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\(^{-1}\)

ANTARCTIC SNOWFALL


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

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

PI: Tristan L’Ecuyer
Deputy PI: Brian Drouin
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 Impact of Incomplete Knowledge

- Atmospheric greenhouse effect
- Low water vapor amounts
- Thin clouds
Influence on Ice Sheet Processes

Temperature

Surface Mass

Melt

Refreeze

Courtesy: N.-J. Schlegel
Larger-Scale Influences

Impacts of Realistic Surface Emissivity in CAM5

Temperature (Mean = 0.31 K)

Sea Ice Fraction (Mean = 0.002)

Courtesy: Xianglei Huang
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) orbit-seach 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.
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)

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

Broadband LW Fluxes

Thermal Energy Flux to the Surface

CloudSat
CESM-LE
Differences

Thin Ice Clouds

[Spectral Surface Emissivity

Water Vapor

Wavelength [Å]

50.00 25.00 16.57 12.50 10.00

Δ Radiance [RU]

0 2

0 2

0 2

0 2

0 2

0 2

200 400 600 800 1000

Wavenumber [1/cm]

2 4 6 8 10 12

Altitude [km]

Water Vapor Jacobian

RU per %10 change in WV

0.05

0.00

-0.05

125 150 175 200 225

-50 0 50

125 150 175 200 225

-50 0 50

125 150 175 200 225

-50 0 50

125 150 175 200 225

-50 0 50

125 150 175 200 225

-50 0 50
Interfacing with Models

Improved Emissivity Models

Climate Models

Ice Sheet Models

Surface Ice Velocity (m/yr)
Back-up
# Science Traceability Matrix

<table>
<thead>
<tr>
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<tbody>
<tr>
<td><strong>Climate Variability and Change</strong></td>
<td><strong>Objective 1.1 (O1.1): Quantify snow and ice FIR emissivity spectra and their variability on seasonal scales</strong></td>
<td>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</td>
<td>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 &gt;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</td>
<td>Spectral Range/Res: 5-45 μm (Table D-3) Spectral Resolution: Δλ ~ 1 μm (Fig D-6) IFOV: ~ 15 km (Table D-3) 2M samples per day for 6 months (Fig D-5) Radiometric accur. &lt; 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</td>
<td>Spectral Range: 0-54 μm Spectral Resolution: Δλ = 0.84 μm IFOV: 1.2” (14 km GSD) Radiometric accur. 1% NEDT 15-54 μm: 1K 0-54 μm: 1K &lt; 0.5%/year absolute calibration drift</td>
<td><strong>Threshold Mission</strong> One 3U CubeSat with FIR imaging spectrometer Inclination at least 82-98° 6 months of operation Altitude 470-550 km Nadir sampling 55-85°N and 70-90°S Pixel Size: 1.3” [15 km @ 650 km orbit] Pointing knowledge &lt; 0.1° Jitter: &lt; 0.1°/sec Accuracy: 5° Swath 16 pixels (224 km)</td>
</tr>
<tr>
<td></td>
<td><strong>Objective 1.2: Quantify the FIR GHE and its response to seasonal variations in cloud cover and water vapor</strong></td>
<td>2/3 of CWV, surface T, and surface conditions poleward of 55°N</td>
<td>Ability to resolve all-sky OLR + FIR monthly flux variability: 5% or 13 Wm⁻² in total OLR (6 Wm⁻² in FIR)</td>
<td></td>
<td></td>
<td><strong>Baseline Mission</strong> Two 3U CubeSats with FIR imaging spectrometers in uncoordinated orbits, each operating for one year</td>
</tr>
<tr>
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<td><strong>Objective 1.3: 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</strong></td>
<td>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</td>
<td>Sampling by two satellites at a range of observation time intervals</td>
<td>Both satellites with stable spectro-radio-metric accuracy for at least 1 year in orbit</td>
<td></td>
<td><strong>Baseline Mission</strong></td>
</tr>
<tr>
<td><strong>Energy and Water Cycle</strong></td>
<td><strong>Objective 2.1: Quantify the influence of thermal emission bias on projected rates of Arctic warming and sea ice loss</strong></td>
<td>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</td>
<td>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</td>
<td>Spectral Range: 0.45 μm Spectral Resolution: Δλ ~ 1 μm Radiometric accur. &lt; 3% NEDT &gt;15 μm: ~1.5K 0-15 μm: ~1.5K</td>
<td></td>
<td><strong>Threshold Mission</strong></td>
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<tr>
<td></td>
<td><strong>Objective 2.2: Determine the impact of improved surface emissivity on modeled ice sheet dynamic processes on hourly scales</strong></td>
<td>Time-differenced surface emissivity spectra from 5-45 μm associated with sub-daily freeze/melt events</td>
<td>Spectral and broadband OLR differences over a range of observation time intervals from 1-9 hours</td>
<td></td>
<td></td>
<td><strong>Baseline Mission</strong></td>
</tr>
</tbody>
</table>
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**

<table>
<thead>
<tr>
<th>Name</th>
<th>Affiliation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tristan L’Ecuyer</td>
<td>Principal Investigator, University of Wisconsin, Madison</td>
<td>Internationally recognized in satellite based climate science; responsible for mission success</td>
</tr>
<tr>
<td>Brian Drouin</td>
<td>Deputy Principal Investigator / Project Scientist, JPL</td>
<td>Experienced spectrometer builder, algorithm data provider</td>
</tr>
<tr>
<td>Aronne Merelli</td>
<td>SSEC/JW, Madison</td>
<td>Cloud/Water vapor retrievals</td>
</tr>
<tr>
<td>Jennifer Kay</td>
<td>University of Colorado</td>
<td>Global modeling</td>
</tr>
<tr>
<td>Xianglei Huang</td>
<td>University of Michigan</td>
<td>Surface spectral emissivity, radiance to broadband conversion</td>
</tr>
<tr>
<td>Brian Kahn</td>
<td>Jet Propulsion Laboratory</td>
<td>Cloud/Water vapor retrievals</td>
</tr>
<tr>
<td>Nicole-Jeanne Schlegel</td>
<td>Jet Propulsion Laboratory</td>
<td>Ice sheet modeling</td>
</tr>
</tbody>
</table>

**TECHNICAL TEAM**

<table>
<thead>
<tr>
<th>Team</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jet Propulsion Laboratory (JPL)</td>
<td>Decades of experience in spacecraft management and instrument development</td>
</tr>
<tr>
<td>University of Wisconsin, Madison (UW)</td>
<td>Experience with Data Center and Data Processing and Ground Operations</td>
</tr>
<tr>
<td>Space Science and Engineering Center (SSEC) at UW</td>
<td>Earth Climate data processing center</td>
</tr>
<tr>
<td>Space Dynamics Laboratory (SDL) (Utah State University)</td>
<td>Small satellite builder and missions operations; one of the nodes on the MC3 network</td>
</tr>
</tbody>
</table>