Calibration and Validation of Microwave Atmospheric Sounders on CubeSats and Small Satellites for Applications in Weather Prediction and Climate Monitoring

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Passive microwave radiometer systems have provided both temperature and water vapor sounding of the Earth’s atmosphere for several decades, including MSU, AMSU, MHS, ATMS, etc. Due to its ability to penetrate clouds, dust, and aerosols, among global datasets, microwave atmospheric sounding provides the most valuable quantitative contribution to weather prediction. Long-term, well-calibrated sounding records can be indispensable for climate measurement and model initialization/validation. Hence, passive microwave sounders are deployed on large, operational satellites and operated by NOAA, EUMETSAT and other similar national/international organizations.

In the past five years or so, advances in CubeSats and other small satellites have enabled highly affordable space technology, providing access to space to private industries, universities and smaller nations. This provides a valuable opportunity for organizations such as NOAA and EUMETSAT to explore the added value of acquiring data from passive microwave sounders on small, low-cost spacecraft for relatively small investments, both for sensor and spacecraft acquisition and launch. This provides the potential for deployment of constellations of low-Earth orbiting microwave sounders to provide much more frequent revisit times than are currently available.

For passive microwave sounding data to be valuable for weather prediction and climate monitoring, each sensor needs to be calibrated and validated to acceptable accuracy and stability. In this context, the first CubeSat-based multi-frequency microwave sounder to provide global data over a substantial period is the Temporal Experiment for Storms and Tropical Systems Demonstration (TEMPEST-D) mission. This mission was designed to demonstrate on-orbit capabilities of a new, five-frequency millimeter-wave radiometer to enable a complete TEMPEST mission using a closely-spaced train of eight 6U CubeSats with identical low-mass, low-power millimeter-wave sensors to sample rapid changes in convection and surrounding water vapor...
every 3-4 minutes for up to 30 minutes. TEMPEST millimeter-wave radiometers scan across track and observe at five frequencies from 87 to 181 GHz, with spatial resolution ranging from 25 km to 13 km, respectively.

The TEMPEST-D satellite was launched on May 21, 2018 from NASA Wallops to the ISS and was successfully deployed on July 13, 2018, into a 400-km orbit at 51.6° inclination. The TEMPEST-D sensor has been operating nearly continuously since its first light data on September 5, 2018. With more than 16 months of operations to date, TEMPEST-D met all of its Level-1 mission objectives within the first 90 days of operations and has successfully achieved TRL 9 for both instrument and spacecraft systems.

Validation of observed TEMPEST-D brightness temperatures is performed by comparing to coincident observations by well-calibrated on-orbit instruments, including GPM/GMI and MHS on NOAA-19, MetOp-A and MetOp-B satellites. Absolute calibration accuracy is within 0.9 K for all except the 164 GHz channel, well within the required 4 K for all channels. Calibration stability is within 0.5 K for all channels, also well within the 2 K requirement. TEMPEST-D has NEDTs similar to or lower than MHS. Therefore, although the TEMPEST-D radiometer is substantially smaller, lower power, and lower cost than operational radiometers, it has comparable performance, i.e. instrument noise, calibration accuracy and calibration stability.