# Incorporation of Bare Ice Capabilities into a Snow Radiative Transfer Model


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# Overview

## Motivation

- Melting of Greenland Ice Sheet (GrIS), which is strongly coupled with albedo, is the largest contributor to sea level rise

## This Work

- We've developed a radiative transfer model that explicitly represents snow and ice albedo (SNICAR-ADv4) & includes relevant light absorbing constituents (LAC)

## Preliminary Results

- SNICAR-ADv4 (1) simulates the albedo of the entire snow-firn-ice spectrum, (2) reproduces measurements well, and (3) includes the influence of LAC

## CESM Relevance

- Dynamic ice albedo modeling within fully coupled climate simulations will improve future sea level rise estimates

# The Greenland Ice Sheet's contribution to sea level rise

- The Greenland Ice Sheet is the largest cryosphere contributor to sea level rise
- The majority of mass loss from the GrIS in the last decade has been attributed to surface melt

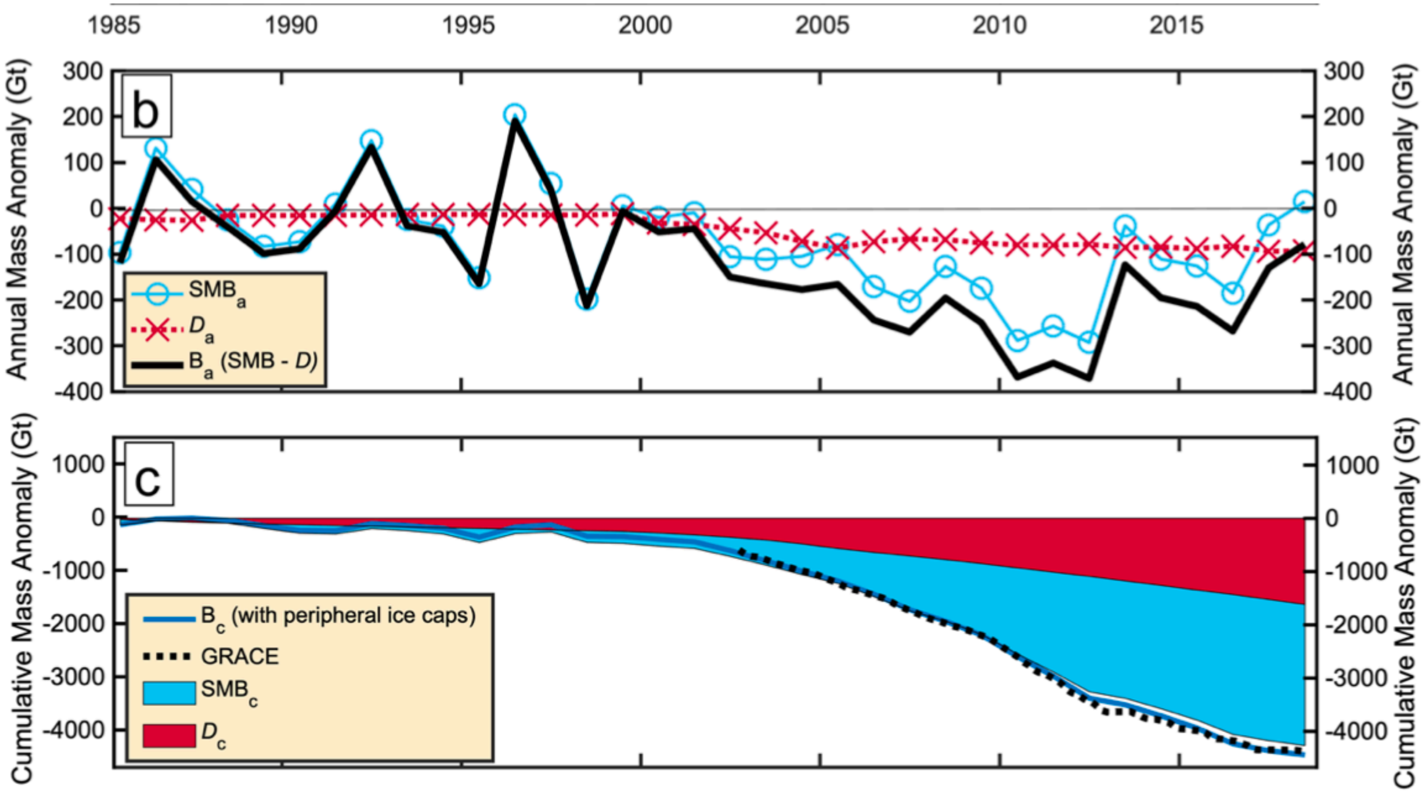



Figure: King et al. (2020)

# Greenland Ice Sheet albedo constrains surface melt

- The albedo of the ice sheet varies widely based on the surface conditions (snow, bare ice, melt ponds) and the light absorbing impurities present
- The south-west ablation zone is the darkest region on the GrIS

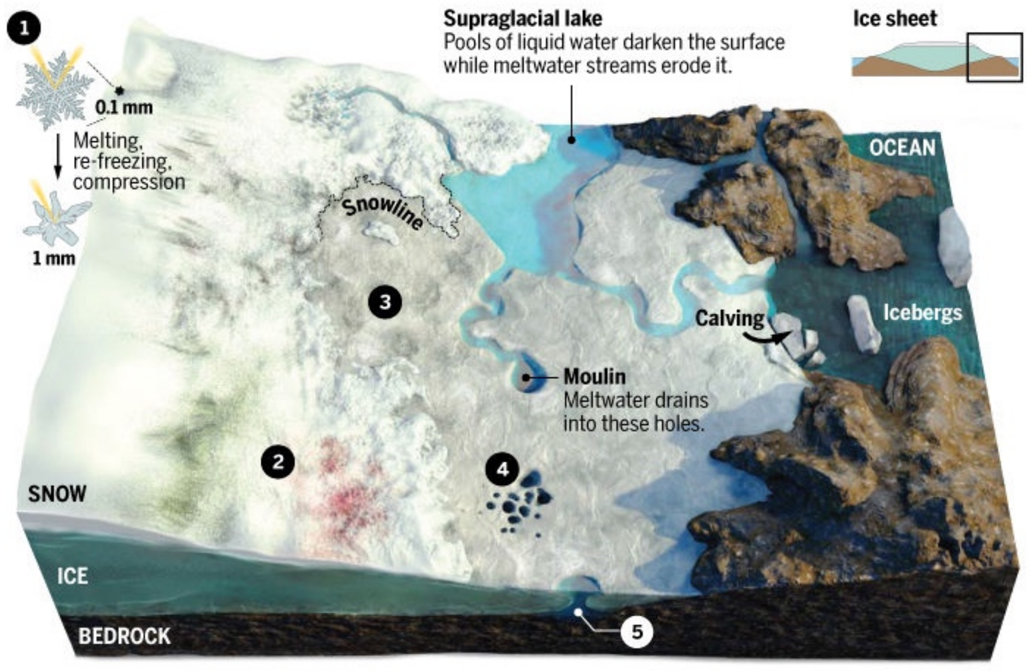
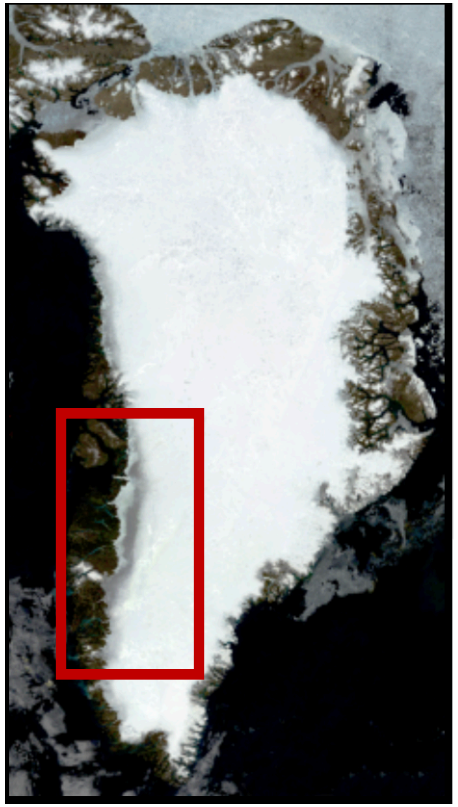



Figure: Kintisch (2017)



Surface melt

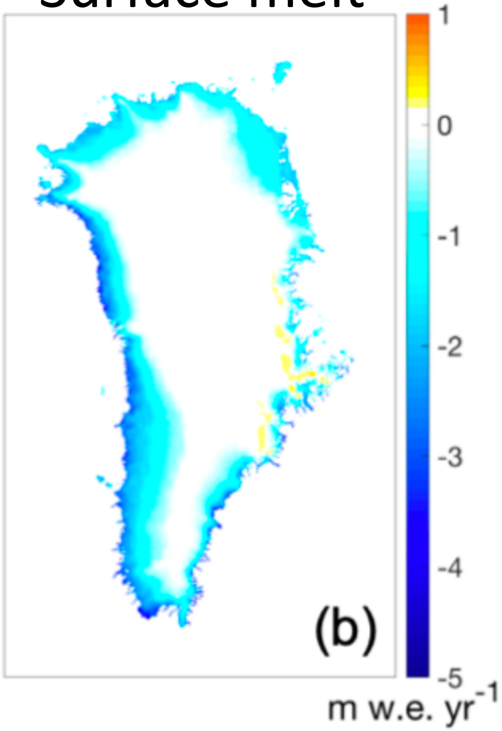
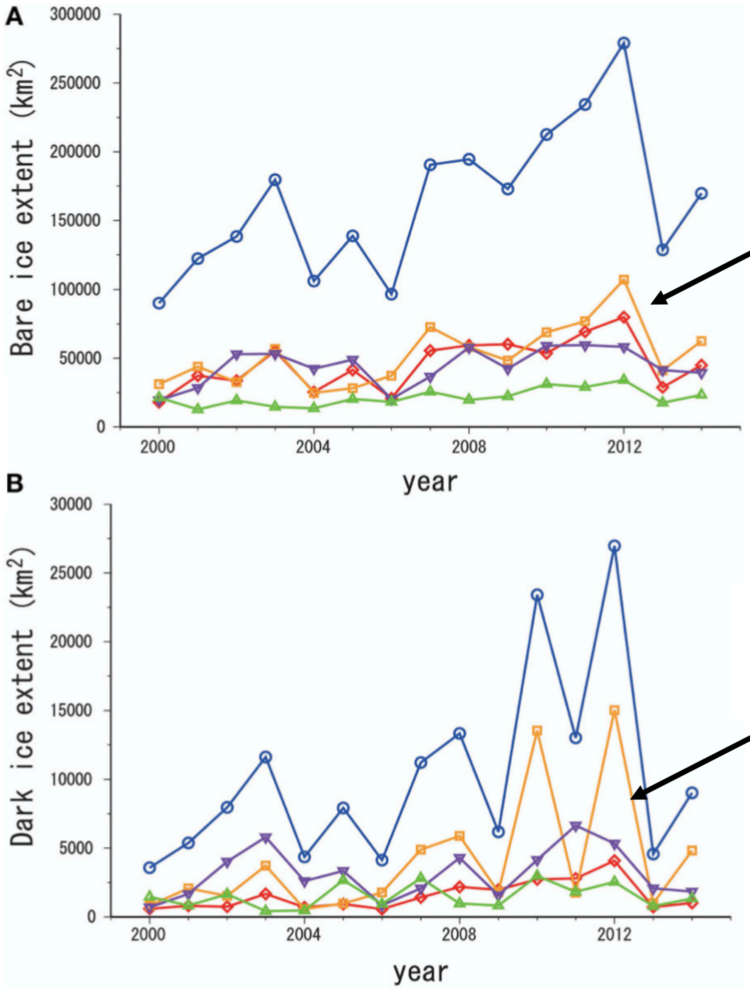



Figure: Goelzer et al. (2020)

# The south-west dark zone is increasing in size and becoming darker

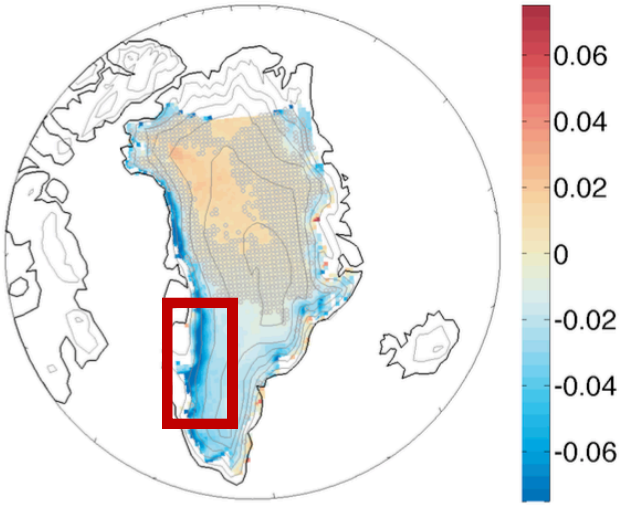
Spatial extent



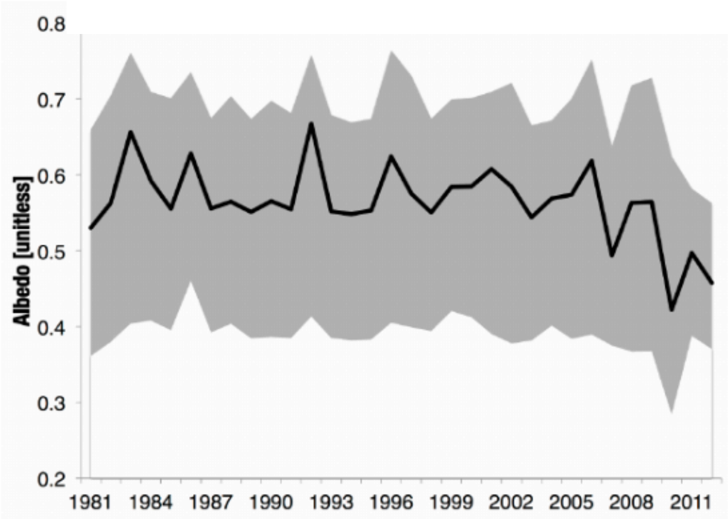

South-west dark zone

South-west dark zone

Figure: Shimada et al. (2016)




Summertime albedo trend (1996-2012)




Albedo trend in the south-west dark zone

Figure: Tedesco et al. (2016)

# The south-west dark zone is primarily darked by bare ice exposure and glacier algae colonization

## Bare ice exposure

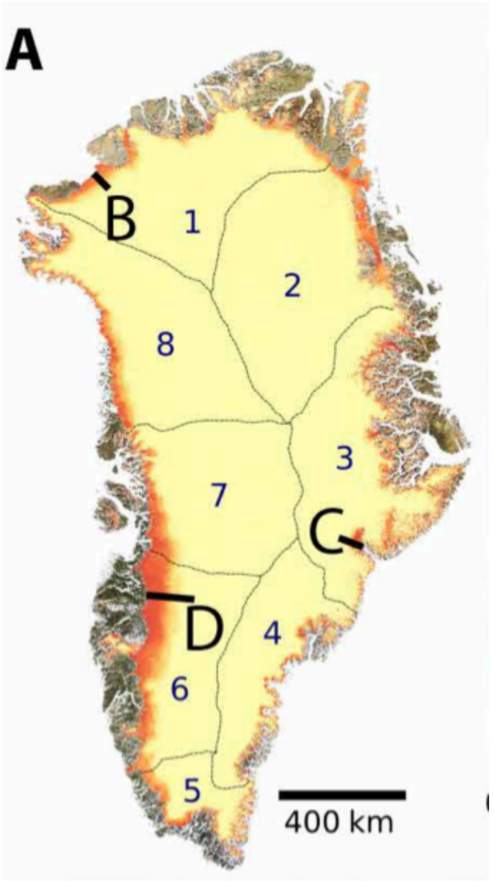



Figure: Ryan et al. (2018)

## Glacier algae growth

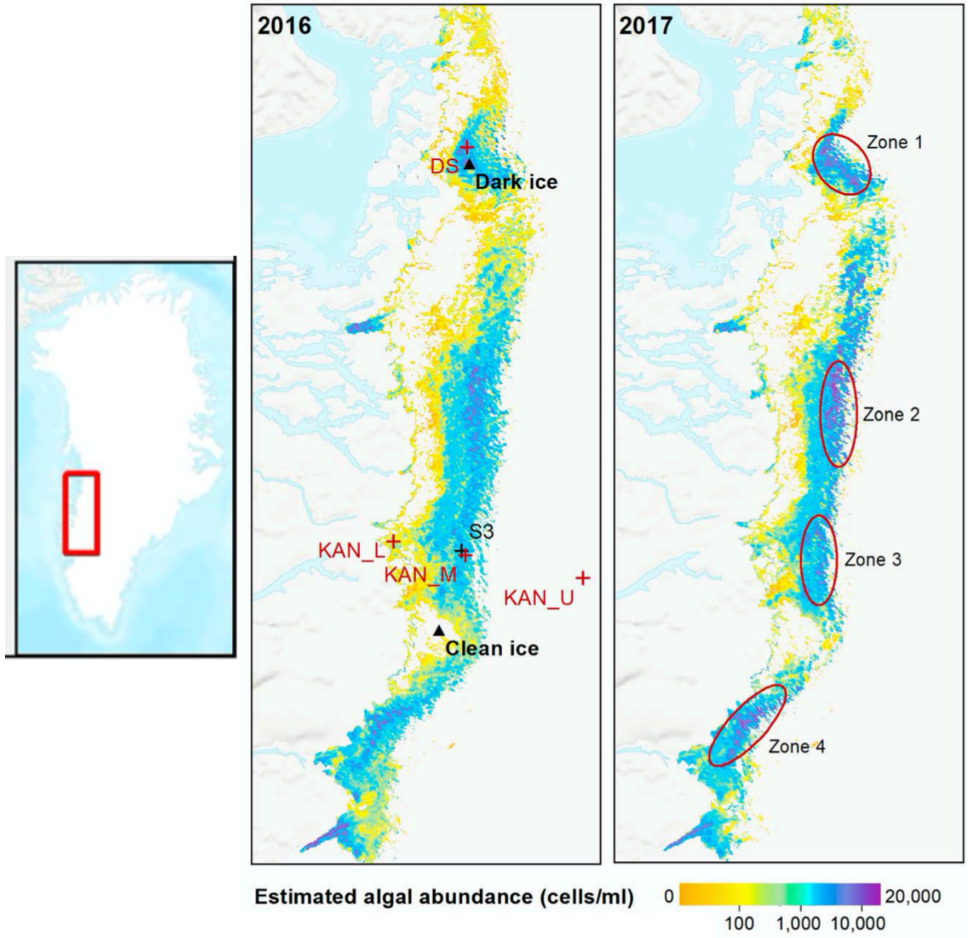



Figure: Wang et al. (2020)

# Significant melt has been attributed to bare ice exposure and glacier algae growth

- Higher snowline elevations lead to more exposed ice and more total runoff

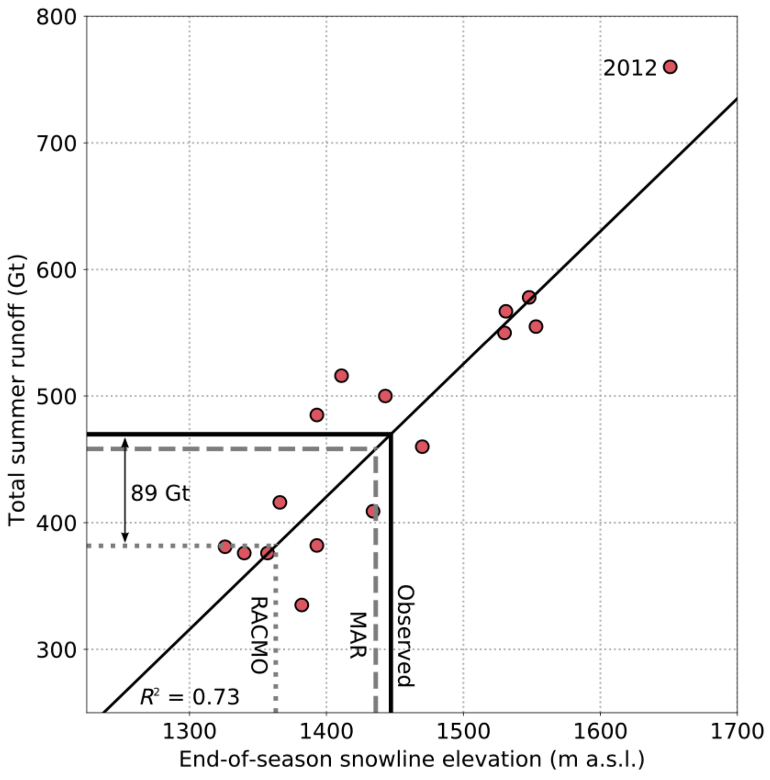



Figure: Ryan et al. (2019)

- In 2017 between **4.4-6 GT** of ice loss could be attributed to surface darkening by glacier algae

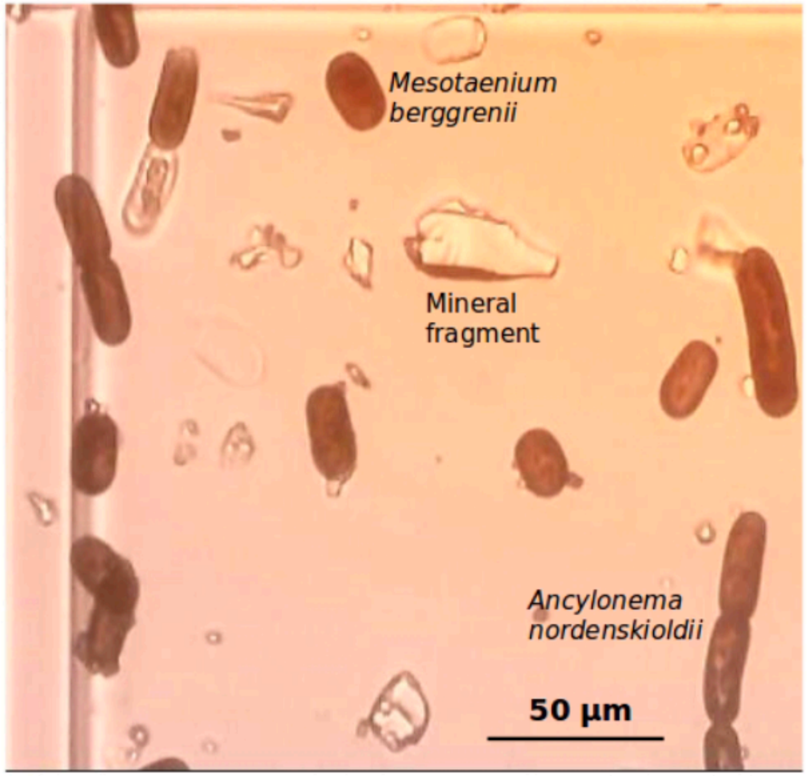


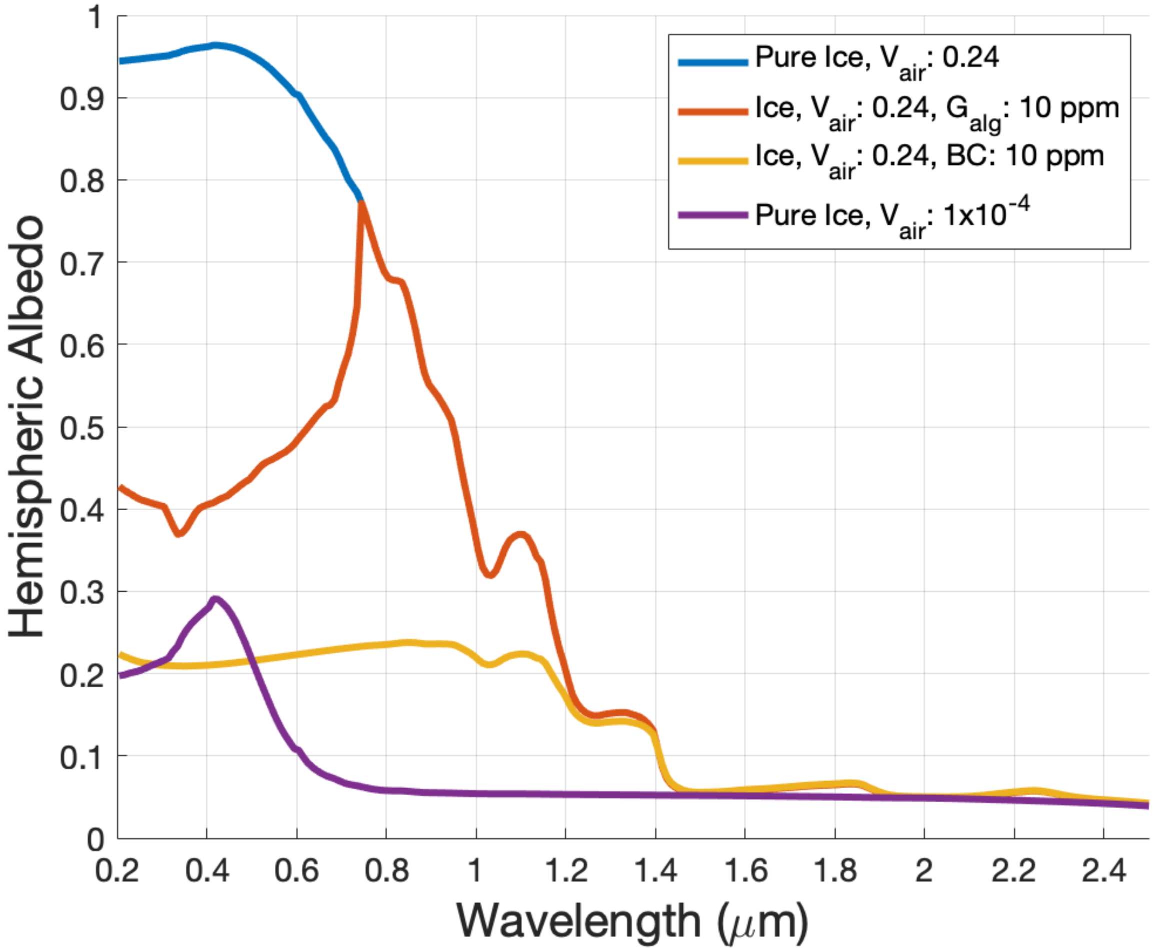

Figure: Cook et al. (2020)

# Current CESM representation of land bare ice albedo

- Within CESM bare ice albedo is parameterized to generally agree with measurements

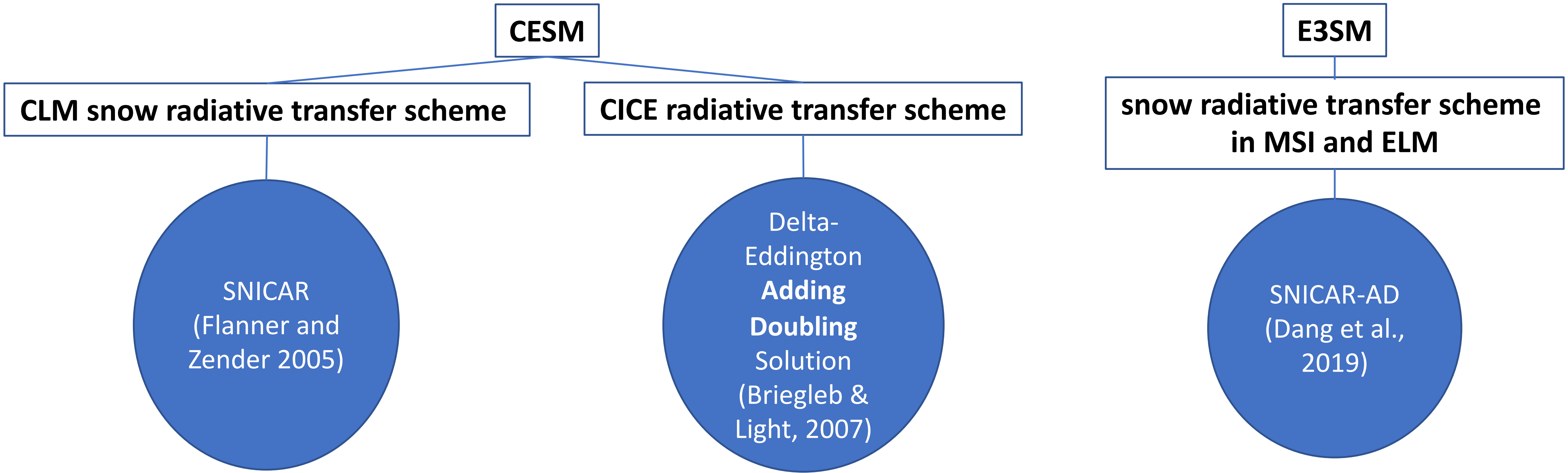
$$\alpha_{vis} = 0.6$$
$$\alpha_{nir} = 0.4$$

- The albedo influence of glacier algae is omitted from CESM

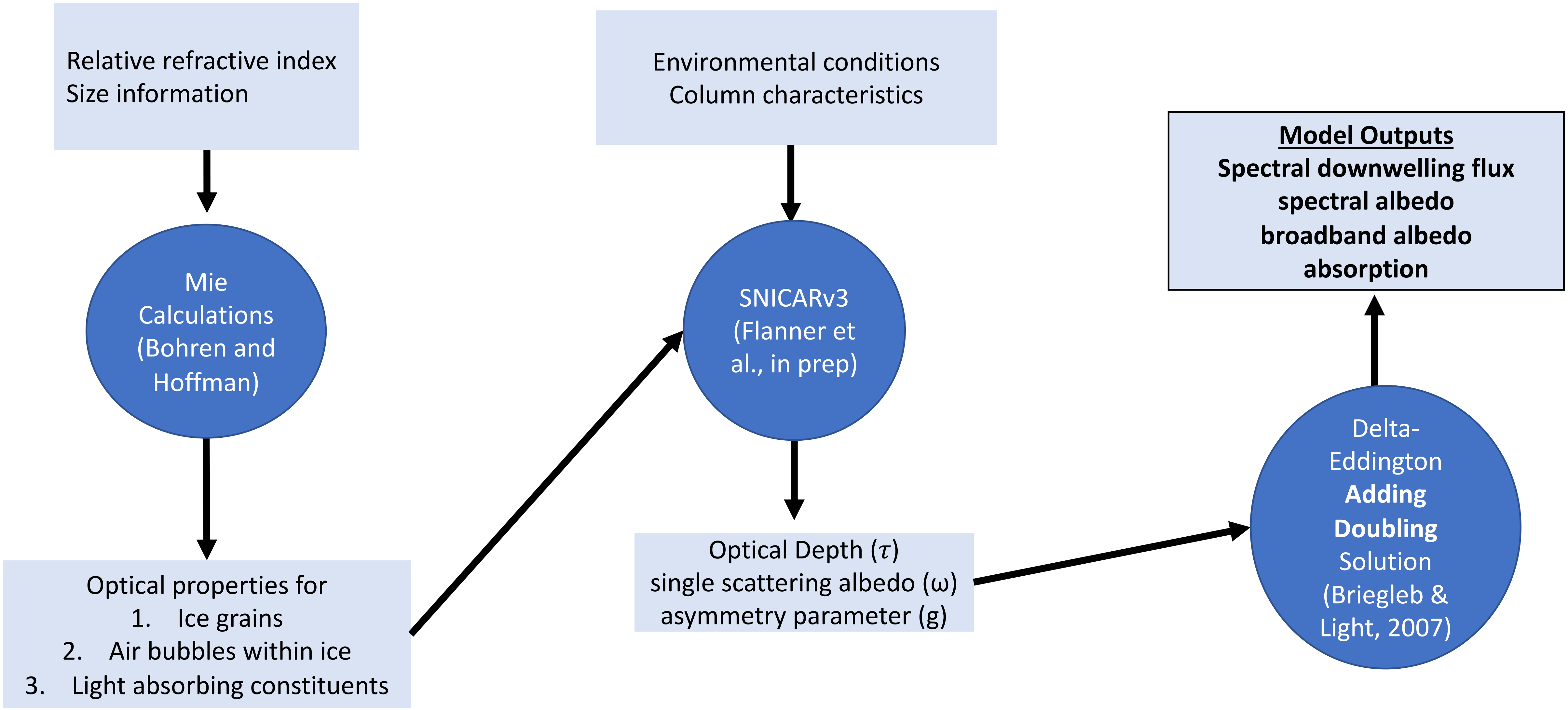


# Our (1st step) solution: SNICAR-AD v4

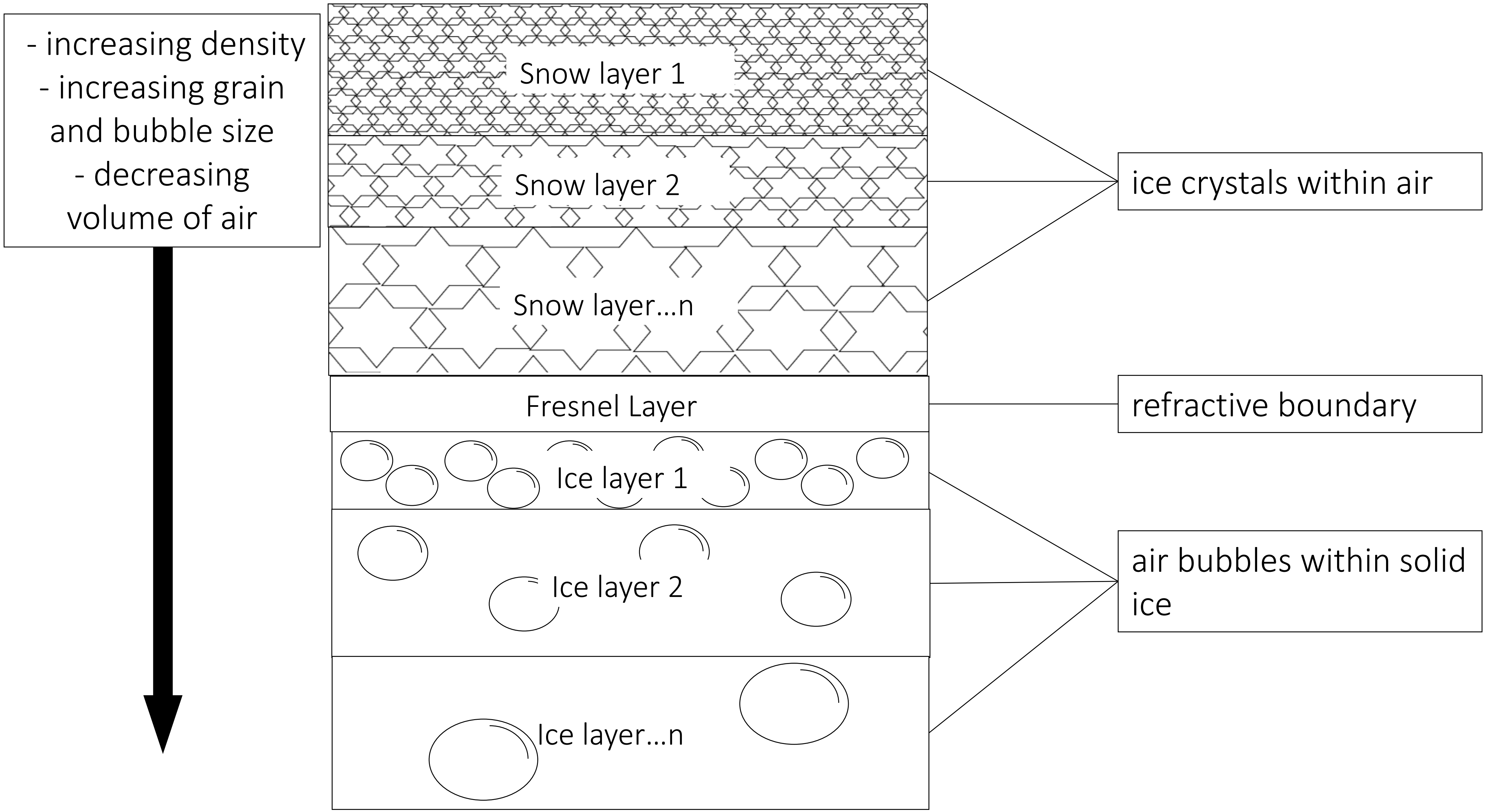
- A single column heterogenous multilayer snow and ice model that explicitly represents the optical properties of (1) snow, (2) ice, and (3) a range of light absorbing constituents
- SNICAR-ADv4 contains a combination of solutions that are already employed within CESM and E3SM



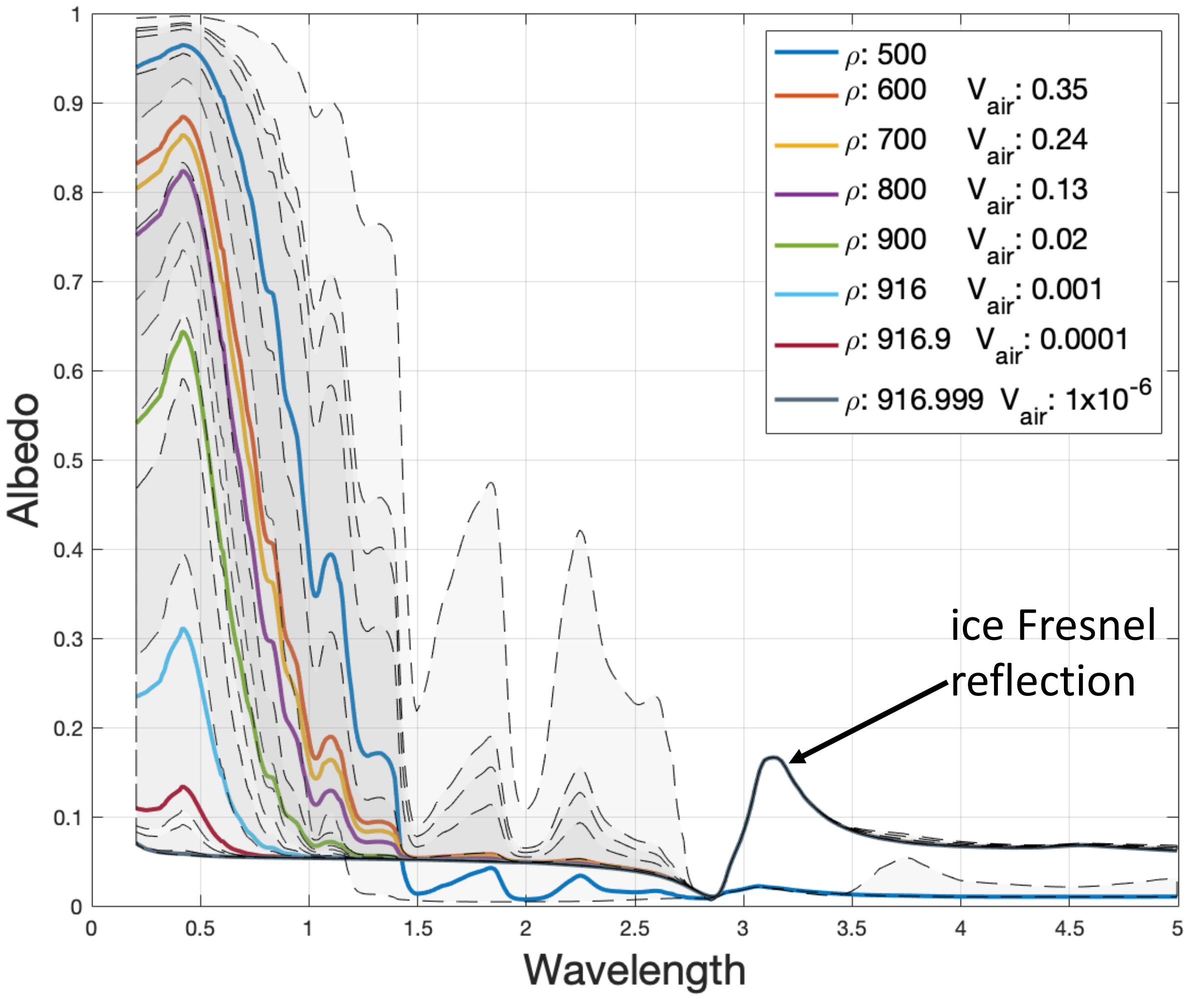
# SNICAR-ADv4: model flow

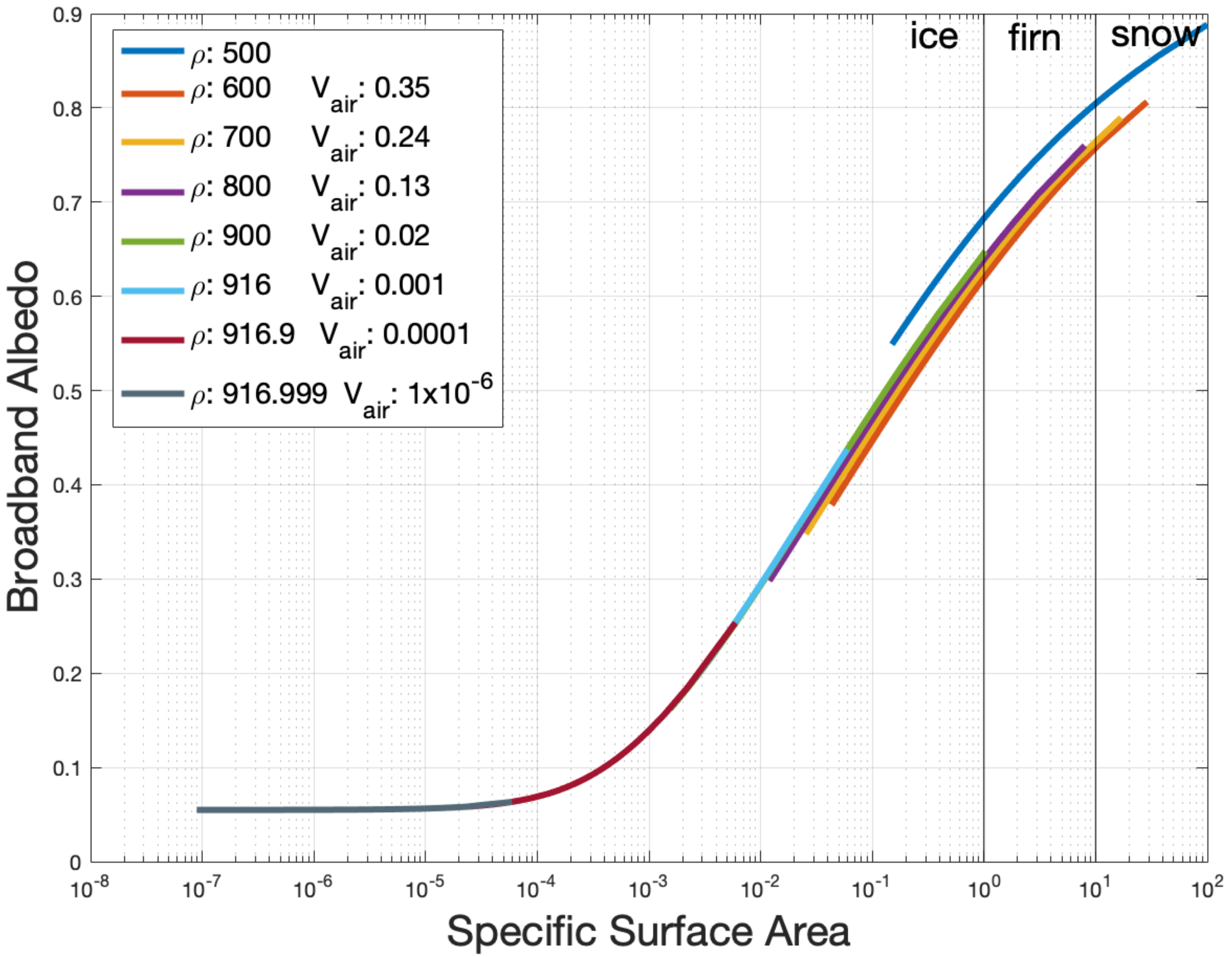


# SNICAR-AD v4: model set up



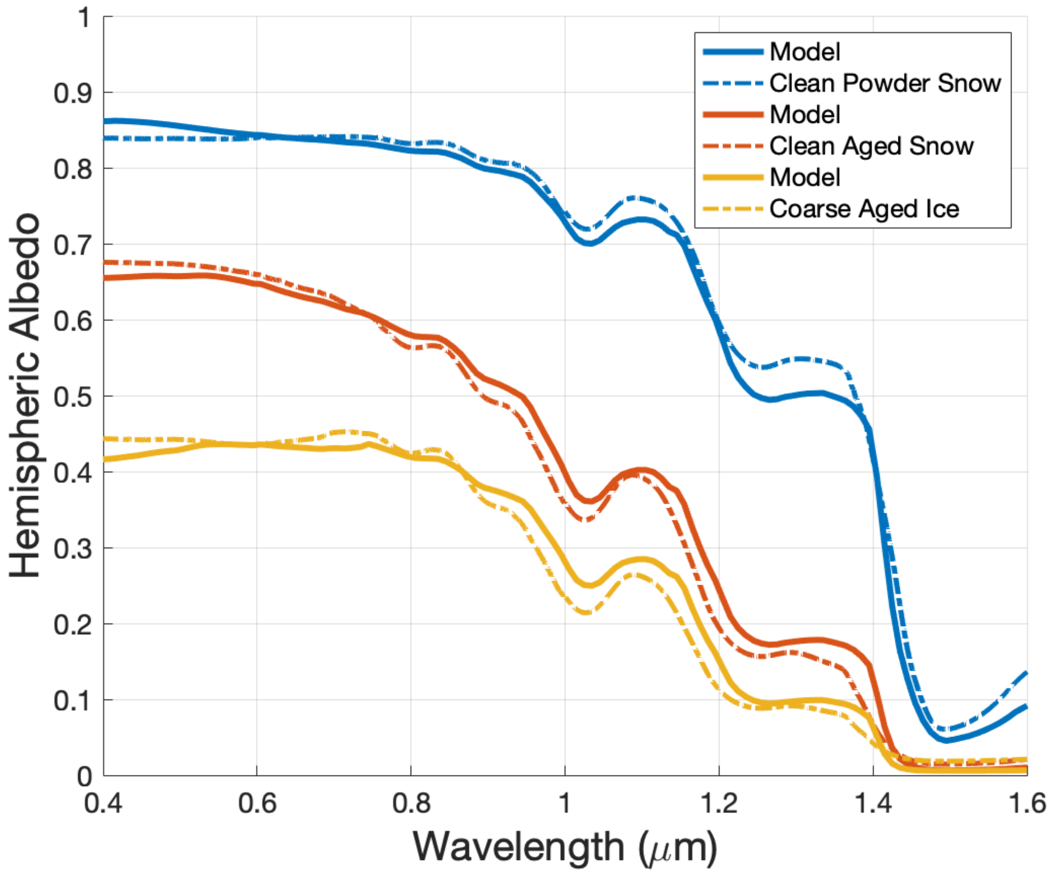
# Results:
# SNICAR-ADv4 simulates a wide range of realistic albedos



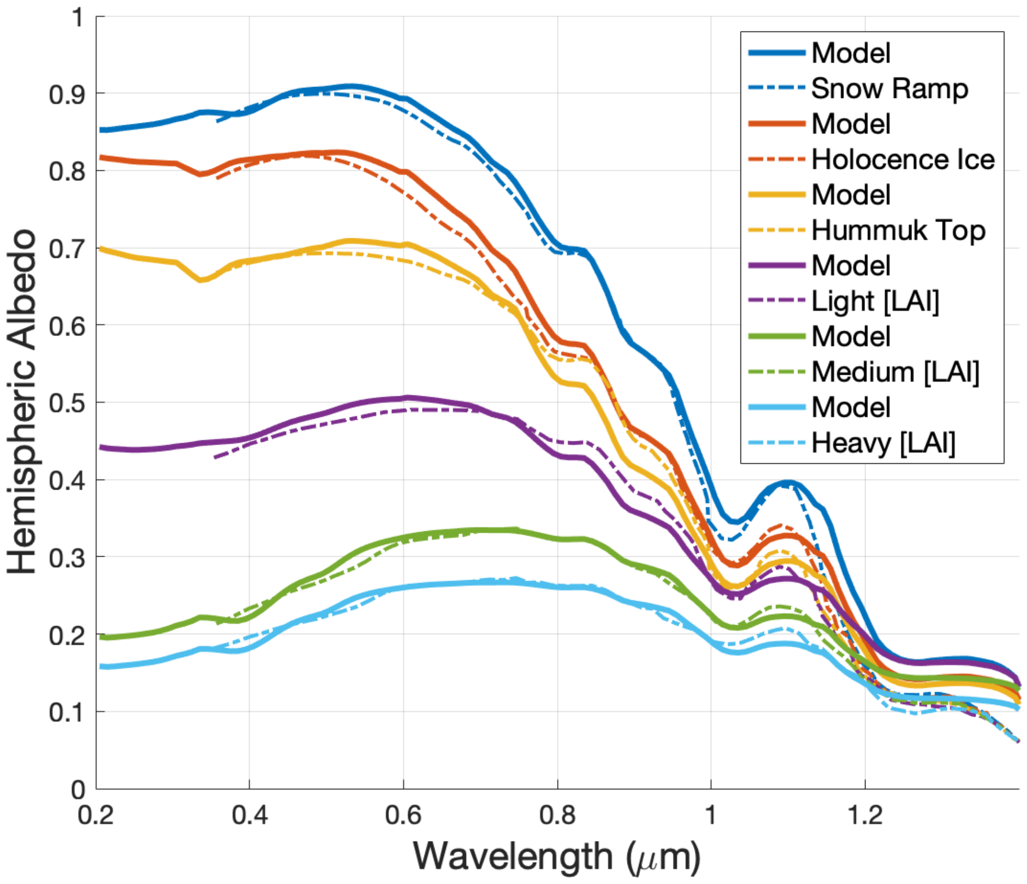



# Results:
# SNICAR-ADv4 comparison to Greenland Ice Sheet albedo

- SNICAR-Adv4 compares well with snow and ice measurements made in different regions of of the Greenland Ice sheet with very different impurity contents and albedos



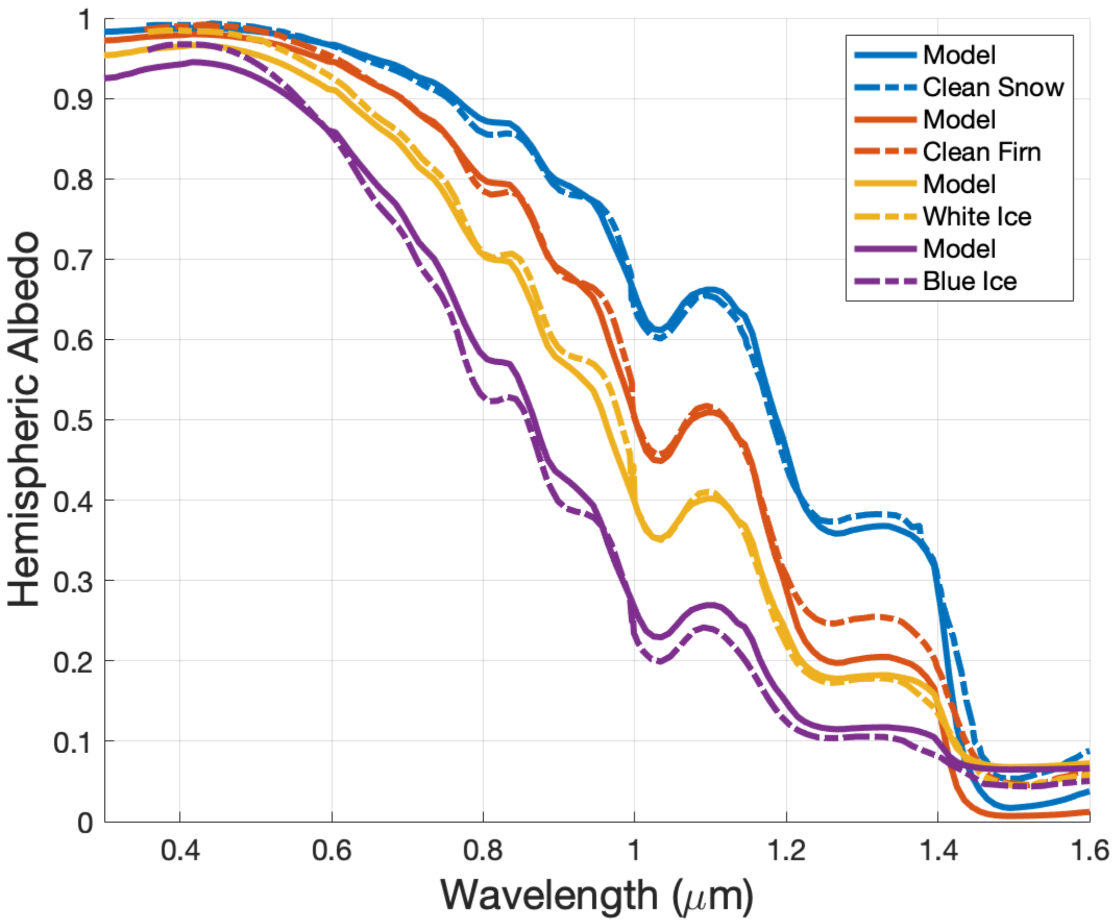

Measurements: Cook et al. (2020)




Measurements: Bøggild et al. (2010)

# Results:
# SNICAR-ADv4 comparison to Antarctica albedo

- SNICAR-Adv4 compares well with snow, firn, and ice albedos made in Antarctica




Measurements: Dadic et al. (2013)

# Conclusion & Relevance for ESM

- Model scheme is already generally compatible with CESM & E3SM
- If implemented in a fully coupled model, dynamic ice albedo simulations will improve projections of surface melt and sea level rise
- SNICAR-ADv4's flexible model scheme and explicit optical properties allow it to be utilized anywhere snow or ice is present

**Thank you!**

**Questions?**