Lessons from WindSat Cal. / Val. Activities

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WindSat Description

- Fully polarimetric at 10.7, 18.7 and 37 GHz
- Swath limited to allow for forward and aft looks
- Three rows of feed horns so for forward look
  - 18.7 GHz scan leads 37 GHz scan
  - 10.7 GHz scan lags 37 GHz scan
- http://www.nrl.navy.mil/windsat

Freq. (GHz)	Channels	BW (MHz)	EIA (deg)	IFOV (km)
6.8	v, h	125	54.0	39 x 71
10.7	v, h, +/- 45, lc, rc	300	50.3	25 x 38
18.7	v, h, +/- 45, lc, rc	750	55.9	16 x 27
23.8	v, h	500	53.5	20 x 30
37.0	v, h, +/- 45, lc, rc	2000	53.5	8 x 13

Sensor Data Records (SDRs)

- All frequencies and polarizations are resampled and averaged to a common footprint.
- Forward swath width is about 900 km
  - 6.8 GHz available over about 3/4 of the swath
- Three resolutions:
  - Low: 50 km x 71 km (operational) (All channels)
  - Medium: 35 km x 53 km (in testing) (No 6.8 GHz channels)
  - High: 25 km x 35 km (in testing) (No 6.8 GHz channels)
- Sampling is the same for all resolutions
  - about 12.5 km along track and along scan
- Retrieval distance to land depends on orientation of elliptical footprint to coastline
  - Low: 80 km to 115 km
  - Medium: 55 km to 80 km
  - High: 35 km to 60 km

On-Orbit Calibration Corrections

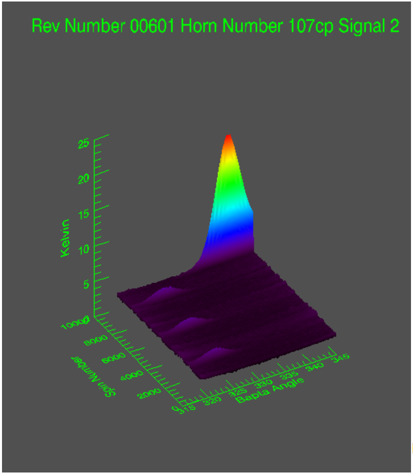
- Geolocation and pointing
- Cold and warm calibration load temperatures
  - Cold load lunar contamination
  - Cold load space-based RFI at 10.7 GHz
  - Warm load thermal gradients
- Antenna temperature corrections
  - Along-scan variations
- “Offset” corrections for the 3rd and 4th Stokes T_bs
- “Shadowing” in the 3rd and 4th Stokes components

Geolocation and Pointing Corrections

- Two methods were used to identify and correct geolocation and pointing errors
  - Coastline matchup geolocation analysis
    - Purdy, *et al*, IEEE TGRS, vol. 44, p. 496
  - Scan bias analysis
    - Meisnner and Wentz, IEEE TGRS, vol. 44, p. 506
- Systematic timing and along scan timing errors in ground data processing
- Spacecraft pitch offset of 0.19 deg. and roll offset of -0.14 deg.
- Small beam azimuth biases in the 23.8 GHz and 37 GHz channels

Contamination of the Cold Load Measurements

- Space-based RFI in the 10.7 GHz channels
  - Sources are transmitters in geosynchronous orbit (based on orbital viewing analysis)
- Lunar intrusion occurs for about 3-4 days centered on the full moon
- Both sources of contamination are short duration and are corrected using:
  - threshold detection
  - linear interpolation

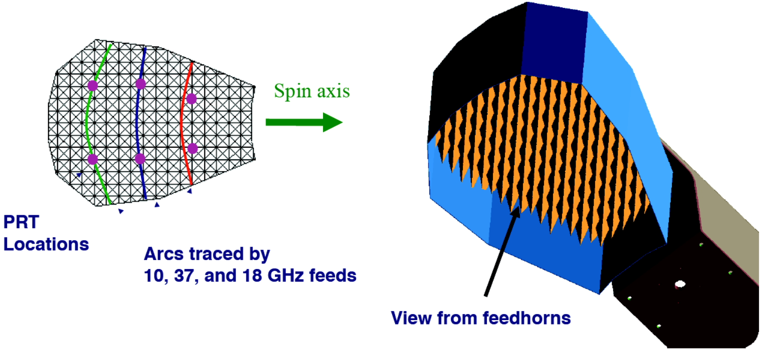


WindSat Warm Load Anomaly

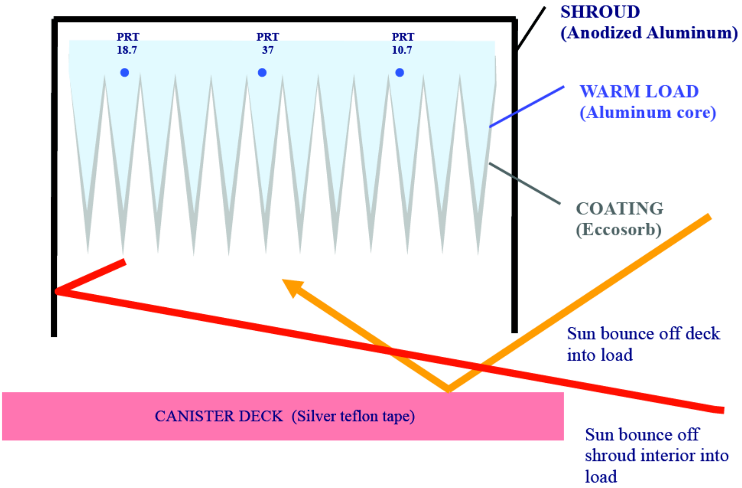
- Sun reflecting into warm load produces thermal gradients in the warm load
  - Not a significant problem during Feb., Mar., Oct. and Nov.
  - Worst in late May through mid-July
  - Effect is most severe for 18.7 GHz channels
  - 6.8 GHz and 23.8 GHz channels show little effect
- PRT measured warm load temperature is not what the radiometer measures
- Detailed problem description in Twarog *et al*, IEEE TGRS, March 2006

Warm Load Geometry

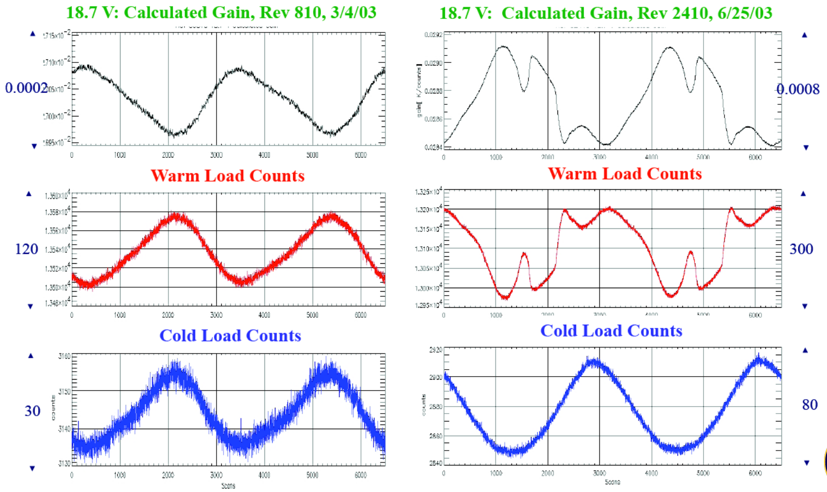
- Warm calibration target is designed for maximum thermal stability - passively warmed by the top deck
- Six PRTs are embedded in the base of the aluminum core



Sun Glint into the Warm Load (conceptual)



Gain, Warm Load, Cold Load Comparison



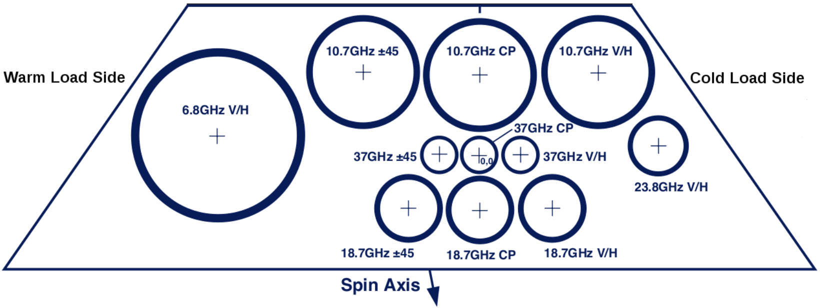
Warm Load Error Mitigation

- Errors in the T_bs due to warm load temperature errors are proportional to the scene temperature
  - Effects are negligible for 3rd and 4th Stokes components
  - Worst in late May through mid-July
- Impact is mitigated using a warm load temperature correction in current SDRs
  - Fit to receiver temperatures
  - Fit varies with satellite latitude and solar angle / time-of-year

Along-scan Variations

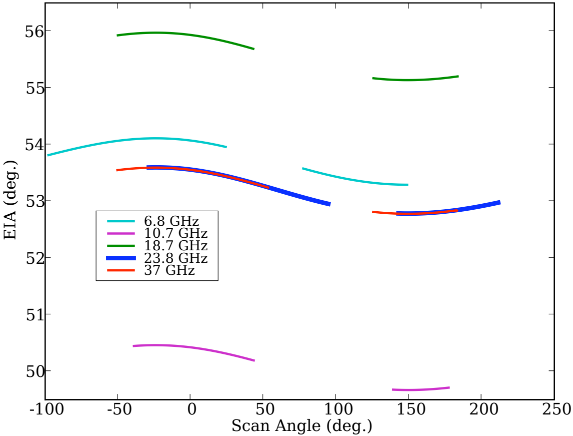
- Along-scan variations in the antenna temperatures result from changes in the feedhorn field-of-view
- Power from the earth scene, cold space, spacecraft and the sensor
- Corrected using along-scan dependent spillover and bias corrections
  - $T_A = \eta T_A^{'} + (1 - \eta) T_C + \beta$
    - T_A is the antenna temperature
    - η is spillover
    - T_C is cosmic background temperature
    - β is a bias term
  - Changes in cross polarization may also be present but are difficult to correct accurately
    - $T_p \approx (1 - a) T'_{Ap} + a(T'_{Av} - T'_{Ah})$ where $a << 1$

Feedbench View from Main Reflector



EIA Along-Scan Variations

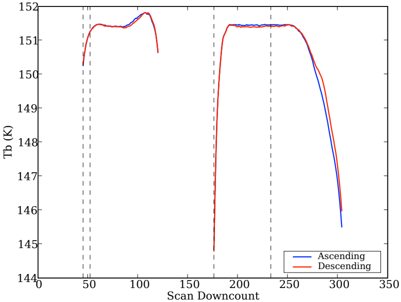
- Earth incidence agle (EIA) varies along scan due to satellite pitch/roll offsets
  - Complicates along-scan analysis; T_bs depend on EIA
- PRA also changes along-scan; must be considered for 3rd Stokes



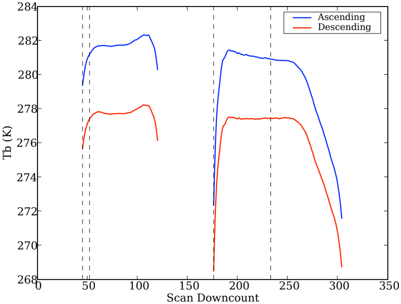
Vicarious Calibration

- Minimum ocean brightnesss temperature provides cold calibration temperature
  - Ruf, *et al*, IEEE TGRS, vol. 38, p. 44, 2000.
  - Ruf, *et al*, IEEE TGRS, vol. 44, p. 470, 2006.
- Tropical forest (Amazon) provides warm calibration target
  - Brown and Ruf, J. Atm. and Ocean. Tech. vol. 22, p. 1340.
  - Mo, IEEE TGRS, vol. 45, p. 958.
- Analysis used 2 months of data ($>$4000 orbits)

Along Scan / 6.8 V TDR



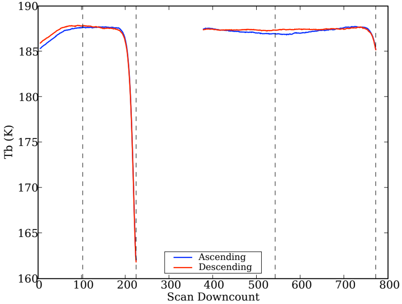
Ocean



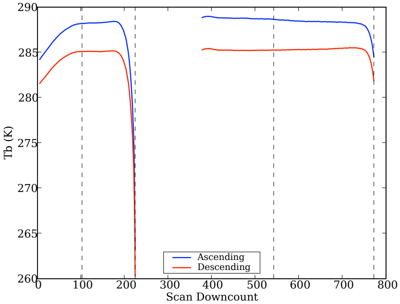
Tropical Forest

Dashed lines note extent of aft and fore SDR swaths.

Along Scan / 23.8 V TDR



Ocean



Tropical Forest

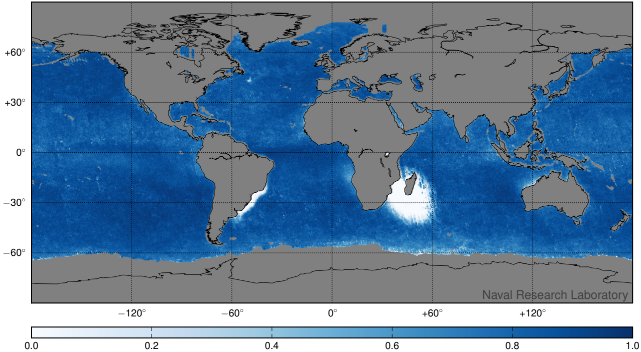
Dashed lines note extent of aft and fore SDR swaths.

Radio Frequency Interference

- Persistent terrestrial and space-based RFI sources at 6.8, 10.7 and 18.7 GHz
  - Space-based RFI: signals from satellites broadcasting from geosynchronous orbit reflect off earth surface
- Detection of RFI over ocean uses chi-squared test from wind retrieval algorithm
  - Adams, *et al*, “Identification of ocean-reflected radio-frequency interference using WindSat retrieval chi-square probability,” IEEE GRSL, to be published.
  - Adams, *et al*, “Ocean-Reflected Radio-Frequency Interference During the WindSat Era,” poster from MicroRad 2010.
- RFI should be screened from data used for calibration analyses
- RFI has changed throughout WindSat Mission

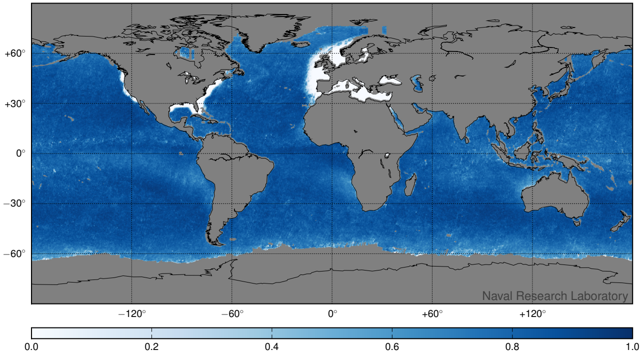
Ocean RFI / Ascending Pass

- 10.7 GHz channels
- Ocean retrieval $(P(\chi^2))^{0.3}$ shown for Oct-Dec 2009



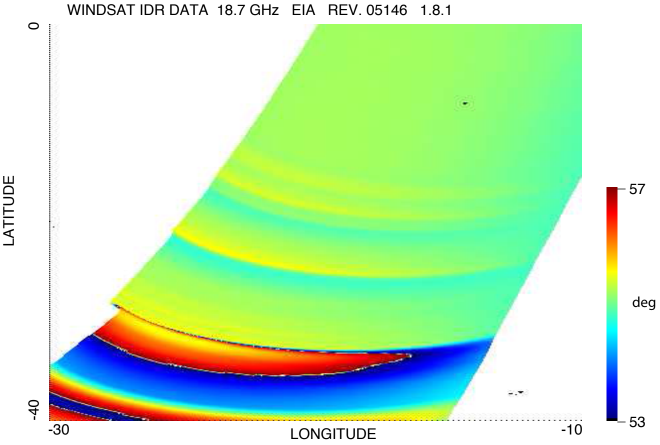
Ocean RFI / Descending Pass

- 10.7 GHz channels near Europe and 18.7 GHz channels coastal US
- Ocean retrieval $(P(\chi^2))^{0.3}$ shown for Oct-Dec 2009



Satellite Attitude Transients

- Anomalies caused by rapid changes in the satellite attitude or reported attitude. Data is flagged.
- Less than 0.5 percent of the data is affected.



Summary

- We have focused on consistent calibration over the swath and time (not absolute or intercalibration with other sensors)
  - Absolute calibration to our radiative transfer model is done during EDR processing
- WindSat brightness temperature calibration compares favorably to other imagers
- We continue to monitor calibration
  - Investigation of variation over mission lifetime in progress
  - RFI monitoring
- WindSat operating nominally after 7 years
  - No significant degradation of sensor mechanical or receiver performance

Backup

Scan Geometry

- Angular distribution of measurements for one scan.
- Radial positions have been shifted for display purposes