Sea ice influences on projected changes in Arctic surface heat budgets

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Projected Change in Surface Air Temperature

Results from CESM-CAM5 Large Ensemble (Kay et al., 2015)

- Amplified Arctic warming
- Warming rates elevated 3-4 times above the global average
- Largest surface air temperature change in fall/winter (>20°C)
Simulated Surface Heat Flux Change

As in other models, the CESM-LE exhibits:

- Surface heating in summer - increased net shortwave
- Increased flux of heat to the atmosphere in fall/winter

2060-2080 relative to 1920-1950 (positive down)
What controls the surface albedo response?

Changes in ice area
Largest at end of melt season (Sept)
Incoming SW <50 W/m²

CESM-LE
September Ice Extent

Sept 1979
7.2 million km² Extent

Sept 2012
3.6 million km² Extent

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What controls the surface albedo response?

- Changes in albedo of ice itself
- Changes in ice area

**Sept 1979**
- 7.2 million km² Extent

**Sept 2012**
- 3.6 million km² Extent

Largest at end of melt season (Sept)
- Incoming SW <50 W/m²

Mostly at melt onset ~June
- Incoming SW >250 W/m²

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Factors affecting the albedo of sea ice are projected to change in the 20\textsuperscript{th}-21\textsuperscript{st} century.

**Day of Melt Onset**

- CESM-LE Simulations

**Arctic Pond Fraction**

- June
- July

**CESM-LE simulations**
Arctic Surface Shortwave Budgets

- With declining ice albedo, more absorbed SW in ice, especially in June & July
- More SW absorbed in ocean with reduced ice cover
Arctic Surface Shortwave Budgets

- With declining ice albedo, more absorbed SW in ice, especially in June & July
- More SW absorbed in ocean with reduced ice cover
- Later in 21st century, ice area change dominates, but ice albedo change remains important in June at melt season start

Change due to ice area loss
Change due to ice albedo
Simulated Arctic Surface SW Budgets

- Surface SW absorption increases
- Incoming shortwave radiation decreases

Change due to ice area loss
Change due to ice albedo
Change due to incoming SW

1990-2009

2040-2059

2060-2079

Change due to ice area loss
Change due to ice albedo
Change due to incoming SW
Investigating Uncertainty in Climate Model Projections

How do these factors affect across-model scatter in climate projections?
Projected Change in Surface Air Temperature

Amplification Factor:
- Change in zonal average relative to global mean change
- All models show amplified warming
- Model scatter in magnitude of amplification is large
Across model scatter in Arctic warming is related to changes in the net solar heating.

Zonal Surface Air Temperature Change Relative to Global Change (2080-2100 minus 1980-2000)

R = 0.83
Projected Changes in Solar Heating at 2050

Net SW Change due to Albedo

Change due to Surface Albedo Change

Net SW Change due to SWDN

Change due to Incoming Solar Radiation Change

Change in Surface Net Shortwave Flux in CMIP5 models at Year 2050

70-90N
Important role of ice area change

- Albedo-related Solar Heating change is strongly correlated with change in ice concentration
- However, even for similar ice loss amount, the heating change can vary by a factor of ~3
For the same ice area loss, change influenced by initial albedo

For the same ice loss, the increase in albedo-related net solar heating can vary by a factor of >3

For the same ice area loss – Larger increases in net solar heating occur in models with higher initial (late 20\textsuperscript{th} century) surface albedo
Late 20th century surface albedo influenced by:

- Simulated surface state
  - snow conditions
  - ponding on sea ice
- Albedo tuning may also play a role
Conclusions

• Net Arctic surface heating is driven by increased shortwave absorption that is partly compensated by declining incoming solar radiation

• Projections of Arctic surface albedo decline include contributions from:
  – Reduced ice albedo
  – Increased open water area

• Models have large uncertainty in their future Arctic change due in part to albedo projections
  – Different ice loss rates
  – Different initial surface albedo
Questions?
Across-Model Scatter in Arctic Shortwave Heating

Change in Annual Net Surface Shortwave Radiation

28 CMIP5 Models
RCP8.5 Forcing

Ann SWNet

Ann SWDN

W m$^{-2}$

70-90N

2020
2040
2060
2080
2100

0
5
10
15
20

2000
Changes in Net Shortwave Radiation due to Incoming Shortwave Change

Relationship to Surface Albedo Changes
Surface Albedo and Net Shortwave Budgets

- Enhanced warming
- Positive Albedo Feedback
- Sea ice melt – ice area loss & changing ice surface
- Reduced Albedo
- Increased solar absorption
- Decreased Multiple Scattering
- Decreased Incoming Surface Solar Radiation
Improving our ability to predict

Sea ice physics
- Improved representation of ice surface properties

Improved coupling
- Better representation of surface fluxes, for example precipitation and radiation
- Cloud interactions

(b) August

Ice Concentration Change

Average Albedo Reduction

-0.4 -0.3 -0.2 -0.1 0.0

Holland et al., 2012

(NASA GSFC, ICESCAPE project)
Changing Surface Albedo and Surface Heating

Surface albedo reductions:
• Enhance solar absorption (enhance warming)
• Affect multiple surface reflections with overlying clouds and reduce incoming solar radiation (reduce warming)
Inter-model Scatter in Arctic Warming due to various feedbacks

Differences in albedo feedback strength are associated with a large fraction of the scatter in Arctic warming

Pithan and Mauritzen
Nature Geosci, 2014
Enhanced warming

Positive Albedo Feedback

Reduced Albedo

Increased solar absorption

Sea ice melt
Model Simulations

- CESM-CAM5 Large Ensemble
- 30 Members
- 1920-2100
- RCP8.5 forcing
- Reach near ice-free Sept (<1 million km$^2$) from 2032-2053
Arctic Surface Shortwave Budgets

- With declining ice albedo, more absorbed SW in ice, especially in June & July
- More SW absorbed in ocean with reduced ice cover

Diagnose changes in surface net shortwave associated with a changing surface albedo

Change for 1990-2009 average relative to 1920-1950

Change due to ice area loss
Change due to ice albedo
Arctic Observations
From the SHEBA Drifting Station

Albedo of Sea Ice

Arctic Ice Extent Trends

(Perovich et al., JGR, 2002)
Arctic Observations
From the SHEBA Drifting Station

Albedo of Sea Ice

Incoming Surface Solar Radiation

(Perovich et al., JGR, 2002)
Simulated Arctic Surface SW Budgets

- Surface SW absorption increases
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Change in Ann SWDN Terms

Transmissivity
Multiple Reflections

(Diagnosed using method from Winton 2005)