NOAA Infrared Sounder Workshop
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Atmospheric Composition from Infrared Sounding

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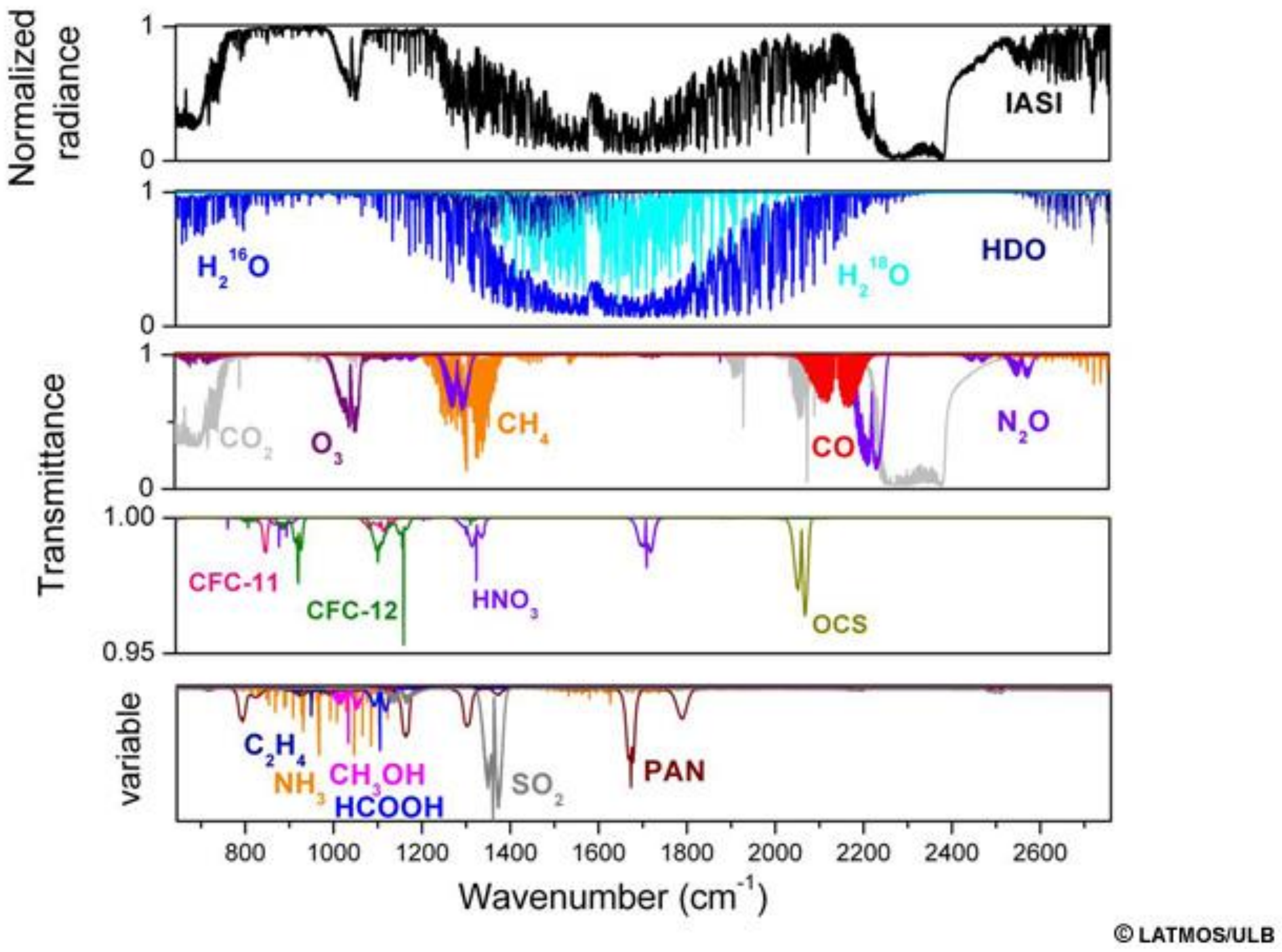
Outline

- Benefits of IR sounder data for atmospheric composition understanding
- Gaps in IR sounder capabilities for atmospheric composition
- Value of combining sounders with other instruments
- Opportunities for the future

Acknowledgements: Shobha Kondragunta, Chris Barnet, Nadia Smith, Rebekah Esmaili, Nick Nalli, Chuanyu Xu, Juying Warner, Joel Mccorkel, Joanna Joiner, Monika Kopacz, Victoria Breeze, Andy Heidinger, Dan Lindsey, Pam Sullivan, Russ Dickerson, Xinrong Ren, Audrey Gaudel, Brian McDonald

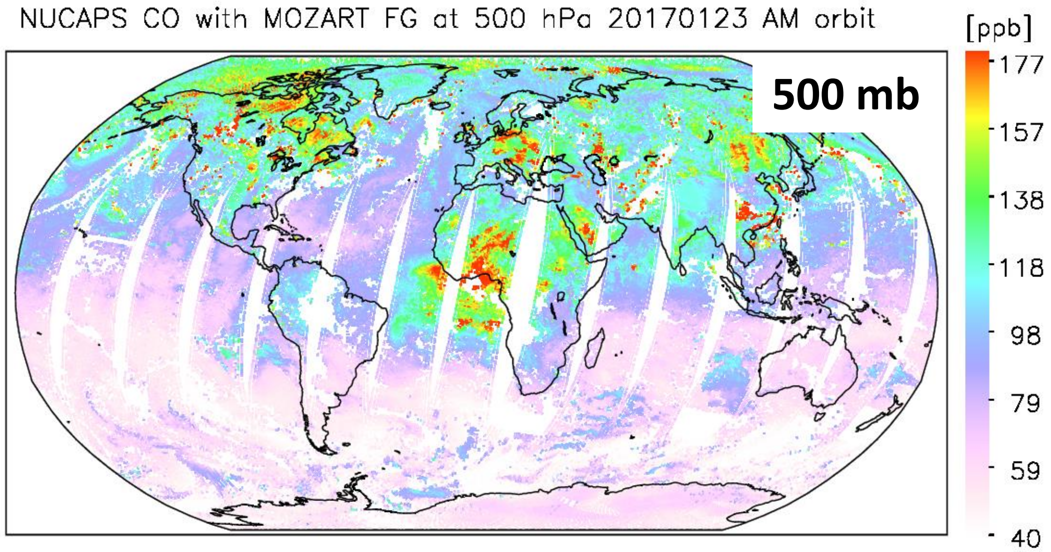
A large number of atmospheric trace gases absorb in the IR



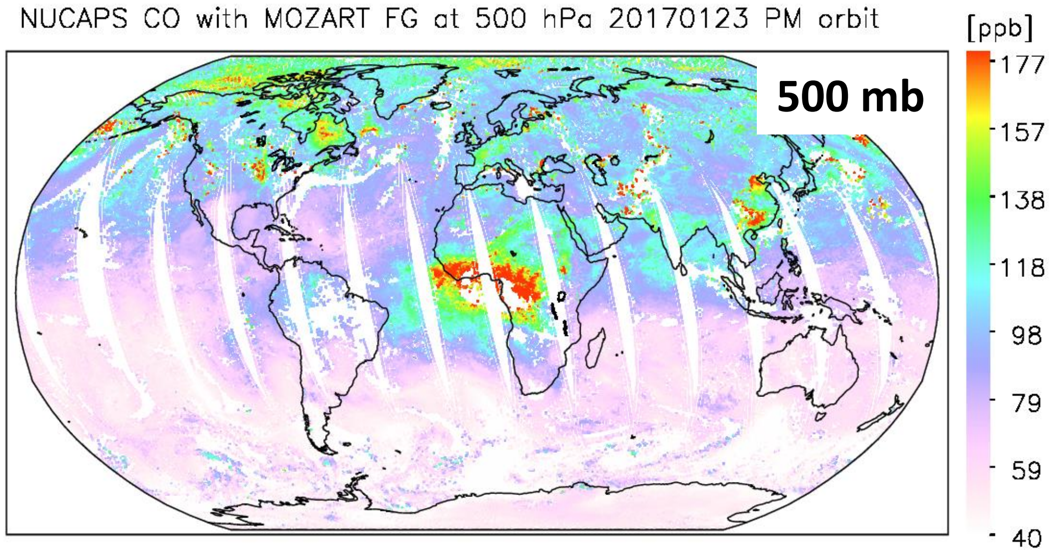
http://kejian1.cmatc.cn/vod/comet/EUMETSAT/atmos_comp/media/graphics/clerbaux_IASI_Spectrum.jpg

IR sounders like CrIS provide continuous atmospheric composition datasets with wide geographic coverage

Night Time



DayTime



NUCAPS detects elevated layers of CO and this allows us to study inter-continental pollutant transport

Figure from Nadia Smith, STC

Long-term records useful for understanding trace gas trends and spatial variability can be derived from sounders

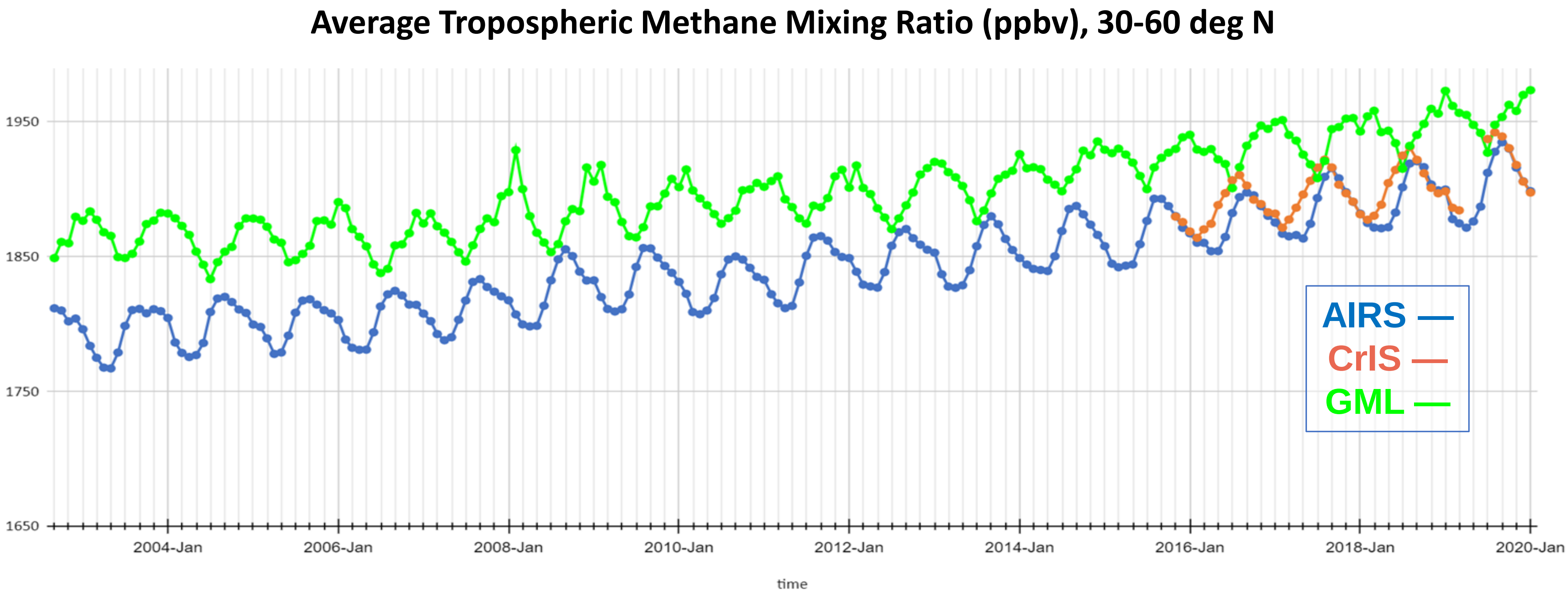


Figure from Nick Nalli, STAR, and Juying Warner, UMD

IR sounders augment other types of trace gas observations by measuring most of the free troposphere, which is otherwise relatively under-sampled

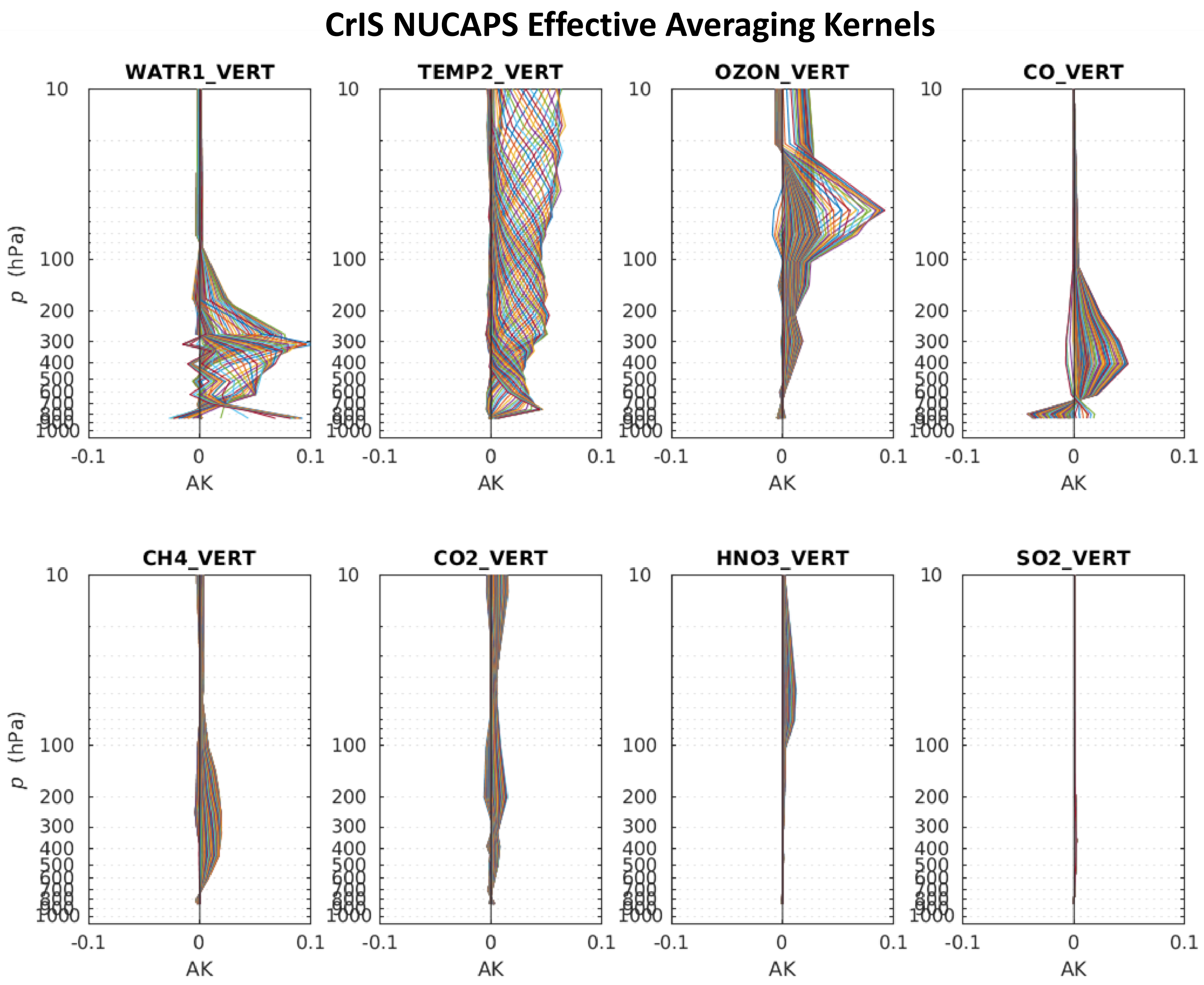
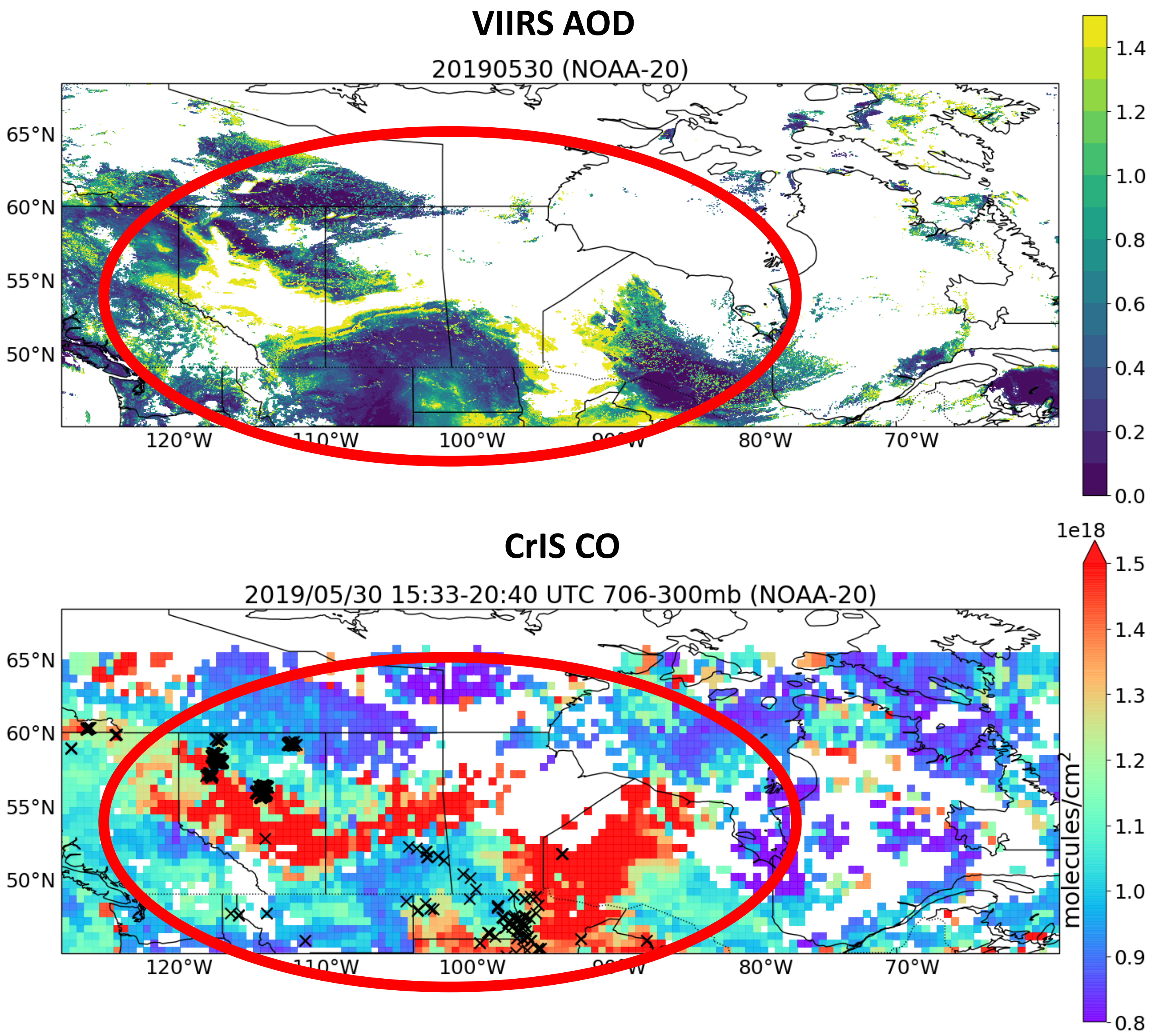


Figure from Nick Nalli, STAR

IR sounders provide information about major air pollution sources, like wildfires, that is complementary to data from other satellite instruments



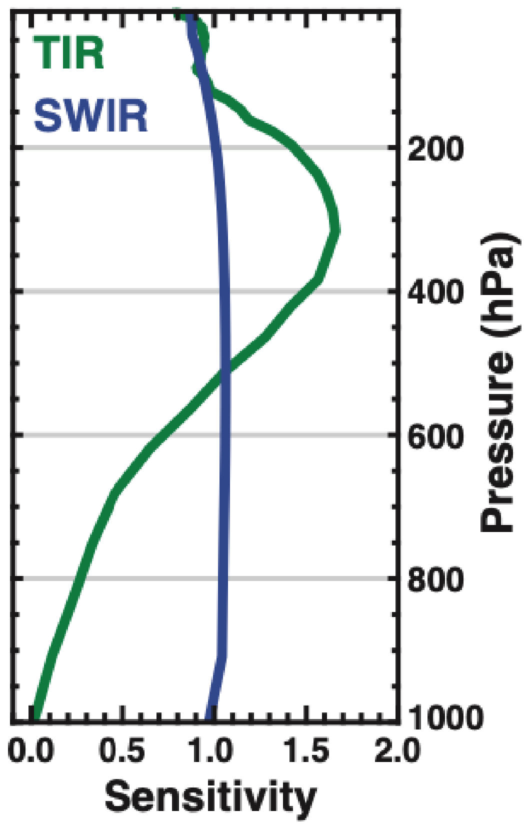
Figures from Rebekah Esmaili et al., STC

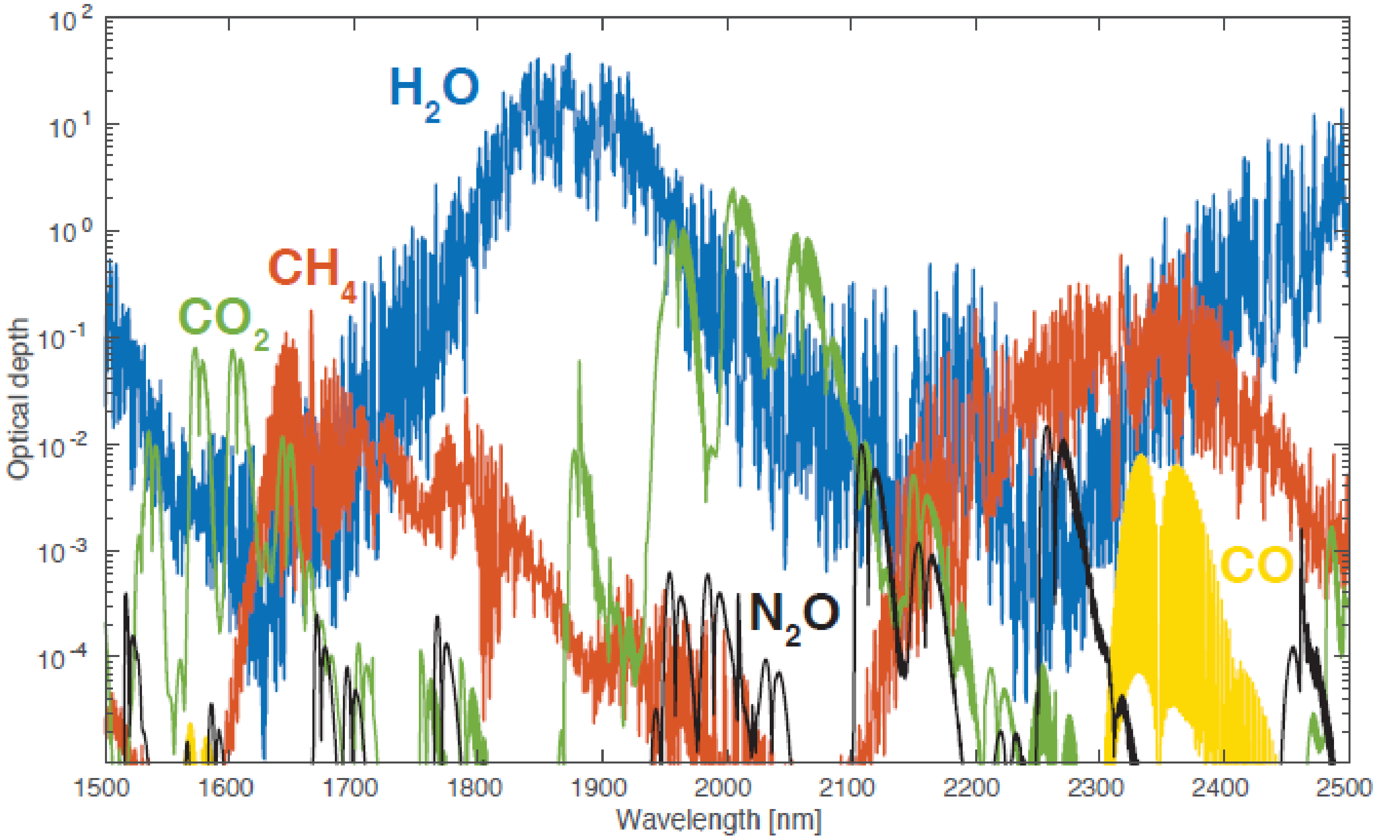
Trace gas quantification on NOAA sounders is a by-product of the retrievals of temperature and water vapor

gas	Range (cm^{-1})	Precision	d.o.f.	Interfering Gases
T	**650-800 2375-2395**	**1K/km**	**6-10**	**H2O,O3,N2O emissivity**
H_2O	**1200-1600**	**15%**	**4-6**	**CH4, HNO3**
O_3	**1025-1050**	**10%**	**1+**	**H2O,emissivity**
CO	**2080-2200**	**15%**	**≈ 1**	**H2O,N2O**
CH_4	**1250-1370**	**1.5%**	**≈ 1**	**H2O,HNO3,N2O**
CO_2	**680-795 2375-2395**	**0.5%**	**≈ 1**	**H2O,O3 T(p)**
Volcanic SO_2	**1340-1380**	**50% ??**	**< 1**	**H2O,HNO3**
HNO_3	**860-920 1320-1330**	**50% ??**	**< 1**	**emissivity H2O,CH4,N2O**
N_2O	**1250-1315 2180-2250**	**5% ??**	**< 1**	**H2O H2O,CO**
NH_3	**860-875**	**50%**	**<1**	**emissivity**
CFCs	**790-940**	**20-50%**	**<1**	**emissivity**

Table from Chris Barnet

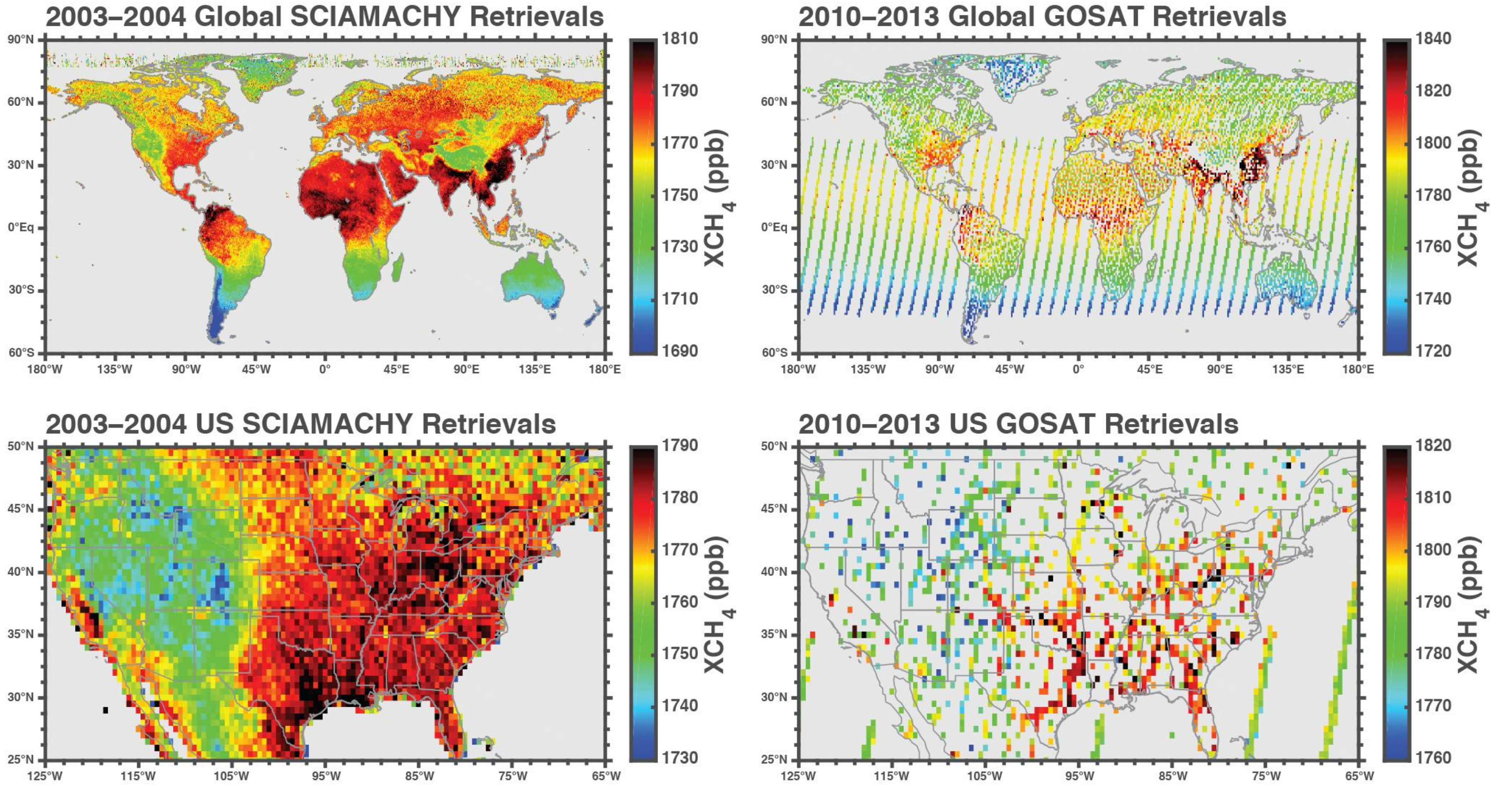
Reflected solar SWIR (1.5 – 2.5 um) is required to retrieve the entire total tropospheric column of carbon dioxide (CO_2), methane (CH_4), and carbon monoxide (CO)





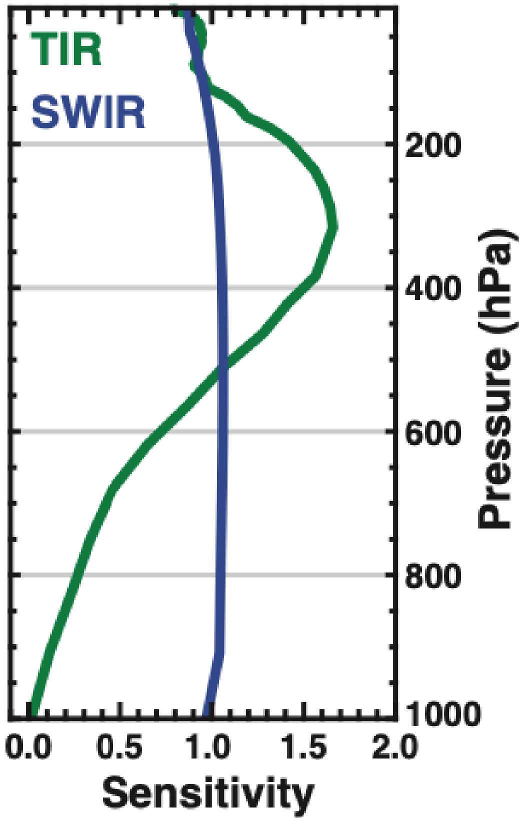
Figures from D. Jacob et al., Atmos. Chem. Phys., 2016

Reflected solar SWIR used for greenhouse gas retrievals: MOPITT, SCIAMACHY, GOSAT, OCO-2, TropOMI, GeoCarb

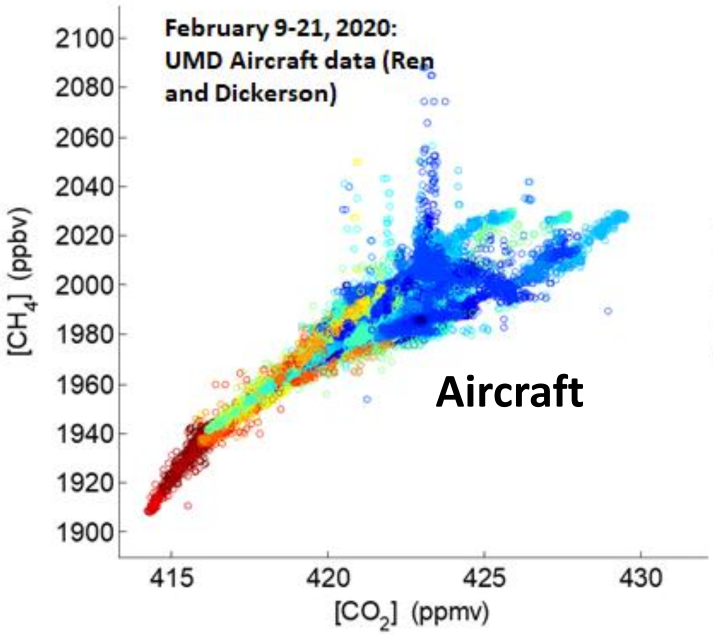


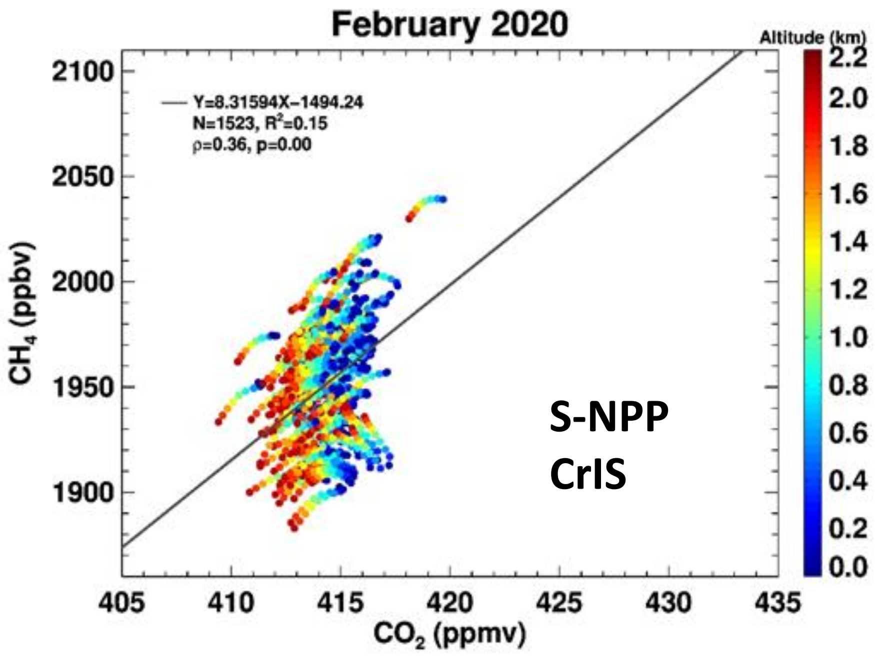
D. Jacob et al., Atmos. Chem. Phys., 2016

Thermal IR (> 2.5 um) cannot resolve CO_2, CH_4, and CO in the lower troposphere, so surface or boundary layer sources of these gases cannot be observed by IR sounders



D. Jacob et al., Atmos. Chem. Phys., 2016





Correlation between CH_4 and CO_2 in the lowest 2.2 km observed by Suomi NPP CrIS during February 2020 in the Washington, DC metropolitan area. The CrIS CO_2 observations do not show the dynamic range of aircraft observations (courtesy of Russ Dickerson and Xinrong Ren, U. Maryland & NOAA Air Resources Lab, respectively)

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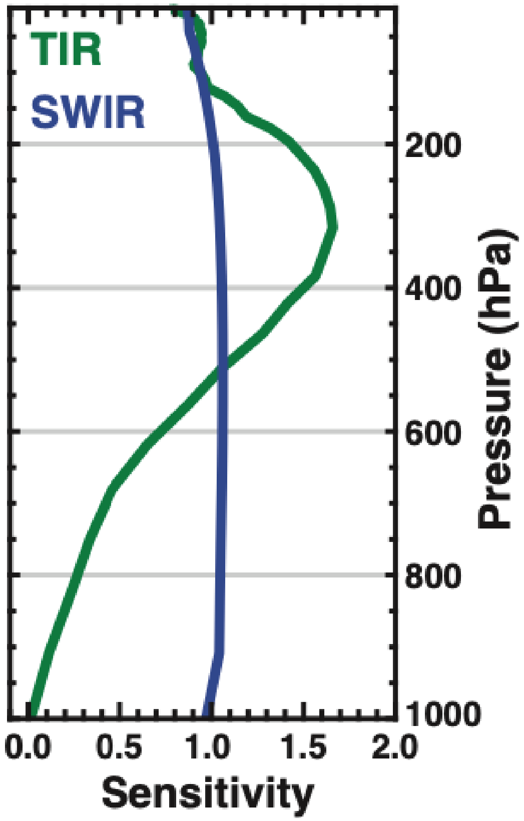
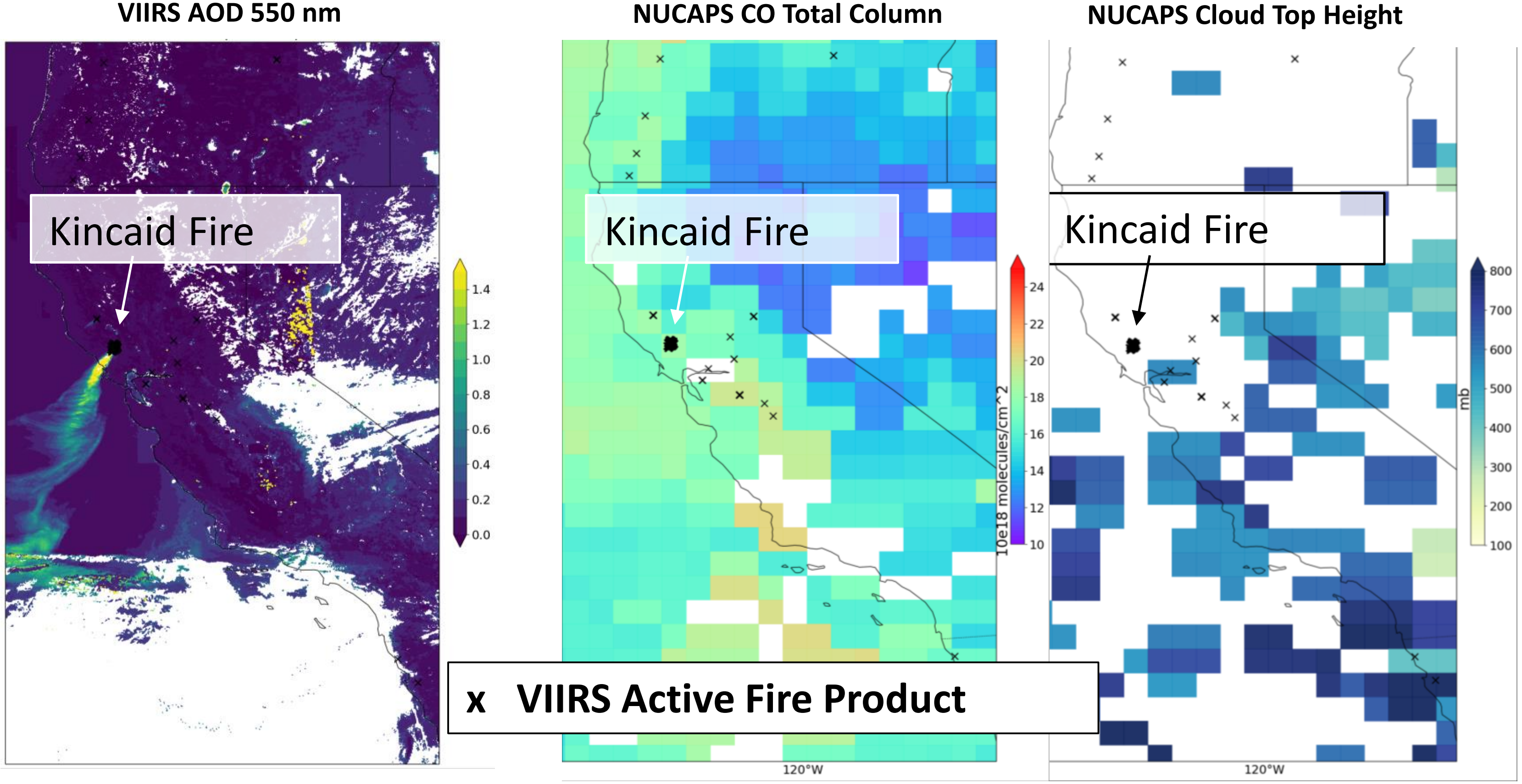


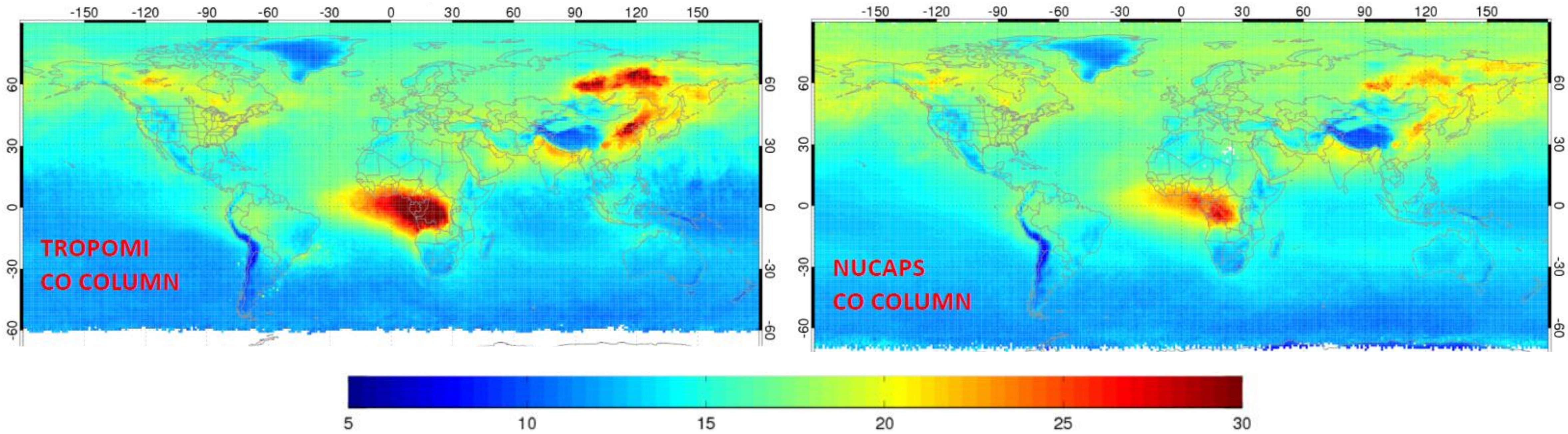
D. Jacob et al., Atmos. Chem. Phys., 2016

NOAA-20 NUCAPS and VIIRS data, 27 October 2019



Figures from Nadia Smith and Rebekah Esmaili, STC

Combination of TIR and SWIR datasets provides additional understanding of carbon monoxide sources



CO total column, 10^{17} molec cm^{-2}

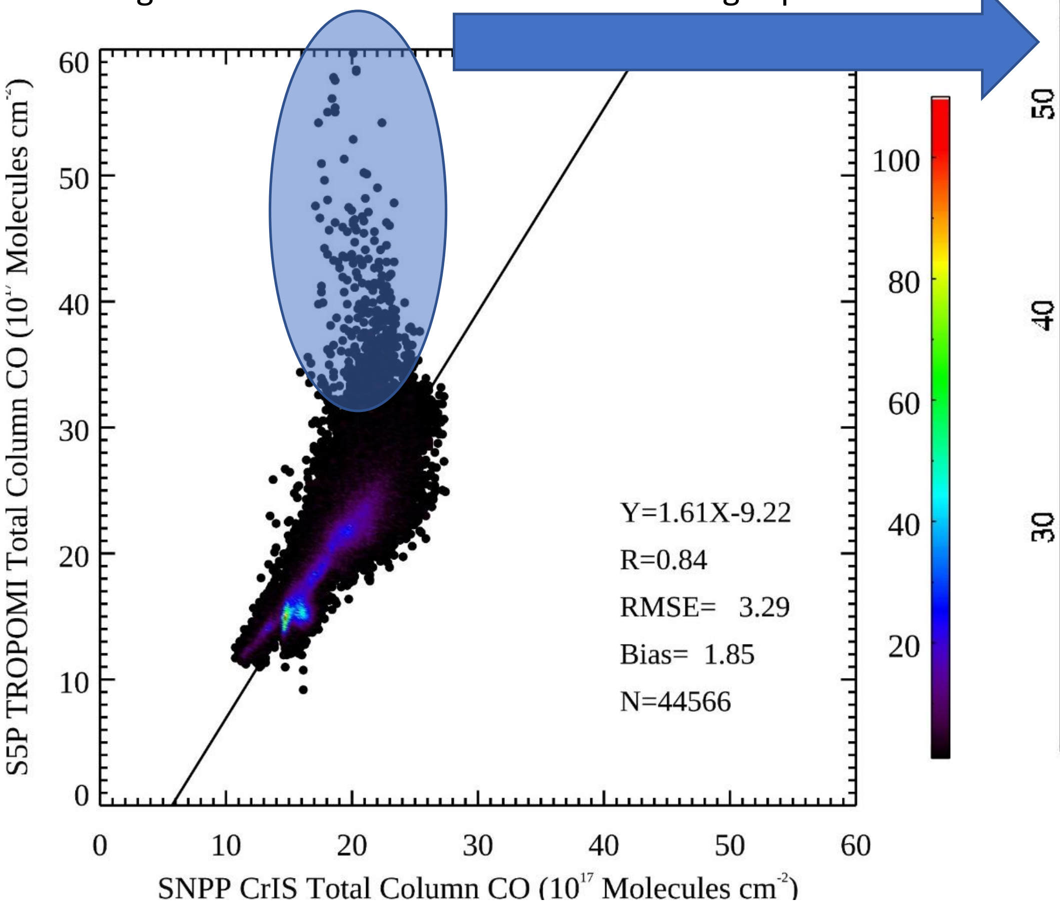
Figure from Shobha Kondragunta, Chuanyu Xu, Juying Warner

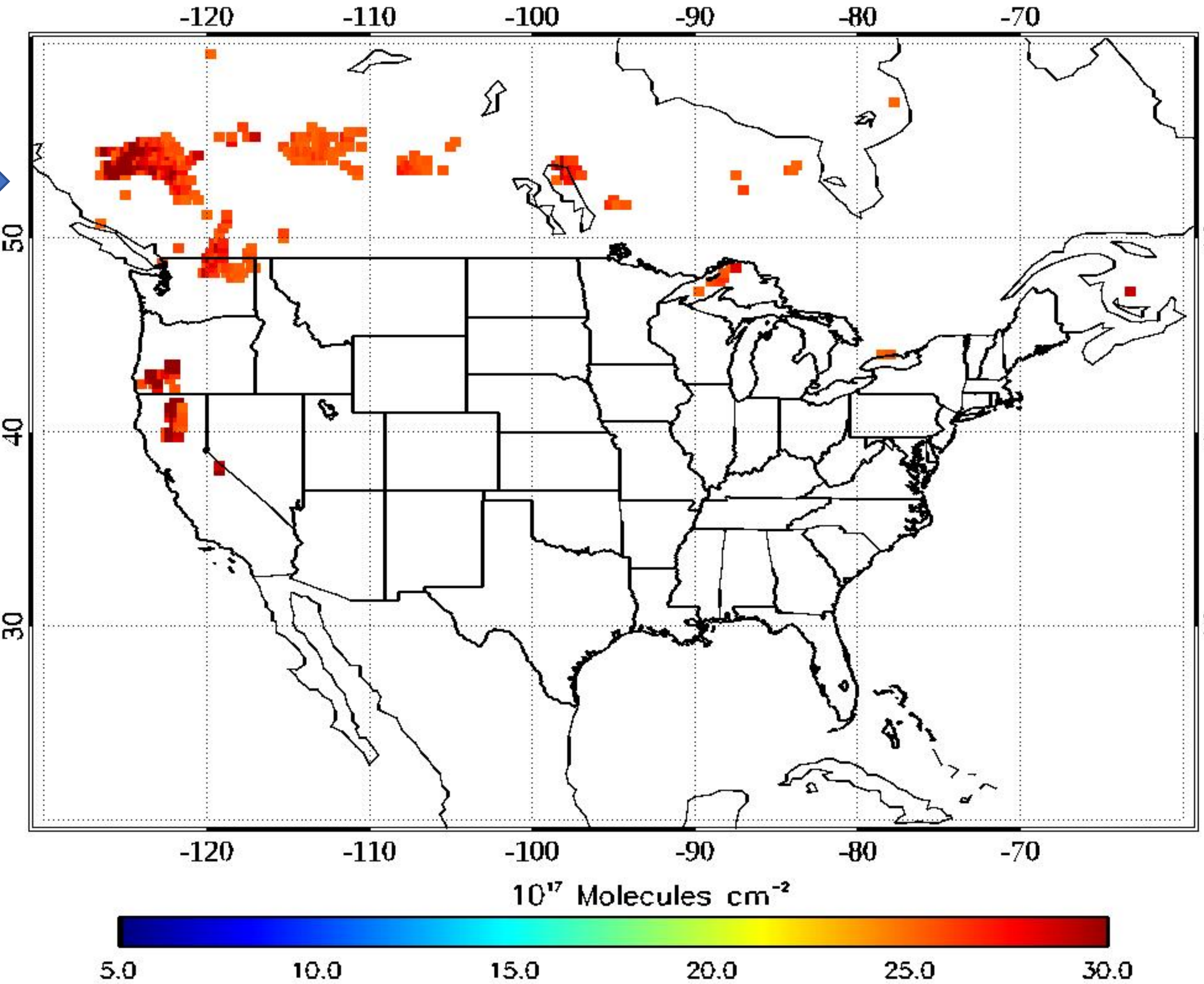
Major source regions of CO from wildfires (Siberia, Africa, Canada) and from urban/industrial pollution (East Asia) are well captured by both CrIS and TROPOMI.

CrIS misses a portion of wildfire CO, due to vertical sensitivity and stricter quality control

TROPOMI vs. CrIS CO

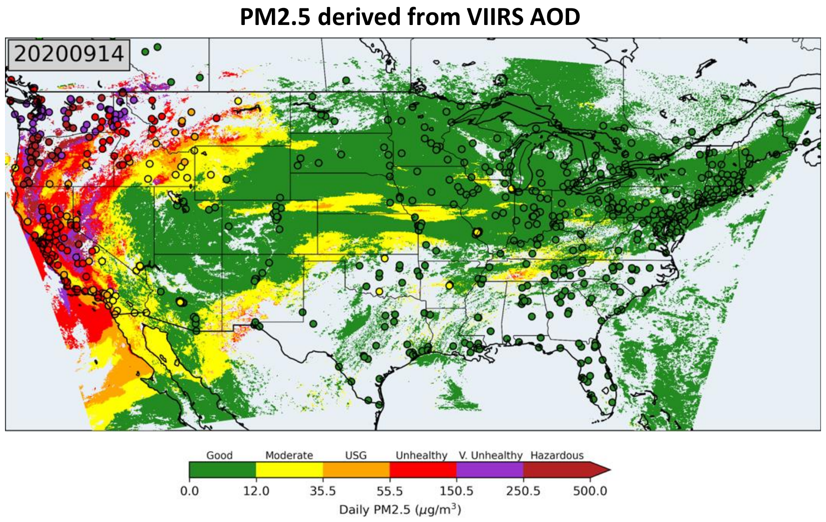
Jul-Aug 2018 means over domain shown in right panel

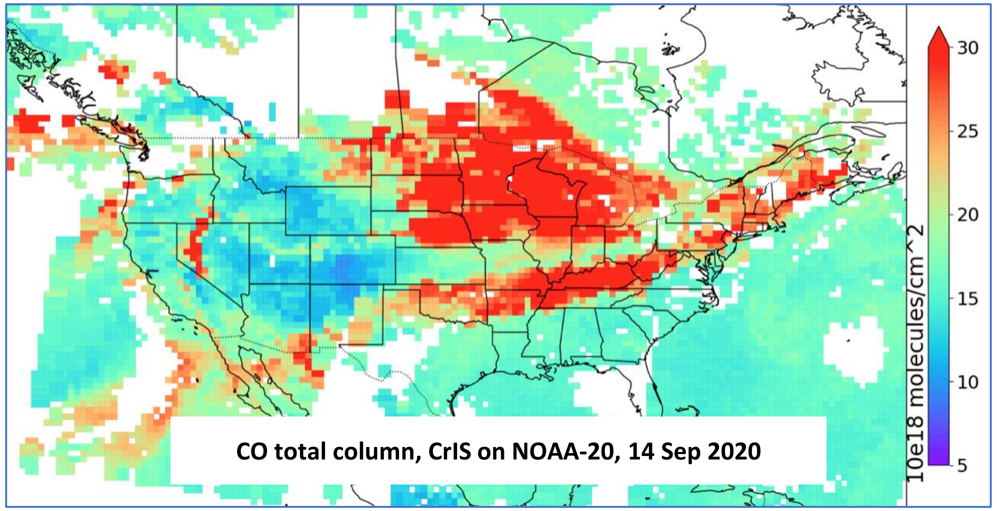


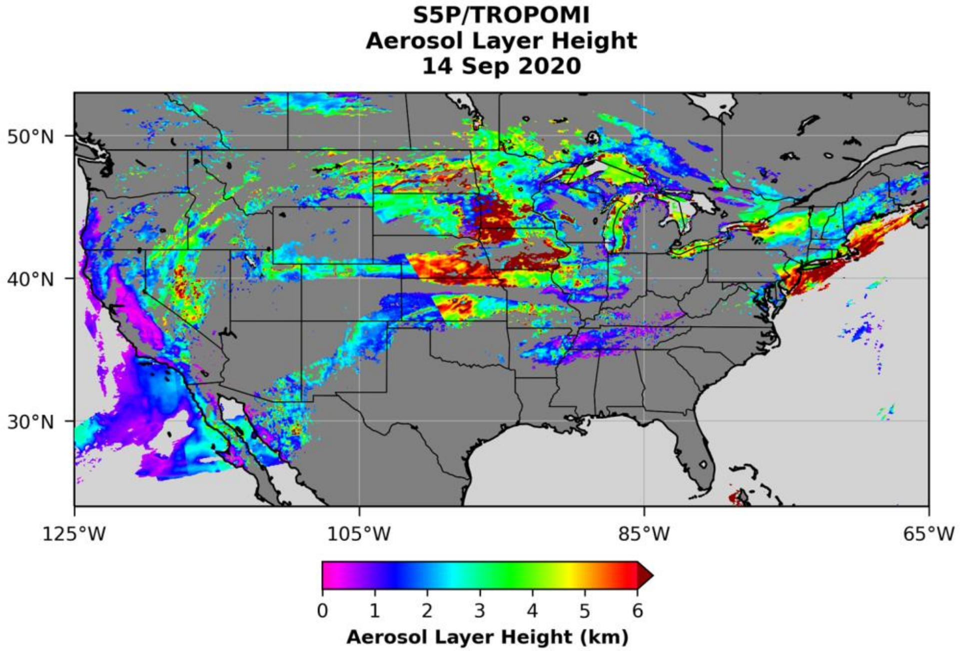


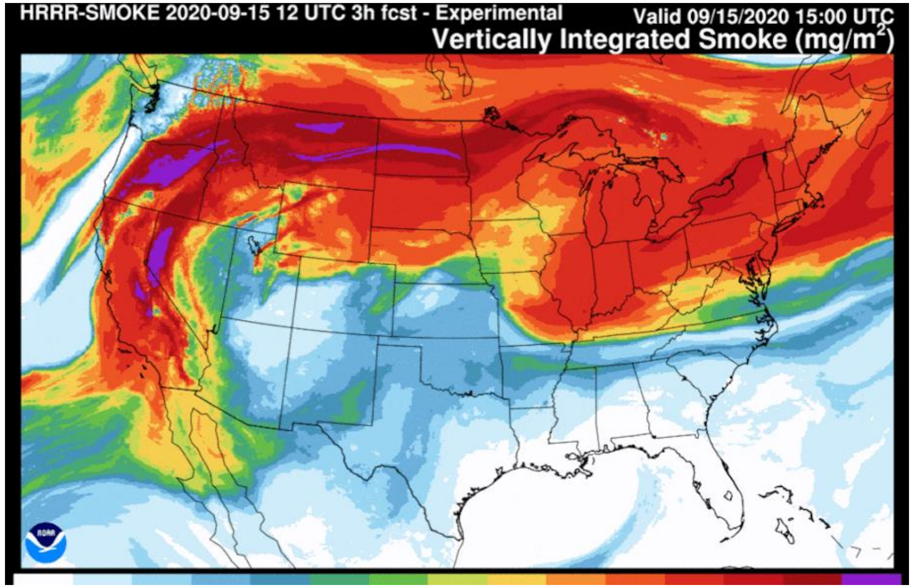
Figures from Shobha Kondragunta, Chuanyu Xu, Juying Warner

Combination of TIR sounder with UV-Vis and SWIR datasets provides powerful dataset for tracking long-range transport and constraining model forecasts

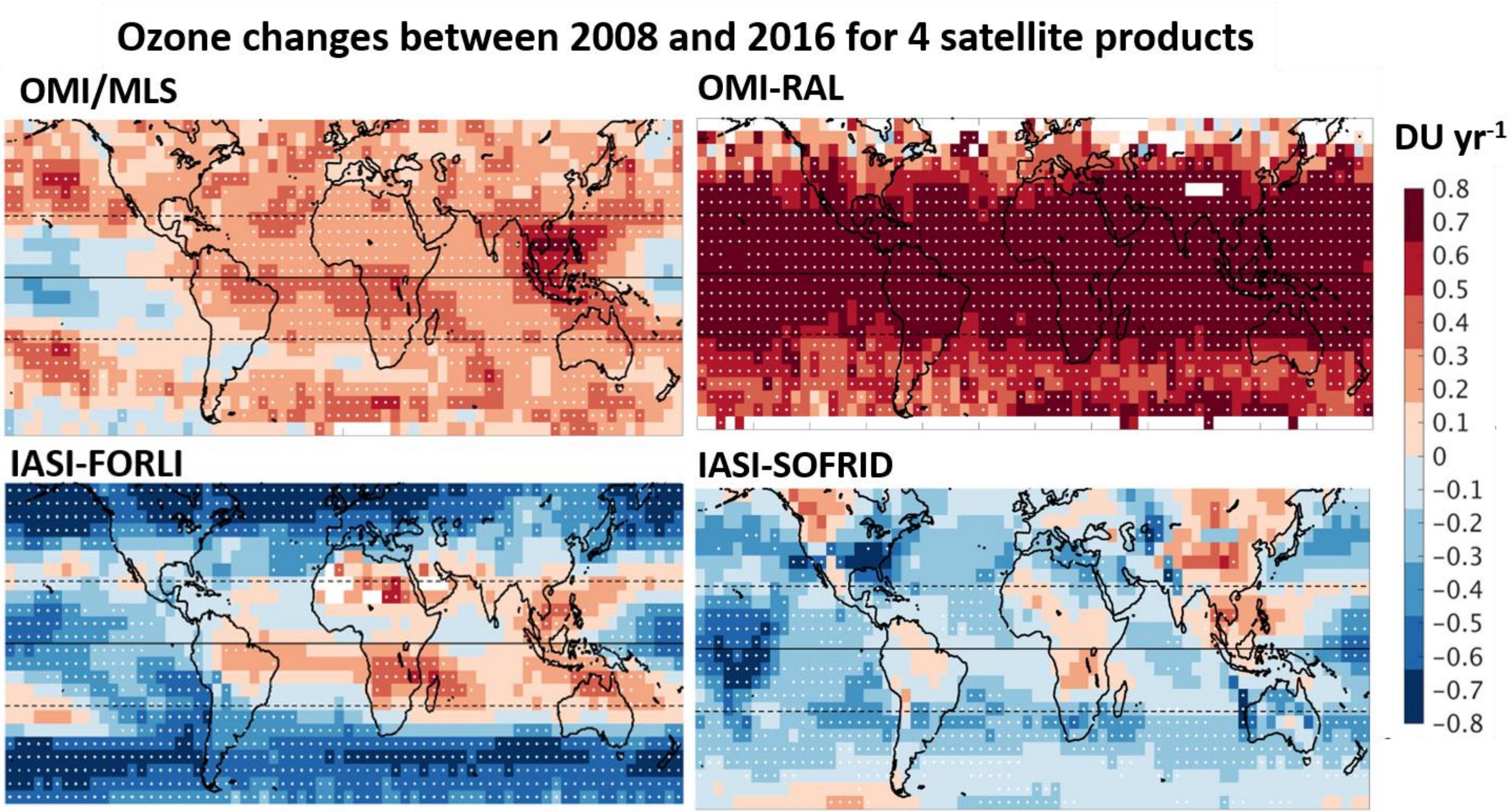






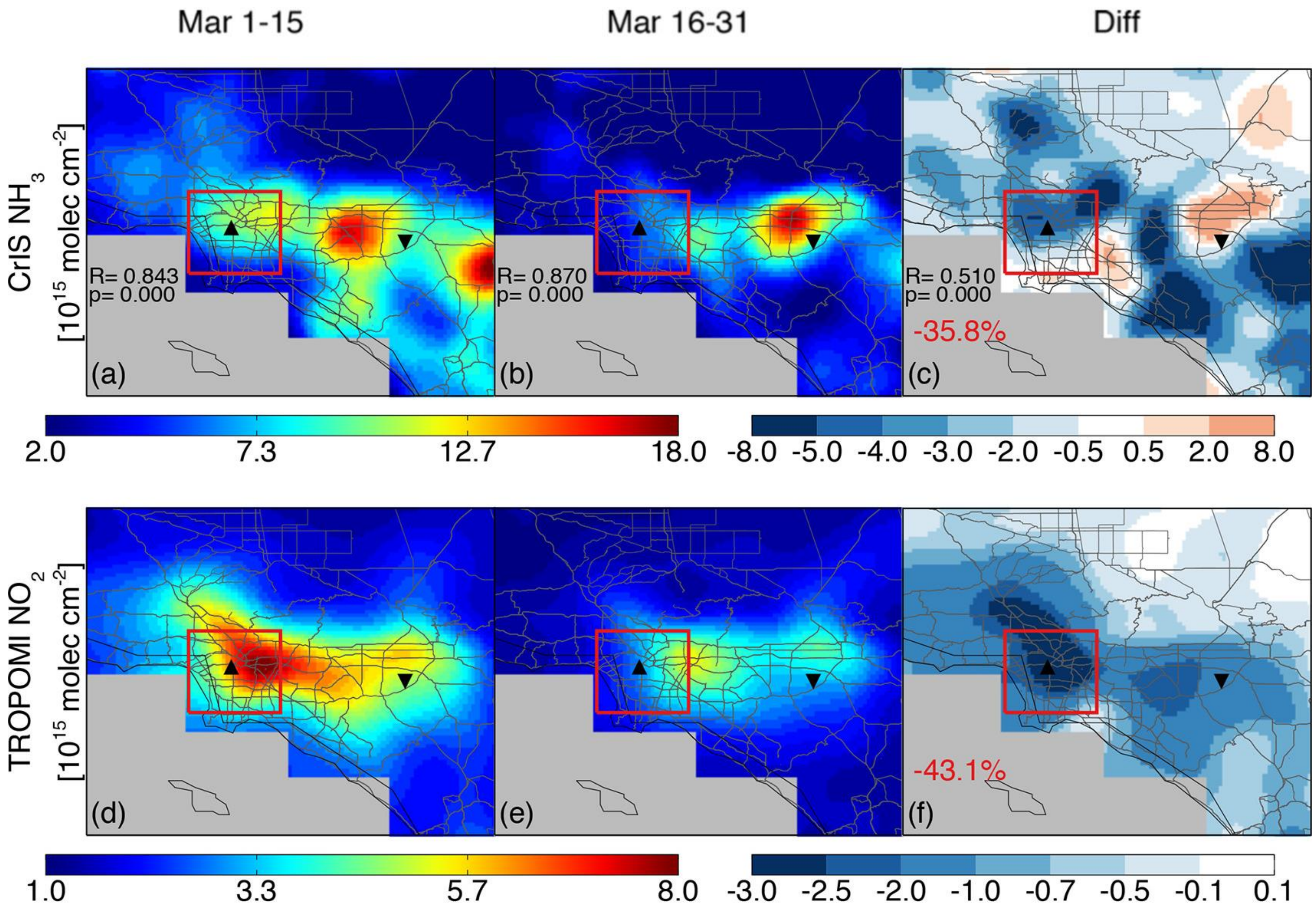


Tropospheric ozone trends can be derived from a combination of TIR and UV-Vis observations



Tropospheric column ozone trends in DU/yr between 2008 and 2016 for two OMI products (OMI/MLS and OMI-RAL, top panels) and two IASI products (IASI-FORLI and IASI-SOFRID, bottom panels). *Figure reprinted from Gaudel et al., Elementa, 2018.*

Combination of TIR and UV-Vis observations can constrain emissions inventories for motor vehicles

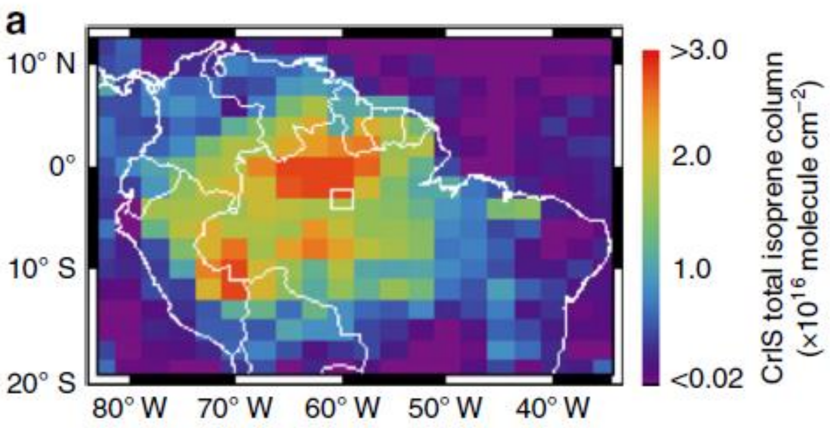


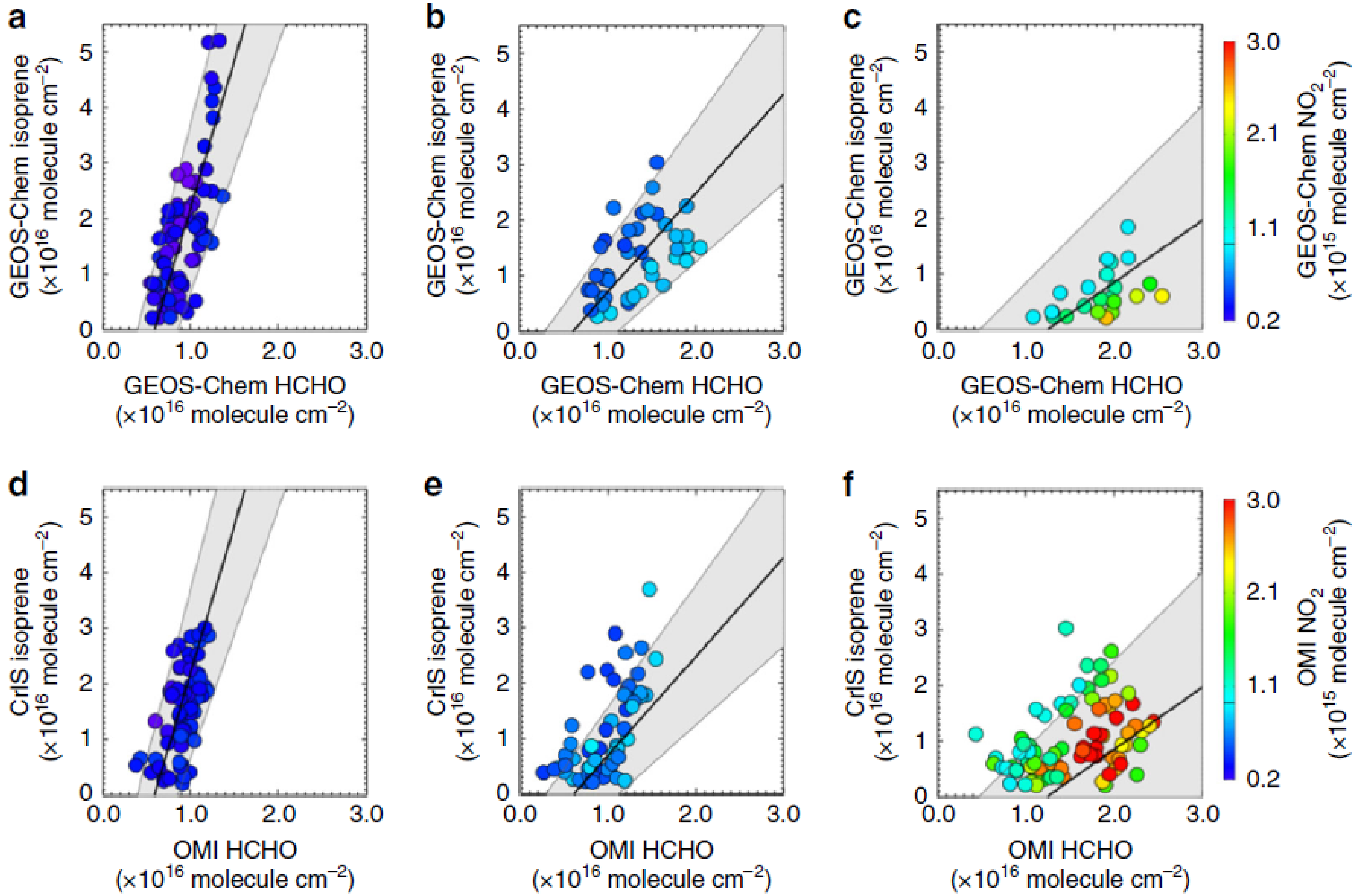
Noticeable reduction in CrIS ammonia (NH_3) during COVID-19 pandemic over West Los Angeles

Decrease in NH_3 similar to decrease in nitrogen dioxide (NO_2) seen by TROPOMI

Cao et al. (*ES&T Lett., 2021*)

Combination of TIR and UV-Vis observations can constrain modeled biogenic emissions and chemistry



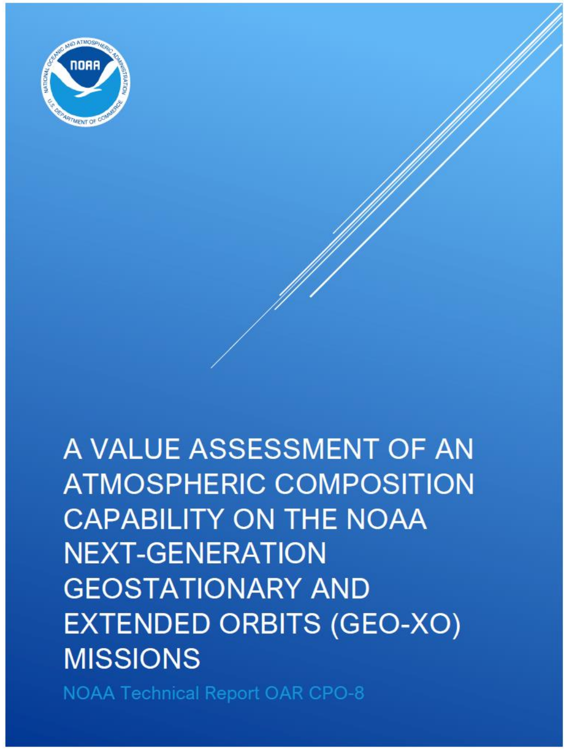


Directly retrieve isoprene from CrIS and combine with OMI formaldehyde measurements to understand emissions and chemistry of isoprene, one of the most prevalent organic compounds emitted by vegetation globally.

Fu et al., Nature Comm., 2019

GeoXO Atmospheric Composition Value Assessment

In 2020, an expert team **assessed the value of geostationary atmospheric composition** (AC) observations for **NOAA's science and operational application areas**, as part of the agency's mission to protect lives and property. **The proposed GEO-XO AC capability addresses the report's recommendations.**



https://doi.org/10.25923/1s4s-t405

NOAA's Atmospheric Composition Applications

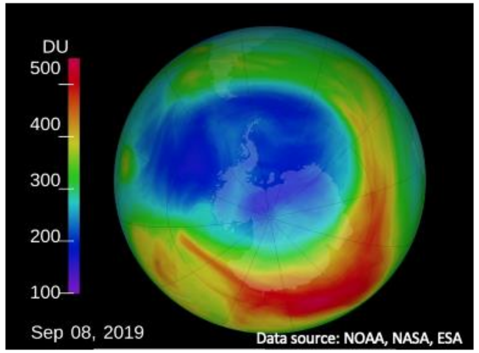
Air Quality

Wildfires

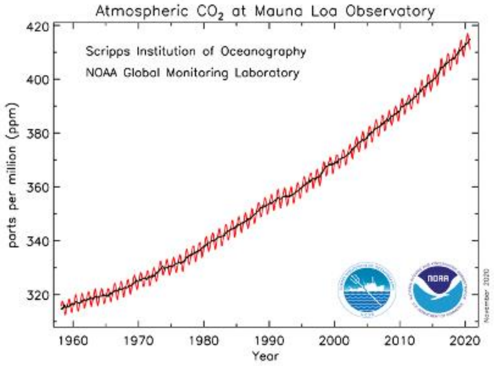
Hazards

Weather and Climate

Stratospheric Ozone



Greenhouse Gases



GeoXO will employ a multi-instrument synergy to measure atmospheric composition

Vis/IR Imager (GXI)
- Fire detection
- Fire radiative power
- Aerosol type
- Aerosol optical depth
- Aerosol concentration

UV/Vis Spectrometer (ACX)
- TEMPO analog
- Ozone
- Nitrogen dioxide
- Sulfur dioxide
- Formaldehyde
- Aerosol layer height

IR Sounder (GXS)
- Ozone
- Carbon monoxide
- Carbon dioxide
- Ammonia

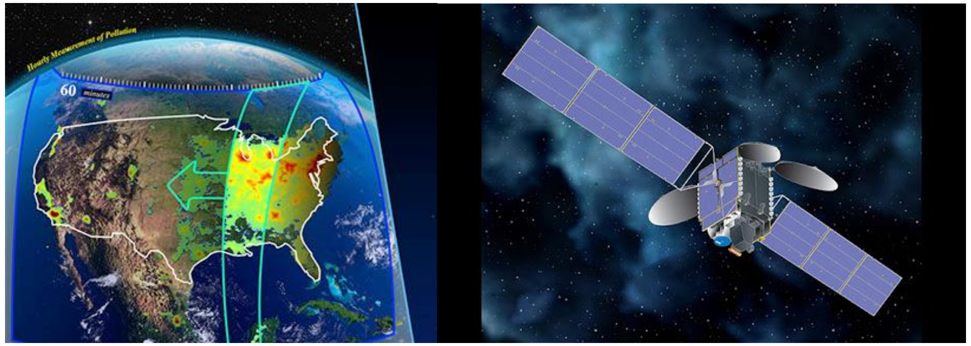
Partner Payload = *Opportunity for SWIR instrument*
- GeoCarb analog?
- Carbon dioxide
- Methane
- Carbon monoxide

Geostationary observations offer capabilities for atmospheric composition that complement polar-orbiting LEO instruments

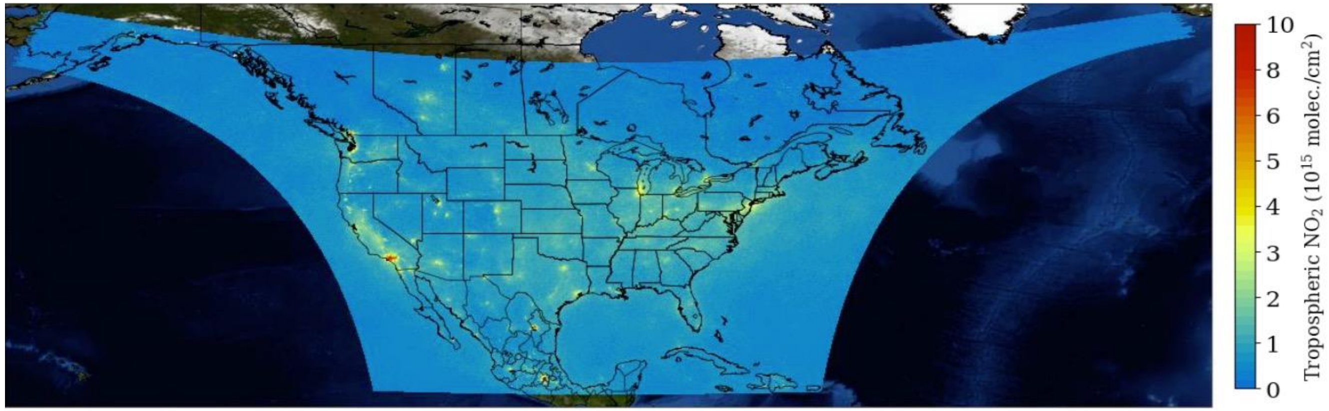
Monitoring hourly variations
- Emissions
- Chemistry
- Biosphere fluxes

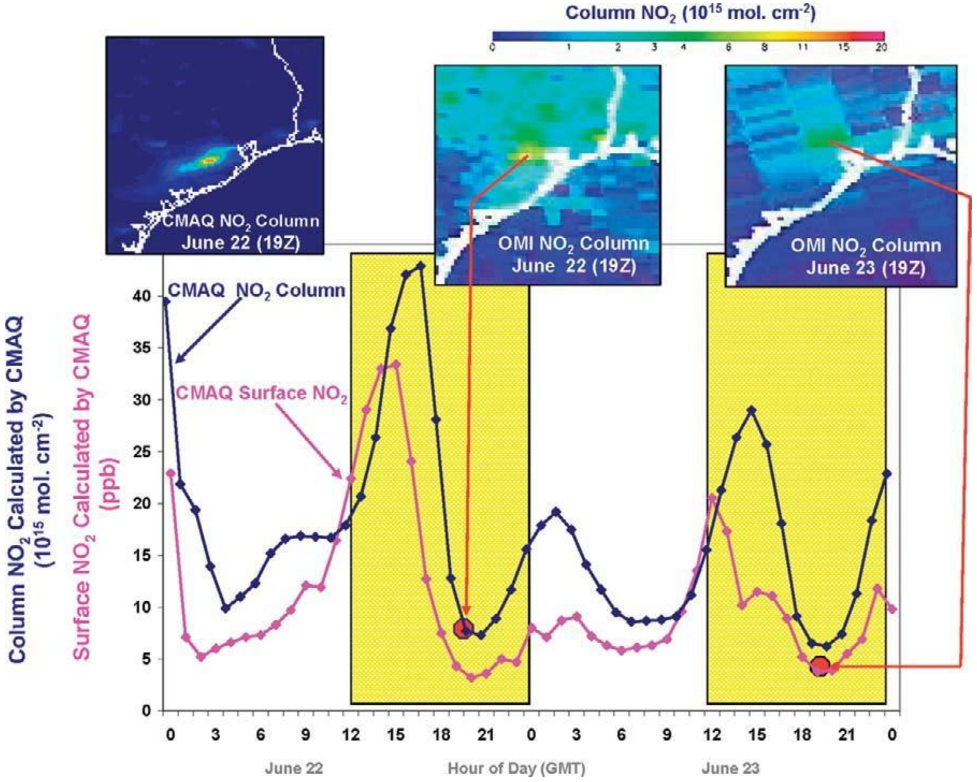
Detecting episodic events
- Fires
- Volcanoes
- Chemical leaks

Increasing data density
- More data in less time than LEO
- Select cloud-free conditions
- Fewer gaps in episodic behavior



TropOMI NO_2 sampled over TEMPO field of regard





Fishman et al., BAMS, 2008

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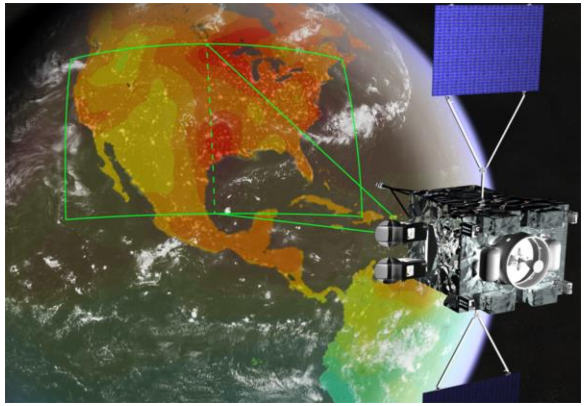
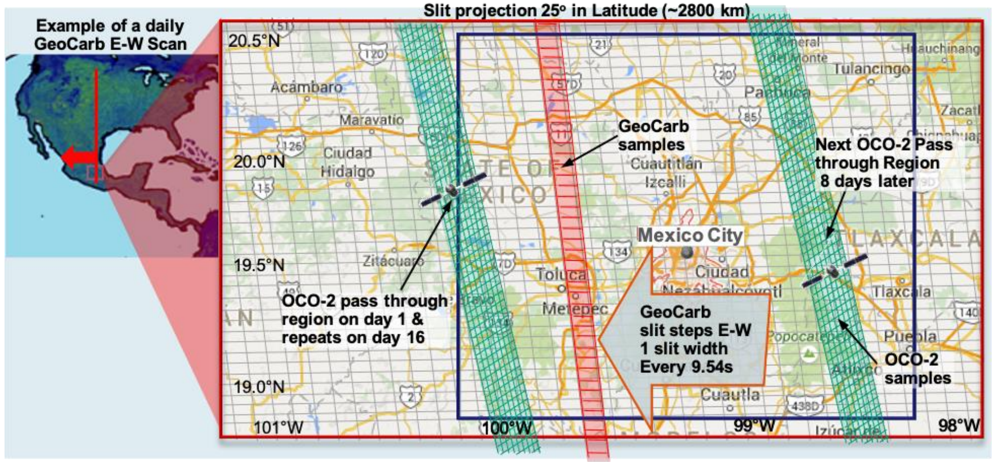
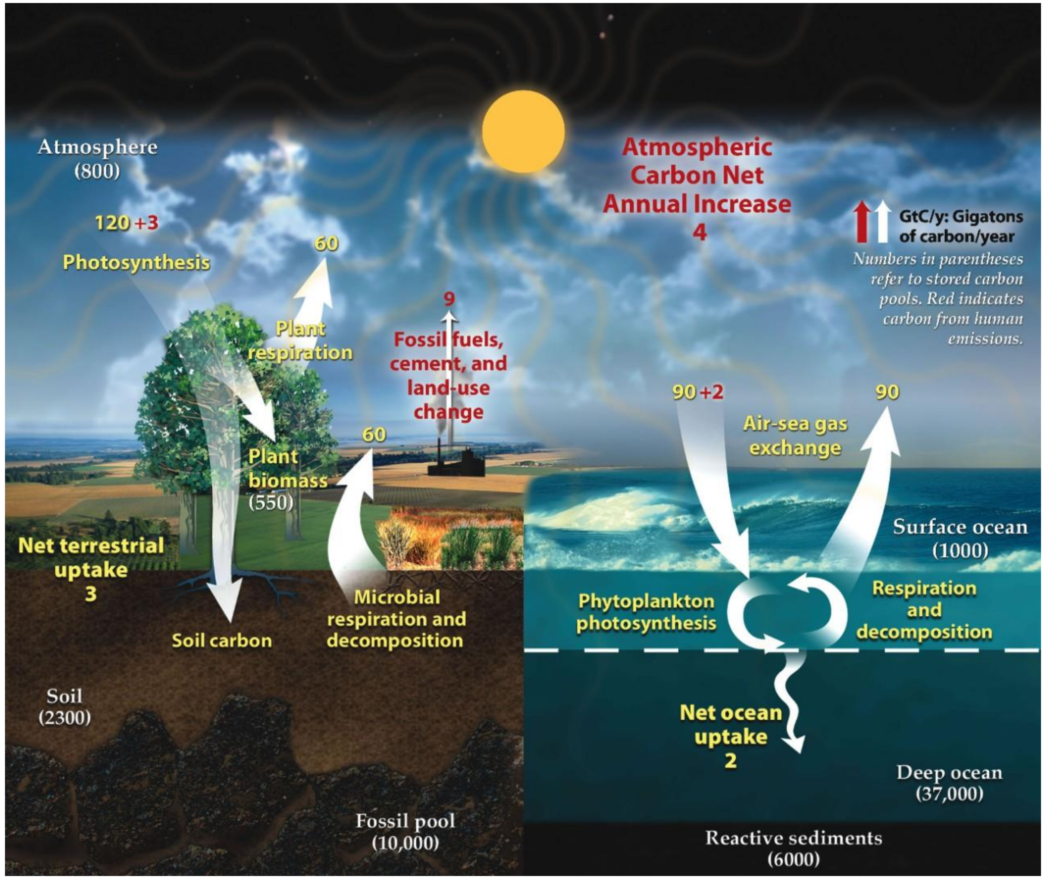






Methane and sulfur dioxide, along with key band for nitrous oxide, will not be measured by GeoXO IR Sounder, at least with the currently proposed spectral windows

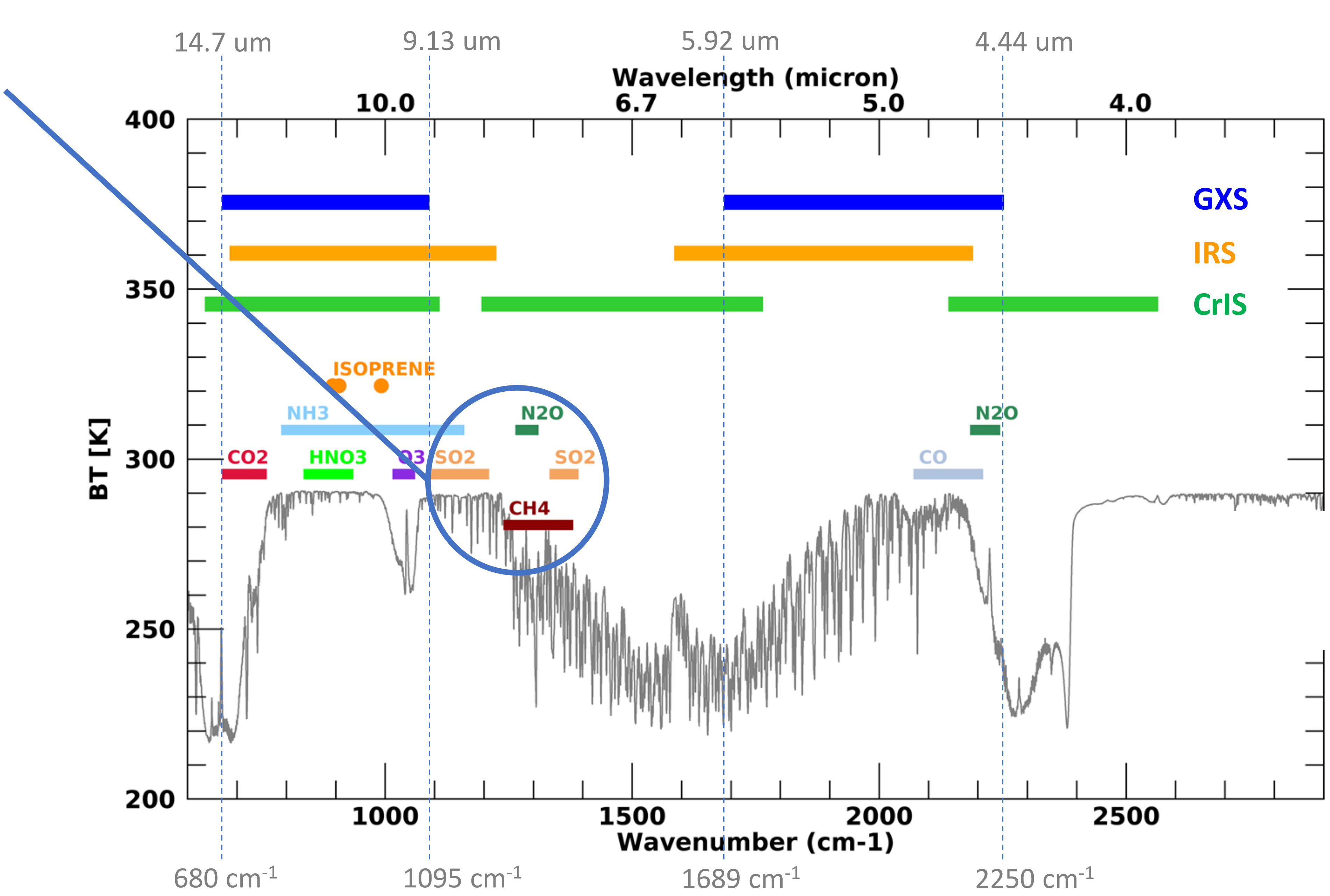
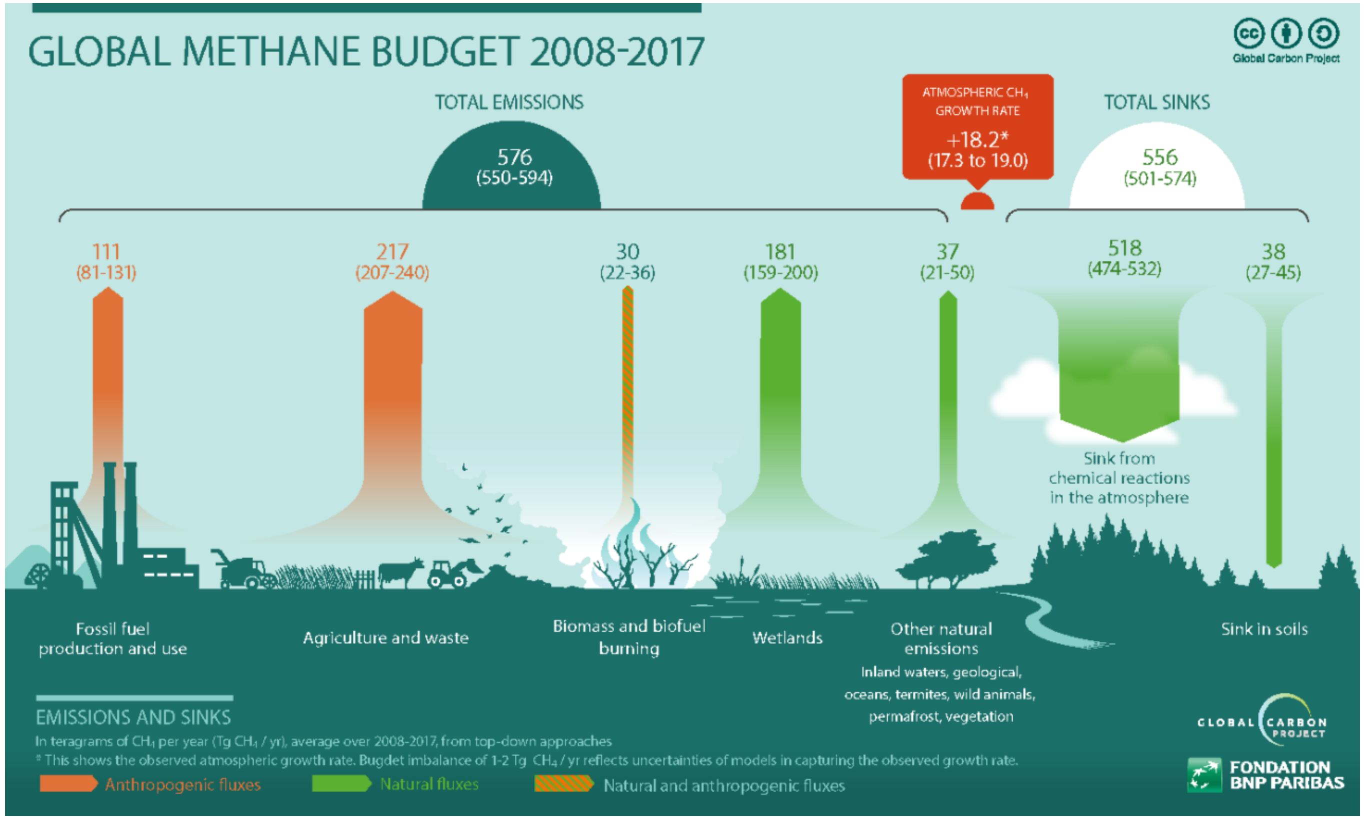
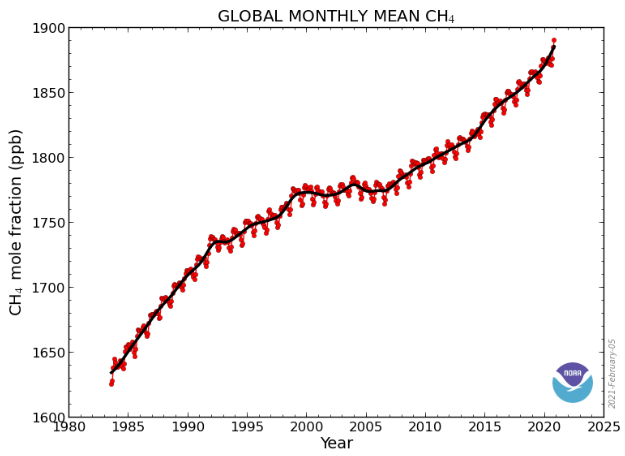


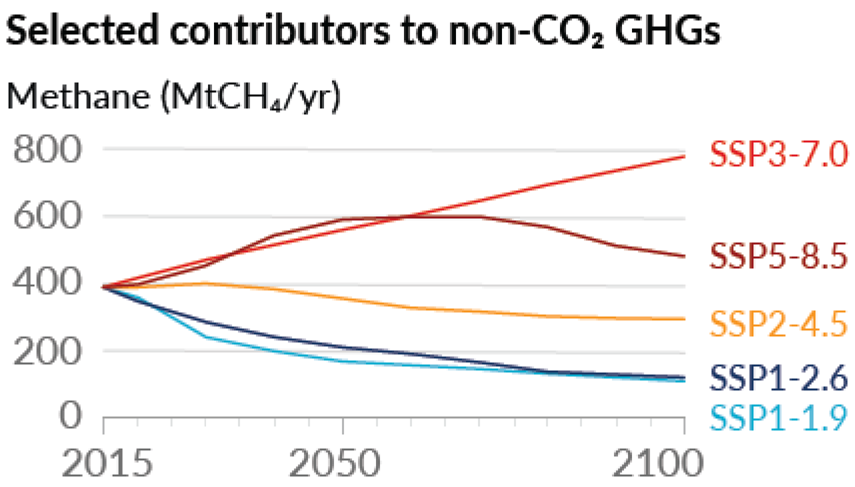
Figure from Joel Mccorkel, NASA

Methane emissions figure prominently in plans to limit warming in the 21st century, requiring a concerted observing approach





Global Methane Pledge



Concluding thoughts

- Thermal IR sounders offer a number of benefits for understanding atmospheric composition including:
    - Wide geographic coverage
    - Continuous observation of under-sampled free troposphere
    - Long-term records for mapping trace gas variability and trends
    - Sampling of some sources for important pollutants
- Shortwave IR (1.5-2.5 um) is needed to track CO_2, CH_4, and CO in the lower troposphere
- Combination of thermal IR, shortwave IR and UV-Vis provides powerful constraints on trace gas sources and chemistry, and the representation of these processes in models
- As geostationary capabilities for atmospheric composition become available, need to think about how best to leverage complementarity with LEO instruments
- Methane is a focus for climate mitigation actions and a priority of the current administration. NOAA needs a concerted approach for methane detection from space