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Global Observations from a Millimeter-wave Sounder/Imager from a CubeSat Mission with More than Two Years on Orbit: Temporal Experiment for Storms and Tropical Systems - Demonstration (TEMPEST-D) Mission

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Passive microwave radiometer systems have been providing both temperature and water vapor sounding of the Earth's atmosphere for several decades, including sensors such as MSU, AMSU, MHS, and ATMS. Long-term, well-calibrated microwave sounding records provide some of the most valuable inputs for initialization and validation of numerical weather forecasting models and well as constraining cloud uncertainties in climate models. For these reasons, passive microwave sounders are deployed on operational satellites operated by NOAA, EUMETSAT and other similar national and international organizations.

In the past several years, dramatic advances in CubeSats and other small satellites have enabled affordable space technology, greatly increasing access to space. This provides a valuable opportunity for organizations such as NOAA and EUMETSAT to explore the added value of acquiring data from constellations of low-Earth orbiting passive microwave sounders on CubeSats and other small satellites with reasonable cost of acquisition, launch and operations. These have the potential of substantially improving the temporal revisit time of measurements.

Global observations of clouds and precipitation processes are essential to improve monitoring and prediction of tropical cyclones and severe storms with substantial impacts on human life and property. Convection plays an important role in influencing global weather patterns and severe weather. However, fundamental gaps remain in our understanding, resulting in one of the 2017 Earth Science Decadal Survey's "most important" science questions, "Why do convective storms, heavy precipitation, and clouds occur exactly when and where they do?"

To improve understanding of cloud and precipitation processes in a variety of climate environments, global observations with short revisit times are necessary. To partially address this need, geostationary satellites provide visible and infrared weather observations with temporal resolution on the order of minutes. However, improving understanding of the processes of deep convection and the surrounding water vapor environment requires millimeter-wave atmospheric sounding observations that penetrate deep into the clouds and respond to cloud water and ice particle absorption and scattering where precipitation forms. To address this critical observational need, the Temporal Experiment for Storms and Tropical Systems (TEMPEST) mission concept consists of constellations of 6U CubeSats with identical low-mass, low-power millimeter-wave radiometers observing at five channels from 87 to 181 GHz. TEMPEST constellations rapidly sample convective processes, filling a critical gap in observations, as well as complementing existing and future science and operational missions.

To demonstrate the first CubeSat-based multi-frequency microwave sounder with global observations, the TEMPEST Demonstration (TEMPEST-D) satellite was launched on May 21, 2018 and was deployed from the ISS on July 13, 2018, into an initial orbit at 410-km altitude and 51.6° inclination. With more than two years of operations during three hurricane seasons, TEMPEST-D met its mission requirements in the first 90 days and achieved TRL 9 for both instrument and spacecraft systems. Comparisons of on-orbit measurements with five reference sensors, including GPM/GMI and MHS on four NOAA and EUMETSAT satellites, indicate that TEMPEST-D is a very well-calibrated, low-noise, highly stable radiometer on a CubeSat. TEMPEST-D observation quality is comparable to and sometimes exceeds that of larger, more expensive operational sensors.

Over its more than two years of operations, TEMPEST-D has performed coincident measurements with other passive and active microwave sensors, including NASA's GPM as well as weather radar on the RainCube mission. We present analysis and results of these coincident measurements of tropical storms, squall lines and other storms.