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Intercalibration of AMSR-E and WindSat Brightness Temperature Measurements over Land Scenes

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Remote Sensing Systems
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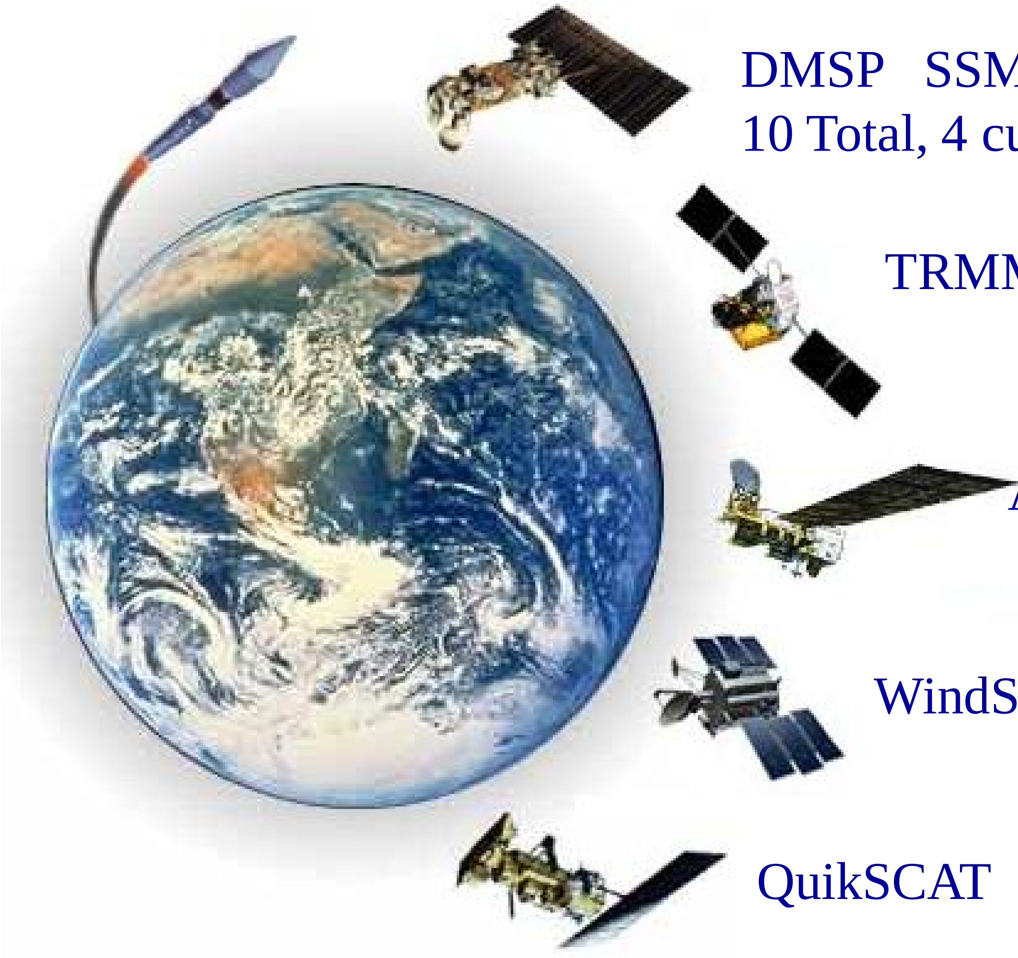
RSS Version 7 Products

Intercalibrated multi-platform suite
100 years satellite data
Release in progress



DMSP SSM/I, SSMIS
10 Total, 4 currently operating

TRMM TMI

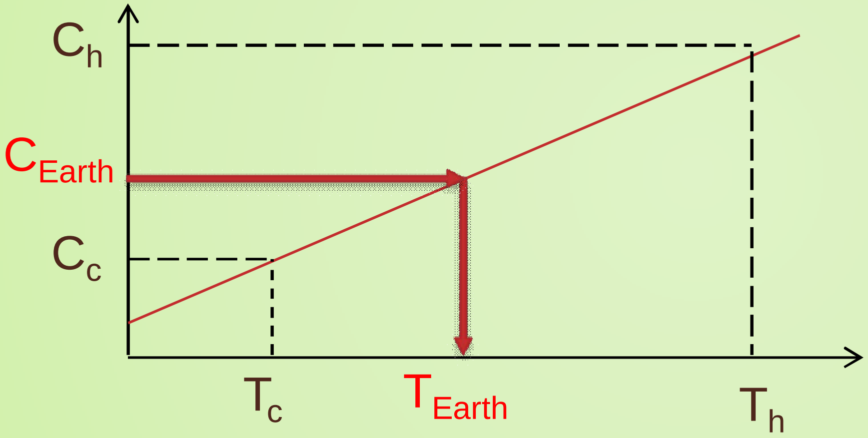
AMSR-E, AMSR

WindSat

QuikSCAT

Radiometric Calibration

- Transformation of radiometer measurements (voltage / counts) into TOA (top of the atmosphere) TB
- Ideally: 2 step linear transformation
  1. Counts to TA (antenna temperatures):
     2 tie points: hot / cold



$$C(T_A) = g \cdot T_A + O$$

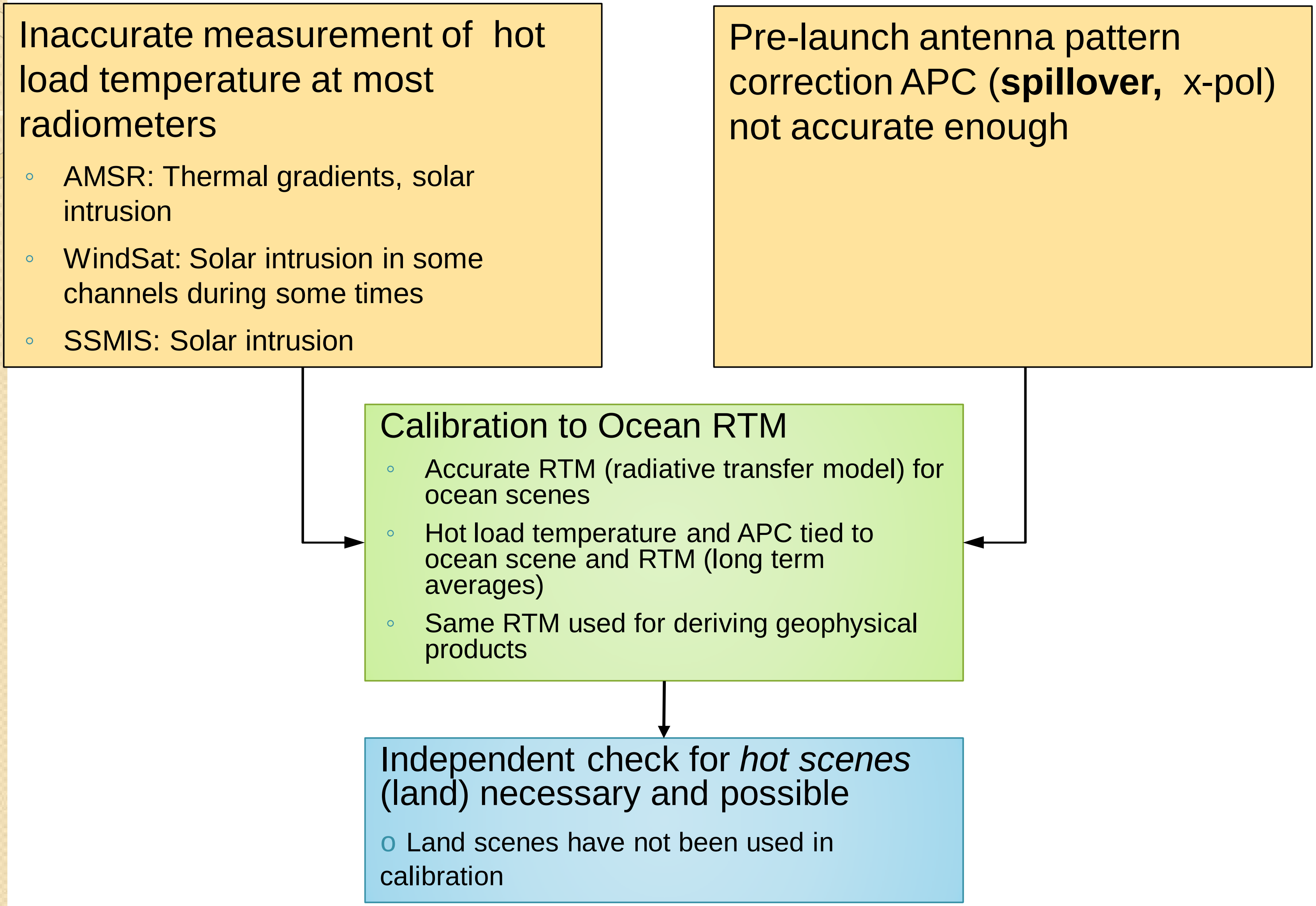
$$\text{gain: } g = \frac{C_h - C_c}{T_h - T_c}$$

$$\text{offset: } O = g - C_h T_h$$

  2. Antenna Pattern Correction (spillover, x-pol): TA to TB

$$T_B = \frac{1}{\eta} \cdot T_A + \ldots$$

Calibration to Ocean RTM



Inaccurate measurement of hot load temperature at most radiometers

- AMSR: Thermal gradients, solar intrusion
- WindSat: Solar intrusion in some channels during some times
- SSMIS: Solar intrusion

Pre-launch antenna pattern correction APC (**spillover,** x-pol) not accurate enough

Calibration to Ocean RTM

- Accurate RTM (radiative transfer model) for ocean scenes
- Hot load temperature and APC tied to ocean scene and RTM (long term averages)
- Same RTM used for deriving geophysical products

Independent check for *hot scenes* (land) necessary and possible

- Land scenes have not been used in calibration

Land – Ocean Calibration Consistency

$$T_A = T_h + \frac{C_{Earth} - C_h}{C_c - C_h} \cdot \left(T_c - T_h\right) \qquad T_B = \frac{T_A}{\eta} \qquad \lambda\left(C\right) \equiv \frac{C - C_h}{C_c - C_h}$$

$$T_B \approx \left(\frac{T_h}{\eta}\right) \cdot \left[1 - \lambda\left(C_{Earth}\right)\right] + \lambda\left(C_{Earth}\right) \cdot T_c$$

spillover + hot load temperature are tied together

$$\Theta_{B,Ocean} : \text{ Ocean RTM} \qquad \Theta_{B,Ocean} = \left(\frac{T_h}{\eta}\right) \cdot \left[1 - \lambda\left(\bar{C}_{Ocean}\right)\right] + \lambda\left(\bar{C}_{Ocean}\right) \cdot T_c$$

- Long term averaging of ocean observations
- Determine T_h/η
- Possibly tied into
    - solar angle (sun intrusion)
    - hot load thermistors

$$T_{B,Land} = \frac{T_h}{\eta} \cdot \left[1 - \lambda\left(C_{Land}\right)\right] + \lambda\left(C_{Land}\right) \cdot T_c$$

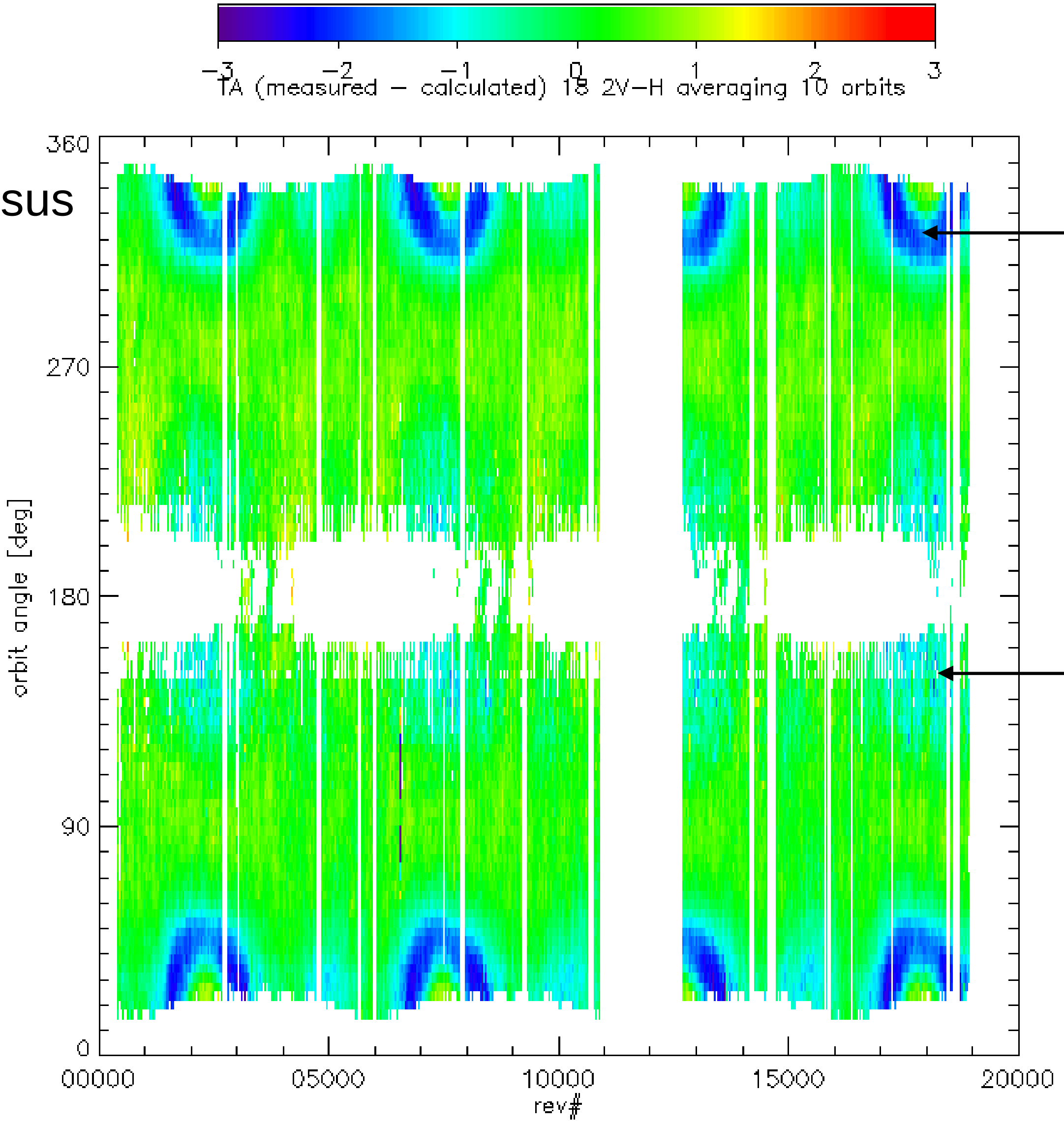
$$T_{B,Land} = \frac{\left[1 - \lambda\left(C_{Land}\right)\right]}{\left[1 - \lambda\left(\bar{C}_{Ocean}\right)\right]} \cdot \Theta_{B,Ocean} + \left\{\lambda\left(C_{Land}\right) - \lambda\left(\bar{C}_{Ocean}\right) \cdot \frac{\left[1 - \lambda\left(C_{Land}\right)\right]}{\left[1 - \lambda\left(\bar{C}_{Ocean}\right)\right]}\right\} \cdot T_c$$

Example: WindSat Hot Load Solar Intrusion

WindSat

measured versus computed TB

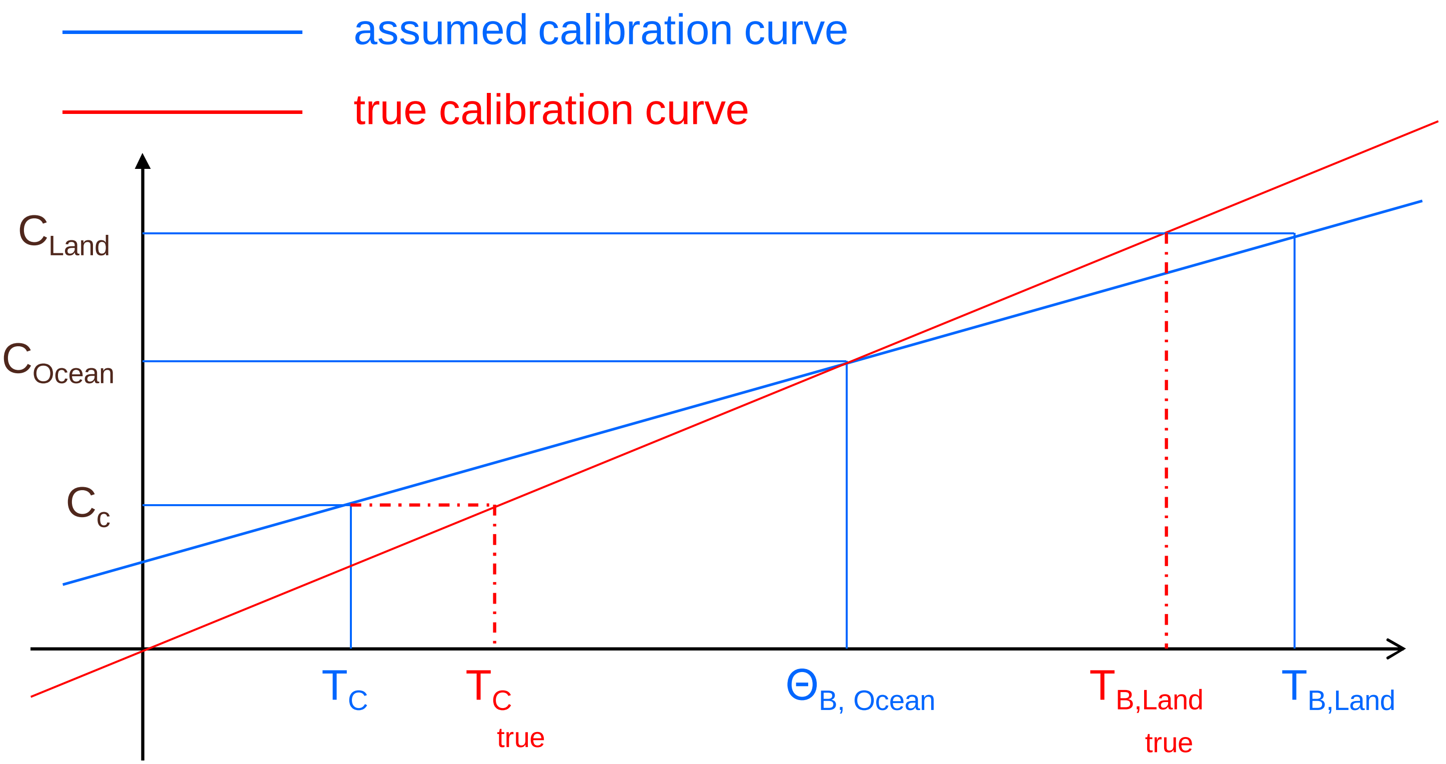
as function of time and orbit position



Intrusion of reflected sun light

Direct Sun Intrusion

Error in Cold Space Temperature

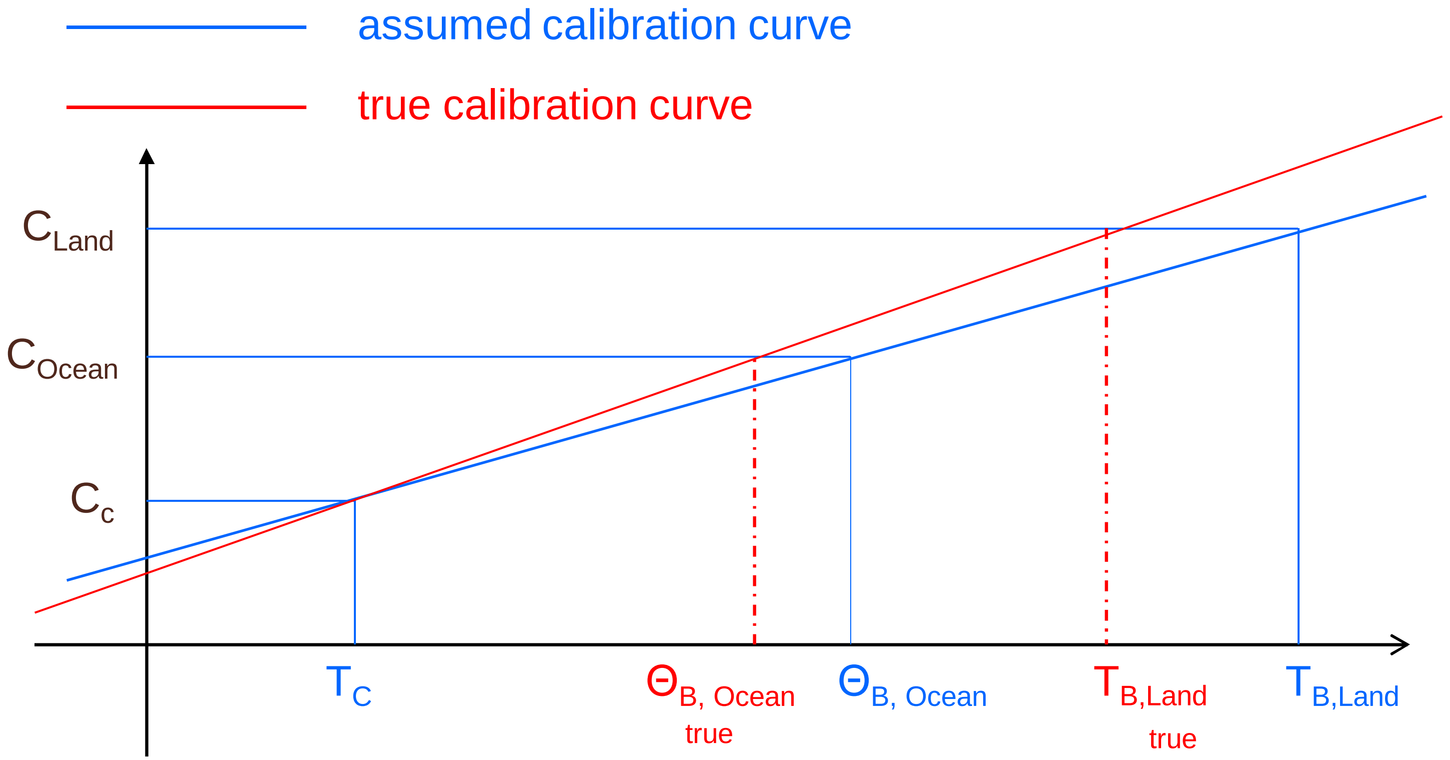


Real cold space temperature higher than assumed

- radiation intrusion from S/C into cold mirror
- radiation intrusion from Earth into cold mirror (backlobes)
- main antenna reflects radiation from Earth into feeds during cold scan
- RFI from geostationary satellites intrusion into cold scan

Real TB over land is lower than assumed

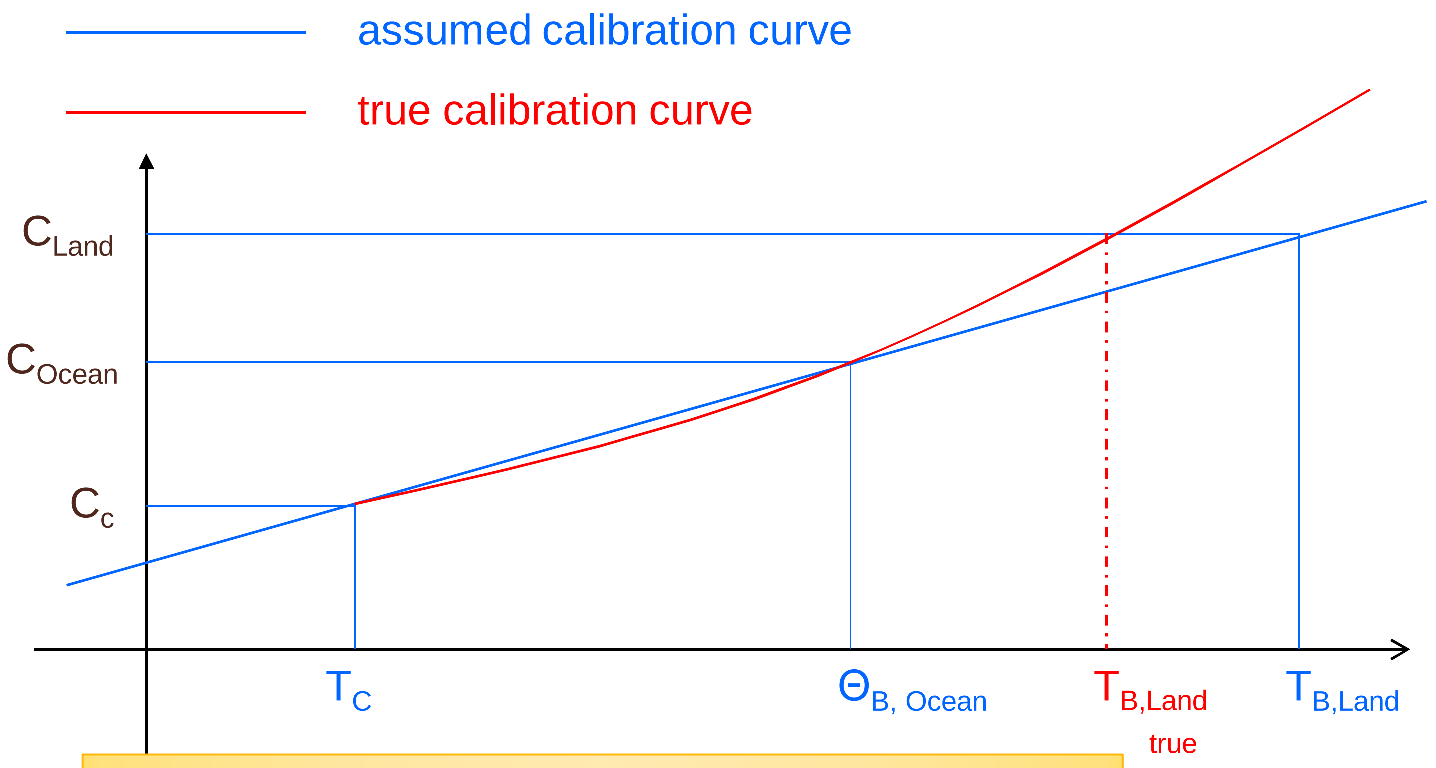
Error in Ocean RTM



Real Ocean RTM TB higher or lower than assumed

Real TB over land is lower or higher than assumed

Receiver Non-Linearity



Count to TA calibration curve non-linear

Real TB over land is lower or higher than assumed

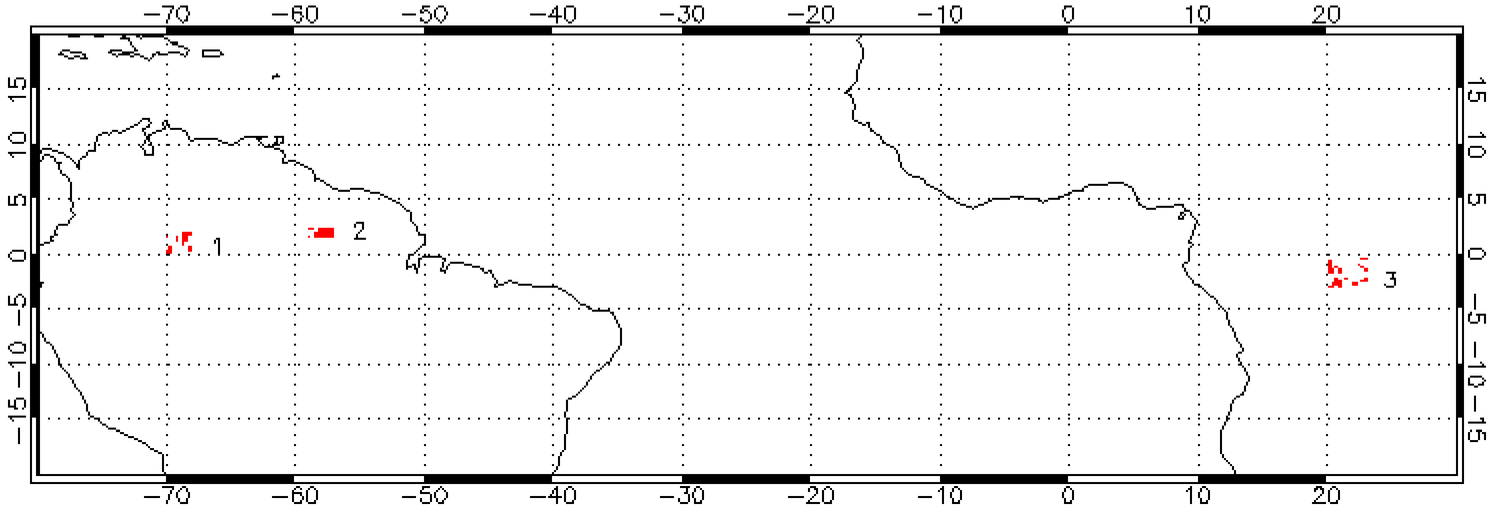
Known non-linearity for AMSR 7 GHz channels

- First guess from comparison between 7 and 11 GHz channels
- AMSR-E 7 GHz land surface TB about 6 – 7 K off without correction
- Taken into account in current RSS AMSR-E calibration (Version 6)

AMSR-E - WindSat Intercalibration

- Collected 1 year of data
- Using current version of AMSR-E calibration (version 6)
- 3 tropical forest calibration sites
  - Classified as *evergreen broadleaf forest* in USGS Global International Geosphere Biosphere Programme (IGBP) maps for whole footprint
  - Allows simple radiative transfer model calculation
- Auxiliary fields for RTM
  - NCEP GDAS land surface temperature
  - NCEP GDAS atmospheric profiles: pressure, temperature, humidity, cloud water
- AMSR-E 1:30 AM (descending) and WindSat 6:00 AM (descending) swaths only
  - Minimize diurnal variations
- Intercomparison between
  - Different frequencies
  - 2 radiometers
- Radiative transfer model over land needed to compensate for
  - Differences in Earth Incidence Angle (EIA)
  - Differences in frequencies
  - Diurnal differences

Calibration Sites



Site #	Latitude	Longitude	Region
1	0 - 2N	70W - 68W	Brazil/Columbia
2	1.5N - 2.5N	59W - 57W	Guiana
3	3S - 0	20E - 23E	Zaire

RTM for Vegetated Land Surfaces

T_B (TOA) =

upwelling atmospheric radiation	$T_{B,atm\uparrow} = \left(1-\tau_{atm}\right)\cdot T_{atm\uparrow}$
radiation emitted from the surface (E_S = *emissivity*, T_S = *temperature*), attenuated by vegetation (τ_{veg}) and atmosphere (τ_{atm})	$E_S\ T_S\ \tau_{veg}\ \tau_{atm}$
downwelling atmospheric + cold space radiation attenuated by vegetation, reflected by surface (R_S = 1 – E_S), attenuated by vegetation and atmosphere	$R_S\left(T_{B,atm\downarrow}+\tau_{atm}T_{cold}\right)\tau^{2}_{veg}\tau_{atm}$ $T_{B,atm\downarrow} = \left(1-\tau_{atm}\right)\cdot T_{atm\downarrow}$
radiation emitted from the vegetation (T_{veg} = temperature), attenuated by atmosphere ω = *single scattering albedo =scattering/extinction*	$\left(1-\omega\right)T_{veg}\left(1-\tau_{veg}\right)\tau_{atm}$
radiation emitted from the vegetation, reflected by the surface, attenuated by vegetation and atmosphere	$\left(1-\omega\right)T_{veg}\left(1-\tau_{veg}\right)\tau_{atm}R_S\tau_{veg}$
downwelling atmospheric radiation, reflected at air – vegetation boundary, attenuated by atmosphere ($\rho_{air\text{-}can}$= *bi-static scattering coefficient*)	$\tau_{atm}\cdot\int d\Omega'\rho_{air-veg}\left(\Omega',\Omega\right)\cdot T_{B,atm\downarrow}\left(\Omega'\right)$

Simplification: Dense Vegetation

- Dense Vegetation: $\tau_{veg} = 0$
  - Rain forest
- $T_{veg} = T_S$
- The term $(1 – \omega)$ plays the role of an effective emissivity $E_{eff}(\theta)$ of the vegetation layer.
  ω = *single scattering albedo =scattering/extinction*
- Reflection at air-vegetation boundary approximated as specular $\int d\Omega' \rho_{air-can}\left(\Omega',\Omega\right)\cdot T_{B,atm\downarrow}\left(\Omega'\right) \approx R_{eff}\left(\theta\right)\cdot T_{B,atm\downarrow}\left(\theta\right)$

$$= \left(1 - E_{eff}\left(\theta\right)\right)\cdot T_{B,atm\downarrow}\left(\theta\right) = \omega\cdot T_{B,atm\downarrow}\left(\theta\right) = \omega\cdot\left(1-\tau_{atm}\right)\cdot T_{atm\downarrow}$$

$$T_B\left(\mathrm{TOA}\right) \approx T_{B,atm\uparrow} + \tau_{atm}\cdot\left(1-\omega\right)\cdot T_{veg} + \tau_{atm}\cdot\omega\cdot T_{B,atm\downarrow}$$

$$= \left(1-\omega\right)\cdot T_{veg} + \left(1-\tau_{atm}\right)\cdot\left\{T_{atm\uparrow} - \left[1-\omega\right]\cdot T_{veg} + \omega\cdot\tau_{atm}\cdot T_{atm\downarrow}\right\}$$

- Atmospheric parameters and T_{veg} from NCEP
- Single scattering albedo ω only parameter

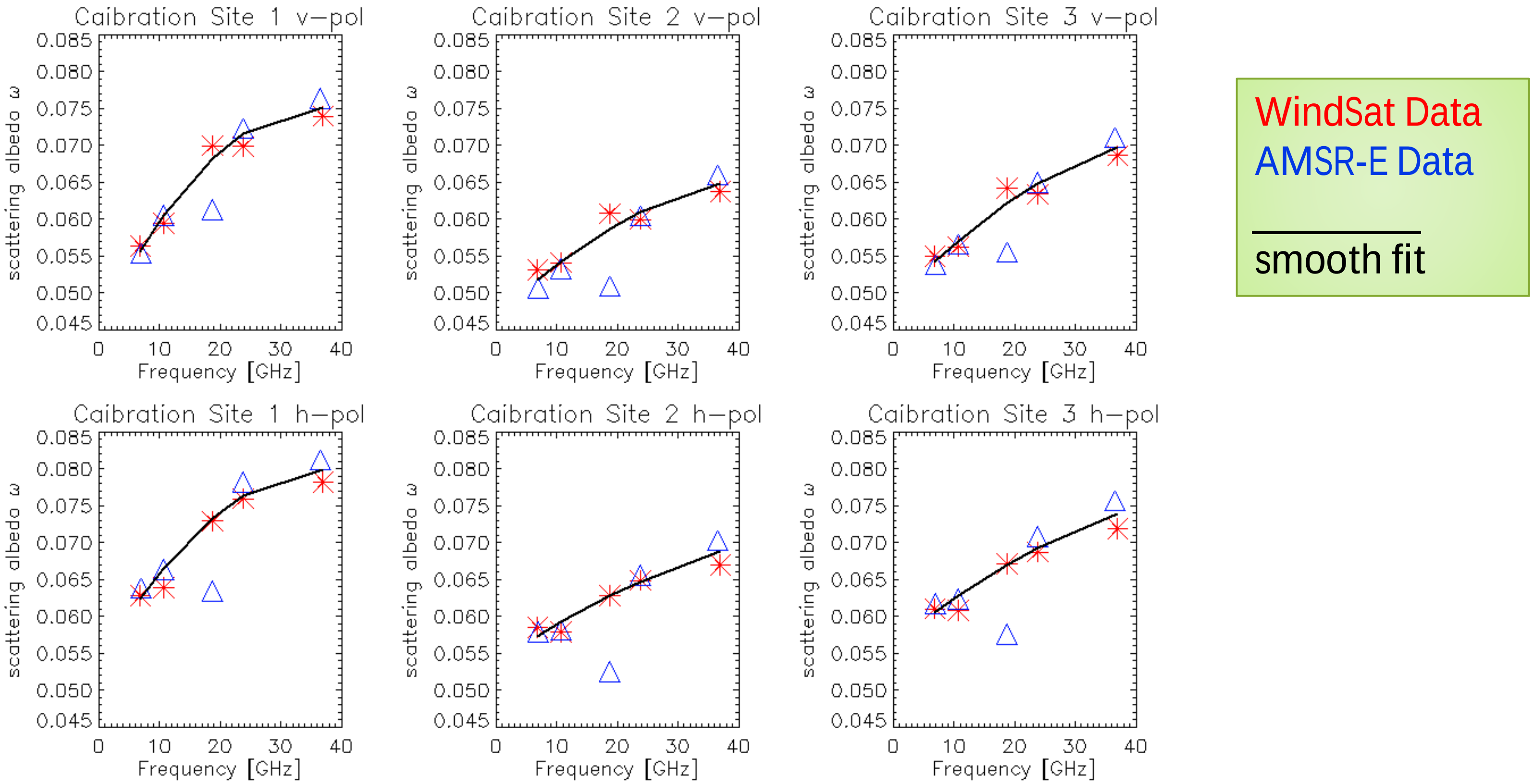
Stability over Calibration Sites

WindSat Site 2 1 year [Kelvin]	6.8 GHz	10.7 GHz	18.7 GHz	23.8 GHz	37.0 GHz
Average v-pol	281.0	281.0	281.5	284.0	281.1
Average h-pol	279.5	279.8	281.0	283.4	280.5
σ v-pol (annual)	1.0	1.1	1.1	1.1	1.8
σ h-pol (annual)	1.1	1.3	1.3	1.2	2.0

$$
\begin{aligned}
T_B(\nu) = {} & \left[1-\omega(\nu)\right]\cdot T_{veg} \\
& + \left[1-\tau_{atm}(\nu)\right]\cdot\left\{T_{atm\uparrow}(\nu)-\left[1-\omega(\nu)\right]\cdot T_{veg}+\omega(\nu)\cdot\tau_{atm}(\nu)\cdot T_{atm\downarrow}(\nu)\right\}
\end{aligned}
$$

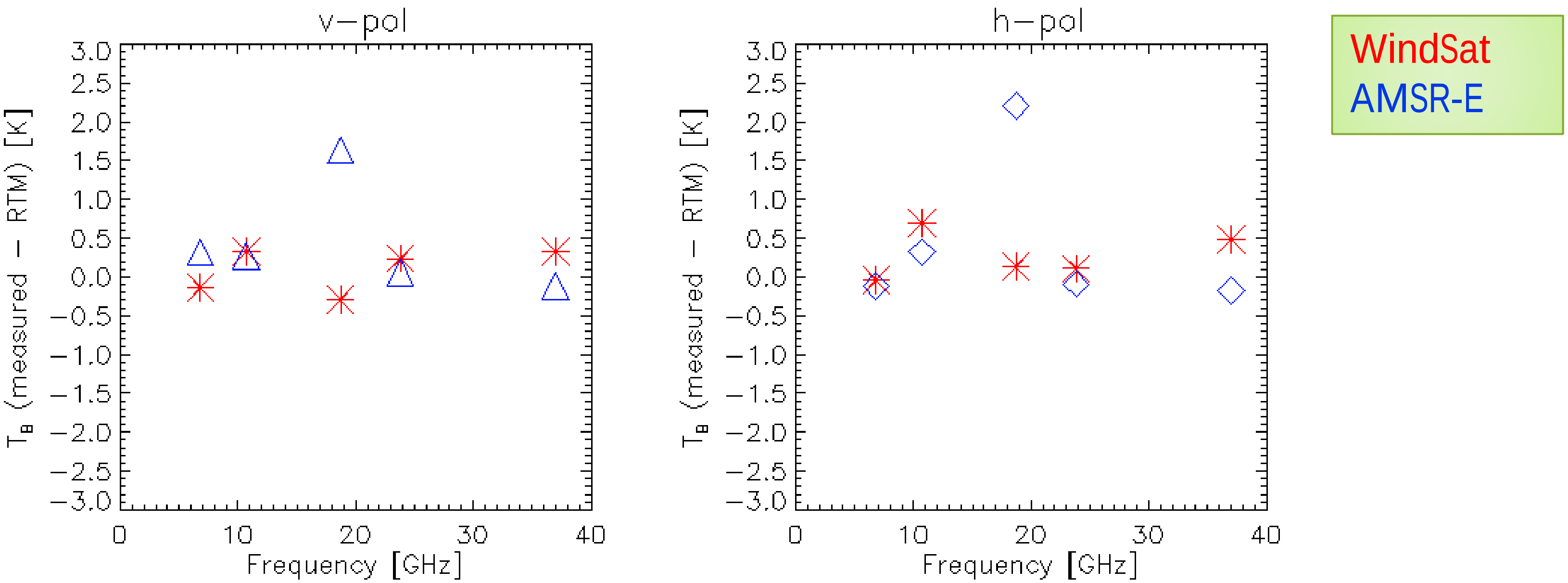
- 2nd term almost 0 (with exception of 23.8 GHz)
  - T_B rather insensitive to atmosphere
- 23.8 GHz has contribution from downwelling atmospheric temperature
- Diurnal effect mainly captured in 1st term

Fit of Scattering Albedo ω



- ω not known accurately a priori
  - needs to be fitted
  - tied to land surface / vegetation temperature
- look for spectral consistency
- AMSR-E 18.7 GHz channels (both v/h) obviously outliers
  - compared to WindSat 18.7 GHz channels and to AMSR-E 23.8 GHz channels

TB measured versus RTM



- Method cannot resolve differences < 0.5 K
  - Knowledge error in scattering albedo
  - Land surface T_B not needed to higher accuracy for most applications
- AMSR-E V6 6.9 GHz consistent with WindSat V7 6.8 GHz
  - Correction for AMSR-E 7GHz receiver non-linearity obviously o.k.
- Both AMSR-E 18.7 GHz channels significantly high
  - v-pol: 1.7 K
  - h-pol: 2.2 K
- Other channels (10.7, 23.8, 36.5/37.0 GHz) consistent between AMSR-E and WindSat

AMSR-E 18.7 GHz

- Too high compared with WindSat 18.7 and AMSR-E 23.8 GHz
  - v-pol: 1.7 K
  - h-pol: 2.2 K
- Candidate 1: Error in cold space temperature
  - Observed error in land T_B translates into 2 K error in cold space temperature due to S/C or Earth intrusion into cold sky view
  - AMSR-E 7 GHz had about 1 K cold sky bias due to earth view intrusion. Large feed
  - No Earth view intrusion into cold sky view at 10.7 GHz
  - Would be a very large effect at 18.7 GHz
- Candidate 2: Error in Ocean RTM
  - Observed error in land T_B translates into 1 K error in ocean RTM
  - RTM used in AMSR-E calibration (version 6) slightly different than for WindSat calibration
  - Would still be a large effect
- Candidate 3: Receiver Non-Linearity
  - most likely scenario

AMSR Version 7

- Part of RSS Version 7 Ocean Products
- Consistent processing of all sensors with one single ocean RTM
- 18.7 GHz channel will be corrected
- Planned release in in 2 – 5 month

DMSP SSM/I, SSMIS
10 Total, 4 currently operating

TRMM TMI

AMSR-E, AMSR

WindSat

QuikSCAT

Conclusion

- Tropical rainforest scenes could (should) be used for future passive microwave radiometric calibration
- Additional calibration point
  - Especially useful if hot load is mute or unreliable
- Relatively simple RTM
  - NCEP climatology
  - Scattering albedo only parameter
- At least good consistency check for absolute radiometric calibration to ocean RTM
  - hot load temperature + spillover
- Can be used
  - directly (measured TB over rainforest versus RTM)
  - spectral intercalibration (compare different channels of same instrument)
  - intercalibration between different instruments.
    It is not necessary to collocate but can compare long term average.
    RTM takes out differences in day time, channel, EIA, …