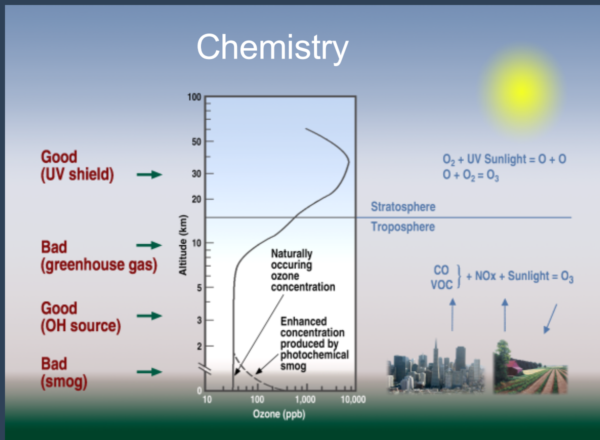
Jet Propulsion Laboratory
California Institute of Technology

TRopospheric Ozone and its Precursors from Earth System Sounding (TROPESS)

Kevin W. Bowman and the TROPESS team

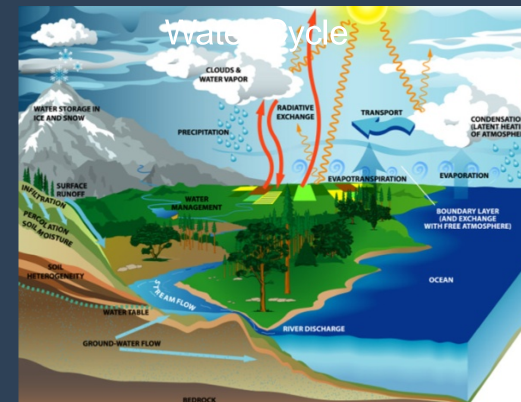
Tropospheric ozone and its precursors are an important objective of Earth System Sounding



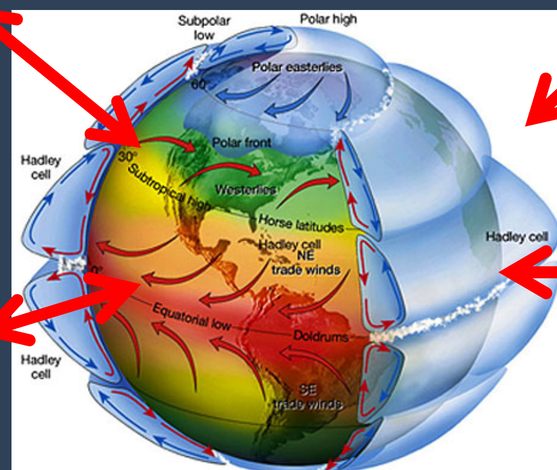
Ozone (O_3), Carbon Monoxide (CO), Methanol (CH_3OH), Formic Acid (HCOOH)

Atmospheric composition plays a critical mediating role in Earth System Cycles.

Atmosphere, Climate

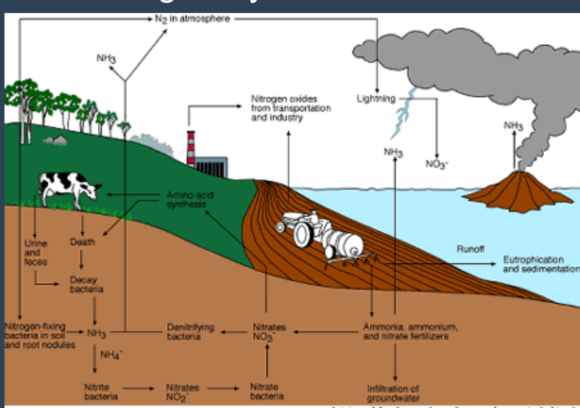


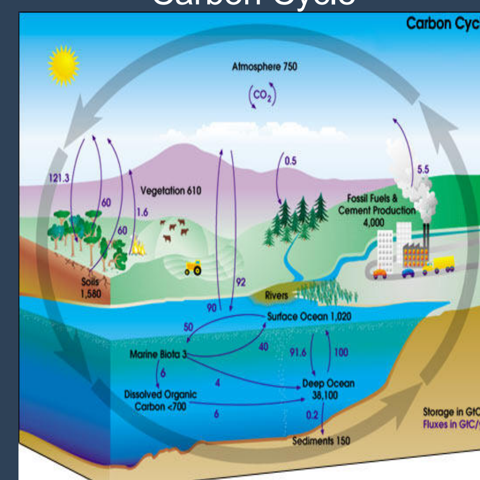
Water Vapor and Isotopes (H_2O and HDO)



Carbon Cycle

Carbon Cycle





Ammonia (NH_3), PAN ($CH_3COOONO_2$)

Radiative Kernels, Surface Temperature, Atmospheric Temperature, Cloud Optical, Depth and Pressure, Surface Emissivity

Carbon Dioxide (CO_2), Methane (CH_4), Carbonyl Sulfide (OCS)

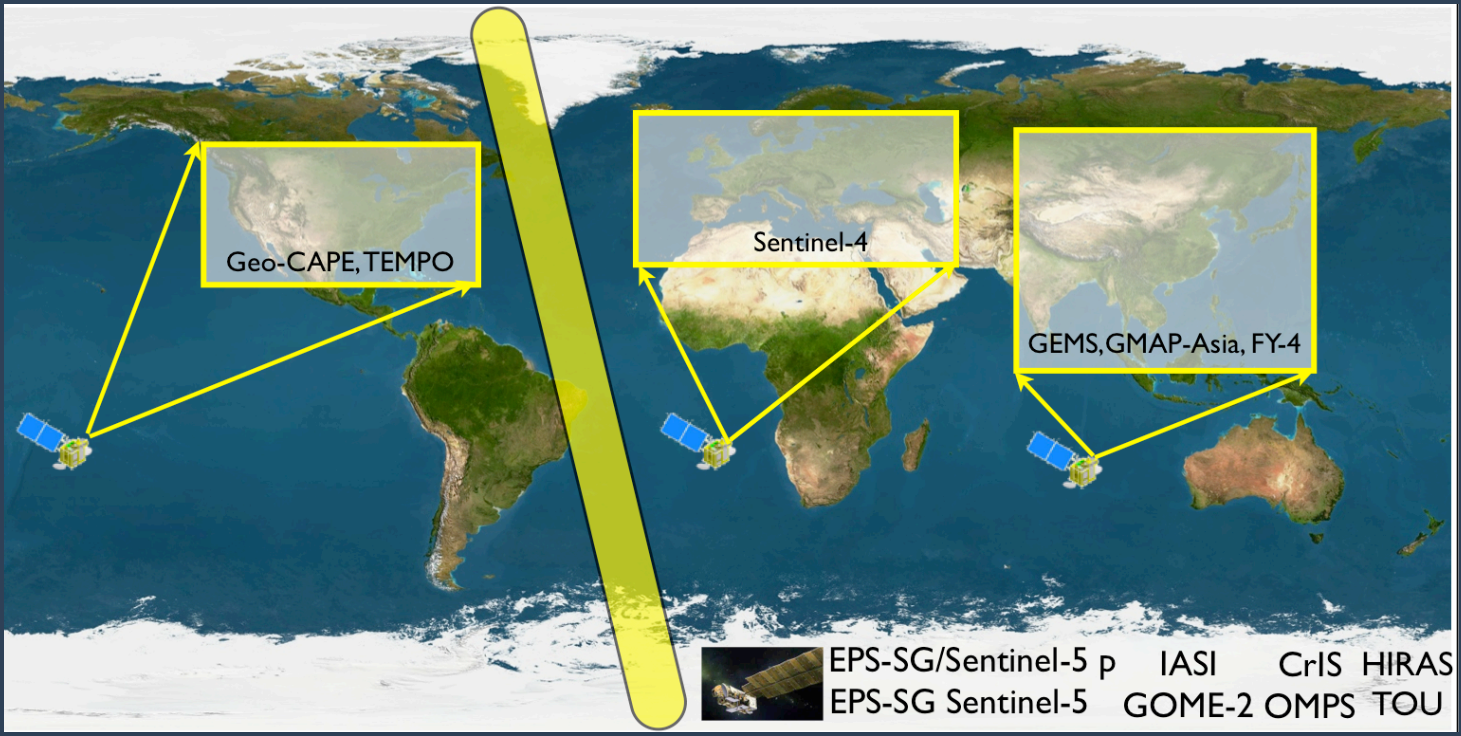
TROPESS: Objectives

- TES has borne witness to a changing trajectory of atmospheric composition in the troposphere and revealed its complex interactions within the broader Earth System
- Characterizing and predicting this trajectory requires a broad suite of well-characterized measurements linking emissions to concentrations in the context of natural and anthropogenic variability.

- TROPESS will produce long term, Earth Science Data Records (ESDRs) with uncertainties and observation operators pioneered by TES and enabled by the MUlti-SpEctra, MUlti-SpEcies, Multi-SEnsors (MUSES) retrieval algorithm and ground data processing system.
- Promote the dissemination, utilization, and assimiliation of these ESDRs to support scientific and application communities, *e.g.*, IGAC, IPCC.
- Support the science of Decadal Survey and CEOS Atmospheric Composition Virtual Constellation (AC-VC) missions through a dependable forward stream of composition ESDR from existing and planned LEO instruments.
- Support NASA activities including fields campaigns, mission formulation, *e.g.*, Observing System Simulation Experiments (OSSES)

Contribution to CEOS AC-VC

Bowman, *Atm. Env.* 2013

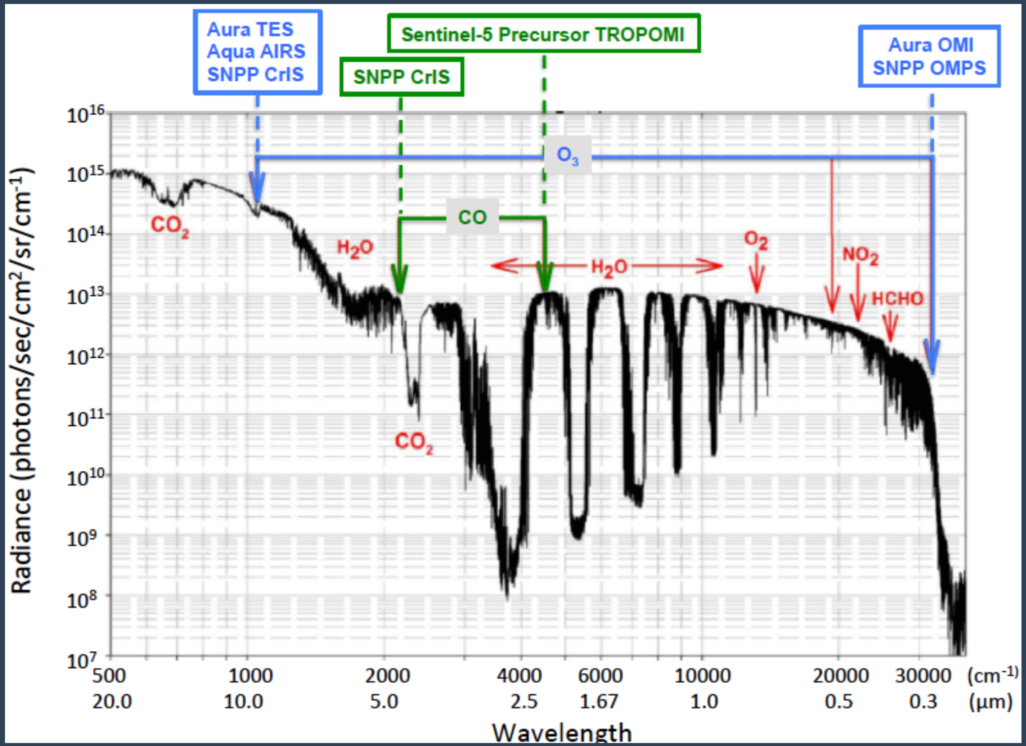


TROPESS will support the exploitation of a Earth System Convoy initiated by Suomi-NPP and Sentinel 5p that will be the pillar of a composition constellation and the backbone of Decadal Survey composition missions.

- Sustained observations for the next decade.
- Continuity with the EOS program
- LEO observations to integrate GEO platforms

More eyes are better than one:
The panspectral approach

IR-NIR
TES
AIRS
IASI
CrIS
OCO-2
TROPOMI



UV-Vis
SCIAMACHY
OMI
GOME
GOME-2
OMPS
TROPOMI

- Panspectral techniques provide better accuracies and vertical sensitivities than individual bands → critical for relating concentrations to emissions
- Systematic errors between instruments and spectroscopy must be assessed.

TROPESS has considerable heritage in multi-spectral, multi-instrument retrieval algorithms for UV, IR,NIR, microwave (Worden et al, GRL, 2007, Luo et al, 2013, Fu et al, ACP, 2013, Kuai et al, 2013, Worden et al, 2015, Fu et al, 2016) for ozone, CO, CO2, and CH4.

Initial Processing Objectives

Forward Stream → Latency expected < 5 days

Instruments	Rate	Dates
AIRS+OMI	10x(GS)/day	2021 onward
CrIS+S5P	10x(GS)/day	2021-onward

← Reanalysis Record is filled in successively

Instruments	Rate	Dates
AIRS+OMI	10x(TES GS)/day	10/04-10/20
CrIS+S5P	10x(TES GS)/day	10/13-10/20

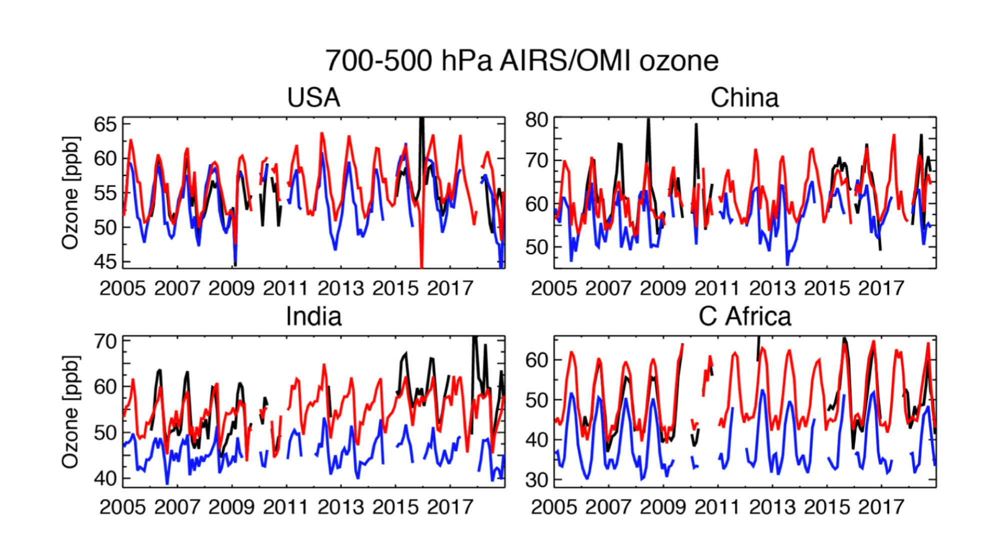
AIRS+OMI: [T,q,Tsur,Emiss, H2O Clouds], O3, CO, CH4, HDO, O3 IRKs
CrIS+S5p+OMPS: O3, CO, CH4, O3 IRKs, HDO, H2O, methanol, ammonia, PAN

*Global Survey~3000 obs/day
AIRS single pixel~3 million obs/day

Special collections for field campaigns and user requests

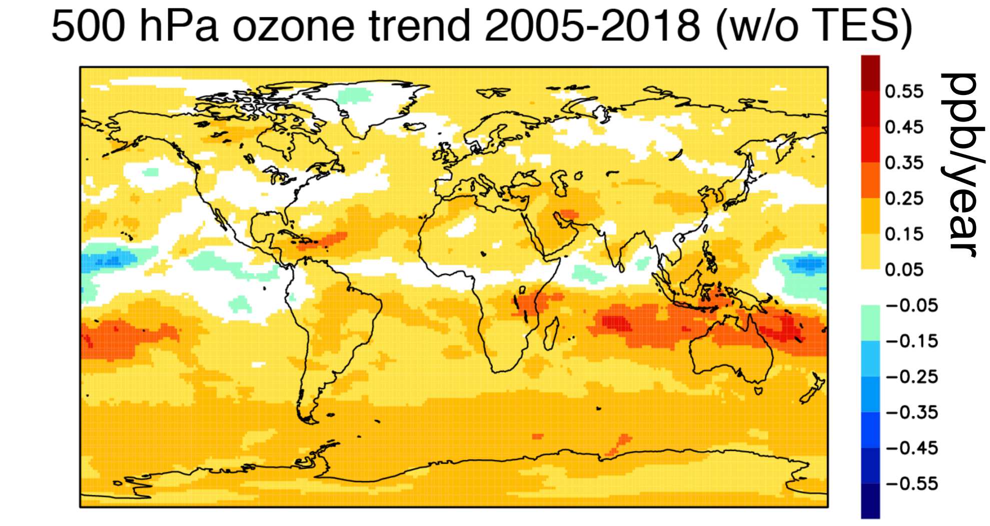
Decadal trends in tropospheric chemical reanalysis

Chemical reanalysis from JPL MOMO-Chem is in closer agreement with AIRS/OMI ozone.



Chemical reanalysis indicates substantial changes in decadal tropospheric ozone.

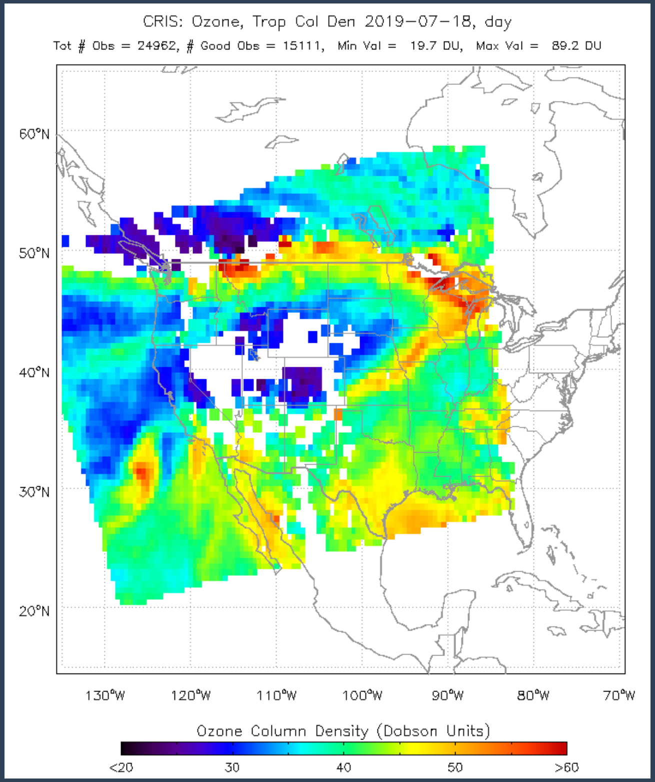
Assimilation of TROPESS ESDRs will Critical to assess and attribute these changes

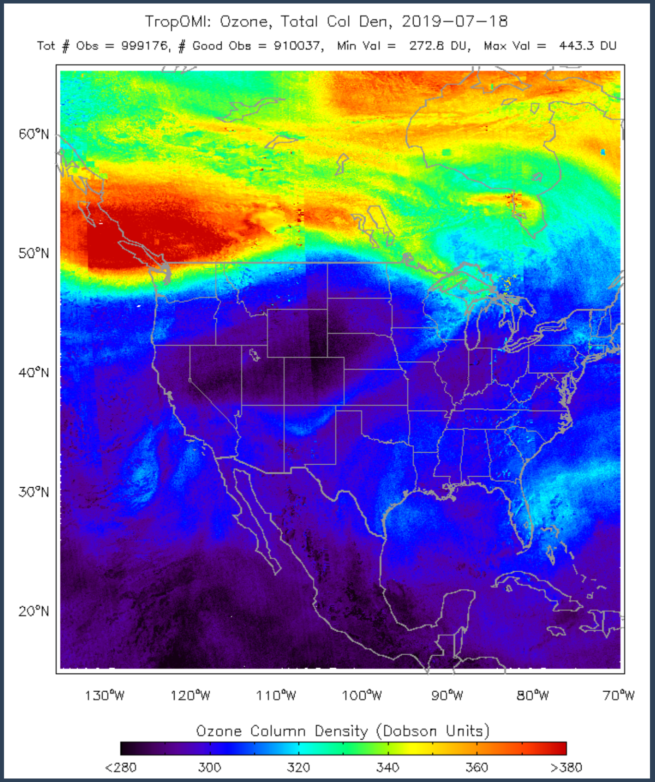


Miyazaki, Bowman, et al, ESSD in review

[Reanalysis available at https://tes.jpl.nasa.gov/chemical-reanalysis/](https://tes.jpl.nasa.gov/chemical-reanalysis/)

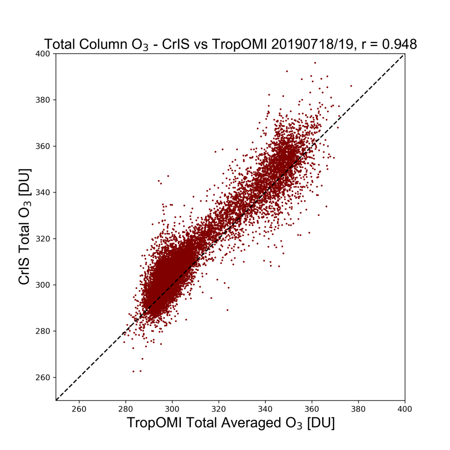
Towards synergy of TROPOMI and CrIS





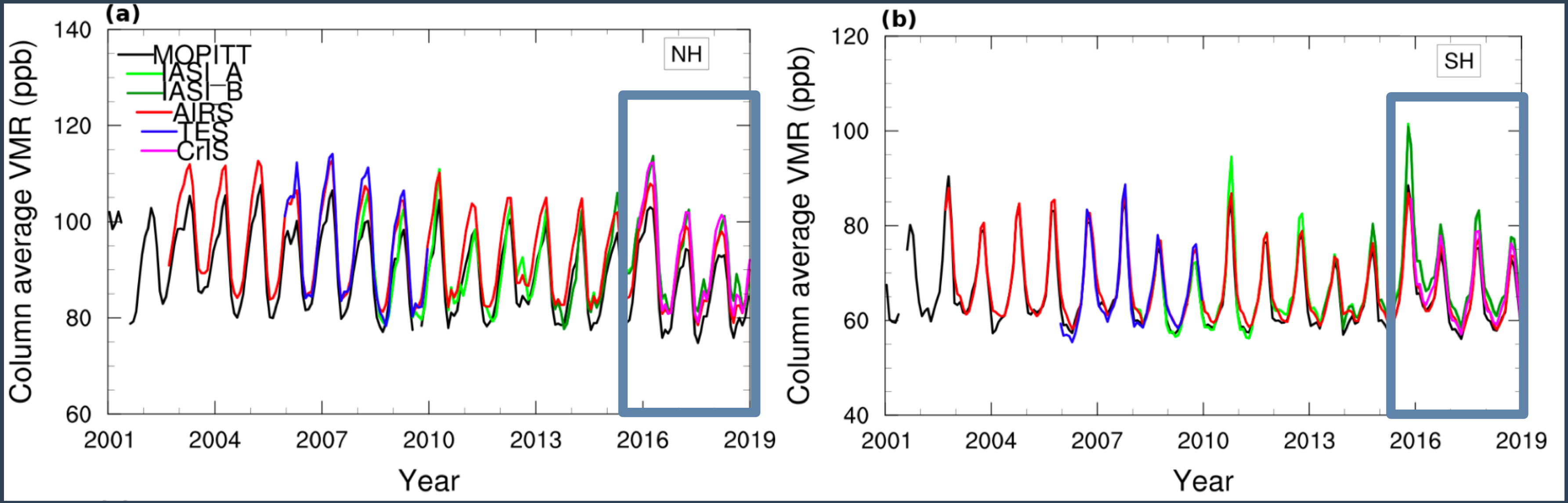
During FIREX-AQ, CrIS total ozone column is correlated at r = 0.948 with TROPOMI.

Tropospheric column reveals complex, dynamically-driven structure



Kurosu et al

Contribution to long-term CO trends

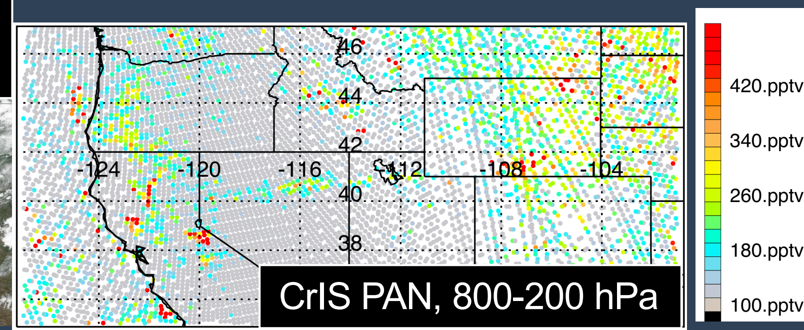


Buchholz, Worden et al, *submitted*

TROPESS CrIS CO show good consistency with other instruments in the NH. The SH CO is closer to MOPITT than to IASI CO.

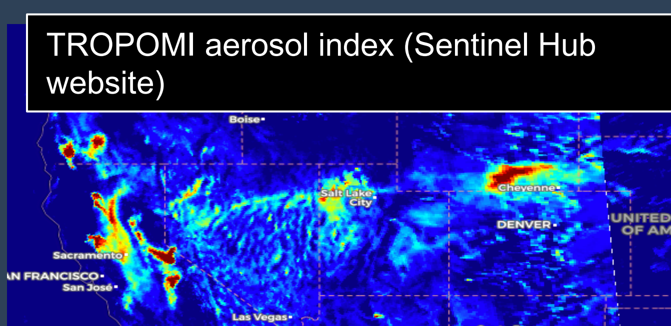
MUSES-CrIS observations of wildfire plumes

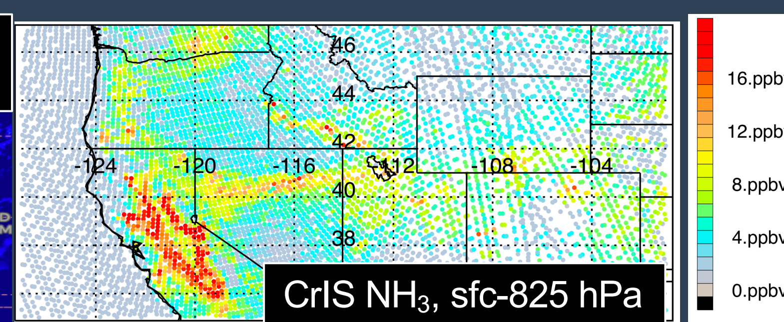
Example day: 6th August 2018. Images show smoke from wildfire over the Western US.



V. Payne (JPL) E. Fischer (CSU)

Peroxyacetyl nitrate (PAN): An important nitrogen reservoir that can impact ozone and air quality far downwind of fires. CrIS is most sensitive to PAN at ~500 mbar.





K. Cady-Pereira (AER)

Ammonia (NH_3): Plays a major role in creation of particulate matter.
CrIS is most sensitive to NH_3 close to the surface

Conclusions

- TROPESS will contribute to CEOS AC-VC based upon a measurement rather than mission-focused approach to atmospheric composition retrievals.
- Characterization of trends will be critical for assessments like the TOAR and for ingestion into chemical reanalysis.
- Preliminary data is available at https://tes.jpl.nasa.gov/multi-instrument-products/airs-omi.
- Chemical reanalysis, which ingests these data, are available at https://tes.jpl.nasa.gov/chemical-reanalysis.

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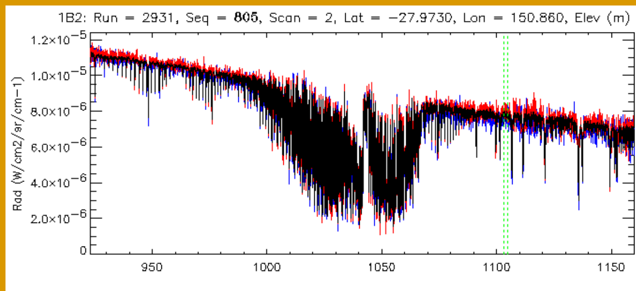
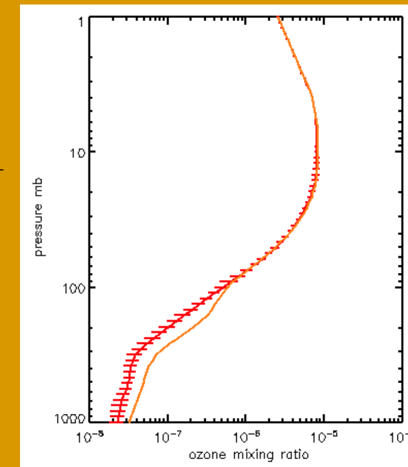
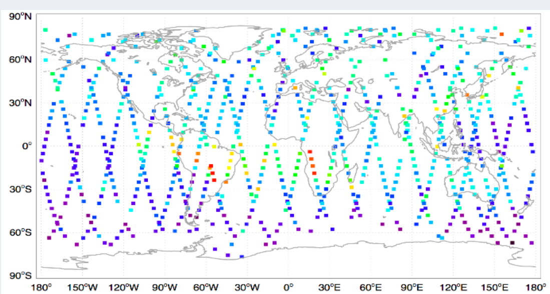
Remote Sensing Science: retrievals and uncertainty



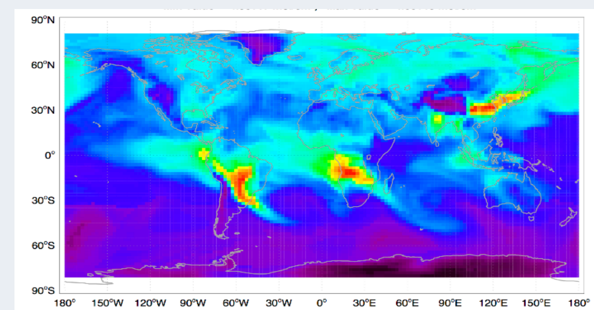
$$||\mathbf{y} - \mathbf{F}(\mathbf{x}_a)||^2_{\mathbf{S}_n^{-1}} + ||\mathbf{x} - \mathbf{x}_a||^2_{\mathbf{S}_a^{-1}}$$



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



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



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

Observation operators enabled by optimal estimation (OE) (e.g., Bowman et al, 2002, 2006; Worden et al, 2004; Kulawik et al, 2006, 2008) are critical for model evaluation and assimilation (Jones et al, 2003, Miyazaki et al, 2015).