RAVAN: Technology demonstration and applicability to Earth radiation budget measurements

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Motivation: Earth’s energy imbalance

• The small imbalance (~1 W/m²) between incoming solar irradiance and Earth outgoing energy (solar reflected + Earth’s thermal emission) drives climate change

• Current space-based assets cannot quantify Earth’s outgoing radiation well enough to resolve the Earth energy imbalance from space

• RAVAN is an Earth radiation (energy) budget constellation pathfinder

TSI/4 ≈ 341 W/m²

TSI = Total Solar Irradiance

TOE = Total Outgoing Energy

RAVAN-like constellation
Context and some conclusions

• RAVAN (InVEST-2012) launched Nov 11, 2016 and is still operating
  - Four radiometers working; one (of two) gallium black bodies failed
  - With one small exception, Blue Canyon CubeSat bus is working well

• Primary conclusions
  - NASA ESTO technology demonstration success
  - Earth radiation budget measurements for future constellation mission (“science goal”) more complicated

• The good
  - Carbon nanotubes (“VACNTs”) work in space, specifically as radiometer absorbers
  - Gallium phase-change black bodies for calibration monitoring
  - Long-term stability demonstrated
  - Reconstruction of spatial information from WFOV “single pixels”
  - Qualitative (at least) agreement with reanalysis and CERES

• The “less good”
  - Short-term fluctuations problematic (for climate-level observations), most likely due to inadequate thermal knowledge and control

• RAVAN today:
  - Still flying, targeting CERES coincidences (as closely as possible)
  - Working with NASA LaRC to assess absolute accuracy vs. CERES
Compact payload hosts two technologies

Technology 1: Carbon nanotube radiometer absorber

Technology 2: Gallium phase-change black body cells
Launched Nov 2016, still flying

RAVAN 3U CubeSat
Blue Canyon Technologies bus

Launch 11/11/16

Credit: United Launch Alliance, Lockheed Martin

RAVAN (~575 km)
130° FoV

(dark space)
Instrument long-term stability, but short-term fluctuations

**Dark offsets**

- Dark Offsets PTOT
- Dark Offsets PSW

**Gains**

- Gains PTOT
- Gains PSW
Gallium melt provides repeatable reference

![Graph showing BB temperature over time with specific dates and temperatures highlighted.]

- Primary Ga BB thermistor (counts)
- BB temperature
- Time (UT h, 23 Feb 2017)
- Approximate temperature (°C)
- Time (relative UT h)
Gallium transition observed by radiometer

BB temperature

Radiometer signal
Instrument long-term stability, but short-term fluctuations

Ga BB observations

Black body for VACNT Total channel failed in March 2017
Solar observations for absolute scale

![Graphs showing relative difference over time for VACNT Total and VACNT SW](image-url)
Solar (eclipse) observations

RAVAN: Solar Eclipse 2017

Fraction of full solar irradiance

Time (18:00 UT minutes)
Nadir observations of outgoing flux
Dataset is episodic (grrr—not by design)

Data downlink hampered by ground-level UHF interference
VACNT and cavity radiometers well correlated

Comparison of first 6 months of mission
“Single-pixel camera” contains spatial information

Single day (June 27, 2017) of RAVAN LW flux (Total – SW)
...however, wide FOV (130°)
Spatial reconstruction from a single day of data

MERRA-2 reanalysis, TOA LW flux, daily mean June 27, 2017

Reconstruction: RAVAN sampling of MERRA-2 hourly TOA LW flux

Reconstruction: RAVAN LW flux data

Reconstructions work of Sonia and Nolan Reilly, student interns
Qualitative agreement with CERES TOA flux

6. Interannual Variability and Long-Term Changes

Tropical convection is caused by the diurnal wave of solar heating travelling around the Earth from east to west. Land masses heat up more quickly than oceans, and therefore tropical convection occurs preferentially over land. Two stable convection maxima—visible as OLR minima in Figure 5—exist over the land masses of South America and Central Africa. A third convection maximum exists around Indonesia, with a western branch towards the Indian Ocean, and an eastern branch towards the Pacific. Since not much land is present in this area, the 'Indonesian' convection maximum is

10-year mean CERES EBAF Flux, Dewitte et al. [2017]
Leveraging ERBE non-scanner work to retrieve RAVAN’s “TOA” flux, for quantitative comparison with CERES

From “On the Lessons Learned from the Operations of the ERBE Nonscanner Instrument in Space and the Production of the Nonscanner TOA Radiation Budget Dataset” [Wong et al., TGRS, in press, 2018]
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