Fire and Ice: Climate Change and Changing Disturbance Regimes in Northern Alaska

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The heat is on!
Total change in annual mean surface air temperature (°C), 1958-2007 [from J. Walsh]
The Greening and the Browning of the Arctic and Boreal regions

- Verbyla 2008
- Goetz et al 2006
Soils underlain by permafrost contain almost 1700 Pg C, about 50% of all soil C and >2x that held in the atmosphere.
Something new on the horizon....
Why are tundra fires important?

Fire

Persistent Deeper Thaw
Depths Following Fire = Permafrost Degradation

Large Carbon and Nutrient losses during combustion

![Graph showing carbon and nitrogen combustion loss over years]

- Carbon: ~50 yrs
- Nitrogen: ~400 yrs
Anaktuvuk River Burn, MODIS, early June 2008

Hu et al. 2010: no fires in this area for past 5000 y
COMBUSTION LOSSES VS ANNUAL NEE OF KUPARUK BASIN:

C loss by combustion was
~2.16 Tg over 1039 km²
(measured by Mack et al. 2011)

Annual NEE of the Kuparuk R. catchment: 0.218 Tg net C LOSS (measured 1995-96 by Oechel et al. 2000) or 0.23 Tg net C GAIN (modeled 1980-2100 by McGuire et al. 2000) in 9200 km².

OR: Fire released as much CO₂ to the atmosphere as annual NEE of ~10 Kuparuk R. watersheds in ~10% of the area of one Kuparuk R. watershed
The US B-53 Nuclear Bomb
Explosive yield \( \sim 9 \) Megatons
1 Megaton = \( 4.2 \times 10^{15} \) Joules

The Anaktuvuk River Burn
Energy released by combustion of organic matter
\( \sim 93 \times 10^{15} \) Joules, equivalent to
\( \sim 22 \) Megatons TNT
Tundra Fire Return Intervals

- Fire return intervals vary by orders of magnitude.
- Tundra fires sensitive to temp.

### Annual Burned Area (10³ km²)

- Present *
- 2050 *

### Ecoregion

- Coastal
- North Slope
- Brooks Range
- Noatak
- Lowlands
- Seward
- South West

### Map Highlights

- Point Hope: ~5000 yrs
- Deadhorse: >10,000 yrs
- Nome: 400 yrs
- Bethel: 1000 yrs

### Graph

- Summer PPT (mm)
- Summer Temp. (°C)
- 2050 *
McGuire et al. 2000:

NEP of PanArctic tundra varies from -30 to +40 g C/m²/y,

NEP of Kuparuk watershed is currently ~15-25 g C/m²/y

Change in NEP due to climate change is ~0.3 g C/m²/y
2007 Anaktuvuk River Fire

Area burned: 1039 km²
C released: ~2.16 Tg
# Summary of initial changes in C balance due to climate change and fire

<table>
<thead>
<tr>
<th>Area</th>
<th>Yearly NEE (mean predicted)</th>
<th>Change in NEE in 1 year due to:</th>
<th>2007</th>
<th>2008</th>
<th>2008</th>
</tr>
</thead>
<tbody>
<tr>
<td>one m²</td>
<td>~-20 g C</td>
<td>Warming</td>
<td>~-0.3 g C</td>
<td>2.02E+3 gC</td>
<td>93 gC</td>
</tr>
<tr>
<td>AR Burn</td>
<td>-2.1E+10 gC</td>
<td>Combustion</td>
<td>2.16E+12 gC</td>
<td>9.7E+10 gC</td>
<td>1-2E+09 gC</td>
</tr>
<tr>
<td>N Slope</td>
<td>-3.8E+12 gC</td>
<td>Recovery</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Aquatic loss</td>
<td></td>
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</tbody>
</table>
Although the area disturbed is relatively small, changes in response to disturbances (fire, thermokarst) are much greater and faster than direct responses to climate.

Changes in C cycling on disturbed sites are large enough that the regional response to climate change may be dominated by changes in disturbance regime, not direct impacts of climate change.
What are the long-term impacts of fire?
Carbon stocks on the ground follow predictions of NEE model first 35 years.

Figure 5. Charred material preserved in soil column. Example of soil plugs taken from the (a) Meade River site and the (b) Ketik River site. Arrows depict charred horizon and smear tests shown in lower left.
Insights from Modeling NEE
Long-term Recovery from Fire

Long term recovery of C stocks is limited by slower recovery of N and P stocks.
Current (stable) climate versus IPCC B1 climate (warmer, wetter, higher CO2)

With a gradually warming (IPCC B1) climate, NEP is more variable but C accumulates at 3-4 g C m⁻² y⁻¹.

Under current climate, C accumulates very slowly (<1 g C m⁻² y⁻¹).
Under current climate it would take 1200-1500 years to recover to pre-burn C stock.

With a warmer, wetter, higher-CO2 (B1) climate it would take 300-500 years to recover to pre-burn C stock.
How much wildfire would it take to cancel long term effects of climate change on North Slope C stocks?
Wildfire vs Climate Change: Which has a greater effect on C balance?

1,039 km² Anaktuvuk River Burn
- C loss by combustion
- Net C loss after 200 years, current climate
- Net C loss after 200 years, B1 climate

188,000 km² N. Slope
- Annual NEE, current climate
- Annual NEE, B1 climate

200 y NEE, current climate
- 200 y NEE, B1 climate
Wildfire and Climate Change

- Combustion losses may dominate regional C balance in year of burning
- Large swings in C balance in recovering burns may dominate local C balance 1-2 decades after fire
- Initial C losses by combustion are not recovered because N and P losses limit C recovery
- Short term effects of climate change on C balance are small relative to combustion losses and initial changes in NEE as vegetation recovers
- Longer term (200 y) changes in C balance are dominated by changes in climate and interactions with N and P inputs and turnover
NEXT PROBLEM: What is the background rate of burning?

Jones et al. 2013 JGR-Bio.
THE END
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