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

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A large number of atmospheric trace gases absorb in the IR
IR sounders like CrIS provide continuous atmospheric composition datasets with wide geographic coverage.

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.
IR sounders provide information about major air pollution sources, like wildfires, that is complementary to data from other satellite instruments.
Trace gas quantification on NOAA sounders is a by-product of the retrievals of temperature and water vapor.

<table>
<thead>
<tr>
<th>gas</th>
<th>Range (cm(^{-1}))</th>
<th>Precision</th>
<th>d.o.f.</th>
<th>Interfering Gases</th>
</tr>
</thead>
<tbody>
<tr>
<td>T</td>
<td>650-800 2375-2395</td>
<td>1K/km</td>
<td>6-10</td>
<td>H(_2)O,O(_3),N(_2)O emissivity</td>
</tr>
<tr>
<td>H(_2)O</td>
<td>1200-1600</td>
<td>15%</td>
<td>4-6</td>
<td>CH(_4), HNO(_3)</td>
</tr>
<tr>
<td>O(_3)</td>
<td>1025-1050</td>
<td>10%</td>
<td>1+</td>
<td>H(_2)O, emissivity</td>
</tr>
<tr>
<td>CO</td>
<td>2080-2200</td>
<td>15%</td>
<td>(\approx 1)</td>
<td>H(_2)O,N(_2)O</td>
</tr>
<tr>
<td>CH(_4)</td>
<td>1250-1370</td>
<td>1.5%</td>
<td>(\approx 1)</td>
<td>H(_2)O,HNO(_3),N(_2)O</td>
</tr>
<tr>
<td>CO(_2)</td>
<td>680-795 2375-2395</td>
<td>0.5%</td>
<td>(\approx 1)</td>
<td>H(_2)O,O(_3) T(p)</td>
</tr>
<tr>
<td>Volcanic SO(_2)</td>
<td>1340-1380</td>
<td>50% ??</td>
<td>&lt; 1</td>
<td>H(_2)O,HNO(_3)</td>
</tr>
<tr>
<td>HNO(_3)</td>
<td>860-920 1320-1330</td>
<td>50% ??</td>
<td>&lt; 1</td>
<td>emissivity H(_2)O, CH(_4), N(_2)O</td>
</tr>
<tr>
<td>N(_2)O</td>
<td>1250-1315 2180-2250</td>
<td>5% ??</td>
<td>&lt; 1</td>
<td>H(_2)O</td>
</tr>
<tr>
<td>NH(_3)</td>
<td>860-875</td>
<td>50%</td>
<td>&lt;1</td>
<td>emissivity</td>
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<tr>
<td>CFCs</td>
<td>790-940</td>
<td>20-50%</td>
<td>&lt;1</td>
<td>emissivity</td>
</tr>
</tbody>
</table>

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
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.

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).

D. Jacob et al., Atmos. Chem. Phys., 2016
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\[ \text{D. Jacob et al., Atmos. Chem. Phys., 2016} \]

\[ \text{Figures from Nadia Smith and Rebekah Esmaili, STC} \]
Combination of TIR and SWIR datasets provides additional understanding of carbon monoxide sources

![Map showing CO total column](image)

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.
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)
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
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

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

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

UV/Vis Spectrometer (ACX)
- TEMPO analog
- Ozone
- Nitrogen dioxide
- Sulfur dioxide
- Formaldehyde
- Aerosol layer height
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
Geostationary observations offer capabilities for atmospheric composition that complement polar-orbiting LEO instruments

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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.
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