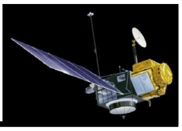
National Aeronautics and Space Administration

Status of the JMR/TMR Recalibration Effort: Algorithm Improvements and the Optimal Calibration System



Shannon Brown[1], Shailen Desai[1], Stephen Keihm[1], Christopher Ruf[2]
[1]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA
[2]University of Michigan, Ann Arbor, MI

Introduction

Significant progress has been made since the last science working team meeting toward the improvement of the JMR and TMR calibration with regards to systematic mm-level errors that are either geographically or temporally correlated.

1. Improved Antenna Pattern Correction Algorithm

- Approach adopted from Obligis et al. (OSTST, 2004)
- Algorithm removes mm-level PD errors 100-500 km from land
- Updated algorithm for both TMR and JMR to ensure consistency

2. Automated Calibration System

- Automatically detects and corrects calibration shifts/drifts
- Algorithm used update calibration for TMR and JMR
- Potential for operational use with AMR on Jason-2

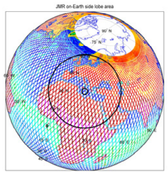
Antenna Pattern Correction Algorithm - Methodology

- Basic approach has not changed
- Improvements made to estimate of on-Earth effective sidelobe brightness, T_E

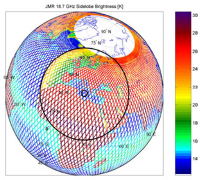
$$T_{MB} = \frac{1}{1-b-c}\left(T_A - bT_E - cT_C\right)$$

T_A – antenna temperature
T_{MB} – main beam brightness temperature
b – fractional received power outside main beam, but on-Earth
c – fractional received power off-Earth
T_E – antenna pattern weighted effective brightness in on-Earth sidelobe region
T_C – cosmic background brightness

- Derive seasonally dependent T_E maps from JMR T_B archive



Gridded Nadir T_B



$T_B^{SL}(\theta_{el}, \phi, Lat_0, Lon_0)$

- Grid nadir JMR T_Bs, six maps annually
- Determine Earth incidence angle of each point relative to antenna boresight
- Use parameterized equation to convert nadir T_Bs to the sidelobe brightness at any given incidence angle, θ_{inc}

$$T_B^{SL}(\theta_{inc}, f) = c_0(\theta_{inc}, f) + c_1(\theta_{inc}, f)T_B(0^\circ, f) + c_2(\theta_{inc}, f)T_B(0^\circ, f)^2$$

where $\vec{c}(f) = \overline{\overline{A}}(f)\vec{\Theta}$

and $\overline{\overline{A}}(f) \in \Re^{3\times5}$, $\Theta = \left[1,\ \theta_{inc},\ \theta_{inc}^2,\ \theta_{inc}^3,\ \theta_{inc}^4\right]^T$

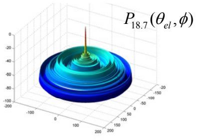
- A(f) coefficient matrix parameterized from radiative transfer model
- sidelobe brightness taken as arithmetic average vertically and horizontally polarized components

$$T_B^{SL}(\theta_{inc}, f) = \frac{1}{2}\left(T_V(\theta_{inc}, f) + T_H(\theta_{inc}, f)\right)$$

- Land brightness assumed invariant with incidence angle

$$T_B^{SL}(\theta_{inc}, f) = T_B(0^\circ, f) \quad for\ T_B(0^\circ, 18.7) > 220K$$

Convolve sidelobe brightness distribution with antenna pattern from 10^0 off-boresight to Earth limb (~55^0 off-boresight) to determine T_E for a given sub-satellite location



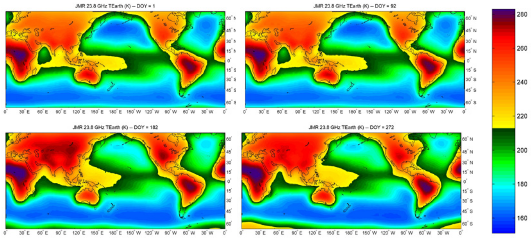
$$T_E(Lat_0, Lon_0) = \frac{\int_0^{2\pi}\int_{\theta_{el}^1}^{\theta_{el}^{\max}} T_B^{SL}(\theta_{el}, \phi, Lat_0, Lon_0)P(\theta_{el}, \phi)\sin(\theta_{el})d\theta_{el}d\phi}{\int_0^{2\pi}\int_{\theta_{el}^1}^{\theta_{el}^{\max}} P(\theta_{el}, \phi)\sin(\theta_{el})d\theta_{el}d\phi}$$

where $\theta_{el}^1 = 10^0$, $\theta_{el}^{\max} = \sin^{-1}\left(\frac{R_e}{R_e + S_{alt}}\right) \approx 55^0$

Form look-up table to interpolate T_E for a given latitude, longitude and day of year

Explicitly accounts for:

- Seasonal migration of water vapor
- Seasonally dependent sea ice concentration
- Land contribution near coasts and inland seas



Optimal Calibration System

Motivation

- Change in hardware (e.g. noise diode brightness) requires time dependent calibration coefficients
- Possible that calibration may change again in the future
- Developed automated calibration approach
  - **–Efficiently and accurately recalibrate the instrument**
  - **–Develop technique to a point where it can be used operationally**

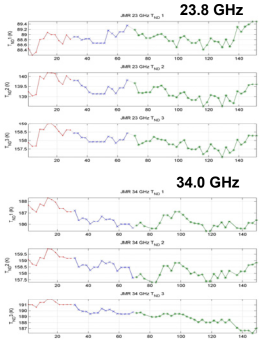
- **Find optimal set of calibration coefficients which minimize the RMS difference between the measured TBs and on-Earth T_B references**
  - –Vicarious Cold Reference *(Ruf, 2000, TGARS)*
    - *–Stable, statistical lower bound on ocean surface brightness temperature*
  - –Amazon pseudo-blackbody regions (18-40 GHz) *(Brown and Ruf, 2005, JTECH)*
    - *–T_{HOT}(frequency, incidence angle, Local Time, Time of year)*

$$\vec{x}^{(k+1)} = \vec{x}^{(k)} - \left[S_a^{-1} + J^T S_\varepsilon^{-1} J\right]^{-1}\left[J^T S_\varepsilon^{-1}\left(\vec{y} - F(\vec{x}^{(k)})\right) - S_a^{-1}\left(\vec{x}^{(k)} - \vec{x}_a\right)\right]$$

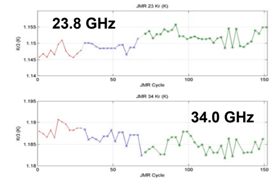
$\vec{x}$ – vector of calibration coefficients to be tuned
$F(x)$ – Calibration algorithms (TA alg., APC; counts $\rightarrow$ T_B, references)
$\vec{y}$ – vector of on-Earth TB references
S_ε – error covariance of TB references
$\vec{x}_a$ – *a priori* vector of calibration coefficients (e.g. pre-launch values)
S_a – error covariance of *a priori* coefficients
J – Jacobian of forward model

- **Use iterative non-linear optimal estimator**
- **Sample references over time and instrument temperature**
  - Implicitly removes instrument temperature dependence
  - Determine time dependent calibration coefficients to remove drifts and offsets

Retrieved JMR Noise Diode Brightness 01/2002 – 03/2006

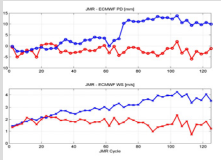


Retrieved JMR Reference Load Coefficient 01/2002 – 03/2006



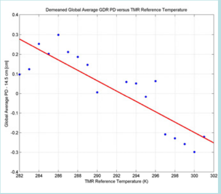
- JMR 18.7 GHz NDs stable to 0.2 – 0.3 % over 4 years
- 23.8 and 34.0 GHz diodes vary by 0.5-2.5 %
- NDs ***not*** the cause of the large PD offset after cycle 69
- Large PD offsets linked to changes in switch

Results for JMR and TMR

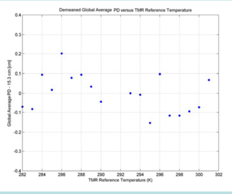


- Time dependent calibration coefficients significantly reduce JMR PD and WS drifts/offsets from GDR version A
- Blue – GDR version A
- Red – Time dependent calibration

TMR GDR



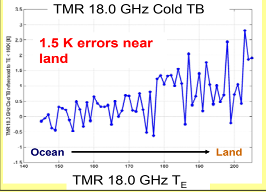
Recalibrated TMR



Reduction of 5-mm TMR Yaw-State PD Bias

- **Updated APC algorithm removes errors correlated with T_E (i.e. proximity to land)**
  - Sample cold reference T_B with respect to 18.0 GHz T_E
  - Take difference from open ocean value (T_E < 160)

Current TMR APC Algorithm



Updated TMR APC Algorithm