Soil moisture estimation from CYGNSS mission data

CE670A Environmental Geodesy — 2020-21 II

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GNSS is multi-constellation system which encompasses United States' GPS, EU's Galileo, Russia's GLONASS, China's BeiDou, India's IRNSS, and Japan's QZSS. Global Navigation Satellite System-Reflectometry (GNSS-R) is a form of bistatic radar that utilizes transmitted navigation signals as the signal source for studying the environment. GNSS-R measures the forward-scattered signal, which has reflected off of the surface of the Earth and back into space.

Cyclone Global Navigation Satellite System (CYGNSS) is commisioned for ocean surface remote sensing instead of navigation. But we repurposed the CYGNSS data to estimate soil moisture over land. As the CYGNSS mission was not designed for soil moisture remote sensing. Data are calibrated and recorded assuming that the rough ocean surface is the target.

The temporal repeat time of GNSS-R is thus statistical. This means that, for a given point of the Earth's surface, observations could be recorded one hour apart, and then there could be no observations for the next several hours. The spatial resolution of the reflecting signal depends on the roughness of the surface at and near the reflection point. If the surface is relatively rough, then the reflected signal is incoherent and comes from an area called the 'glistening zone,' which is on the order of several kilometers (25 km in the case of the ocean surface). If the surface is relatively smooth, then the reflected signal is coherent and comes from an area defined by the first Fresnel zone. For a low Earth orbiting GNSS-R satellite, this area is on the order of ½ a kilometer, though this depends slightly (+/- a few hundred meters) on incidence angle. CYGNSS functions as a constellation of passive sensors that receive the signal of surface-reflected GPS pulses

Theory

The reflected GNSS signal is recorded by the receiver in the form of what is called a delay-Doppler map (DDM). A DDM is created by cross correlating the received signal with a locally-generated replica for different path delays. The maximum power of each DDM is affected by both surface roughness and the dielectric constant of the surface. The observables that are commonly used for soil moisture estimation are the peak cross-correlation of each DDM, or the peak divided by the noise floor (signal to noise ratio, SNR). The value of the peak cross-correlation of each DDM (called Pr,eff in this document) is related to surface characteristics at the specular reflection point of the GNSS signal— including the roughness of the surface and the surface dielectric constant.

Γ_{rl} (in dB) that has been corrected for all of these effects $P_{r,eff}$, which stands for effective reflectivity.

$$P_{rl} = \frac{P_r^t G^t}{4\pi(R_{ts} + R_{sr})^2} \frac{G^r \lambda^2}{4\pi} \Gamma_{rl}$$

where P_r^t is the transmitted RHCP power, G^t is the gain of the transmitting antenna, R_{ts} is the distance between the transmitter and the specular reflection point, $R_{sr}$is the distance between the specular reflection point and the receiver, G^r is the gain of the receiving antenna, λ is the GPS wavelength (0.19 m), and Γ_{rl} is the surface reflectivity.

The total scattered power is the sum of the contributions from the coherent and incoherent scattered powers:

$$P_{rll}^r = P_{rll}^c + P_{rll}^i$$

Where the subscript r and l indicate that the transmitted and reflected polarizations are right hand circularly polarized (RHCP) and left hand circularly polarized (LHCP), respectively, P_r is the total reflected power, and P_c and P_i are the coherent and incoherent scattered powers, respectively.

Since this analysis is only concerned with changes in surface reflectivity. Solving for reflectivity and making an additional correction for background noise (N), we have (in dB):

$$P_{r,\text{eff}} = 10\log\Gamma_{rl} \propto 10\log P_{rl}^{c} - 10\log N - 10\log G^{r} - 10\log G^{t} - 10\log P_{r}^{t} + 20\log(R_{ts} + R_{sr})$$

Data

CYGNSS contains 4 different datasets namely Level-0, Level-1, Level-2, Level-3. Level-0 contains raw, fully resolved and sub-sample DDMs. Level-1 provide calibrated DDMs of received power and scattering cross-section. Level-2 provide Ocean Surface Windspeed and Mean Square Slope. Level-3 provides Gridded Ocean Surface Windspeed and Mean Square Slope. Also Level-3 provides sub-daily Soil Moisture.

In this project you'll be downloading 1 year data. The appropriate Level should be chosen by you for extracting the surface reflectivity and Soil Moisture from SMAP & ESA CCI.

To read more about the data products :
`https://clasp-research.engin.umich.edu/missions/cygnss/data-products.php` and
`https://podaac.jpl.nasa.gov/CYGNSS?tab=mission-objectives&sections=about%2Bdata%2Bresources`

Objective

Calculate the surface reflectivity and do the scatter plot between surface Relectivity and surface SM from SMAP & ESA CCI. Then establish a relation between the surface relectivity and surface SM from SMAP & ESA CCI.

Also Perform Principal Component Analysis(PCA) on CYGNSS SM, SMAP SM and ESA CCI SM to extract the principal modes.

Technical report and software documentation

As per the protocol, you will need to submit a short report (maximum 5 pages including graphs and figures), software written as a toolbox and its documentation. The report must be structured as follows: abstract, introduction, mathemtical details, methods, results, discussion and conclusion. Your project will be evaluated for ease of use of the software, the clarity of your documentation and the scientific quality of your report. All results should be reproducible, and therefore, please submit your code that you used for creating your figures, tables and other results. Otherwise, the results will be considered plagiarised. Plagiarism of any form will be dealt with severely. Since it is a project work, you are also expected to do some literature review and study about the project topic at your end.

Evaluation

The evaluation for the project will be continous, and therefore, you will have weekly deliverables.

Week 1	Literature review and data collection	5 %
Week 2	Exploration of data and data visualization	5 %
Week 3	First results	5 %
Week 4	Final results, project report, software and its documentation, and presentation	15 %

References

[1] Soil Moisture Sensing Using Spaceborne GNSS Reflections: Comparison of CYGNSS Reflectivity to SMAP Soil Moisture C. C. Chew E. E. Small doi: http://dx.doi.org/10.1029/2018GL077905, 2018.