Profiles of Tropospheric O_3, CO, and CH_4 Retrieved from Multiple Satellite Instruments

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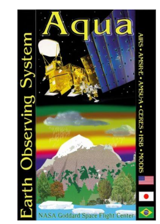
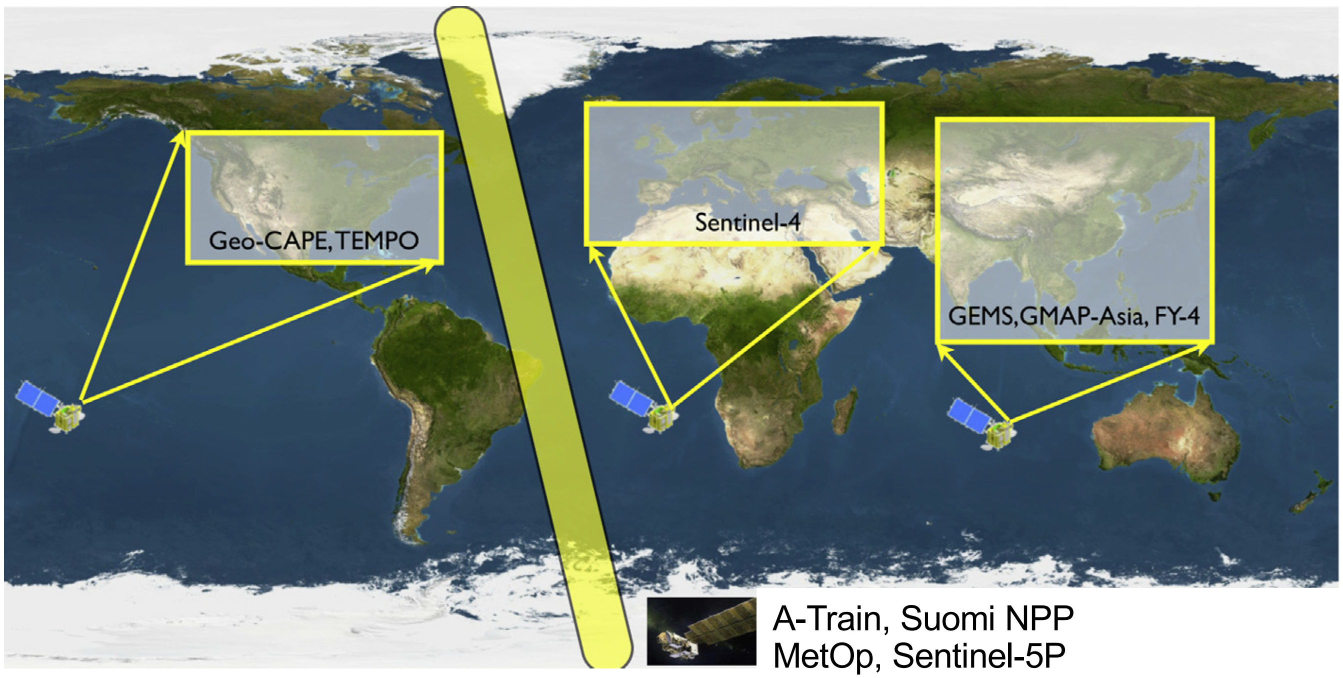


A new Atmospheric Composition Constellation to Observe Global and Regional Pollution and Greenhouse Gases

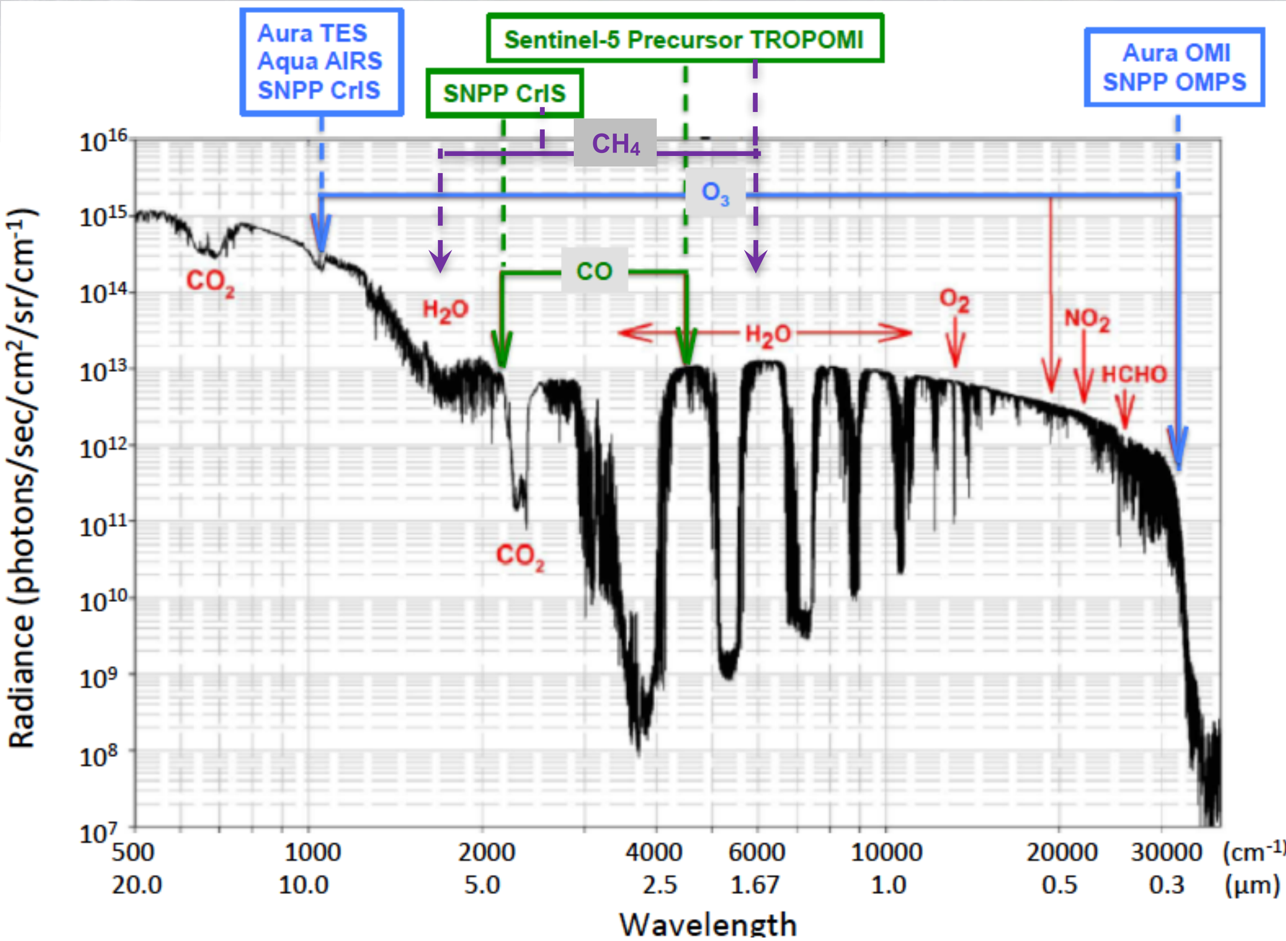
The rapid change in global emissions and their impact of air quality and climate requires a new observing system of GEO and LEO sounders to quantify global sources of local pollution and inferring surface carbon fluxes [Fu *et al.*, 2013; Bowman, 2013; Fu *et al.*, 2016].

- 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.
- LEO joint CrIS/TROPOMI measurements can provide the high resolution CO/CH_4 profile data [Worden *et al.*, 2015; Fu *et al.*, 2016].



Adapted from Bowman, Atm. Env., 2013

Spectral Regions Used in Joint Retrievals



O_3

- **Aqua/Aura**
  Joint AIRS/OMI
- **NPP-JPSS**
  Joint CrIS/OMPS

CO and CH_4

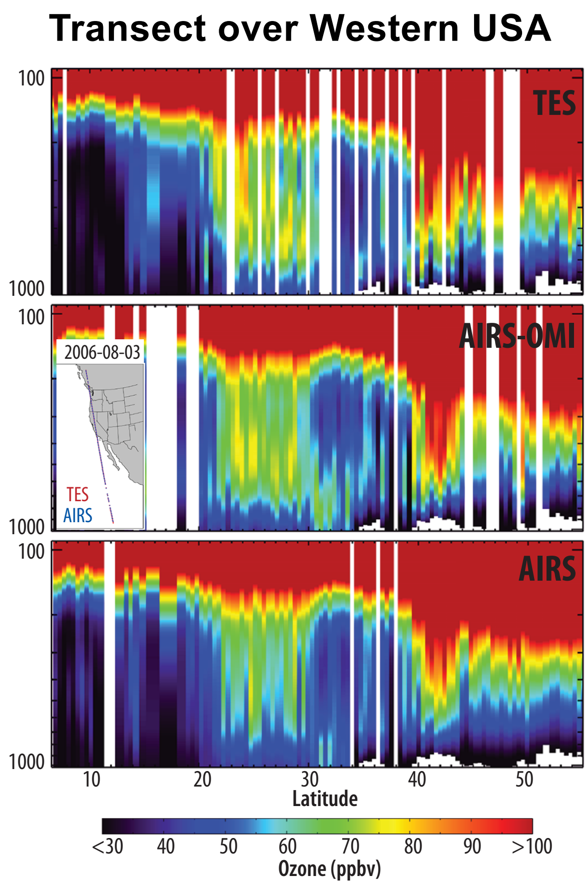
- **MOPTT, Joint TES/GOSAT**
- **NPP-JPSS/S5P**
  Joint CrIS/TROPOMI

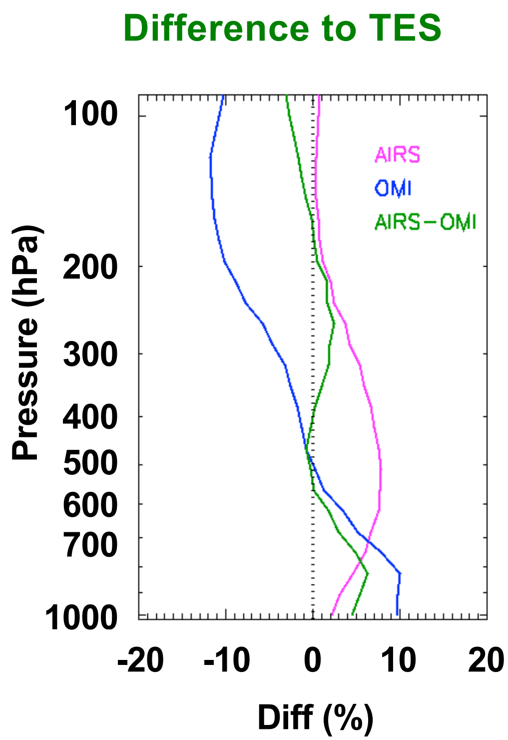
Measurements from TIR (LW) are sensitive to the free-tropospheric trace gases.
Measurements from UV-Vis-NIR (SW) are sensitive to the column abundances of trace gases.
Joint LW/SW measurements can distinguish upper troposphere from lower troposphere.

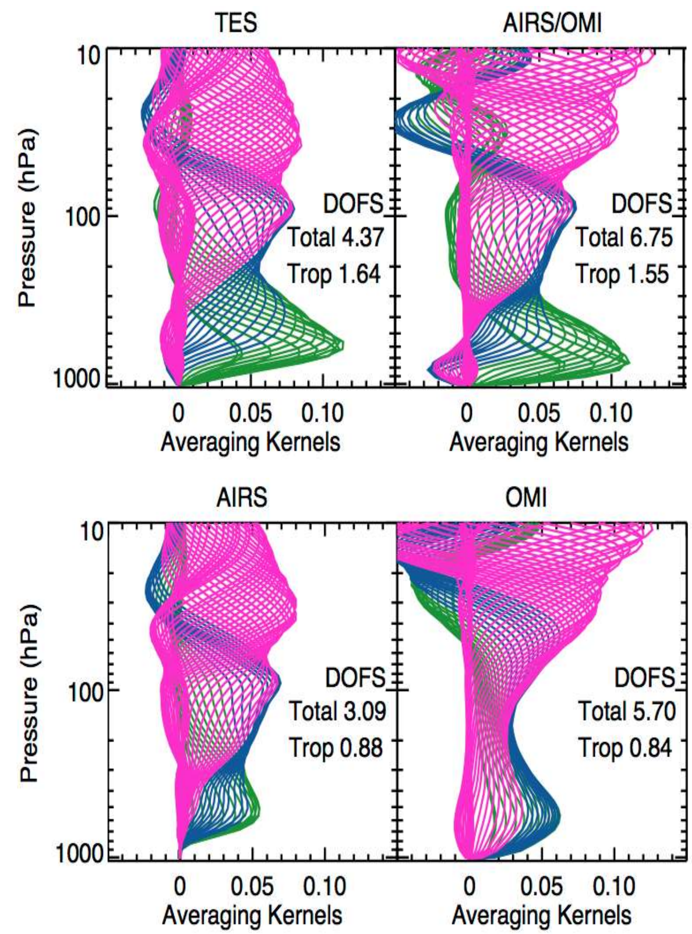
Joint AIRS/OMI and TES observations on August 23, 2006 during TexAQS Aircraft Flight Campaign

Joint AIRS/OMI ozone retrievals

- **Mu**lti-**Sp**ec**tra**, **Mu**lti-**S**pe**c**ies, **Mu**lti-**Se**nsors (MUSES)
- Show best agreement to TES, in comparisons to each instrument alone

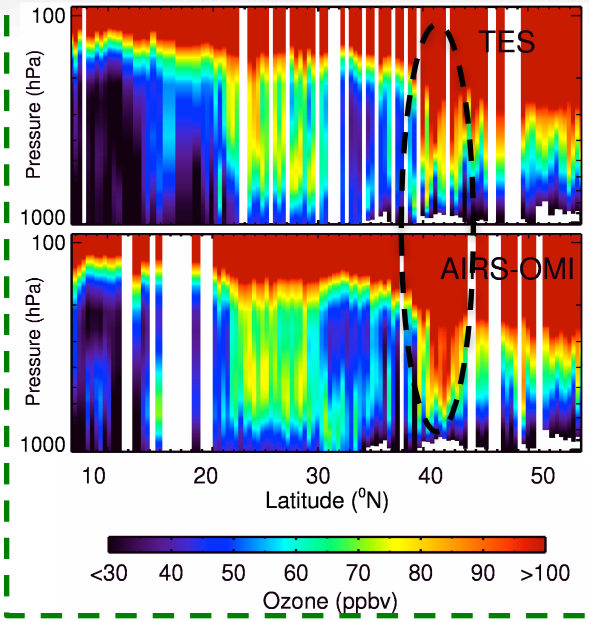




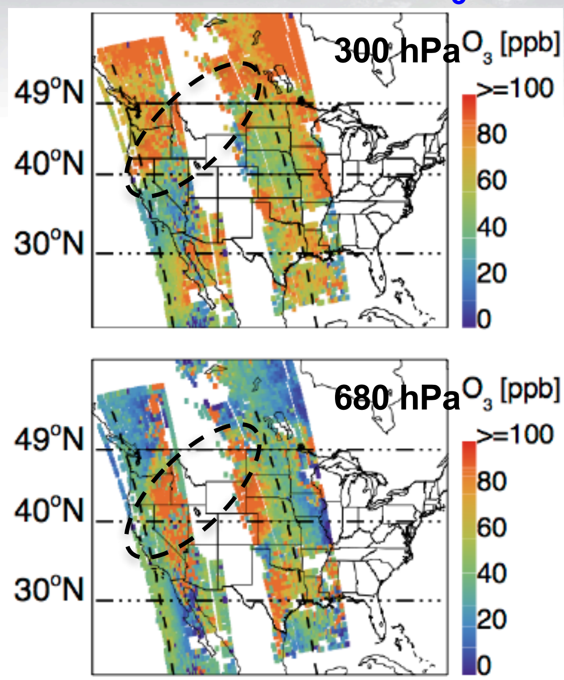


Impact of Biomass Burning on Ozone Distribution on August 23, 2006 during TexAQS Aircraft Flight Campaign

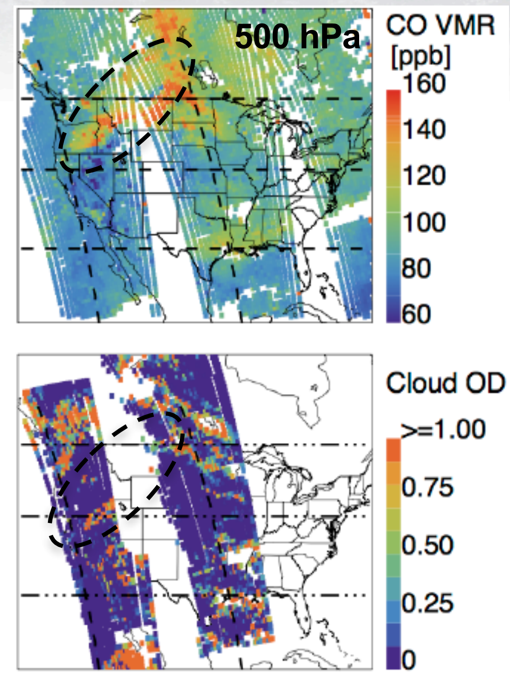
Collocated TES & Joint AIRS/OMI O_3 Measurements over Western USA



Joint AIRS/OMI O_3



AIRS CO and Cloud

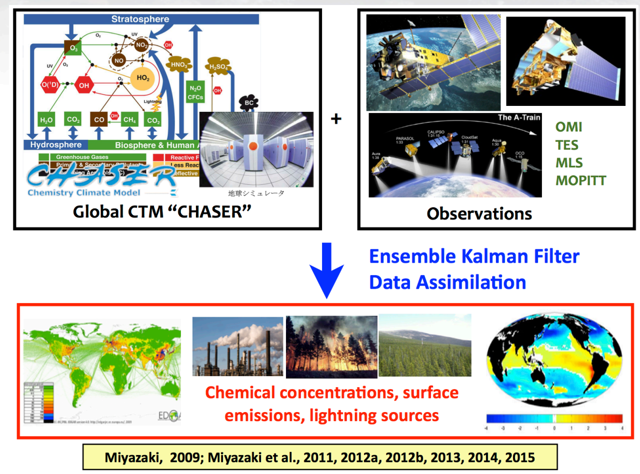


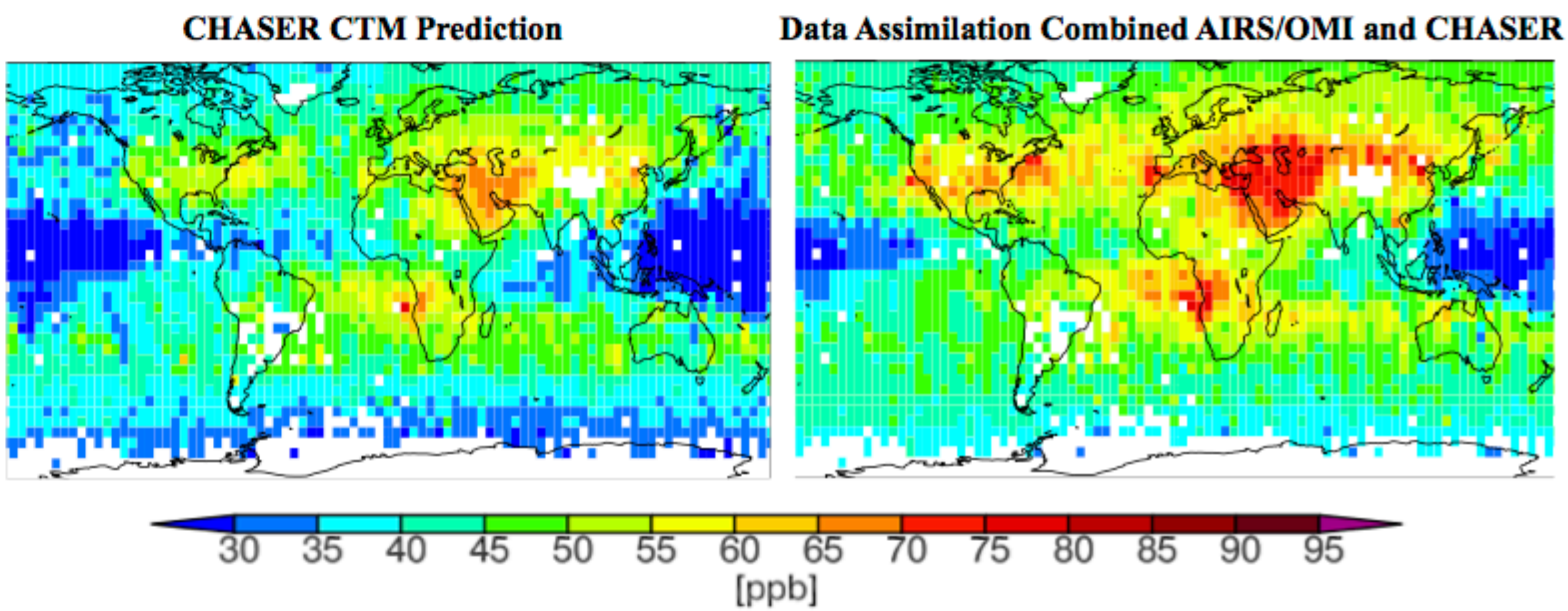
- The enhanced ozone at 680 hPa is collocating to the enhanced CO due to the fire emissions.
- Joint AIRS/OMI retrievals distinguish the amount of O_3 between lower and upper trop, similar to TES, with broader spatial coverage, which helps in distinguishing between stratospheric influences and biomass burning.
- MUSES has been extended to additional species (NH_3, CH_3OH, HCOOH, CH_4, PAN) using measurements from multiple space sensors (TES, AIRS, CrIS, OMI, OMPS, TROPOMI).

Data Assimilation System of the NASA A-Train Observations

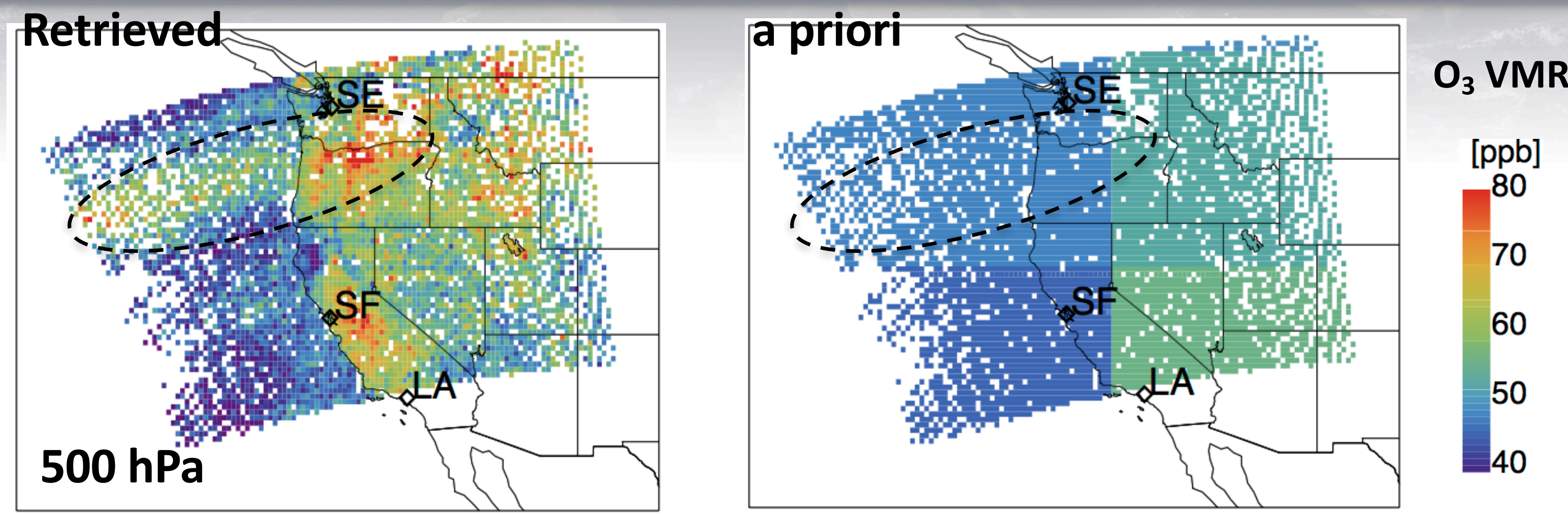
- MUSES algorithm delivered joint AIRS/OMI ozone and observation operator that enable data assimilation, e.g., the CHASER-DA.
- Assimilations of AIRS/OMI ozone leads to enhanced concentration over middle east and south Africa.
- Consistent to the previous study of the summertime buildup of tropospheric ozone abundances over the Middle East [Liu et al. 2009]

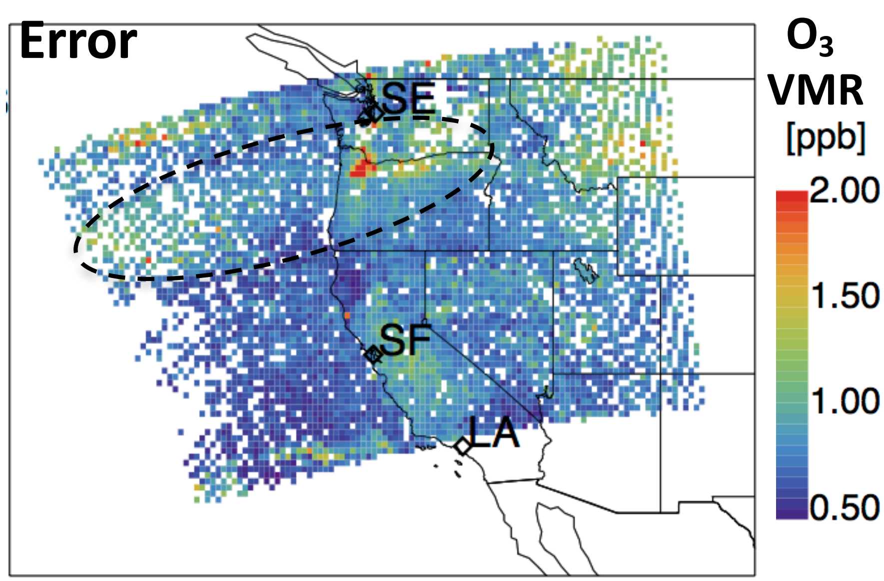
- Dr. Kazuyuki Miyazaki, implemented the CHASER data assimilation system.





Retrievals Using MUSES Algorithm and SNPP Measurements in Support of the coming NOAA FIREX Intensive Campaign

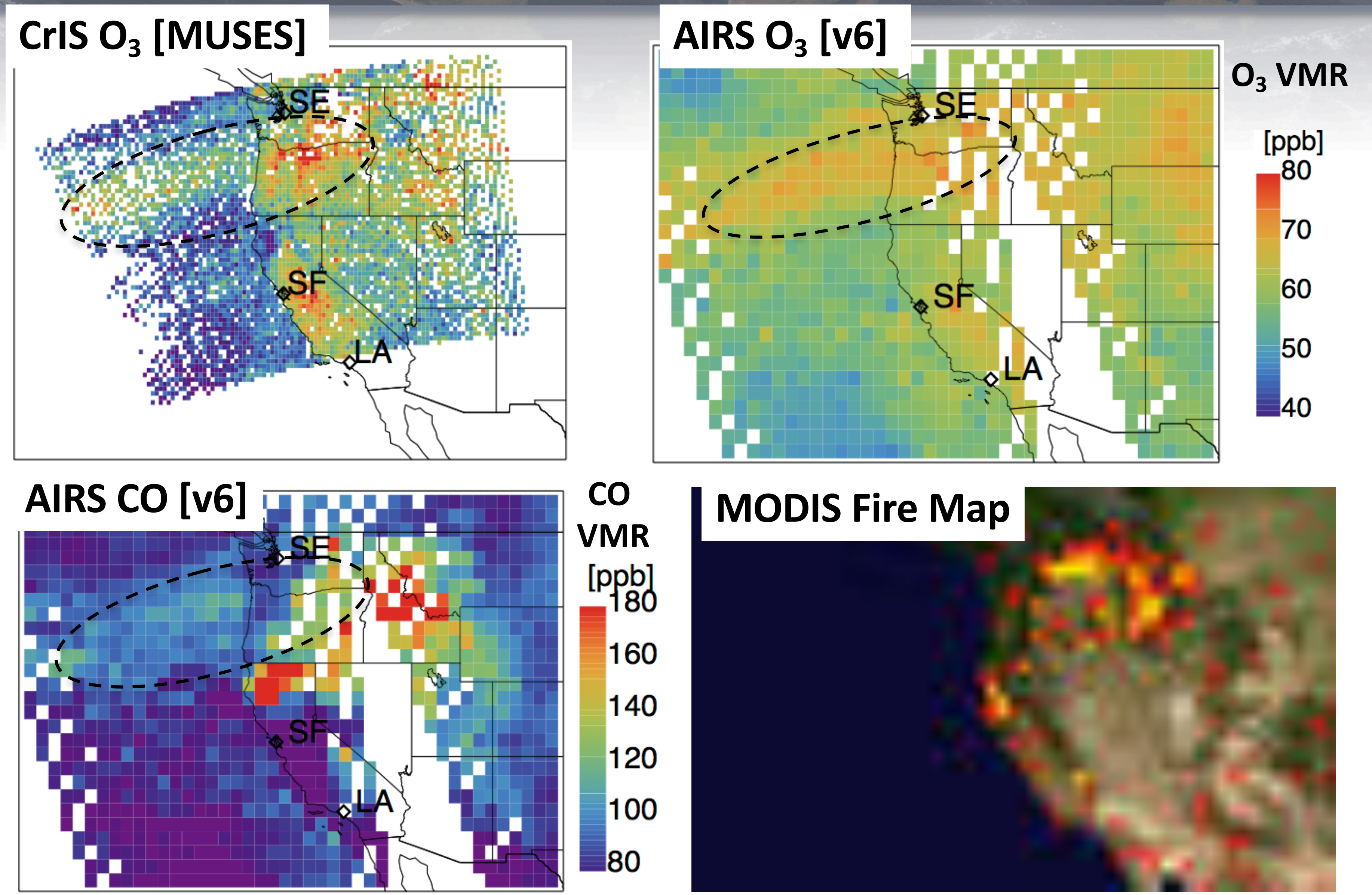




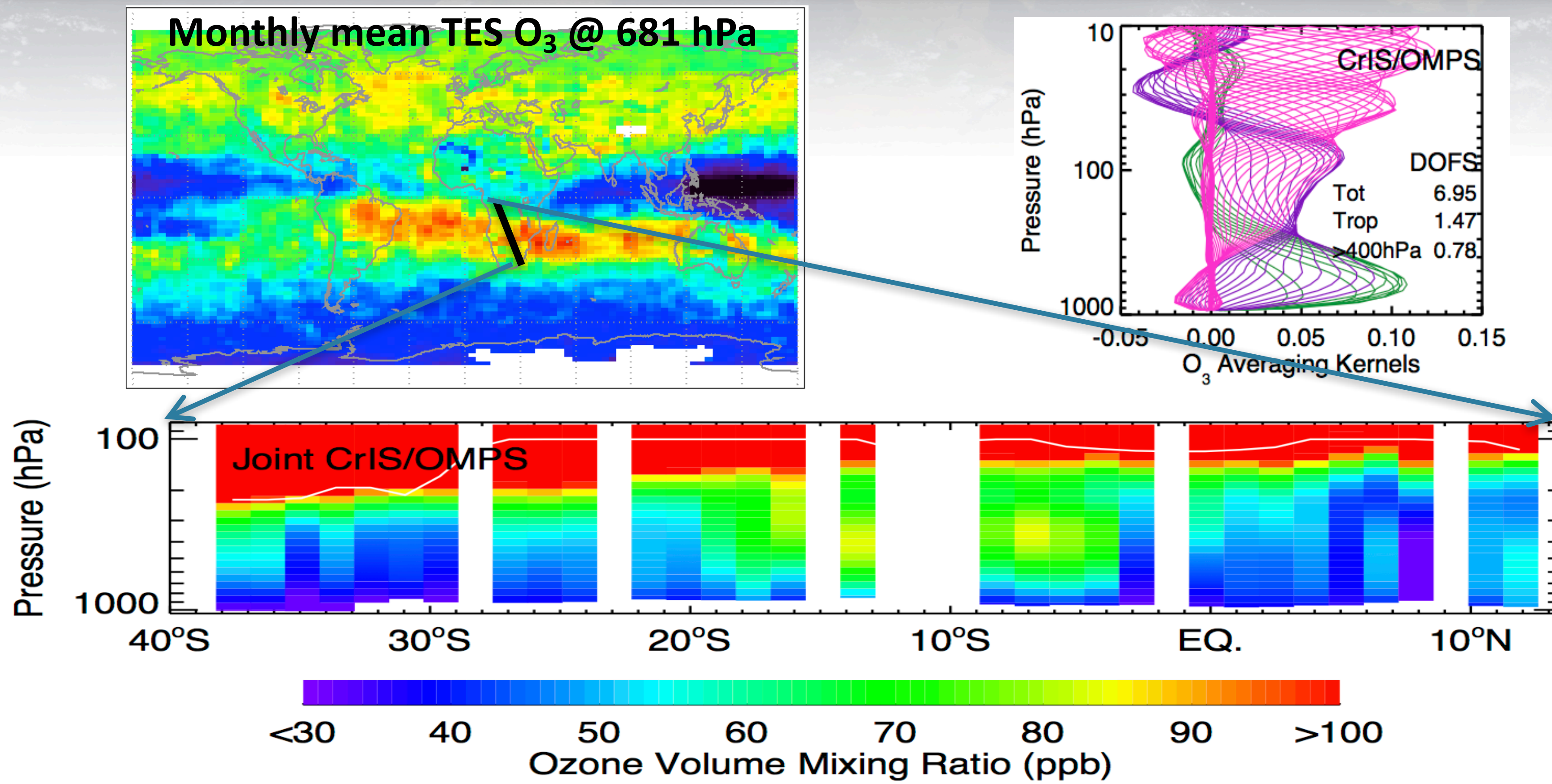
CrIS O_3 retrievals using MUSES

- August 19, 2015
- Single footprint (14 x 14 km^2 at Nadir)
- Full spectral resolution
- Provides observation operator (H) needed for data assimilation
- Cloud OD <= 1.0

Observations from AIRS, CrIS and MODIS on Aug 19, 2015



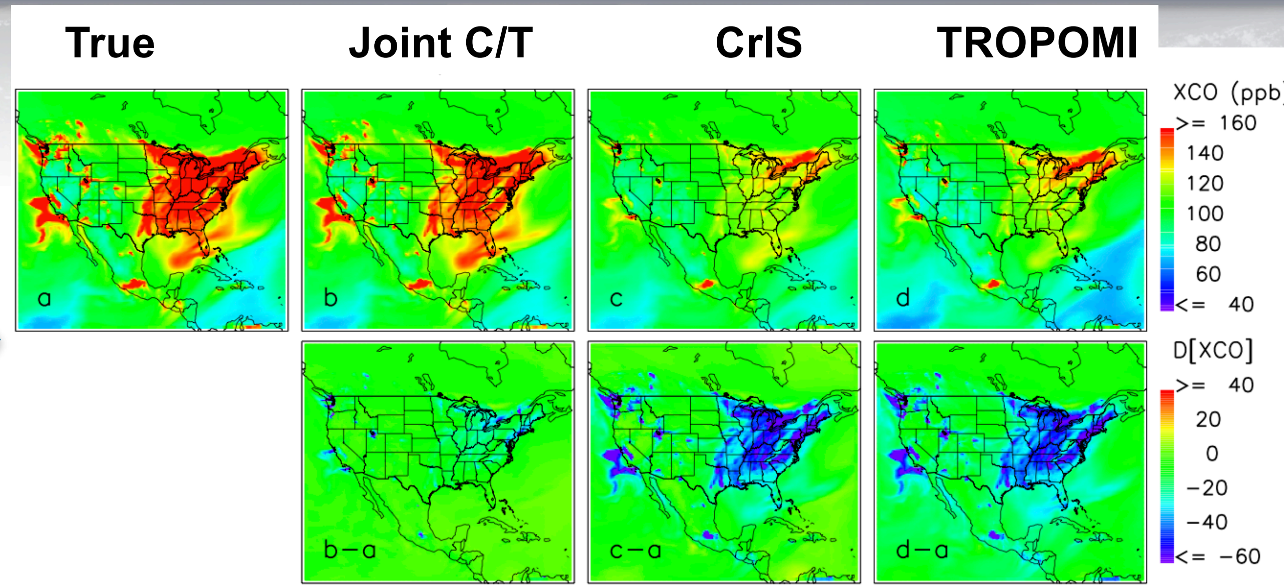
Extension to Joint CrIS/OMPS O_3 Retrievals



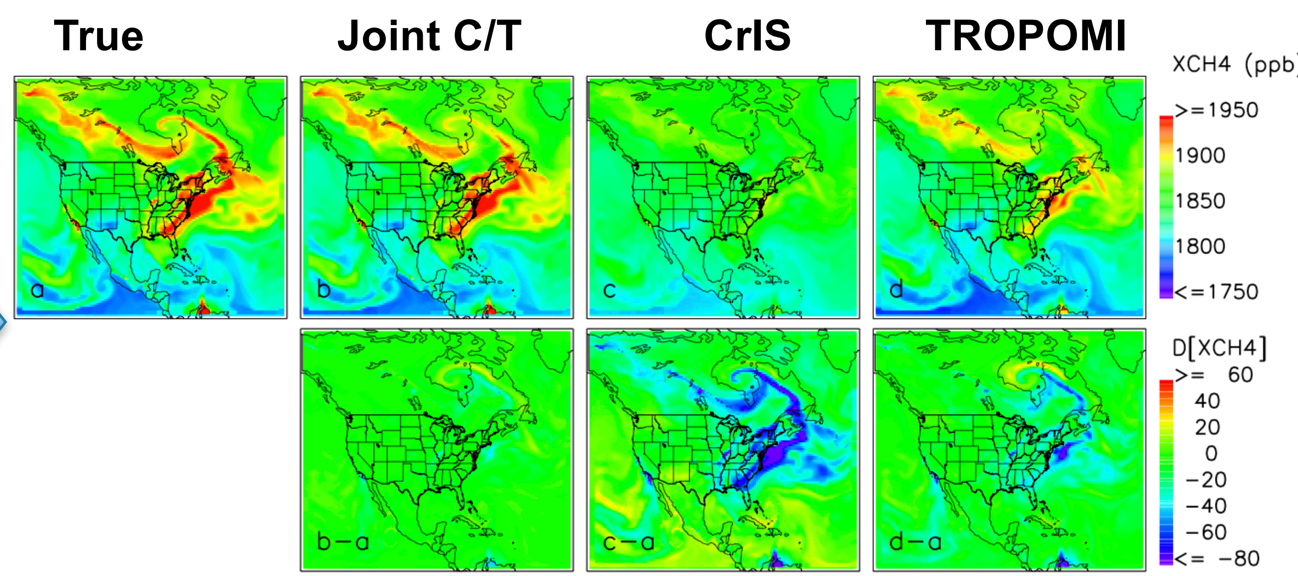
- MUSES has been applied to joint CrIS/OMPS ozone retrievals over Africa on October 21, 2013.
- The elevated ozone concentrations between 2 - 20° S are associated with biomass burning.
- Joint CrIS/OMPS O_3 and CrIS CO retrievals using MUSES will support the NOAA FIREX flight campaign (Fire Influence on Regional and global Environments Experiment) – an intensive study of the impacts of western North America fires on climate and air quality.

High Resolution CO/CH_4 Near Surface Data Through Combining CrIS/TROPOMI Measurements

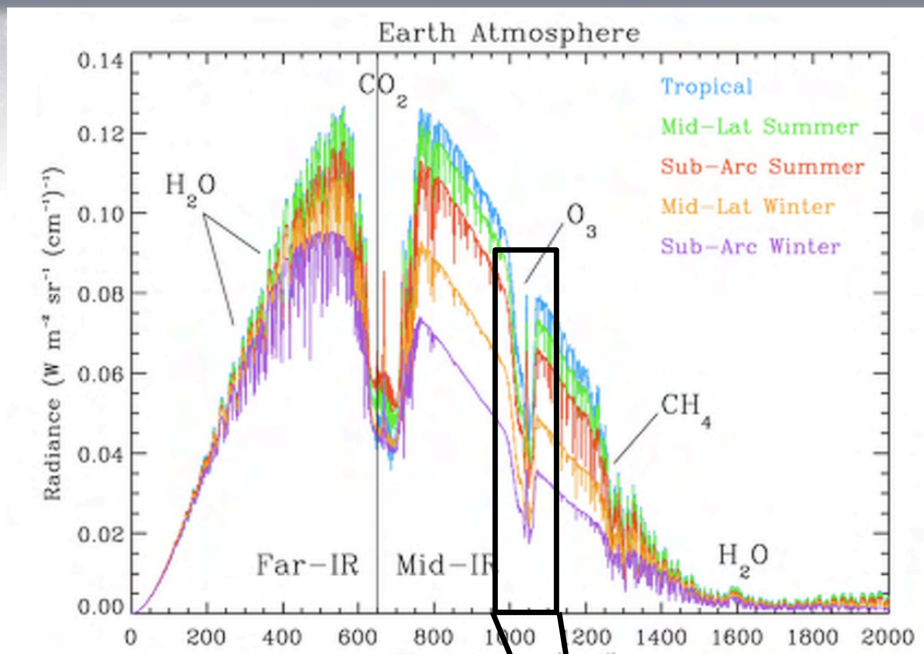
- **XCO:** Near surface partial column averaged VMR [surface to ~750 hPa]
- Extend and improve the MOPITT joint TIR/NIR **CO** data [Fu et al., AMT, 2016]

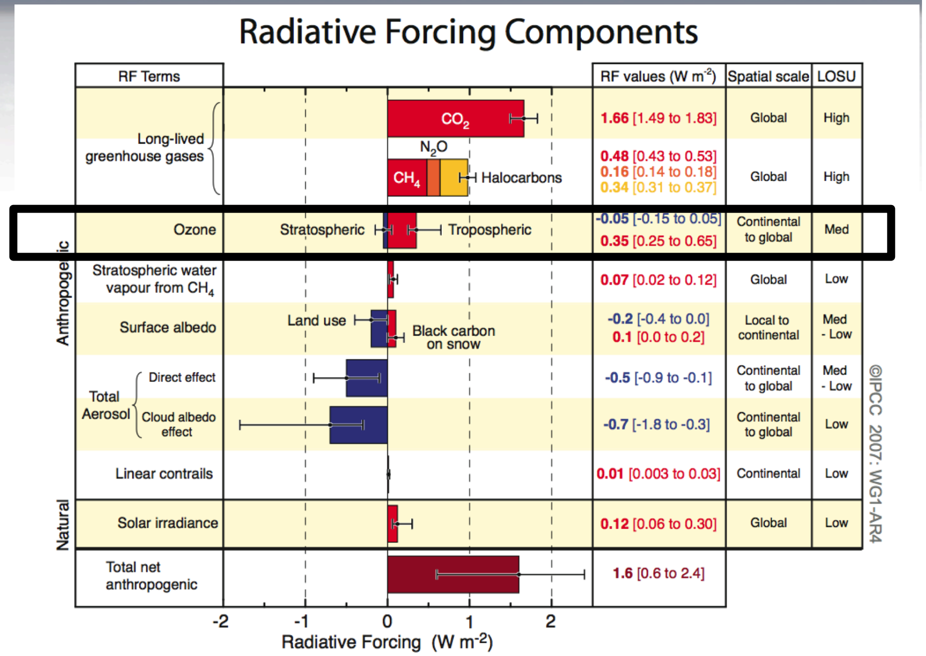


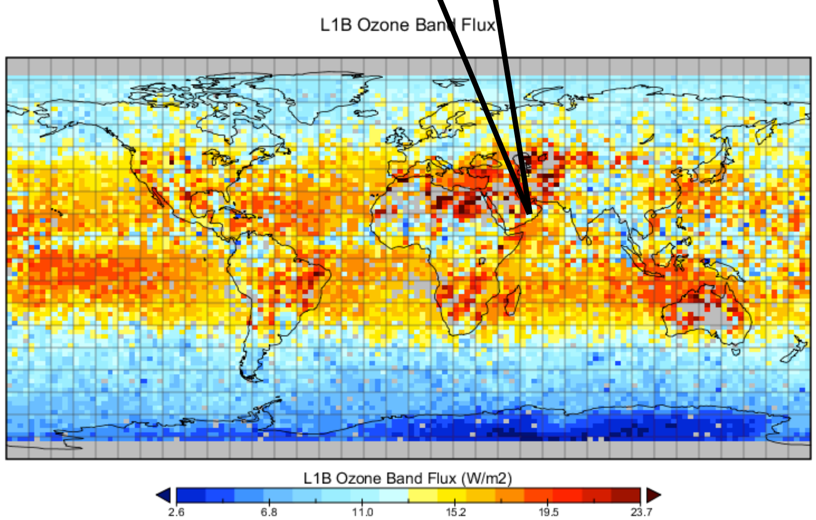
- **XCH_4**: Near surface partial column averaged VMR [surface to ~750 hPa]
- Extend and Improve the joint TES/GOSAT **CH_4** data [Worden et al., AMT, 2015]



Composition-Climate Coupling: Ozone







Inter-model radiative forcing from ozone: 0.35 [0.25-0.65] W/m^2 (IPCC AR4)

Radiative forcing uncertainties:

- Pre-industrial background ozone
- Spatial distribution
- Vertical distribution

Summary

- MUSES retrieval algorithm can combine radiances measured from LW and SW sensors including TES, AIRS, CrIS, OMI, OMPS, TROPOMI.
  - Joint AIRS/OMI and CrIS/OMPS retrieved O_3 profiles can distinguish the abundances in the upper troposphere from the lower troposphere, and show better agreement to the well-validated TES data products.
  - Joint CrIS/TROPOMI
    - retrieved CO profiles show similar vertical resolution as MOPITT TIR/NIR, but with a factor of two finer footprint size and daily global coverage.
    - retrieved CH_4 profiles would provide similar vertical resolution as joint TES/GOSAT, but with a factor of ~100 times daily spatial coverage.
- The observation operators of joint AIRS/OMI data products enable data assimilation, e.g., "CHASER-DA", demonstrating the significant impacts on ozone distributions.
- The multiple spectral observations enable the continuation of key EOS observations including TES and MOPITT which do not have follow on missions.
- These critical observations will form the pillar of the LEO and GEO air quality and climate constellations [Bowman, 2013; Fu et al., 2016].
- Thank you for attention. Questions?

Backup

IIP-2016 Concept: A Polarization UV-Vis Imaging Spectrometer (PUVIS) for the Composition in the Lower Most Troposphere

PI: Dejian Fu, JPL

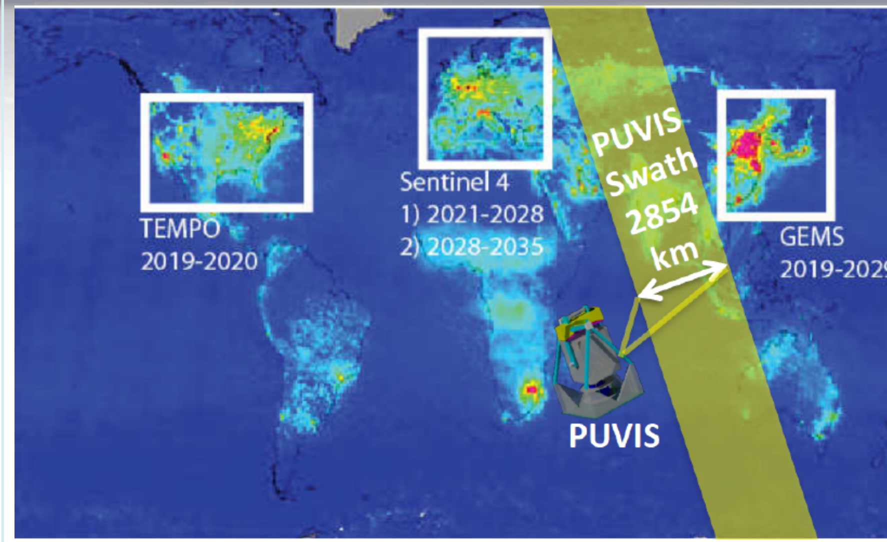
Description and Objectives:

The proposed effort will advance the state of art in the imaging spectropolarimetric technology thus enabling new Earth measurement capabilities of atmospheric composition in the Lower Most Troposphere (0-2 km) with meeting the accuracy/precision/resolution requirements specified by the 2017 NASA Decadal Survey science community [Neu J.L. et al., 2016; Pickering K. et al., 2016] and the 2015 NASA workshop on Outstanding Questions in Atmospheric Composition named "Air Quality in the Developing World".

PUVIS not only enables new Earth science measurements, its design substantially reduces the size, mass, power, volume, and cost of the instrumentation needed to accomplish key air quality and climate science objects identified by science community.

Air-PUVIS: to fit readily on a NASA aircraft for demonstrating the technology and advancing TRL. When flying on ER-2 (cruise altitude: ~20 km a.b.s.l.), the spatial resolution would be 100 × 100 m^2 with a swath width of 31 km.

Satellite-PUVIS: to provide unique high spatial resolution (4 × 4 km^2) and high sensitivity measurements of LMT O_3 and NO_2, and a set of trace gases (HCHO, SO_2, BrO, $C_2H_2O_2$, Aerosol & Cloud properties), with a swath width of 2,854 km when onboard a 12 U platform in a LEO orbit (altitude ~ 824 km a.b.s.l.) or form a constellation that consists of two 6U satellites.



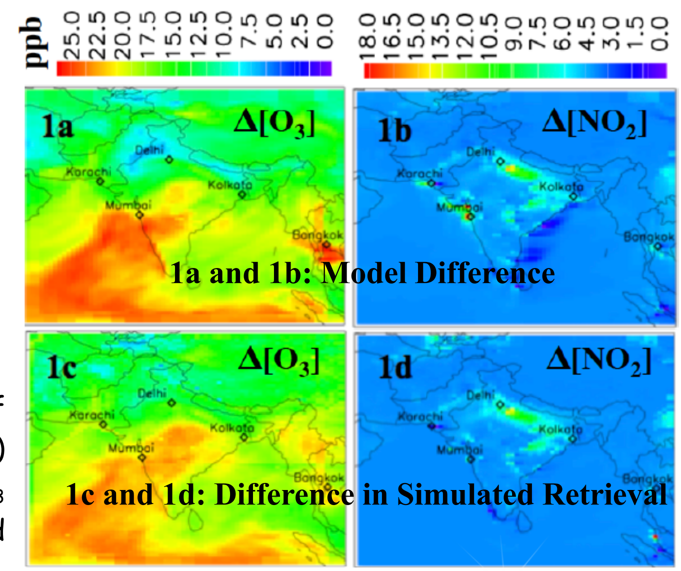


Figure 1: (Upper Panel) Unprecedented global LMT O_3 and NO_2 measurements of PUVIS, covering key regions not observed by the slated future GEO missions. (1a-d) Estimated performance of PUVIS measurements in capturing the changes of LMT O_3 and NO_2 between polluted and clean days over India: True differences of O_3 (1a) and NO_2 (1b); Simulated PUVIS measurements of O_3 (1c) and NO_2 (1d).

JPL MUSES Retrieval Algorithm

Multi-**Sp**ectra, **Mu**lti-**Sp**ecies, **Mu**lti-**Se**nsors (MUSES)

- Builds off of heritage from the Aura Tropospheric Emission Spectrometer (TES) optimal estimation (OE) algorithm to combine *a priori* and satellite LW and SW data [Worden et al., 2007; Fu et al., 2013; Fu et al., 2016]

$$\mathbf{x}_{i+1} = \mathbf{x}_i + \left[\mathbf{S}_a^{-1} + \underbrace{\mathbf{K}_{SW}^T \mathbf{S}_{\varepsilon\,SW}^{-1} \mathbf{K}_{SW}}_{SW} + \underbrace{\mathbf{K}_{LW}^T \mathbf{S}_{\varepsilon\,LW}^{-1} \mathbf{K}_{LW}}_{LW}\right]^{-1}$$

$$* \left[\mathbf{S}_a^{-1}(\mathbf{x}_a - \mathbf{x}_i) + \underbrace{\mathbf{K}_{SW}^T \mathbf{S}_{\varepsilon\,SW}^{-1} (\mathbf{L}_{SW} - \mathbf{F}_{SW}(\mathbf{x}))}_{SW} + \underbrace{\mathbf{K}_{LW}^T \mathbf{S}_{\varepsilon\,LW}^{-1} (\mathbf{L}_{LW} - \mathbf{F}_{LW}(\mathbf{x}))}_{LW}\right]$$

  - Use common a priori **X**a and **S**a, and instrument specific precision $\mathbf{S\varepsilon}_{LW}$, $\mathbf{S\varepsilon}_{SW}$
  - Forward model (**F**) and Jacobians (**K**) for LW and SW sensors
- MUSES provides observation operator (H) needed for data assimilation

$$H(x) = x_a + \mathbf{A}(x_{model} - x_a)$$

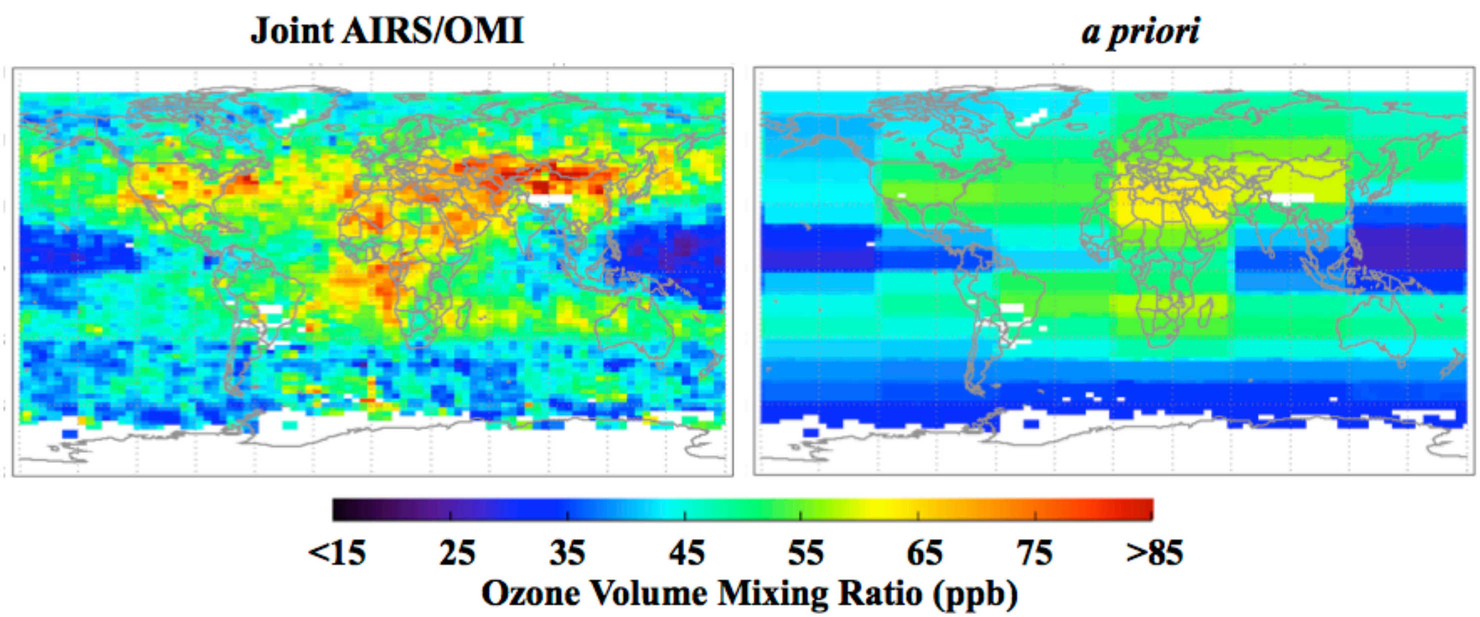
  - Averaging kernel matrix (A) is the sensitivity of the retrieved state to the true state.
  - The trace of averaging kernel matrix is the degree of freedom for signals (DOFS).

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

The JPL MUSES has been implemented and applied to joint AIRS/OMI ozone retrievals over global scale. We are processing June to August 2006 data.

Characteristics (e.g., August 2006)

- 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*



CrIS and MOPITT CO during Biomass Burning on August 27-28, 2013

Motivation: MOPITT's unique thermal IR/near IR multispectral CO measurements, which are able to separate near-surface from the free troposphere, have no planned follow-on.

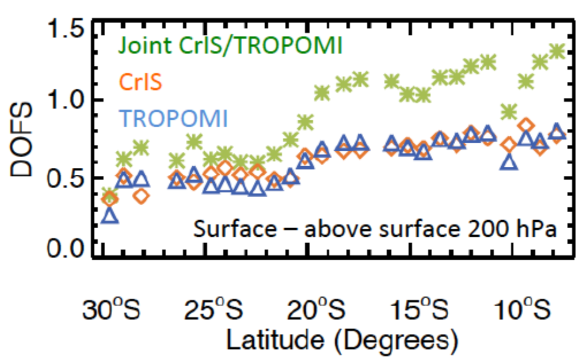
We applied the MUSES algorithm to the retrieval of CO VMR profiles from the NOAA/NASA CrIS Measurements. An analysis showed that combining CrIS TIR with the Sentinel 5p TROPOMI NIR data would have comparable to vertical sensitivity of MOPITT but with daily coverage (Fu *et al.*, 2016).

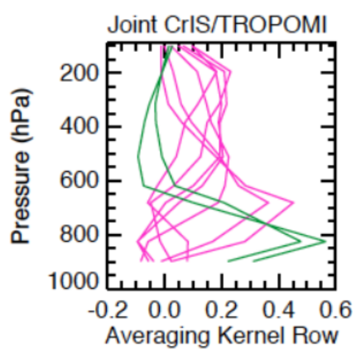
MOPITT and CrIS

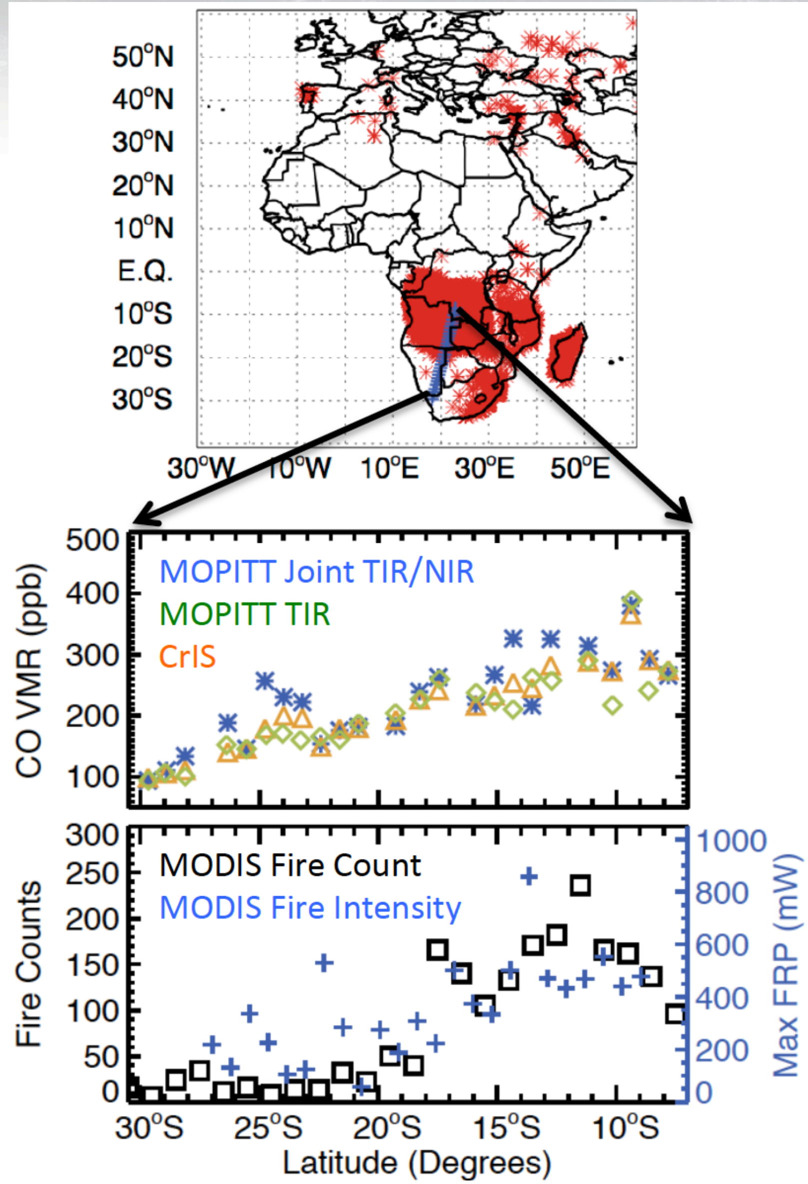
- Real CrIS single footprint, full spectral resolution measurements
- MUSES algorithm was used in

Joint CrIS/TROPOMI

- Synthetic retrievals with realistic conditions
- MUSES algorithm







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