URSI GASS 2021, Rome, Italy, 28 August - 4 September 2021

Precipitation Estimation Using Measurements from the TEMPEST-D CubeSat Mission

Chandrasekar Radhakrishnan[1], V. Chandrasekar[1], Wesley Berg[1] and Steven C. Reising[1]
[1]Colorado State University, Fort Collins, CO, USA
Shannon T. Brown[2]
[2]NASA/Caltech Jet Propulsion Laboratory, Pasadena, CA, USA

The estimation of surface rainfall is essential to a variety of scientific and societal applications both over land and ocean. It is also essential to validate numerical weather prediction (NWP) models and improve their forecast skill. Ground-based weather radar networks are currently used to provide precise rainfall information throughout the U.S. and many other areas of the world. However, only satellites can provide precipitation data on a global basis. For example, low Earth orbiting (LEO) satellites such as NASA's Global Precipitation Mission (GPM) core satellite provide data from both active radar and passive microwave radiometry. One limitation of LEO satellite systems is revisit time, or temporal coverage. Recently, CubeSat technology has matured to the point that constellations of small satellites may soon be deployed at reasonable cost. To this end, the Temporal Experiment for Storms and Tropical Systems (TEMPEST) is focused on observing rapidly-evolving convective clouds and precipitation with greatly improved temporal resolution. The TEMPEST constellation's mission concept involves a constellation of 6-8 similar 6U CubeSats with 3-4 minute spacing deployed in the same orbital plane. To demonstrate the necessary radiometer technology and data quality, TEMPEST-D (D for demonstration) satellite was launched on May 21, 2018, deployed into orbit on July 13, 2018, and has completed more than two years of operations. TEMPEST-D has demonstrated performance from a 6U CubeSat that is similar to or in some cases exceeding that of much larger and more expensive operational missions. On this basis, TEMPEST-D has unequivocally confirmed the technological capabilities required for the TEMPEST constellation to succeed. The TEMPEST-D CubeSat radiometers measure at five millimeter-wave frequencies (87, 164, 174, 178, and 181 GHz) that provide moisture profiles and observe deep inside convective storms. TEMPEST millimeter-wave radiometers are cross-track sounding/imaging radiometers that observe at the 87 GHz window channel as well as at four moisture sounding frequencies from 164 to 181 GHz to exploit the pressure broadening characteristics of the water vapor absorption line near 183 GHz. The radiometers are calibrated using a mechanically scanning reflector that provides two-point end-to-end calibration every two seconds. Since the launch, TEMPEST-D has acquired global observations for more than two years to date. Precipitation products from TEMPEST-D are described in this paper. Ground-based weather radars measure reflectivity from clouds and precipitation, and dual-polarization observations such as differential reflectivity and differential phase permit generation of rainfall rate products. On the other hand, TEMPEST-D measured brightness temperature is a measure of the path-integrated emission, reflection, and scattering of passively generated thermal radiation from the Earth's surface, atmospheric gases and cloud and precipitation hydrometeors. Since both observations measure clouds and precipitation, a machine learning model is used to map the relationship between the two measurements. This paper presents a model to estimate surface precipitation from TEMPEST-D observations. Artificial neural networks (ANNs) were used to build the rainfall estimation model from TEMPEST-D observations. TEMPEST-D brightness temperature (TB) observations at five frequencies were used as inputs, and the Multi-Radar/Multi-Sensor System (MRMS) radar-only rain rate product at the surface was used as target to train the model. The training data set was generated from 14 storm events simultaneously observed over CONUS by the ground radar network and TEMPEST-D. For independent testing, five storm events were used. Results demonstrated that the TEMPEST-D estimated surface rain rate agreed well with MRMS in terms of rain rate intensity, area, and structure of the rainfall field.