From Flakes to Floes: Snow in the Changing Arctic Sea-Ice System

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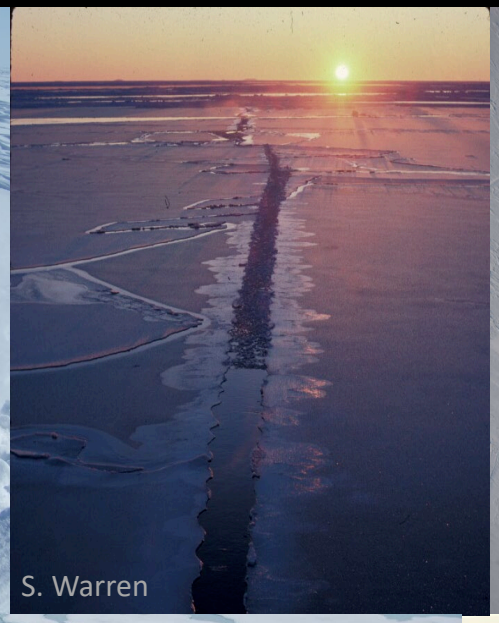
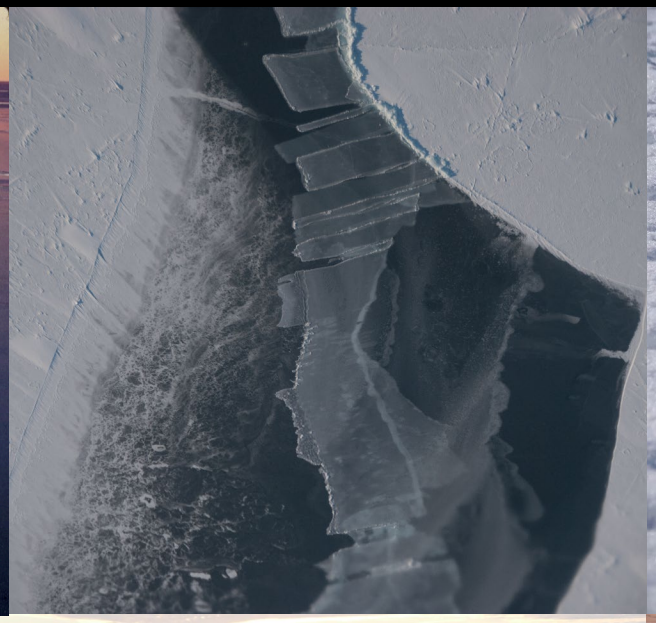
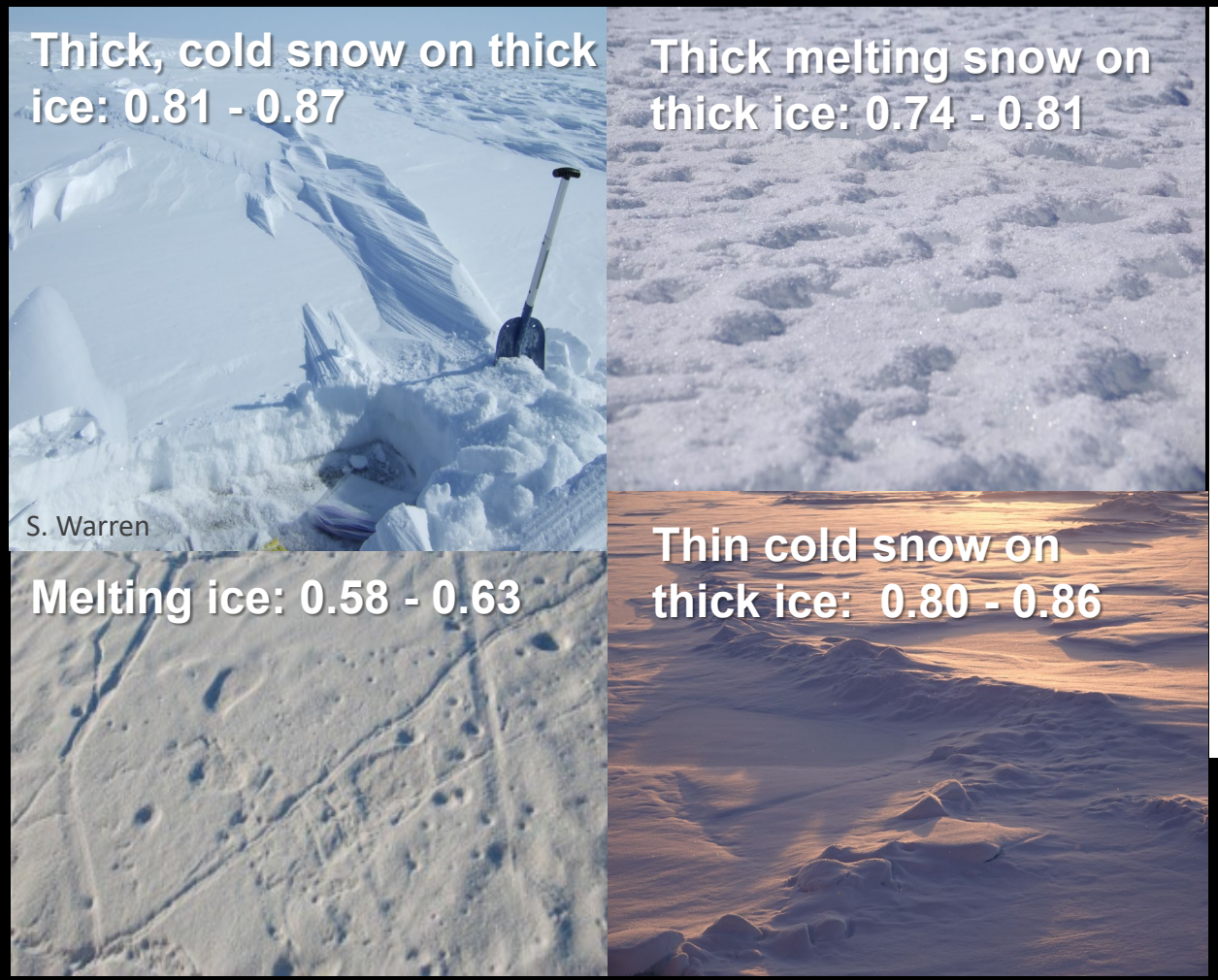
NASA

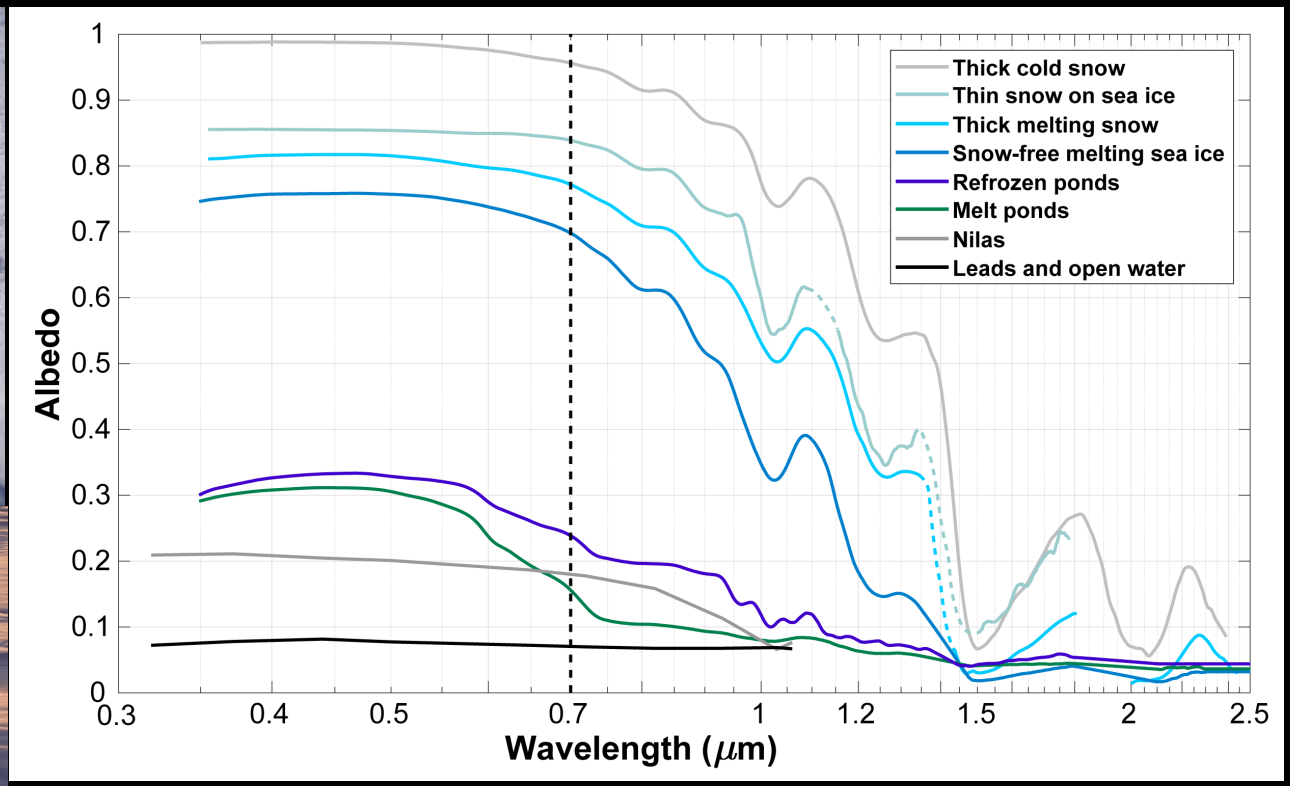
Sea ice has a complex, heterogeneous surface:





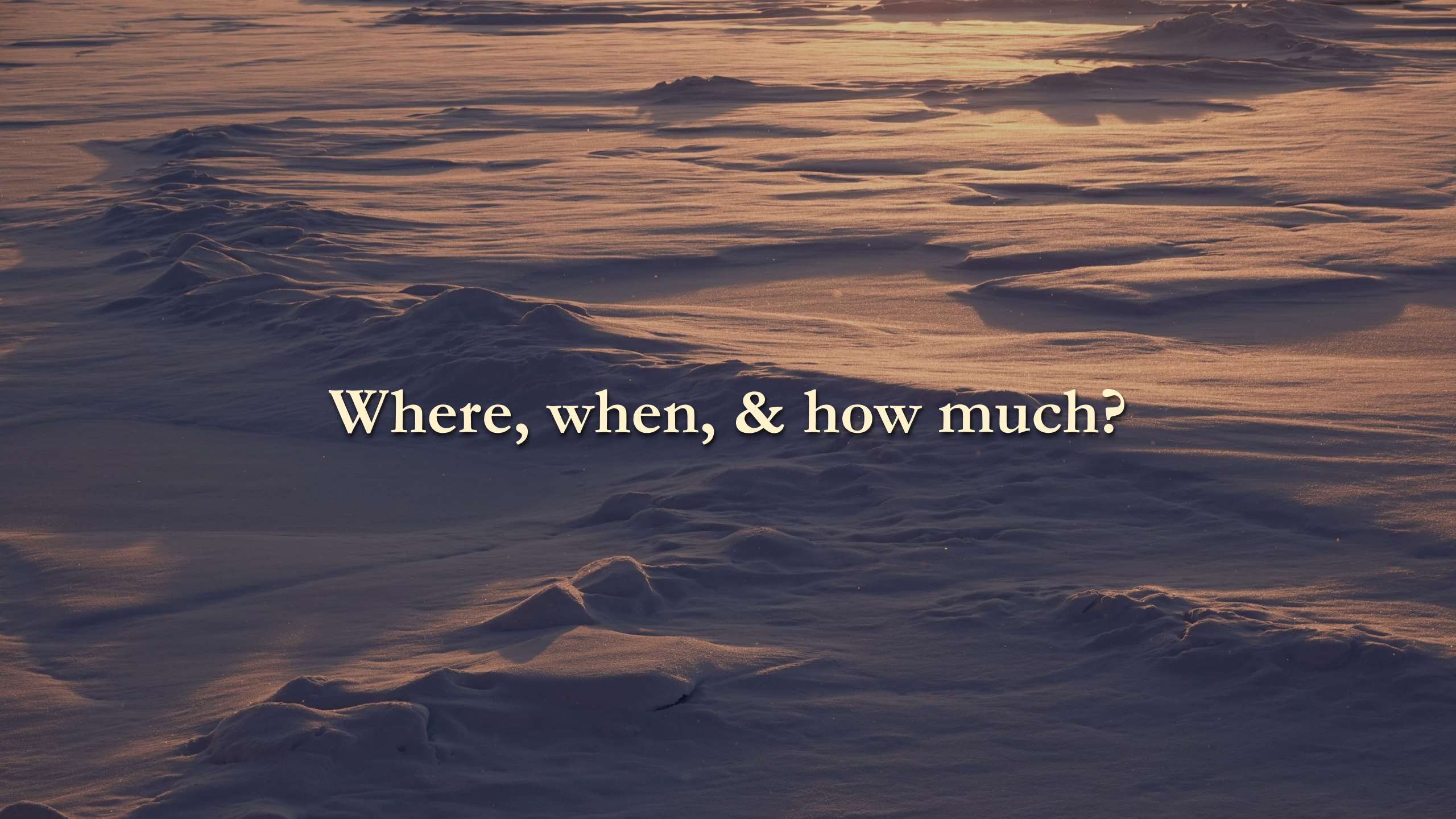
The dominant surface types are… snow-covered!





- Snow covered-ice is the most widespread surface condition.
- Snow covers sea ice most of the year.

Webster & Warren (2022), *Earth's Future*


Where, when, & how much?


Snowy Summers

What may cause snowy summers?

1. Leftover snow from autumn-spring accumulation,
2. New snow accumulation.

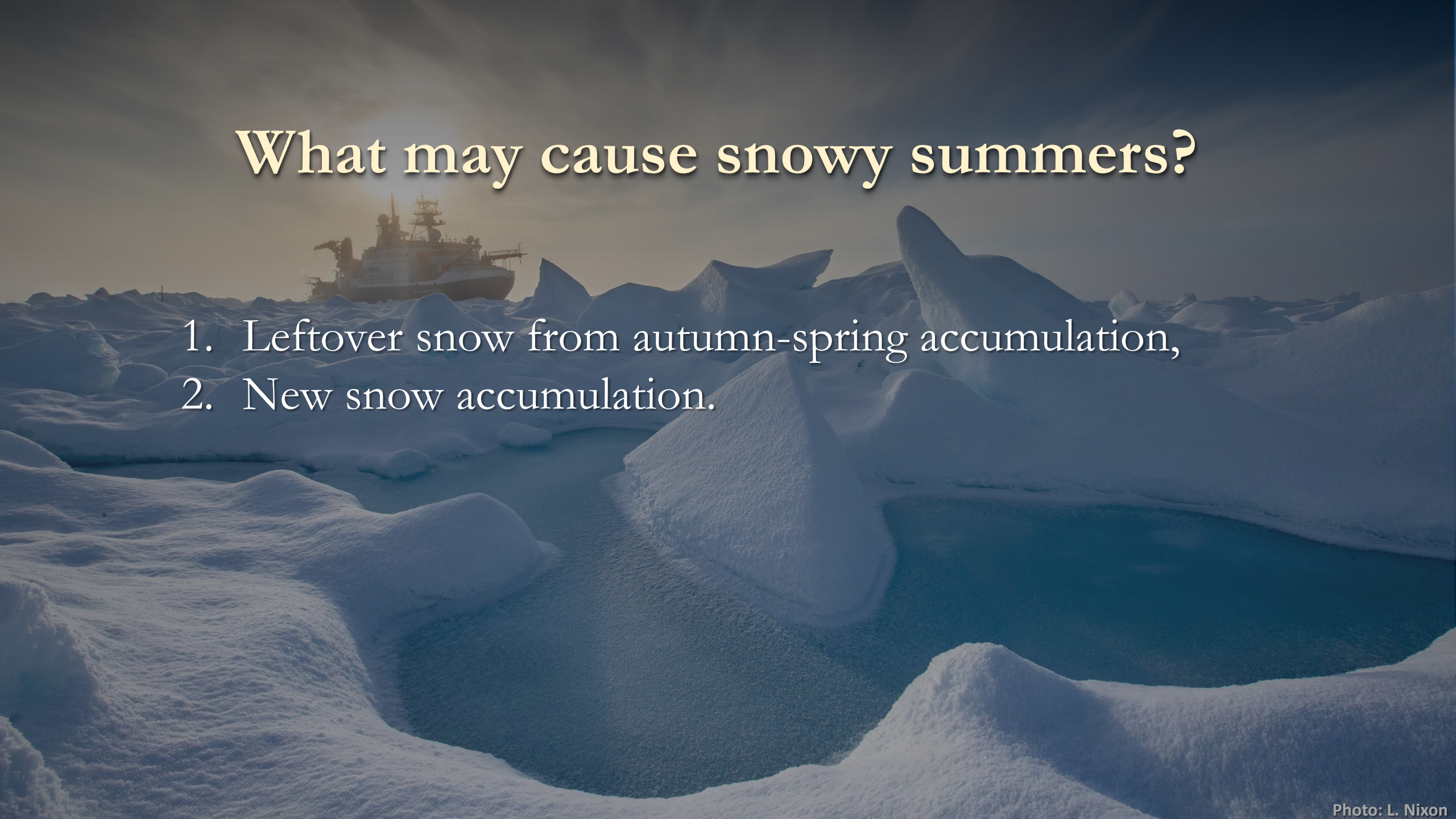
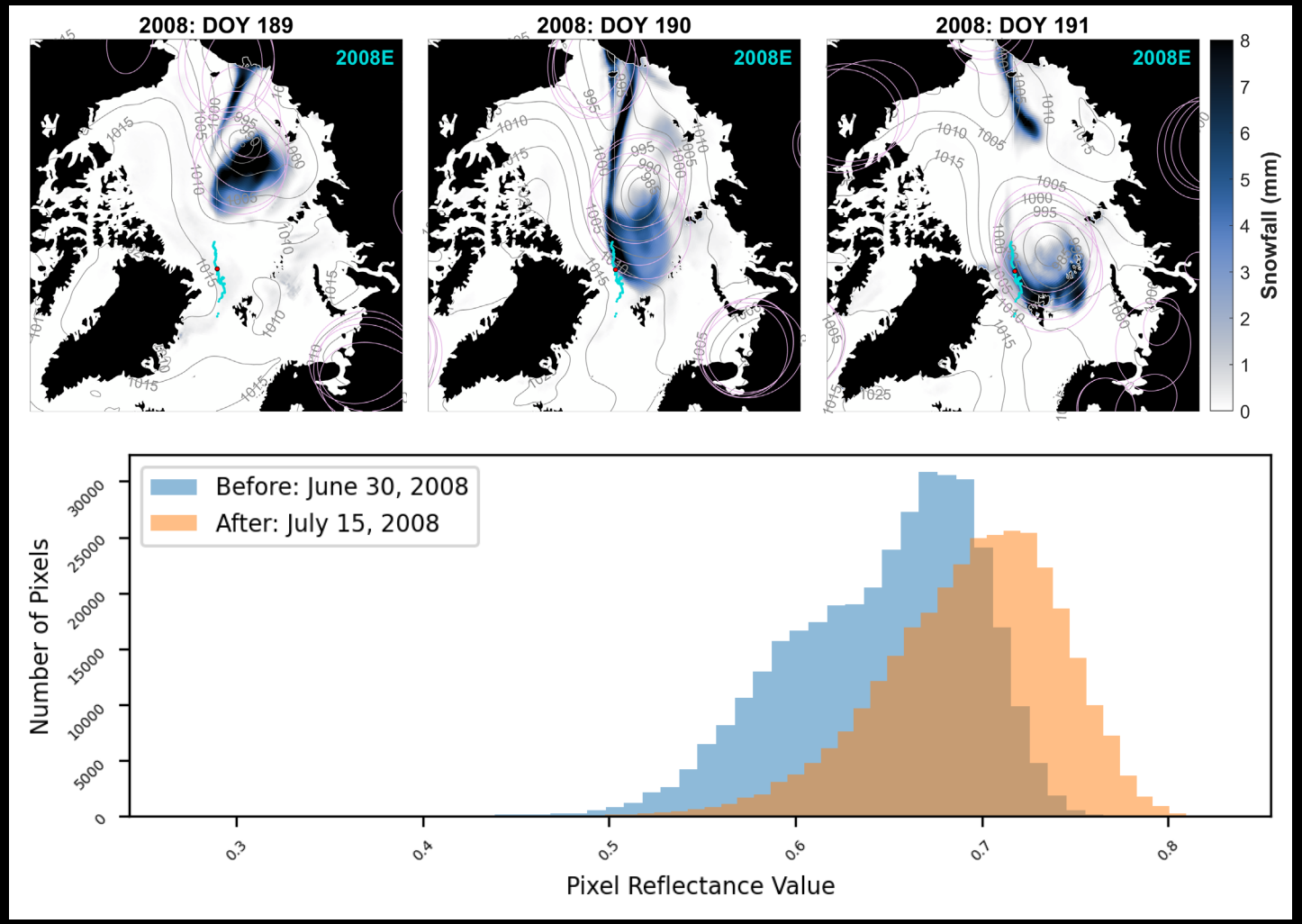


Photo: L. Nixon

Is it snowy in summer?

- MOSAiC: ~15% of spring snow cover persisted throughout summer*.
- **Summer snow events: 2-3 times, accumulates ~2 cm, & lasts ~3 days.
  → annual TOA radiative forcing decreases by 0.09 ± 0.02 W m^{-2}.



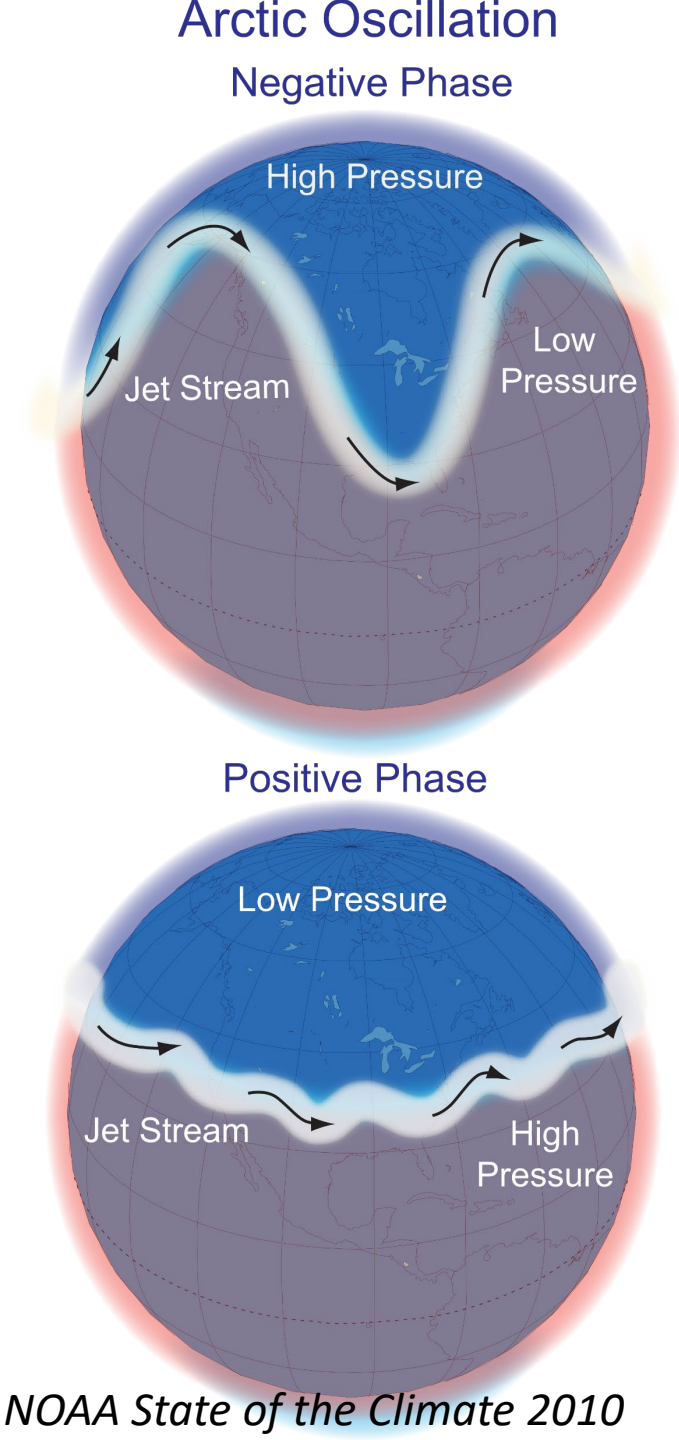
*Webster et al. (2022), *Elementa;* **Chapman-Dutton & Webster (2024), *JGR Atmos.*

The Arctic Oscillation

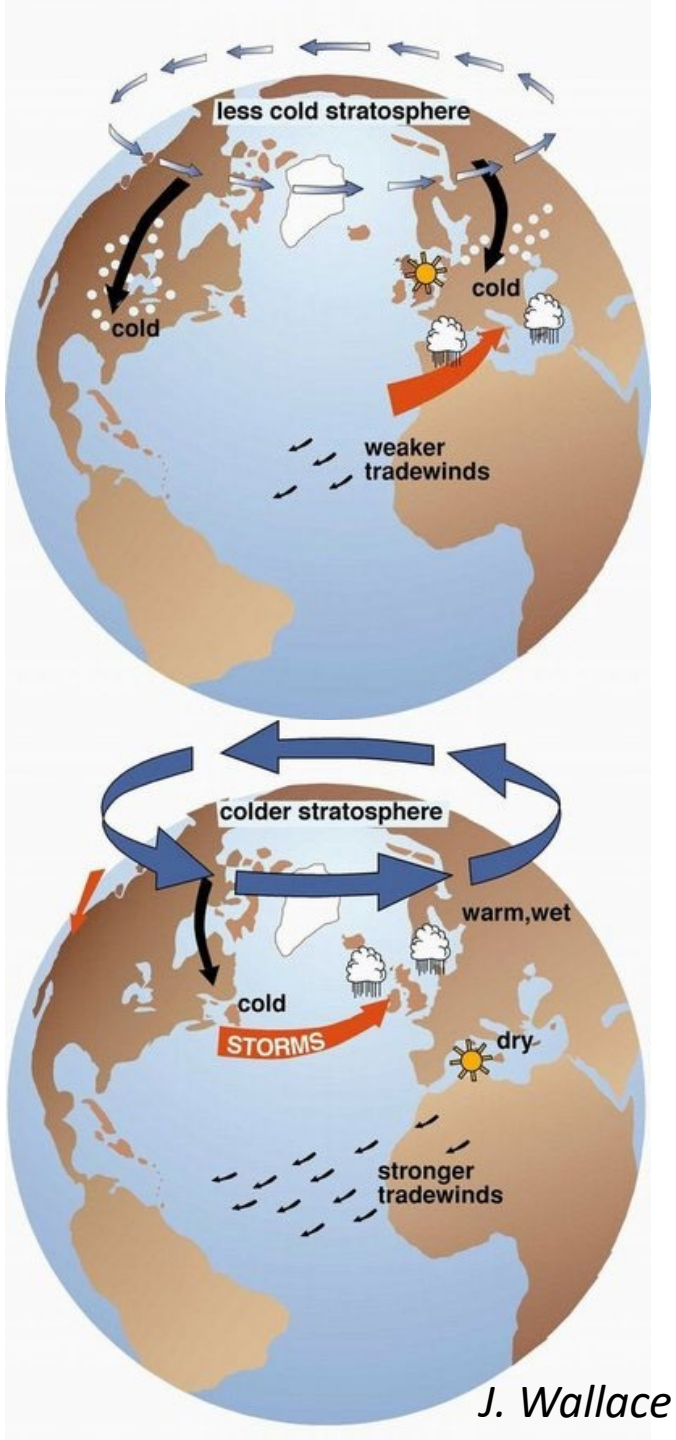
Affects:

- Temperature,
- Cyclone tracks,
  → Cyclones the key mechanism for establishing a snow cover on Arctic sea ice.
- Precipitation patterns.

…Shouldn't it then affect snow on sea ice?



NOAA State of the Climate 2010



J. Wallace

The main tools:

SnowModel-LG (Liston):

- single-column, Lagrangian-tracked parcels
- multilayer (tracked layers)
- rain-on-snow
- superimposed ice
- blowing snow (turned off)
- snow density evolution
- grain size evolution
- thermal conductivity (vertical grain profile)
- melt

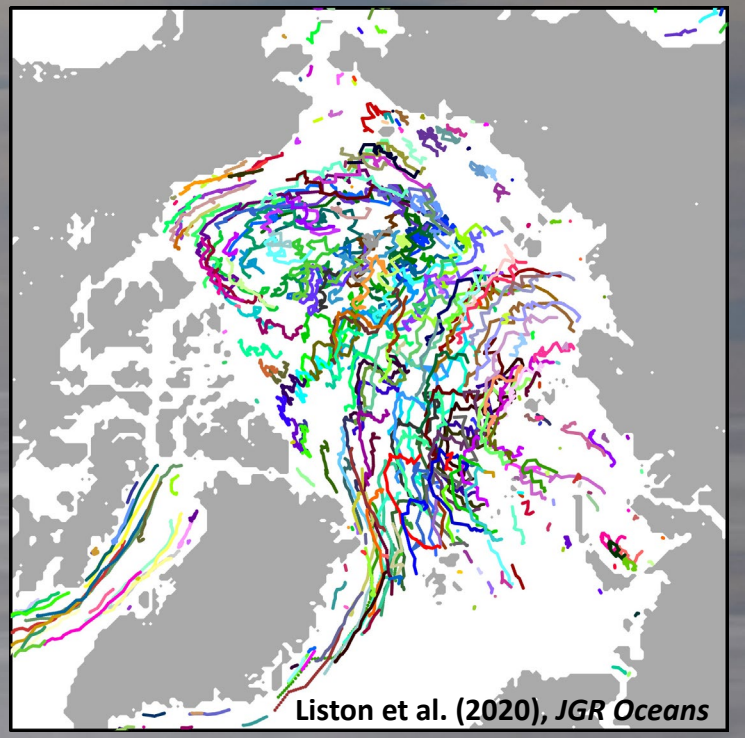
Atmospheric reanalysis: ERA5 (Hersbach)

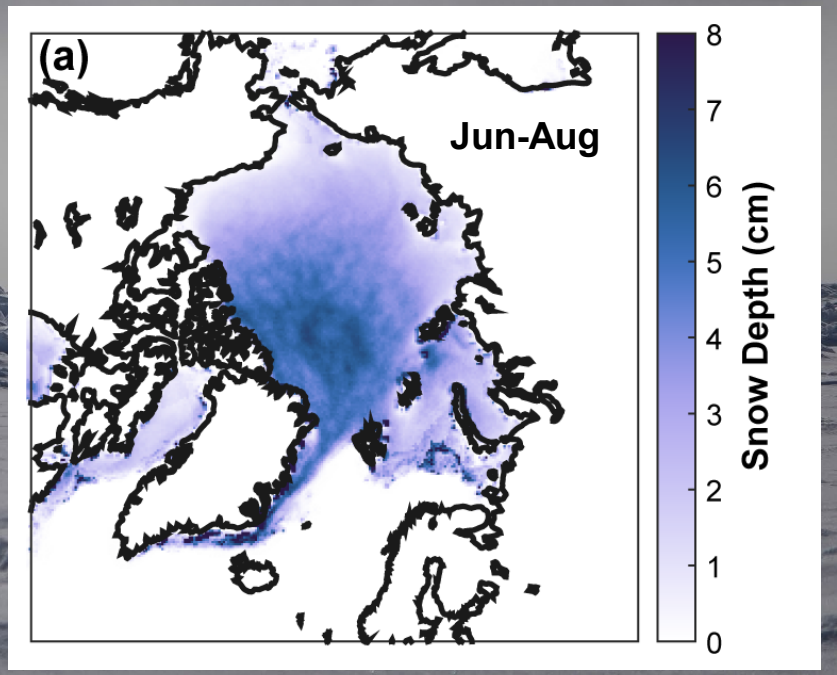
Satellite albedo: CLARA-SAL (Riihelä)

Satellite Melt/freeze onset: passive microwave (Markus)

Satellite sea ice concentration: passive microwave Bootstrap (Comiso)

In situ: surveys, buoys

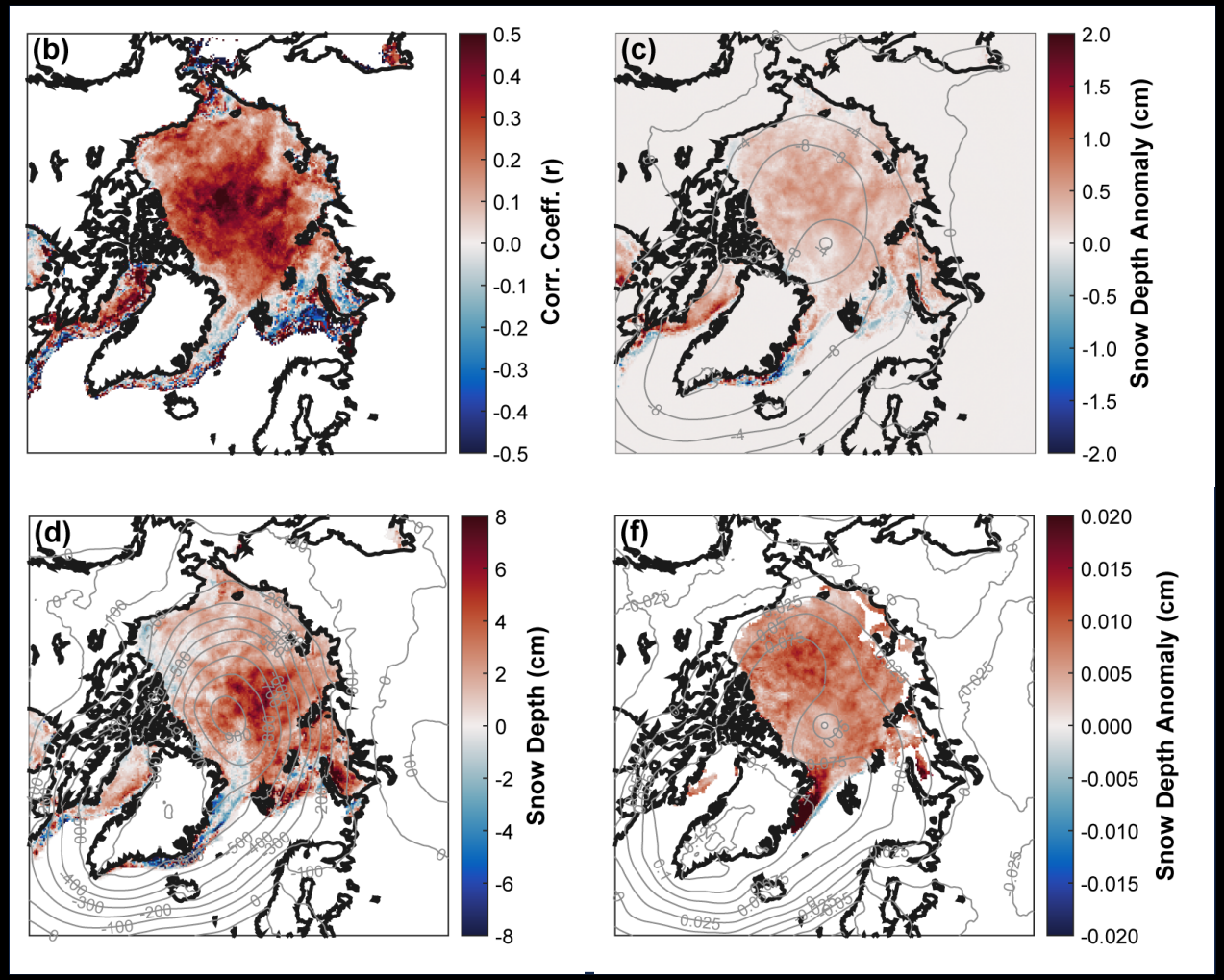




Sea ice has a snowy summer response to a positive AO

Correlation w. AO

Regressed onto AO



Linear Response

1st Princ. Component

For June-August:

- Snow depth anomalies, 1st principal component, & linear response strongly related to AO.
  - Up to ~4.5 cm near the North Pole in AO+.
- ~0.10 increase in albedo.
  - Evaluated "continuous ice zone".

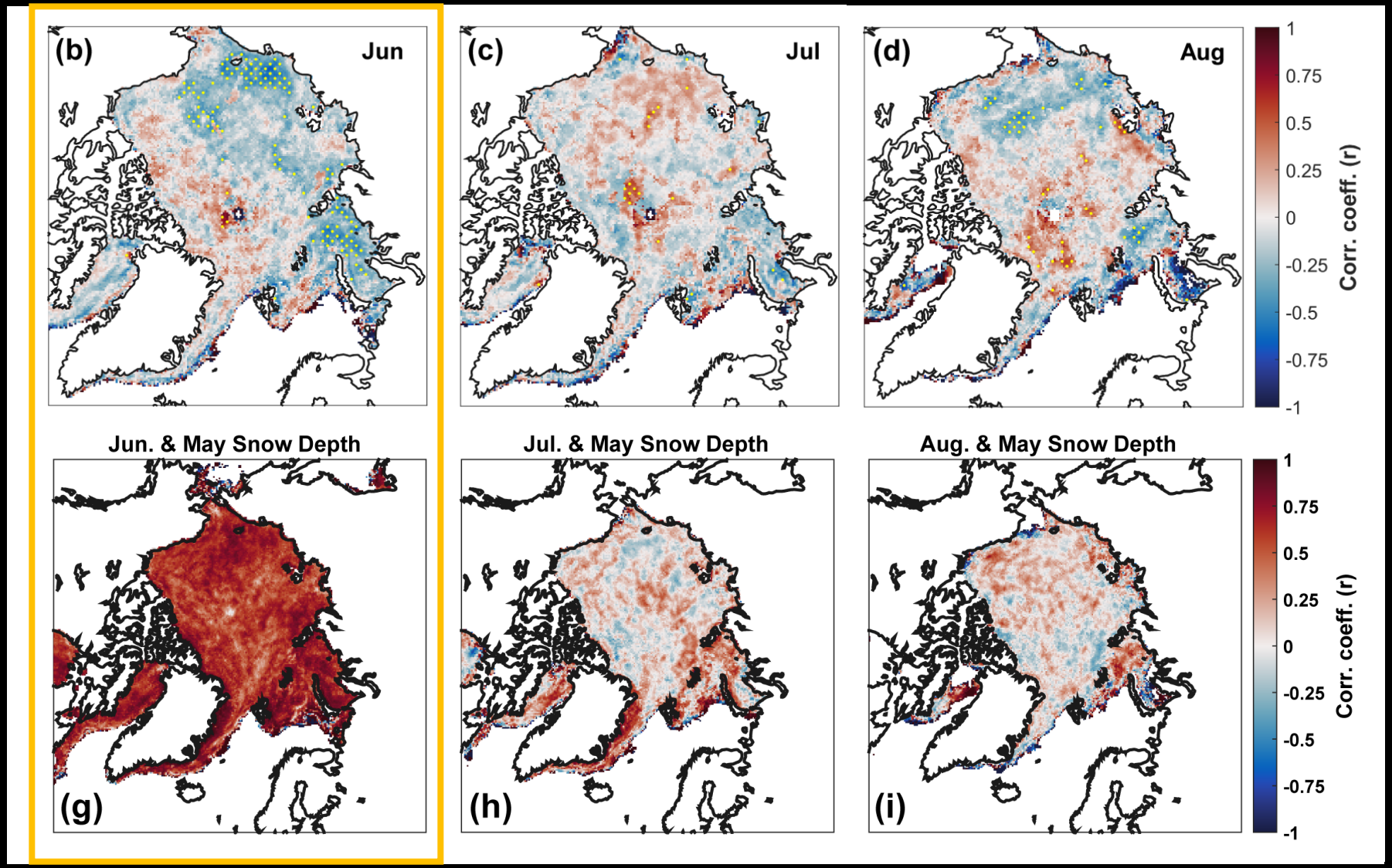
Was this remnant snow or fresh snow?

Webster et al. (2024), *Nature Geo.*

Leftover snow matters for June variance

Lagged freeze-up timing

Lagged monthly snow depths



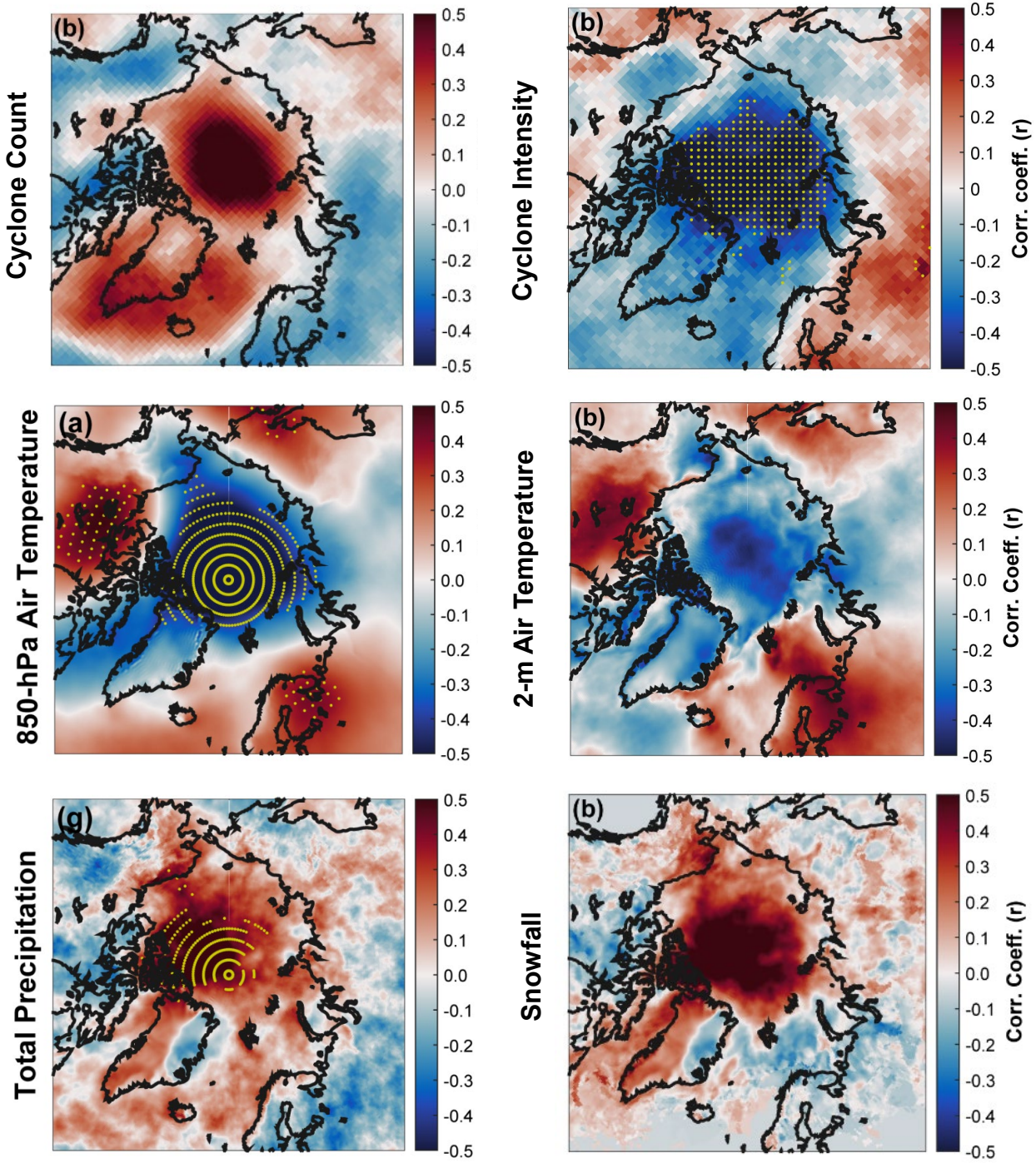
Remnant spring snow strongly affects June snow depth variability.

Webster et al. (2024), *Nature Geo.*

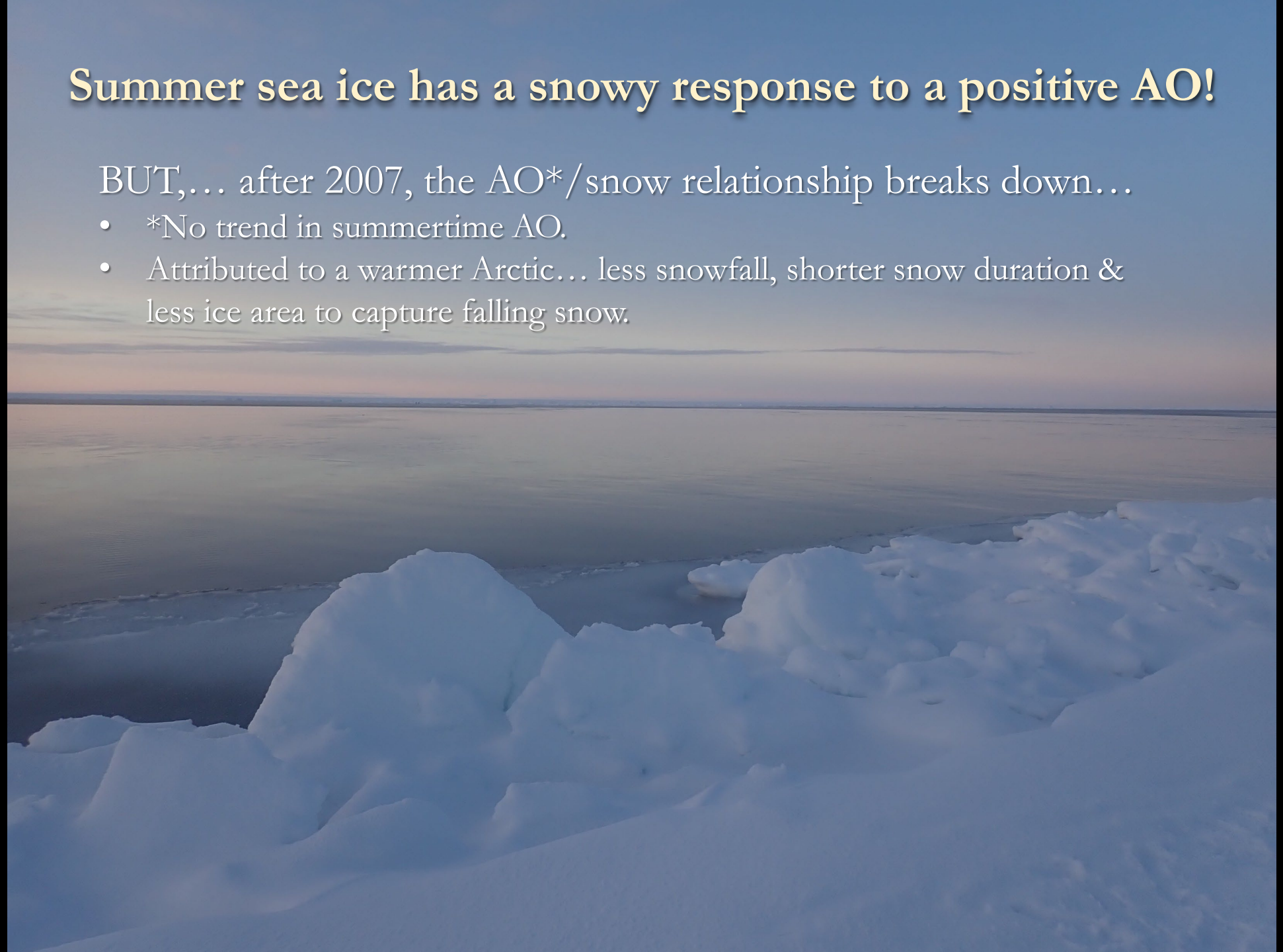
It's all about the atmosphere in July-August:

In summers with AO+, there are:

- More northerly & stronger cyclones.
- Cooler temperatures aloft,
  → More precipitation & in the form of snow.
- Surface temperatures somewhat cooler (not statistically significant)
  → <u>probably did not</u> lead to more persistent snow cover.
  → Good to remember what biases exist in ERA5 (e.g., no snow on sea ice).



Webster et al. (2024), *Nature Geo.*



Summer sea ice has a snowy response to a positive AO!

BUT,… after 2007, the AO*/snow relationship breaks down…

- *No trend in summertime AO.
- Attributed to a warmer Arctic… less snowfall, shorter snow duration & less ice area to capture falling snow.

Snowy Questions for Climate Models:

How persistent is spring snow on Arctic sea ice?

- Majority gone by mid-July → present during peak insolation.

How often & how much does it snow in summer?

- Initially snow-free conditions: 2-3x, 2-cm accumulation, & 3-day duration.
  - ~15% optically-thick snow accumulation, 6-day duration.
  - ~0.10 albedo increase.

→ What TOA radiative forcing effect does summer snow have?

Is there a snowy response to positive AO summers?

- Is the response predominantly driven by remnant snow or enhanced storm activity?
- Does the AO-snow relationship break down over time…?
  - → Why?


Thank you
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