A surface energy budget approach to understanding the CMIP5 inter-model spread in Arctic Amplification

Patrick Taylor and Robyn Boeke
Climate Science Branch
NASA Langley Research Center
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In 2018, there have already been 61 hours above freezing at Cape Morris Jesup, Greenland.

The previous record was 16 hours before the end of April in 2011.

8:02 PM - Feb 25, 2018

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Source: https://www.theweathernetwork.com/
Associated rare polynya: Lasting more than 3 week.
Transformation form multi-year to first-year sea ice.

Arctic sea ice cover continues to decline.

Source: NSIDC
Nature of Arctic Amplification

More model disagreement in the Arctic than any other region

Most warming in fall/winter

Bottom heavy warming profile
Where and when do CMIP5 model differ on Arctic warming projections?

Largest differences between CMIP5 models occur in fall and winter in the Barents-Kara Seas and the Chukchi-Beaufort Seas regions.

Boeke and Taylor (in revision)
Method: Surface energy budget decomposition
Lu and Cai (2009)

Surface energy budget Eq.:
\[ Q = (1 - \alpha) S \downarrow_{sw\ down} + F \downarrow_{lw\ down} - \varepsilon \sigma T_s \uparrow_4 - (S + L) \]

Rewriting using clear-sky fluxes and cloud radiative effects and solving for \( \Delta T_s \)
\[ \Delta T_s = \text{(the sum of)} \]

<table>
<thead>
<tr>
<th>FEEDBACK</th>
<th>PTC (K)</th>
<th>ANNUAL MEAN (K)</th>
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</thead>
<tbody>
<tr>
<td>Surface Albedo Feedback (SAF)</td>
<td>[ \frac{-(\Delta \alpha)(S \downarrow + \Delta S \downarrow)}{4 \sigma T_s^3} ]</td>
<td>1.82 ± 0.77</td>
</tr>
<tr>
<td>Cloud Forcing (CRE)</td>
<td>[ \frac{(1 - \alpha) \Delta S \downarrow_{CLD} + \Delta F \downarrow_{CLD}}{4 \sigma T_s^3} ]</td>
<td>0.69 ± 0.88</td>
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<tr>
<td>non-SAF shortwave clear-sky feedbacks</td>
<td>[ \frac{(1 - \alpha) \Delta S \downarrow_{CLR}}{4 \sigma T_s^3} ]</td>
<td>-0.43 ± 0.20</td>
</tr>
<tr>
<td>Longwave clear-sky feedbacks (LWCS)</td>
<td>[ \frac{\Delta F \downarrow_{CLR}}{4 \sigma T_s^3} ]</td>
<td>7.27 ± 1.4</td>
</tr>
<tr>
<td>Change in ocean heat storage (HSTOR)</td>
<td>[ \frac{-\Delta Q}{4 \sigma T_s^3} ]</td>
<td>-0.30 ± 1.2</td>
</tr>
<tr>
<td>Change in latent and sensible heat fluxes (HFLUX)</td>
<td>[ \frac{-\Delta (S + L)}{4 \sigma T_s^3} ]</td>
<td>-1.67 ± 0.86</td>
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LW clear-sky feedbacks dominate the Arctic warming signal.
Contributions to surface temperature change--Strong seasonality

SAF strongly warms surface in summer.

HSTOR “cools” surface in summer and “warms” surface in summer.

HFLUX show no change in summer and cool surface in fall/winter.

The seasonality of these contributions is amazingly consistent across models.
How are the model differences spatially distributed?

Radiative feedback spread => spatially uniform

Surface non-radiative feedback spread => regionally-focused
Regions that warm most have the largest feedback contributions…most of the time

SAF exhibits a U-shape meaning that both regions of small and large warming exhibit a strong feedback.

Boeke and Taylor (in revision)

Two models dominate the spread in cloud feedback

HSTOR and HFLUX show equal and opposite values.
A complete picture of Arctic Amplification?

Local Mechanism:
- Sea Ice → Summer SAF → Summer HSTOR
- Warmer, moister, cloudier Arctic atmosphere
- Fall/Winter HFLUX

Remote Mechanism:
- LWDN
- Fall APHT
- Non-polar circulations changes

LWDN is the dominant term contributed to Arctic Amplification.

Key Terms:
- APHT = Atmos. Poleward heat transport
- LWDN = Downward LW radiation
- SAF = Surface Albedo Feedback
- HSTOR = Ocean heat storage/transport
- HFLUX = Surface turbulent fluxes
Atmospheric poleward heat transport induces a spatially uniform warming.
Local mechanism sets the spatial structure of Arctic amplification.

Driver of inter-model spread!
A larger annual cycle ocean heat storage amplitude increase => larger projected warming

A strong positive correlation is found between the changes in the seasonal amplitude of ocean heat storage and projected Arctic Amplification.

Thus, processes controlling the seasonality of ocean heat storage (upper ocean mixing, absorbed solar radiation, surface turbulent fluxes) may hold the key to unraveling inter-model differences in Arctic Amplification.

Summer => ability to store energy (mixed layer depth, ASR)
Fall/winter => ability to release energy (surface turbulent fluxes)
Models increase both SAF and fall/winter HFLUX

Surface turbulent flux changes in the Barents-Kara Seas region are show a statistically significant relationship with the model simulated SAF.
LWCS sets the Arctic-wide magnitude of warming, and explains why all models produce AA. Both models and spatial regions with the largest LWCS increases, warm more.

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We hypothesize that the connection between the B-K Seas region and the rest of the Arctic (via LWCS) is controlled by the atmospheric circulation response.
Takeaway messages:

(1) Physical process of Arctic Amplification. Barents-Kara Sea region as a pacemaker of warming.

(2) Do clouds matter to Arctic Amplification and sea ice loss? Yes. However, the most important aspect may not be the direct impact, but rather indirect impacts by modulating other responses (e.g., the circulation response).

(3) What is the way forward? System approaches and multi-disciplinary perspectives.
Increased B-K Sea region surface turbulent fluxes have an Arctic-wide impact

Surface turbulent flux changes in the Barents-Kara Seas region show an Arctic-wide impact on LWCS, magnitude of which is strongest locally.