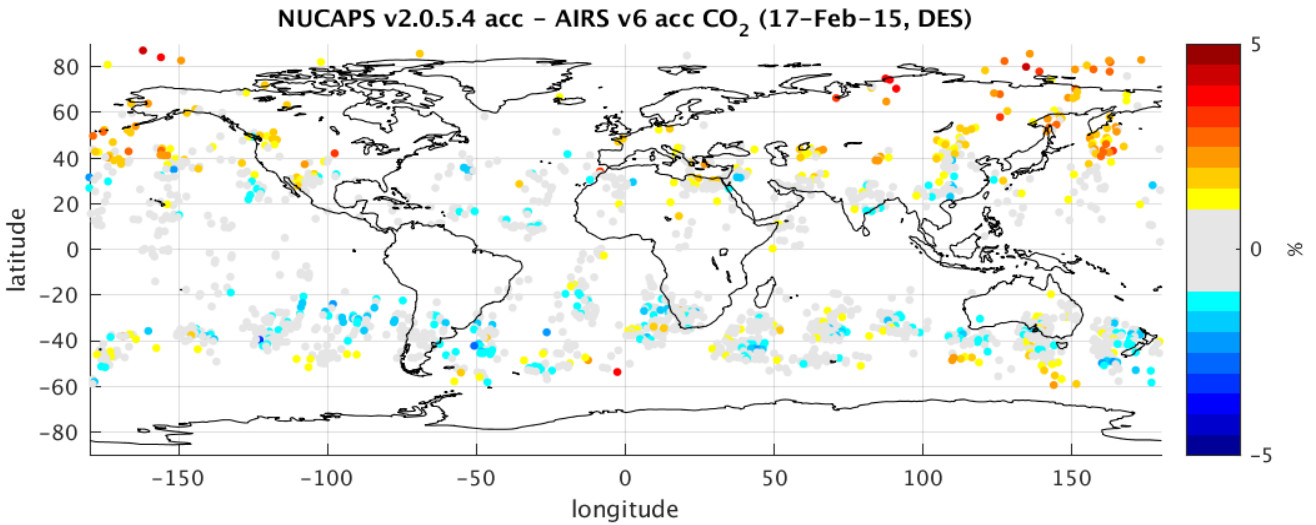




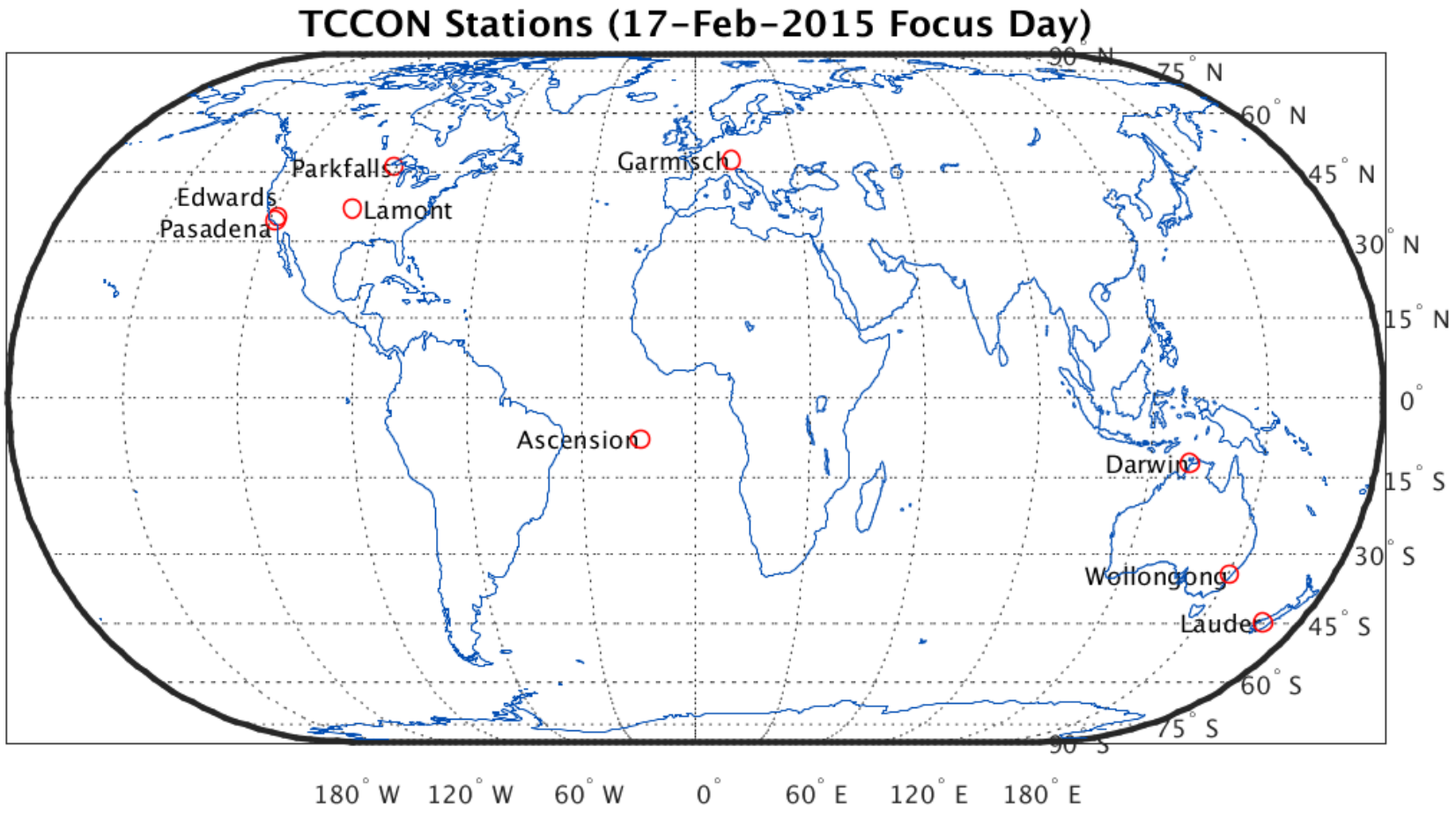
NUCAPS v2.0.5.4 CO_2 – AIRS v6 CO_2

17 Feb 2015 Focus Day, Accepted Cases





Total Carbon Column Observing Network (TCCON)
17 Feb 2015 Focus Day

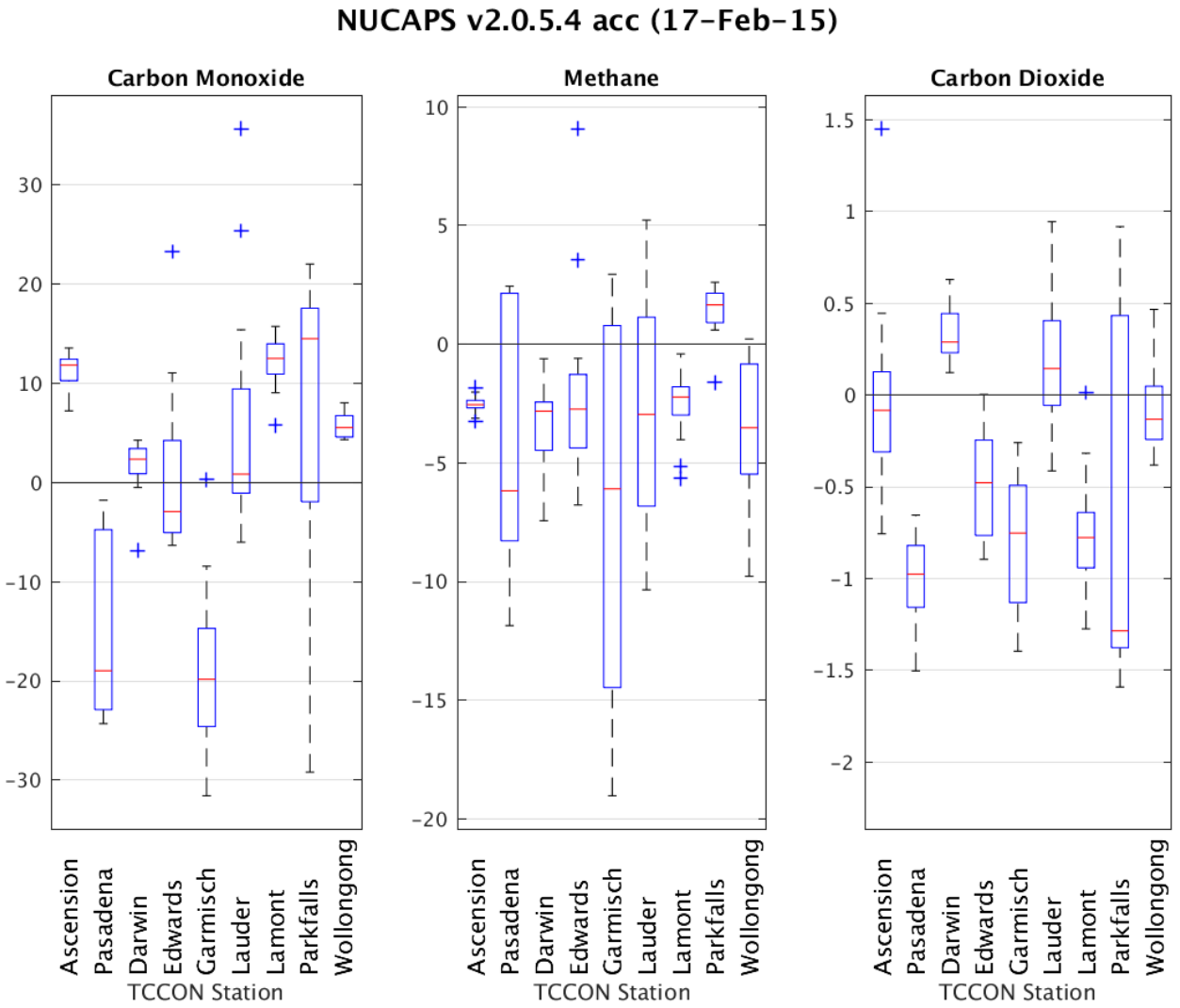


TCCON (*Wunch et al.* 2011)

NUCAPS-AIRS vs TCCON Box Plots
17 Feb 2015 Focus Day

All FOR within threshold radius (150 km)

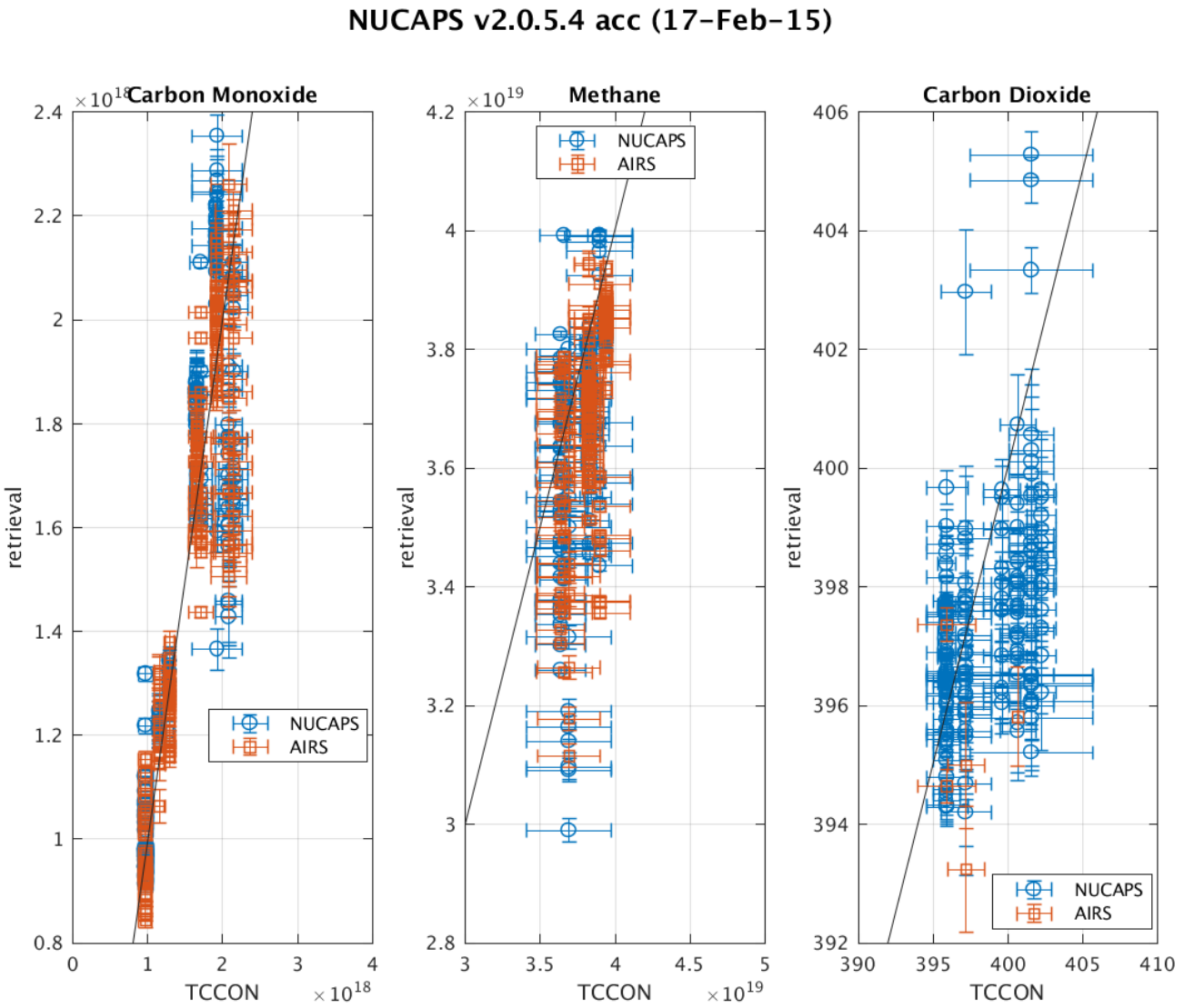
Time window (±6 hours) versus mean TCCON



NUCAPS-AIRS vs TCCON Box Plots
17 Feb 2015 Focus Day

All FOR within threshold radius (150 km)

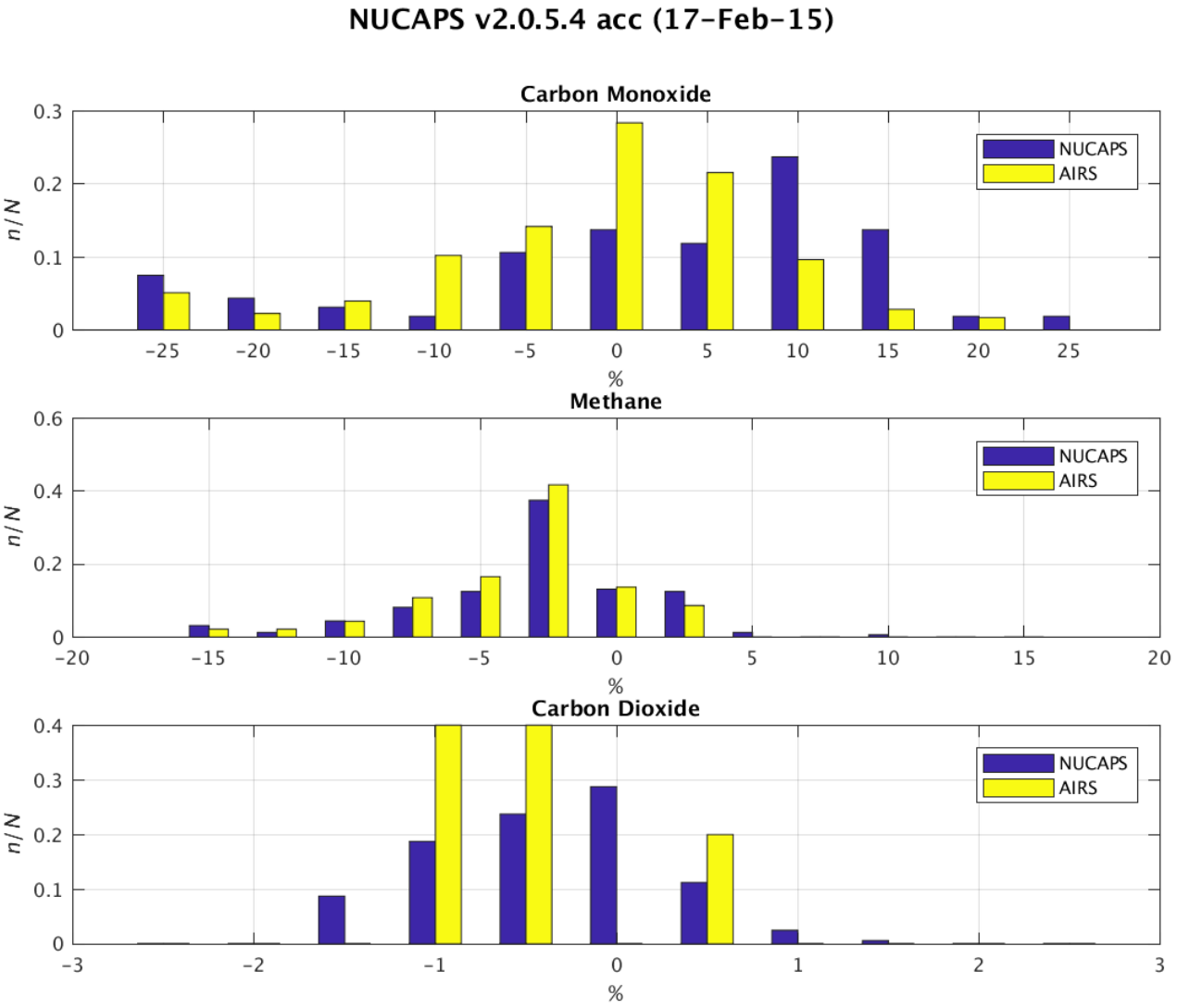
Time window (±6 hours) versus mean TCCON



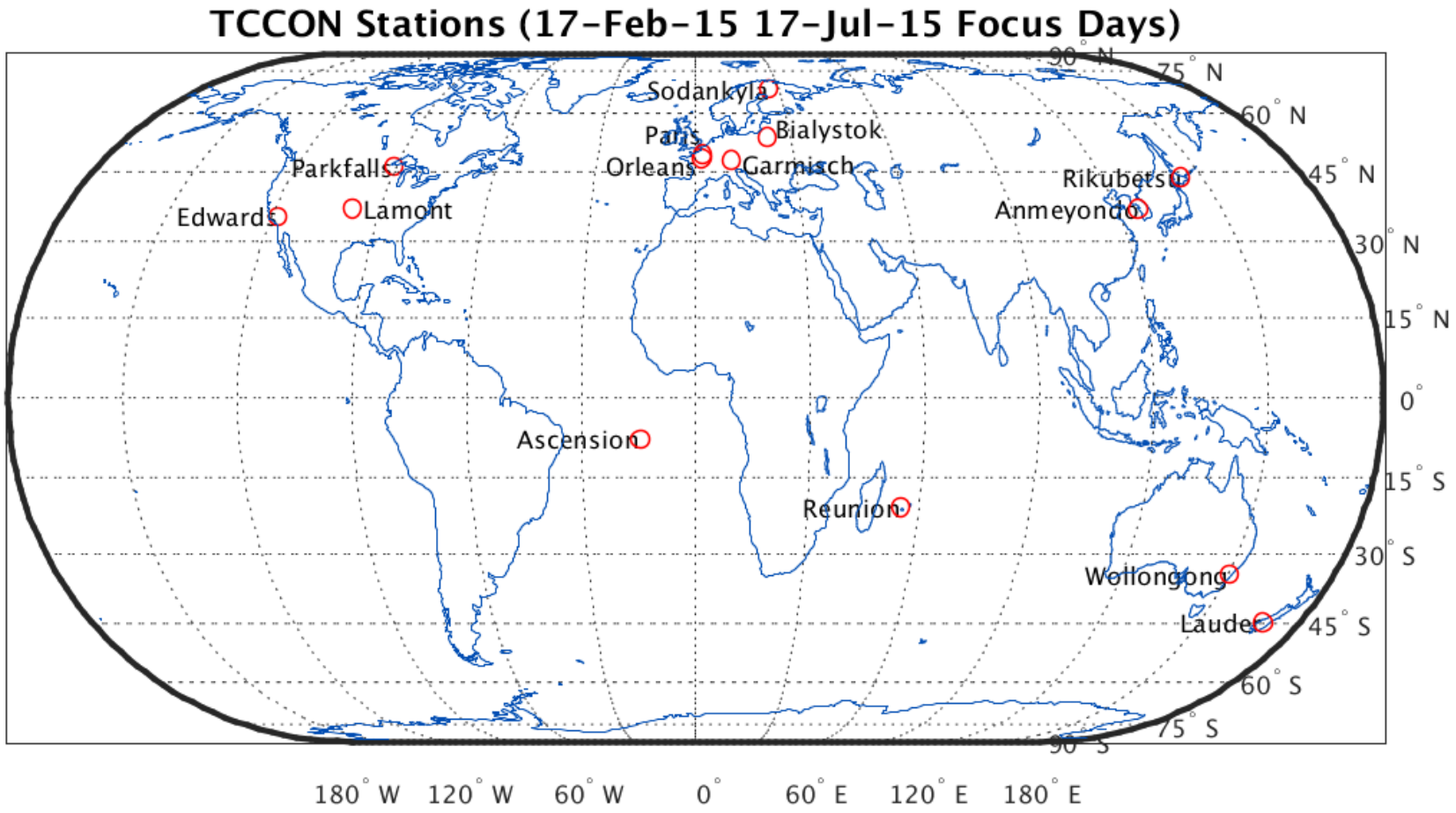
NUCAPS-AIRS vs TCCON Histograms
17 Feb 2015 Focus Day

All FOR within threshold radius (150 km)

Time window (±6 hours) versus mean TCCON



Total Carbon Column Observing Network (TCCON)
17 Feb 2015 and 17 Jul 2015 Focus Days

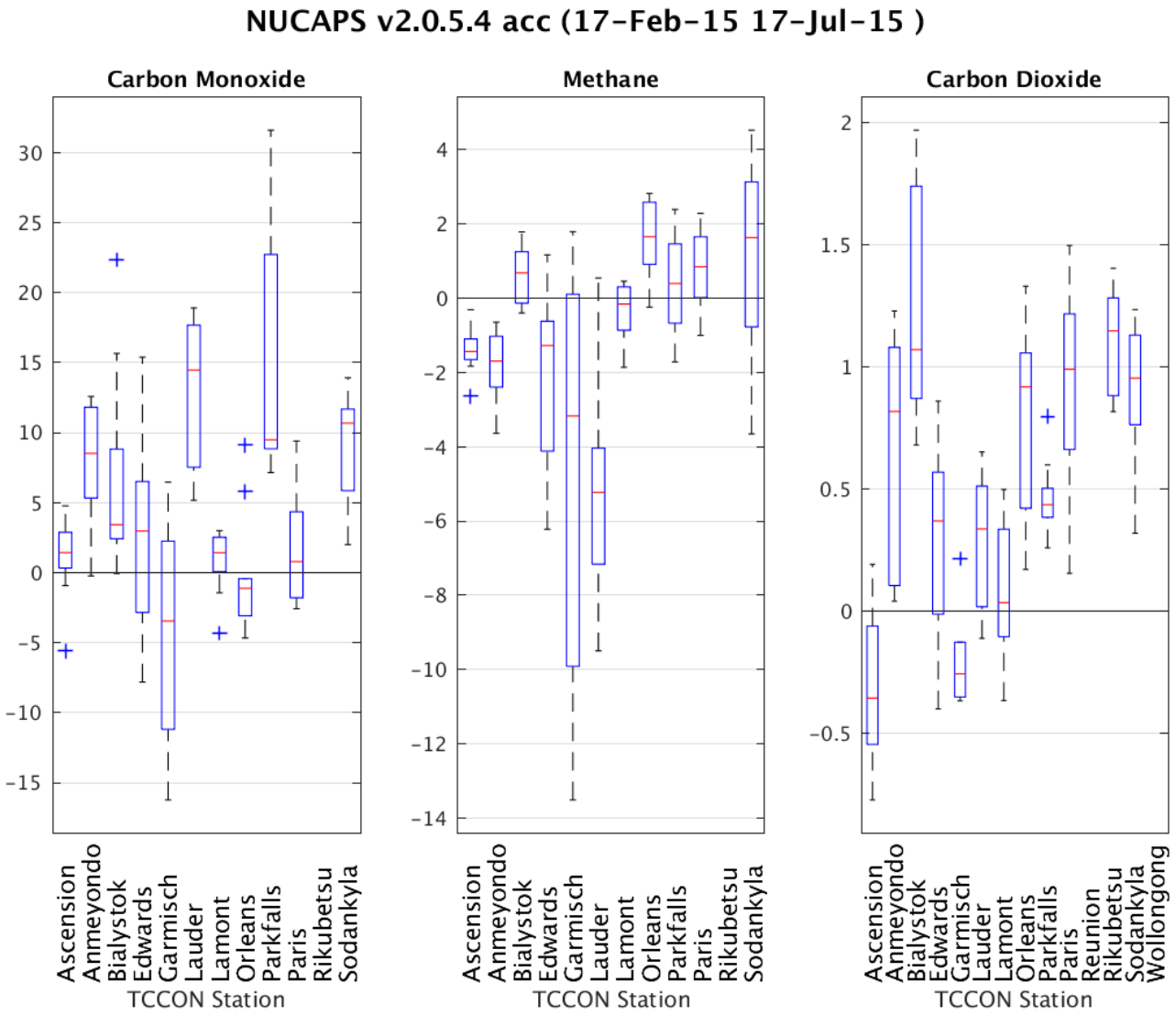


TCCON (*Wunch et al.* 2011)

NUCAPS vs TCCON Boxplots
17 Feb 2015 and 17 Jul 2015 Focus Days

All FOR within threshold radius (100 km)

Time window (±6 hours) versus mean TCCON

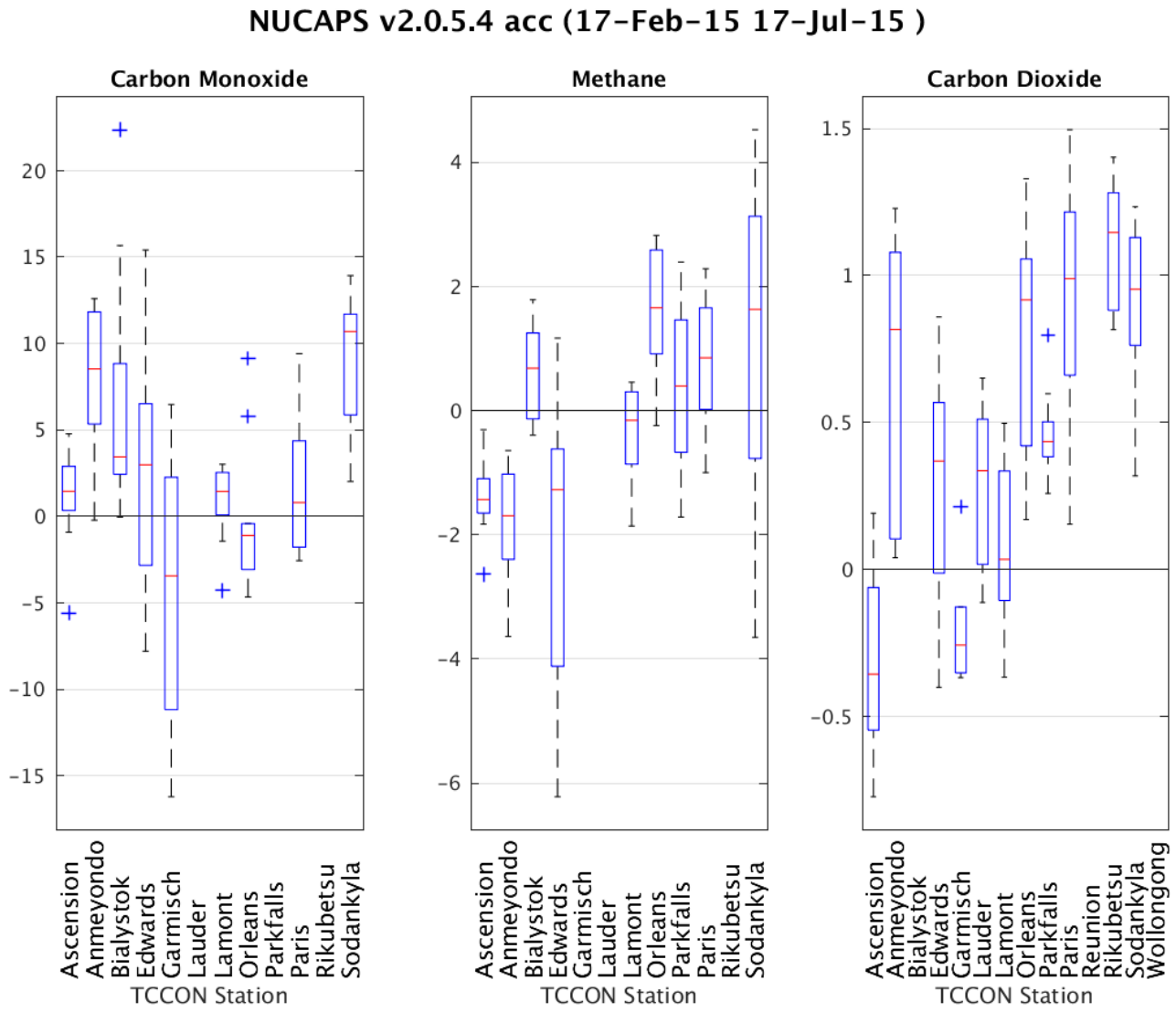


NUCAPS vs TCCON Boxplots
17 Feb 2015 and 17 Jul 2015 Focus Days

All FOR within threshold radius (100 km)

Time window (±6 hours) versus mean TCCON

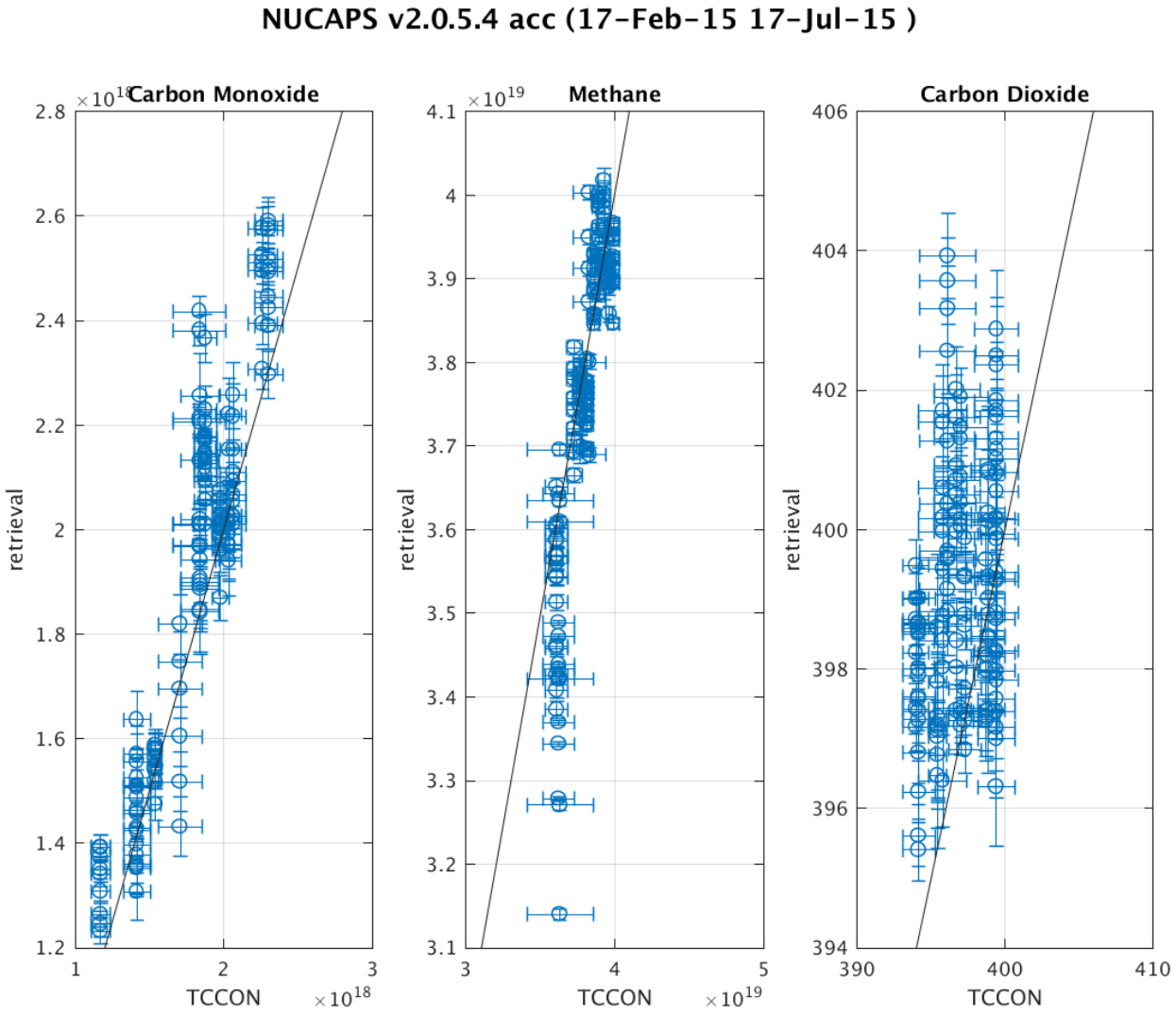
Outlier sites removed



NUCAPS vs TCCON Scatterplots
17 Feb 2015 and 17 Jul 2015 Focus Days

All FOR within threshold radius (100 km)

Time window (±6 hours) versus mean TCCON

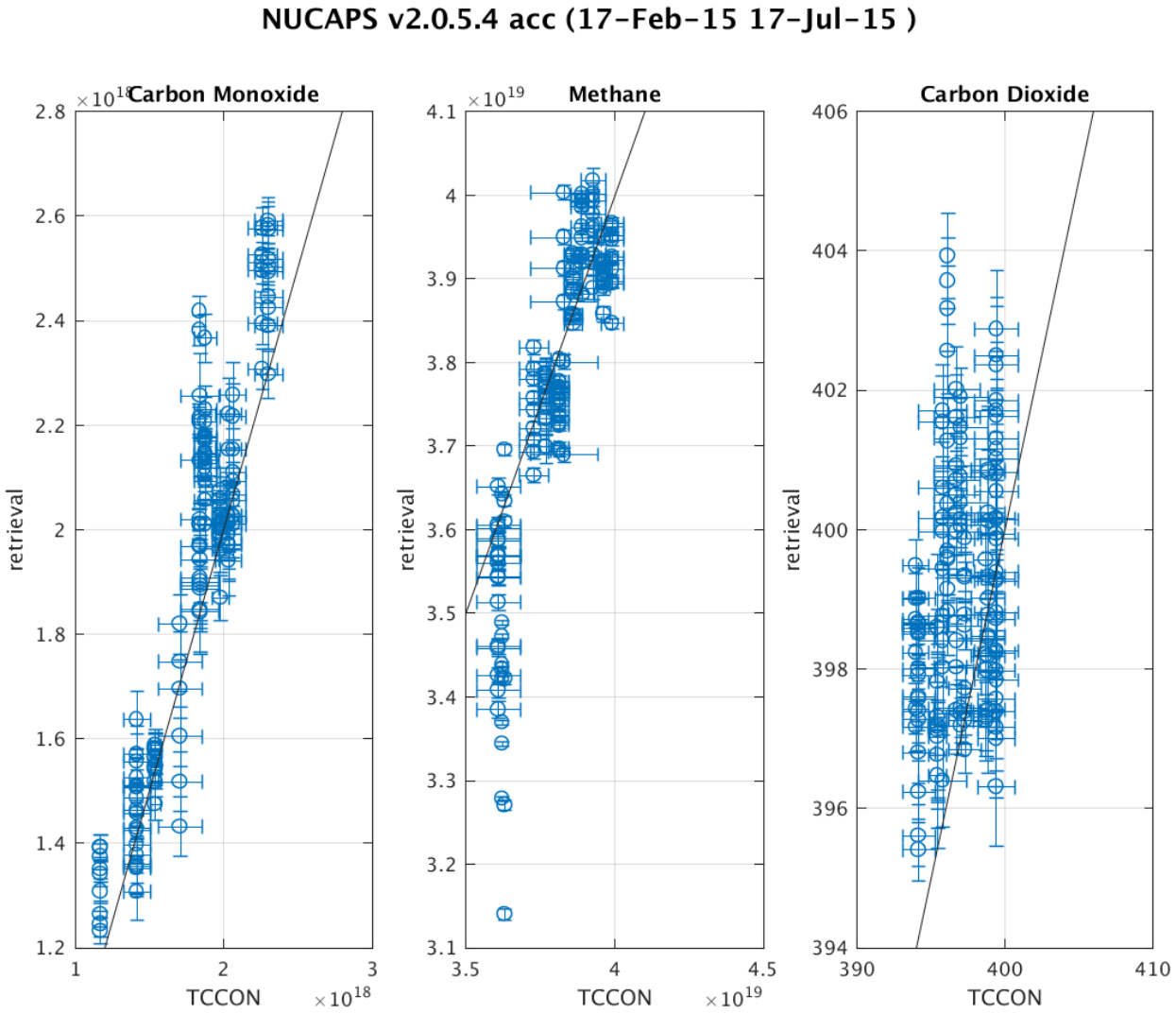


NUCAPS vs TCCON Scatterplots
17 Feb 2015 and 17 Jul 2015 Focus Days

All FOR within threshold radius (100 km)

Time window (±6 hours) versus mean TCCON

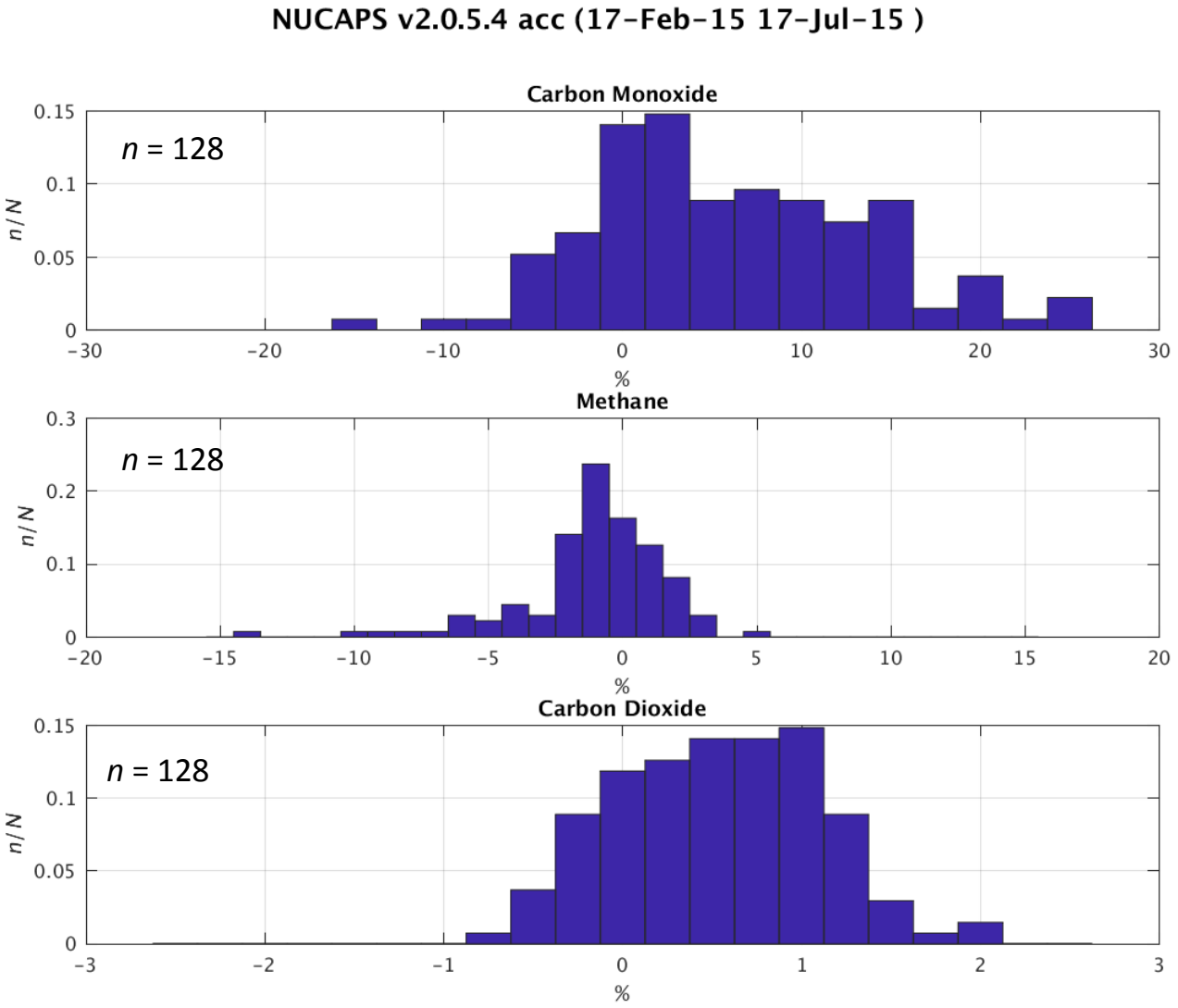
Outlier sites removed



NUCAPS vs TCCON Histograms
17 Feb 2015 and 17 Jul 2015 Focus Days

All FOR within threshold radius (100 km)

Time window (±6 hours) versus mean TCCON

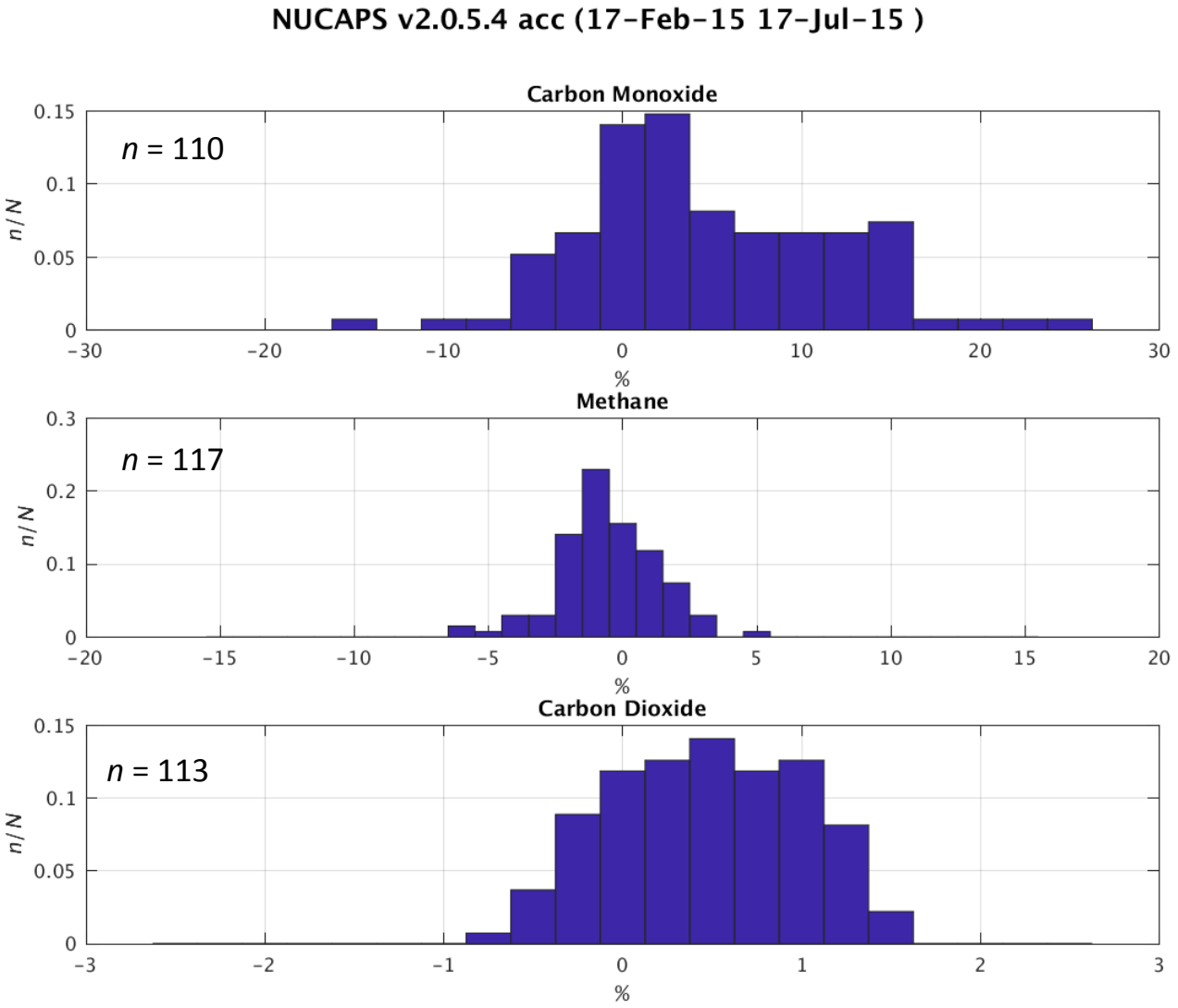


NUCAPS vs TCCON Histograms
17 Feb 2015 and 17 Jul 2015 Focus Days

All FOR within threshold radius (100 km)

Time window (±6 hours) versus mean TCCON

Outlier sites removed



NUCAPS v2.0 FSR Trace Gas Summary Stats

	TCCON Baseline One Focus Day *N* = 151			TCCON Baseline Two Focus Days *N* = 128			AIRS Baseline One Focus Day *N* = *O*(100,000)		
Trace Gas EDR	**BIAS (%)**	**STD (%)**	**RMS (%)**	**BIAS (%)**	**STD (%)**	**RMS (%)**	**BIAS (%)**	**STD (%)**	**RMS (%)**
CO	**+2.1** (±5.0)	**12.9** (15.0)	13.1	**+6.0** (±5.0)	**8.0** (15.0)	10.0	**+3.0** **+3.3** **(±5.0)**	**9.2** **8.9** (15.0)	9.7 9.5
CO_2	**−0.3** (±1.0)	**0.6** (0.5)	0.7	**+0.5** (±1.0)	**0.6** (0.5)	0.8	**+0.2** **+0.1** **(±1.0)**	**0.9** **1.0** (0.5)	0.9 1.0
CH_4	**−3.0** (±4.0)	**4.4** (1.0)	5.3	**−1.1** (±4.0)	**2.6** (1.0)	2.9	**+0.6** **+0.8** (±4.0)	**1.7** **1.6** (1.0)	1.8 1.8
	Yield = 83.4%			Yield = 83.7%			Yield = 83.4%		

NUCAPS v2.0 FSR Trace Gas Summary Stats

	TCCON Baseline One Focus Day *N* = 151			TCCON Baseline Two Focus Days Outlier Sites Removed			AIRS Baseline One Focus Day *N* = *O*(100,000)		
Trace Gas EDR	BIAS (%)	STD (%)	RMS (%)	BIAS (%)	STD (%)	RMS (%)	BIAS (%)	STD (%)	RMS (%)
CO	**+2.1** (±5.0)	**12.9** (15.0)	13.1	**+4.7** (±5.0)	**7.1** (15.0)	8.5	**+3.0** **+3.3** **(±5.0)**	**9.2** **8.9** (15.0)	9.7 9.5
CO_2	**−0.3** (±1.0)	**0.6** (0.5)	0.7	**+0.5** (±1.0)	**0.5** (0.5)	0.7	**+0.2** **+0.1** **(±1.0)**	**0.9** **1.0** (0.5)	0.9 1.0
CH_4	**−3.0** (±4.0)	**4.4** (1.0)	5.3	**−0.6** (±4.0)	**1.8** (1.0)	1.9	**+0.6** **+0.8** (±4.0)	**1.7** **1.6** (1.0)	1.8 1.8
	Yield = 83.4%			Yield = 83.7%			Yield = 83.4%		

NUCAPS EDR Maturity Status

Slide courtesy of Lihang Zhou, STAR/JPSS

S-NPP EDR Validated Maturity Oct. 2016-Current: NUCAPS

Sensor	Product	Priority	Validated Maturity Review Date & Status		Review Panel Recommendations
CrIS/ATMS	Atm. Vertical Moisture Profile (AVMP)	3	*	✓ V	September 2014
CrIS/ATMS	Atm. Vertical Temperature Profile (AVTP)	3	*	✓ V	September 2014
CrIS/ATMS	Ozone Profile EDR	3	Oct-2016	✓ V	Panel recommended the following: (1) Work with EMC and NWS on user applications (2) Validate against OMPS NP data (3) Extend validation to more ozonesondes
CrIS	Outgoing Longwave Radiation	3	Oct-2016	✓ V	Panel recommended the following: (1) Investigate the use of VIIRS for helping to understand the differences between OLR from CrIS and CERES. (2) Compare anomaly events from CERES OLR (e.g. ENSO, MJO) to CrIS OLR data (3) Provide information about how algorithm will be updated to utilize CrIS FS data
CrIS/ATMS	Carbon Monoxide	4	&	✓ P	Validated Maturity Review for Fall 2017
CrIS/ATMS	Carbon Dioxide	4	&	✓ P	Validated Maturity Review for Fall 2017
CrIS/ATMS	Methane	4	&	✓ P	Validated Maturity Review for Fall 2017

*Product reached validated maturity in September 2014.

&Product reached provisional maturity in January 2013. NUCAPS Phase IV/Part II ARR completed on July 6, 2017.

✓ Validated ✓ Provisional

5

O_3, CO, CH_4, CO_2 Trace Gas Summary

- **NUCAPS IR ozone (O_3) profile EDR products generally meet JPSS Level 1 requirements**
  - **NUCAPS (v1.5 NSR)** reached **Validated Maturity** based upon coarse/broad layer statistical analyses versus
    - Collocated **global ozonesondes**, including **dedicated ozonesondes** (Validation Hierarchy Method #4)
    - **Global Focus Day** (17 February 2015) **ECMWF** output (Validation Hierarchy Method #1)
    - Statistics are comparable to those reported by *Divakarla et al.* (2008) for the AIRS Version 5 ozone product
  - **NUCAPS Phase 4 v2.0 FSR also meets Level 1 requirements** and have reached **Provisional Maturity** based upon coarse/broad layer statistical analyses versus global **Focus Day ECMWF**
    - Statistics are comparable to the ozonesonde-validated NUCAPS v1.5

- **Carbon trace gas EDR validation** versus program-established uncertainty specifications was a new task beginning with the transition to the FSR CrIS NUCAPS. Preliminary validation versus AIRS and TCCON truth datasets show the products are reasonably close to meeting JPSS Level 1 requirements

- **Next Steps / Future Work**
  - **Acquire additional Focus Days** to increase the TCCON data sample
    - Currently collecting 2 additional days for Spring and Autumn seasons
  - **Apply TCCON AKs**
  - Develop objective methods for eliminating TCCON "outlier sites"
    - **Check for altitude gradients** within collocation radii
    - **Check for land/sea boundaries** within collocation radii
  - **Develop Trace Gas EDR quality flags**
  - **Acquire field campaign datasets** (e.g., ATom)
  - **Further optimization of NUCAPS trace gas *a priori*** (viz., O_3, CH_4 and CO_2)

Status of NUCAPS FSR Trace Gas EDR Validation

THANK YOU! QUESTIONS?

FORWARD MODEL IMPROVEMENTS: PRESENT AND FUTURE

L. Larrabee Strow, Sergio deSouza-Machado, Steven Buczkowski

JPSS STM – August 14, 2017

Joint Center for Earth Systems Technology and
UMBC Department of Physics

Outline

- CrIS FSR forward model
- CrIS minor gas trend retrievals
- Single footprint retrievals

FSR Forward Model

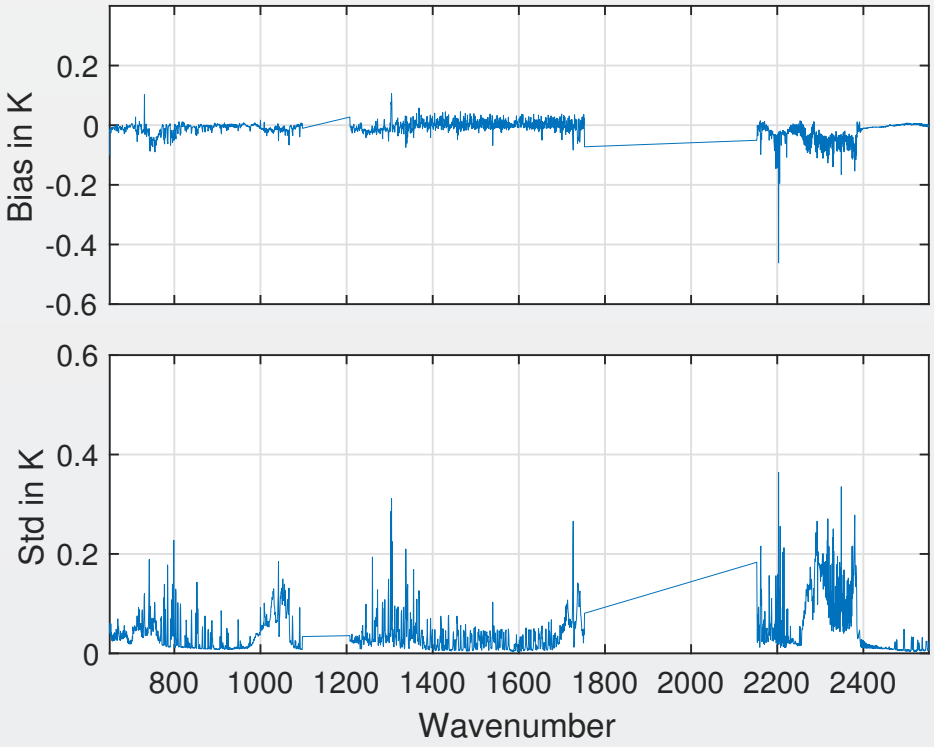
Summary of FSR SARTA

- CrIS high-resolution ILS
- HITRAN 2012 (vs 2008 in original CrIS RTA)
- LBLRTM Line Mixing for CO2 and CH4, H2O continuum
- UMBC line-by-line for water
- Code Change: improved reflected thermal for high secant angles
- Tested on 750+ profiles (from ECMWF selected subset), regressed on 49 profiles
- Error covariance estimates available from 750+ profile testing

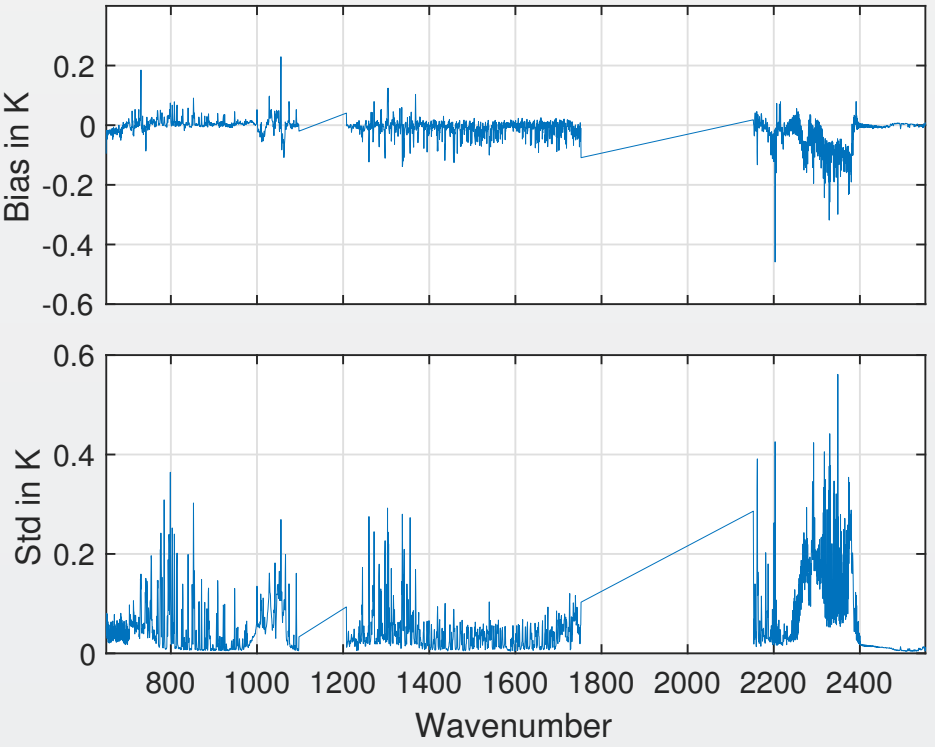
kCARTA (LBL) partially trained on LBLRTM allows us to compute 25,000 plus monochromatic test profiles!

Parameterization Errors

Regression Profiles: 49*7



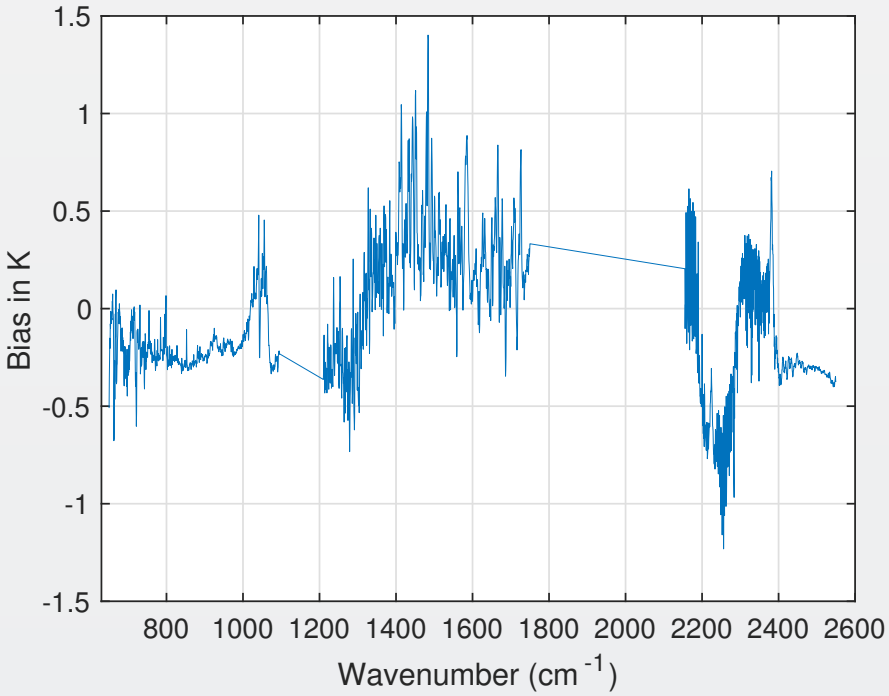
SAF Profiles: 705*7



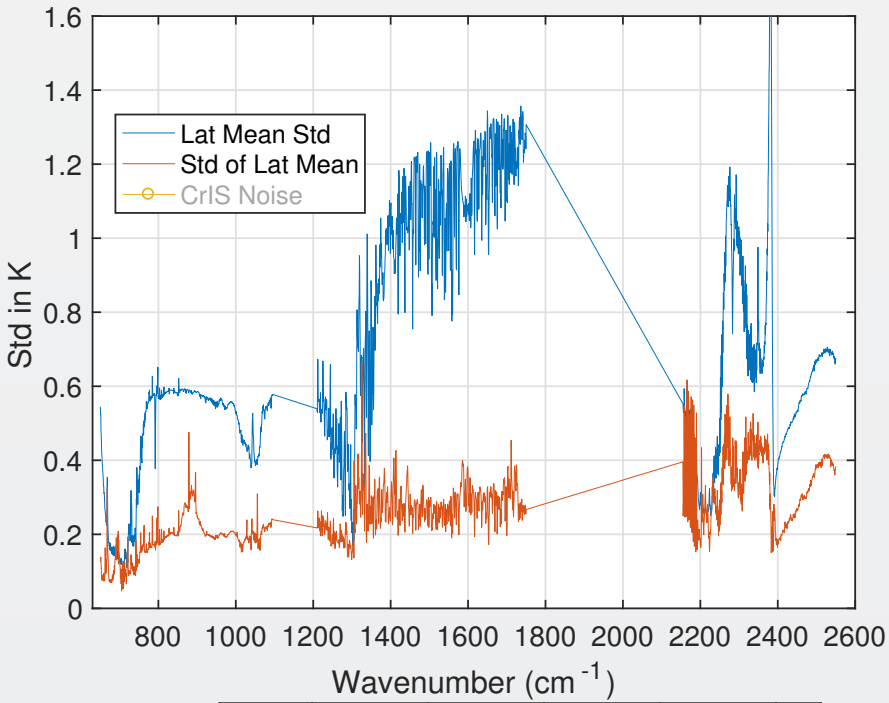
Some increase in Mean/Std errors with SAF. Can diagonose with so many test cases.

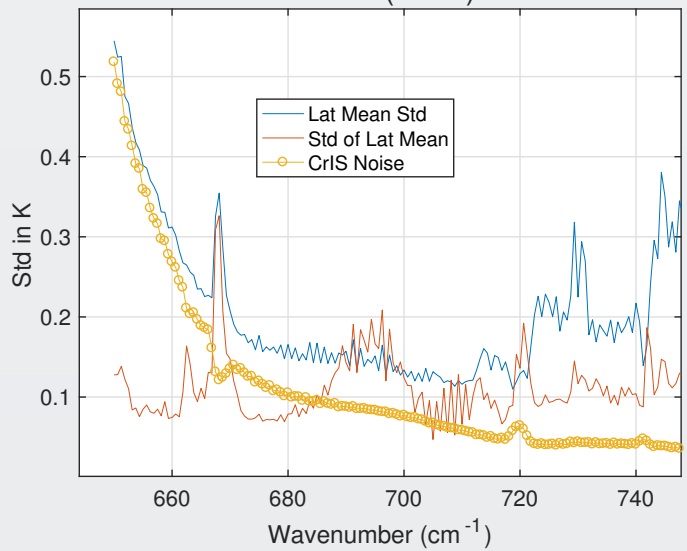
Bias/Std versus ECMWF: 3 days ocean clear

Bias

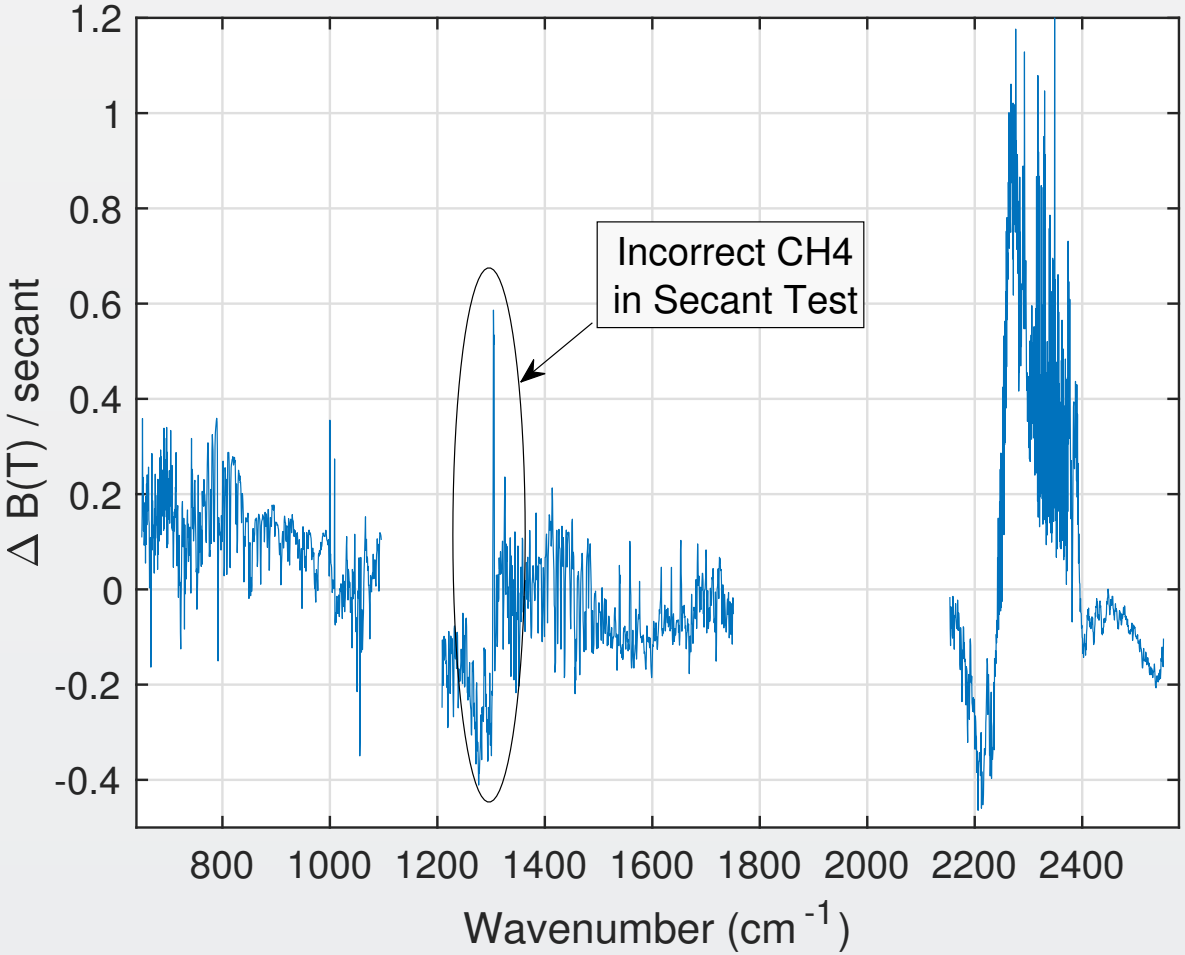


Std





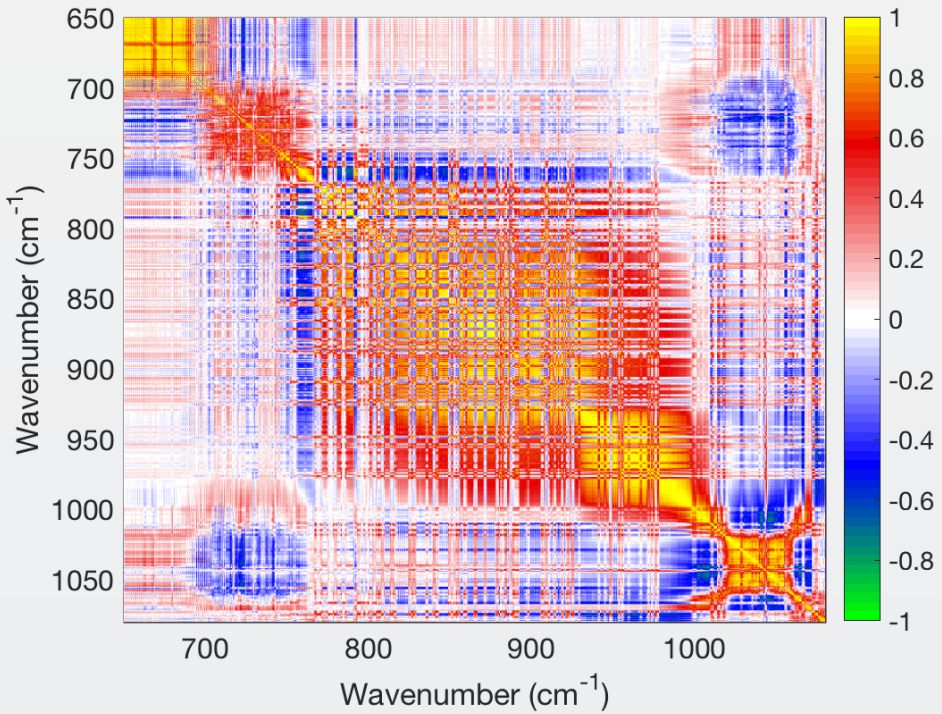
Secant Angle Dependence



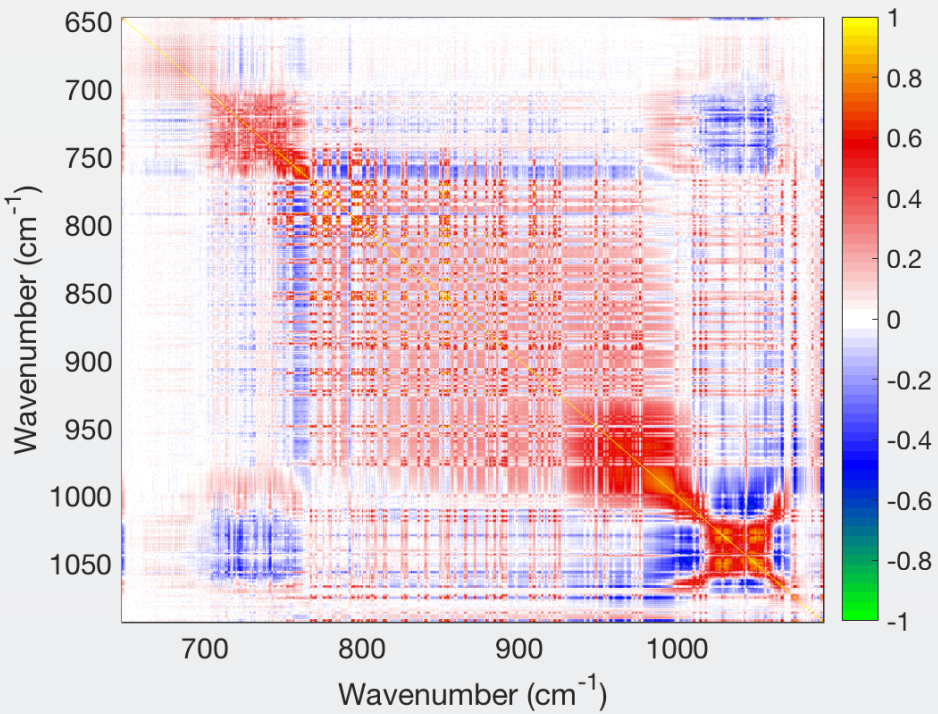
- Fit for slope of each channel versus secant of viewing angle
- Used 10 angles from nadir to max scan angle
- Errors are about ± 0.1K except less near 700-720 cm^{-1}

RTA (SARTA) Parameterization Error Correlations

Raw: No Noise



With CrIS Noise

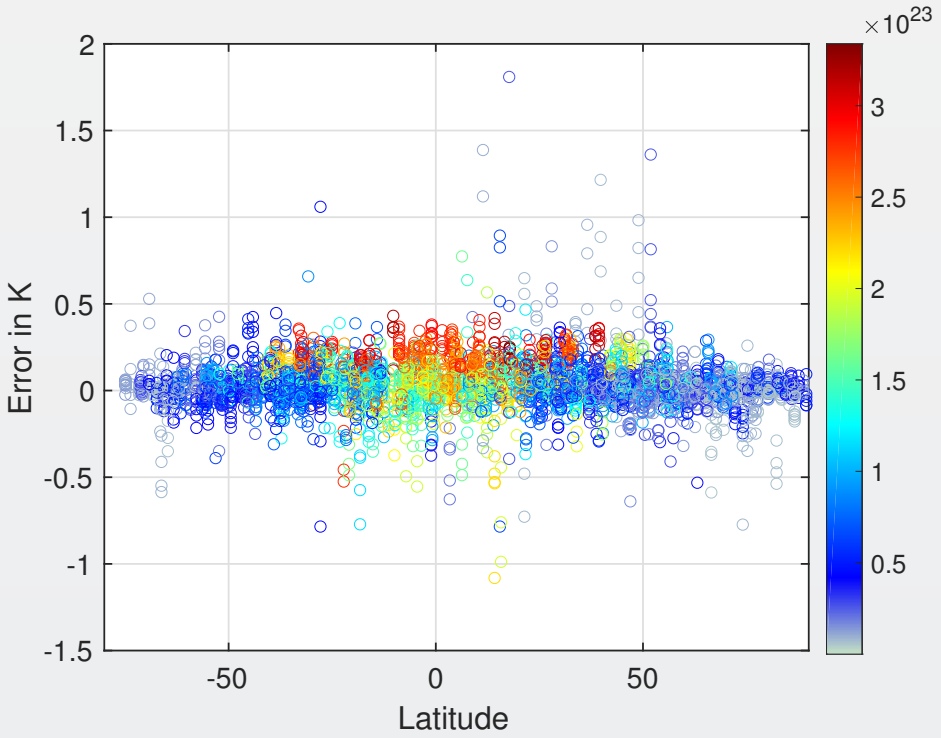


- 705 global profiles
- Computed correlations for LBL (kCARTA) minus fast RTA (SARTA)
- Same kCARTA used to create SARTA parameterizations

Water region errors (no shown) highly correlated.

Future Improvements?

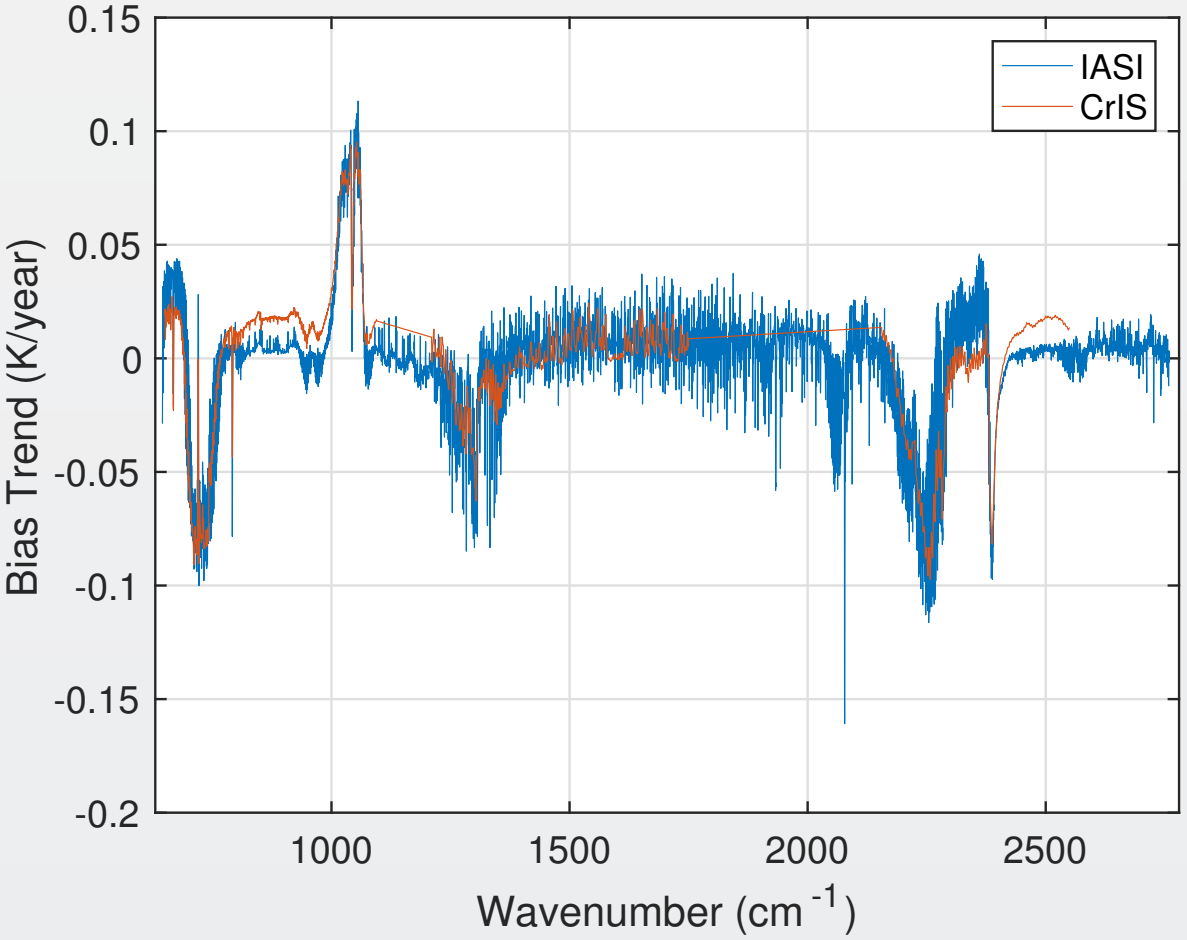
- Testing neural-net (2-3 layer, feed-forward) for parameterization of absorption coefficients
- Done for each optran layer, but hoping can use one net for all layers
- Using SAF 705*7 profile set, can expand to 25,000 profiles
- Really helps finding problem profiles, regression set is pretty good!



Neural net error for 1691.25 cm^{-1} channel versus total column water

CrIS Minor Gas Trends

OE Minor Gas Retrievals from BT Trends: CO_2

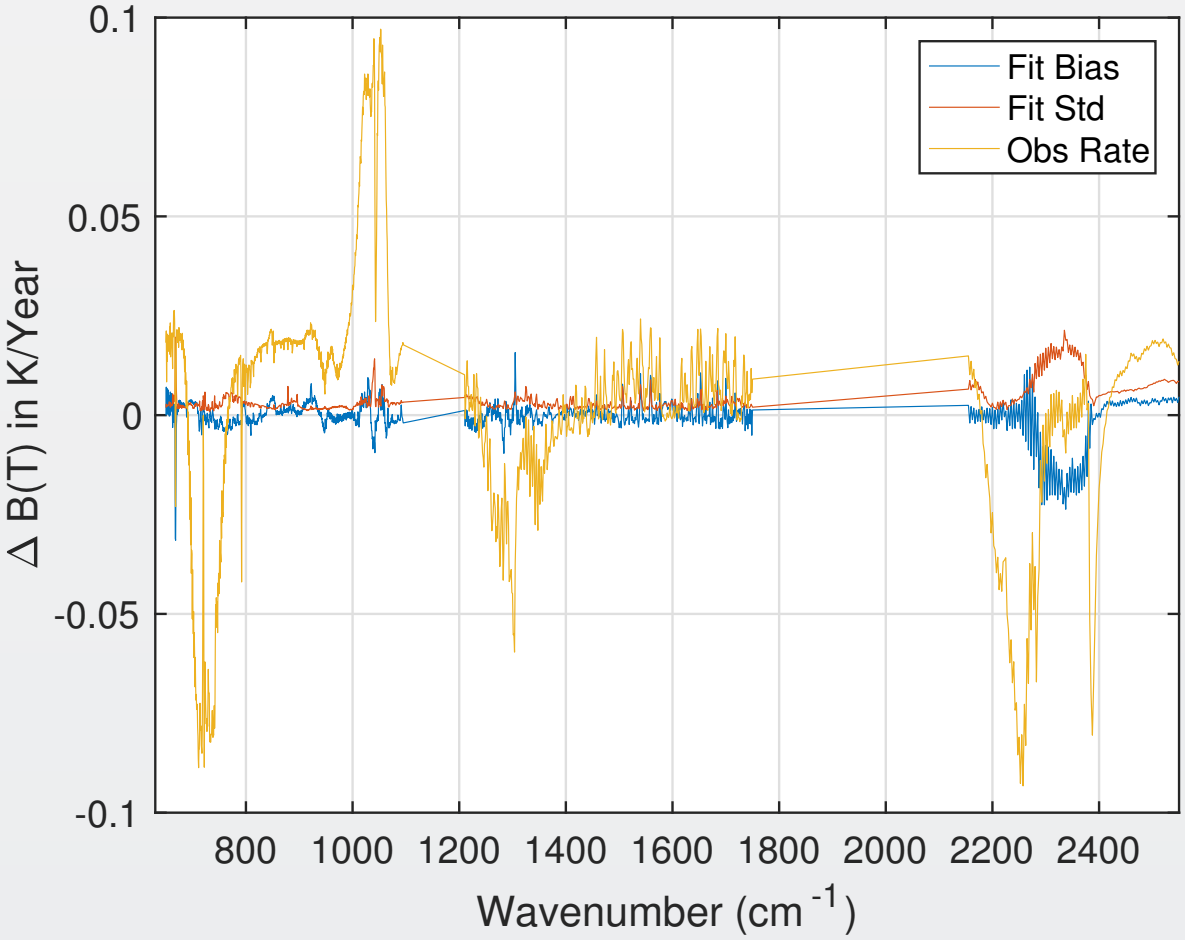


MLO: 2.49 ppm/year (last 5 years)

CriS Tropics: 2.56 ppm/year (last 5 years)

Difference = 0.0035K/year in possible drift!

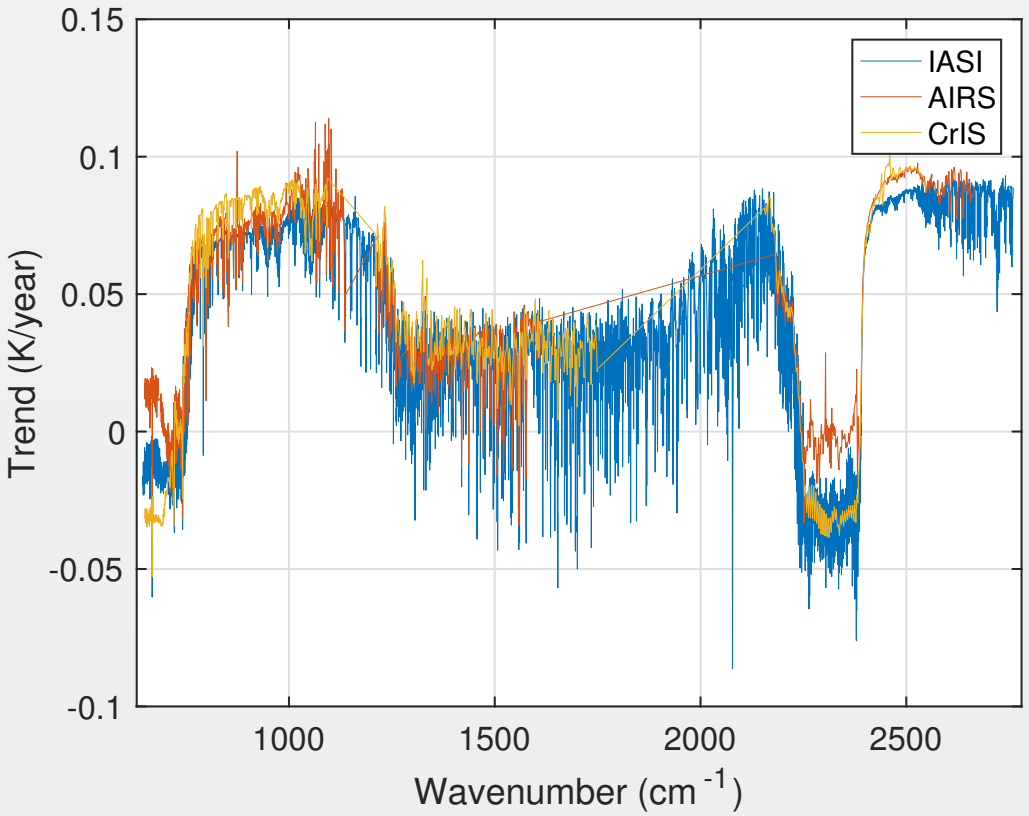
OE Minor Gas Retrievals from BT Trends: CH_4:



SST vs ERA (ghrsst): 0.0035K/year in BT units

CH_4 vs MLO: ~0.01K/year (MLO: 8.6 ppb/year, CrIS: 8.1 ppb/year)

CrIS All-Sky Trends



For 900 cm^{-1} channels:

CrIS: 0.085 K/year

AIRS: 0.076 K/year

IASI: 0.072 K/year

±0.05K uncertainty including lag-1 corrections

Latitude variability high: ±0.2-0.3K/year BUT within 2σ estimated uncertainties.

This is a short time period. 14-year AIRS trend is ~0.015K ±0.01K.

Single Footprint Retrievals with SARTA

Scattering SARTA

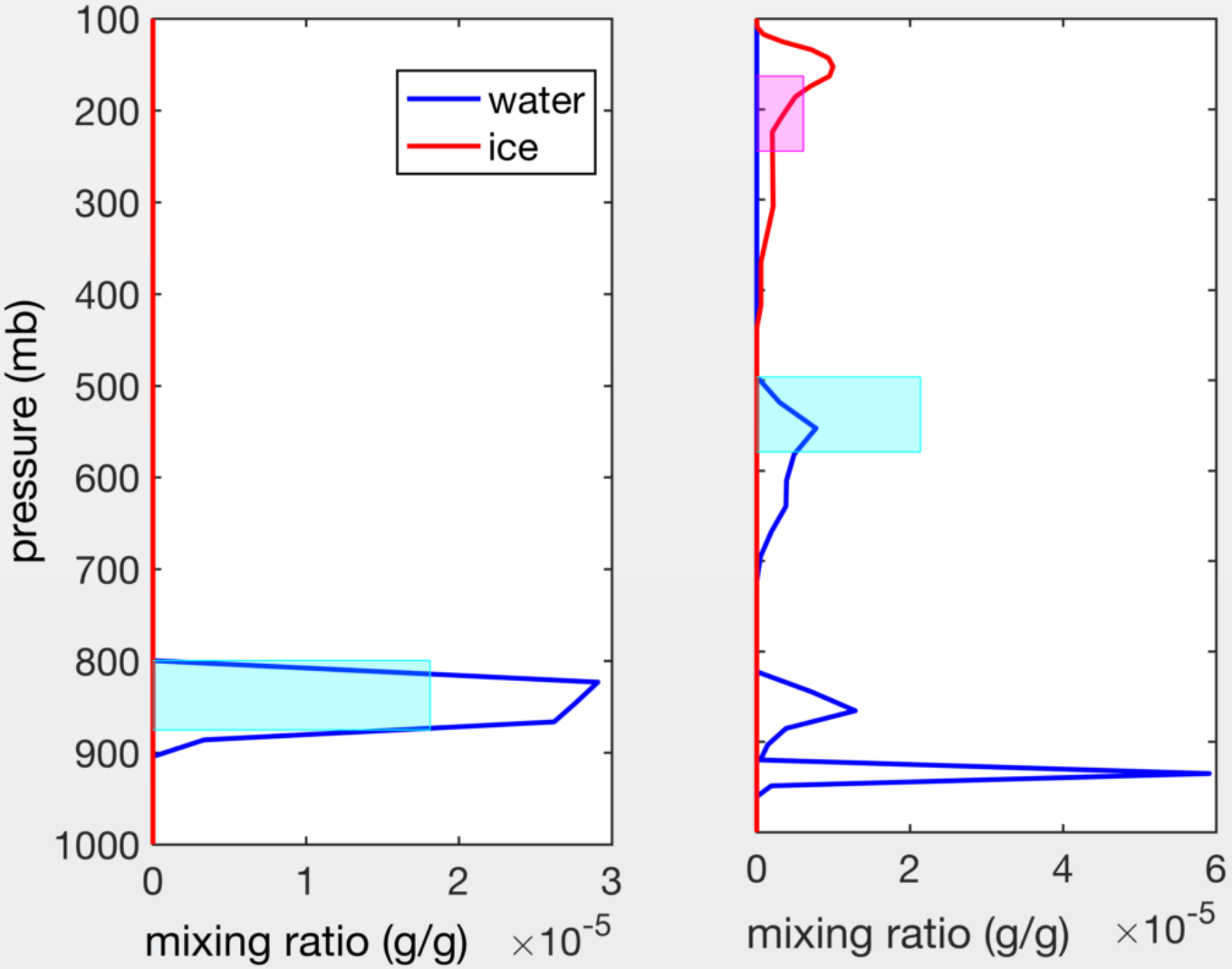
- Designed to mimic what *can be retrieved*.
- Very simple scattering, 2X slower than clear SARTA
- Two scattering layers, some mix of ice cloud, water cloud, aerosol (dust, volcanic ash)
- Two major liens vs PCRTM tests with ECMWF (Xu Liu)
  - 2 layers, no statistical cloud overlap computations
  - Less accurate scattering, likely only an issue with solar in SW

Single Footprint Retrievals

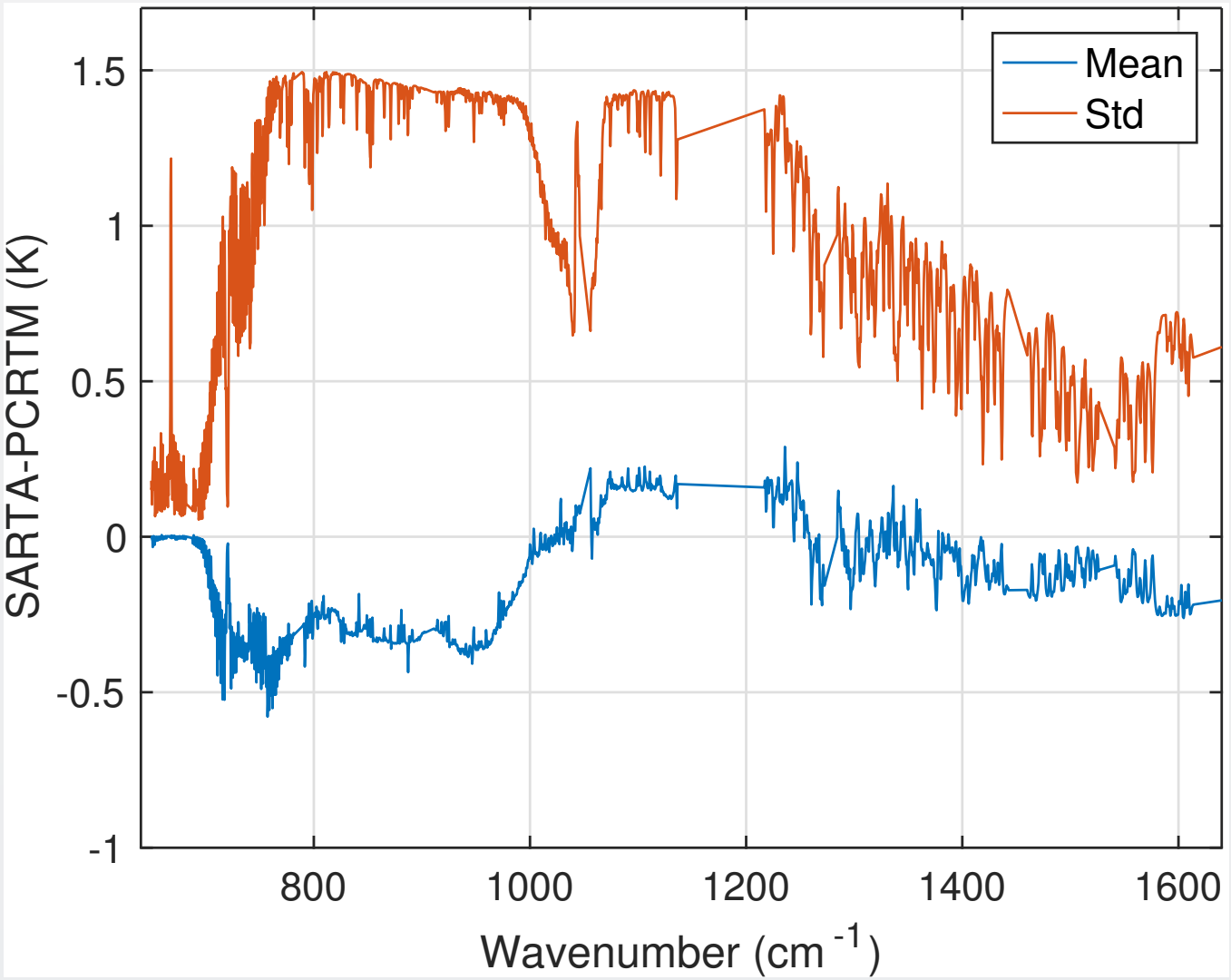
- Cloud initialization by using NWP model (ERA) clouds (find close-by grid point similar to observations)
- Could be initialized with climatology
- Fixed cloud heights, fit for cloud amount and particle size
- Tested first with smooth a-priroi climatology
- Then, move to ERA a-apriori
- Mostly used for trend retrievals. Hope to use for radiosonde intercomparisons
- Lots of testing, mostly analyzing special cases.

OE framework very good at accuracy estimates, let's you naturally Q/A cloud problems (thick clouds)

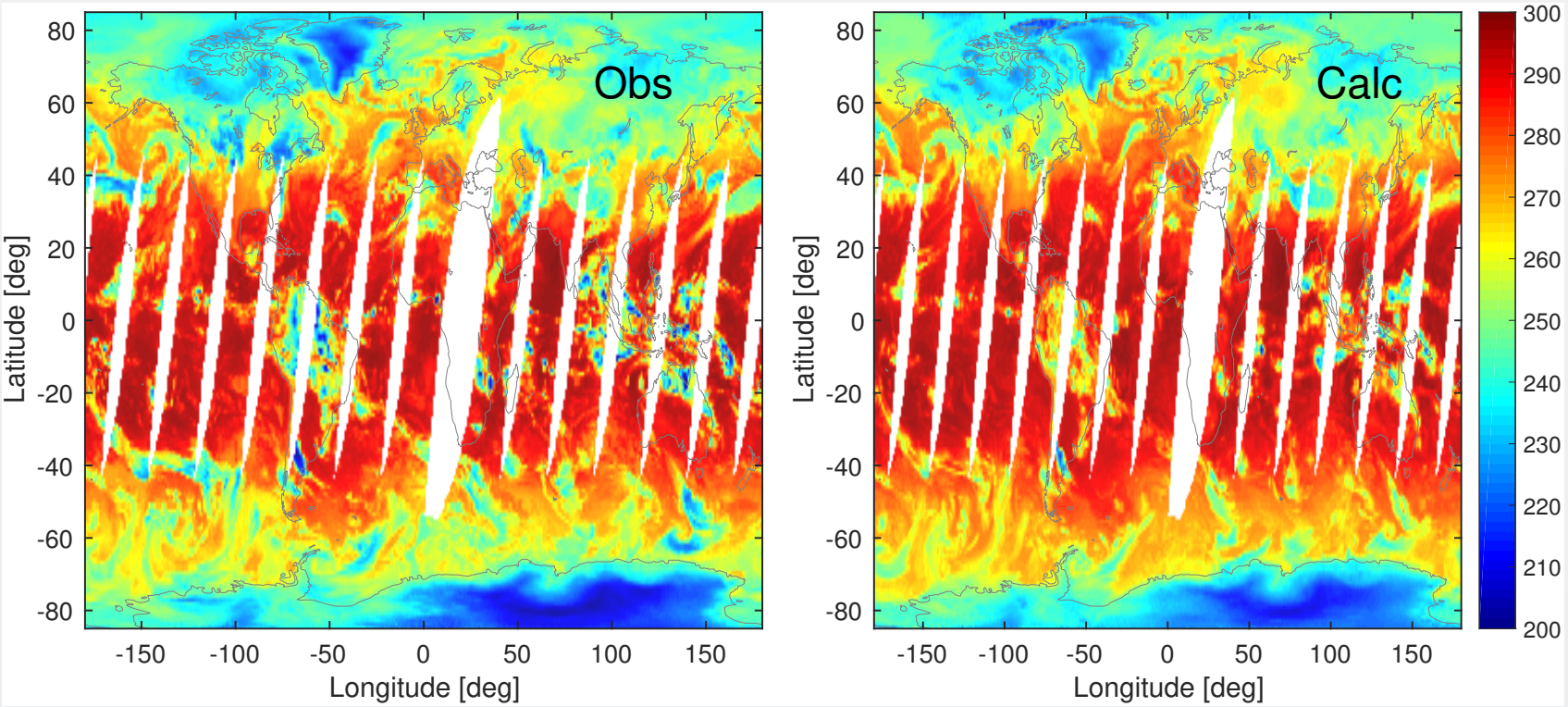
ECMWF 91 to SARTA 2 layer cloud conversion



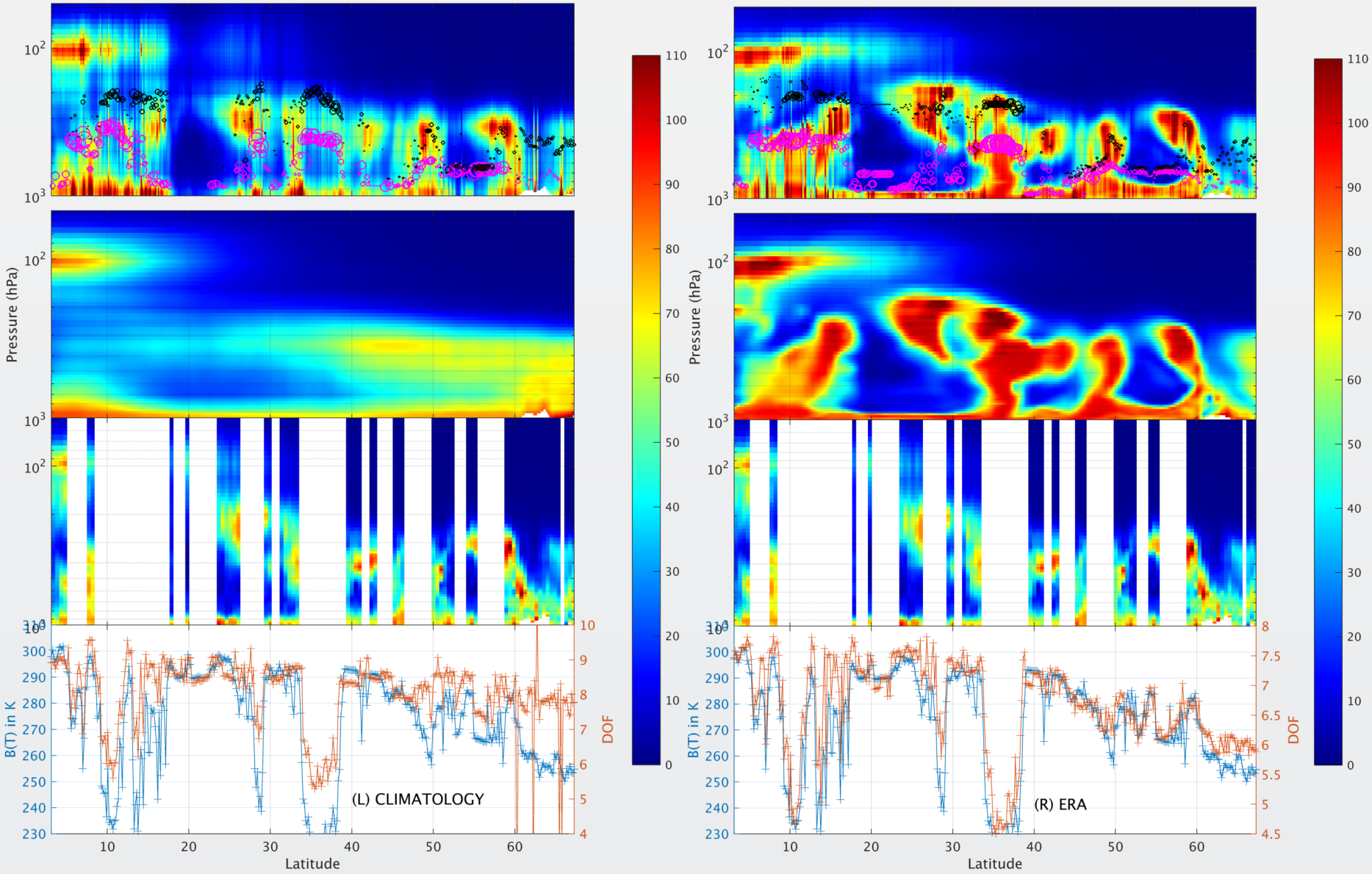
Comparison to PCRTM (with Statistical Cloud Overlap)



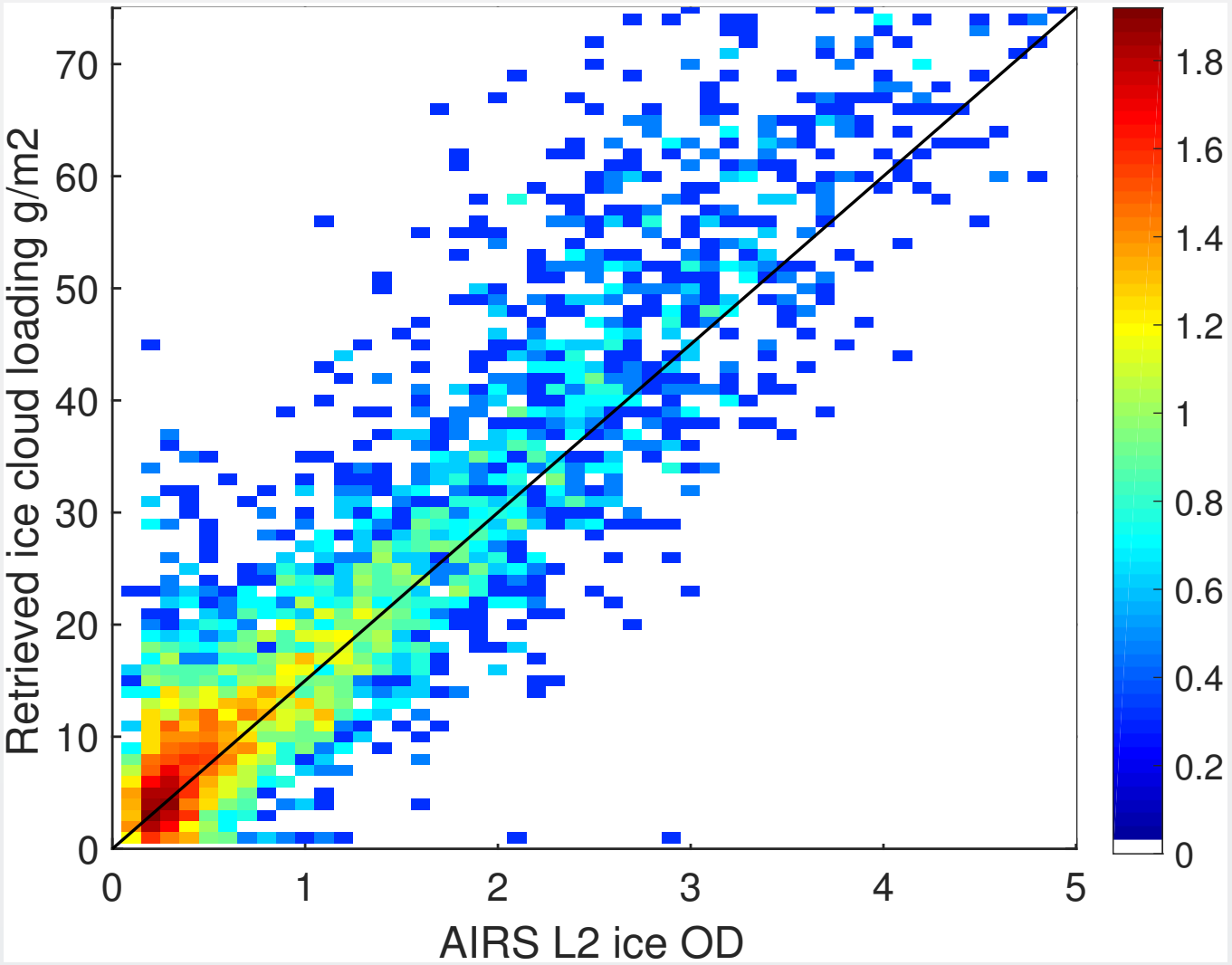
Global Simulation from ERA



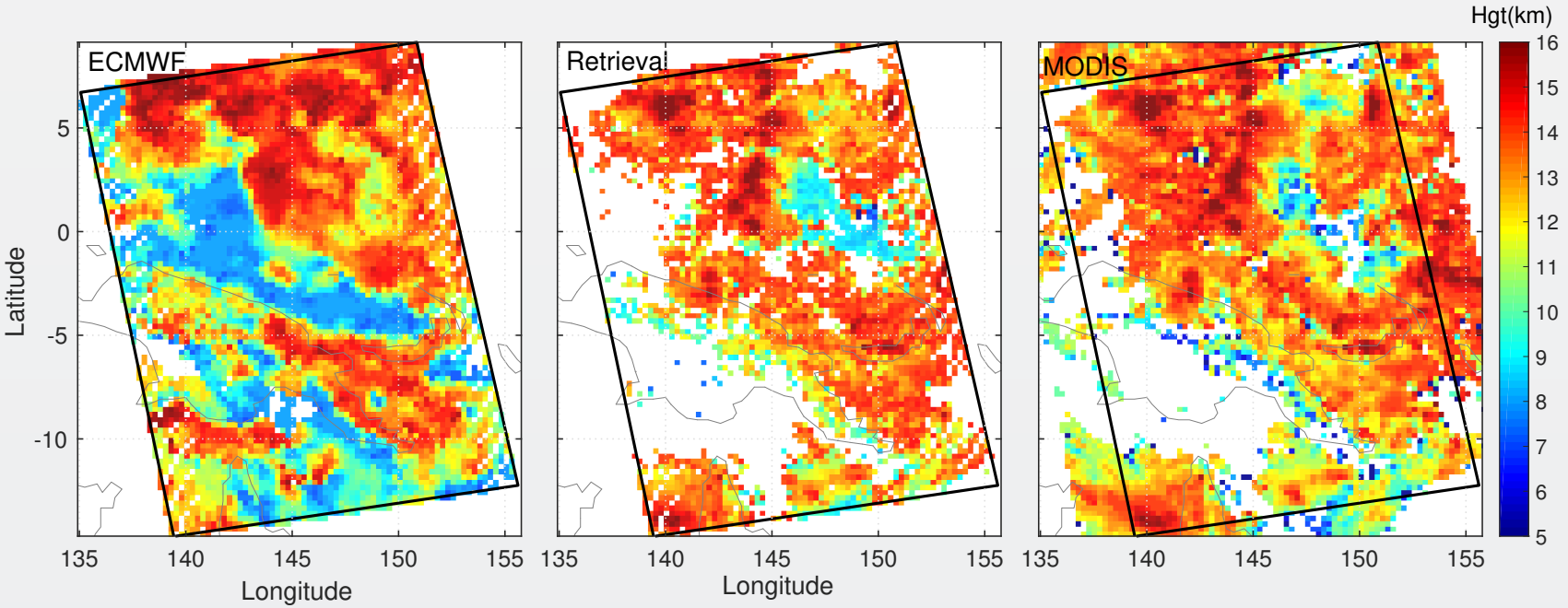
Retrieval Sample: RH for Atmospheric River



Cirrus Cloud Optical Depth Comparisons with AIRS



Cloud Top Height Comparisons with MODIS



What are NUCAPS trace gas products good for?



Nadia Smith*

In collaboration with

JPSS NUCAPS team and PGRR initiatives

(addressing the white elephant in the room)

* STC SCIENCE & TECHNOLOGY CORP.

O_3 CH_4 N_2O CO HNO_3 CO_2 SO_2

Who uses NUCAPS trace gas products operationally?

Do you know anyone who makes (or has made) a real-world decision with information provided by NUCAPS trace gas products?

(…crickets…)

Why not?

What are the NUCAPS trace gas products?

By-products of physical retrieval system:

(1) …to stabilize T/q retrievals

(2) …to enable full connectivity between EDR + SDR for quality monitoring

(3) …to enable air chemistry applications from weather satellite systems

O_3 CH_4 N_2O CO HNO_3 CO_2 SO_2

What is the baseline? Where are we at, exactly?

(1) NUCAPS trace gas validation (NOAA/STAR)

- Operational requirements

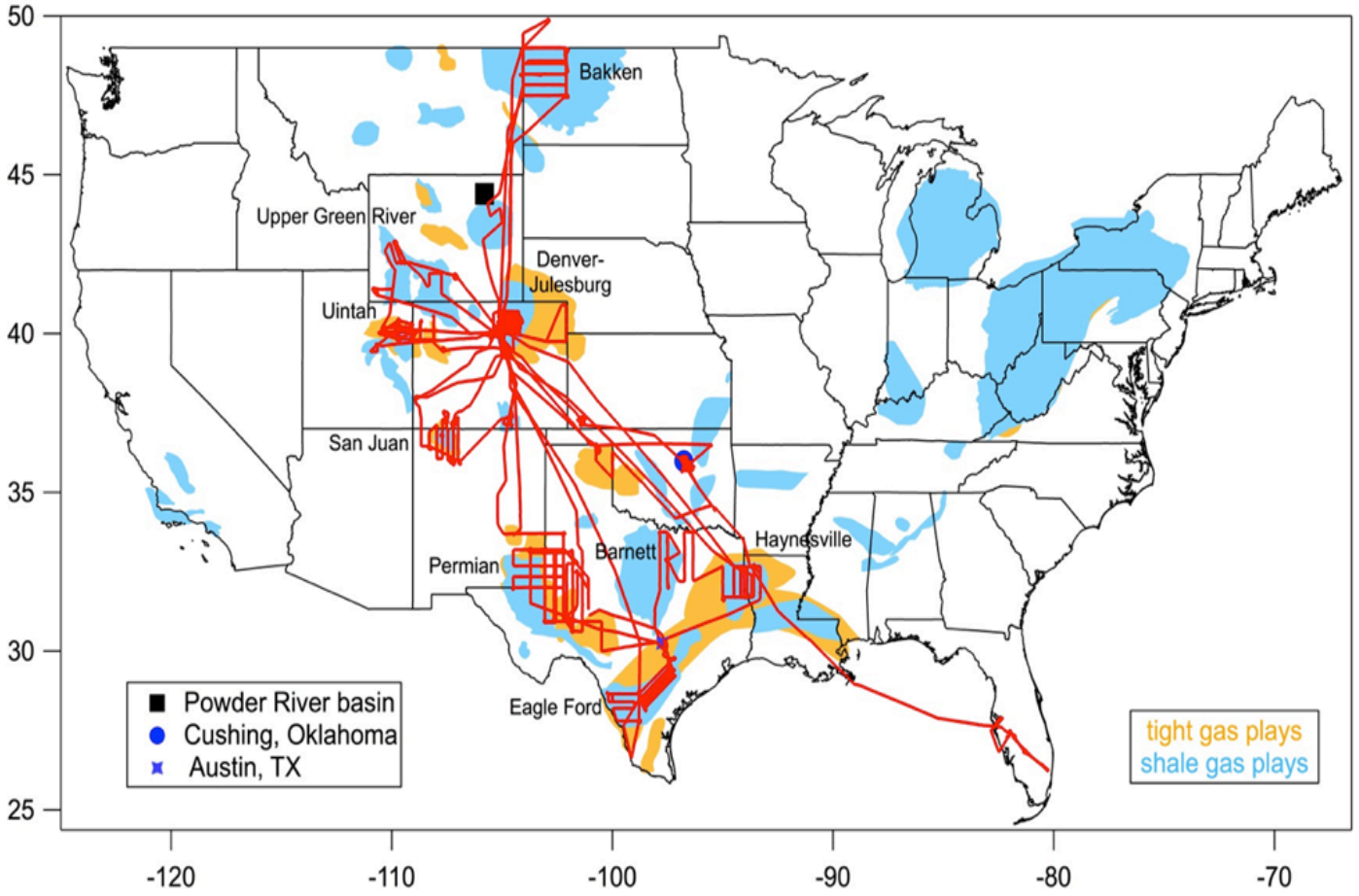
(2) NUCAPS trace gas evaluation (NOAA/JPSS PGRR initiatives)

- Suitability for real-world applications
- Creative exploration in strong, productive, multi-agency partnerships (NOAA/ESRL, NOAA/STAR, UW/SSEC; CSPP; STC, etc.)

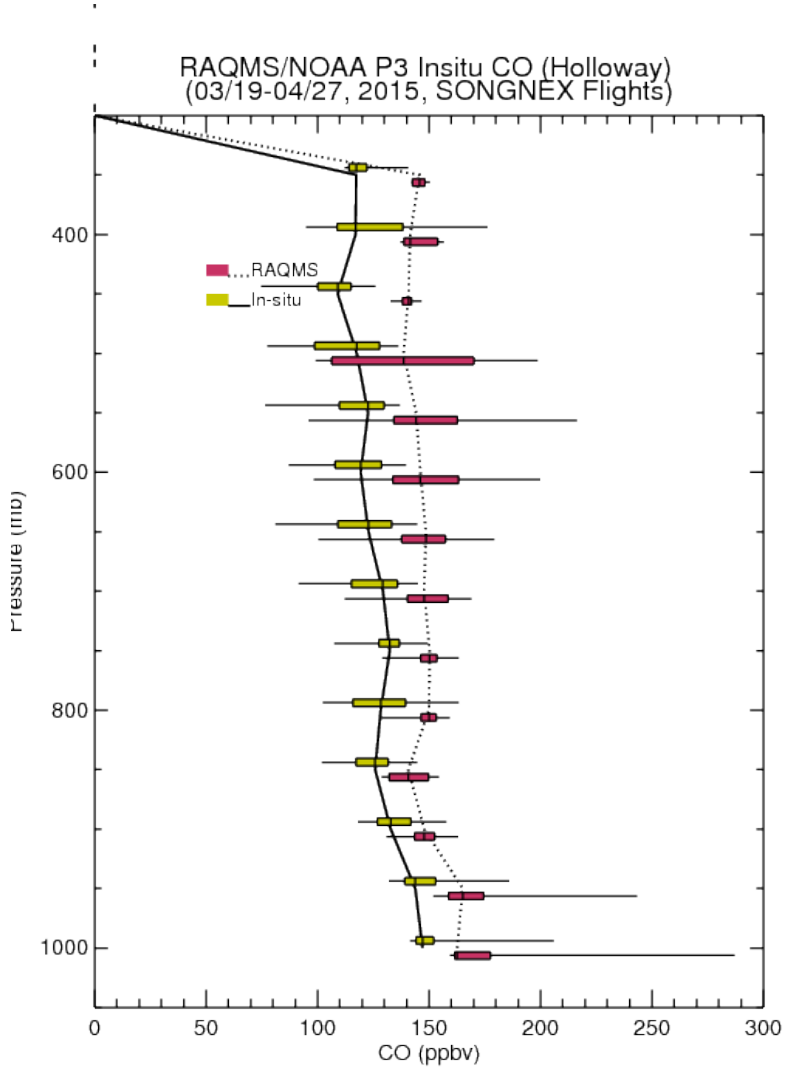
NOAA PGRR – Sounding and Fire+Smoke Initiatives

JPSS Proving Ground/Risk Reduction (PGRR) project is a collaborative effort combining expertise in satellite retrieval development (STC), airborne trace gas measurements (ESRL/CIRES), and satellite trace gas validation (STAR/CIMSS) to characterize NUCAPS retrieval quality, with the goal of improving the accuracy of the NUCAPS daily global measurements of methane (CH4) and carbon monoxide (CO).

2014 NOAA CrIS Atmospheric Chemistry Data User's Workshop Report (http://docs.lib.noaa.gov/noaa_documents/OAR/CPO/AC4/CrIS_workshop_2014.pdf) which concluded "*that the current state of validation of the NUCAPS trace gas retrievals is insufficient for the use of these retrievals in most atmospheric chemistry applications*" and recommended that the "*CrIS retrieval development community should closely coordinate with the project teams of upcoming field campaigns (aircraft, surface, balloon, etc.) on trace gas validation activities*".



NOAA P-3 aircraft flight paths over the western US during the **SONGNEX field campaign**, March-April, **2015**.



Comparisons between RAQMS and in situ CO measurements during SONGNEX show that RAQMS has a mean high bias of 29ppbv above 700mb and tends to overestimate the observed mid tropospheric variability

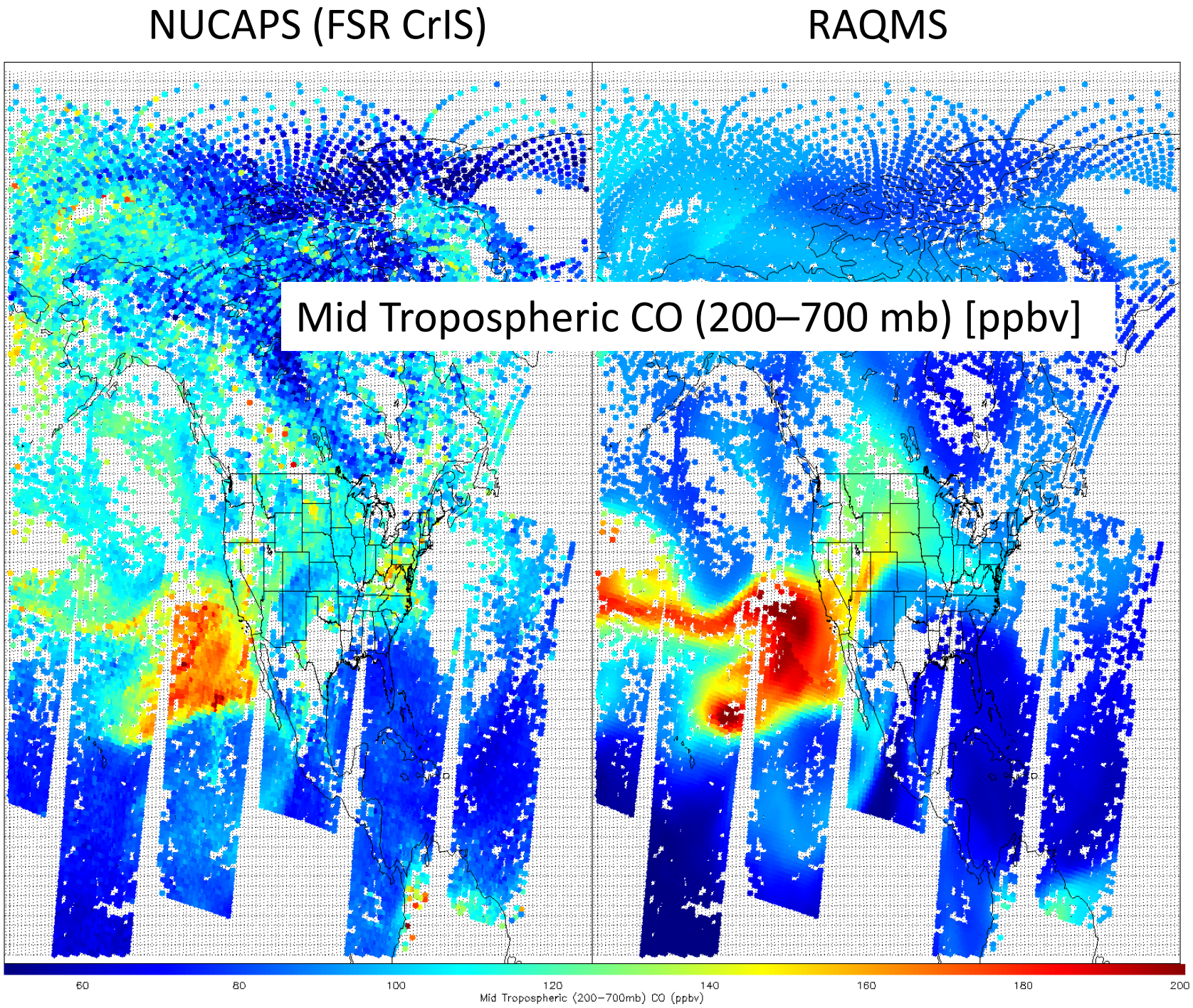
Brad Pierce (NOAA/STAR); Greg Frost (NOAA/ESRL)

Comparisons between bias corrected RAQMS and NUCAPS mid tropospheric CO suggests that NUCAPS has a 6.8 ppbv high bias relative to the in situ aircraft measurements

In **2016** CSPP NUCAPS supported a field campaign in real-time (**ENRR**) for the first time.

Building on lessons learned, CSPP NUCAPS will support **FIREX** in **2018/2019**

Brad Pierce (NOAA/STAR)



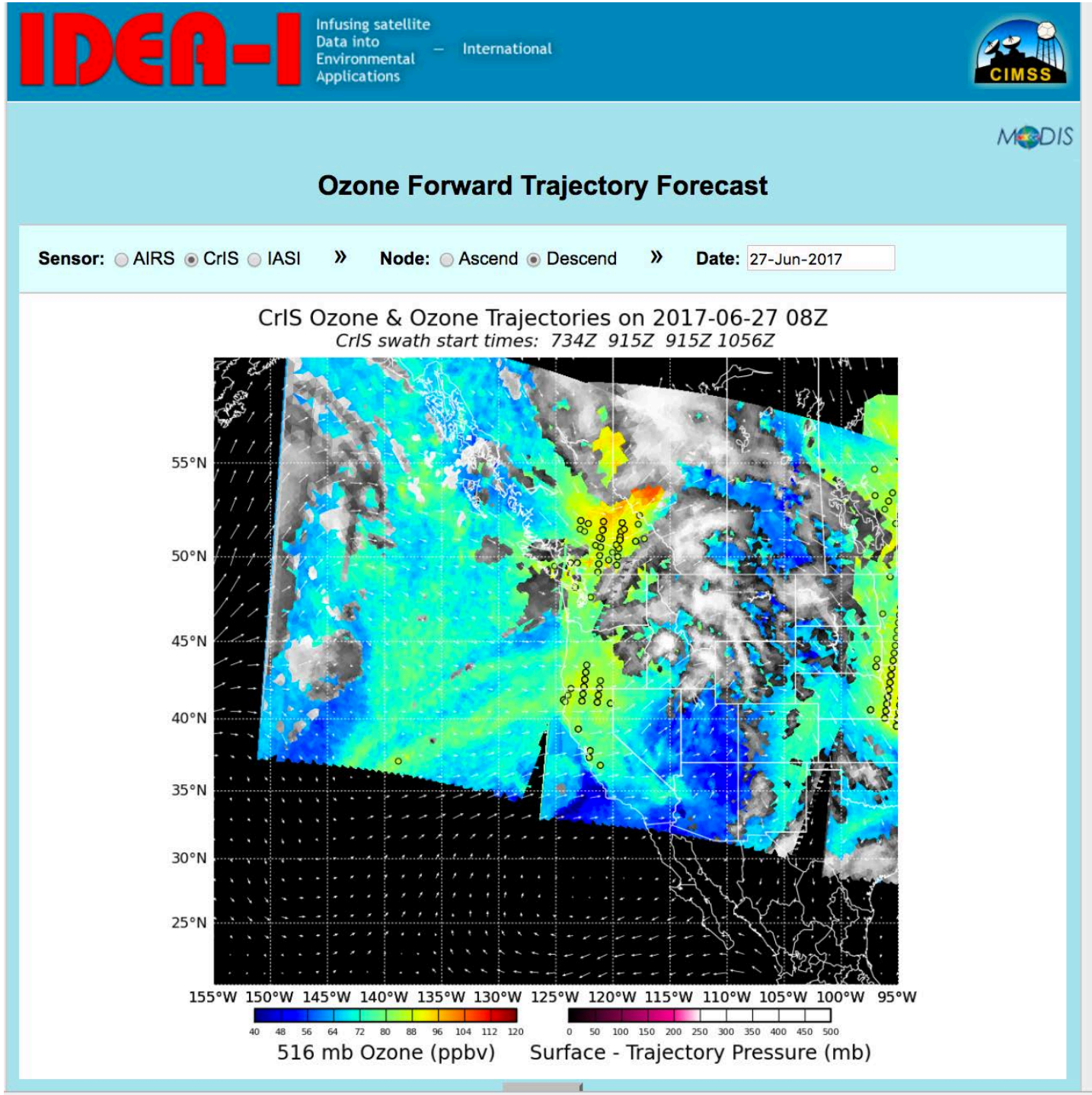
CSPP NUCAPS in IMAPP application

http://cimss.ssec.wisc.edu/idea-i/USozone/

Real-time stratospheric intrusion forecasts

The background basemap is the daily AIRS, IASI, or CrIS Dual Regression (CSPP HSRTV) Ozone retrievals at 516mb, which is used in conjunction with Dual Regression dewpoint temperature retrievals to initialize trajectories which show where the stratospheric intrusion (high ozone/dry air) is expected to move in the next ~48 hours. The products are derived from AIRS, IASI and CrIS data acquired and processed directly from the Terra, METEOP-A, and SNPP satellites, respectively

As soon as CrIS FSR SDR is available in CSPP we will ingest NUCAPS CO retrieval in IDEA-I to initialize smoke dispersion forecasts

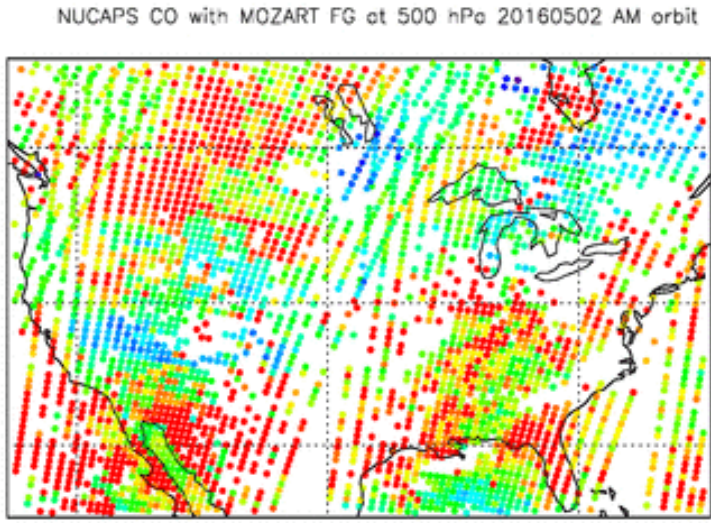


Brad Pierce (NOAA/STAR)

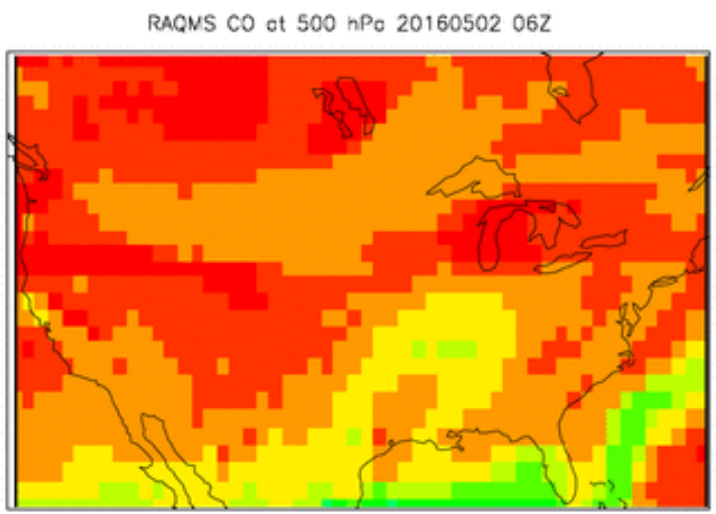
User-Developer partnership helps evaluate FSR NUCAPS CO ahead of operational deployment

Ft. McMurray Fire; 1-16 May 2016: NUCAPS CO vs RAQMS

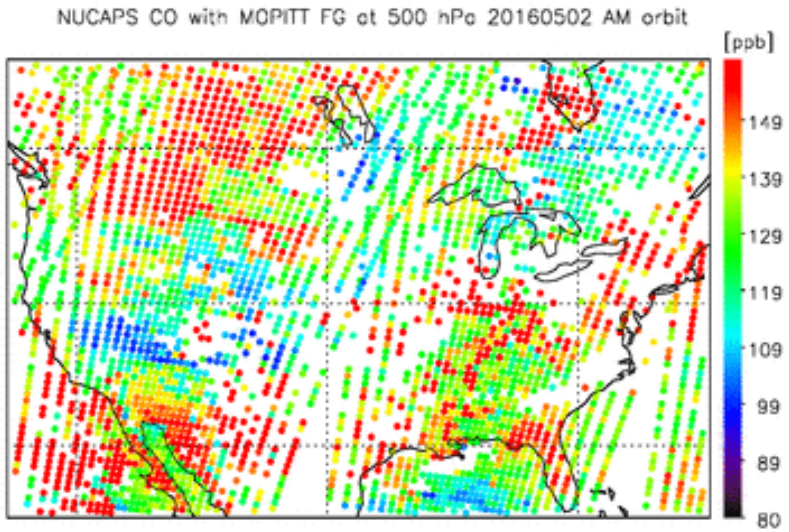
FSR NUCAPS with MOZART FG



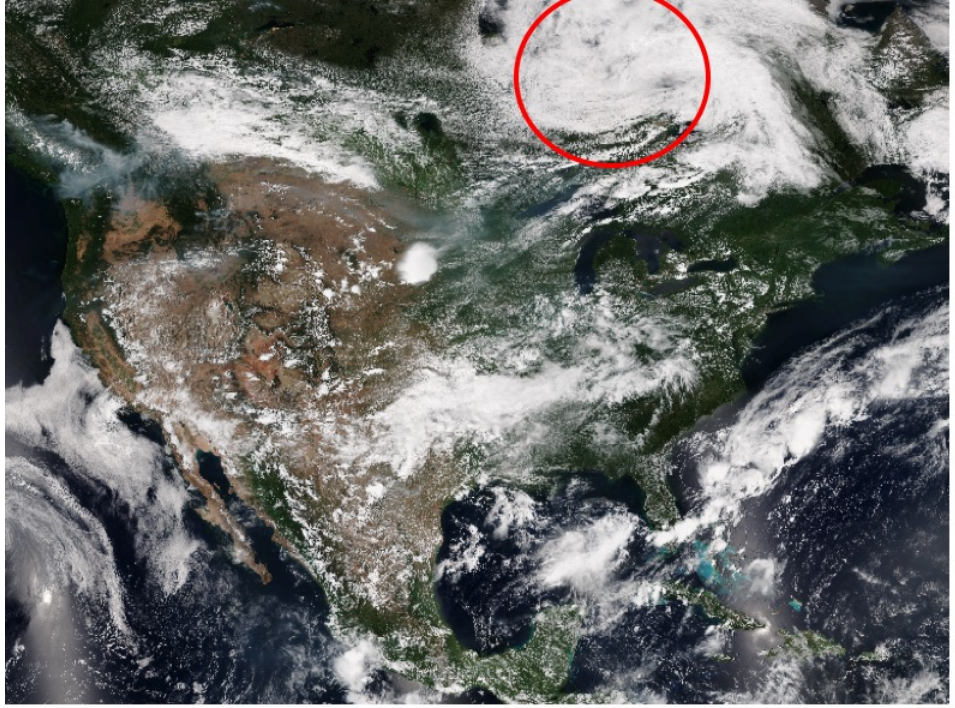
RAQMS CO MR @ 500 hPa

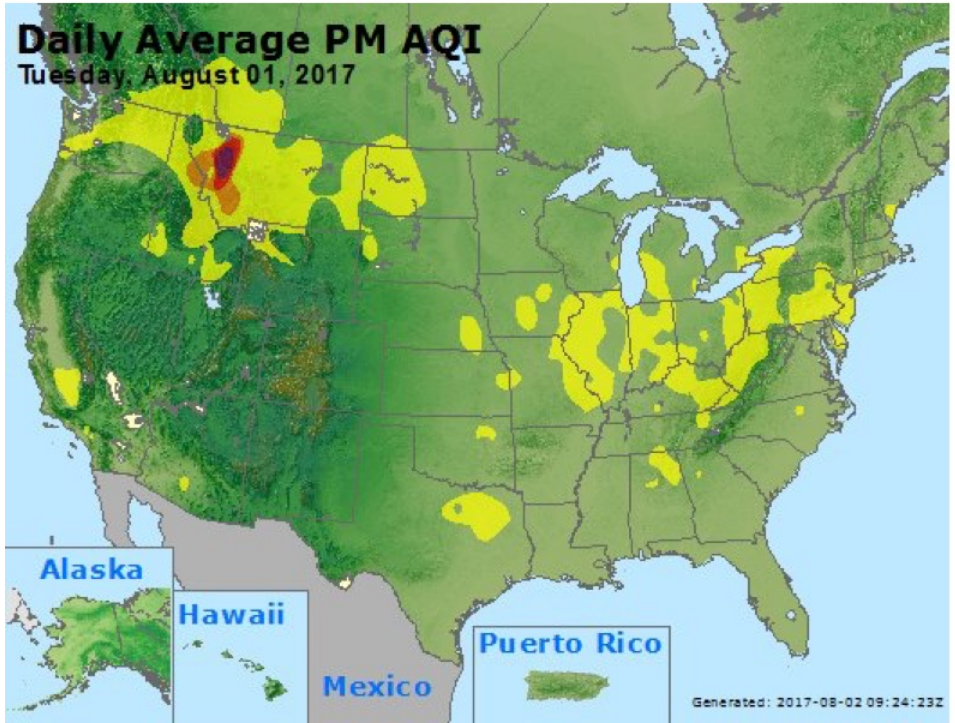


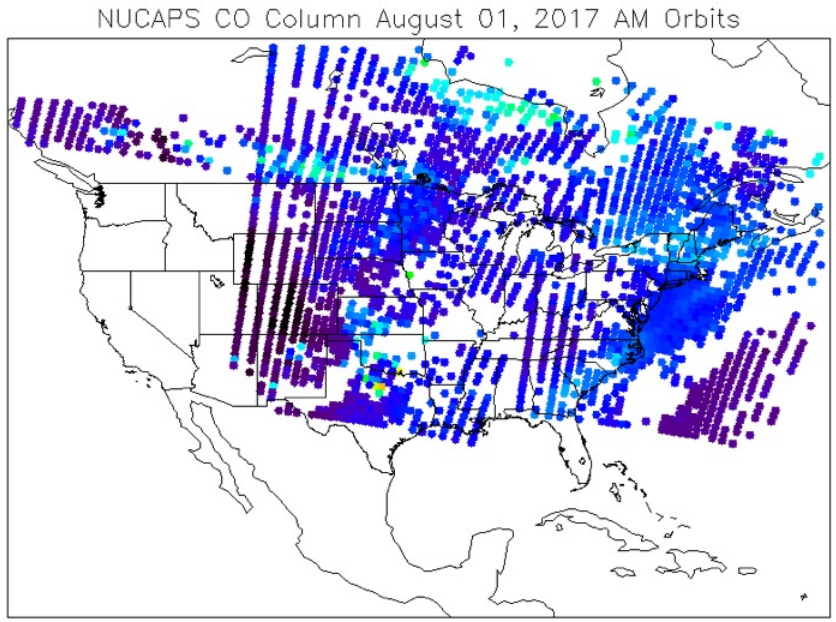
FSR NUCAPS with MOPITT FG

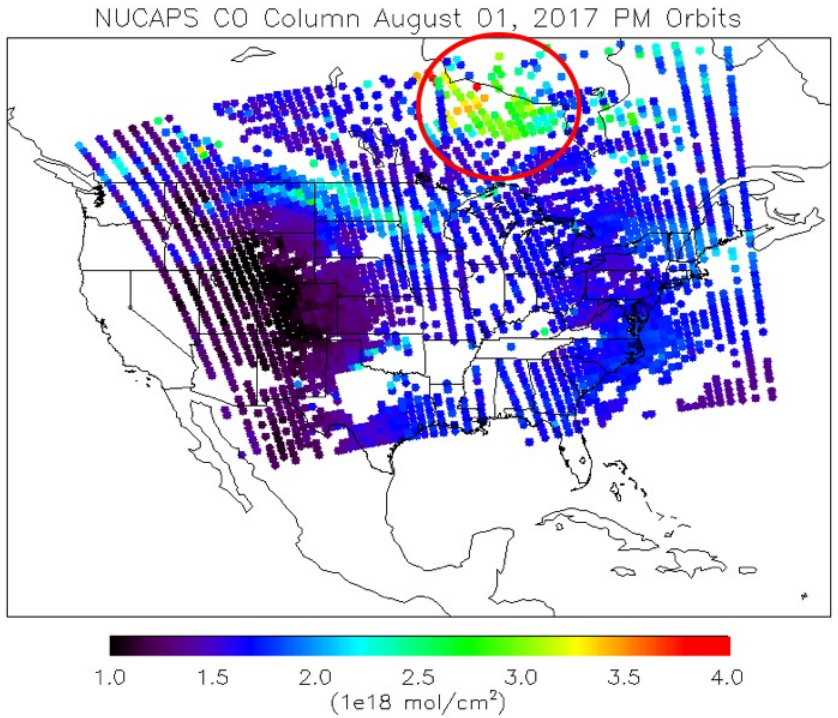


Brad Pierce 6 April 2017: ”Since we have aircraft measurements in the SH with ATom, it might be interesting to compare all three first guess retrievals during the Atom flights.”

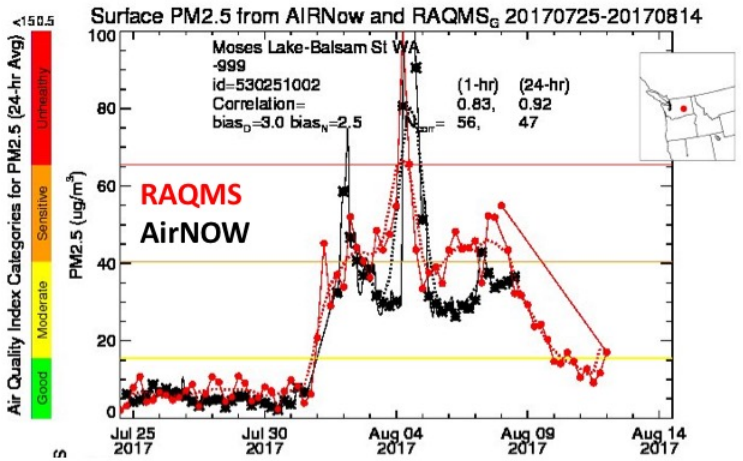


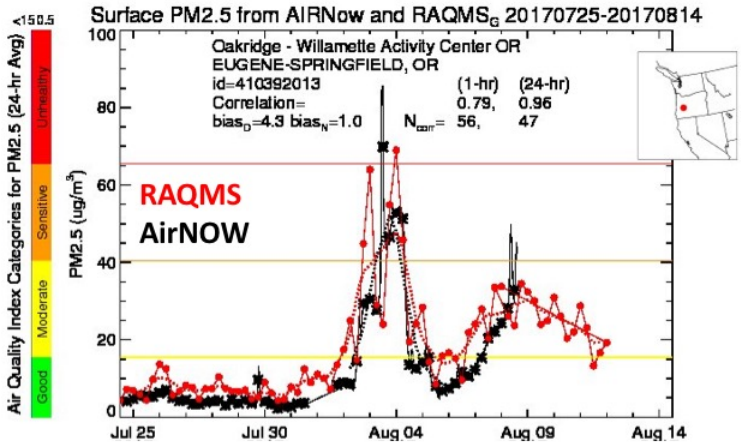


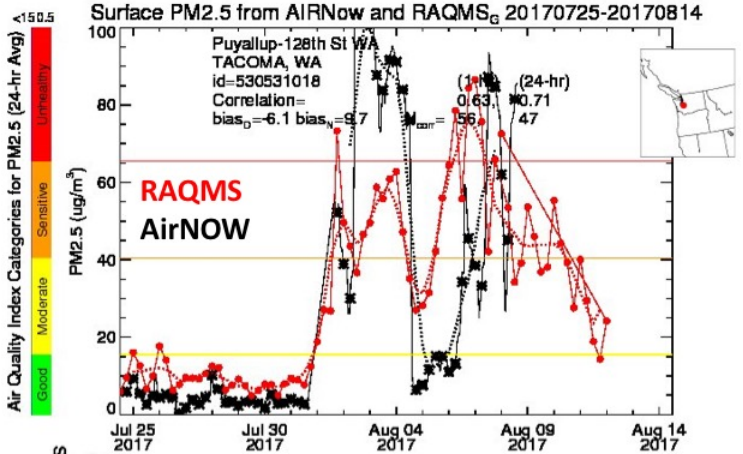




Brad Pierce
(NOAA/STAR)

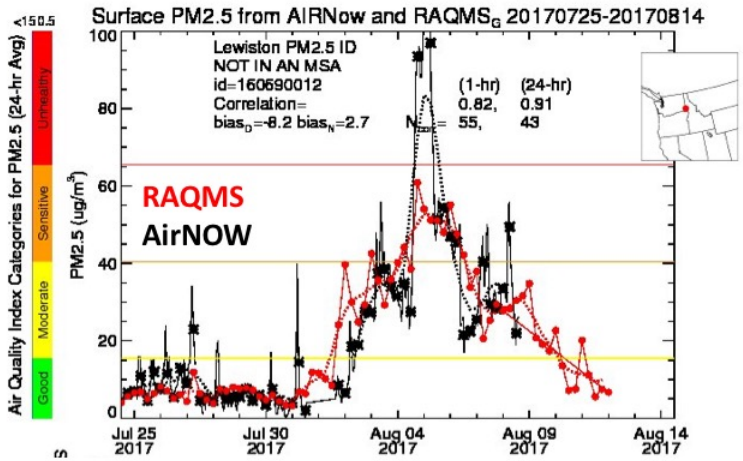


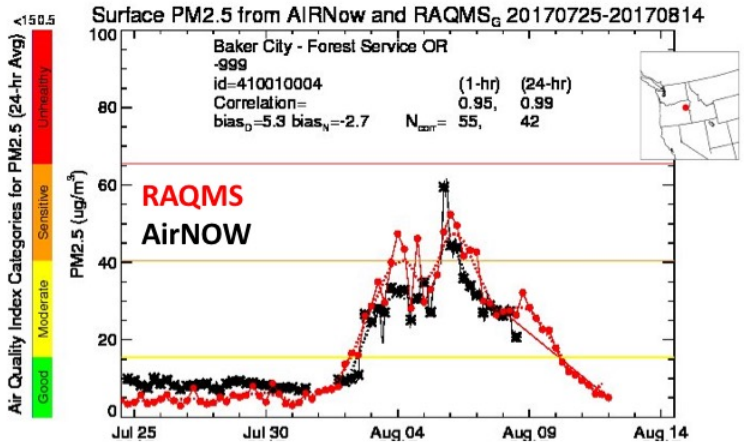


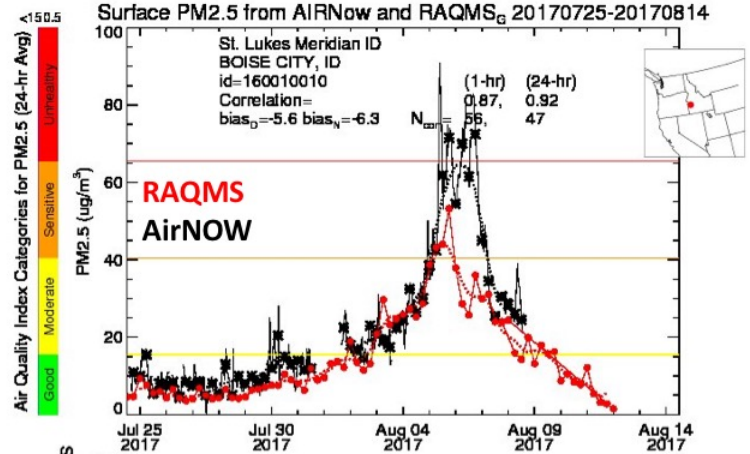


The Real-time Air Quality Modeling System (RAQMS) aerosol analysis captures the timing and magnitude of the surface smoke over the Pacific Northwest during the July 25-August 8, 2017 period.

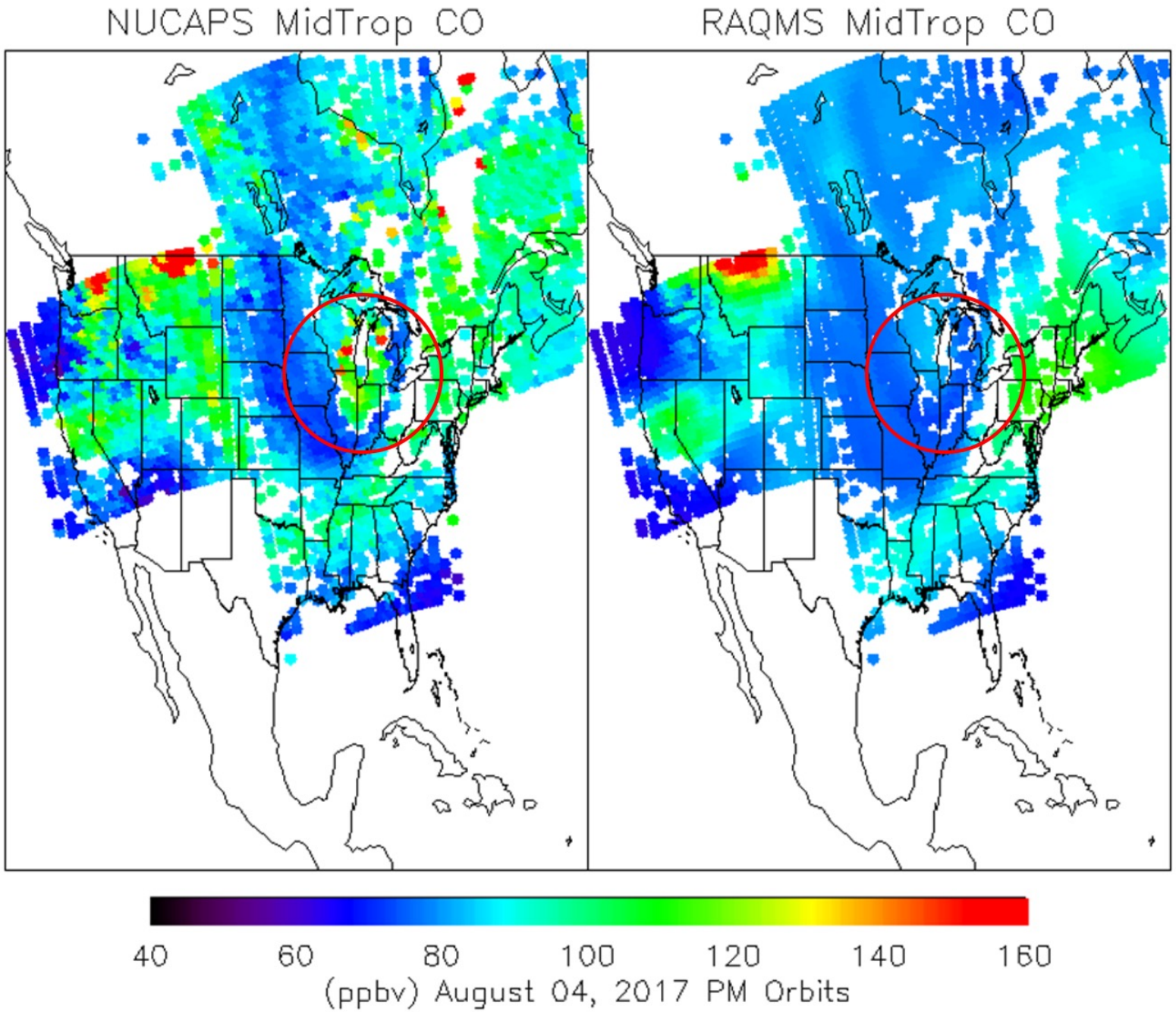
Comparisons between RAQMS and NUCAPS CO columns can be used to evaluate the NUCAPS CO retrieval







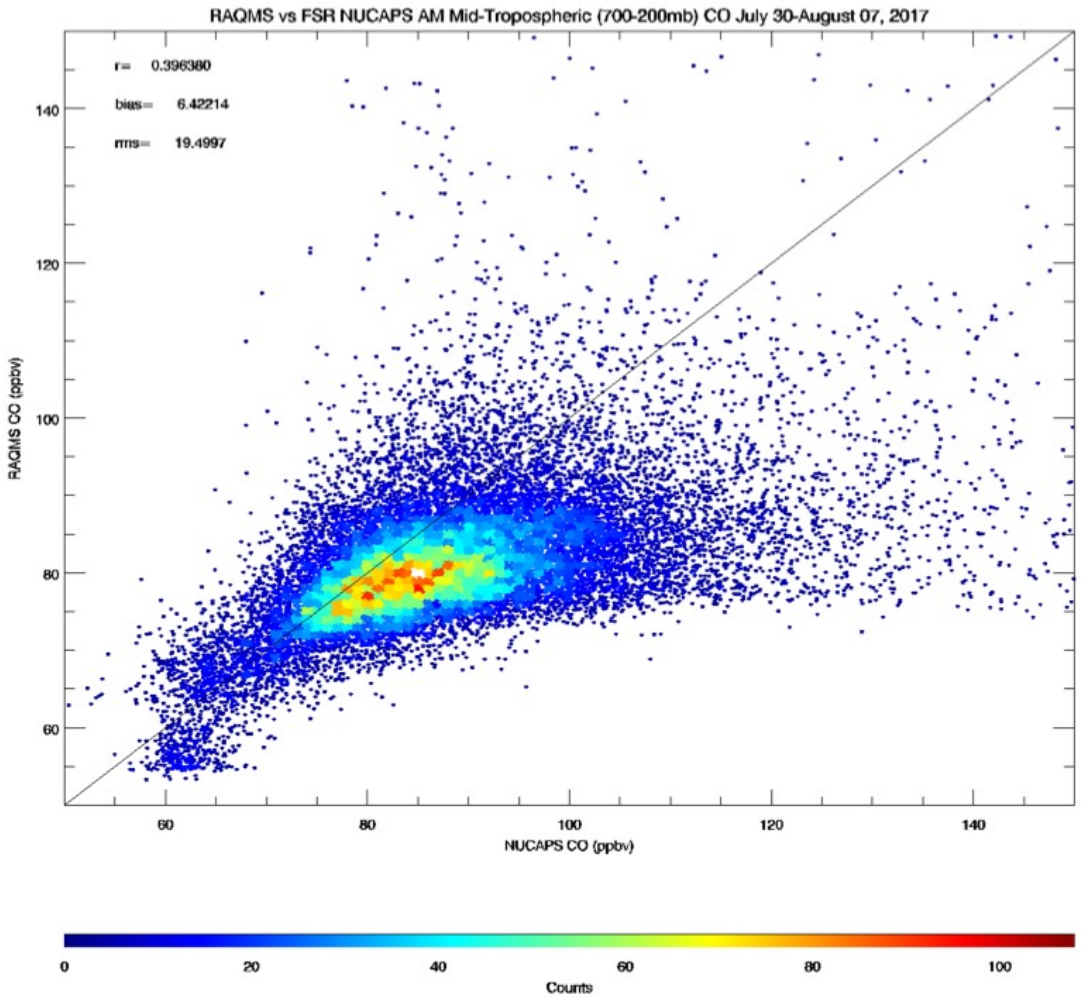
Brad Pierce
(NOAA/STAR)



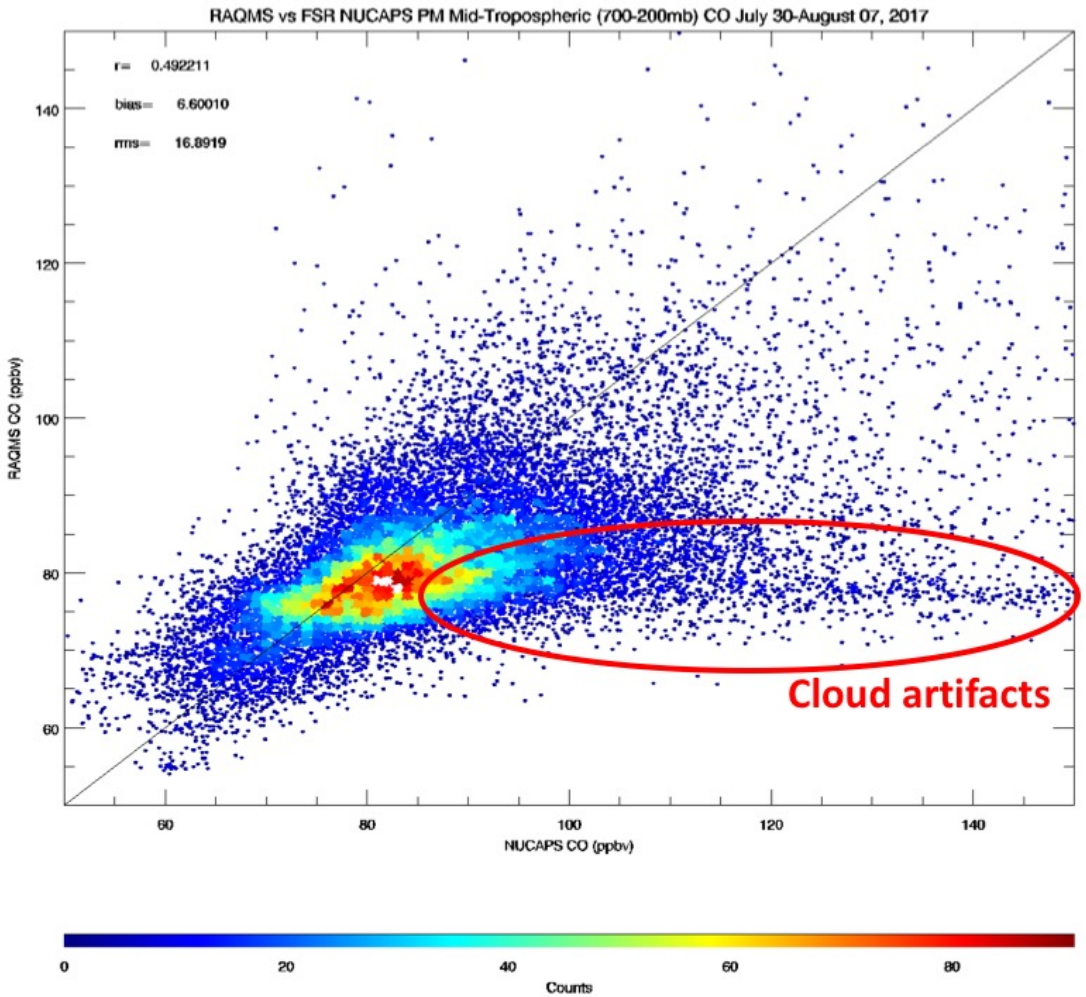
Brad Pierce
(NOAA/STAR)

RAQMS vs FSR NUCAPS Mid-Tropospheric CO

RAQMS vs NUCAPS mid-trop CO; Night time



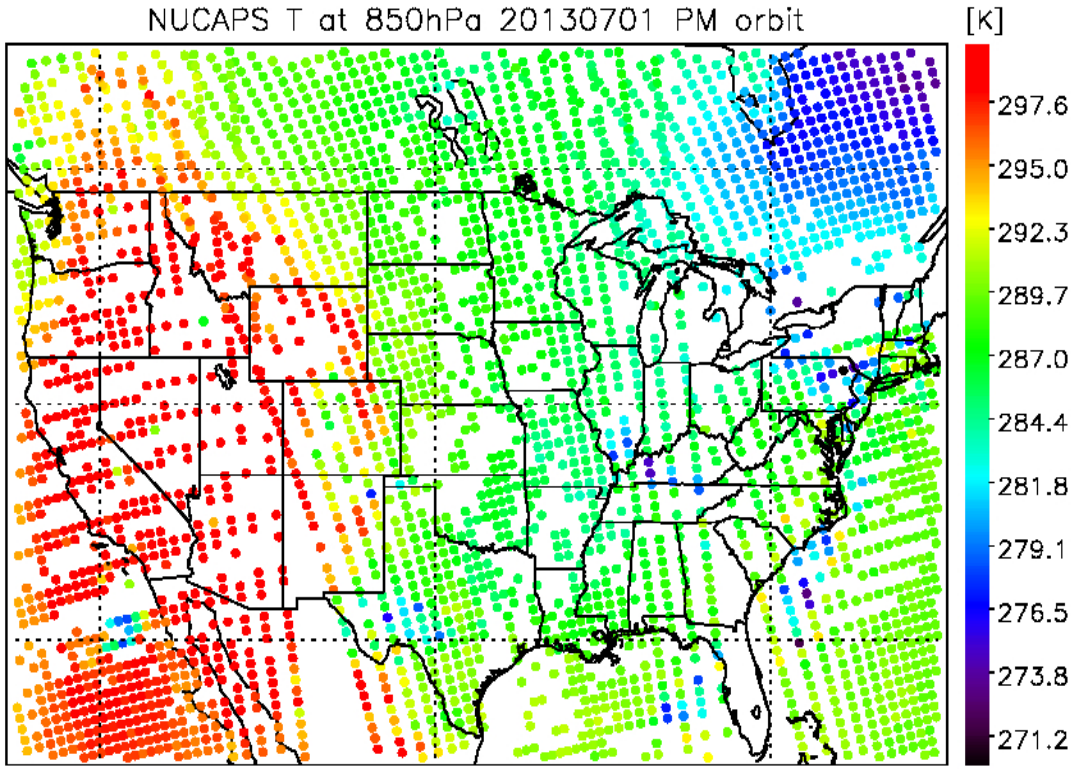
RAQMS vs NUCAPS mid-trop CO; Day time



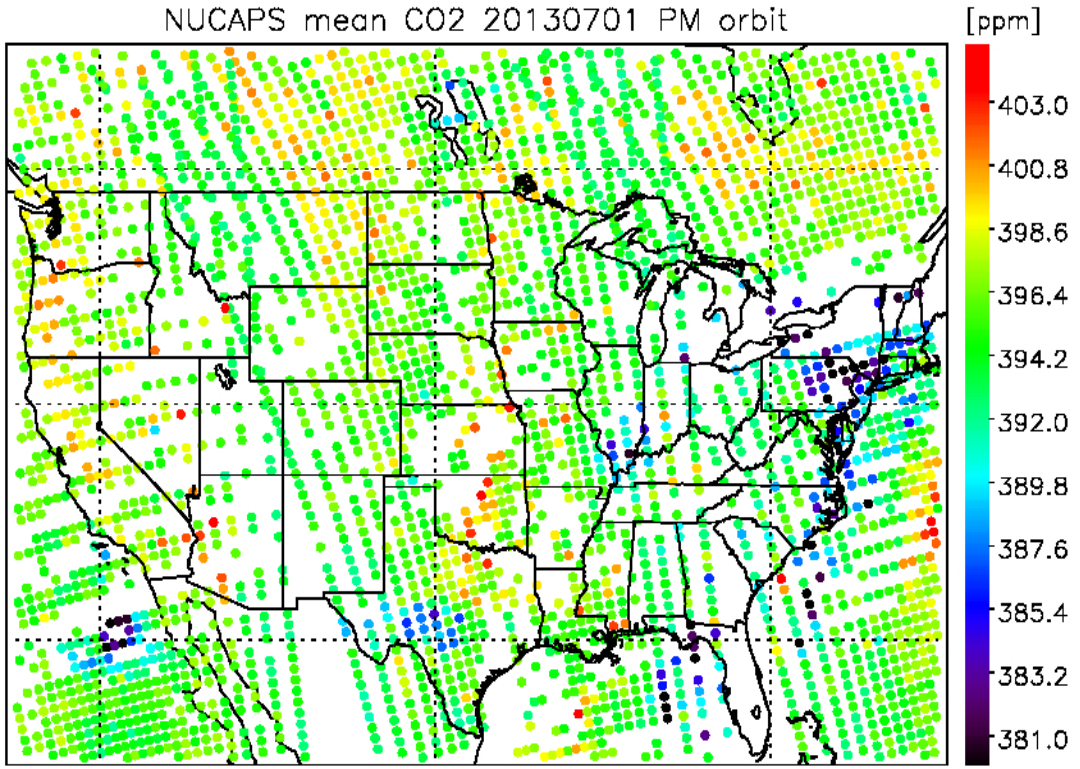
NUCAPS CO_2 helps determine T/q retrieval quality

Comparing NUCAPS Temperature with NUCAPS CO_2 highlight cloud contamination not filtered out by QC

Temperature @ 850 hPa



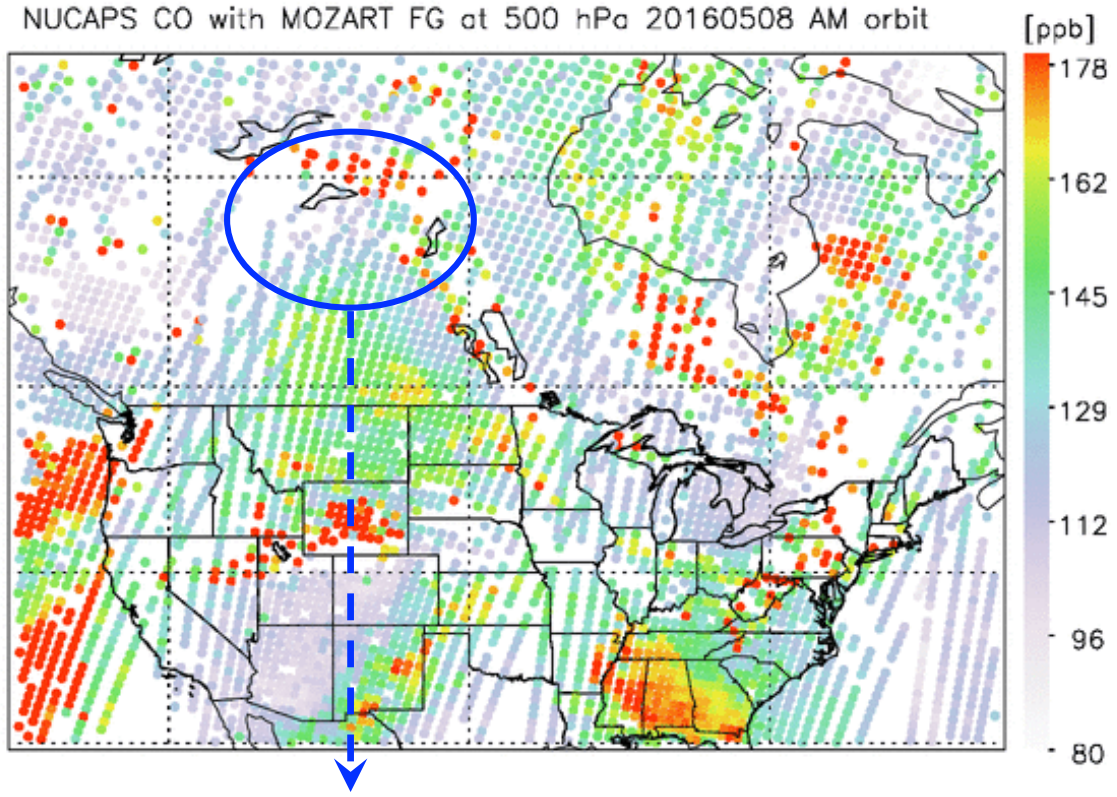
Column integrated CO2



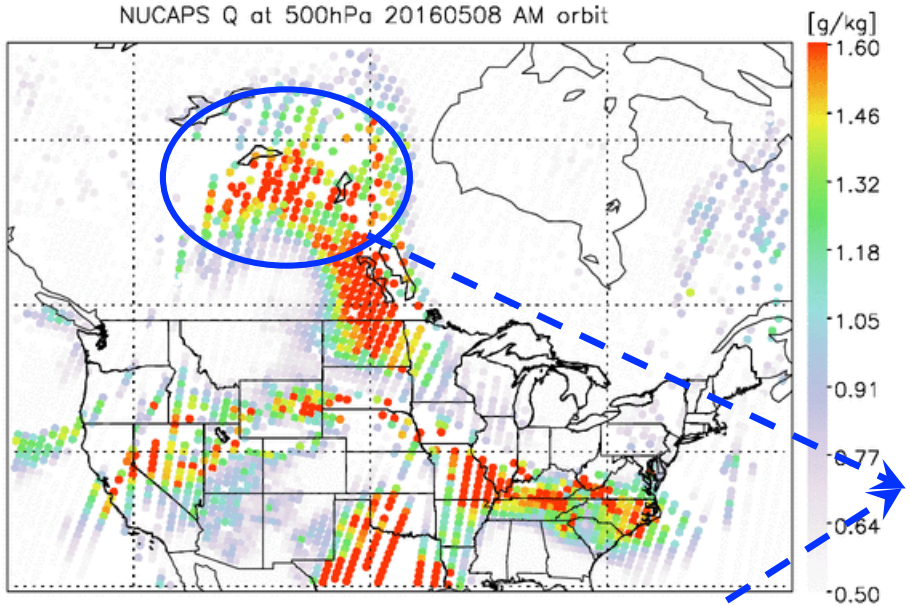
User-Developer partnership helps evaluate NUCAPS CO applications

investigating the presence of elevated H2O mixed layer due to large scale biomass burning

Carbon Monoxide [500hPa]

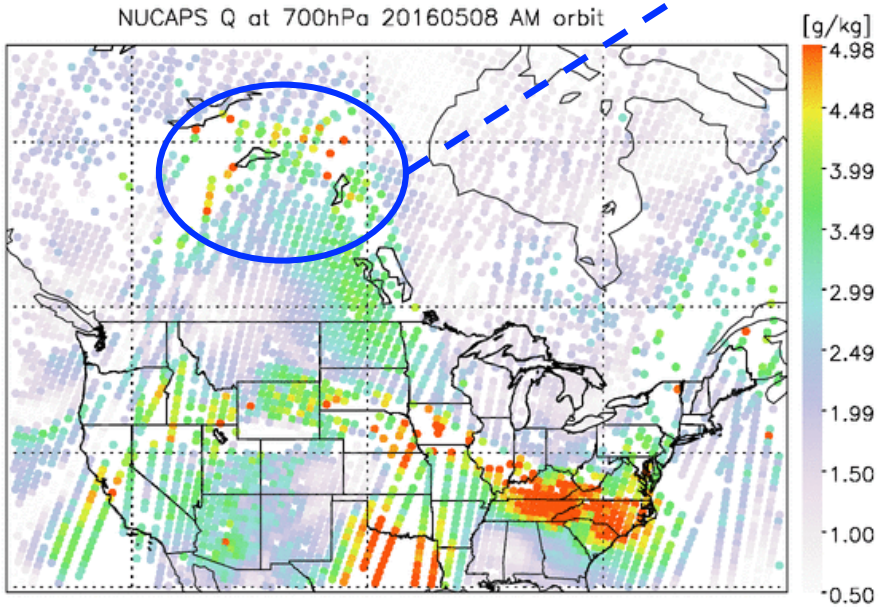


Ft McMurray Mega-Fire CO emissions



H2O Mixing Ratio [500hPa]

Elevated mixed layer due to megafire

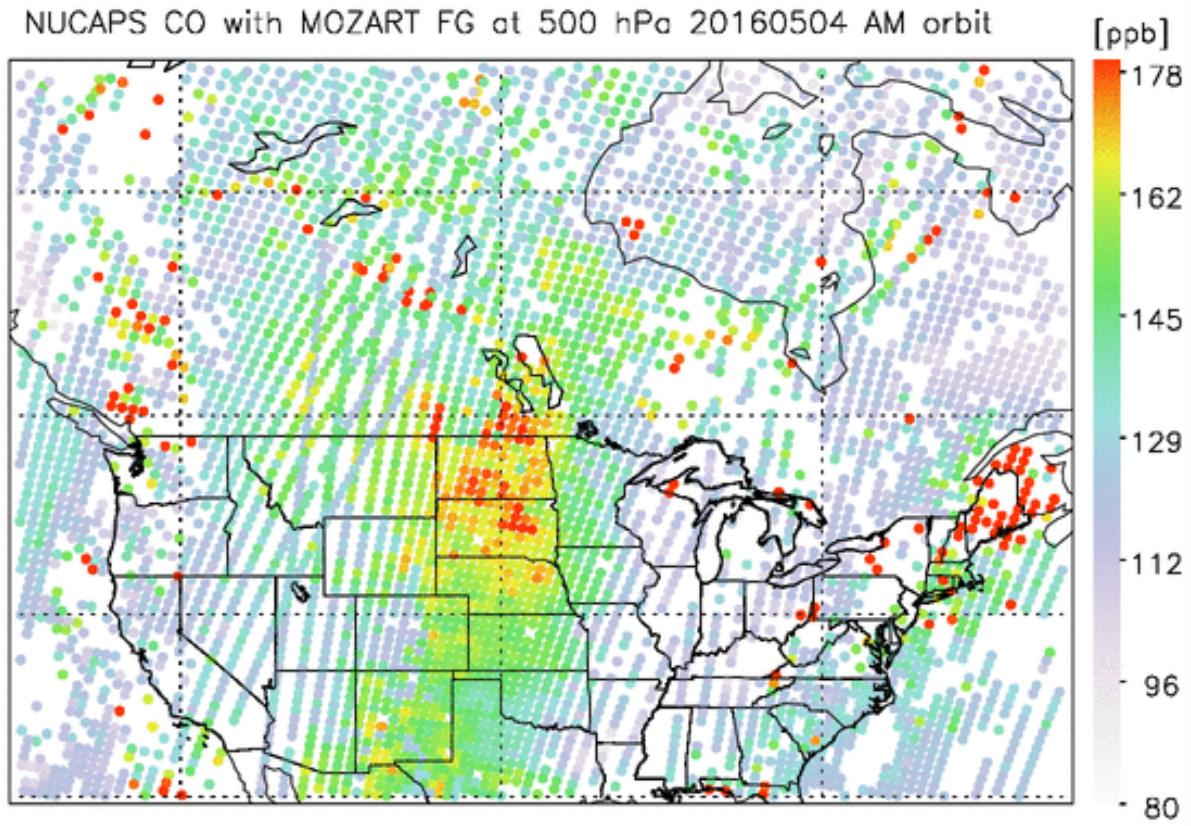


H2O Mixing Ratio [700hPa]

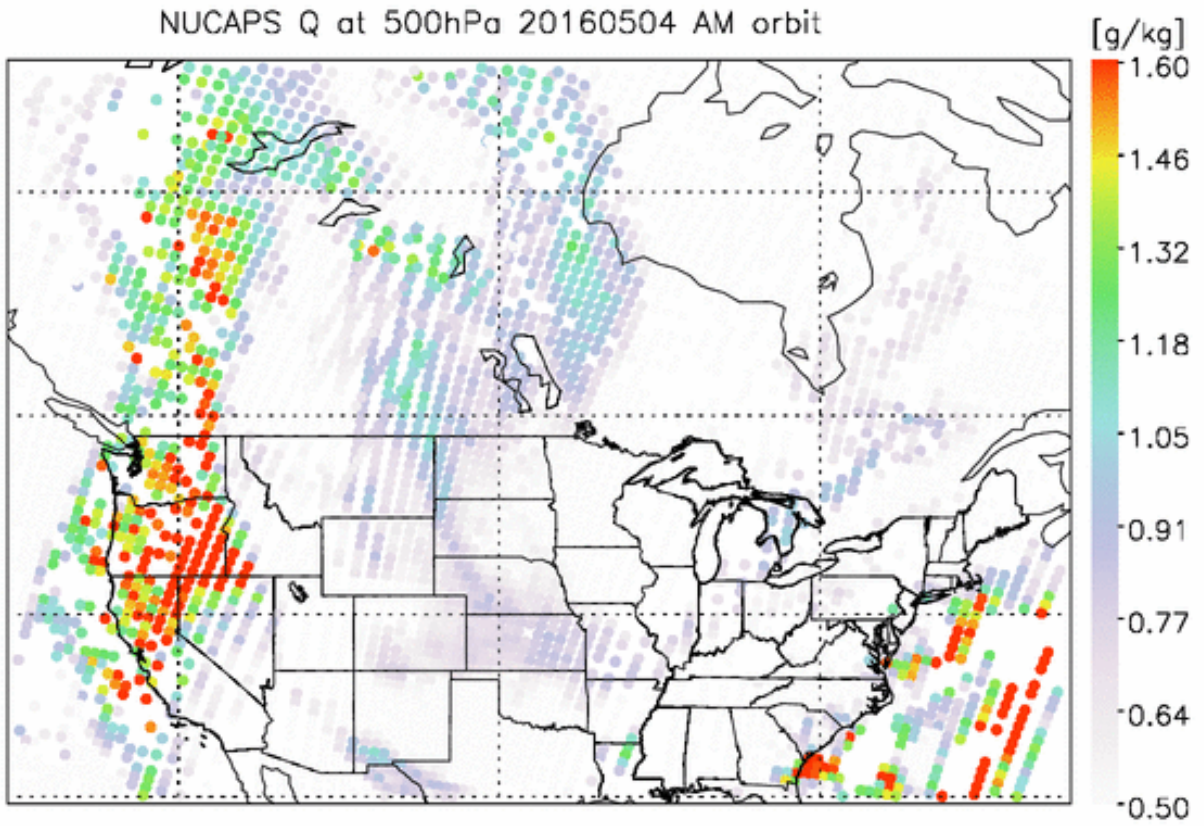
Nadia Smith

User-Developer partnership helps evaluate NUCAPS CO applications

Carbon Monoxide [500hPa]



H2O Mixing Ratio [500hPa]



With NUCAPS it is possible to investigate CO emissions as well as the change in moisture regime due to large scale burning

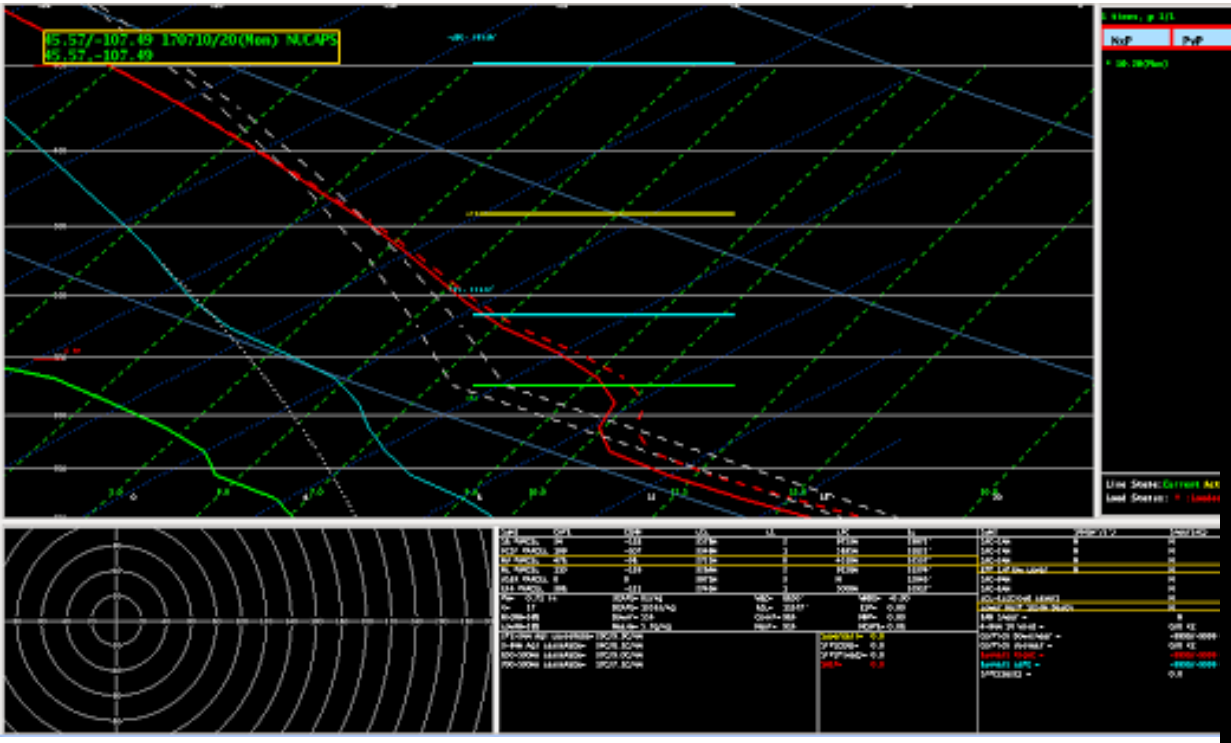
We have done (and continue to do) validation

We have determined that there is potential for strong applications

So what is next?

NUCAPS T/q used in AWIPS to monitor fire weather

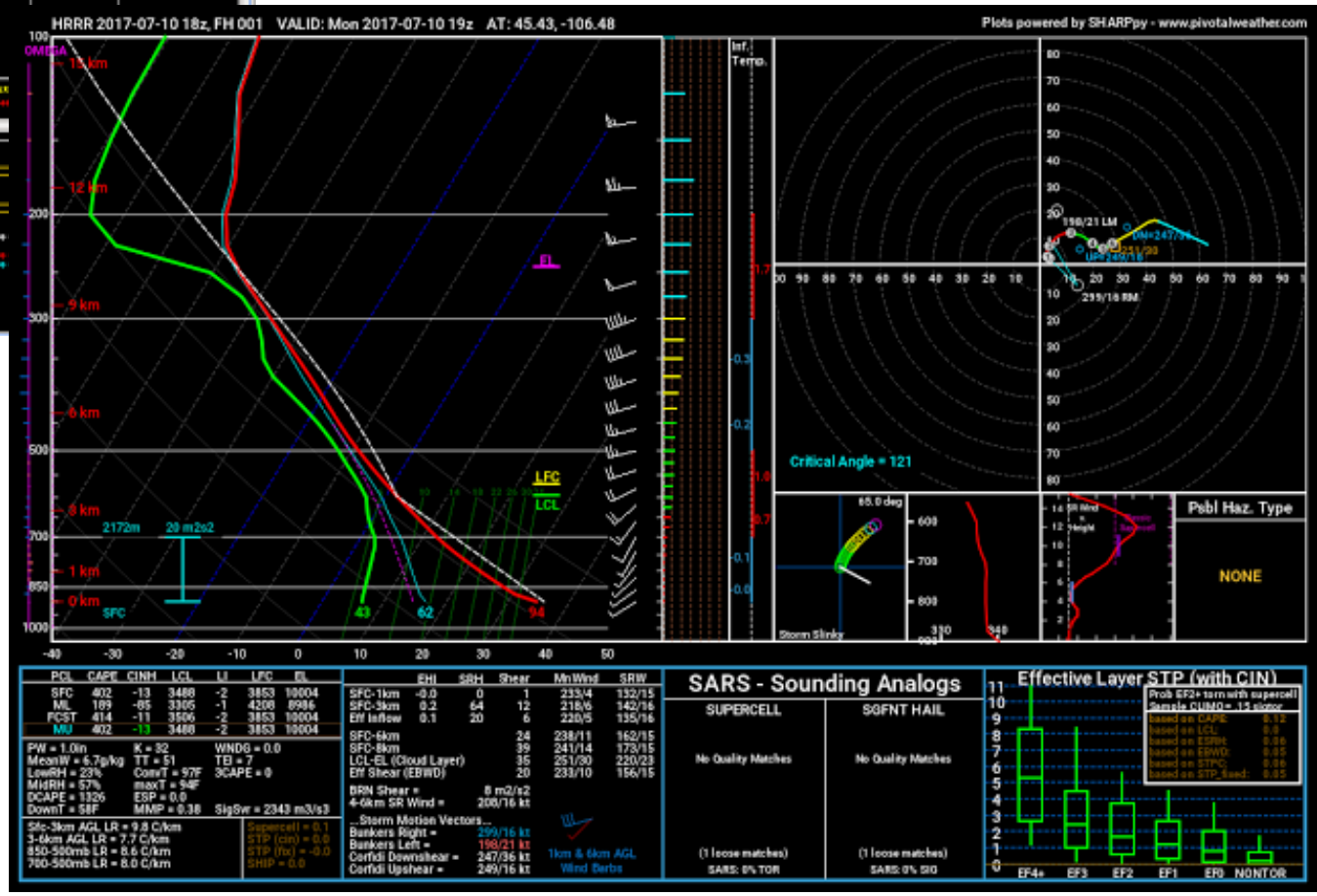
Slide by Michael Bowlen; HWT 2017



NUCAPS Sounding

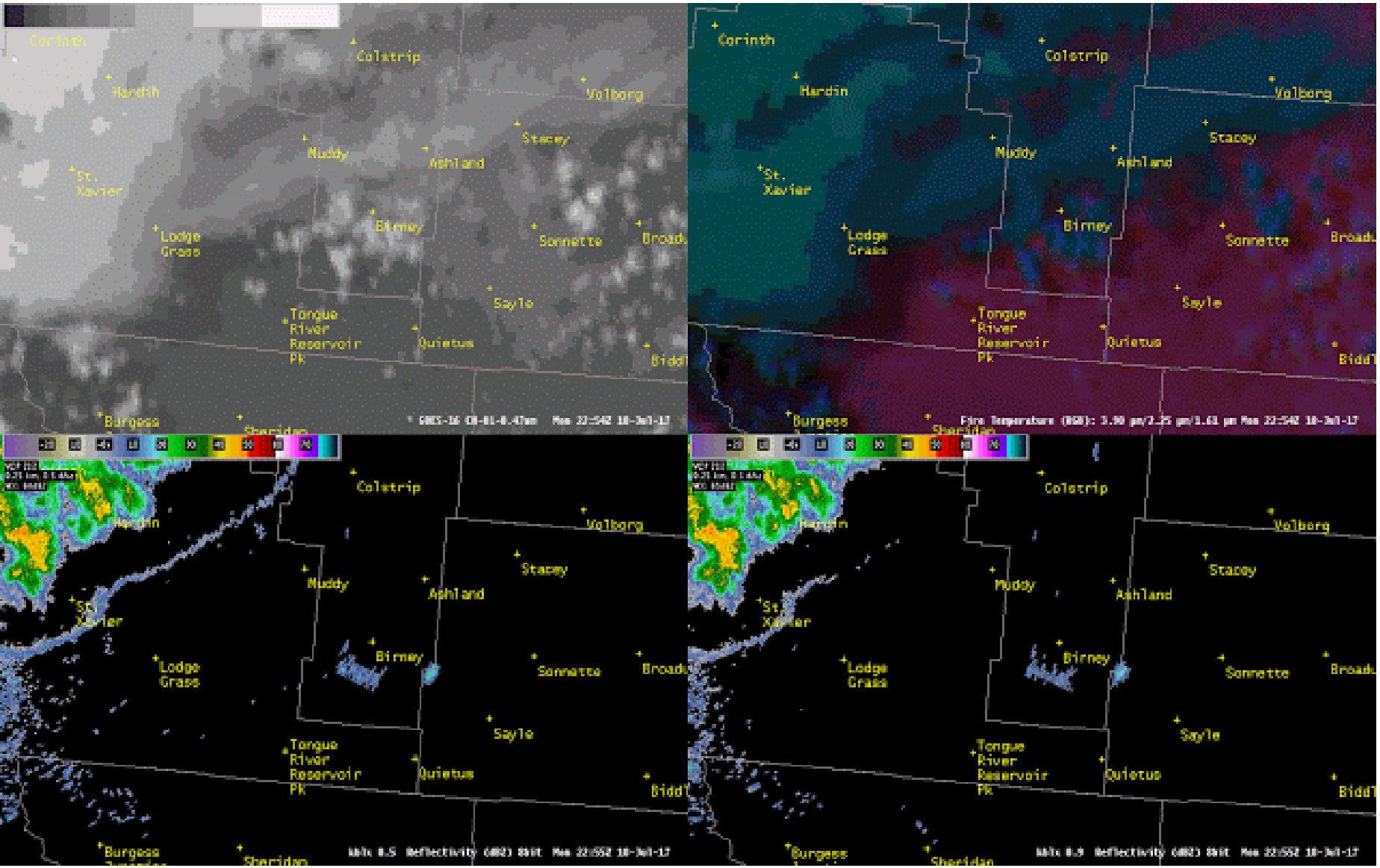
- A noticeable inversion was detected near/just above 700mb.
- Compared to HRRR, RAP, and NAM soundings taken at a similar time, guidance was unable to detect this feature.
- Decided to investigate a smoke plume seen from KBLX radar

HRRR Forecast Sounding



NUCAPS T/q used in AWIPS to monitor fire weather

Slide by Michael Bowlen; HWT 2017



- "The placement of the fire and smoke plume suggests some accuracy of the NUCAPS capture of the inversion, which is missing from model guidance."
- "Additionally, it has been noticed that as convection has pushed eastward this afternoon, it's intensity has been decreasing, which could be an impact of the inversion."

What about NUCAPS trace gas products – would they have been valuable here in AWIPS?

npr WAMU 88.5 news arts & life music programs shop

http://www.npr.org/sections/thetwo-way/2017/03/03/518323094/rise-in-smog-in-western-u-s-is-blamed-on-asias-air-pollution

the two-way BREAKING NEWS FROM NPR

AMERICA

Smog In Western U.S. Starts Out As Pollution In Asia, Researchers Say

March 3, 2017 · 10:21 AM ET

BILL CHAPPELL



Nitrogen oxide pollution in India and China is offsetting U.S. gains in cutting emissions, researchers say. This photo from October shows road traffic, along with smoke and smog, in front of the landmark India Gate in New Delhi.

Manish Swarup/AP

"A global perspective is necessary when designing a strategy to meet US O_3 air quality objectives," the scientists wrote

They concluded that the spike in man-made emissions in Asia "is the major driver" of the rise in ozone levels in the western U.S. for both spring and summer in recent decades.

Lin et al. 2017, ACP, doi.org/10.5194/acp-17-2943-2017

How can this research make its way into the public domain?
NUCAPS has the quality and coverage to contribute to air quality monitoring at global scales….

"… even quick-look images of CO … during fire periods would be very useful to us. We don't need a fancy display"
Greg Frost (NOAA/ESRL)

"Now-casting tools are important in case of disasters?" Tony Wimmers (SSEC/CIMSS)

"We need to be able to monitor trace gases over time" Monica Kopacs (NOAA/CPO)

https://worldview.earthdata.nasa.gov/
https://realearth.ssec.wisc.edu/
http://www.esri.com/

We need more options for interactive display

Quality Validation –> Application Evaluation –> Every-day Verification

O_3 CH_4 N_2O CO HNO_3 CO_2 SO_2

The questions really should be:

Do you know what NUCAPS trace gas products look like for today?

Will you be able to look at NUCAPS trace gas products tomorrow when this meeting is over?

NOAA • NESDIS
JPSS
Joint Polar Satellite System



A JPSS Proving Ground/Risk Reduction Project

2017 STAR JPSS Annual Meeting

Evaluating NUCAPS CH_4 and CO

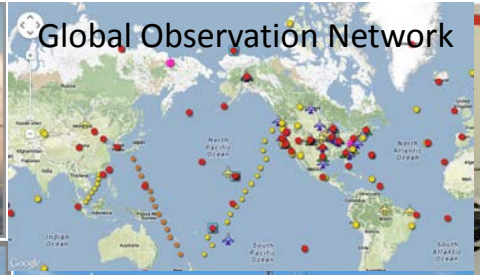
NOAA OAR ESRL: Gregory Frost, S. McKeen, L. Zhang, R. Ahmadov, W. Angevine, J. Brioude, Y. Cui, K. Froyd, C. Granier, G. Grell, S.-W. Kim, K. McKain, D. Murphy, T. Ryerson, J. Roberts, K. Rosenlof, J. Schwarz, C. Sweeney, M. Trainer , C. Warneke
STC: N. Smith, A. Gambacorta, C. Barnet
NOAA NESDIS STAR: R. B. Pierce
NOAA NESDIS NCEI: C. Elvidge

Close collaboration of ESRL, NESDIS, and STC

- Critical to project's success
- Retrieval developers work directly with science users
- Leads to improved algorithms and products
- Adds value to PGRR investment

NOAA OAR's Atmospheric Composition Tools

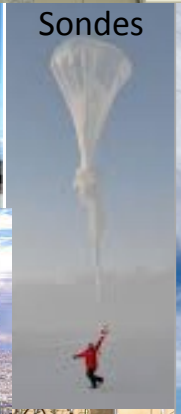




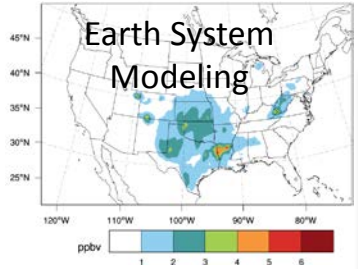






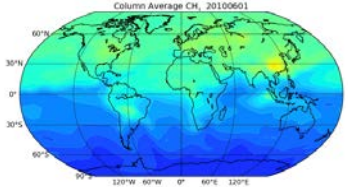


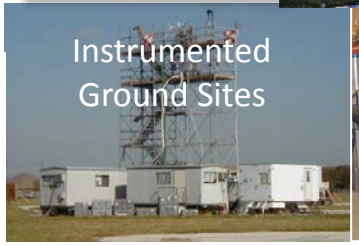














Observing the atmosphere at multiple spatial and temporal scales with a suite of complementary approaches

State-of-the-art earth system modeling and data analysis

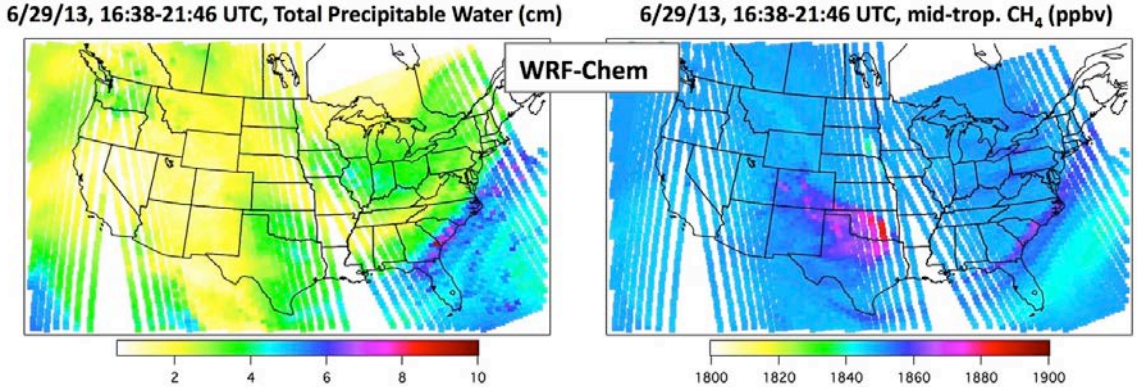
http://www.esrl.noaa.gov

Approach for this project

Aircraft data from field research studies are the basis of our NUCAPS evaluations, providing…

- high accuracy and precision
- fine horizontal and vertical resolution
- repeated sampling

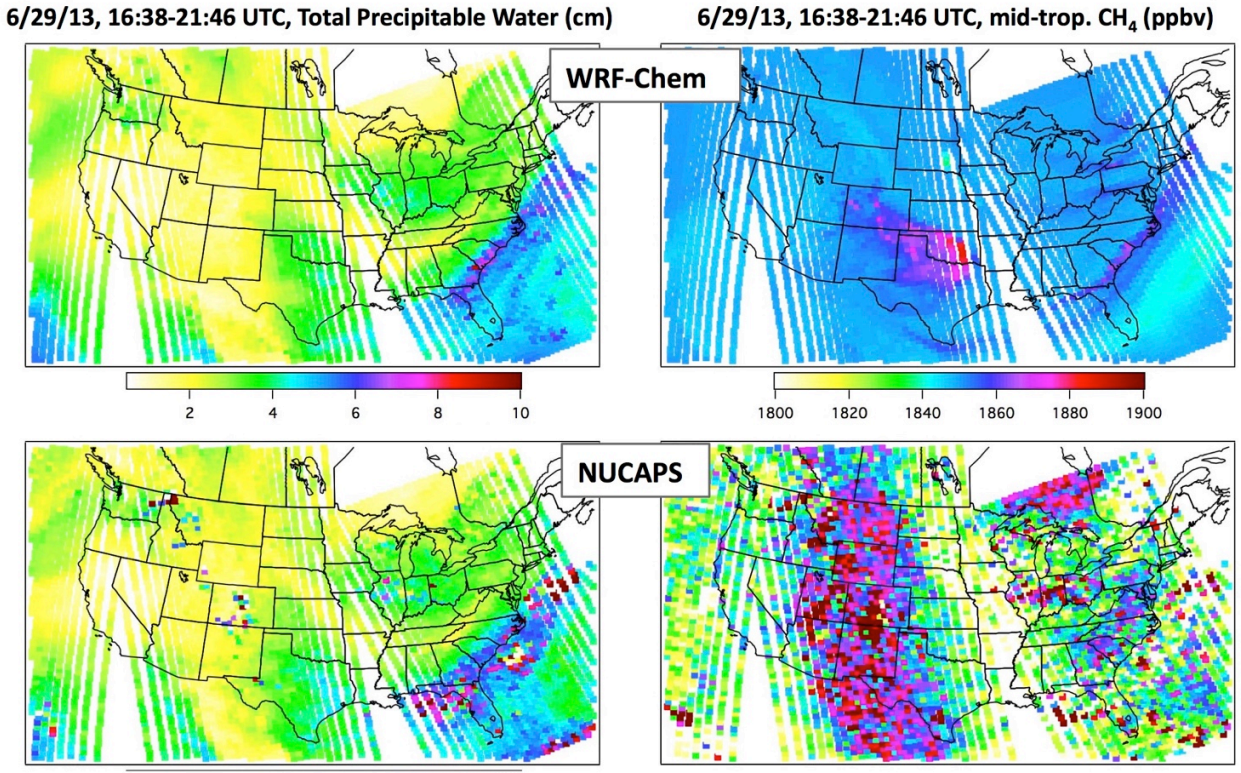




Atmospheric chemical-transport models evaluated and improved by aircraft data enable direct assessment of NUCAPS trace gases and meteorological products, by…

- Extending temporal and spatial domain beyond sparse aircraft sampling
- Simulating atmospheric quantities to match NUCAPS retrievals

NUCAPS - Model Comparisons → Improved Retrievals



Initial comparisons of NUCAPS data suggested issues with NUCAPS CH_4

- NUCAPS trace gas retrievals used quality control (QC) thresholds optimized for meteorological variables

STC refined its NUCAPS retrieval algorithms

- Updated, more restrictive QC thresholds specific to CH_4 and to 7 other trace gases

Assessing NUCAPS Scale Variance

How do we characterize NUCAPS true signals versus noise?

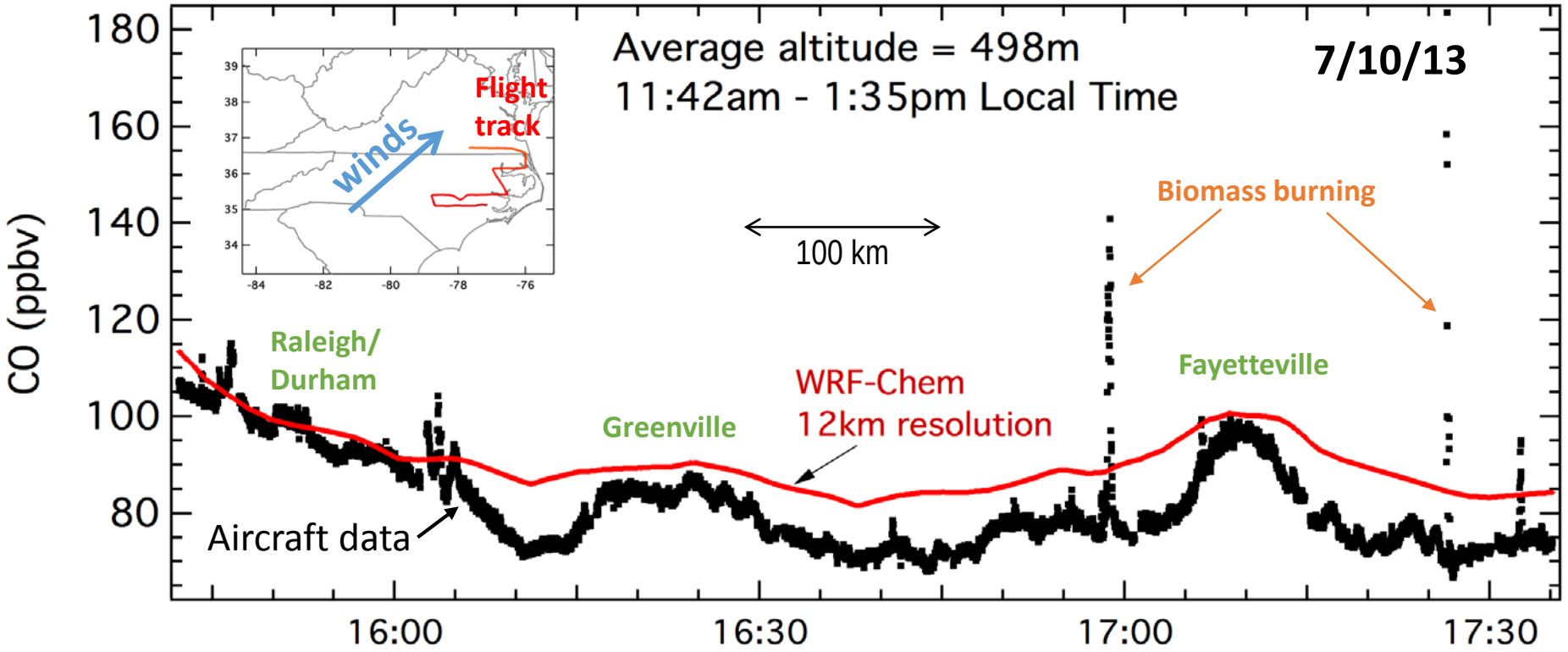
- Assess spatial averaging needed to produce meaningful NUCAPS trace gas data

Decomposition of time series into orthogonal functions has previously been used to analyze the temporal or spatial variance of a measurement

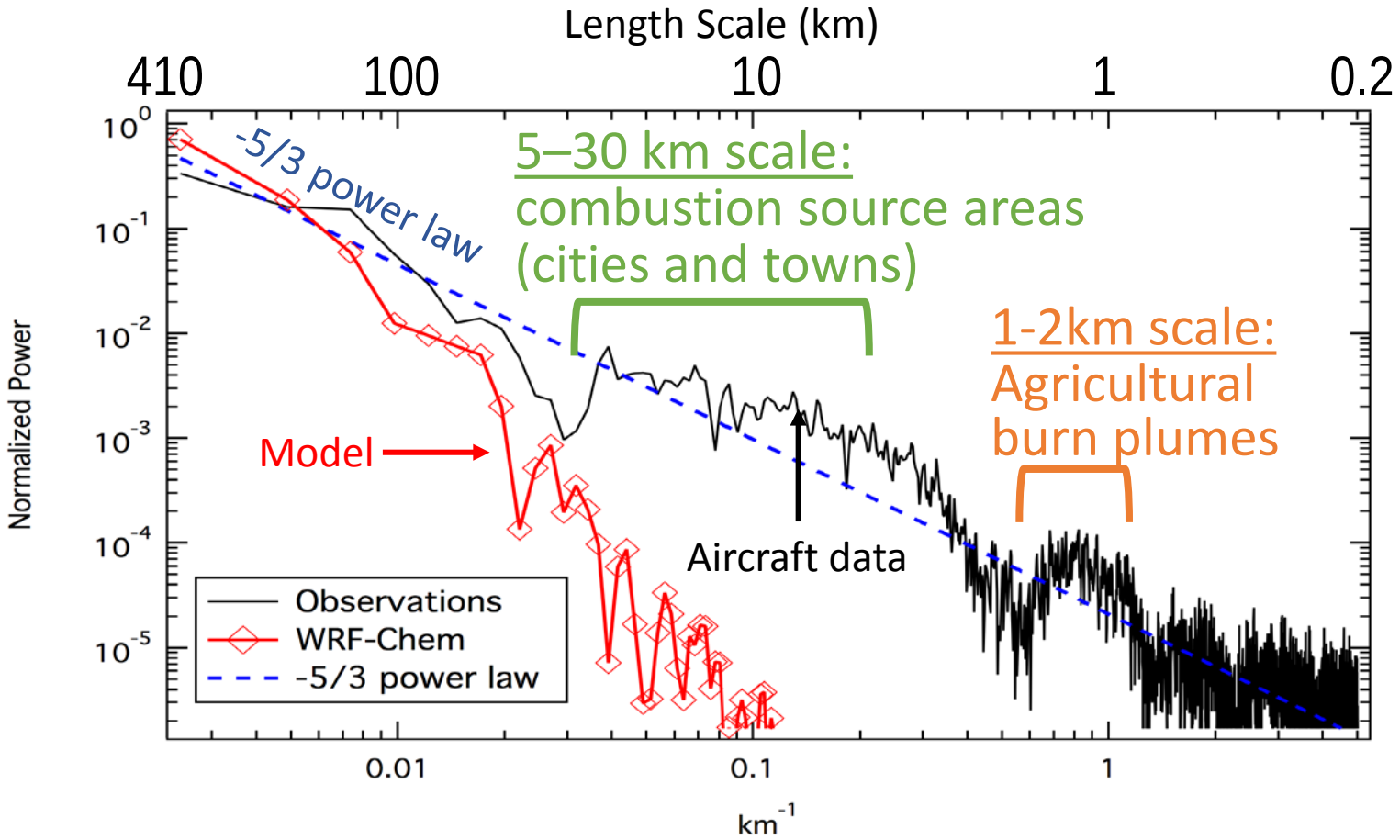
- Dynamic turbulence within the atmosphere is known to be the determining factor in the scale dependence of variance
- Chemical constituents display same scale dependence as thermodynamic and momentum-based quantities (Tuck and Hovde, 1999)

➢ Use power spectrum analysis of scale variance to determine the quality of NUCAPS retrievals

Time series of aircraft and model CO



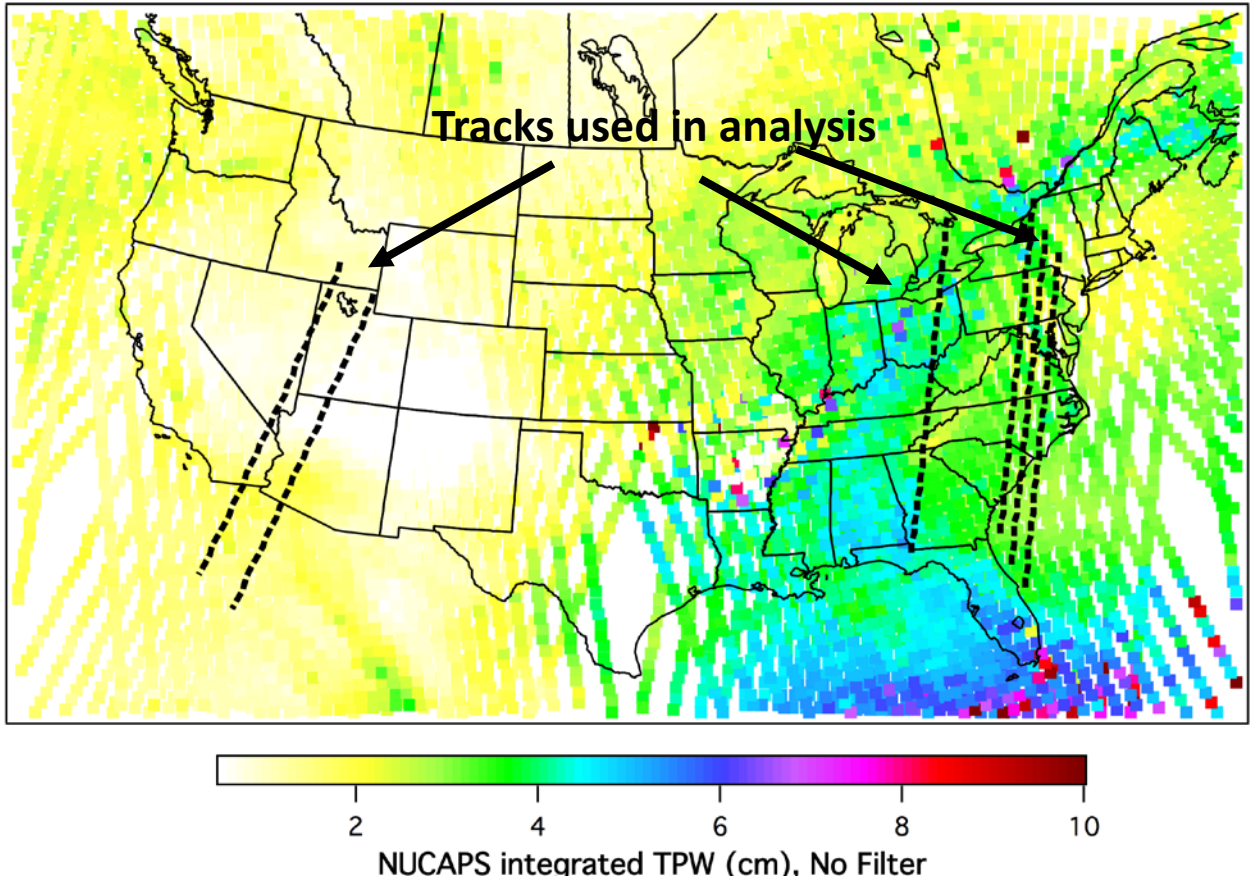
Power spectra of aircraft and model CO



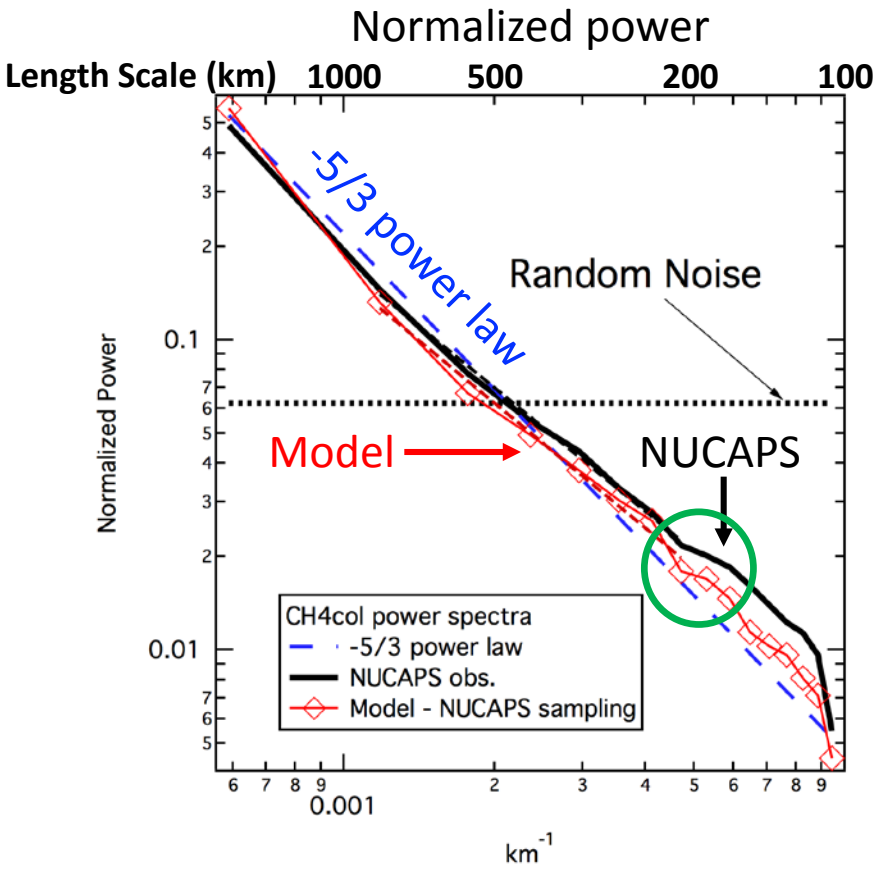
Domain for comparisons of NUCAPS to model

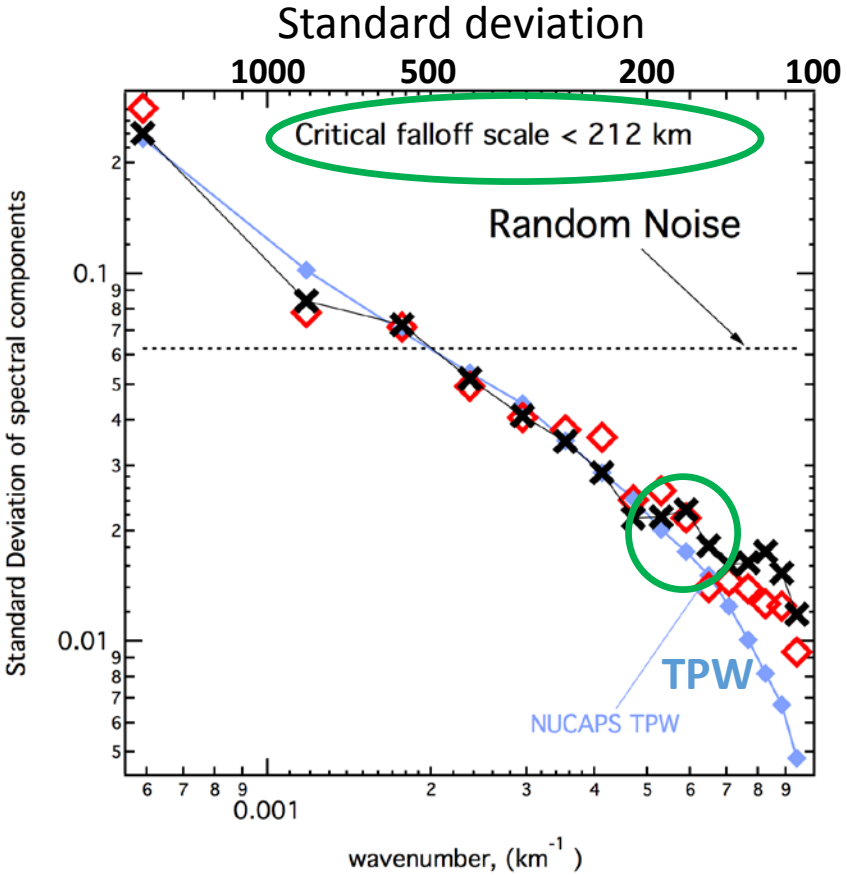
NUCAPS total precipitable water
1 June 2013 shown
1 June – 15 July 2013 data were analyzed

Colored pixels = No QC flag filtering
Dotted lines = 6 NUCAPS tracks that meet QC criteria

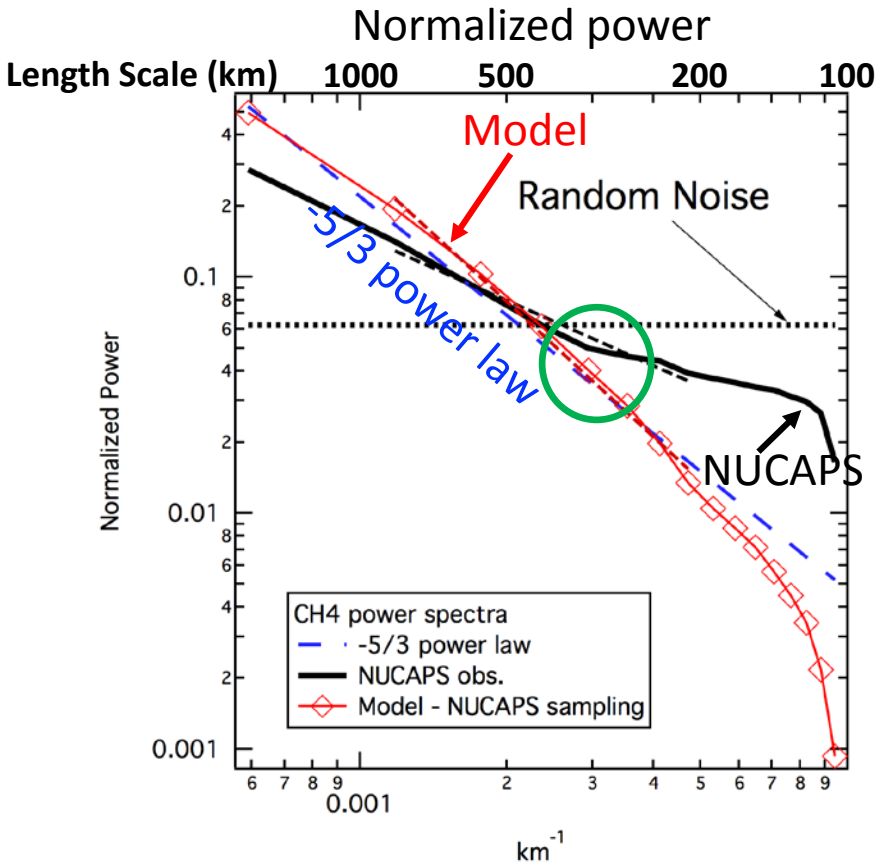


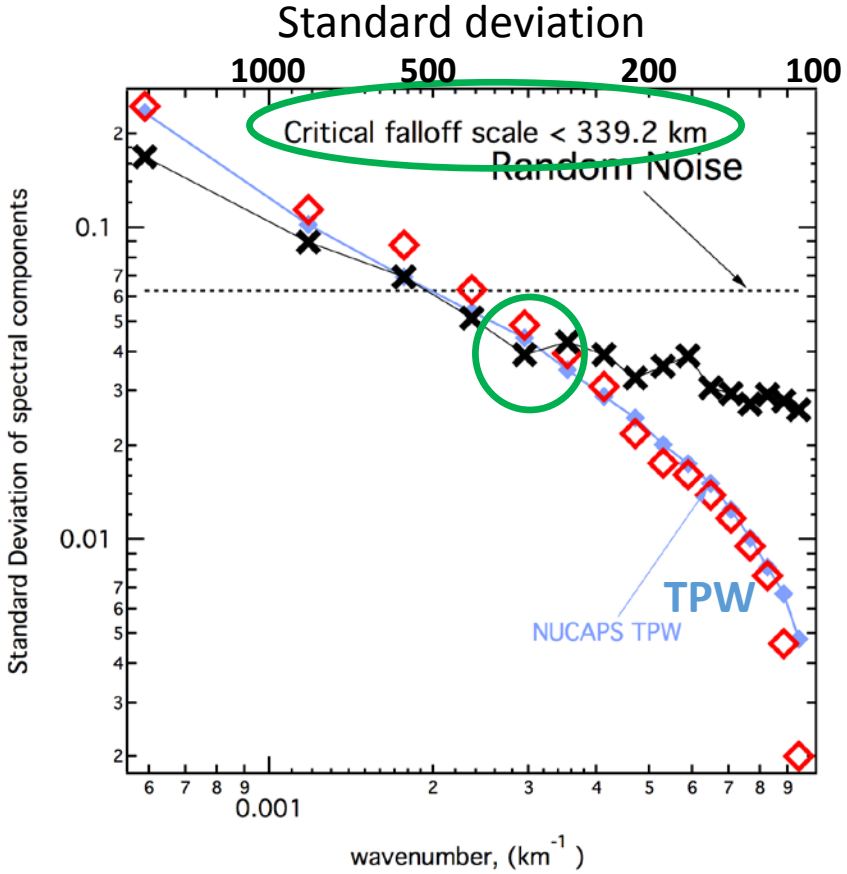
Power spectra: NUCAPS and model column CH_4



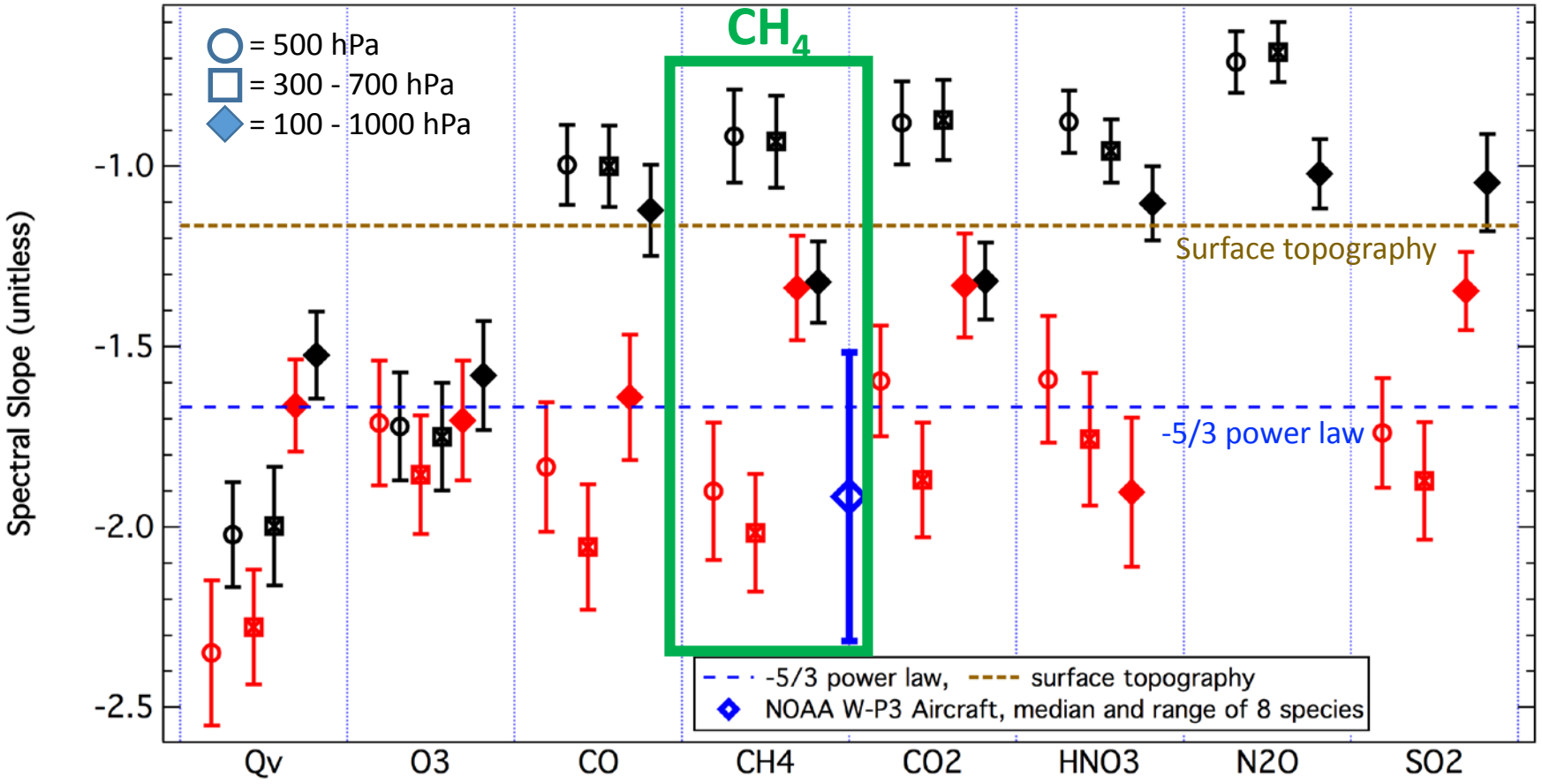


Power spectra: NUCAPS and model 500-hPa CH_4





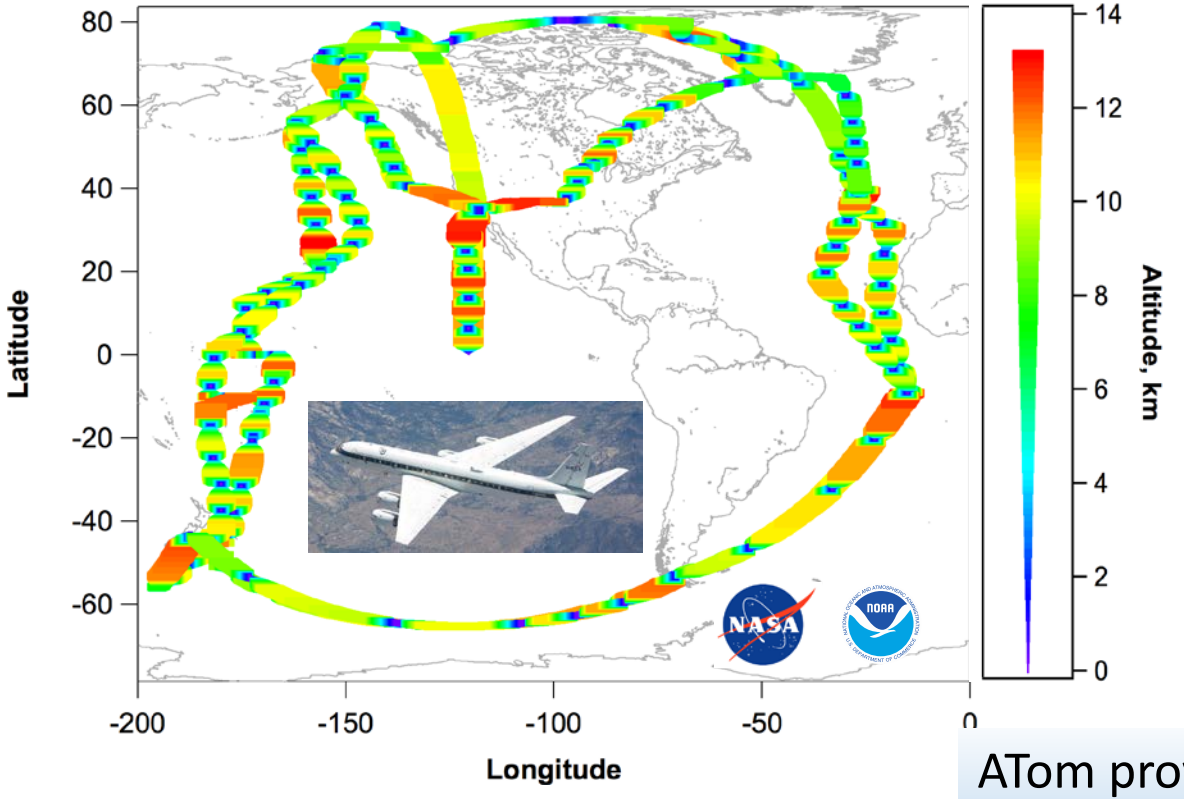
Power spectral slopes: NUCAPS, model, aircraft



Interim conclusions from the project

- Aircraft research observations provide evaluation of atmospheric model
- Evaluated model in turn provides comparison data for NUCAPS retrievals
- Aircraft-model-NUCAPS comparisons → customized trace gas QC thresholds
  - Improved NUCAPS retrievals
  - Larger NUCAPS science dataset compared with operational products
- Scale variance analysis helps distinguish NUCAPS true signals vs. noise
- NUCAPS CH_4 data are meaningful with adequate spatial averaging:
  - *vertically* over full tropospheric column + *horizontally* at scales ≥ 200 km
  - *vertically* in mid-troposphere + *horizontally* at scales ≥ 340 km
- Need full spectral resolution CrIS radiance products for similar analysis of NUCAPS CO
- In-situ observations should be averaged similarly for meaningful comparison to NUCAPS
  - Averaging limits direct comparison opportunities, thus necessitating use of evaluated chemical-transport models for understanding NUCAPS retrievals

Ongoing work: Atmospheric Tomography Mission



NASA's **A**tmospheric **Tom**ography Mission is conducting continuous pole-to-pole profiling from 0.2 to 12 km altitude in 4 seasons between 2016 and 2018.

Within NOAA's NGGPS (Next Generation Global Prediction System), ATom data are used to assess performance of global chemical-transport models.

https://espo.nasa.gov/home/atom/content/ATom

ATom provides excellent evaluation opportunities for JPSS trace gas and aerosol products.



Ongoing Work: Fire Influence on Regional and Global Environments Experiment (FIREX)



2019 NOAA & NASA aircraft studies

FIREX is NOAA's multi-faceted wildfire research program

- Emissions
- Chemical transformations
- Model evaluation
- Coordinate with others:

FIRE-Chem **FASMEE** **WE-CAN**

JPSS fire detection products and trace gas and aerosol retrievals will be critical tools for mission planning/forecasting and analysis of aircraft data

Next Steps

- Finalize scale variance analysis
- Continue model validation with ATom data
- Analyze NUCAPS CH_4 and CO during ATom deployments
  - Need full spectral resolution CrIS CO data
- Begin planning for FIREX in 2019, and explore applications of JPSS fire-detection and trace gas products

Recent Improvement of NUCAPS CH_4 from CrIS FSR Data

Xiaozhen (Shawn) Xiong[1,2], Lihang Zhou[2]

Antonia Gambacorta[1,3], Nick Nalli[1,4] , Changyi Tan[1,4]

Flavio Iturbide-Sanchez[1,4], Kexing Zhang[1,4]

[1]CICS-MD
[2]NOAA/NESDIS/STAR
[3] STC Inc
[4] IMSG

4th NOAA JPSS Meeting, College Park, MD, 2017

Outline

- **Recent Improvements in CH_4 Retrievals from CrIS FSR Data**
  - Sensitivity (mid-upper troposphere) and Requirement of CH_4 products (based on total amount) --- need a good CH_4 firstguess in the lower troposphere;
  - Optimization: First guess, Channel Selection, and tuning;
  - **Quality control (CH_4QC) – to be added soon;**

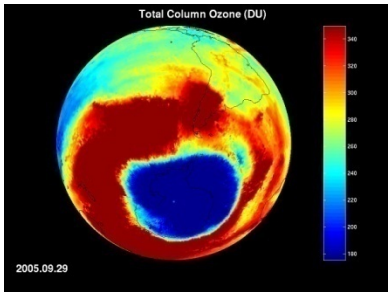
- **Validation:**
  Comparison of CrIS CH_4 profiles with model, AIRS and TCCON data;

- **Examples:**
  - Monitoring the leakage of CH_4 from California **Aliso Canyon Oil Field and Gas Storage Facility;**
  - Monitoring the CO plume from 2016 **Fort McMurray wildfire**; Monitoring the CO plume from **Indonesia Fires (9/20-11/8, 2015);**

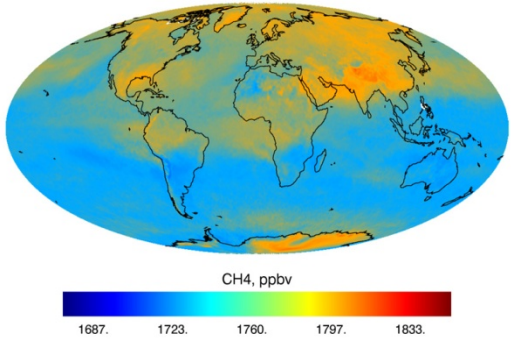
- **Summary and Future works**

Requirements of Trace Gases Products from CrIS

Ozone

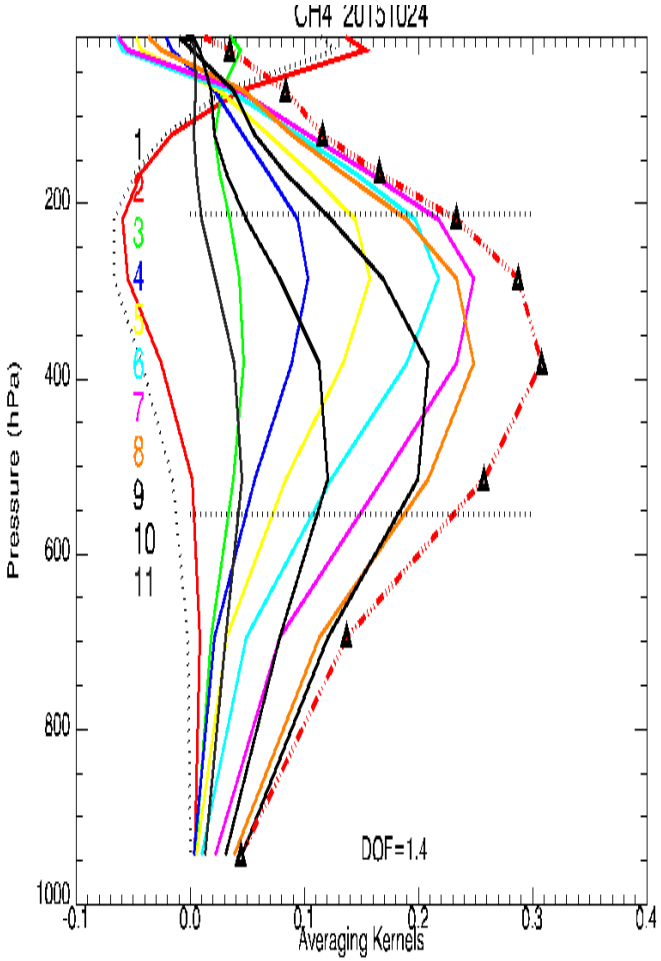


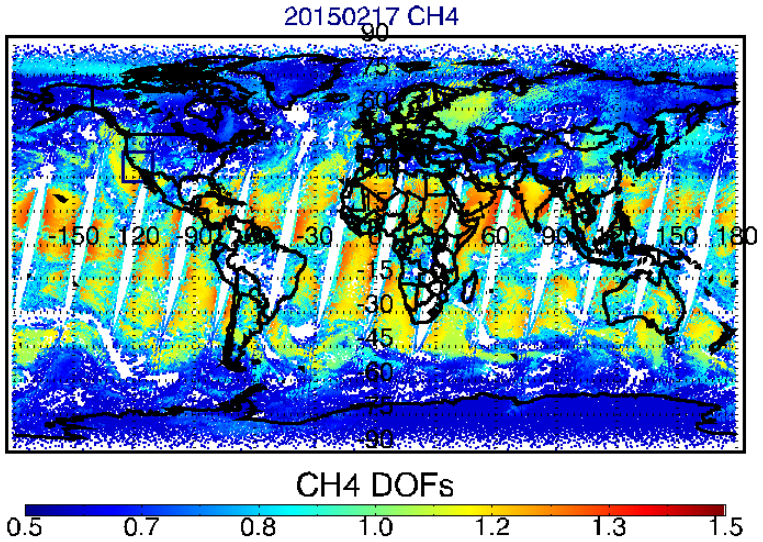
Methane



EDR Attribute	CO	CO_2	CH_4
Vertical Coverage	Total Column	Total Column	**Total Column**
Horizontal Resolution	100 km	100 km	100 km
Mapping Uncertainty, 3 sigma	25 km	25 km	25 km
Measurement Range	0 – 200 ppbv	300 – 500 ppmv	1100 – 2250 ppbv
Measurement Precision	15%	0.5% (2 ppmv)	**1% (~20 ppbv)**
Measurement Accuracy	±5%	±1% (4 ppmv)	**±4% (~80 ppbv)**
Refresh	24 h	24 h	24 h
Note			

Sensitivity of CrIS to CH_4



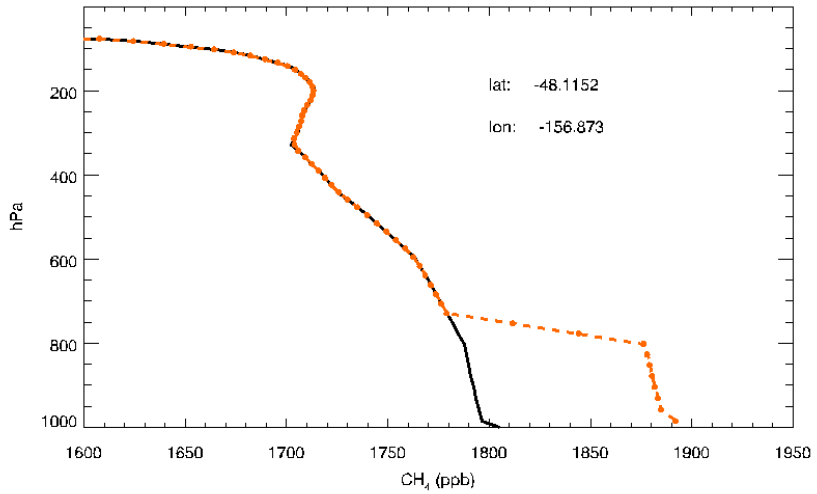


- **Major sensitivities are in the mid-upper troposphere – not near the surface where the variation is impacted by emissions;**

- **Sensitivities in the polar are lower than tropics and mid-latitude**

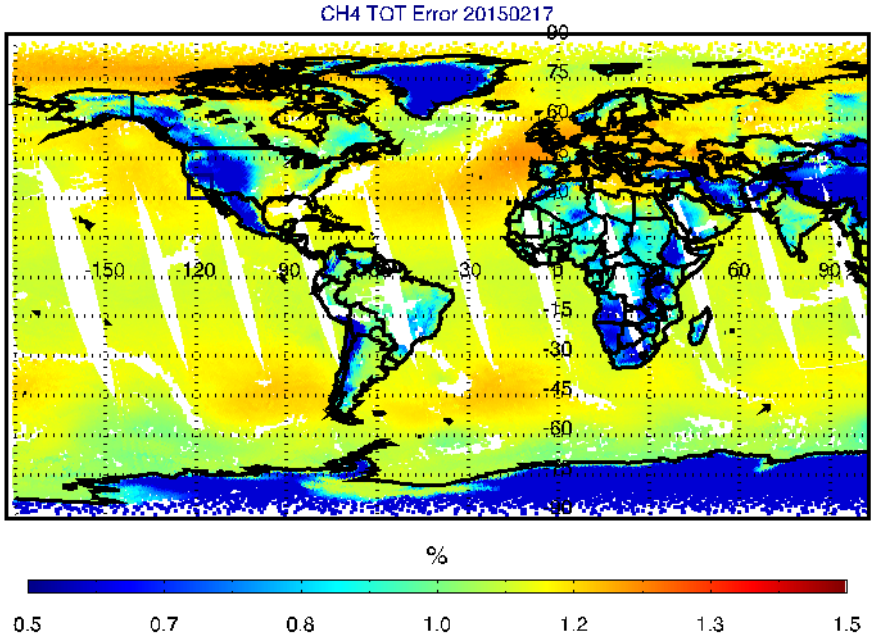
CH_4 Total Amount Error

assuming 5% error of CH4 profile in lower troposphere (below 800 hPa)



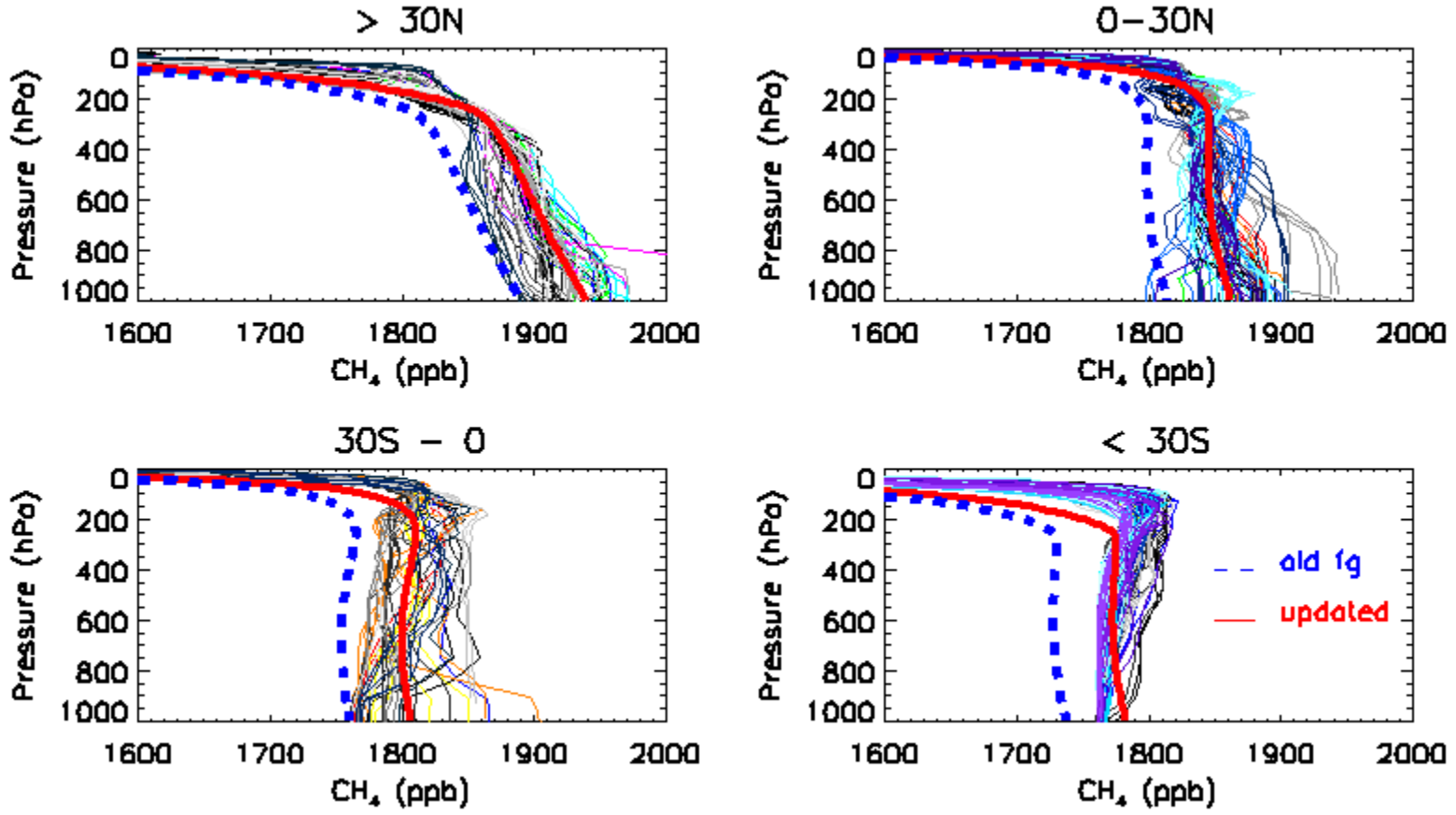
Assuming 5% error of CH4 profile in lower troposphere(below 800 hPa), the error in total amount is about 1.2%.

- to meet the requirement of total amount in 1%(accuracy) is hard;
- It requires a very good a priori



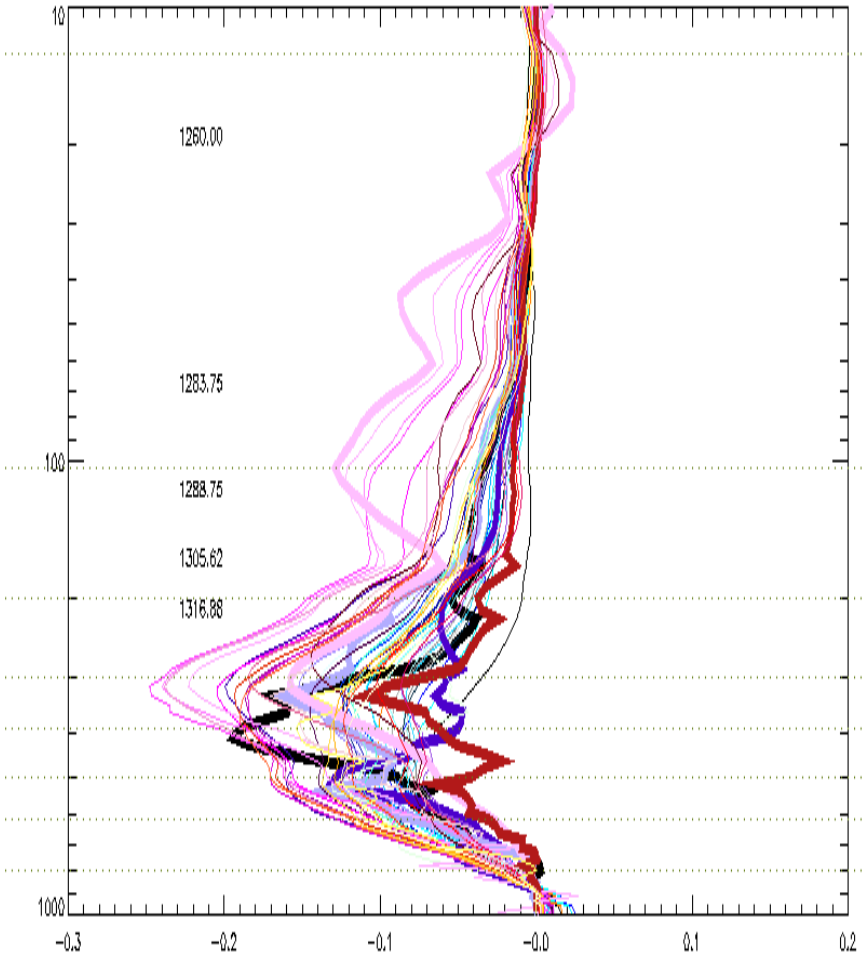
CH_4 First-guess Update

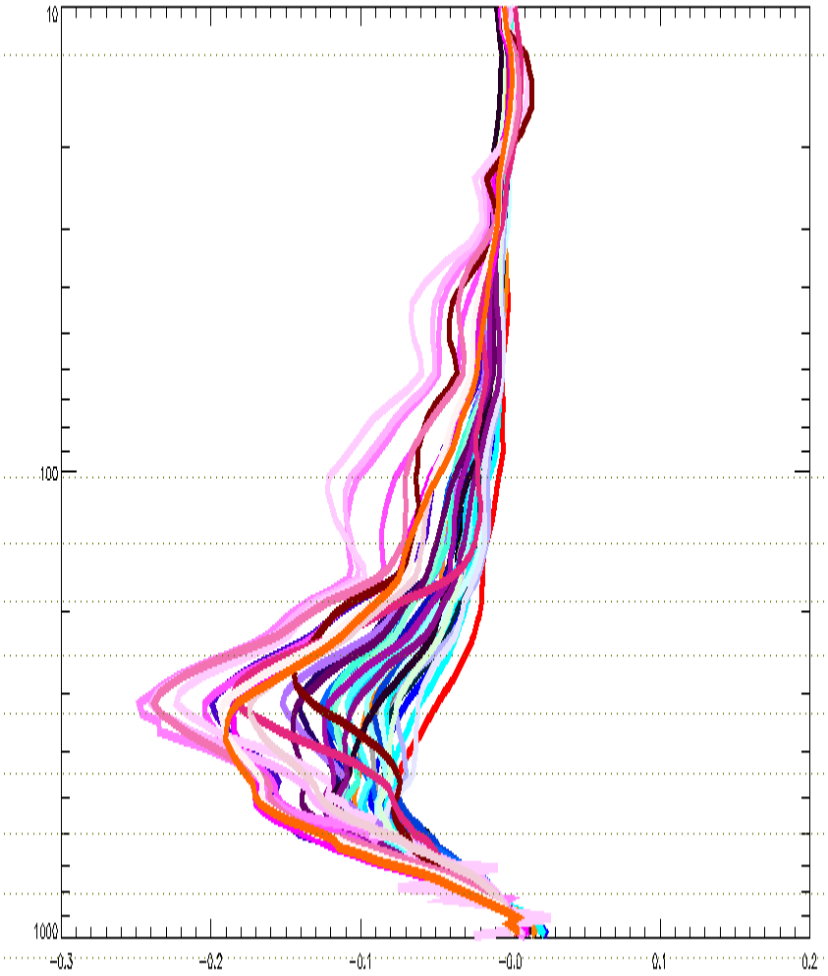
(about +2.5%)



--- Old fg is the one used in AIRS-V7 and NOAA IASI system

Continued Optimization: Channel Selection (1)

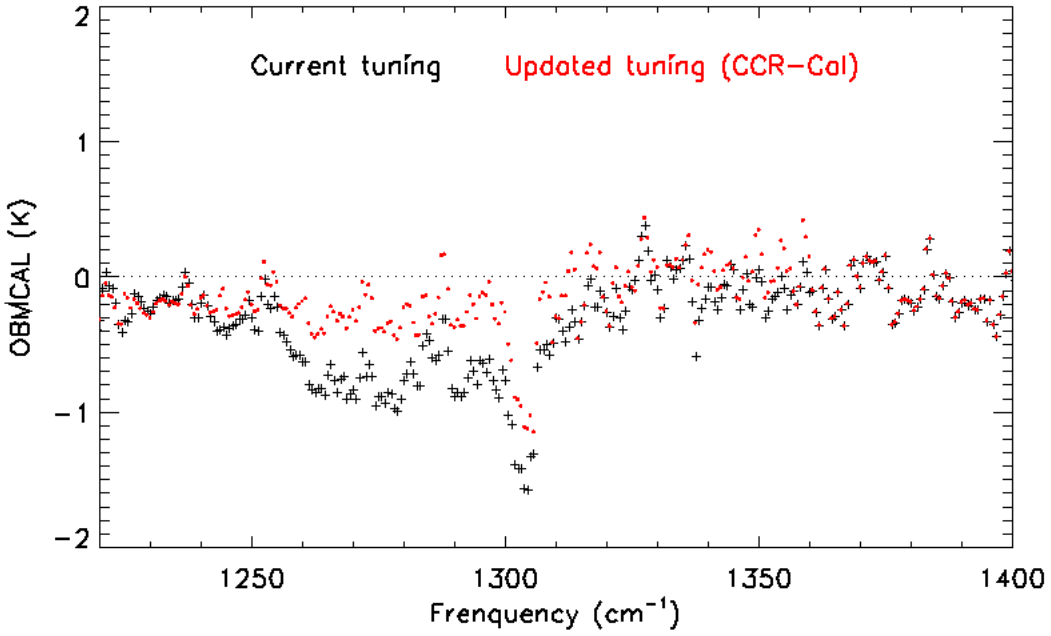




Current one – delivered in July

Updated one – to be delivered in Oct/Nov

Continued Optimization(2): Re-tuning to CH_4 bands



- CH_4 is very sensitive to upstream temperature and water vapor products;
- Cloud-clearing is a good thing to the yield of retrievals but could be poisonous to trace gases products;

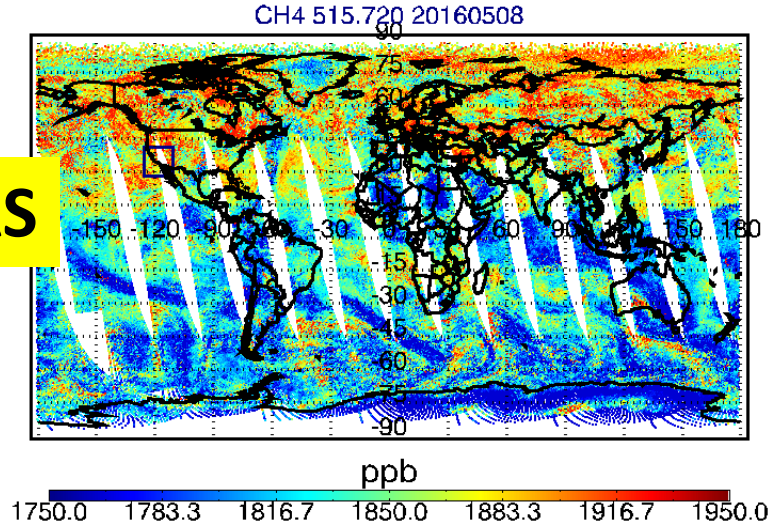
Method of Re-tuning to CH_4 bands

1) Using SARTA to simulate the global radiance with inputs
   - T,Q profiles from NUCAPS retrievals;
   - CH_4, N_2O and CO_2 from model simulations;
2) read CCR and applied QC (MW+IR) = 0;
3) Computed the difference of $[R_{simu} - R_{CCR}]$;
4) Modified the tuning file in CH_4 bands ONLY (from 1200-1360 cm^{-1}) → ***no impact to T & q products***;

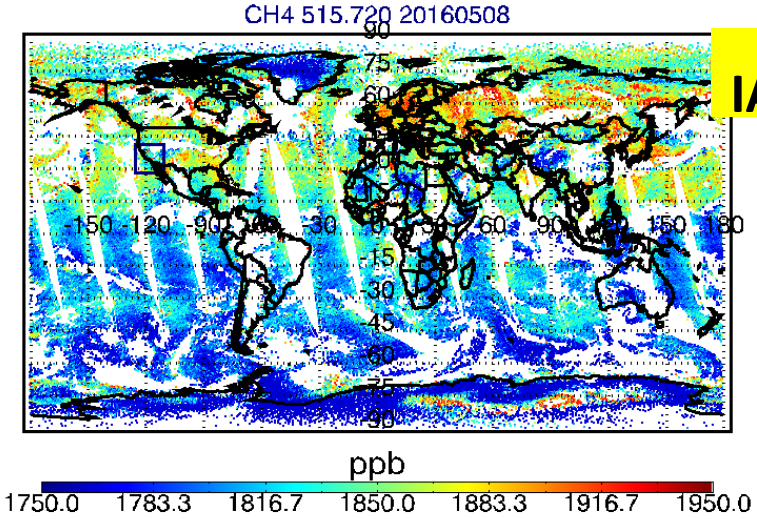
One day data (45°S-45°N) on 2/17/2015 is used;

Comparison of CH_4 from AIRS, IASI and CrIS (20160508, @515hPa) – NO QC to CrIS CH_4 products

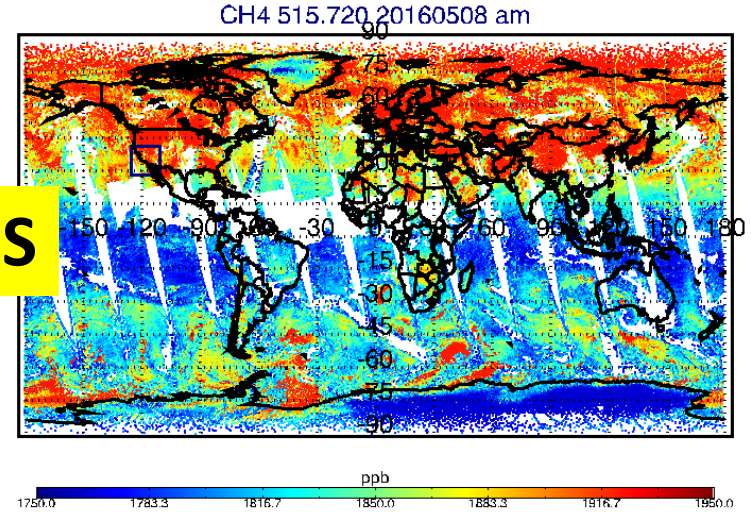
AIRS



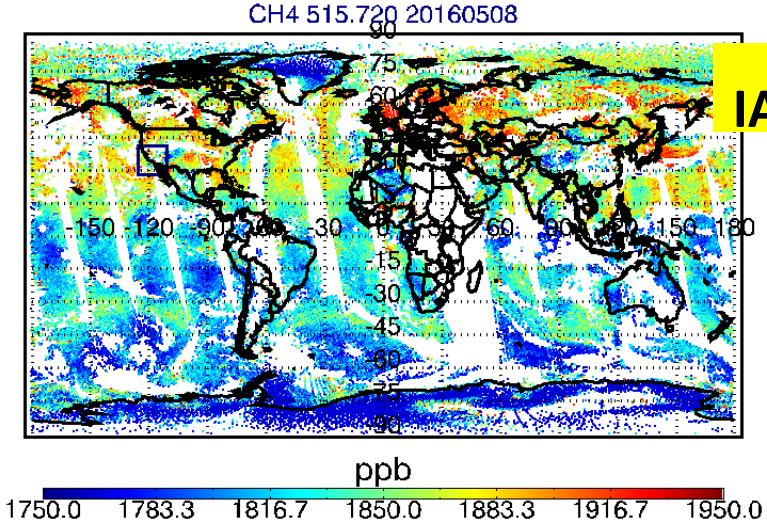
IASI-A



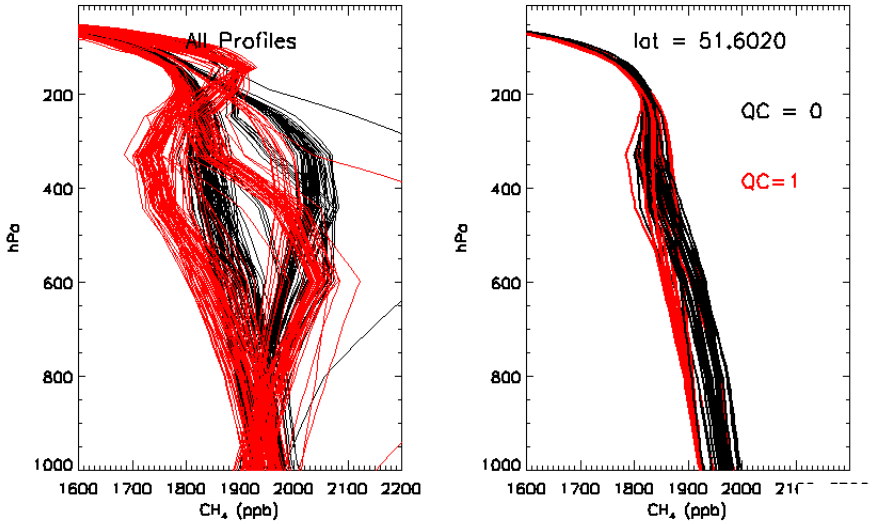
CrIS



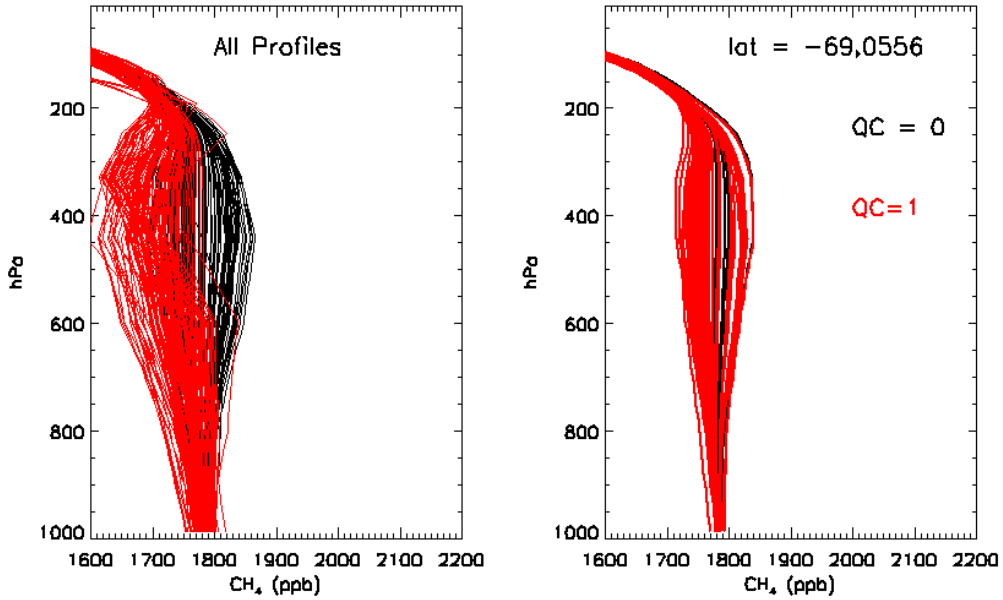
IASI-B



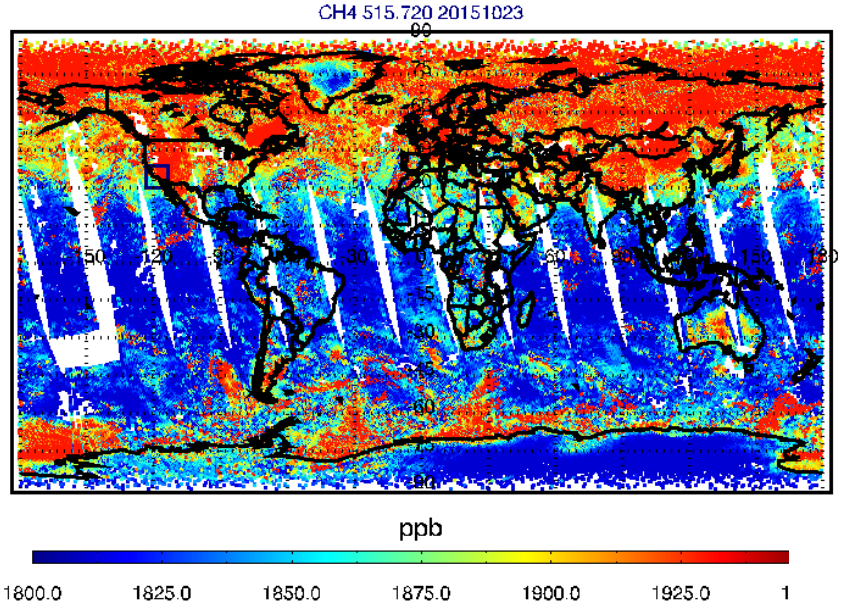
Examples of Quality Control (CH_4QC)



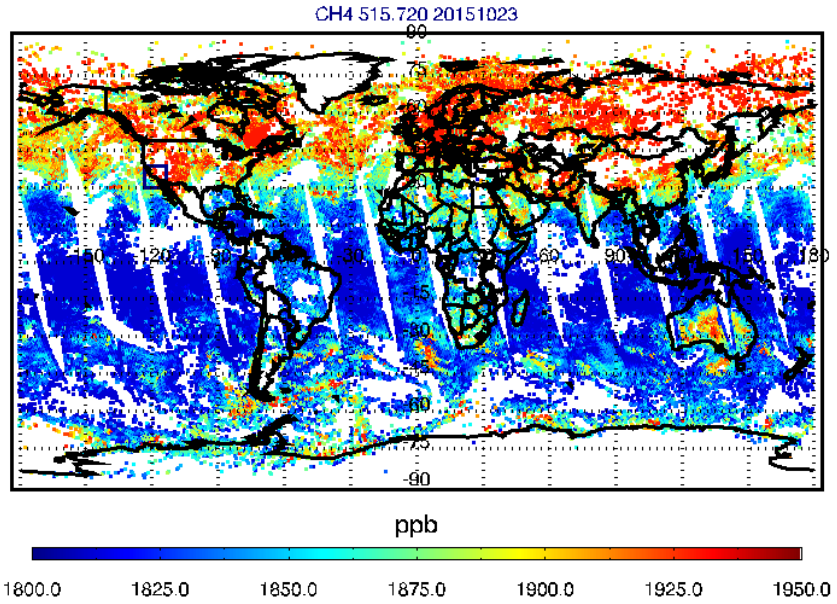
- **For two granules**
- **Left panels: red lines are from current version and black lines are from updated retrievals;**
- **Right panels: Profiles from new version and after using CH_4QC**



Example of CH_4 map with the CH_4QC



With CH_4QC



Yields after using CH_4QC

50.8%

Descending	Yield (%)	Percentage relative to NO CH_4QC (%)
QC=0	37.4	45.0
QC=1	13.4	16.0
QC=2	49.2	

54.7%

Ascending	Yield (%)	Percentage relative to NO CH_4QC (%)
QC=0	43.6	52.0
QC=1	11.1	13.2
QC=2	45.2	

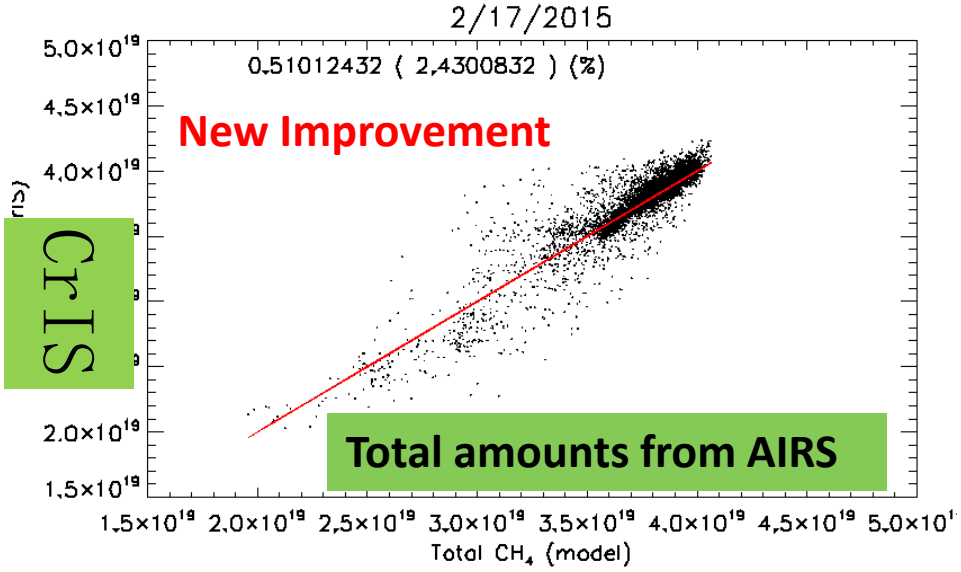
Some Results

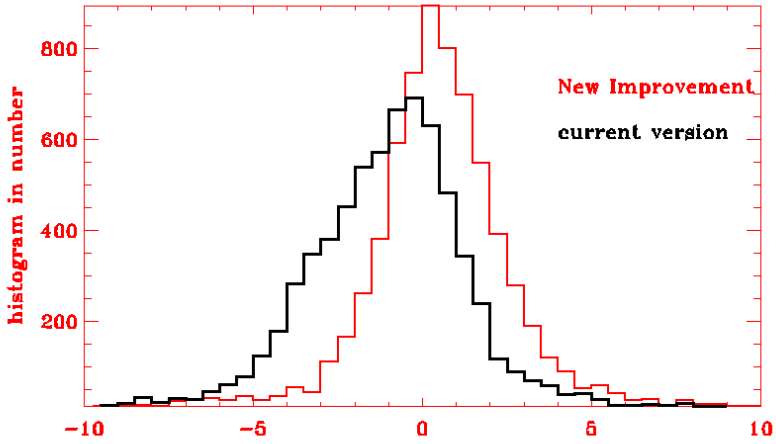
Validation: comparison with model, AIRS and TCCON data;

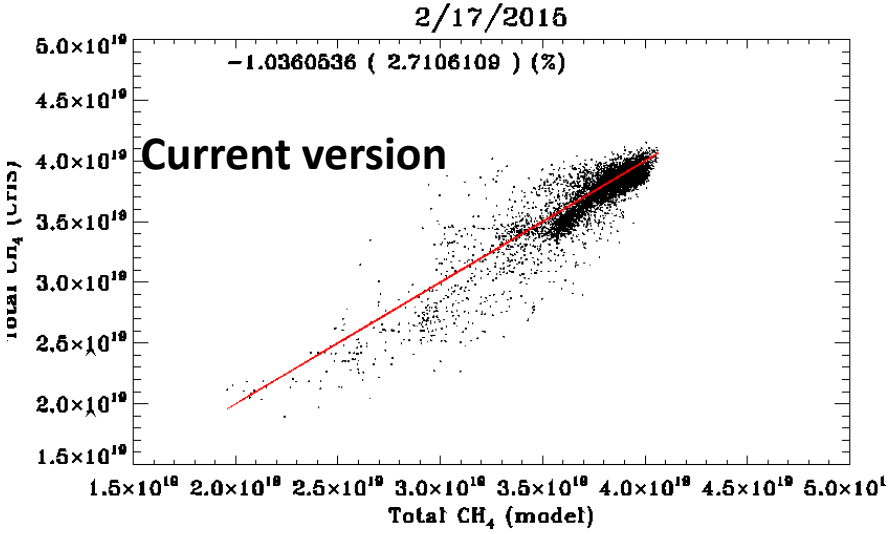
Examples:

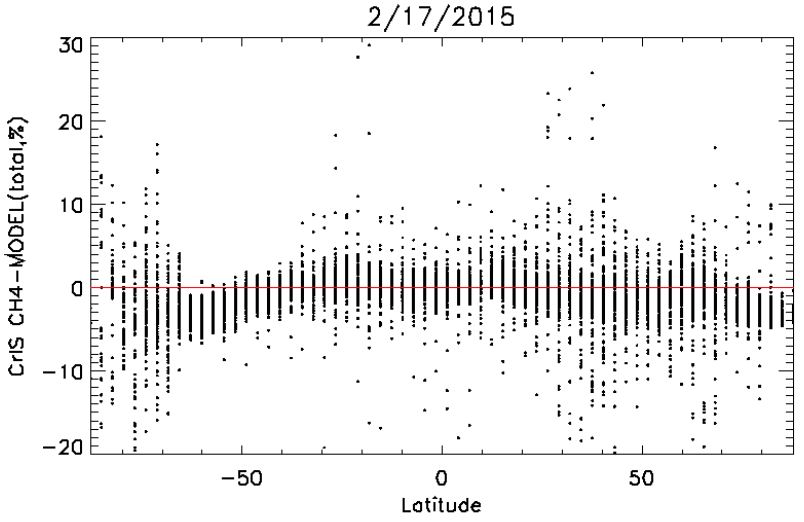
- Monitoring the leakage of CH_4 from California **Aliso Canyon Oil Field and Gas Storage Facility;**
- Monitoring the CO plume from 2016 **Fort McMurray wildfire**;
- Monitoring the CO plume from **Indonesia Fires (9/20-11/8, 2015);**

Comparison with model CH_4 – improvement is obvious but accuracy is large than 1%

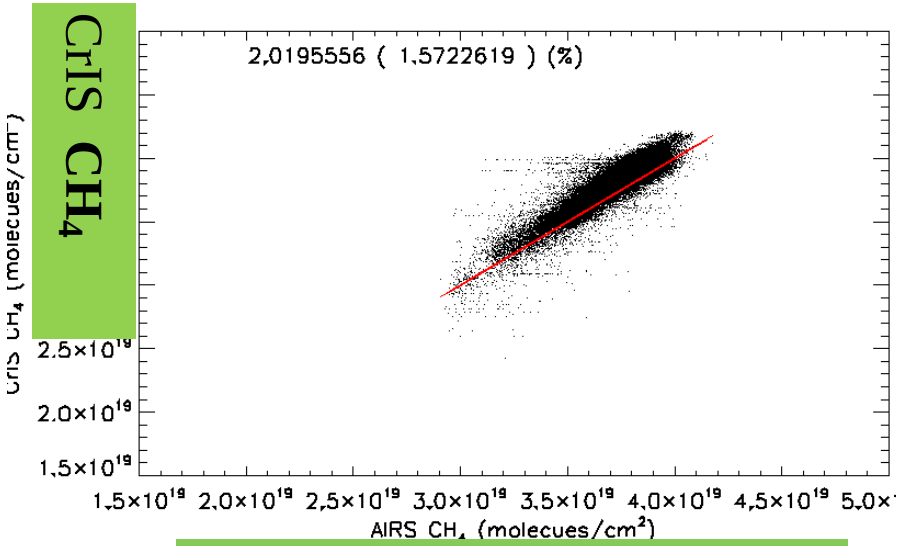




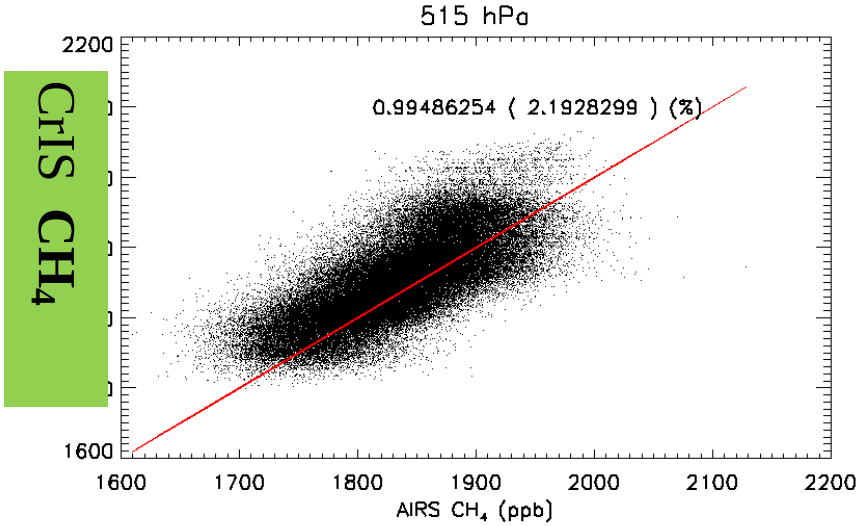




Comparison of CrIS and AIRS CH_4

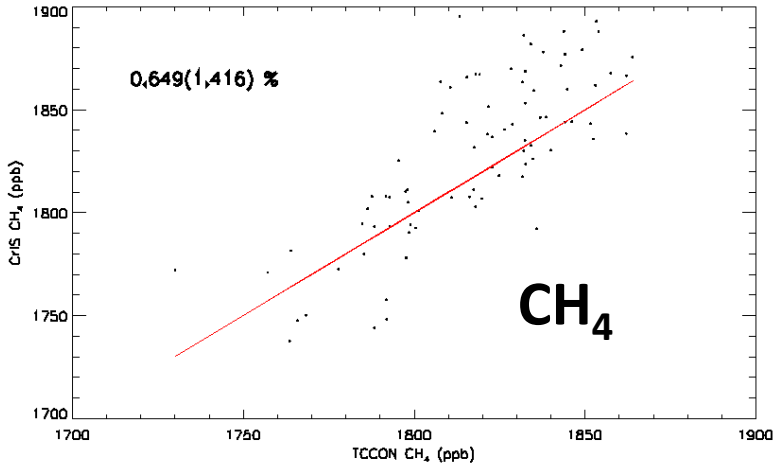


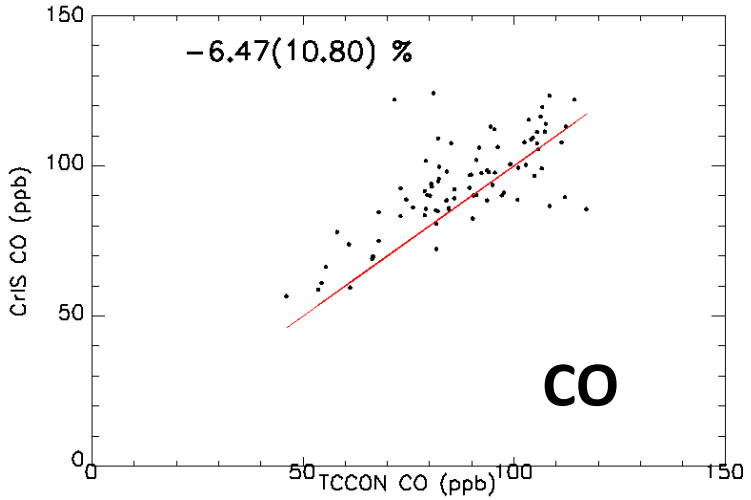
Total amounts of CH_4 from AIRS

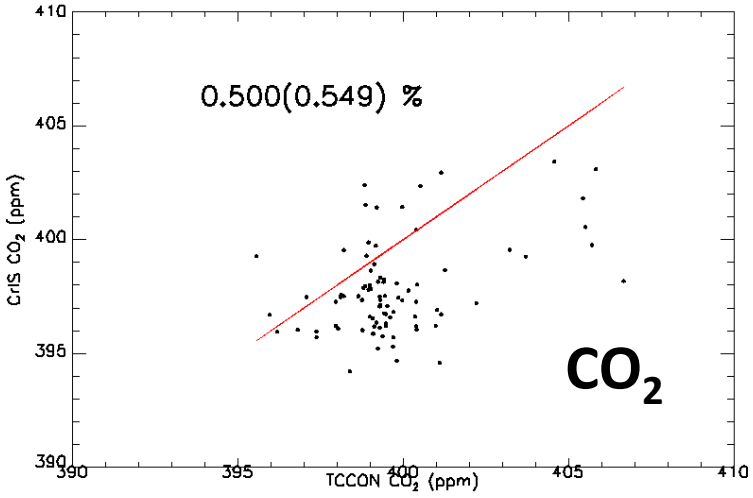


AIRS CH_4 at 515 hPa

Comparison of CrIS xCO/xCO_2/xCH_4 with TCCON Measurements





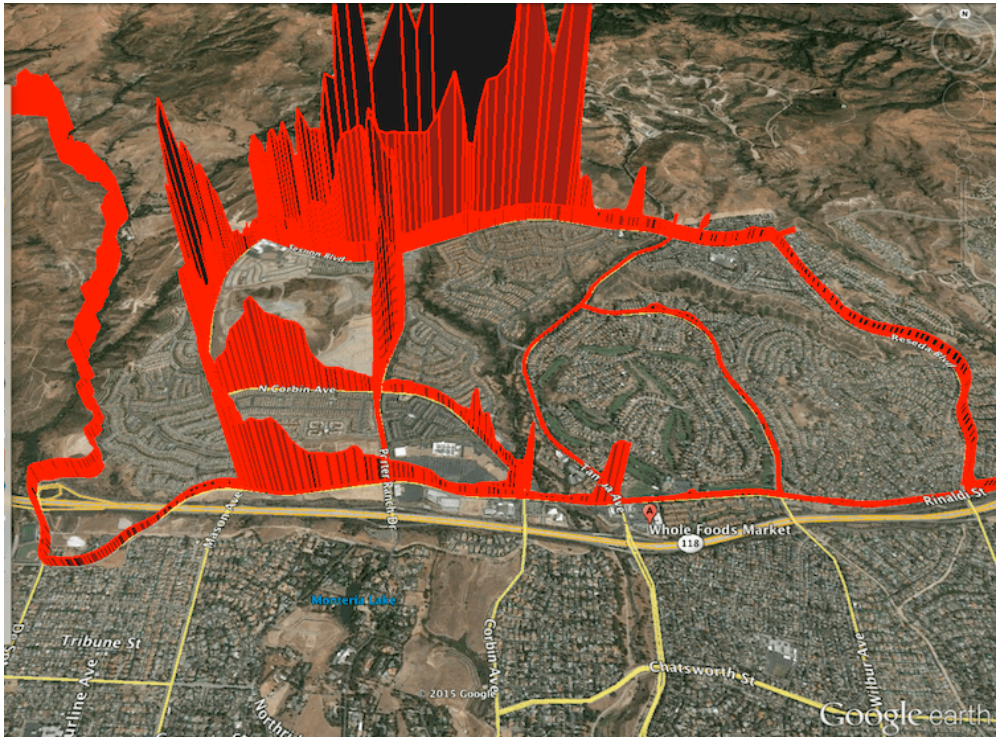


- Data of 10 days is used;
- This is a simple comparison by averaging TCCON data within 1 hours of satellite overpass and satellite data within 200 km over the ground site;
- Better agreement can be achieved if using of averaging kernels

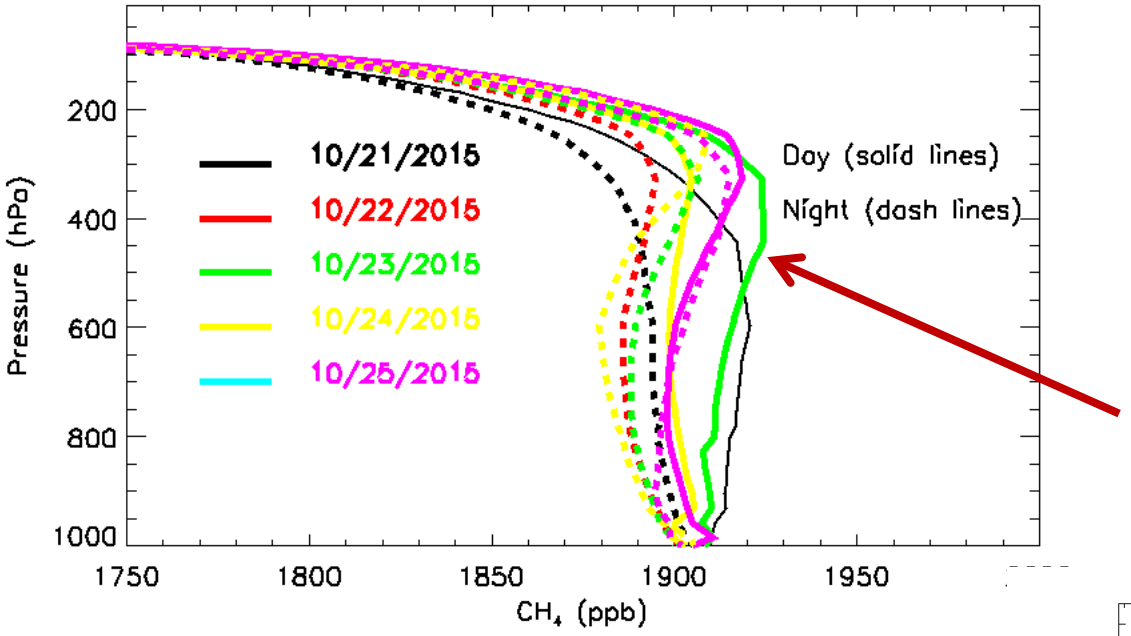
Example : Largest leakage in U.S. history
Aliso Canyon Gas Leakage (10/23/2015- 2/18/2016)

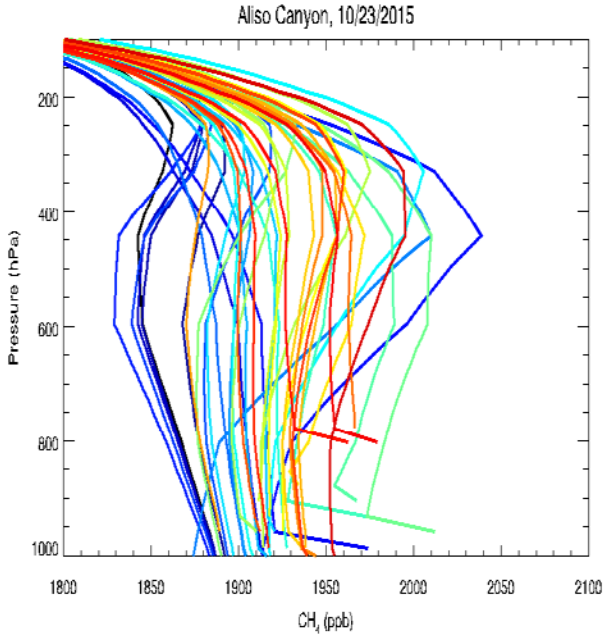


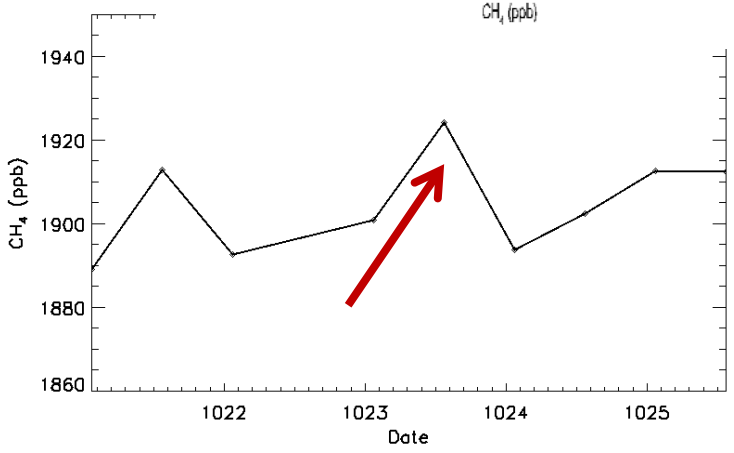
Surface Measurements



Can CrIS Capture the Leakage of CH_4?

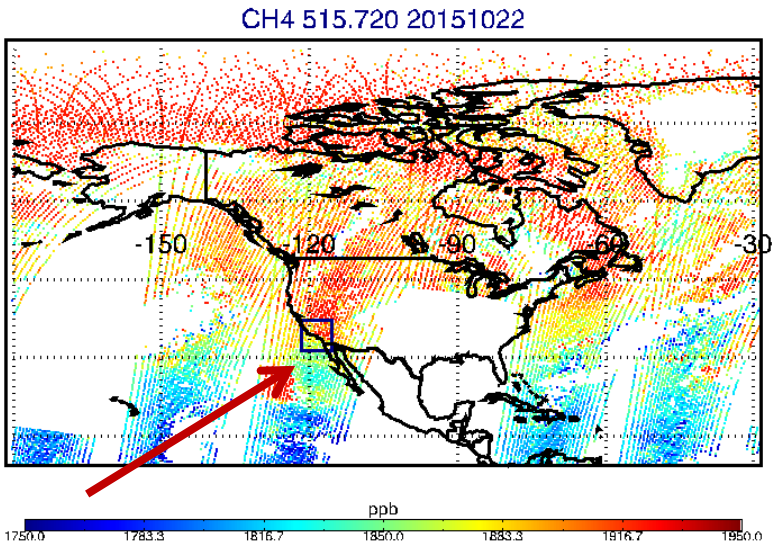


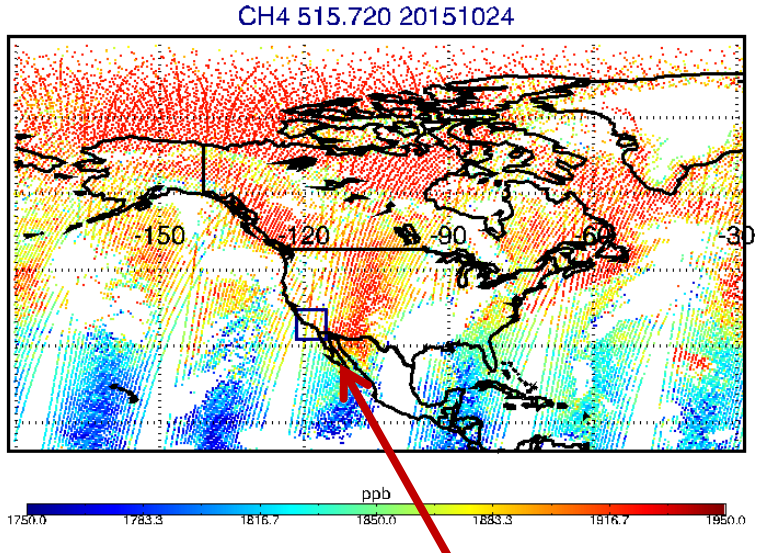


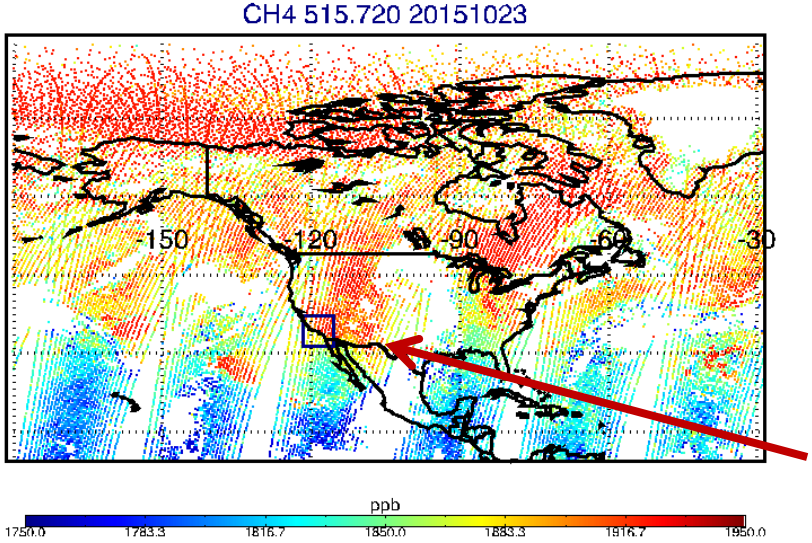


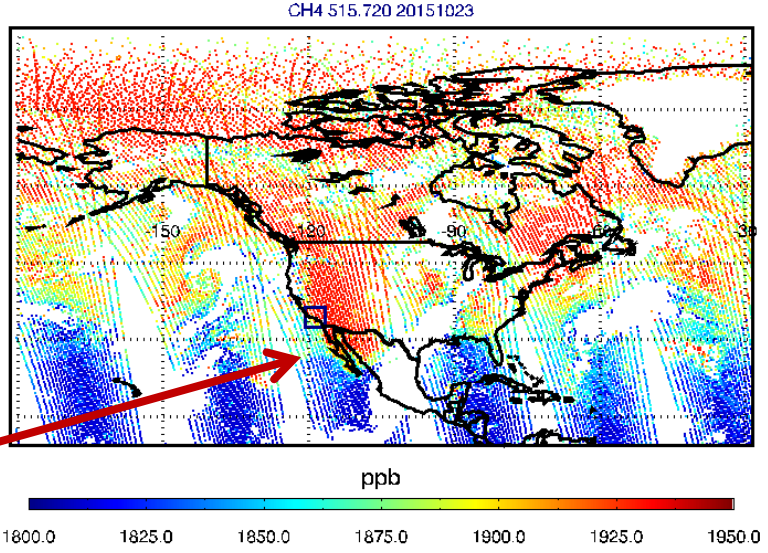
In daytime the retrieved CH_4 is larger than in the night time;
There are

Can CrIS Capture the Leakage of CH_4 – cont'd ?

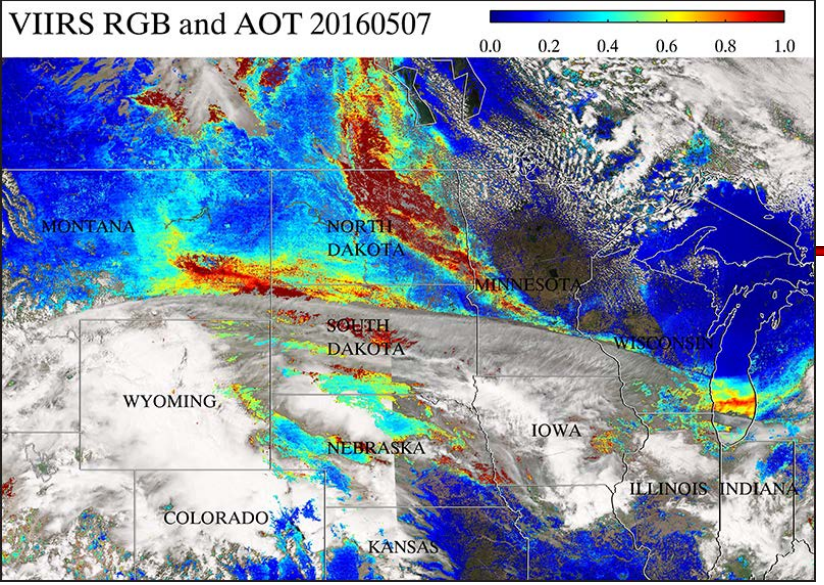








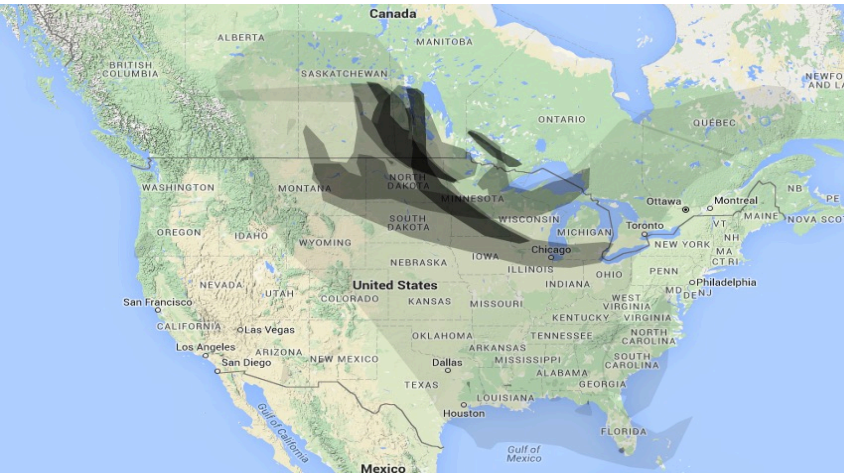
Example of CO: 2016 Fort McMurray Wildfire



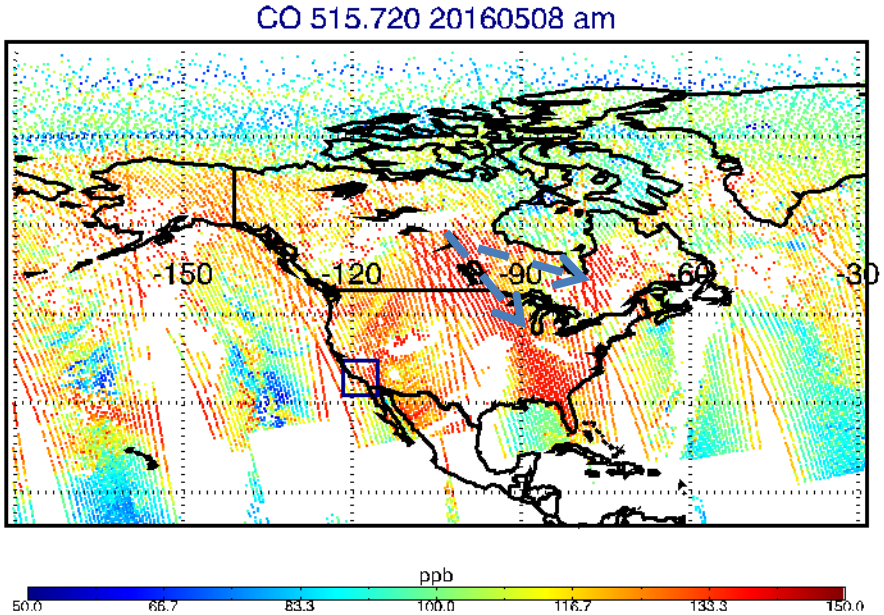
Huff and Kondragunta, EOS, V98, 6, 2017



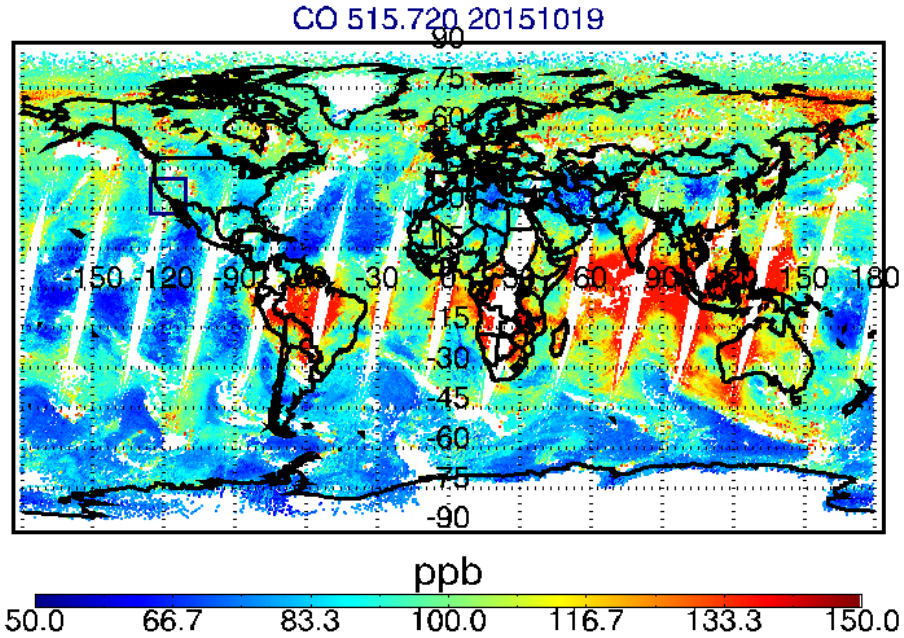
MODIS/Aqua captured smoke from the Ft. McMurray wildfire and other Canadian wildfires billowing across the Atlantic Ocean.

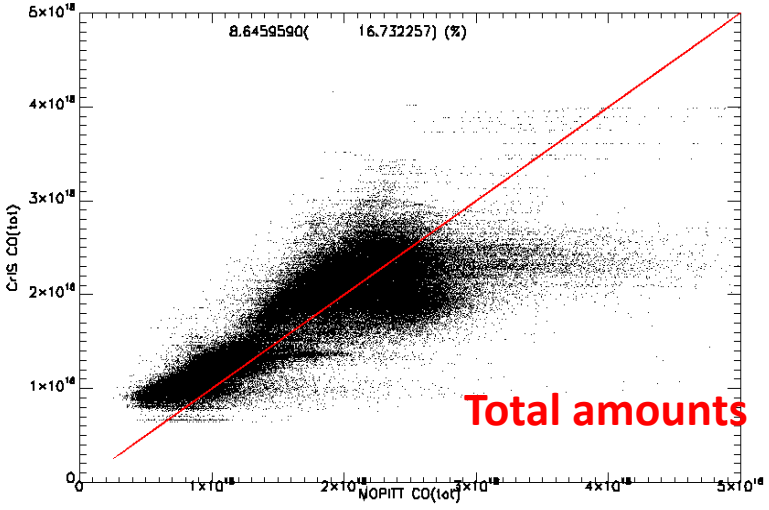


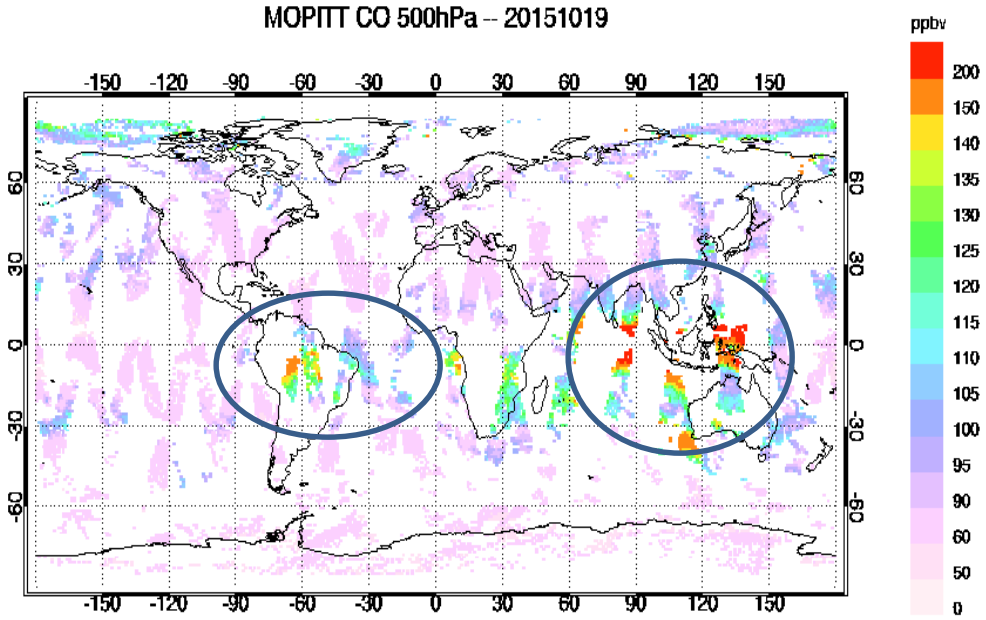
Wildfire Smoke map, 4:30 p.m. May 8, 2016, from Weatherunderground,

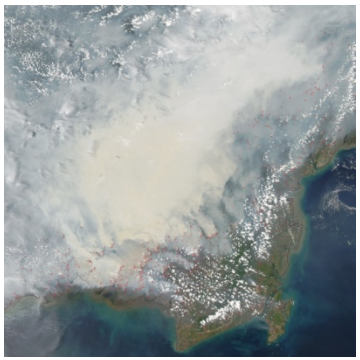


Example of CO (2): Fires in Indonesia (9/20-11/8,2015)









Brownish-gray smoke obscured the island of Borneo from MODIS in October 19, 2015. Image from [NASA Earth Observatory.]

Summary

1. The major sensitivity of CrIS is in the mid-upper troposphere but it is very small in the lower troposphere, so CrIS cannot capture the surface emission. 5% error of the firstguess in the lower troposphere will lead to 1.2% error in the total amount – making it hard to meet the requirement in 1% accuracy.

2. Cloud-clearing is a great part from NUCAPS but we have to be very careful to set QC for all trace gases;

3. Recent improvements (firstguess, channel selection, tuning and CH_4QC) are promising, but more works need to be done, particularly we need more profile validation using aircraft measurements.

4. The examples show some promising results to use CrIS to observe the **CO plume** from wildfires, and the possibility to capture the **CH_4 leakage** from Aliso Canyon Oil Field and Gas Storage Facility in California.

Future Works

- Trace gases maturity review will be made in Nov/Dec., and this is the deadline for us to finalize the update to trace gases algorithms; Another delivery will be delivered by that time frame;

- In addition to the operational system, I will use an offline system with more update to trace gases retrievals to reprocess SNPP CrIS FSR data since Dec.4, 2014 to present. Any update with new sciences can be considered, and these work will help our future update to NUCAPS operational system.

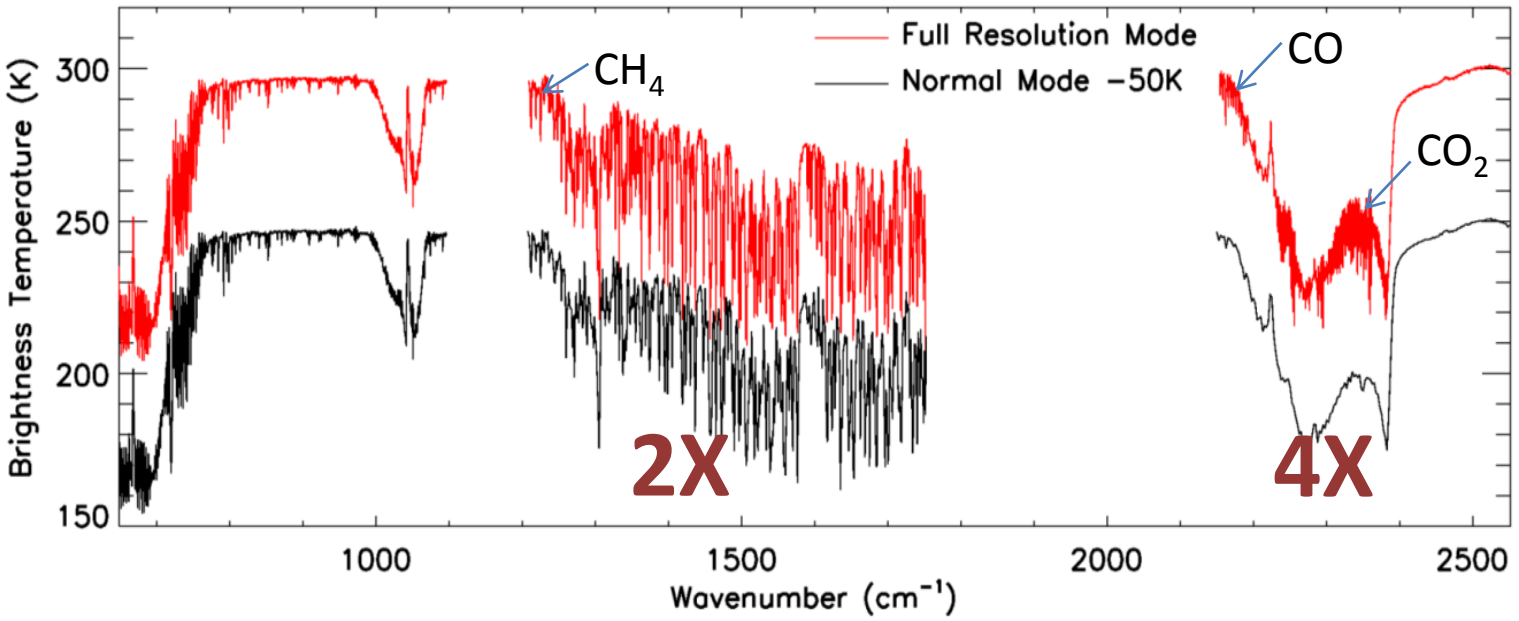
Xiaozhen.Xiong@noaa.gov

Questions/Suggestions



Xiaozhen.Xiong@noaa.gov

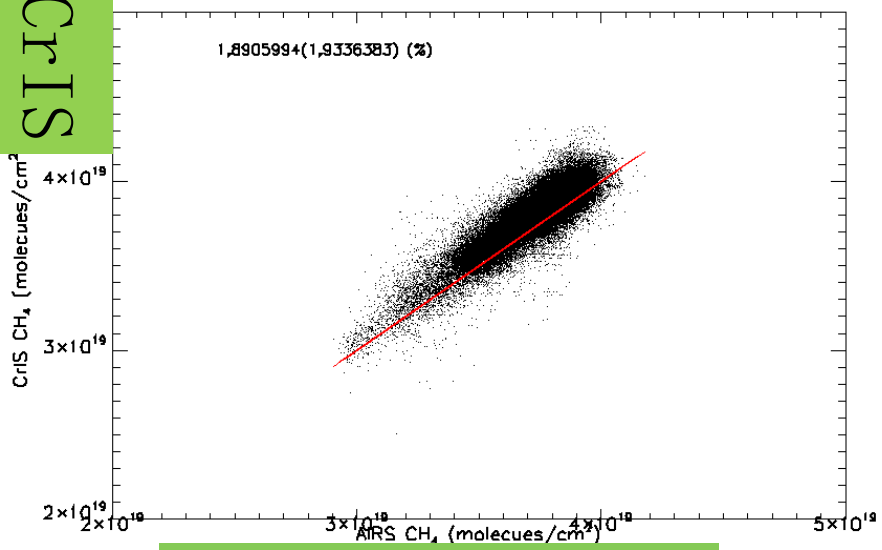
FSR Data of Cross-track Infrared Sounder (CrIS) on S-NPP



Increase of spectral resolution by 4X in SLW greatly benefits CO retrieval;
Not used for CO2 (so far)
Increase of spectral resolution by 2X in MLW benefits CH4 retrieval;

CrIS (old) vs AIRS CH_4

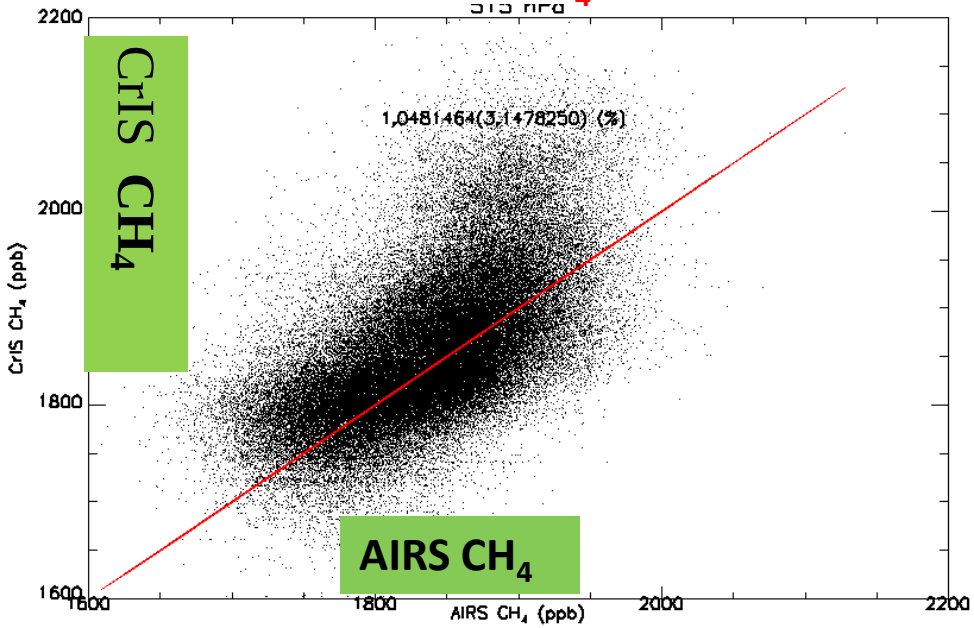
CrIS



Total amounts from AIRS

CH_4 @ 515hPa

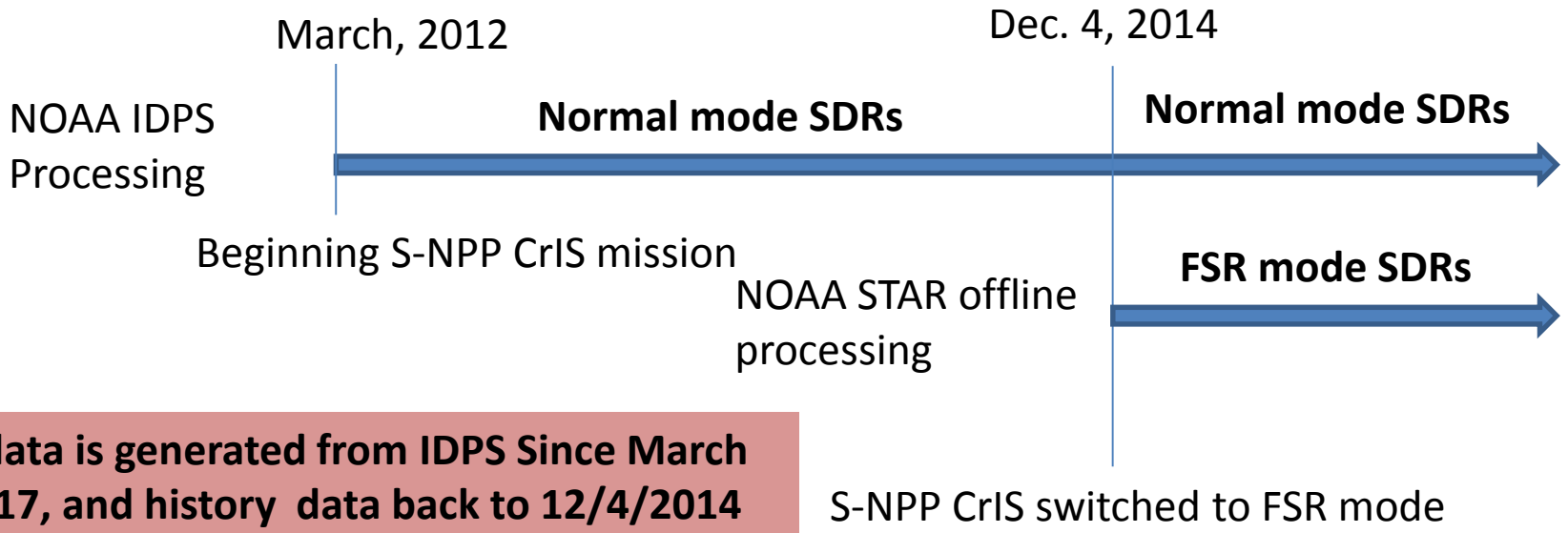
CrIS CH_4



AIRS CH_4

Cross-track Infrared Sounder (CrIS) on S-NPP and JPSS-1

Soumi National Polar-orbit partnership (S-NPP)
Joint Polar Satellite System (JPSS)



FSR data is generated from IDPS Since March 8, 2017, and history data back to 12/4/2014 can be obtained from STAR

- **CrIS started to operate in the full spectral resolution (FSR) mode since Dec.4, 2014, with spectral resolution of 0.625 cm^{-1} for all three bands, thus has 2211 channels as compared to 1305 channels in normal mode;**

Using NH_3 Retrievals from the Cross-track Infrared Sounder to Improve Emission Inventories and Models

M. J. Alvarado[1], K. E. Cady-Pereira[1], M. Shephard[2], C. R. Lonsdale[1], E. Winijkul[1], C. M. Brodowski[1], D. K. Henze[3], and S. Capps[3,*]

[1]Atmospheric and Environmental Research
[2]Environment and Climate Change Canada
[3]University of Colorado - Boulder
*Now At Drexel University

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Copyright 2017, Government sponsorship acknowledged.

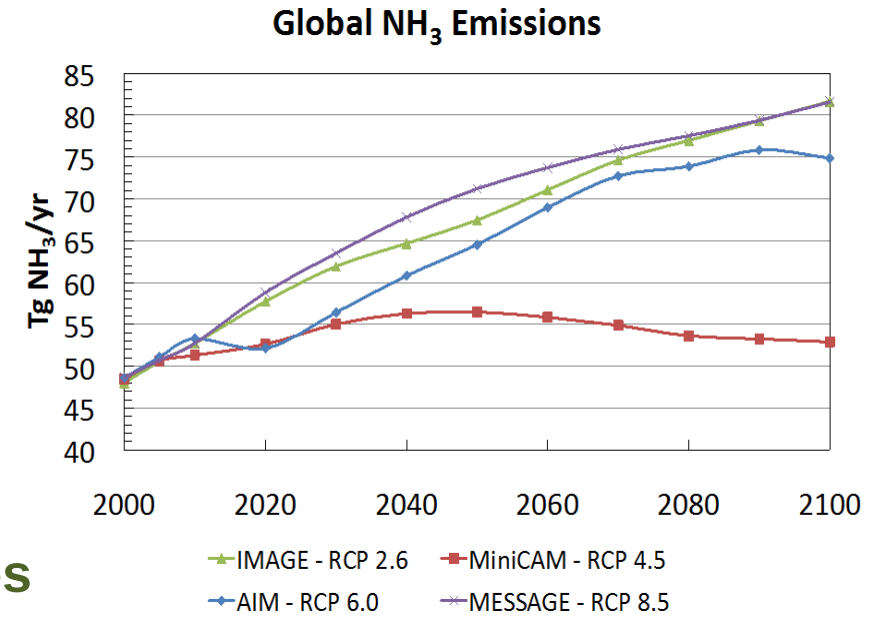
NH_3 is a $PM_{2.5}$ precursor and reactive N species

$NH_3 + HNO_3 \leftrightarrow NH_4NO_3$

$2\,NH_3 + H_2SO_4 \rightarrow (NH_4)_2SO_4$

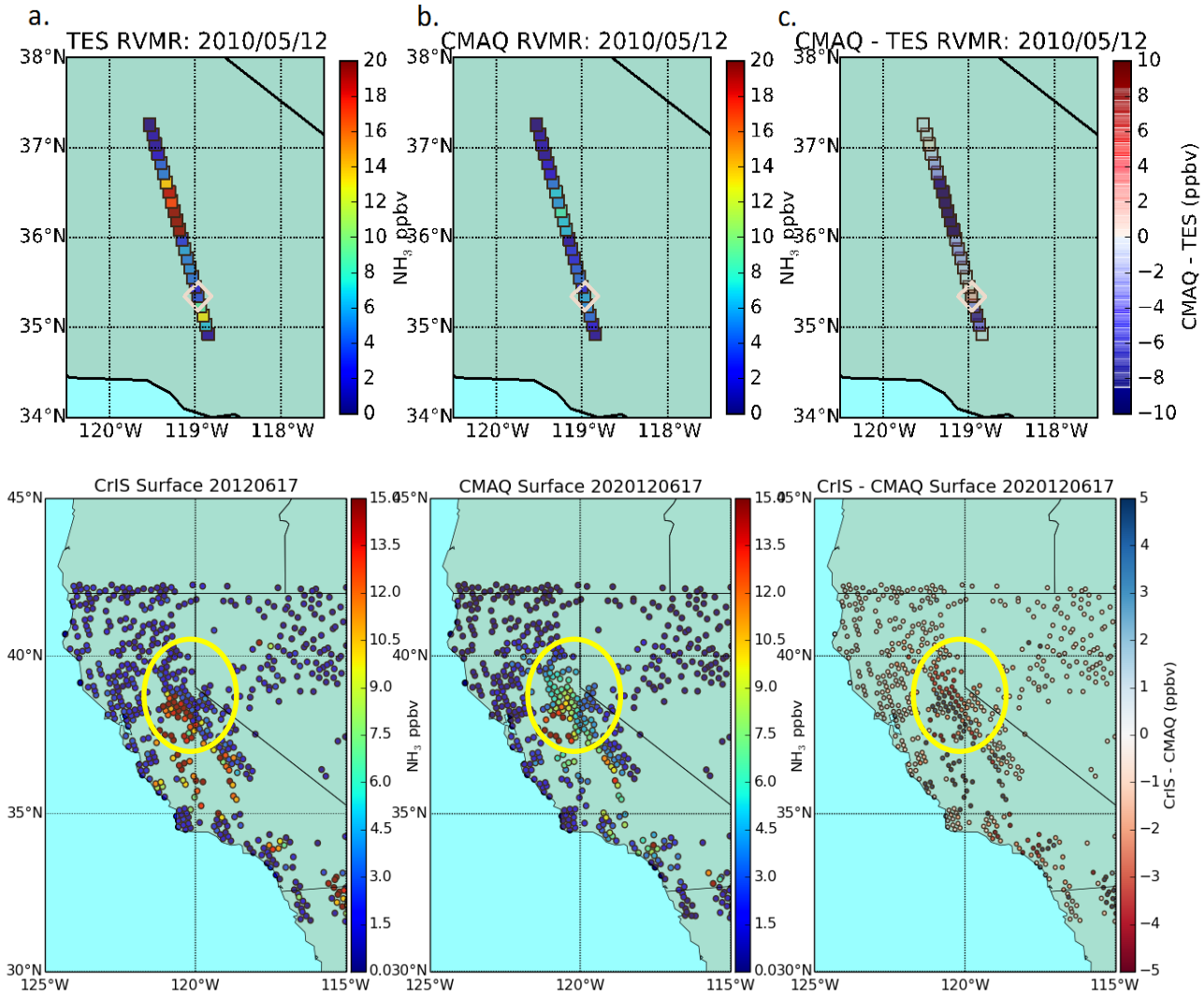
- **Increase incidence of cardiovascular and respiratory diseases**
- **Increase number of CCN**

- **NH_3 is also one of the most important reactive nitrogen species**
  - **Leads to soil acidification, water eutrophication (e.g. algal blooms)**
  - **Ammonia is the least well understood part of the nitrogen cycle**



SO_2, NO_X emissions decreasing due to controls, but NH_3 increasing!

Using Satellites to Investigate NH_3 Sources



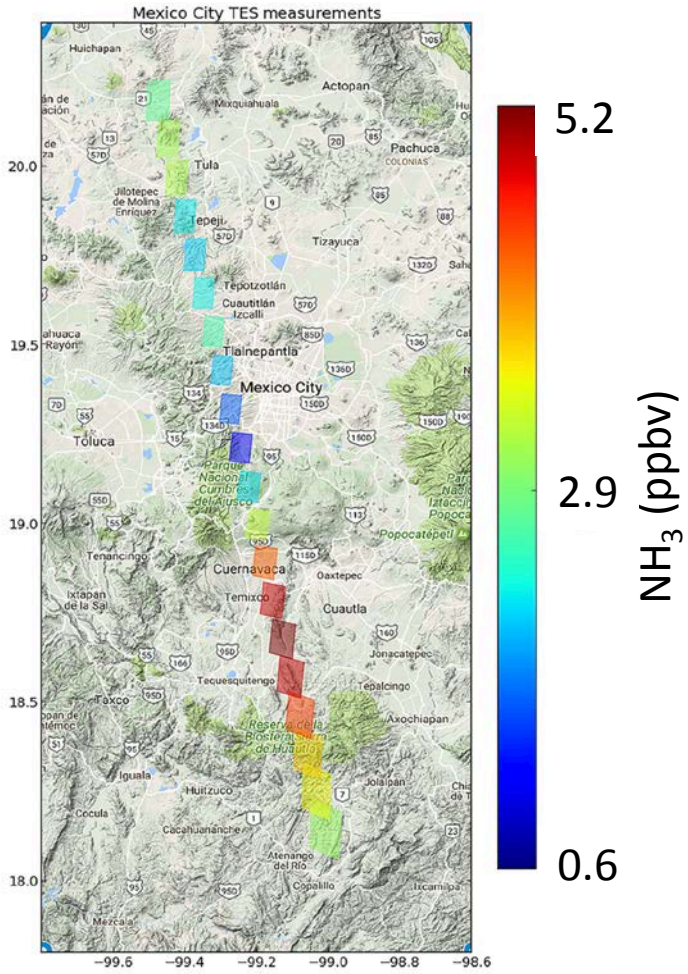
- TES NH_3 transects over Bakersfield in CalNex suggested a x2 underestimate in afternoon due to diurnal cycle errors (Lonsdale et al., ACP, 2017)
- 2012 CrIS NH_3 is consistent with CalNex TES results.
- Some evidence of a transport error on June 17 – flow along slope not correct?

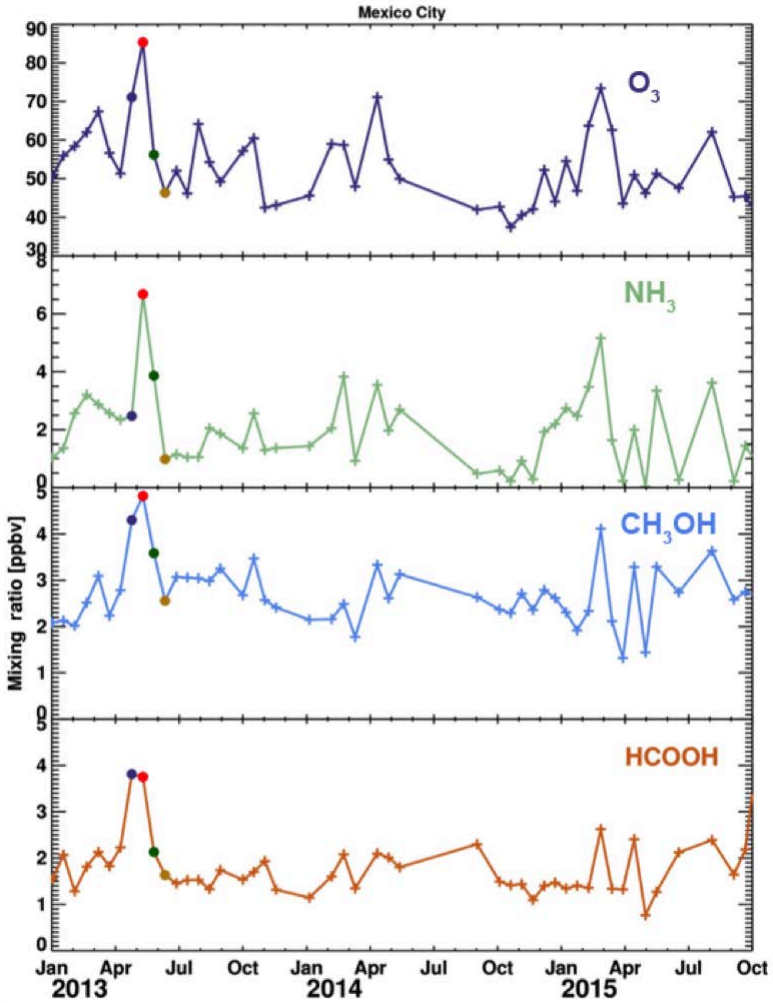
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TES Long-term Megacity Records of NH_3

Mexico City Observations (Cady-Pereira, AMT, 2017)

Mar-May Mean

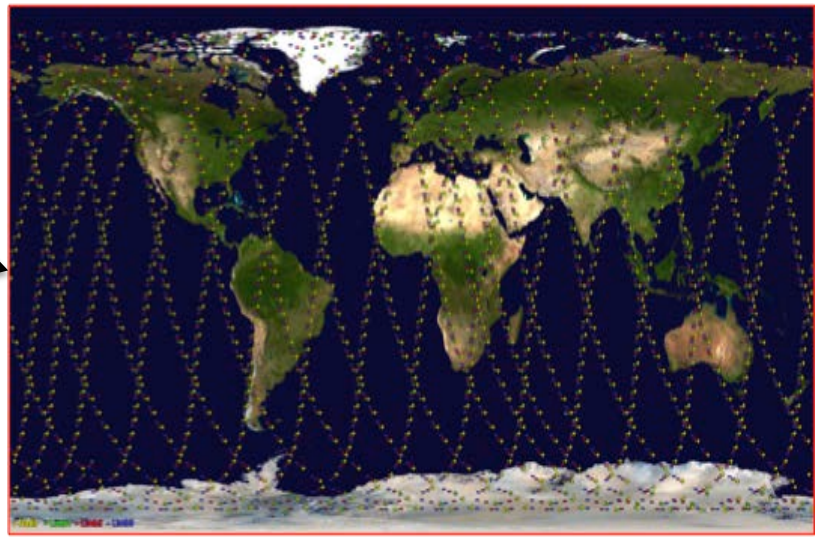




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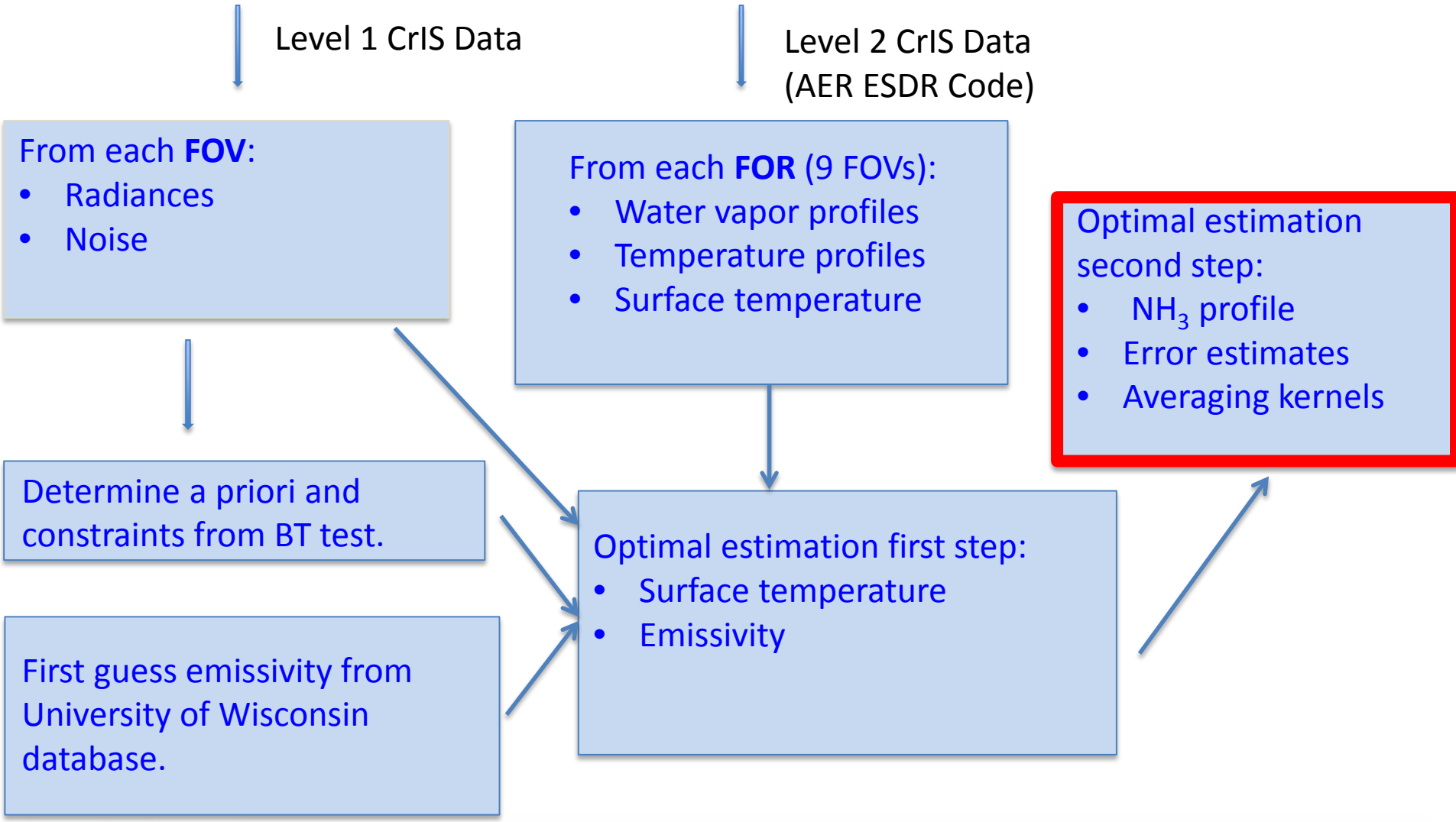
Why switch to CrIS?

- TES is past its design lifetime and has low spatial coverage
- **CrIS could monitor global NH_3 with high spatial coverage for many more years (>2022)**

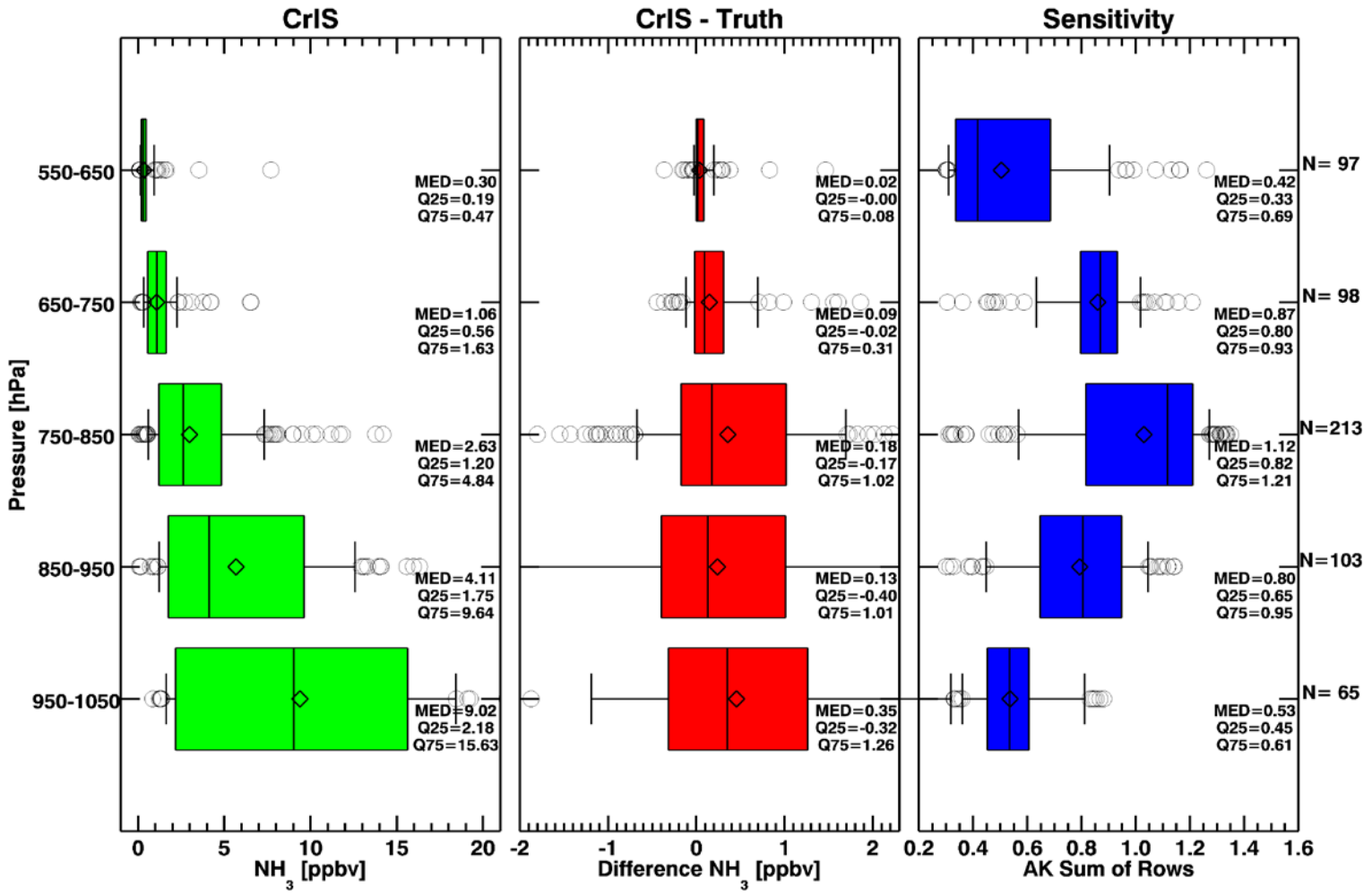


	TES	CrIS
Satellite	AURA	NPP
Available Data	July 2004-present	October 2011-present
Resolution	0.06 cm^{-1}	0.625 cm^{-1}
Footprint	5x8 km rectangle	14 km diameter circle
Repeat cycle	Once every 16 days	Daily
Equatorial crossing	1:30 am and 1:30 pm	1:30 am and 1:30 pm
Noise in NH_3 window	0.09 – 0.12 K	0.03 – 0.06 K

NH_3 Algorithm structure



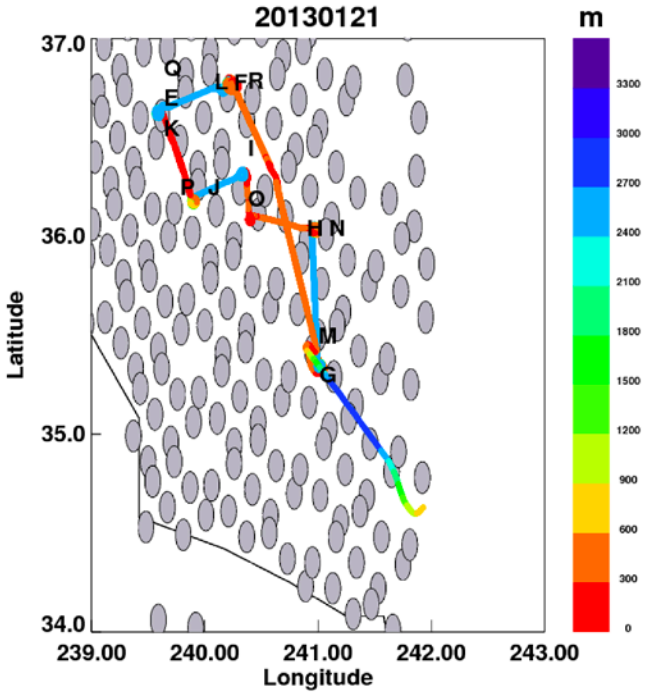
CrIS NH_3 Retrieval: Simulated Spectra

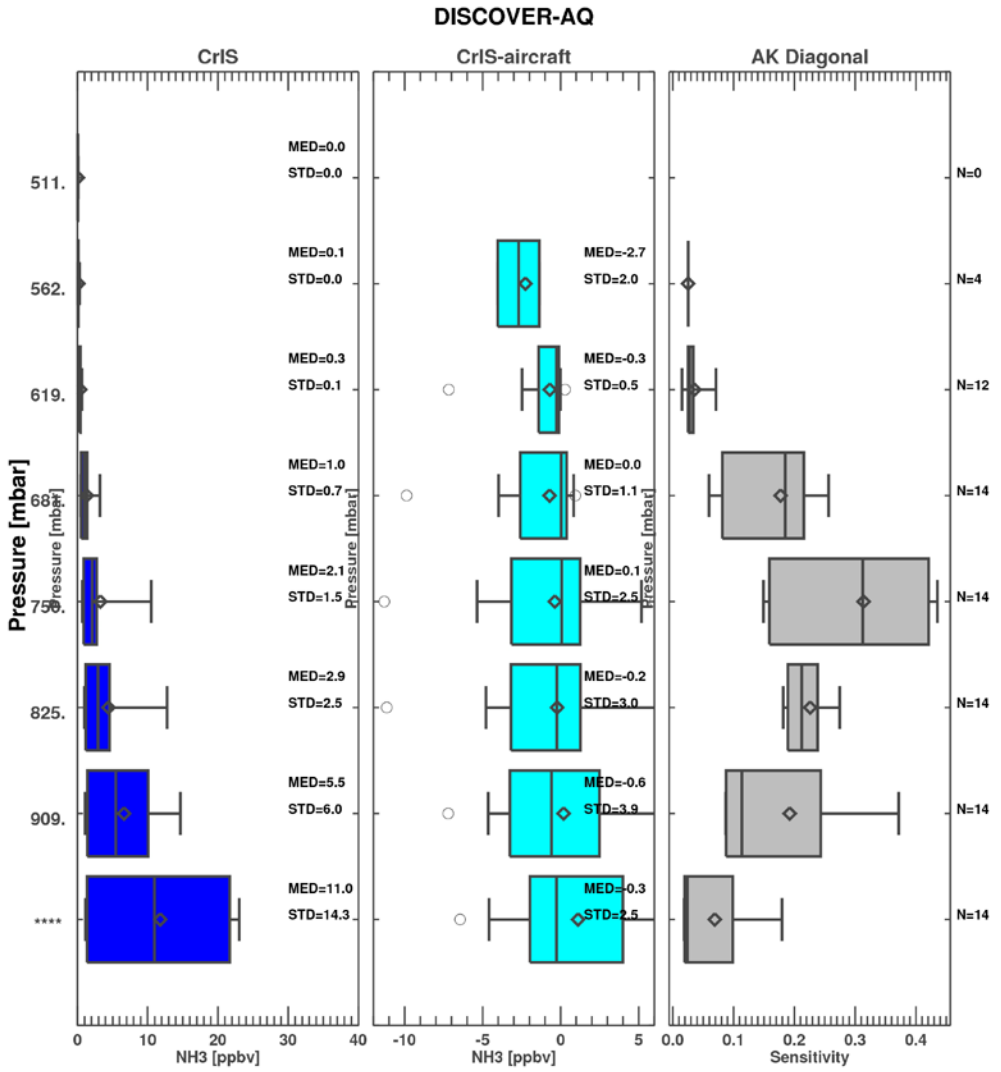


Shephard and Cady-Pereira, AMT, 2015

How CrIS compares with spirals

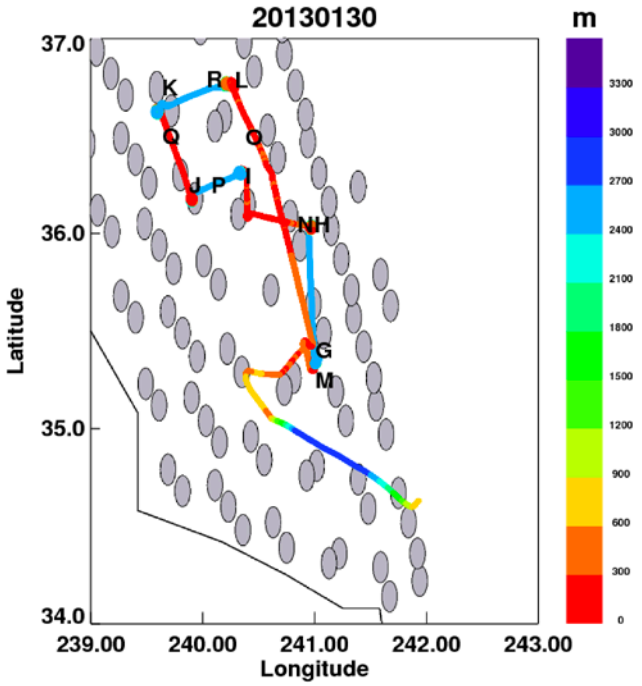
- January 21, 2013
- Matched each spiral to closest CrIS observation
- 14 spirals were compared
- Used log AK in CrIS operator
- Mismatch between CrIS surface pressure and aircraft surface pressure: shifted aircraft profiles up.

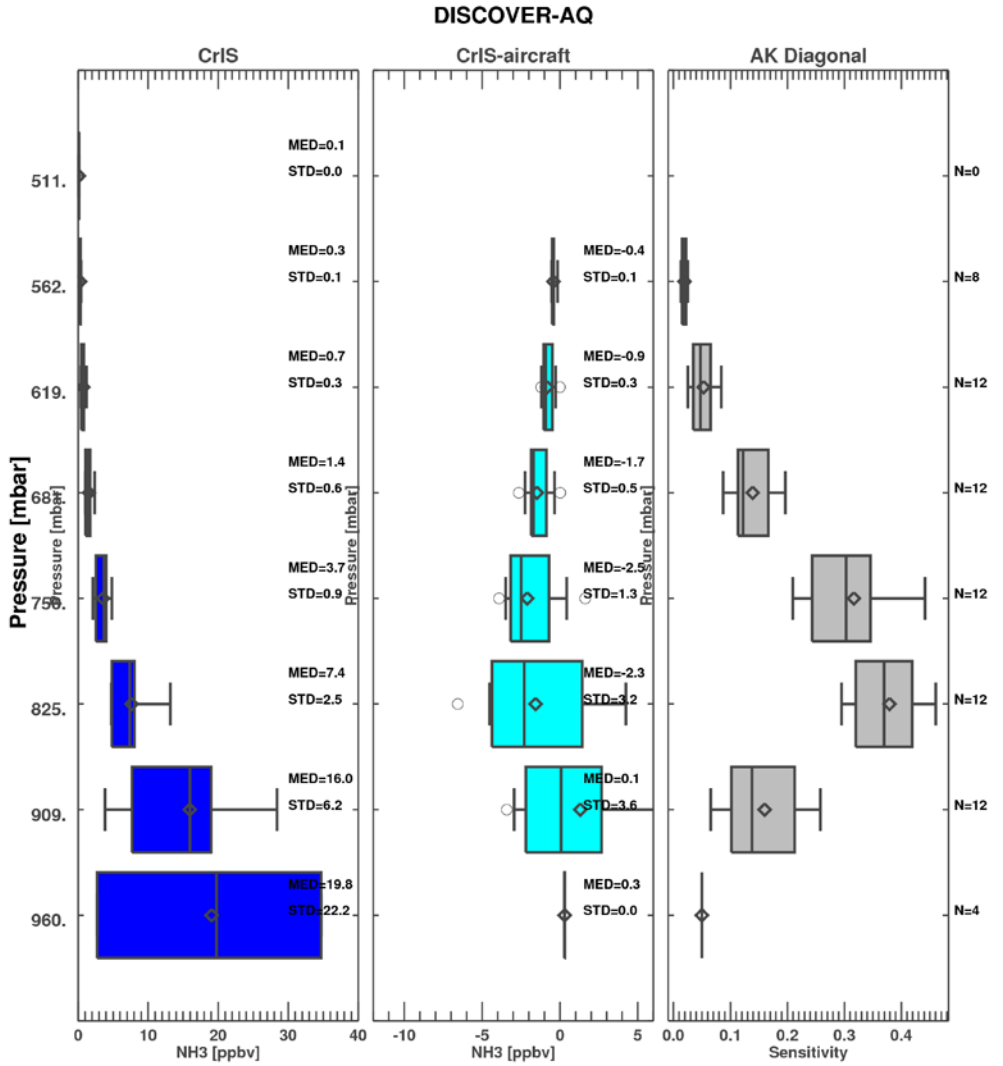




How CrIS compares with spirals

- Same as previous slide for January 30
- Rapidly growing PBL

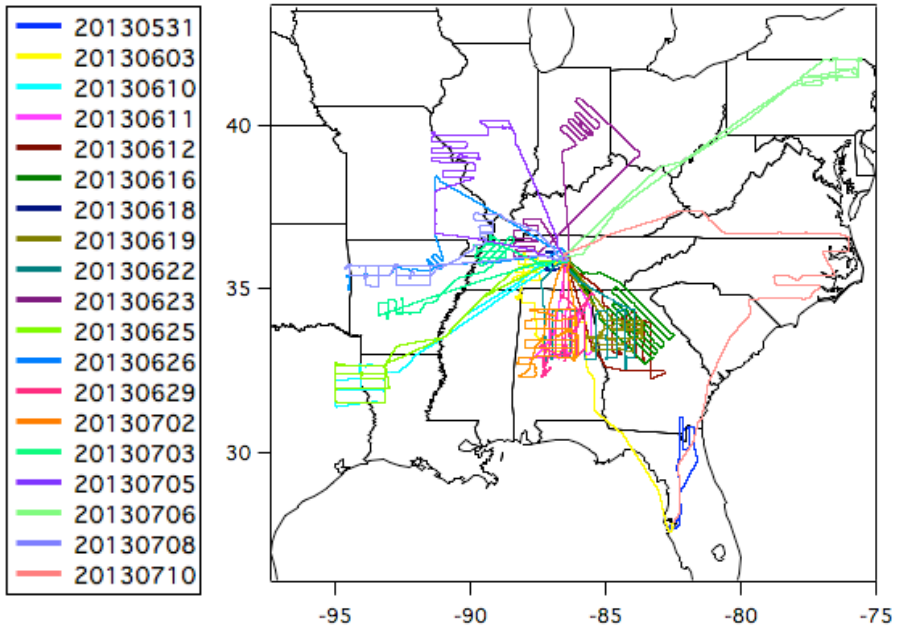




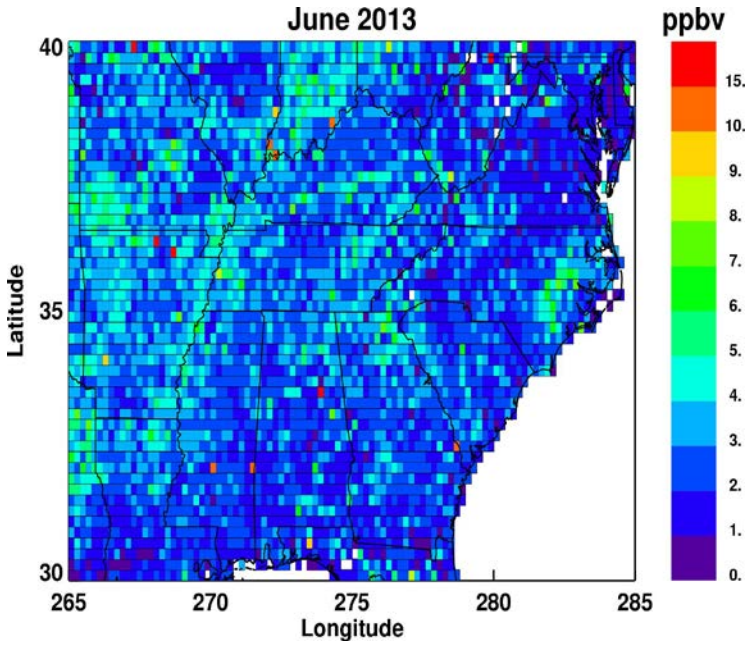
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NOAA SENEX Campaign (June-July 2013)

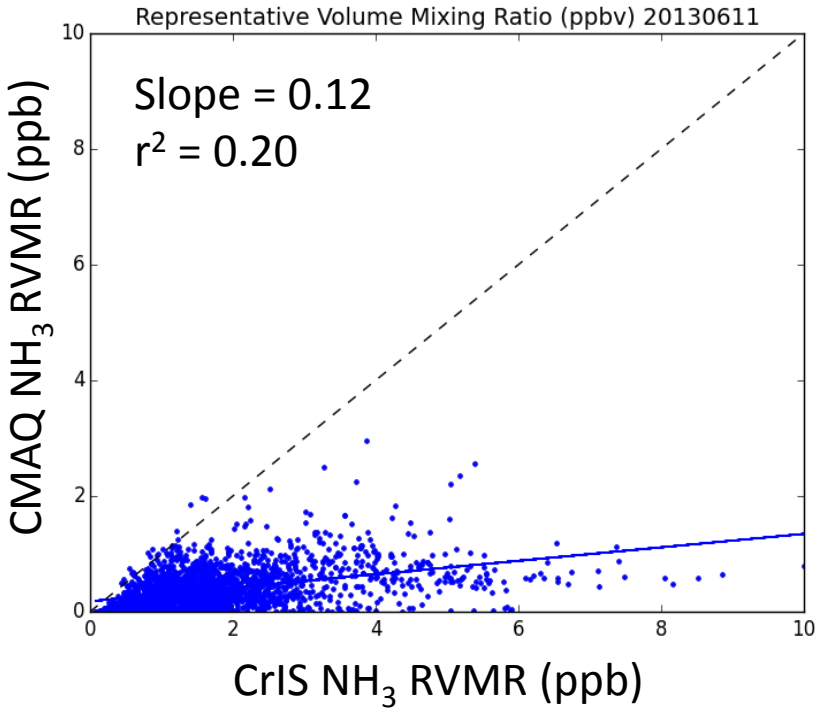
NOAA P-3 Aircraft

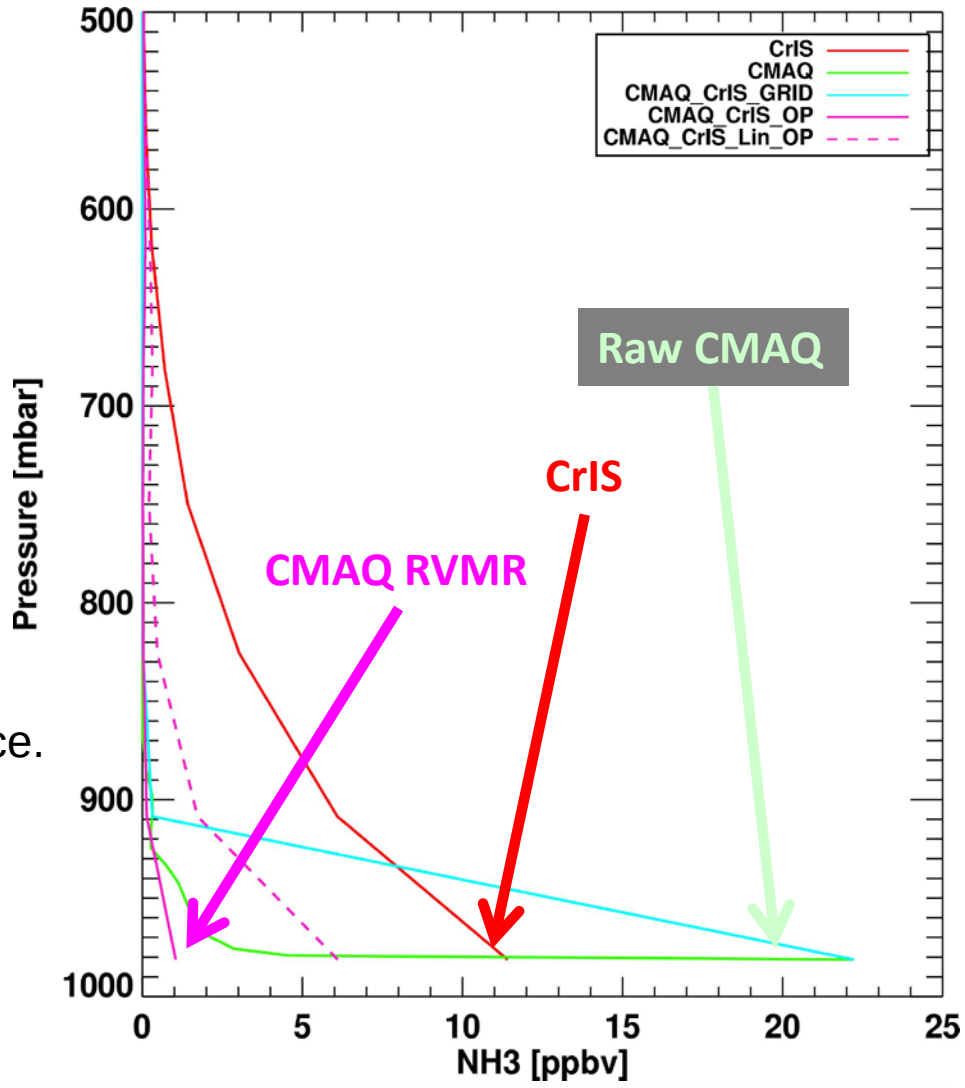


CrIS NH_3



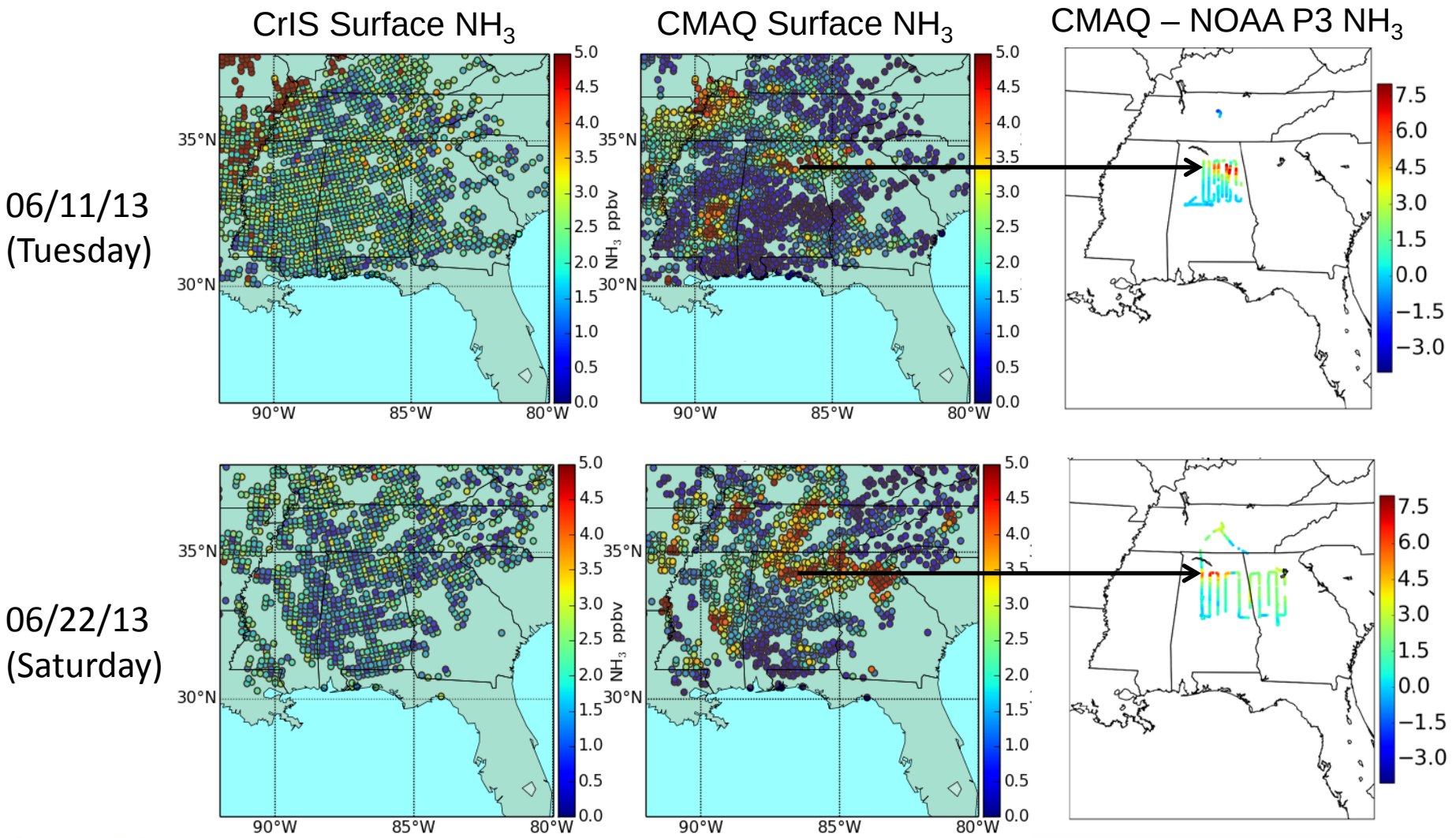
Difficulties Using NH_3 RVMR with CMAQ



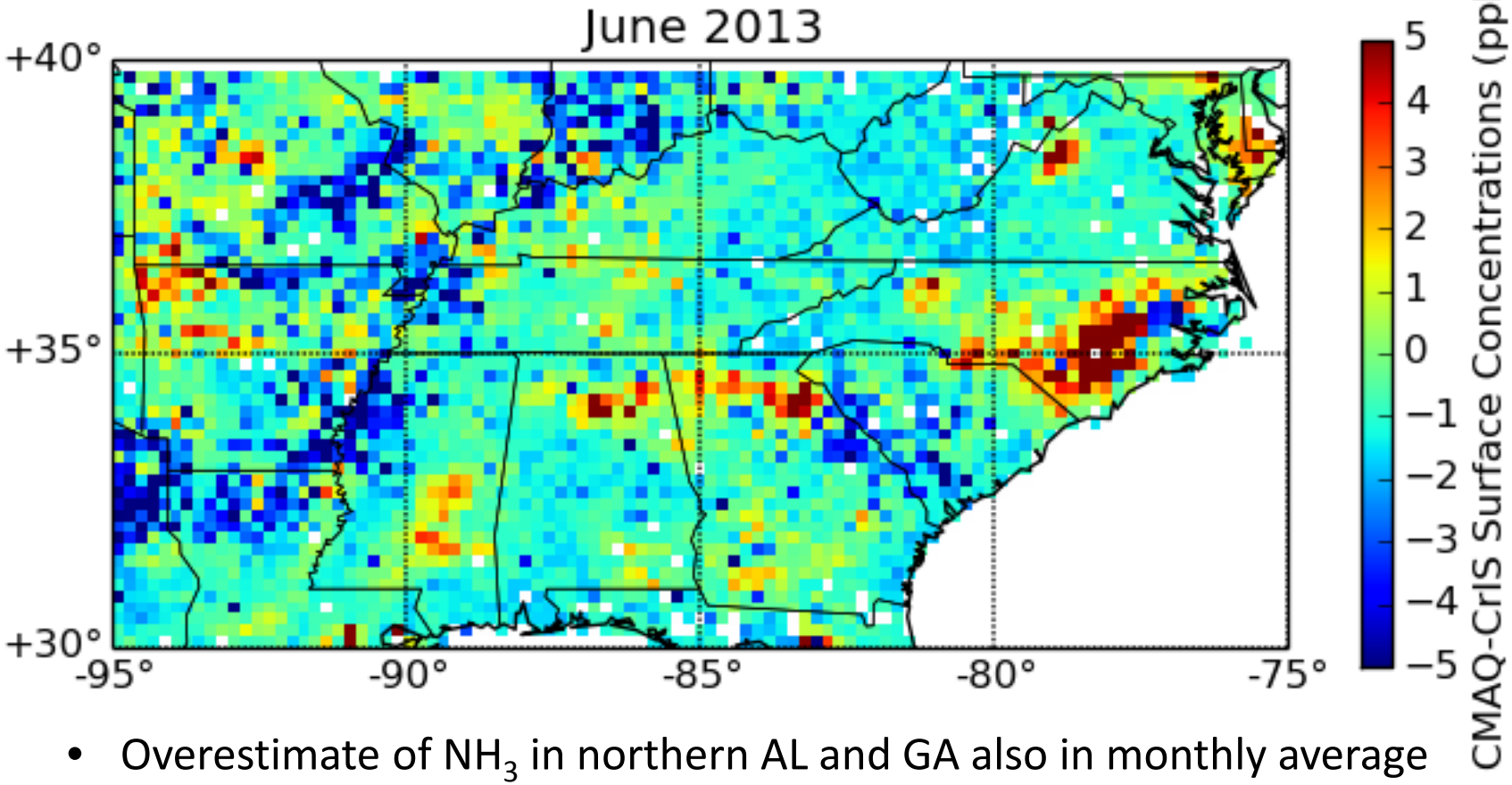


- CMAQ NH_3 profiles concentrated at surface.
- CrIS sensitivity is at higher altitudes than TES
- Using RVMR (Shephard et al., 2011) thus leads to spuriously low CMAQ values
- Instead focus on NH_3 surface gradients

Feed lot NH_3 emissions overestimated in AL

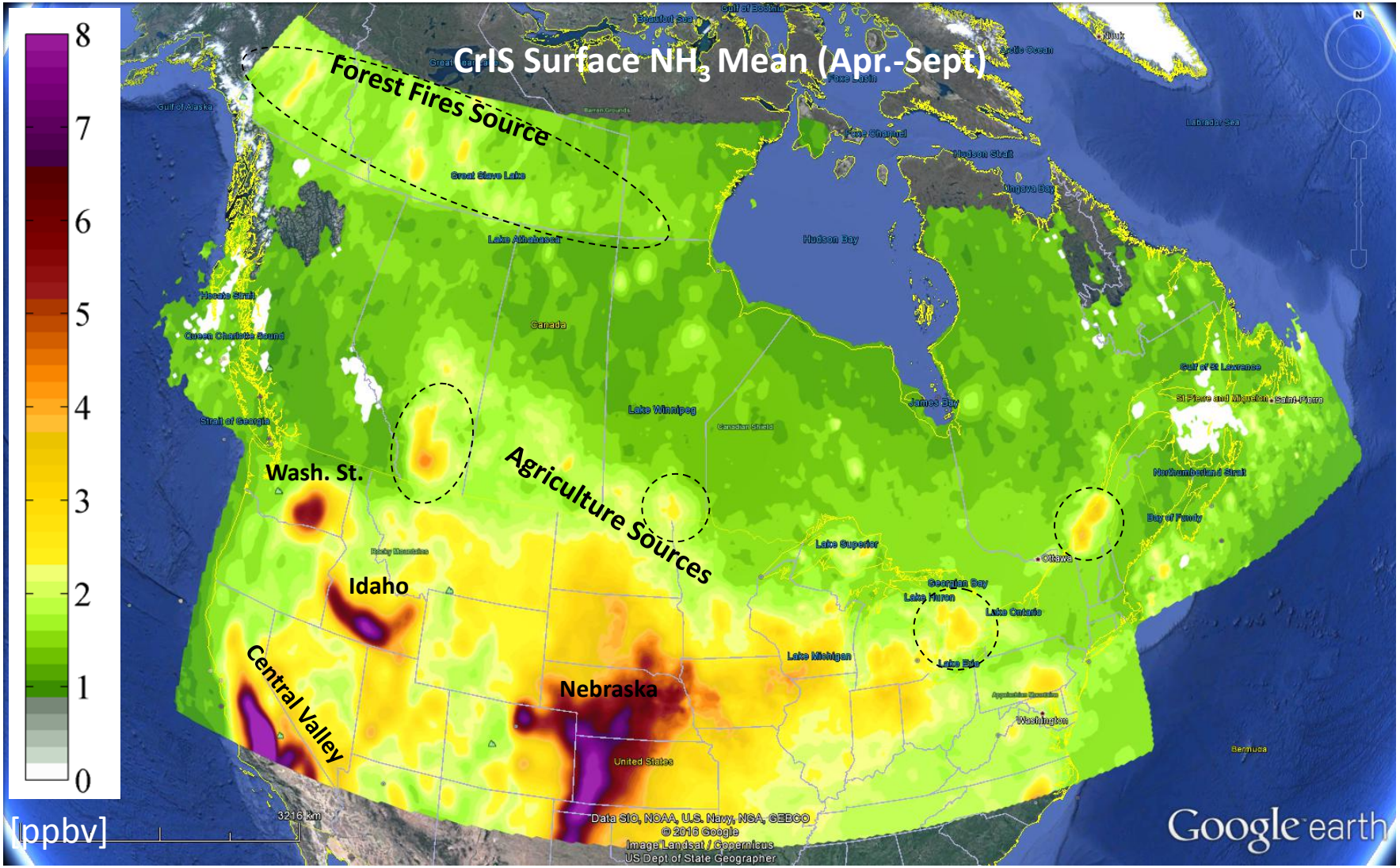


CrIS shows other errors in monthly-average NH_3 from CMAQ



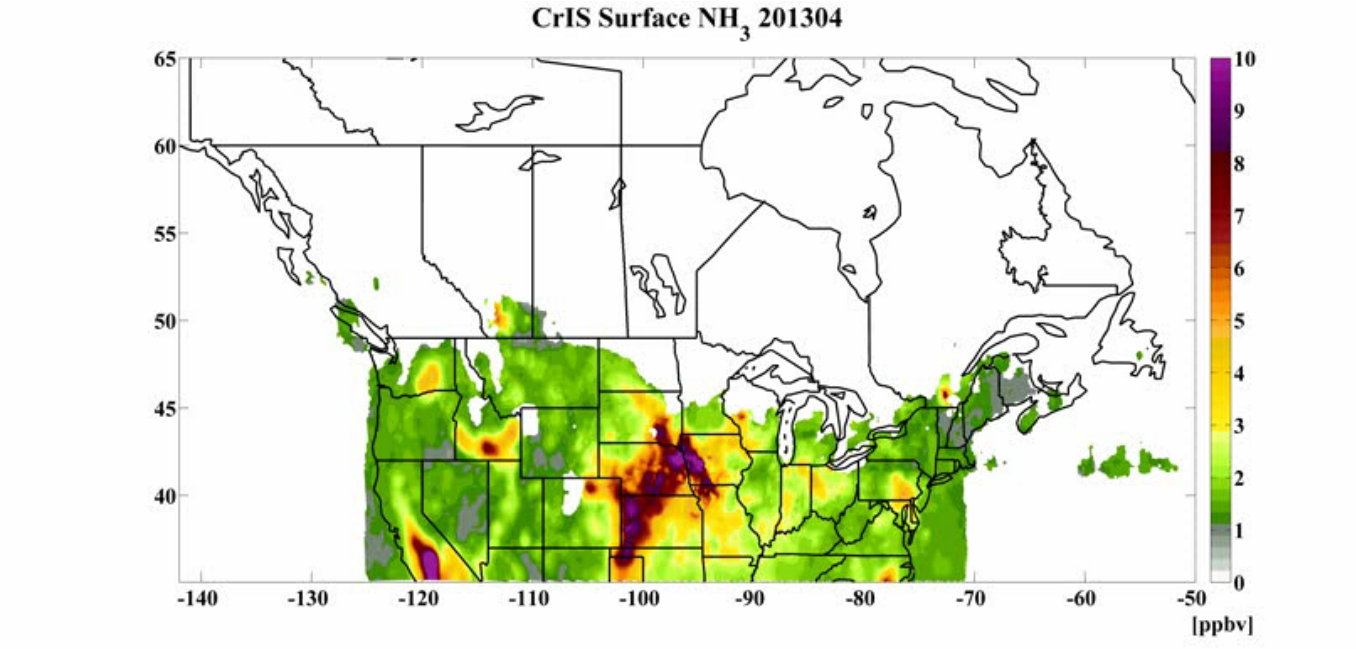
- Overestimate of NH_3 in northern AL and GA also in monthly average
- Similar overestimates in NC, MI, VA
- Underestimate along Mississippi River?

CrIS NH_3: N. America Warm Season Average 2013



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CrIS NH_3: North America Monthly Averages April to October, 2013



Captures expected temporal and spatial distributions of ammonia

- Spring fertilizer applications (May over Canada)
- Episodic events (e.g. Northern forest fires in middle of summer)

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CrIS NH_3: Example of Daily Spatial Variability of Surface NH_3 over North America on August 10 2013

MODIS

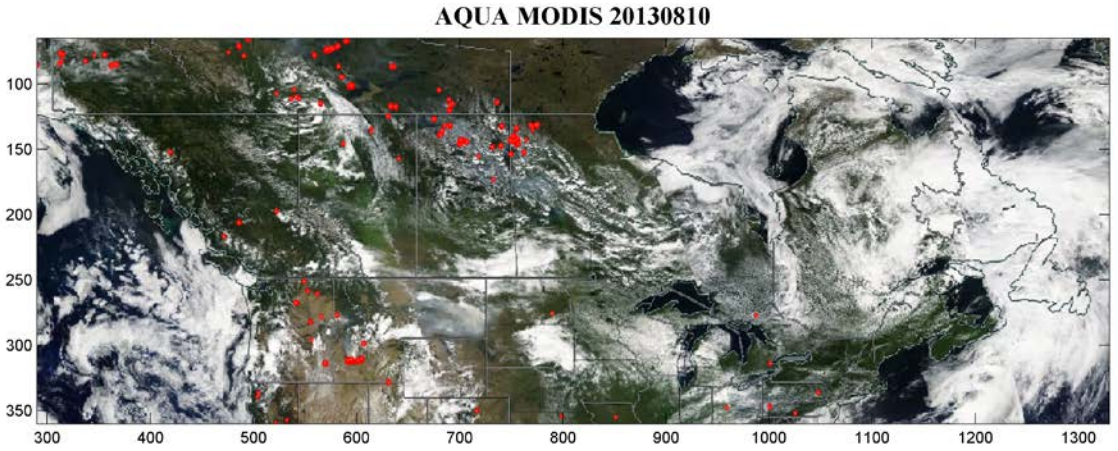
Infrared:

Fire Detection (red)

Visible:

Cloud (White)

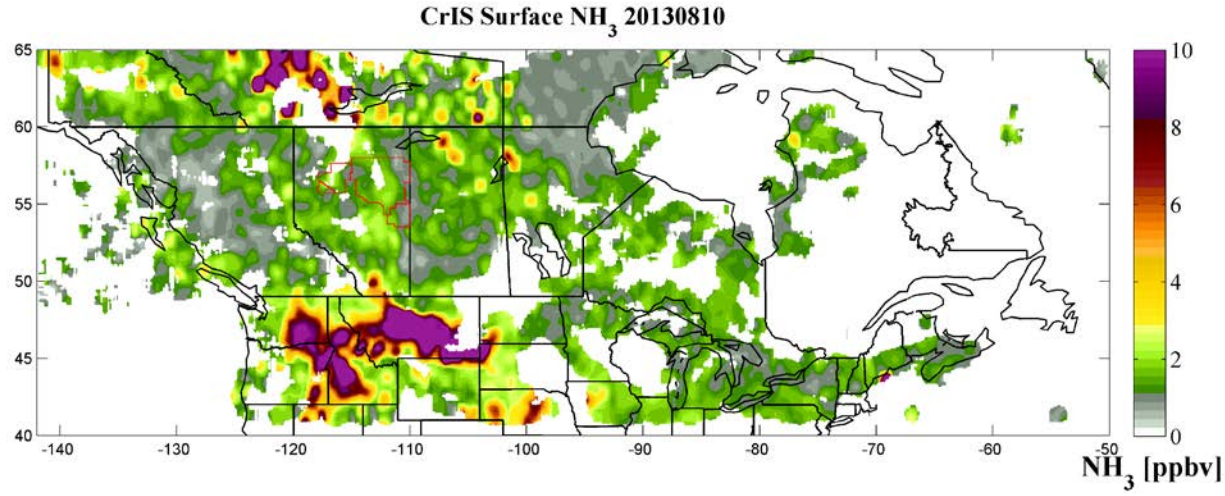
Smoke (blue/gray)



CrIS

Infrared:

NH_3



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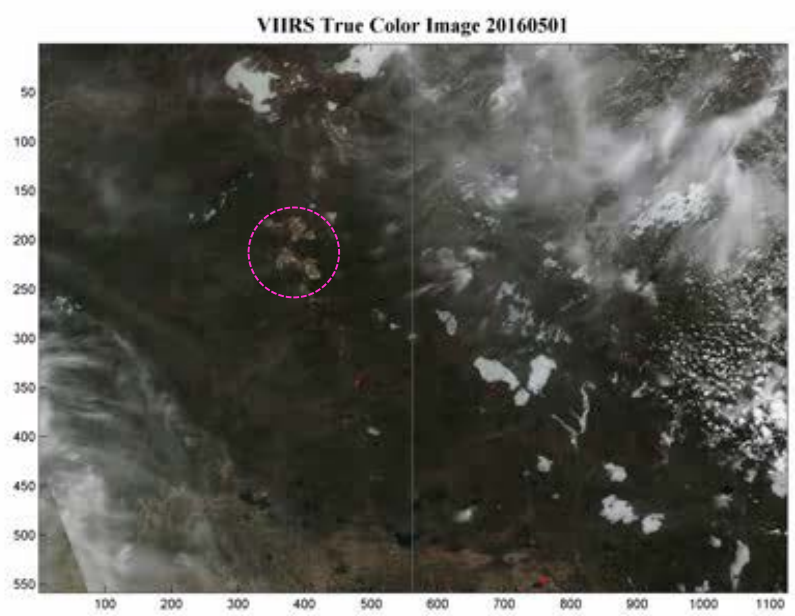
CrIS NH_3: Fort McMurray forest fires Daily values in May 2016

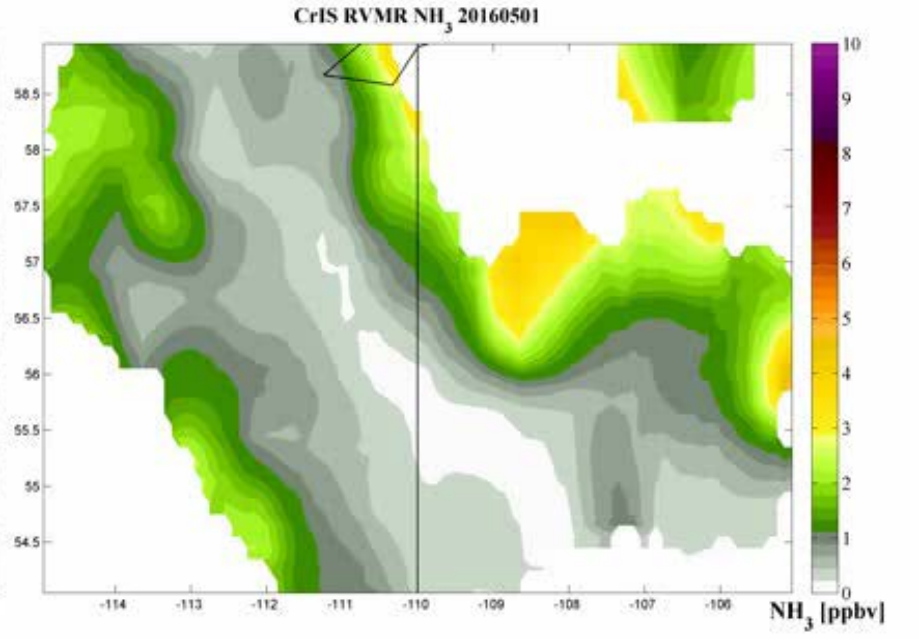
VIIRS

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

CrIS

Infrared: Ammonia (NH_3)



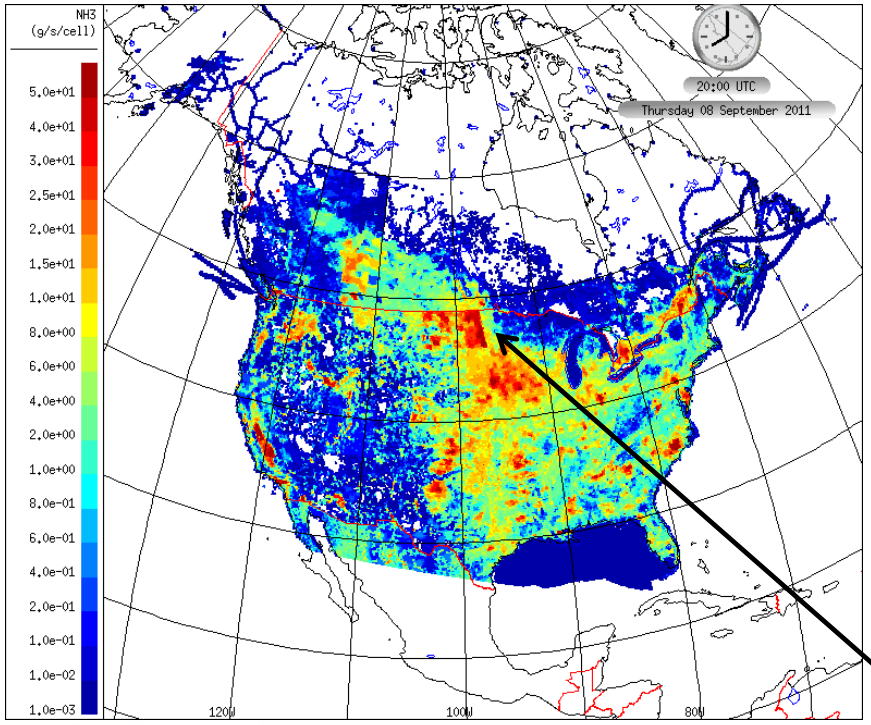


Click image to view Movie

Model Evaluation: GEM-MACH Spatiotemporal Emissions

GEM-MACH Emissions

- 15-km emissions from annual/monthly inventory using monthly/weekly/diurnal activity-based temporal profiles
- 20:00UTC hourly snapshot corresponding to satellite overpass
- No forest fire emission included

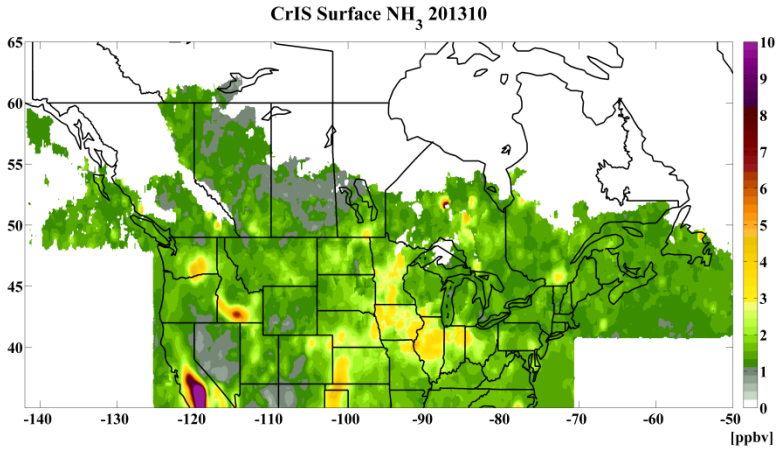


Model emission improvement study led by Junhua Zhang

CrIS Surface Concentrations

- Monthly Mean
- Satellite overpass (~1:30 local time)
- Includes contributions from forest fire

Sept 2013



Spatial and temporal distributions are generally consistent

- **some regions need improvement**
  - North Dakota (spring/fall)
- **use satellite to improve model spatial and temporal emissions**

Summary

- CrIS is able to retrieve NH_3 with similar skill to TES, but much higher spatial coverage.
- CrIS NH_3 retrievals compared well with spirals made during DISCOVER-AQ in California.
- CrIS and NOAA P-3 observations show NH_3 emissions from feed lots in northern Alabama are lower than in the 2011 NEI.
- CrIS is able to measure seasonal and spatial patterns of NH_3 from fertilizer applications and fires over US and Canada.
- Ongoing work is being done to use this data to improve NH_3 emission inventories for models.

Acknowledgements

- NOAA CPO AC4 Program Grant Numbers NA13OAR4310060 and NA14OAR4310129
- NOAA CSD and SENEX science team (A. Neuman, J. Nowak, J. Holloway, T. Ryerson, A. Middlebrook, J. Jimenez, J. Fry)
- Environment and Climate Change Canada (C. McLinden, M. Shephard)
- EPA (K. Baker, H. Pye)
- UNC CMAS Center (B.H. Baek, Z. Adelman)

Full-chemistry Volcanic Fog Forecast over Hawaii

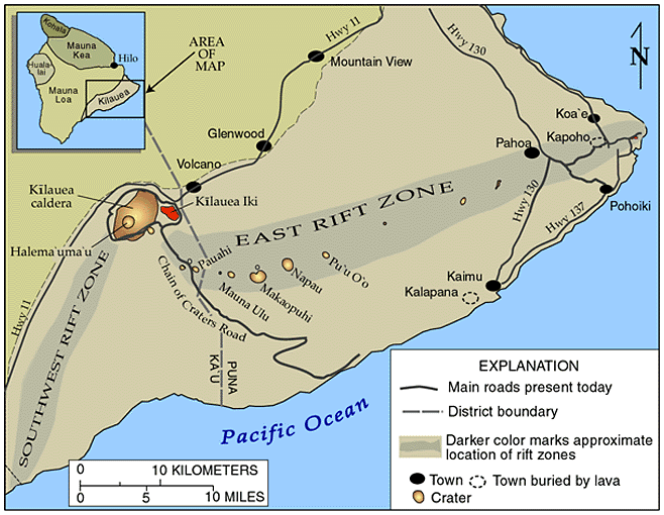
Daniel Tong, Youhua Tang, Barry Baker, Li Pan, and Pius Lee
NOAA Air Resources Laboratory

Jianping Huang and Jeff McQueen
NOAA NWS/NCEP/EMC

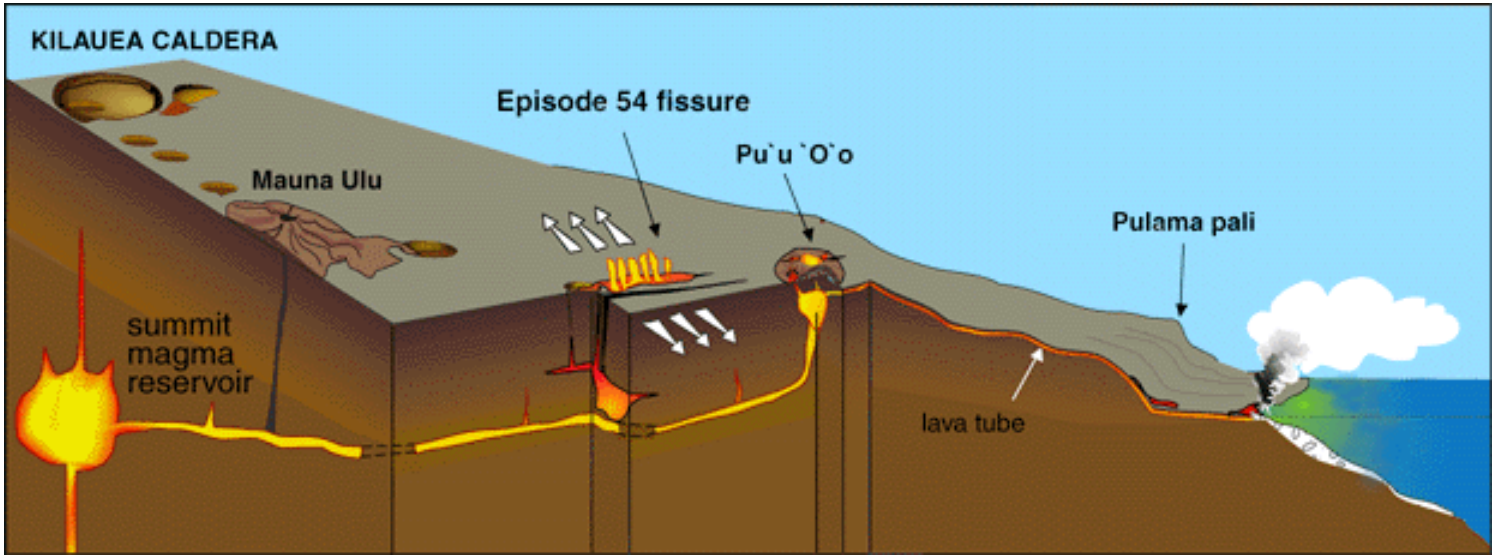
Kai Yang
Dept. of Atmospheric and Oceanic Science,
University of Maryland, College Park

A pulse of magma moving through Kīlauea's east rift zone

Kilauea Volcano over the Hawaii Island







(Source: Hawaiian Volcano Observatory: http://hvo.wr.usgs.gov)

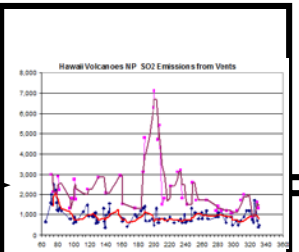
Methodology for Modeling Volcanic Emissions



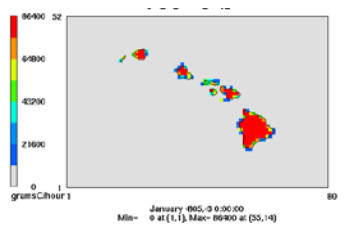
In-Situ SO_2 Measurement



Daily web update



Pre-processor



Emission Processing

Hawaiian Volcano Observatory

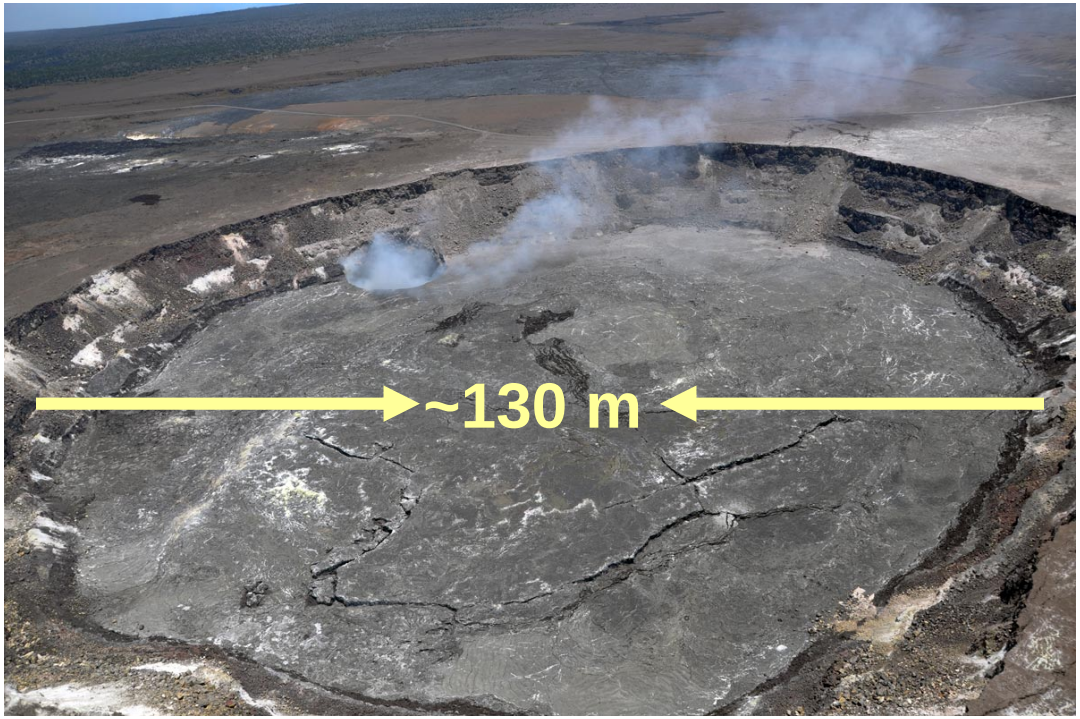
NOAA Air Resources Lab

- SO_2 measurement
  Correlation Spectrometer (COSPEC);

- Simple plume rise:
  Distributed from ground to 100 m above;

Plume Rise of Volcanic Emissions

Make it simple since we know so little about it…

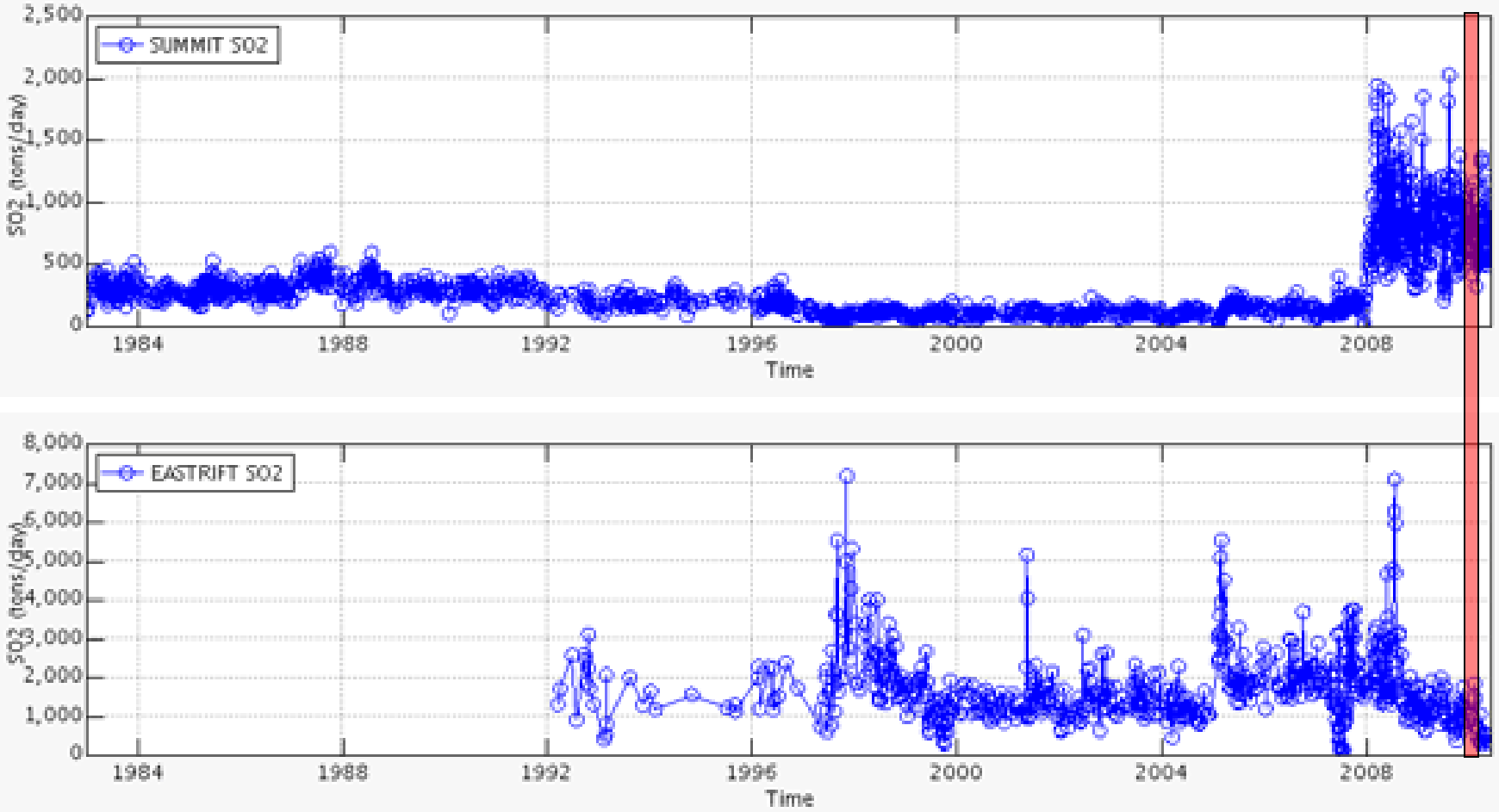






- **Multiple and moving emitting points;**
- **Emitting point below surface;**
- **Dynamic magma movement;**
- **Difficult to implement plume rise algorithms, such as Briggs (1972).**

Kilauea SO_2 Emissions

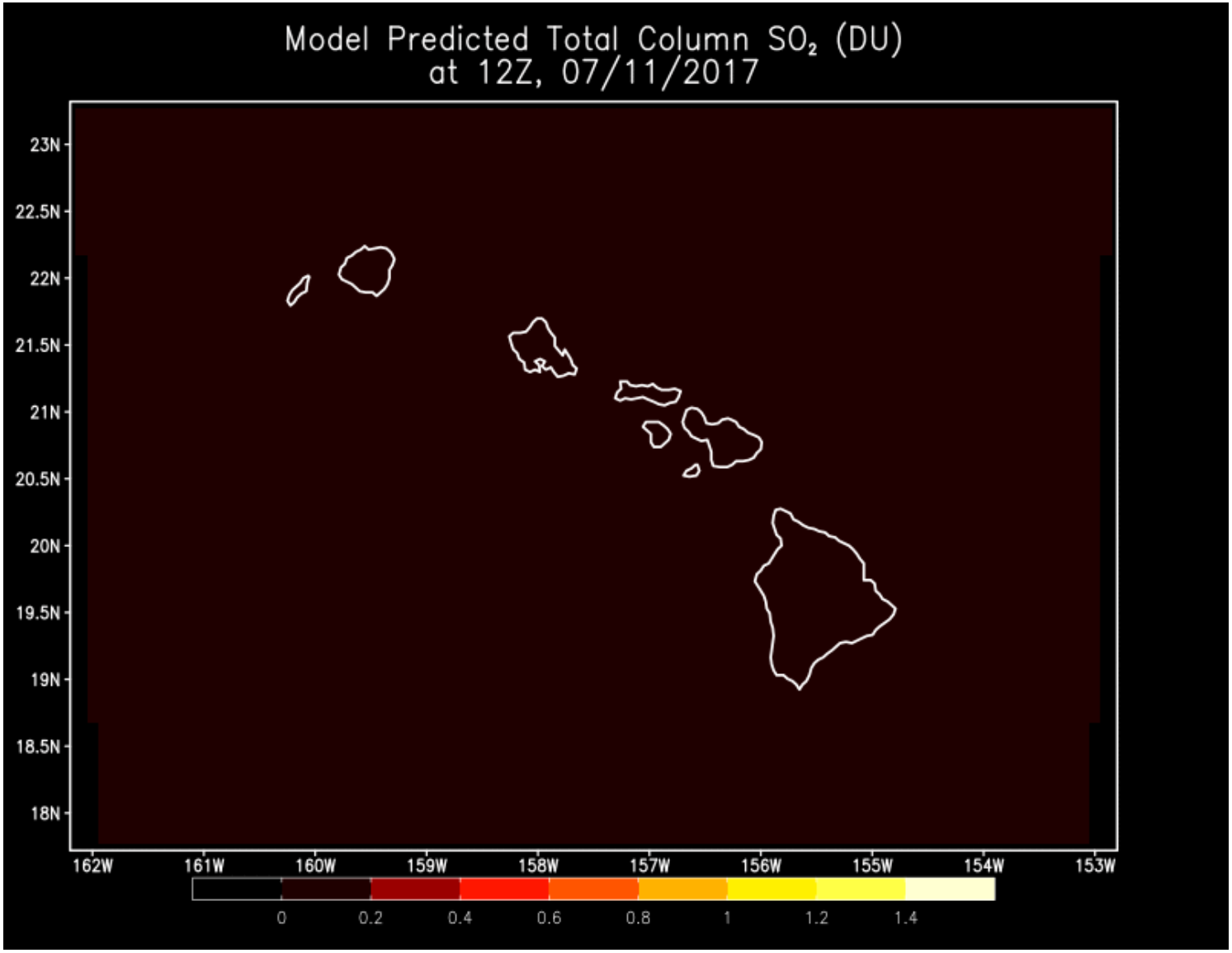


(Source: Hawaiian Volcano Observatory: http://hvo.wr.usgs.gov)

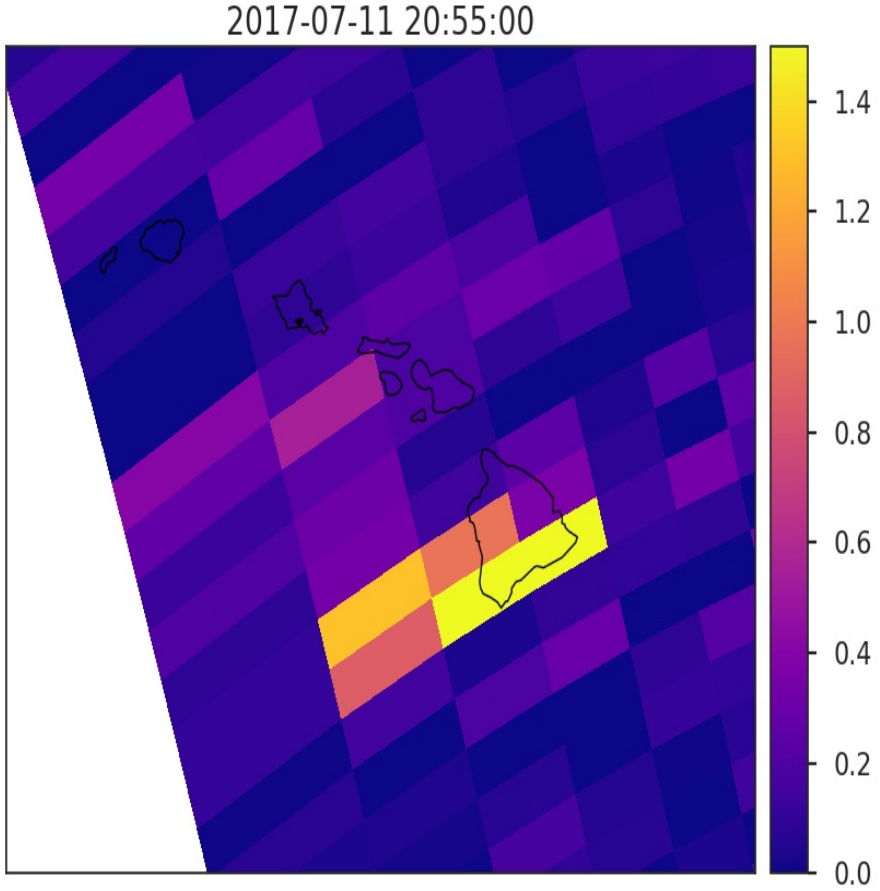
Model Configurations

- **Volcano SO2 emissions:**
  - Summit Emissions: 650 - 800 tons/day;
  - East Rift Zone: ~400 tons/day;

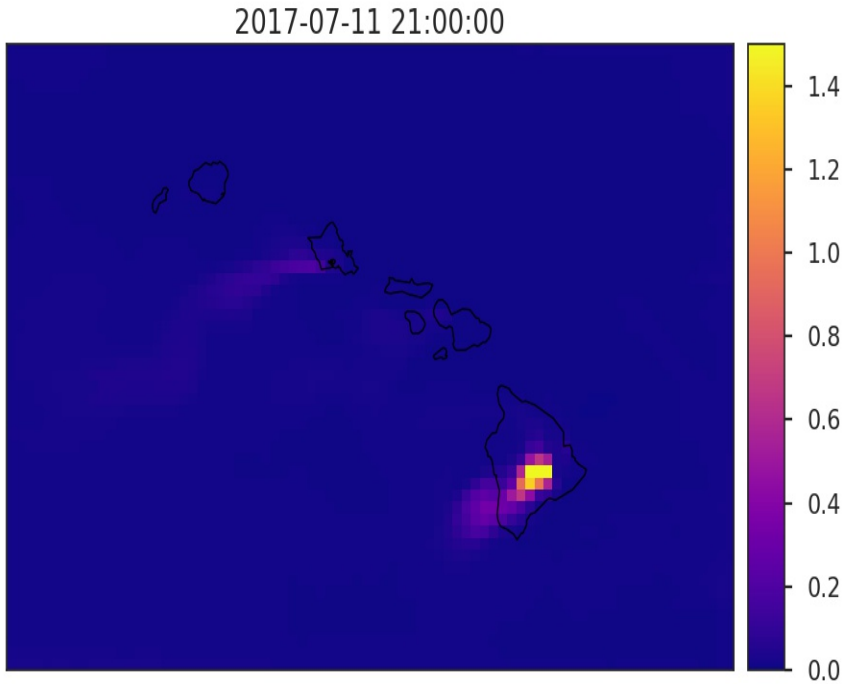
- **Model (National Air Quality Forecast Capability (NAQFC))**
  - CMAQ 5.0.2 CB05-AQ-AERO6 gas, aqueous and aerosol chemistry
- **NAQFC's Hawaii Domain**
  - 80 x 52 grid cells (All islands and surrounding water)
- **Horizontal resolution:** 12x12 km^2
- **Vertical level:** 35 layers
- **Meteorological inputs**
  - NAM(NMM-B) 12 km
- **Lateral boundary conditions**
  - GEOS-Chem precursors with Hilo monthly mean ozonesonde


Model Predicted Total Column SO_2 (DU)
at 12Z, 07/11/2017
23N
22.5N
22N
21.5N
21N
20.5N
20N
19.5N
19N
18.5N
18N
162W
161W
160W
159W
158W
157W
156W
155W
154W
153W
0
0.2
0.4
0.6
0.8
1
1.2
1.4

OMPS SO_2 Total Column (DU)

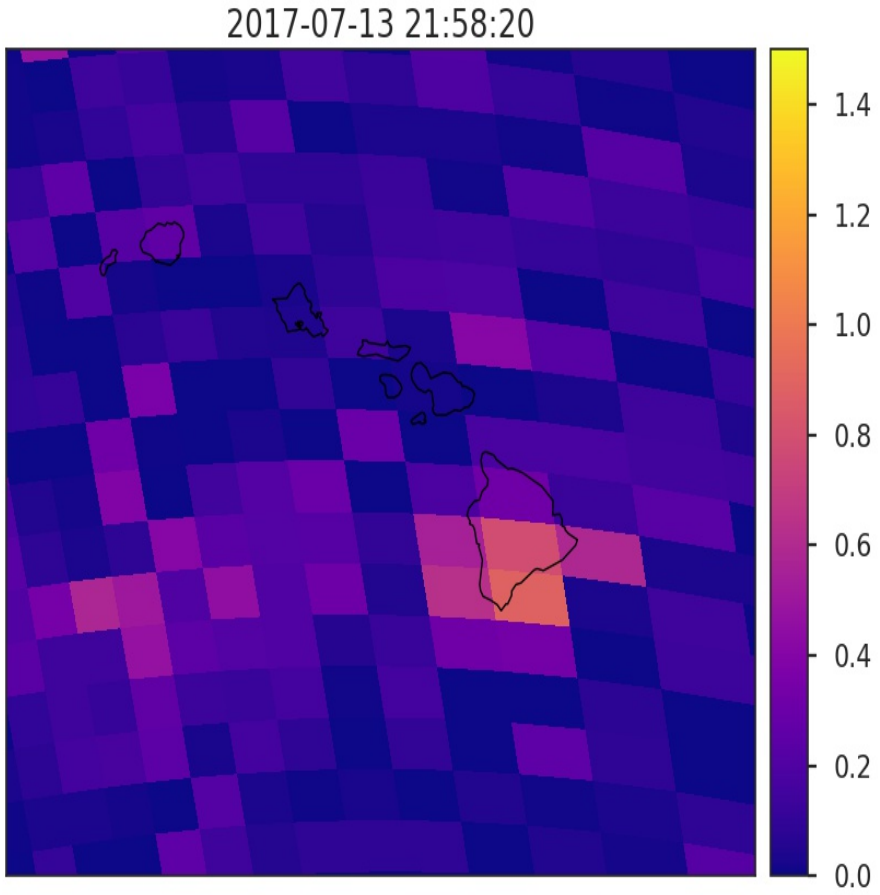


Model SO_2 Total Column (DU)

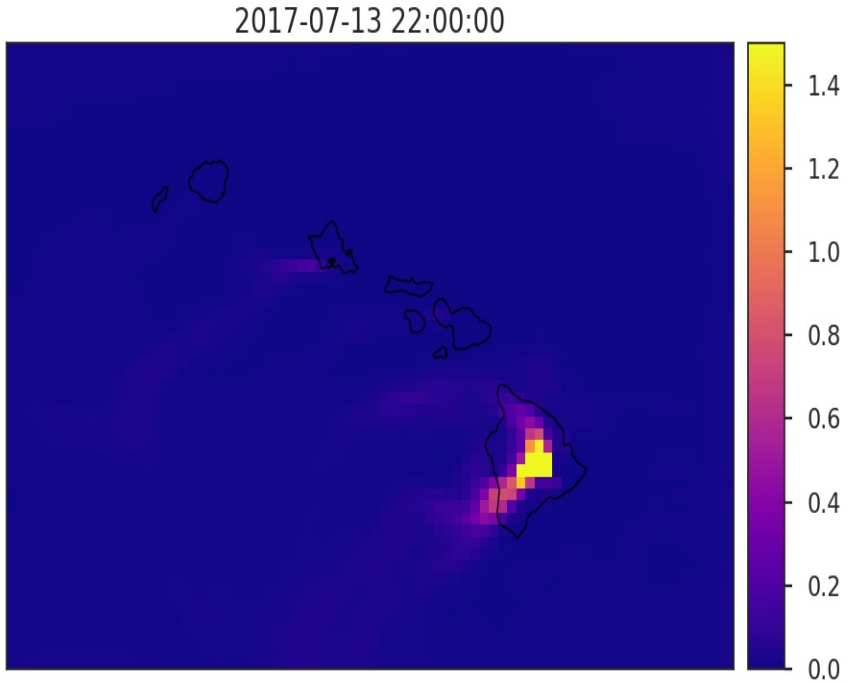


(OMPS SO_2 data is downloaded from NASA retrievals, https://so2.gsfc.nasa.gov)

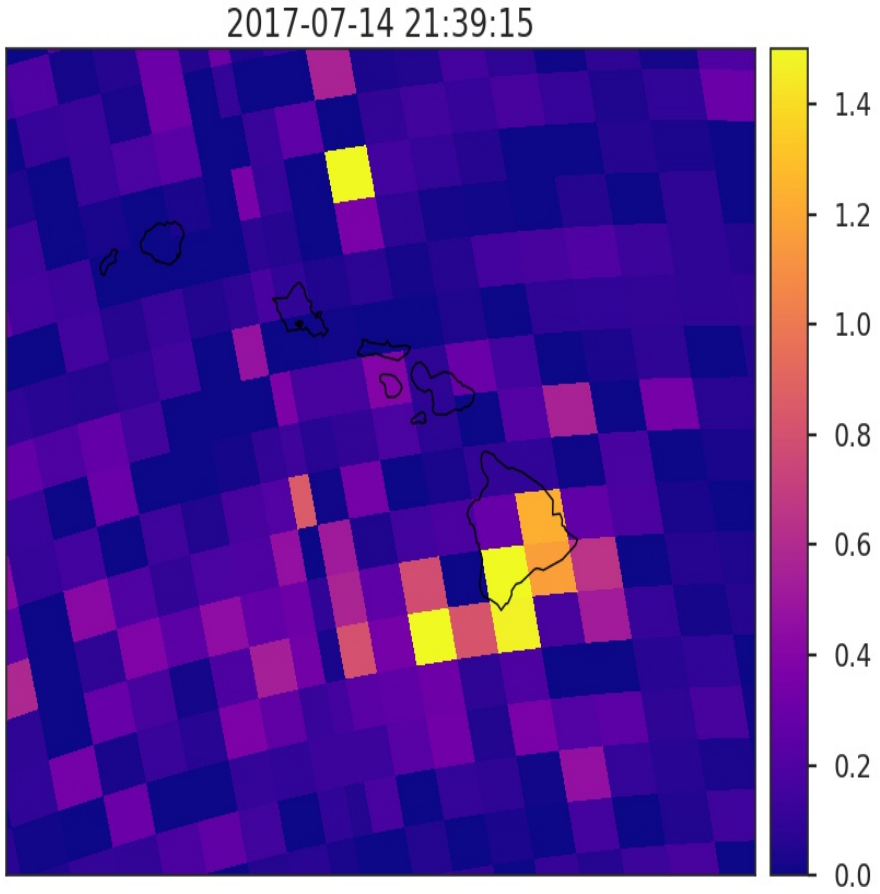
OMPS SO_2 Total Column (DU)



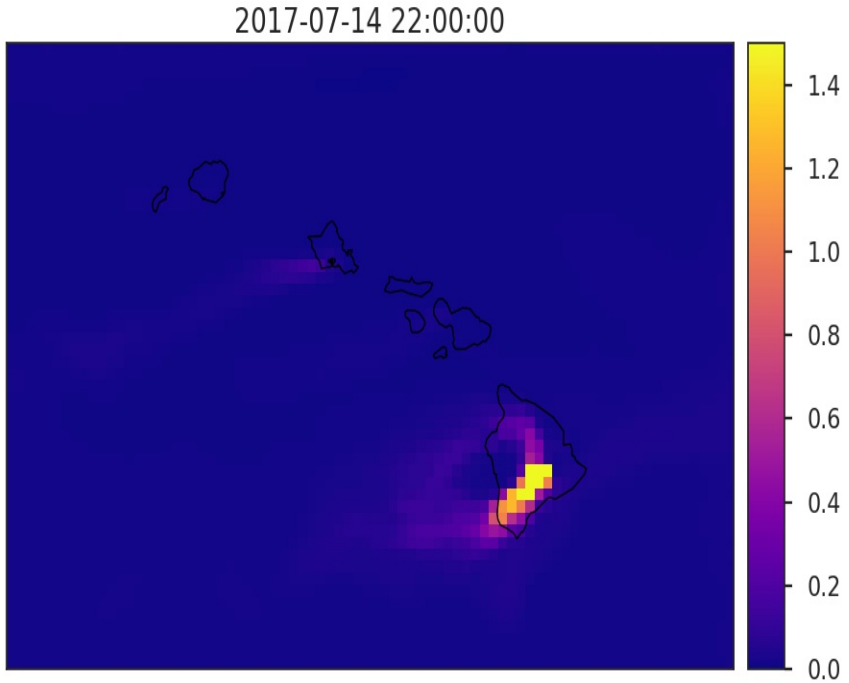
Model SO_2 Total Column (DU)



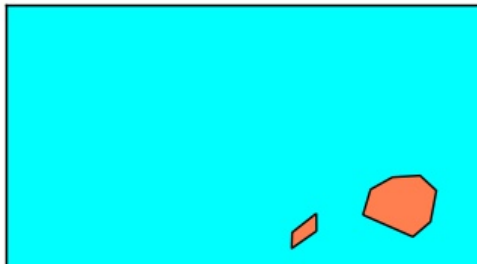
OMPS SO_2 Total Column (DU)



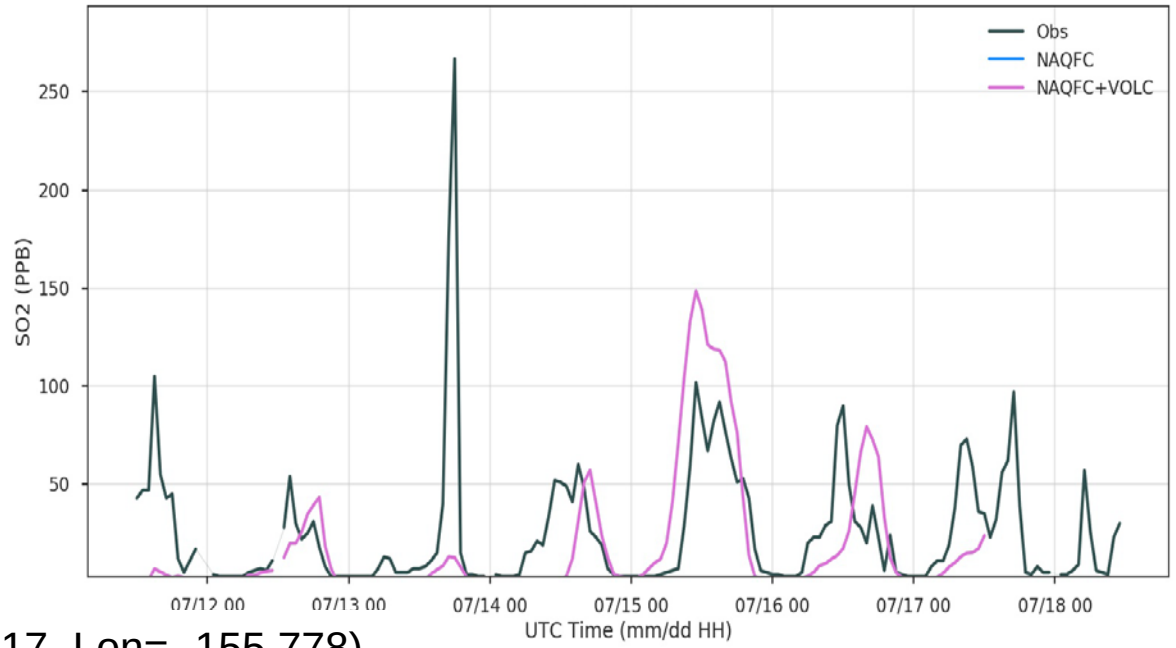
Model SO_2 Total Column (DU)



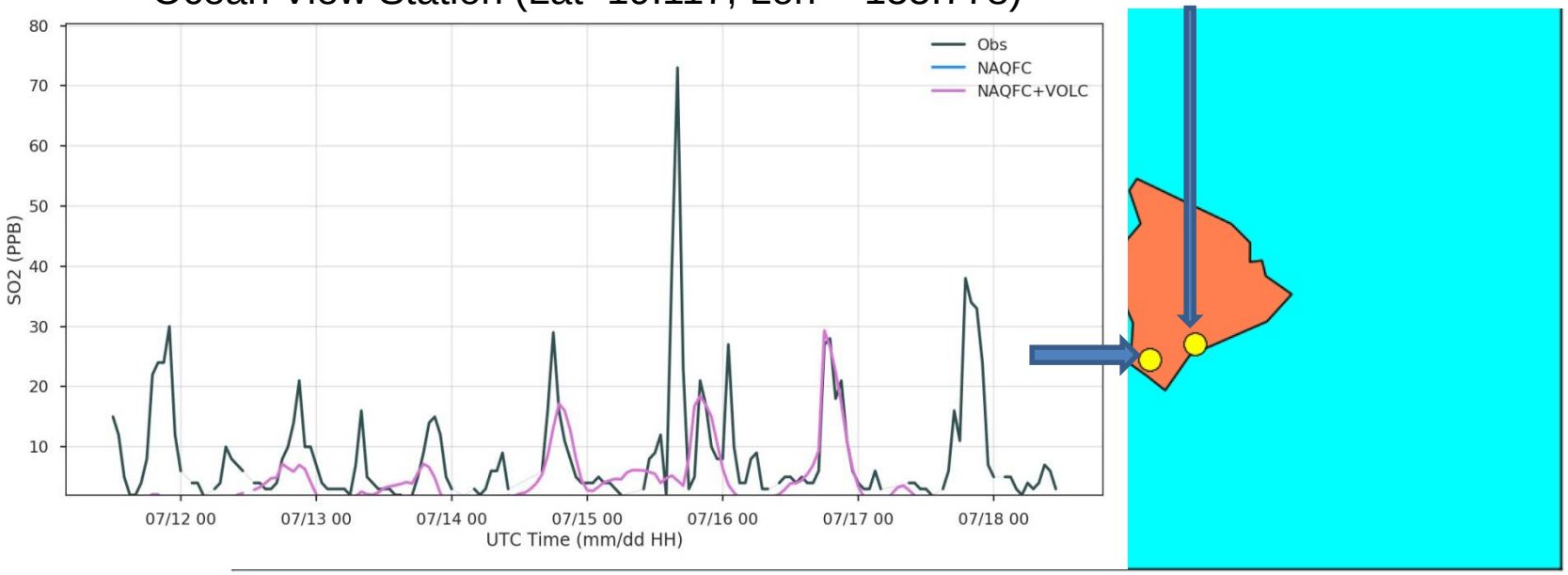
compared to surface SO_2 monitering data



Pahala Station (Lat=19.206, Lon= -155.469)

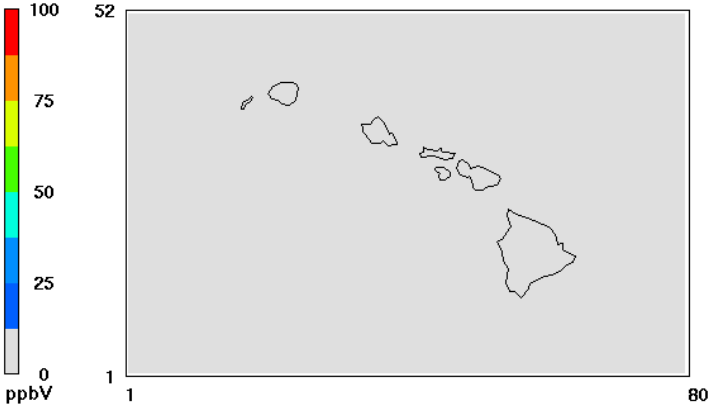


Ocean View Station (Lat=19.117, Lon= -155.778)

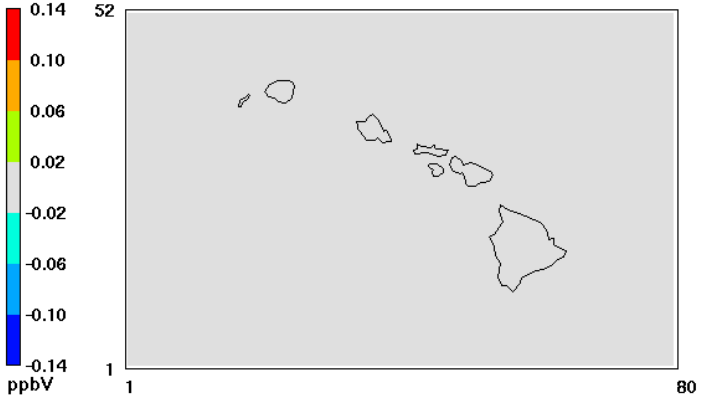


Effects on Air Quality

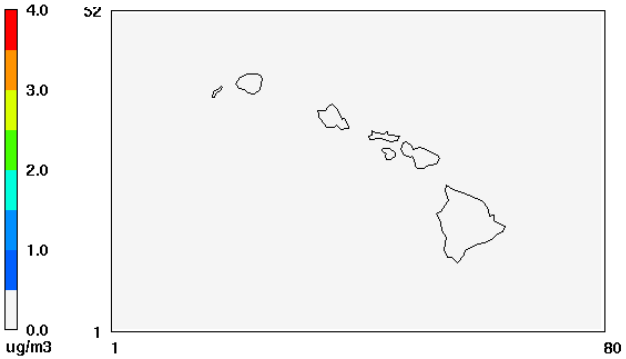
SO_2



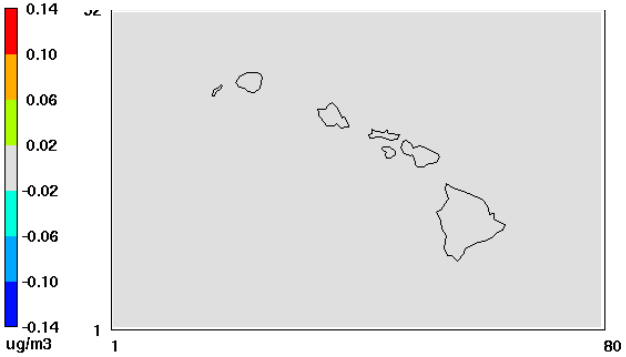
O_3



Sulfate



Nitrate



H_2O_2



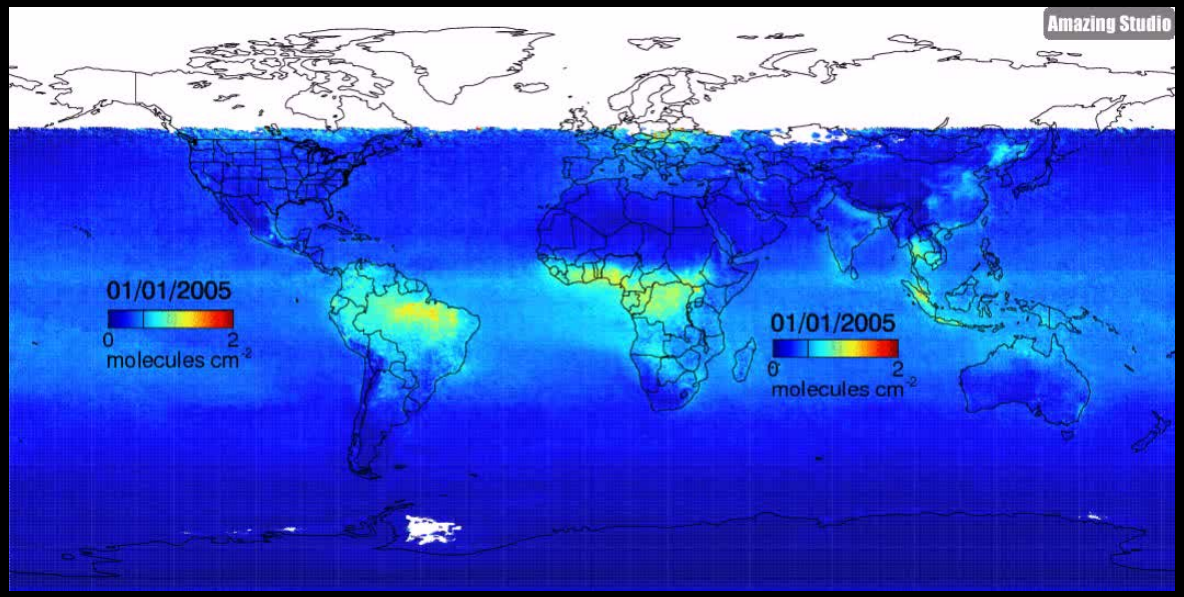
Summary

- With the proper volcano SO_2 emission, we have capability to predict the Hawaii SO_2 plume, which is comparable to the surface measurements.
- OMPS SO_2 retrievals are comparable to the model results. After suitable Cal/Val, it can be used to verify/assimilate Hawaii volcano SO_2 concentration or emission.
- There are still uncertainties in the volcano emissions, such as plume heat fluxes etc, which can be adjusted with the proper satellite retrieval, such as FRP.

Future Works

1. Apply the similar OMPS SO_2 product to verify/assimilate the power-plant SO_2 emissions, which is the major SO_2 source over CONUS.
2. As SO_2 is the precursor of sulfate, we should be able see PM2.5 and AOT enhancement in the downstream areas, which can be verified with the VIIRS AOT product.

Smithsonian Astrophysical Observatory OMPS Nadir Mapper formaldehyde retrievals



Gonzalo González Abad, Kelly Chance and Xiong Liu

STAR JPSS 4th Annual Science Team Meeting

17th August 2017

Outline

- Formaldehyde in the atmosphere
- Smithsonian Astrophysical Observatory OMPS formaldehyde retrieval:
  - Spectral fitting
  - Air mass factor correction
  - Reference sector correction
- Intercomparison between SAO OMI and OMPS formaldehyde retrievals
- Towards a long-term data record
- Next steps

Formaldehyde in the atmosphere:
Formation of tropospheric ozone, organic aerosols, and tropospheric oxidation capacity

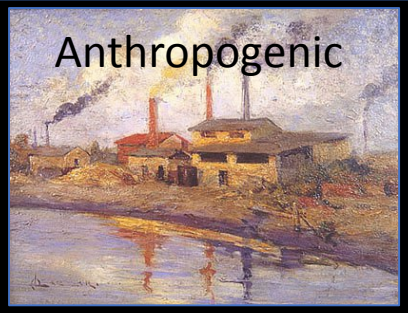
Tropospheric chemistry

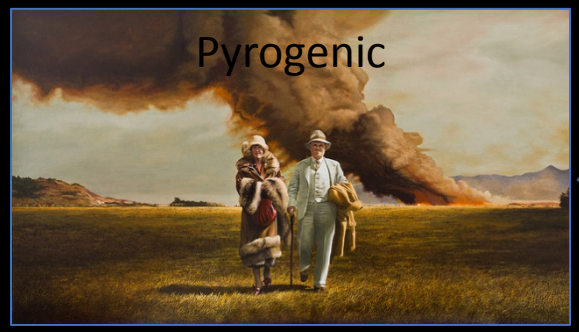
Air quality

Climate

Formaldehyde in the atmosphere: sources and sinks







CH_4

Oxidation

NMVOCs

HCHO

OH radical

Photolysis

H_2O; HCO

H; H_2; CO; HCO

Formaldehyde in the atmosphere: satellite observations

Short tropospheric lifetime
→ NMVOCs proxy

Biogenic Emissions

Pyrogenic Emissions

Anthropogenic Emissions

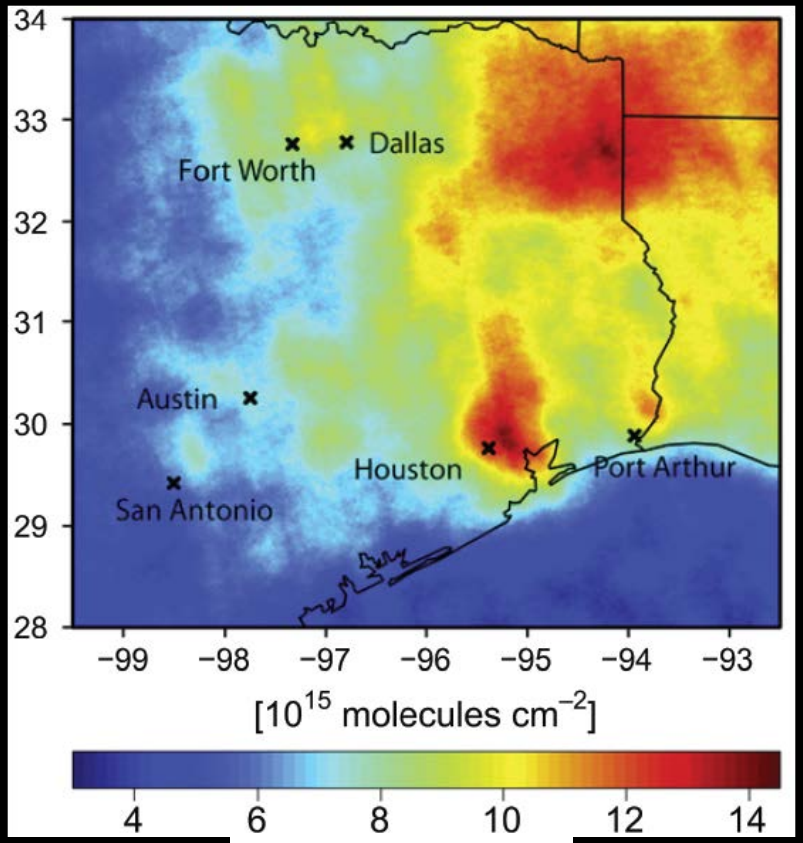
Aerosol formation

Ozone pollution and sensitivity

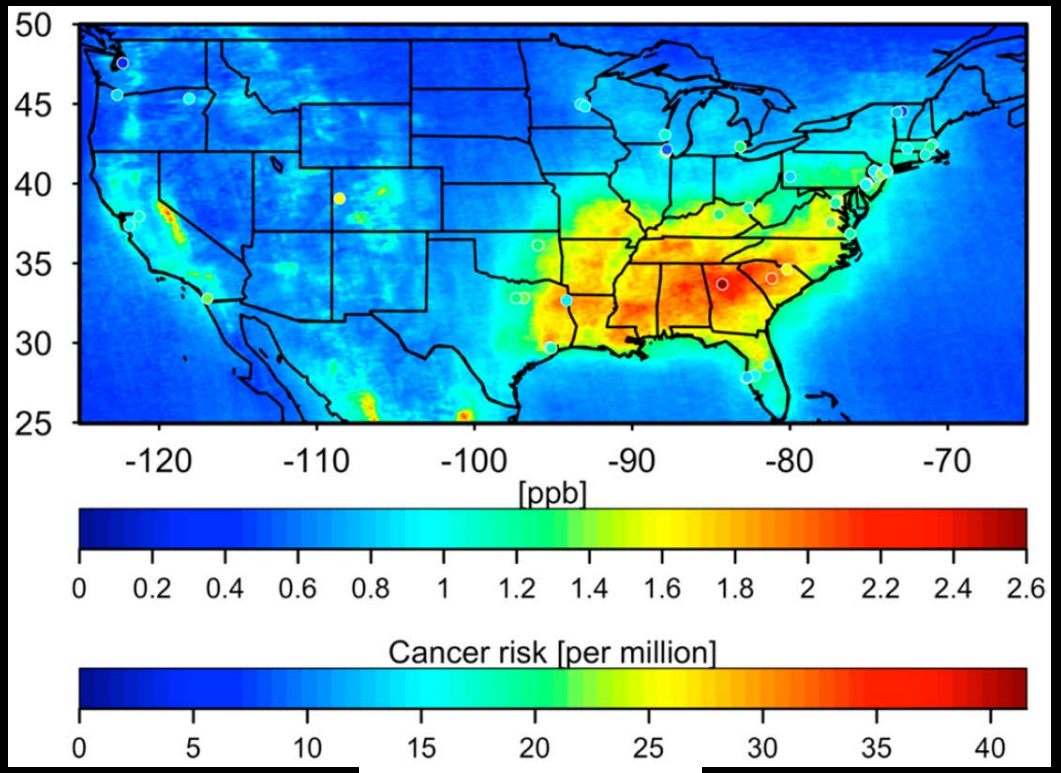
Health studies

Long term trends

Formaldehyde in the atmosphere: satellite observations



Zhu et al., 2014



Zhu et al., 2017

Smithsonian Astrophysical Observatory formaldehyde retrieval

(González Abad et al., AMT, 2016, doi:10.5194/amt-9-2797-2016)

1

Spectral fitting (ΔSCD)

2

Air mass factor correction (ΔVCD)

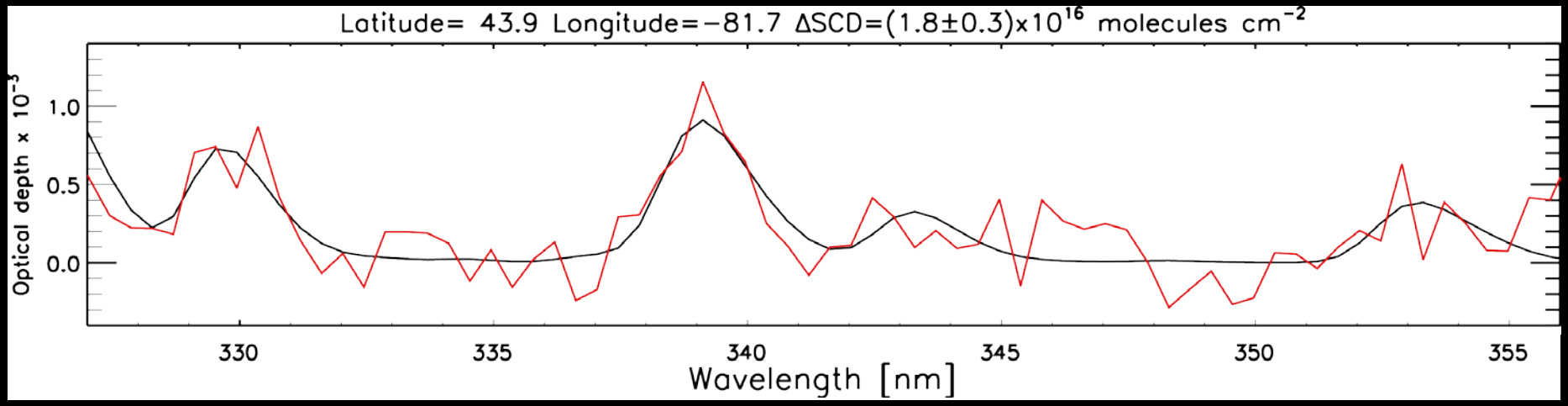
3

Reference sector correction (VCD)

Smithsonian Astrophysical Observatory formaldehyde retrieval

Direct spectral fit of radiances

$$I = \left[(aI_o + \sum_i \alpha_i X_i) e^{-\sum_j \alpha_j X_j} + \sum_k \alpha_k X_k\right] ScalPoly + BasePoly$$



Smithsonian Astrophysical Observatory formaldehyde retrieval

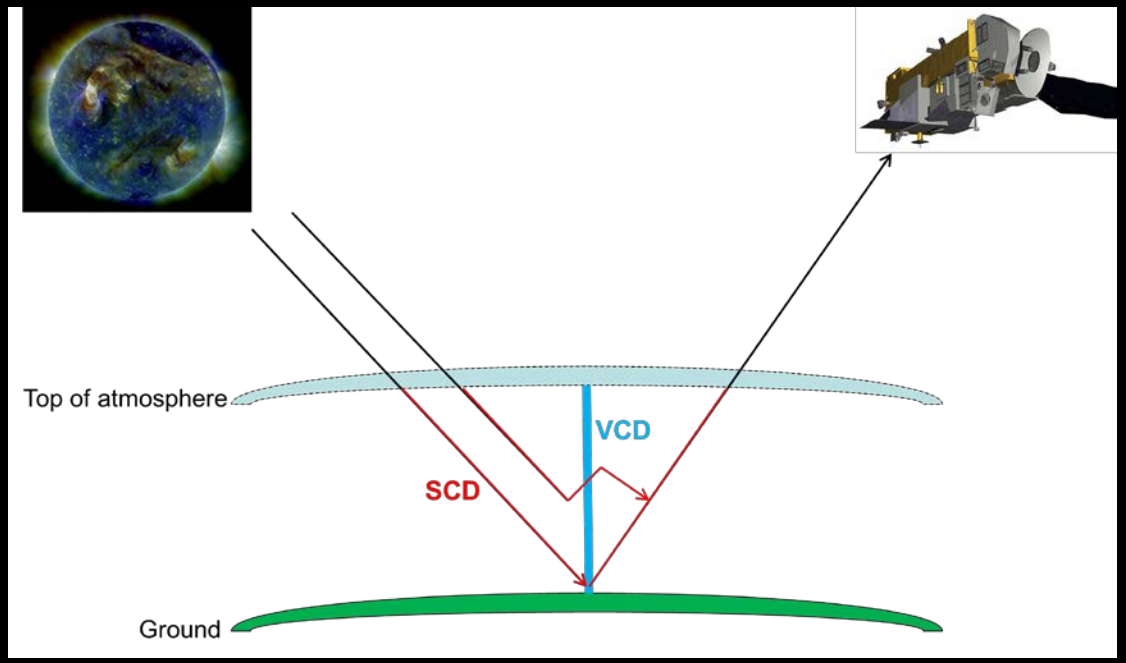
Direct spectral fit of radiances

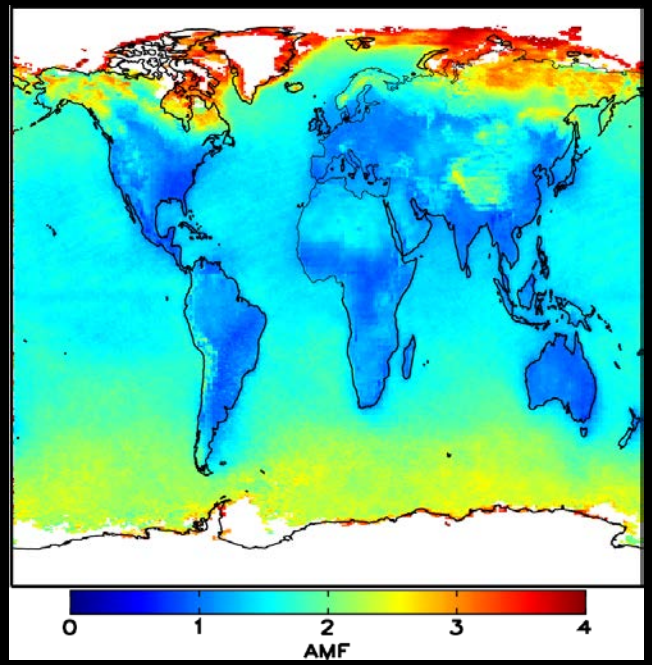
Fitting window	327.7 nm - 356.0 nm
Radiance reference spectrum	Computed online over the remote Pacific ocean between 30° N and 30° S
Baseline polynomial	3rd order
Scaling polynomial	3rd order
Instrument slit function	Pre flight measurements
Solar reference spectrum	Chance and Kurucz (2010)
H_2CO cross-sections	Chance and Orphal (2011), 300 K
O_3 cross-sections	Malicet et al. (1995), 228 K & 295 K
NO_2 cross-sections	Vandaele et al. (1998), 220 K
BrO cross-sections	Wilmouth et al. (1999), 228 K
O_2-O_2 collision complex cross-sections	Thalman and Volkamer (2013), 293 K
Molecular Ring cross sections	Chance and Spurr (1997)
Undersampling correction	Computed online (Chance et al., 2005)

Smithsonian Astrophysical Observatory formaldehyde retrieval

Air mass factor correction

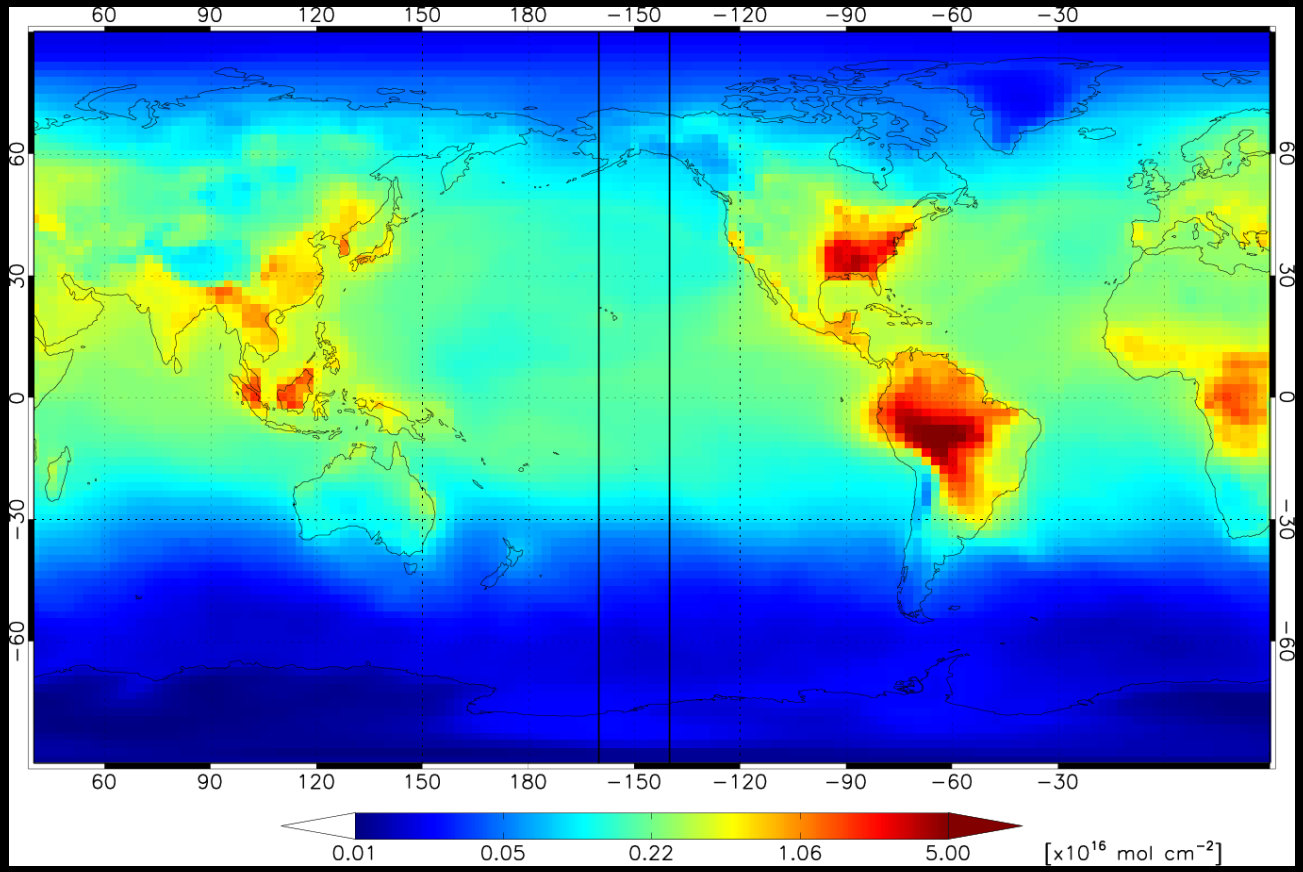
$$\Delta VCD = \frac{\Delta SCD}{AMF}$$





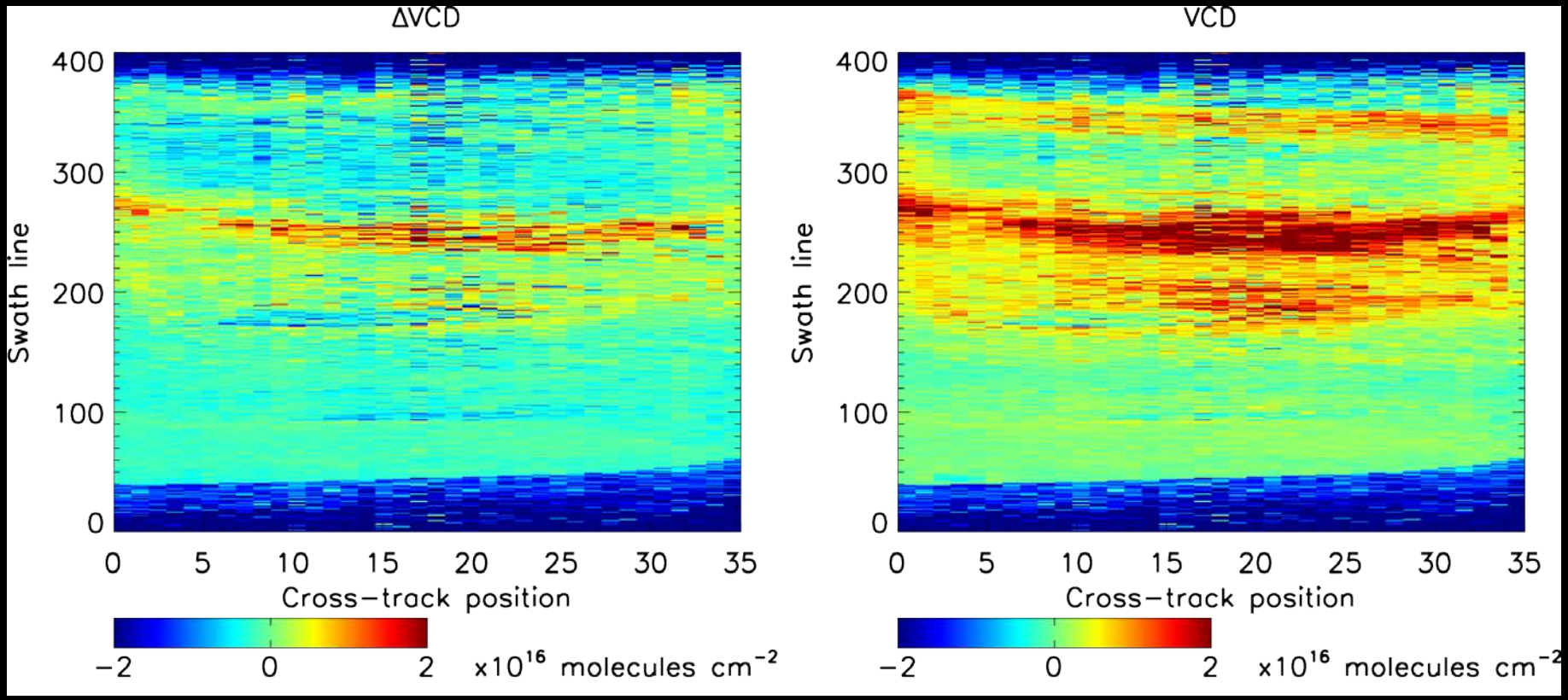
Smithsonian Astrophysical Observatory formaldehyde retrieval

Pacific Ocean Reference Sector Correction



Smithsonian Astrophysical Observatory formaldehyde retrieval

Pacific Ocean Reference Sector Correction



Intercomparison between SAO OMI and OMPS formaldehyde retrieval

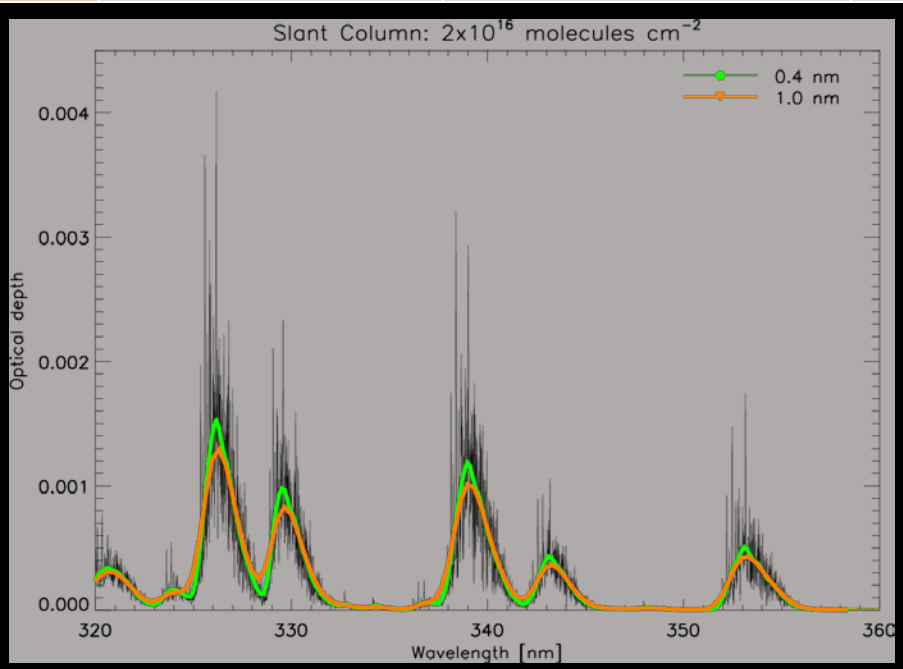
	Spectral Resolution [nm]	Spectral Coverage [nm]	Nadir Spatial Resolution [km^2]	Swath Size [km]	Overpass local time
OMPS	1.00	300-380	50 x 50	2800	13:30
OMI	0.42 (UV-2)	270-500	13 x 24	2600	13:42

Major differences between SAO OMPS and OMI formaldehyde retrievals

SAO retrieval	Fitting window [nm]	Surface Reflectance	Cloud parameters (cloud fraction and cloud pressure)
OMPS	327.7 – 356.0	TOMS climatology	Rotational Raman (Vasilkov et al., 2014)
OMI	328.5 – 356.5	OMI 5 year climatology (Kleipool et al., 2008)	O_2-O_2 absorption (Stammes et al., 2008)

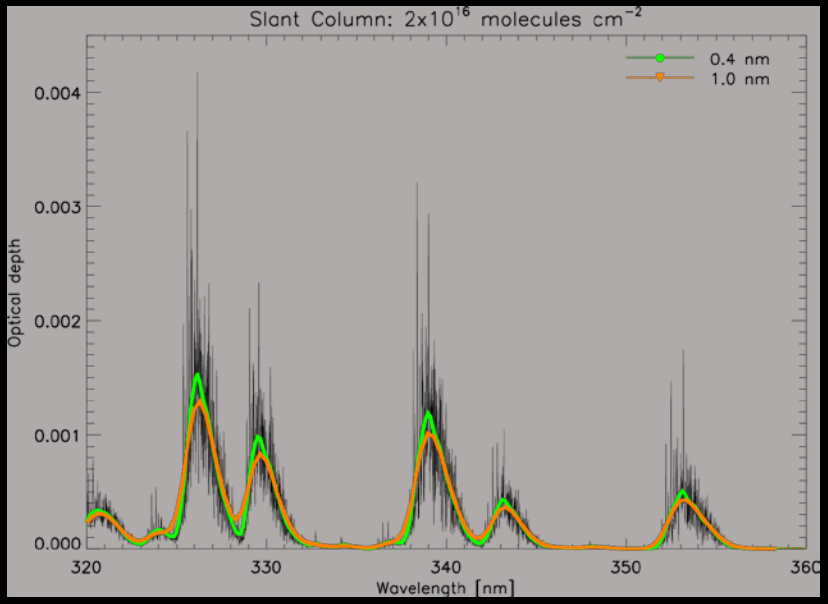
Intercomparison between SAO OMI and OMPS formaldehyde retrieval

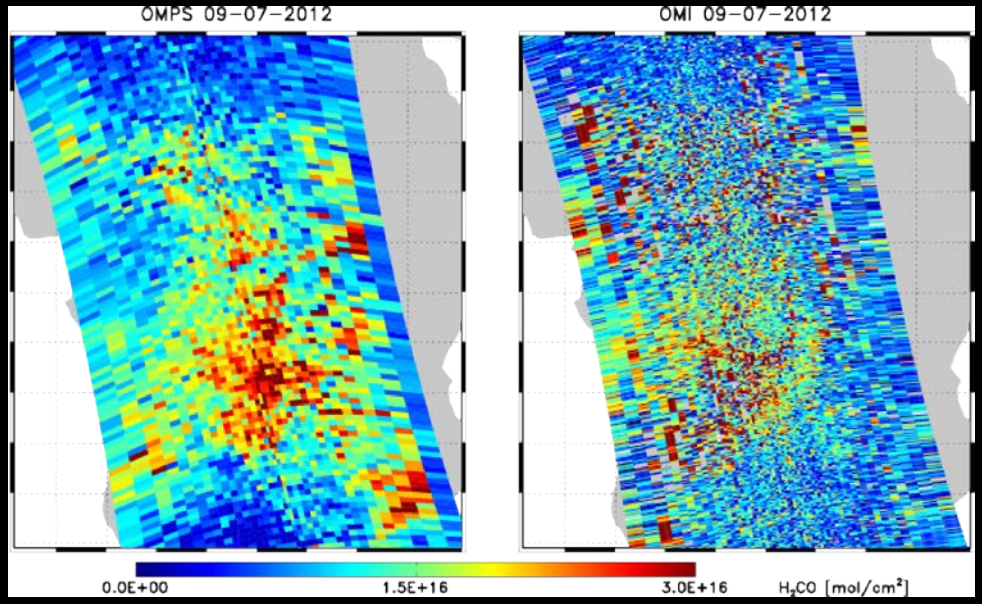
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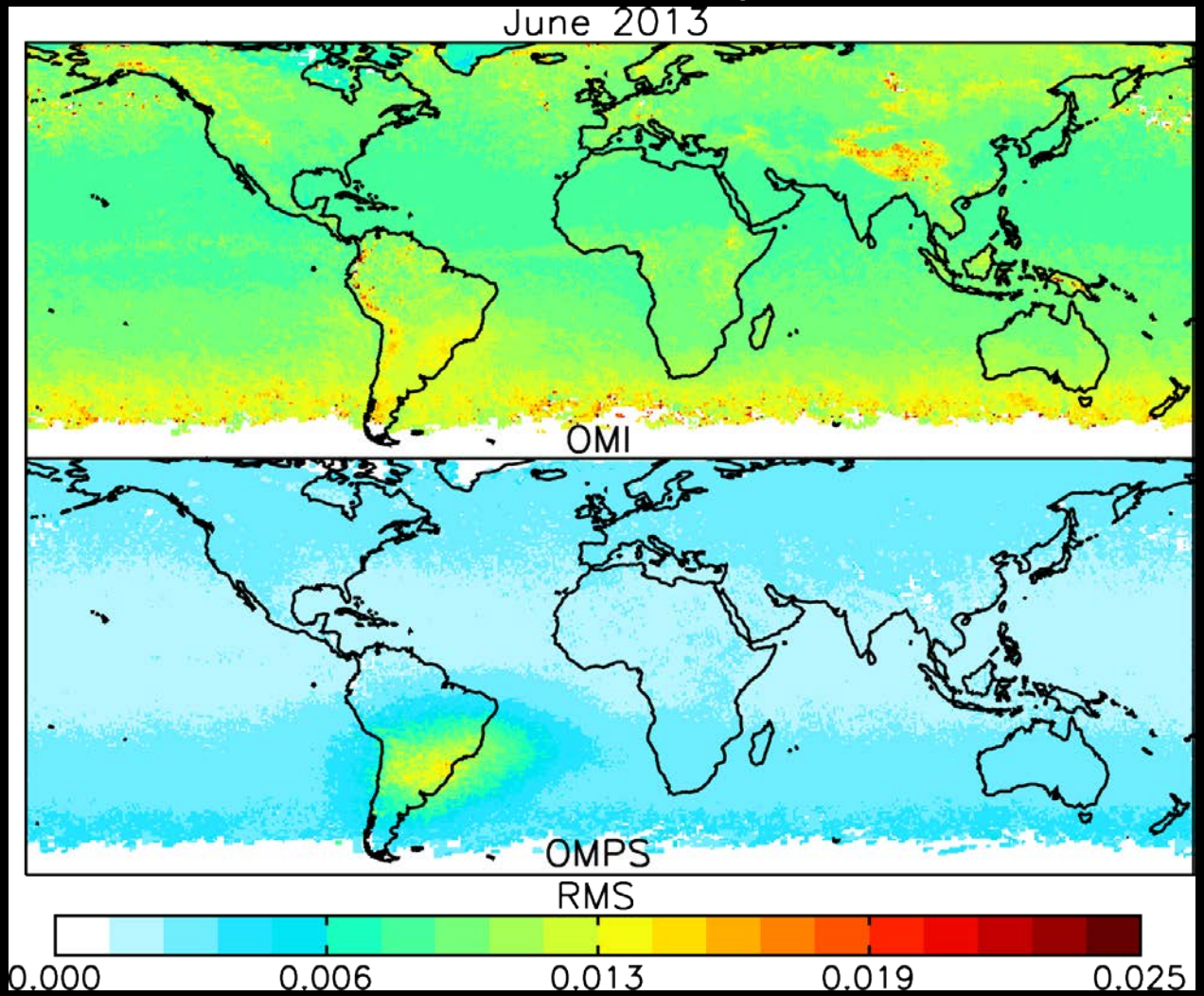
Intercomparison between SAO OMI and OMPS formaldehyde retrieval

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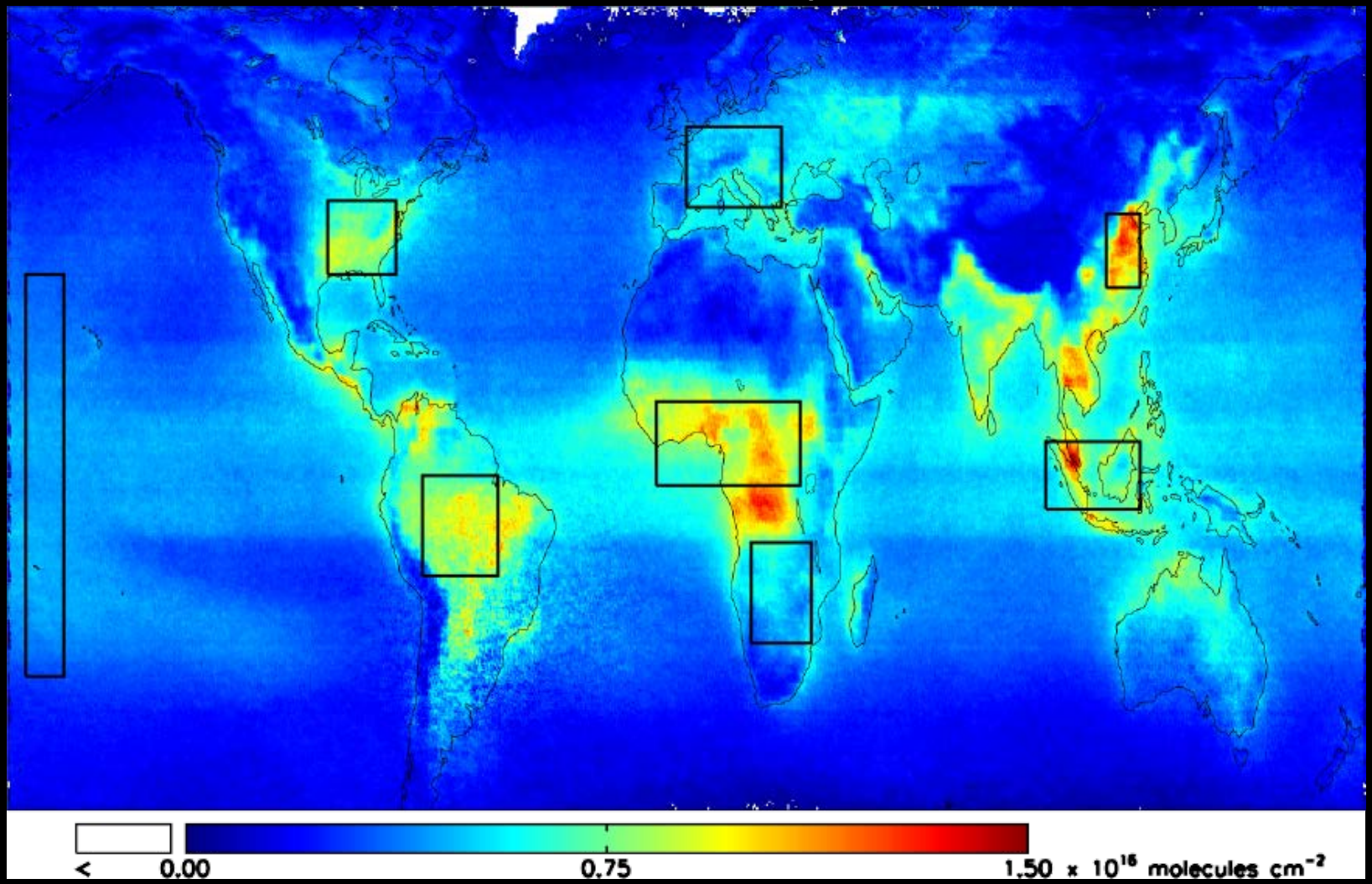




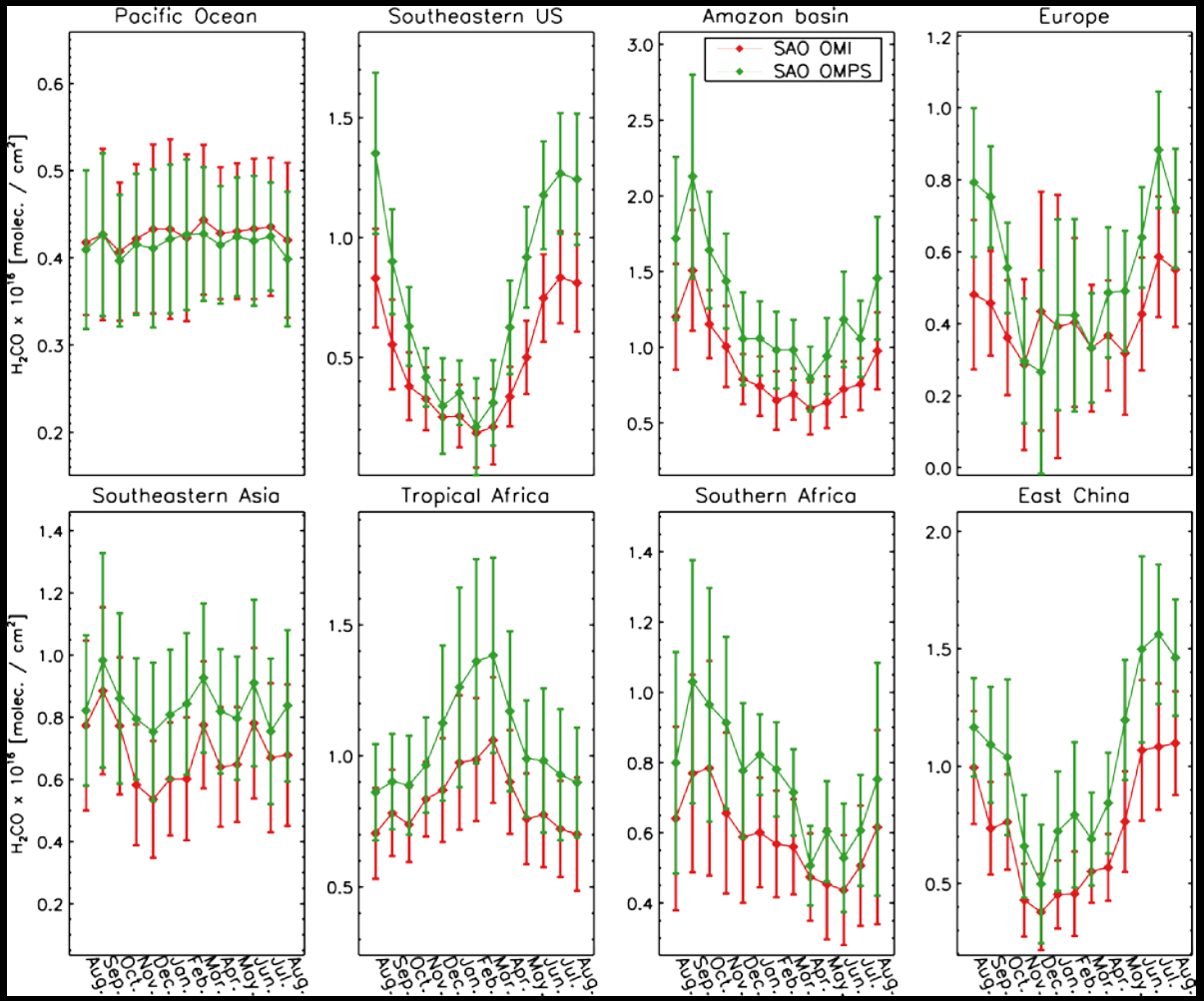
Intercomparison between SAO OMI and OMPS formaldehyde retrieval



Intercomparison between SAO OMI and OMPS formaldehyde retrieval



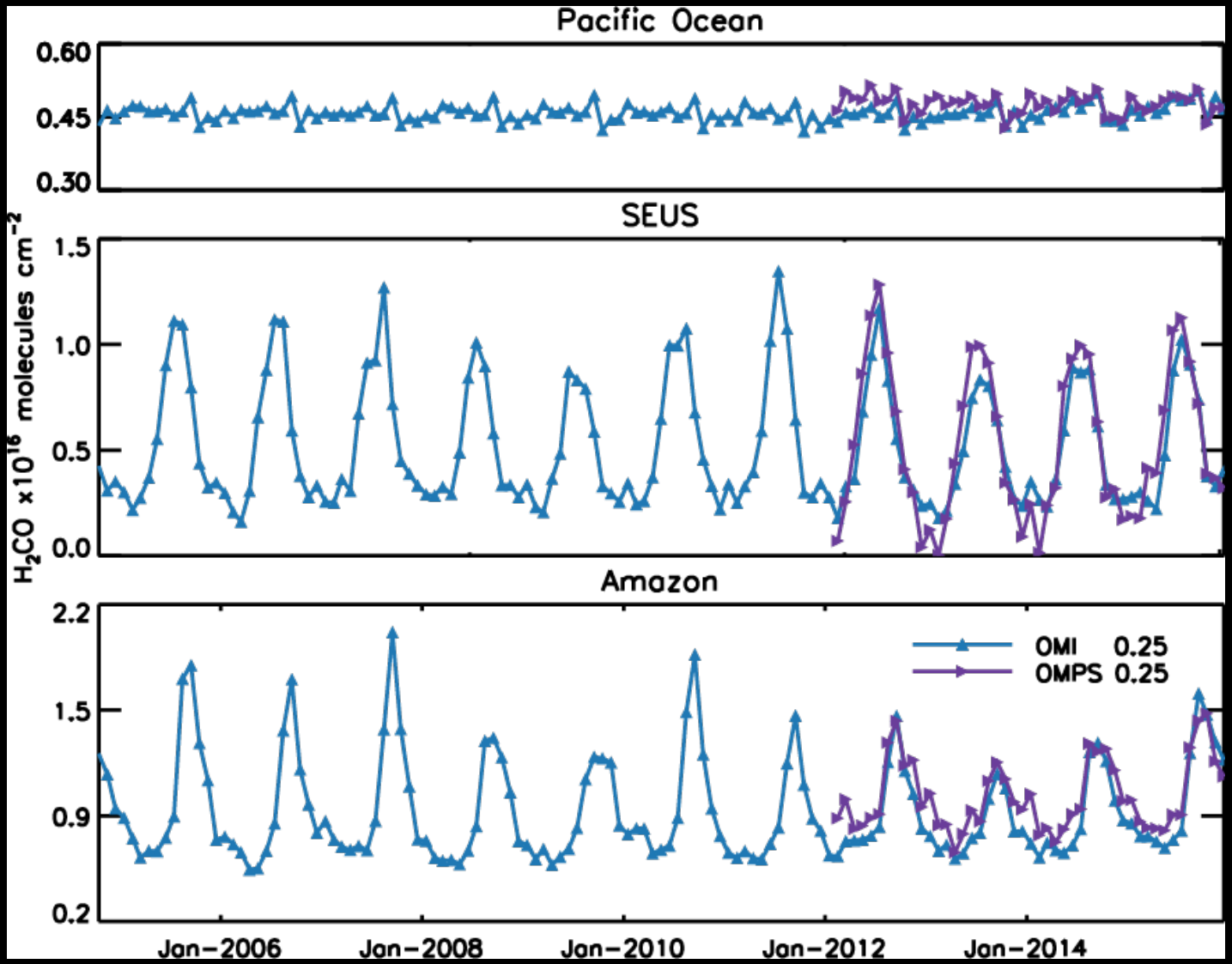
Intercomparison between SAO OMI and OMPS formaldehyde retrieval



Region	Correlation
Pacific Ocean	0.71
SEUS	0.99
Amazon	0.99
Europe	0.77
SE Asia	0.86
Tropical Africa	0.97
Southern Africa	0.95
East China	0.96

For these eight regions OMPS retrievals are biased high with respect to OMI retrievals 23%.

Towards a long-term data record



Future work

- Reprocess whole data record with new L1B radiances, upgraded calibration and AMF calculation.
- Perform validation studies following Zhu et al., 2016 methodology (GEOS-Chem as intercomparison platform)
- Set up SAO public web page for data distribution

Campaign	Time Period	Location	Agency
TORERO	Jan. – Feb. 2012	Eastern Tropical Pacific	NCAR
DISCOVER-AQ	Jan. – Feb. 2013	California	NASA
NOMADSS	Jun. – Jul. 2013	Southeast U.S.	NCAR
SENEX	Summer 2013	Southeast U.S.	NOAA
DISCOVER-AQ	Aug. – Sep. 2013	Texas	NASA
SEAC^{4}RS	Aug. – Sep. 2013	Southeast U.S.	NOAA
CONTRAST	Jan. – Feb. 2014	Western Tropical Pacific	NCAR
FRAPPÉ	Jul. – Aug. 2014	Colorado	NCAR
DISCOVER-AQ	Jul. – Aug. 2014	Colorado	NASA
WINTER	Jan. – Mar. 2015	Mid-Atlantic U.S.	NOAA
SONGNEX	Mar. - May 2015	Western U.S.	NOAA
KORUS-AQ	May – Jun. 2016	South Korea	NASA

Thanks for your attention



This study was supported by NASA Atmospheric Composition Program/Aura Science Team (NNX11AE58G) and internal Smithsonian Institution funds from the Consortium for Unlocking the Mysteries of the Universe







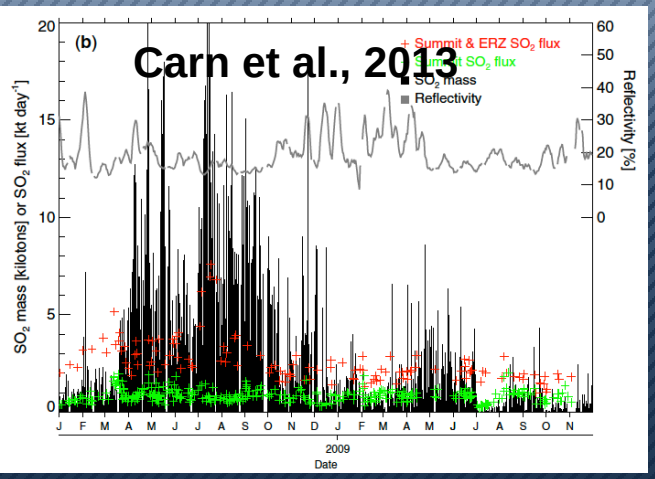

Development of Multi-sensor JPSS SO_2 Products for Volcanic Cloud Monitoring

Michael J. Pavolonis

NOAA/NESDIS/STAR

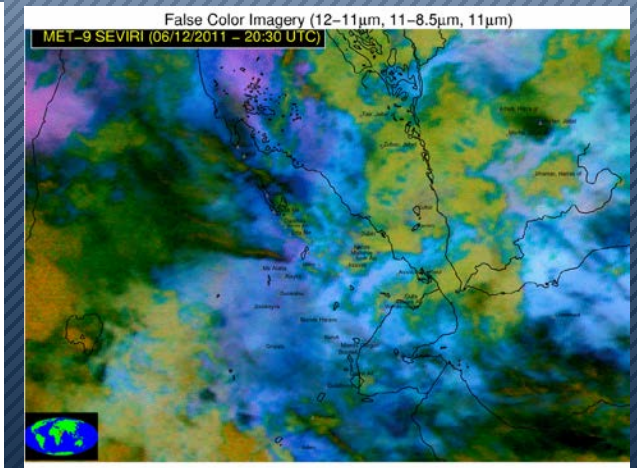
Motivation

Volcano Monitoring



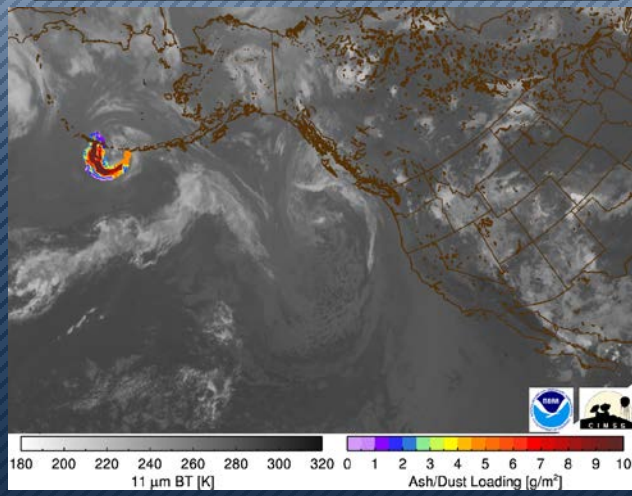
Carn et al., 2013

Hazard Avoidance

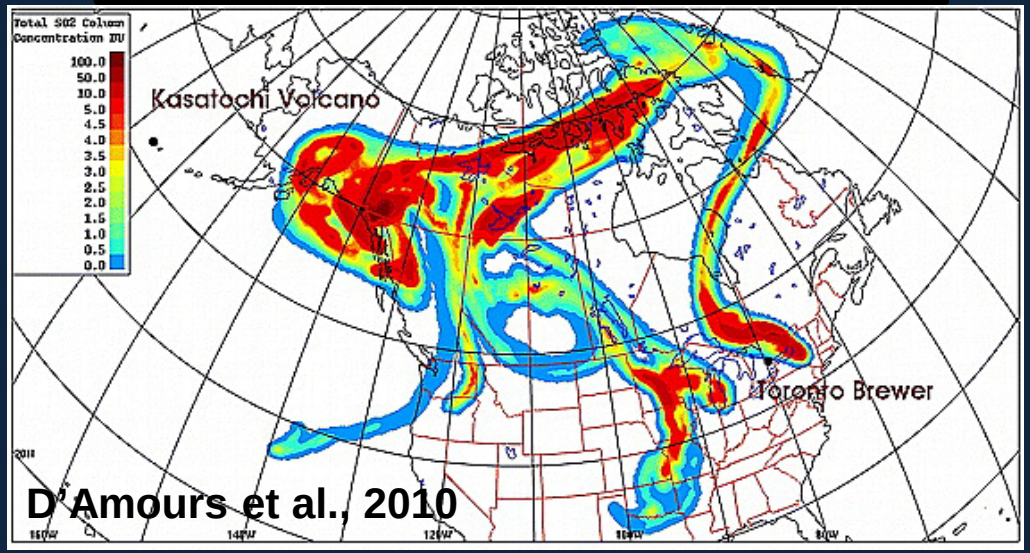


2011 Nabro Eruption

Volcanic Ash Tracking

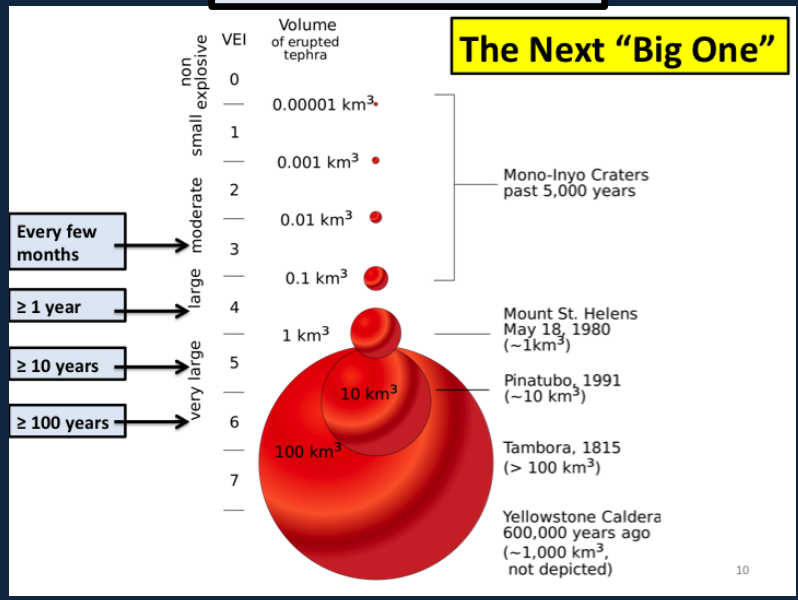


Dispersion and Transport Modeling



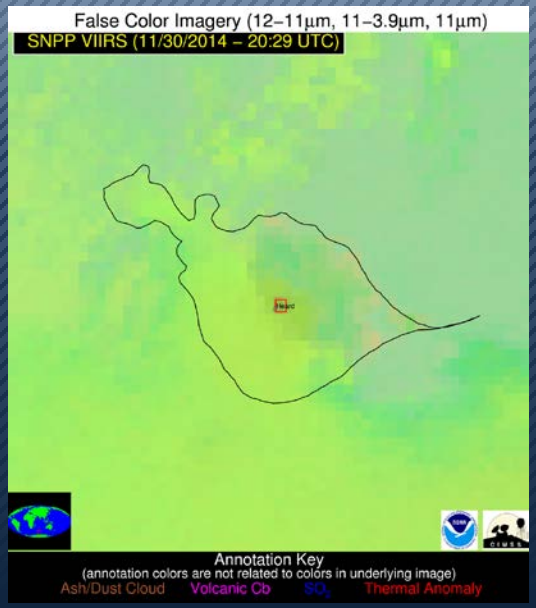
D'Amours et al., 2010

Climate



VOLcanic Cloud Analysis Toolkit (VOLCAT)

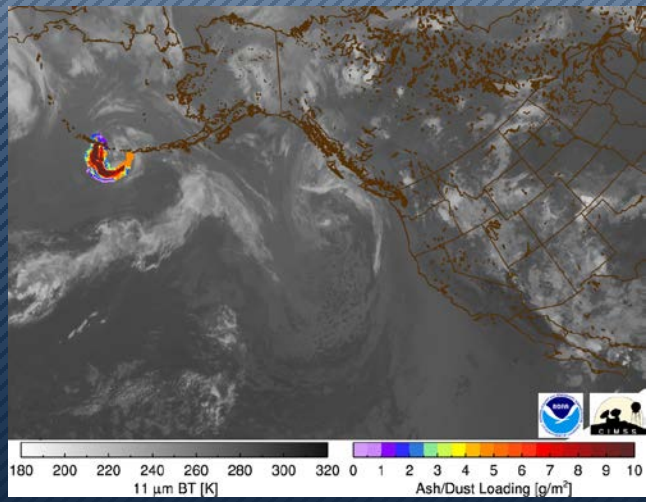
1). Unrest Alerts



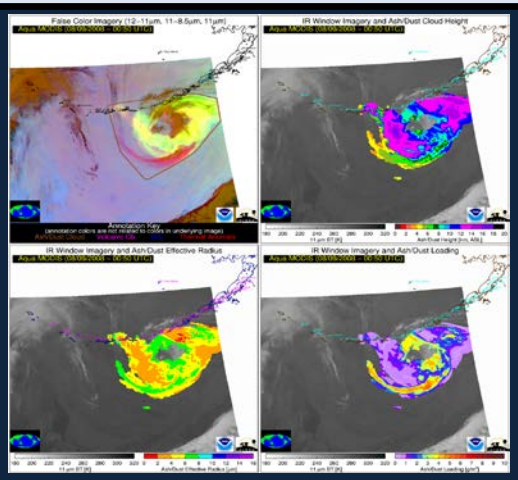
2). Eruption Alerts



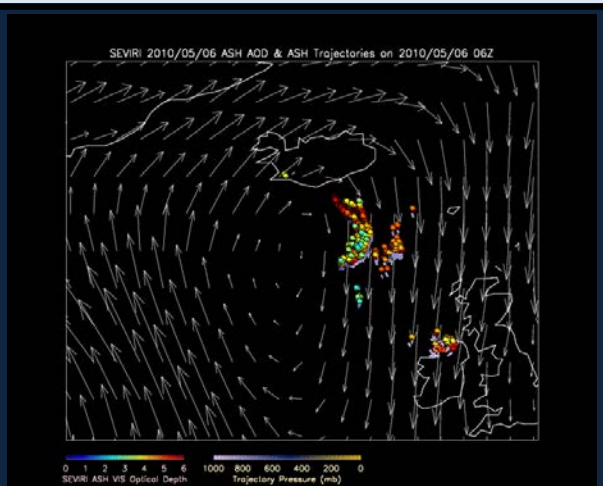
3). Volcanic Cloud Tracking



4). Volcanic Cloud Characterization



5). Dispersion Forecasting



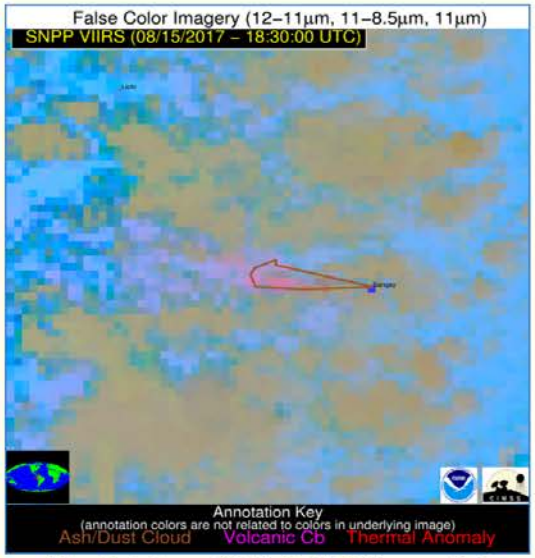
Example NRT Volcanic Ash Alerts from VOLCAT

Volcanic Cloud Alert Report

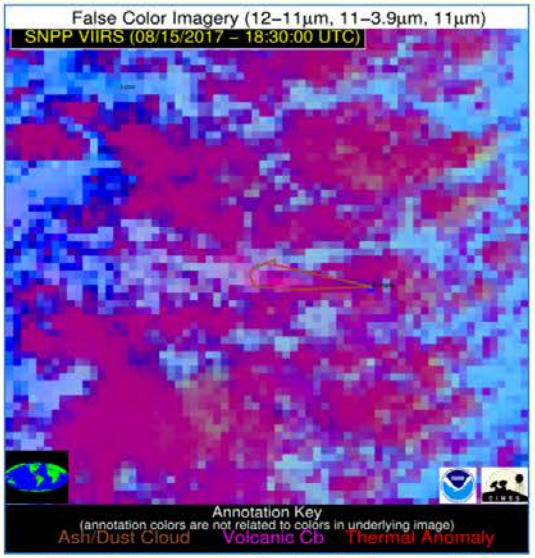
Date:	2017-08-15
Time:	18:30:00
Production Date and Time:	2017-08-15 20:18:05 UTC
Primary Instrument:	NPP VIIRS

More details ▼

Possible Volcanic Ash Cloud



False Color Image (12-11, 11-8.5, 11) [zoomed-in]



False Color Image (12-11, 11-3.9, 11) [zoomed-in]

Basic Information

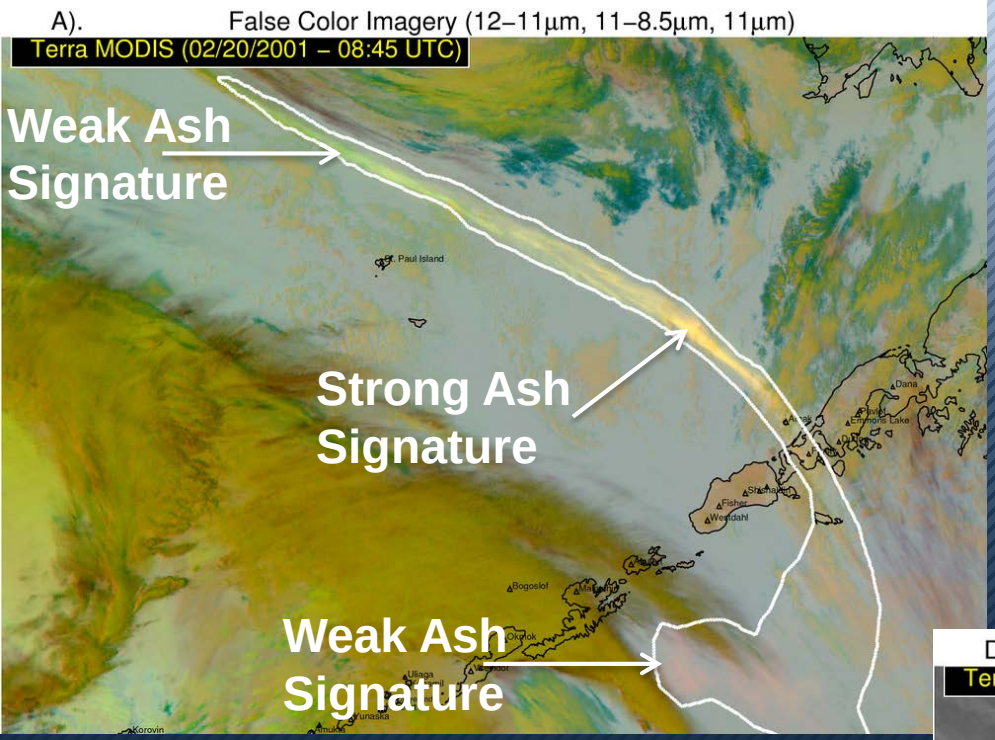
Volcanic Region(s)	South America
Country/Countries	Ecuador
Volcanic Subregion(s)	Ecuador
VAAC Region(s) of Nearby Volcanoes	Washington
Identification Method	Plume
Mean Object Date/Time	2017-08-15 18:34:06UTC
Radiative Center (Lat, Lon):	-2.010°, -78.340°
Nearby Volcanoes (meeting alert criteria):	Sangay (0.00 km) Licto (39.30 km) Tungurahua (60.90 km) Chimborazo (80.10 km) Quilotoa (142.80 km)
Maximum Height [AMSL]	7.20 km ; 23622 ft
90th Percentile Height [AMSL]	6.60 km ; 21654 ft
Mean Tropopause Height [AMSL]	16.50 km ; 54134 ft

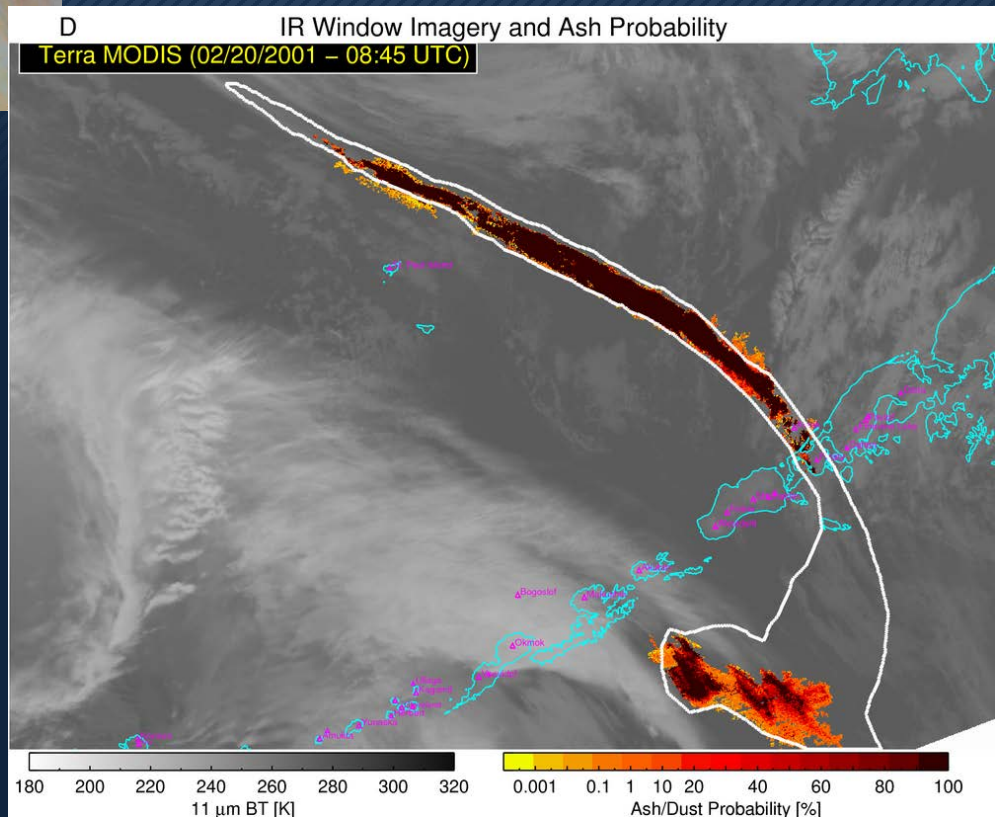
Show More ▲ | View all event imagery »

Sangay
(not detected with ABI)

Spatial Analysis: Cloud Objects

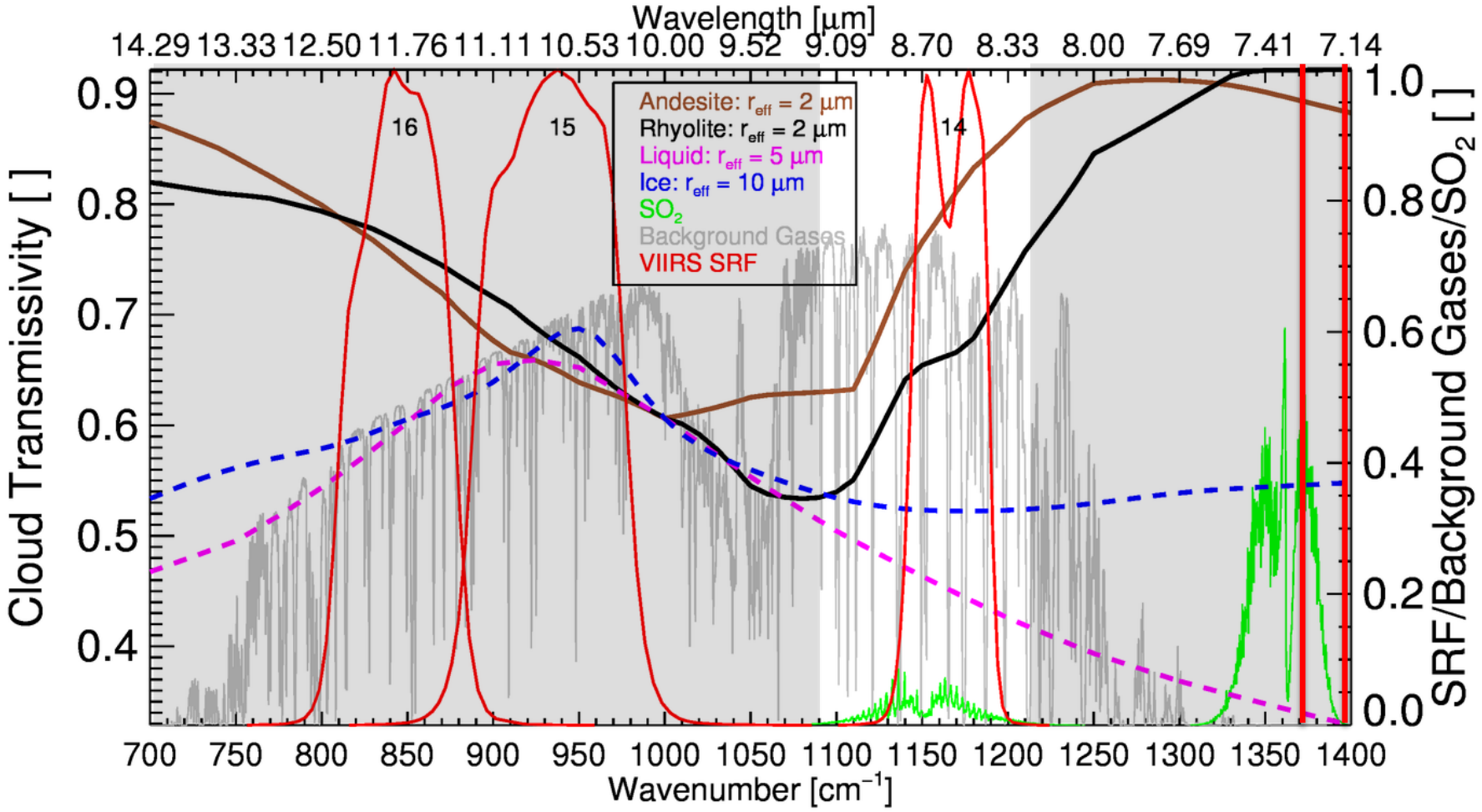
volcanic clouds, spectral metrics are used to estimate ash probability





Pavolonis et al. (2015a);
Pavolonis et al. (2015b)

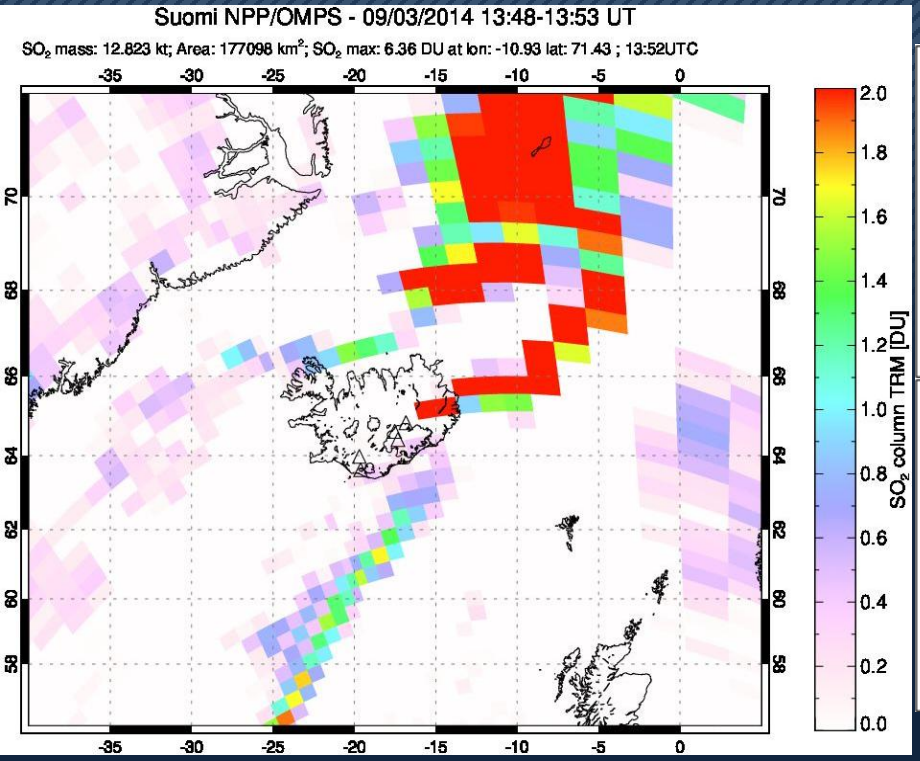
JPSS – Infrared Capabilities



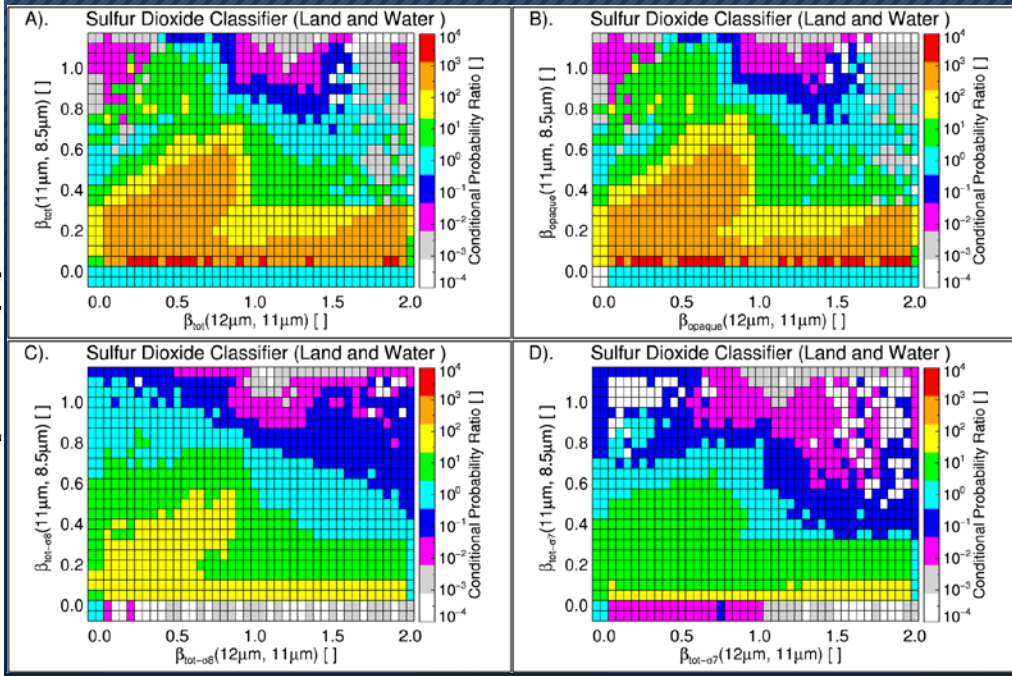
BTD SO_2 = BT(1407.50 cm^{-1}) – BT(1371.25 cm^{-1})

VIIRS SO_2 Probability: Naïve Bayesian Classifier

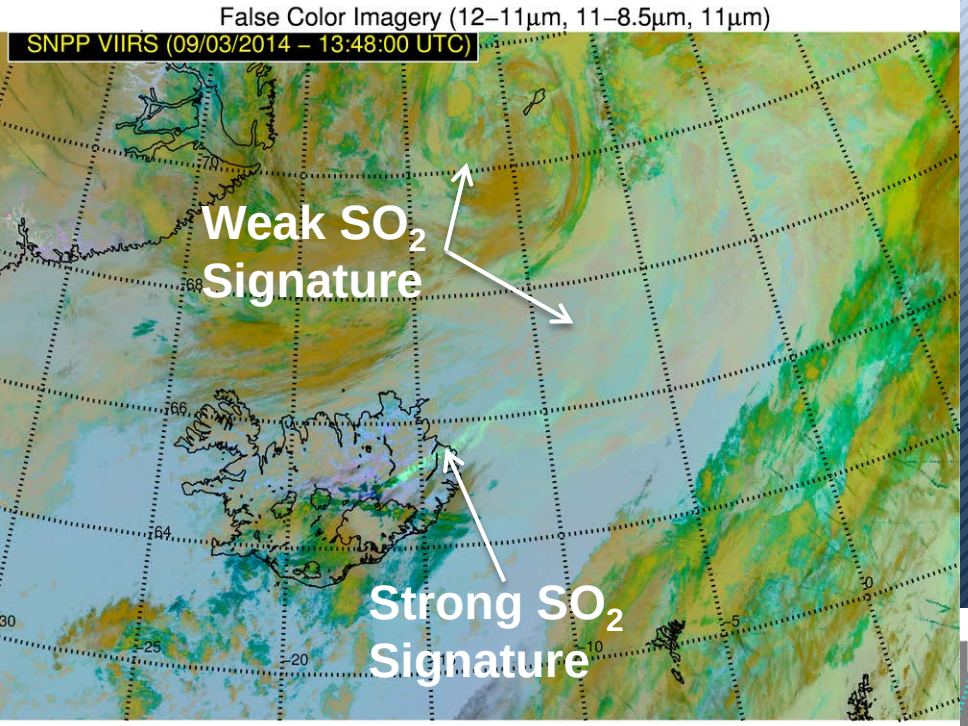
***A priori* Probability:** CrIS SO_2 BTD mapped to VIIRS swath and smoothed



Class Conditional Probabilities: Multivariate predictors trained using manual analysis of many volcanic events

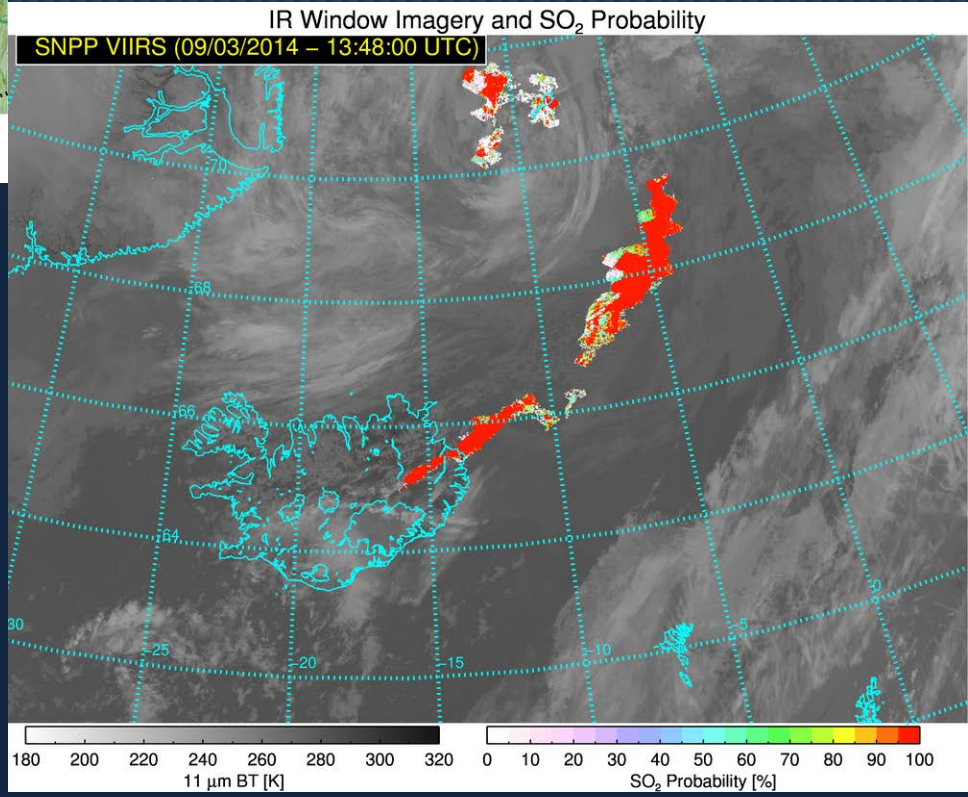


The VIIRS predictors capture the influence of SO_2 absorption on 8.5 µm and the lack there of at 11 and 12 µm.

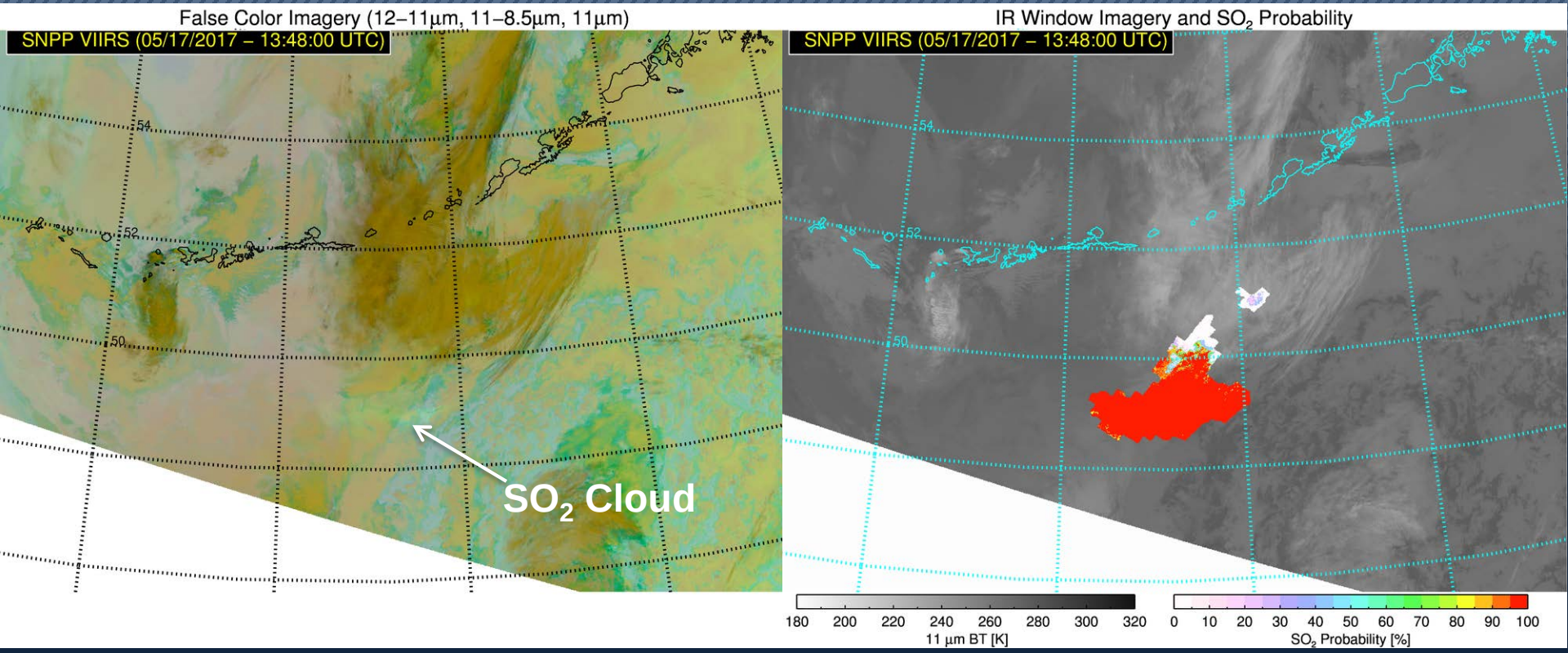


VIIRS SO_2 objects that contain spectrally robust VIIRS and/or CrIS SO_2 spectral signatures are selected

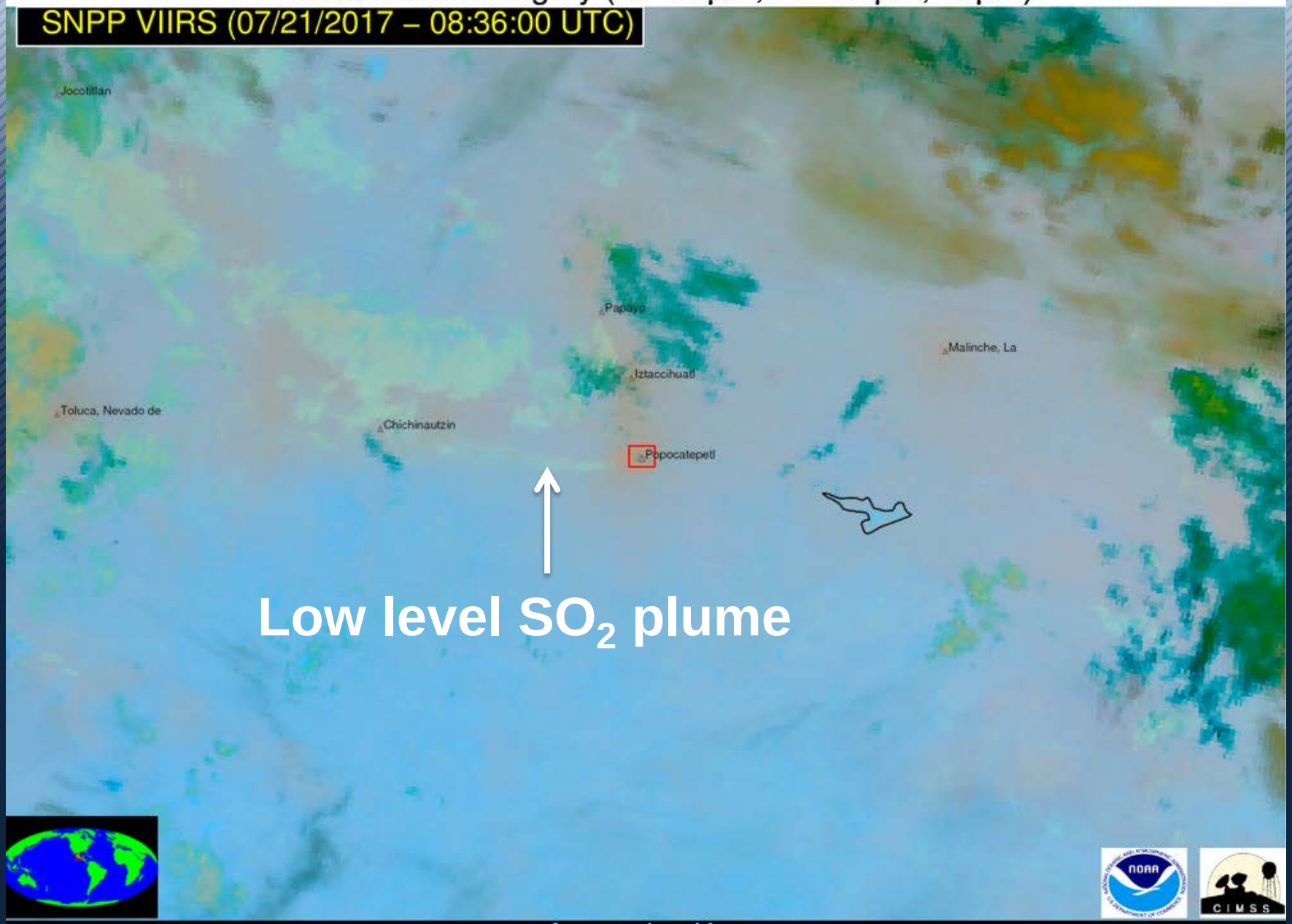
VIIRS contributions are minimal in the northern parts of the SO_2 cloud

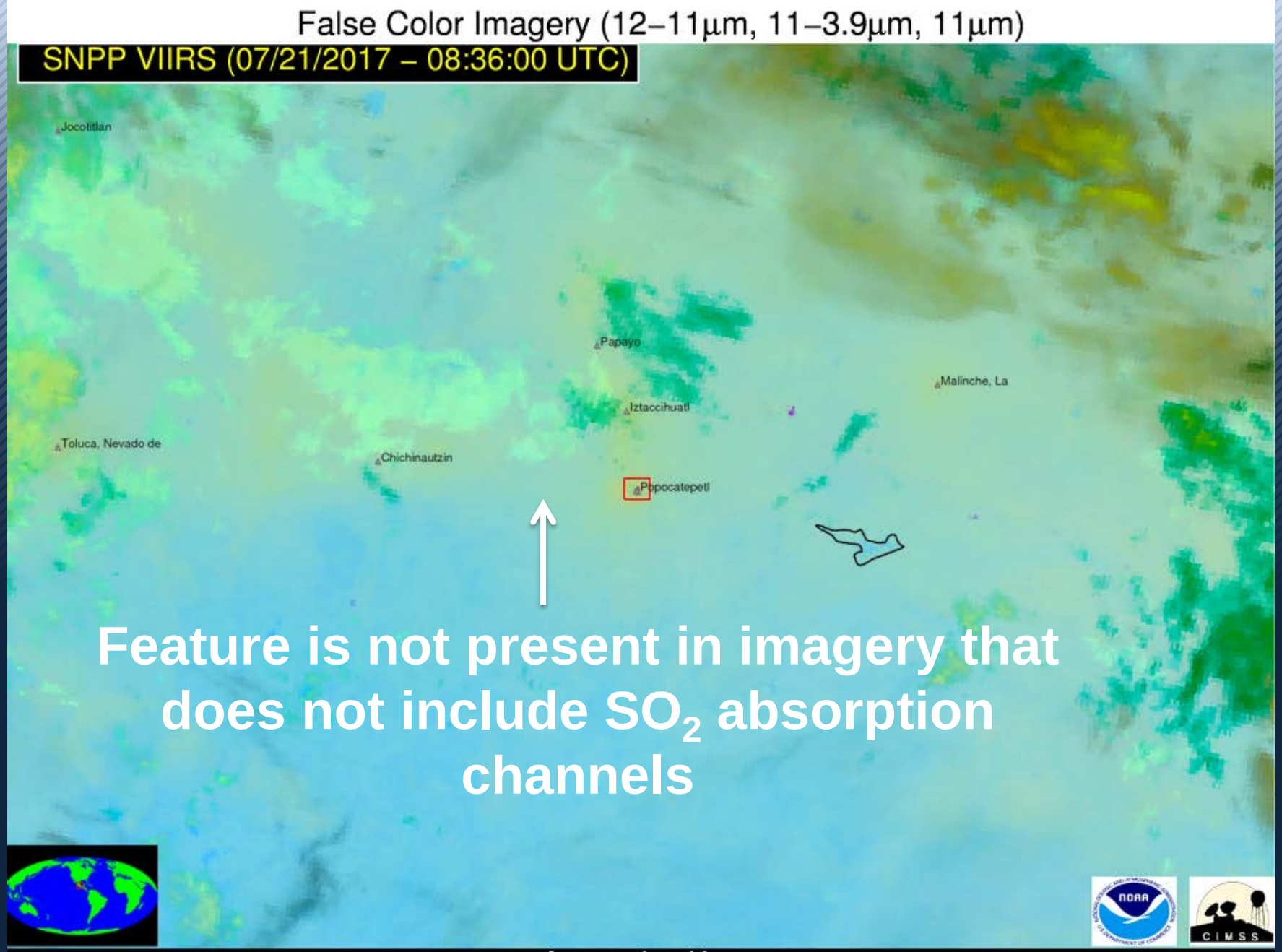


Bogoslof (Alaska)



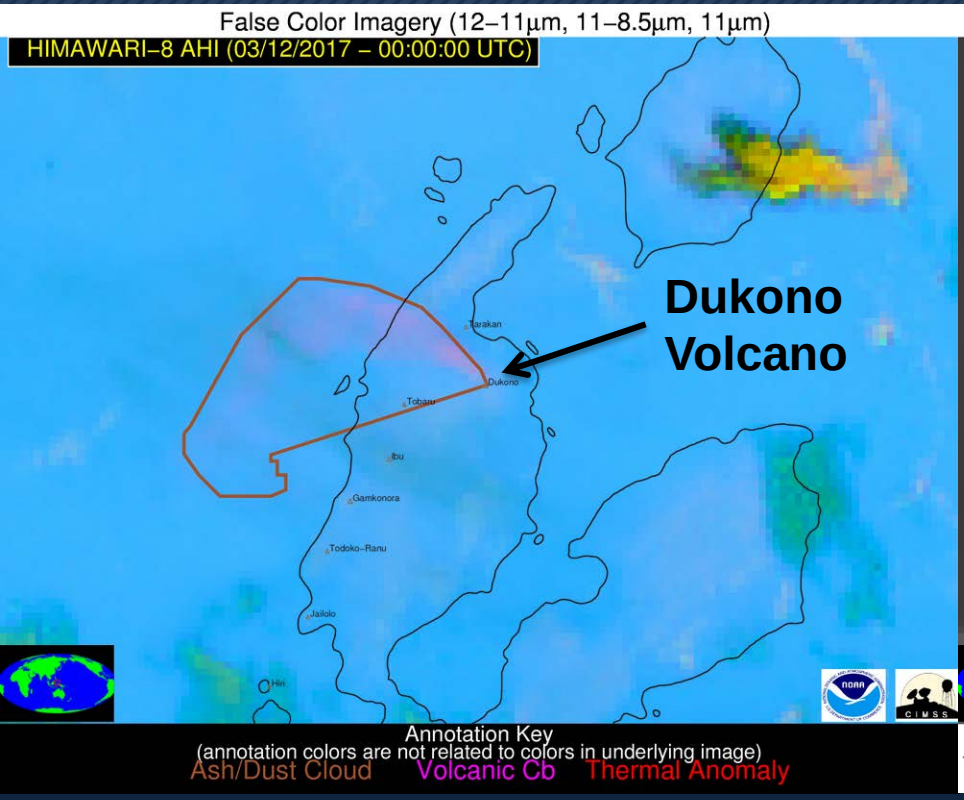
For well dispersed SO_2, OMPS and CrIS will have the greatest influence on results, but displaying SO_2 information on VIIRS images stills add value for users.

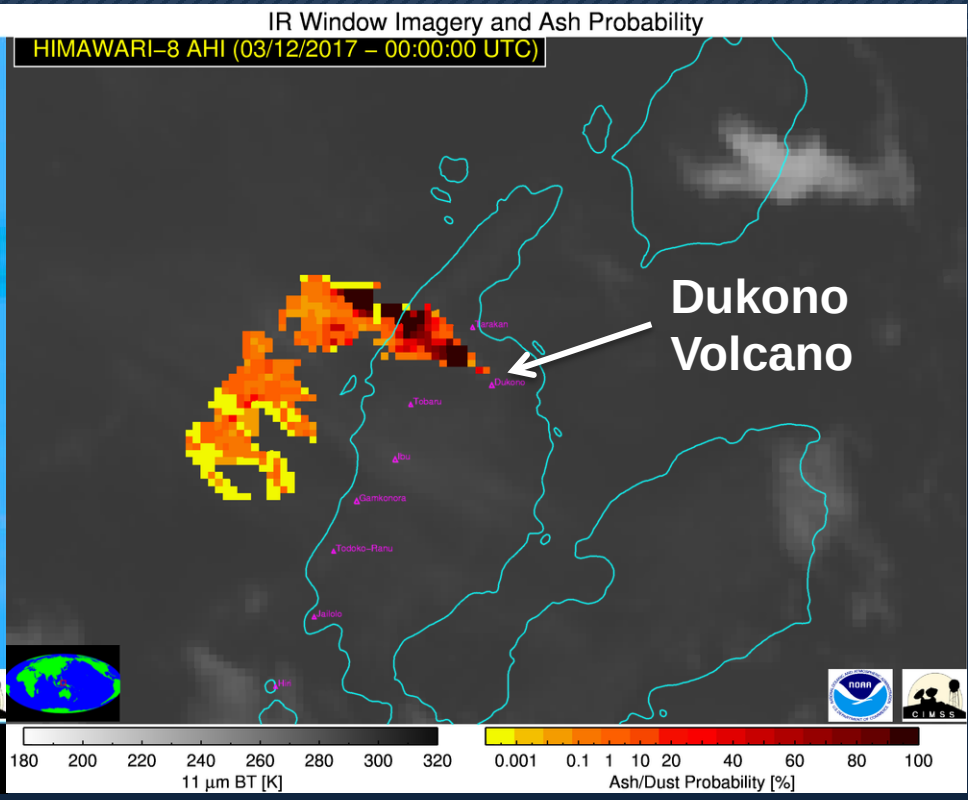

False Color Imagery (12–11μm, 11–8.5μm, 11μm)
SNPP VIIRS (07/21/2017 – 08:36:00 UTC)
Jocotitlan
Papayo
Malinche, La
Iztaccihuatl
Toluca, Nevado de
Chichinautzin
Popocatepetl
Low level SO_2 plume
NOAA
CIMSS
Annotation Key
(annotation colors are not related to colors in underlying image)
Ash/Dust Cloud
Volcanic Cb
Thermal Anomaly

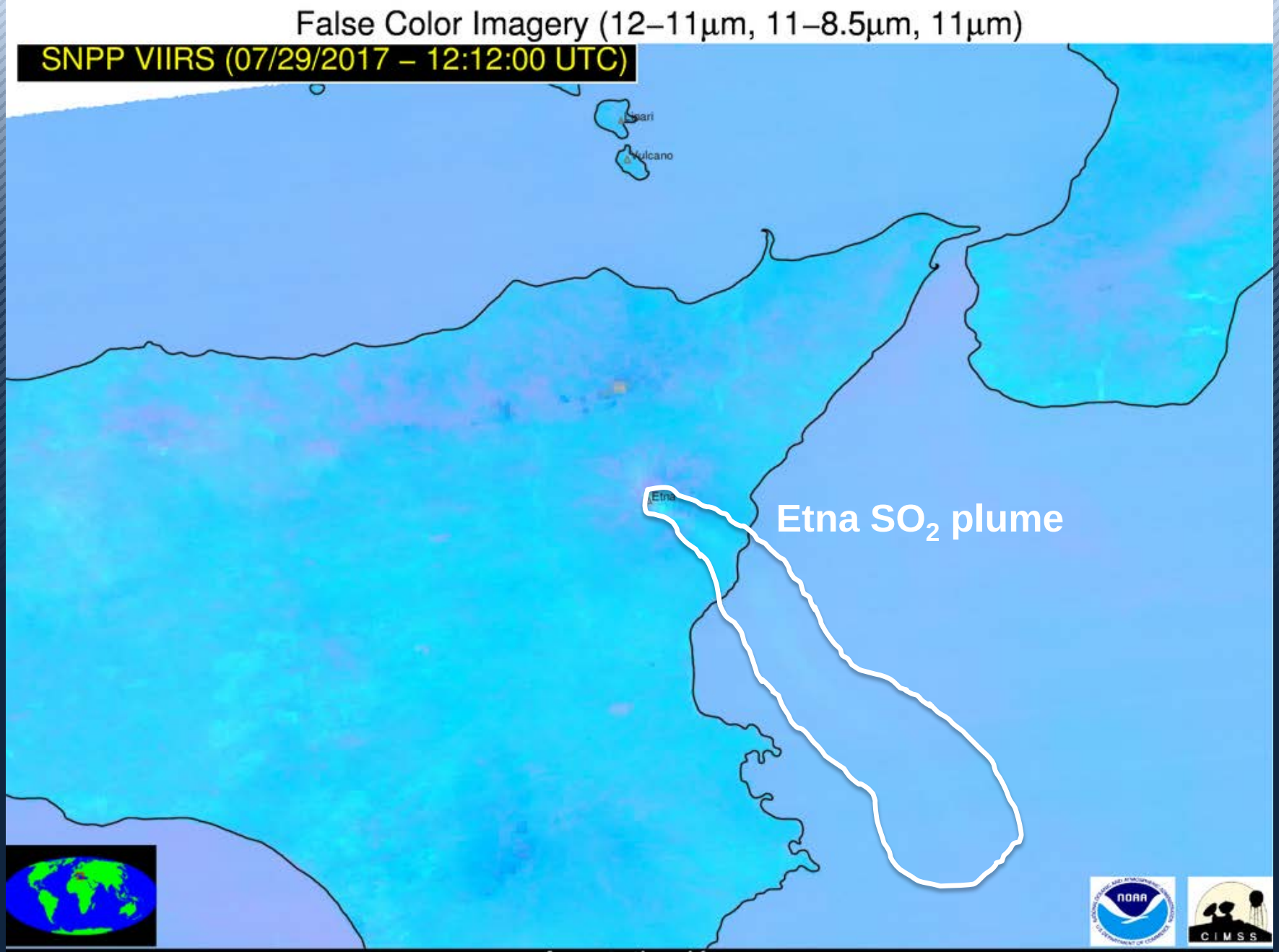

False Color Imagery (12–11μm, 11–3.9μm, 11μm)
SNPP VIIRS (07/21/2017 – 08:36:00 UTC)
Jocotitlan
Papayo
Malinche, La
Iztaccihuatl
Toluca, Nevado de
Chichinautzin
Popocatepetl
Feature is not present in imagery that does not include SO_2 absorption channels
Annotation Key
(annotation colors are not related to colors in underlying image)
Ash/Dust Cloud
Volcanic Cb
Thermal Anomaly

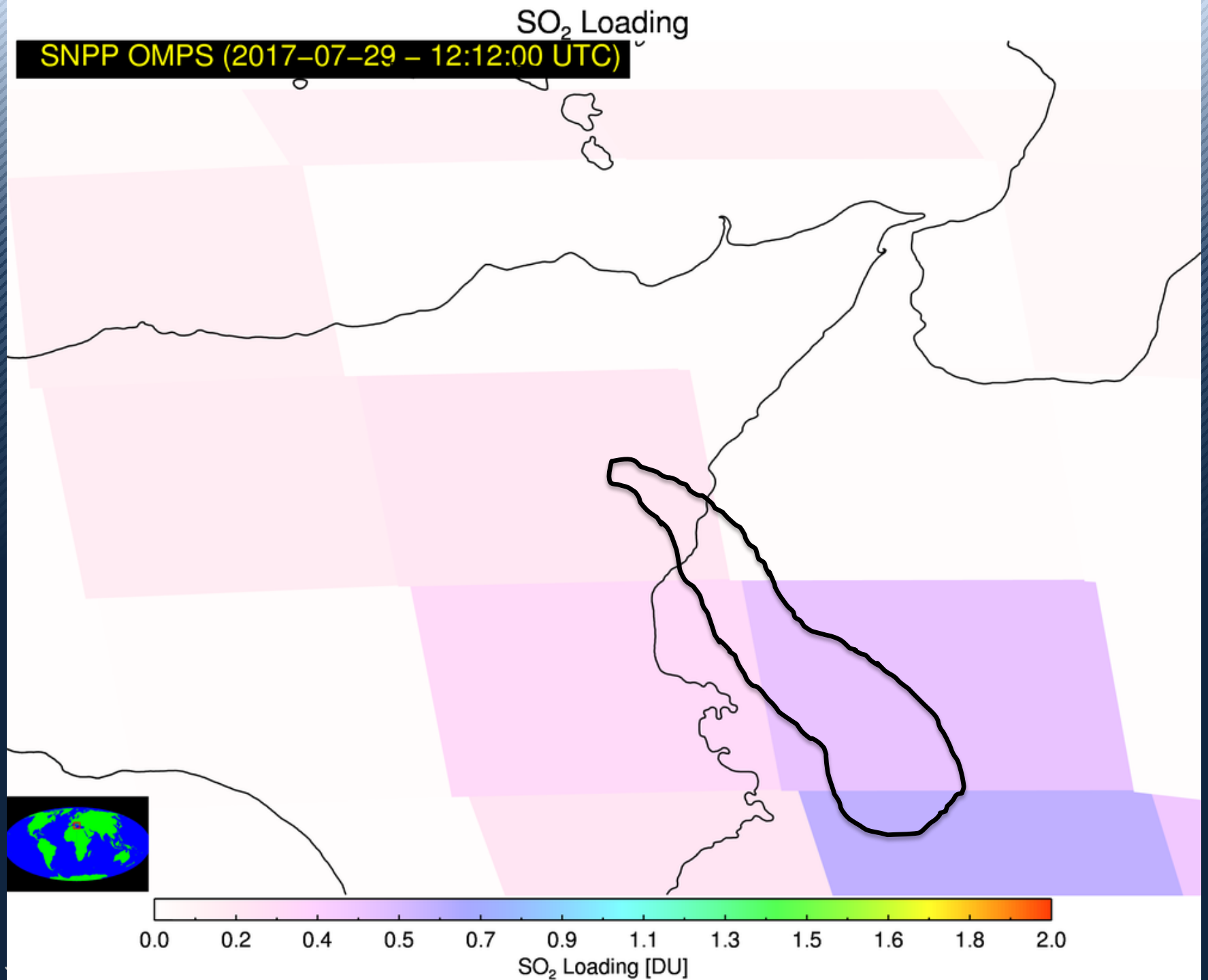
Spatial – Geometric Properties

Most everyday volcanic ash emissions have a weak multi-spectral signature. They are identifiable in imagery due to the combination of spectral signature and plume like shape.

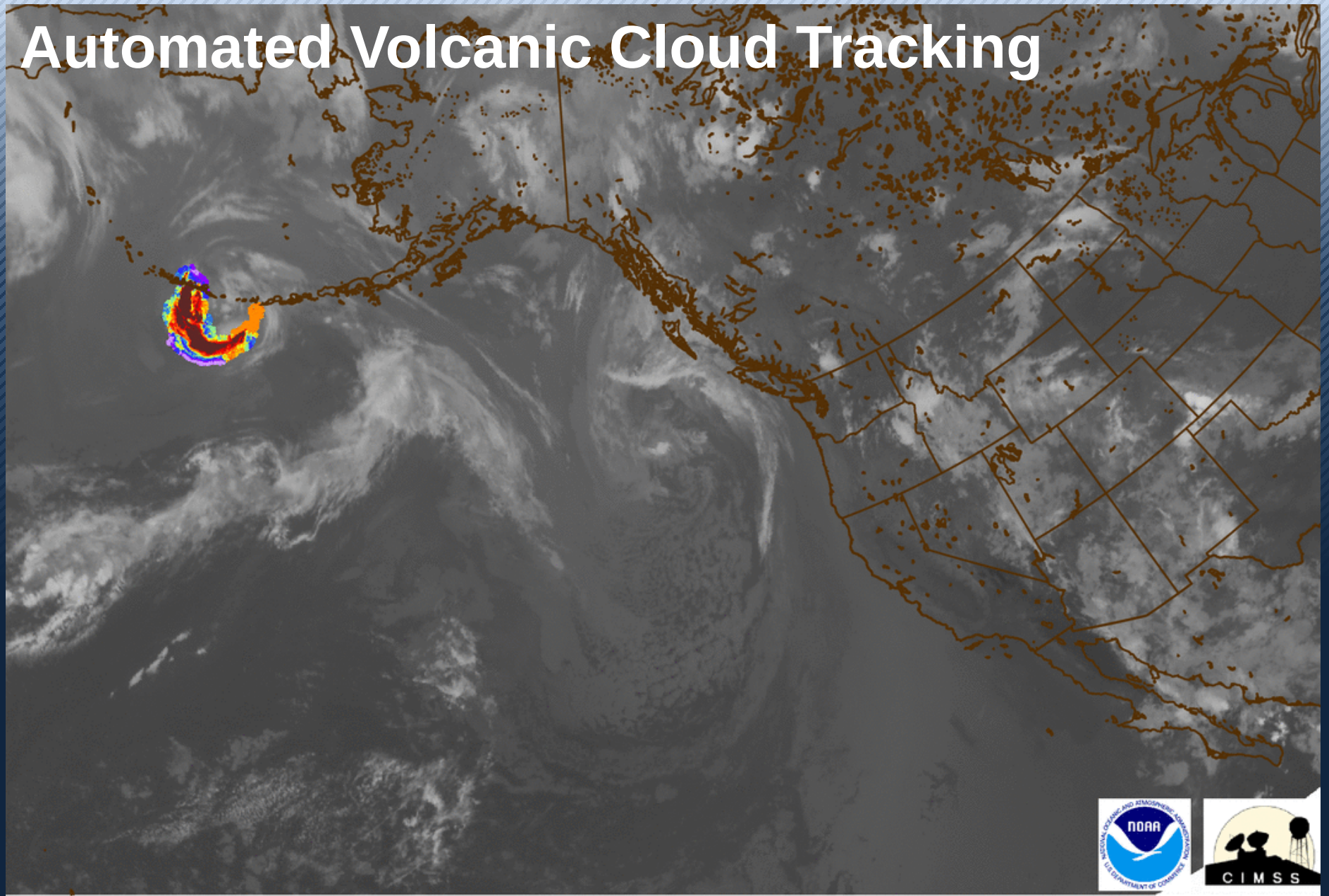




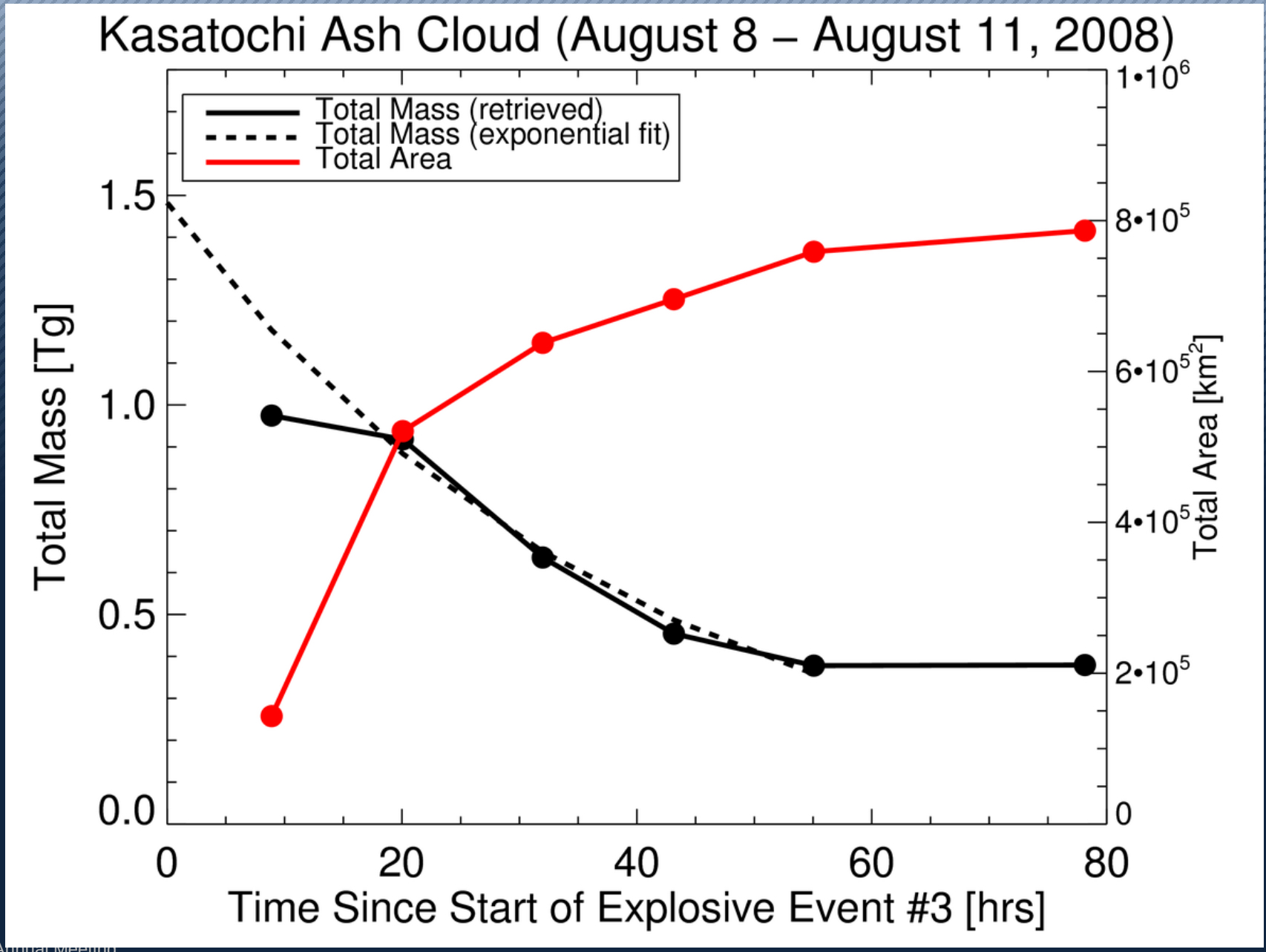

False Color Imagery (12–11μm, 11–8.5μm, 11μm)
SNPP VIIRS (07/29/2017 – 12:12:00 UTC)
Stromboli
Vulcano
Etna
Etna SO_2 plume
NOAA
CIMSS
Annotation Key
(annotation colors are not related to colors in underlying image)
Ash/Dust Cloud
Volcanic Cb
Thermal Anomaly


SO2 Loading
SNPP OMPS (2017-07-29 – 12:12:00 UTC)
0.0
0.2
0.4
0.5
0.7
0.9
1.1
1.3
1.5
1.6
1.8
2.0
SO2 Loading [DU]

Automated Volcanic Cloud Tracking



Automated Volcanic Cloud Time Series

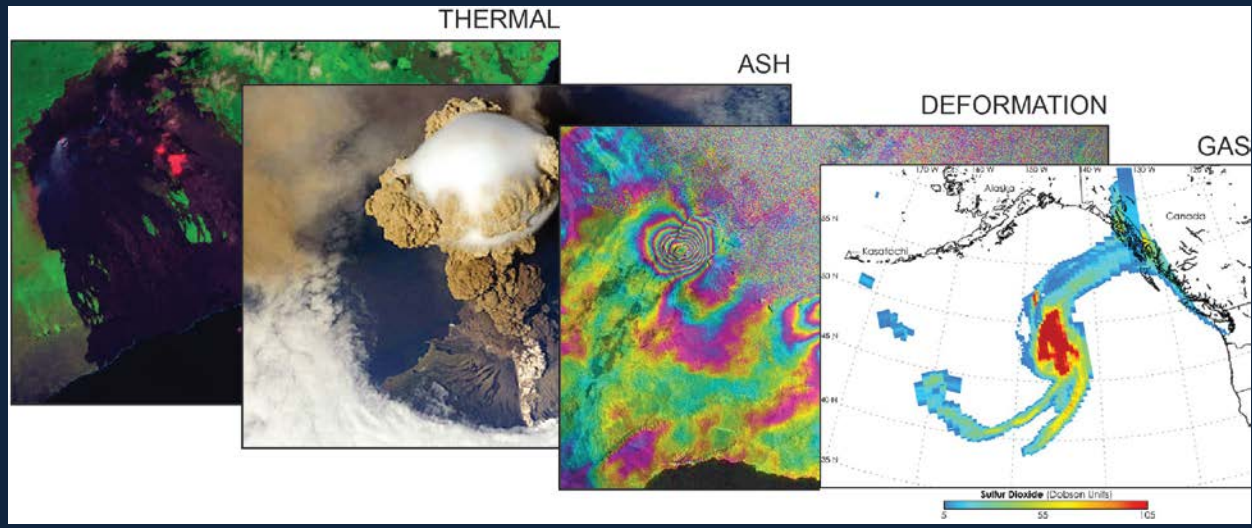


Collaboration

Matt Pritchard (Cornell) - PI
Mike Poland (USGS) – PI
Ben Andrews (Smithsonian)
Juliet Briggs (U. Bristol)
Simon Carn (Mich. Tech)
Julie Griswold (USGS)
Brenda Jones (USGS)
Sue Louglin (British Geological Survey)
Taryn Lopez (UAF)
Paul Lindgren (JPL)
Franz Meyer (UAF)
Mike Pavolonis (NOAA)
Ivan Petiteville (ESA)
Kevin Reath (Cornell)
Dave Schneider (USGS)
Greg Vaughan (USGS)
Christell Wauthier (Penn St.)
Rick Wessels (USGS)
Rob Wright (U. Hawaii)

USGS Powell Center

USGS
science for a changing world



Ongoing Work

So Far: Primary focus on accurately quantifying the horizontal bounds of volcanic SO_2 clouds

Continuing Work: Incorporation of OMPS, merged SO_2 loading estimates, merged SO_2 alerts and time series (including GOES-R)

User interactions: Close relationship with NOAA VAAC's, USGS, and many international partners

Other Collaborations: NOAA ARL (HYSPLIT) group

References

Pavolonis, M. J., W. F. Feltz, A. K. Heidinger, and G. M. Gallina, 2006: A daytime complement to the reverse absorption technique for improved automated detection of volcanic ash. J.Atmos.Ocean.Technol., **23**, 1422-1444.

Pavolonis, M. J., 2010: Advances in Extracting Cloud Composition Information from Spaceborne Infrared Radiances-A Robust Alternative to Brightness Temperatures. Part I: Theory. Journal of Applied Meteorology and Climatology, **49**, 1992-2012, doi:10.1175/2010JAMC2433.1 ER.

Pavolonis, M., A. Heidinger, and J. Sieglaff, 2013: Automated retrievals of volcanic ash and dust cloud properties from upwelling infrared measurements, J. Geophysical Research, **118(3)**, 1436-1458.

Pavolonis, M., J. Sieglaff, and J. Cintineo (2015a), Spectrally Enhanced Cloud Objects (SECO): A Generalized Framework for Automated Detection of Volcanic Ash and Dust Clouds using Passive Satellite Measurements, Part I: Multispectral Analysis, Journal Geophysical Research, **120**, 7813-7841.

Pavolonis, M., J. Sieglaff, and J. Cintineo (2015b) Spectrally Enhanced Cloud Objects (SECO): A Generalized Framework for Automated Detection of Volcanic Ash and Dust Clouds using Passive Satellite Measurements, Part II: Cloud Object Analysis and Global Application, Journal Geophysical Research, **120**, 7842-7870.