Far-infrared radiance measurements of clear-sky, cirrus cloud and snow surfaces and the application to emissivity

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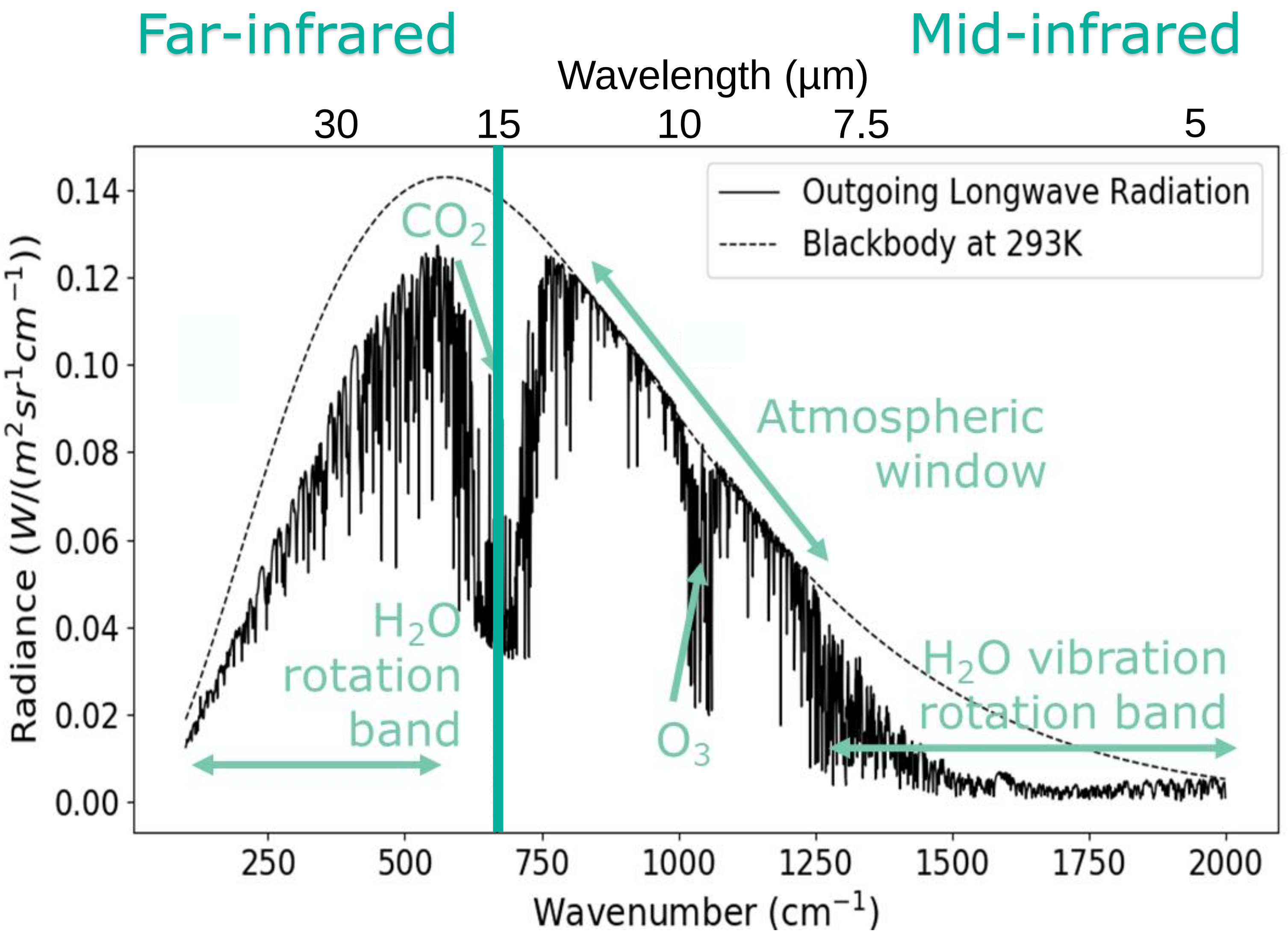
What is the far-infrared?



- Wavelengths > 15 µm or wavenumbers < 667 cm^{-1}
- 50% of OLR in the global mean
- Atmosphere mostly opaque but surface sometimes visible in cold/dry regions
- Currently not observed from space but will be with PREFIRE in 2024 and FORUM in 2027

Imperial College London

Far Infrared Spectrometer for Surface Emissivity

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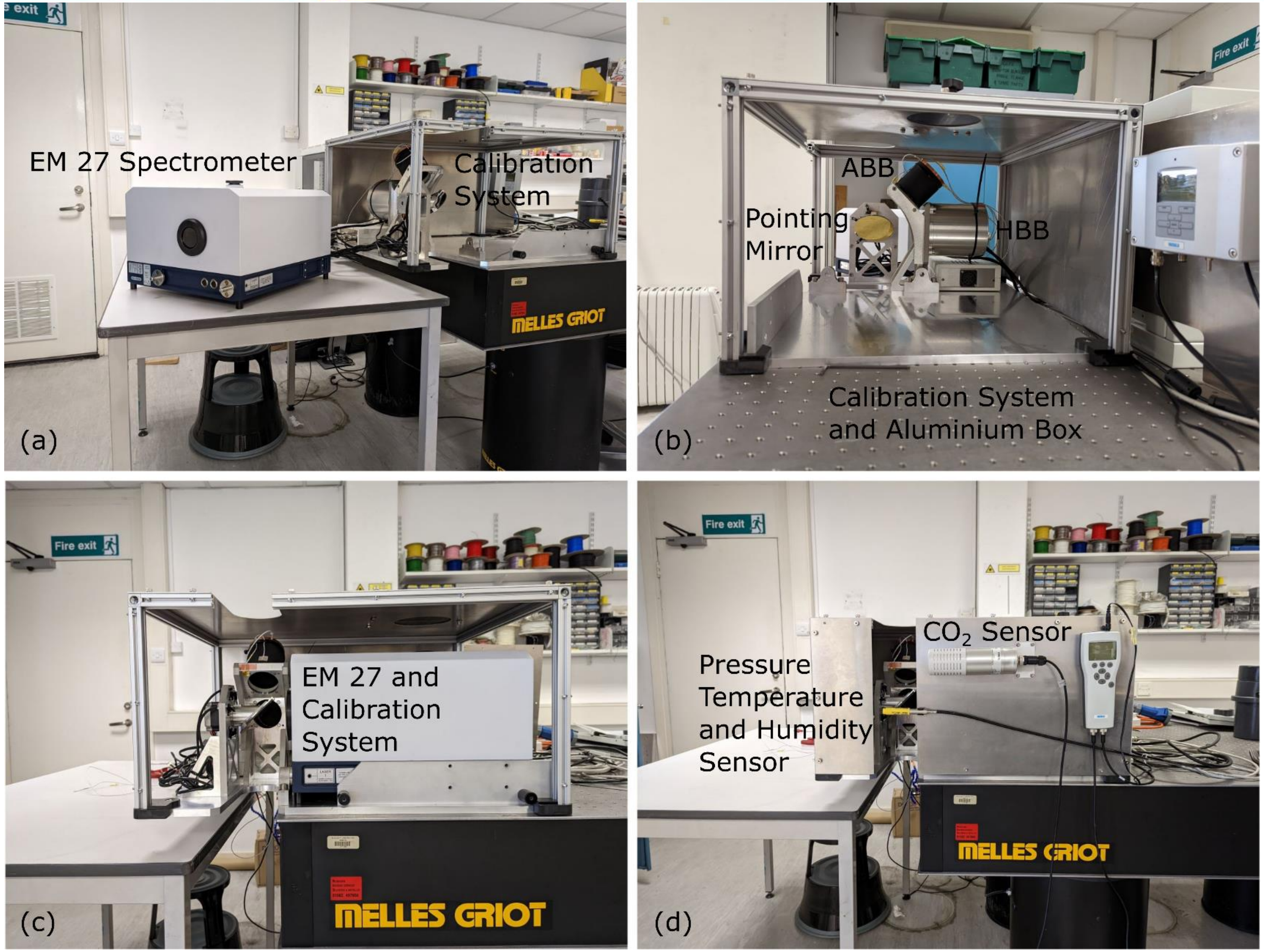
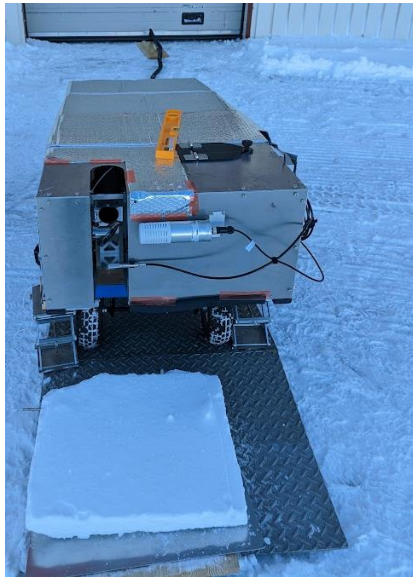


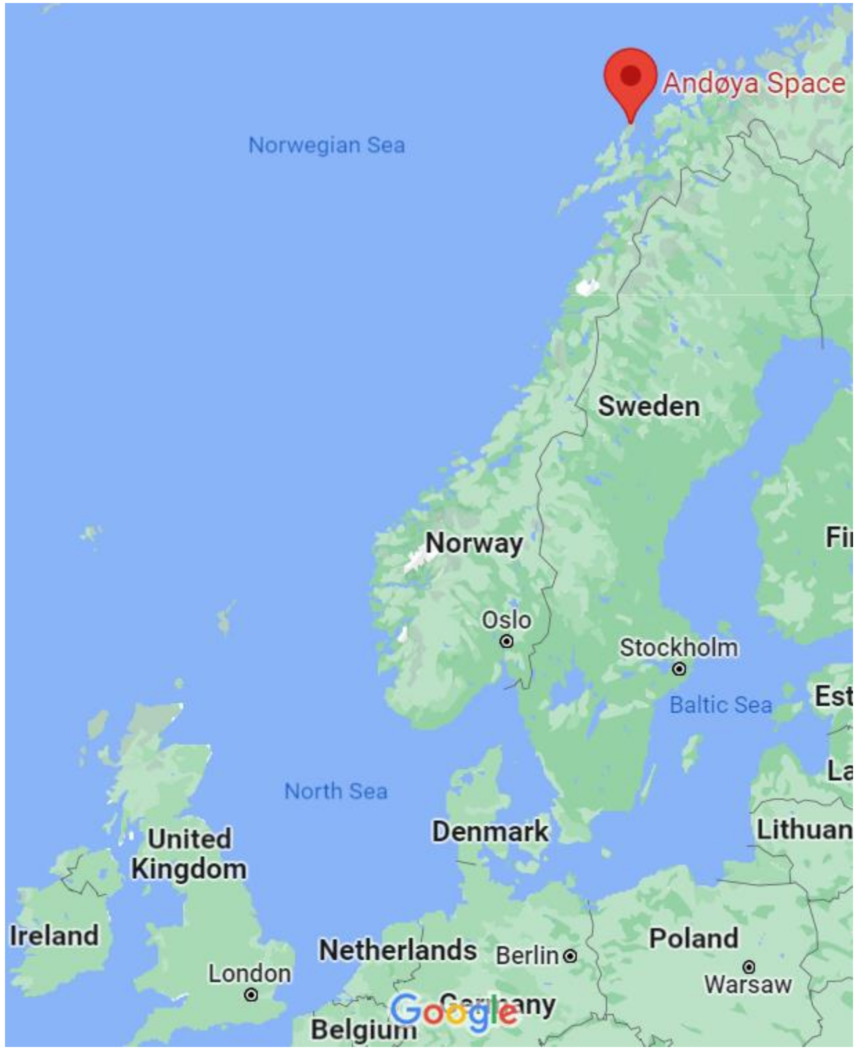
Wavenumber Range	400-1600 cm^{-1}
Nominal Resolution	0.5 cm^{-1}
Scan time	~1.5 s
Single spectrum NESR ($mW\ m^{-2} sr^{-1} (cm^{-1})^{-1}$)	~1 @ 450 cm^{-1} ~0.5 @ 800 cm^{-1}
Calibration error ($mW\ m^{-2} sr^{-1} (cm^{-1})^{-1}$)	~1 @ 450 cm^{-1} ~2 @ 800 cm^{-1}
Detector	MCT-B liquid nitrogen cooled
Window	Diamond
Additional measurements	Pressure, temperature, humidity, CO_2

Murray et al. *The Far INfrarEd Spectrometer for Surface Emissivity (FINESSE). Part 1: Instrument description and level 1 radiances. Accepted AMT*

Data collection - Deployment to Andøya Norway

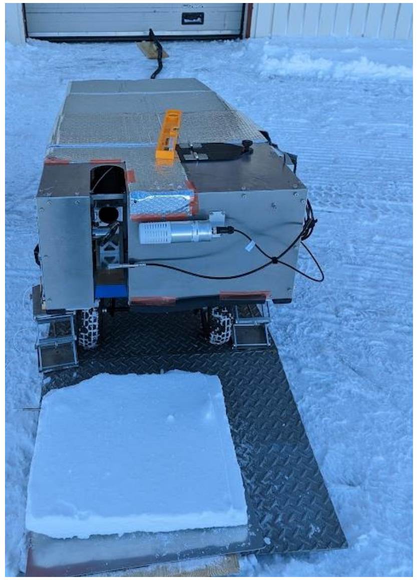
- Imperial College invited deploy FINESSE to Andøya, northern Norway 69.2°N 16.0°E
- Piggybacking on to preplanned ICEPACKS campaign organized by the University of Oslo
- Additional ground-based instrumentation and in-situ cloud measurements from INCAS Atmoslab aircraft





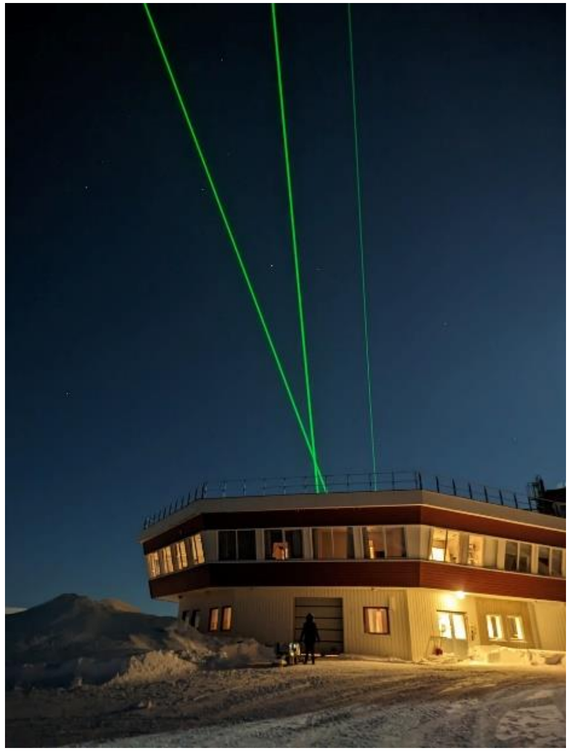
Andøya - Objectives

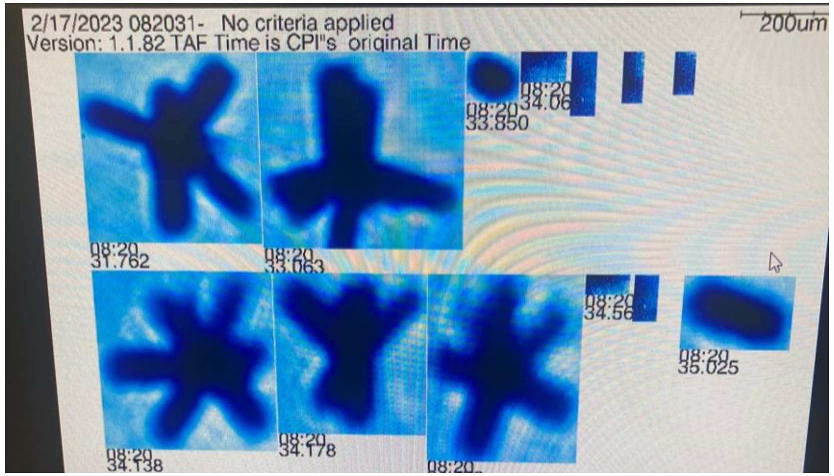
1. Deploy the new FINESSE spectrometer to an Arctic environment
2. Investigate stability of the instrument in harsher operating conditions
3. Measure the downwelling radiative signature of ice clouds with in-situ measurements
4. Measure the emissivity of snow/ice surfaces
5. Measure the downwelling radiance of other scenes



Andøya - Instrumentation

- Ground based measurements
  - MMR (micro rain radar)
  - **HATPRO (humidity and temperature profiler)**
  - **Ceilometer w. depolarisation**
  - Ice nucleating particles
  - Multi Angle Snowflake Camera
  - Precipitation gauge
  - Troposphic LiDAR
  - FINESSE
- **Radiosonde**
- Airborne measurements
  - **SPEC Hawkeye**
  - **DMT CAPS**

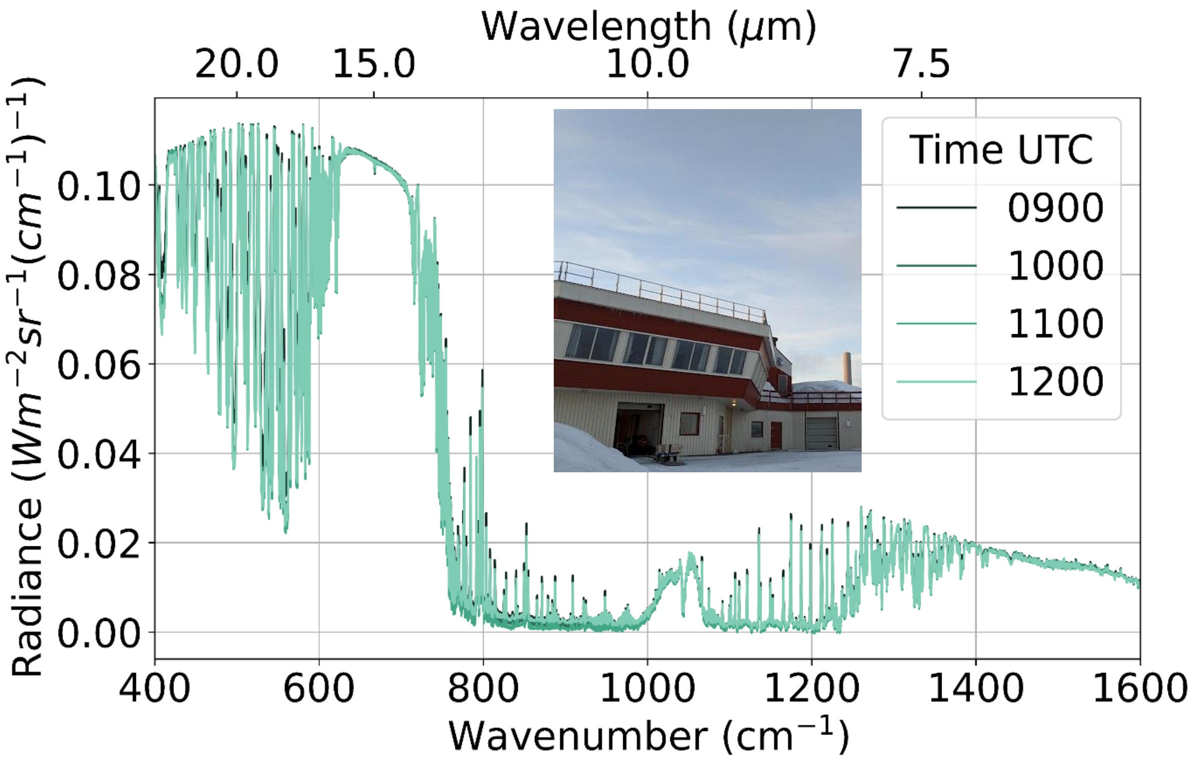




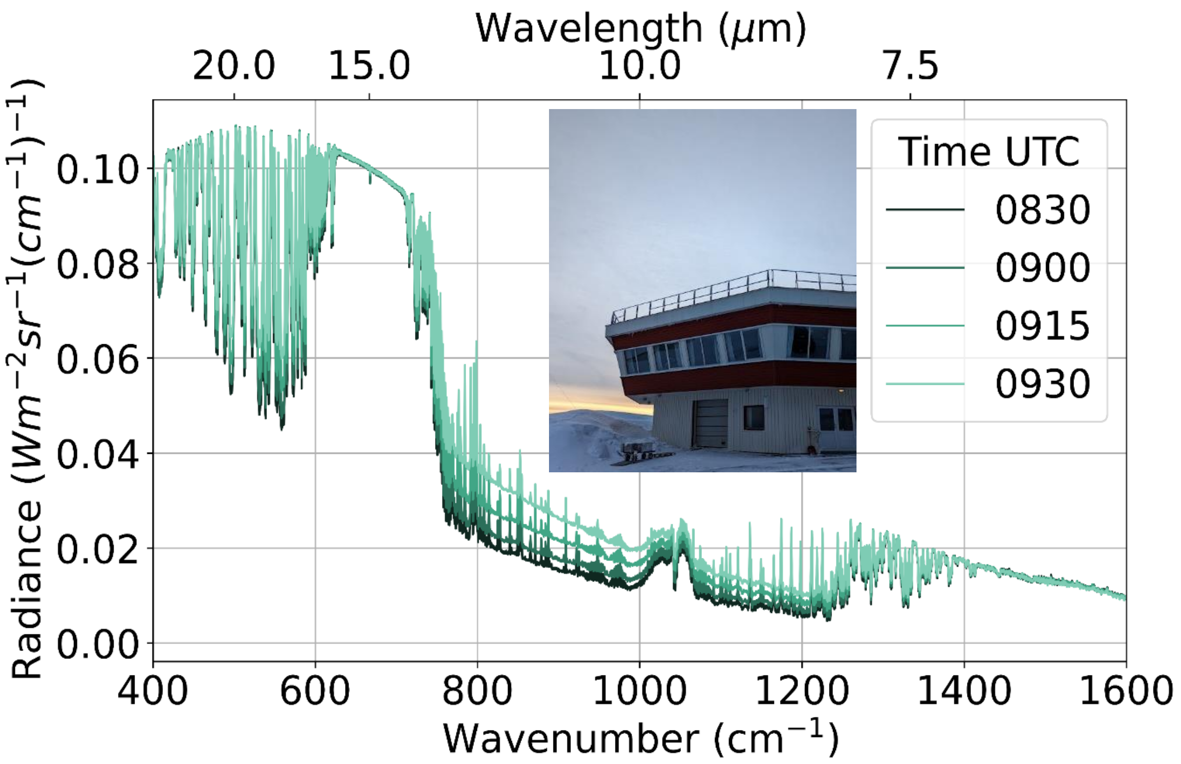
Bullet rosettes from 17 Feb
courtesy of Rob David, Univ. Oslo

Andøya – Example spectra

17 Feb 2023 - Patchy cirrus clouds



22 Feb 2023 – Frontal cirrus clouds

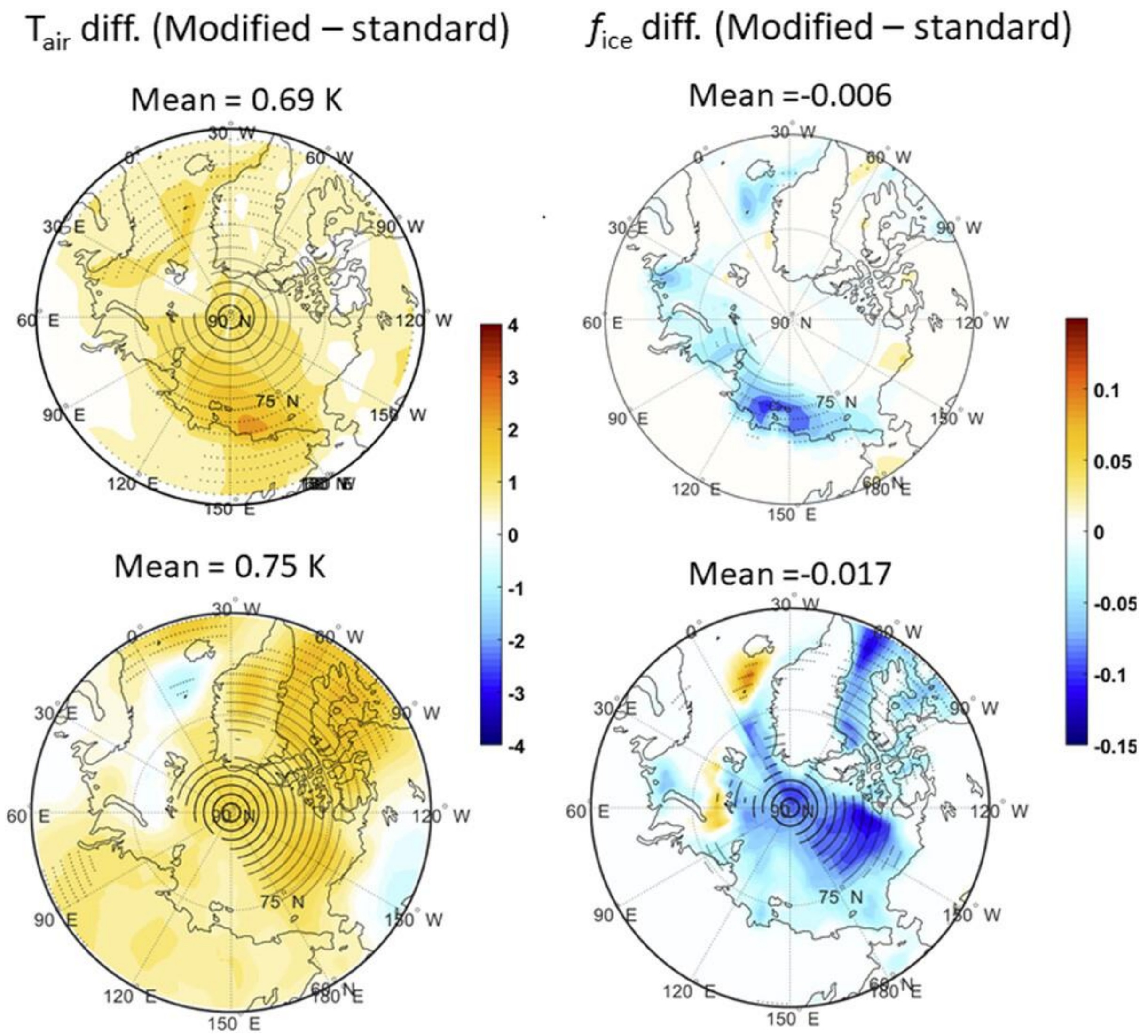


Retrieval of far-infrared surface emissivity

Motivation – the importance of far-infrared emissivity

- In cold and dry conditions, the atmosphere is less opaque in the infrared
- The far-infrared surface properties can impact the top of atmosphere outgoing radiation
- Including far-infrared emissivity values in a global climate model can affect the predicted surface temperature and sea-ice extent (see figure)

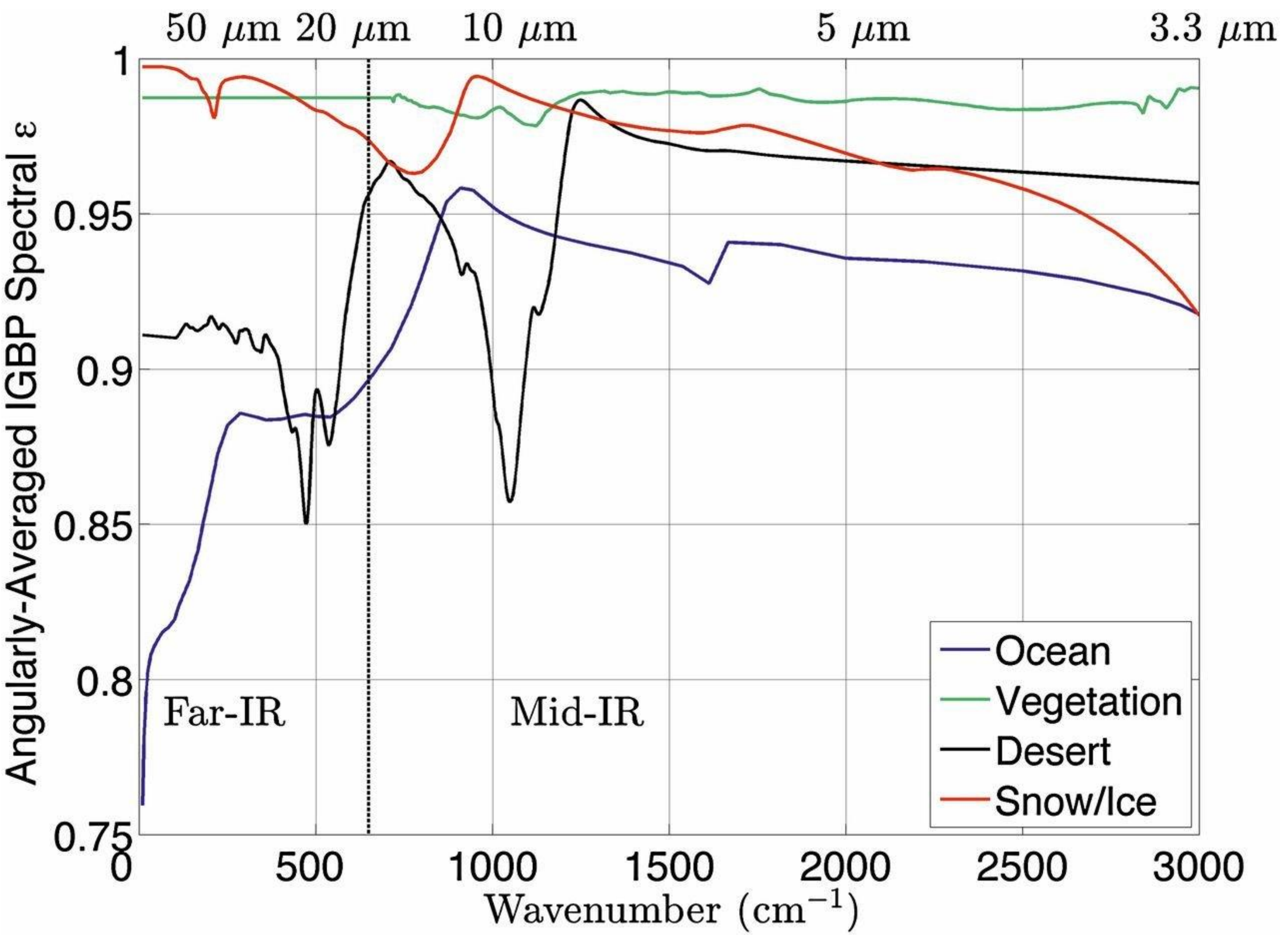
L'Ecuyer et al. 2021.
https://doi.org/10.1175/BAMS-D-20-0155.1



Motivation – Emissivity modelling

- Those results use modelled emissivity
- Dataset compiled by Hunag et al. (2016)

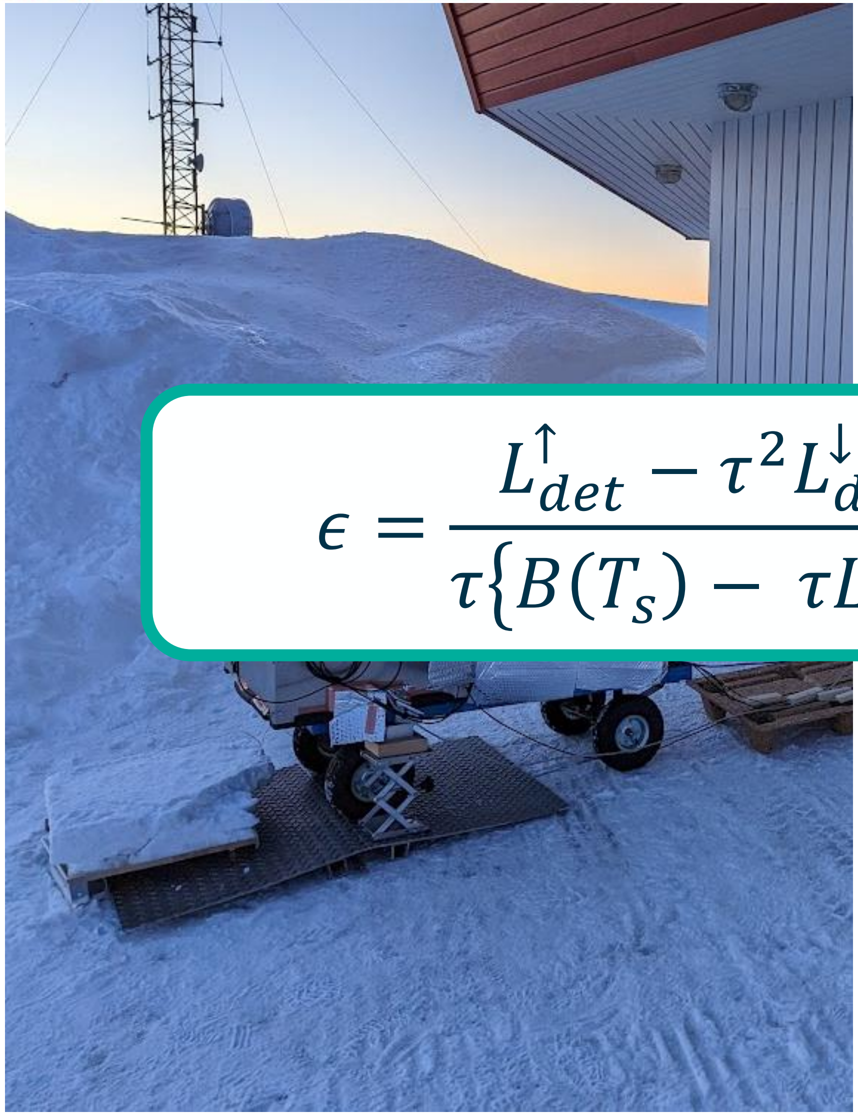
- **The dataset has not been systematically tested against measurements in the far-infrared**



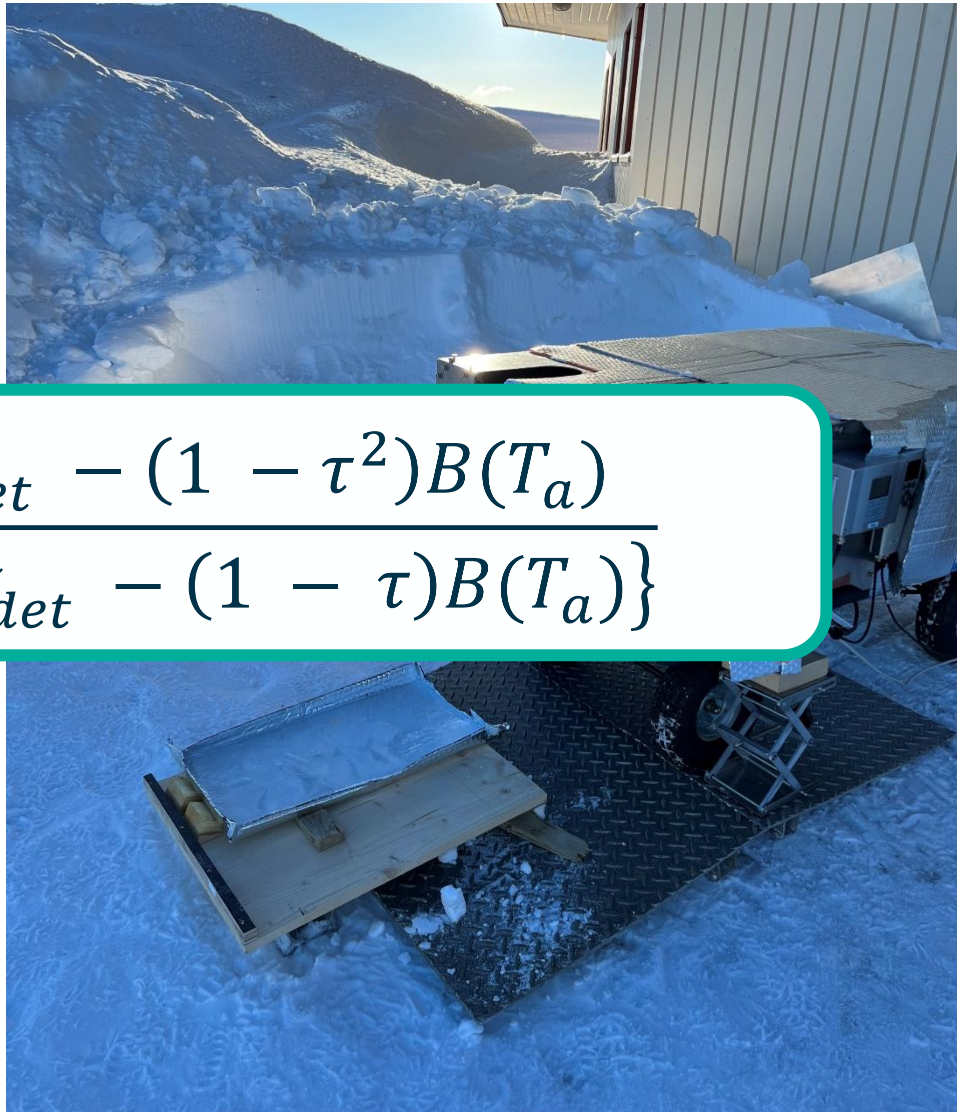
Feldman et al. 2014
https://doi.org/10.1073/pnas.1413640111

Radiance Measurements of ice and snow samples

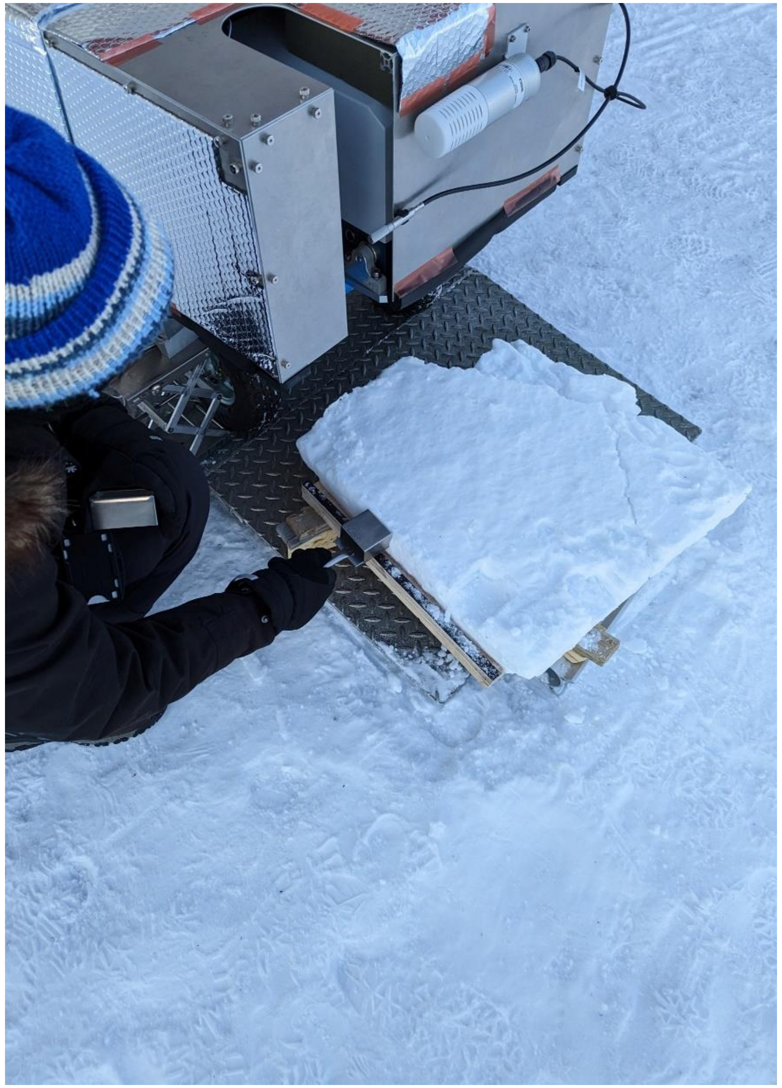
- Measurements made of a snow and ice sample
- Surfaces viewed at angles of 35°and 50°interspersed by sky views at 145°and 130°
- Emissivity and surface temperature retrieved from radiance measurements

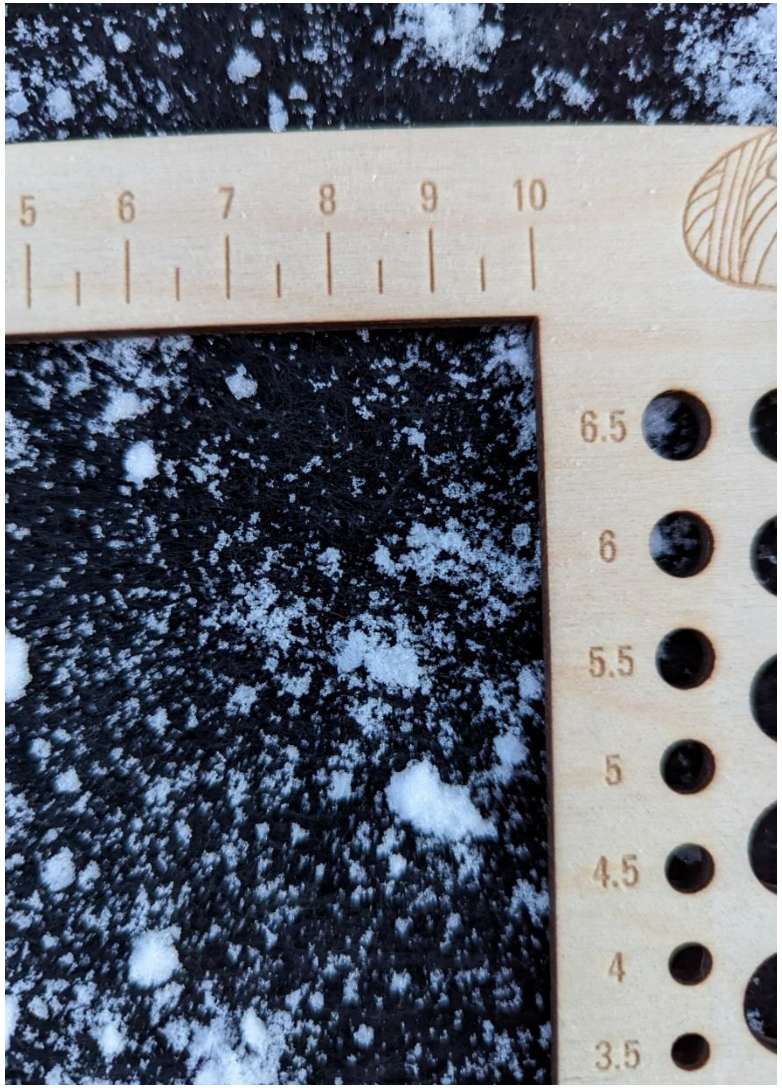


$$\epsilon = \frac{L_{det}^{\uparrow} - \tau^{2} L_{det}^{\downarrow} - (1 - \tau^{2}) B(T_a)}{\tau\left\{B(T_s) - \tau L_{det}^{\downarrow} - (1 - \tau) B(T_a)\right\}}$$

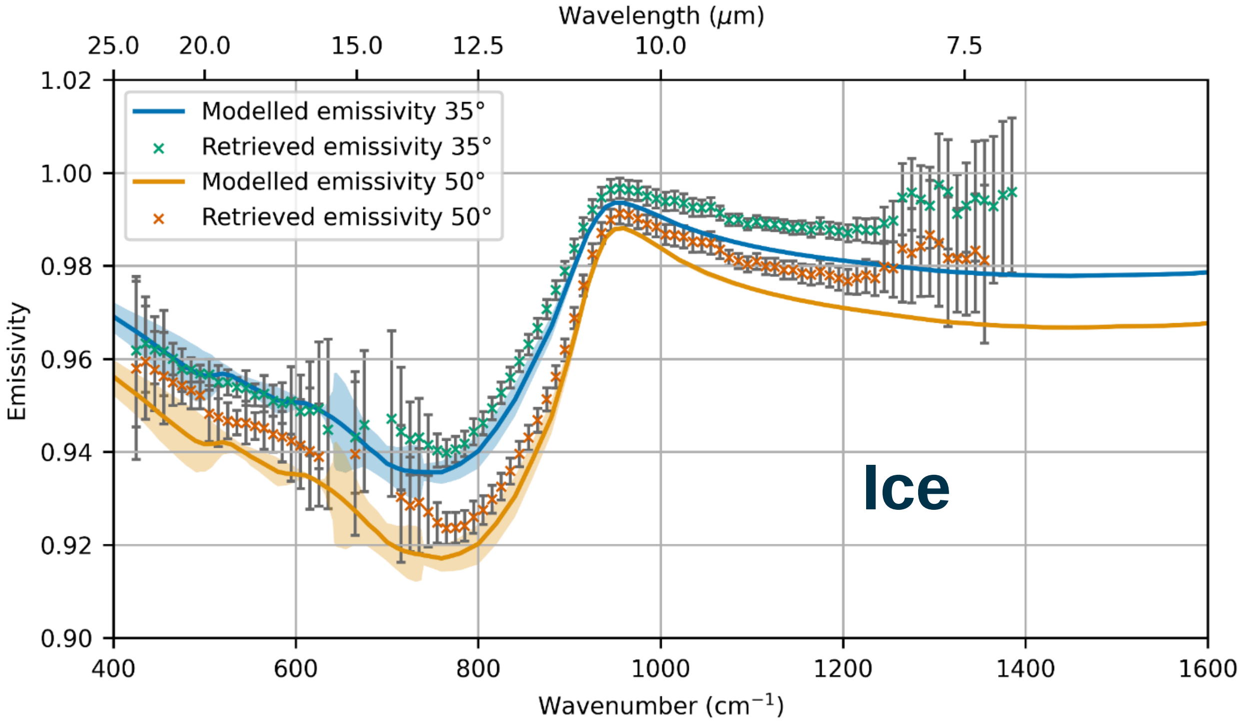


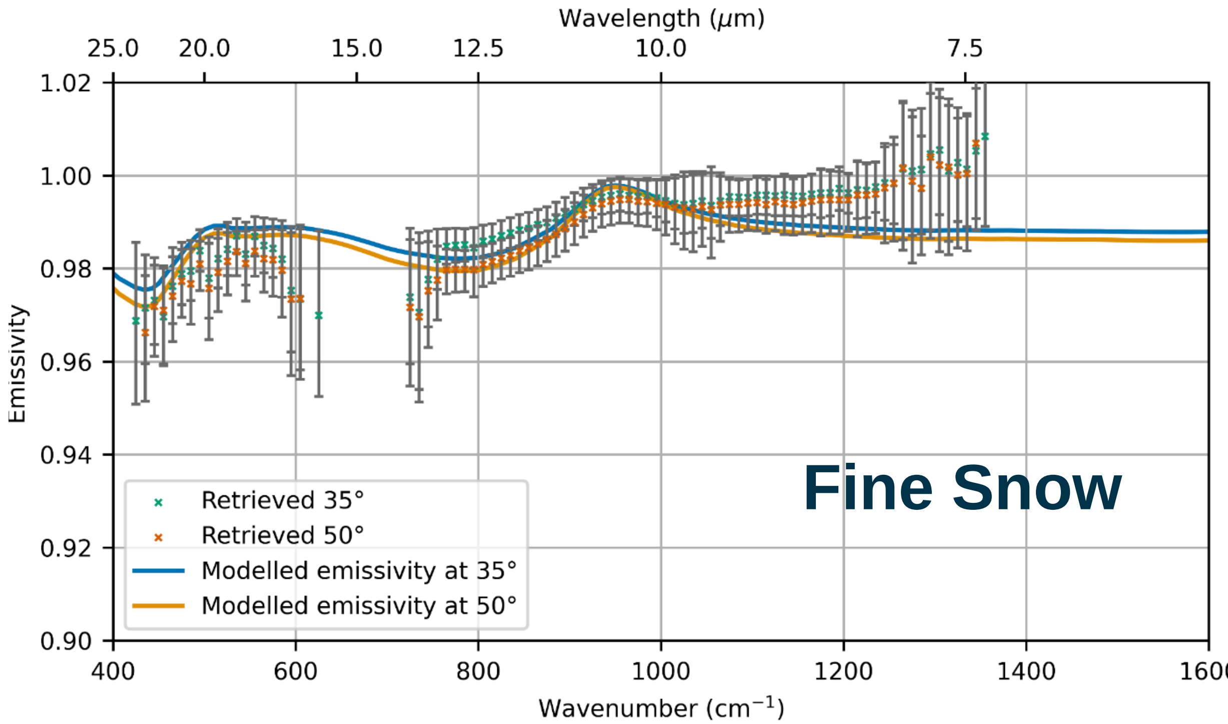
Data collection - Snow sampling





Results - Retrieved Emissivity

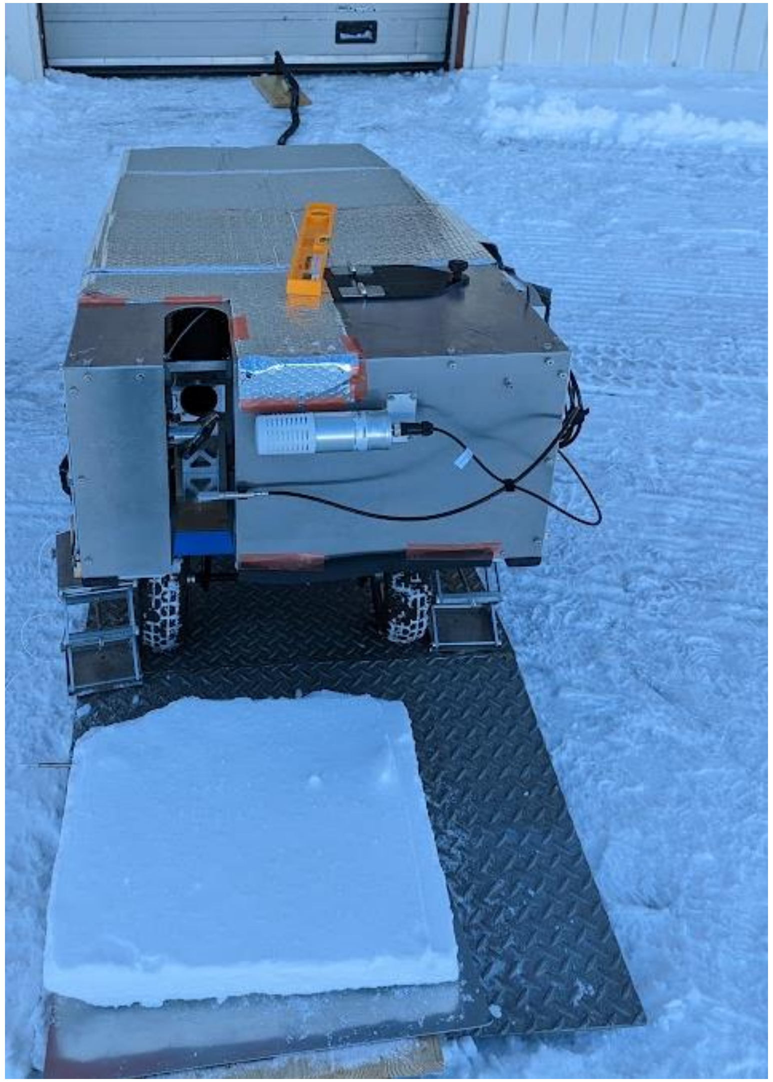




- Retrieved emissivity compares well to modelled emissivity
  - Ice model using Fresnel equations
  - Snow model from the emissivity model described in Huang (2016)
- But these are only two cases

Ice refractive index from: Warren and Brand. 2008. doi:10.1029/2007JD009744

Outlook for Emissivity and the Campaign



- Good agreement between modelled and measured snow and ice emissivity
- Emissivity model needs to be tested for more diverse snow conditions
- Improvements should be made to snow sampling
- Emissivity retrieval expanded to other surfaces

- Clear sky and cirrus cloud data from the campaign are being analysed!

Data from ESA campaigns can be found on the **ESA EO Gateway**

With thanks to the whole campaign and analysis team!

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Imperial College London

National Centre for Earth Observation
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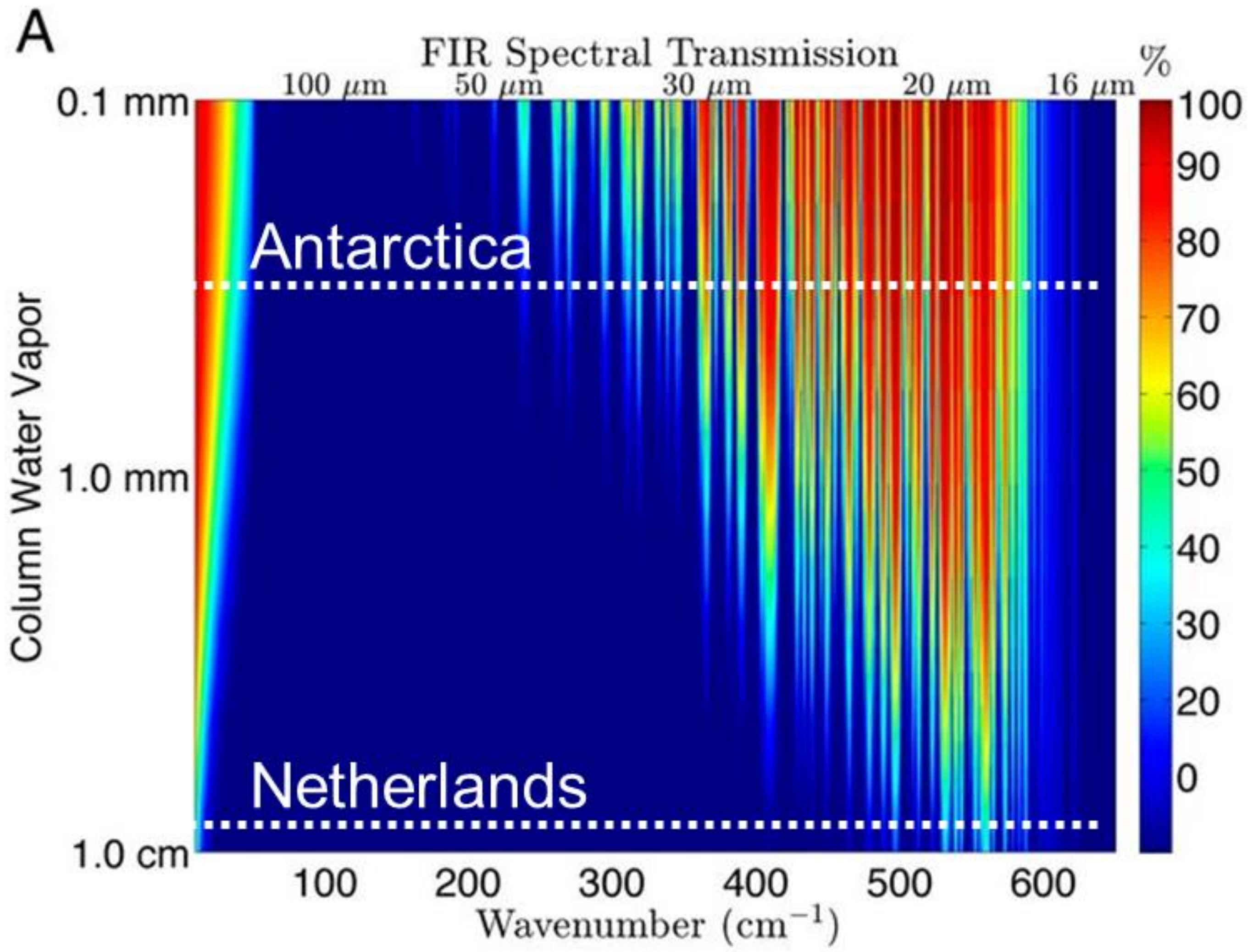
The Earth's Surface in the Far-infrared

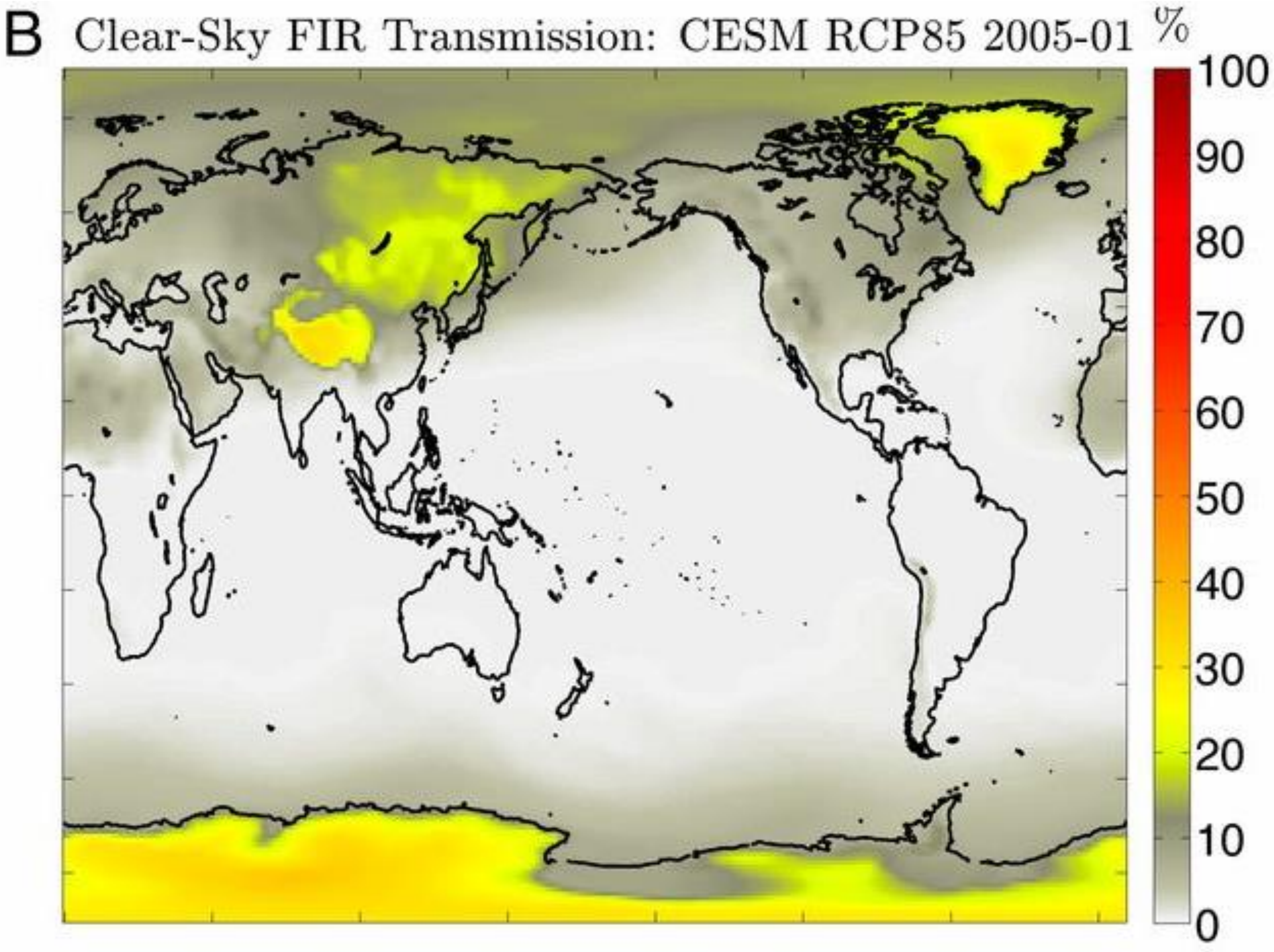


Feldman, D. et al. (2014) . Far-infrared surface emissivity and climate. *PNAS.*

- The atmosphere in the far infrared is mostly opaque due to water vapour absorption

- However, in cold, dry conditions radiation from the surface can escape directly to space

The Earth's Surface in the Far-infrared



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Andøya - Cases sampled

Date	Conditions	Measurements	Ground Observations	Airborne measurements
17 Feb	Patchy cirrus clouds	Zenith	Radiosonde HATPRO	YES
20 Feb	Low clouds and clear sky	Zenith	HATPRO	
21 Feb	Snow emissivity	Emissivity	HATPRO	
22 Feb	Frontal cirrus	Zenith	Radiosonde HATPRO	YES
7 March	Snow emissivity and cirrus clouds	Emissivity and Zenith	Radiosonde HATPRO Ceilometer LiDAR	
8 March	Snow and ice emissivity and clear sky	Emissivity and Zenith	Radiosonde HATPRO Ceilometer LiDAR	

Snow collection method

Collecting snow sample from the snowbank

Measuring the density of the snow

Several samples of snow density were taken before and after the radiative measurements.

There was not a significant change in density before and after the measurements.

Photos analysed to determine crystal sizes

Distance scale determined using the rule on the knitting aid

Size of smaller crystals then measured as larger shapes assumed to be agglomerations of smaller crystals

10 crystals measured per image

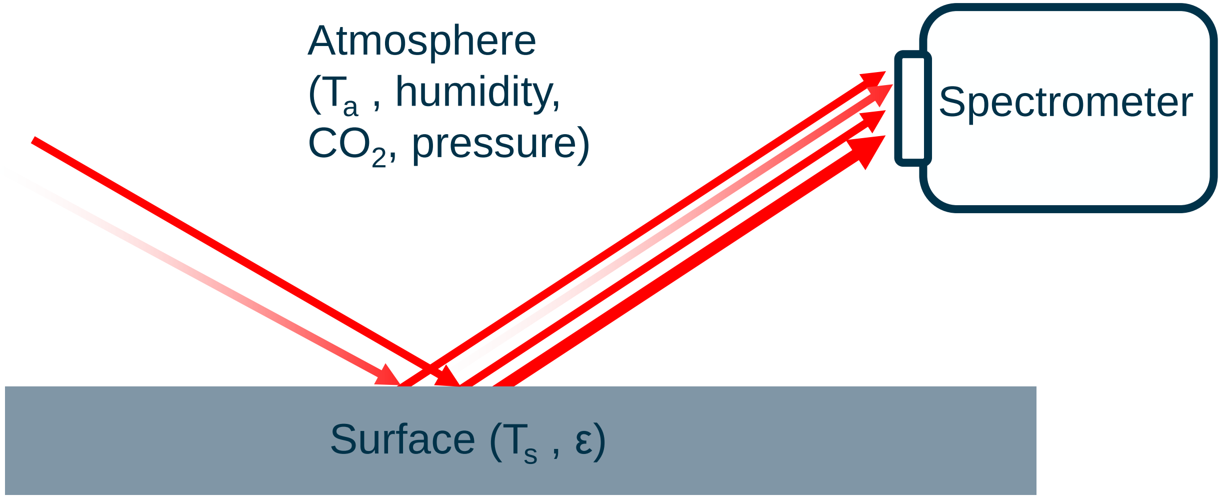
In total 6 images pre sample and 4 post sample

No change in average crystal size between samples

Method - Emissivity measurement

- Requirements for method
  - In-situ
  - No need to heat material
- Adapting method used in mid-infrared by Newman et al.
- This method produced emissivity values that agree well with Fresnel calculations in the mid-infrared
- Surface temperature determined via spectral smoothness

Newman, S M et al. (2005). Temperature and salinity dependence of sea surface emissivity in the thermal infrared. *Q. J. R. Meteorol. Soc,* 131, 2539–2557



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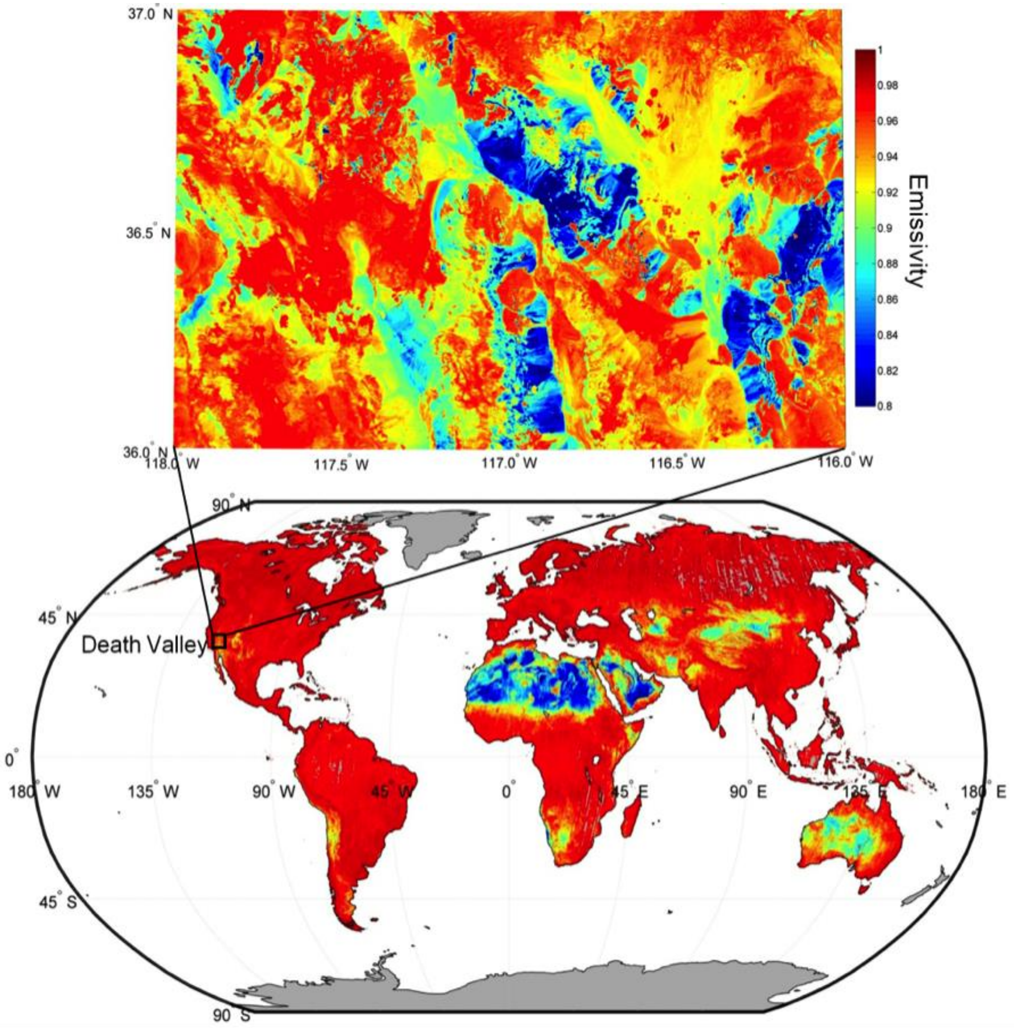
Motivation - Far-infrared Emissivity

- Emissivity $(\varepsilon) = \dfrac{\text{Radiation emitted by surface}}{\text{Radiation emitited by perfect emitter}}$
- Depends on
  - Material - Wavelength - Viewing angle - Surface properties
- Important for surface energy budget and TOA radiances
- Well known in the mid-infrared but **very** few measurements in the far-infrared
- FORUM and PREFIRE will fill this observational gap

In-situ measurements accompanied by surface characterisation are needed!



https://terra.nasa.gov/news/aster-global-emissivity-database-100-times-more-detailed-than-its-predecessors

Results - Measured Radiance