Jet Propulsion Laboratory
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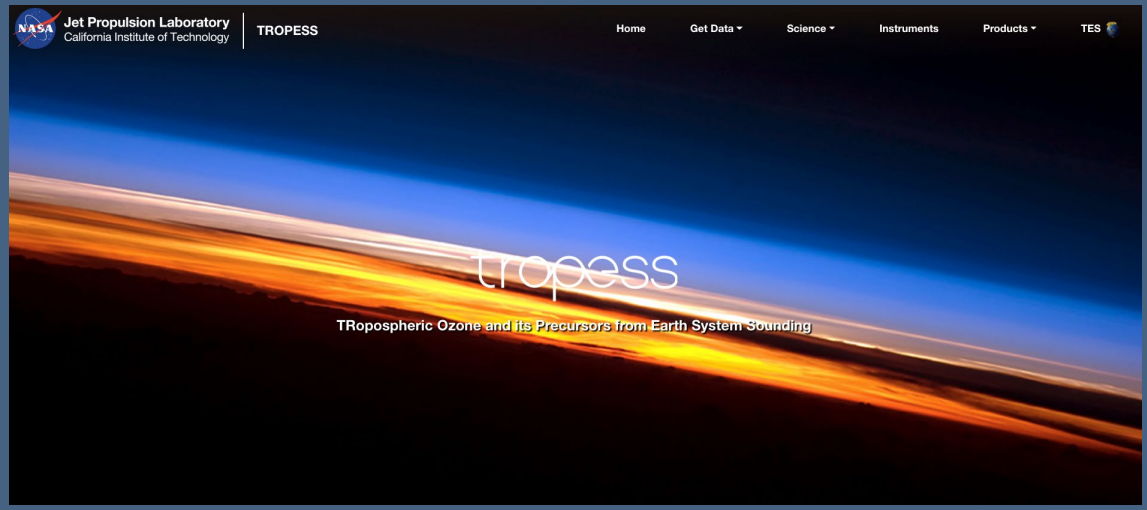


https://tes.jpl.nasa.gov/tropess/

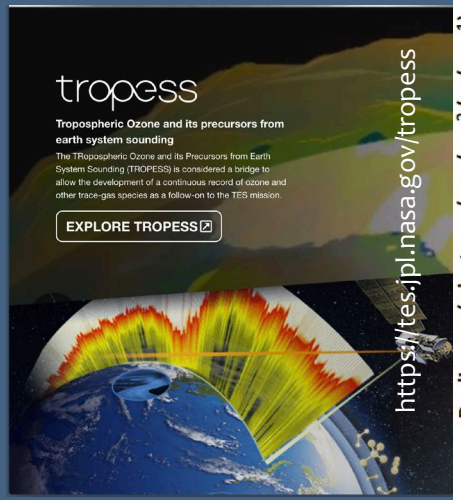
"Towards a new synthesis of atmospheric composition measurements from space: the NASA Tropospheric Ozone and Its Precursors from Earth System Sounding (TROPESS)"

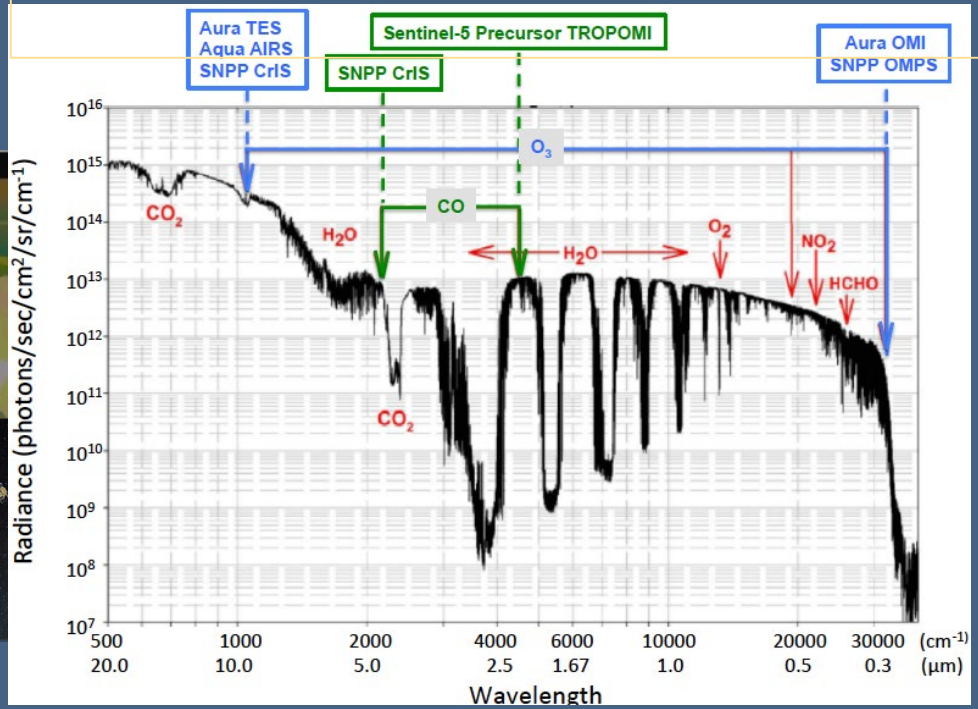
Kevin W. Bowman and the TROPESS team

tropess

Tropospheric Ozone and its Precursors from Earth System Sounding

TROPESS takes a panspectral approach, combining radiances from multiple instruments to generate Earth Science Data Records with degrees of freedom superior to a single instrument.





Products

- O_3
- CO
- NH_3
- CH_4
- PAN
- HDO
- T/q
- IRK

TROPESS has 3 processing modes:

- Forward processing: Low latency (<1 week) for AIRS+OMI, Suomi-NPP (2/21-5/21), JPSS-1 CrIS (5/21-present)
- Reanalysis: Reprocessing over full record with fixed algorithm version (Start, May. 2022)
- Special Collections: regional processing in support of exceptional events

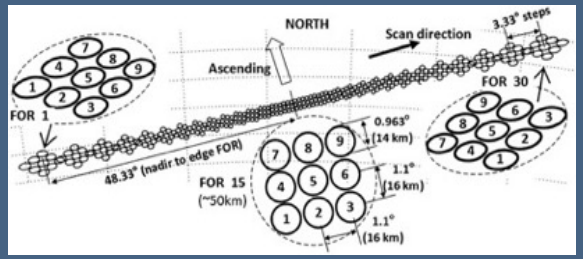
TROPESS Processing Schedule

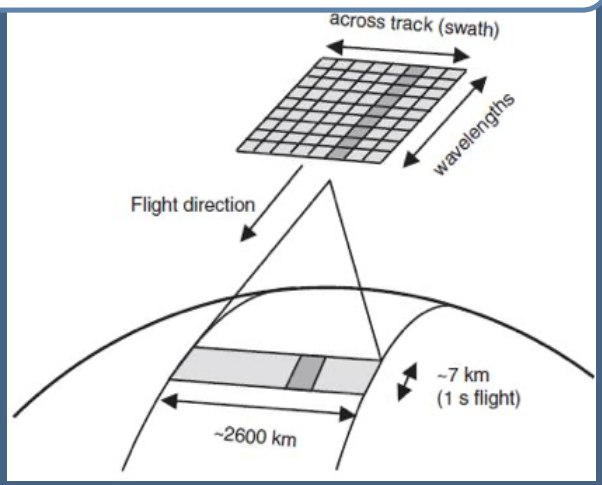
Instrument(s)	Stream	Time Range	Expected Completion
AIRS/OMI	Forward Stream	2021/2-present	Ongoing
Suomi-NPP CrIS (Midwave loss in May, 2021)	Forward Stream	2021/2-present	Ongoing
JPSS-1 CrIS	Forward Stream	2021/4-present	Ongoing
SNPP CrIS (1x) Full Spectral Resolution (FSR)	Retrospective Stream	2015/12-2022/12	Complete
SNPP CrIS (1x) Nominal Spectral Resolution (NSR)	Retrospective Stream	2012/1-2015/12	11/2023
AIRS/OMI (1x)	Retrospective Stream	2004-2009/2015-2020	10/2023

Suomi NPP CrIS and S5P/TROPOMI

CrIS is a TIR FTS instrument making daily measurements in three separate bands (650-1095 cm^{-1}, 1210-1750 cm^{-1}, 2155-2550 cm^{-1})

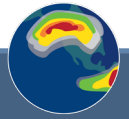
TROPOMI is a UV-SWIR imaging spectrometer making daily measurements in a number of spectral bands, from 270-2380 nm.



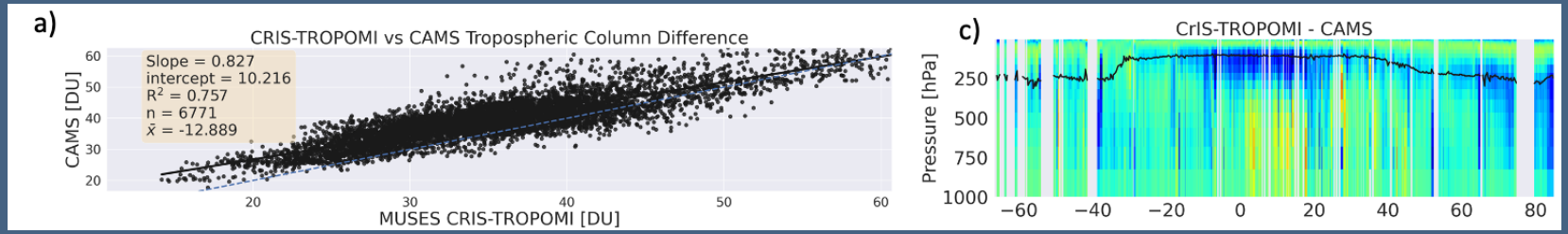


CrIS ground track illustration taken from Han et al., 2013. MUSES algorithm allows FOV thinning to reduce processing overheads.

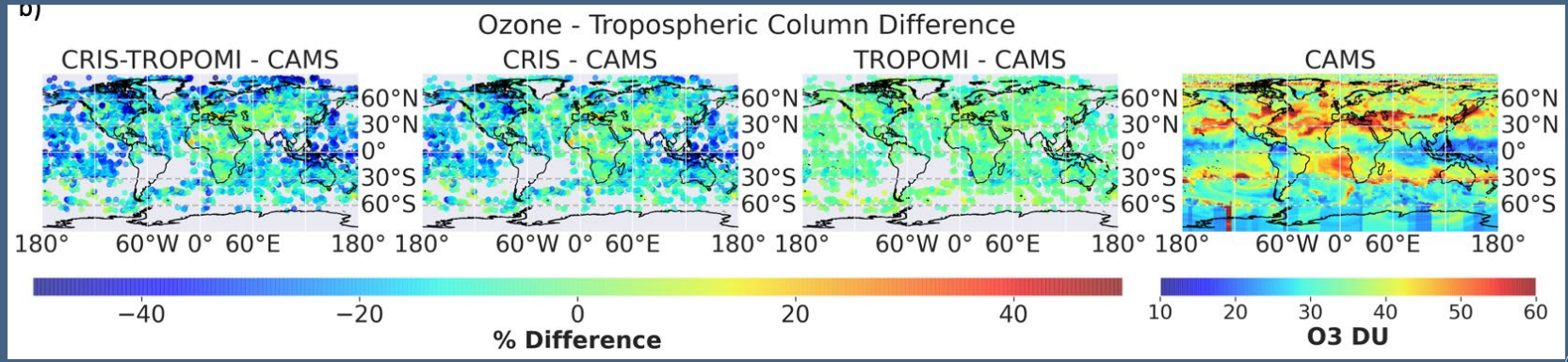
TROPOMI ground track illustration taken from Veefkind et al., 2012.



Cross Comparisons: CrIS/TROPOMI and CAMS Global Reanalysis (August 2020)



While in generally good agreement, CAMS shows about 20% less variability than CrIS/TROPOMI ozone with structural differences in the tropics.



MOMO-Chem: TCR-3

MLS (O_3, CO, HNO_3)

TES, AIRS/OMI (O_3)

Long-lived GHGs

Oxidation capacity (OH) → **CH_4**

AQ-GHG co-emissions → **CO_2**

"Decadal Aura era"
"New satellite era"
chemical reanalysis

Secondary pollutants
Ozone, PAN,
Secondary aerosols
(nitrate, sulfate, ammonium)

Chemistry

Validation

VIIRS (AOD)

CrIS (O_3,PAN)

OMPS (SO_2,NO_2)

Primary pollutants
SO_2, NOx, CO, VOCs, NH_3,
Primary aerosols (dust, carbon)

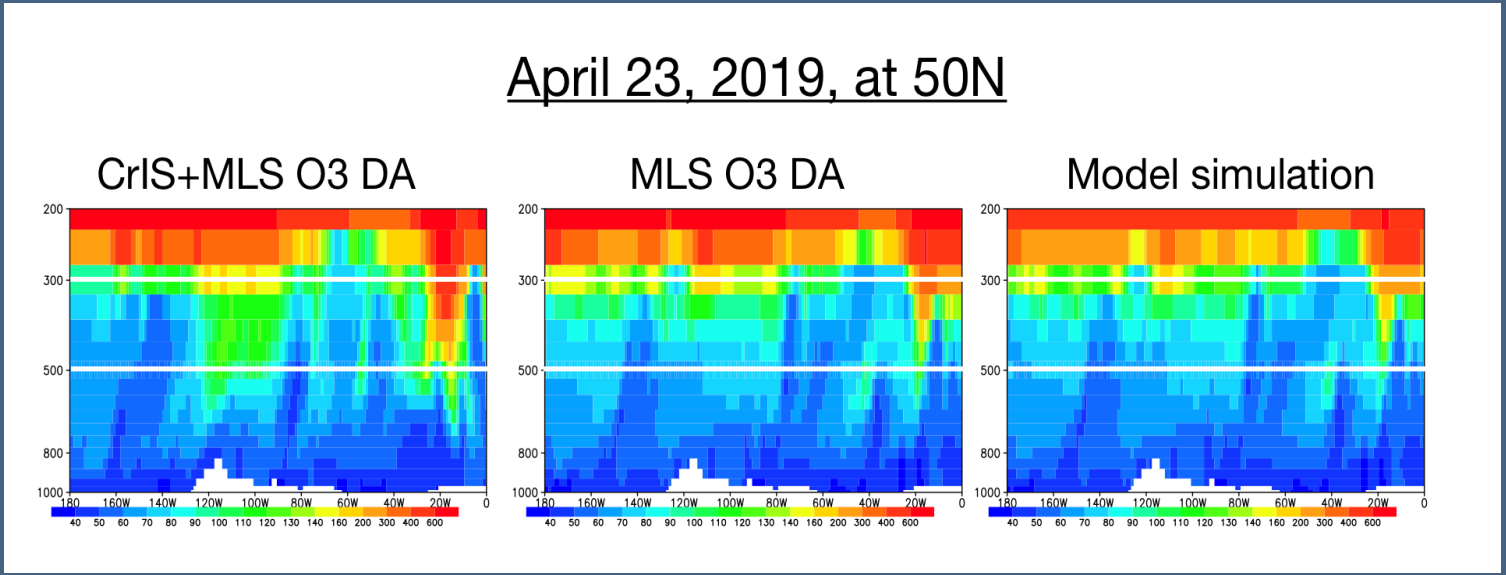
Assimilation

OMI, TROPOMI (SO_2,NO_2,, CH_2O)

CrIS (NH_3)

MOPITT (CO)

Observation impact of CrIS O3



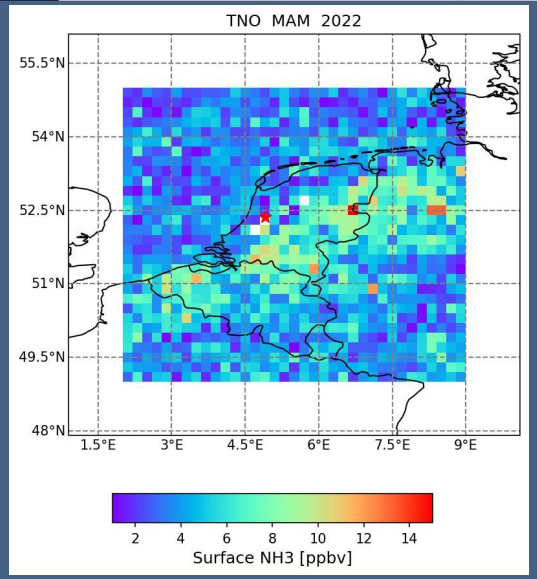
TROPESS CrIS has some substantial impact on free tropospheric ozone analysis in MOMO-Chem chemical data assimilation

AIRS NH_3 over NW Europe in 2022

AGRICULTURE

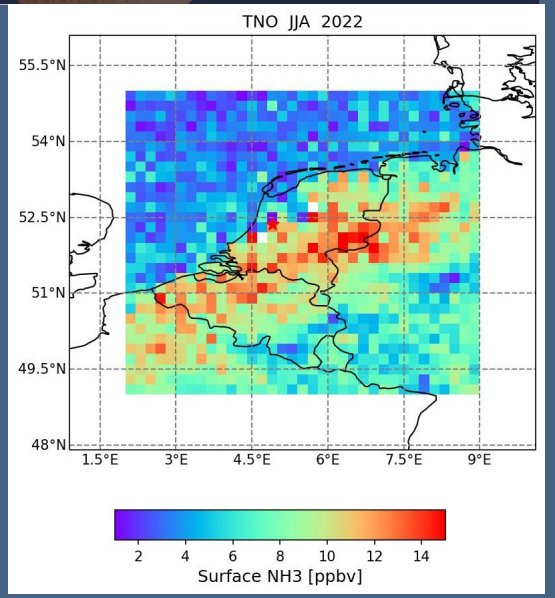
13 JUNE 2023 - 8 min. read

Nitrogen Wars: How the Netherlands Hit the Limits to Growth



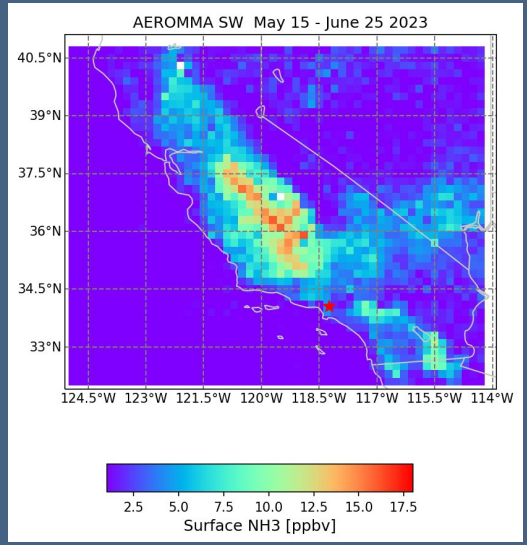
Increases in nitrogen production and deposition has led to substantial impacts on air and water pollution, economic investments, and political dynamics.

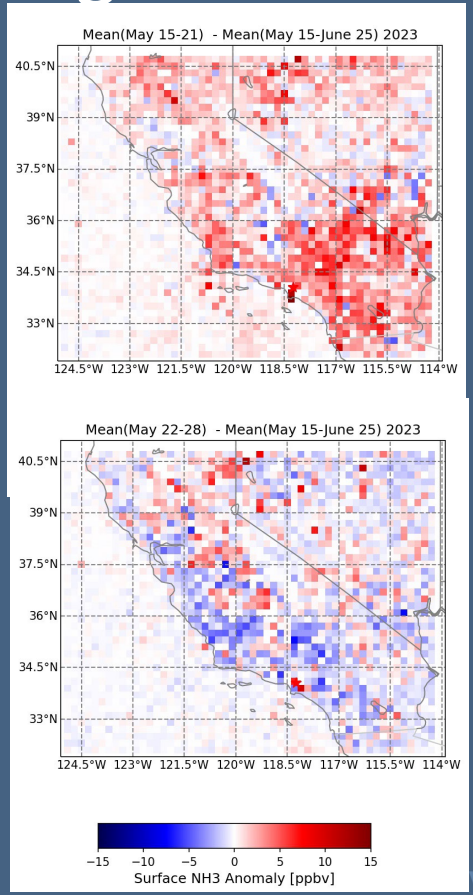
Collaborating with TNO to process AIRS NH3 in NW Europe to assess long-term changes.



CrIS NH_3 coincident with AEROMMA campaign

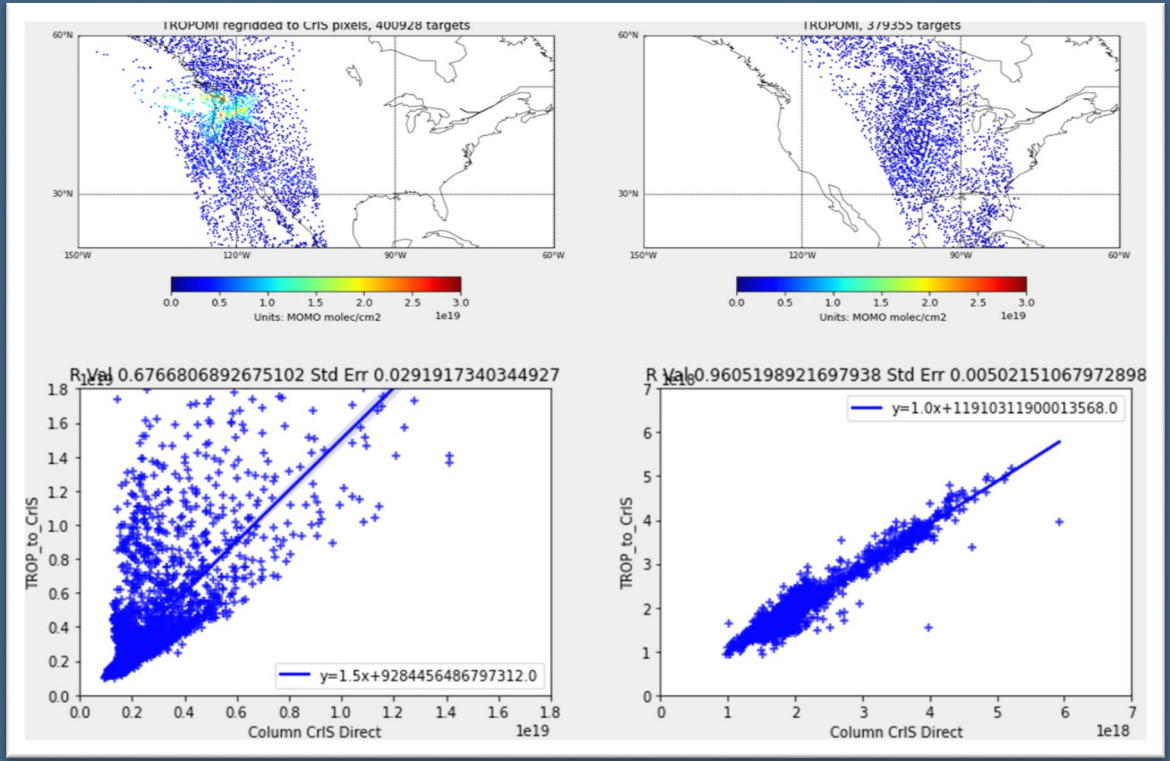
- TROPESS supported the NOAA/NASA AEROMMA campaign.
- Monthly mean show strong NH3 signal in the Central Valley.
- Weekly anomalies are positive (May 15-21) but negative (May 22-28).
- Data was delivered to NOAA for additional science investigation





The 2020 California Fires

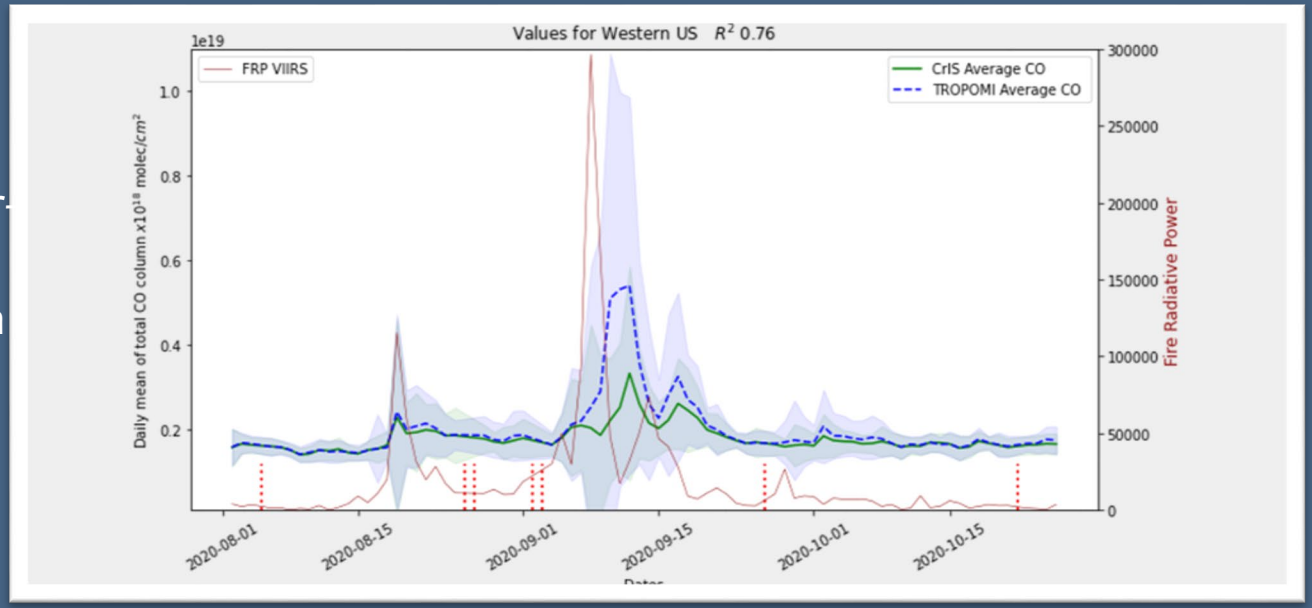
- The California fires in 2020 were one of the most devastating in history
- In downwind plumes, TROPOMI and CrIS show remarkably good agreement (R=0.96, Slope = 1.0)
- Over the fires, TROPOMI and CrIS differences attributable to near-surface CO (R=0.67, Slope = 1.5)



Neyra et al, in prep

Fire dynamics

- Fire radiative power increases first.
- TROPOMI increases next, reflective of near-surface CO build-up
- CrIS reaches maximum due to convective lofting
- Agreement between CrIS and TROPOMI beforeh and after.

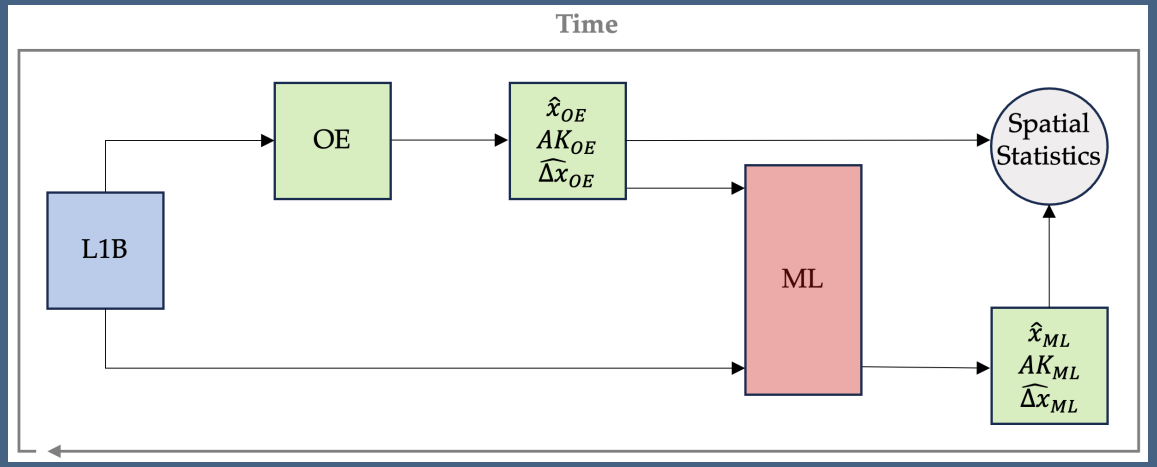


Towards a hierarchical retrieval system

Building the best of both worlds

Threading Optimal Estimation and Machine Learning Techniques

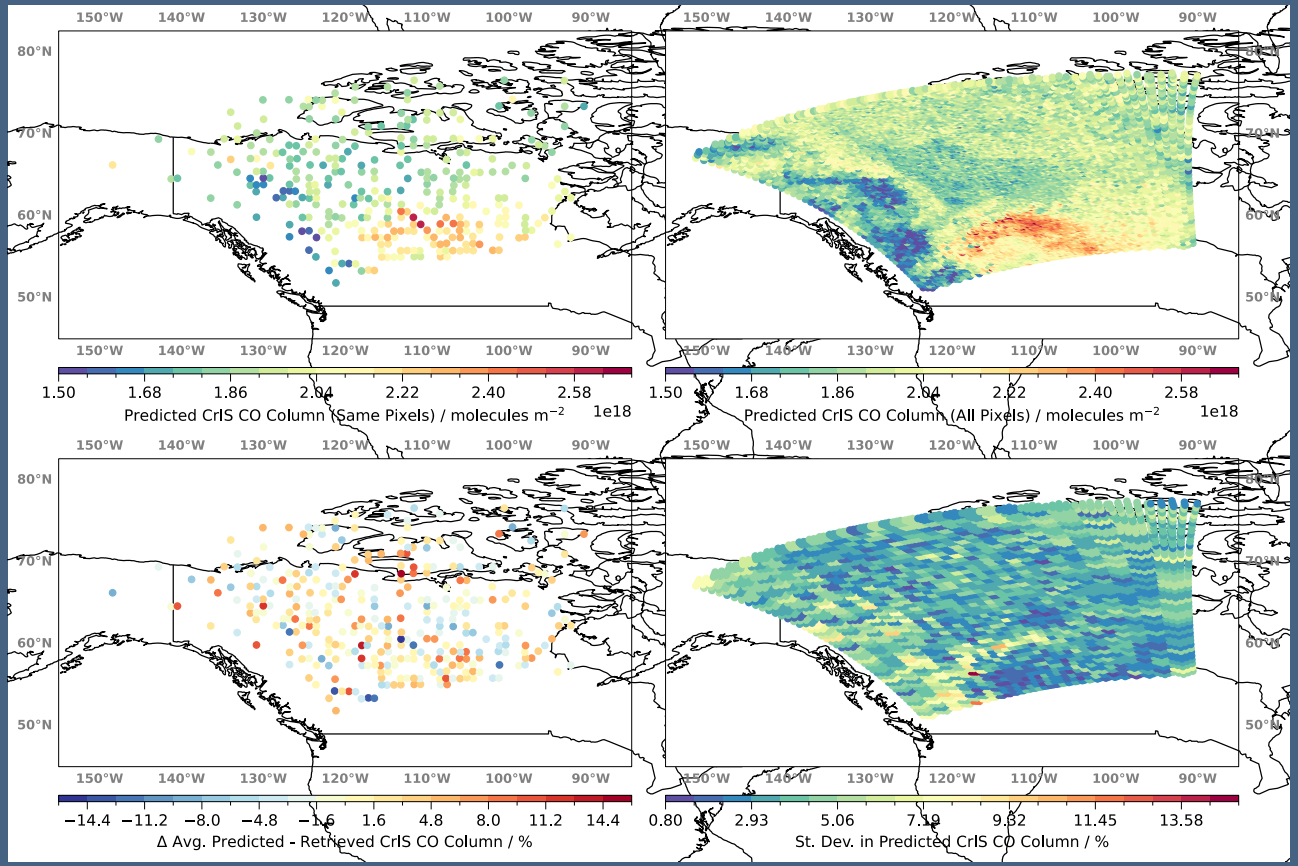
- Optimal estimation is the workhorse of modern satellite remote sensing.
- OE has the advantage of error characterization and observation operators
- However, OE is expensive to compute for all data.
- Machine Learning can be trained to mimic OE estimates *and* their uncertainty.

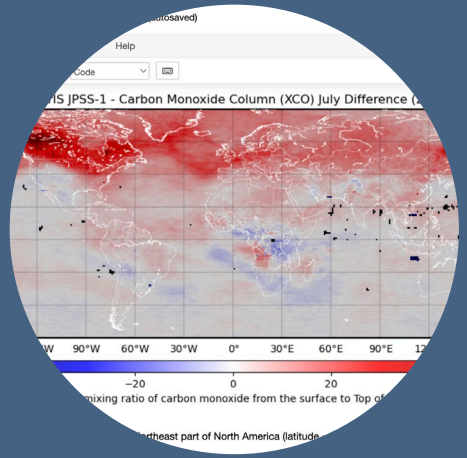


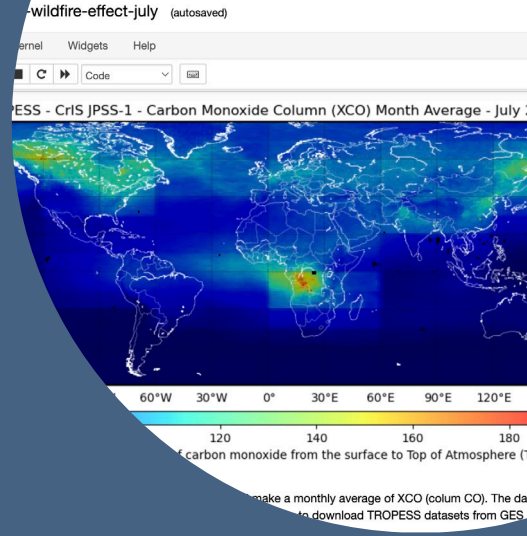
Mind the gaps

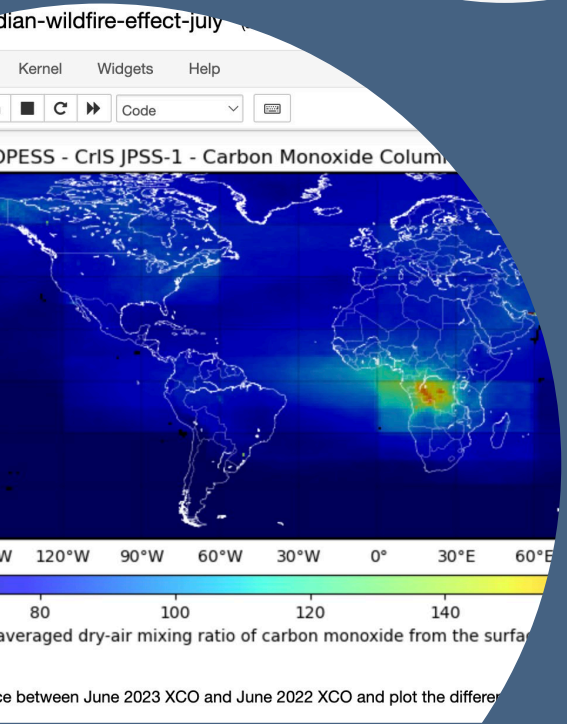
Canadian Carbon

- CrIS granule for May 1, 2023.
- ML model was trained on TROPESS forward stream column CO.
- Mean prediction error is ~0.2% of ML-based estimates of TROPESS products.









jupyter

Open Science with TROPESS

Deploying juypter notebooks to access and analyze data.

https://tinyurl.com/sk9runrz

Conclusions/Future Directions

- TROPESS is delivering composition products for AIRS, CrIS, AIRS/OMI in short-term (forward stream), long-term (retrospective), and regional (special collections): tes.jpl.nasa.gov/tropess.
  - Preliminary retrievals of CrIS/TROPOMI products will be discussed at AGU.
  - Hierarchical retrieval strategy shows promise for "having your cake and eating it too": accuracy, characterization, and speed.
  - Demonstrated results in atmospheric chemistry, reactive nitrogen cycle and carbon cycle point to the value of sounders for Earth System Science
- Approaches will be pathfinders for near-term missions such as Sentinel 5.
- TROPESS outcomes point to the continuing role of LEO sounders as a pillar for the CEOS-AC-VC air quality constellation.
- New efforts to improve accessibility of data consistent with NASA Transform to Open Science Initiative (https://science.nasa.gov/researchers/open-science/)

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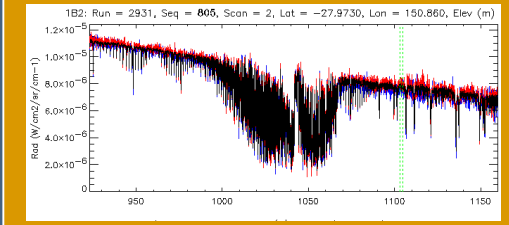
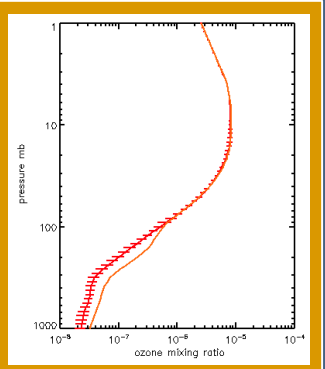
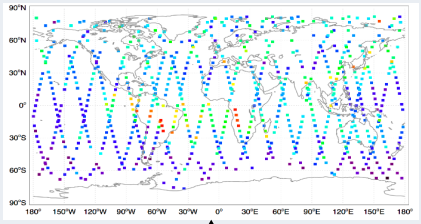
Remote Sensing Science: retrievals and uncertainty



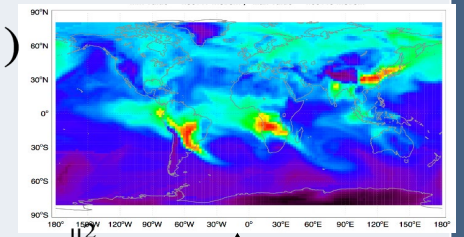
$$\|\mathbf{y}-\mathbf{F}(\mathbf{x}_a)\|^2_{\mathbf{S}_n^{-1}}+\|\mathbf{x}-\mathbf{x}_a\|^2_{\mathbf{S}_a^{-1}}$$



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



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



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

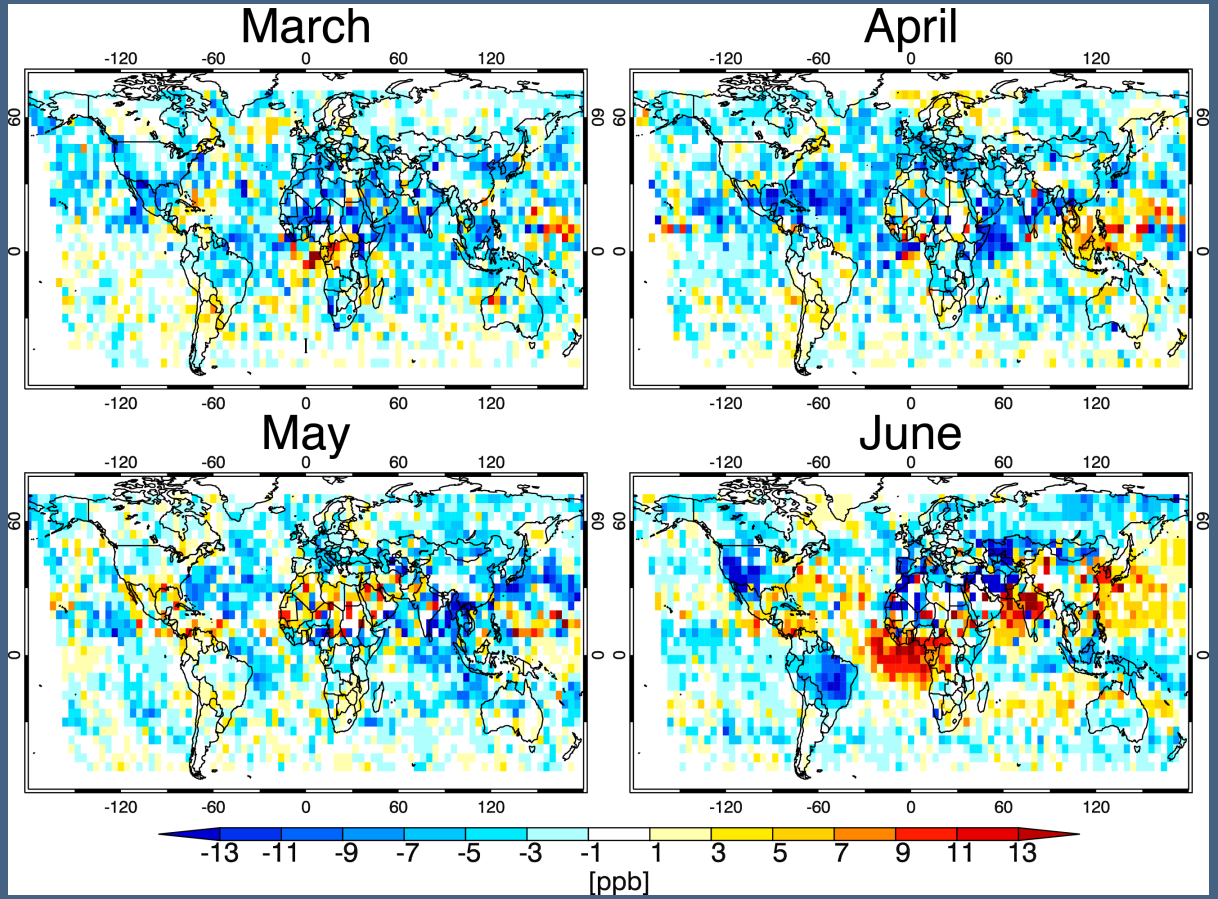
Optimal estimation (OE) techniques and error diagnostics (e.g., Bowman et al, 2002, 2006; Worden et al, 2004; Kulawik et al, 2006, 2008) provide instrument operators for evaluation against models and assimilation (Jones et al, 2003, Miyazaki et al, 2015).

The science community has come to expect these tools for rigorous science and assimilation of remote sensing data, e.g., Alvarado et al, 2015

The atmospheric pollution signature of COVID-19

CrIS (JPL TROPESS) ozone 700 hPa: 2020 minus 2019

The CrIS observations also show clear reductions in the free tropospheric ozone from 2019 to 2020 by 1 to 12 ppb over most of the polluted areas, with reductions of zonal mean concentrations **by up to 4 ppb at NH** mid latitudes from March through June



Miyazaki et al, Science Advances, 2021