JOHNS HOPKINS
APPLIED PHYSICS LABORATORY

RAVAN: Technology demonstration and applicability to Earth radiation budget measurements

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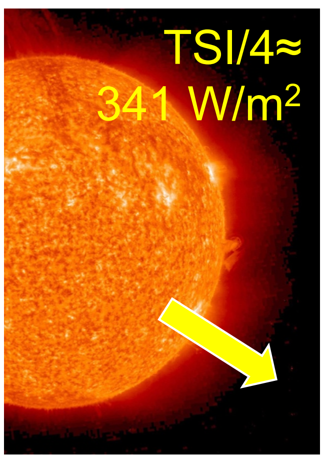
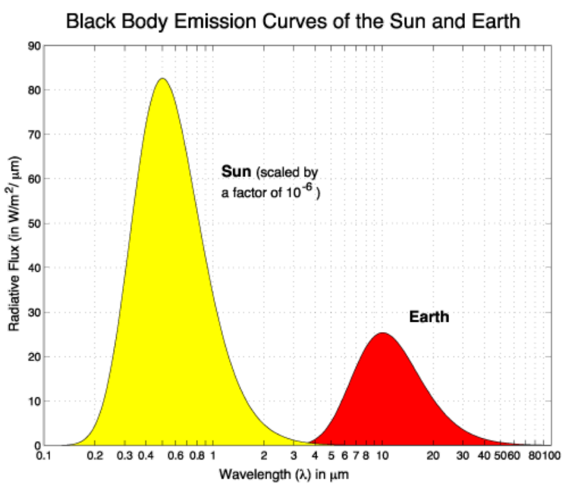
Motivation: Earth's energy imbalance

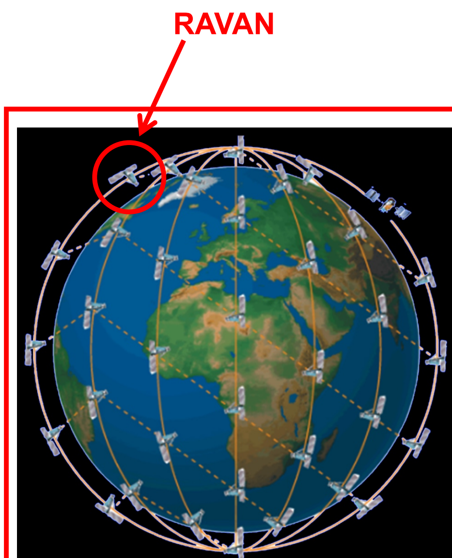
- The small imbalance (~1 W/m^2) between incoming solar irradiance and Earth outgoing energy (solar reflected + Earth's thermal emission) drives climate change
- Current space-based assets cannot quantify Earth's outgoing radiation well enough to resolve the Earth energy imbalance from space
- RAVAN is an Earth radiation (energy) budget constellation pathfinder



TSI = Total Solar Irradiance

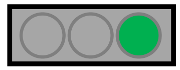
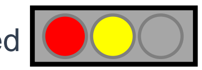


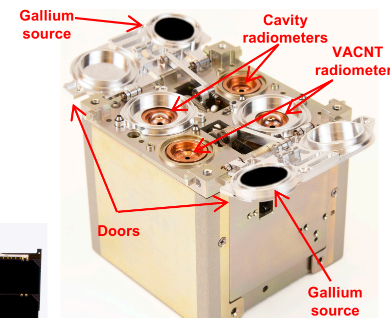
TOE = Total Outgoing Energy



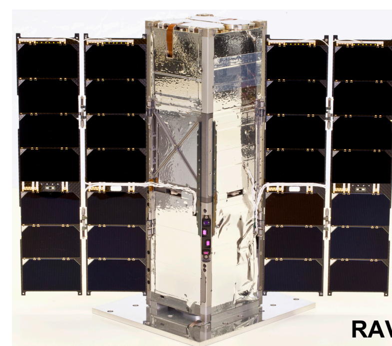
RAVAN-like constellation

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

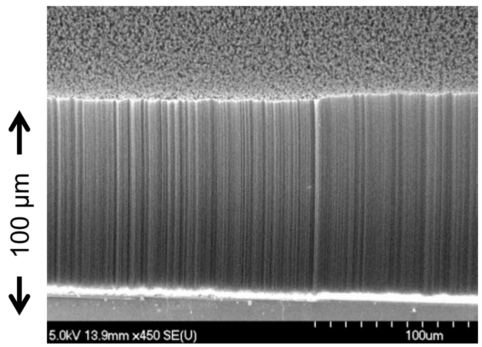


Payload


RAVAN

Compact payload hosts two technologies

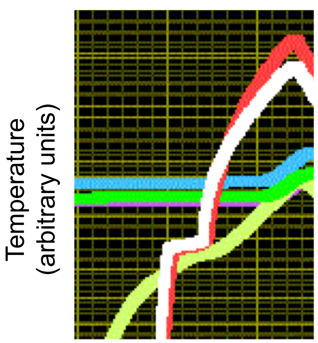
Technology 1: Carbon nanotube radiometer absorber



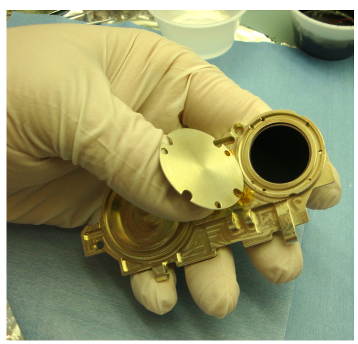
Carbon nanotube “forest”

Radiometer head assembly

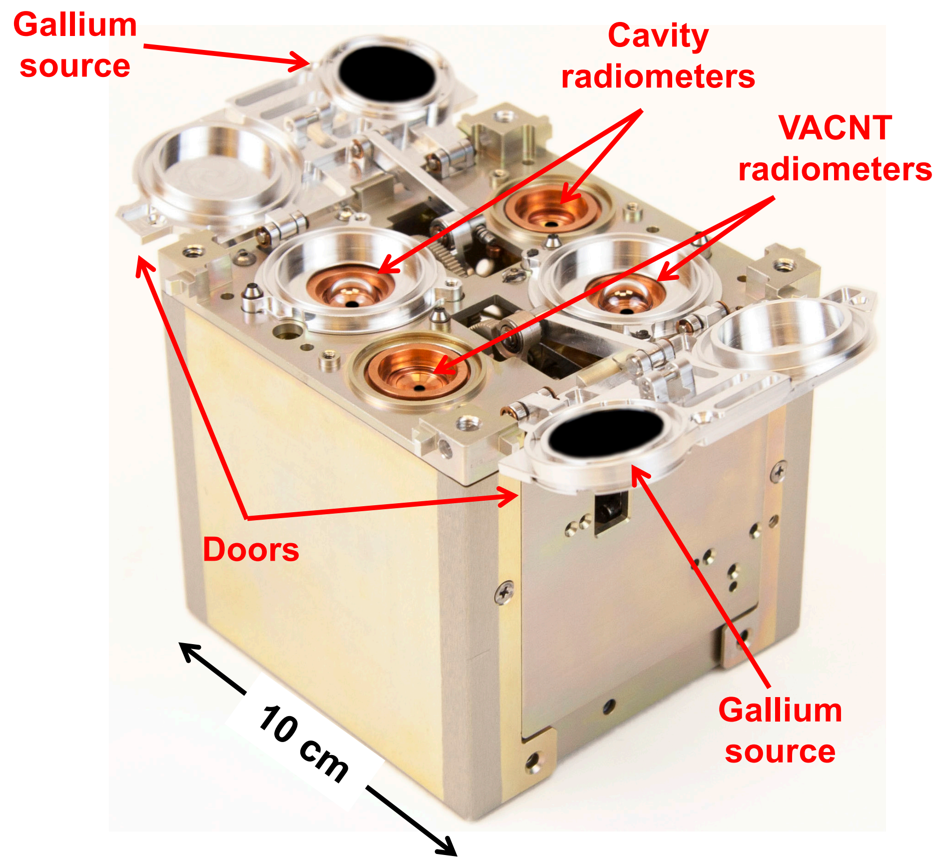
Technology 2: Gallium phase-change black body cells



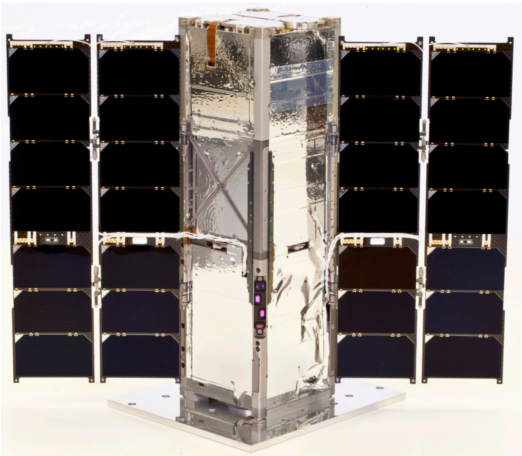
Ga solid–liquid phase transition



Payload door assembly

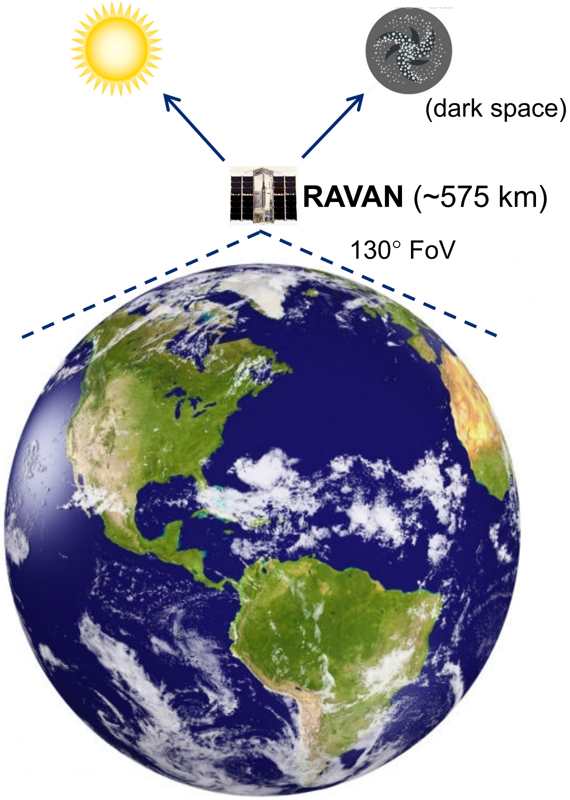


Launched Nov 2016, still flying



RAVAN 3U CubeSat
Blue Canyon Technologies bus

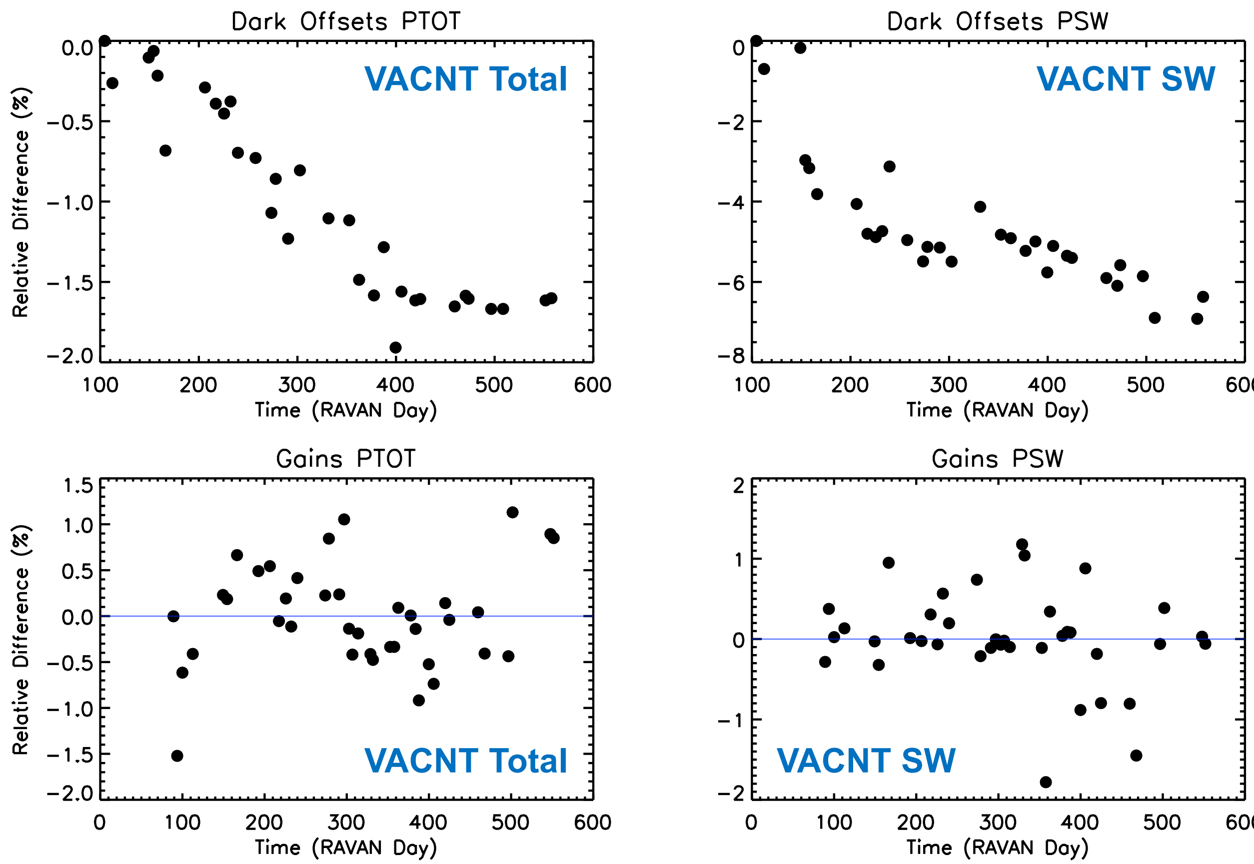
Launch 11/11/16



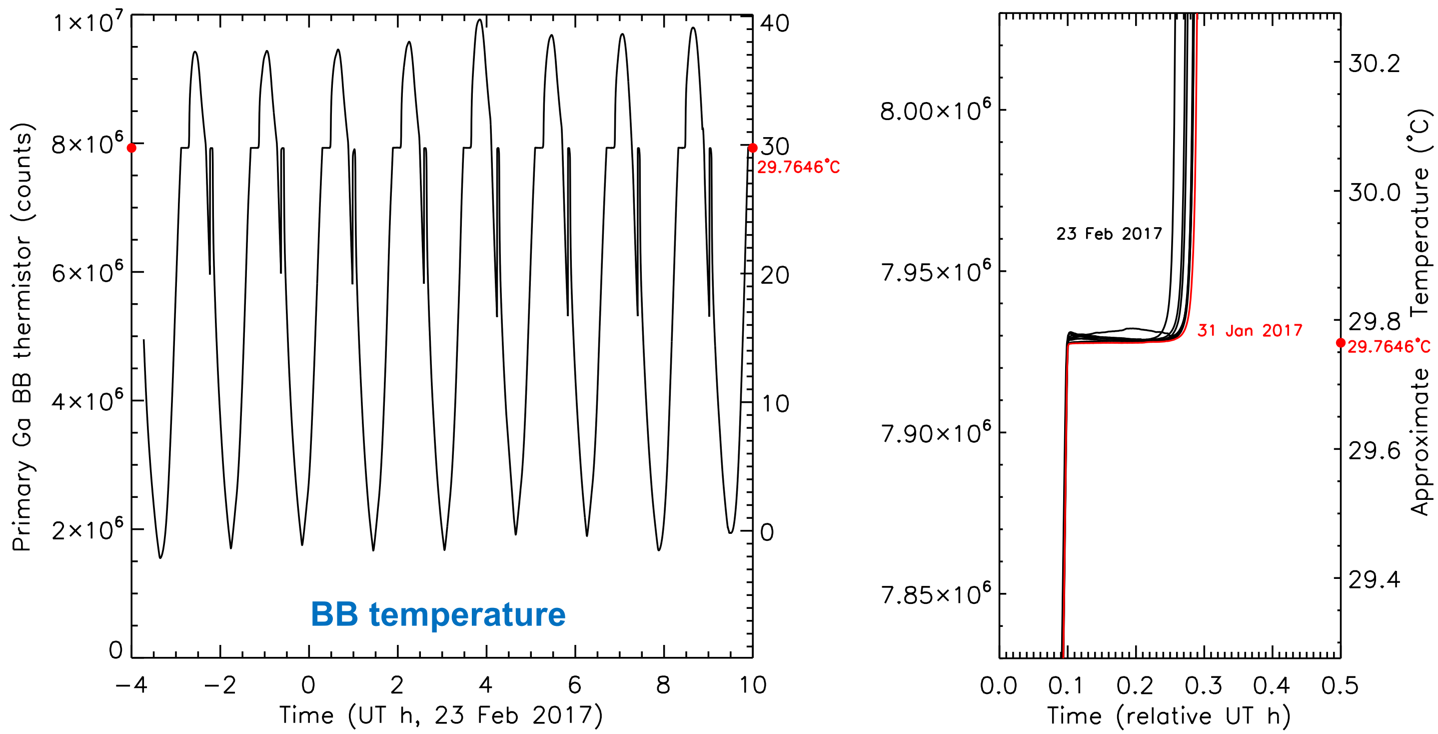
Instrument long-term stability, but short-term fluctuations

Dark offsets

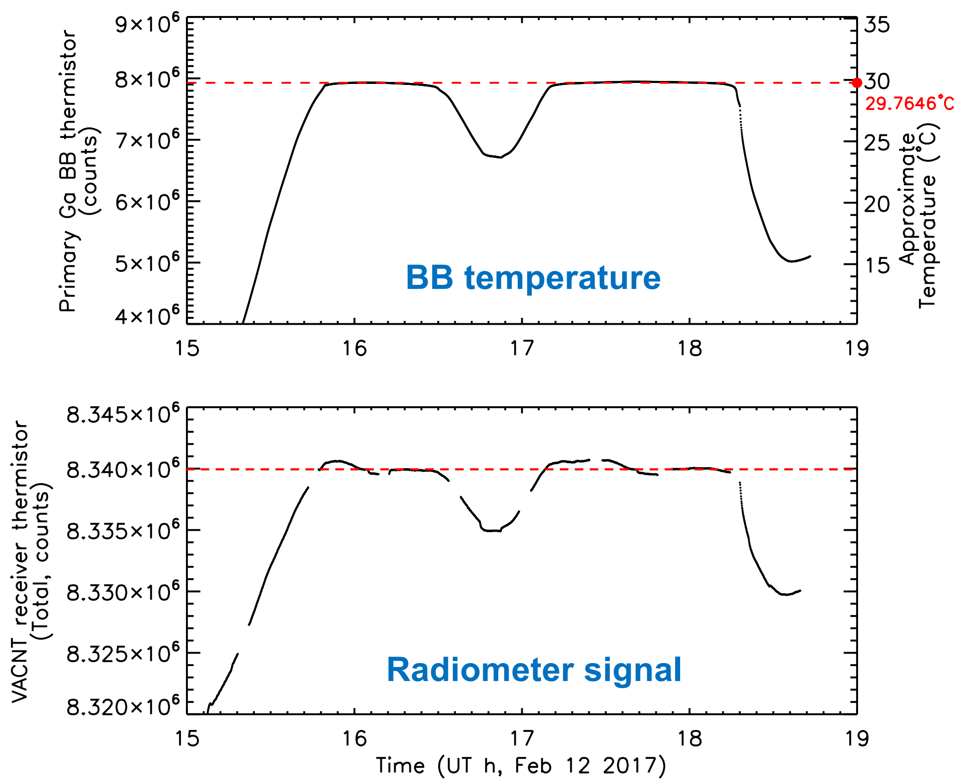
Gains



Gallium melt provides repeatable reference

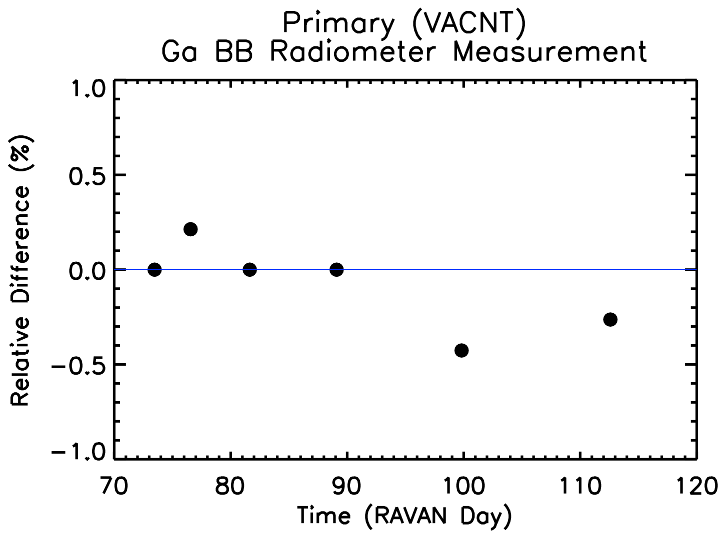


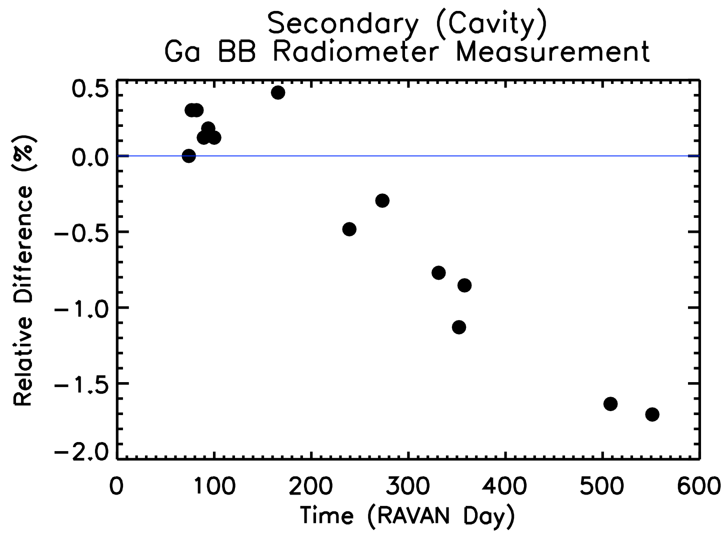
Gallium transition observed by radiometer



Instrument long-term stability, but short-term fluctuations

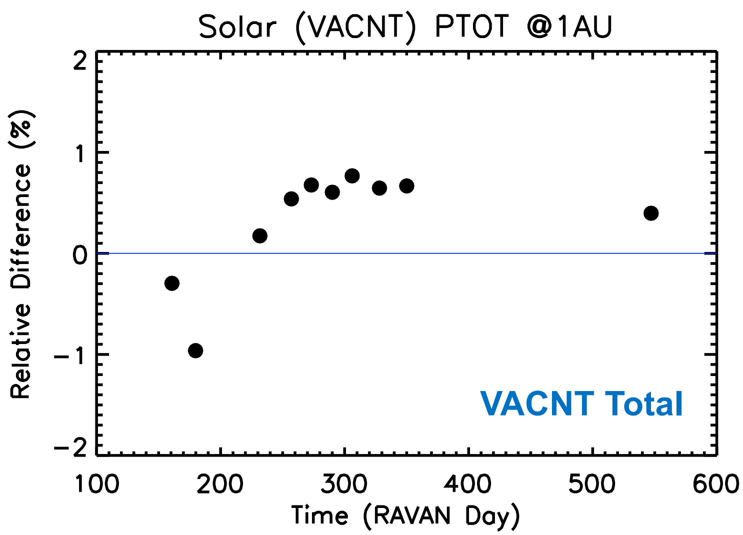
Ga BB observations

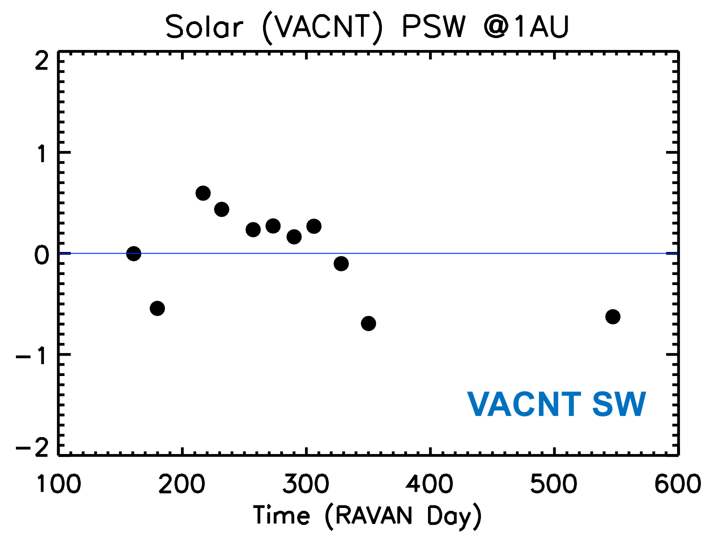




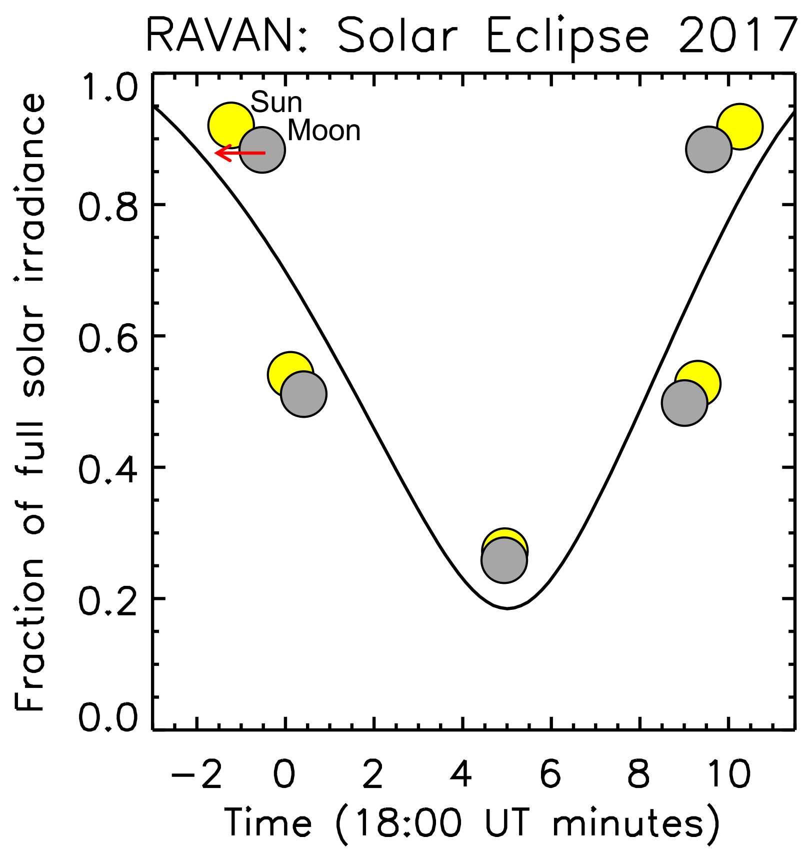
Black body for VACNT Total channel failed in March 2017

Solar observations for absolute scale

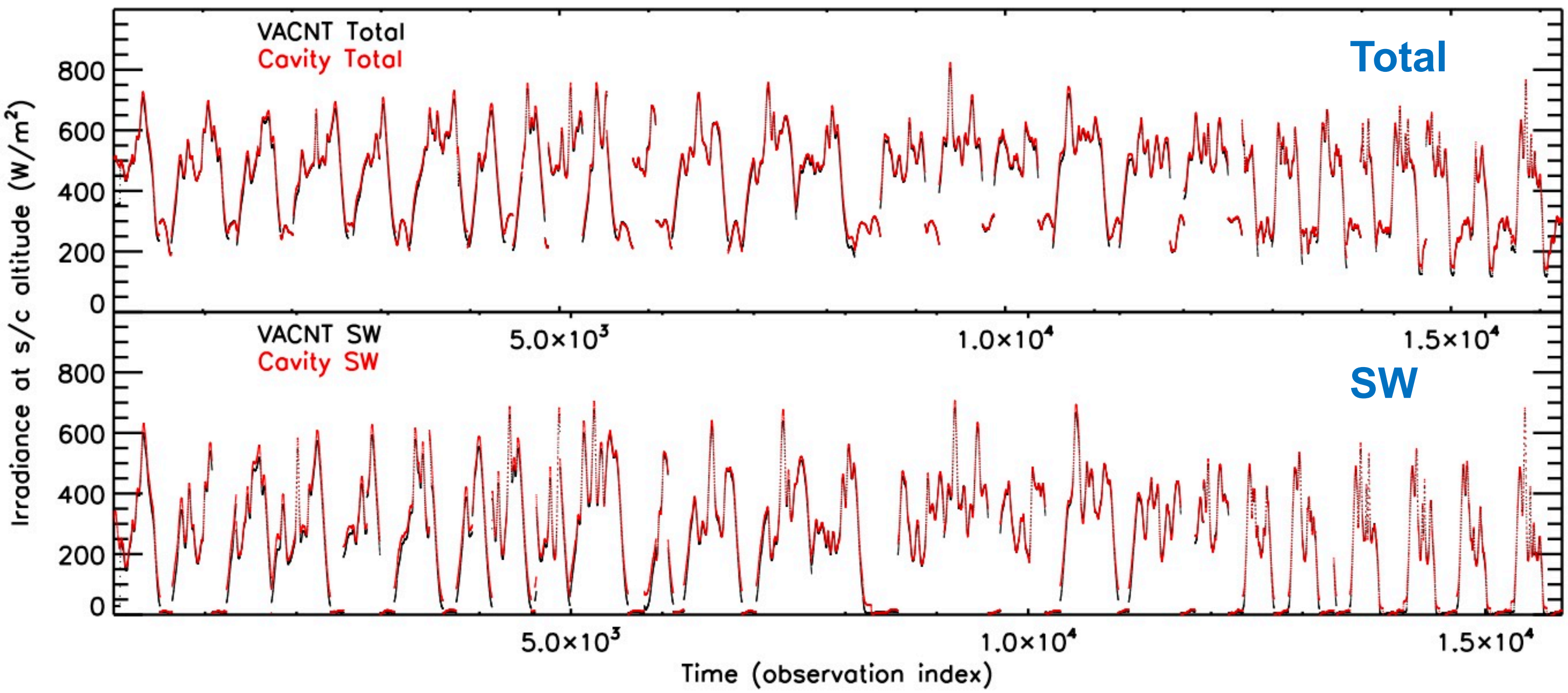




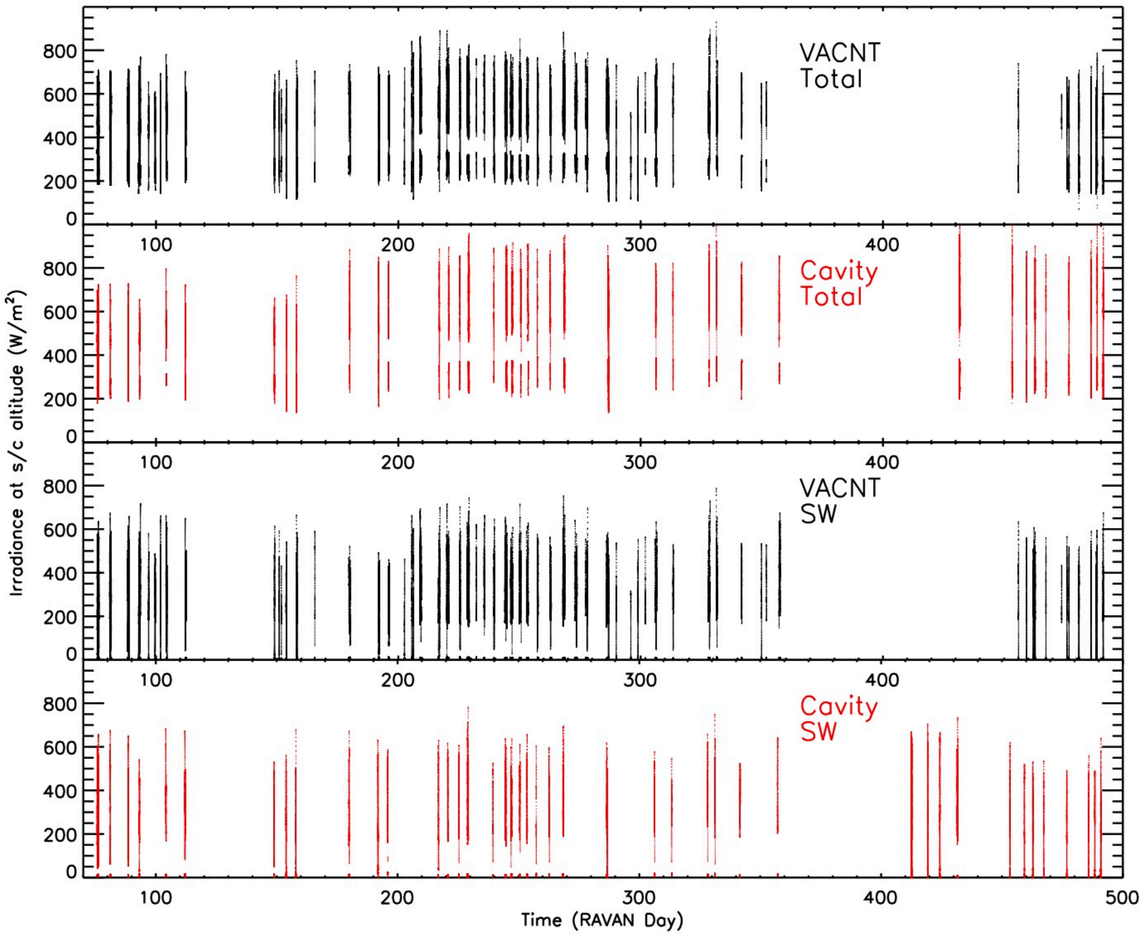
Solar (eclipse) observations



Nadir observations of outgoing flux



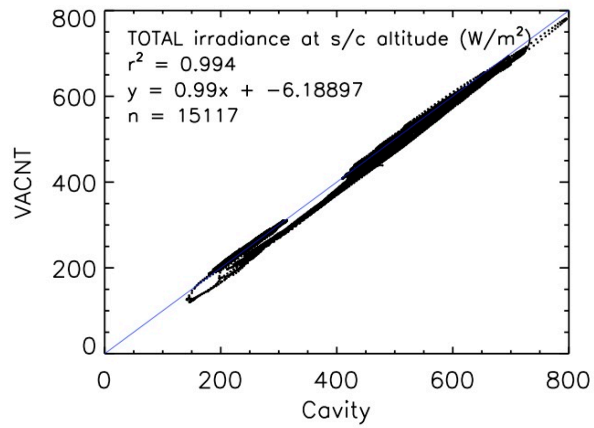
Dataset is episodic (grrr—not by design)

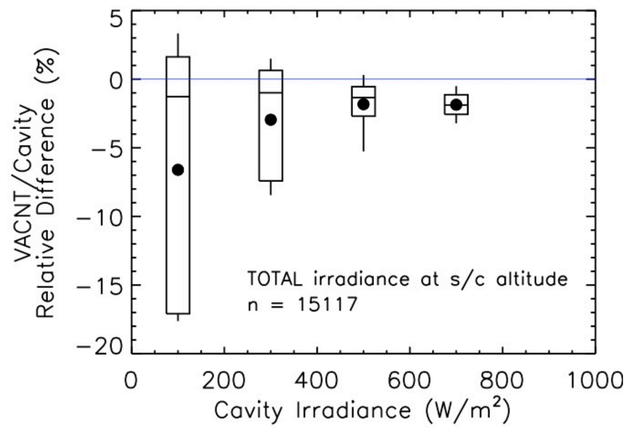


Data downlink hampered by ground-level UHF interference

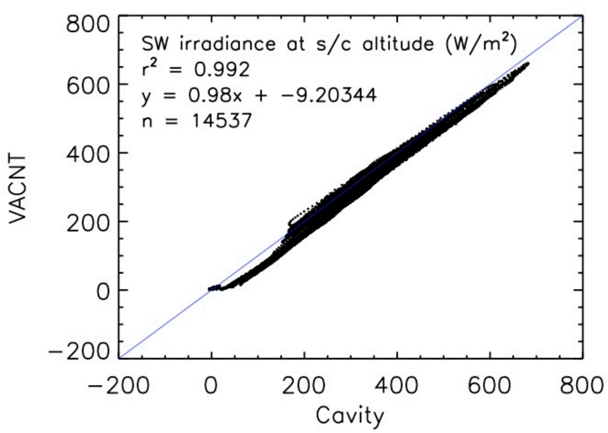
VACNT and cavity radiometers well correlated

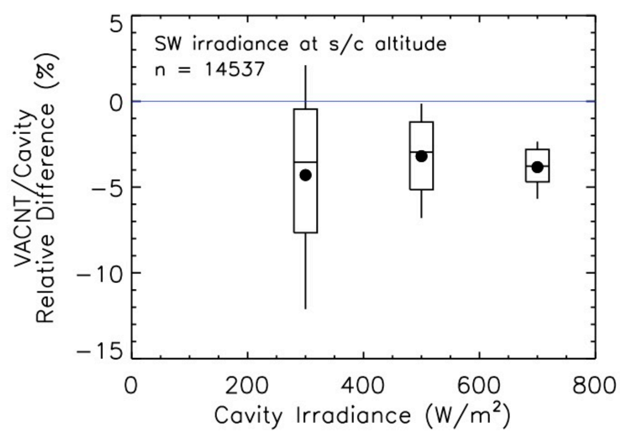
Total





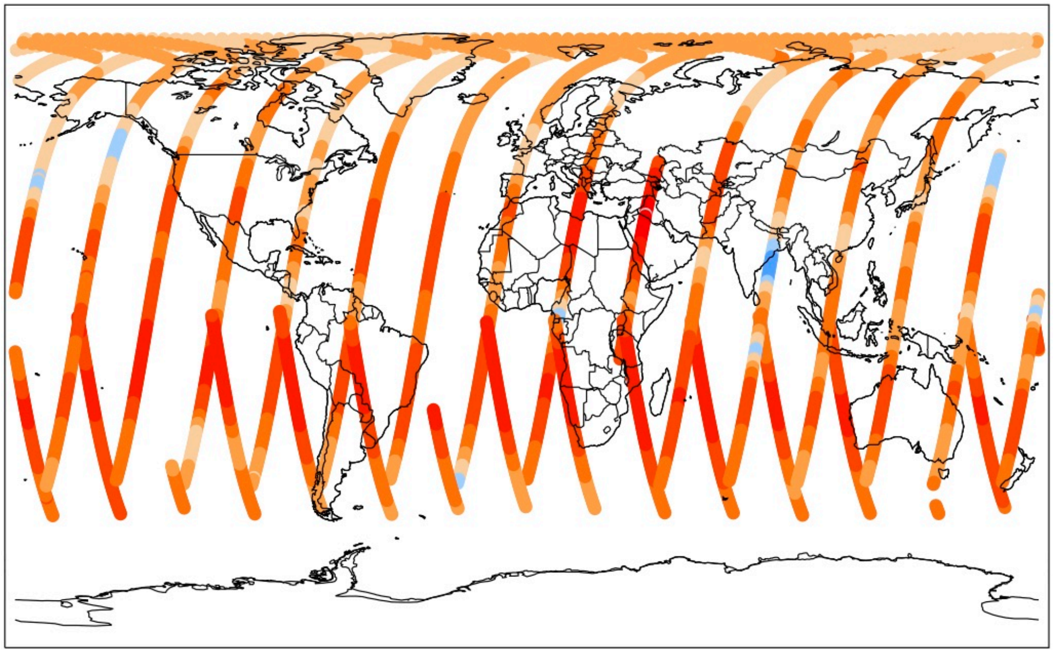
SW





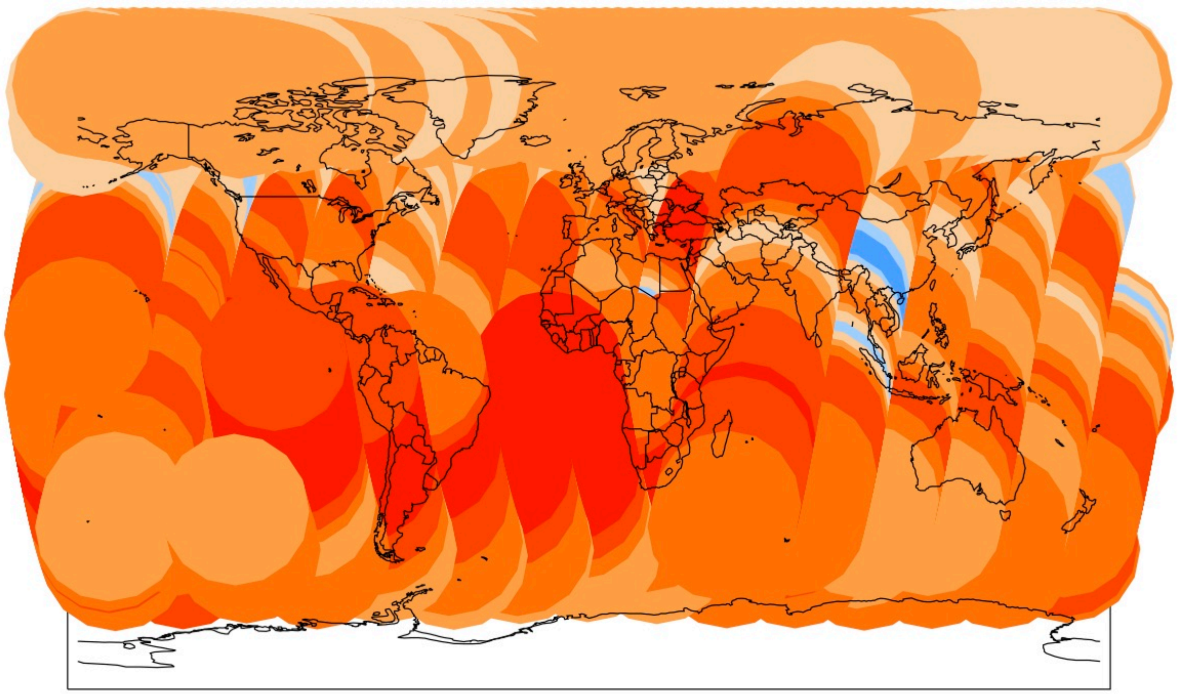
Comparison of first 6 months of mission

“Single-pixel camera” contains spatial information



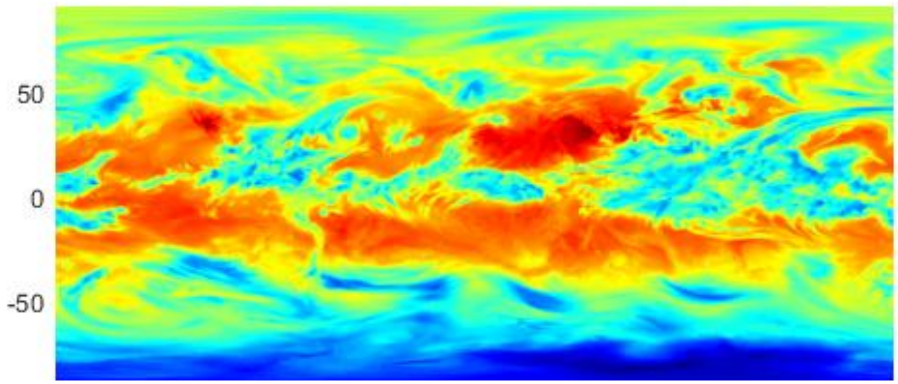
Single day (June 27, 2017) of RAVAN LW flux (Total – SW)

...however, wide FOV (130°)

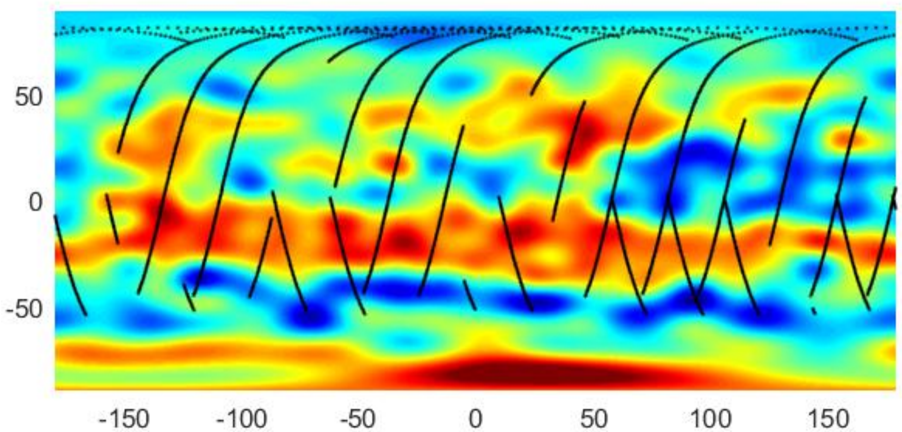


Single day (June 27, 2017) of RAVAN LW flux (Total – SW)

Spatial reconstruction from a single day of data

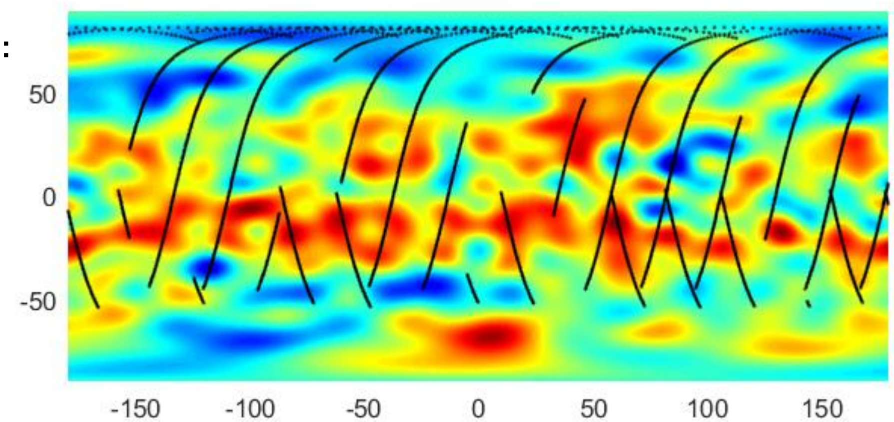


MERRA-2 reanalysis, TOA LW flux, daily mean June 27, 2017



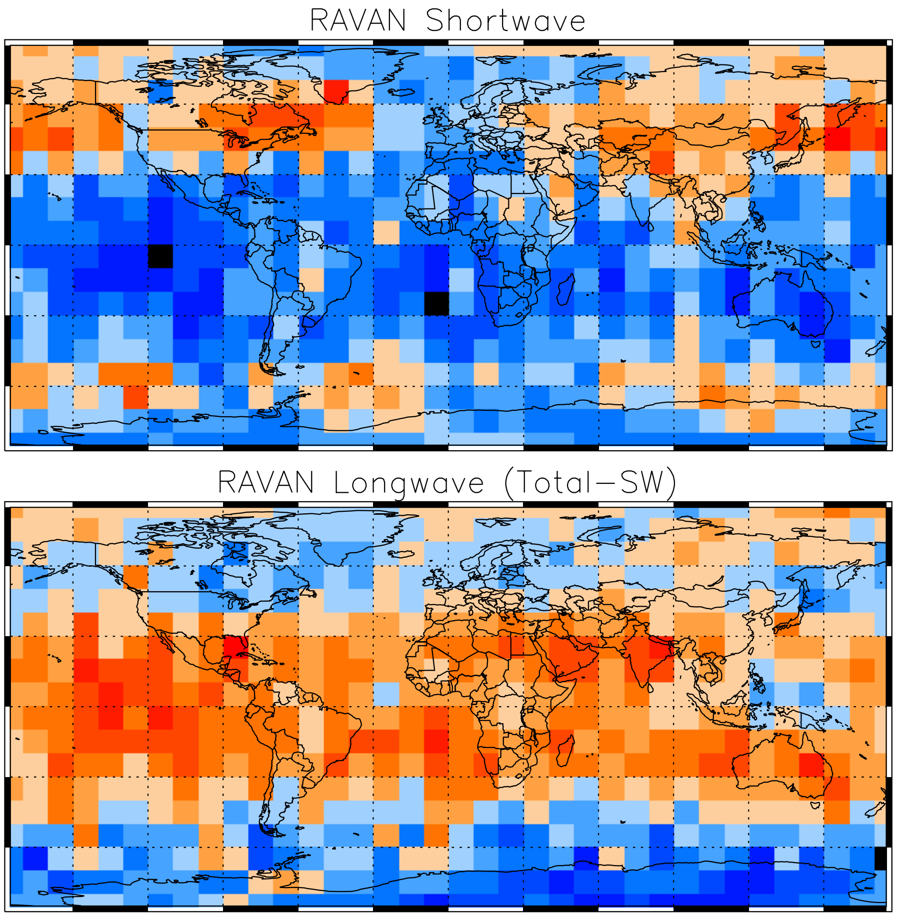
Reconstruction: RAVAN sampling of MERRA-2 hourly TOA LW flux

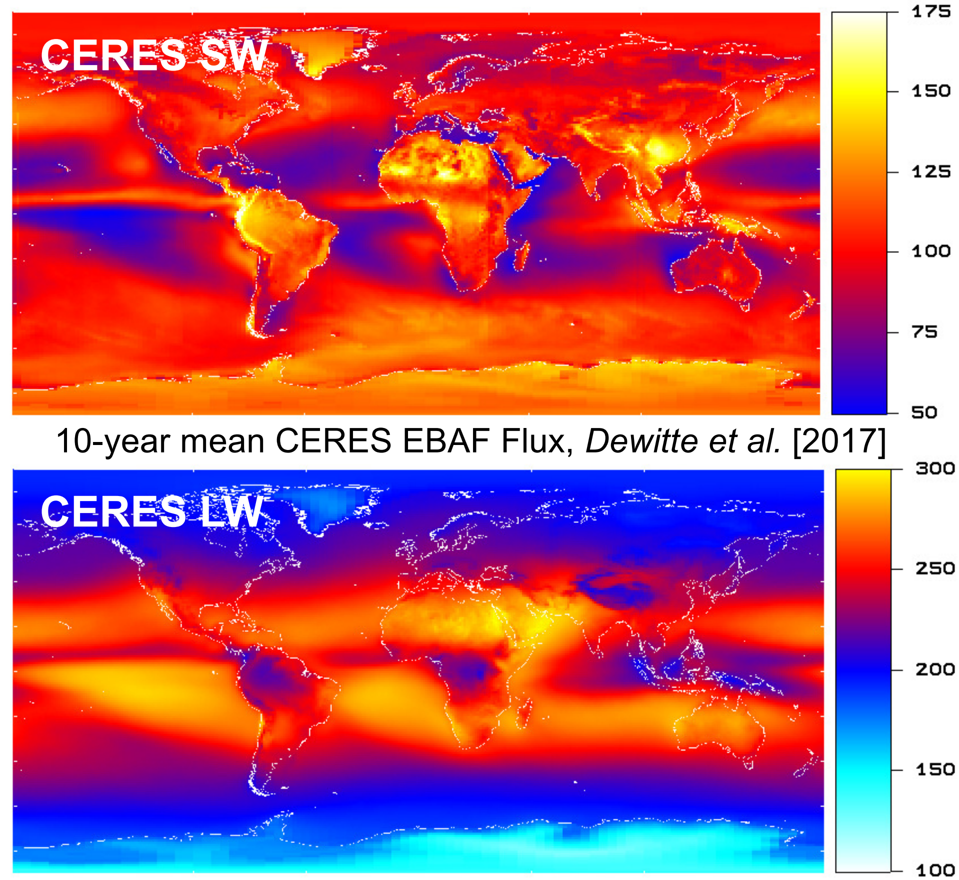
Reconstruction: RAVAN LW flux data



Reconstructions work of Sonia and Nolan Reilly, student interns

Qualitative agreement with CERES TOA flux





Leveraging ERBE non-scanner work to retrieve RAVAN's "TOA" flux, for quantitative comparison with CERES

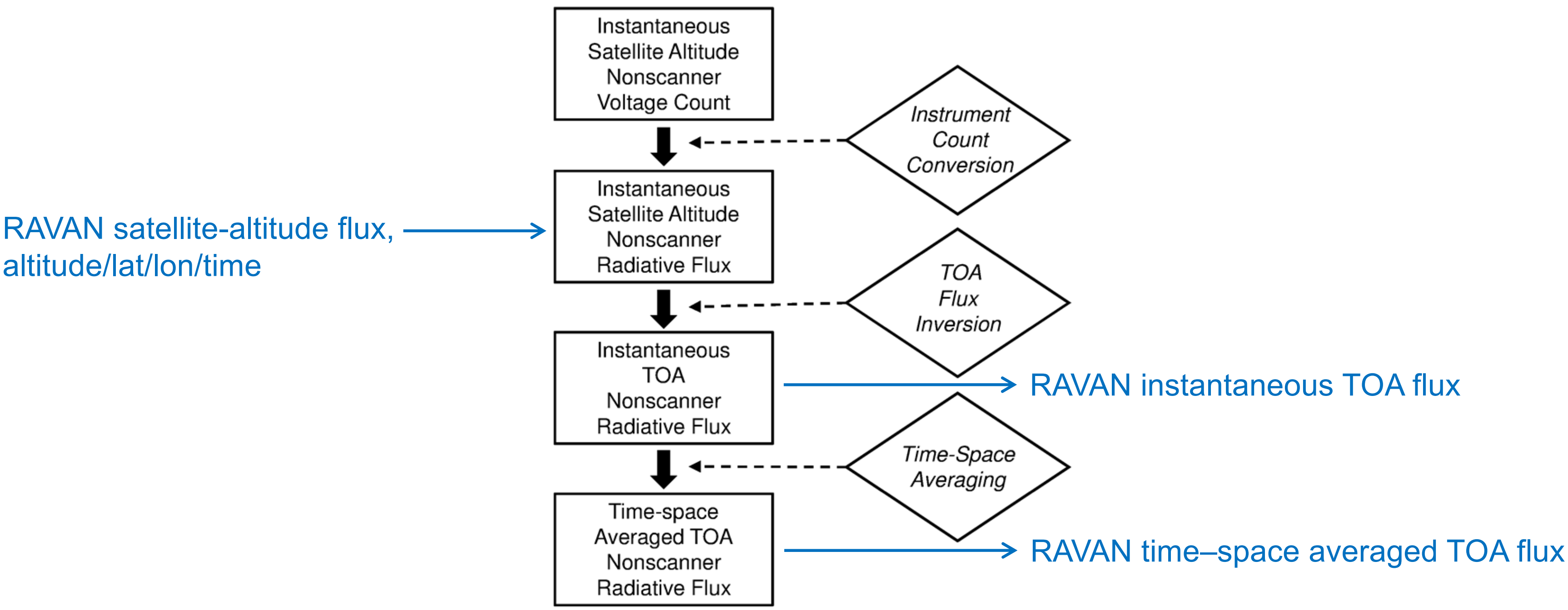


Fig. 3. ERBE nonscanner data processing system diagram.

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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