# The Global Environmental Monitoring System (GEMS) Constellation of Passive Microwave Satellites


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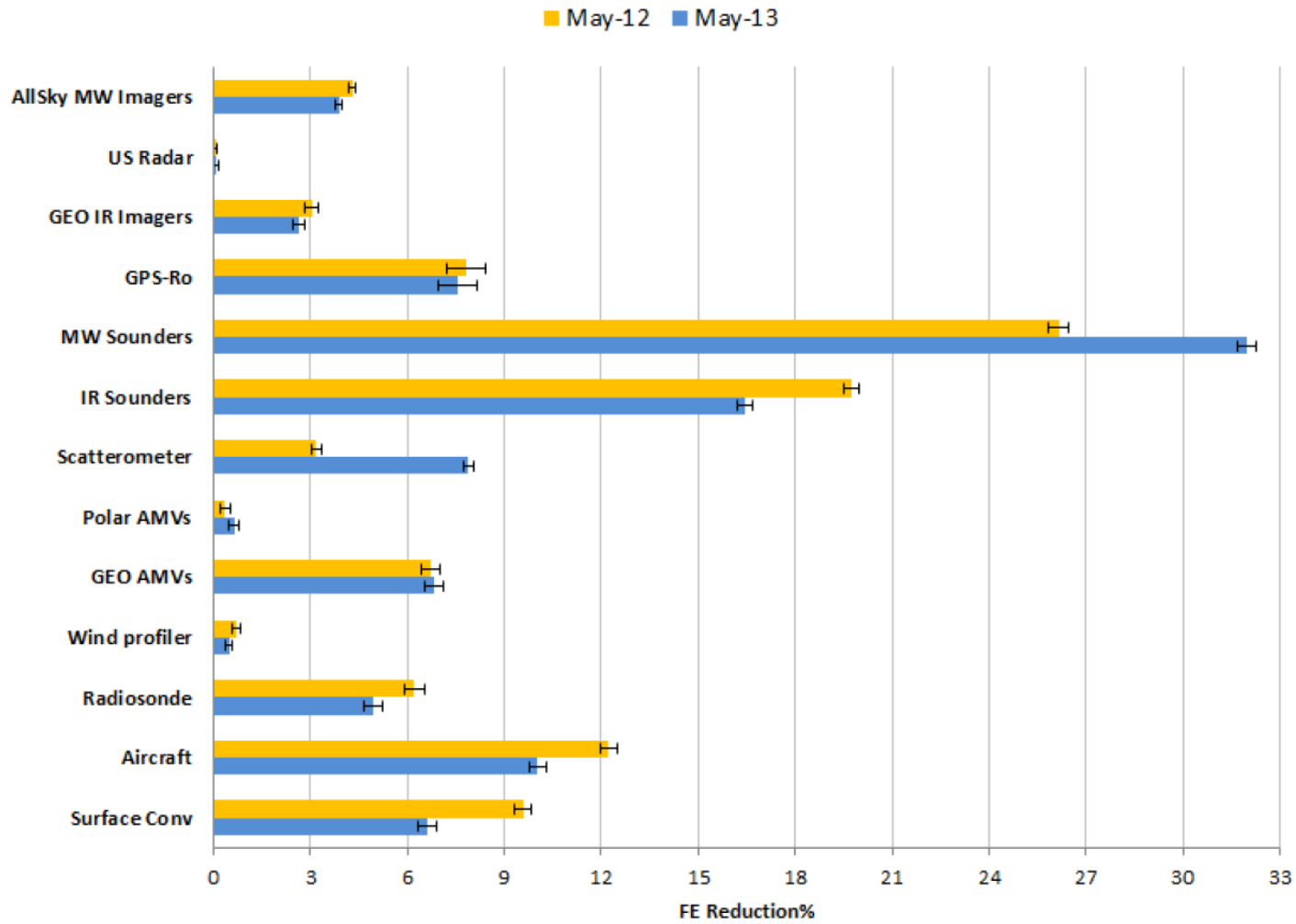
# Observation System Impact on Forecast Error

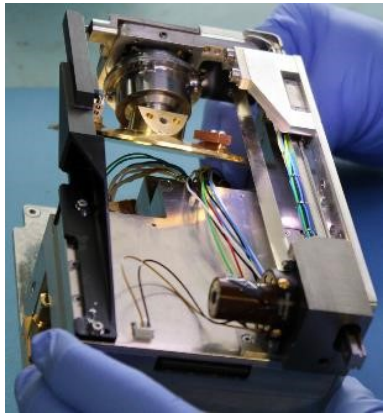


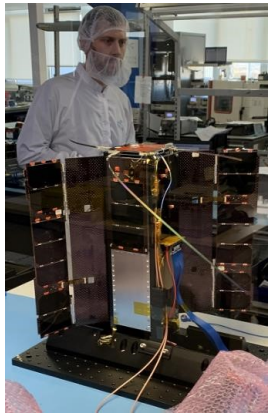

← Percentage contribution of various observation types to the total forecast error reduction:

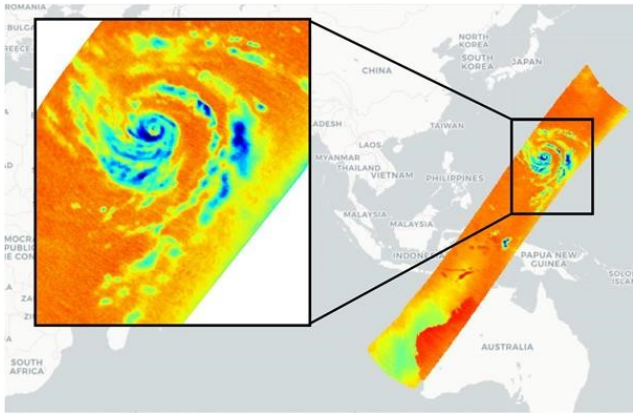
- Microwave sounders provide the largest forecast error (FE) reductions relative to all other systems.
- Key fundamental reasons include their relative insensitivity (WRT IR) to clouds in sensing meso-γ scale T,Q thermodynamic variables.
- Primary challenges to deployment include spatial resolution, calibration, and scale-up costs for high temporal resolution sampling.

* English, S., T. McNally, N. Bormann, K. Salonen, M. Matricardi, A. Horanyi, M. Rennie, M. Janisková, S. Di Michele, A. Geer, E. Di Tomaso, C. Cardinali, P. de Rosnay, J. Muñoz Sabater, M. Bonavita, C. Albergel, R. Engelen and J.-N. Thépaut, ECMWF Technical Note 711, October 2013, http://www.ecmwf.int/publications/.

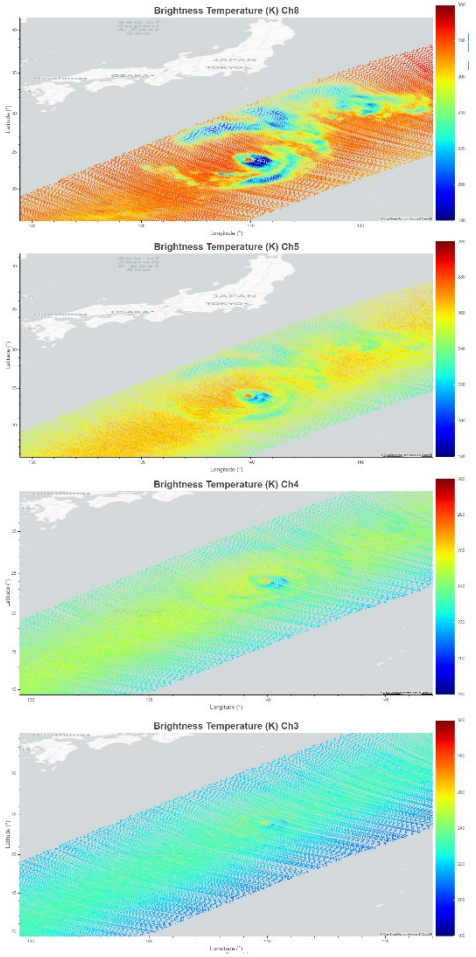
# GEMS-01 In Orbit Demonstration (IOD) Mission





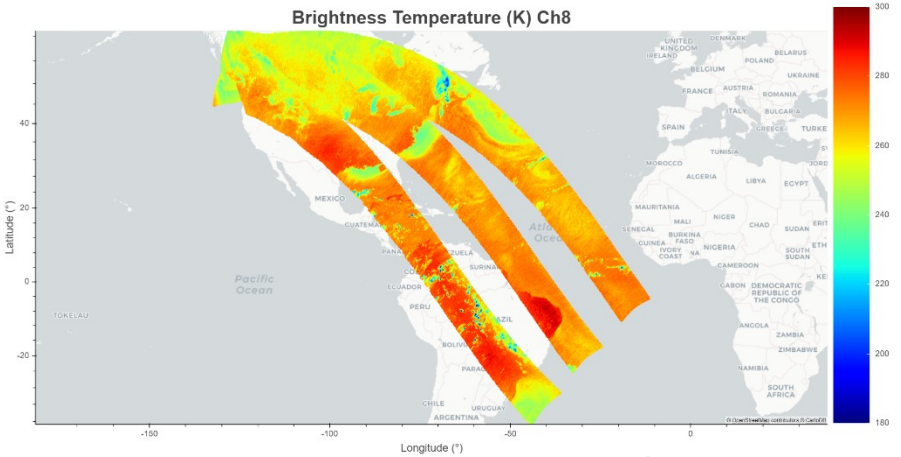
Super Typhoon Hagibis - October 8th, 2019




Hagibis - October 10th, 2019

GEMS MiniRad-01 Radiometer:

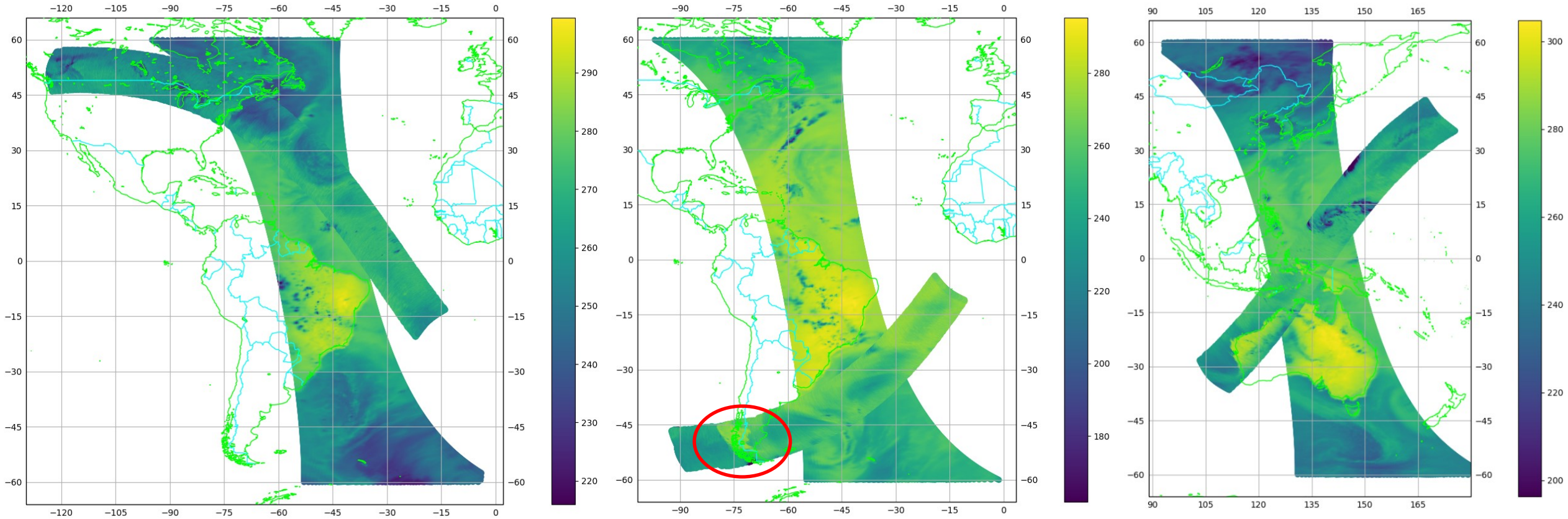
- First commercial passive microwave mission
- Cross-track scanned, 410 km release orbit
- 8 channels at 118.7503 GHz $O_2$ resonance
- 16 km 3dB nadir spatial resolution
- Nyquist sampling across and along track
- 3U CubeSat, 1.5U payload, 4W, 14kB/s
- ~15% achieved average duty cycle
- Total mission cost <$2M




The Americas – October 23rd, 2019

Launch April 2019 on ISS resupply mission, commissioning complete 10/2019, ~7 months of successful acquisition to date. L1c pre-launch (day 1) calibration algorithm used in initial data release.

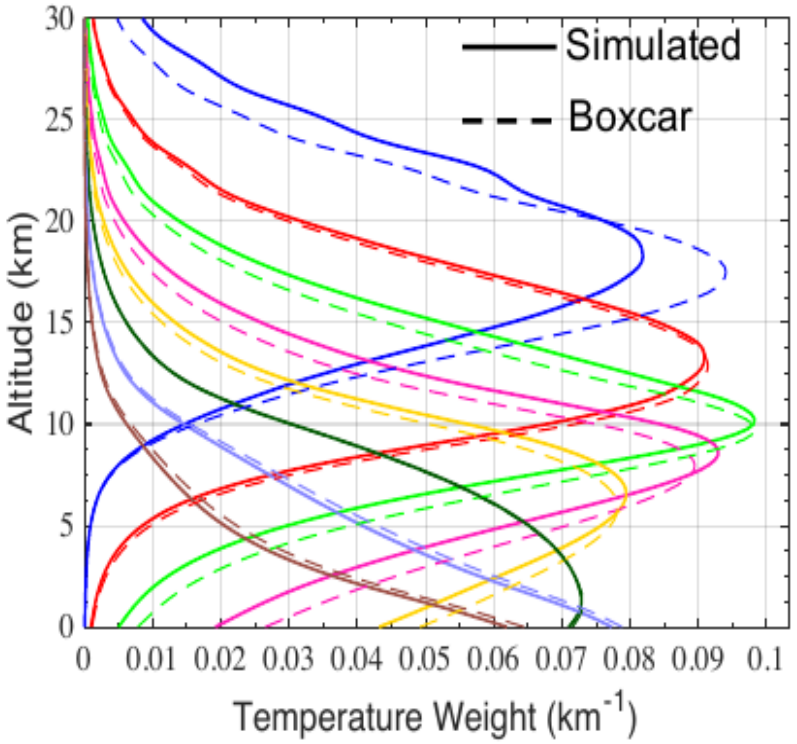
# GEMS-01 IOD / FY3C Imagery Validation

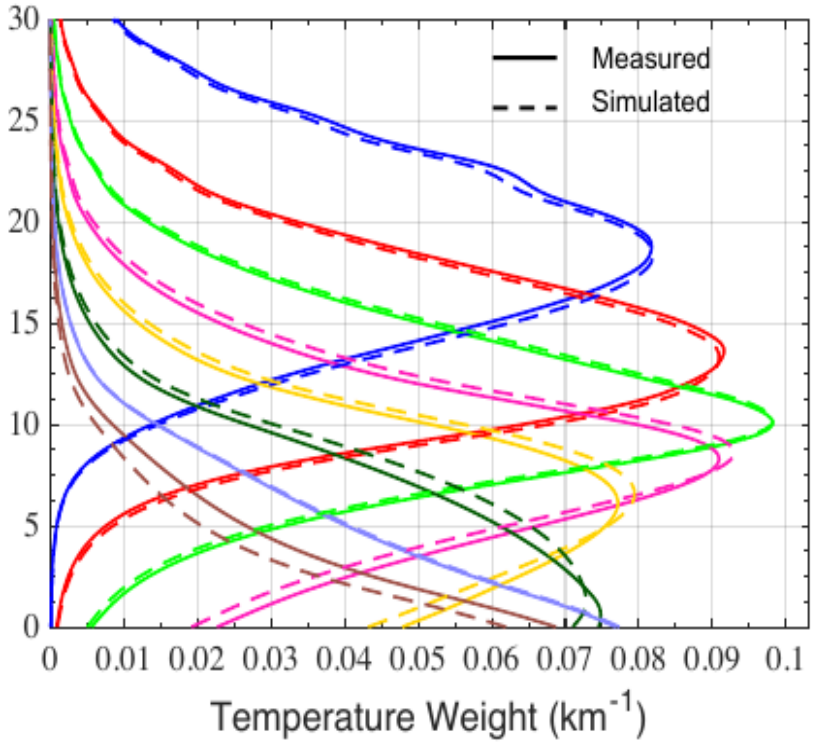


GEMS-01 Ch 8 (±3.7-6.3 GHz) overlays on FY3C MWHS-2 Ch 9 (±4-6 GHz) with ~15-min overpass coincidence

- MiniRad-01 spatial resolution and $\Delta T_{rms}$ prelaunch goals (as engineered) achieved to within ~1.2x
- GEMS-01 bus-limited georegistration goal of ~2 beam widths maximum error
- MiniRad-01 radiometer exhibited zero faults or sporadic samples during 8+ months on-orbit

# GEMS-01 IOD Weighting Functions &




Designed, measured (by IF sweep), and idealized boxcar weighting function closely match.

Negligible passband variation with temperature observed during testing.

CRTM effective-passband coefficient generation and on-orbit $\Delta T_{rms}$ estimation in progress.

| Ch # | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| $B_C$ (MHz) | 265.72 | 204.22 | 674.29 | 563.00 | 665.85 | 676.14 | 2031.0 | 2708.7 |
| $\Delta T_{rms}$ (K) (theoretical) | 2.22 | 2.36 | 1.21 | 1.28 | 1.21 | 1.20 | 0.74 | 0.58 |

Integration time = 4.096 ms

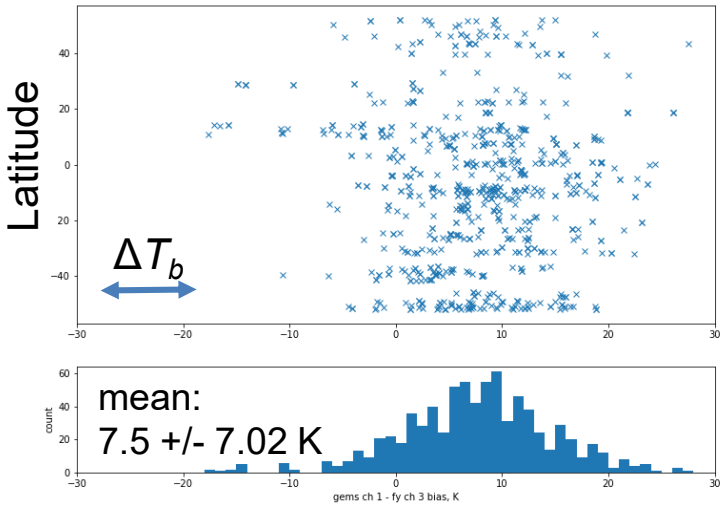
Convolutional Bandwidths:

$$B_C = \frac{\left( \int_0^{+\infty} T_{SYS}(f) G_{SYS}(f) |H_{BPF}(f)|^2 df \right)^2}{\int_0^{+\infty} T_{SYS}^2(f) G_{SYS}^2(f) |H_{BPF}(f)|^4 df}$$

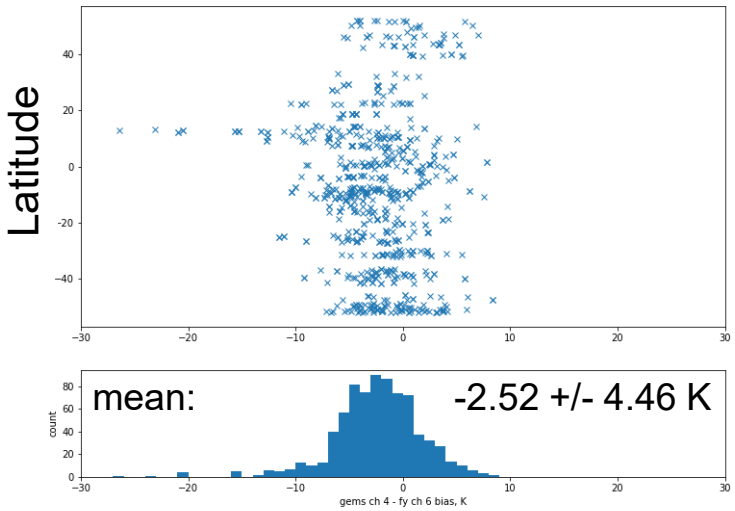
L. Periasamy, Ph.D. Thesis, University of Colorado at Boulder, 2019

# GEMS-01 IOD / FY3C Nadir Radiance Validation

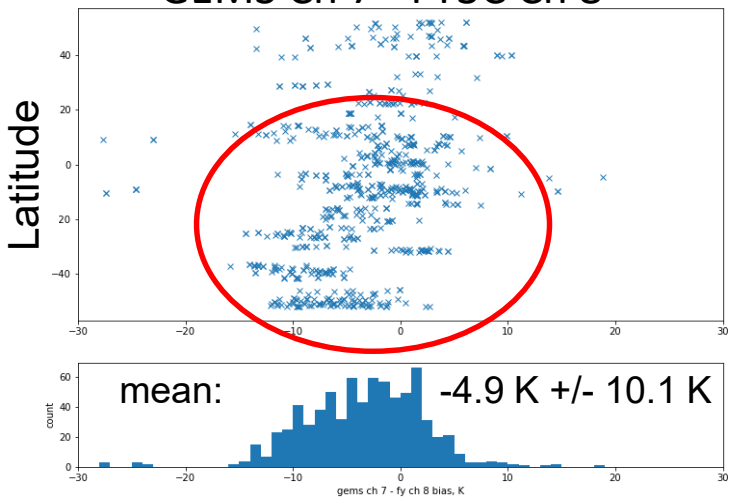
GEMS Ch 1 - FY3C Ch 3



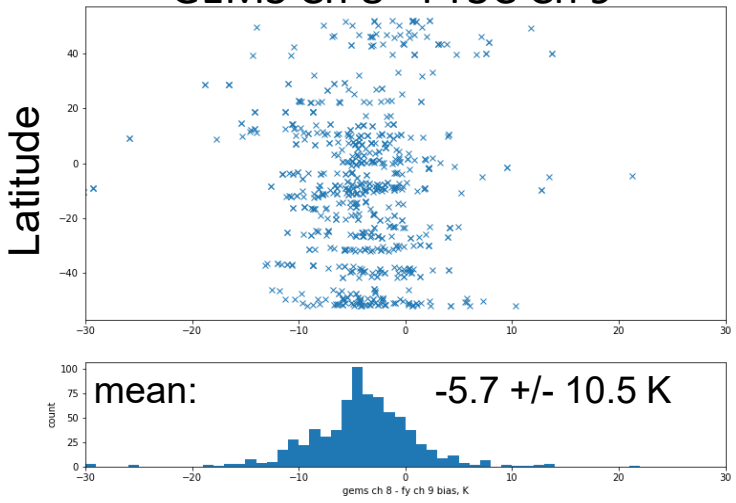

GEMS Ch 4 - FY3C Ch 6

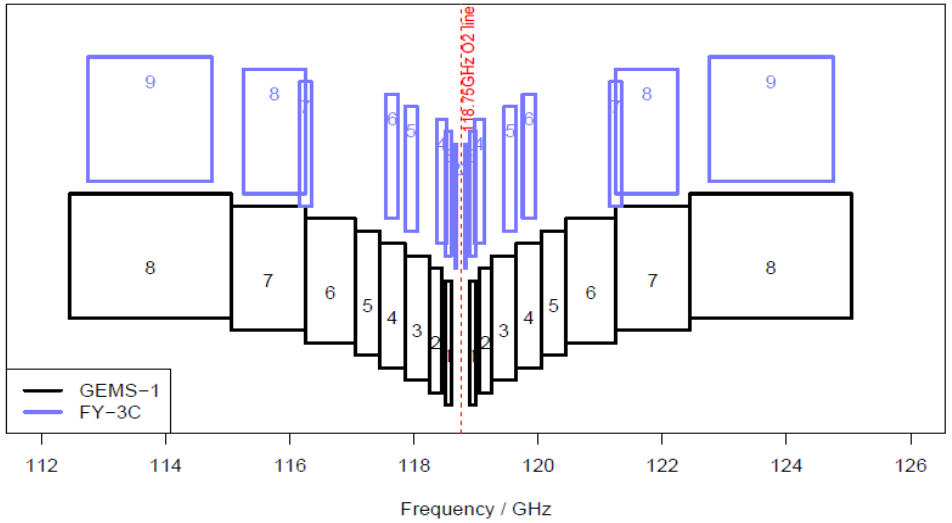



GEMS Ch 7 - FY3C Ch 8



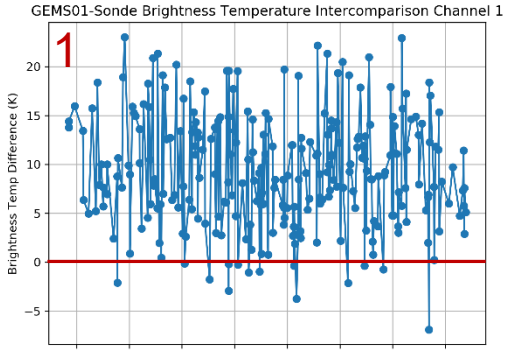

GEMS Ch 8 - FY3C Ch 9

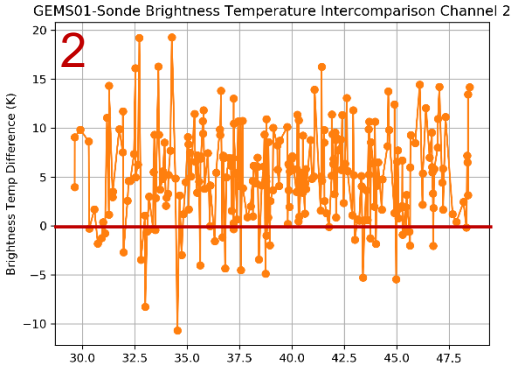


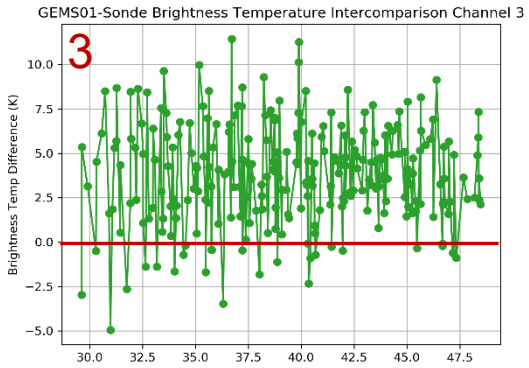



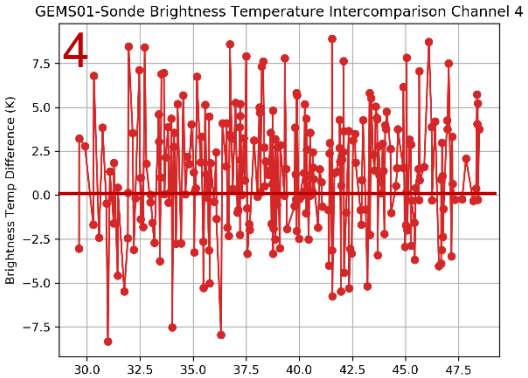

- GEMS-01 L1c pre-launch (day 1, v1.0) calibration algorithm
- Matchup latitude range <55°
- Nadir 15km / 5 min matchups
- No passband response corrections
  - ➢ High stability over 3 months
  - ➢ Channel response corrections underway
  - ➢ Post-launch recalibration underway (v1.1)

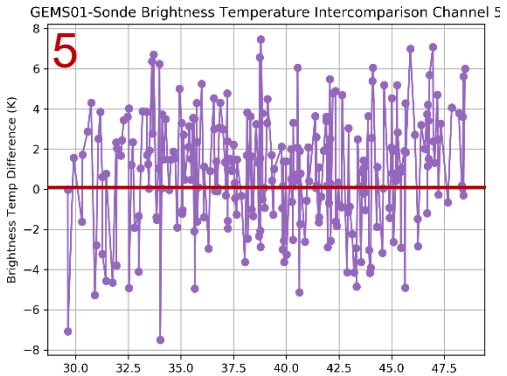
# GEMS-01 IOD Radisonde Validation

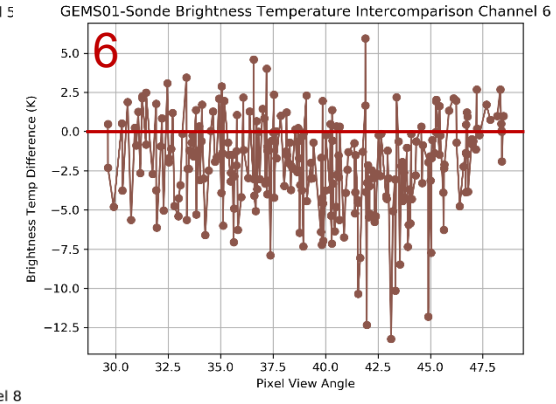


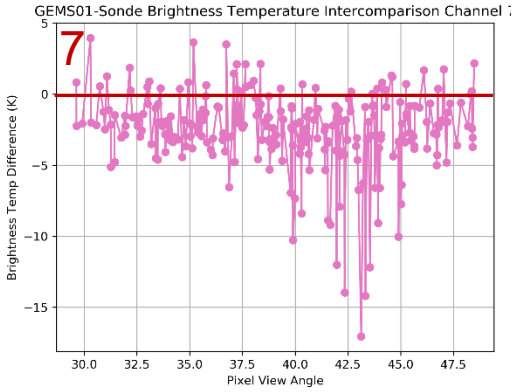



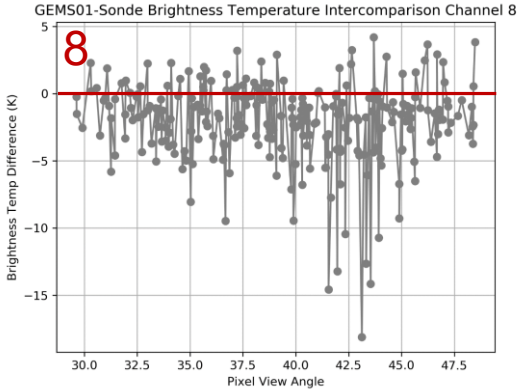




18 total soundings from NOAA Integrated Global Radiosonde Archive (IGRA) Version 2, Zhengzhou sonde CHM00057083 @ (34.7167,113.6500)

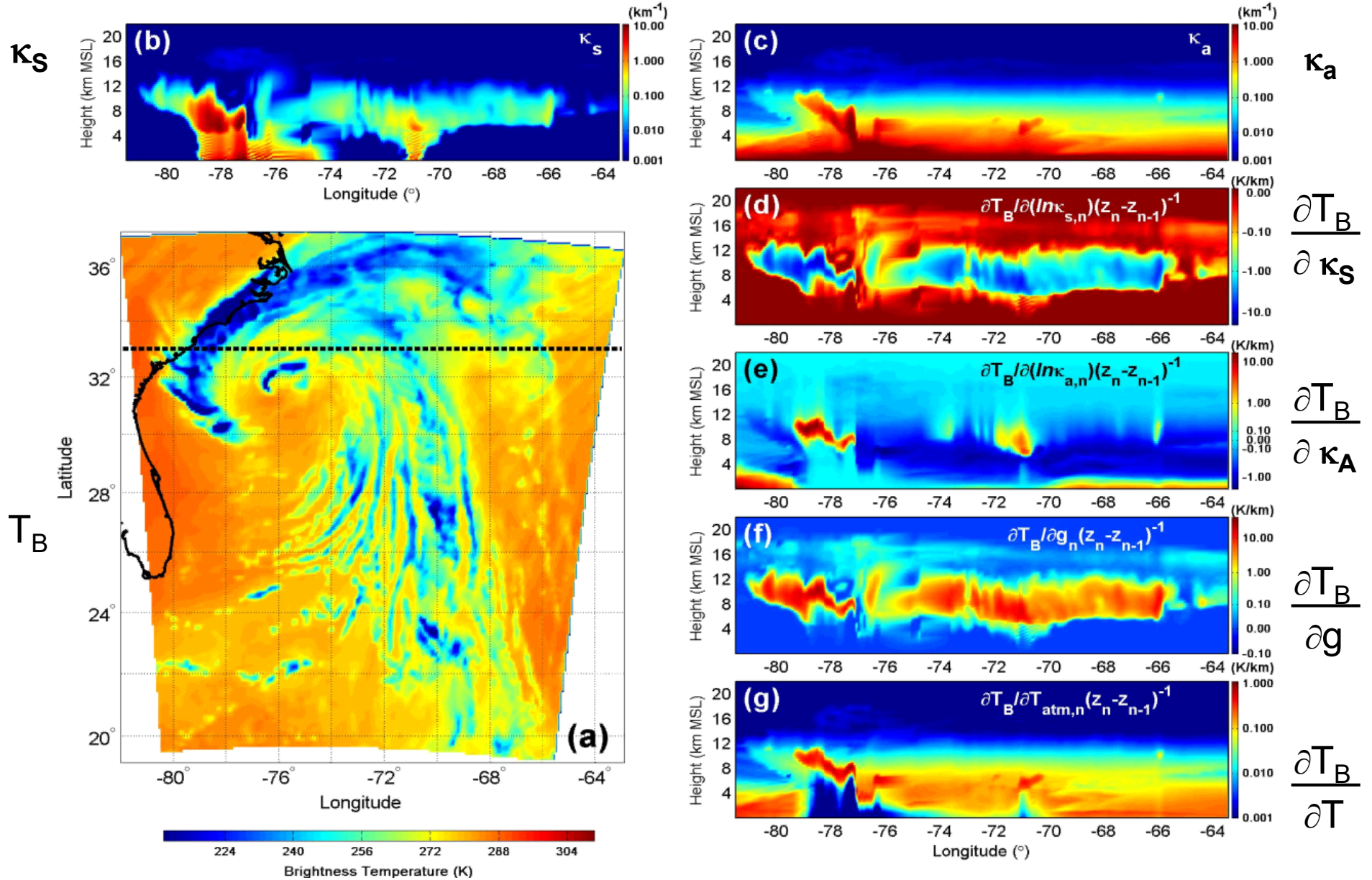
Clear-air, 15 minute/0.5° coincidence

MRT (Liebe MPM87) forward RT model calculations, land background with 5% reflectivity, multiple view angles 29-48°

$\langle\Delta\rangle \sim 8$ to -2 K, roughly consistent with FY3C comparisons

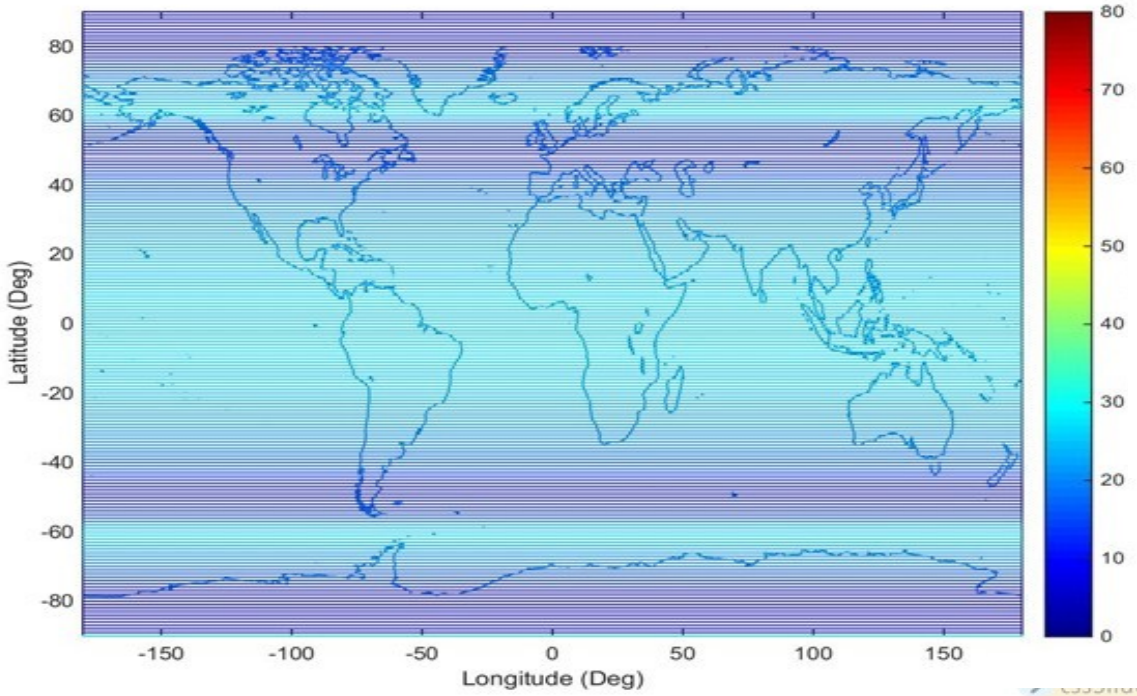
Biases being considered along with FY3C matchups for post-launch v1.1 recalibration

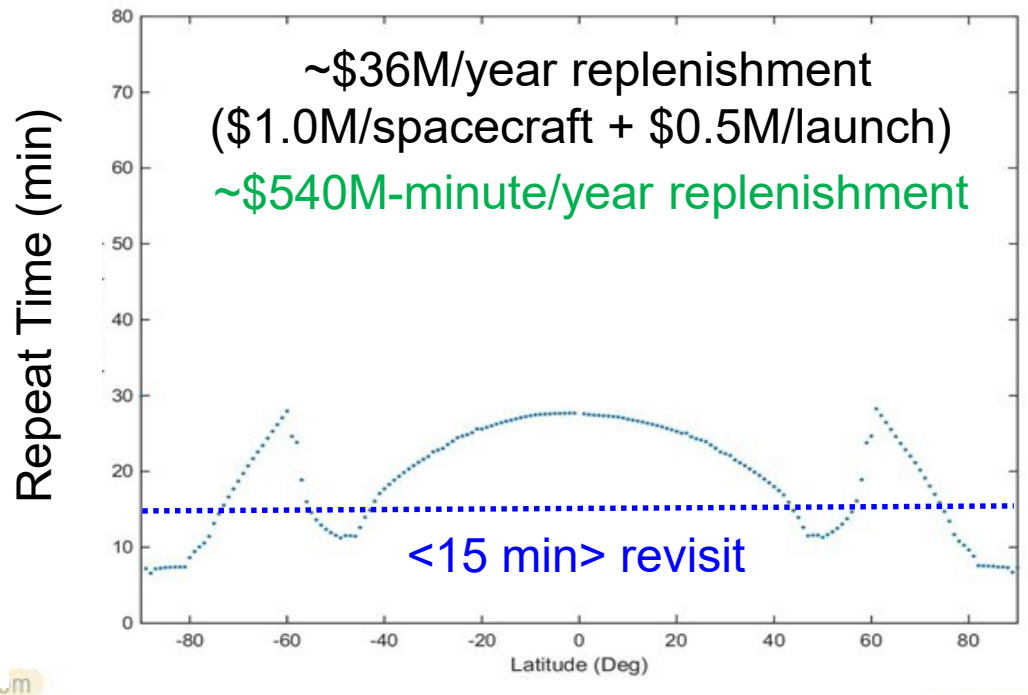
MM5/DO Hurricane Bonnie 183.3101 - 17GHz 26 August 1998 00:15 UTC



# OMS GEMS Constellation: 48x Revisit Times

## Minimum 2 year average on-orbit lifetime (6U)




| Simulation Number | Planes | Satellites per Plane | GPS | ISS | A-Train | Global Star | Iridium |
|---|---|---|---|---|---|---|---|
| 1 | 8 | 3 | 1 | 3 | 1 | 0 | 3 |
| 2 | 10 | 3 | 2 | 3 | 1 | 0 | 4 |
| 3 | 12 | 3 | 2 | 4 | 2 | 0 | 4 |
| 4 | 14 | 3 | 2 | 5 | 2 | 0 | 5 |
| 5 | 16 | 3 | 2 | 6 | 3 | 0 | 5 |

Assumed 2-year lifetime at 450-500 km altitude is conservative.

~10-25 minute average revisit time achievable using a large “random orbit” 48-satellite GEMS constellation array.

# Summary

- **The GEMS-01 IOD mission is achieving its planned engineering and observational goals**
  - Nyquist sampling – highest resolution microwave temperature sounder to date!
  - Highly stable radiometric performance, validation with pre-launch L1c calibration algorithm validation, post-launch re-calibration underway
  - Georegistration and spatial resolution within engineered design specifications
  - Compelling cost model feeding into future GEMS instrument designs and risk reduction
  - Improvements include additional bands and channels, improved calibration accuracy, spatial resolution, and bus navigation and communications capabilities.