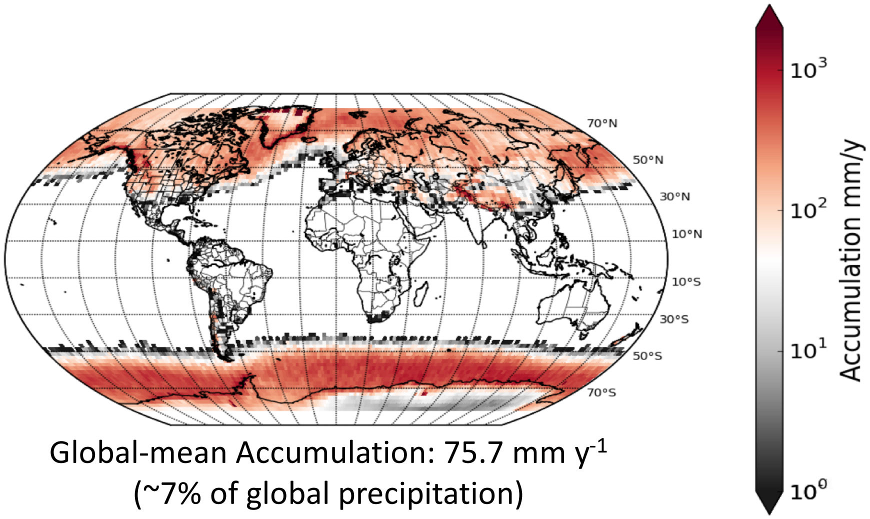
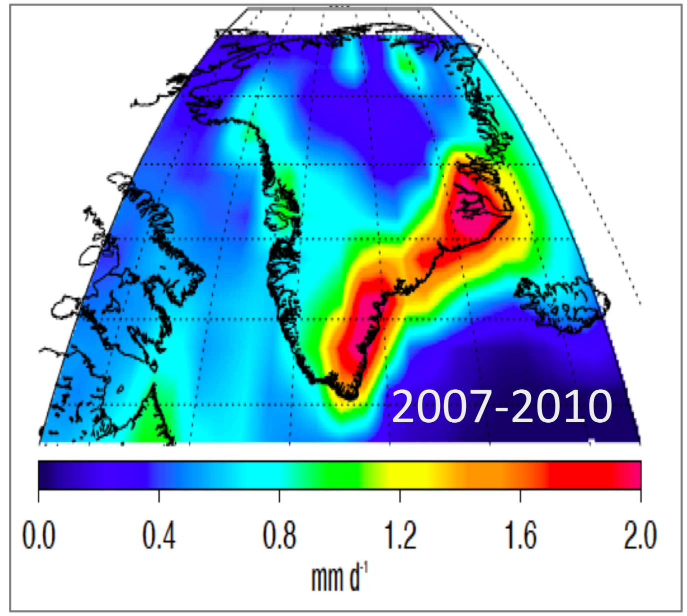
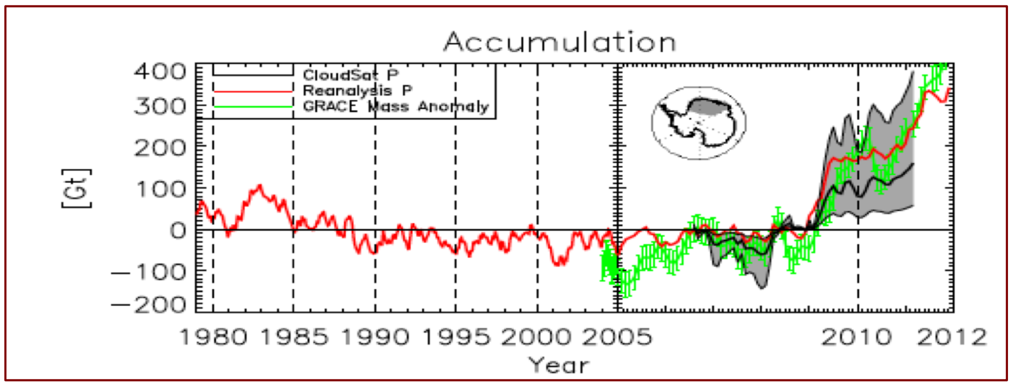
CloudSat Polar Precipitation Observations (2006-present)



Global-mean Accumulation: 75.7 mm y^{-1}
(~7% of global precipitation)

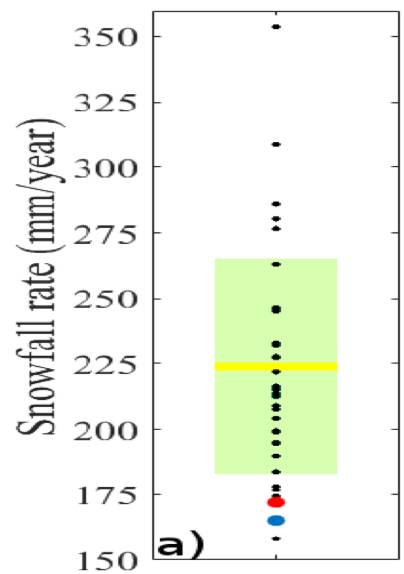


Annual mean accumulation on the GrIS: 650 Gt y^{-1}



Boening et al, *Geophys. Res. Letters*, (2012): Trends in independent estimates of Antarctic snowfall accumulation from CloudSat, GRACE, and ERA-interim reanalysis in excellent agreement.

ANTARCTIC SNOWFALL



CloudSat = 172 mm y^{-1}
ERA-interim = 167 mm y^{-1}
CMIP5 Mean = 215 mm y^{-1}
CMIP5 Max = 285 mm y^{-1}

Palerme et al, *Climate Dynamics*, (2017): Climate models over-estimate Antarctic precipitation; models that better reproduce CloudSat observations predict larger increases in RCP scenarios.

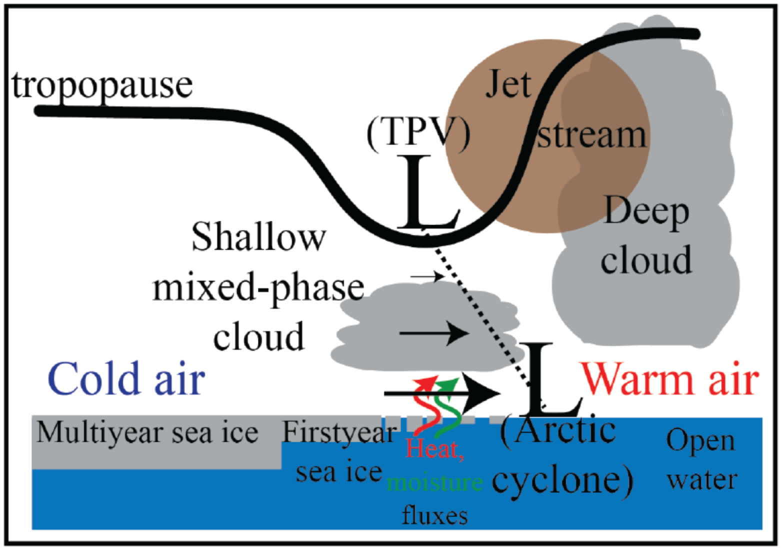
PREFIRE: An Upcoming Satellite Mission to Improve Arctic Surface Energy and Mass Budgets

Science Team: Brian Kahn
Jen Kay
Xianglei Huang
Aronne Merelli
Nicole-Jeanne Schlegel

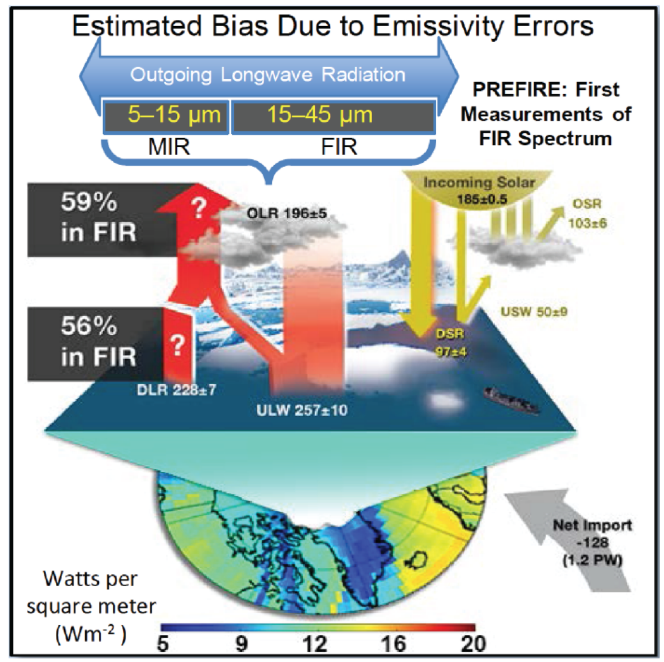
WISCONSIN UNIVERSITY OF WISCONSIN–MADISON
PI: Tristan L'Ecuyer
Deputy PI: Brian Drouin
Jet Propulsion Laboratory California Institute of Technology

Observations to Improve Knowledge of Arctic Processes

New *aircraft* observations aimed to improve atmospheric and sea ice dynamics



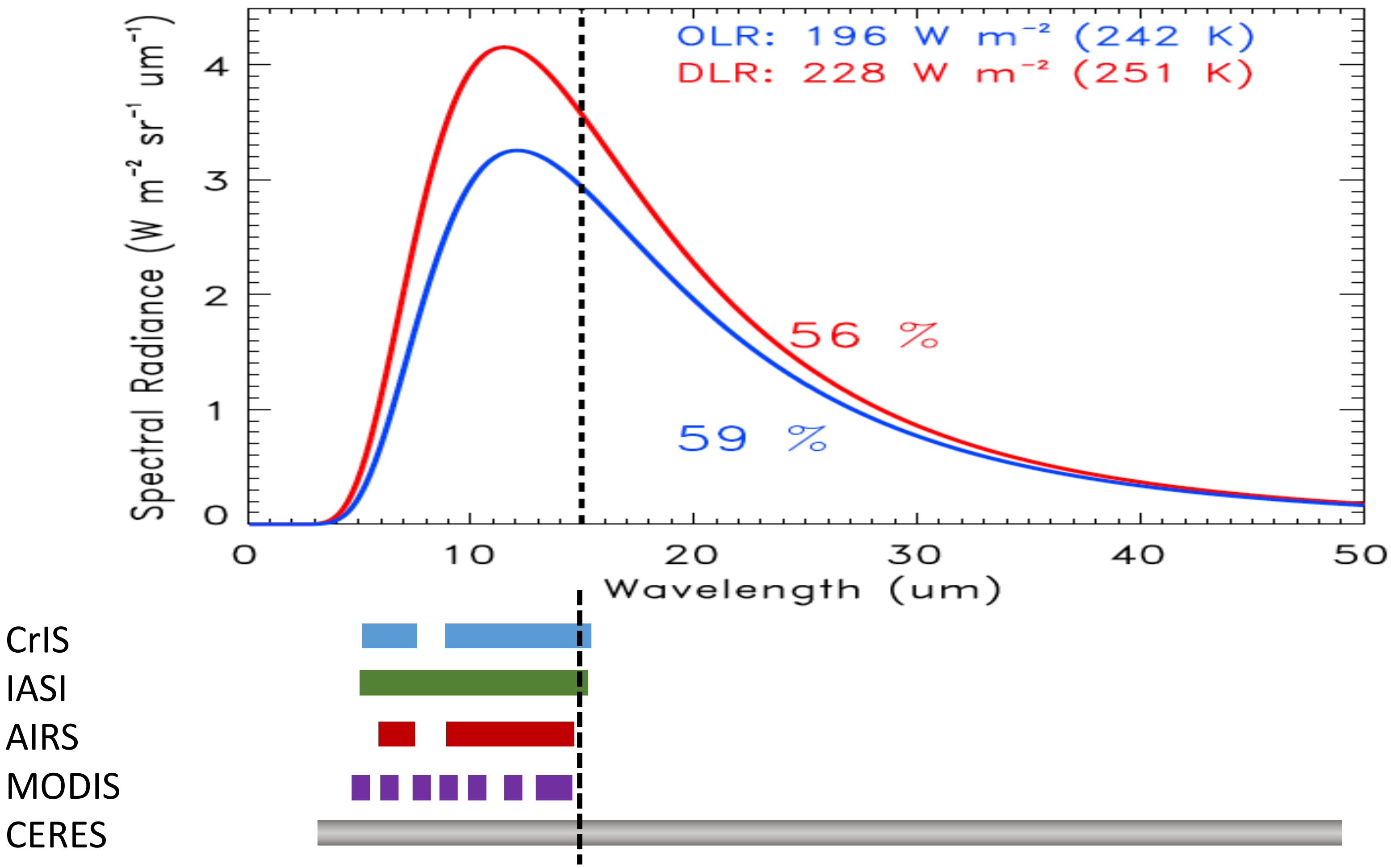
New *satellite* observations aimed to improve surface radiation budget



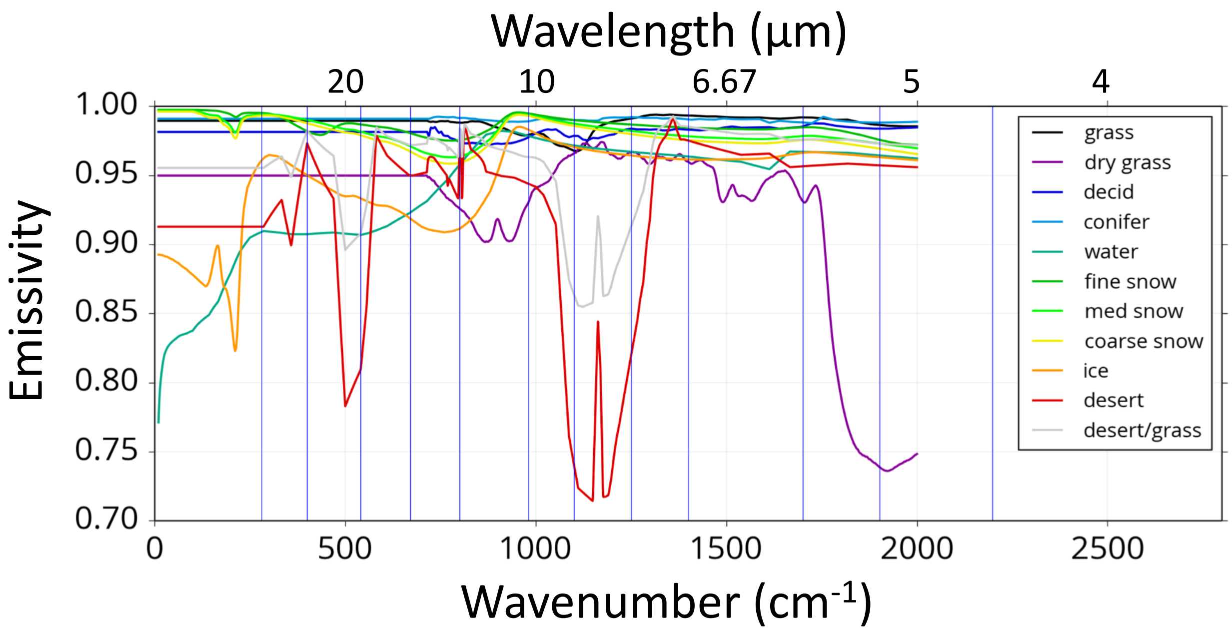
- TPVs ⟷ Arctic cyclones ⟷ Sea ice (THINICE; Cavallo)
- Surface thermal radiation ⟷ Sea ice/ice sheets ⟷ Water vapor/clouds (PREFIRE; L'Ecuyer)

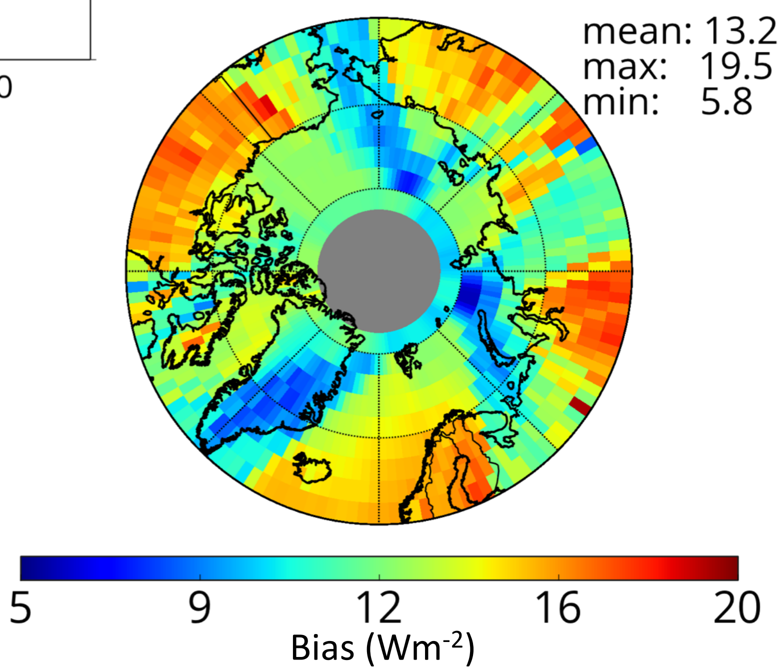
The Far-Infrared Observing Gap

Arctic Emission



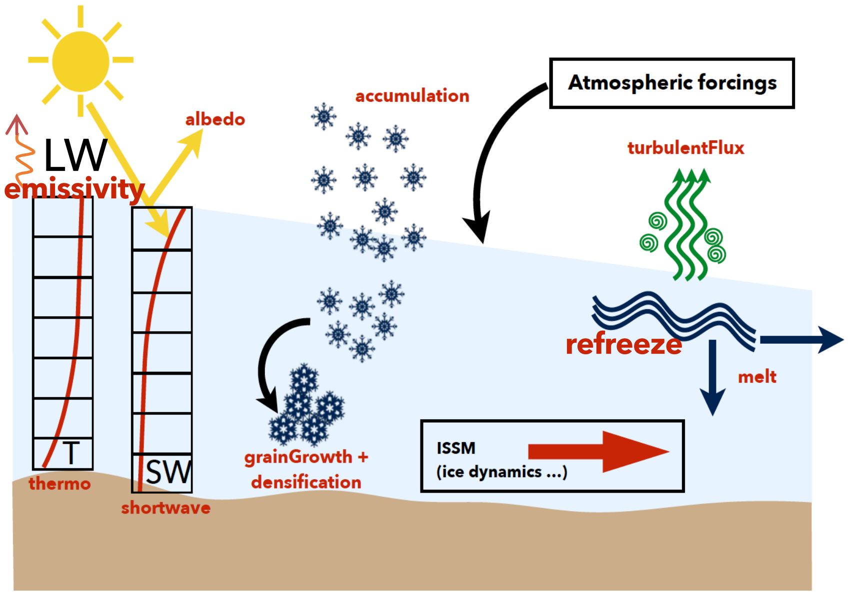
The Impact of Incomplete Knowledge

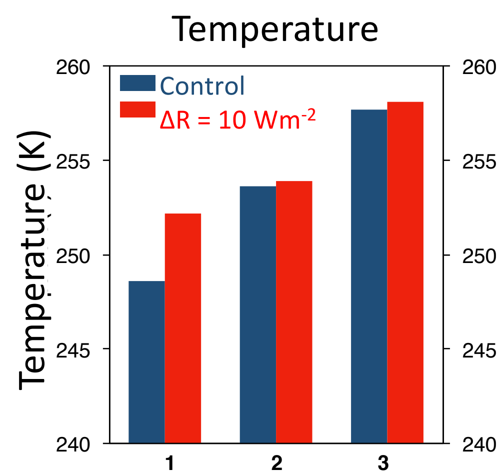


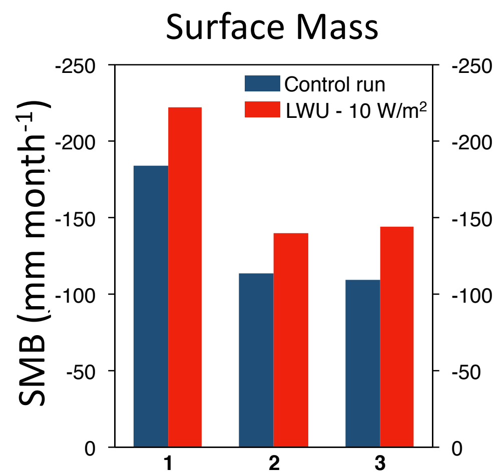


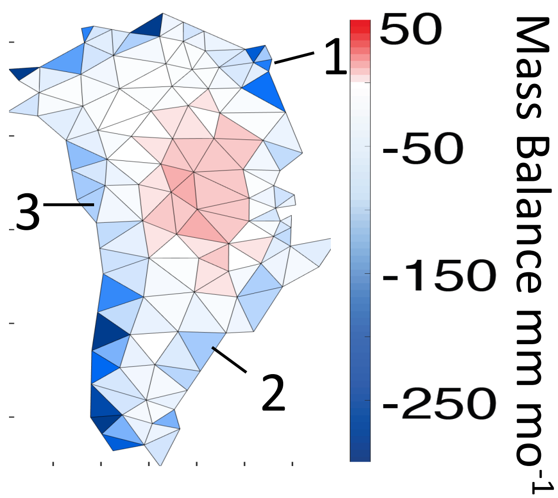
- ❑ Atmospheric greenhouse effect
- ❑ Low water vapor amounts
- ❑ Thin clouds

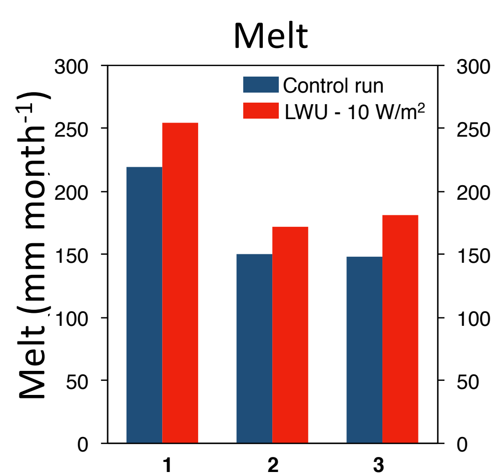
Influence on Ice Sheet Processes

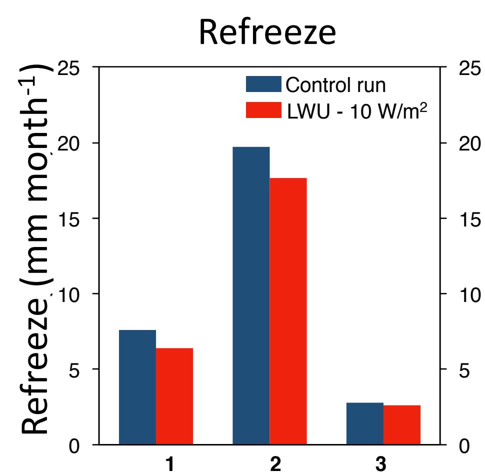






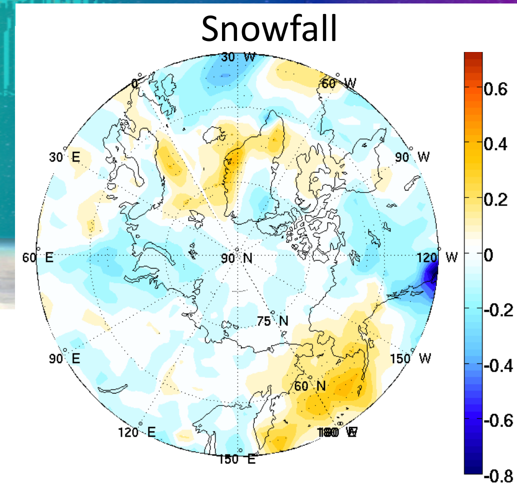




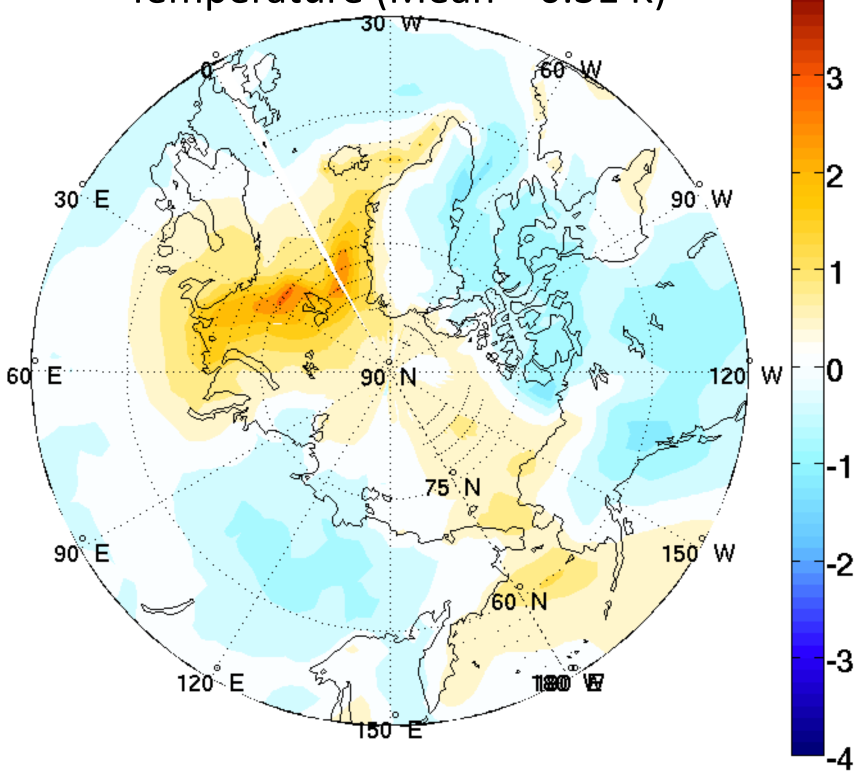


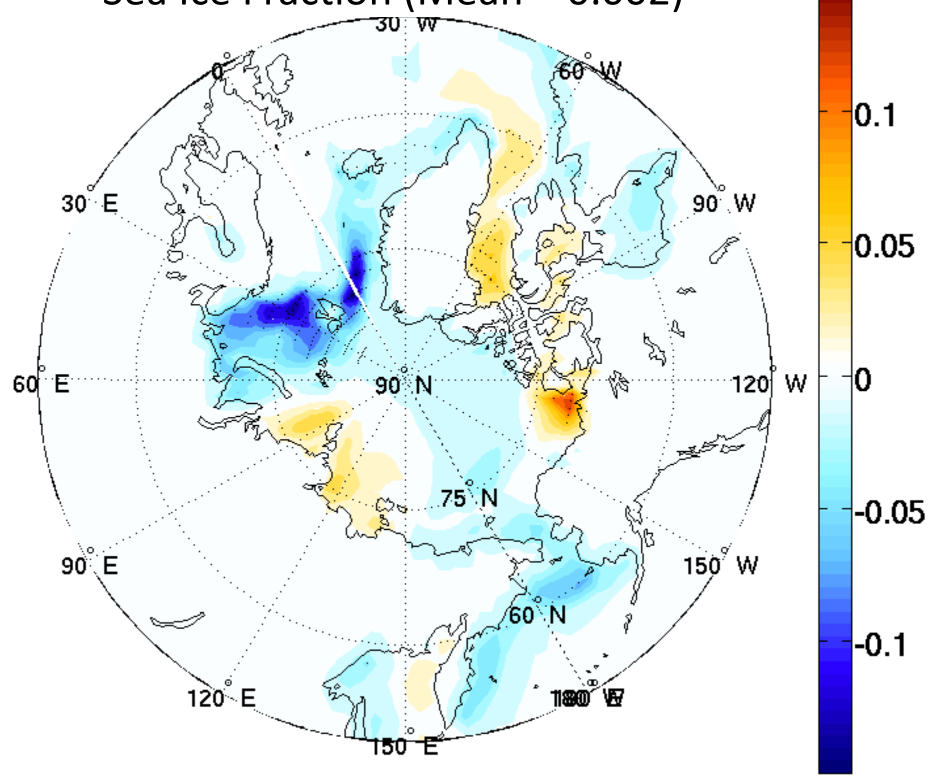
Courtesy: N.-J. Schlegel

Larger-Scale Influences



Impacts of Realistic Surface Emissivity in CAM5





Courtesy: Xianglei Huang

Polar Radiant Energy in the Far InfraRed Experiment (PREFIRE)

Revealing fluctuations in Earth's thermostat by capturing the full spectrum of Arctic radiant energy

Principal Investigator: Tristan L'Ecuyer, UW-Madison

Project Scientist: Brian Drouin, JPL/CalTech

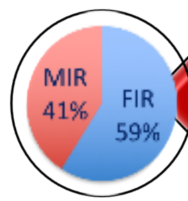
PREFIRE Hypotheses

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.

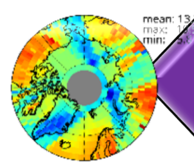
PREFIRE will document, for the first time, variability in spectral fluxes from 5-45 μm on hourly to seasonal timescales.

Two 3U CubeSats in distinct 470–650 km altitude, near-polar (82°-98° inclination) orbitseach carrying a miniaturized IR spectrometer, covering 0-45 μm at 0.84 μm spectral resolution, operating for one seasonal cycle (a year).

The Arctic is Earth's thermostat. It regulates the climate by venting excess energy received in the tropics.



Nearly 60% of Arctic emission occurs at wavelengths > 15 μm (FIR) that have never been systematically measured.



PREFIRE improves Arctic climate predictions by anchoring spectral FIR emission and atmospheric GHE

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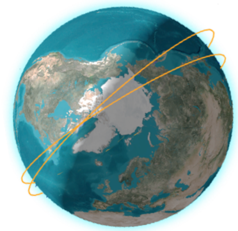
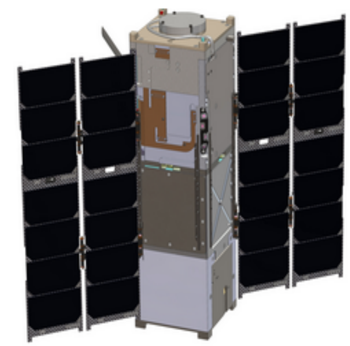
Why Are PREFIRE Measurements Now Possible?

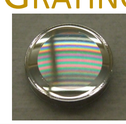
- Two 3-U CubeSats in asynchronous polar orbits
  - Power subsystem, attitude control, command and data handling, high data rate telecommunications
  - Solar panels configured to minimize thermal variations

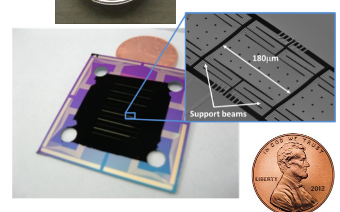




- Thermal IR Spectrometer (TIRS)
  - Ambient temperature FIR spectral imager
  - Thermopile focal plane
  - Offner architecture: 0.97 kg and fits within 1U
  - Shaped groove grating (Silicon with gold plating)

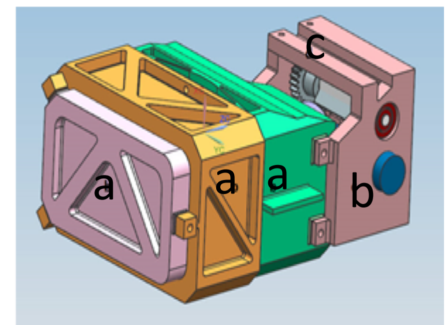
GRATING





THERMOPILE

Thermal Infrared Spectrometer



a - Optical bench assembly
b - Calibration motor assembly
c - Calibration target

Thermopile array	Spectral resolution	Spatial coverage	Mass	Data rate	Power peak/avg
64 × 16 pixels	0.84 µm from 0–45 µm	16 cross-track pixels with 1.2° footprints	0.97 kg	35 kbps	6.74 / 1.74 W

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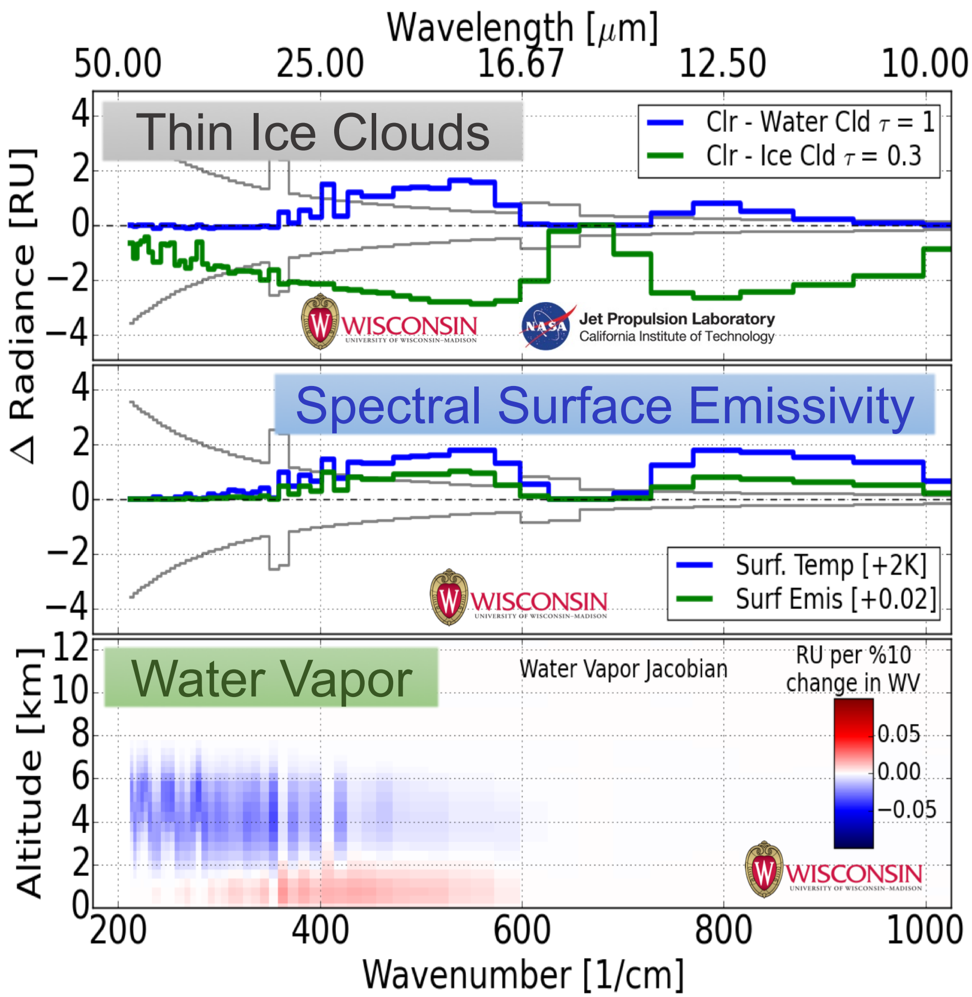
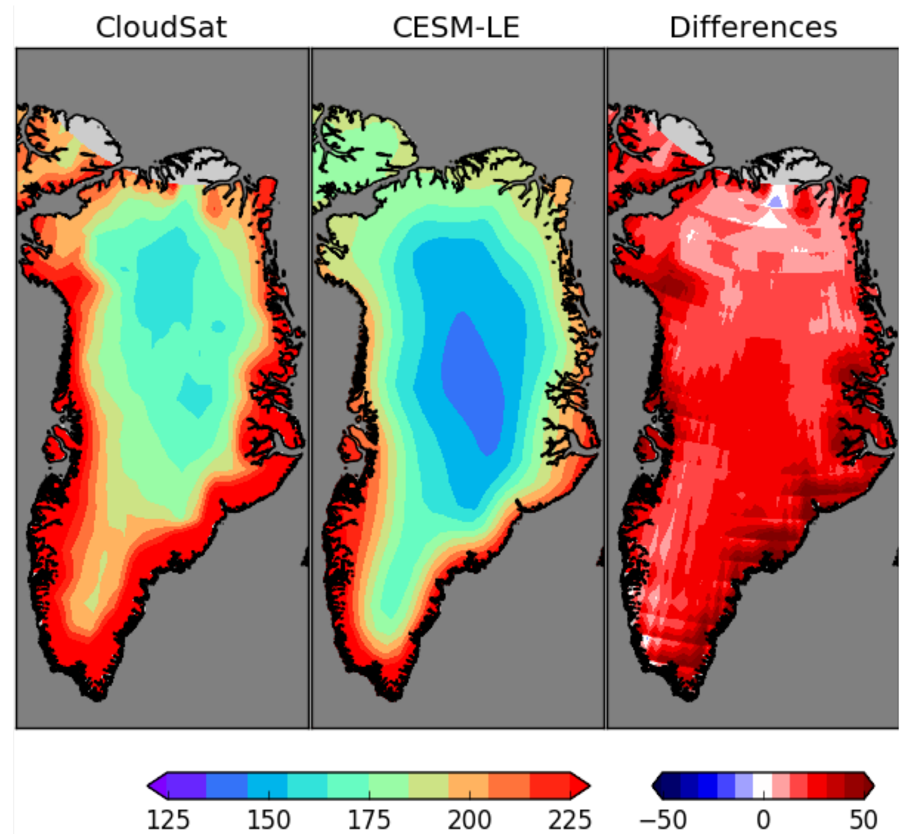
Data Products



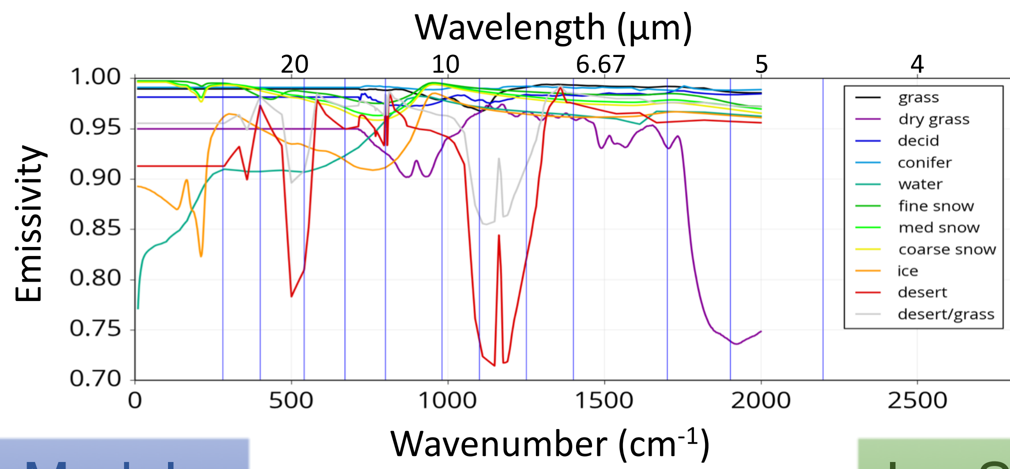
Broadband LW Fluxes

Thermal Energy Flux to the Surface

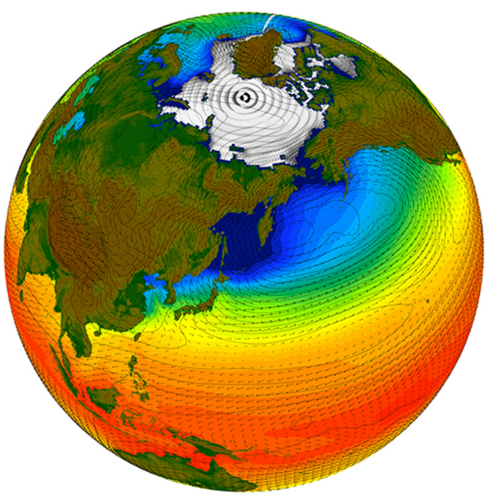


Interfacing with Models

Improved Emissivity Models

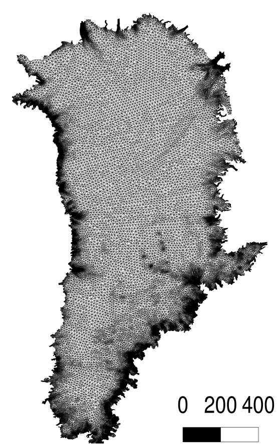


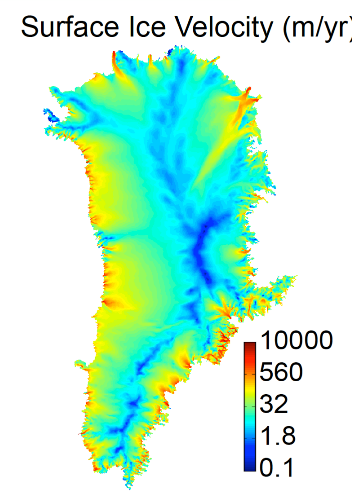
Climate Models



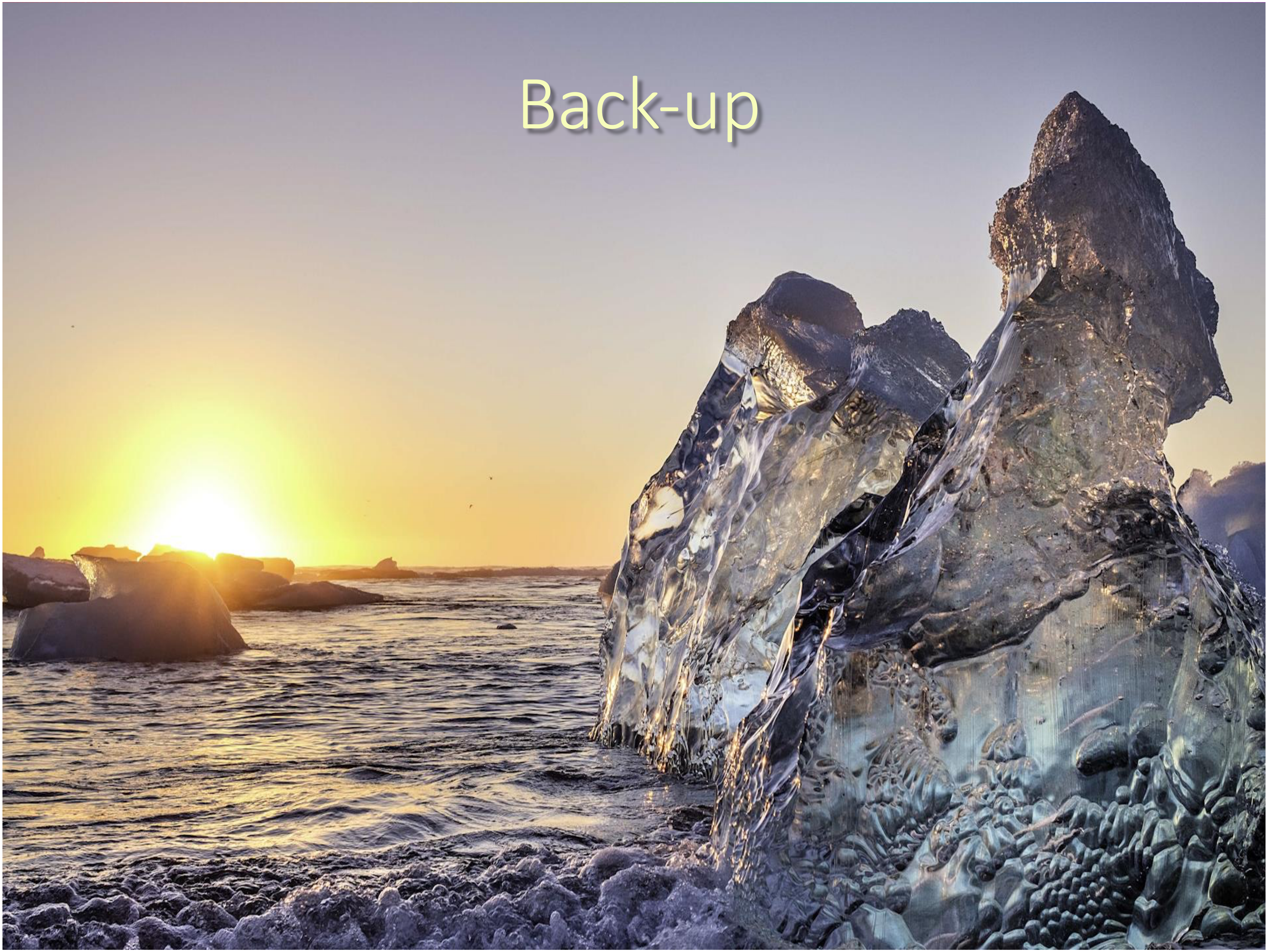
University of Colorado Boulder

Ice Sheet Models





Jet Propulsion Laboratory
California Institute of Technology


Back-up

NASA Science Themes	Science Objectives and Questions	Scientific Measurement Requirements: Observables	Scientific Measurement Requirements: Physical Parameters and Requirements	Instrument Functional Requirements	Projected Instrument Performance	Mission Functional Requirements
Climate Variability and Change	**Objective 1.1 (O1.1):** Quantify snow and ice FIR emissivity spectra and their variability on seasonal scales	Clear-sky spectral radiances across FIR for 2/3 of the CWV, surface T, and surface conditions poleward of 55°N over the complete annual cycle supplemented with spectral radiances in the colder, drier, and less variable interior Antarctic ice sheet	Ability to resolve clear-sky OLR + FIR monthly flux variability: 3% or 8 Wm^{-2} in total OLR (4 Wm^{-2} in FIR) Water continuum and surface emissivity sensitivity >15 µm with spectral resolution to discriminate emission features of snow, ice, and open ocean surfaces Broad coverage of thermal emission with spatial resolution to distinguish cloudy and clear scenes	Spectral Range/Res: 5-45 µm (Table D-3) Spectral Resolution: $\Delta\lambda$ ~ 1 µm (Fig D-6) IFOV: ~ 15 km (Table D-3) 2M samples per day for 6 months (Fig D-5) Radiometric accur. < 3% NEDT >15 µm: ~1.5K 5-15 µm: ~1.5K (Fig D-6) Stable spectro-radio-metric accuracy for at least 6 months in orbit	Spectral Range: 0-54 µm Spectral Resolution: $\Delta\lambda$ = 0.84 µm IFOV: 1.2˚ (14 km GSD) Radiometric accur.1% NEDT 15-54 µm: 1K 0-54 µm: 1K < 0.5%/year absolute calibration drift	**Threshold Mission** One 3U CubeSat with FIR imaging spectrometer Inclination at least 82-98˚ 6 months of operation Altitude 470-650 km Nadir sampling 55-85˚N and 70-90˚S Pixel Size: 1.3˚ [15 km @ 650 km orbit] Pointing knowledge < 0.1˚ Jitter: < 0.1˚/sec Accuracy: 5˚ Swath 16 pixels (224 km)
	O1.2: Quantify the FIR GHE and its response to seasonal variations in cloud cover and water vapor	2/3 of CWV, surface T, and surface conditions poleward of 55°N	Ability to resolve all-sky OLR + FIR monthly flux variability: 5% or 13 Wm^{-2} in total OLR (6 Wm^{-2} in FIR)			
Energy and Water Cycle	**O1.3:** Quantify variability in Arctic spectral surface emission and the atmospheric GHE across the FIR owing to transient cloud and water vapor and sub-daily melt processes	Time-differenced spectra on time-scales representative of changes in surface characteristics during melt / freeze cycles and cloud cover (Δt from 1-9 hours) Sampling over one complete annual freeze/melt cycle	Sampling by two satellites at a range of observation time intervals	Both satellites with stable spectro-radio-metric accuracy for at least 1 year in orbit	< 0.5%/year absolute calibration drift on each CubeSat	**Baseline Mission** Two 3U CubeSats with FIR imaging spectrometers in uncoordinated orbits, each operating for one year
Climate Variability and Change	**O2.1** Quantify the influence of thermal emission biases on projected rates of Arctic warming and sea ice loss	Spectral surface emissivity from 5-45 µm for 2/3 of the CWV, surface T, and surface conditions poleward of 55°N All-sky and clear-sky spectral fluxes at TOA	Computed spectral fluxes from observed spectral radiances subject to integral broadband constraint Spectral and broadband OLR over a wide range of geophysical variables defined by typical seasonal cycle	Spectral Range: 0-45 µm Spectral Resolution: $\Delta\lambda$ ~ 1 µm Radiometric accur. <3% NEDT >15 µm: ~1.5K 0-15 µm: ~1.5K	Spectral Range: 0-54 µm Spectral Resolution: $\Delta\lambda$ = 0.84 µm IFOV: 1.2˚ (14 km GSD) Radiometric accur. 1% NEDT 15-54 µm: 1K 0-54 µm: 1K	**Threshold Mission**
Energy and Water Cycle	**O2.2:** Determine the impact of improved surface emissivity on modeled ice sheet dynamic processes on hourly scales	Time-differenced surface emissivity spectra from 5-45 µm associated with sub-daily freeze/melt events	Spectral and broadband OLR differences over a range of observation time intervals from 1-9 hours			**Baseline Mission**

The PREFIRE Team

Who is doing the work and how?

PREFIRE utilizes university partnerships for data analysis, spacecraft, and ground systems along with advances in planetary detector technology, SDL flight-proven spacecraft, and JPL instrumentation.

SCIENCE TEAM		
Tristan L'Ecuyer	Principal Investigator, University of Wisconsin, Madison	Internationally recognized in satellite based climate science; responsible for mission success
Brian Drouin	Deputy Principal Investigator / Project Scientist, JPL	Experienced spectrometer builder, algorithm data provider
Aronne Merelli	SSEC/UW, Madison	Cloud/Water vapor retrievals
Jennifer Kay	University of Colorado	Global modeling
Xianglei Huang	University of Michigan	Surface spectral emissivity; radiance to broadband conversion
Brian Kahn	Jet Propulsion Laboratory	Cloud/Water vapor retrievals
Nicole-Jeanne Schlegel	Jet Propulsion Laboratory	Ice sheet modeling

TECHNICAL TEAM	
Jet Propulsion Laboratory (JPL)	Decades of experience in space-project management and instrument development
University of Wisconsin, Madison (UW)	Experience with Data Center and Data Processing and Ground Operations
Space Science and Engineering Center (SSEC) at UW	Earth Climate data processing center
Space Dynamics Laboratory (SDL) (Utah State University)	Small satellite builder and missions operations; one of the nodes on the MC3 network