Validation of PARMIO with WindSat TB

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Development of Ocean Retrieval Algorithms for the Copernicus Imaging Microwave Radiometer CIMR

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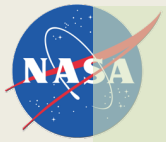
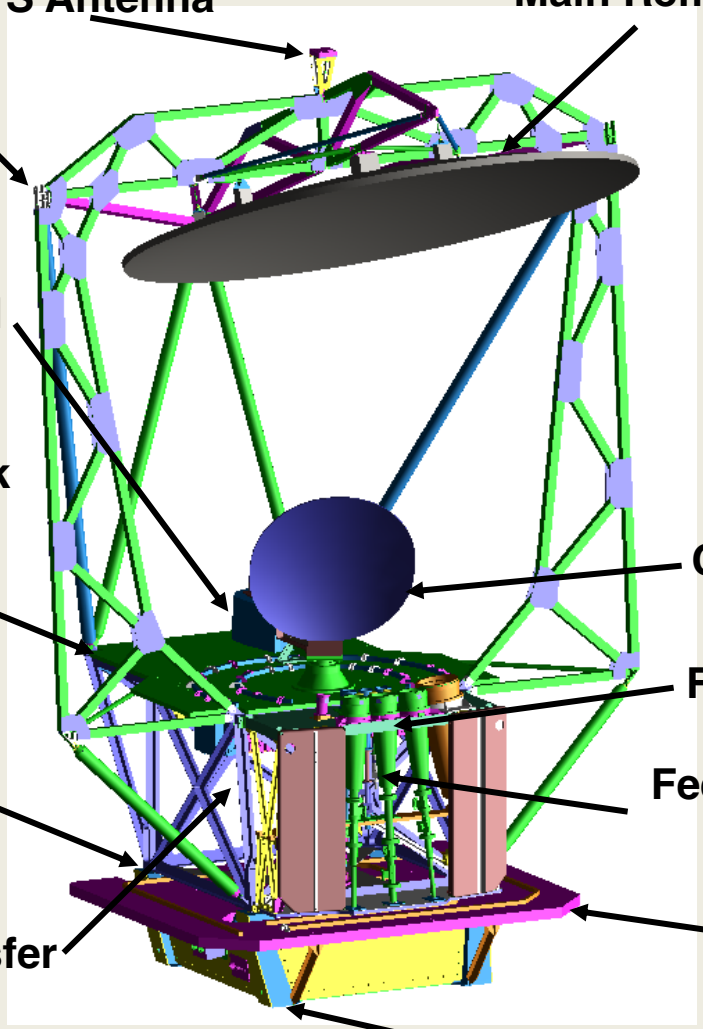


Topics

1. WindSat Sensor Configuration.
2. Calibration.
3. WindSat TB Data Set provided by RSS.

WindSat Payload Configuration



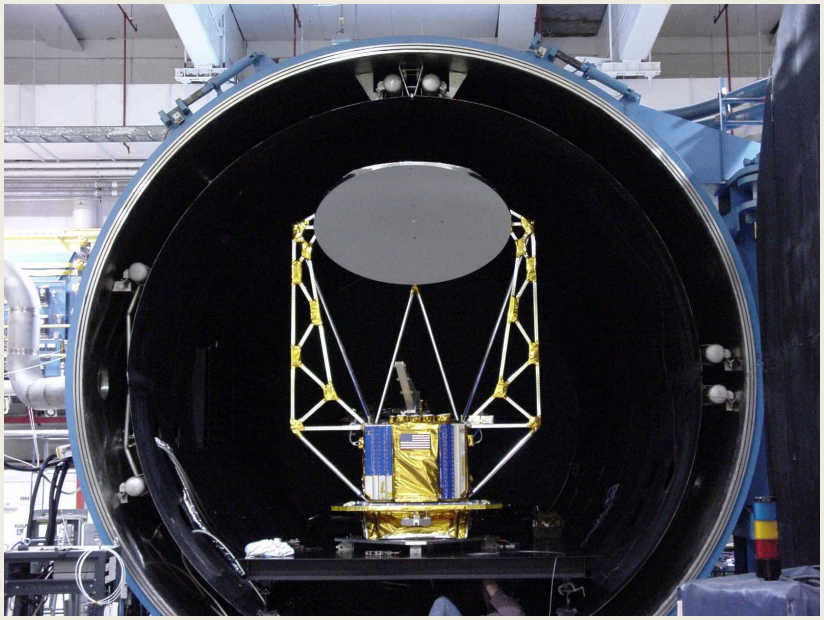
Height	320 cm
Width	251 cm
Weight	306 kg
Power	295 Watts
Spin Rate (Nom)	31.6 rpm
RF	22 Channels 5 Frequencies

External calibration (hot + cold load)
like AMSR, SSM/I

Figure provided by NRL (M. Bettenhausen)

WindSat Flight Build

WindSat in TVAC Chamber



WindSat Feed Horn Array

Coriolis Satellite at Launch Site

Operating: 2003 - 2020

Figure provided by NRL (M. Bettenhausen)

WindSat Channel Configuration

Frequency [GHz]	Polarizations	BW [MHz]	τ [msec]	NEDT (1)	EIA [deg]	IFOV [km x km]
6.8	VH	125	5.00	0.48	53.8	39 x 71
10.7	VH PM LR	300	3.50	0.37	50.1	25 x 38
18.7	VH PM LR	750	2.00	0.39	55.6	16 x 27
23.8	VH	500	1.48	0.55	53.2	20 x 30
37.0	VH PM LR	2000	1.00	0.45	53.2	8 x 13

- 5 frequency bands.
  - Different EIA: 50.1 – 55.6 deg.
- 11 feed horns.
  - Dual polarization (VH) at 6.8 and 23.8 GHz.
  - Fully polarimetric at 10.7, 18.7, 37.0 GHz.
- Separate feeds for +/-45 (PM) pol and left/right (L/R) pol.
  - 3rd Stokes: S3 = P - M
  - 4th Stokes: S4 = L - R

(1) NEDT for IFOV, WindSat at 25°C, Warm load=281 K

RSS WindSat Ocean Products

Ocean Product	Spatial Resolution [km x km]	Channels used
SST	39 x 71	6.8 VH, 10.7 VH,18.7 VH, 23.8 VH, 37.0 VH
Wind Speed low resolution	25 x 38	10.7 VH,18.7 VH, 23.8 VH, 37.0 VH
Wind Direction	25 x 38	10.7 VHPMLR, 18.7 VHPMLR, 37.0 VHPMLR
Wind Speed medium resolution	16 x 27	18.7 VH, 23.8 VH, 37.0 VH
Columnar Water Vapor	16 x 27	18.7 VH, 23.8 VH, 37.0 VH
Columnar Cloud Liquid Water	16 x 27	18.7 VH, 23.8 VH, 37.0 VH
Rain Rate	8 x 13	37.0 VH
All-Weather Wind Speed TC Wind Speed	25 x 38 no rain 39 x 71 in rain	6.8 VH, 10.7 VH

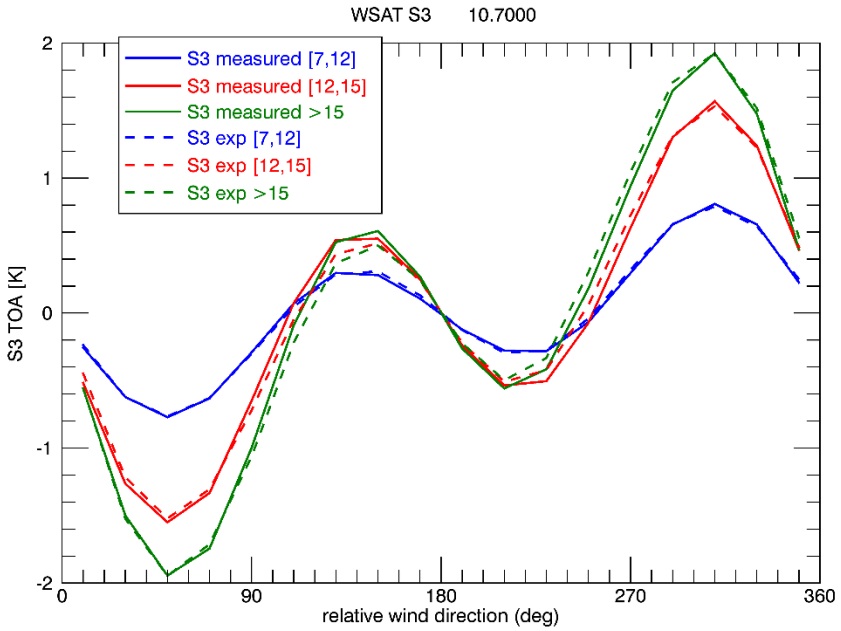
WindSat as Proxy for CIMR

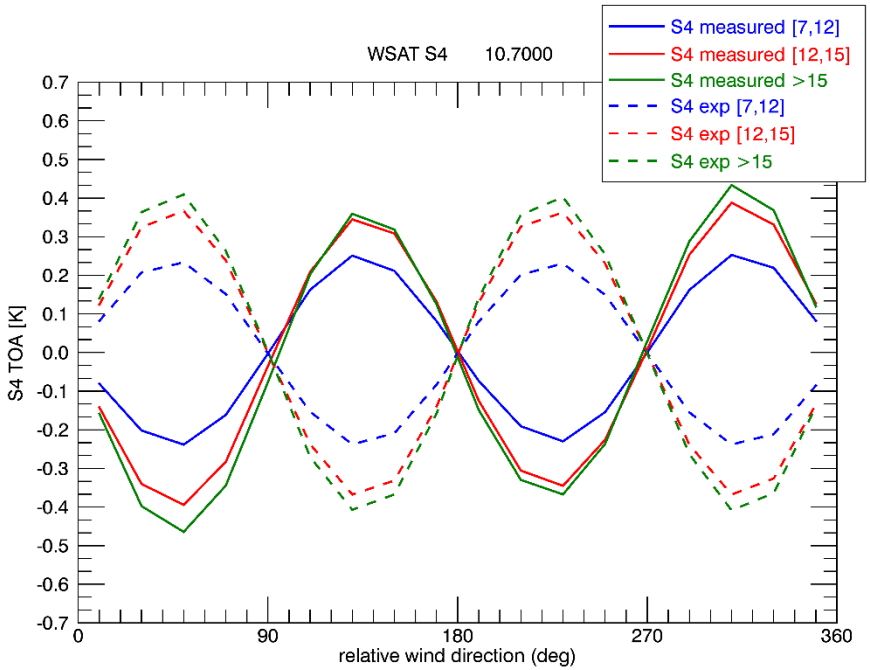
1. Measures at 6 – 37 GHz:
   - 6.8, 10.7, 18.7, 23.8, 37.0 GHz bands
2. Fully polarimetric
   - At 10.7, 18.7, 37.0 GHz
   - 3rd and 4th Stokes.
3. Fore and aft looks.
4. Local ascending node time: 18:00
   - **Same as SMAP**.
   - Allows easy WindSat – SMAP collocations: Proxy for CIMR bands.
   - Currently most CIMR pre-launch studies are based on AMSR2 (>=C-band) – SMOS (L-band) match-ups.
   - **Using WindSat – SMAP match-ups will be a better testbed.**
5. Well calibrated sensor.
   - Best calibrated microwave radiometer before GMI.
   - Reaches close to absolute calibration.

WindSat as Testbed for PARMIO/SURFEM

- Absolute calibrated sensor.
  - Similar potential for testing as GMI.
- Important outstanding task:
  Check wind directional signal:
  - V, H, S3, S4.
  - Plot $\Delta T_B = T_B(\text{meas}) - T_B(\text{RTM, isotropic})$ as function of relative wind direction ϕ_r at various wind speeds W and compare with PARMIO.
  - Need to go to winds > 8 m/s to see a signal.
  - External W and ϕ_r (ERA5, NCEP, CCMP).
  - Check sign conventions.
  - I am skeptical!

WindSat S3 + S4





full lines = WindSat data. dashed lines = RSS RTM, consistent with Yueh papers.
S3 = P – M S4 = L – R
relative wind direction = azimuth - meteorological (out of) wind direction

wind direction:
from N, 0
from E, + 90 …

4th Stokes needs to be flipped: either the RTM or S4 = R – L.
Our WindSat wind vector algorithm does the latter one.

Follow-Up Sensor: WSF-MWI

- >= 2023
- US DoD
- Weather System Follow on Microwave Radiometer.
- **Combines polarimetric capabilities of WindSat with absolute calibration accuracy of GMI**.
- 4-point calibration system.
- 10.85 VHPMLR, 18.85 VHPMLR, 23.8 V, 37 VHPMLR
- no C-band.

Follow-Up Sensor: COWVR

- Compact Wind Vector Radiometer.
- Major goal: Low-cost radiometer with wind vector capabilities.
- Operating since January 2022
- US DoD / JPL.
- Only antenna rotates. Feed-horn bench stays fixed.
- Fully polarimetric at 18.7, 23.8, 33.9 GHz.
- No C or X-band channels ⇒ No skill in rain.
- Internal calibration.
- Full polarization mixing: 2nd Stokes Q and 3rd Stoked S3. Polarization angles go from 0 to 360 deg.
- Rotation needs to be correction. Strict pointing requirements.
- Data release late 2022.
- Results promising.

Calibration and Intercalibration (1)
WindSat Vicarious Calibration

- Major tasks: Determine of instrument parameters.
  - Biggest issue: Antenna spillover (cold space fraction).
  - General: Antenna backlobes gain hard to measure.
- 1st RSS WindSat release (Version 7).
  - Ocean target (vicarious) calibration.
  - **T_B (measured) – T_B (RTM)** over (global) **ocean** to adjust calibration parameters (spillover, cross-pol).
  - Depends on RTM (dielectric constant model, wind emissivity model, atmospheric absorption).

Calibration and Intercalibration (2)

GMI Intercalibration

- Latest RSS WindSat release (Version 8) inter-calibrates WindSat to GMI.
  - GMI is the best MW radiometer.
  - Reaches absolute calibration standard.
    - **Wentz, F.J. and D. Draper**, 2016: On-Orbit Absolute Calibration of the Global Precipitation Measurement Microwave Imager. *J. Atmos. Oceanic Technol.*, 33, 1393–1412, DOI: 10.1175/JTECH-D-15-0212.1.
  - 4-point calibration system.
    - External hot and cold targets + 2 internal targets (noise)-diodes.
  - No (or only very minor) calibration anomalies.
  - Antenna spillover determined by back-lobe maneuvers.
    - Antenna backlobes looking at the Earth.
    - Found very good agreement with pre-launch spillover.

Calibration and Intercalibration (3)

Absolute Calibrated WindSat TB

- **GMI TB calibration is independent of specific RTM.**
- **So are the intercalibrated WindSat TB.**
- **You can (and should) test your RTM with the absolutely calibrated WindSat (GMI) TB.**
- Exception: WindSat C-band TB.
- Consider on-orbit inter-calibration CIMR – WSF-MWI (X-band + higher).

Calibration and Intercalibration (4):
WindSat Calibration Anomalies

- Pointing errors (roll, pitch specification).
- Hot load anomaly.
  - Thermal gradients in hot load. Mainly 18 GHz.
- Cold mirror anomalies.
  - Earth view intrusion.
  - Moon intrusion.
  - RFI intrusion from geo-stationary satellites.
- Small receiver non-linearities.
- …
- Has all been removed / corrected for.
- Meissner, T, F.J Wentz, D Draper, 2012, GMI Calibration Algorithm and Analysis Theoretical Basis Document, https://images.remss.com/papers/rsstech/2012_041912_Meissner_GMI_ATBD_vG.pdf.

RSS WindSat TB Data Set
Grid and Sampling (1)

- All channels have been resampled on fixed Earth grid.
  - Different EIA for different channels makes swaths very complicated.
  - Backus – Gilbert (BG) Optimum Interpolation (OI).
  - 1 file per orbit.
  - 1/8 deg regular grid.
    - Dimension 3120 x 1440
    - X- dimension: extra 35 deg to accommodate orbit tails.
  - Separate fore + aft grids.
  - Each grid cells contains measurements of 11 horns (22 channels), where available.
- 3 years: 2016, 2017, 2018.
  - Can be extended if wanted.
- netCDF4.

RSS WindSat TB Data Set

Grid and Sampling (2)

- All channels (X-band and higher) are sampled on the footprint size of the X-band (25 x 38 km) channels.
  - Results in noise reduction of higher frequency channels (Ku-band and higher).
  - Exception C-band, which is kept at its native resolution (39 x 71 km).
  - Guided by requirements for retrieving wind vectors.
- Basic Q/C flag is included in the data:
  - Missing or bad data.
  - Sun glint.
  - RFI glint over ocean from known geo-stationary satellites.
  - Land fraction.
  - Observation falls within climatological sea-ice mask.

RSS WindSat TB Data Set

Grid and Sampling (3)

- We have other sampling schemes prepared and can produce resampled TB data if wanted.
  - All channels sampled onto C-band resolution.
    - Typically employed for SST retrievals.
  - Ku-, K-, and Ka-band channels sampled onto Ku-band resolution.
    - Typically employed for vapor, cloud or high-resolution / high noise wind speed retrievals.
  - Ka-band at its native resolution.
    - Typically employed for rain rate retrievals.

RSS WindSat TB Data Set

Variables

1. Latitude and Longitude of grid cell.
2. Observation time.
   - Seconds since 01 JAN 2000 00Z.
3. Orbit position (fractional rev.).
4. EIA.
5. Looking azimuth angle.
6. Scan angle.
   - Average for samples that fall within grid cell.
7. Q/C flag.
8. Land fraction.
9. TB of all 22 channels.

RSS WindSat TB Data Set

Access

- Publicly available.
- Access
  - https://images.remss.com/~RSS-TB/
  - FTP client:
    - Host: ftp.remss.com.
    - User: RSS-TB.
    - Password: free.kwen.see.wind.waves
- Conditions of use:
  Please cite data set if used in publication.

Caveat: RFI

- Observed for geo-stationary TV satellites and to some extent also stationary sources (oil-platforms).
  - Especially a problem at 10.7 GHz.
  - Wide band width (300 MHz).
  - No RFI mitigation.
  - We have removed (flagged) observations reflection from geo-stationary satellites over the ocean as much as possible.
- **No RFI removal or flagging for land scenes!**

Next Step: Collocated WindSat – SMAP TB Set

- Adds L-band channel -> CIMR configuration.
- WindSat and SMAP have same ascending node time.
  - Allows easy match-up creation.
- Add ancillary data (ERA5, NCEP):
  - SST.
  - Wind speed.
  - Wind direction.
  - SSS.
  - Atmospheric profiles.