NOAA EON-IR CubeSat Study for Operational Infrared Soundings

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IR Sounders Support Weather Forecasting and Climate Science

AIRS Channels for Tropical Atmosphere with $T_{\text{surf}} = 301\,\text{K}$

- Full Spectrum
- Water Vapor Climatology (Pierce, Scripps, 2006)
- Water Vapor Feedback (Dessler, Texas A&M, 2008)

AIRS

Forecast error contribution ($\bar{\epsilon}$)

NOAA NESDIS/NCEP

JPL/GSFC

NASA

JCSD
Microwave and infrared atmospheric sounders on polar orbiting satellites have a large positive impact on reducing numerical weather prediction forecast error.

Observation Type and % Impact to Reducing Forecast Errors

Microwave Sounders, 31
Hyperspectral Infrared, 27
GPS RO, 5
Scatterometers, 4
Atmospheric Motion Vectors, 6
Surface Reports, 4
Nadir View, 3
Buoys, 3
Geostationary IR, 3
Other, 1

Credit: ECMWF

Imagery from polar orbiting satellites provides enhanced coverage in high-latitudes where geosynchronous satellite coverage is diminished.
Why SmallSats?

- Current environmental satellites are expensive
  - No ability for spares in LEO orbit
  - Long development cycle
  - Failure means lack of data availability

- SmallSats could be the future for some observations
  - Lower cost alternatives
    - Use commercially available parts
    - Less weight means low launch costs
    - Can afford to have a spare for Gap Mitigation
  - Much shorter development time
  - Commercial launch availability
  - Loss of a single spacecraft does not result in the loss of all instruments

- Better capability for partnering opportunities ~ DoD and NASA

Incorporating SmallSats into future architecture plans
# Strategy for SmallSat Integration

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**Microwave Sounding**

Potential Enabling Technology: NASA investment in CubeSat based mid-wave IR sounders for the JPL CubSat Infrared Atmospheric Sounder (CIRAS) mission (Pictured).

**Infrared (IR) Sounding**

Potential Enabling Technology: NOAA’s EON-MW concept is based on NASA funded MIT/LL CubeSat based microwave sounder technology demonstrations MiRata and MicroMAS-2/TROPICS (pictured).

**Visible / IR Imaging**

Potential Enabling Technology: Department of Defense investment in low-light CubeSat based imagers such as AeroCube-4 (pictured).
Challenges for CubeSat IR sounder

- Temperature control is among the highest challenges, along with a larger aperture size required for longer wavelengths.
- IR sensors are extremely sensitive to noise due to thermal emission of the optics and Johnson noise in the detectors, especially in the LWIR, and require a significant amount of cooling.
- Other technology risk areas include Focal Plane Array (FPA) technologies, miniature reliable cryo-coolers, compact optics, and IR Immersion grating spectrometers.

![Figure 1: Electromagnetic Spectrum Transmission in the Infrared Wavelength](image)
2015 Study

- NESDIS and JPL began studying the optimal performance of a CubeSat based infrared sounder in comparison to CrIS performance.
- TRL assessment of all mission components and subsystems
- Recognizing the difficulty with the thermal and power requirements of LWIR sounding, the study focused on design of the MWIR only in a 6U CubeSat.
- The study addressed the optical, mechanical, thermal, detector and electronic requirements from such a system.
- The EON-IR (MWIR-Only) instrument that resulted employed passive cooling for the spectrometer and a micro pulse tube cryocooler for cooling the detector.
- After completion of this first study, the ESTO funded CIRAS project began the design phase.
- Immediately it was found that the fully functional design arrived at during the NOAA study was not affordable for the CIRAS and a few changes were made including adding a second cryocooler for the spectrometer since passive cooling was more complex, and replacing the pulse tube cryocooler with a commercial less expensive and less reliable cooler.
CIRAS Key Technologies Development Status

- **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 low 1/f noise.
  - Detector/ROIC (Sensor Chip Assembly, SCA) complete. SCA’s under test.

- **MWIR Grating Spectrometer (MGS) (TRL 5)**
  - All refractive grating spectrometer with a 16 degree Field of View. Covers 4.08-5.13 µm and 625 channels. MGS design complete. Build by Ball Aerospace with immersion grating and slit by JPL.
  - MGS in final design and parts procurement phase at Ball. Slit in design, procuring immersion grating substrate.

- **Black Silicon IR Blackbody (TRL 5)**
  - A cryo-etched silicon surface that exhibits less than 0.2% reflectance across a broad spectral band. Developed at JPL
  - CIRAS Black Si Slit and Blackbody currently in the design phase.

- **All technologies will be advanced to TRL 7 at the end of the spaceflight mission**
1. Improve the design of EON-IR to increase reliability commensurate with a mission of two years in length or longer. This task will examine the reliability and mission assurance of the EON-IR and its subsystems, primarily electronic, including the spacecraft.

2. Examine the ability to provide full swath scanning. This task will explore the ability to scan the EON-IR to achieve full swath as currently obtained from the operational sounders. Model the scanning mechanism and impacts on the sensor collection as well as the dwell times.

3. Improve the EON-IR thermal/mechanical design. Model designs for an FPA mount and cold shield/filter for EON-IR with sufficient fidelity to estimate total photon flux at the detector for accurate predictions of noise performance, and estimate total thermal load at the detector cryocooler cold finger. Provide a better estimate of the amount of heat needed to dissipate by the cryocoolers and radiators.

4. Identify drivers and limitations to expand the EON-IR pathfinder channel capability to CrIS sensor capabilities. The objective is to determine if there are viable options to expand EON-IR beyond the Mid-wavelength Infrared (MWIR) to include Long-wavelength Infrared (LWIR). This task should look at thermal impacts as well and also possible increase in CubeSat size to accommodate additional capability.
EON-IR 2016/17 Study Results

• The study was to benefit from the InVEST CIRAS program and identify the additional risks associated with the requirements of an EON-IR system.

• Task 1: Mission Reliability Improvement
  – Major portions of the EON-IR concept have low risk due to the commonality with CIRAS, however, further definition of EON-IR revealed several life limiting components which needed further reliability study and would possibly change the TRL of EON-IR.
    • Electronics: Parts identified with SEL sensitivity.
    • Scanning: Commercial scan motor has not undergone life testing.
    • Cryocoolers: Ricor K508N used on CIRAS not best choice for EON-IR. Alternate long-life microcoolers identified

• Task 2. Full Swath Scanning Study
  – Task demonstrated that full swath scanning is achievable with desired scan rates

• Task 3. Improve the MWIR portion of EON-IR Thermal/Mechanical Design
  – Results demonstrated that the heat generated by electronics and active cooling of the optics and detectors can be passively radiated by the 6U CubeSat structure

• Task 4. Expand the EON-IR Channel Capability
  – A Team-X study demonstrated that an LWIR Sounder can be designed to comfortably fit into a 12U CubeSat using a combination of active and passive cooling
EON – Microwave and Infrared Data Impact Studies

- **Scope:**
  - Determine the quantitative value of MicroMAS-2 and CIRAS in the reduction of forecast error in global and regional numerical weather prediction (NWP) models:
    - Impact of MicroMAS-2 in the absence of ATMS
    - Impact of CIRAS in the absence of CrIS
- **Recent Work:**
  - Created simulated MicroMAS-2 and CIRAS data CubeSat Sounders for studying impact
  - Created orbit simulator for MicroMAS-2 and CIRAS
- **Next Steps:**
  - Complete work to quantify and summarize impacts on simulated global NWP models
Conclusion

- NOAA, NASA, and JPL are all working together to provide IR sounding technology in a CubeSat
- IR soundings have major impacts on weather forecast models
- MWIR is viable and being demonstrated on a CubeSat format in CIRAS
- LWIR concepts have been developed to fit onto a 12U CubeSat form
- EON-IR expands beyond the technology demonstration to a longer operational mission life