Retrievals of tropospheric ozone profiles from the synergism of AIRS and OMI: methodology and validation

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with thanks to KORUS-AQ, TES, AIRS, OMI, and CrIS teams

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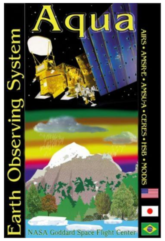
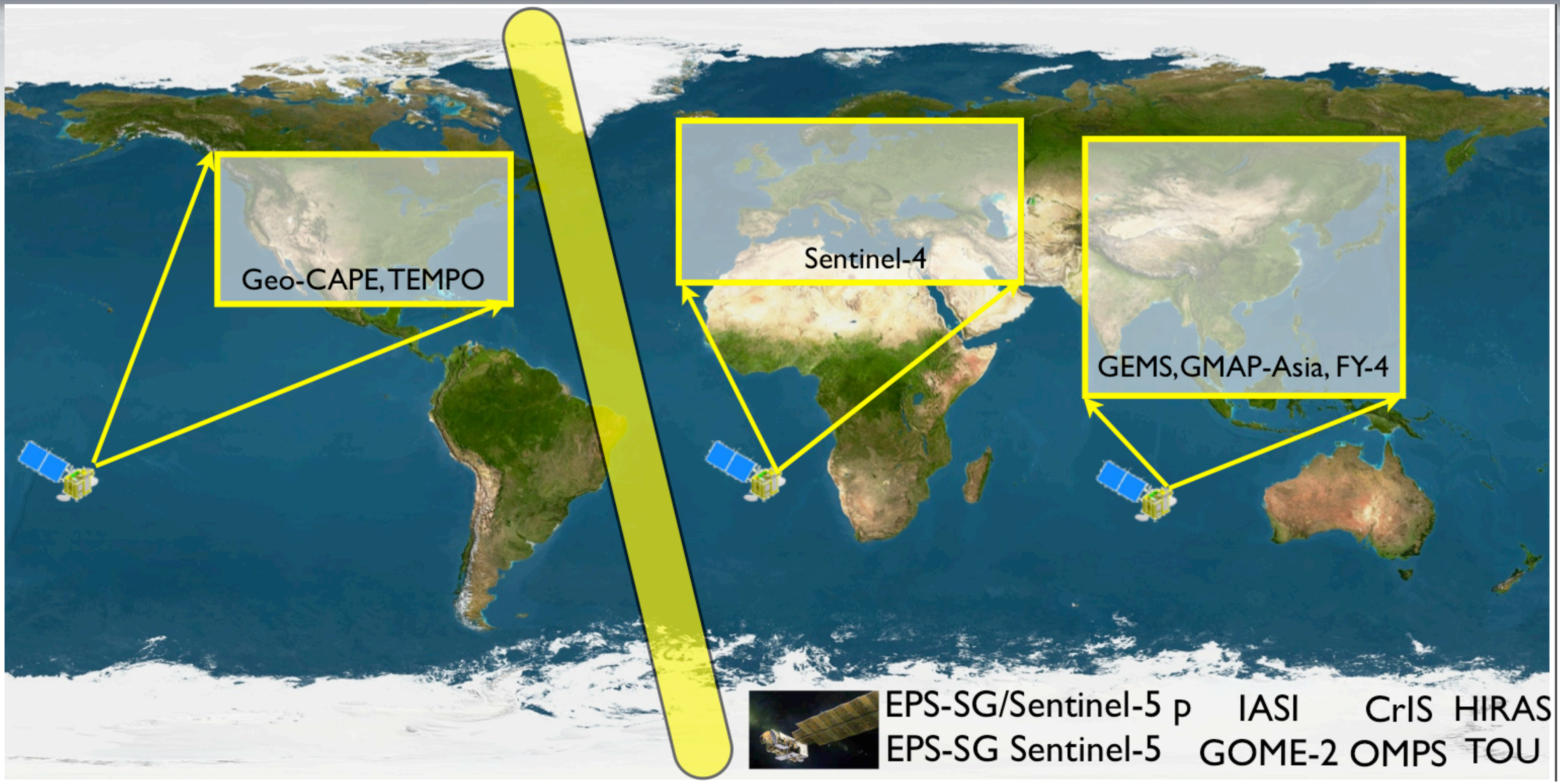


Towards an Air Quality Constellation

Bowman, *Atm. Env.* 2013



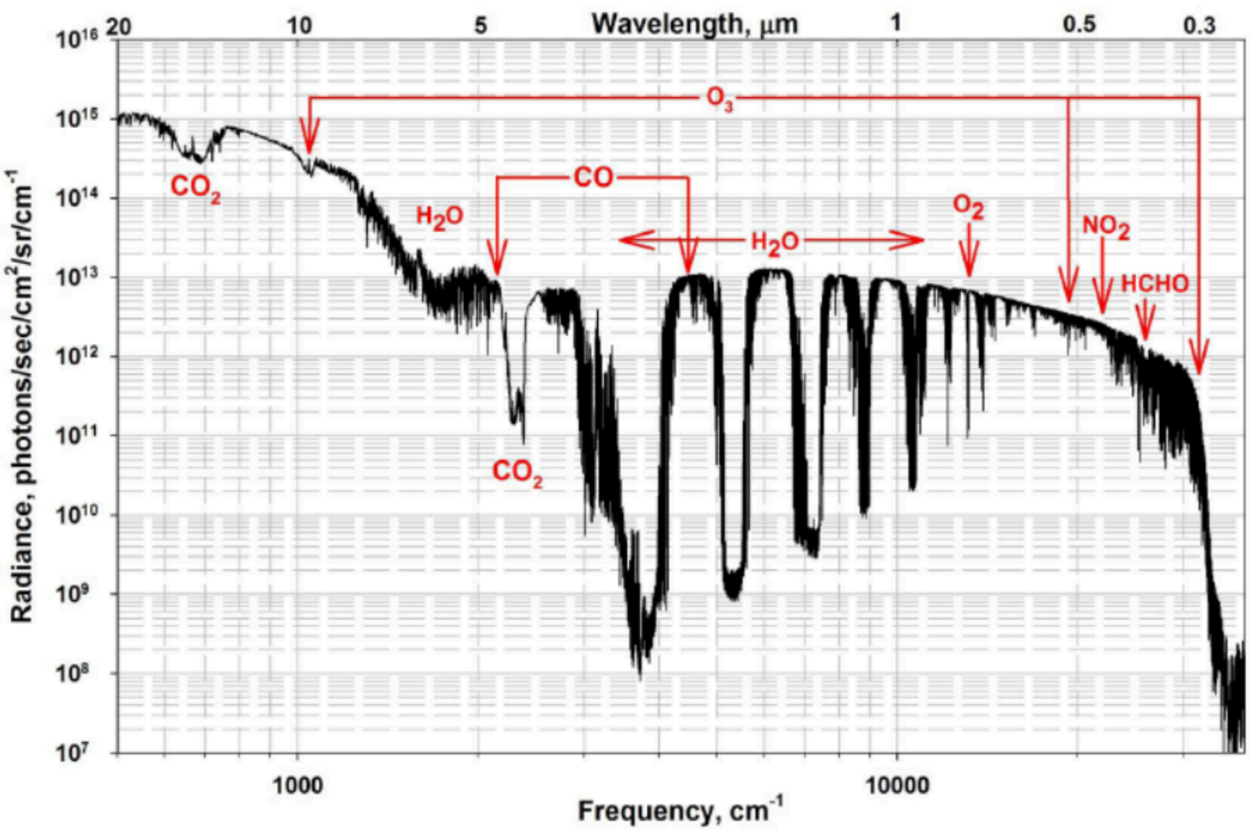
How does the constellation improve knowledge of global air quality?

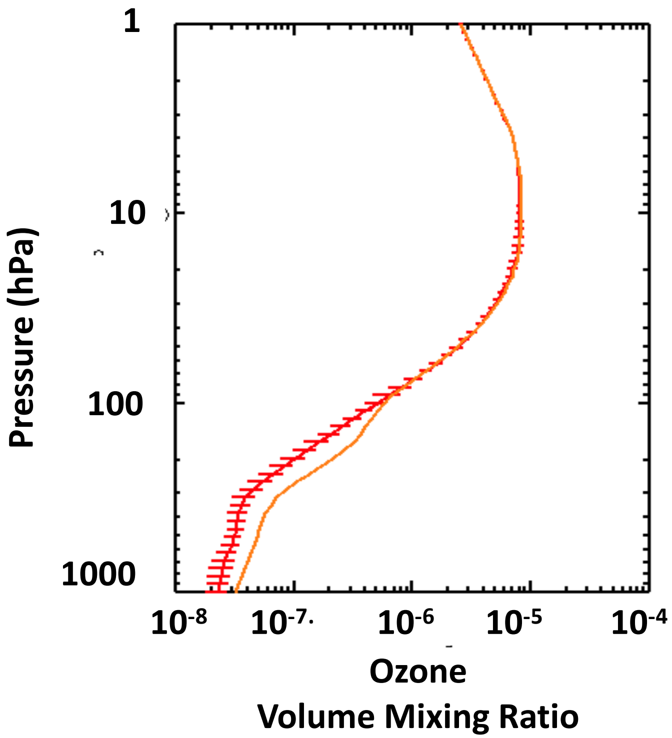
- GEO sounders (GEO-CAPE, TEMPO, Sentinel-4, GEMS) will provide an unprecedented number of composition observations at high spatial resolution.
- LEO sounders (IASI, CrIS, S5p) provide the global picture and thread the GEO observations together.

The Synergic Observations

Joint LW/SW or ultra-high spectral resolution measurements distinguish upper/lower troposphere.

- TIR observations are sensitive to the free-tropospheric trace gases.
- UV-Vis-NIR observations are sensitive to the column abundances of trace gases.

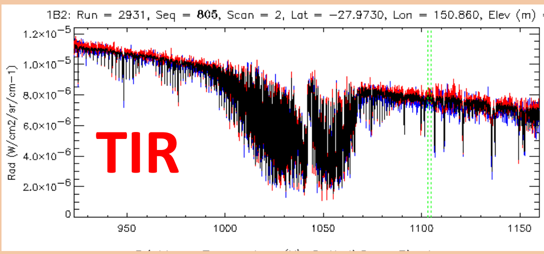


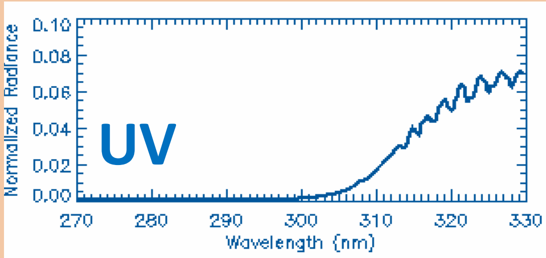


MUlti-SpEctra, MUlti-SpEcies, MUlti-SEnsors (MUSES) Retrieval Algorithm

Connecting Remote Sensing to Assimilation

JPL MUSES algorithm delivers both retrieved trace gas concentration profiles and observation operators needed for trend analysis, climate model evaluation, and data assimilation.

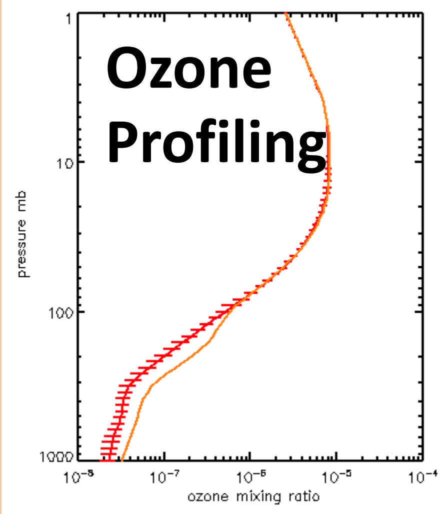




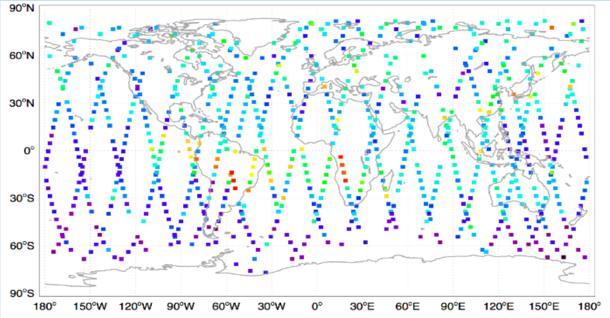
$$\|\mathbf{y}-\mathbf{F}(\mathbf{x}_a)\|^2_{\mathbf{S}_n^{-1}} + \|\mathbf{x}-\mathbf{x}_a\|^2_{\mathbf{S}_a^{-1}}$$

MUSES Retrieval Algorithm

$$\hat{\mathbf{x}} = \mathbf{x}_a + \mathbf{A}(\mathbf{x}-\mathbf{x}_a) + \mathbf{G}\mathbf{n}$$

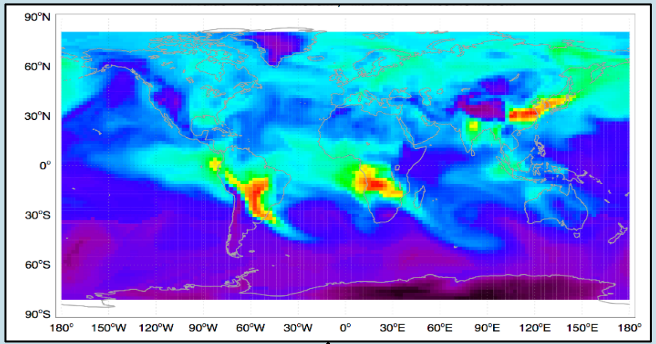


Operational Data Processing



Data Assimilation

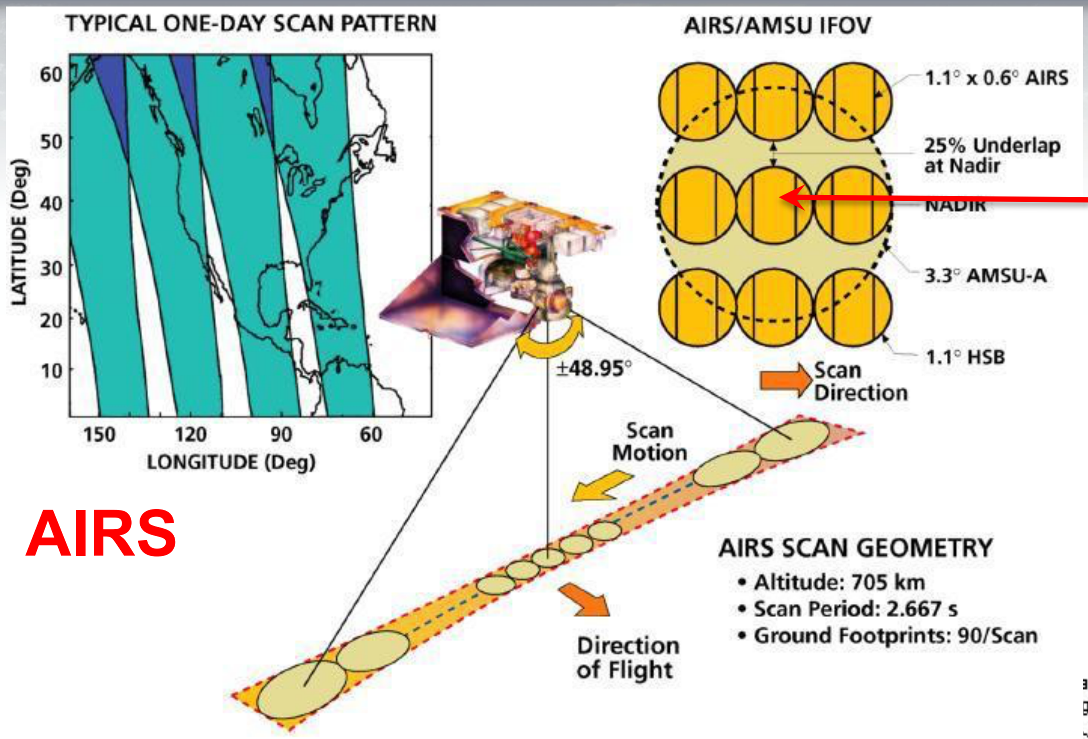
$$\mathbf{H}_i(\bullet) = \mathbf{x}_a + \mathbf{A}_i(\bullet - \mathbf{x}_a)$$



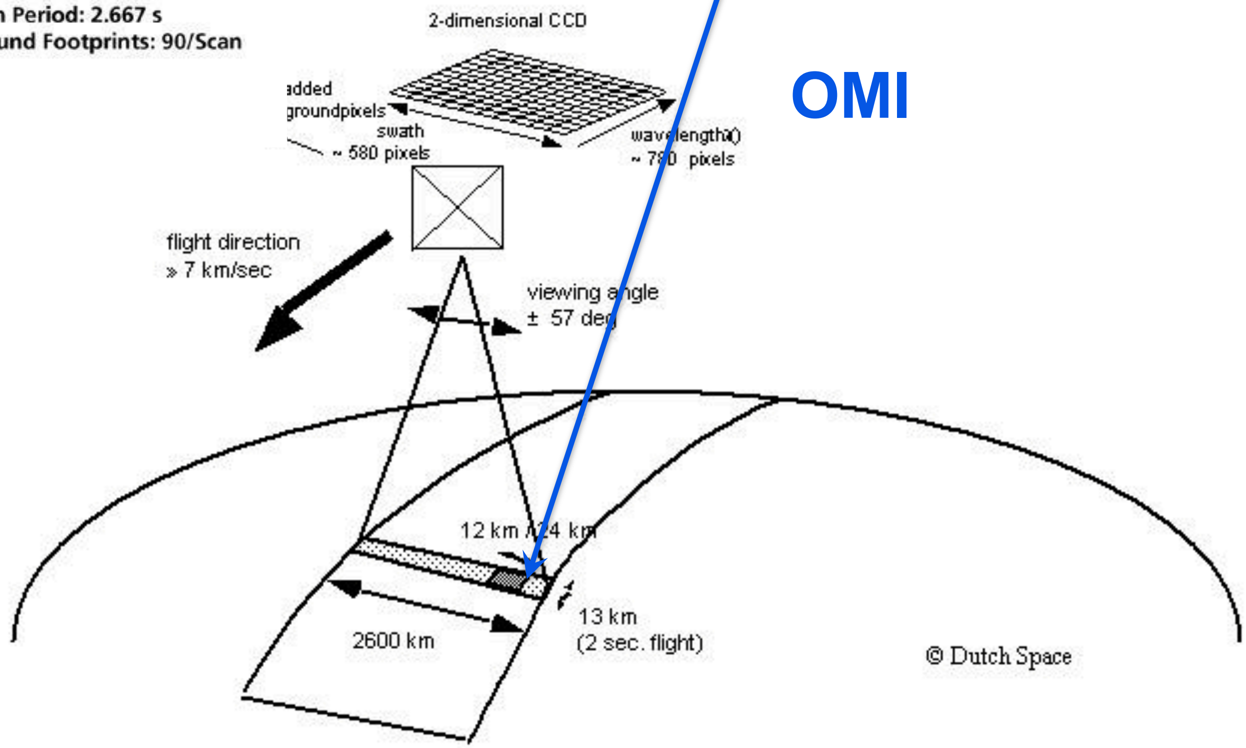
$$\sum_i \|\hat{\mathbf{x}}_i - \mathbf{H}_i(\mathbf{x})\|^2_{(\mathbf{G}_i\mathbf{S}_n^i\mathbf{G}_i^T)^{-1}} + \|\mathbf{x}_0 - \mathbf{x}_B\|^2_{\mathbf{B}^{-1}}$$

Combined AIRS Single Footprint to OMI Measurements

This work combines **AIRS single footprint L1B radiances** to **OMI measured radiances** for retrieving O_3 profiles.



AIRS



OMI

Data Processing of Joint AIRS/OMI O_3 Retrievals

Configured in two modes: global survey (GS) and regional mapping (RE).

GS – Provides profiles with a spatial sampling similar to TES global survey

- 2006 – 2009, processed for all months
- 2011 - 2017, processed for some months specified by the user community
- Forward Processing: Oct, 2017 to Present
- Reanalysis Processing: 2005 to 2017 (10x spatial coverage, completion expected in 2019)

RE – Processes all available measurements for flight campaigns

- KORUS-AQ, Apr – Jun 2016
- ORACLES, Aug, Sept 2016
- POSIDON, Sept, Oct 2016
- Mexico City, Oct 2013
- *CrIS CO and O_3 over CONUS for the FIREX-AQ campaign.*

L2 data access:

- Data products have been saved in Hierarchical Data Format, a common format used in the NASA Earth Observation System level 2 products
- Data products access + validation report & IDL Reader via following link: https://tes.jpl.nasa.gov/multi-instrument-products/airs-omi

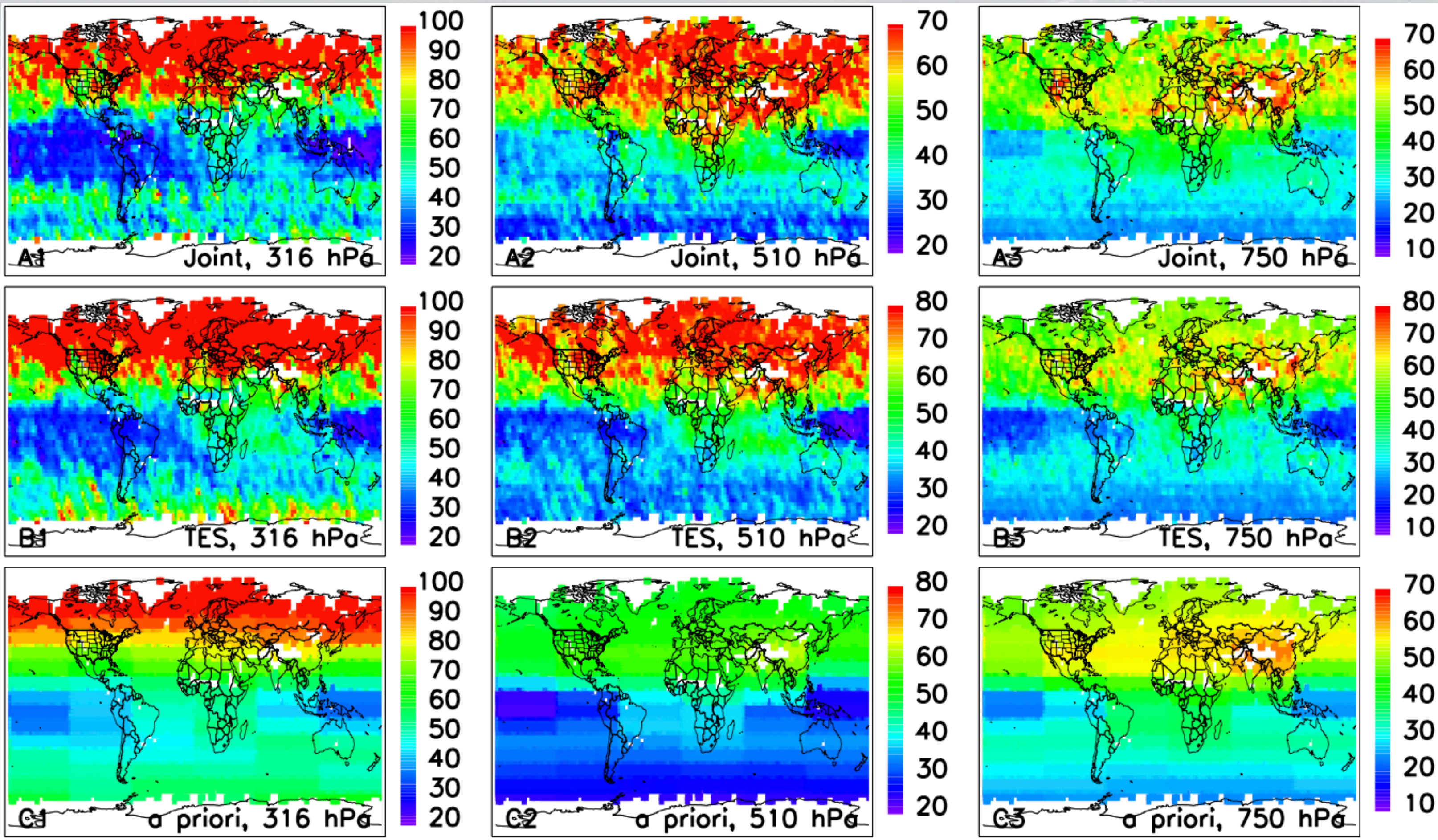
Welcome/thanks community help on scientific applications and performance evaluation/characteristics this decade long data for future algorithm optimization.

Joint AIRS+OMI O_3 vs. TES Global Survey Mode

Joint AIRS/OMI

TES version 6.0

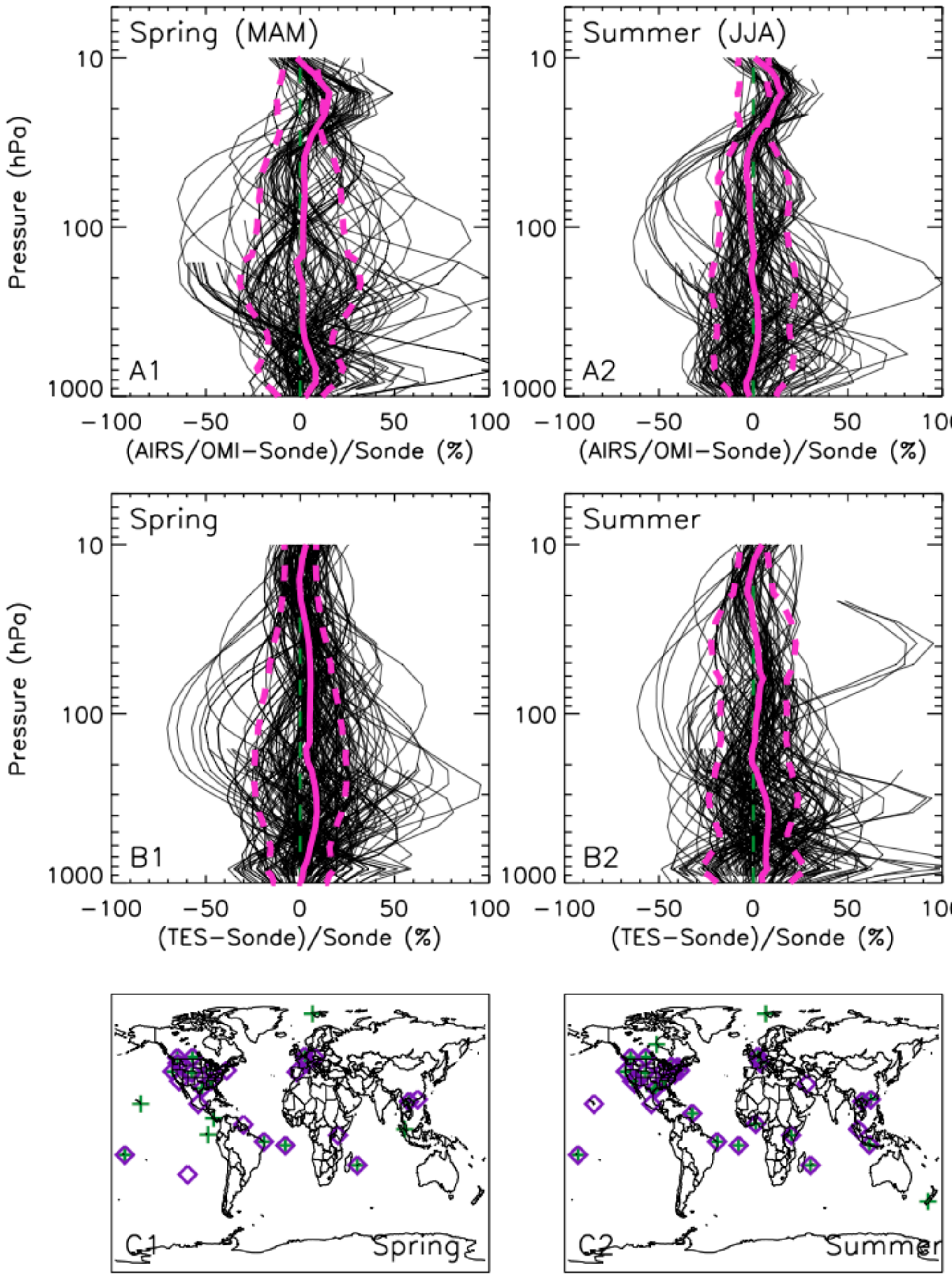
A priori



Fu et al., *"Retrievals of tropospheric ozone profiles from the synergism of AIRS and OMI: methodology and validation"*, AMT, 11, 5587-5605, 2018.

- The correlation coefficients of joint AIRS+OMI vs. TES ozone data: 0.71 - 0.92 for all months.
- The characteristics of the joint AIRS+OMI retrievals, in terms of vertical sensitivity and estimated uncertainty characteristics, are equivalent to those of TES data.

Comparisons to WOUDC Ozonesondes



		Spring	
	316 hPa	AIRS+OMI	TES
	Mean (ppb)	2.8	6.1
	Mean (%)	1.3	8.6
	RMS (ppb)	17.1	19.2
	RMS (%)	25.6	23.7
		Spring	
	510 hPa	AIRS+OMI	TES
Differences (Satellite – WOUC Sonde with Satellite Observation Operator Applied)	Mean (ppb)	1.3	3.6
	Mean (%)	3.8	7.0
	RMS (ppb)	7.6	9.2
	RMS (%)	17.2	17.4
		Spring	
	750 hPa	AIRS+OMI	TES
	Mean (ppb)	2.4	1.7
	Mean (%)	8.0	3.4
	RMS (ppb)	7.6	6.9
	RMS (%)	21.1	16.2
Number of WOUDC Sonde Sites		20	25
Number of Satellite/Sonde Coincidences		131	197

Coincident criteria

- Passed retrieval quality check
- Distance < 300 km; Time diff. < 4 hours
- Day Time
- Cloud optical depth < 2.0

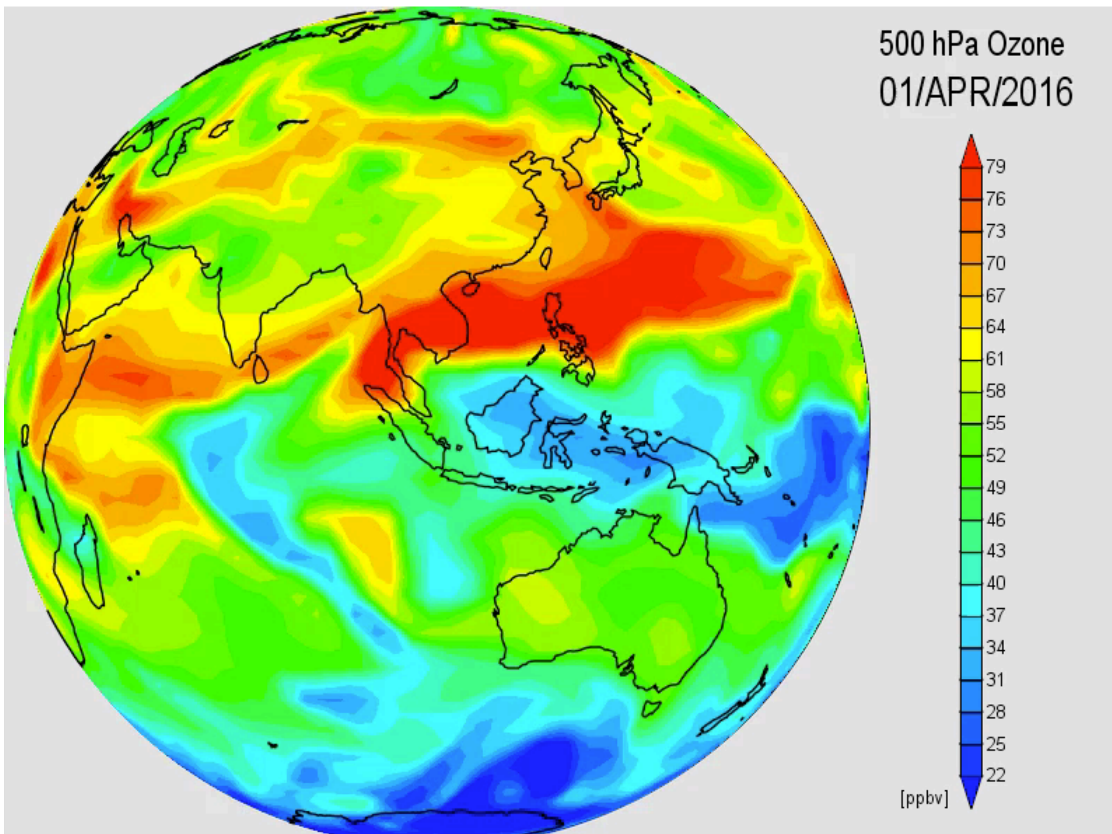
AIRS/OMI tropospheric ozone assimilation and chemical reanalysis during the NASA KORUS-AQ aircraft campaign

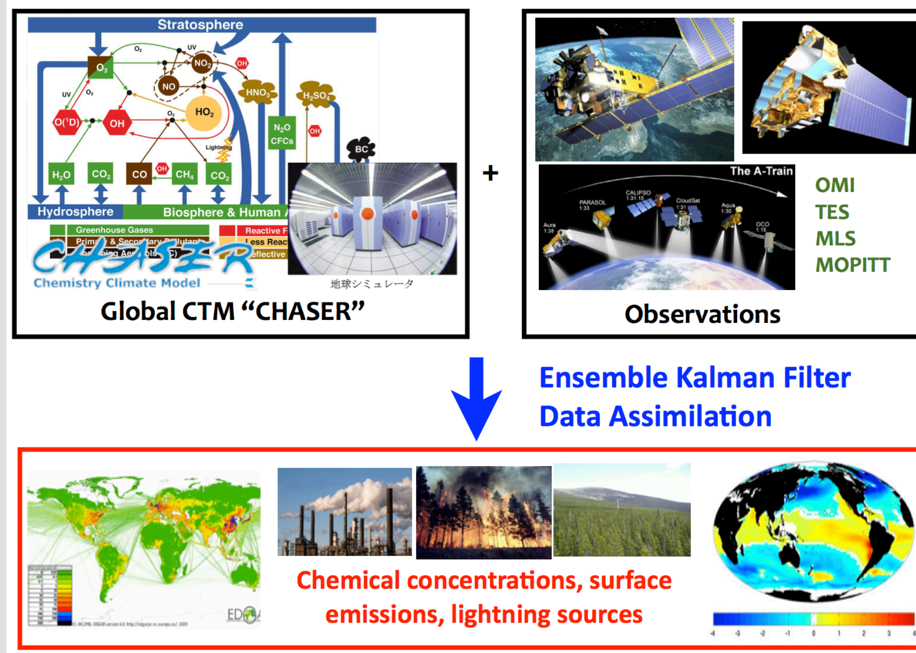
K. Miyazaki [1], D. Fu[1], K. W. Bowman[1], J. Neu[1], G. Osterman[1], S. S. Kulawik[2], T. Sekiya[3], K. Sudo[3], Y. Kanaya[3], M. Takigawa[3], K. Ogochi[3], B. Gaubert[4], J. Barre[4], L. Emmons[4], and KORUS-AQ team

[1] NASA Jet Propulsion Laboratory, California Institute of Technology, USA
[2] NASA Ames Research Center, USA
[3] Japan Agency for Marine-Earth Science and Technology, Japan
[4] National Center for Atmospheric Research, USA

Assimilated Global Ozone Fields

- Joint AIRS/OMI ozone profiles have been assimilated into CHASER system (Miyazaki et al., JGR, 124, 387–413, 2019).
- CHASER system assimilated the OMI (NO_2), GOME-2 (NO_2) MLS (HNO_3 and O_3), MOPITT (CO) for KORUS-AQ ,recently assimilated AIRS/OMI ozone profile data

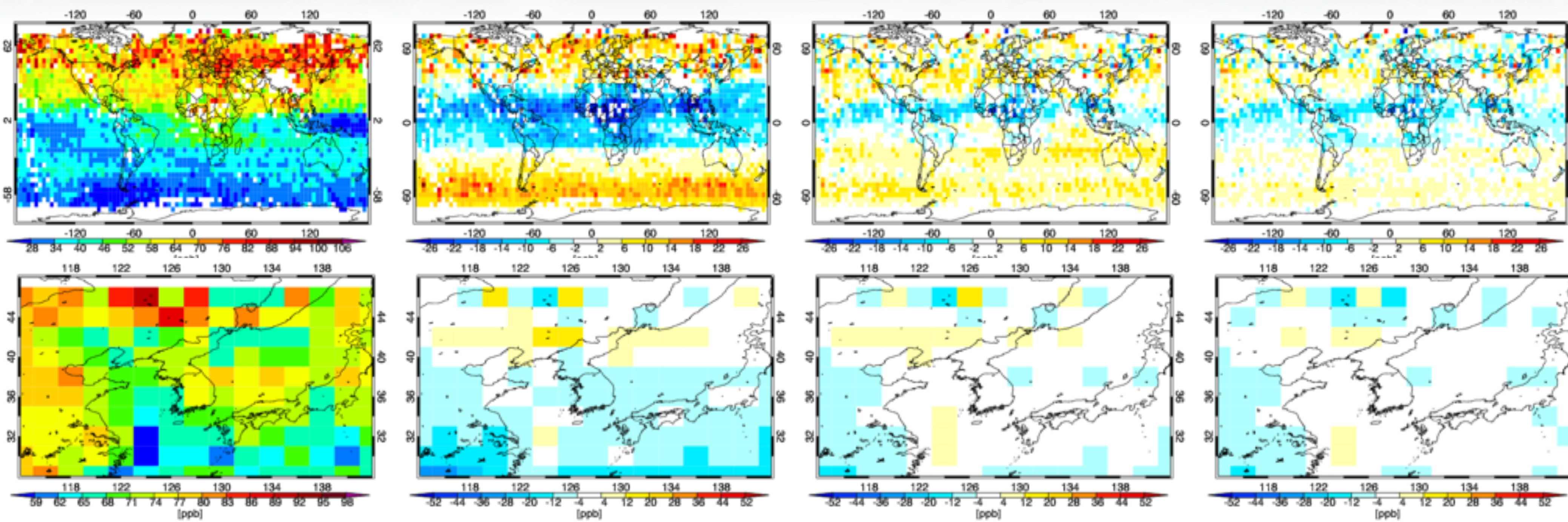




Miyazaki, 2009; Miyazaki et al., 2011, 2012a, 2012b, 2013, 2014, 2015

AIRS/OMI applications for chemical reanalysis

Obs (AIRS/OMI) | **Model - Obs** | **Reanalysis - Obs** | **Reanalysis + AIRS/OMI - Obs**

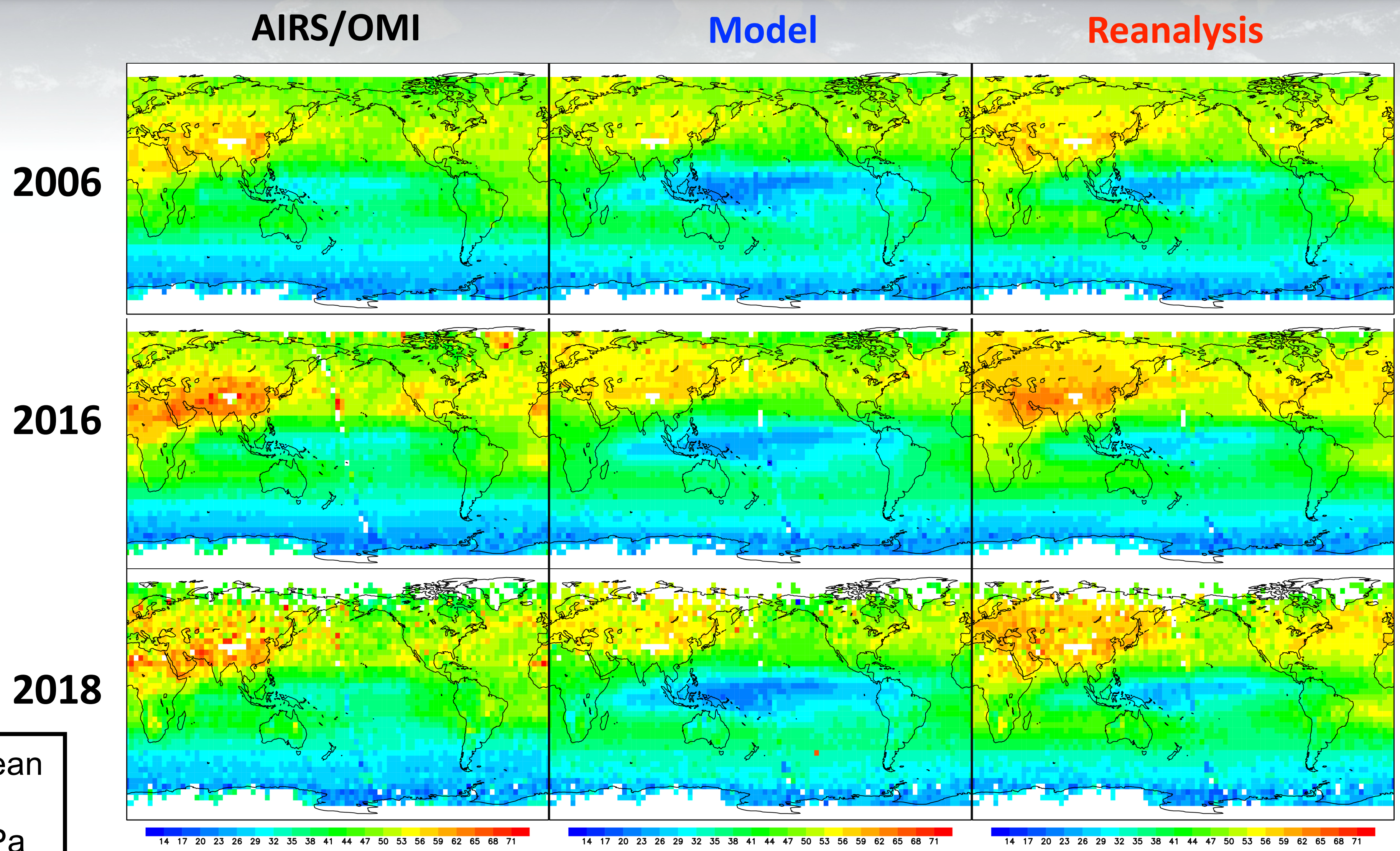


Ozone at 510 hPa during NASA KORUS-AQ

AIRS/OMI data was successfully assimilated.

- **Miyazaki et al.,** "*Evaluation of a multi-constituent chemical reanalysis during KORUS-AQ: Role of dynamics and emissions*", JGR, 124, 387–413, 2019.
- Based on DC-8 comparisons, we confirmed that combining precursors' emission optimization and direct ozone assimilation from AIRS/OMI is an effective method to obtain sufficient corrections on the entire tropospheric ozone profiles for any meteorological condition.

AIRS/OMI applications for chemical reanalysis



Annual mean ozone at 700 hPa

- AIRS/OMI data are available for multiple full years (2006, 2016, 2018)
- Good agreements with ozone reanalysis assimilated multi-constituent satellites
- Provide additional constraints on decadal global ozone reanalysis

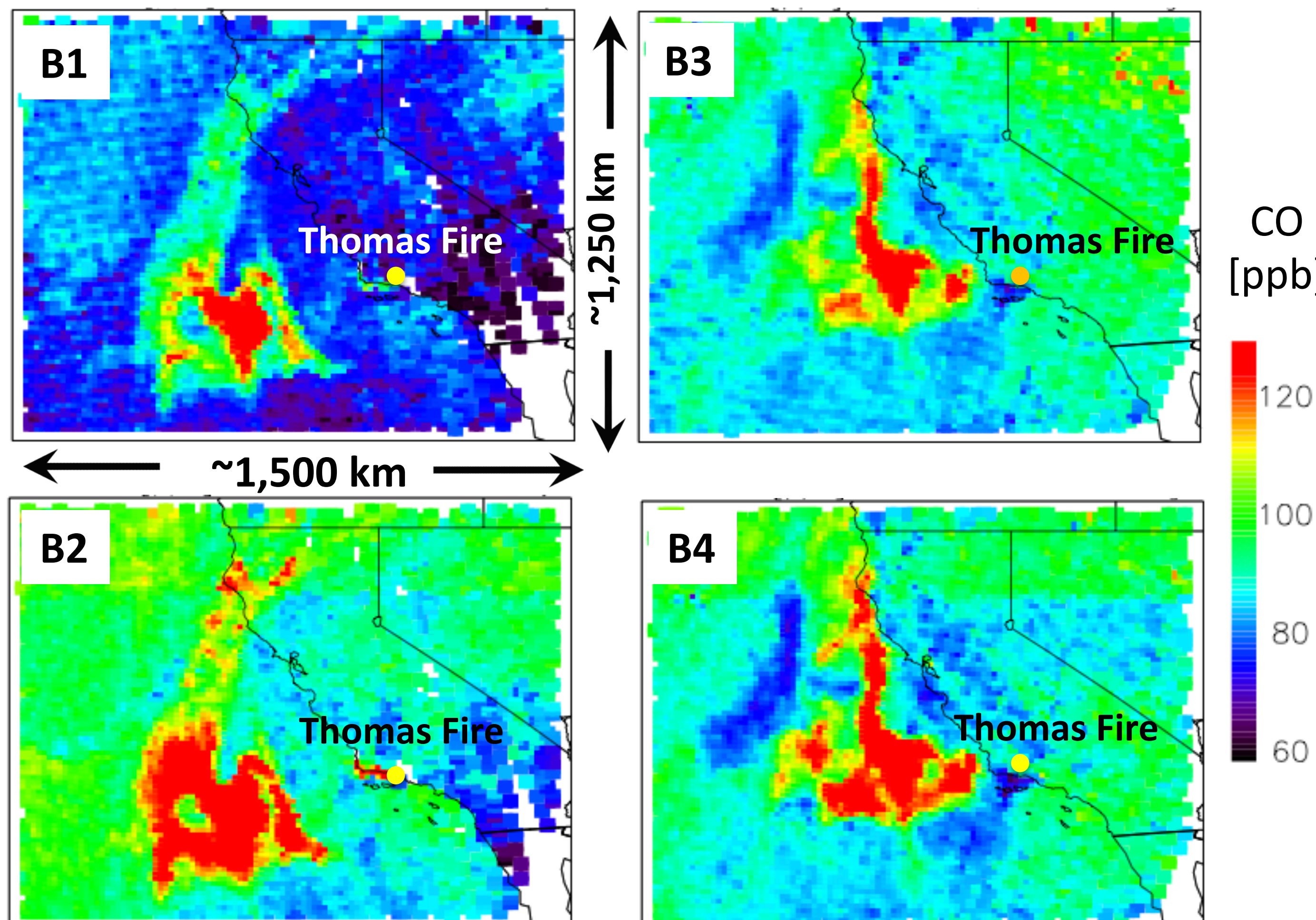
CrIS Carbon Monoxide Observations for Thomas Fire

Email Contact: dejian.fu@jpl.nasa.gov

Hazard of Thomas Fire

Location: near Los Angels, California, USA
Date: Dec 4, 2017 - Jan 12, 2018
Burn Area: 281,893 acres; ~1,140 km^2
Buildings Destroyed: 1,063
Fatalities: 1 firefighter, 1 civilian (20 indirectly)

- CO volume mixing ratio profiles (VMR) retrieved using JPL multi-spectra, multi-Species, multi-sensors (MUSES) [Fu et al, 2013, 2016]
- Provides retrieved profiles and observation operators
- 9X finer spatial resolution than the operational AIRS/CrIS products
- Algorithm heritage of TES, OMI, OCO-2, have been applied to TES, AIRS, CrIS, TROPOMI, OMI, OMPS, OCO2 for a suite of species including CO, O3, CH4, H2O, HDO, CH3OH, PAN, NH3, CO2



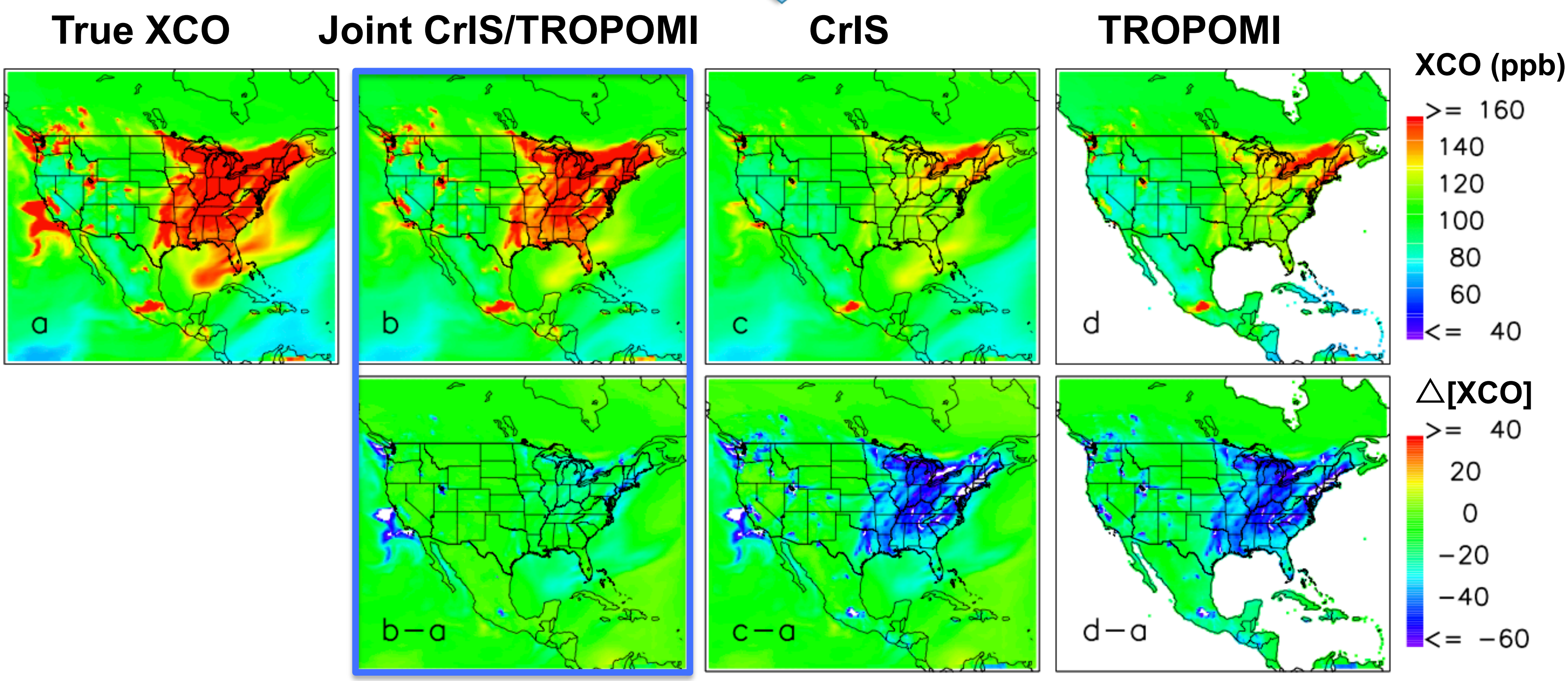
SNPP Synergic Observations

December 12, 2017

[A] VIIRS image of fire plume
[B1-4] CrIS Carbon monoxide VMR
[B1] Day time; 316 hPa
[B2] Day time; 510 hPa
[B3] Night time; 316 hPa
[B4] Night time; 510 hPa

High Resolution Near Surface CO Data via Combining CrIS/TROPOMI Measurements

- In October 13, 2017, ESA Sentinel 5 Precursor (S5P) launched successfully, forming a satellite constellation with Suomi-NPP satellite.
- It provides an unique opportunity to extend and improve the MOPITT joint TIR/NIR CO data, via combining CrIS/TROPOMI measurements [Fu *et al.*, AMT, 2016]
- **XCO maps:** near surface partial column averaged VMR [surface to ~750 hPa]



Summary

- MUSES retrieval algorithm combines radiances measured from long wavelength (TES, AIRS, CrIS) and short wavelength (OMI, OMPS, TROPOMI) space sensors to retrieve the vertical concentration profiles of primary gaseous pollutants including O_3 and CO.
  - Joint AIRS/OMI and CrIS/OMPS retrieved O_3 profiles can distinguish the abundances in the upper troposphere from the lower troposphere (Fu et al., AMT, 2018).
  - Joint CrIS/TROPOMI would help in extending the MOPITT CO profile data (Fu et al., AMT, 2016).
- The observation operators of joint AIRS/OMI data products enable data assimilation, e.g., "CHASER-DA", demonstrating the significant impacts on ozone distributions (Miyazaki et al., JGR, 2019).
- The O_3 and CO data products from MUSES algorithm could help in the quantitative attribution of anthropogenic emissions and natural influences of pollutants.
- AIRS/OMI and multispectral products will continue through NASA Tropospheric Ozone Trends Science program. With the MUSES Science Data Processing System (MUSES-SDPS), the sampling will increase 10x relative to TES GS starting in FY21.

Thank you!