Changes in Sea Ice Extent Will Outweigh Changes in Snow Cover in Future Arctic Climate Change




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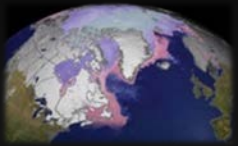
Motivation

- Recent declines in Arctic sea ice and snow extent have led to an increase in solar energy absorption at the surface, resulting in additional heating and a further decline in snow and ice.
- How do the trends in absorbed (net) solar radiation at the surface over land and ocean compare? What is the relative importance of the ice-albedo and the snow-albedo feedbacks?
- Here we examine how changes in surface albedo over the ocean and land areas of the Arctic have affected shortwave absorption differently, and how this interplay between albedo and shortwave absorption may change in the future.

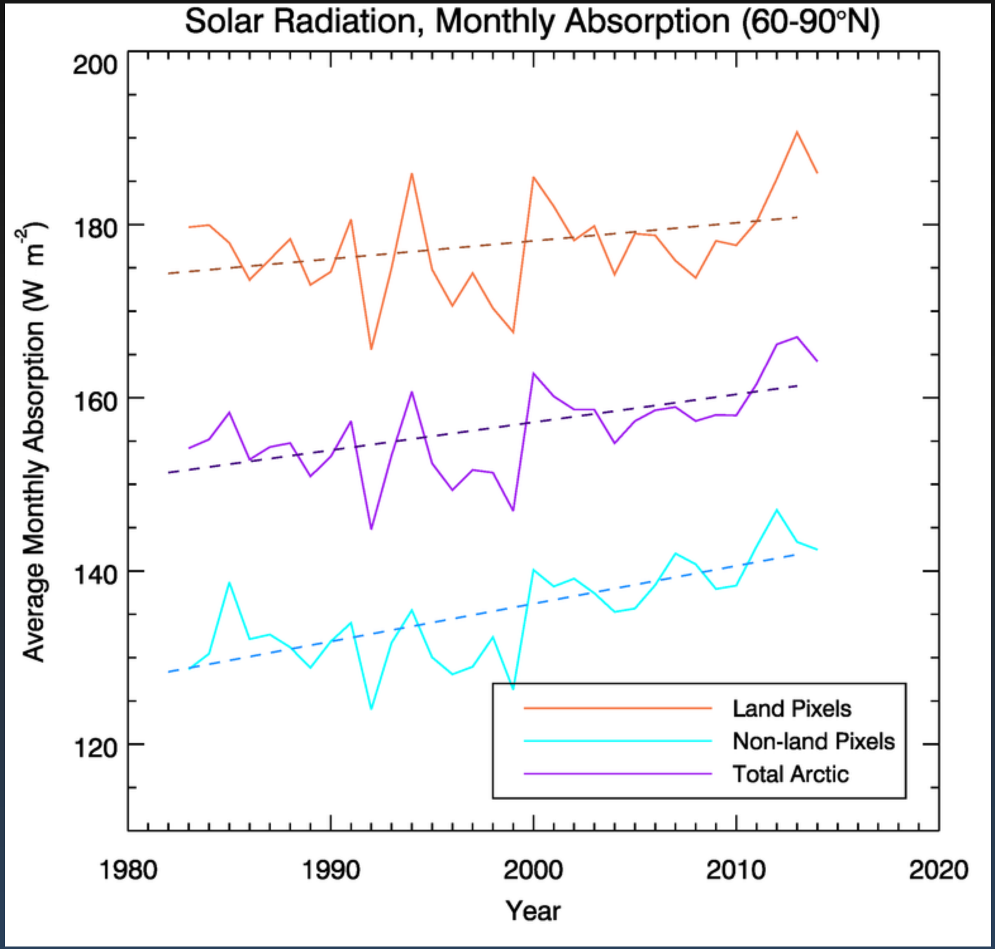
Data and Methods

- Primary dataset: AVHRR Polar Pathfinder Extended (APP-x), 1982 – 2015 (it actually is available up to the present), 25 km, high-sun time (14:00 local solar time). APP-x includes surface radiation, surface temperature, surface albedo, cloud properties, and more.
- Reanalysis: NASA MERRA2 (Modern-Era Retrospective Analysis for Research and Applications 2) is used to provide verification of the results from APP-x.
- Study area: Land and ocean, 60-90°N latitude. Over this domain, land and ocean areas have almost the same area (ocean is 3.6% larger).



Trends in Absorbed Solar Radiation

The annual mean absorbed solar radiation at the Arctic surface has increased over the period 1982-2015, though the magnitude and rate were different over land and ocean. Land: 0.21 W m^{-2} yr^{-1}; ocean: 0.43 W m^{-2} yr^{-1}. Absorption over the ocean increased by 0.3% of the annual mean absorption per year, resulting in an approximate 10% increase over 34 years. Over land, the increase was 0.09% of the annual mean per year, or about 2.7% over the study period.



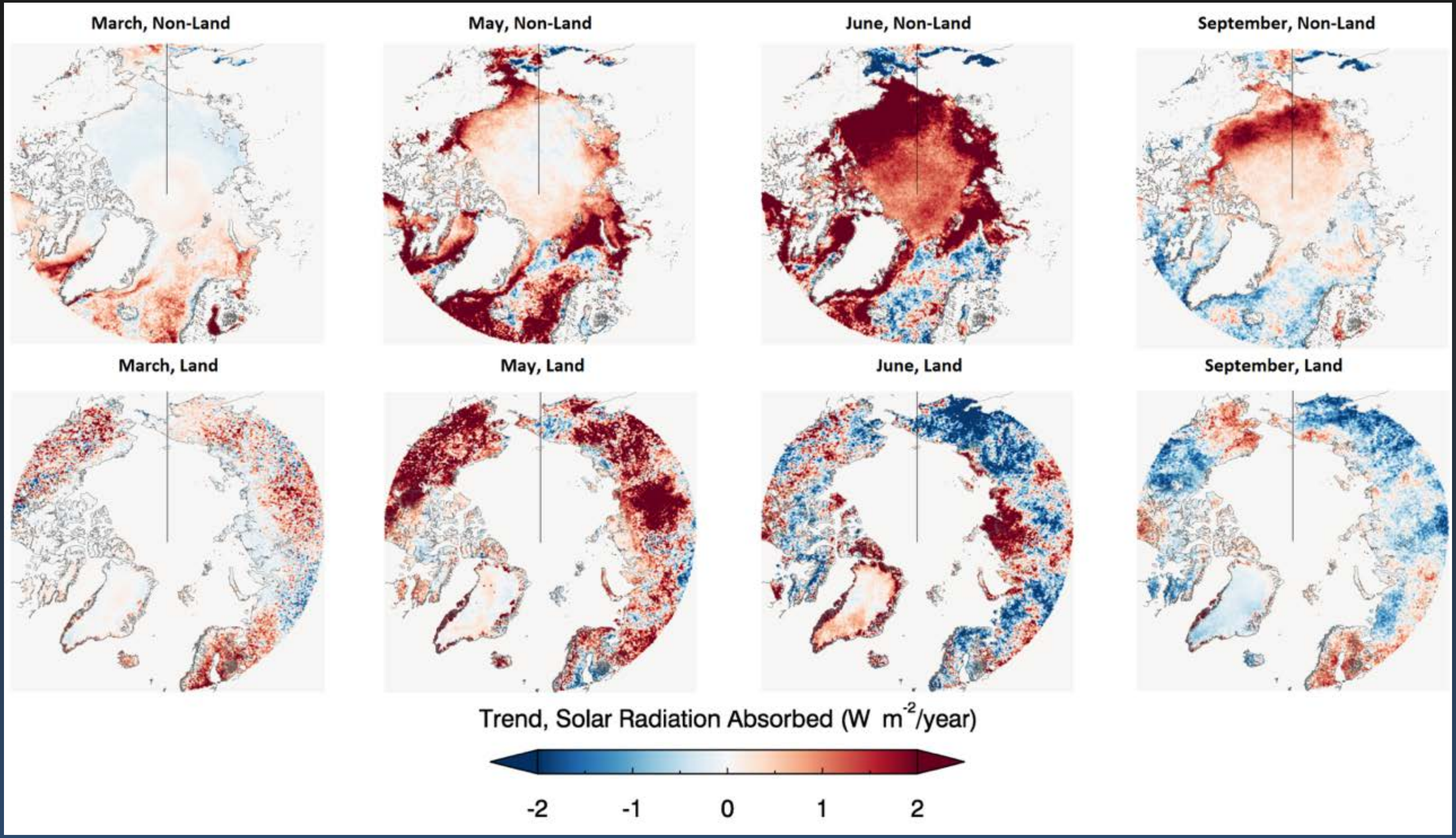
Average monthly shortwave absorption per year (W m^{-2}), 60-90°N for combined land and ocean (purple), land only (orange), and ocean only (cyan). Dotted lines are linear trends.

Spatial Distribution of Trends

A strong increase in absorption due to decreasing springtime snow cover is seen in May. June to October, the ocean area absorption rate increased faster than absorption over land.

Ocean

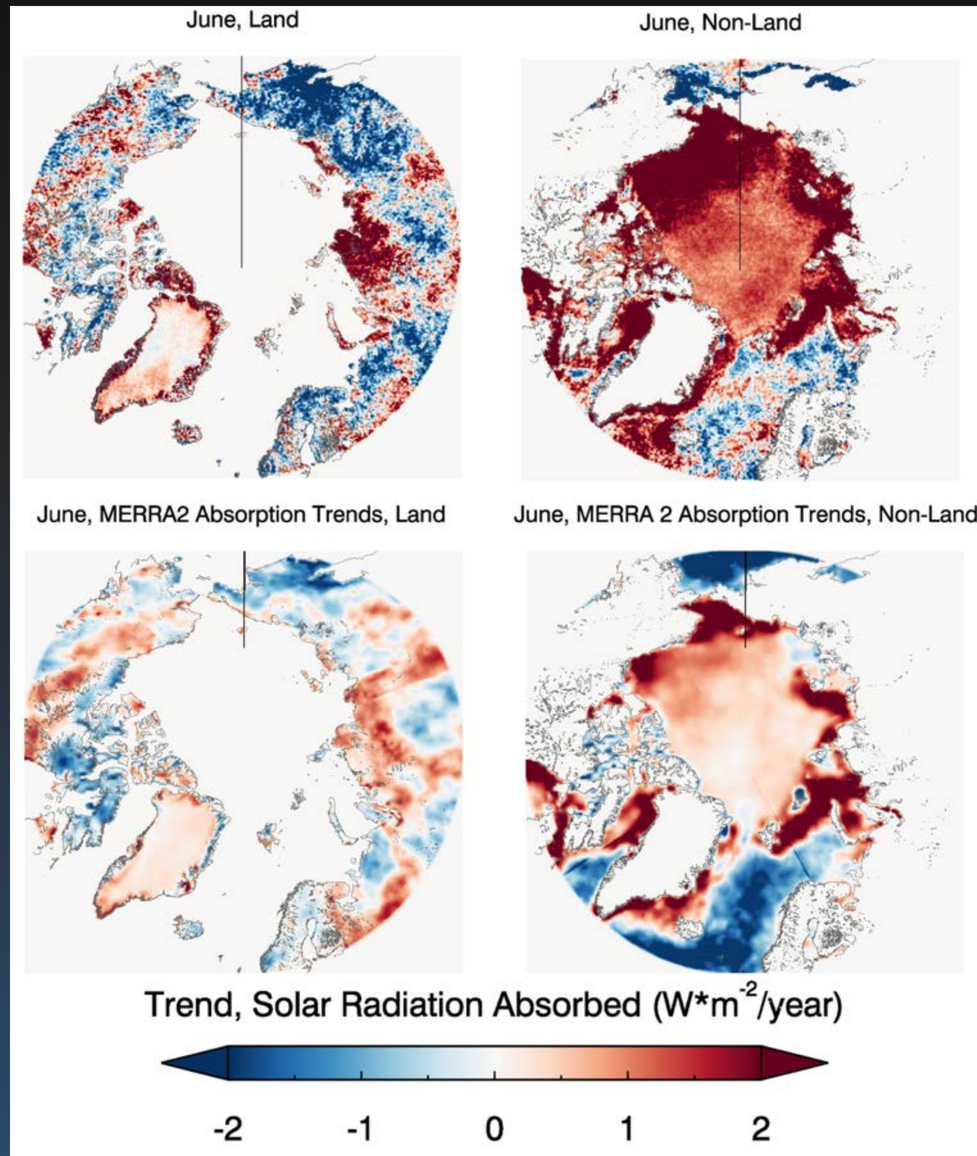
Land



Trends in absorbed radiation for selected months over ocean (top) and land (bottom).

APP-x vs MERRA2

The trends in absorbed radiation from APP-x and MERRA2 show similar patterns, though with larger magnitudes in APP-x.



APP-x

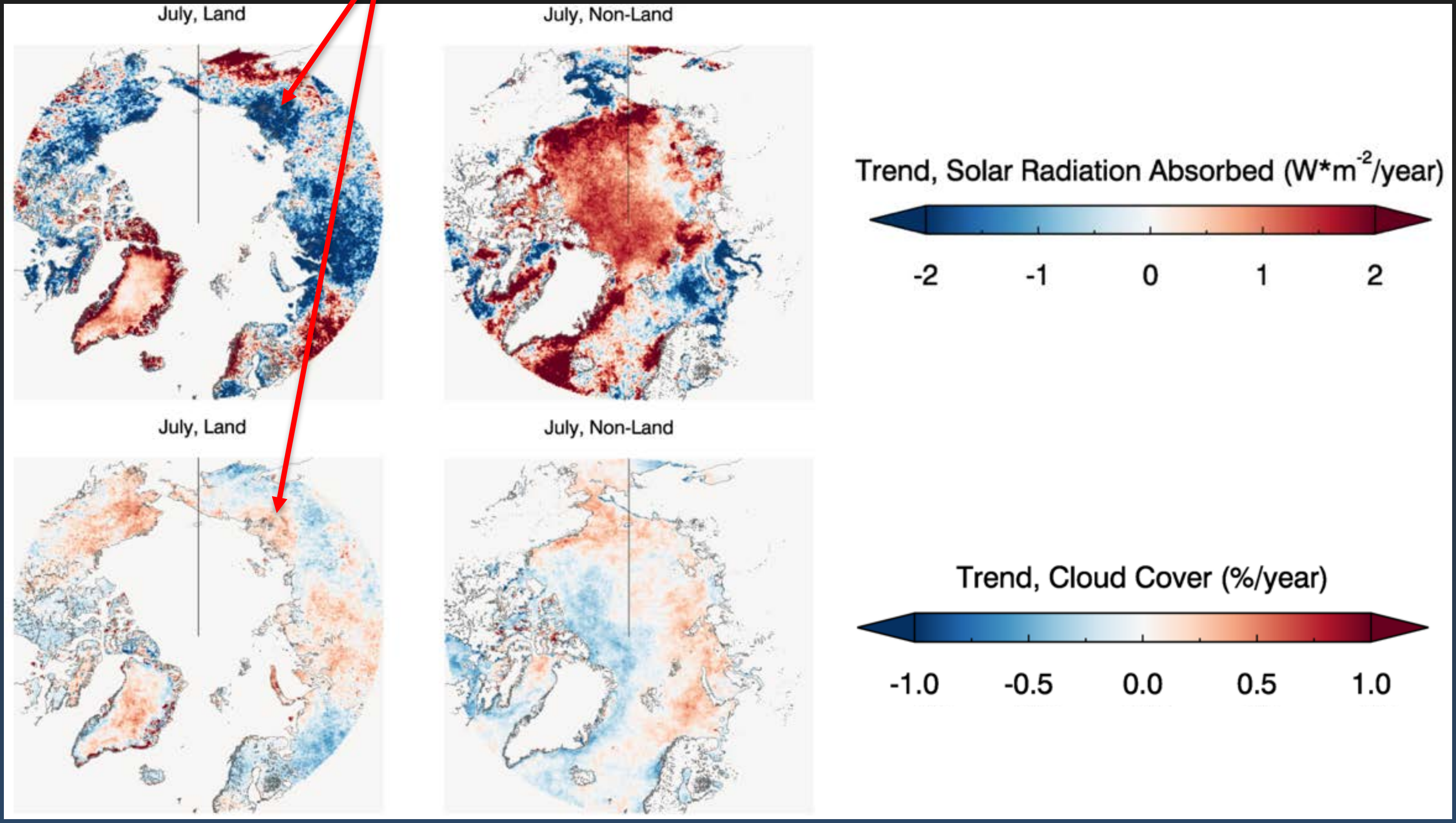
MERRA2

Trends in absorbed radiation from APP-x over land (top left) and ocean (top right) compared to trends from MERRA2 over land (bottom left) and ocean (bottom right).

Cloud Cover

Over land, an increase (decrease) in highly reflective cloud cover is associated with an decrease (increase) in surface absorption.

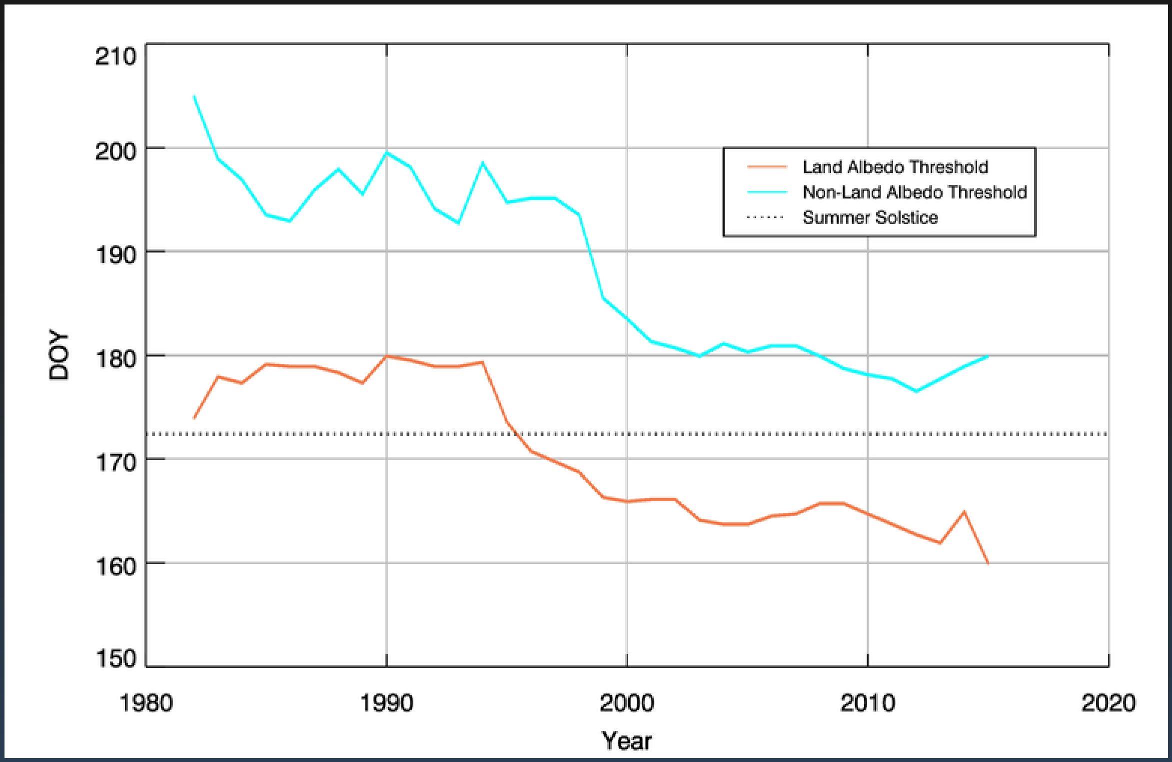
The ocean also experienced changes in cloud cover, but the effect on trends in absorption is less because most of the ocean is ice-covered and the reflectivities of ice and cloud are similar.



Trends in absorbed radiation over land (top left) and ocean (top right), and cloud cover trends over land (bottom left) and ocean (bottom right).

Timing of Low Albedo

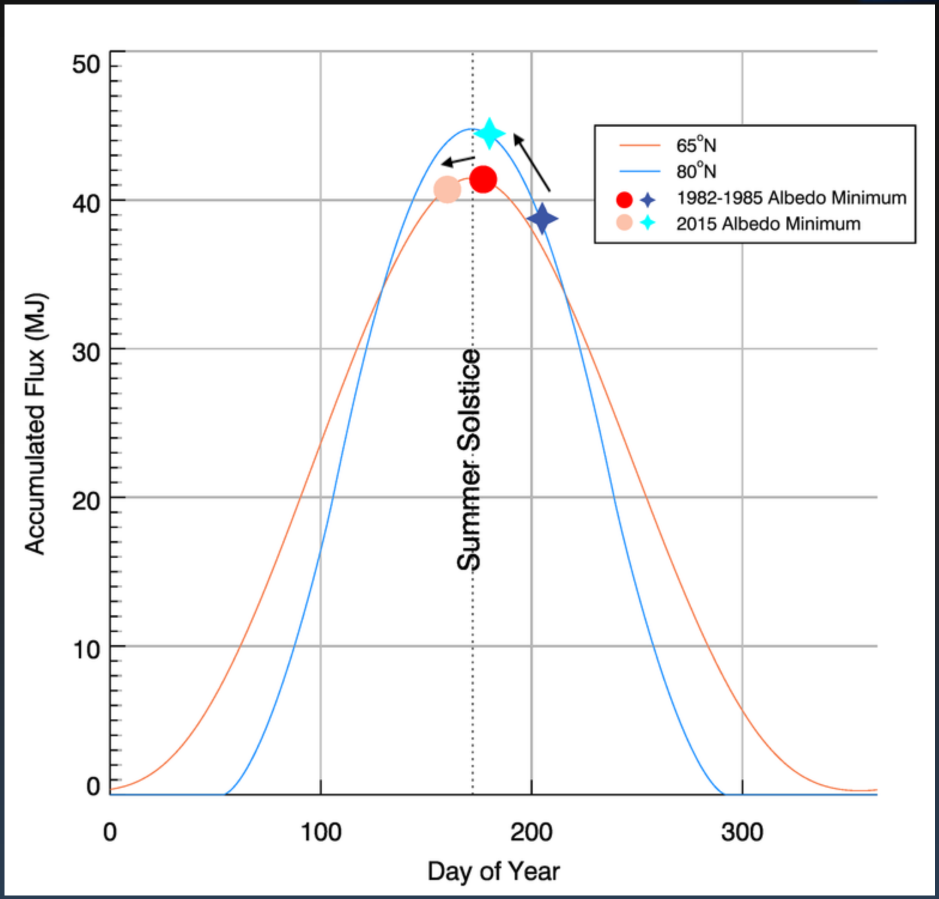
In the first few years of APP-x (1982-1985), the minimum average albedo over the Arctic Ocean was reached during the first two weeks of September. The mean minimum albedo during this period was 0.265. This is the “ocean low-albedo threshold”. A similar “land low-albedo threshold” (0.268) was found, which occurs between late June and early July. The day-of-year (DOY) that these low-albedo thresholds were reached over land and ocean was determined for each year of the study period.



Day of year (DOY) when the low-albedo threshold was reached over land (orange) and ocean (cyan), 1982-2015. The dotted line is the summer solstice.

Timing of Low Albedo, cont.

Over ocean, the movement of lower albedos to earlier in the year means that more sunlight was absorbed over the ocean in 2015 than in 1982. Over land, the regression of low albedo towards earlier in the year still results in an increase in absorbed energy, but it can only increase asymptotically due to decreasing sunlight further from the summer solstice.



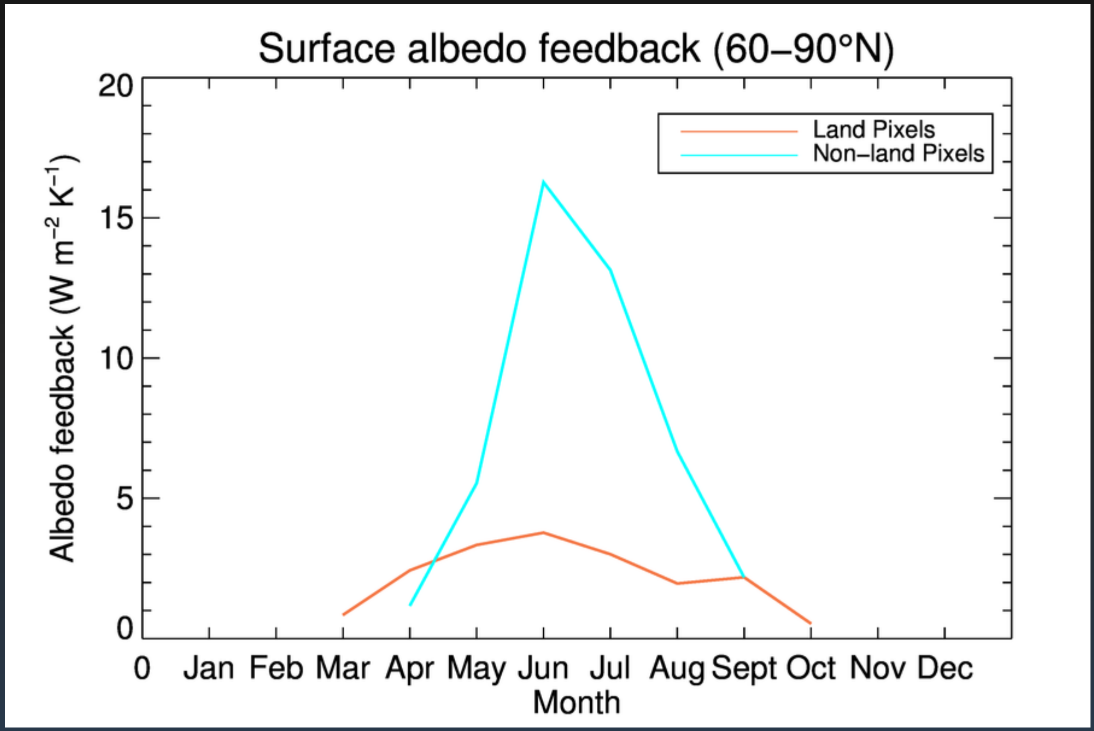
Average TOA insolation at 14:00 Local Solar Time over the 65°N (orange) and 80°N (blue) latitudinal bands, roughly representing the Arctic Ocean and Arctic land. Darker symbols represent the day of year that the low-albedo threshold was reached over land (circle) and ocean (star) in 1982-1985, while lighter symbols show the day of year of the 2015 threshold.

Albedo Feedbacks

The strength of the albedo feedback can be quantified as the change in TOA net shortwave radiation with respect to surface temperature due to changes in surface albedo:

$$\frac{\partial Q}{\partial T} = -I \frac{\partial \alpha_p}{\partial \alpha_s} \frac{d\alpha_s}{dT}$$

where Q is the net (absorbed) shortwave radiation at the top of the atmosphere (W m^{-2}), I is incoming solar radiation at the top of the atmosphere (TOA) surface (W m^{-2}), T is surface temperature (K or C), α_p is the planetary (TOA) albedo, and α_s is the surface albedo.



The snow-albedo and ice-albedo feedbacks for Arctic land (orange) and ocean (cyan) for the period 1982-2015.

The magnitude of the ice-albedo feedback is four times that of the snow-albedo feedback in summer.

Summary

Using 34 years of satellite data, we found that:

- The trend of solar absorption over the ocean is more than double that over land.
- The magnitude of the ice-albedo feedback is four times that of the snow-albedo feedback in summer. The stronger surface albedo feedback over the ocean at the high-sun time of the year will amplify the warming effect.
- The low albedo period each year has been changing such that over ocean it is moving toward the summer solstice, while over land it is moving away from the solstice. Therefore, decreasing sea ice cover, not changes in terrestrial snow cover, may be the foremost radiative feedback mechanism affecting future Arctic climate change.