SI-Traceable Calibration of Satellite Microwave Radiometers

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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

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Satellite MW Radiometer Cal Example

Example: ATMS

On-board Blackbody target

Cosmic MW Background

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
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 and Tb Standards

- 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
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
NIST Blackbody Calibration Standard

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.)

Hollow Cone geometry
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 × 1.6m × 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

on

JPSS-2/3/4

70x60x40 cm

6 March 2019
Status and Future Plans

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

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Thank you!

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