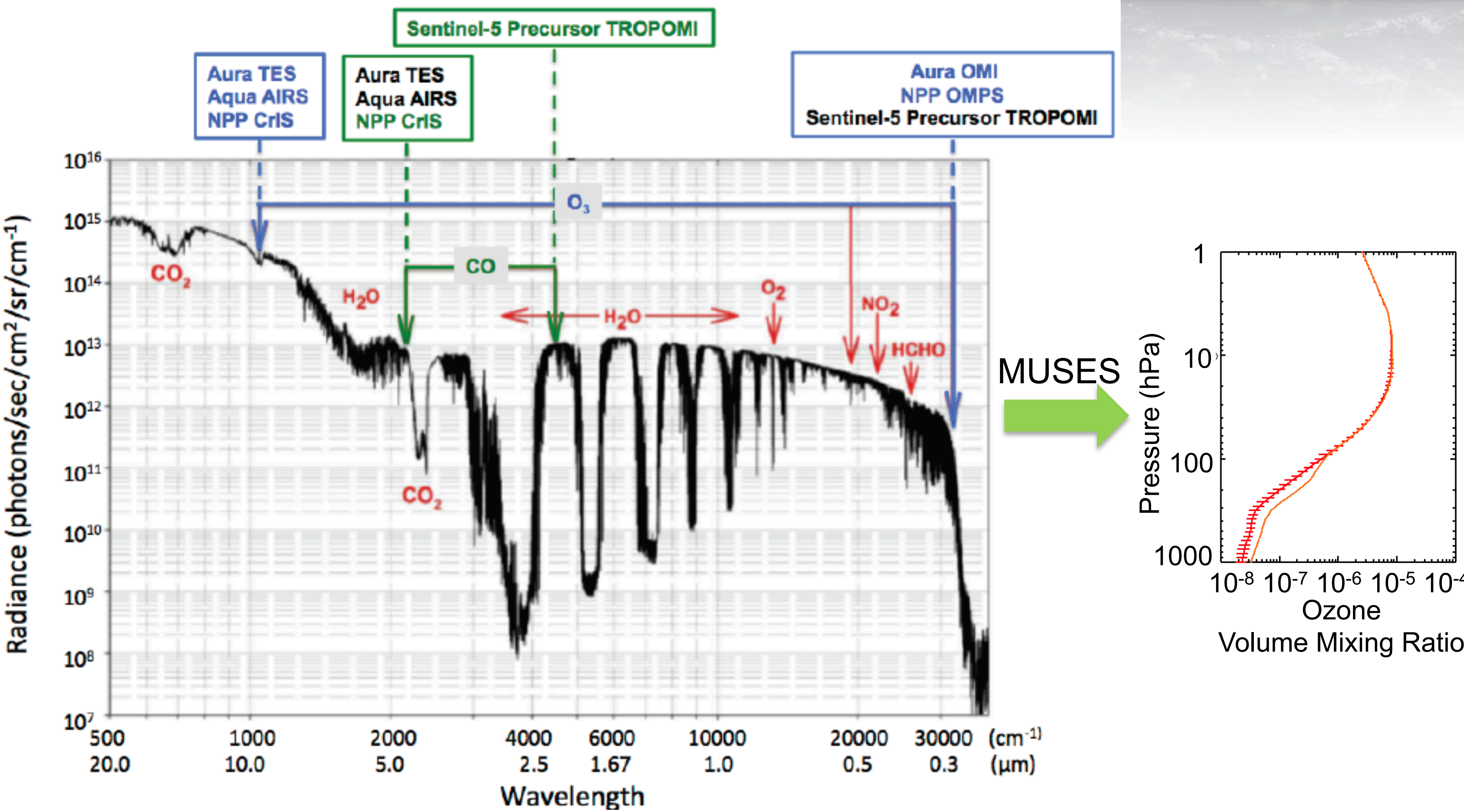
MUlti-SpEctra, MUlti-SpEcies, Multi-SEnsors Retrievals of Trace Gases: Updates on Validation and Science Applications

Dejian Fu[1], S. Kulawik[1,2], K. Miyazaki[3], K. Bowman[1], B. Pierce[4], H. Worden[5], J. Worden[1], V. Payne[1], J. Neu[1], R. Herman[1], G. Osterman[1], F. Irion[1], H. Yong[6], L. Strow[7], with thanks to TES, AIRS, OMI, CrIS, OMPS, TROPOMI teams

[01] NASA Jet Propulsion Laboratory, California Institute of Technology, USA
[02] NASA Ames Research Center, USA
[03] Japan Agency for Marine-Earth Science and Technology, Japan
[04] NOAA/NESDIS Center for Saellite Applications and Research, USA
[05] National Center for Atmospheric Research, USA
[06] NOAA Center for Satellite Applications and Research, USA
[07] University of Maryland Baltimore County, USA

Spectral Regions Used in JPL MUSES Algorithm



Measurements from TIR (LW) are sensitive to the free-tropospheric trace gases.
Measurements from UV-Vis-NIR (SW) are sensitive to the column abundances of trace gases.
Joint LW/SW or ultra-high spectral resolution measurements can distinguish upper/lower troposphere.

Characteristics and Diagnostics of O_3 data

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

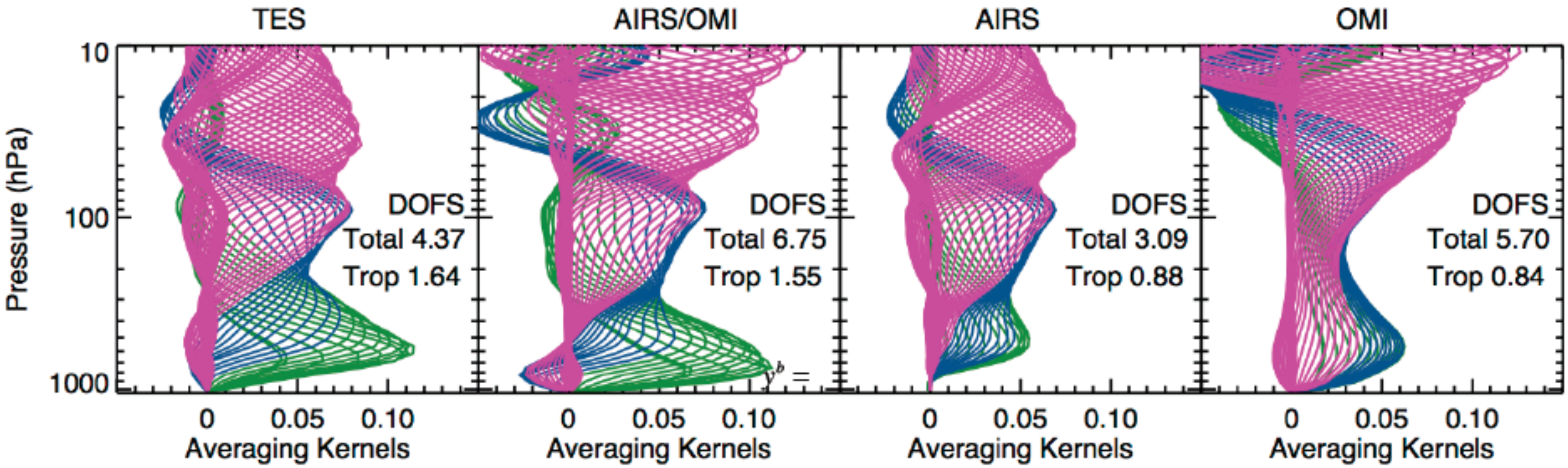
E.g., a data assimilation system applies an observation operator (**H**)

$$\mathbf{y}^s = \mathbf{H}(\mathbf{x}) = \mathbf{x}_a + \mathbf{A}(\mathbf{x}_{model} - \mathbf{x}_a)$$

$\mathbf{y}^s$ is the model profiles; $\mathbf{x}_a$ is *a priori* profiles used in the retrievals; **A** is the averaging kernels of satellite observations.

After applying observation operator to model profiles, the satellite-model differences ($\mathbf{y}^o$- $\mathbf{y}^s$) is not biased by the *a priori* used in the retrievals.

$$\Delta\mathbf{y} = \mathbf{y}^o - \mathbf{y}^s = \mathbf{A}(\mathbf{x}_{true} - \mathbf{x}_{model}) + \varepsilon$$



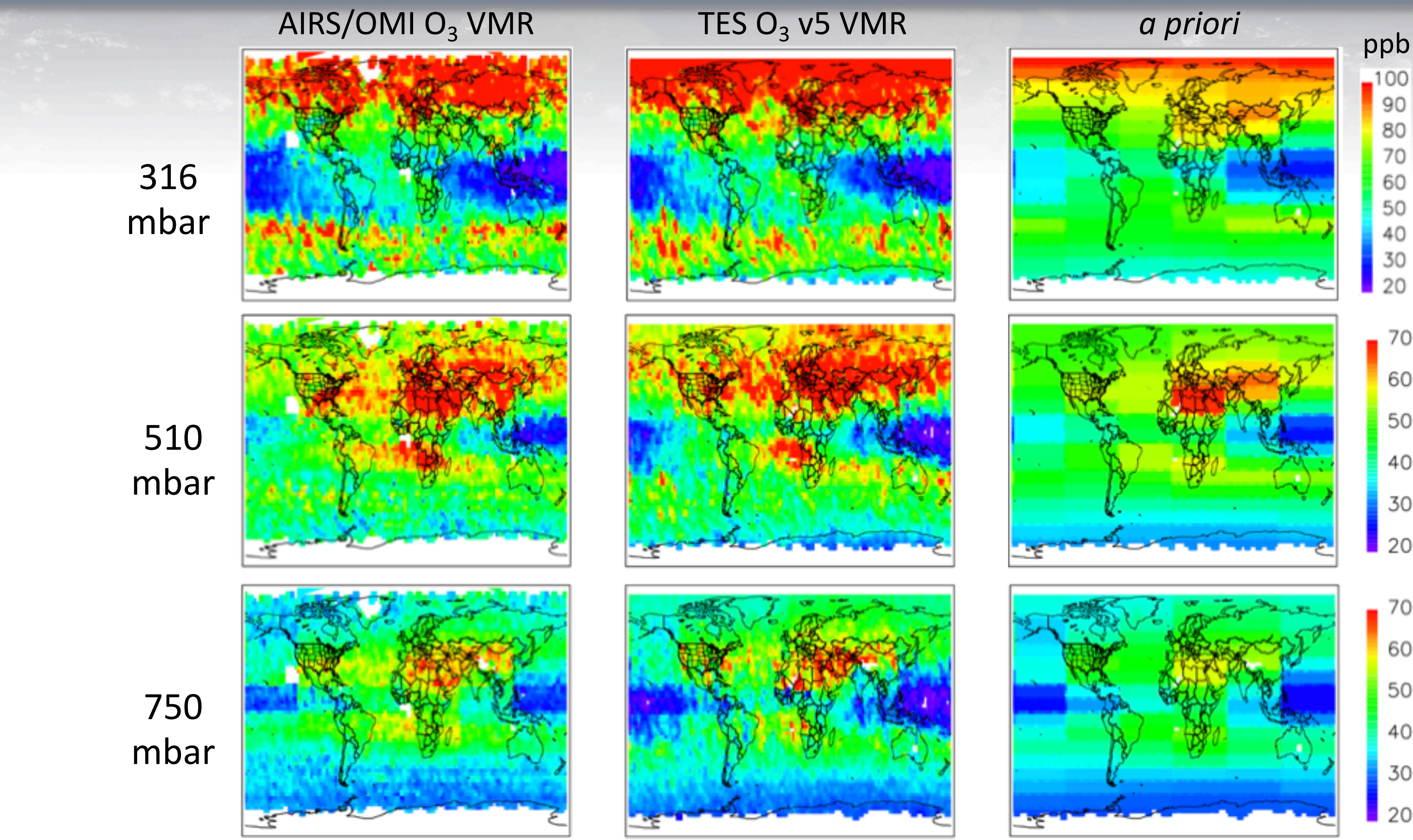
Joint AIRS/OMI O_3 Retrievals

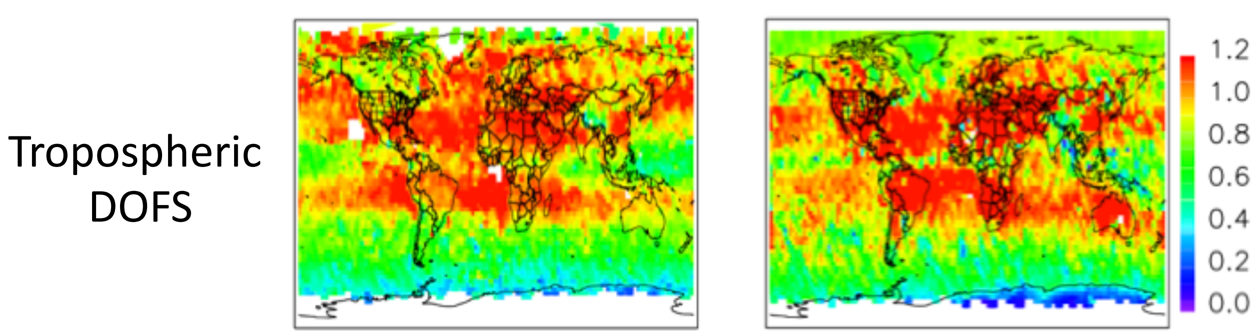
The AIRS/OMI O_3 retrievals have been configured in two modes.

- Global survey mode
  - Provides profile data with a spatial sampling similar to TES global survey
  - 22-month data have been processed including
    - 2006 Jun – Aug
    - 2009 Jan – Jul, Oct – Dec
    - 2010 Jan – May
    - 2016 Mar – Jun
  - All of 2006 GS data will be available in weeks.
  - December 2017, an estimated release date of AIRS/OMI ozone v1 data
- Regional mapping mode
  - Processes all available measurements for flight campaigns including
    - KORUS-AQ, Apr – Jun 2016
    - ORACLES, Aug, Sept 2016
    - POSIDON, Sept, Oct 2016

Data products have been saved in Hierarchical Data Format, a common format used in the NASA Earth Observation System level 2 products

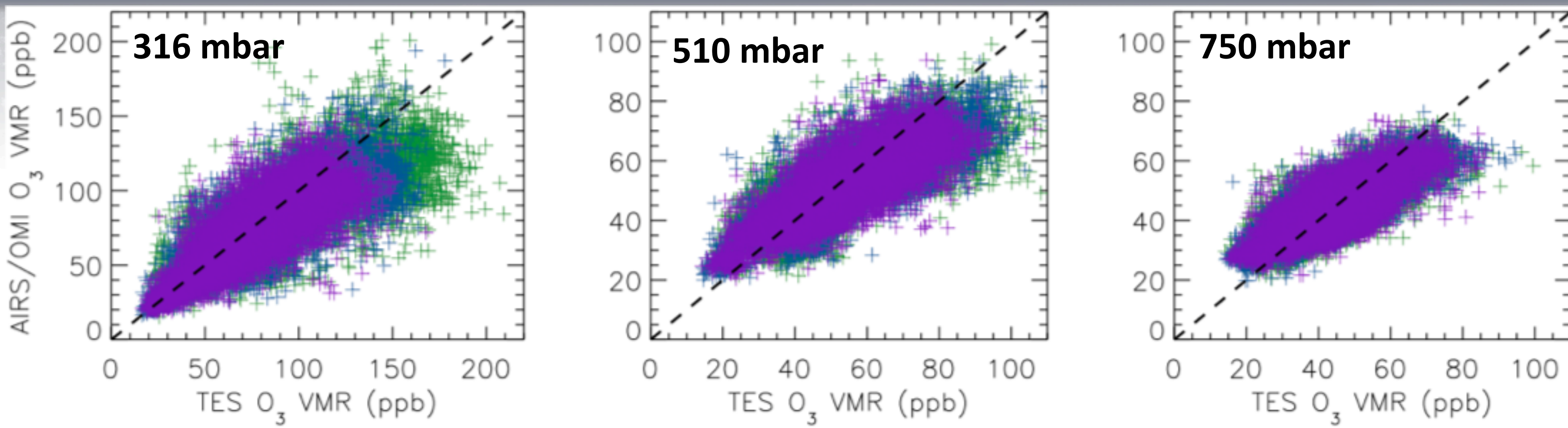
AIRS/OMI Vs. TES v5 GS O_3 Profile Data on August 2006





Combined AIRS single footprint L1B radiances to OMI measurements for retrieving O_3 profiles.

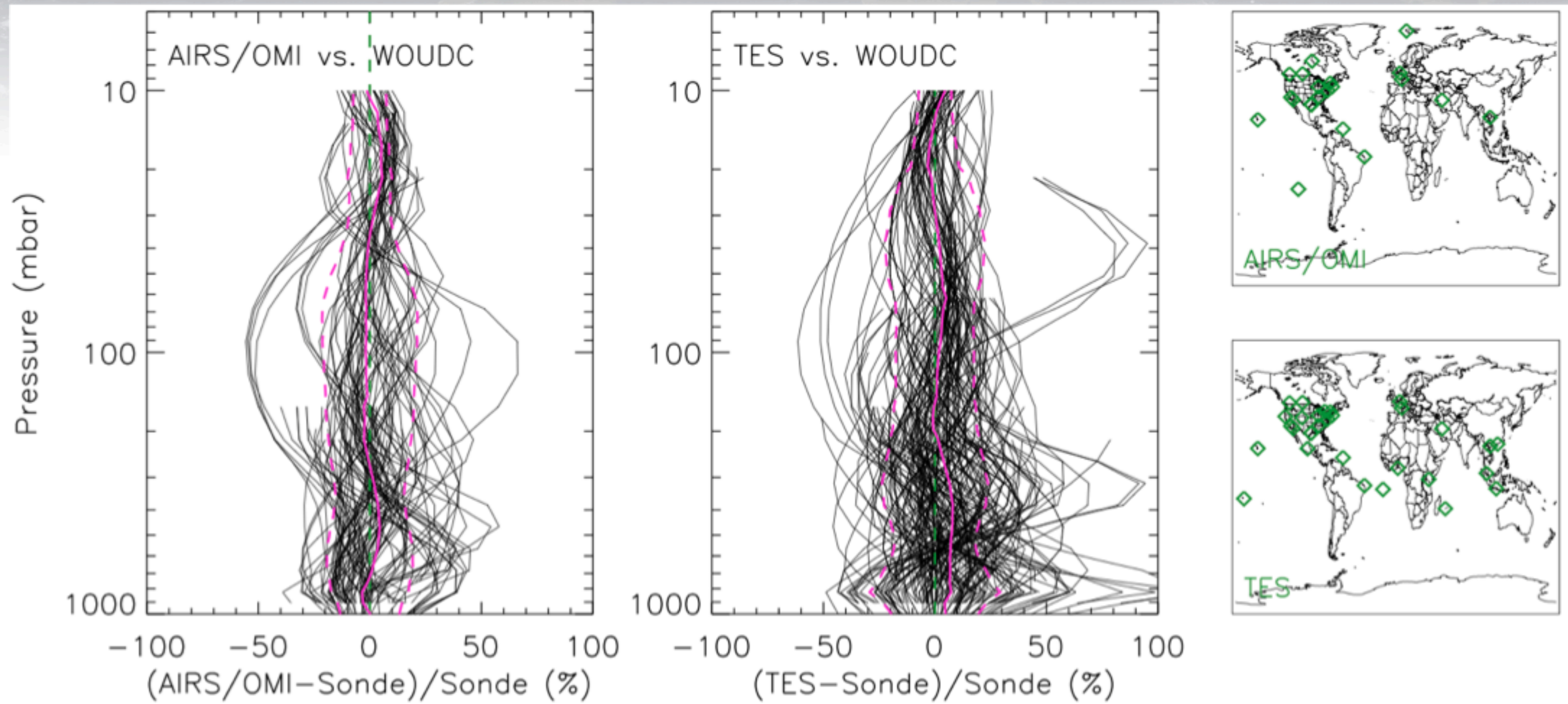
Joint AIRS/OMI vs. TES GS O_3 During Summer 2006



- Relative bias < 2-5%. Standard deviation of the differences < the estimated uncertainty.

		316 mbar			510 mbar			750 mbar		
		Jun	Jul	Aug	Jun	Jul	Aug	Jun	Jul	Aug
Correlation Coefficient (r)		0.85	0.85	0.84	0.83	0.82	0.80	0.81	0.77	0.75
Mean Diff. (Joint-TES)	ppb	-7.4	-6.2	-4.0	-3.4	-3.3	-2.9	-1.8	-1.5	-1.8
100 x (Joint-TES)/TES	%	-4.8	-4.4	-3.8	-1.9	-2.1	-2.7	-0.8	-0.4	-1.6
Standard Deviation of Diff.	ppb	20.5	17.7	14.3	10.9	10.0	8.5	7.6	7.3	7.0
100 x (Joint-TES)/TES	%	24.6	22.5	19.5	21.0	19.7	16.8	19.6	19.4	17.9
AIRS/OMI Total Uncertainty	%	27.8	27.8	27.6	22.5	22.5	22.3	24.1	23.9	23.5
TES v5 Total Uncertainty	%	22.0	22.0	22.2	19.5	19.5	19.7	23.9	23.9	23.5

Comparisons to WOUDC Ozonesondes



	316 mbar		510 mbar		750 mbar		# of Sites	# of Pairs
	Mean	RMS	Mean	RMS	Mean	RMS		
	100 x (Satellite - Sonde_AppliedAK)/Sonde_AppliedAK							
AIRS/OMI	1.9	15.8	4.0	18.3	-0.7	17.9	21	93
TES	6.6	22.6	7.3	17.9	6.6	22.6	30	171

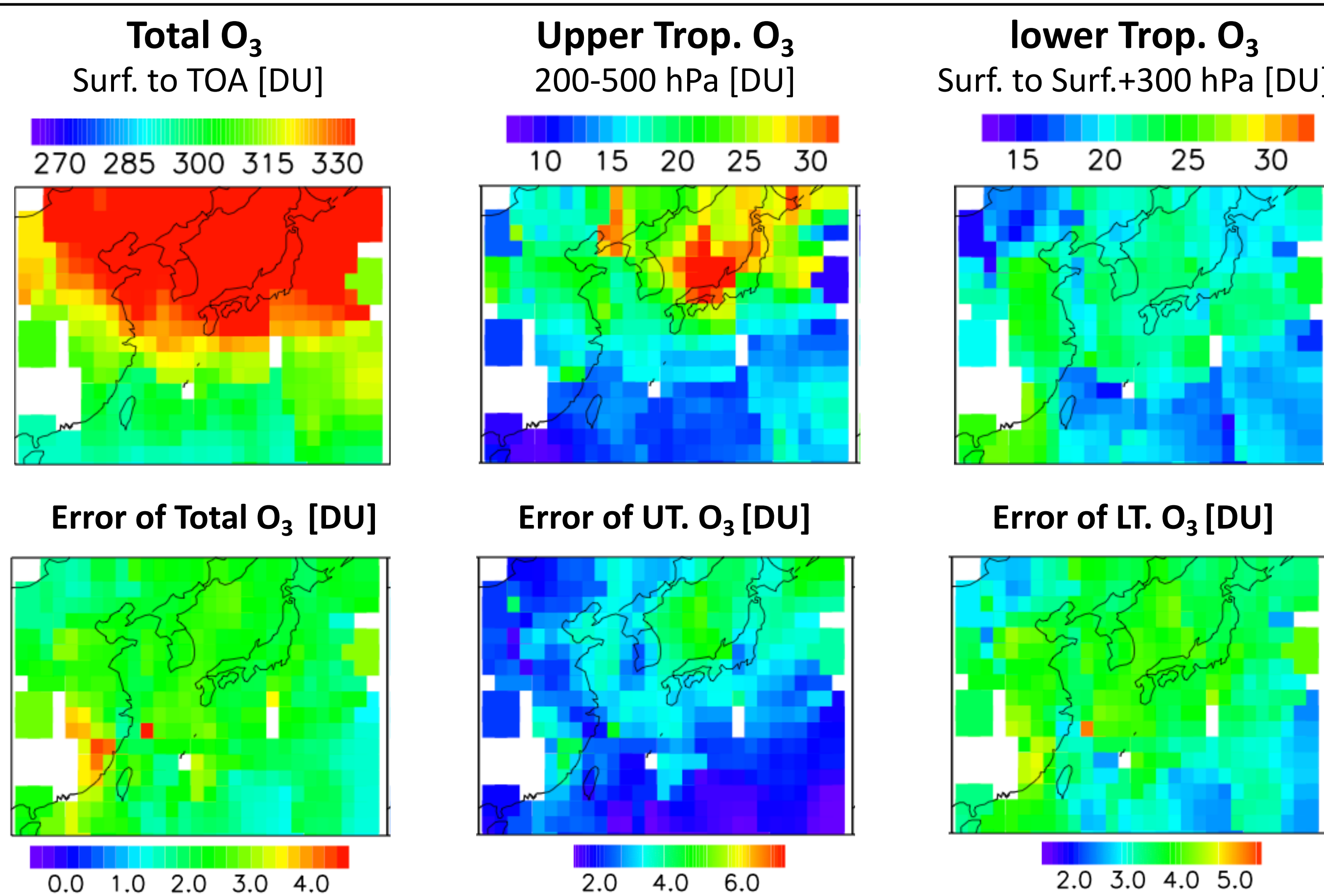
Coincident criteria

- Passed retrieval quality check
- Distance within 300 km
- Time diff. within 4 hours
- June, July, August 2006

Joint AIRS/OMI O_3 Maps for KORUS-AQ Campaign

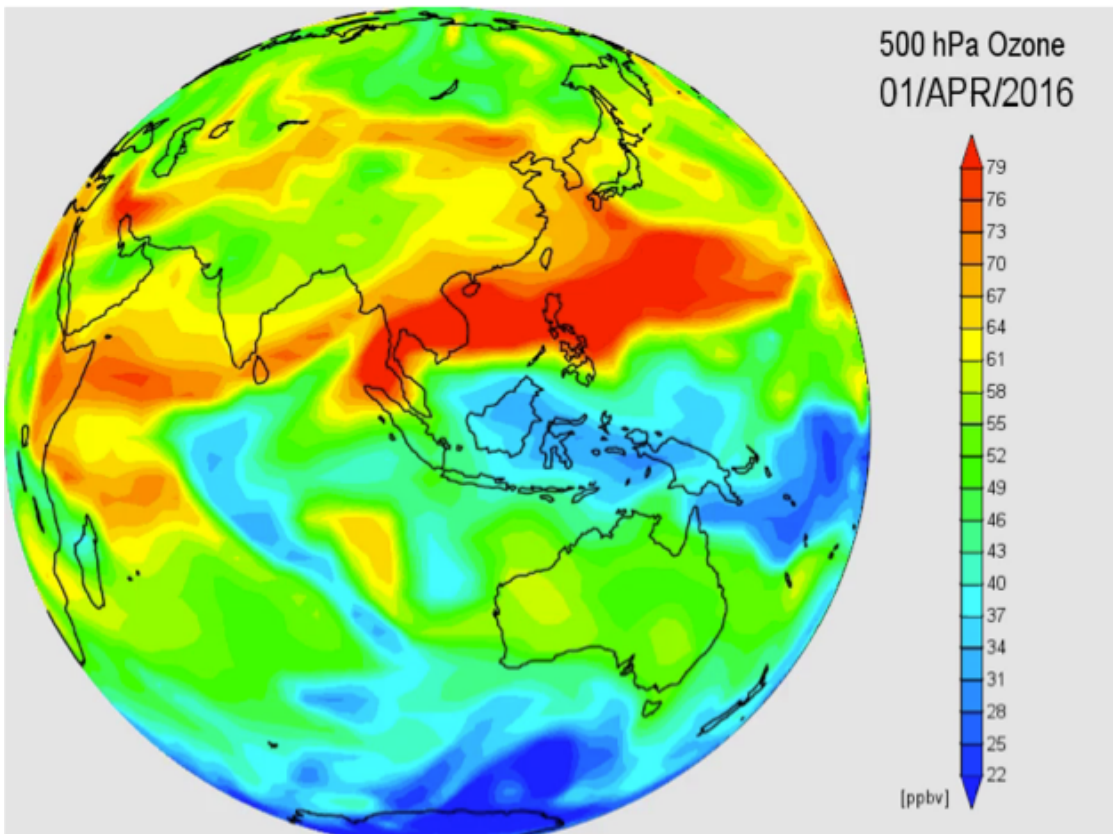
- Korea-US Air Quality study (KORUS-AQ) - International Cooperative Air Quality Field Study
- Joint AIRS/OMI O_3 profile data
  - Total ozone shows strong latitudinal dependence, dominated by stratospheric ozone.
  - The pattern of enhancement (Upper tropospheric > Lower tropospheric) over Korean peninsula <-> Japan suggests either lofting and transport of pollution from the surface or the influence of stratosphere-troposphere exchange.

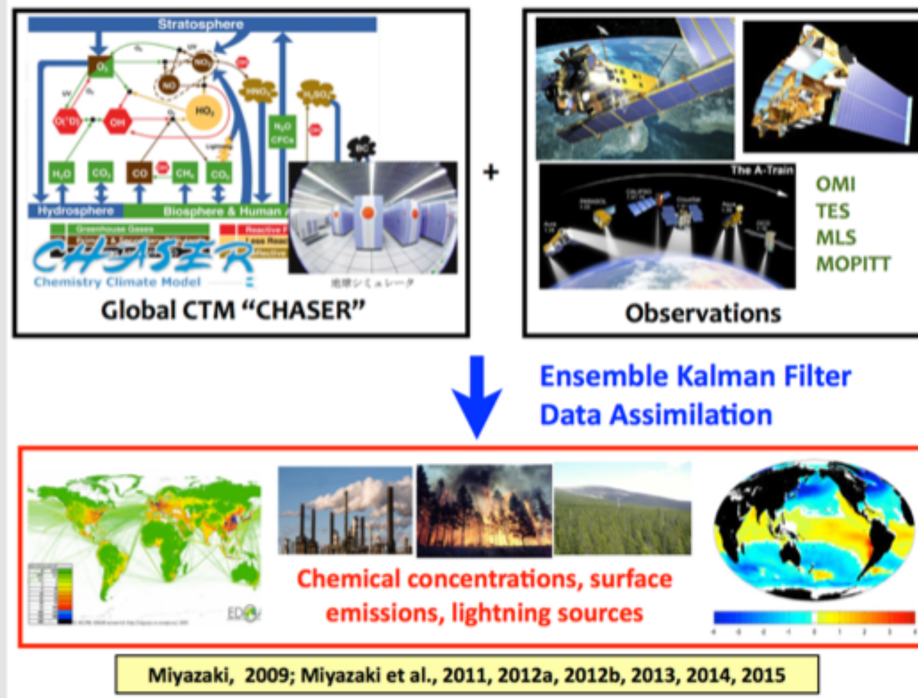
Three-day averaged May 18-20, 2016.



Assimilated Global Ozone Fields

- Joint AIRS/OMI ozone profiles have been assimilated into CHASER system.
- 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





JPL/UW-Madison Team for NOAA FIREX

Fire Influence on Regional and Global Environments Experiment (FIREX) is to study the impact of biomass burning of western north america fires on climate and air quality.

JPL/UW-Madison team will combine high vertical/spatial resolution O_3 and CO data with chemical data assimilation to provide a critical synoptic context for quantifying the role of fires on atmospheric composition and air quality.

JPL MUSES algorithm will provide

- CrIS CO profile data
  - nine times higher spatial resolution vs. the CrIS operational data products
- Joint CrIS/OMPS O_3 profile data
  - could distinguish upper/lower troposphere, similar to AIRS/OMI $O_{3,}$ but 3X spatial coverage
- Both CO and O_3 profile data products provide full observation operators readily for data assimilation/model evaluation

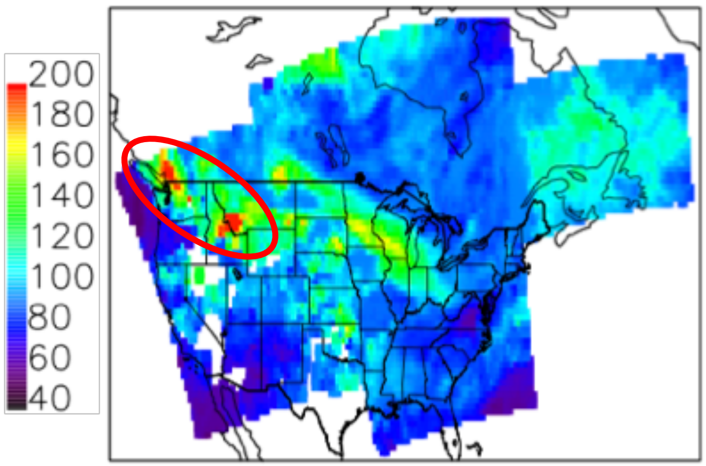
UW-Madison Real time Air Quality Modeling System (RAQMS) will provide

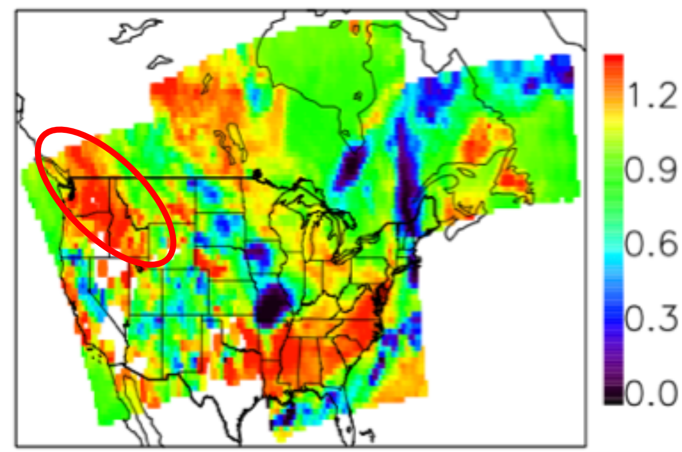
- Real-time assimilation
  - Aura-MLS stratospheric ozone profiles (>50mb)
  - Aura-OMI total ozone column (cloud cleared)
  - MODIS aerosol optical depth
- Real-time fire detection via MODIS data
- Will assimilate JPL CrIS CO and joint CrIS/OMPS O_3 profile data

MUSES-CrIS CO Maps for NOAA FIREX

- Plume of biomass burning observed on August 5, 2017
- CrIS CO profiles were retrieved using single footprint CrIS full spectral resolution data.
- MUSES algorithm retrieves trace gases profiles, cloud optical depths, surface properties and temperature profiles.

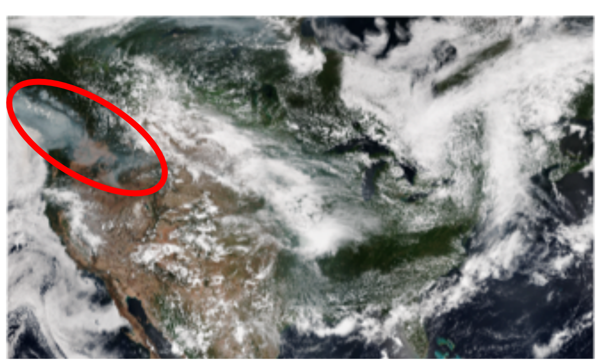
CO VMR
@510 mbar
ppb

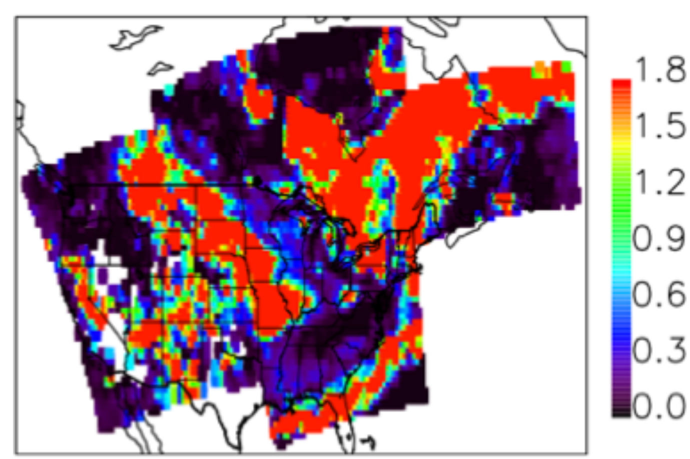




CrIS Trop.
CO DOFS

MODIS
Image

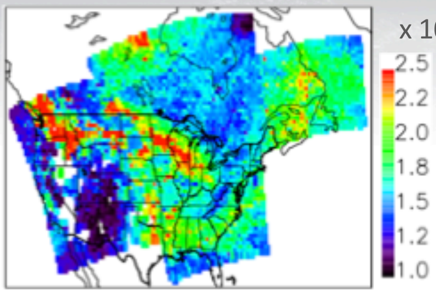




CrIS Cloud
OD

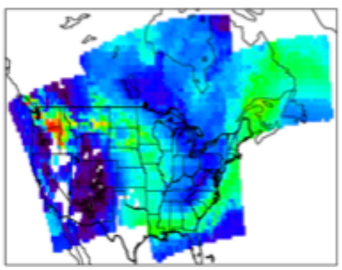
Comparisons of MUSES-CrIS and RAQMS CO Data

CrIS CO Tropospheric Column

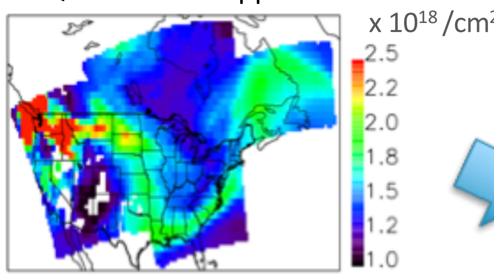


- Used CrIS single footprint full spectral resolution L1B radiances in the retrievals
- MUSES CrIS CO data show agreement to the RAQMS model fields that were applied the observation operators of CrIS CO.
- Collaborating with Dr. Pierce at UW-Madison for assimilating CrIS CO data into the RAQMS model

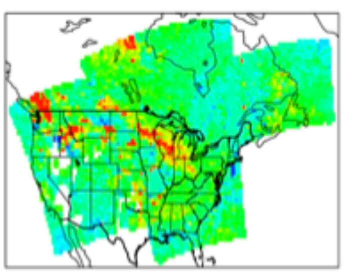
RAQMS after applying CrIS Ak



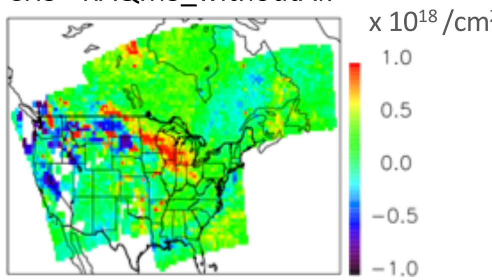
RAQMS without applied CrIS Ak

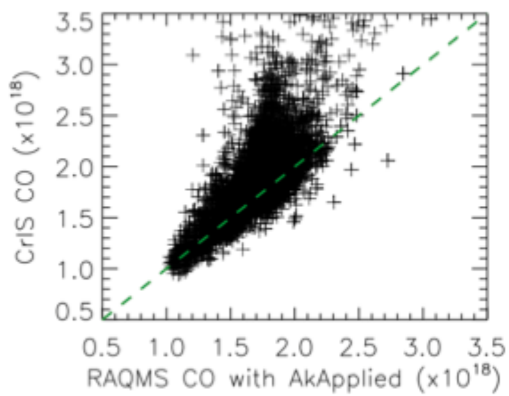


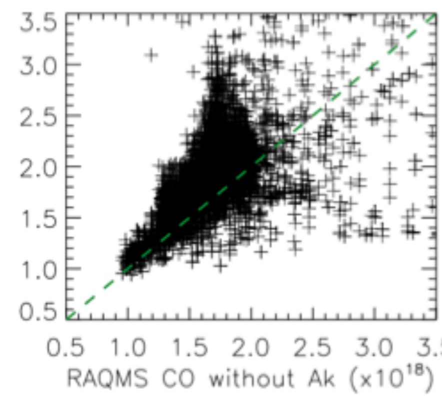
CrIS - RAQMS_AkApplied



CrIS - RAQMS_withoutAk



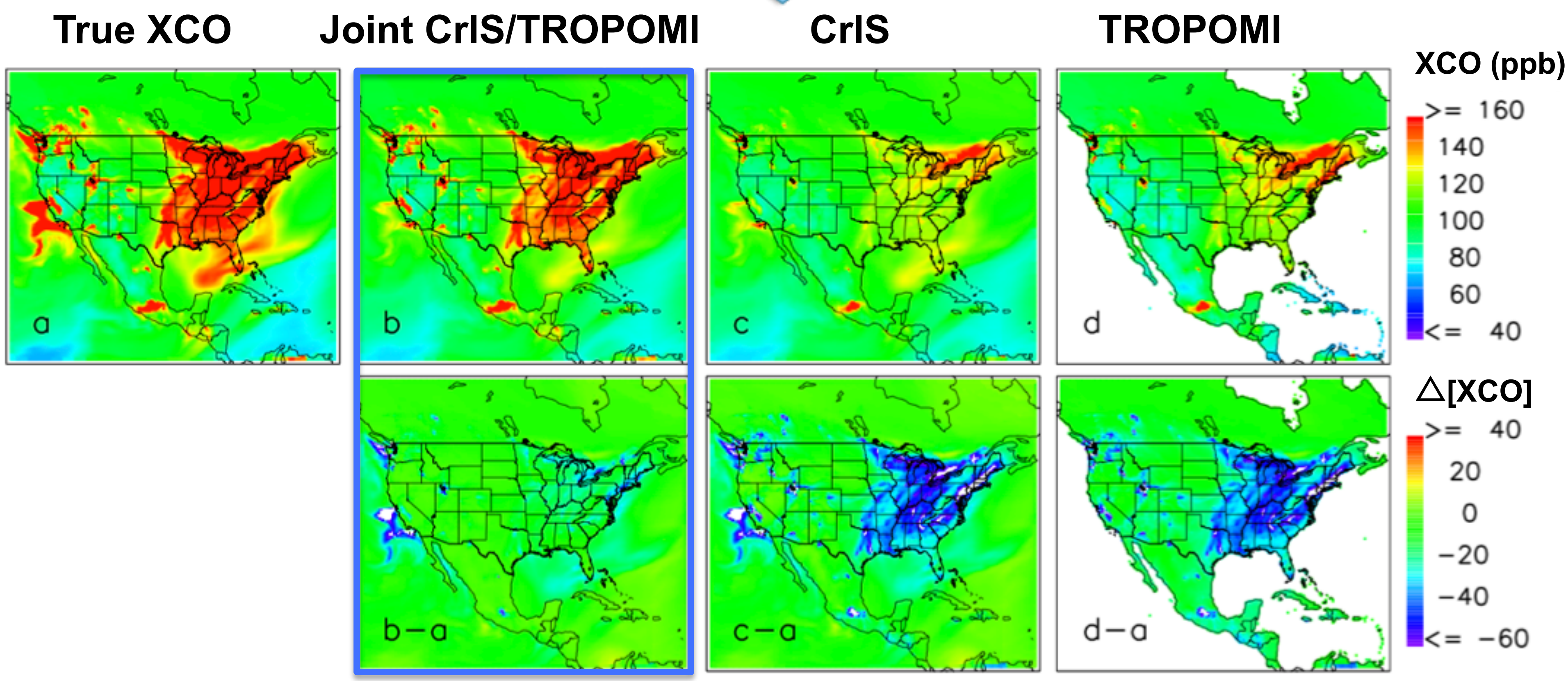




Applying MUSES CrIS CO Observation Operator to RAQMS Predicted CO Fields	Correlation Coefficient	Mean Diff		RMS	
		$x10^{18}$	%	$x10^{18}$	%
With	0.68	-0.15	6.9	0.27	11.1
Without	0.40	-0.15	6.6	0.45	25.7

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 can combine 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.
  - Joint CrIS/TROPOMI would help in extending the MOPITT CO profile data.
- The observation operators of joint AIRS/OMI data products enable data assimilation, e.g., "CHASER-DA", demonstrating the significant impacts on ozone distributions.
- The O_3 and CO data products from MUSES algorithm could help in the quantitative attribution of anthropogenic emissions and natural influences of pollutants for NASA KORUS-AQ and NOAA FIREX.

Thank you for attention!

Questions?