# Sea Ice Surface Temperature from C-band Passive Microwave Observation

## Development for CIMR

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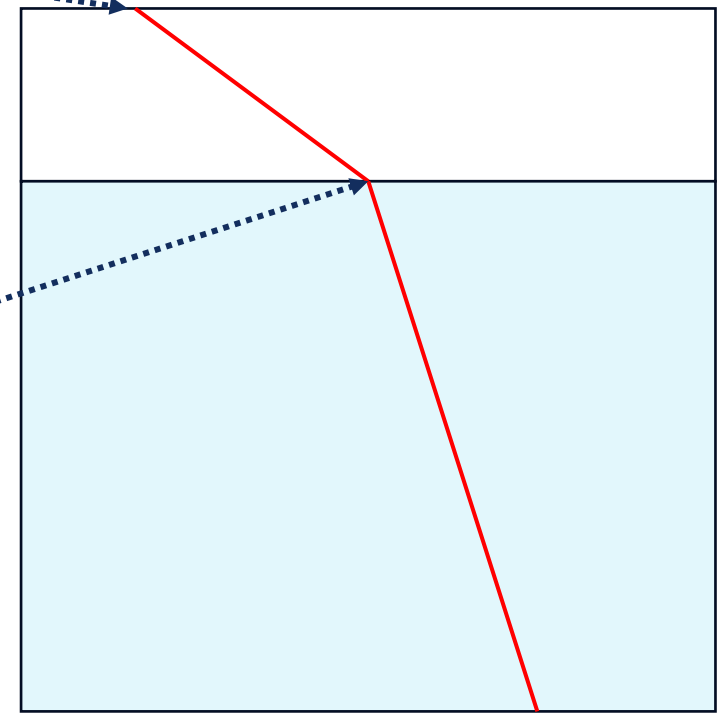
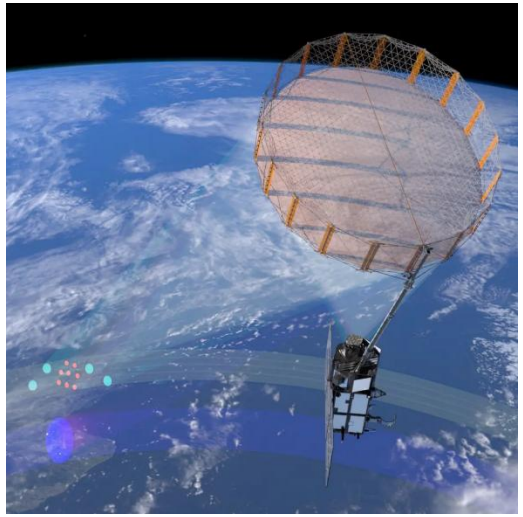
# Sea Ice Surface Temperatures (IST)

- **IR ice surface temperature**
  - Represents the air-snow surface temperature
  - Satellite observations are quite accurate, but are blocked by cloud cover
- **PMW ice surface temperature**
  - Represents the snow-ice interface temperature
  - Less accurate, but enables more frequent and complete monitoring of IST



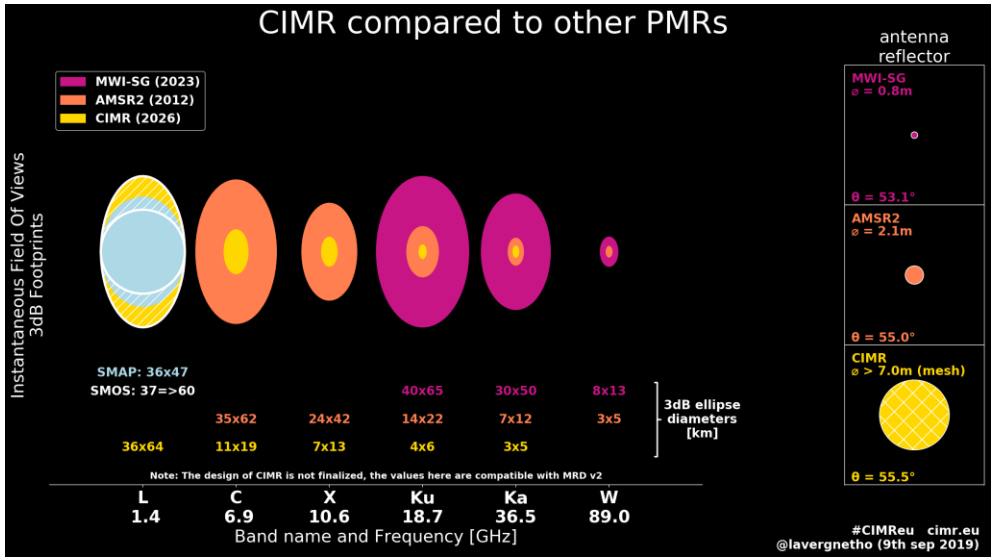
# Copernicus Imaging Microwave Radiometer





**CIMR** is being developed by ESA for launch in the late 2020s.

CIMR will improve **measuring sea ice and the polar ocean**, and contribute to global monitoring of terrestrial surfaces **at higher spatial resolution and accuracy**.




Learn More

CIMR L2PAD

**CIMR L2PAD project**

- To prepare Polar Oceans and Global Land Level-2 algorithms for CIMR
- All software, data, and algorithm documentations from CIMR L2PAD will be open
- DMI is responsible for IST and SST processors

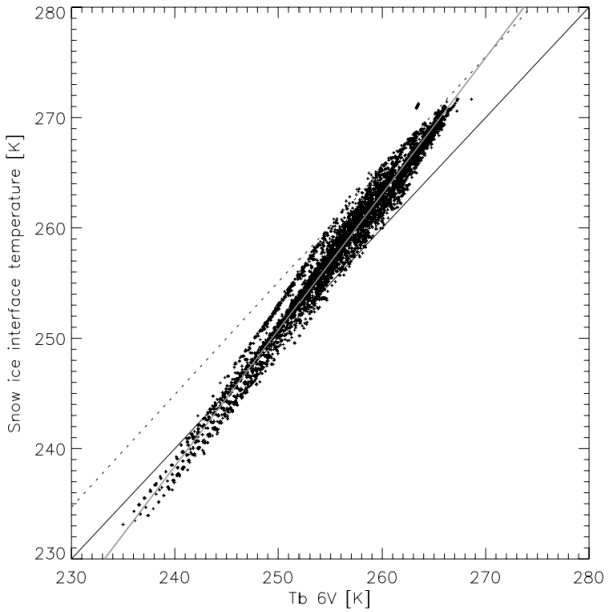
https://github.com/CIMR-L2PAD

# PMW IST retrieval using C-band

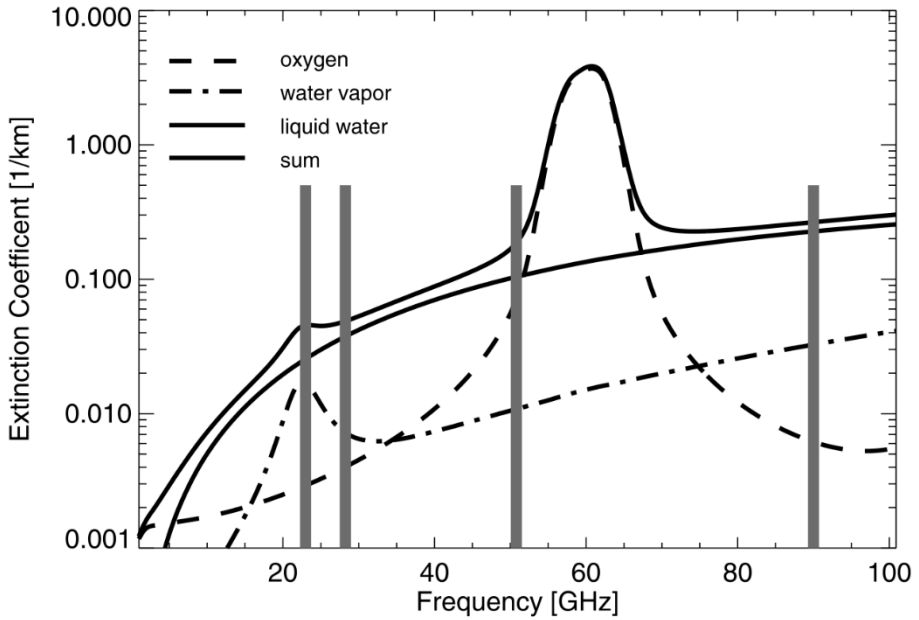


## Key assumptions for the baseline algorithm (Lee and Sohn, 2015)

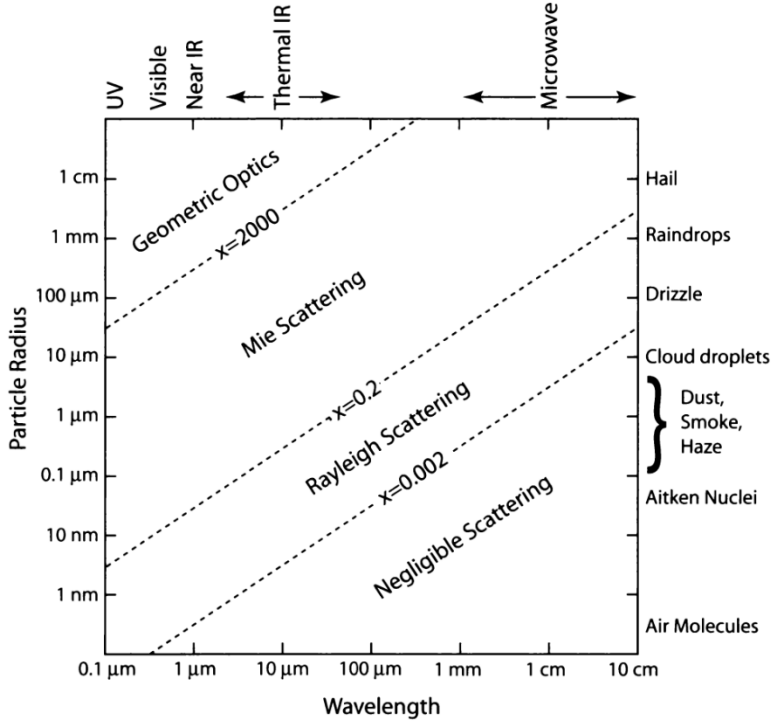
- The snow-ice interface is an effective emitting layer for C-band
- The atmosphere and snow layer on sea ice are almost transparent at C-band
- The sea ice surface is specular at C-band, and its reflectivity can be described by the Fresnel equations




Tonboe et al. (2011)



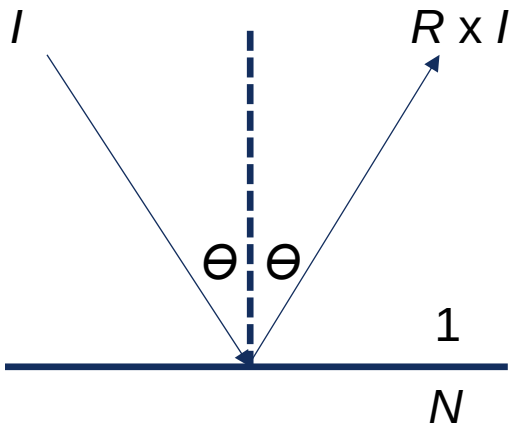

Löhnert and Crewell (2003)




Petty (2006)

# Fresnel Equations

- Equations that describe the reflectance of a specular surface




$$R_h(N,\theta) = \left\| \frac{\cos\theta - \sqrt{N^2 - \sin^2\theta}}{\cos\theta + \sqrt{N^2 - \sin^2\theta}} \right\|^2$$

$$R_v(N,\theta) = \left\| \frac{N^2\cos\theta - \sqrt{N^2 - \sin^2\theta}}{N^2\cos\theta + \sqrt{N^2 - \sin^2\theta}} \right\|^2$$

- Combined Fresnel equation (Sohn and Lee, 2013)
  - Vertically polarized reflectance can be formulated as a function of horizontally polarized reflectance and OZA

$$R_v = R_h^2 \left( \frac{1 + R_h^{-1/2}\cos 2\theta}{1 + R_h^{1/2}\cos 2\theta} \right)^2 = f_{CF}(R_h, \theta)$$

- Emissivity + Reflectance = 1
  - From energy conservation

# Radiative Transfer Equation



$$T_p(\theta) = T_{\text{up}}(\theta) + \epsilon_p(\theta) T_s \tau(\theta) + (1 - \epsilon_p(\theta)) T_{\text{down}}(\theta) \tau(\theta)$$

| Symbol | Description | Units |
|---|---|---|
| $T_p$ | TB at the top of the atmosphere with polarization $p$ | K |
| $\epsilon_p$ | surface emissivity with polarization $p$ | 1 |
| $\theta$ | observation zenith angle | degrees |
| $T_s$ | surface temperature (i.e., SIST) | K |
| $\tau$ | atmospheric transmittance | 1 |
| $T_{\text{up}}$ | upwelling TB of atmospheric radiation at the top-of-the-atmosphere | K |
| $T_{\text{down}}$ | downwelling TB of atmospheric radiation at the surface (including the cosmic microwave background contribution) | K |

# Finding a solution for IST



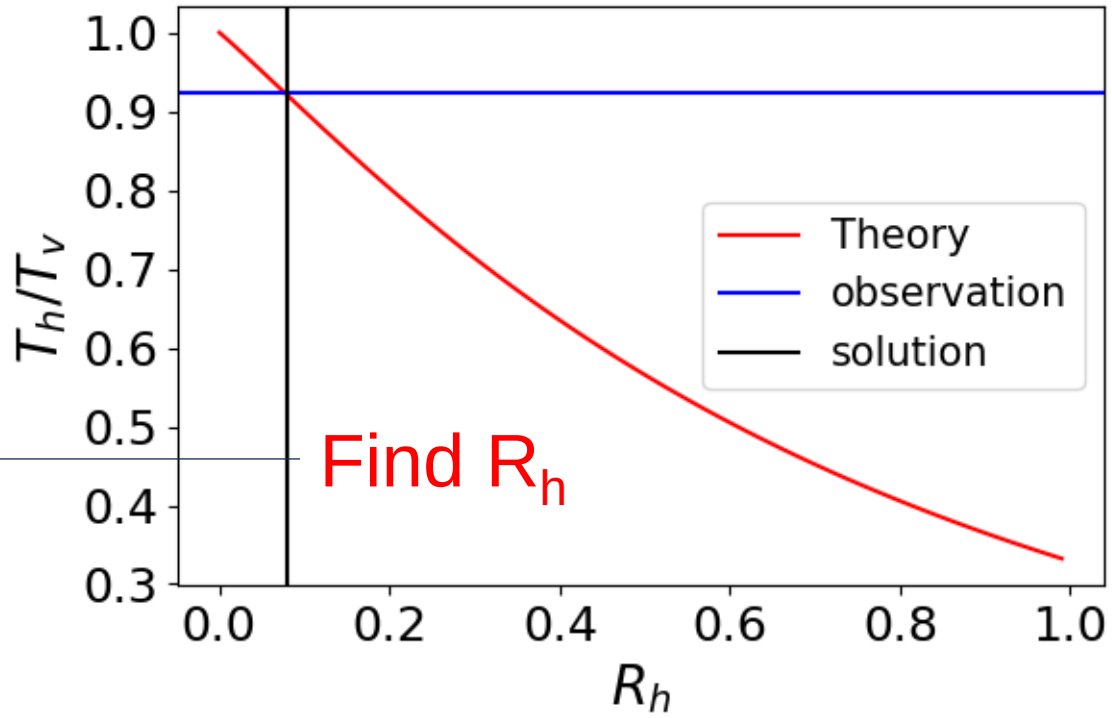
$$\epsilon_h = \frac{T_h - T_{\text{up}} - \tau T_{\text{down}}}{\tau(T_s - T_{\text{down}})}$$

$$\epsilon_v = \frac{T_v - T_{\text{up}} - \tau T_{\text{down}}}{\tau(T_s - T_{\text{down}})}$$

$$\rightarrow \quad \frac{\epsilon_h}{\epsilon_v} = \frac{T_h - T_{\text{up}} - \tau T_{\text{down}}}{T_v - T_{\text{up}} - \tau T_{\text{down}}} \quad \rightarrow \quad \frac{1 - R_h}{1 - f_{CF}(R_h, \theta)} = \frac{T_h - T_{\text{up}} - \tau T_{\text{down}}}{T_v - T_{\text{up}} - \tau T_{\text{down}}}$$

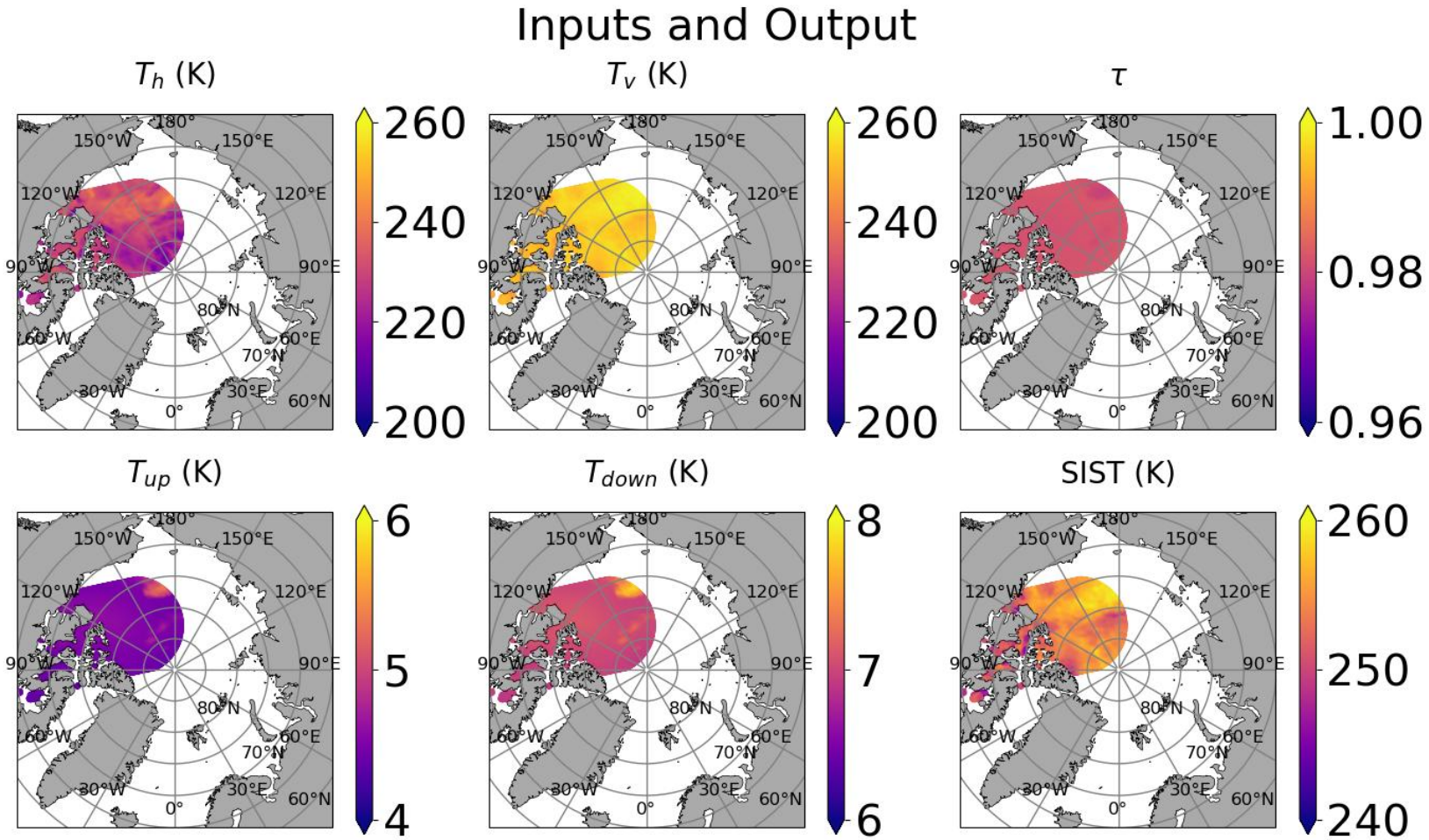
Compute emissivity

$$T_s = \frac{T_h - T_{\text{up}} - (1 - \epsilon_h)\tau T_{\text{down}}}{\tau \epsilon_h}$$



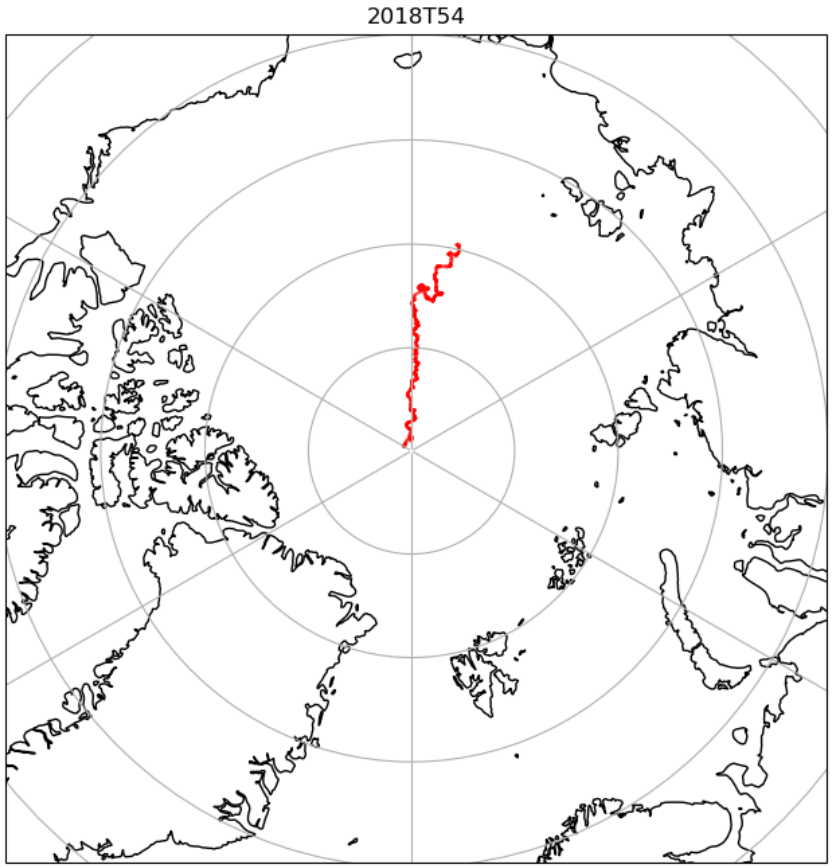
# Demonstration

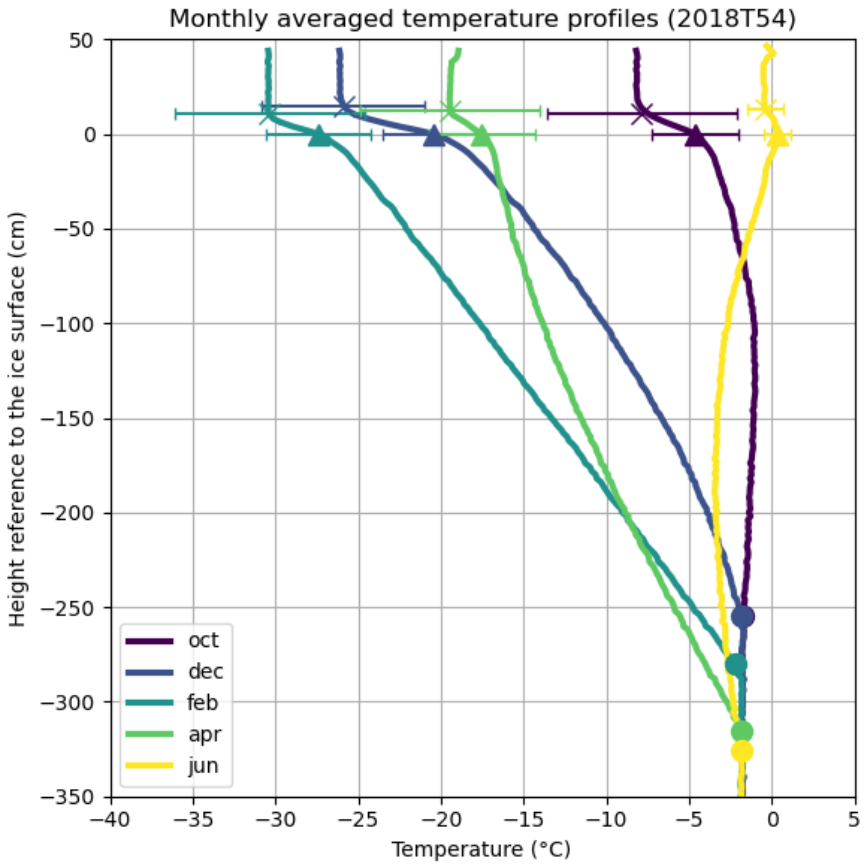
- Input data
  - AMSR2 6.9 GHz TB
  - ERA5 ATM profiles
- Atmospheric RTM
  - RTTOV13



# Validation Plan

- Make a comparison between the retrieval and buoy measurements



# Future R&D

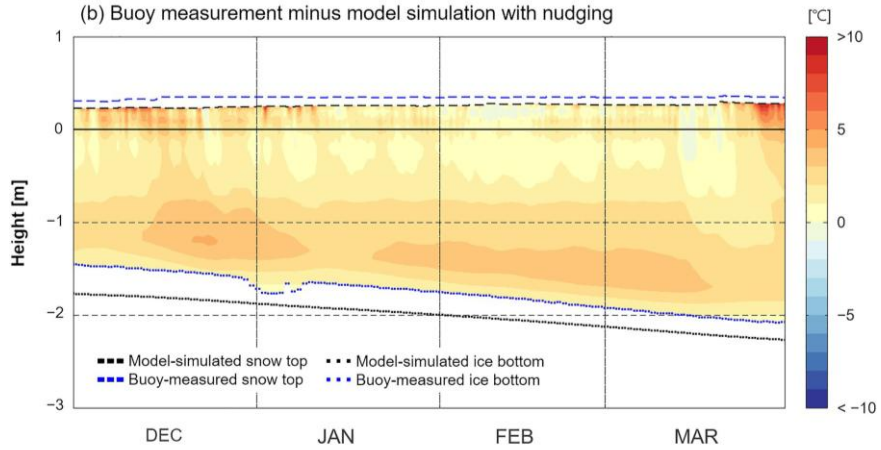
- Bias Correction Method
  - There could be a **systematic bias** between the retrieved and actual IST **depending on the snow conditions**.
  - We will first compare satellite-derived IST and in situ measurements of IST from buoys and analyze the corresponding difference/bias.
  - Then, **predictors** that can be used for correcting the bias will be explored by **combining various Stokes parameters from higher frequency channels**.
  - Before CIMR becomes operational, AMSR2 will be used for the development, and the developed correction method will be updated with CIMR observations afterward.

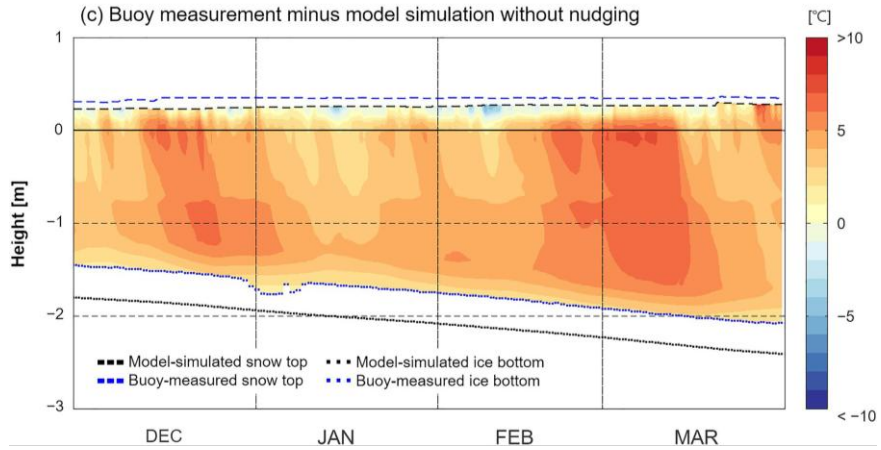
# Application Examples



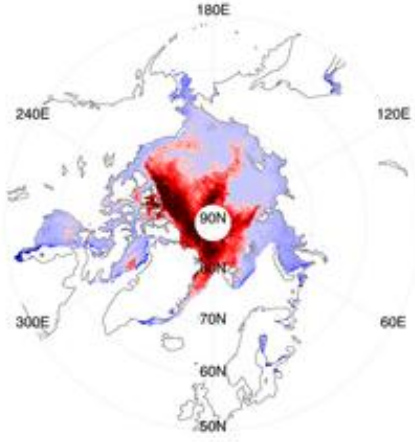
- Sea ice emissivity and type
- Sea ice thickness and snow depth
- Sea ice model data assimilation
- Supplement surface temperature?
  - Could be a good predictor for IR IST?

Kang et al. (2021)

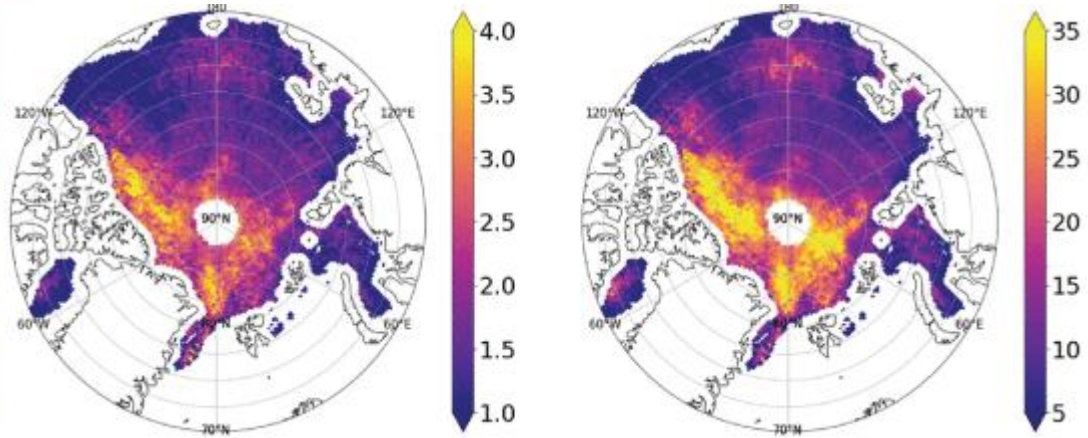



Lee et al. (2017)




Shi et al. (2023)



# Thank you for your attention!