Chemistry-driven changes strongly influence climate forcing from vegetation emissions

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BVOC Emissions Changes

Forest Land Use Change

SSP projections
Riahi et al (2017)

Biosphere – Climate Feedbacks

Global Temperature
Atmospheric composition
BVOC Emissions
Sign and magnitude uncertain
Positive but magnitude uncertain
BVOCs and Atmospheric Composition

Positive forcing / warming

Negative forcing / cooling

+ BVOCs

Reaction with OH, O₃ and NO₃

- OH

+ CH₄ (via reduced OH)

+ O₃

Secondary Organic Aerosol (SOA)

Sulphate Aerosol?

SO₂ + OH → SO₄²⁻

Aerosol Scattering

Seeding Clouds

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How does the model description of chemistry affect the climatic impact of BVOCs?
ST & CS2
CS2 only

isoprene

0.03 Sec_Org

Condensation to aerosol

Mechanistic Differences

HO$_2$

ISOPOOH

Isoprene Nitrate

Further chemistry

NO, NO$_3$

Methyl vinyl ketone & Methacrolein

Further chemistry

NO, NO$_3$, RO$_2$

HPALD, RO$_2$, HO$_3$

hv

Further chemistry, including HO$_x$ recycling

1,6 H-shift

0.13 Sec_Org

Condensation to aerosol, Nucleation of aerosol

\alpha\text{-}pinene

\beta\text{-}pinene

+ OH, O$_3$, NO$_3$

RO$_2$, RCHO & ROOH

Further chemistry

ST - 73 species, 305 reactions

CS2 - 228 species, 766 reactions
30-year Atmosphere-only runs in pre-industrial (1850) atmosphere

| Run     | Mechanism | BVOC Emissions |
|---------|-----------|----------------|
| $ST_{\text{con}}$ | ST | Control |
| $ST_{2x}$     | ST | 2x |
| $CS2_{\text{con}}$ | CS2 | Control |
| $CS2_{2x}$     | CS2 | 2x |

**Radiative Forcing Components**

| Component          |          |
|--------------------|----------|
| $\text{CH}_4$      | $O_3$    |
| Aerosol Scattering | Cloud Changes |
Mechanism Comparison

Components and Net Forcing

- Forcing / mWm^{-2}

| Component                      | ST            | CS2            |
|--------------------------------|---------------|----------------|
| O_3                            | 50 ± 10       | 90 ± 10        |
| CH_4                           | 150 ± 15      | 250 ± 20       |
| Aerosol Scattering (DRE)       | -200 ± 50     | -100 ± 20      |
| Cloud Changes (CRE)            | 100 ± 15      | 50 ± 10        |
| Net                            | 300 ± 20      | 150 ± 10       |

43% lower in CS2

Global Temperature
BVOC Emissions
Greater OH reduction with ST ➔ greater increase in CH$_4$ lifetime (concentration)

Greater increase in O$_3$ in region with greatest radiative efficiency in ST than CS2 despite overall lower burden increase
Aerosol Scattering

Increase in SOA with $2x E_{BVOC}$... but less dispersed in CS2

Forcing from aerosol scattering

(c) IRF$_{DRE}$: ST$_\Delta$ -0.260 Wm$^{-2}$

(d) IRF$_{DRE}$: CS2$_\Delta$ -0.244 Wm$^{-2}$

Total forcing in ST is 1% weaker over land but 25% stronger over oceans than CS2
Cloud reflectivity (albedo) increases with cloud droplet number concentration (CDNC)

\[
\frac{dA}{dN} \approx \frac{A(1 - A)}{3N}
\]

Greatest impact where:

\( A \sim 0.5 \)

Low background CDNC

Credit: Pyle and Schmidt
Cloud albedo changes (2)

\[
\text{SO}_2 
\xrightarrow{+ \text{OH}_\text{(g)}} \quad \text{H}_2\text{SO}_4 \
\xrightarrow{\text{condensation to existing aerosol}} \quad \text{New particle formation}
\]

\[
\quad \text{SO}_4^{2-} \quad \text{Increases aerosol mass concentration only}
\]

\[
\quad \text{Increases aerosol number and mass concentration}
\]

\[
\quad \text{CCN / CDNC}
\]

c.f. O’Connor et al (2021)
Cloud albedo changes (3)

Reduction in $\text{SO}_2 + \text{OH}$  
Reduction in $\text{H}_2\text{SO}_4$  
Reduction in new aerosol formation  
lower CDNC

Reduction in cloud albedo and positive cloud forcing

+SOA

$\text{ST}_{2x} - \text{ST}_{con}$

- $\text{SO}_4^{2-}$

CDNC column

$\text{CS}_{2x} - \text{CS}_{2\ con}$

$10^{10}$ droplets m$^{-2}$
Cloud Forcing

Greater cloud albedo reduction in ST → stronger positive forcing
Aerosol, chemistry and oxidants

More complex story when chemistry and oxidants considered.
Takeaways

1. Improvements to simulated chemistry can have wide-ranging impacts on climate via gas and aerosol phase processes.

2. This also invites assessment into the dependence of other natural chemistry-climate feedbacks on simulated chemistry (e.g., DMS).

3. The central role of oxidants suggests the climatic response to BVOC changes will also depend on the background atmospheric state.