Global isoprene measurements from CrIS constrain emissions and atmospheric oxidation

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Isoprene = the dominant biogenic VOC emitted to atmosphere; uncertainties in bottom-up emissions and chemistry persist

Global Annual Emissions (Tg/yr)

<table>
<thead>
<tr>
<th></th>
<th>Isoprene</th>
<th>Methane</th>
<th>Anth VOCs</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>535</td>
<td>570</td>
<td>150</td>
</tr>
</tbody>
</table>

Bottom-up emissions sensitive to land cover, meteorology, canopy parametrization, etc.

Guenther et al., 2012

Same emission model & met data, different vegetation = 463 v 750 TgC/y

Arneth et al., 2011

OH, hv

CO, O₃, HCHO

Secondary Organic Aerosols (SOA)

Isoprene affects aerosols, O₃, atmospheric oxidation, N-cycling
Isoprene = the dominant biogenic VOC emitted to atmosphere; uncertainties in bottom-up emissions and chemistry persist.

**OH = primary atmospheric oxidant**
Model OH is generally too low over low-NO\(_x\) isoprene source regions.

How much OH recycling occurs in high isoprene, low-NO\(_x\) conditions?

- Model OH with standard mechanism
- Model OH with enhanced recycling

\[
\text{Isoprene} + \text{OH} \rightarrow \text{RO}_2 + \text{HO}_2
\]

\[
\text{NO} + \text{NO}_2 \rightarrow \text{NO}_2 + \text{NO}
\]

\[
\text{HO}_x = \text{HO}_2 + \text{OH}
\]

\[
\text{NO}_x = \text{NO}_2 + \text{NO}
\]

*e.g., Lelieveld et al., 2008; Fuchs et al., 2013*
Space-based HCHO provides top-down constraints on emissions; uncertain due to chemical complexities and non-isoprene sources

HCHO = formaldehyde, a high-yield isoprene oxidation product
Short lifetime, detectable from space in near-UV

• HCHO yield from isoprene is a non-linear function of NO\textsubscript{x}
• HCHO also produced from fires, other VOCs

We must rely on models to accurately capture these effects
Measurements of TIR absorption cross section of isoprene enable direct measurements of isoprene from space

Cross-track Infrared Sounder (CrIS):
- 10/2011 (Suomi-NPP), 11/2017 (NOAA-20), expected 2022
- Near global coverage twice daily
- Afternoon overpass
- Low noise

Key for isoprene!

OE retrievals over Amazonia (Fu et al., 2019)

Individual CrIS spectra, 30 Sept 2014

CrIS isoprene column

CrIS v aircraft

$r = 0.6$
Slope = 0.9
We employ an artificial neural network to derive the global isoprene distribution from the CrIS $T_b$ difference.

Monthly-mean $T_b$ difference: $\Delta T_b = T_{b,\text{off-peak}} - T_{b,\text{peak}}$

Single-footprint, cloud-screened Level 1B data;
**Pro**: fast way to process a large dataset (~9e6 spectra/day)
**Con**: Can be subject to interferences

HNO$_3$ column
Thermal contrast
H$_2$O vapor column
Surface pressure
Satellite view angle

Input layer

Hidden layers

Output layer

Isoprene column

e.g., IASI NH$_3$, methanol, formic acid, PAN, acetone (Whitburn et al., 2016; Franco et al., 2018; 2019)
The first global space-based isoprene distribution

Observed Amazonia hotspots more localized than in GEOS-Chem

January 2013

July 2013

CrIS isoprene column

GEOS-Chem v11-02e isoprene column

0.00e+00 6.67e+15 1.33e+16 2.00e+16 [molec/cm²]
CrIS isoprene is consistent with OE retrievals and aircraft measurements

July 2013, using GEOS-Chem as a transfer standard

Amazonia OE retrievals (Fu et al., 2019)

Highest observed isoprene over Ozarks

July 2013 US Southeast

r = 0.6
slope = 1.3

r = 0.5
slope = 1.3

r = 0.9
slope = 0.8
Space-based isoprene and HCHO provide combined constraints on emissions and chemistry in isoprene source regions

GEOS-Chem, July 2013

Isoprene column

Isoprene emissions (MEGANv2.1)

Isoprene column distribution distinct from that of emissions

Highest columns

Highest emissions

Isoprene column distribution

τ ~ 1h

τ > 12h

Isoprene BL lifetime

0.00 0.67 1.33 2.00

$[10^{18} \text{molec/cm}^2]$
Space-based isoprene and HCHO provide combined constraints on emissions and chemistry in isoprene source regions

Isoprene column

Isoprene emissions (MEGANv2.1)

Global ensemble of isoprene column vs. isoprene emissions

Low NO\textsubscript{x}, non-SS
Suppressed OH

High NO\textsubscript{x}, steady state slope \( \sim \tau_{\text{isoprene}} \)

At low NO\textsubscript{x}, isoprene increases superlinearly as it begins affecting its own sink

GEOS-Chem, July 2013
Space-based isoprene and HCHO provide combined constraints on emissions and chemistry in isoprene source regions

GEOS-Chem, July 2013

Isoprene column

- Isoprene emissions (MEGANv2.1)

- Global ensemble of isoprene:HCHO column ratio v isoprene lifetime

Isoprene:HCHO ratio = proxy for atmospheric oxidation capacity in source regions

HCHO is more buffered to OH variability:
- Loss to photolysis still occurs at low OH
- Loss proportional to [isoprene]×[OH]
Space-based isoprene:HCHO ratio supports current model treatment of OH chemistry in isoprene source regions

**CrIS isoprene:OMI HCHO**

Lowest model NO\(_2\) columns not seen in observations

**GEOS-Chem isoprene:HCHO**

Agreement within 10-40% at low-to-moderate NO\(_x\) argues against substantial missing OH recycling

**OMI QA4ECV HCHO and NO\(_2\)**
Observed isoprene lifetime consistent with observed NO\textsubscript{2} over Amazonia, large scale NO\textsubscript{x} bias evident in model

\[ \tau_{\text{isop}} = \Omega_{\text{isop}} \cdot \Omega_{\text{HCHO}} / 0.18 \]

Measured lifetime agrees with chemical expectations = additional confirmation of our approach

Large scale NO\textsubscript{x} bias likely due to underestimated soil NO\textsubscript{x} emissions (Liu et al., 2016)
A long-term record of isoprene from CrIS will give us new insights into interannual variability and chemistry-climate couplings

Onset of 2015/2016 El Niño = warmer temperatures, drought stress?
Next steps: next generation CrIS isoprene retrieval based on Hyperspectral Range Index (HRI)

\[
HRI = \frac{K^T S_y^{-1} (y - \bar{y})}{\sqrt{K^T S_y^{-1} K}}
\]

- Measured spectrum
- Mean background spectrum
- Spectral Jacobian
- Background spectral covariance

CrIS HRI looks more “isoprene-like” than \(\Delta T_b\)

- HRI uses full active spectral range for isoprene = enhanced sensitivity, less subject to interferences

CrIS \(\Delta T_b\)

CrIS HRI

July 2013
Next steps: apply HRI-based retrieval to look at other species, advance understanding of VOC sources and chemistry-climate-ecosystem interactions

Simultaneous measurements of multiple VOCs from CrIS will provide powerful new information to better understand biosphere-atmosphere interactions, biomass burning, and pollution across the globe!

<table>
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<tr>
<th>Species</th>
<th>Primary Sources</th>
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</thead>
<tbody>
<tr>
<td>Methanol</td>
<td>Biosphere, biomass burning</td>
</tr>
<tr>
<td>Ethene</td>
<td>Biosphere, biomass burning, vehicles</td>
</tr>
<tr>
<td>Ethyne</td>
<td>Combustion</td>
</tr>
<tr>
<td>Acetone</td>
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<tr>
<td>PAN</td>
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<td>Combustion</td>
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- Dejian Fu, Kevin Bowman, Evan Manning, Ruth Monarrez, Irina Strickland (JPL)
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Science questions to be answered by long-term TIR sounder records

We can do A LOT of science with even a weak signal! More species would be key to answering the below questions:

1) What does interannual variability tell us about the links between climate and VOC emission drivers?
2) How are VOC emissions (and OH!) changing over time?
3) As anthropogenic emissions decrease in the US and elsewhere, how is atmospheric composition changing?
What should be the highest priorities for new trace gas products?

1) A greater suite of species active in TIR (not detectable with other sensors!) for doing detailed source apportionment globally over long timescales
2) Evaluation of sensitivity (AK) over different source types (biogenic versus biomass burning, etc)
3) Near-real-time quick look-type product for specific events (e.g., large wildfires)

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What are the key observational gaps?

1) Diurnal variability: net biogenic VOC emissions are high during the day and low (or negative!) at night; can we quantify emission processes from space versus just net emission strength?

2) Smaller footprints to look at fire impacts and urban plumes; more information about BVOC emissions as a function of plant type