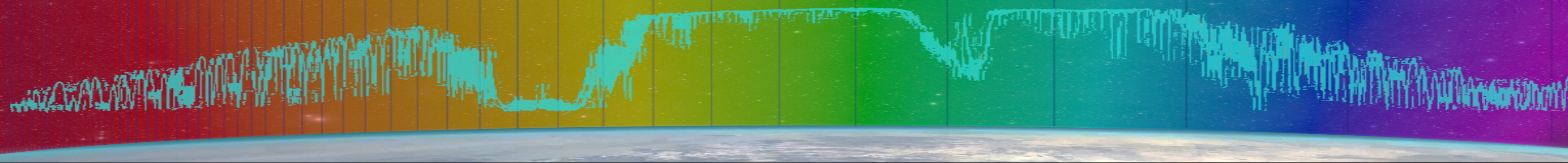

Documenting the Spectral Character of Earth's Emission with PREFIRE

Tristan L'Ecuyer

https://prefire.ssec.wisc.edu

Brian Drouin
Xianglei Huang
Brian Kahn
Jen Kay
Jonah Shaw
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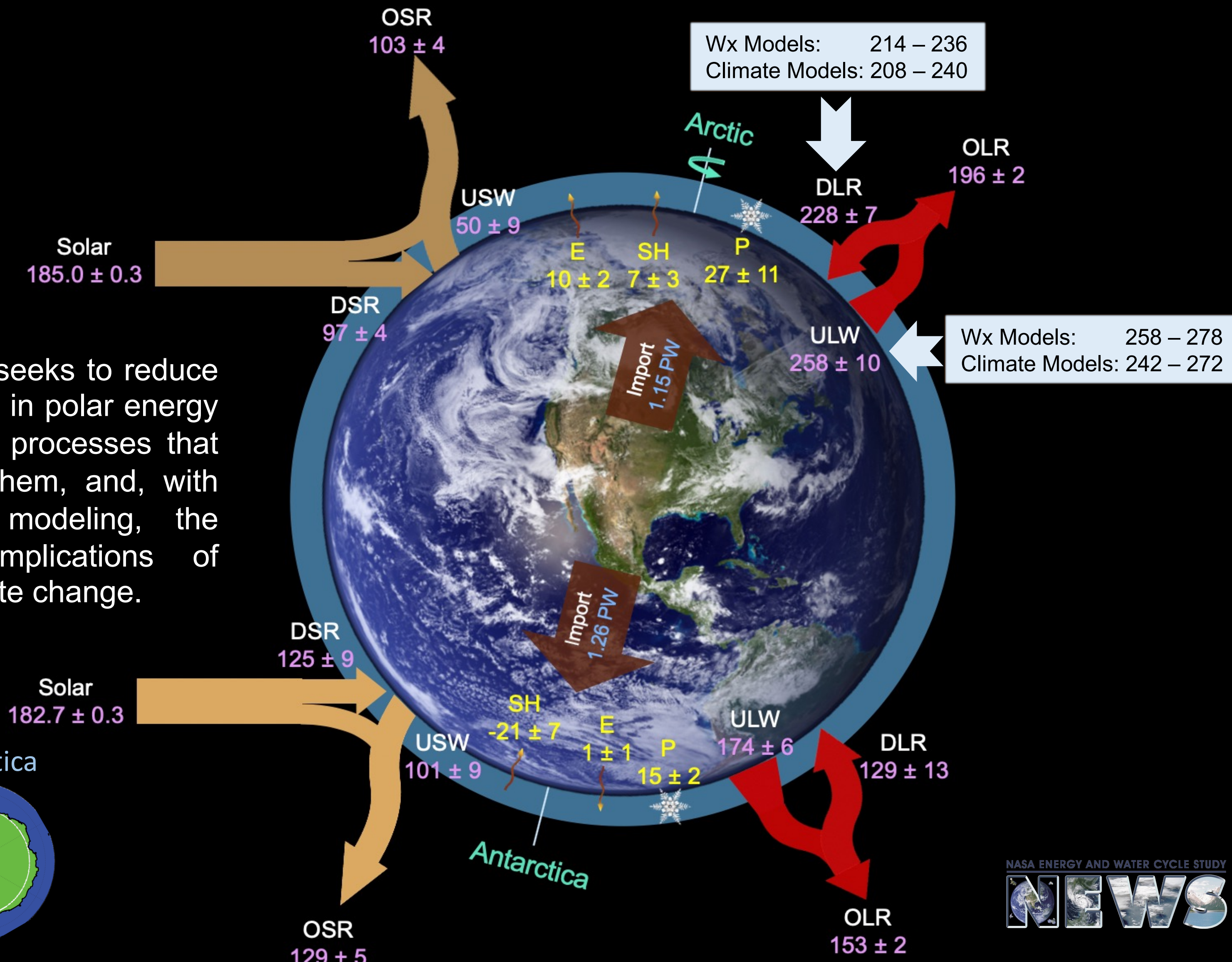
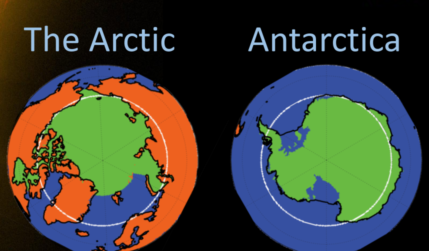
Jet Propulsion Laboratory
California Institute of Technology
WISCONSIN
UNIVERSITY OF WISCONSIN–MADISON
BLUE CANYON TECHNOLOGIES

Polar Energy Imbalances

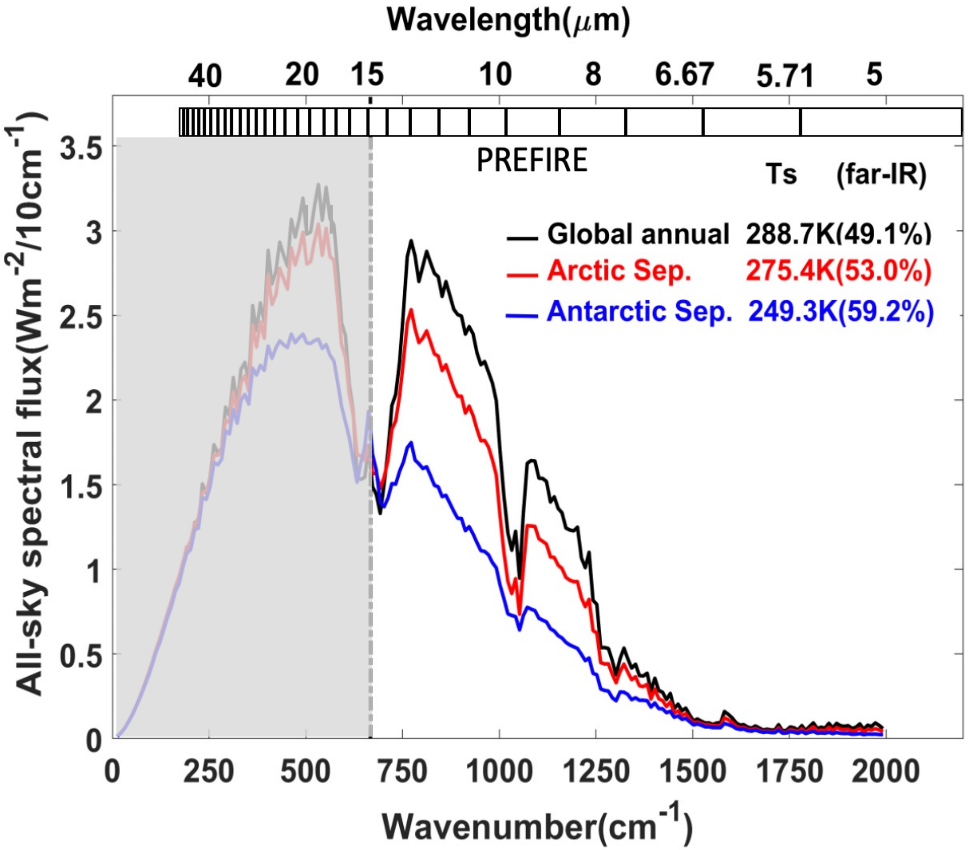


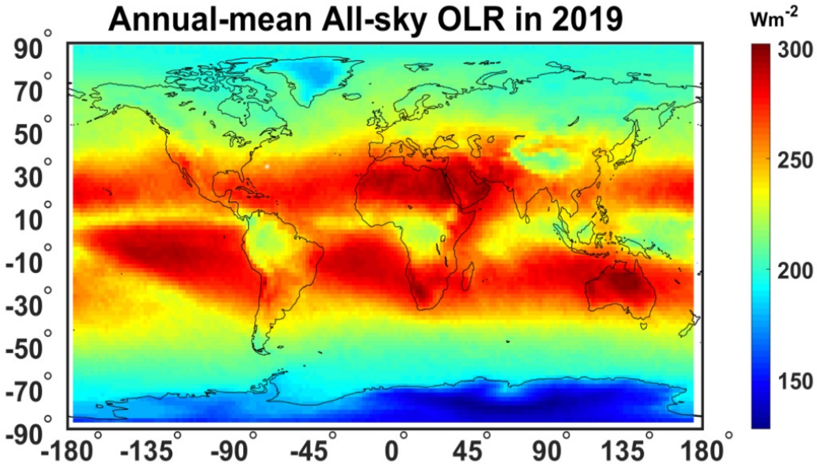
PREFIRE seeks to reduce uncertainty in polar energy fluxes, the processes that influence them, and, with improved modeling, the societal implications of polar climate change.

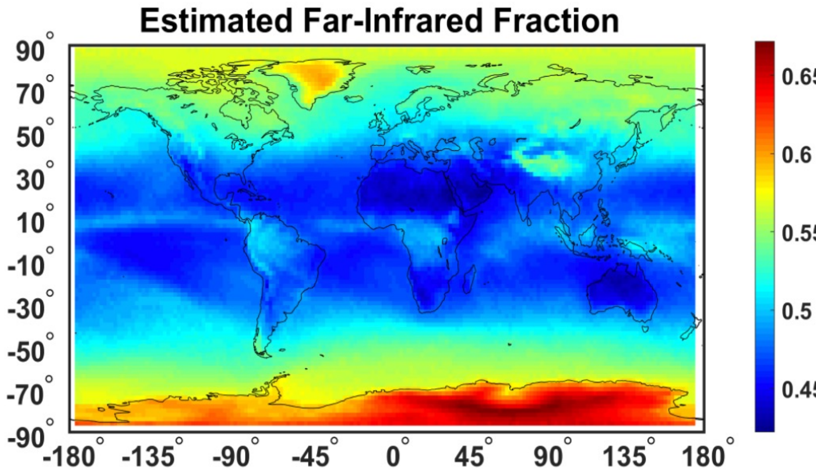


L'Ecuyer and Mateling, in preparation

The Far-Infrared Observing Gap







Current Spectral Measurements

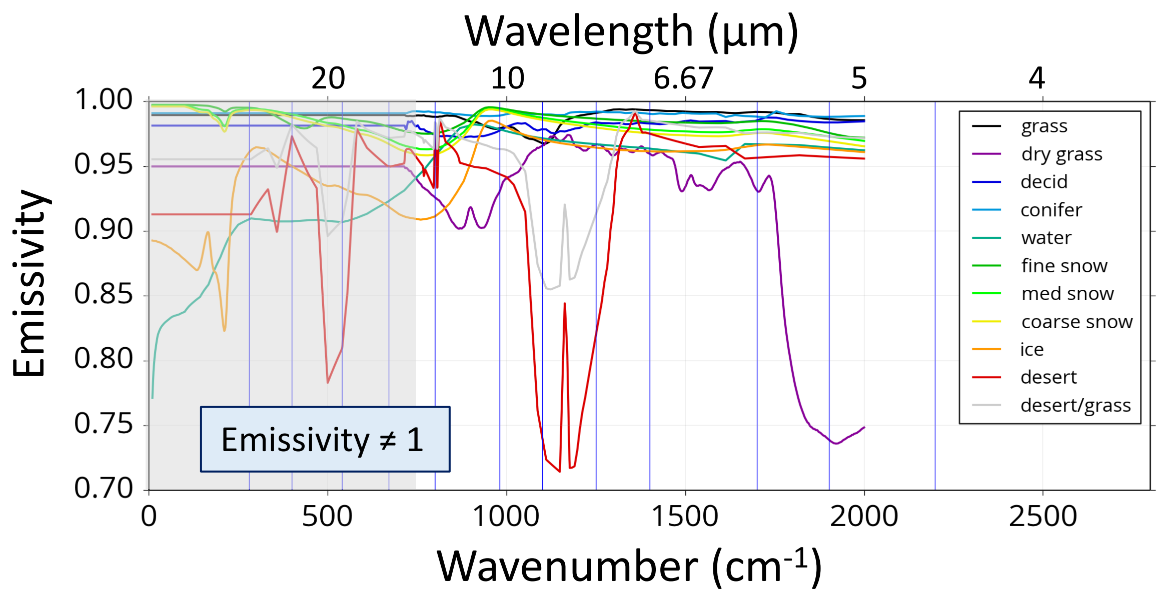
CERES/Libera

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

Incomplete Observations → Incomplete Knowledge

PREFIRE

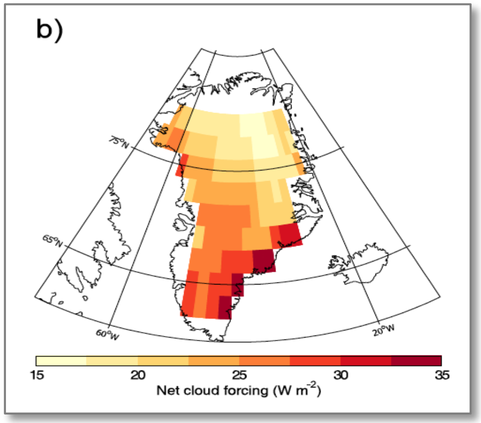
Surface Flux Exchanges Revisited



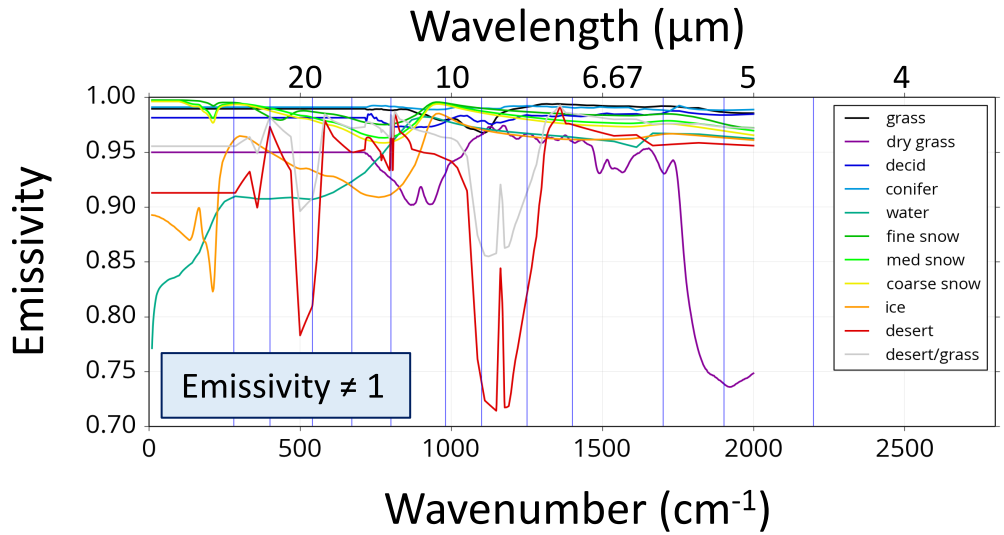
Far-infrared surface emissivity exhibits substantial variability across surfaces common in polar regions.

The atmospheric greenhouse effect is sensitive to thin clouds and small water vapor concentrations that have strong far infrared signatures.

Cloud Impact on AGHE

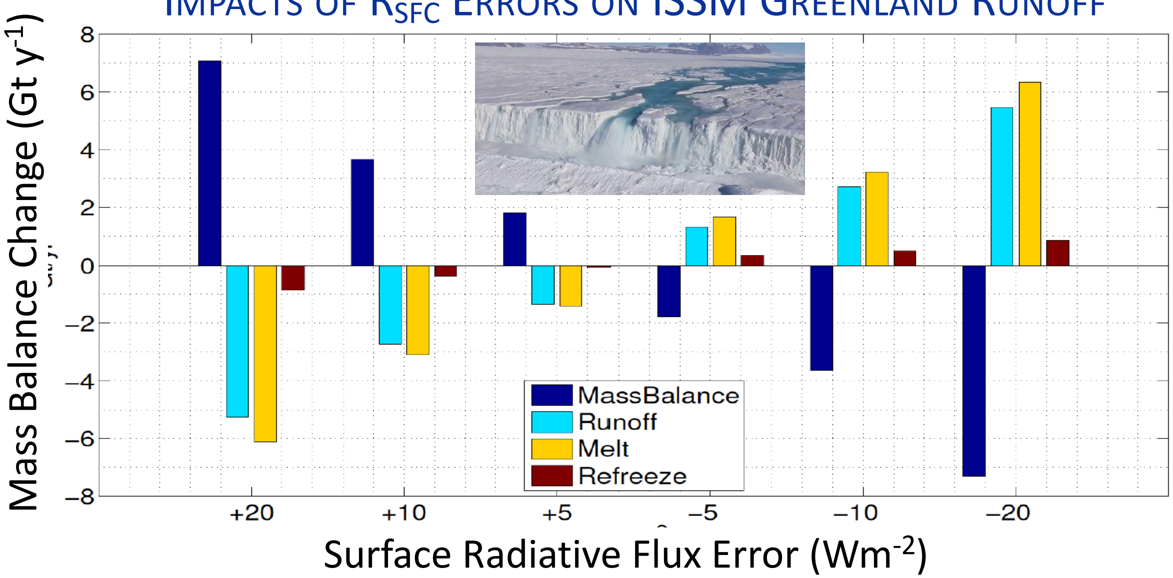


Imcomplete Knowledge → Uncertainty

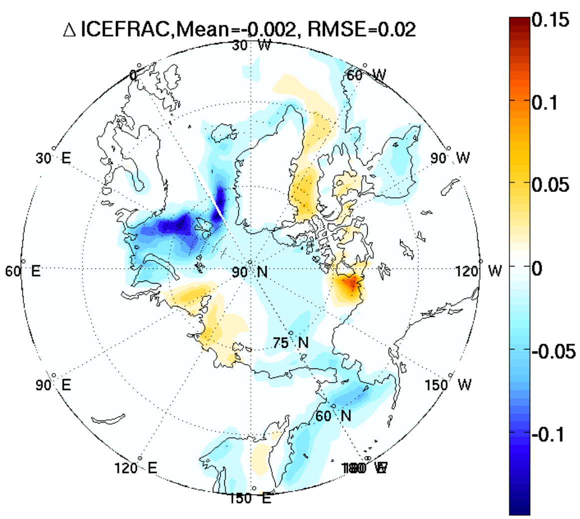


Surface emissivity strongly influences surface energy balance, melt processes, and Arctic circulations.

Impacts of R_{SFC} Errors on ISSM Greenland Runoff



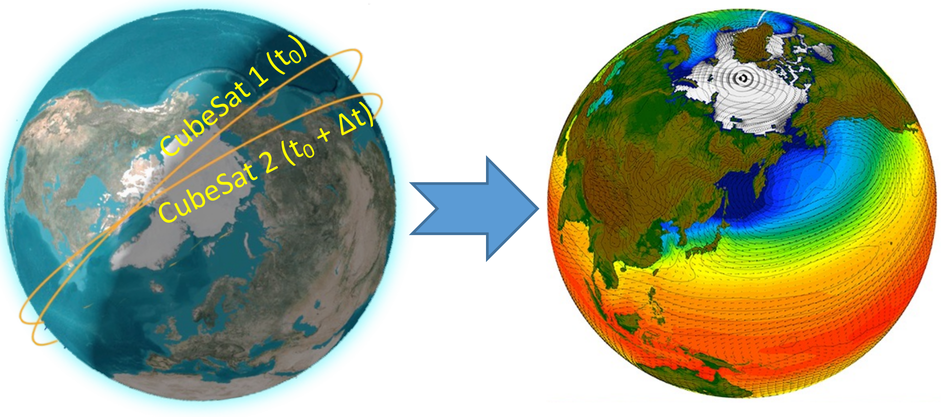
Impacts of ε_λ Errors on CESM Present Day Sea Ice Evolution



Polar Radiant Energy in the Far InfraRed Experiment

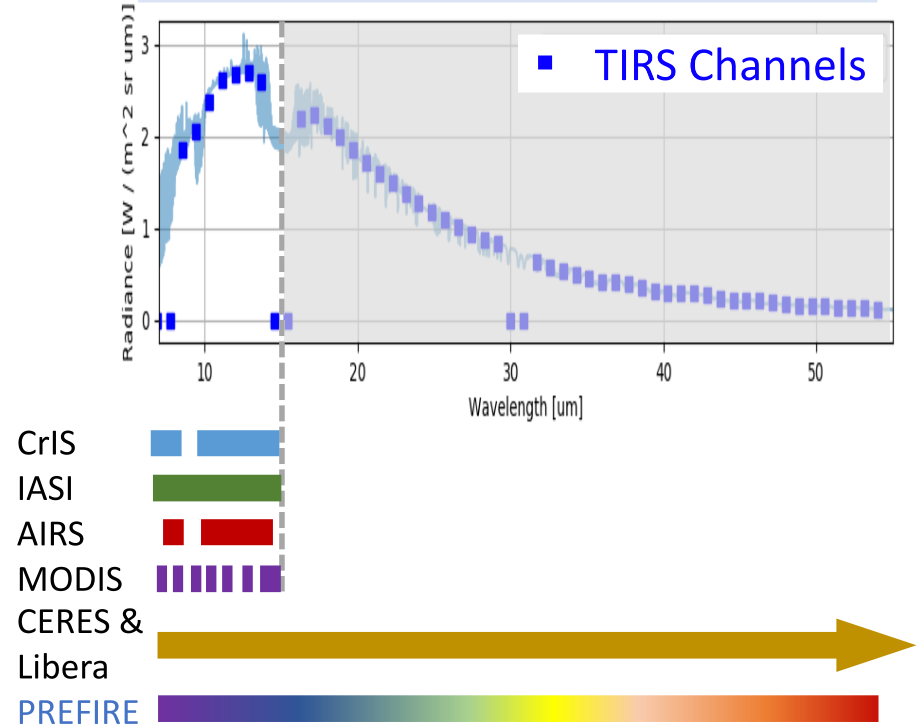
PREFIRE fills the far-infrared observing gap by documenting variability in spectral fluxes from 5 - 53 µm on hourly to seasonal timescales.

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



PREFIRE maps polar far infrared emission spectra with two CubeSats flying in distinct 510–540 km altitude, near-polar (82°-98° inclination) orbits each carrying a miniaturized infrared spectrometer, covering 5-53 µm with 0.84 µm spectral sampling, operating for one seasonal cycle (a year).

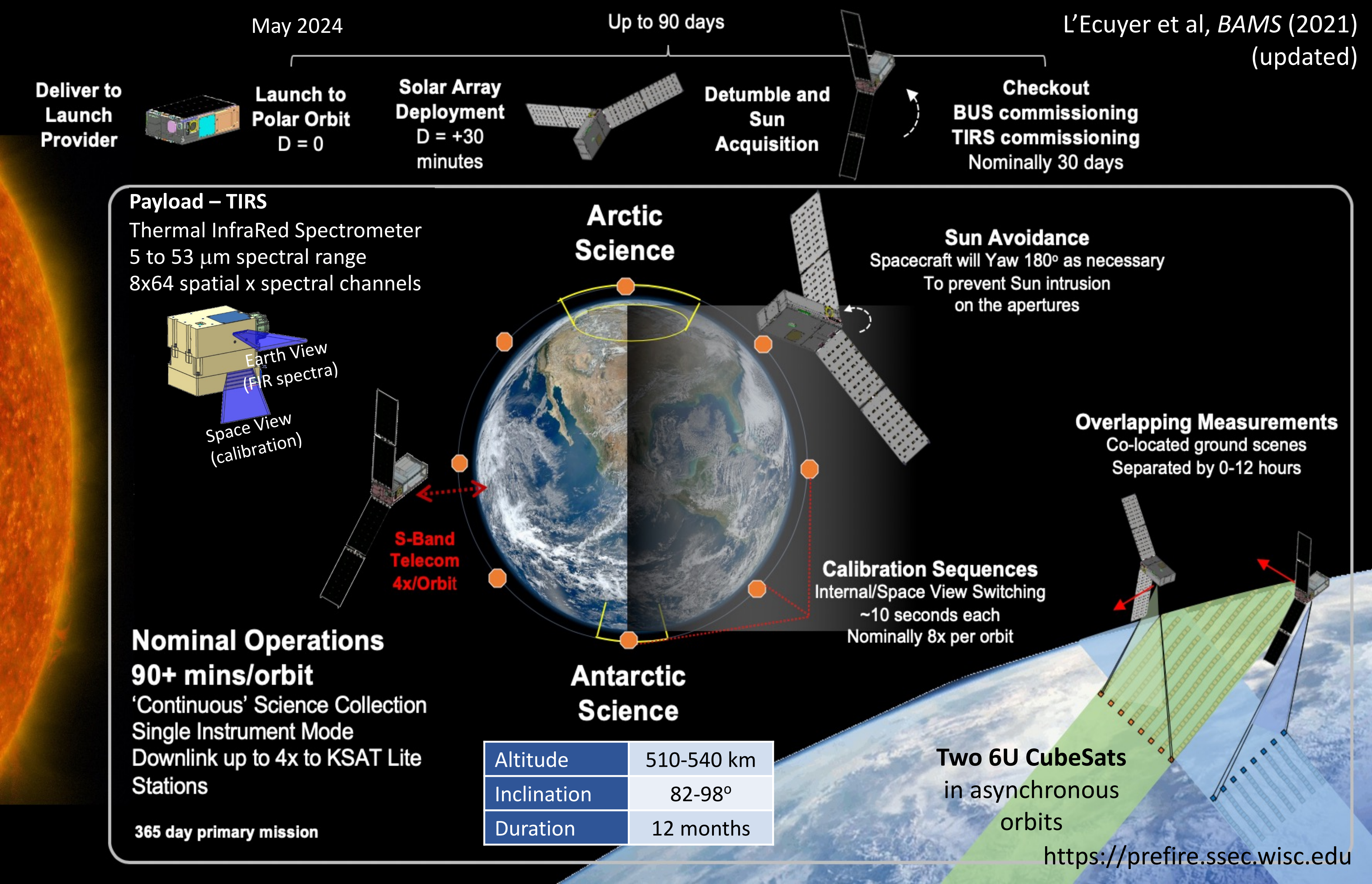
Greenland Emission Spectrum



https://prefire.ssec.wisc.edu

Mission Concept

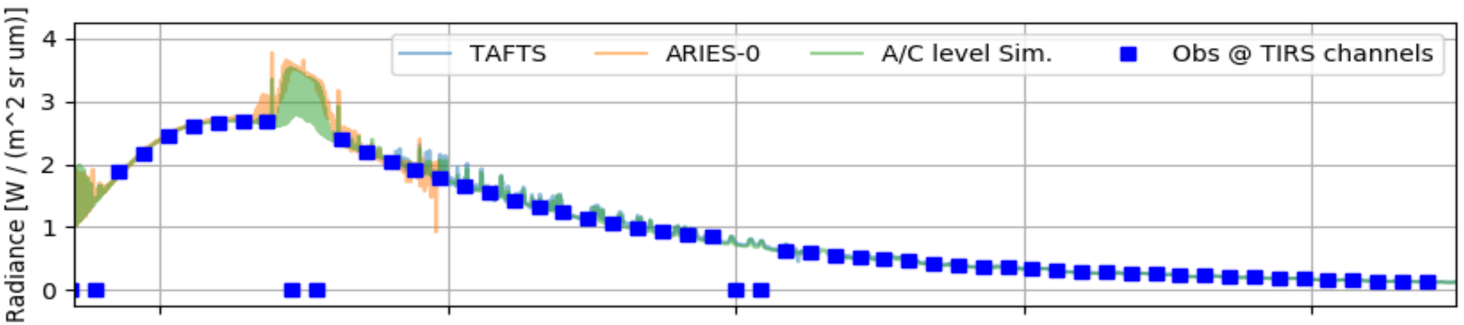
L’Ecuyer et al, *BAMS* (2021) (updated)



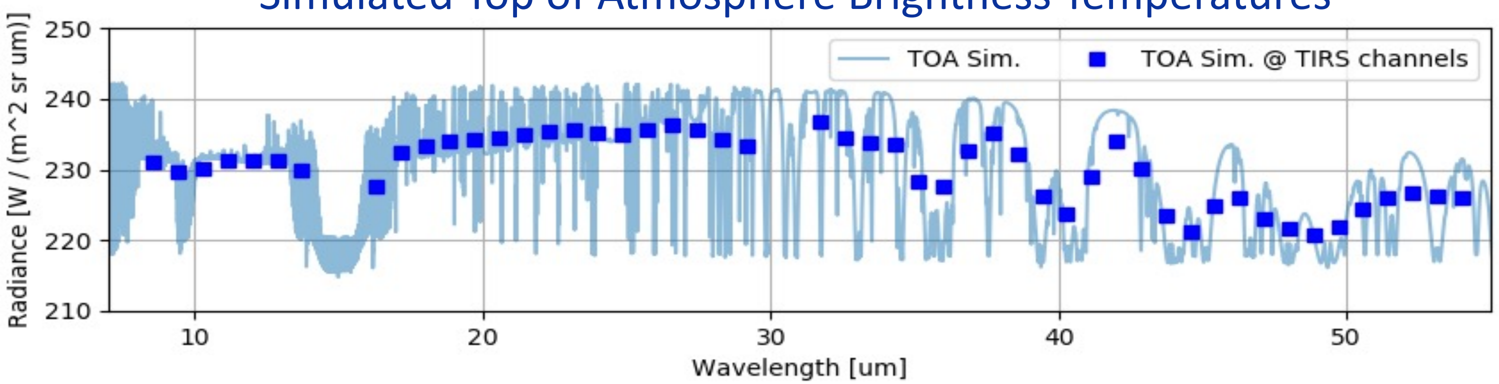
Altitude	510-540 km
Inclination	82-98°
Duration	12 months

https://prefire.ssec.wisc.edu

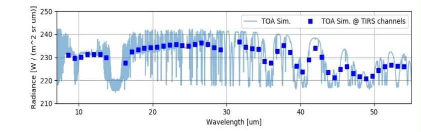
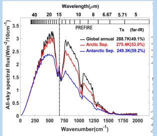
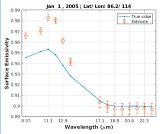
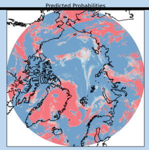
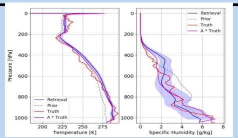
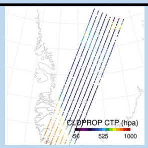
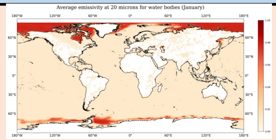
PREFIRE Measurements



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

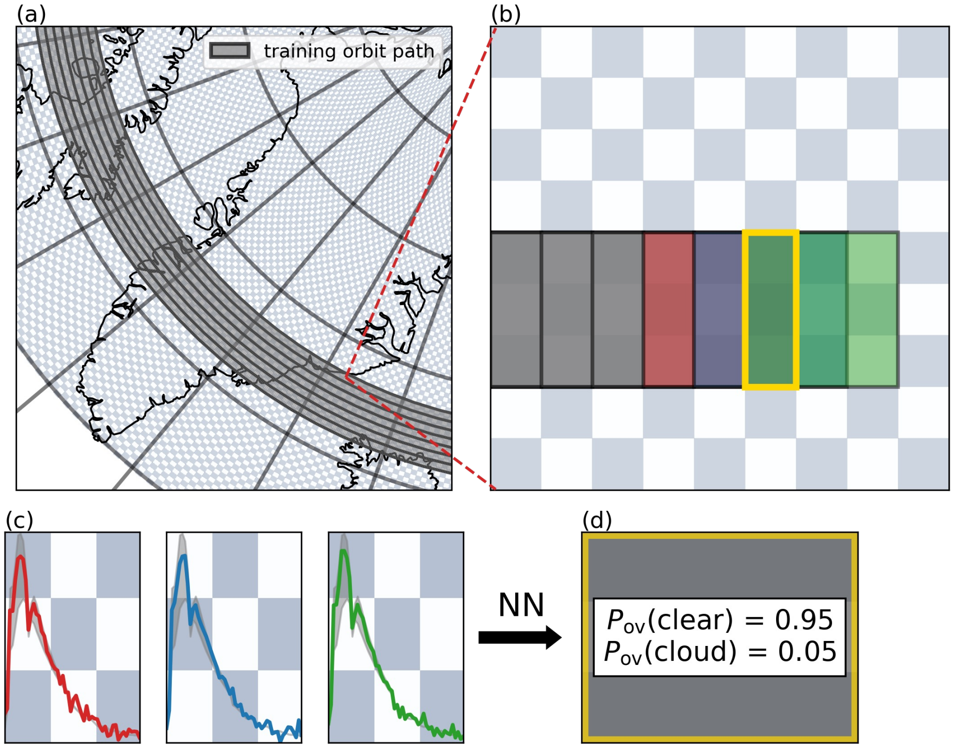


PREFIRE Data Products

Product	Contact	Details	Examples
L0 (telemetry+ instrument)	B. Drouin	Time-stamped instrument and spacecraft data	
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 Emissivity	X. Huang	Surface type, temperature, and spectral emissivity to 0.01 accuracy; optimal estimation and neural-network	
L2B Cloud Mask	B. Kahn	Detect 80-90% of clear-sky occurrences; confidence flags; neural-network and principal component	
L2B Atmospheric Properties	A. Merrelli	T/q profiles; 10% accuracy for column water vapor; optimal-estimation	
L2B Cloud Properties	N. Miller	Cloud top pressure, cloud optical thickness, effective cloud fraction, cloud phase, ice particle size	
L3 Gridded Climatology	N. Vos	Daily and monthly gridded products for each CubeSat	

Student-Led: Neural-Network Cloud Mask

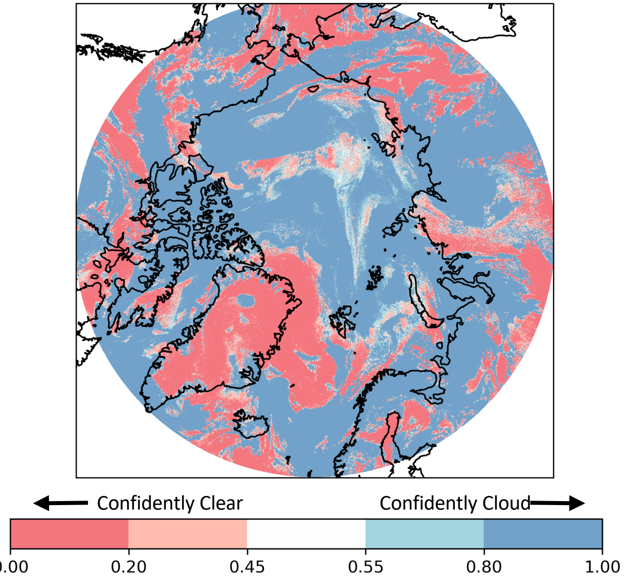
Neural Network-Based Cloud Detection



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

Truth (cloud = white)

Predicted Cloud Probabilities



Synergy with CERES/Libera: Spectral Fluxes

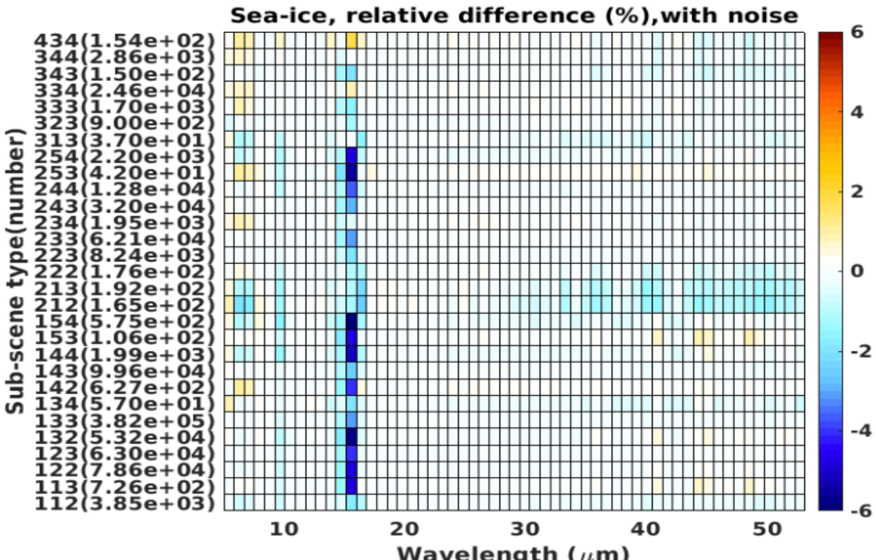
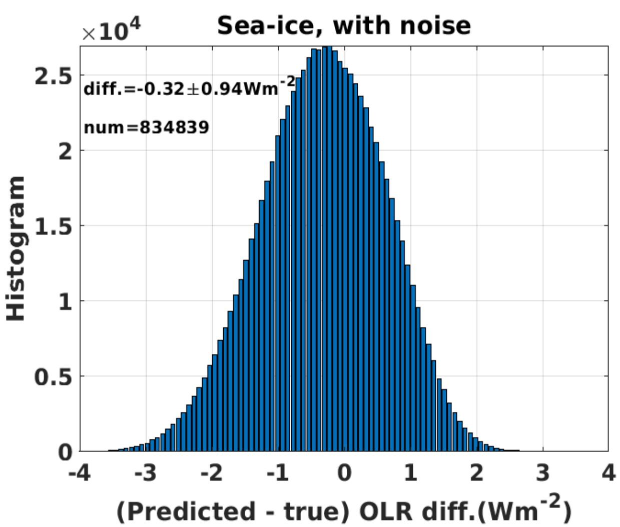
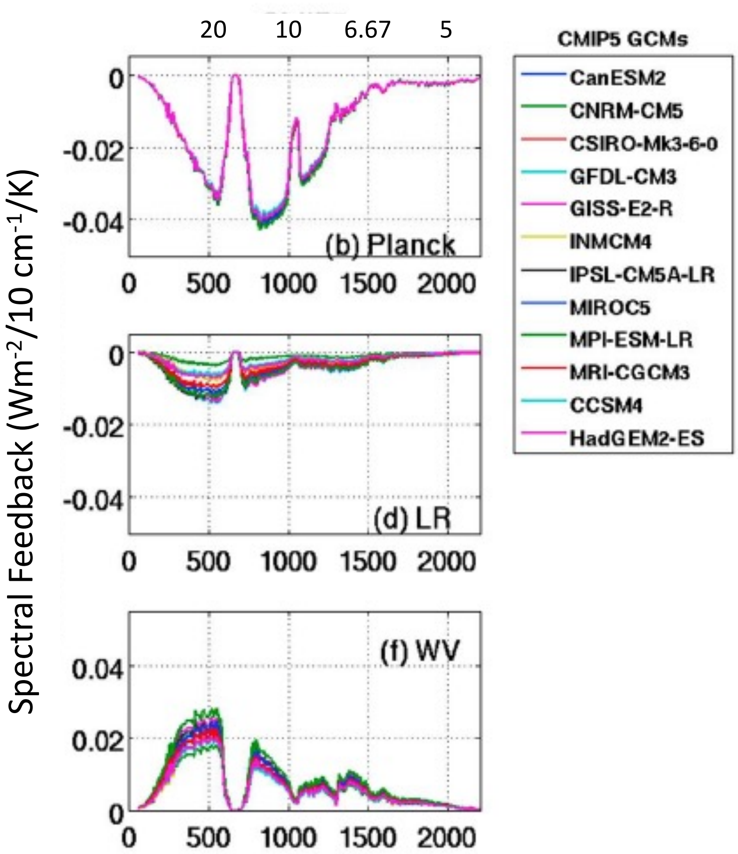


Fig.1: Mean bias for each sub-scene type over the sea ice surface, expressed in percentage difference.



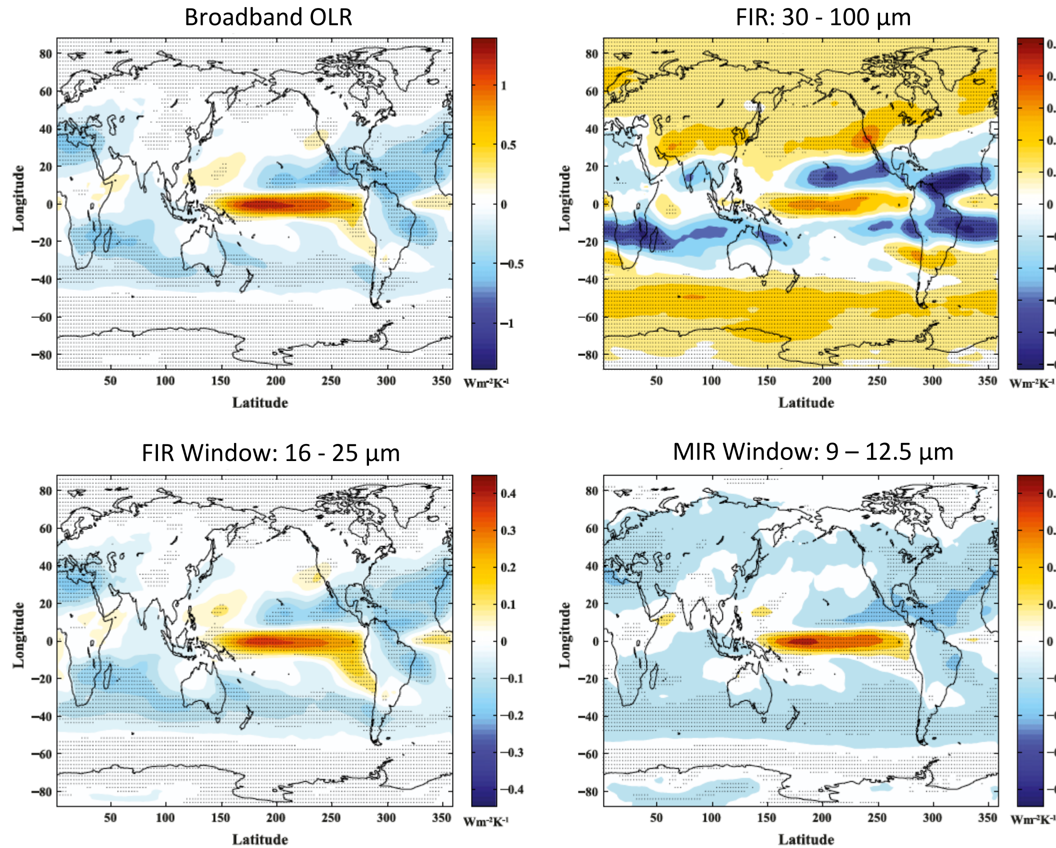
- Longwave spectral fluxes using methods developed and validated for AIRS (Huang et al, 2008; 2010; 2014; and Chen et al, 2013) but spanning a factor of three larger spectral range
- Spectral flux for each TIRS channel estimated from a pre-constructed spectral ADM (anisotropic distribution model)
- Flux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

Far-Infrared Feedback Fingerprints



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

RH Feedback in CMIP5

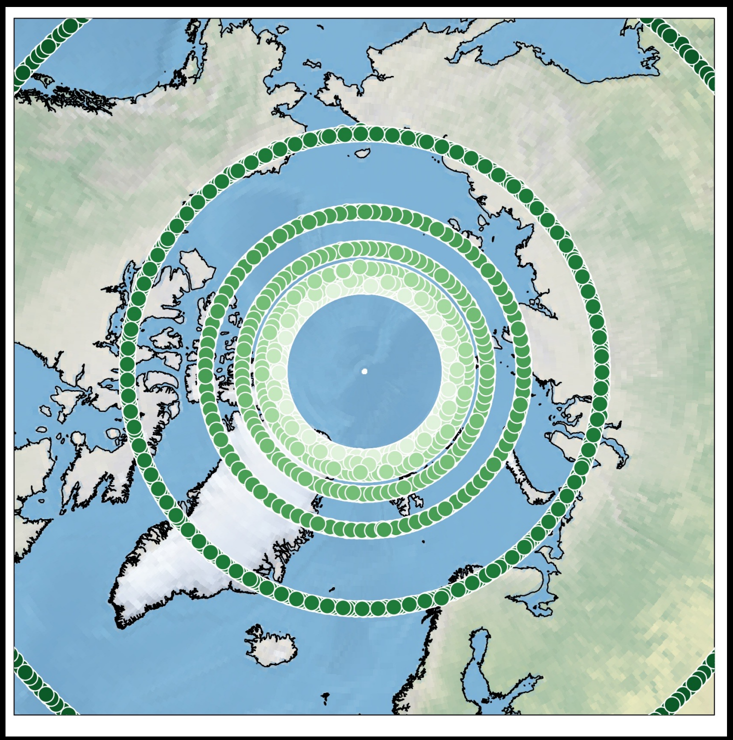


Pan and Huang, J. Climate (2018)

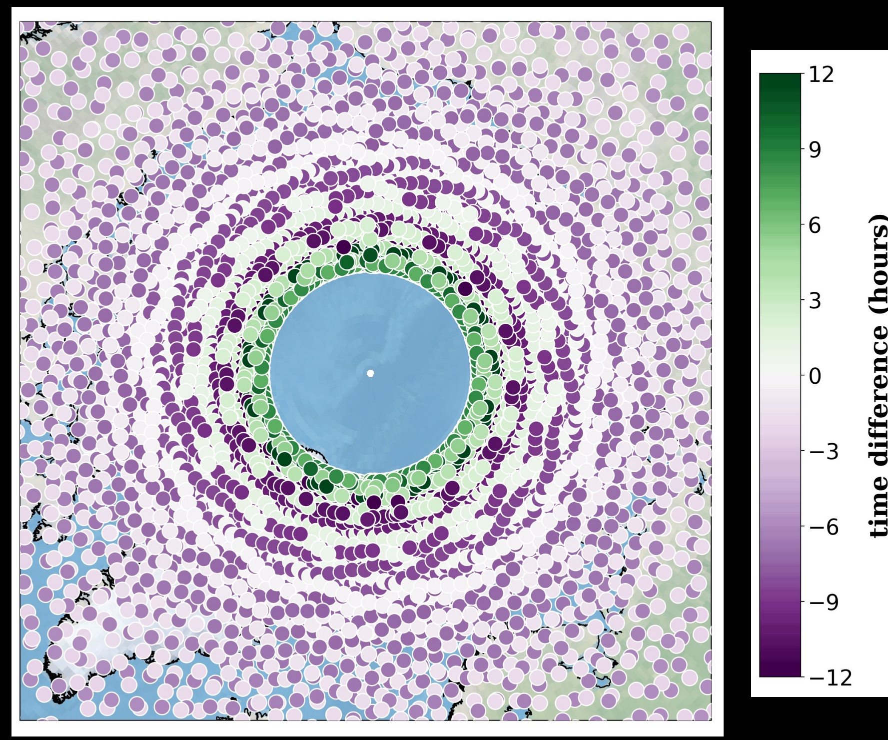
Measuring the complete infrared emission spectrum distinguishes the fingerprints of several important feedback processes.

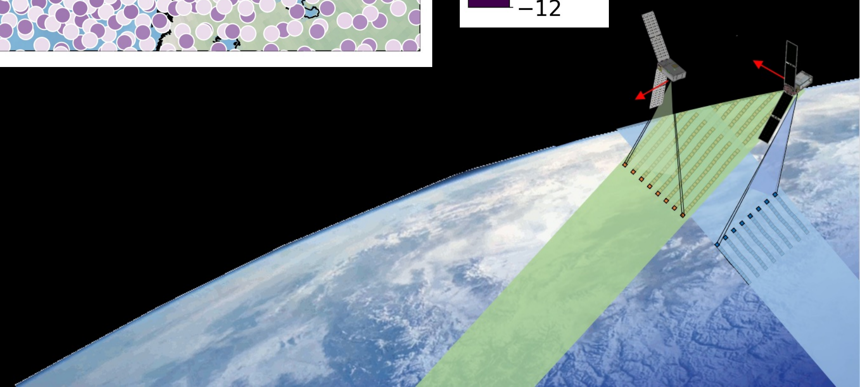
Student Led: Intersection Science

One Satellite

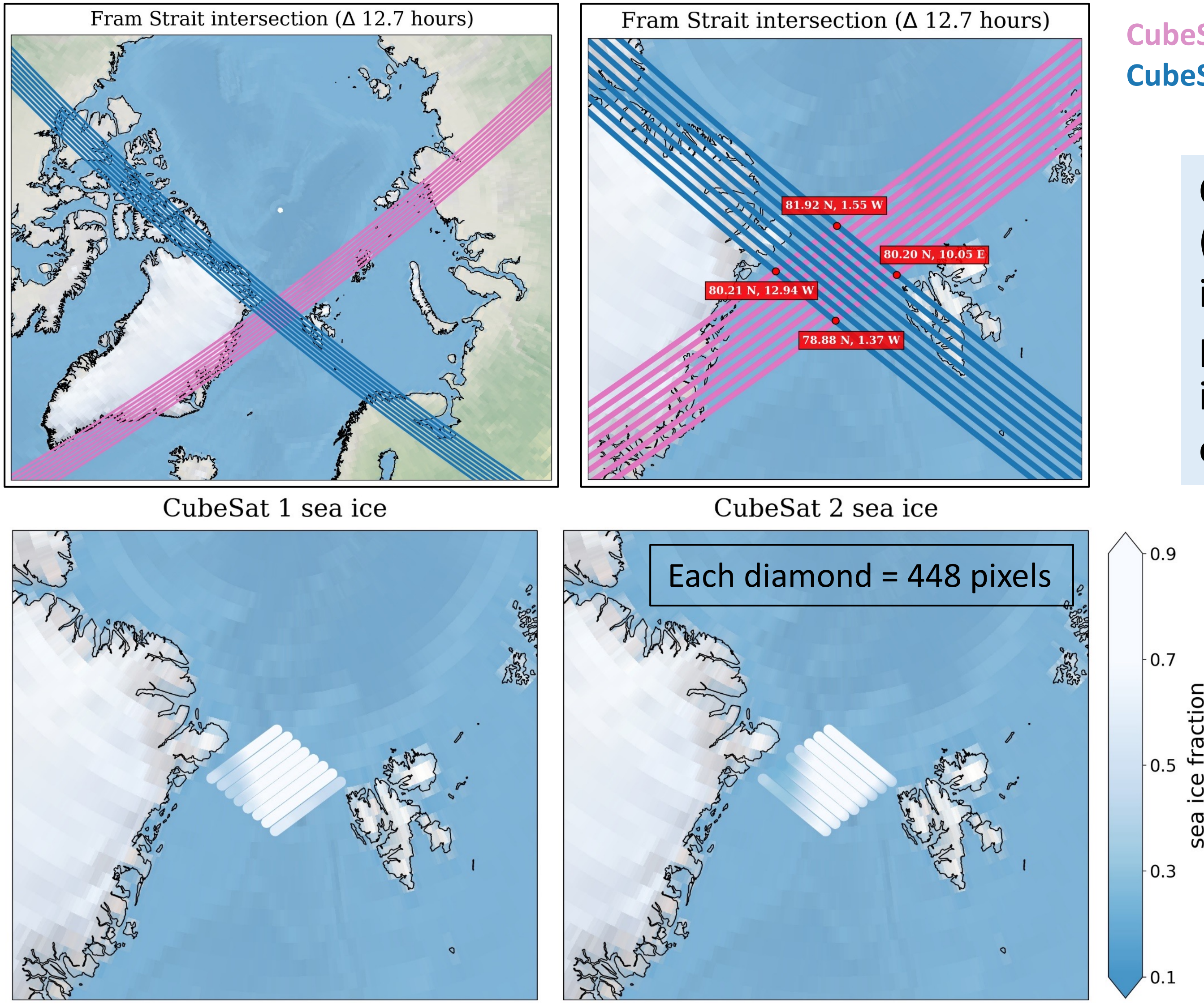


Two Satellites
(Altitude Difference: 15 km)





Student-Led: PREFIRE Intersection Science

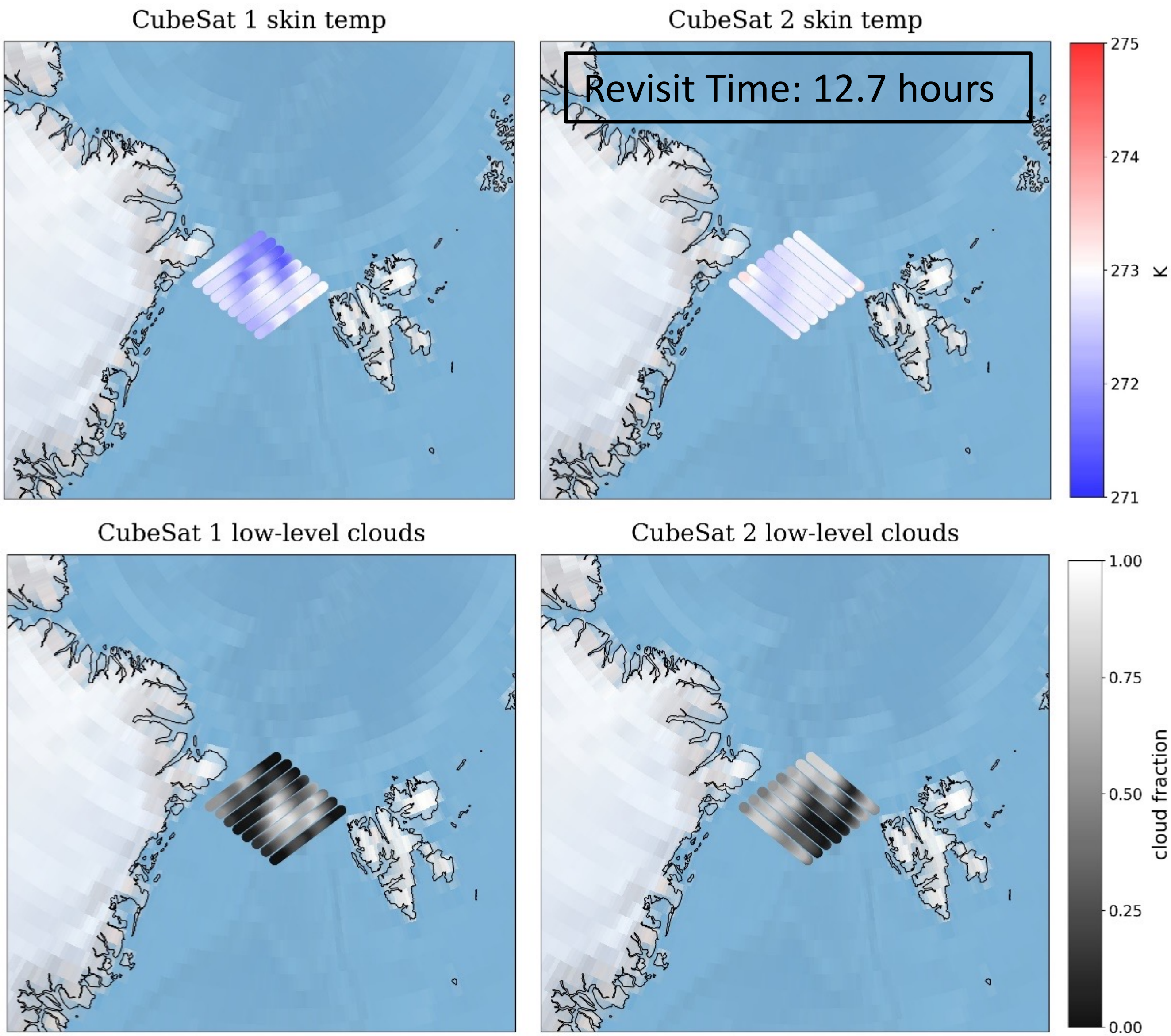


CubeSat 1 time: 6/27/2021 23:38 UTC
CubeSat 2 time: 6/28/2021 12:19 UTC

Orbit intersections (revisits) provide insights into the processes that influence the emission spectrum.

* Actual orbit tracks and intersections will not be known until after launch.

PREFIRE Intersections – Other Changes

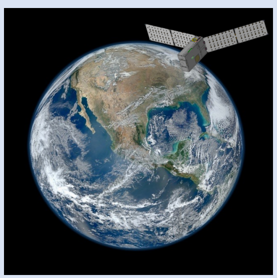


Interfacing with Climate Models

PRFIRE 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.

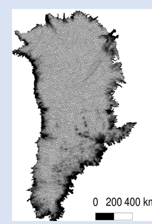
Observe FIR Spectra at the Poles

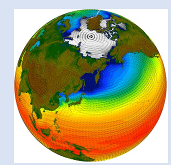


Establish Climatologies and Process Signatures

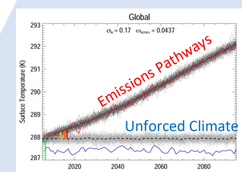
- Aggregate data using contextual data
- Time-difference TIRS 1 & 2 spectra

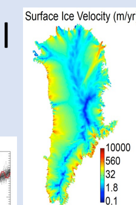
Evaluate and Improve Process and Climate Models





Perform New Process and Climate Model Simulations





Calibrate; geolocate; apply L2 algorithms

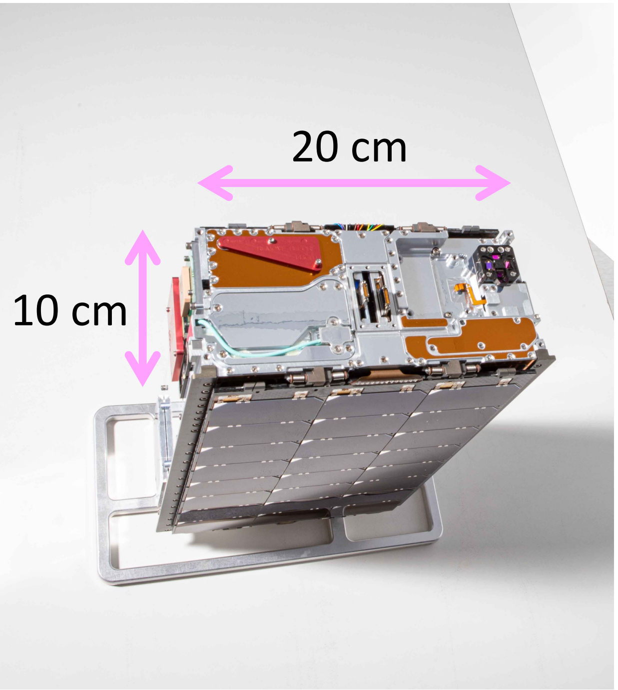
Analyze L3 Products

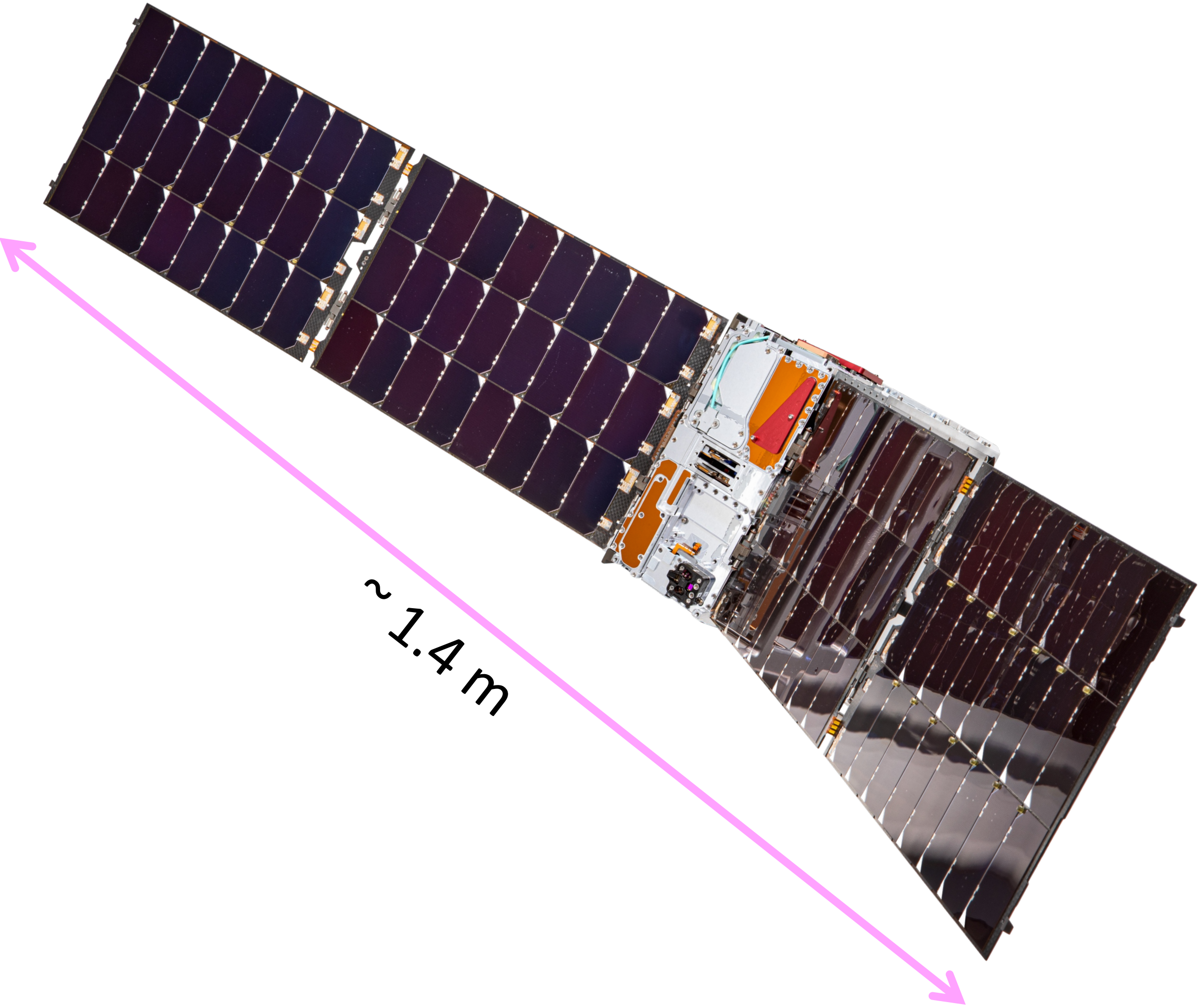
Integrate and Test Emissivity Modules

Hypothesis 1 is addressed by comparing observed spectral fluxes with those simulated from model output using a <u>PREFIRE simulator</u> being developed for COSP.

Hypothesis 2 is addressed by implementing new <u>emissivity models</u> and examining impacts on ice sheet dynamics, ice sheet melt, Arctic warming, sea ice loss, and sea level rise.

Mission Status





Anticipated Launches:

CubeSat 1: May 1, 2024
CubeSat 2: May 15, 2024

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 help translate this information into improved understanding of polar climate.

https://prefire.ssec.wisc.edu

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

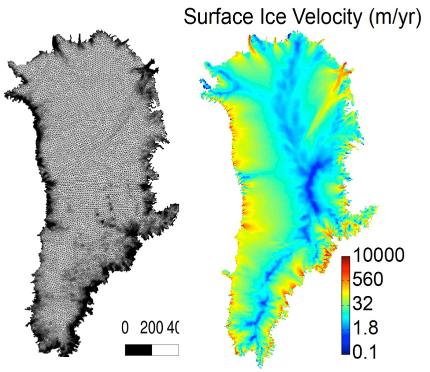
More on Climate Model Interfaces

- Ensuring that PREFIRE observations influence model development is essential to mission success.
- PREFIRE observations interface with polar models in two ways:
  - New spectral surface emissivity models that span the mid and far-infared;
  - Spectral signatures of the factors that force polar climate for model evaluation via simulators

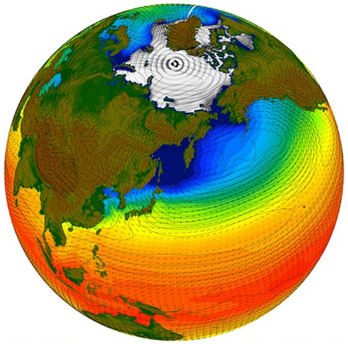
Modeling Activities

- Develop general spectral emissivity coupler for surface-atmosphere interfaces
- Implement PREFIRE spectral surface emissivity models
- Develop and implement TIRS simulator in the CFMIP Observation Simulator Package (COSP)
- Conduct CESM simulations to assess impact of emissivity uncertainty on current and future climate
- Couple ISSM to CESM output to establish impacts on ice sheet dynamical processes

Ice Sheet Models



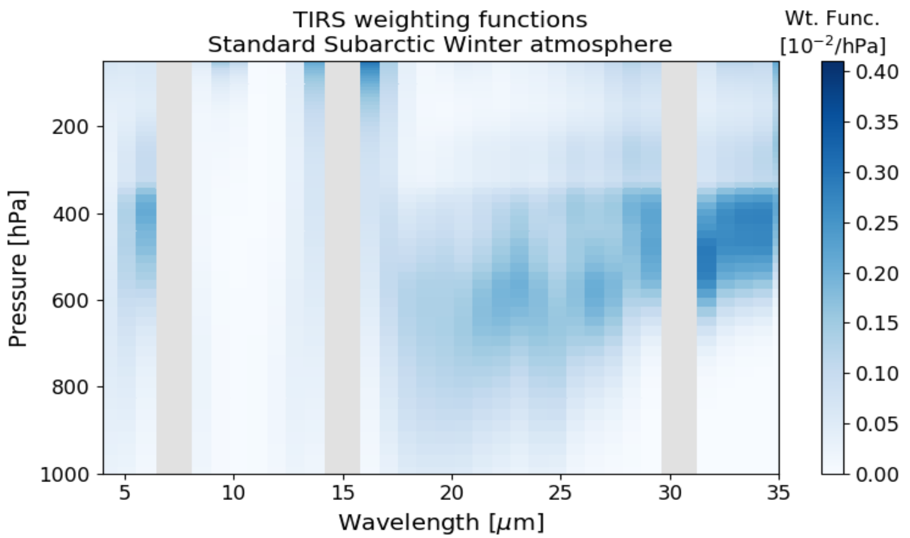
Climate Models



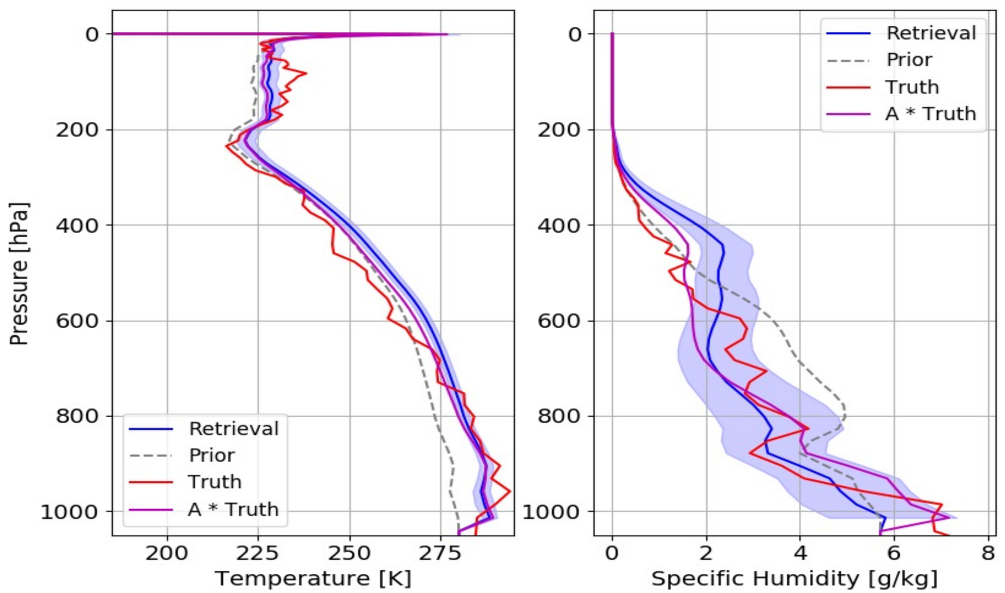
PREFIRE measurements improve Arctic climate predictions by anchoring spectral far infrared emission and atmospheric greenhouse effect.

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

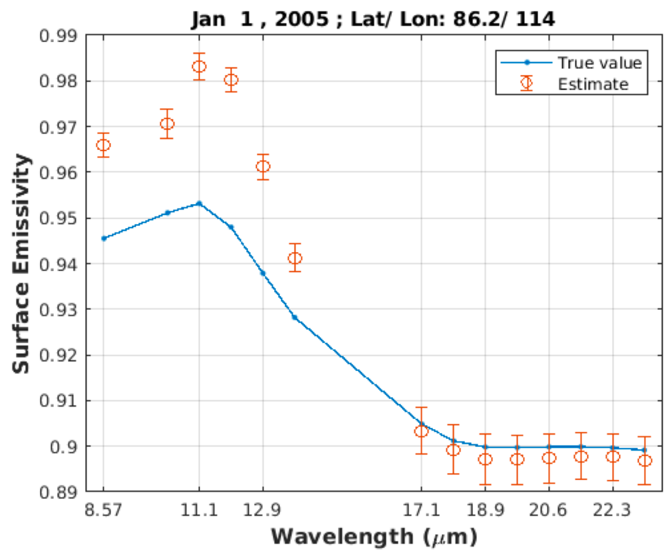


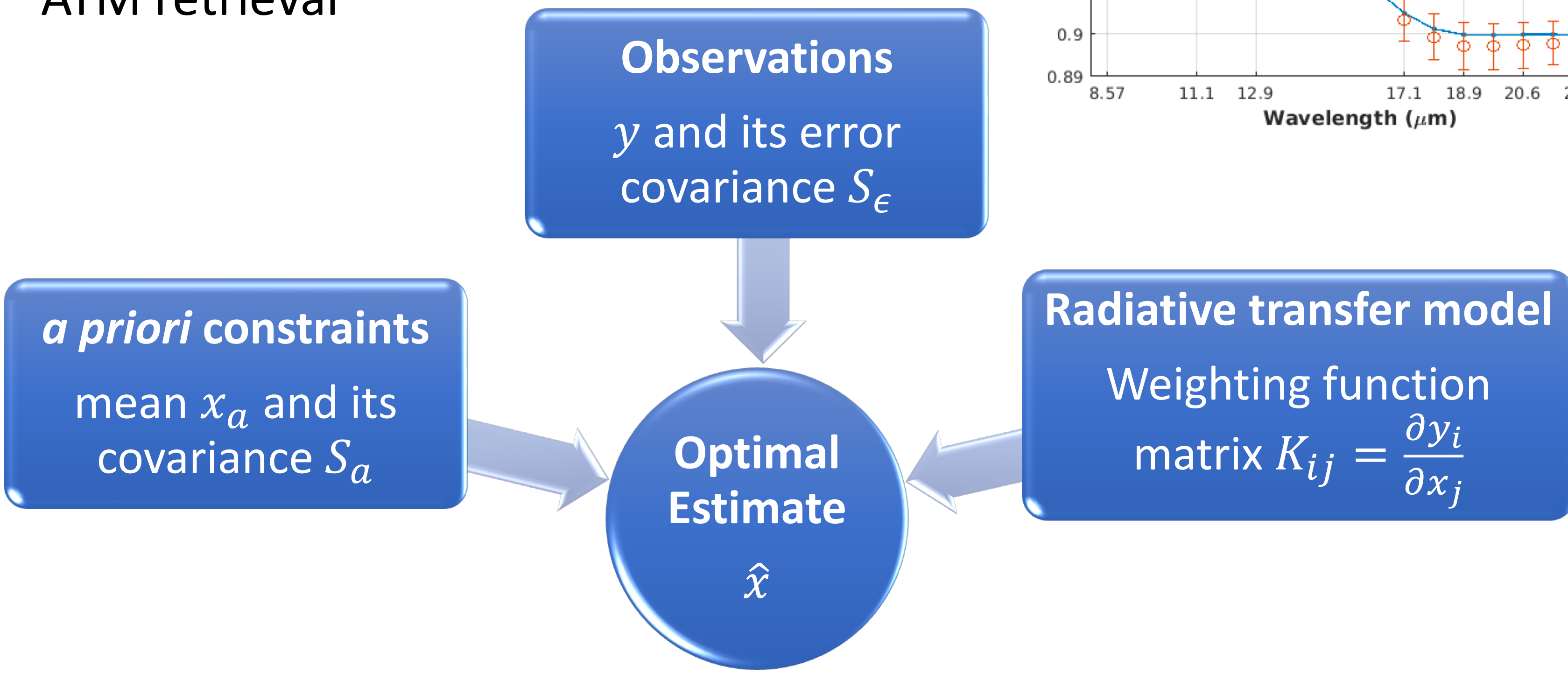
Sample Retrieval of Perturbed ERA5 Profile



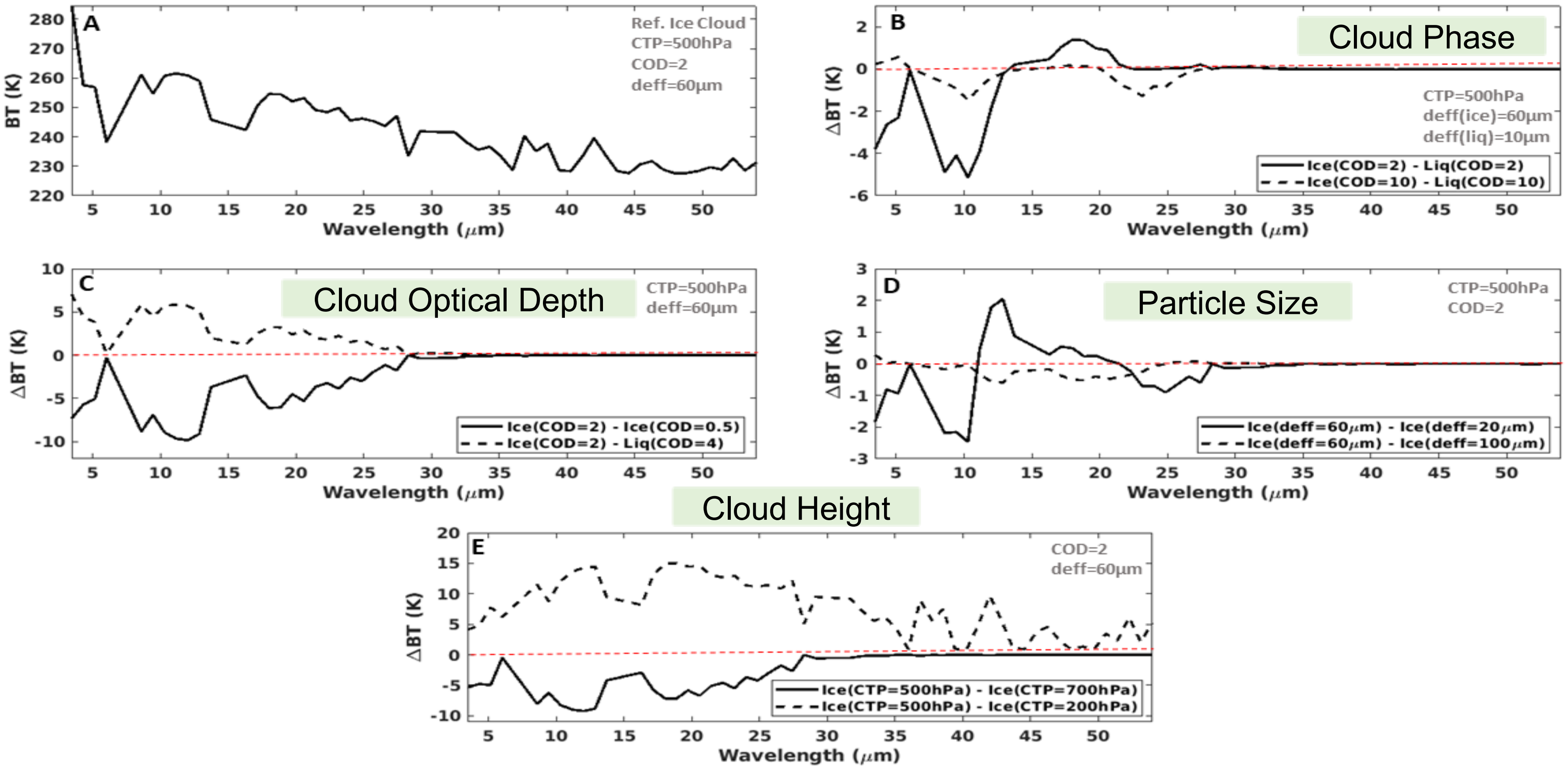
Clear Scenes: Spectral Surface Emissivity (SFC)

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



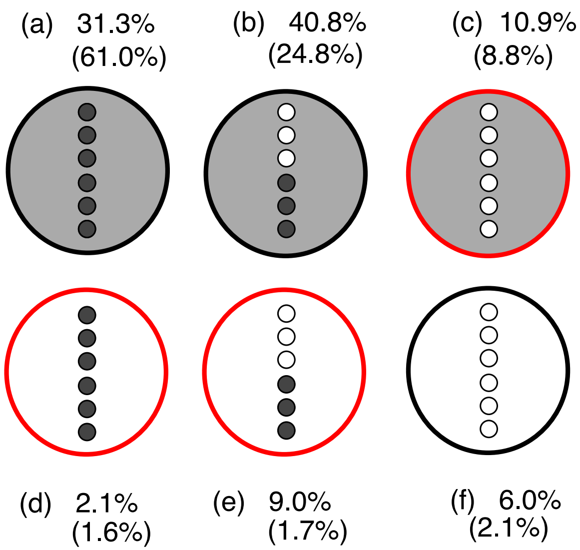


Cloudy Scenes: Cloud Property Retrievals



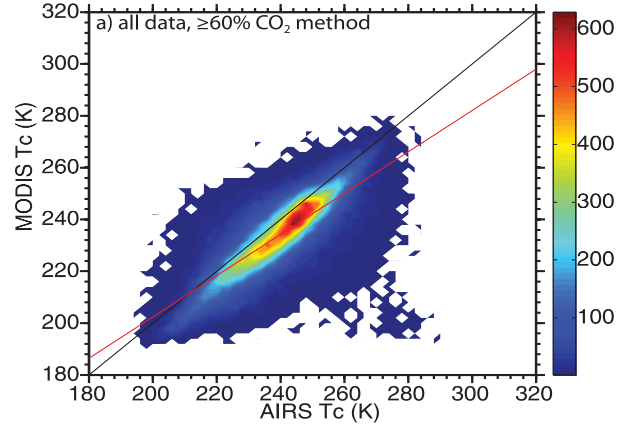
In cloudy scenes, TIRS radiances carry the spectral signatures of cloud phase and ice particle size

Level-2 Validation Strategy and Examples



- PREFIRE level-2 products will be compared against satellite and ground-based active observations
- Aggregated statistics computed from pixel-scale matches
- Heritage in AIRS, CloudSat/CALIPSO, ARM comparisons: (Kahn et al., JGR, 2007 and Kahn et al., 2008, ACP)

Cloud Top Temperature

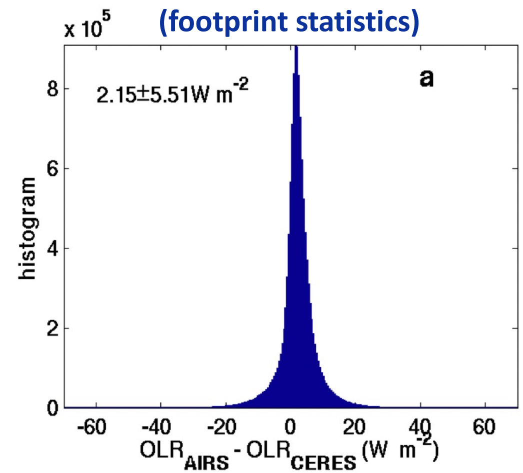


Validation of L2 Cloud Products

Compare cloud fraction and cloud top temperature with JPSS VIRSS/CrIS SNOs

Broadband Fluxes

AIRS vs. CERES Cloudy-sky OLR (footprint statistics)



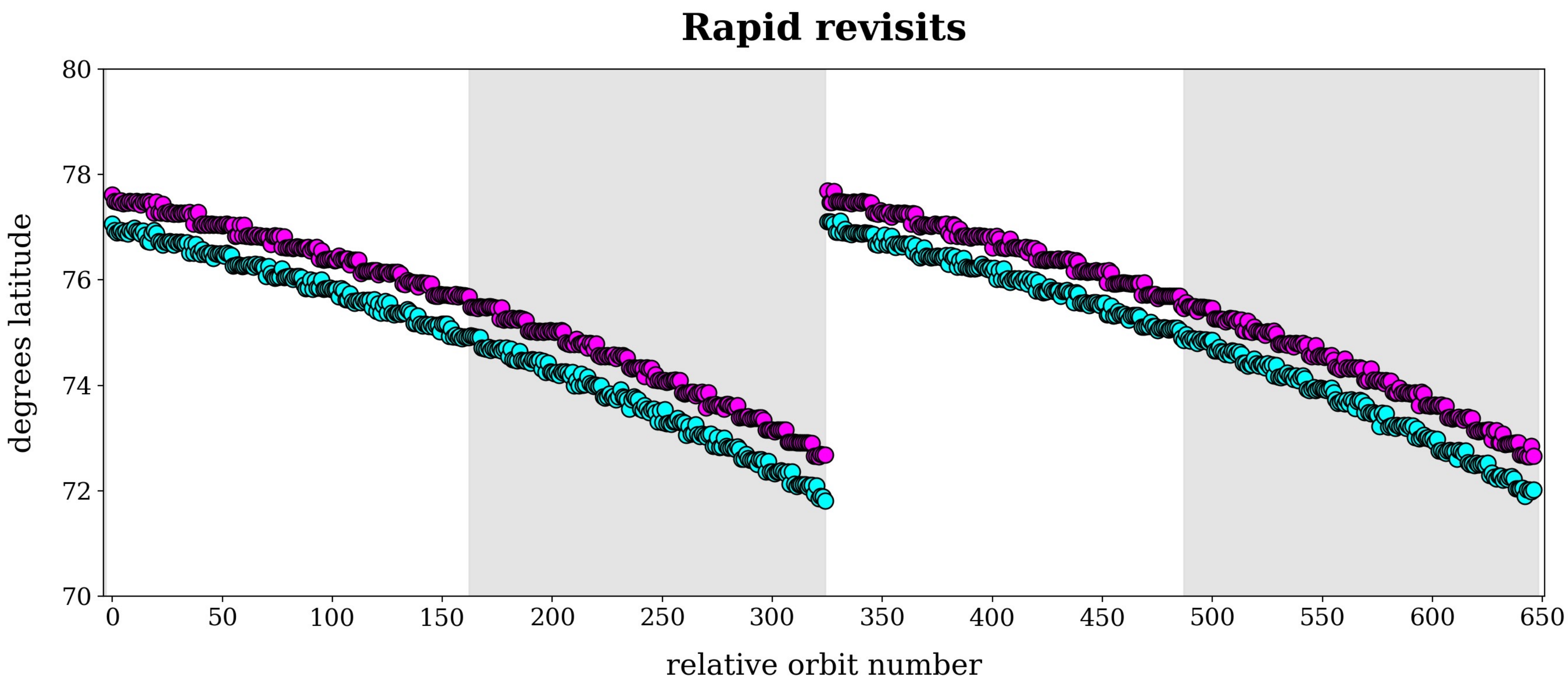
(Huang et al., 2008; 2010)

Validation of L2 Spectral Fluxes

Compare broadband OLR with CERES OLR for all PREFIRE and JPSS-1 and Aqua SNOs

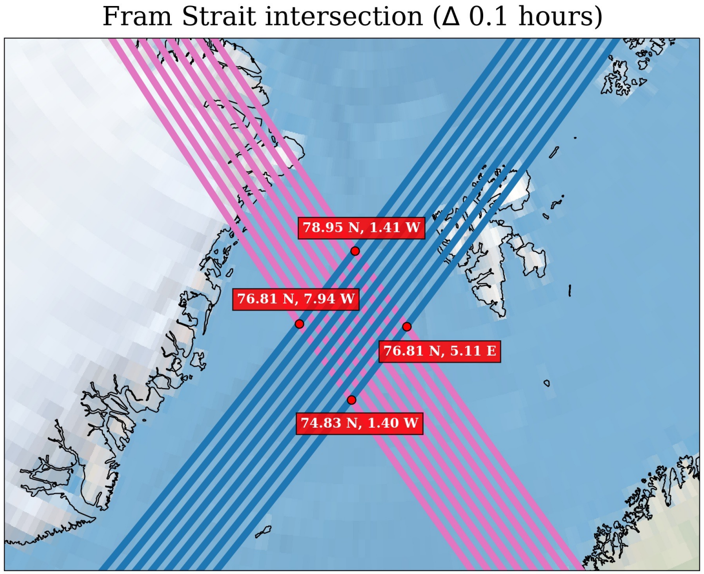
Simultaneous overpasses (frequent over the poles) provide a wealth of information for verifying PREFIRE level-2 data products.

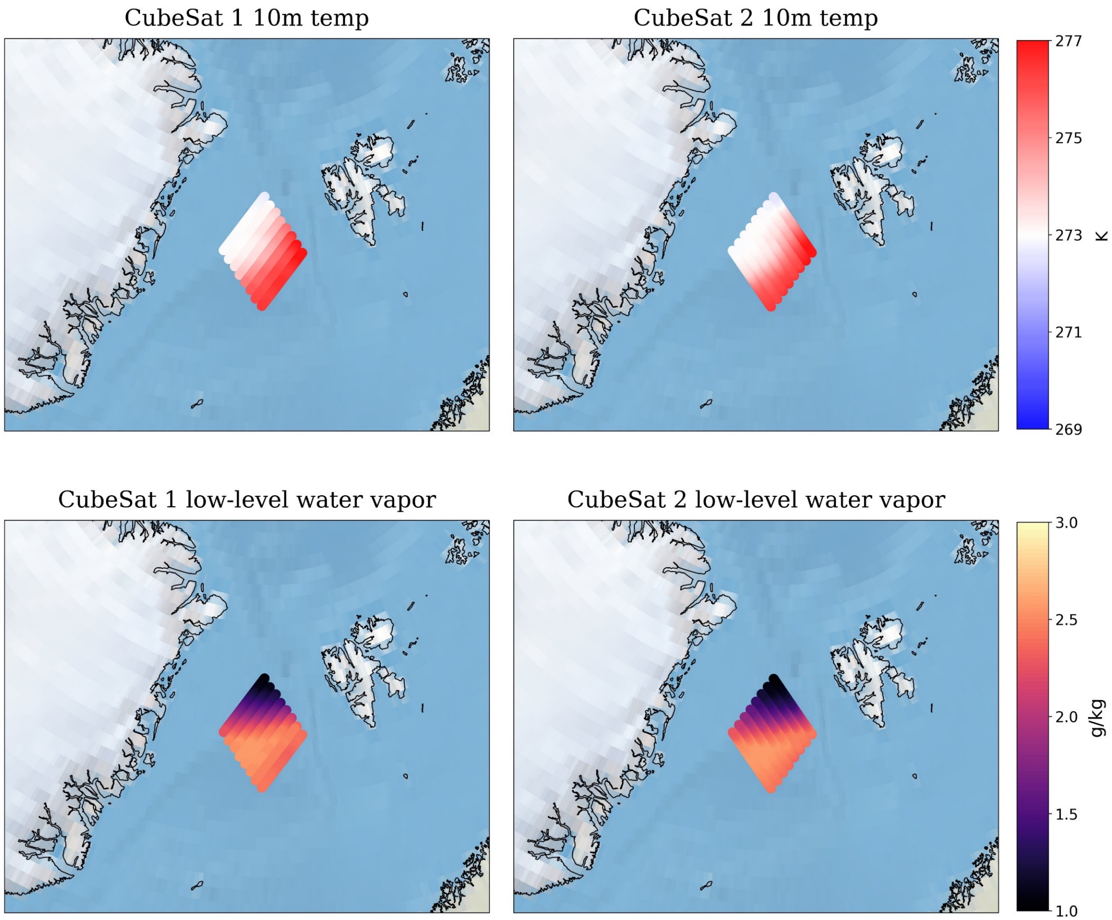
Arctic Rapid Revisits for Inter-Calibration



Calibration Intersections

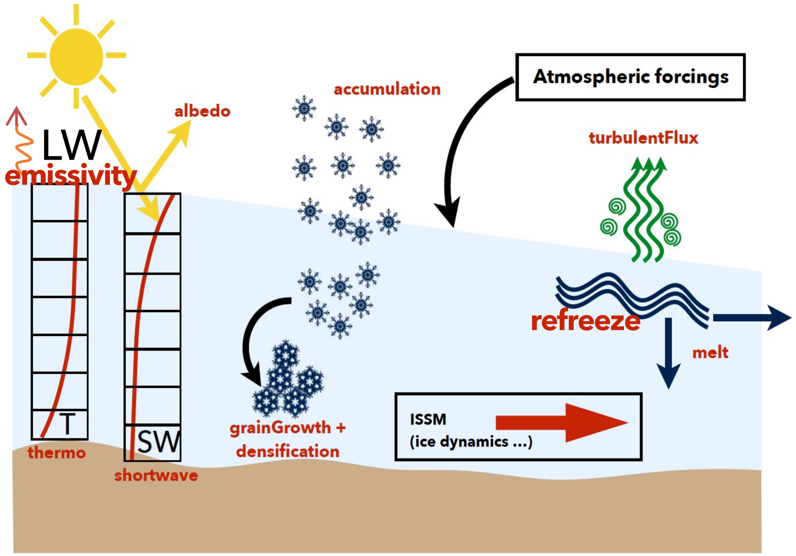
Revisit Time: 6 minutes!

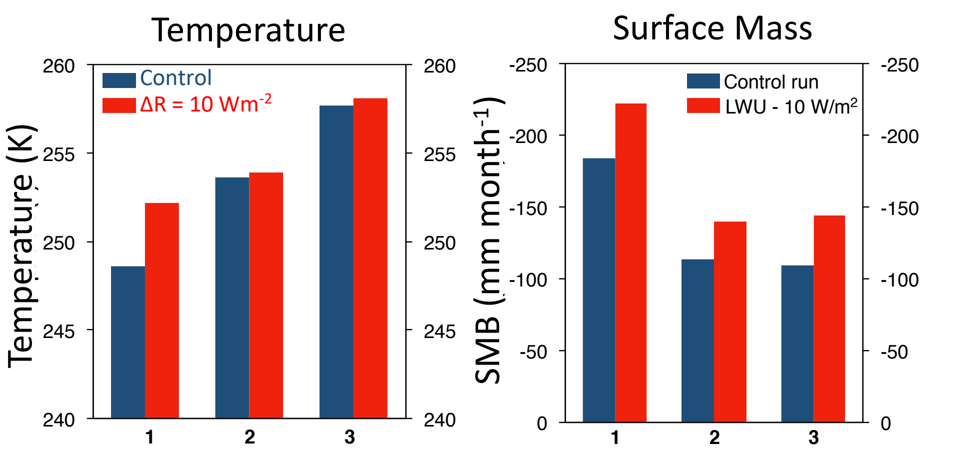


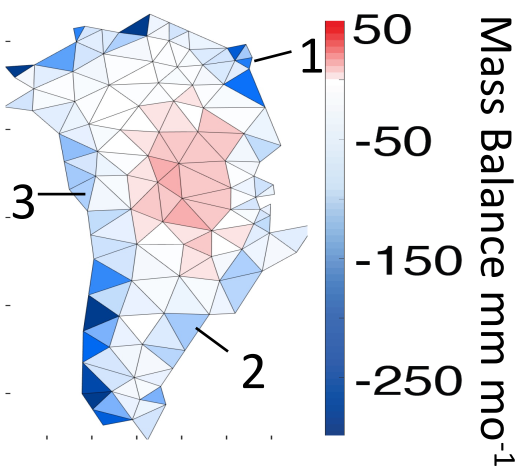


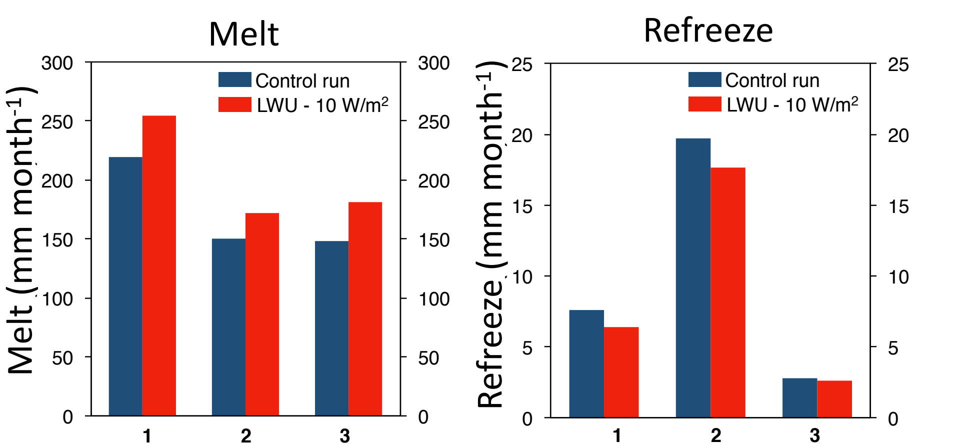
The subset of "rapid revisits" (intersections with very short time-differences) will be used to intercalibrate the two CubeSats. These occur around 77° and ARCSIX could provide valuable independent ground truth in such scenarios.

Implications for Ice Sheet Processes





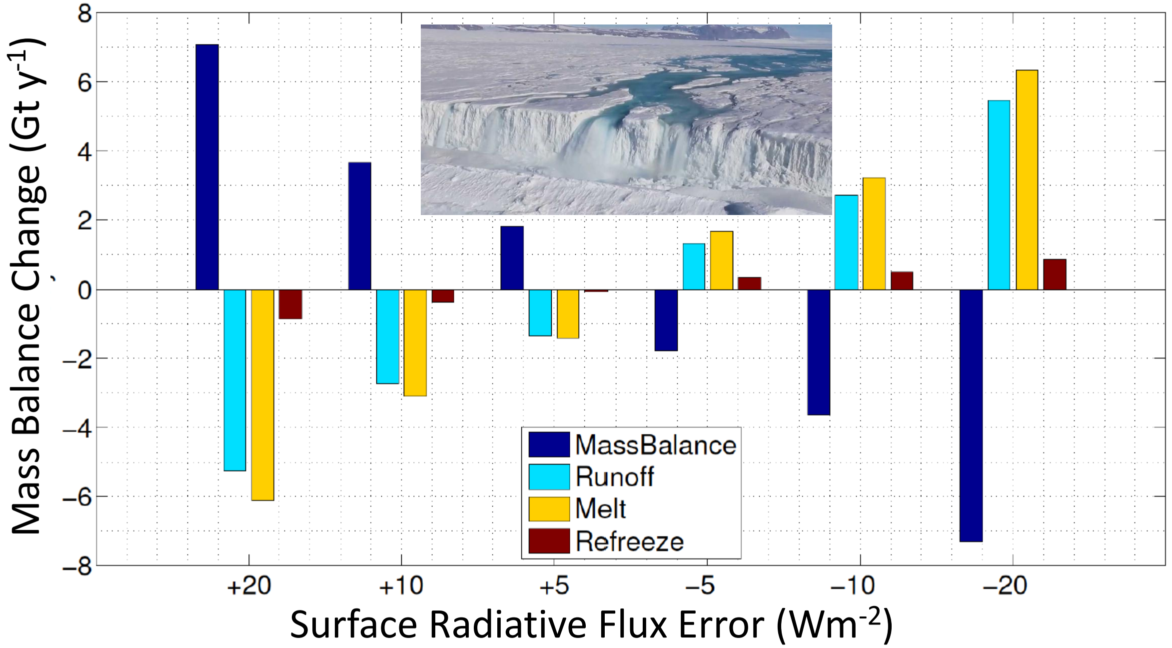




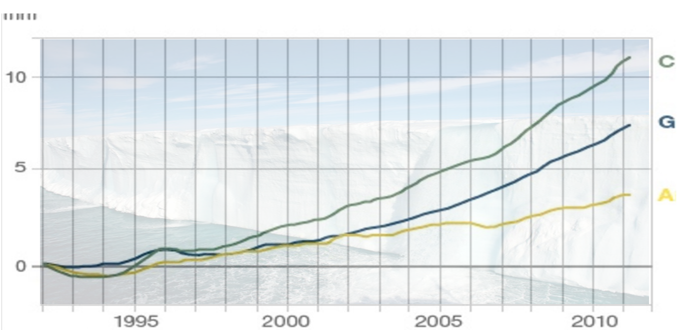
Schlegel and L'Ecuyer, in preparation

Implications for Global Sea Level

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



Global Sea Level Rise



Source: NASA/ESA/Planetary visions

Thermal InfraRed Spectrometer (TIRS)

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