Using Cosmic-ray Neutron Probes in Validating Satellite Soil Moisture Products and Land Surface Models

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Background, Motivation & Aim of the Study

Motivation

Soil water content is one of the most influential variables that is used in decision support systems of land and water management studies. However, in order to utilize soil moisture data, it has to be in an applicable spatial and temporal resolution.

Resolutions of Soil Moisture Measurements

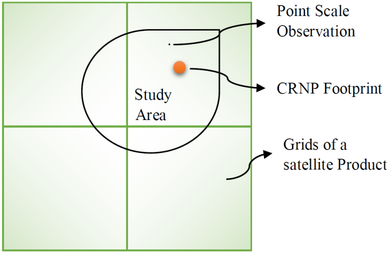


Figure 1: Spatial resolution of soil moisture data

In order to fill the gap between spatial and temporal resolutions of point and satellite soil moisture products,

Ground measurements having intermediate spatial resolution (such as CRNP) constitute an important potential.

Aim of the Study

The aim of this study is to assess the use of CRNPs in validation of satellite products and Land Surface Models that can be used in further hydrological and agricultural studies.

Figure 2: The Cakit Basin CRNP Station

Figure 3: CRNPs in the COSMOS Database

Satellite and Land Surface Model Based Soil Moisture Products

Satellite and Land Surface Model Based SM Products

- METOP-A/B Advanced Scatterometer (ASCAT)
- Soil Moisture and Ocean Salinity (SMOS)
- Soil Moisture Active and Passive (SMAP)
- Advanced Microwave Scanning Radiometer (AMSR)
- Climate Change Initiative (CCI)
- Global Land Data Assimilation System (GLDAS)

Additionally, CRNP soil moisture values of Cakit Basin were compared with a stand alone Noah Land Surface Model with in-situ meteorological data and a TDR installed at the site.

METOP-A/B Advanced Scatterometer (ASCAT)

ASCAT is an active microwave remote sensing instrument.(Isaksen and Stoffelen, 2000)

EUMETSAT H113 and H114 products were obtained as saturation index values at pixels having (12.5x12.5)km dimensions.

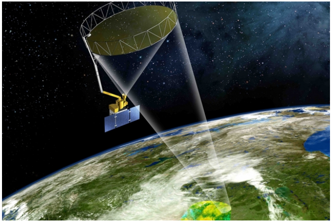
In order to convert saturation index to volumetric soil moisture ratio; saturation index values were multiplied by the average porosity values obtained from GLDAS and HWSDB datasets.

Soil Moisture and Ocean Salinity (SMOS)

SMOS is a passive microwave remote sensing instrument. (McMullan et al., 2008) It is an Earth Observation satellite mission of European Space Agency (ESA).

In this study, level 3 SMOS data obtained from Barcelona Experts Center (BEC) have been used for ascending orbit daily volumetric soil moisture data at pixels having (25x25)km dimensions.

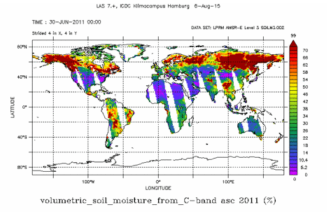
Soil Moisture Active and Passive (SMAP)



SMAP measures the amount of water in the top 5 cm of soil anywhere on the Earth surface. This product is also able to distinguish frozen or thawed ground. (Entekhabi et al., 2010, 2014)

For this study, SMAP Level 4 (L4) EASE-Grid Surface and Root Zone Soil Moisture Analysis products were utilized at pixels having (9x9)km dimensions

Advanced Microwave Scanning Radiometer (AMSR)

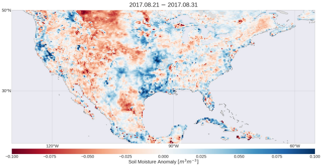


AMRS is a passive remote sensing product operated by the Japan Aerospace Exploration Agency (JAXA).(Parinussa et al., 2015)

AMSR2 C-band (6.93 GHz) soil moisture products were utilized at (9x9) km resolution.

AMSR2 soil moisture products are produced by using Land Parameter Retrieval Model (LPRM) which converts space-borne observed brightness and temperatures to soil moisture.

Climate Change Initiative (CCI)



The CCI soil moisture dataset has being produced by combining different satellite soil moisture products.(Liu et al., 2012; Dorigo et al., 2017; Gruber et al., 2017)

In order to test the effectiveness of a combined soil moisture dataset; active, passive and combined soil moisture datasets were utilized for pixels having (25x25)km resolutions.

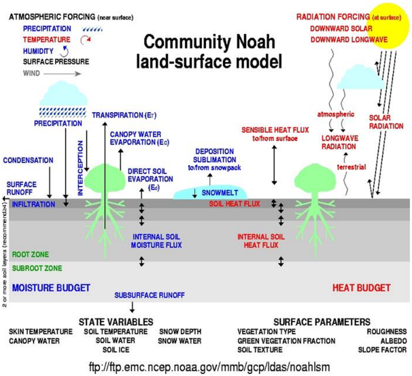
Global Land Data Assimilation System (GLDAS)

GLDAS (Rodell et al., 2004) provides land surface model data which are derived from a global meteorological dataset (Sheffield et al., 2006).

Noah LSM level 4 data (Rodell and Beaudoing, 2013) was used for pixels having (25x25)km resolutions.

0-10cm soil layer output was selected in order to have a reasonable comparison with the other soil moisture products.

Noah Land Surface Model (Noah LSM)



Besides GLDAS, a stand-alone, uncoupled and 1-D column version of Noah LSM which makes use of the in-situ meteorological data was utilized (Chen et al., 1996).

Soil moisture values between 0-10cm depths are used in this study in order to compare the data with satellite based soil moisture products.

Validation of Soil Moisture Products

Stations of COSMOS Database

The COsmic-ray Soil Moisture Observing System (COSMOS) has more than a hundred number of CRNP stations data available on the internet which are accessible via the project website (cosmos.hwr.arizona.edu).

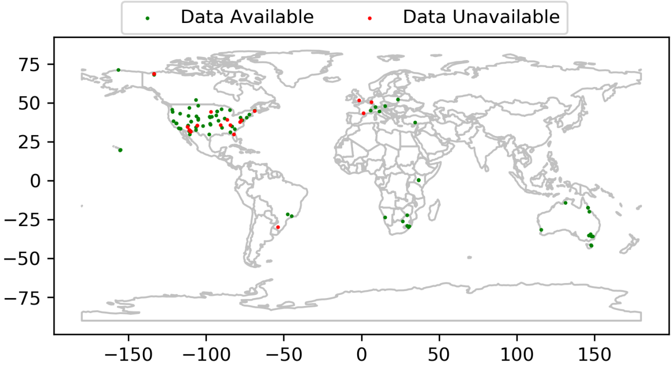


Figure 4: CRNPs in the COSMOS Database and the Cakit Station CRNP

Cakit Basin CRNP

- Study Area: South part of Turkey (526 km^2 area)
- CRNP: CRS200B - Hydroinnova
- TDR: CS616 at 5cm depth
- Location of the Sensors: 37.51°N 34.49°E
- Elevation: 1459m
- Annual Precipitation:300 mm
- Mean Annual Temperature:10°C
- Land Cover: Young cherry trees, pasture and shrub.

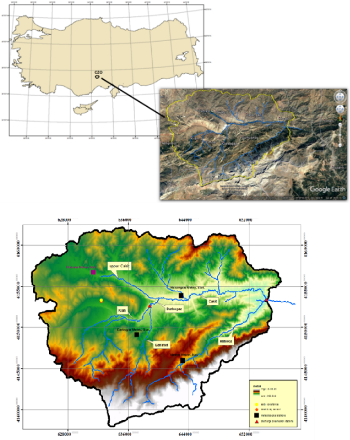


Figure 5: Cakit Basin

Correction of Neutron Counts - Incoming Neutron Flux

Each CRNP measurement will reflect its own site characteristics for elevation, air pressure and absolute humidity, they have to be corrected by considering environmental factors. (Zreda et al., 2012)

Real-time neutron intensity data for various neutron monitoring stations around the globe is available in the Neutron Monitor Database (NMDB; www.nmdb.eu).

Athens NMDB station has been used for intensity correction - geomagnetic cutoff rigidity (8 GV).

A computer program written in Python is used to retrieve the hourly data to perform the corrections and to obtain the hourly soil moisture data for Cakit CRNP.

Results (r^2)

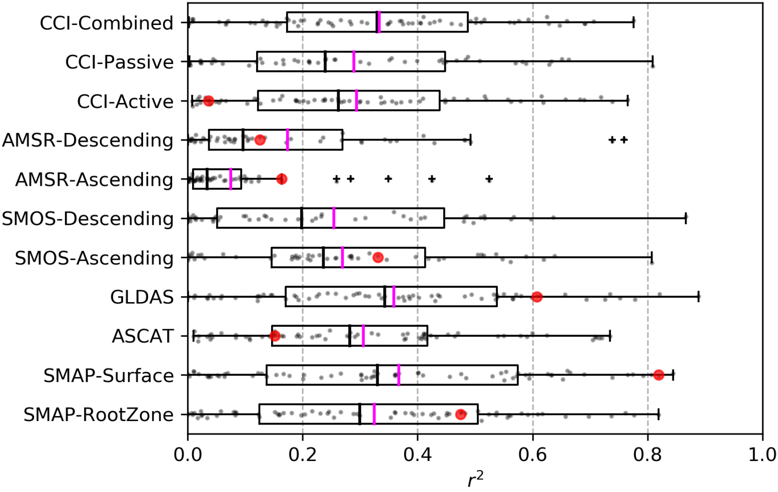


Figure 6: r^2 values between CRNPs in the COSMOS Database and the Space-borne Satellite Products

Results (RMSE)

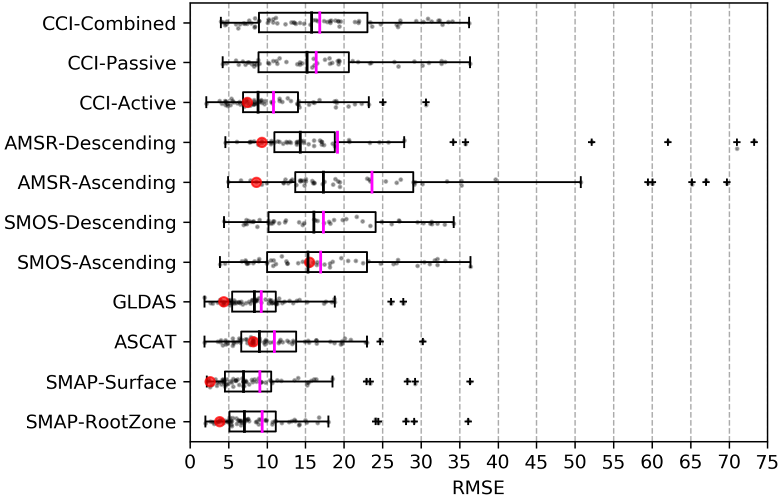


Figure 7: RMSE values between CRNPs in the COSMOS Database and the Space-borne Satellite Products

Results (SMAP Surface Product)

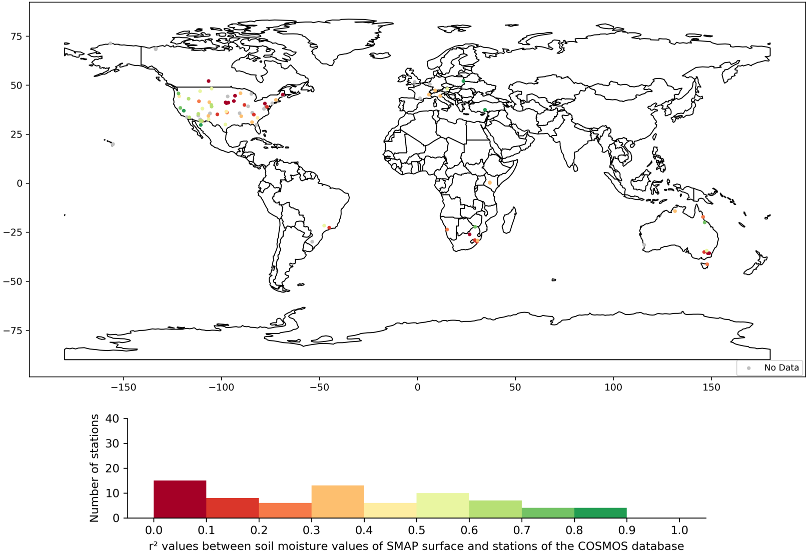


Figure 8: r^2 values between SMAP and CRNPs shown on the world map

Results (Cakit CRNP)

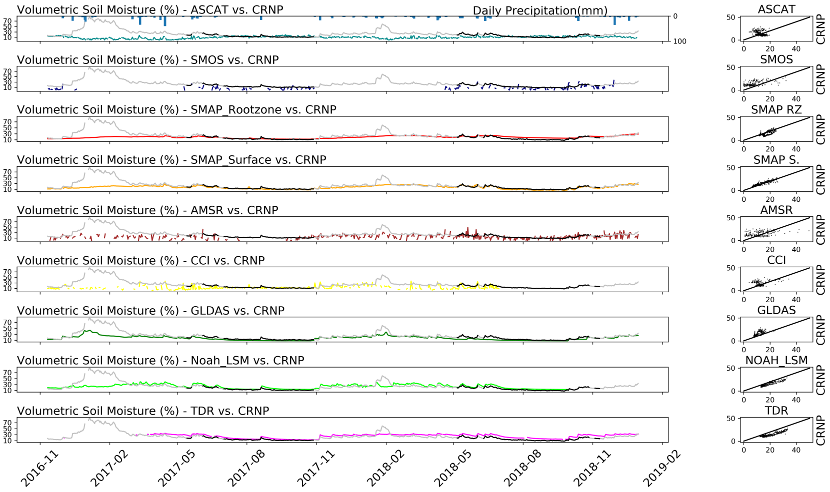


Figure 9: Comparisons Between Different Soil Moisture Products and CRNP

Results (Triple Collocation - Cakit CRNP)

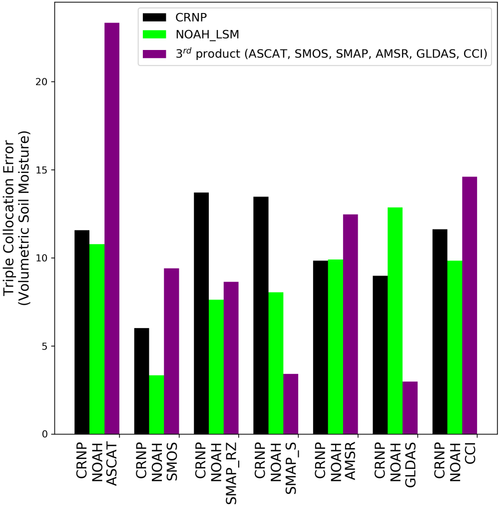


Figure 10: Triple collocation errors of soil moisture products

Conclusion and Future Studies

Conclusions (Satellite Products) i

- Cakit Basin CRNP station and TDR have very good correlation for soil moisture, which proves that measurements of CRNP by means of soil water content is reliable. Both sensors show consistent changes in soil moisture due to the storm events.
- SMOS, ASCAT and AMSR products show larger variation and noise compared to SMAP, CCI and GLDAS soil moisture products.
- CRNP has the limitation to measure soil moisture under snow cover. For this reason, soil moisture data obtained from satellite soil moisture products can be used in conjunction with CRNP for soil water deficit investigations and agricultural decision making processes.

Conclusions (Satellite Products) ii

- SMAP products and CRNP values have generally higher correlation at arid-semi arid regions than vegetative ones whereas ASCAT is better at vegetated areas.
- CCI dataset which was established by using many different soil moisture datasets is not more successful than the SMAP surface product alone.

Conclusions (Land Surface Models)

- Soil water content values obtained from land surface models well represent the CRNP and TDR soil moisture measurements.
- Stand alone Noah LSM model is slightly better at representing site characteristics than Noah LSM outputs obtained from GLDAS which uses a global dataset as input.
- However, GLDAS soil moisture data are very close to the Noah LSM results which may indicate that the global dataset that the GLDAS using is reliable for the Cakit Basin.

Future Studies

- CRNP soil moisture values can be studied for different soil layers using data assimilation techniques and neutron transport models to better represent root zone soil moisture values.
- SMAP rootzone soil moisture product can be used for the validation of different soil moisture values.
- Soil moisture values can be inferred by using a more complex methodology that takes other sources of hydrogen and changes in the vegetation into account.
- Snowy days are usually filtered out for the analyses with CRNPs, a general method can be developed to make use of the snow data and extract soil moisture at snowy days.

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Thank You for Your Attention

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