Global monitoring capabilities with NDACC HR-FTIR: from retrieval optimization to model evaluation and extreme events

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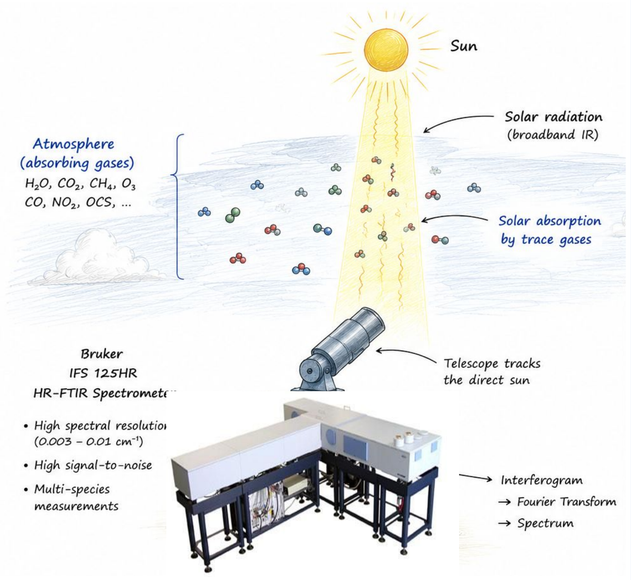
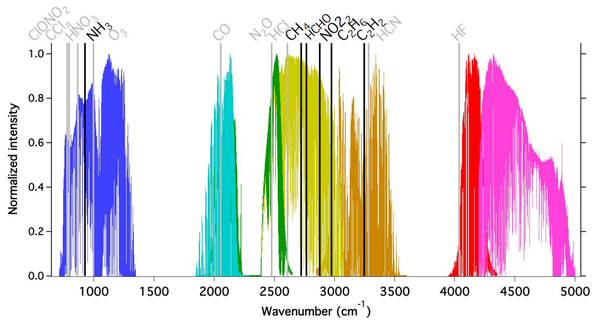
IRWG Measurements and Capabilities

The IRWG consists of a global network of high-resolution Fourier Transform Infrared (HR-FTIR) spectrometers that perform solar absorption measurements of atmospheric trace gases. These observations provide vertically resolved profiles and total and partial column abundances for a broad suite of atmospheric constituents, supporting studies of atmospheric composition, variability, trends, and satellite validation.

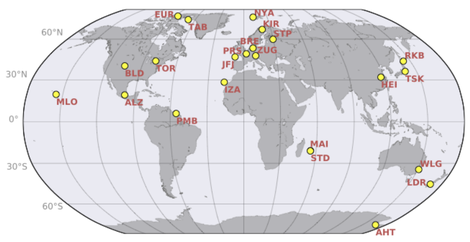


Example of solar transmission spectra acquired using different band-pass filters



In this work, infrared (IR) solar absorption spectra are analyzed using the SFIT4 retrieval package, which employs forward radiative transfer modeling and regularized inversion to retrieve atmospheric state vectors. The retrievals are characterized using averaging kernel matrices and uncertainty estimates accounting for measurement, spectroscopic, and smoothing contributions.

Example map illustrating the coordinated IRWG sites used to investigate OCS trends (Hannigan et al., 2022).

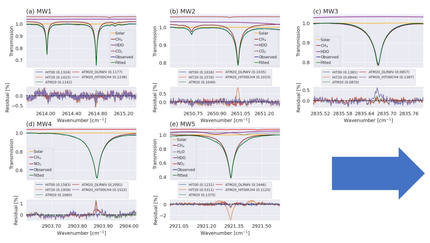


Category	Species
Greenhouse gases and climate tracers	CO_2, CH_4, N_2O, CO, H_2O, HDO, CFCs, HCFCs
Ozone chemistry and stratospheric composition	O_3, HCl, HNO_3, HF, NO_2, $ClONO_2$
Anthropogenic, biogenic, and biomass-burning tracers	C_2H_6, C_2H_2, C_2H_4, HCOOH, H_2CO, HCN, CH_3OH, NH_3, OCS

(1) CH_4: From retrieval to model evaluation

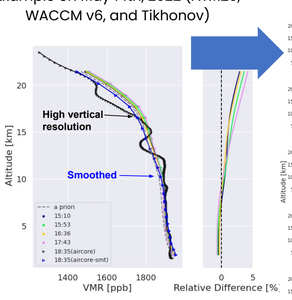
We optimized CH_4 retrieval strategies by evaluating spectroscopic databases, micro-window selection, and regularization methods. Using AirCore and aircraft in situ profiles, we validated the vertical distributions and partial column of FTIR observations at the Boulder, Colorado site (Ortega et al., 2025).

Retrieval fit example of CH_4 for November 18th, 2019 (SZA = 60.0)

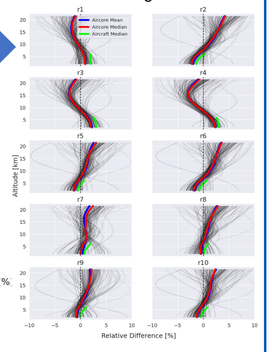


- Spectral contributions for various species (top panels)
- The bottom plots shows the residuals with distinct colors indicating different spectroscopy.

Example on May 14th, 2022 (ATM20, WACCM v6, and Tikhonov)



Aircore differences (< 22 km) for 10 strategies



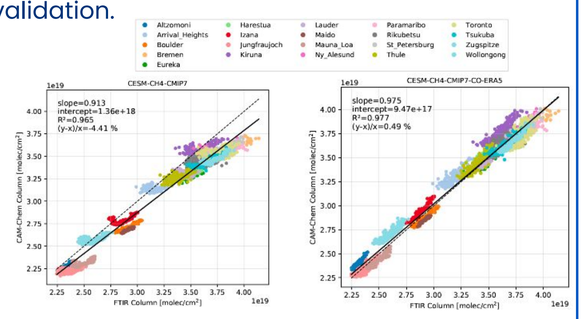
Median bias < 0.4 % in the troposphere and < 1% in the stratosphere.

Model evaluation

Models are transitioning from concentration-driven to emission-driven CH_4 frameworks, adding non-linear feedbacks (e.g., SLH chemistry) to refine OH variability. These updates often result in small but significant adjustments (< 2 %), demanding high-precision validation.

Community Earth System Model version 2.2 (CESM2.2) - CAM-Chem.

Can we use FTIRs and capture small variations in these simulations? → YES



The analysis shown above is based on total column products from the current NDACC archive. However, the new retrieval strategy (Ortega et al., 2025) is expected to improve the tropospheric and stratospheric columns.

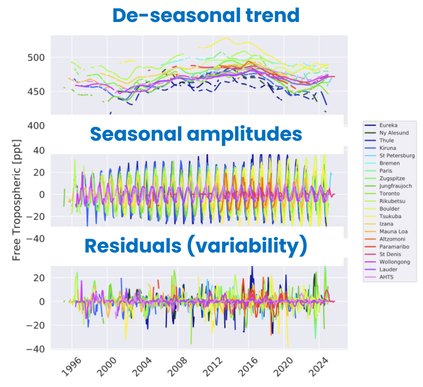
(2) Long-term global OCS Trends from the NDACC IRWG

We developed a global homogeneous long-term (up to 35y) of vertically resolved OCS dataset on three altitude regimes lower and free troposphere and stratosphere (Hannigan et al., 2022)

Example of OCS free tropospheric anomalies

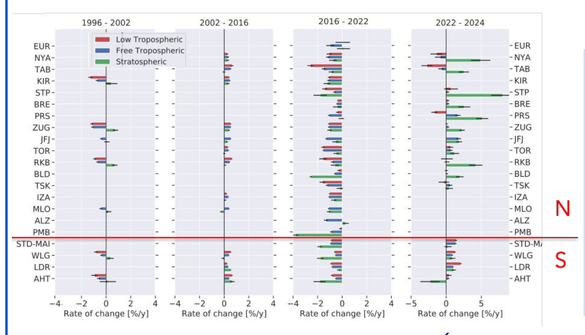


Below is a Seasonal-Trend decomposition using LOESS (STL) from python statsmodels.tsa.seasonal.STL.
Trend → long-term changes; Seasonal → repeating patterns (monthly); Residual → inter-annual variability



Trends globally, are not linear. Inflections in trends appear across all latitudes. Generally ~2002, ~2008, ~2016 and lately 2024..

Anthropogenic / industrial sources dominate through 2012 an maybe after 2024.



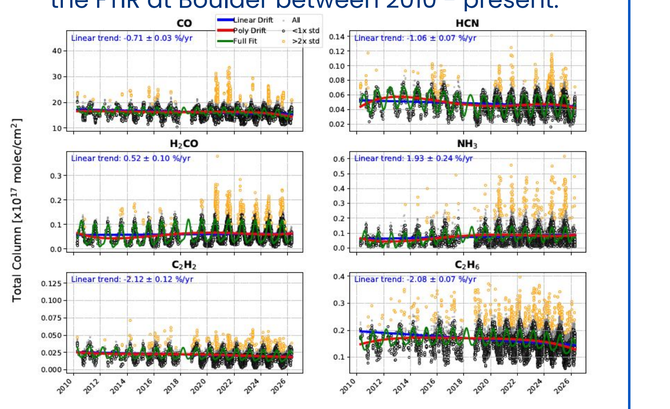
Trend summary (< 2024)

- **1996–2002:** Divergent trends; tropospheric decrease vs. stratospheric increase.
- **2002–2016:** Moderate tropospheric/stratospheric growth, primarily driven by anthropogenic emissions.
- **2016–2022:** reversal to a sustained 6-year global decline.
- **2022–2024:** Tropospheric declines persist at high Northern Latitudes and Paris.
- **2024:** It appears there is an increase in stratospheric OCS at mid latitude sites

The analysis is expected to continue (under new funding) and will be expanded to include updated trend assessments, retrieval optimization, homogenization of satellite products, and the simulation of OCS using chemistry transport models.

(3) Wildfire and Oil & Natural Gas enhancement events observed in Boulder, Colorado

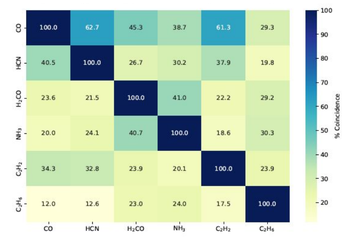
Time series of Total Columns of gases derived from the FTIR at Boulder between 2010 - present.



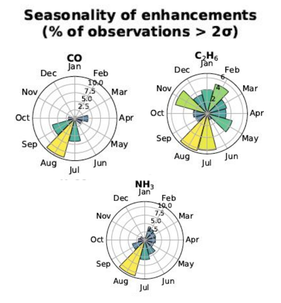
Green line is the seasonal modulation and trend component
Blue line linear component
Red line a polynomial fit to capture inflection points
Orange points → Enhancements (residuals > 2 x std)

Boulder is affected by emissions from oil and natural gas production, feedlots, and summertime wildfire smoke. Can trace gas observations be used to separate and quantify these source contributions?

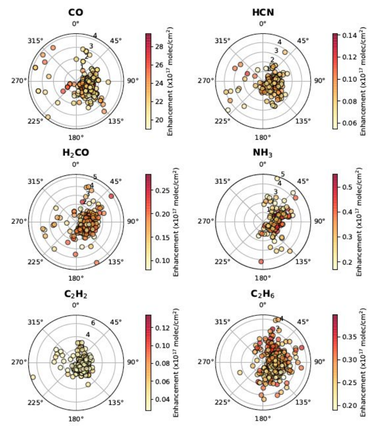
Enhancement Coincident Matrix (If Y-axis gas occurs, % chance X-axis gas also occurs)



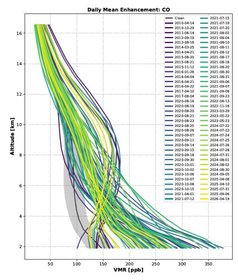
Seasonality of enhancements (% of observations > 2σ)



Enhancement magnitude relative to wind direction and speed

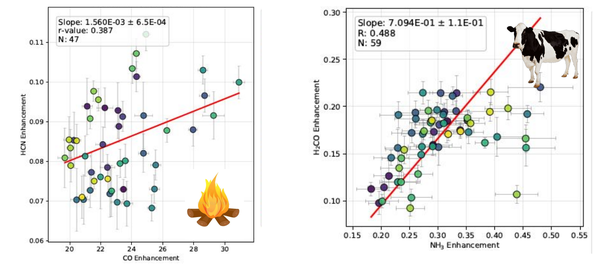


Can we capture enhancements occurred in the upper trop low stratosphere?

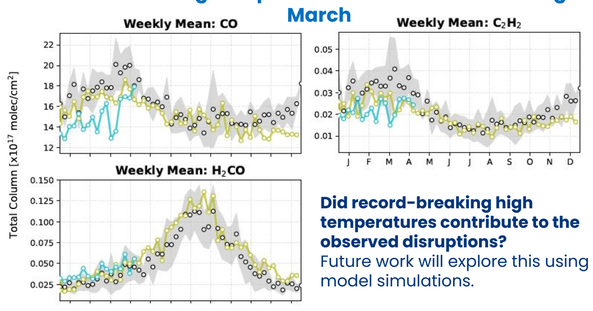


Enhancement ratios (e.g., HCN/CO for wildfire emissions and H_2CO/NH_3 for feedlot emissions) can be used to distinguish source contributions.

Below are daily enhancement correlations; circles are color-coded by date to help identify potential source influences.



Observed Atmospheric Gas Variability During Record-Breaking Temperatures in 2026: A Record High in March



Did record-breaking high temperatures contribute to the observed disruptions?
Future work will explore this using model simulations.

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