Sea ice survivability across the Arctic Ocean: Influencing factors and regional variability

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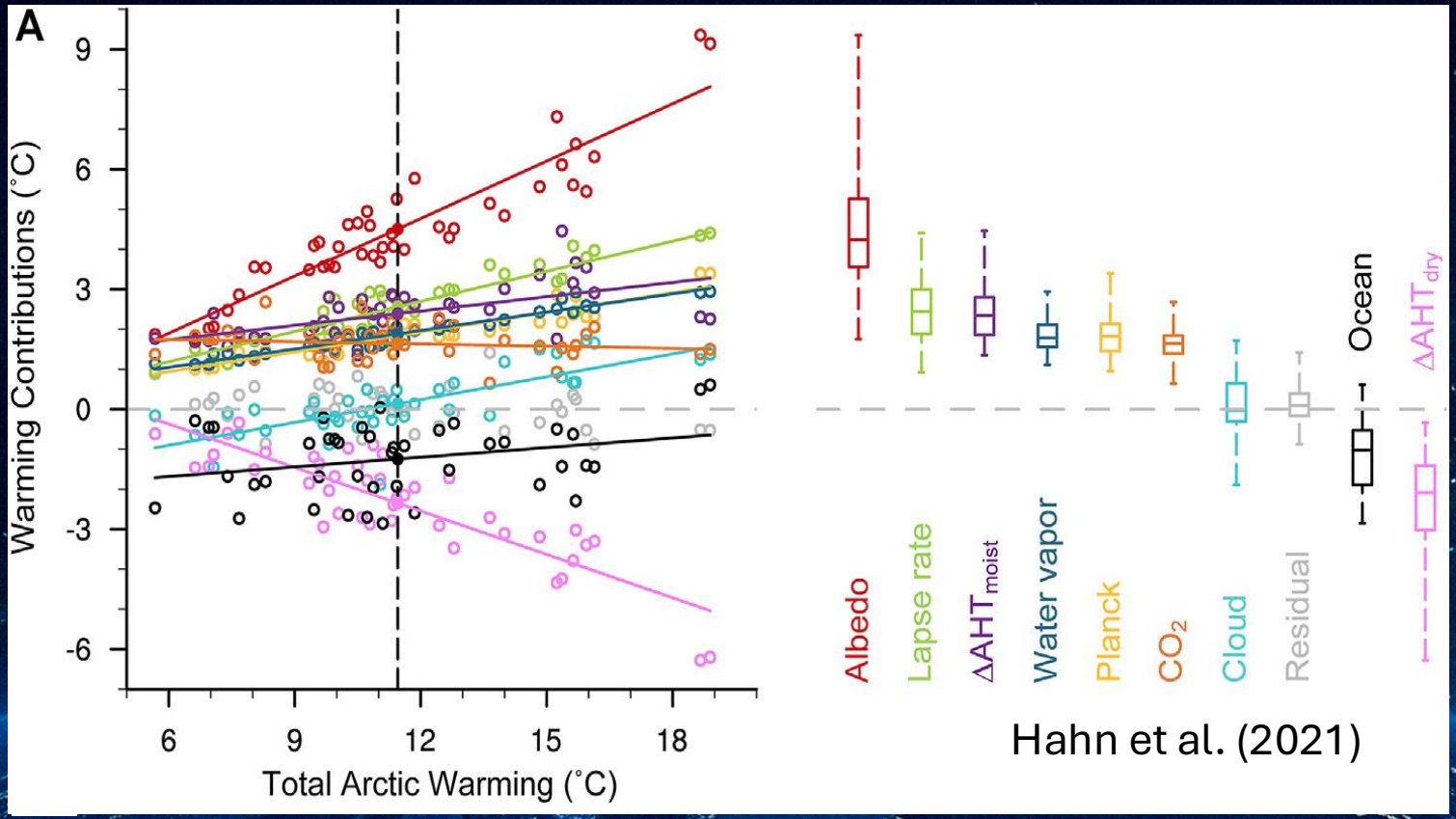
CERES STM Spring 2026

Sea Ice Albedo Feedback



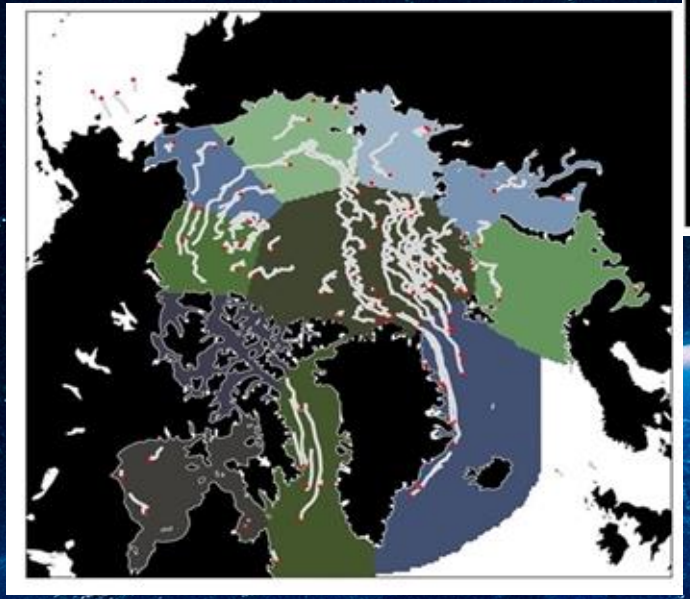



Surface albedo feedback: Leading source of uncertainty in Arctic climate projections




What factors influence whether sea ice survives or melts during summer?

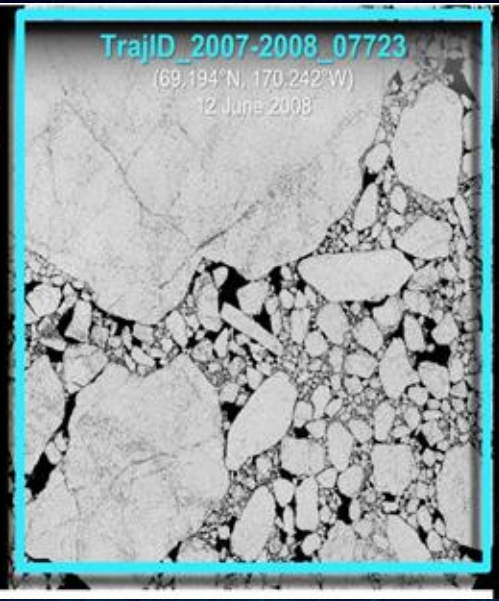
Sea ice parcel data base (Horvath et al. 2022)



Sea Ice Characteristics:
Ice Type (Buoys/SSM/I): First Year
Concentration (NSIDC/CDR): 90%
Snow Depth (SnowModelLG): 0.06 m
Sea Ice Thickness (PIOMAS): 2.10 m
Surface Albedo (CERES): 0.50
Ice Surface Temperature:

Lifecycle:
Formation: 22 Nov. 2007
Duration: 211 days
End: 20 June 2008
Origin & End Region: Chukchi Sea
Survived: No

Flags:
Cyclone (Melbourne U. Tracker): n/a
Cyclone properties (ERA5): n/a



Atmospheric State:
Air Press. (ERA5/MERRA2): 1018 hPa
Cloud Cover (CERES): 15%
Precipitable Water (ERA5/MERRA2): 19 kg m^{-2}
Liq. Water Path (CERES): 112 g m^{-2}
Ice Water Path (CERES): 96 g m^{-2}
Air T.(ERA5/MERRA2): 0.95°C
Wind Speed & Direction (ERA5/MERRA2): 8.4 $m\text{-}s^{-1}$ & 39°
Spec. Humidity (ERA5/MERRA2): ~0%
Snowfall (ERA5/MERRA2): n/a
Total Precipitation (ERA5/MERRA2): n/a

Surface Energy Budget:
Upwelling SW (CERES): 134 W m^{-2}
Downwelling SW (CERES): 267 W m^{-2}
Upwelling LW (CERES):312 W m^{-2}
Downwelling LW (CERES): 284 W m^{-2}
Sensible Heat (AIRS): -30 W m^{-2}
Latent Heat (AIRS): ~0 W m^{-2}

Arctic sea ice parcel database:
>1,000,000 parcels from 2002-2020

Parcel-level survivability defined:

The likelihood that a sea ice parcel survives through the summer melts season.

Survivability

$$= \frac{\text{Number of parcels that survive}}{\text{Total number of parcels}}$$

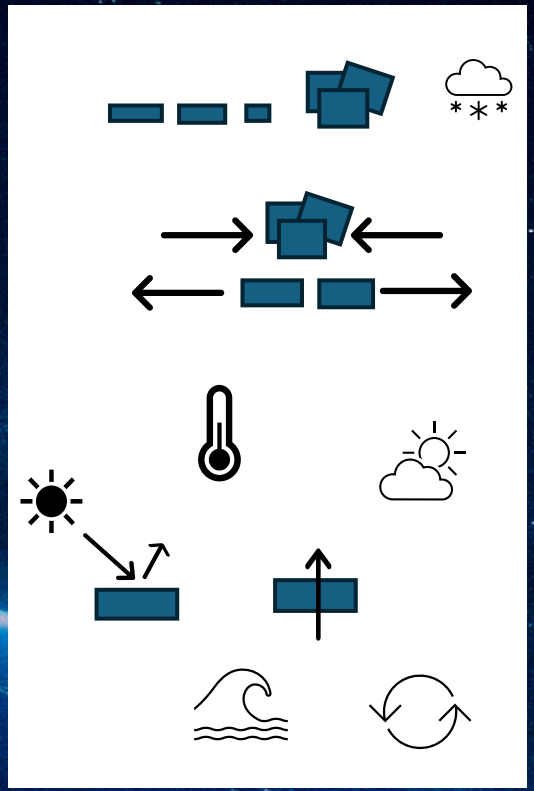
Survived

+

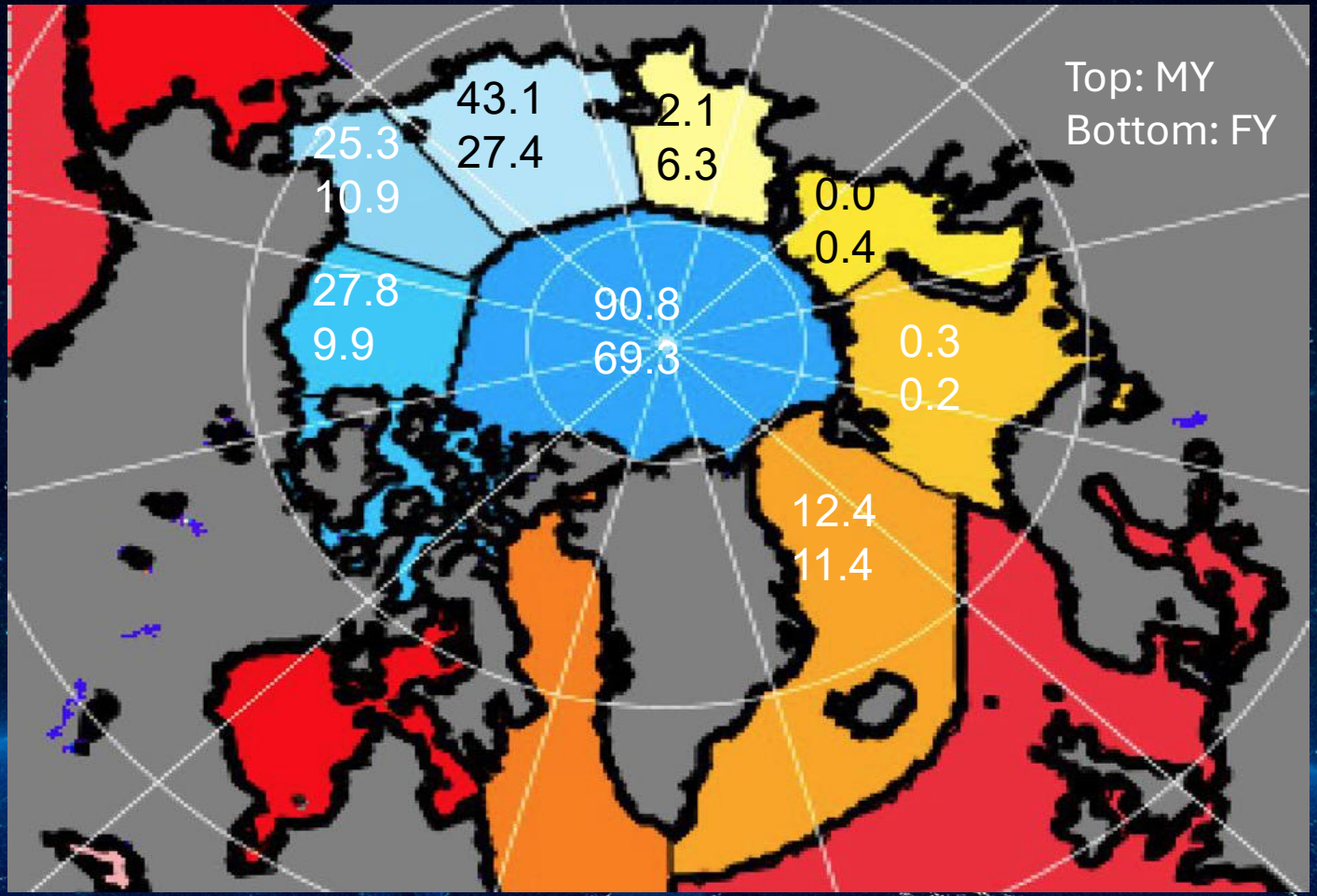
Melted

Factors influencing sea ice melt

- Sea ice properties (thickness, concentration, topography/roughness, snow depth)
- Sea ice dynamics (convergence and divergence)
- Atmospheric conditions (temperature, humidity, clouds)
- Surface energy budget (turbulent fluxes, conductance, albedo)
- Ocean conditions (waves, turbulence, and heat flux)



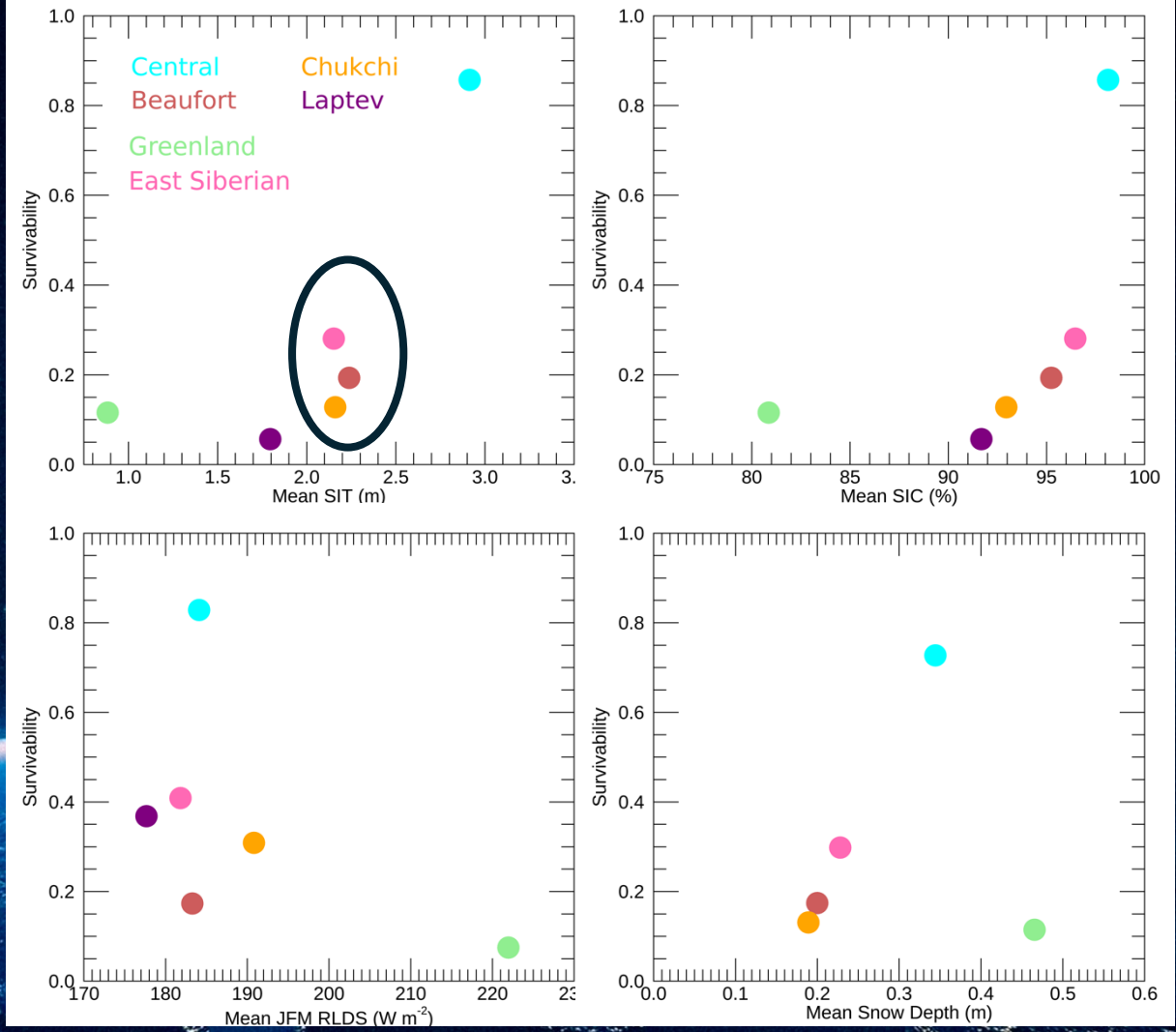
Regional survivability

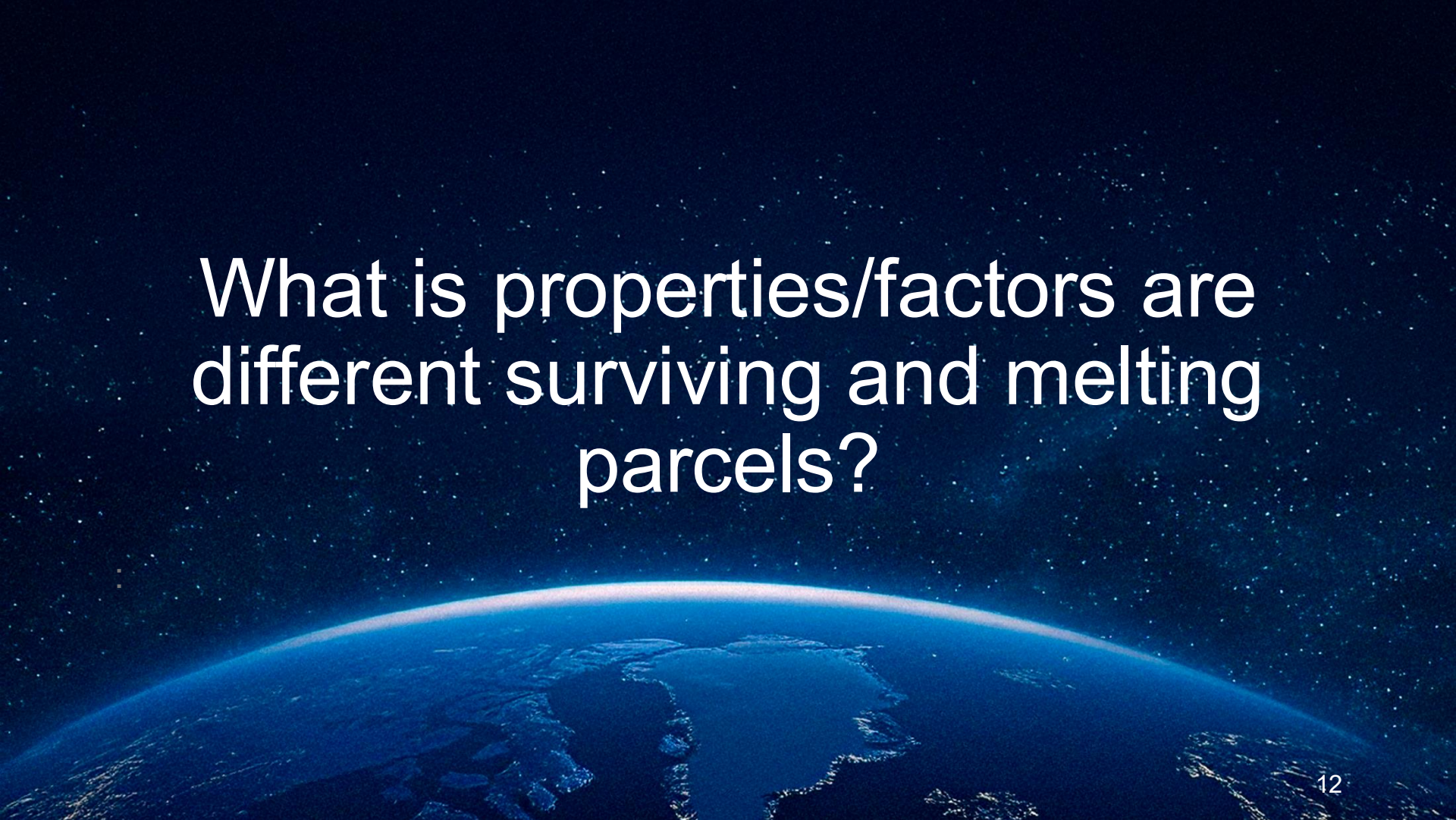



Where does this spatial pattern come from?

Regional mean state differences

Regional survivability correlates most strongly with sea ice concentration and snow depth.




What is properties/factors are different surviving and melting parcels?

Annual cycle composites: Sea ice variables

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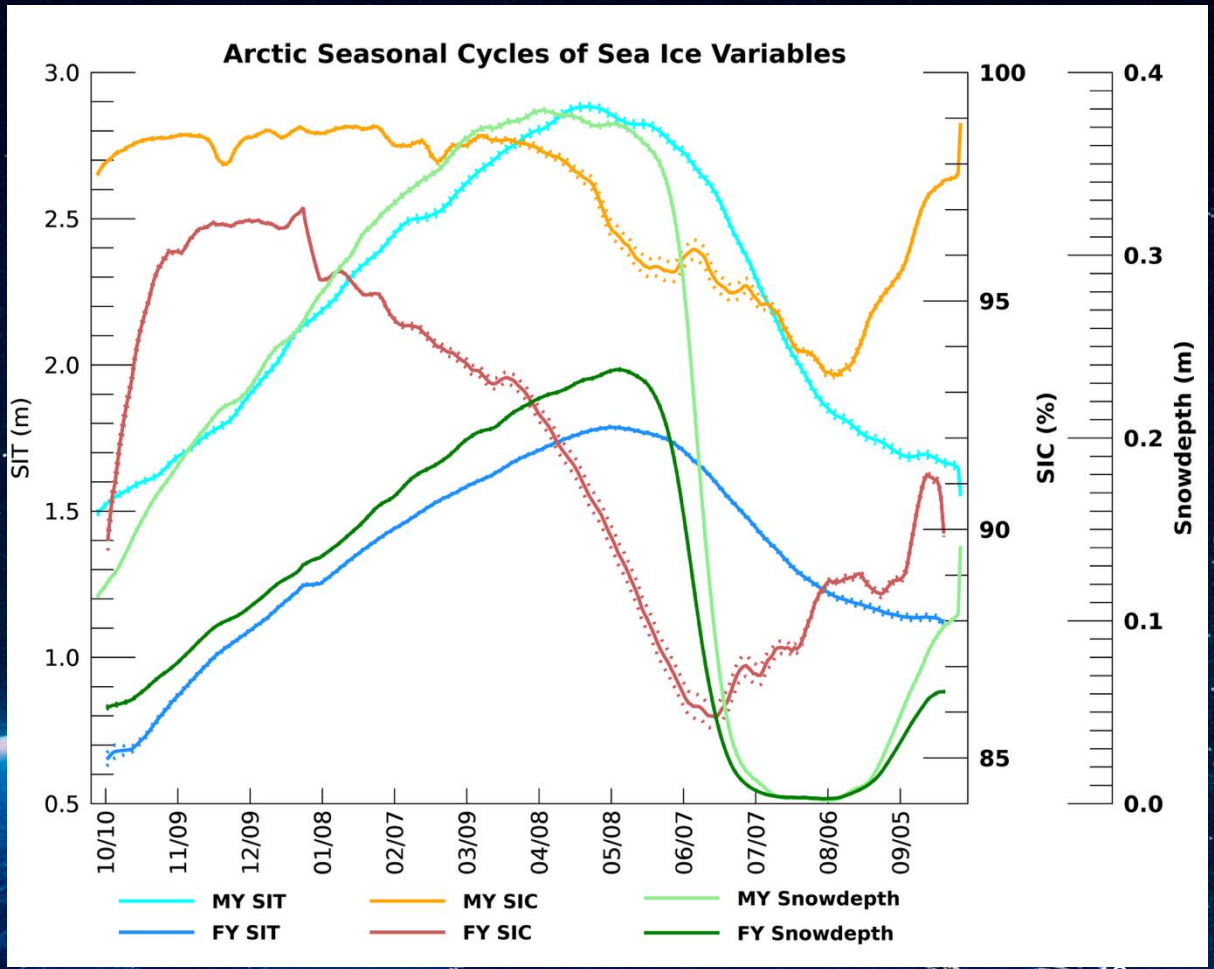
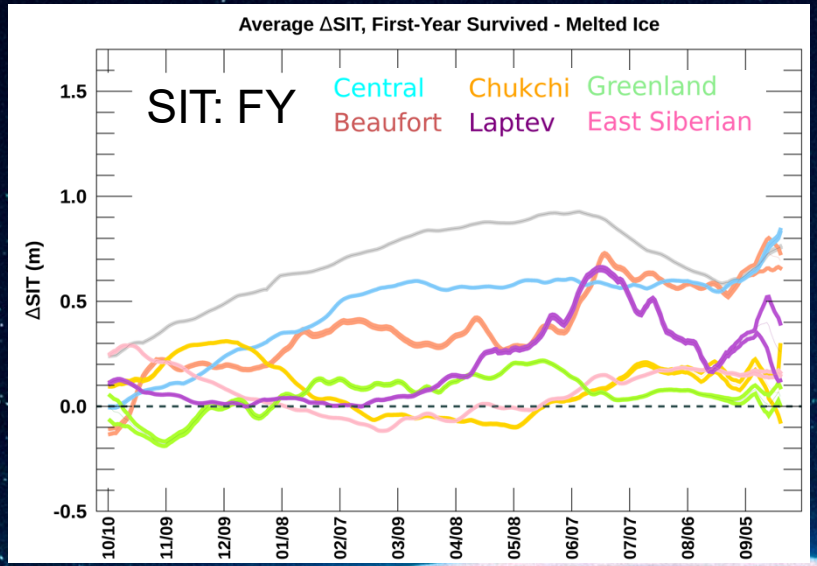
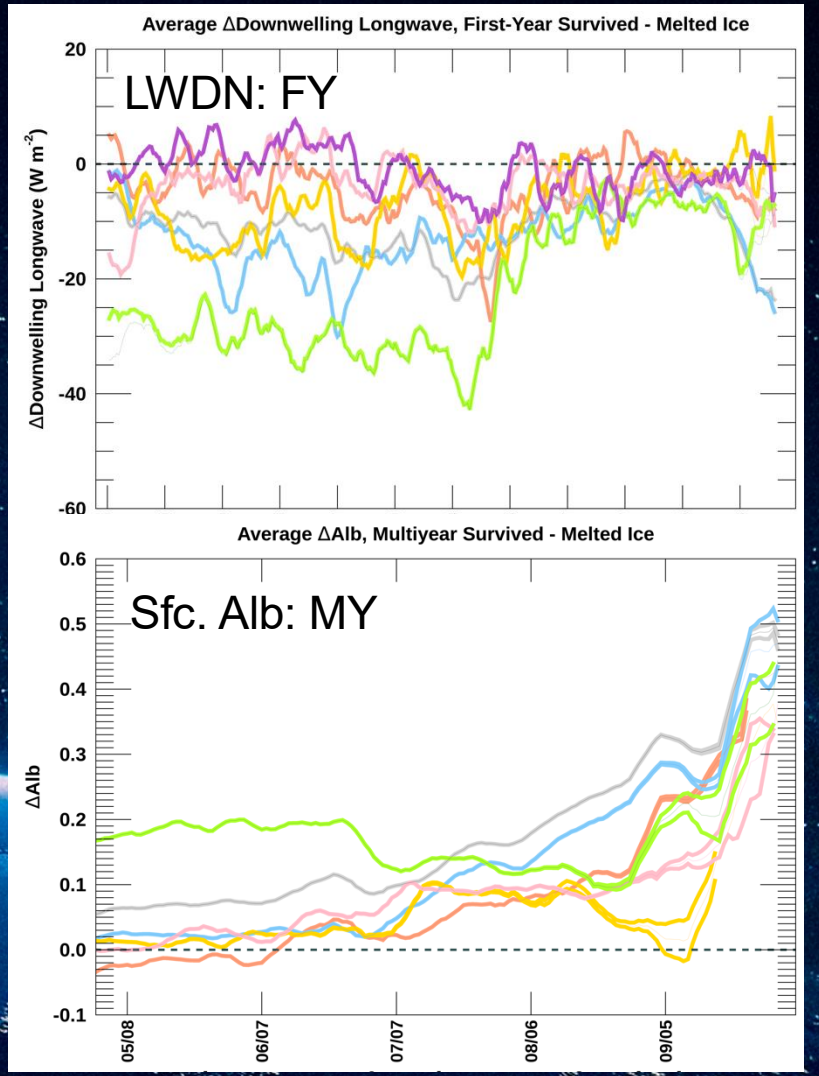


Annual cycle composite differences: What factors differ?





All plots show composite differences, surviving minus melted

Surviving minus Melted annual cycle composite differences:

Differences:

- Sea ice thickness
- Snow depth
- Sea ice concentration
- Surface albedo/SWnet
- Surface temperature

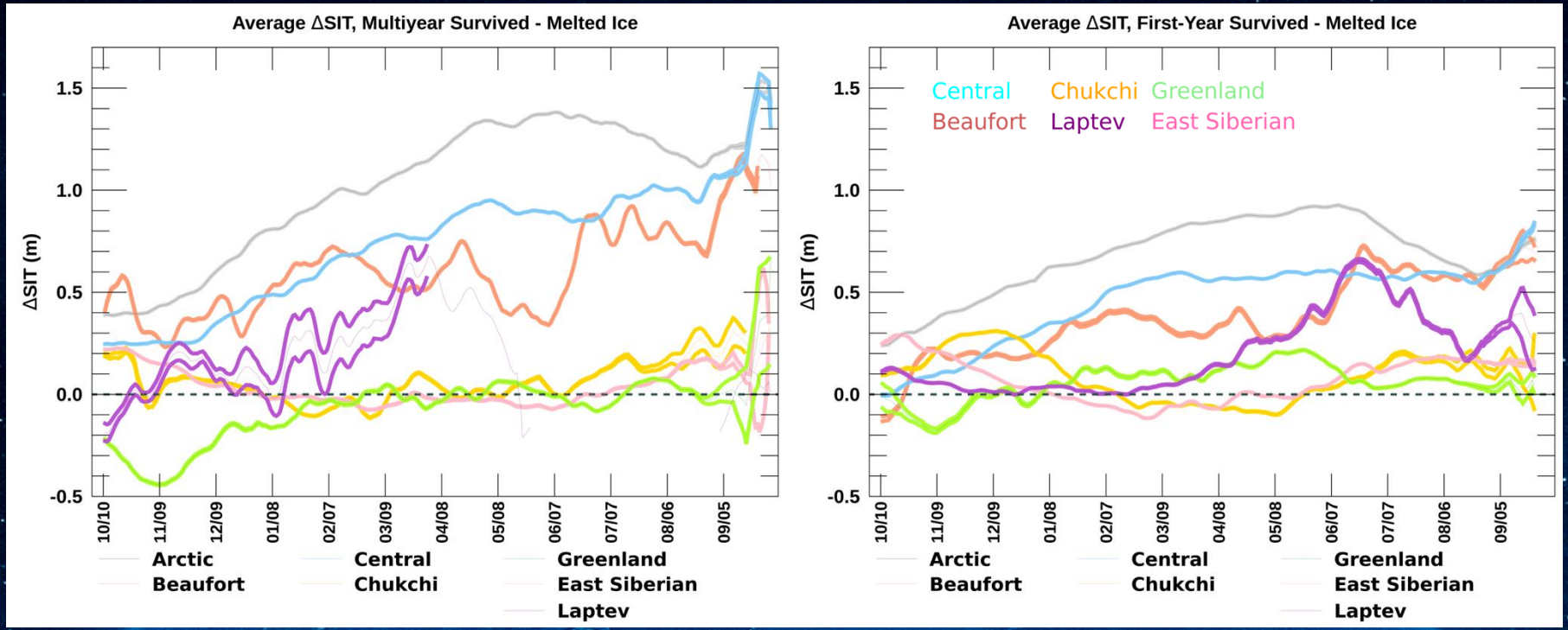
No Differences:

- LW downwelling
- LW cloud radiative effects
- Surface turbulent fluxes

The sea ice thickness story

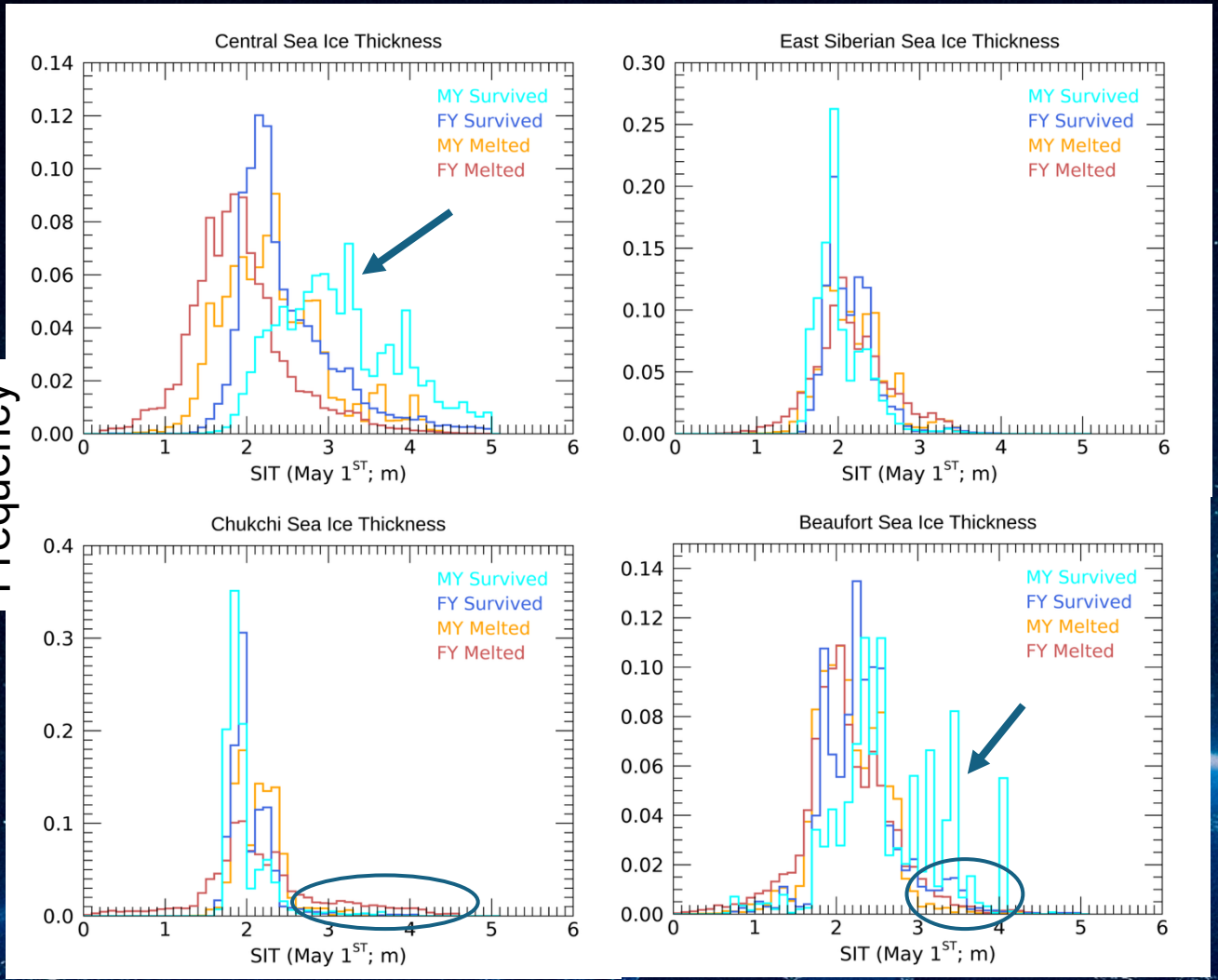
Takeaway: Parcel thickness has a regionally dependent relationship with survivability.

Composite sea ice thickness evolution: Surviving minus Melted



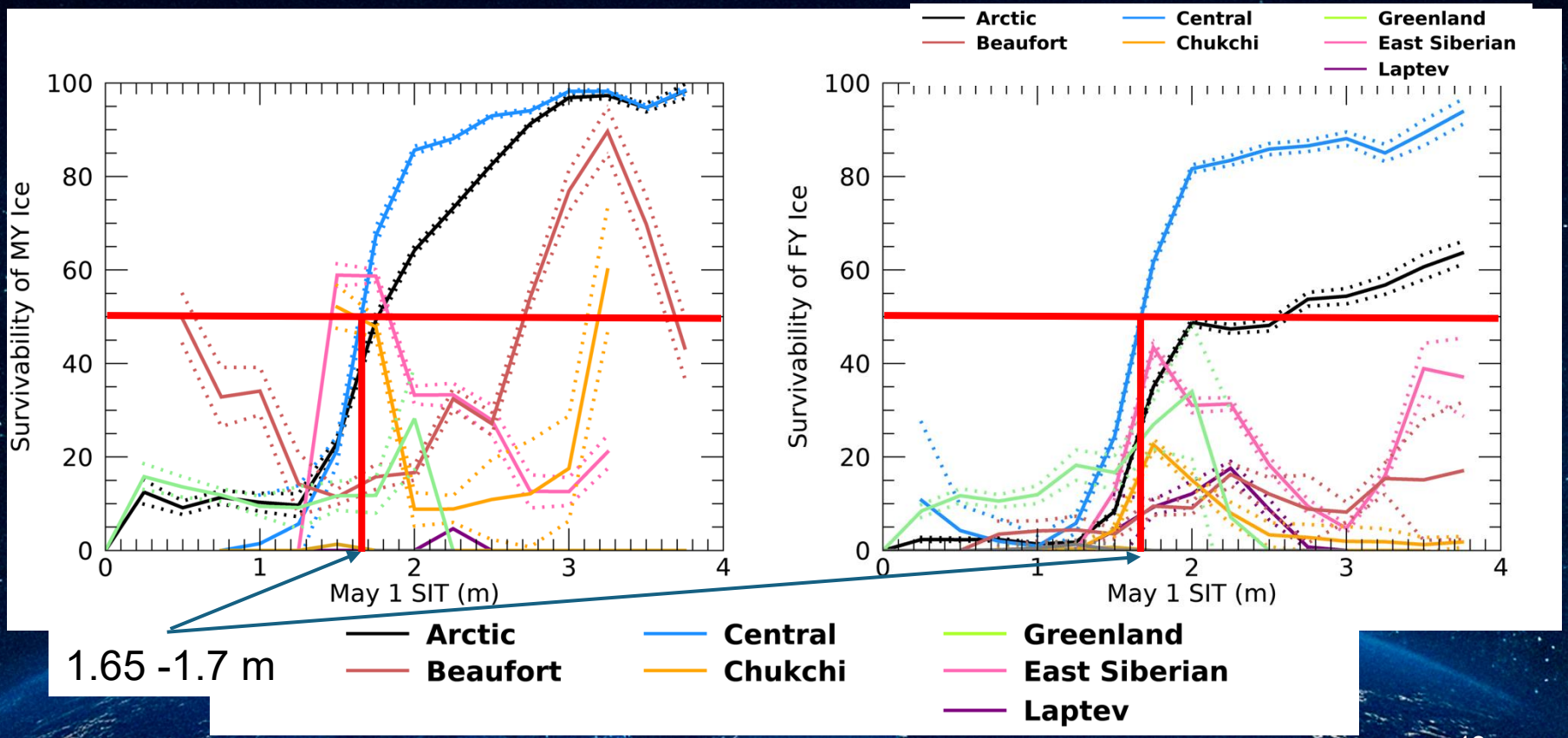
SIT differences are not significantly different in every region.

Sea ice thickness distributions



Parcel thickness does not always make or break parcel survivability.

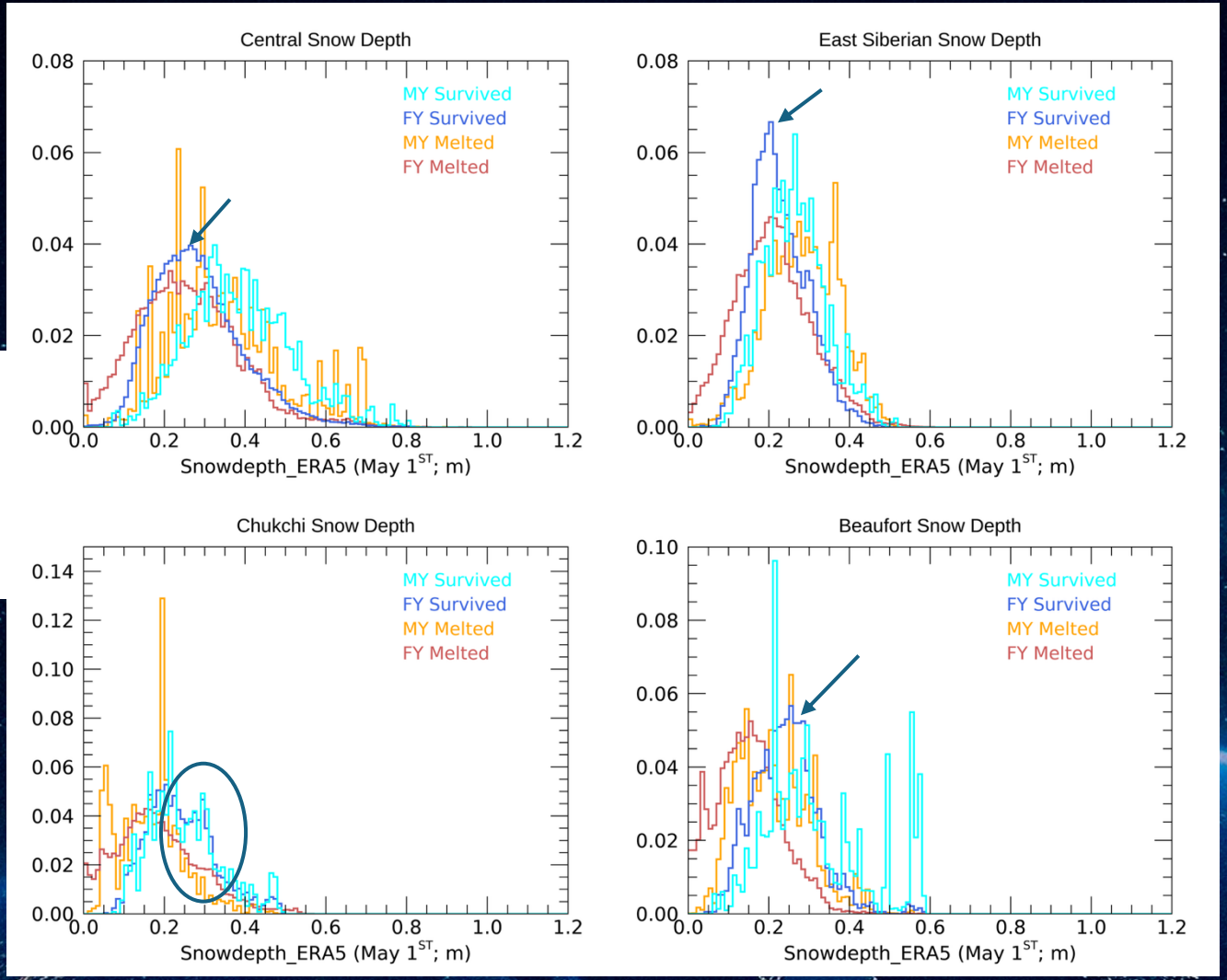
Survivability dependence to SIT



The snow story

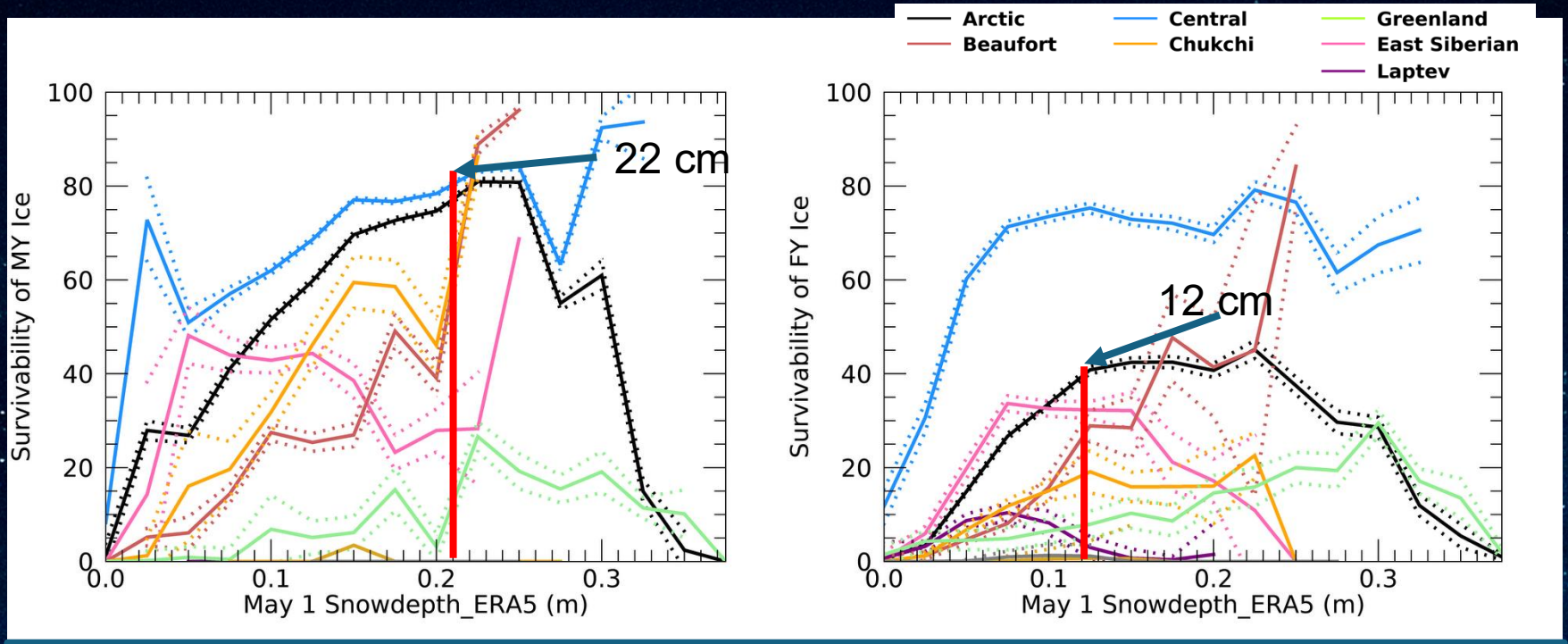
Takeaway: Snow depth increases survivability exhibiting a threshold behavior where increased snow depth increases survivability until ~10-20 cm after which there is no additional impact.

May 1st Snow Depth



Deeper snow is generally found on surviving parcels.

Survivability dependence on snow depth

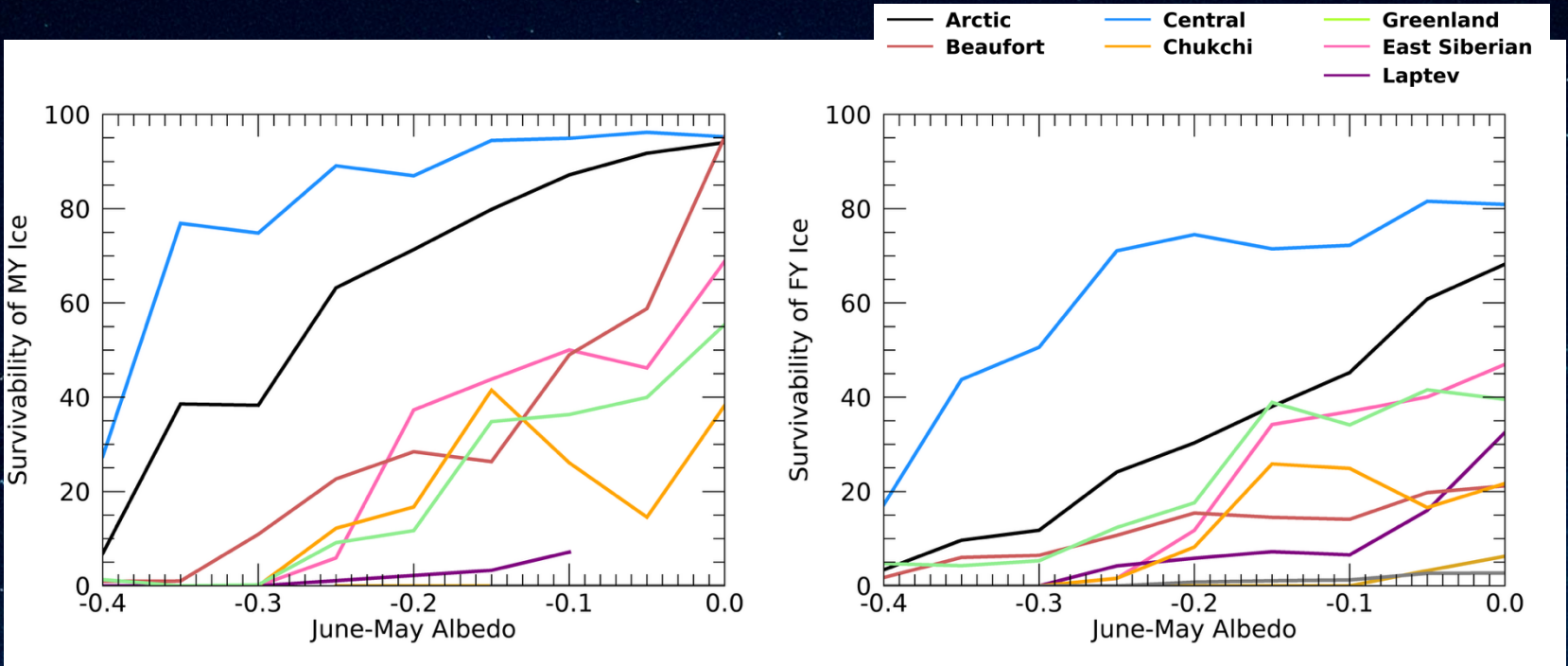


Survivability increases with increasing May 1st snow depth to a point (FY: ~25cm MY: ~45 cm) after which the effect plateaus.

The sea ice albedo story

Takeaway: Parcels with a stronger early season surface albedo decline are less likely to survive the summer melt.

Survivability and June-May surface albedo



Survivability is less for parcels that experience a greater early summer decline in surface albedo.

Discussion: Sea Thickness

- Parcel thickness does not always make or break parcel survivability.
- In the peripheral ice thickness is not a strong predictor of summer melt
- Sometimes thicker parcels are more likely to melt than thinner ones: ESS

What does the relationship with SIT mean?

- There is enough heat around in the peripheral seas to melt most sea ice
- Gradients exist in the energy inputs in regions (e.g., ocean heat contribution)

Summary and Discussion: Snow depth

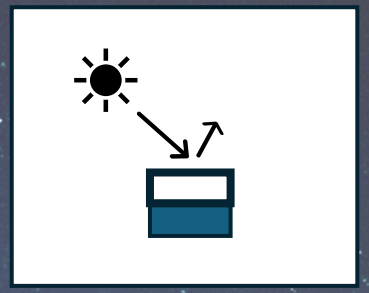
Findings:

- Parcels with greater snow depth have a higher survival rate.
- The influence of snow depth on parcel survival exhibits a threshold behavior.
- The snow depth threshold-survivability relationships exhibits strong regional variability.

Summary and Discussion: Snow depth

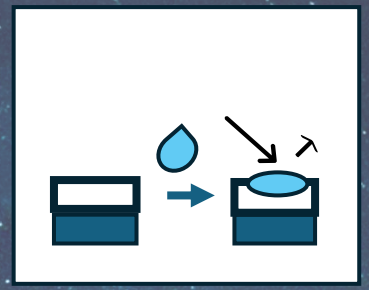
What causes the snow depth survivability relationship?

- Parcels with a greater snow depth generally have a lower early summer SWnet and slower summer albedo decline. More energy is required to melt the snow before sea ice melt.



What is causing the threshold behavior?

- A saturation of the snow effect on albedo due to greater snow depth resulting in more melt water and more melt ponds.



What causes regional variations in the threshold behavior?

- Differences in sea ice roughness/topography
- Differences in snow properties and metamorphosis (e.g., more compaction with greater depth, density)
- Role of atmospheric and ocean forcings? (moisture sources?)


Thank you for
your attention.
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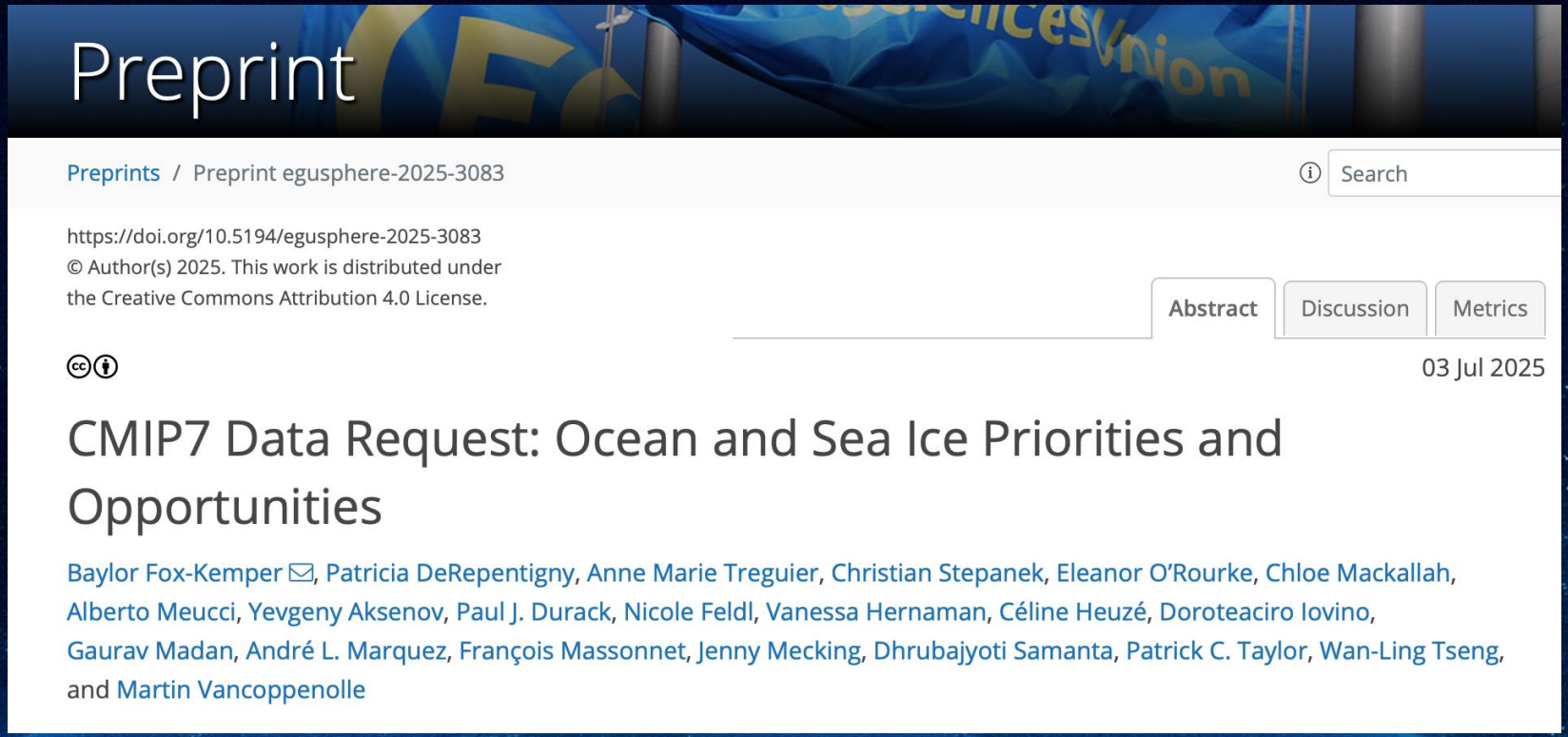
Action 1: Causality of Polar Amplification Opportunity



Preprint

Preprints / Preprint egusphere-2025-3083

Search

https://doi.org/10.5194/egusphere-2025-3083

Abstract | Discussion | Metrics

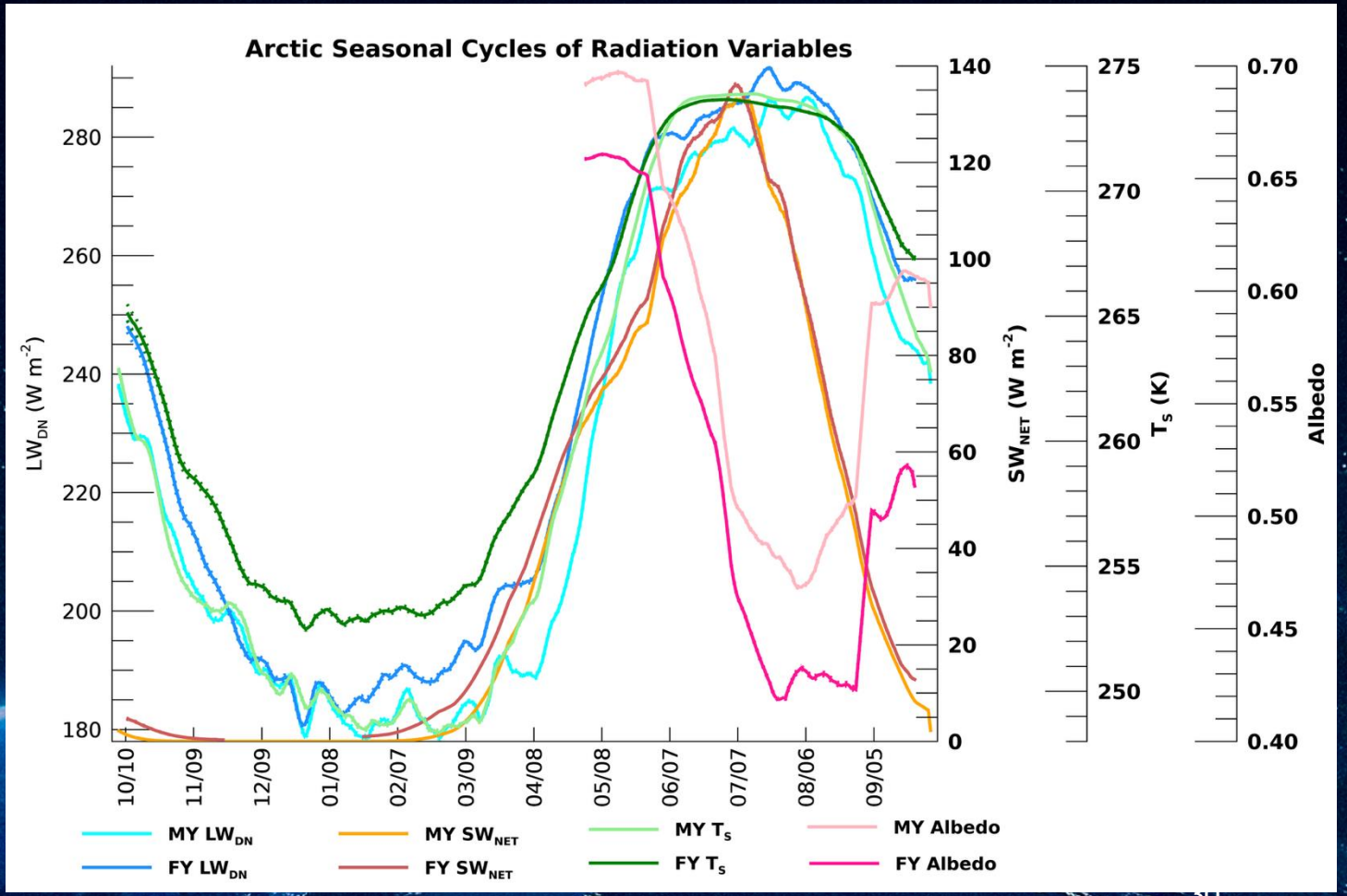
03 Jul 2025

CMIP7 Data Request: Ocean and Sea Ice Priorities and Opportunities

Baylor Fox-Kemper, Patricia DeRepentigny, Anne Marie Treguier, Christian Stepanek, Eleanor O'Rourke, Chloe Mackallah, Alberto Meucci, Yevgeny Aksenov, Paul J. Durack, Nicole Feldl, Vanessa Hernaman, Céline Heuzé, Doroteaciro Iovino, Gaurav Madan, André L. Marquez, François Massonnet, Jenny Mecking, Dhrubajyoti Samanta, Patrick C. Taylor, Wan-Ling Tseng, and Martin Vancoppenolle

High frequency (daily) output for sea ice, atmosphere, and ocean variables to diagnose the factors contributing to sea ice melt.

Annual cycle composites: Radiation variables



Sea ice graveyards and havens

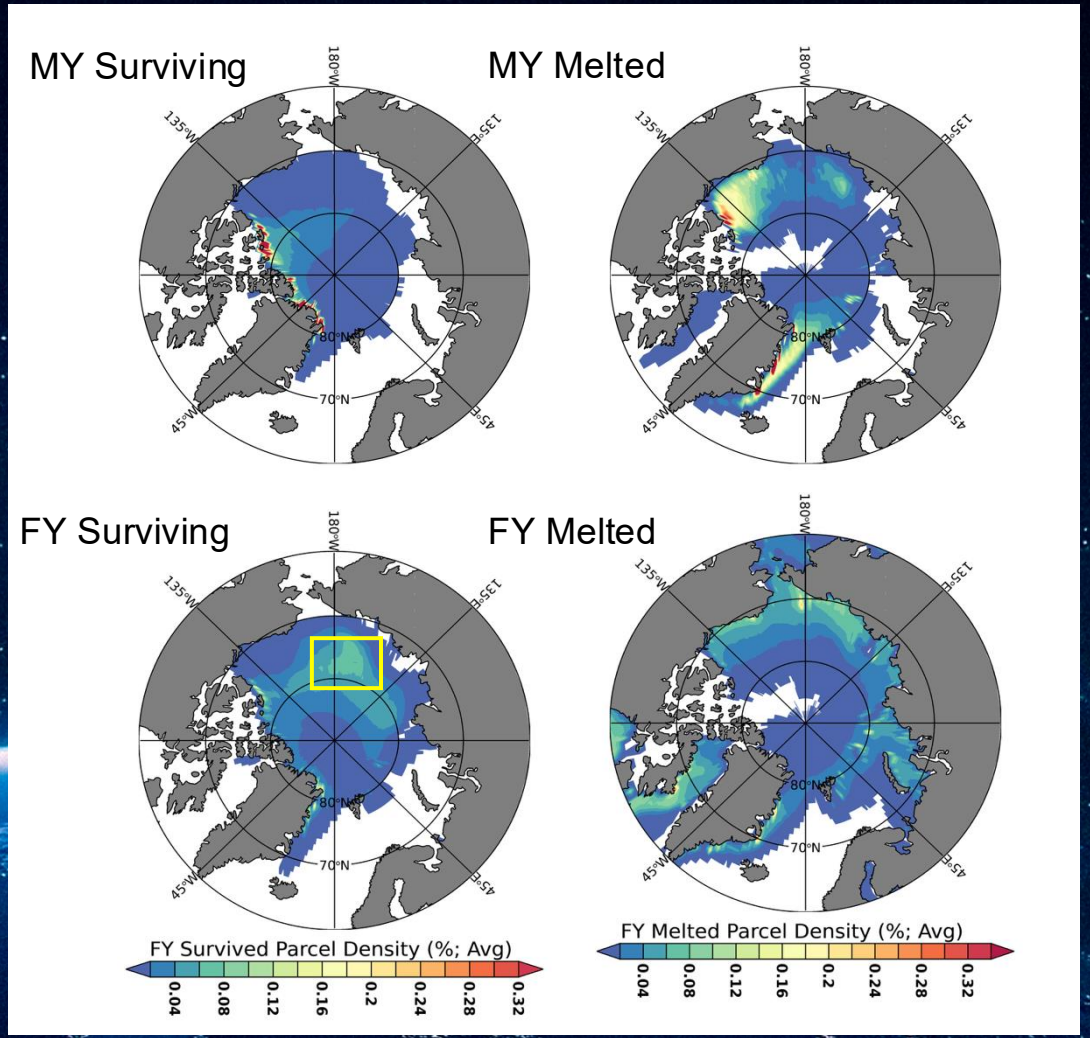
Haven:

- MY: North of Greenland and Canadian Archipelago
- FY: East Sib. Sea

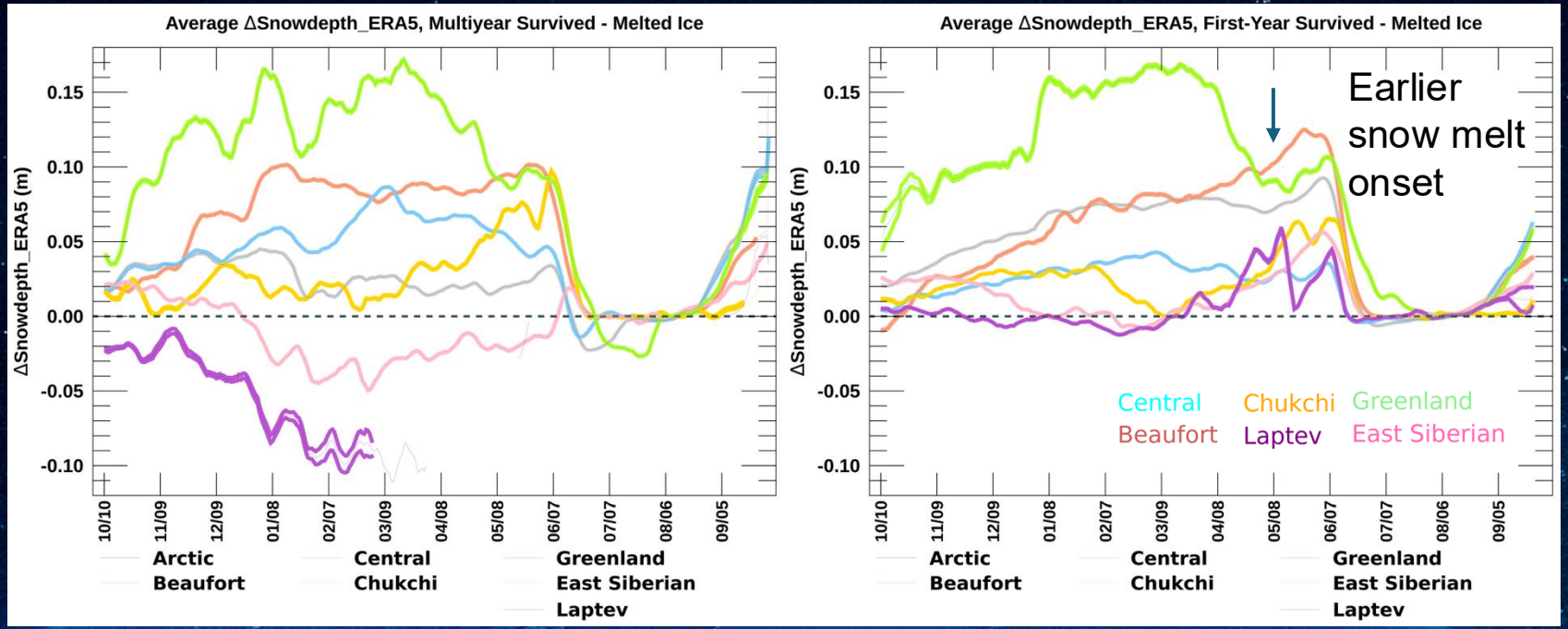
Graveyards

- MY: Fram Strait and Beaufort Sea
- FY: Latitudes south of ~78N

These locations are strongly influenced by sea ice drift.



Composite snow depth evolution: Surviving minus Melted



Snow depth tends to be greater on surviving vs. melting parcels.

Summary of SIFs

- **Sea ice thickness:** Parcel thickness has a regionally dependent relationship with survivability.
- **Snow depth:** exhibits a threshold behavior where increased snow depth corresponds to increased survivability until ~25 cm (FY) and ~45 cm (MY) after which there is no additional impact.
- **Sea ice concentration:** Spring and early summer sea ice concentration differences emerge between survived and melted parcels.
- **LW downwelling flux:** Differences have little effect on survivability outside of the central Arctic.
- **Surface temperature:** Differences are found through winter plays a regionally varying role.
- **SW fluxes**: Parcels with a greater SWdown and SWnet are less likely to survive.
- **LW Cloud radiative effects:** Influence survivability in the central Arctic but not in the Pacific Sector.