CubeSat Infrared Atmospheric Sounder (CIRAS)

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CIRAS Agenda

• Background
• Overview
• Experiment Objectives
• Measurement Approach
  - Measurement Requirements
  - Measurement Approach
  - Implementation
  - High Resolution Mode
• Project Schedule
• Summary and Conclusions
CIRAS reduces cost of future lower tropospheric sounding measurements

- Atmospheric Infrared Sounder (AIRS)
  - Launched May 4, 2002 on the EOS Aqua Spacecraft
  - Grating Spectrometer, Active Cryocoolers, HgCdTe
  - Highest Forecast Impact of Any Single Instrument (tied with European IASI)
  - Leading Data Set downloaded in Obs4MIPS for CMIP5 to Validate Climate Models
  - AIRS expected to be fully operational beyond 2022

- Crosstrack Infrared Sounder (CrIS)
  - CrIS on NPP and JPSS-1 and JPSS-2
  - Similar Performance to AIRS
  - Gap could happen if loss of JPSS-1 or JPSS-2

- CIRAS InVEST Primary Motivations
  - Selected by NASA InVEST Program Sept. 2015
  - Project Start, March 1, 2015
  - Technology Development for Atmospheric Sounding
  - CubeSat Implementation for Low Cost, Fast Deployment
  - Lower Tropospheric Only. (MWIR Only)
  - Comparable Spatial Resolution and Swath to AIRS, CrIS
  - Higher spatial resolution (3km) reduced swath mode
  - Constellation Compatible for Improved Timeliness

Figure 11. 24-hour forecast error contribution (code “IP”) of the components (types) of the observing system during September, October, November and December 2008. Negative (positive) values correspond to a decrease (increase) in the error norm of forecast error.
From Cardinalei (ECMWF Tech. Memo. 599, 2009)

CIRAS will Mitigate a Gap in Coverage between NPP and J-2

AIRS Shows High Forecast Impact

CrIS Continuity with AIRS
CIRAS Objectives and Mission Summary

CIRAS is a *technology demonstration* mission to enable hyperspectral infrared atmospheric sounding on a low-cost, quick-turnaround platform.

**CIRAS Objectives**
- In-Space Technology demonstration for key infrared subsystems: LM MPT Cryocooler, JPL HOT-BIRD IR Detectors, JPL Grism Spectrometer
- Demonstration of Mid-wavelength Infrared (MWIR) temperature and water vapor sounding. Limited to mid to lower troposphere. Supports operational weather prediction and scientific research on the atmosphere

**Implementation Summary**
- 6U CubeSat (approx. 30 x 20 x 10 cm, 9 kg)
- Deployed into LEO Sun Synchronous Morning Orbit (400 km – 850km)
- Minimum Mission Duration: 3 months
- JPL Builds Payload
- Subcontract for 6U spacecraft and I&T
- CubeSat Launch Initiative for Launch Services
- Launch-ready June 2018
CIRAS Key Technologies to Demonstrate

- **CIRAS Demonstrates In-Space Key Technologies Required for Hyperspectral Infrared Measurements**

  - **HOT-BIRD Detectors (TRL 6):** The new High Operating Temperature Barrier Infrared Detector (HOT-BIRD) detector materials developed at JPL provide superior uniformity and operability, higher operating temperature, and lower 1/f noise with comparable performance as HgCdTe at these wavelengths, and can be made at a significantly reduced cost.

  - **Coaxial Micro Pulse Tube (MPT) Cryocooler (TRL 6):** The Lockheed Martin (LM) built active MPT cryocooler used in CIRAS is the smallest flexure-bearing cooler available, built for low vibration and long life and ideal for Earth science missions requiring multi-year data sets.

  - **MWIR Grating Spectrometer (MGS) (TRL 5):** The CIRAS MGS is a high dispersion immersion grating spectrometer enabling IR remote sensing of atmospheric temperature and water vapor profiles in a CubeSat package.

  - **Black Silicon IR Blackbody (TRL 5):** A cryo-etched silicon surface that exhibits less than 0.1% reflectance across a broad spectral band

- **Extensive use of commercial technologies**
  - Camera electronics, scan motor and controller, cryocooler, cryocooler electronics, and spacecraft

- **All technologies will be advanced to TRL 7 at end of experiment**
Measure Temperature and Water Vapor Spectrum
1965-2090 cm\(^{-1}\)

Sensitivity is Comparable to Legacy Sounders in Lower Troposphere

Spatial Resolution and Coverage Comparable to Legacy Sounders:
Global Daily Coverage at 13.5 km

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Legacy (CrIS) Performance</th>
<th>CIRAS Requirement</th>
<th>CBE</th>
<th>Margin</th>
</tr>
</thead>
<tbody>
<tr>
<td>Orbit</td>
<td>824 km</td>
<td>600-850 km</td>
<td>600 km</td>
<td>Positive: 250 km</td>
</tr>
<tr>
<td>Vertical Range</td>
<td>0-50 mb</td>
<td>0-500 mb</td>
<td>0-500 mb</td>
<td>Positive: 200 mb</td>
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<tr>
<td>Temperature Profile</td>
<td>(\leq 1.5 \text{K}/\text{km})</td>
<td>(\leq 1.5 \text{K}/\text{km})</td>
<td>(\leq 1.2 \text{K}/\text{km})</td>
<td>Positive: 0.3 K/\text{km}</td>
</tr>
<tr>
<td>Humidity Accuracy</td>
<td>15%/2km</td>
<td>20%/2km</td>
<td>15%/2km</td>
<td>Positive: 5%/2km</td>
</tr>
<tr>
<td>Spatial Res. (nadir)</td>
<td>13.5 km</td>
<td>13.5 km</td>
<td>13.5 km</td>
<td>N/A: By Design</td>
</tr>
<tr>
<td>Scan Range</td>
<td>2040 km</td>
<td>1450km</td>
<td>2040</td>
<td>Positive: 590 km</td>
</tr>
<tr>
<td>Spectral Range</td>
<td>3.9-15.4µm</td>
<td>4.78-5.03µm</td>
<td>4.78-5.09µm</td>
<td>Positive: 0.06 µm</td>
</tr>
<tr>
<td>Spectral Resolution</td>
<td>0.625 cm(^{-1})</td>
<td>1.0 cm(^{-1})</td>
<td>0.5 cm(^{-1})</td>
<td>Positive: 0.5 cm(^{-1})</td>
</tr>
<tr>
<td>NEdT</td>
<td>&lt;0.25 K</td>
<td>&lt;0.35K</td>
<td>&lt;0.25K</td>
<td>Positive: 0.1 K</td>
</tr>
</tbody>
</table>
Temperature and water vapor retrievals using IASI data in only CIRAS band show good sensitivity in lower troposphere.

Chris Barnet, STC
CIRAS Measurement Approach

Scan Pattern on the Ground
Slit Projection (163 km x 0.8 km)

1 Scan

Scan Motion

Orbit 1
Orbit 2

±55° Scan JPSS Orbit Shown

12 FOVs Per Superframe
FOV = 13.5 km x 13.5 km

Slit
506 (track) x 2.5 (scan) Pixels
(Projects onto 625 Pixels, λ)

FOV
42 Pixels (track) X 7 Frames (scan @ 30 Hz)
(Pixels Summed On-board)

Detector
640 x 512 Pixels

625 Pixels, λ

506 Pixels, x

Used Region

4.78 µm

Unused Region 5.09 µm

625 Pixels, λ
CIRAS System Configuration and Resource Reqmts.

<table>
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<th>Legacy (CrIS) Performance</th>
<th>CIRAS Requirement</th>
<th>CBE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Size</td>
<td>1.4 x 0.8 x 0.8 m³</td>
<td>6U</td>
<td>6U</td>
</tr>
<tr>
<td>Mass</td>
<td>177 kg</td>
<td>&lt;14 kg (TBR)</td>
<td>8.5 kg</td>
</tr>
<tr>
<td>Power</td>
<td>256W</td>
<td>&lt;50 W</td>
<td>37.5 W</td>
</tr>
</tbody>
</table>

x, track
y, space
z, nadir

Telescope and MGS (JPL)
Batteries
HOT-BIRD Detectors (JPL)
Micro Pulse Tube Cryocooler (Lockheed Martin)
Black Si. Blackbody (JPL)
Earth View
Scanner

Solar Panels
Spacecraft
Space View Side

M. Lane (JPL), T. Dissaro (JPL)
Higher Resolution Sounders Needed to Initialize and Validate Next-Gen GCM’s

- Need 1-2 km by 2025

Global Models:
- 1974: 450 Global GISS 4dx5d
- 1976: 250 GISS
- 1980: 300 Spectral NML
- 1998: 100 GEOS-3
- 1999: 50 GEOS-4
- 2009: 35 NCEP
- 2004: 25 GEOS-4,5
- 2009: 3.5 GEOS-5 Limited Run
Higher Spatial Resolution will Improve Water Vapor Accuracy Near Clouds

AIRS Water Vapor

50 km Current, (AIRS L2)

15 km, (AIRS L1b)

H. Aumann (JPL)
CIRAS can demonstrate higher spatial resolution hyperspectral IR sounding

- Native resolution of CIRAS is 1.6 km
- CIRAS bins pixels and multiple frames while scanning to achieve desired spatial resolution
- Pixel binning scheme and scan rate are programmable while in orbit
- Changing scan range (and rate) and pixel binning can improve spatial resolution at the expense of coverage (see right)
CIRAS Technologies can be Extended to Other Spectral Regions to retrieve Trace Gases in Infrared

AIRS O₃ Isosurface, Sept, 2014

AIRS O₃ VMR, 2014. Isosurface at 5 x 10⁻⁷ ppmv. Altitude Scale: 100, Altitude Offset: 10 km, Max Altitude (above which transparent): 18 km
Summary and Conclusions

- CubeSat Infrared Atmospheric Sounder (CIRAS) Selected for development by the NASA InVEST Project
- Development starts March 1, 2015
- CIRAS will be based on the advanced cubesat sounder resulting from the NOAA Advanced IR Sounder Study performed at JPL
- CIRAS demonstrates 3 Key Technologies for IR Spectroscopy
  - Higher spatial resolution is possible with tradeoffs
  - Method can be extended to other bands in the infrared