# CYGNSS Physical-Model-Based Soil Moisture Retrieval

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Soil moisture retrieval based on a physical-based algorithm for the Cyclone Global Navigation Satellite System (CYGNSS) [1] reflectometry data is presented. CYGNSS, a mission launched by the National Aeronautics Space Administration (NASA) in 2017, collected reflected signals from the Global Navigation Satellite System (GNSS), has the potential to provide soil moisture at a spatial resolution of about 5 to 25 km. We have developed a geophysical model function, which links the reflectivity to soil moisture, vegetation optical depth (VOD), and surface roughness. The model coefficients were derived using a data-driven approach.

We have completed the matchup of CYGNSS data with SMAP Single Channel-V soil moisture, surface roughness from SMAP dual-channel algorithm, and Vegetation Water Content (VWC) derived from the Moderate Resolution Imaging Spectroradiometer (MODIS) Normalized Difference Vegetation Index (NDVI) data. The matchup thresholds are 1 day in time difference and 15 km in spacing. The CYGNSS V2.1 Level 1 data were processed using the coherent reflection model to derive the surface reflectivity. The matchup data were binned as a function of SMAP soil moisture, surface roughness, VWC and CYGNSS incidence angle. The CYGNSS reflectivity for low VWC (<1 kg/m$^2$) increases by about 3.5 dB for soil moisture increasing from 10 to 40 percent, consistent with the change of Fresnel surface reflectivity computed using the Mironov dielectric constant model for soil surfaces. Our comparative analysis of the NDVI-derived VWC and CYGNSS data shows that the CYGNSS reflectivity in dB decreases approximately linearly versus the VWC when the NDVI VWC is 5 kg/m$^2$ or lower. For higher values of VWC, the decreasing rate slows down and the reflectivity also become less sensitivity to soil moisture, suggesting the contribution of incoherent scattering by vegetation or surface roughness. Our data analysis further revealed the dependence of CYGNSS reflectivity on surface roughness. To generate a self-consistent surface roughness value for CYGNSS retrieval, we use the SMAP soil moisture to estimate the flat surface reflectivity and NDVI VWC to estimate the VOD, which are then subtracted from the CYGNSS data to isolate the surface roughness contribution. The residuals are then used to estimate the surface roughness value at each CYGNSS footprint. Gridding and averaging were then performed to construct monthly surface roughness maps. The physical forward model for CYGNSS reflectivity is then established based on a multiplication of the surface reflectivity computed using Mironov's dielectric constant model for flat surfaces and attenuation factors due to vegetation and rough surfaces [2].

The retrieval of soil moisture from CYGNSS Version 3 data was performed using NDVI VWC and CYGNSS-derived monthly surface roughness maps as ancillary. The spatial pattern of retrieved CYGNSS soil moisture is in general consistent with the SMAP soil moisture. The Root-Mean-Square-Difference (RMSD) for many regions with relatively low VWC can be 5% or lower. However, there could be large differences between CYGNSS and SMAP soil moisture retrievals over regions with a high VWC (>5 kg/m$^2$), such as the eastern part of United States. Validation of the CYGNSS soil moisture with in-situ data from SMAP core calibration/validation sites has been performed to provide quantitative assessment of CYGNSS soil moisture products with results indicating an unbiased Root-Mean-Square-Error (RMSE) of about 0.06 cm$^3$/cm$^3$.

## References

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