Improved O_3 and CO Profile Retrievals Using Multispectral Measurements from NASA "A Train", Suomi NPP, and S5P Satellites

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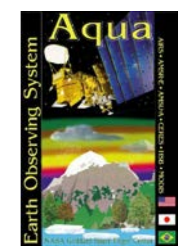
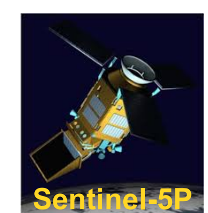
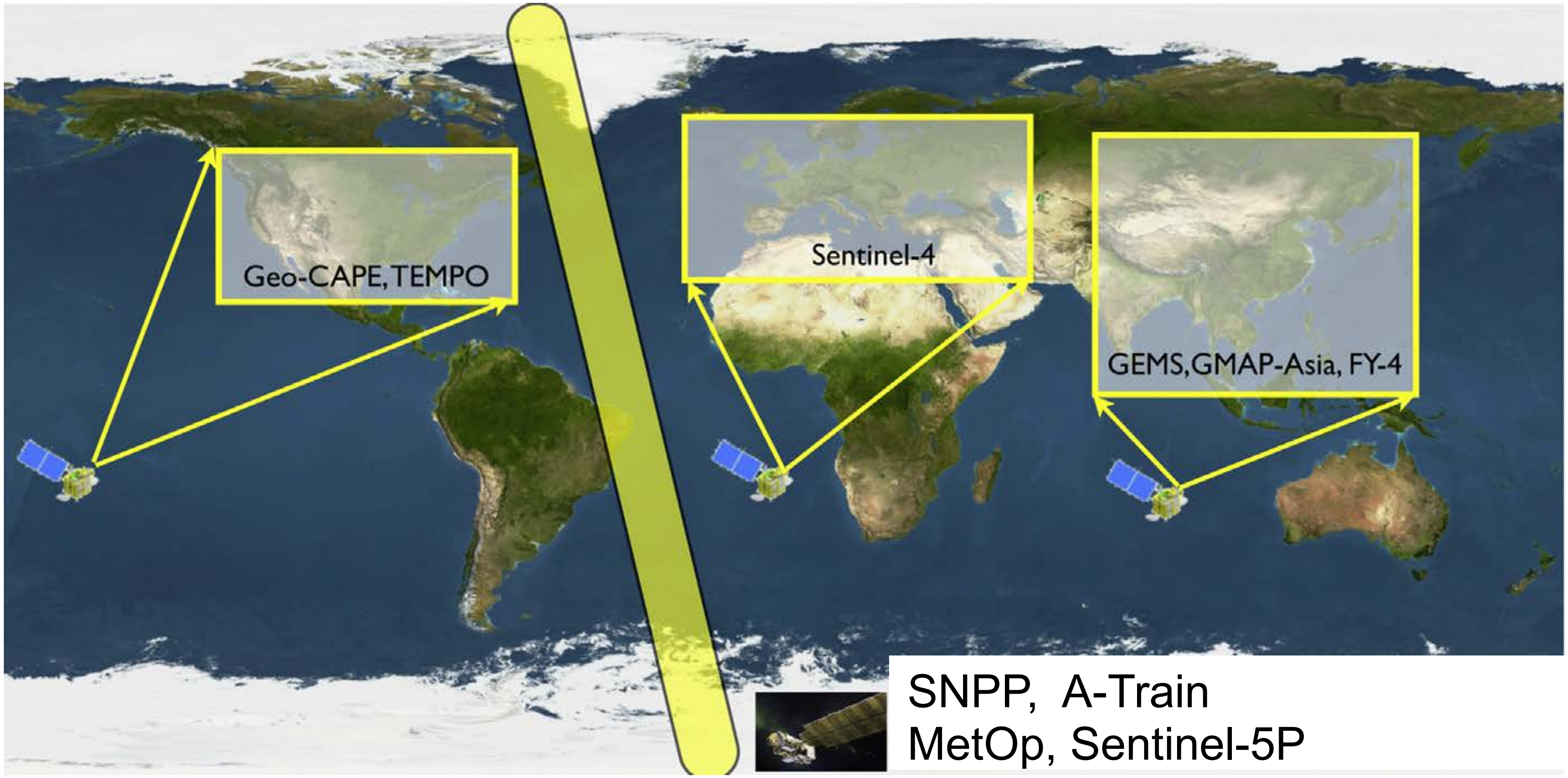




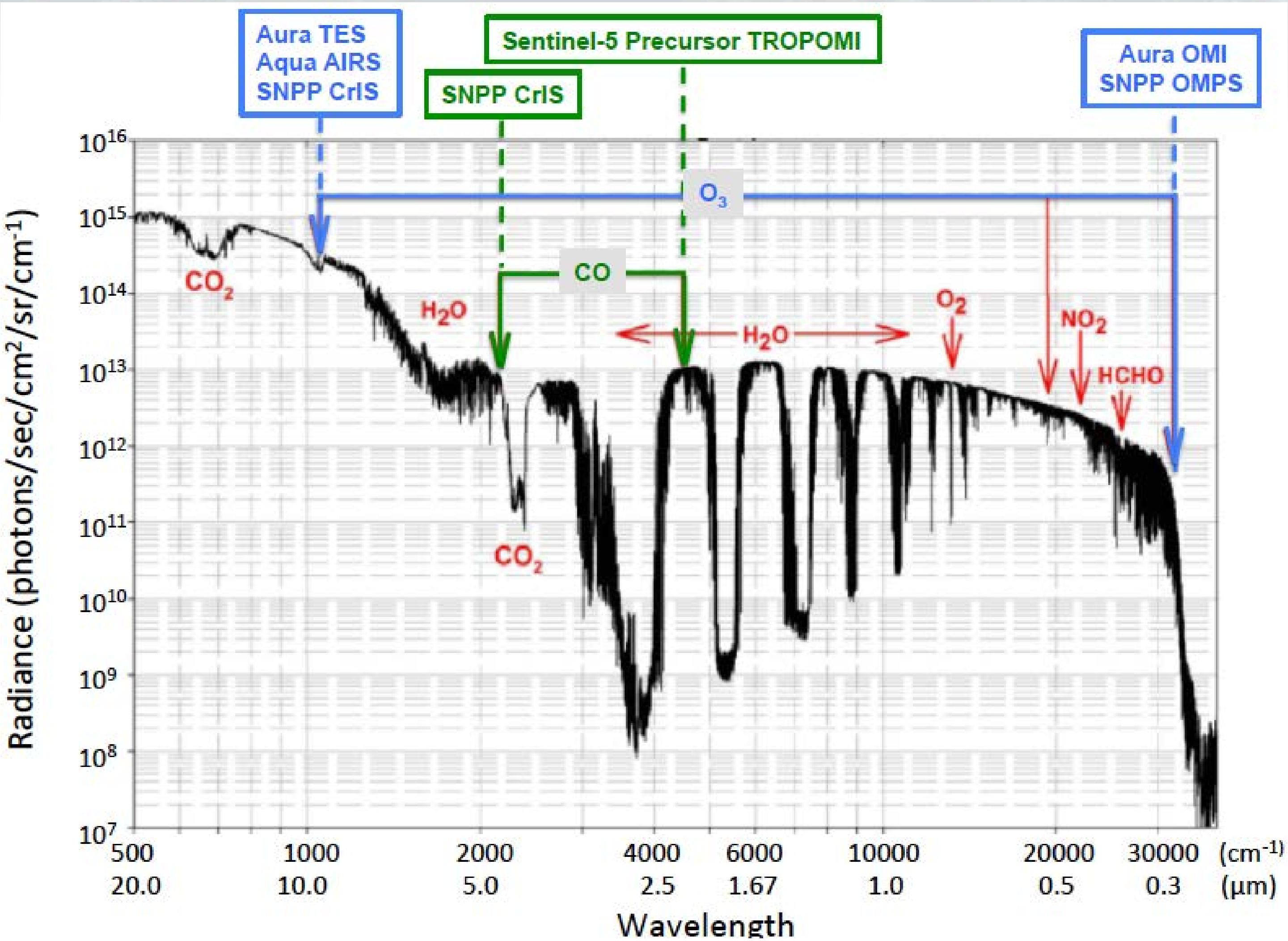
A new Atmospheric Composition Constellation to Observe Global and Regional Pollution

The rapid change in global emissions and their impact of air quality and climate requires a new observing system of GEO and LEO sounders to quantify global sources of local pollution.

- LEO A-Train AIRS/OMI and SNPP CrIS/OMPS can support this constellation by distinguishing lower and upper tropospheric O_3 signals
- LEO sounders will be a crucial link between GEO sounders over America, Europe and Asia as well as the sole satellite observations in the SH.



Spectral Regions Used in Joint Retrievals



This presentation will mainly report

- Joint AIRS/OMI ozone profile retrievals
- Joint CrIS/TROPOMI carbon monoxide profile retrievals

JPL MUSES Retrieval Algorithm

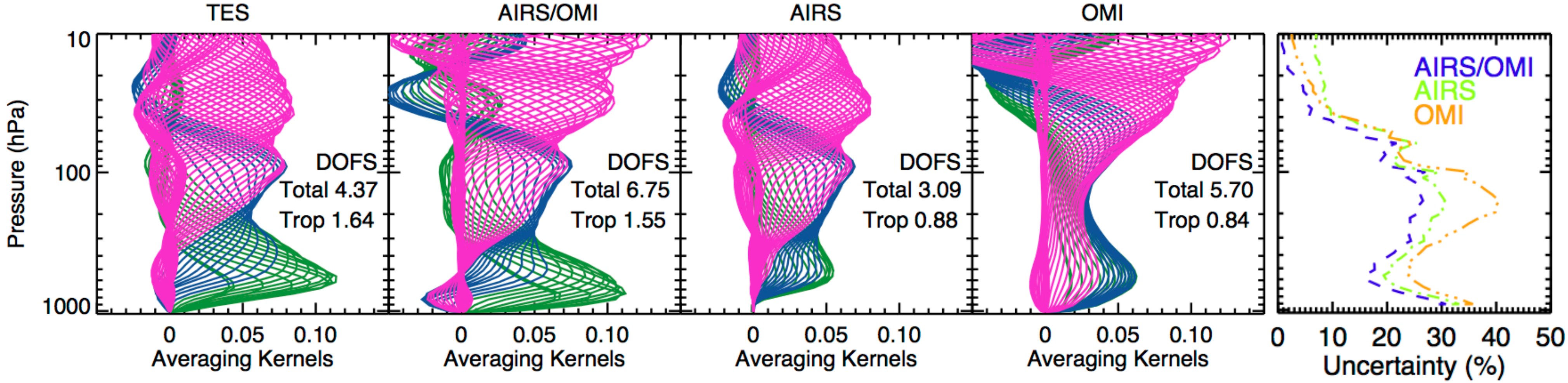
Multi-**Sp**ectra, **Mu**lti-**S**p**e**cies, **Mu**lti-**Se**nsors (MUSES)

- Builds off of heritage from the Tropospheric Emission Spectrometer (TES) optimal estimation (OE) algorithm to combine *a priori* and satellite data; including rigorous error analysis diagnostics and observation operators needed for trend analysis, climate model evaluation, and data assimilation
- has generic design to incorporate forward model radiances from hyperspectral measurements from multiple sensors into the joint retrieval algorithm.
- We will demonstrate through prototype studies the following missions:
  - ozone profiles
    - ✓ TES/OMI -> probe the variability of [O_3] in the LMT (Fu D., *et al.*, ACP, 2013; Worden *et al.*, AMT 2013).
    - ✓ AIRS/OMI/MLS -> provide decade long global record of O_3 profiles with the highest vertical resolution and accuracy compared to any single platform on A-Train satellites
    - ✓ CrIS/OMPS -> extend EOS O_3 data records with the highest vertical resolution and accuracy compared to any single nadir sensor on SNPP satellite
  - carbon monoxide profiles
    - ✓ CrIS/TROPOMI -> extend EOS MOPITT CO data records
      - – submitted to AMTD 2015.

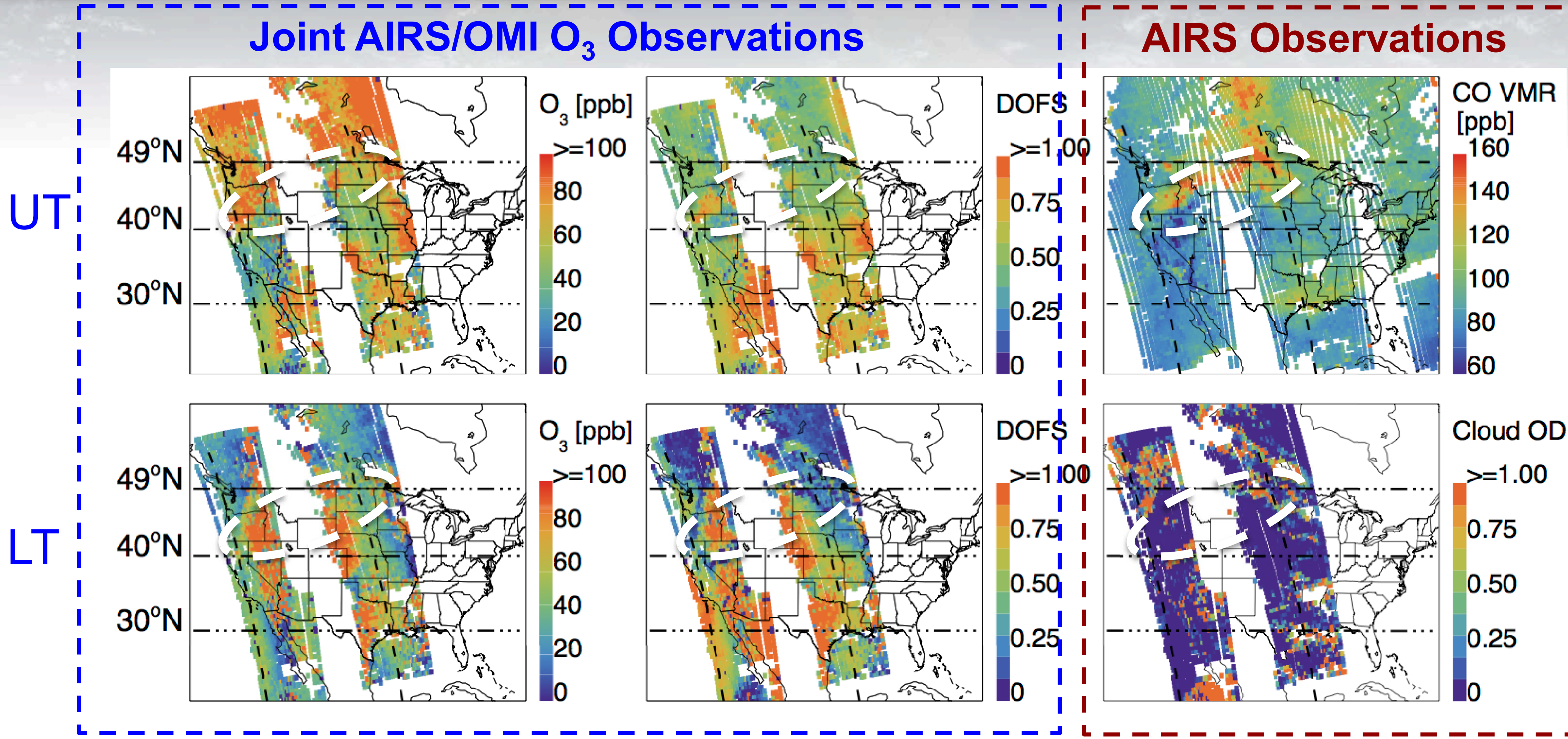
Sample Averaging Kernels and Estimated Uncertainty

- JPL MUSES provides rigorous error analysis diagnostics and observation operators needed for trend analysis, climate model evaluation, and data assimilation

- Joint AIRS/OMI vs. each instrument alone
  - use single footprint L1B radiances into the retrievals
  - show improved vertical sensitivity and resolution
  - show smaller total error



Joint AIRS/OMI Observations for TexAQS-II Aircraft Flight Campaign on August 23, 2006



The TexAQS-II aircraft flight campaign is a joint regional air quality and climate change study.

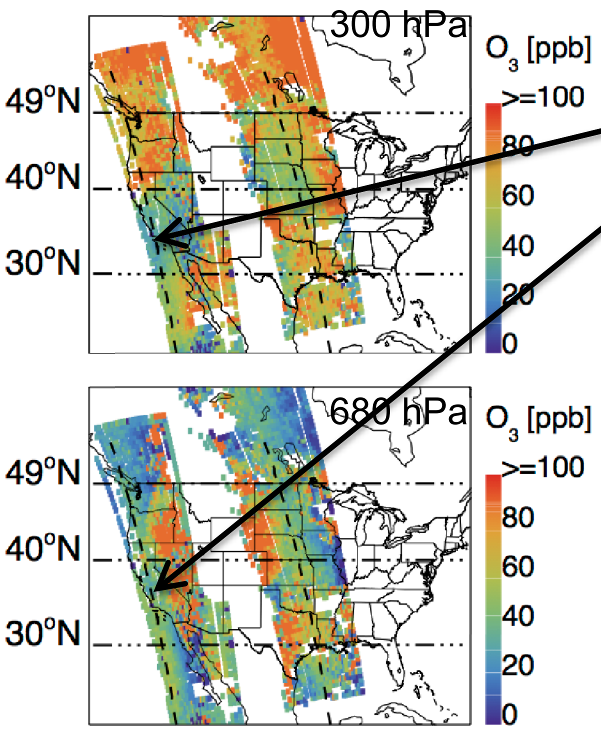
- Joint AIRS/OMI shows capability of distinguishing the amount of O_3 between LT and UT.
- AIRS operational L2 CO data products showed enhanced CO plume from North Dakota into Washington States due to the fires. Joint AIRS/OMI detected enhanced O_3 collocated in those plumes, where the averaging kernels indicate high sensitivity in the plume.

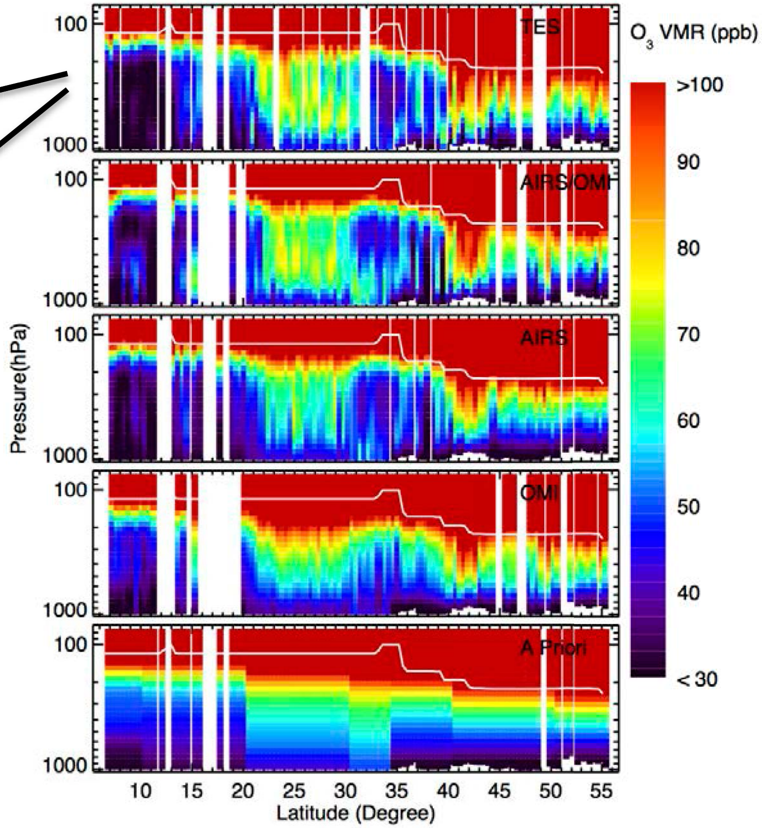
Comparisons to Aura-TES Operational L2 O_3 Data Products

Joint AIRS/OMI ozone retrievals

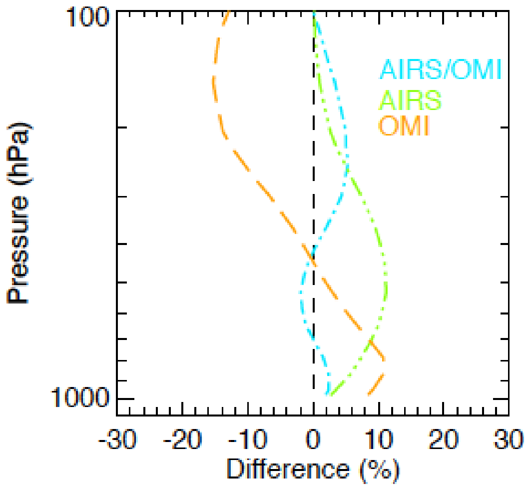
- Differ from the *a priori* profiles
- Present similar vertical and horizontal distribution to TES
- Show best agreement to TES, in comparisons to each instrument alone

Collocated Transect Measurements over Western USA





Mean differences to TES

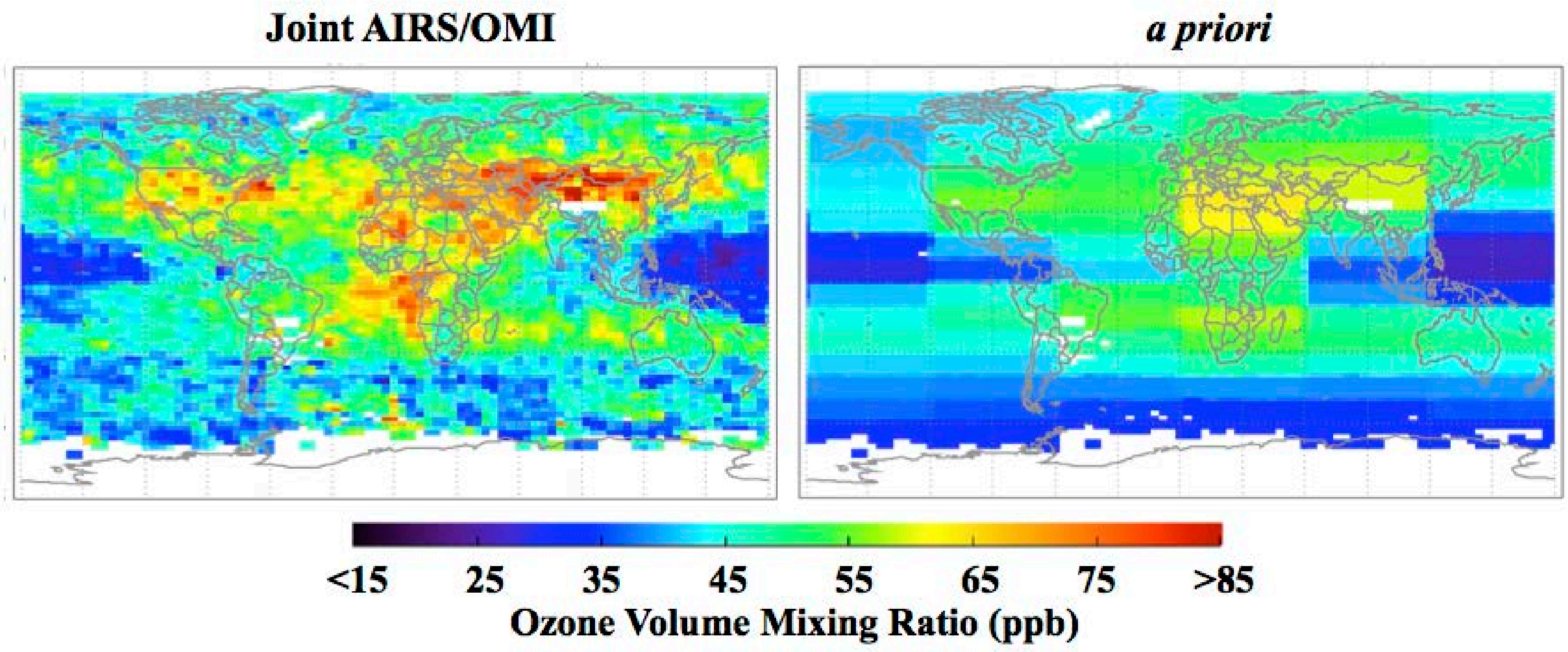


Monthly O_3 Global Maps – towards Providing Decade Long Global Record of Ozone Profiles

The JPL MUSES has been implemented and applied to joint AIRS/OMI ozone retrievals over global scale for August 2006

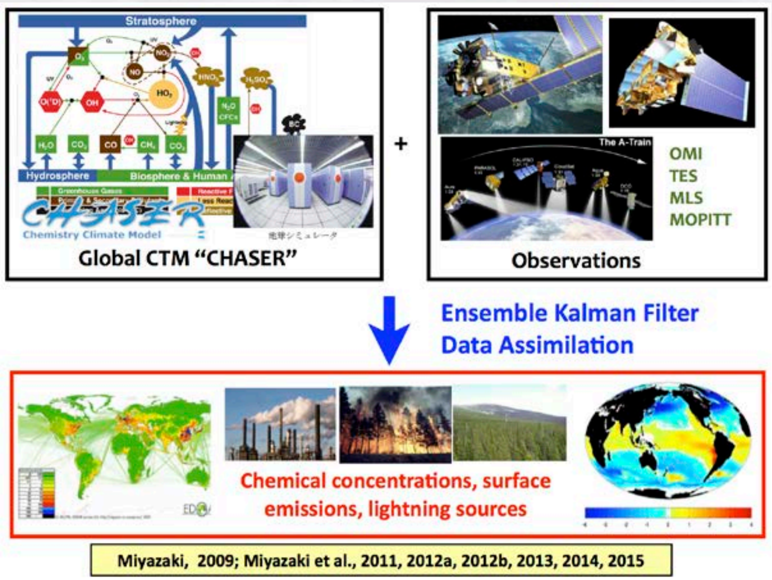
Characteristics

- Both TES and Joint AIRS/OMI show similar spatial patterns, e.g., capturing the enhanced ozone over the continental outflow and biomass burning active regions
- Differ from *a priori*

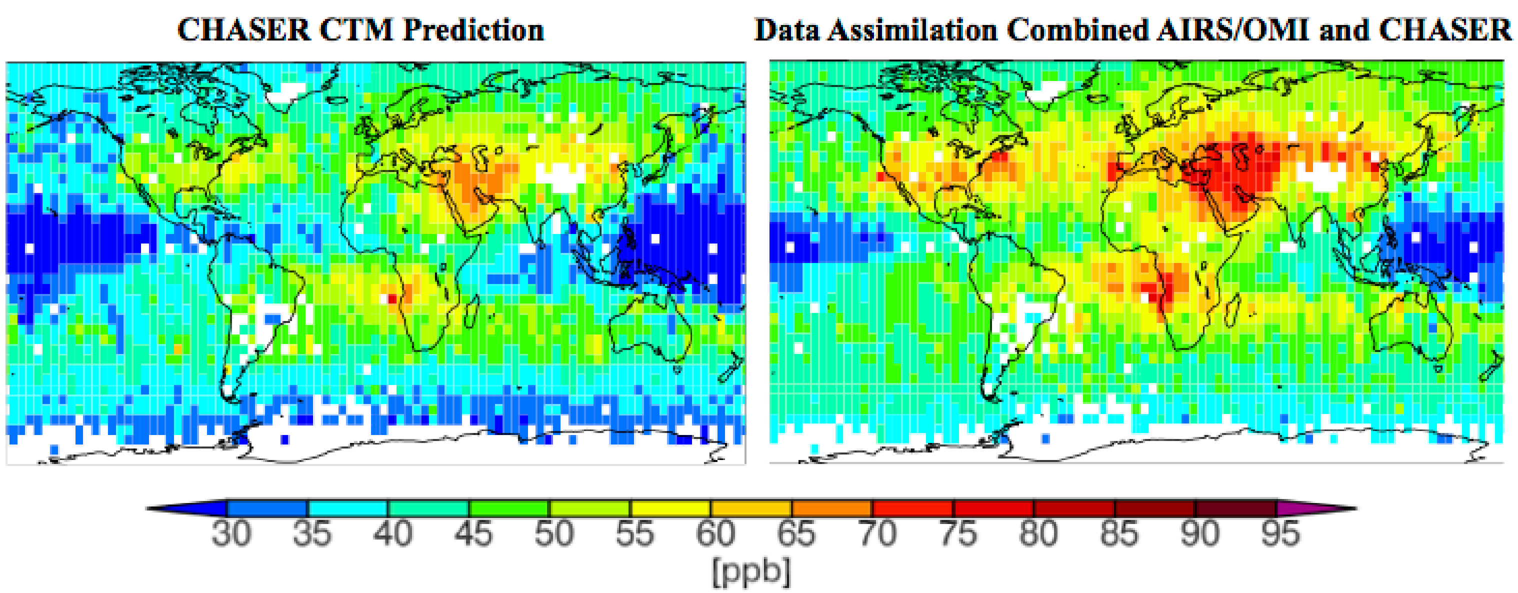


Data Assimilation System of the NASA A-Train Observations

- Dr. Kazuyuki Miyazaki, implemented the CHASER data assimilation system.



- Joint AIRS/OMI ozone data has been assimilated into the CHASER-DA, which has a proven capability to assimilate the atmospheric composition observations from multiple A-Train instruments.
- CHASER-DA leads to chemically/dynamically consistent integrated atmospheric state.



Joint CrIS/TROPOMI Retrievals – towards Extending Earth Observing System CO Data Records

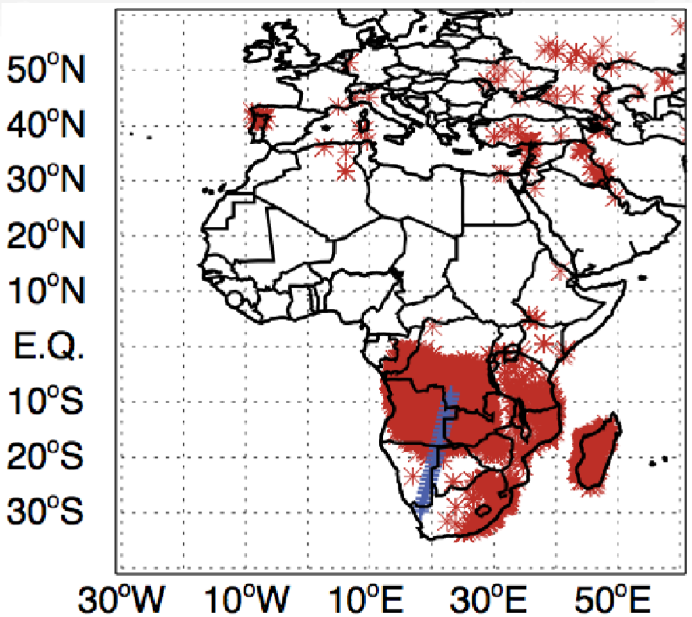
- All NASA space missions capable of measuring atmospheric CO concentration from space, have passed their nominal lifetime longer than 5 years.
- MOPITT is the only satellite borne senor now or in planning that has both TIR and NIR channels.
- Joint TROPOMI/CrIS measurements are the only space sensors in the coming decade that could extend the MOPITT multi-spectral data record.

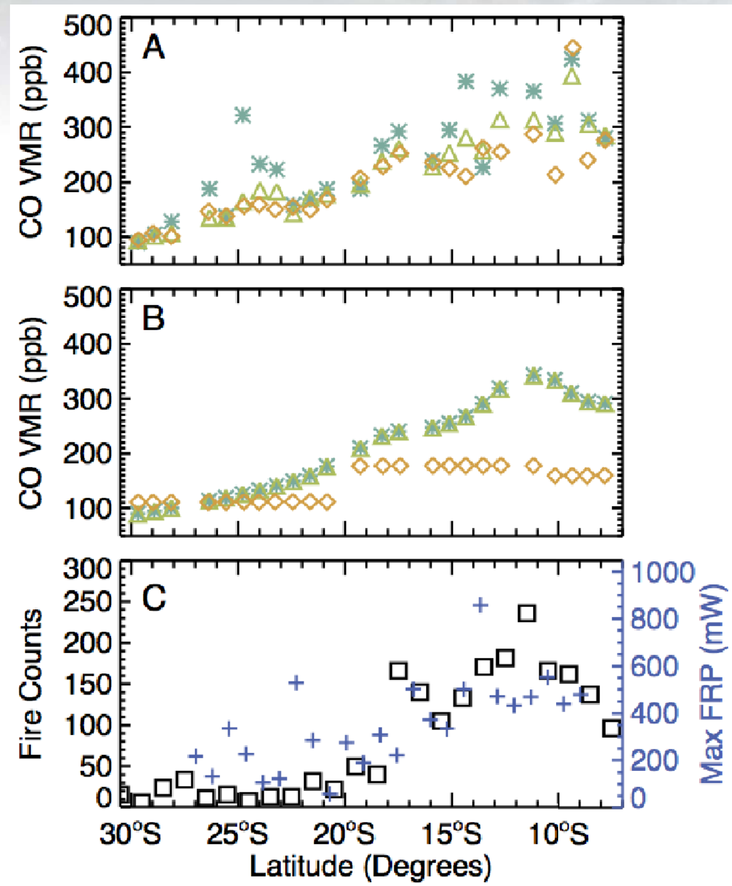
Mission	Nominal Life Time	Years after Its Design Life Time	Spectral Resolution		Footprint Size	Swath Width
	Start – End	Year	TIR[a] cm^{-1}	NIR[b] cm^{-1}	km^2	km
CrIS/TROPOM	**2016 – 2023**	**0**	**0.625**	**0.458**	**14 × 14**	**2200**
MOPITT	2000 – 2006	9	0.500	0.500	22 × 22	640
CrIS	2011 – 2026	0	0.625	NA	$\pi \times (14/2)^2$	2200
TES	2004 – 2010	5	0.060	NA	8 × 5	5
AIRS	2002 – 2008	7	~ 1.800	NA	$\pi \times (14/2)^2$	1600
TROPOMI	2016 – 2023	0	NA	~ 0.458	7 × 7	2600
SCIAMACHY	2002 – 2007	Terminated	NA	~ 0.485	30 × 60	960

[a] First fundamental band of carbon monoxide, centered around 4.6 μm in the thermal infrared.
[b] First overtone band of carbon monoxide, centered around 2.3 μm in the near infrared.

CrIS Retrievals and Comparisons to MOPITT Operational Level 2 Data Products for August 27-28, 2013

MOPITT and CrIS pixel location
MODIS fire location





[A] Retrieved CO VMR mean [surface to 700 hPa]
- **Joint MOPITT TIR/NIR**
- **MOPITT TIR**
- **CrIS**

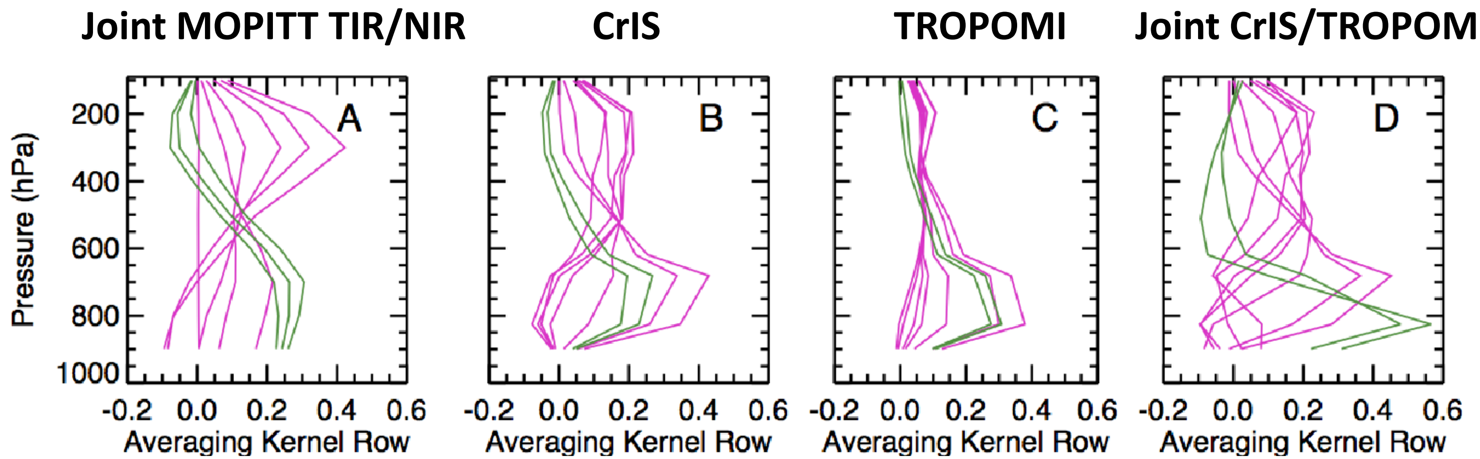
[B] A priori CO VMR mean [surface to 700 hPa]
- **MOPITT**
- **CrIS**

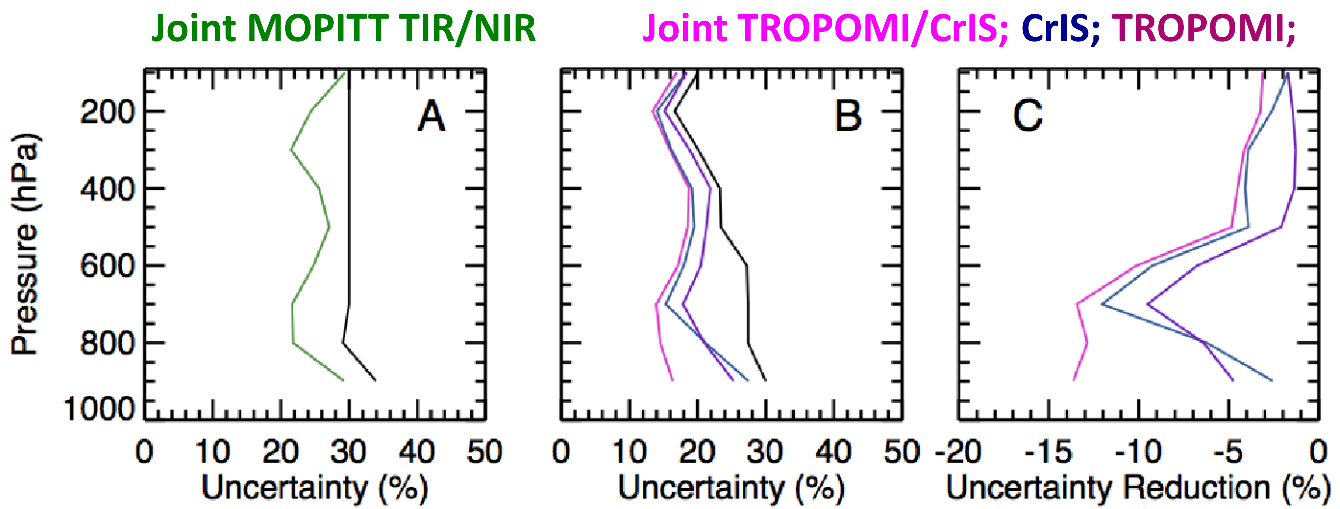
[C] MODIS
- **Fire Counts**
- **Fire Radiative Power**

Data Products in Comparisons	Mean ppb	1 σ Standard Deviation ppb
CrIS - MOPITT TIR	-6.93	22.77
CrIS - MOPITT Joint TIR/NIR	-22.91	38.80

Joint CrIS/TROPOMI CO Retrievals – Improving Vertical Sensitivity and Reducing Uncertainty

Altitude	Sensor	TIR	NIR	Joint TIR/NIR
Surface to TOA	MOPITT	1.44	0.51	1.88
	CrIS	1.57	-	2.22
	TROPOMI	-	1.32	





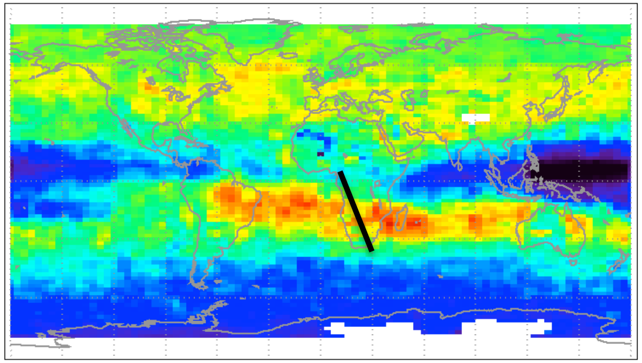
Summary

- The JPL MUSES retrieval algorithm has the capability of combining AIRS and OMI measurements to provide improved ozone data products, in compared to each instrument alone.
  - are able to distinguish the ozone abundances in the upper troposphere from the lower troposphere
  - show better agreement to the well-validated TES data products
- The JPL MUSES retrieval algorithm is able to process joint AIRS/OMI observations over global scale – leading to provide the decade long global ozone data records that fully satisfy the NASA EOS data product standards.
- The joint AIRS/OMI data products have been assimilated in global CTM "CHASER", demonstrating the potentials of this data products.
- The flexibility of JPL MUSSE has demonstrated through the prototype retrievals for multi-satellite missions [TES/OMI, AIRS/OMI, CrIS/OMPS].
- We are preparing manuscripts that summarize the JPL MUSES retrieval algorithm, sample retrievals and their characteristics.
- Thank you for attention. Questions?

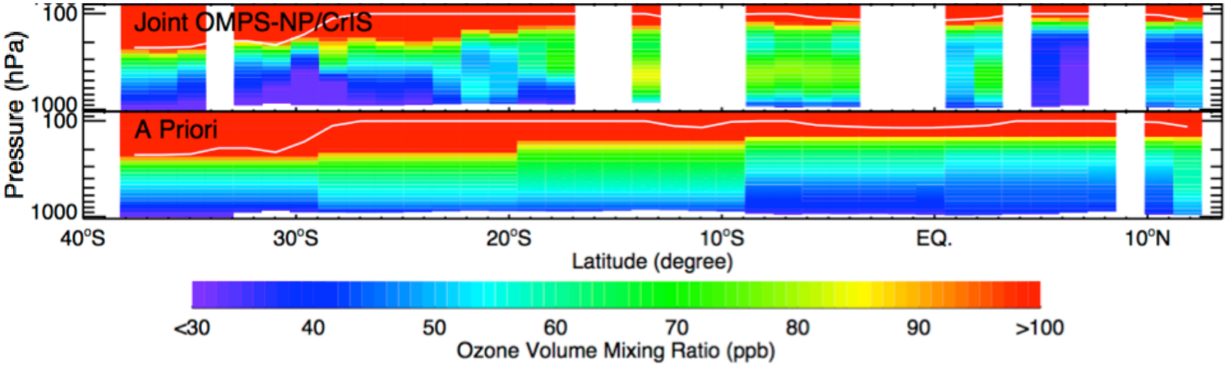
Backup

Joint CrIS/OMPS Retrievals – towards extending Earth Observing System O_3 data records

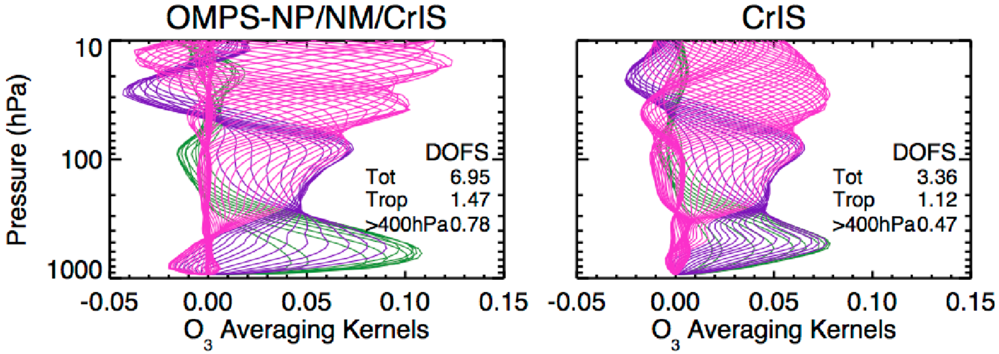
Monthly mean TES O_3 @ 681 hPa



Joint CrIS/OMPS Retrievals over Africa on October 21, 2013

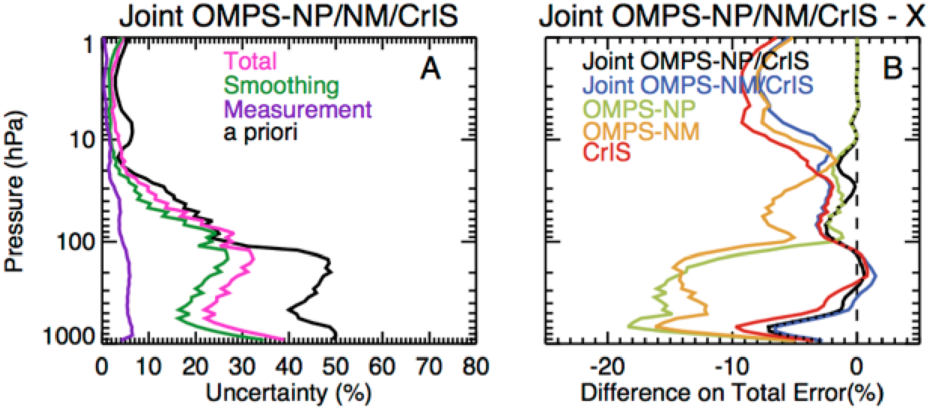


Averaging kernels of joint CrIS/OMPS vs. CrIS



[A] Uncertainty of joint CrIS/OMPS retrievals

[B] Error reduction of joint CrIS/OMPS retrievals



Joint OMI/AIRS/MLS Retrievals: towards Decade Long Global Record of Ozone Profiles

- By incorporating the assimilated Aura MLS ozone profiles into the joint retrievals, the vertical resolution and error characteristics of these joint OMI/AIRS tropospheric ozone estimates can be substantially improved, compared to joint OMI/AIRS measurements.
- This increased sensitivity is critical for evaluating the radiative response of ozone to surface emissions and the role of stratospheric / tropospheric exchange, long range transport, and tropical fires (or pyro-convection) on the tropospheric ozone distribution.