Two-year record of trace gas fluxes and dynamics in snowpack and soils

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NSF PLR Project: Soil-Snow-Atmosphere Exchange of Mercury in the Interior Arctic Tundra Obrist & Helmig
DOE Office of Biological and Environmental Research Project: Yang, Obrist et al.
Goals

1. Constrain elemental cycling in the Arctic tundra
   • Contaminants: Hg, other trace metals
   • Trace gases: elemental Hg (Hg$^0$), O$_3$, NOx
   • GHG: CO$_2$ and CH$_4$

2. Trace gas exchange and dynamics:
   • Atmosphere-surface exchange using micrometeorological techniques
   • Atmosphere-snowpack-soil concentration profiles to quantify sink and sources
   • Temporal patterns including in mid-Arctic winter
Hg Cycling

Local and Regional transport

Dry deposition (gas and particulates)
- Hg$^0$ (>95%)
- Hg$^{II}$ gas
- Hg$^{II}$ particulate

Wet deposition (rain and snow)
- Hg$^0$
- Hg$^{II}$ gas
- Hg$^{II}$ particulate

Dry deposition (gas and particulates)
- Emission

Hg Cycling
Study Location – Toolik Field Station
Trace gas instrumentation – atmosphere

Net exchange (aerodynamic-MBR approach)

Elemental Hg\(^0\) (Tekran 2537 Air Hg Analyzers)

CO\(_2\)/CH\(_4\)/H\(_2\)O Analyzers (LGR Inc.)

Air temperature gradients, wind speed, RH, net radiation

O\(_3\)/NO\(_x\) Analyzers (Thermo Scientific)
Trace gas instrumentation – snow tower

Snow tower: measure snowpack gas concentration profiles (1 permanent over tundra, 1 seasonal over frozen lake)

Inlet heights

- 110 cm (atmosphere)
- 30 cm
- 20 cm
- 10 cm
- 0 cm

Gaseous $\text{Hg}^0 / \text{CO}_2 / \text{CH}_4 / \text{H}_2\text{O} / \text{O}_3 / \text{NOx}$
Trace gas instrumentation – soil wells

Soil wells: measure soil pore gas concentrations (3 soil depths [10, 20, 40 cm], 2 locations)

Gaseous Hg\(^{0}\)/ CO\(_2\)/ CH\(_4\)/ H\(_2\)O
Comprehensive field sampling to develop mass inventories in tundra plants, soils, snowpack (C, N, Hg, Al, Sr, Zr, Rb, Ti, Mn, Fe, Cr, Zn, Pb, Cu)

Hedge et al., Poster
Deposition dominated by gaseous Hg\(^0\) (71%; 6.5±0.7 μg m\(^{-2}\) yr\(^{-1}\))
Wet deposition (Hg\(^{II}\)) was 30 x lower (0.2±0.1 μg m\(^{-2}\) yr\(^{-1}\))
Dry deposition of Hg\(^{II}\) was 2.5 μg m\(^{-2}\) yr\(^{-1}\) (range 0.8 - 2.8 μg m\(^{-2}\) yr\(^{-1}\))
Hg\(^0\) in snow and soil

Atmosphere-snow-soil concentration profiles of gaseous Hg\(^0\)
Hg$^0$ in snow and soil

Atmosphere-snow-soil concentration profiles of gaseous Hg$^0$
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Hg\(^0\) in snow and soil

Atmosphere-snow-soil concentration profiles of gaseous Hg\(^0\)

- **Surface-atmosphere exchange (deposition)**
- **Diffusive and advective transport through snowpack**
- **Soil Hg\(^0\) uptake/sink**
Soil CO$_2$ concentrations

Soil concentrations of CO$_2$: 2 years

CO$_2$ concentration

Soil CO$_2$ source!

Soil conc. ('organic profile')

Soil conc. ('mineral profile')

Atmospheric conc.

<table>
<thead>
<tr>
<th>September 2014</th>
<th>September 2015</th>
<th>September 2016</th>
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<tbody>
<tr>
<td>Atmosphere</td>
<td>Soil conc.</td>
<td>Soil conc.</td>
</tr>
<tr>
<td>(-40) mineral soil</td>
<td>(-20) organic soil</td>
<td>(-10) mineral soil</td>
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</table>
Soil CO$_2$ concentrations

Soil concentrations of CO$_2$: wintertime

![Graph showing soil CO$_2$ concentrations from Oct 2015 to Apr 2016. The graph indicates that the highest soil CO$_2$ build-up occurs in fall/early winter and springtime.](chart)

- Atmospheric conc.
- Highest soil CO$_2$ build-up in fall/early winter and springtime

Soil CO$_2$ concentrations

Consistent wintertime CO$_2$ evolution

Micrometeorological Fluxes

$CO_2$ Exchange (mg m$^{-2}$ hr$^{-1}$)

-500 -400 -300 -200 -100 0 100 200 300 400

1000 2000 3000 4000 5000 6000 7000 8000 9000 10000

Oct-15 Nov-15 Jan-16 Mar-16

Soil temperatures

Air and soil temperatures

- Soil temperature < 10 °C
- Air temperature -40 °C
Soil CH$_4$ concentrations

Soil concentrations of CH$_4$: 2 years

- **Soil source!**
- **Soil sink!**
- **Atmospheric conc.** ('mineral profile')
- **Soil conc.** ('organic profile')

Legend:
- Red: atmosphere
- Orange: mineral soil
- Green: organic soil

CH$_4$ concentration (ppm)

- Sept 2014
- Sept 2015
- Sept 2016
Soil CH$_4$ concentrations

Soil concentrations of CH$_4$: wintertime

Micrometeorological Fluxes

- **Winter 2015/16**
- **Summer 2016**
Soil CH$_4$ concentrations

Soil concentrations of CH$_4$: wintertime

Poster D. Howard: CO$_2$ and CH$_4$ evolution under controlled freeze/thaw cycling
Soil CO₂ production in Toolik soils occurs throughout the year – incl. in mid-winter.

For CH₄, sinks and sources are in close proximity, and show different temperature sensitivities.

Soil diffusivity strongly determines concentration profiles (i.e., during freezing and thawing).
Atmosphere-snow-soil gas profiles reveal temporal and spatial information on sinks and sources.

Surface-atmosphere flux measurements are consistent with concentration profiles.

Two year deposition mass balance for Hg shows that gaseous Hg\textsuperscript{0} dominates (71\%) as a Hg source in the tundra.
Thank you