The Polar Radiant Energy in the Far InfraRed Experiment (PREFIRE)

Documenting the Spectral Character of Polar Emission

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https://prefire.ssec.wisc.edu

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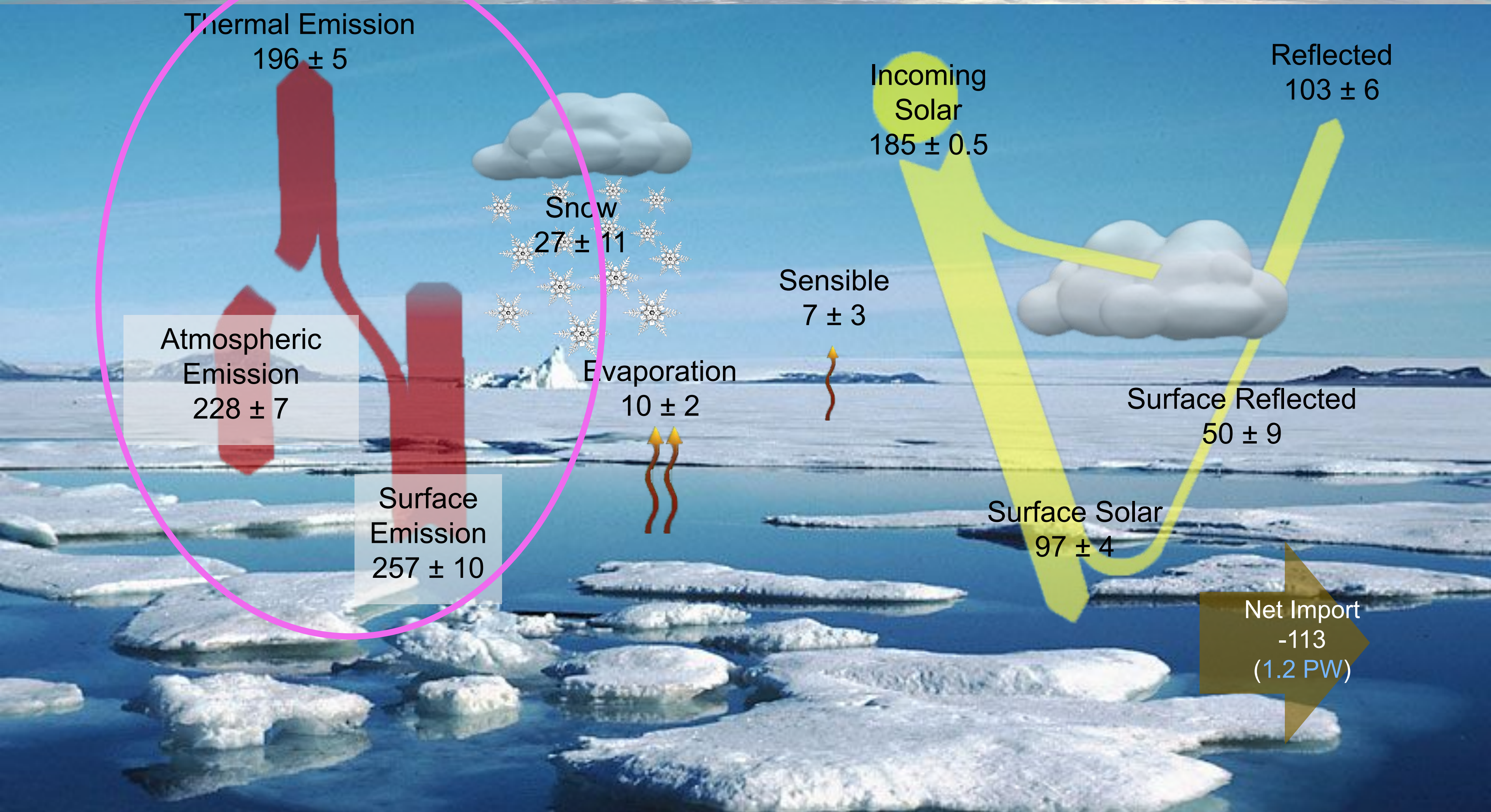
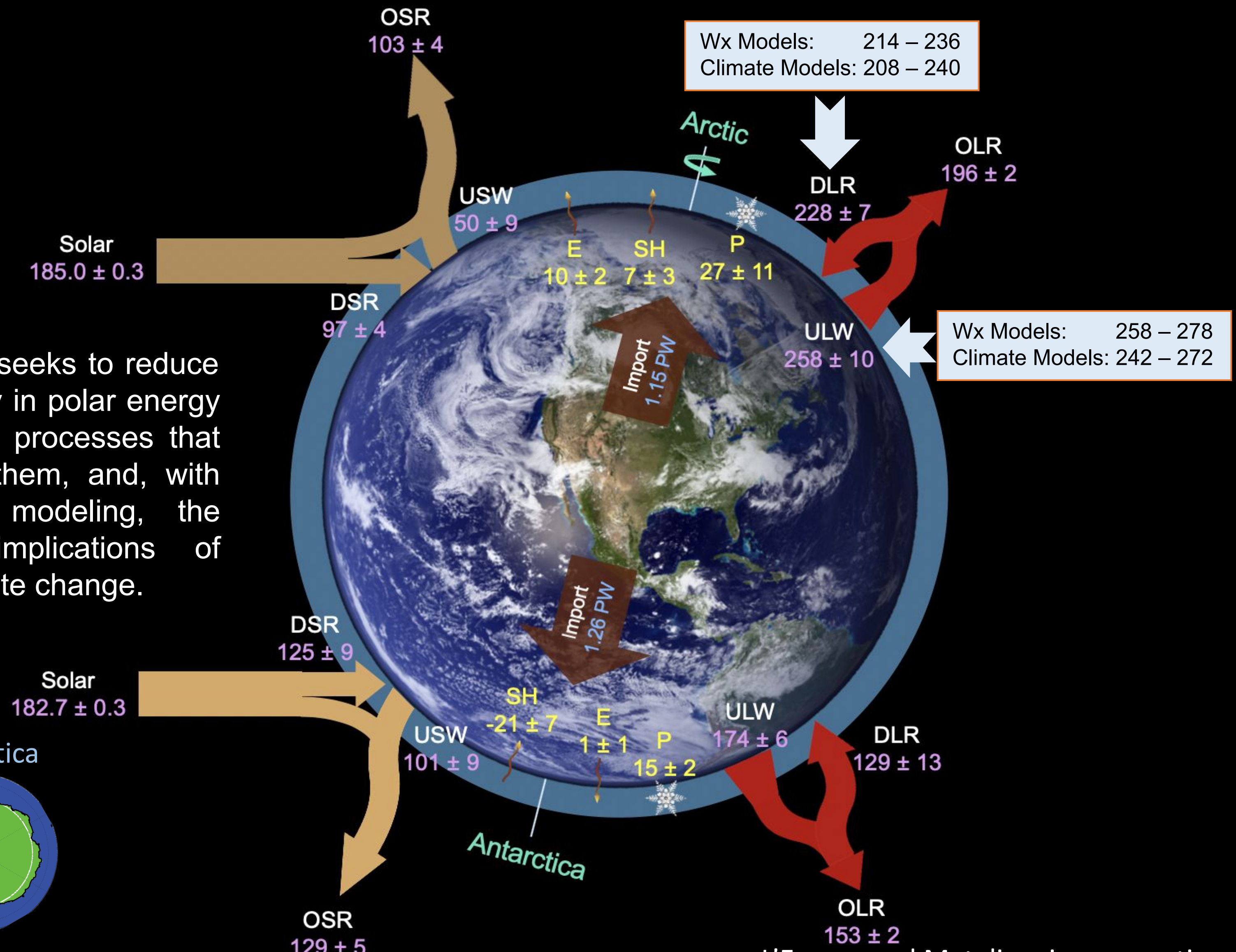
BLUE CANYON TECHNOLOGIES

Arctic Energy Balance

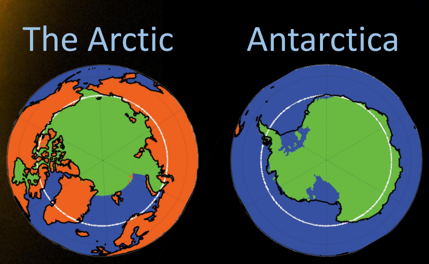


The poles emit more than twice as much energy as they recieve from the sun

Uncertainties

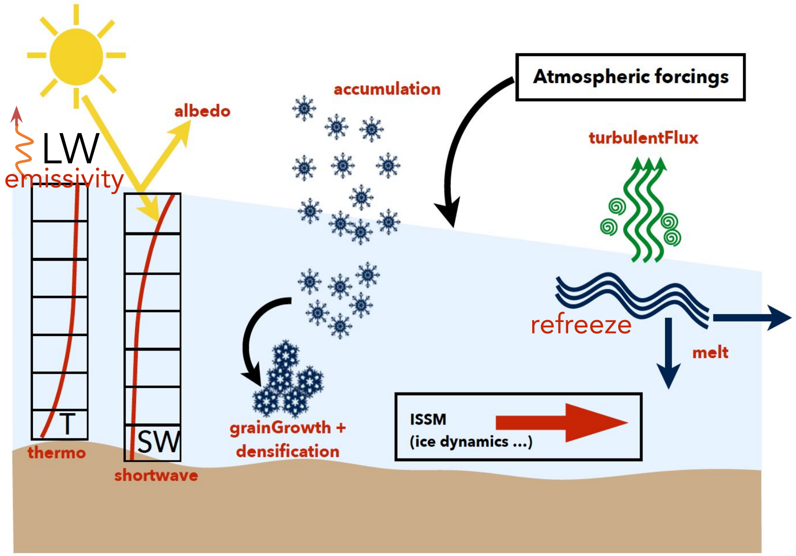


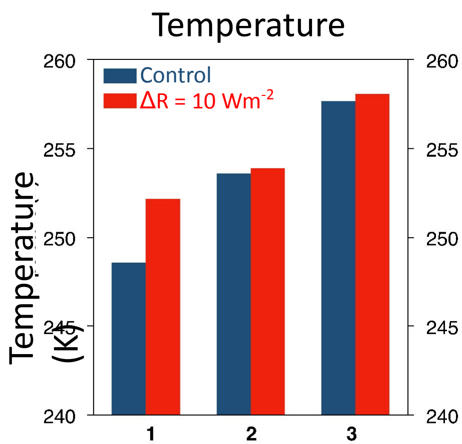
PREFIRE seeks to reduce uncertainty in polar energy fluxes, the processes that influence them, and, with improved modeling, the societal implications of polar climate change.

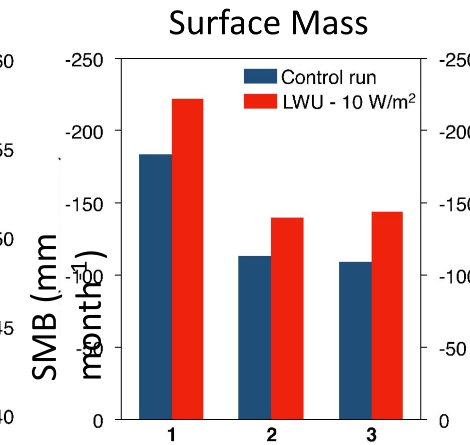


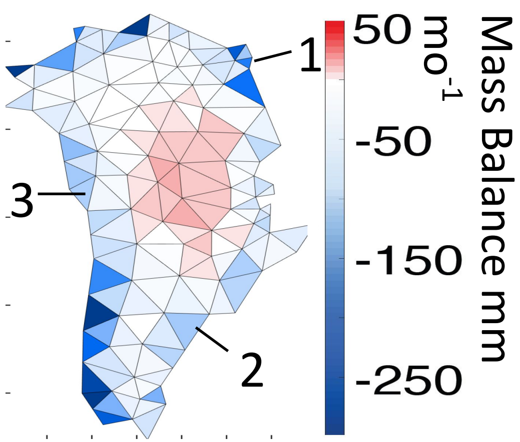
L'Ecuyer and Mateling, in preparation

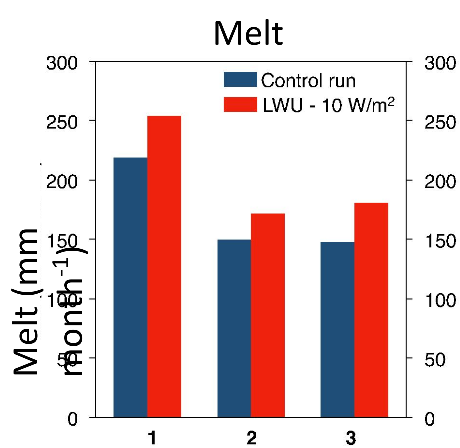
Influence on Ice Sheet Processes

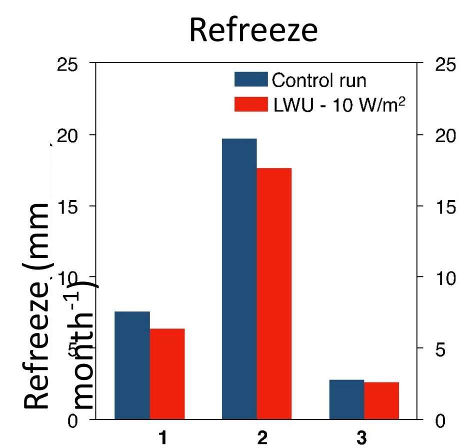








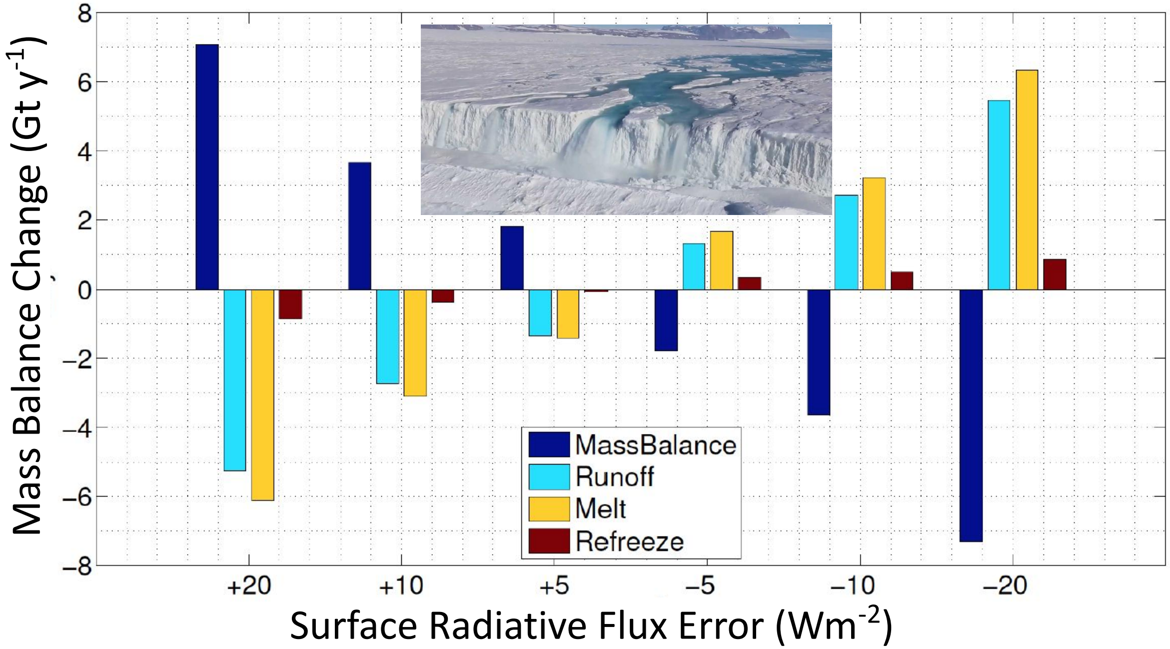




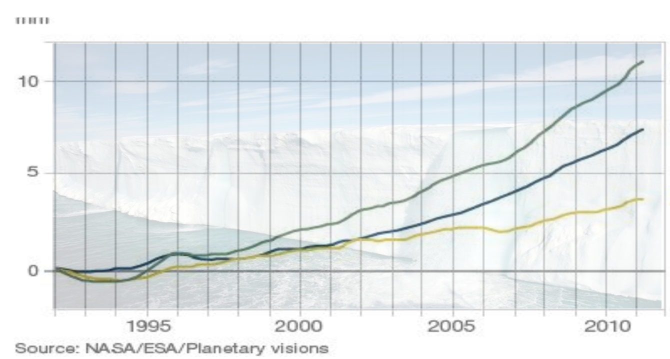
Schlegel and L'Ecuyer, in preparation

Implications for Global Sea Level

Substantial Impacts on Predicted Rates of Greenland Runoff and Sea Level Rise

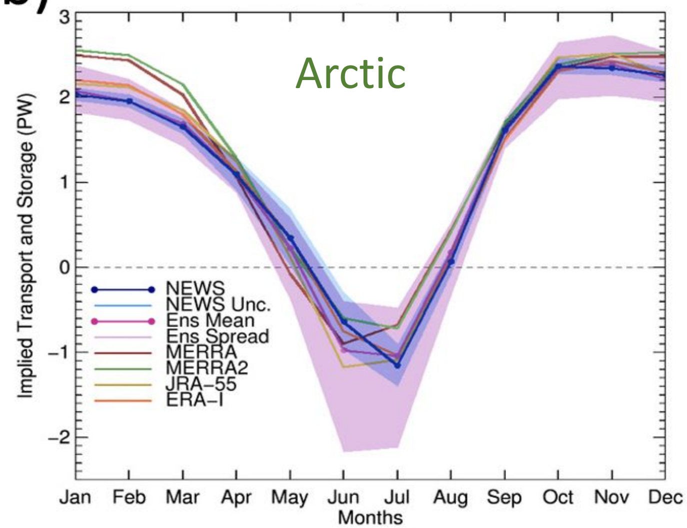


Global Sea Level Rise

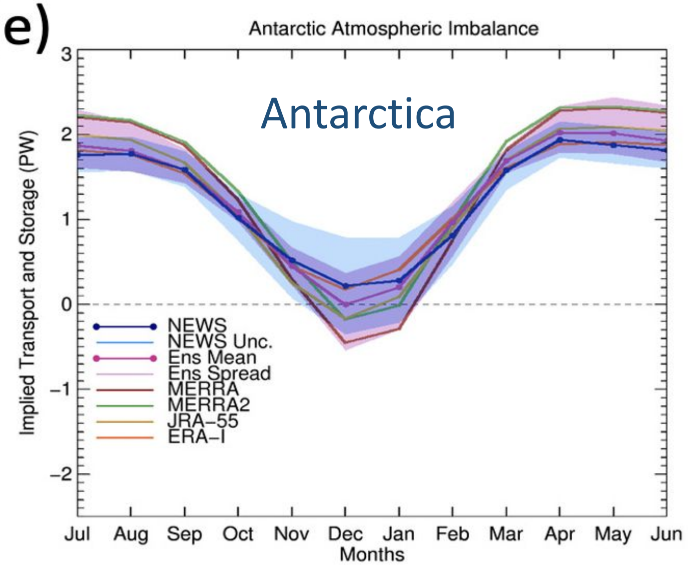


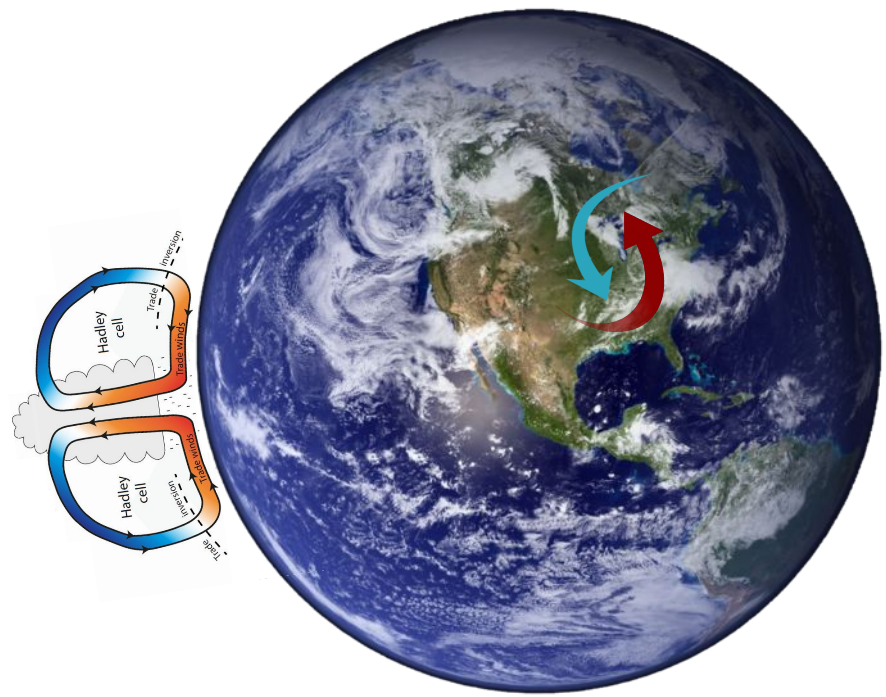
Implications for Heat Transport

(b) Atmospheric Imbalance



(e)

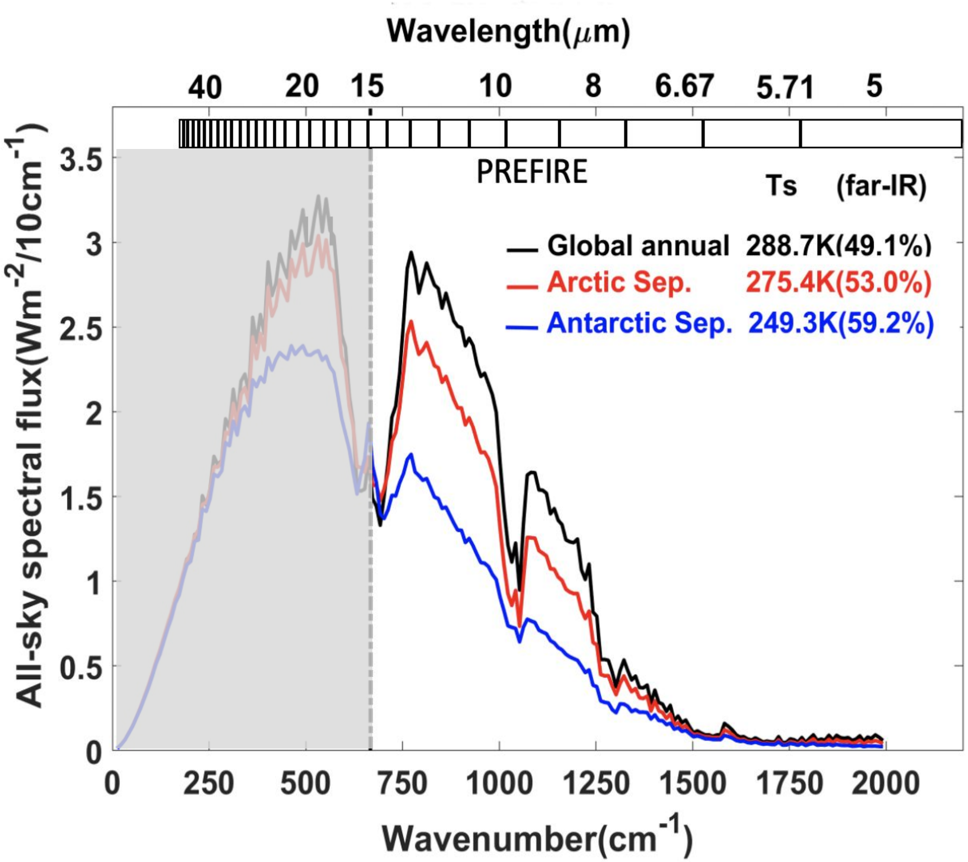




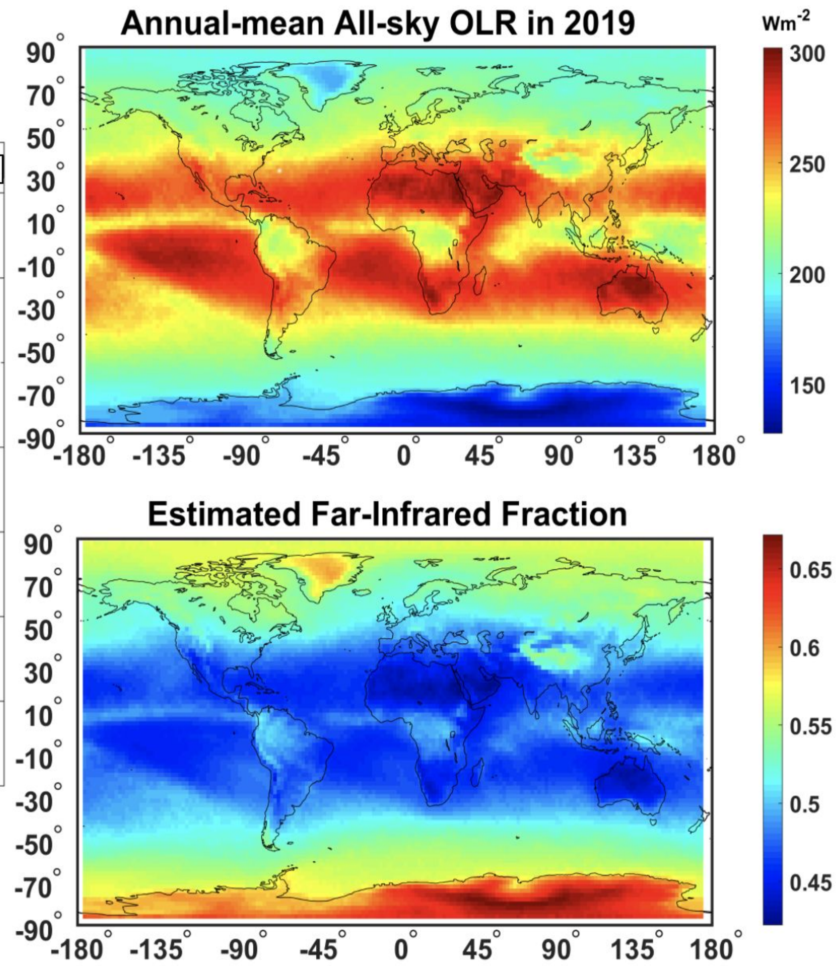
Models, reanalyses, and observations vary widely in estimates of implied heat flows into the Arctic (and Antarctica)

Mateling and L'Ecuyer, in preparation

The Far-Infrared Observing Gap



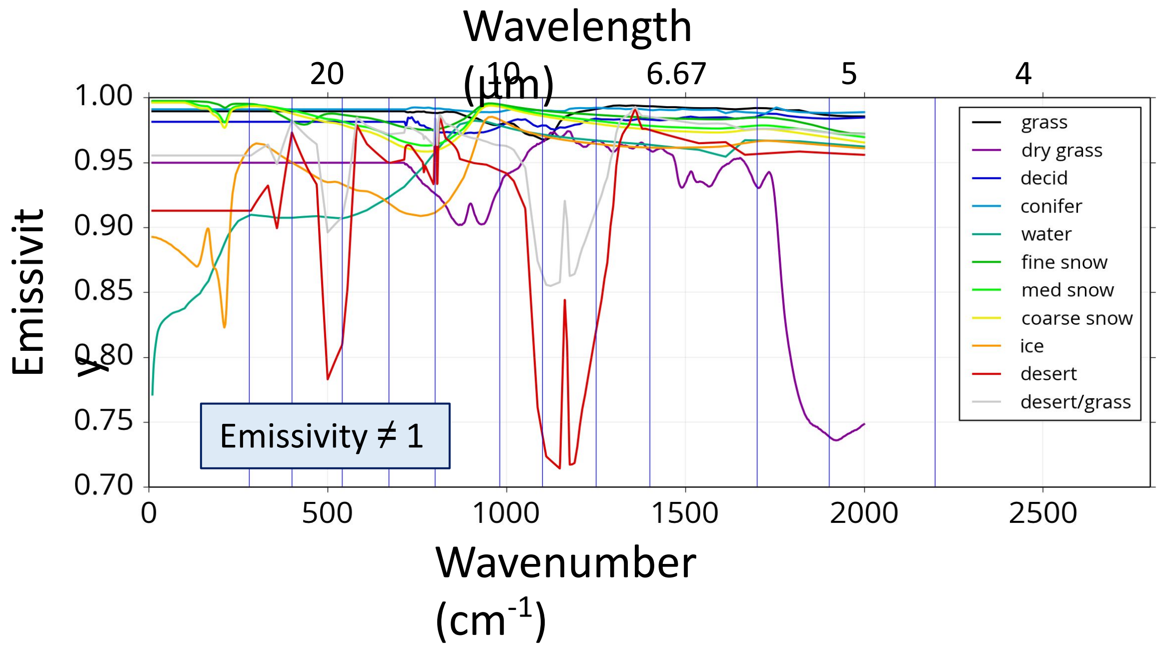
Current Spectral Measurements



L'Ecuyer et al, *BAMS* (2021)

Incomplete Observations □ Incomplete Knowledge

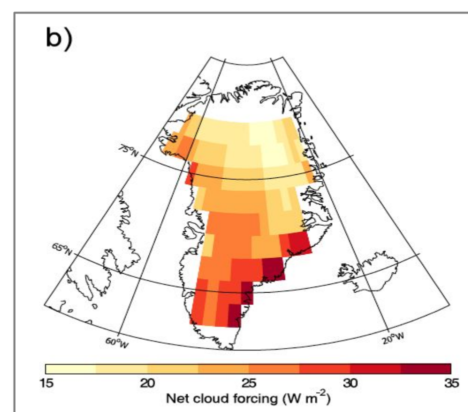
Surface Flux Exchanges Revisited



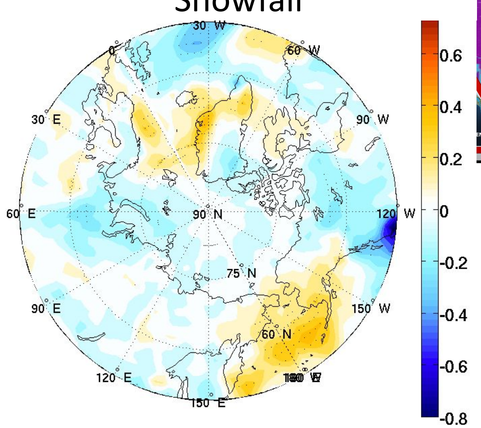
Surface emission depends on both temperature AND emissivity. Incomplete knowledge of the latter causes large errors in surface energy exchanges.

The atmospheric greenhouse effect is sensitive to thin clouds and small amounts of water vapor that have strong far infrared signatures but are currently very difficult to detect.

Cloud Impact on AGHE

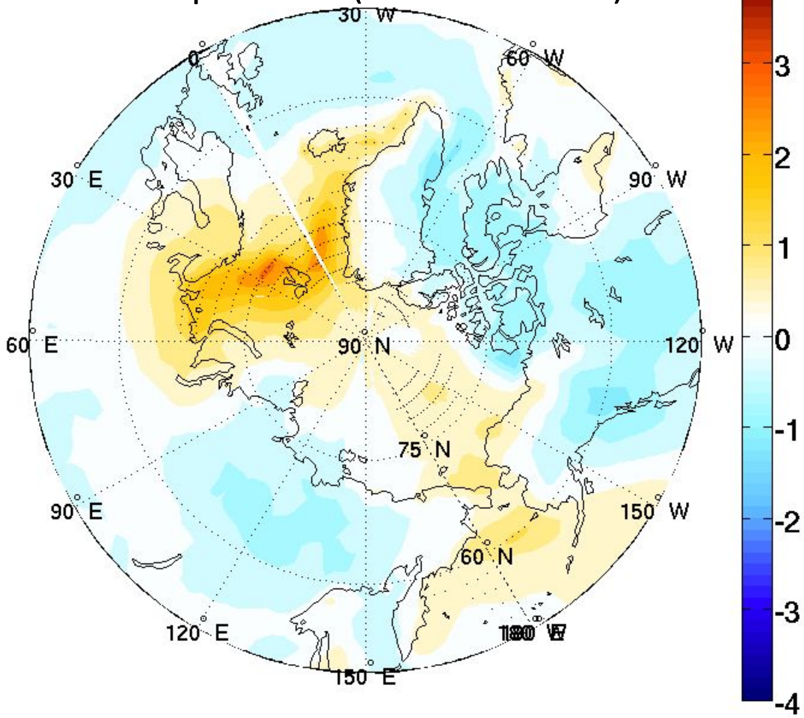


Simulated Pan-Arctic Influences

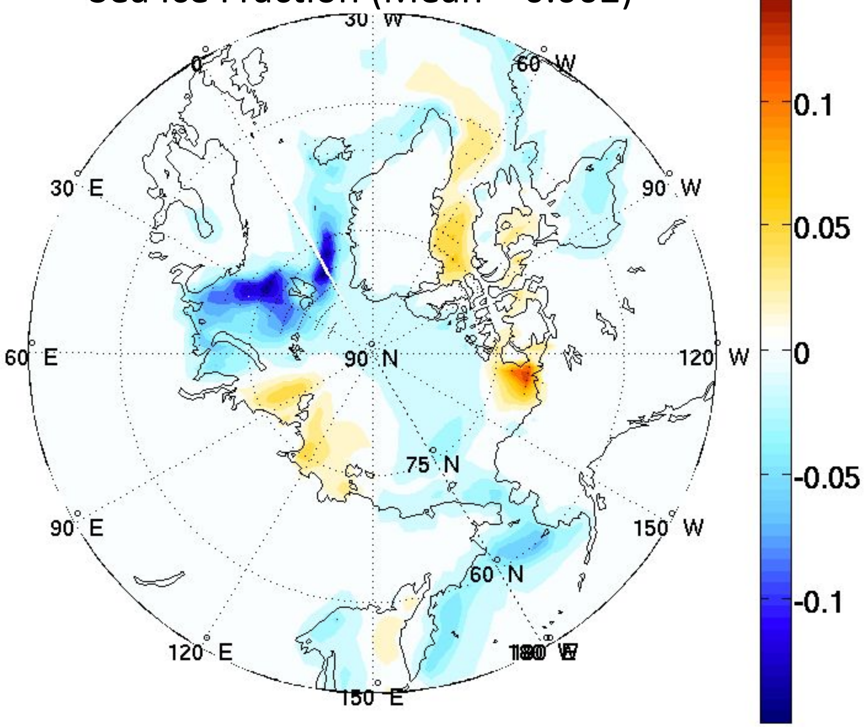


Impacts of Realistic Surface Emissivity in CAM5

Temperature (Mean = 0.31 K)

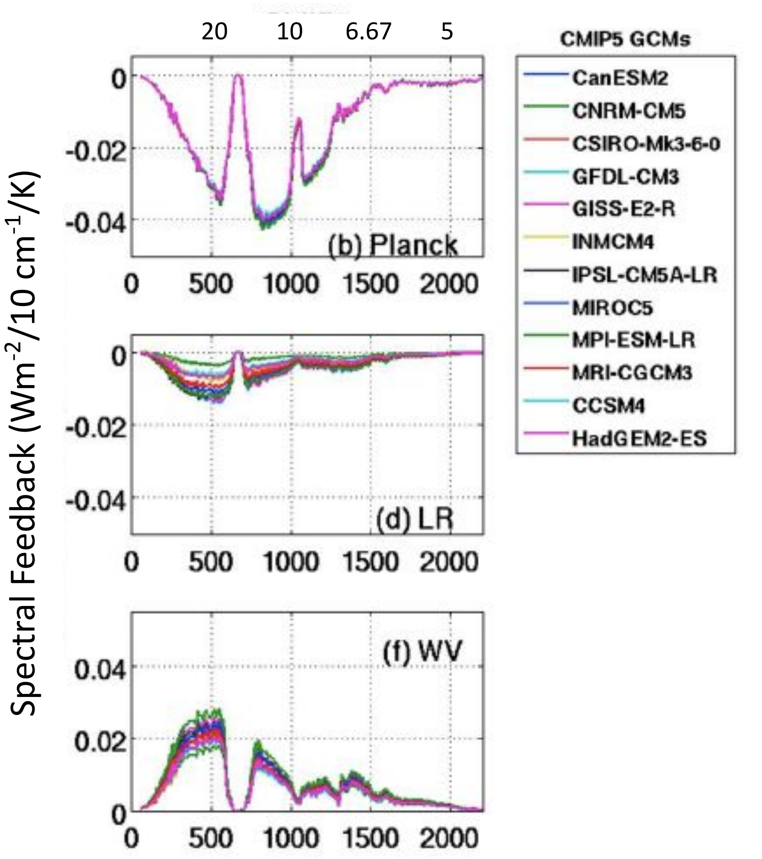


Sea Ice Fraction (Mean = 0.002)



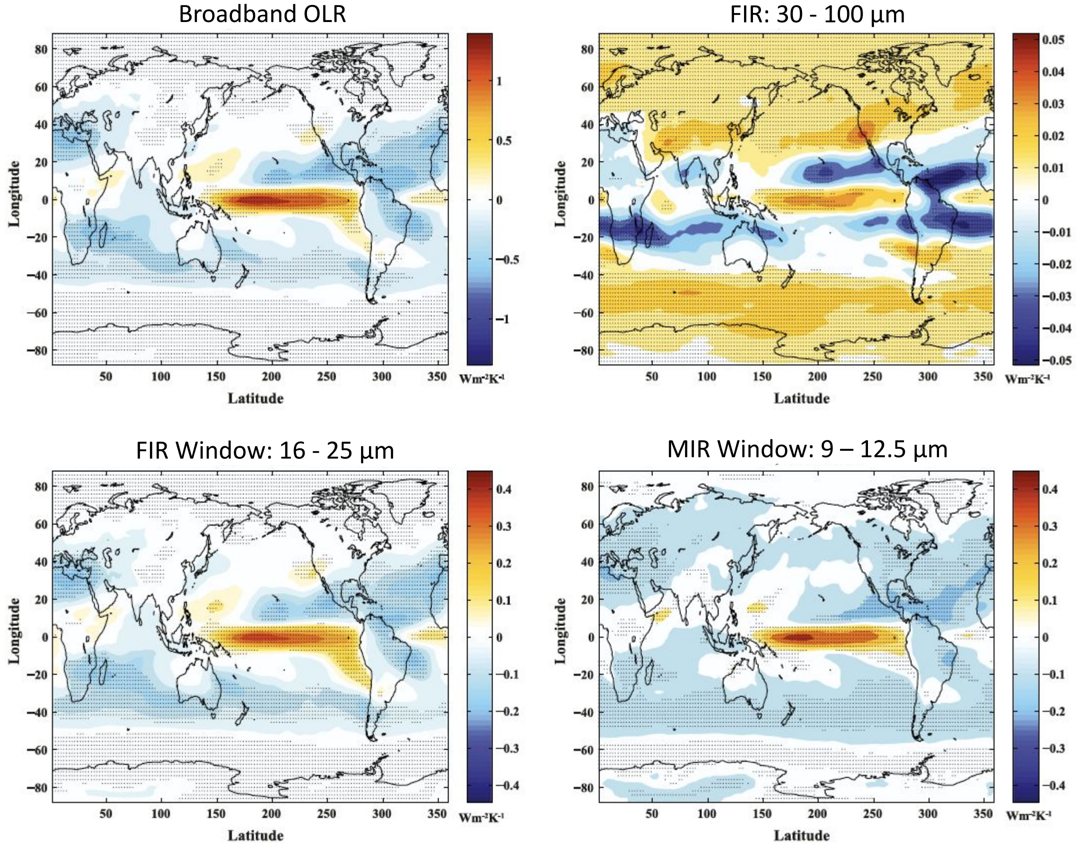
Huang et al, J. Climate (2018)

Infrared Feedback Fingerprints



Huang et al, Geophys. Res. Letters (2014)

RH Feedback in CMIP5



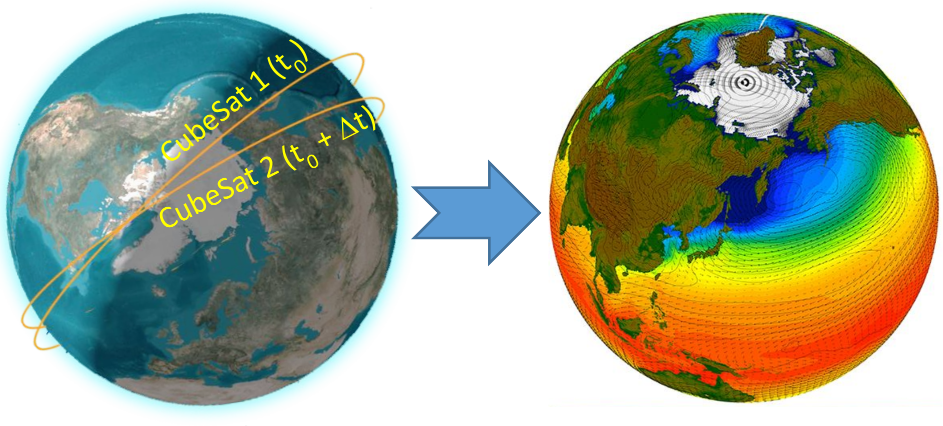
Pan and Huang, J. Climate (2018)

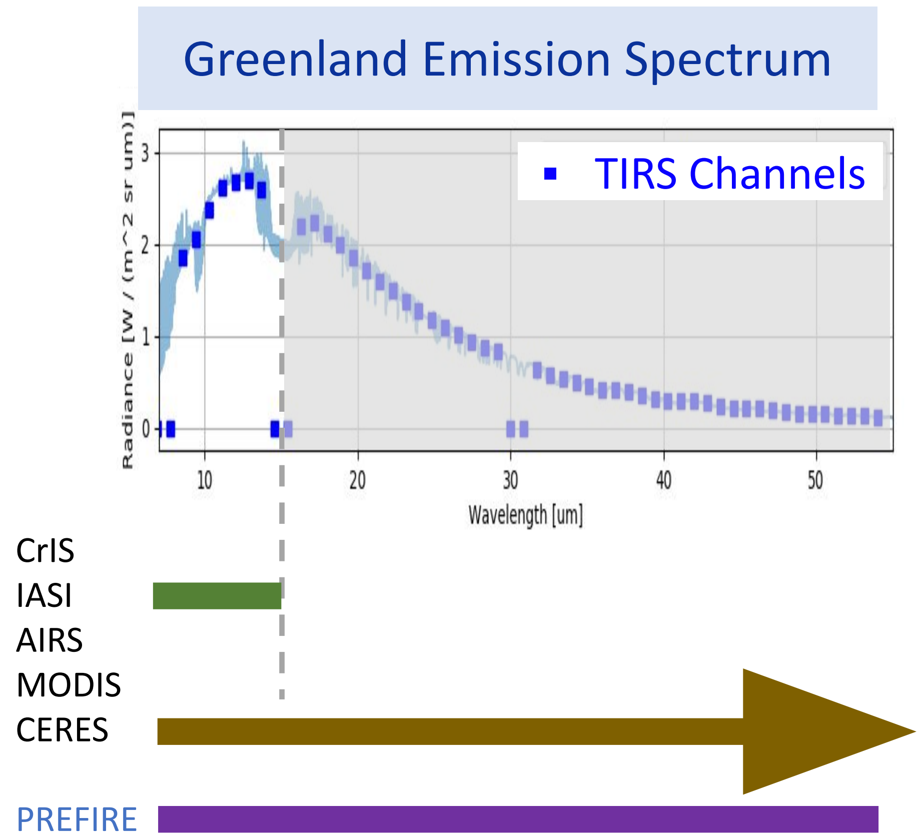
Measuring the complete infrared emission spectrum distinguishes the fingerprints of several important feedback processes.

Polar Radiant Energy in the Far InfraRed Experiment

PREFIRE fills the far-infrared observing gap by documenting variability in spectral fluxes from 5 - 54 µm on hourly to seasonal timescales.

L'Ecuyer et al, *BAMS* (2021)





PREFIRE maps polar far infrared emission spectra with two CubeSats flying in distinct 470–650 km altitude, near-polar (82°-98° inclination) orbits each carrying a miniaturized infrared spectrometer, covering 5-54 µm with 0.84 µm spectral sampling, operating for one seasonal cycle (a year).

https://prefire.ssec.wisc.edu

Mission Concept

L'Ecuyer et al, *BAMS* (2021)

Summer 2023 (anticipated)

Up to 90 days

Deliver to Launch Provider

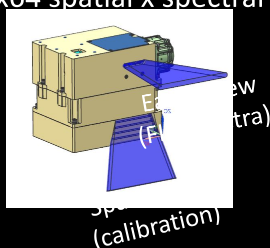
Launch to Polar Orbit
D = 0

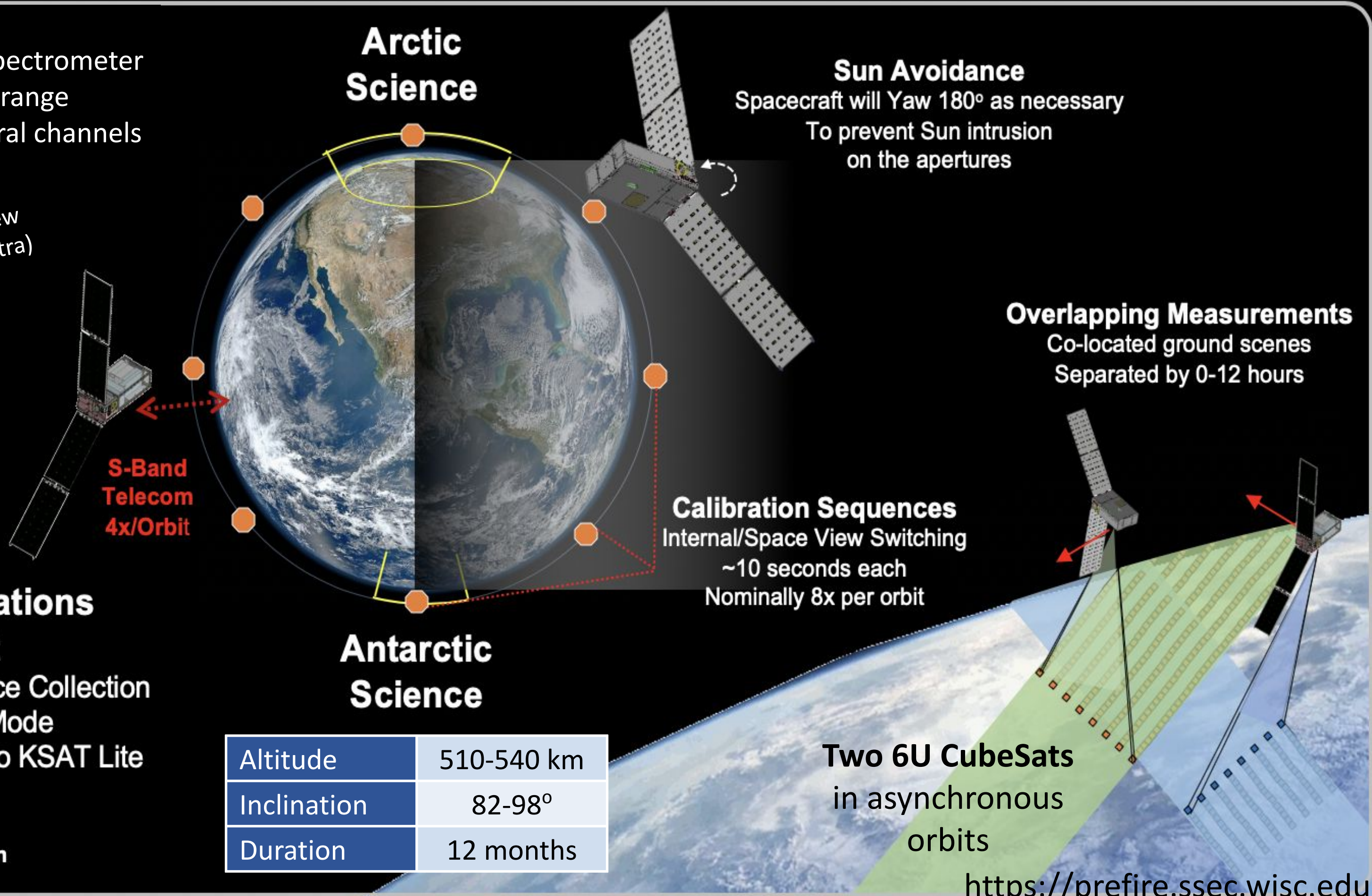
Solar Array Deployment
D = +30 minutes

Detumble and Sun Acquisition

Checkout
BUS commissioning
TIRS commissioning
Nominally 30 days

Payload – TIRS
Thermal InfraRed Spectrometer
5 to 54 μm spectral range
8x64 spatial x spectral channels





Nominal Operations
90+ mins/orbit
'Continuous' Science Collection
Single Instrument Mode
Downlink up to 4x to KSAT Lite Stations

365 day primary mission

Altitude	510-540 km
Inclination	82-98°
Duration	12 months

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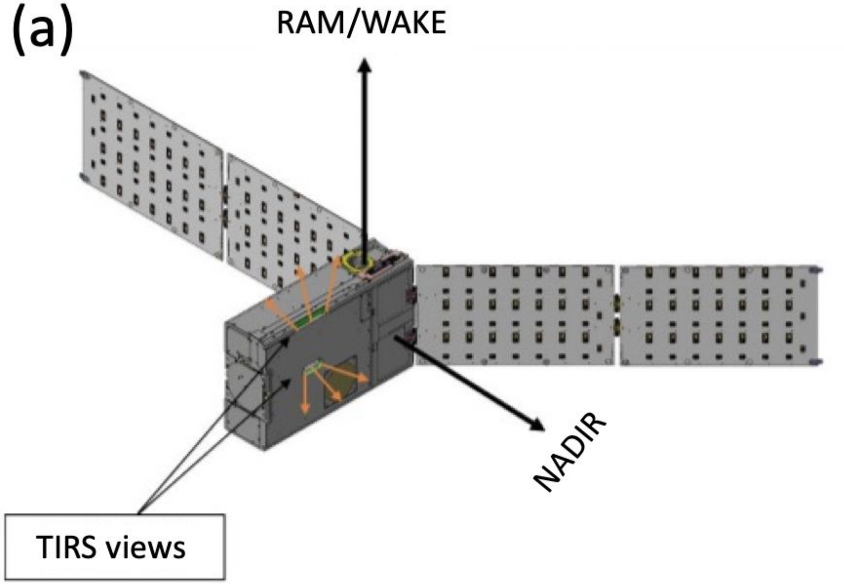
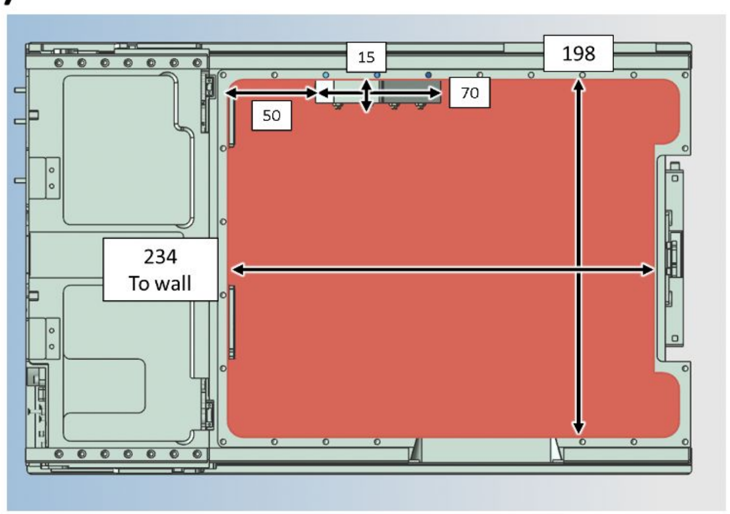
Thermal InfraRed Spectrometer (TIRS)

(a)

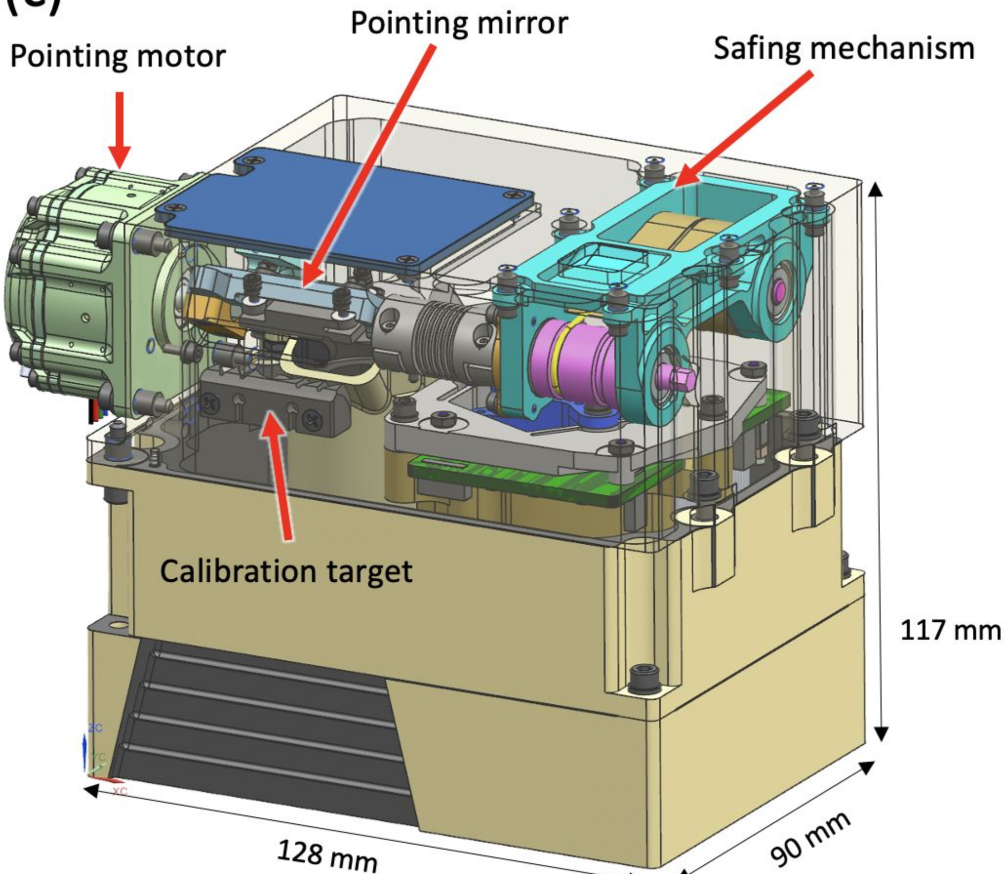


Spectral Sampling	Spatial Resolution	Mass	Average Power
0.86 μm from 5-54 μm	12-15 km	< 3 kg	4.5 W

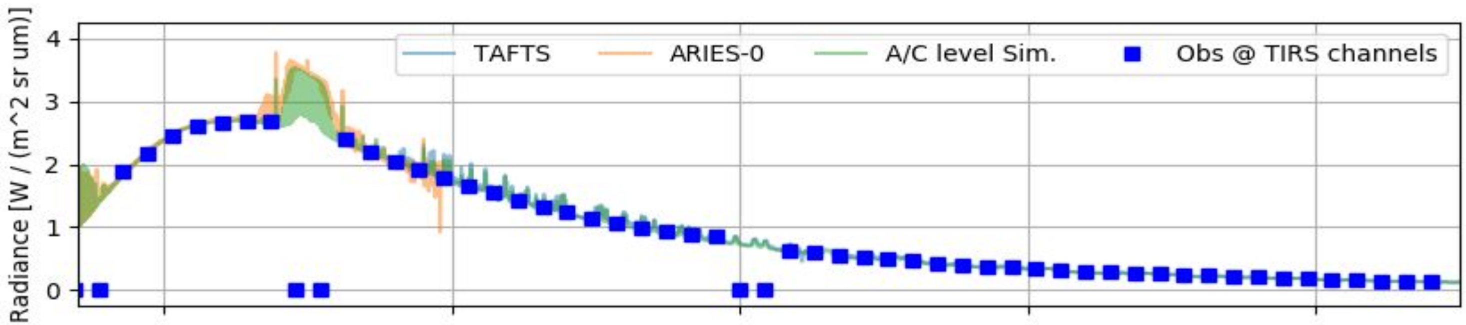
(b)



(c)

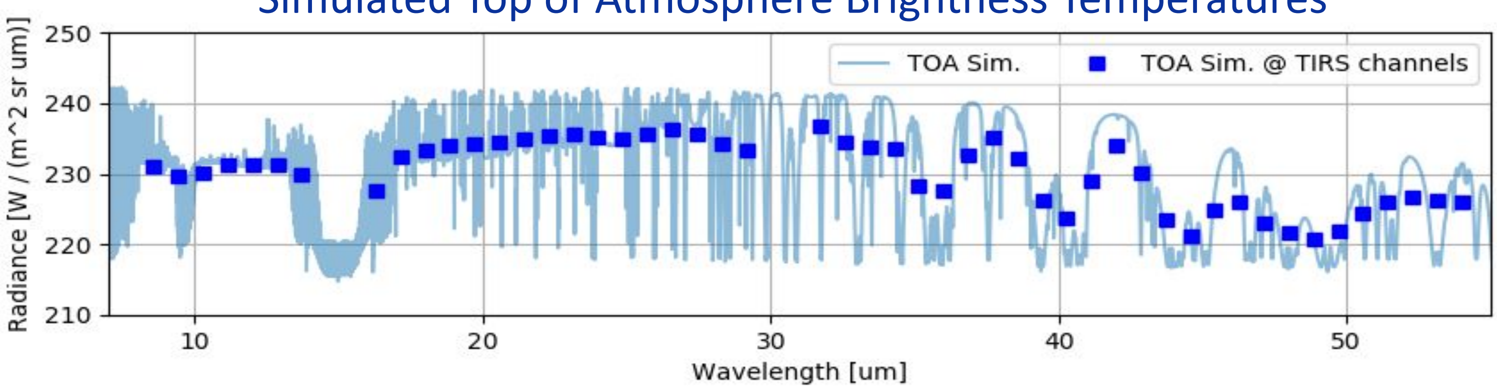


PREFIRE Measurements



* Original TAFTS data courtesy J. Murray and H. Brindley (FORUM)

Simulated Top of Atmosphere Brightness Temperatures



Filling the Gaps

Current Sensors

Current Sensors + PREFIRE

Measuring the complete infrared emission spectrum distinguishes the fingerprints of several important feedback processes.

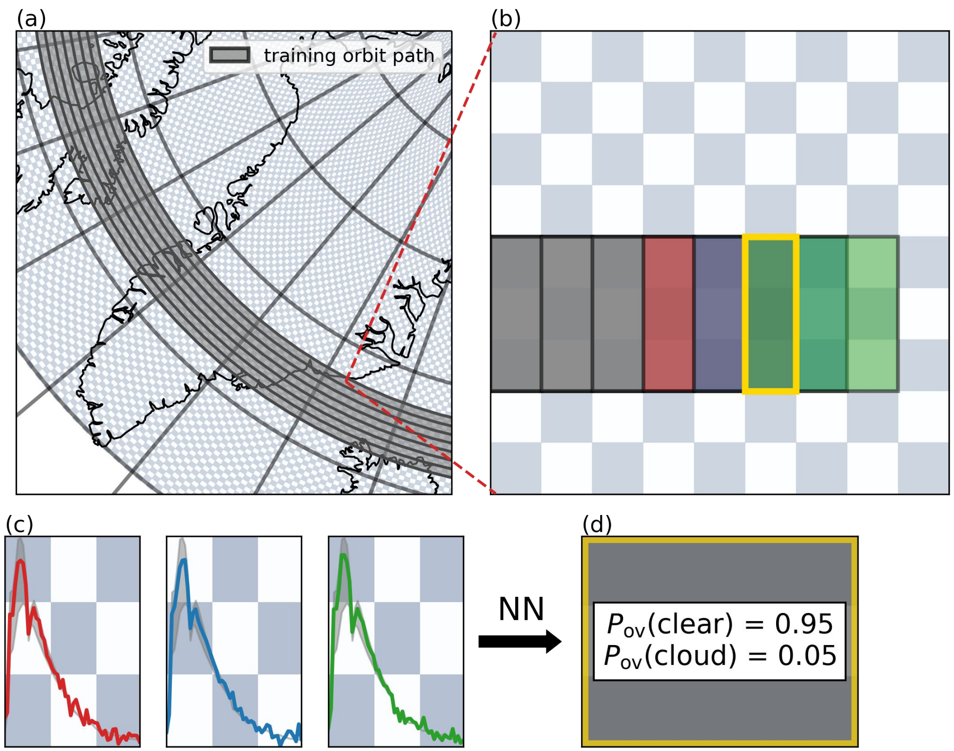
PREFIRE Data Products

Product	Contact	Details
L0 (telemetry+ instrument)	B. Drouin	Time-stamped instrument counts & housekeeping Time-stamped geolocation and spacecraft orientation data Spacecraft housekeeping
L1A Engineering	B. Drouin	Time-stamped and verified geolocation and spacecraft orientation data
L1A Radiometric Coefficients	B. Drouin	Pre-launch and on-orbit calibration
L1B Radiances/ Fluxes	B. Drouin	Instrument model
L2B Flux	X. Huang	3% accuracy (8 W/m^2 for total and 4 W/m^2 for FIR)
L2B Surface Properties	X. Huang	1% accuracy spectral emissivity
L2B Cloud Mask	B. Kahn	Detect 80-90% of clear-sky occurrences; confidence flags; MODIS and AIRS heritage
L2B Atmospheric Properties	A. Merrelli	T/q profiles; 10% accuracy for column water vapor

Product	Contact	Details
L3 Radiance Climatology	B. Drouin	Daily and monthly gridded products for each CubeSat
L3 Flux Climatology	X. Huang	Daily and monthly gridded products for each CubeSat
L3 Surface Climatology	X. Huang	Daily and monthly gridded products for each CubeSat
L3 Atmospheric Climatology	A. Merrelli	Daily and monthly gridded products for each CubeSat
L3 Sorted Climatology	PREFIRE Team	Regime-based L3; histograms following MODIS L3 methodology
Auxiliary Meteorology	A. Merrelli	NWP/reanalysis T/q profiles, surface properties
Auxiliary JPSS	E. Nelson	VIIRS cloud mask; high-res VIS/IR imagery; CrIMSS cloud products

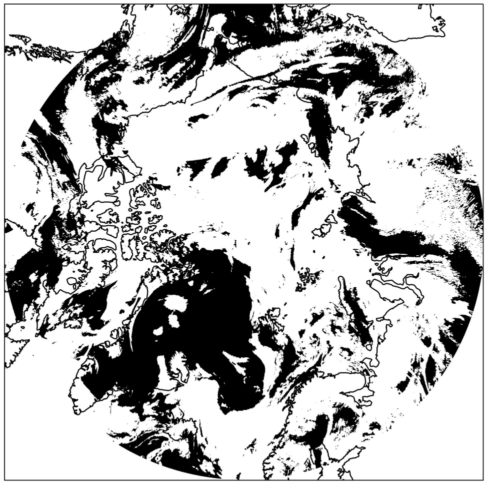
Candidate Cloud Mask

Neural Network-Based Cloud Detection

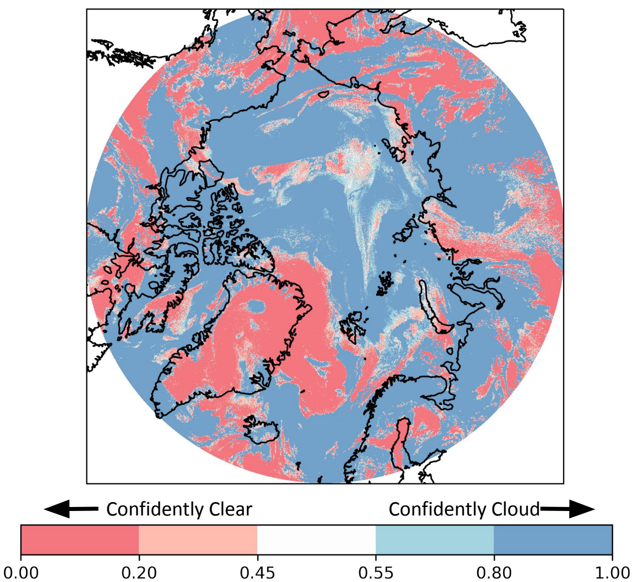


Bertossa et al.,submitted to *J. Tech.*

Truth (cloud = white)

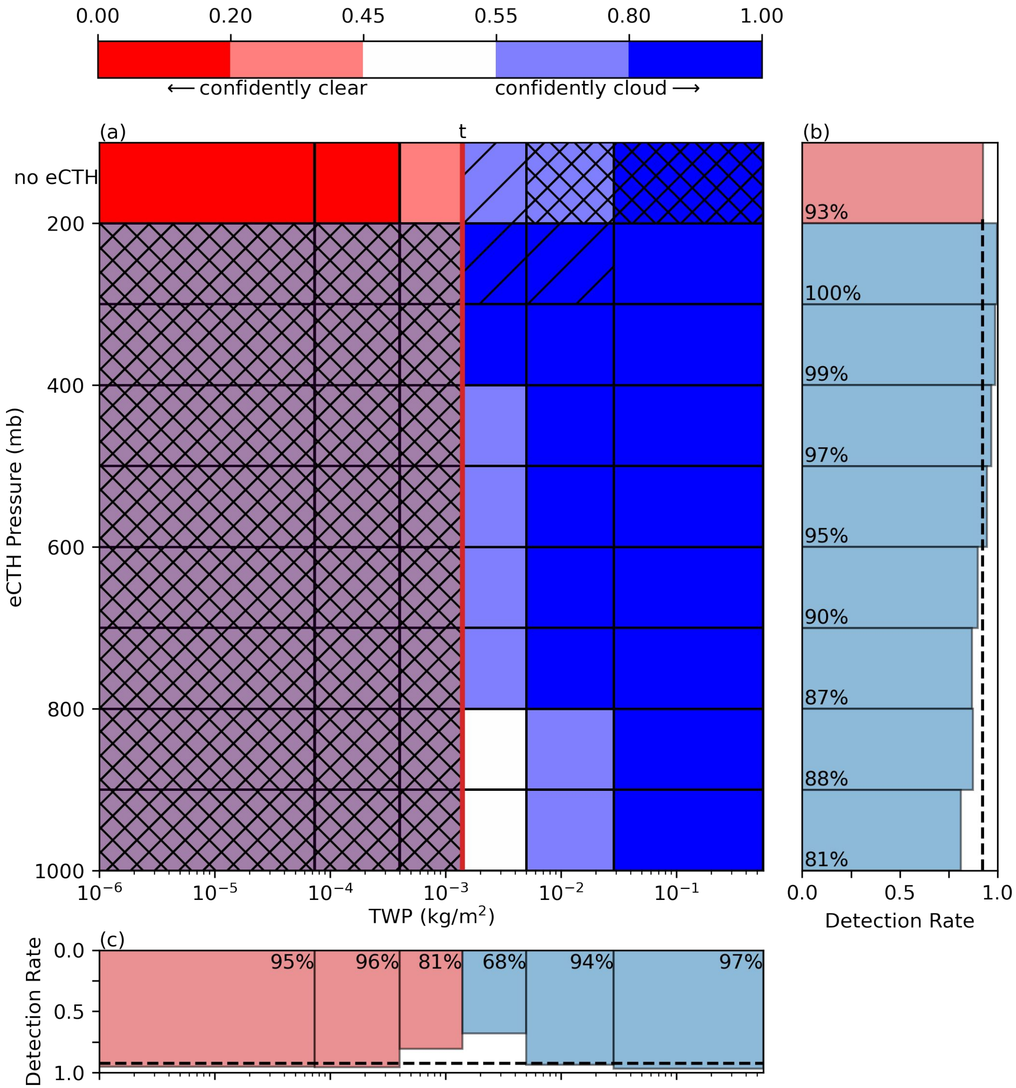


Predicted Cloud Probabilities



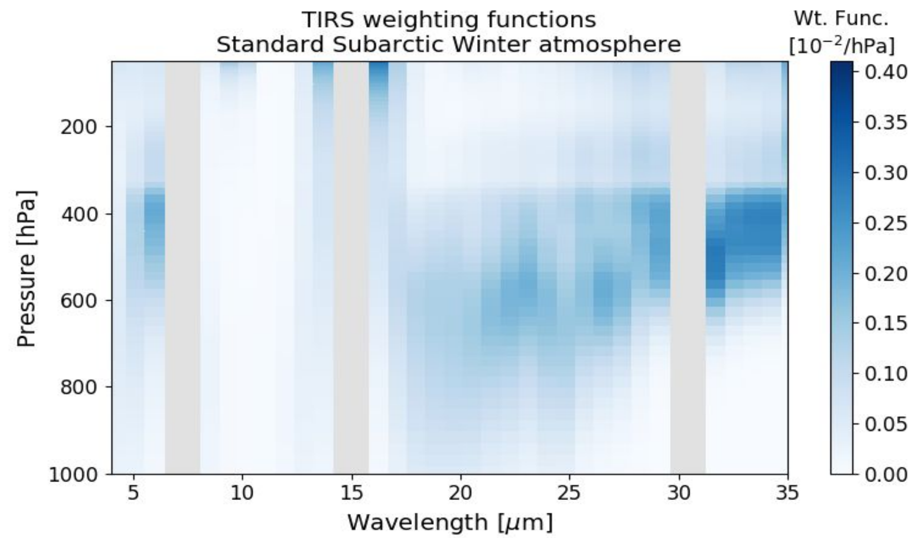
Performance by Scene Type (Simulated)

Confidence

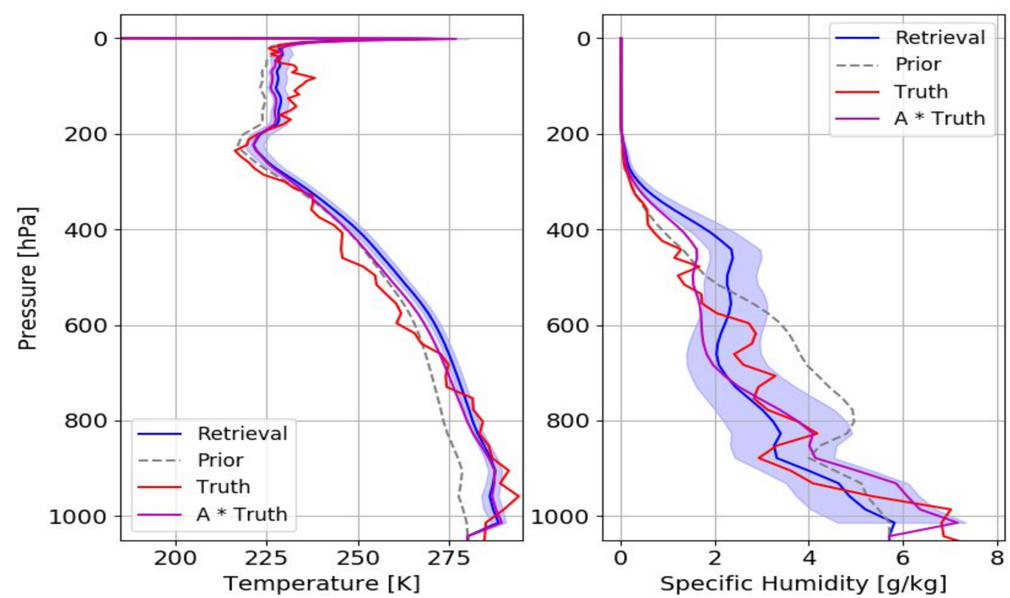


Clear Scenes: Atmospheric Temperature and Water Vapor (ATM)

- In clear skies, TIRS radiances will be used to infer temperature and water vapor
- Full spectrum provides sensitivity to water vapor at different altitudes
- Two-stage retrieval:
  - PC-Regression
  - Optimal Estimation with the PCR result as a prior

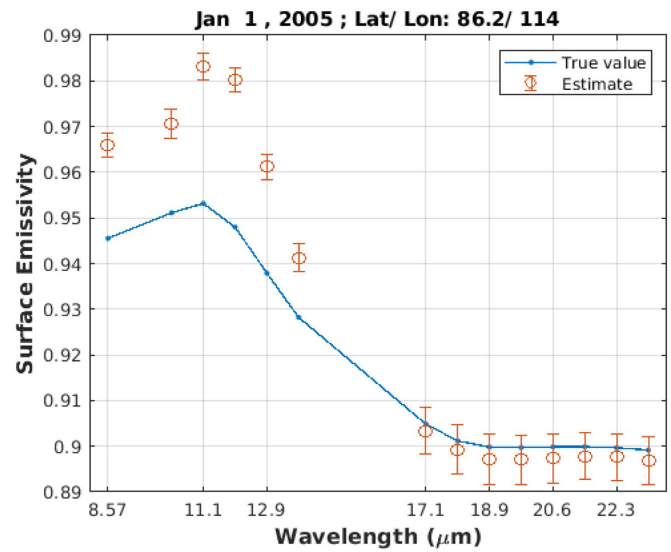


Sample Retrieval of Perturbed ERA5 Profile



Clear Scenes: Spectral Surface Emissivity (SFC)

- An optimal estimation approach estimates surface emissivity in multiple channels
  - Incorporates measurement uncertainty
  - Yields uncertainty estimates
- May include water vapor constraint from ATM retrieval



Observations

and its error covariance

***a priori* constraints**

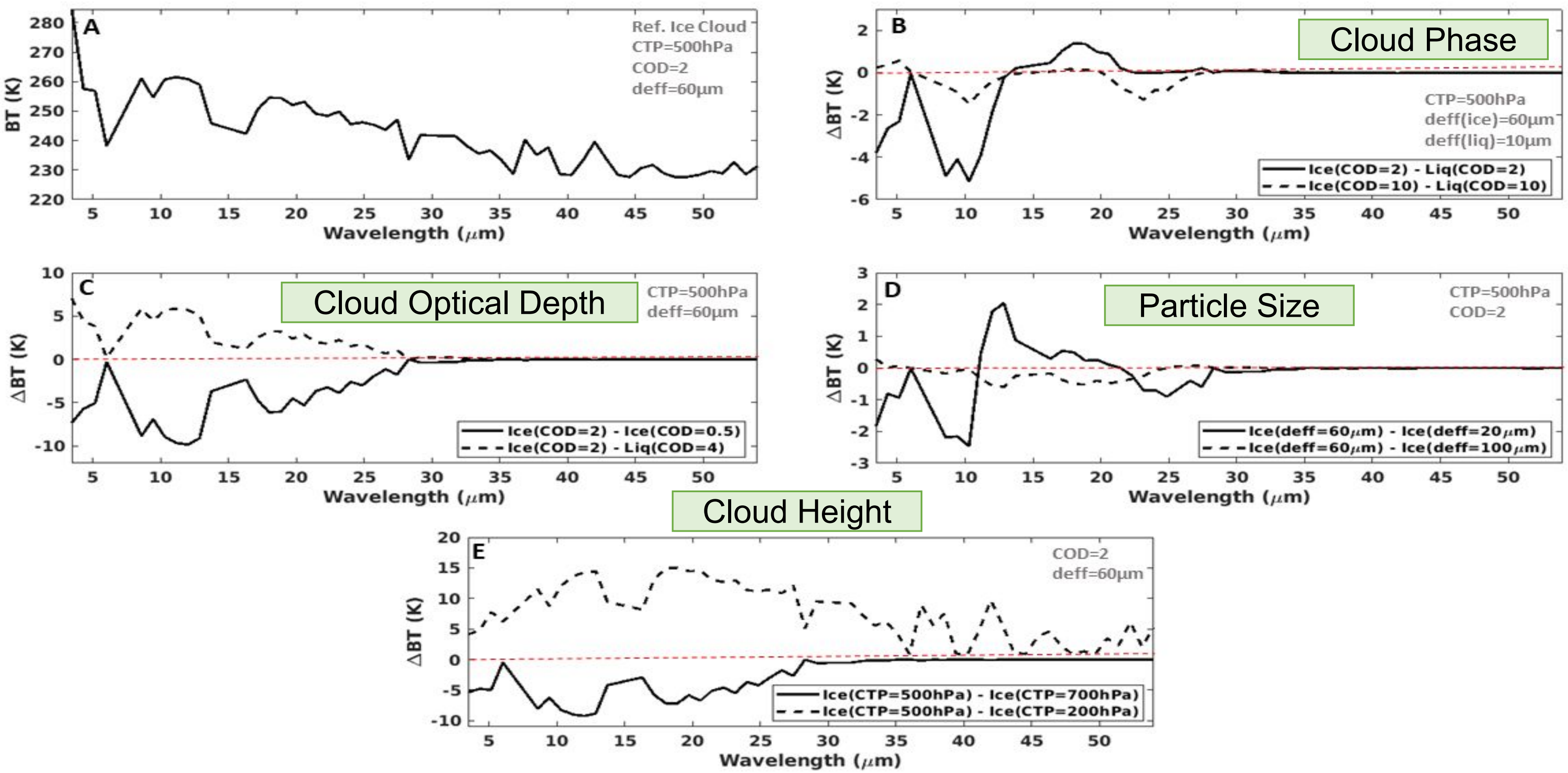
mean and its covariance

Optimal Estimate

Radiative transfer model

Weighting function matrix

Cloudy Scenes: Cloud Property Retrievals



In cloudy scenes, TIRS radiances carry the spectral signatures of cloud phase and ice particle size

All Scenes: Longwave Spectral Fluxes

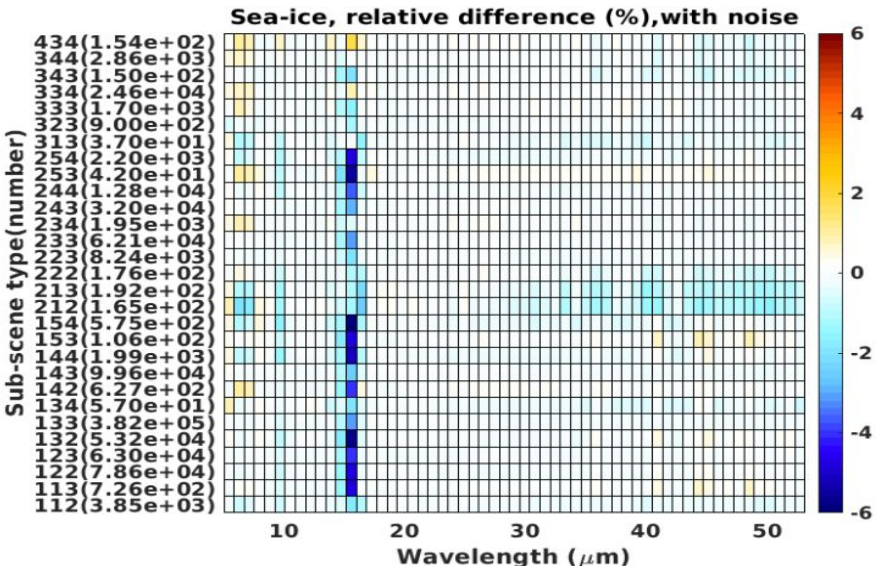
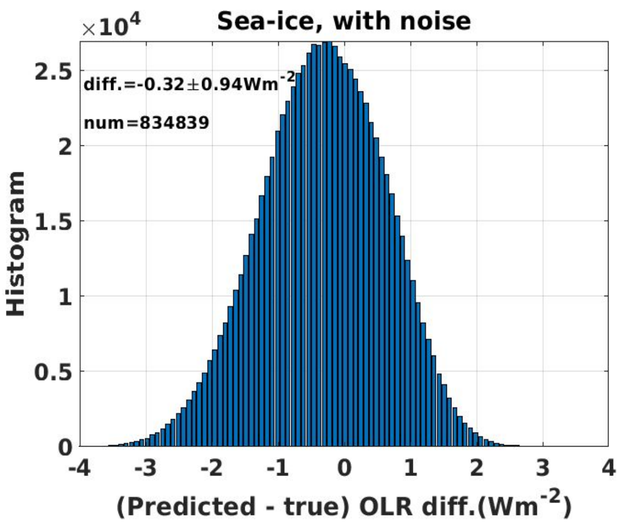


Fig.1: Mean bias for each sub-scene type over the sea ice surface, expressed in percentage difference.



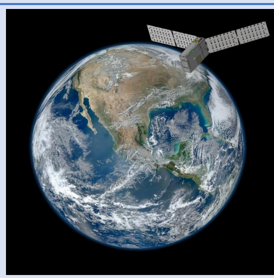
- Longwave spectral fluxes using methods developed and validated for AIRS (Huang et al, 2008; 2010; 2014; and Chen et al, 2013) but spanning a factor of three larger spectral range;
- Spectral flux for each TIRS channel estimated from a pre-constructed spectral ADM (anisotropic distribution model);
- Flux over spectral gaps not covered by the PREFIRE will be estimated using a PCA-based multilinear regression scheme;
- 0^{th} order channel provides integral constraint at night;
- Integrated OLR errors < 2 Wm^{-2} for 90% of scenes.

PREFIRE Science

PREFIRE Tests Two Hypotheses By Coupling Observations to Models

1. Time-varying errors in far infrared emissivities and atmospheric greenhouse effects (GHE) bias estimates of energy exchanges between the surface and the atmosphere in the Arctic.
2. These errors are responsible for a large fraction of the spread in projected rates of Arctic warming, sea ice loss, ice sheet melt, and sea level rise.

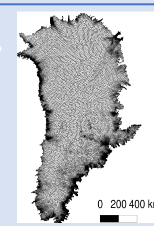
Observe FIR Spectra at the Poles

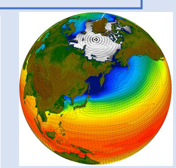


Establish Climatologies and Process Signatures

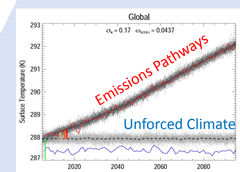
- Aggregate data using contextual data
- Time-difference TIRS 1 & 2 spectra

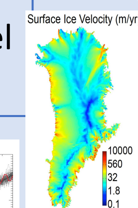
Evaluate and Improve Process and Climate Models





Perform New Process and Climate Model Simulations





Calibrate; geolocate; apply L2 algorithms

Analyze L3 Products

Integrate and Test Emissivity Modules

Hypothesis 1 is addressed by comparing observed spectral fluxes with those simulated from model output.

Hypothesis 2 is addressed by modifying emissivity models and examining impacts on ice sheet dynamic processes, ice sheet melt, Arctic warming, sea ice loss, and sea level rise.

Summary

- PREFIRE aims to reduce uncertainty in polar infrared fluxes, the processes that modulate them, and, by coupling to models, the implications of polar climate predictions.
- Identical TIRS on two 6U CubeSats will measure far-infrared spectra from 5-54 µm at 0.84 µm resolution.
- Observed radiances across the mid- and far-infrared will be used to derive surface properties, water vapor, temperature, and cloud properties.
- Time-differenced measurements from two CubeSats will quantify the spectral signatures of sub-daily processes including melt and snow events.
- Model simulations will help translate this information into improved understanding of polar climate.

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L'Ecuyer et al, *BAMS* (2021)