SI-Traceable Calibration of Satellite Microwave Radiometers

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Acknowledgements: David Walker, NIST retired
Outline

Background (what)
- SI-traceable Microwave Radiometer calibration

Motivation (why)
- NWP, FCDR

Technology (how)
- NIST blackbody target

Standards

Status & Future Plans

CAVEAT
- Ongoing work !!
- “The answer” not completely known
Example: ATMS

Cosmic MW Background

On-board Blackbody target

Figure 6. Scan sequence (flight direction is toward the reader)
Typical MW Radiometer TB Calibration

(highly simplified version)

- Build your radiometer as linear as practical
- Point it at 2 calibration targets (1 hot, 1 cold) to determine the cal curve (a line)
- Cal targets are typically black bodies with emissivity ~1, so TB = physical temperature

Typical black body used to calibrate satellite MW radiometers: 2D array of pyramids

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What “SI traceable” is not

- Traceability implies a rigorous uncertainty assessment—true
- Using an SI unit as the standard provides a well-defined reference—true
- Your measurement will have unusually good accuracy—not necessarily
- In other words, just because you know the size of your error bars very well, doesn’t guarantee that the error bars are small
SI-traceable *inter-calibration* of Satellite MW Radiometers

- My *personal* forecast (so not NOAA or NASA policy): future sounder obs will need to combine smallsats + anchor sounders like ATMS, MWS
- Example: GPM constellation—"X-cal" effort has harmonized TBs with respect to one member radiometer (GMI)
- According to NIST, this is inter-*comparison*, not inter-*calibration* because the reference (GMI) isn’t traceable to a *standard*
- Adding traceability to a standard would make it inter-*calibration*
- Traceability to a SI standard would be *SI-traceable intercalibration*
- Traceability to a standard implies absolute calibration
- Traceability to which SI unit?
• GNSS-RO is SI-traceable through *frequency* standards.
  • Connected to atmospheric Temperature & Humidity via density & refraction modeling
  • Relies on 1-2 GHz signals chosen for low sensitivity to atmosphere
  • Spatial coverage: best altitude range 8-25 km, 300 km horizontal resolution, ~1 km height resolution
  • Creates reliable long-term RO data record
• MW Radiometry can be SI-traceable with *TB* standards.
  • More direct connection to atmospheric Temperature & Humidity via radiative transfer
  • Relies on 18-183 GHz bands chosen for high sensitivity to atmospheric temperature & humidity
  • Finer horizontal resolution, similar vertical resolution, wider altitude range
  • Creates reliable long-term Tb data records
• Comparable uncertainties achievable: 0.1--1 K (single retrieval)
• Strengths & limitations are complementary
Motivation

- Inter-calibration for constellation systems
- Absolute TB calibration
- Benefits to NWP and FCDRs
- What is not addressed by SI-traceable TB cal?
Benefit to Constellation Systems

- Constellation systems need TB inter-calibration
- Example: anchor sounders + smallsat sounders
- Pre-launch inter-calibration can reduce burden on post-launch inter-cal
- Still want post-launch inter-cal to handle issues like footprint matching, but the portion due to just TB inter-cal would be well-quantified by SI-traceable TB calibration
- Post-launch traceable inter-cal also appears possible, which would extend traceability to on-orbit
- Pre- or post-launch inter-cal would provide immunity to temporal gaps

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6 March 2019
Benefit to NWP forecasting

- NWP & climate models subtract biases

- Bias sources include:
  1) Radiometer sensor
  2) Radiative transfer model (RTM)
  3) Forecast model

- Bias corrections are larger than forecast model errors
- Bias from RTM & forecast models (#2 & #3) are often artificially assigned to sensor bias (#1) in order not to disturb the models
- This is unphysical
- Impedes progress in actually fixing the models (thus presumably improving forecasts)
The potential benefits of improved radiometric calibration for NWP and climate reanalysis

- Forecast model errors are ~0.1K for mid-trop. T- sounding channels
- Bias corrections (parametrised, accounting for radiometric & spectral biases, RT & forecast model biases) are larger
- Improved, traceable, absolute radiometric calibration would help:
  - Partition & bound the contribution due to radiometric uncertainties
  - Reduce the magnitude of residual biases being assimilated
  - Reduce analysis uncertainties (as RT model and forecast model biases are also, inevitably, reduced in time)
Fundamental Climate Data Records (FCDRs)

- Focus on TB FCDR
  - decades-long time-series of TB
- TB FCDR is foundation for various geophysical retrievals
- Used to look for climate trends
- Need to remove calibration jumps when transitioning sensors
- Or bridging gaps
- Should help separate calibration drifts from real climate trends

Pre-launch traceable TB calibration would help attribute uncertainties properly & better quantify them
What SI-traceable TB Cal Does Not Address

- Careful! Total TB = f(footprint, scaling, amplitude)
  - Traceable TB cal helps quantify the amplitude uncertainty
  - Still need other techniques to address the effects of the footprints & scaling
  - What is addressed via harmonization or homogenization and what is addressed by SI-traceable TB cal is TBD
The Technology of Traceable TB Calibration

- NIST blackbody target
- Traceable calibration methodology
- Formal standards
- Upcoming satellite mw radiometers
Broadband passive microwave blackbody
NIST primary standard; traceable to SI kelvin
18-220 GHz design frequency range
Result of Derek Houtz’s PhD thesis

Design requirements:
Maximize emissivity
Minimize temperature gradients
Variable temperature operation
Minimize IR radiation effects
Compatible with ATMS (2 targets: 12 & 23 cm dia.)
Basic methodology:

- Alternately viewing reference target(s) while adjusting new target until radiometer raw response (counts) matches
- Results in transfer of cal to new target/system
- Status: additional engineering work needed
  - Thermal uniformity
  - Temperature range
  - Temperature sensors
  - Vacuum compatibility
  - adjust for coupling geometry
Formal Standards for MW Radiometer Calibration

ISO 20930:2018—approved

Space systems — Calibration requirements for satellite-based passive microwave sensors

IEEE Geoscience and Remote Sensing Society (GRSS) has just started to explore whether to create an IEEE standard for calibration of all microwave radiometers (including ground & airborne)
Potential Opportunities to Calibrate Future Satellite MW Radiometers

- Metop-SG radiometers (particularly MWI, MWS)
- ATMS beginning on JPSS-3 or 4
- AMSR x?
- Cubesat radiometers
- Other future sounders & imagers
Radiometers under development at ESA

**Microwave Sounder (MWS)**
- 24 channels, 23 GHz -230 GHz
- 155 kg, 190 W
- 1m x 1.5m x 0.6m

**Microwave Imager (MWI)**
- 26 channels (18.7 to 183 GHz)
- 285 kg (150 kg rotating), 250 W
- 2m x 1.4m x 1.4m

**Ice Cloud Imager (ICI)**
- 13 channels (183 to 664 GHz)
- 175 kg (68 kg rotating @45rpm), 130 W
- 1.3m x 1.6m x 0.8m

3 flight models each will be launched between 2022 and 2036, providing operations at least until mid-2040's. MWS and MWI could benefit from SI traceability as similar instruments are operational or planned.

Ville Kangas, ESA
Radiometers under development at NASA

ATMS

JPSS-2/3/4

70x60x40 cm

Anti-sun (y)

Nadir (z)

Velocity (x)
Status:

- NIST prototype conical blackbody standard for TB has been designed/fabricated for 18-220 GHz
- Enables traceability to SI-kelvin & incorporation of rigorous standards-level quantification of Type A and Type B uncertainties
- Physical blackbody standard would enable rigorous pre & post-launch inter-calibration of constellation systems plus long time-series records (e.g., FCDRs) including gaps
- Absolute TB calibration would permit more realistic NWP uncertainty allocation (eventually leading to better forecasts) & enhance our ability to generate FCDRs from TB observations
- New standard ISO 20930 for satellite MW radiometer calibration

Future Plans:

- Additional development and analysis work on conical BB target; demonstrate practical calibration transfer to satellite instrument (ATMS?)
- Possible use with future Metop-SG radiometers and/or ATMS on JPSS-3 or 4
- IEEE standard being considered for MW radiometer cal (all MW radiometers, not just satellite)
May 20, 2019
World Metrology Day

• Basic definitions of fundamental SI units will be updated
  • All 7 fundamental SI units will be quantum-based

• Example expected outcomes:
  • SI kilogram definition will go from a metal block to quantum-based
  • SI kelvin definition will become entirely quantum-based
  • https://www.bipm.org/en/measurement-units/rev-si/

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Thank you!

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