Toward High-Resolution Soil Moisture Monitoring over India by Combining Remote Sensing Products with Land Surface Models

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Abstract

Soil moisture is a vital climatic variable driving environmental and biological processes. Large scale soil moisture can be estimated using Land Surface Models or observed using active and passive microwave remote sensing. Increasing availability of remotely sensed soil moisture retrievals has allowed for constraining Land Surface Model (LSM) estimates. Though the accuracy of remote sensing datasets is constrained by soil roughness, vegetation, and surface temperature, combining them with LSMs allow us to reduce errors in soil moisture estimates. This study assimilates the SMOPs-ASCAT, ESA-CCI and SMAP soil moisture retrievals into a land surface model u sing an ensemble Kalman filter. The open-loop and data assimilated soil moisture outputs are evaluated against the ground-based sensor data. This demonstrates the establishment of an Indian Land Data Assimilation System (ILDAS) with the goal of providing accurate soil moisture products at high spatial and temporal resolution over India.

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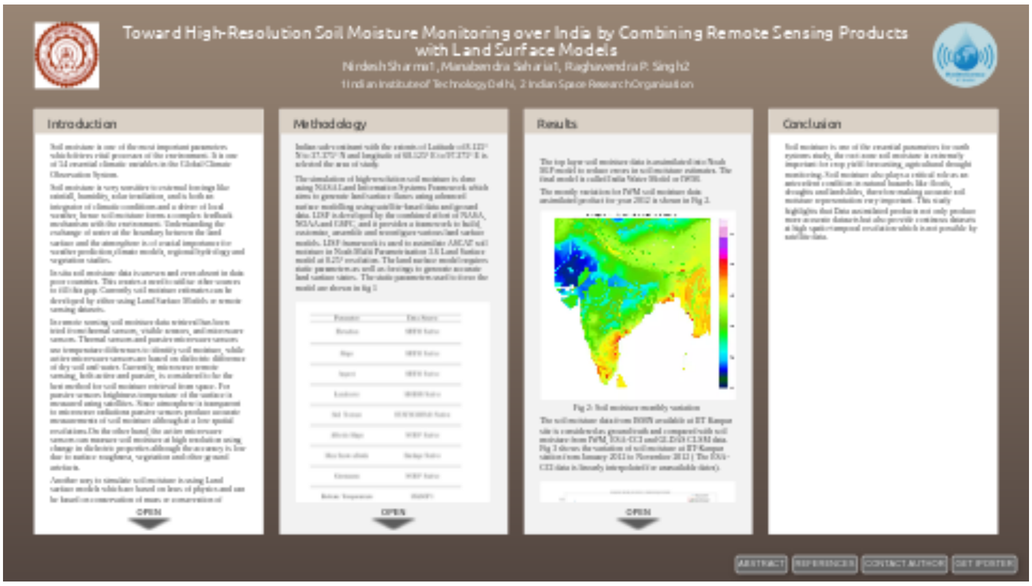

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INTRODUCTION

Soil moisture is one of the most important parameters which drives vital processes of the environment. It is one of 54 essential climatic variables in the Global Climate Observation System.

Soil moisture is very sensitive to external forcings like rainfall, humidity, solar irradiation, and is both an integrator of climatic conditions and a driver of local weather, hence soil moisture forms a complex feedback mechanism with the environment. Understanding the exchange of water at the boundary between the land surface and the atmosphere is of crucial importance for weather prediction,climate models, regional hydrology and vegetation studies.

In situ soil moisture data is uneven and even absent in data poor countries. This creates a need to utilise other sources to fill this gap. Currently soil moisture estimates can be developed by either using Land Surface Models or remote sensing datasets.

In remote sensing soil moisture data retrieval has been tried from thermal sensors, visible sensors, and microwave sensors. Thermal sensors and passive microwave sensors use temperature differences to identify soil moisture, while active microwave sensors are based on dielectric difference of dry soil and water. Currently, microwave remote sensing, both active and passive, is considered to be the best method for soil moisture retrieval from space. For passive sensors brightness temperature of the surface is measured using satellites. Since atmosphere is transparent to microwave radiations passive sensors produce accurate measurements of soil moisture although at a low spatial resolutions.On the other hand, the active microwave sensors can measure soil moisture at high resolution using change in dielectric properties although the accuracy is low due to surface roughness, vegetation and other ground artefacts.

Another way to simulate soil moisture is using Land surface models which are based on laws of physics and can be based on conservation of mass or conservation of energy. An energy land surface model's primary motive is to calculate the energy distribution into the latent heat flux, sensible heat flux and energy diffusion, given the land surface type, vegetation type, and other relevant forcings. With recent developments in satellite technology which lead to a better parametrization of vegetation, soils the energy transfer models are used more widely in the scientific community.

The knowledge of our physical understanding of the system is embodied in land surface models. These models can sometimes be simple due to the absence of inputs or contain errors due to inaccurate measurement of inputs. The satellite datasets, on the other hand, have their own bias due to calibration errors and surface artefacts.In this study we combine the data from Land Surface models with satellite datasets synergistically to minimize errors from individual sources and generate ensemble product with higher accuracy. Since models and satellite data capture very different attributes of the same phenomena, the final estimates are superior to both models as well satellite data

METHODOLOGY

Indian sub-continent with the extents of Latitude of 8.125° N to 37.375° N and longitude of 68.125° E to 97.375° E is selected the area of study.

The simulation of high-resolution soil moisture is done using NASA Land Information Systems Framework which aims to generate land surface fluxes using advanced surface modelling using satellite-based data and ground data. LISF is developed by the combined effort of NASA, NOAA and GSFC, and it provides a framework to build, customize, assemble and reconfigure various land surface models. LISF framework is used to assimilate ASCAT soil moisture in Noah Multi Parametrization 3.6 Land Surface model at 0.25° resolution. The land surface model requires static parameters as well as forcings to generate accurate land surface states. The static parameters used to force the model are shown in fig 1

Parameter	Data Source
Elevation	SRTM Native
Slope	SRTM Native
Aspect	SRTM Native
Landcover	MODIS Native
Soil Texture	STATSGOFAO Native
Albedo Maps	NCEP Native
Max Snow albedo	Barlage Native
Greenness	NCEP Native
Bottom Temperature	ISLSCP1

Fig 1: Static parameters for Noah MP3.6

The model is forced by Princeton V2.2 data which is a blended product of satellite reanalysis and observations. Princeton V2.2 provides near-surface meteorological data for driving land surface models. The model time step is set at 15 min with output every day. The Noah MP LSM for the present study is initialized by multi-year spinup with forcings from 1 Jan 2008 31 Dec 2010 to reach a steady state.

Soil Moisture Operational Products System (SMOPS) is a multi-satellite global soil moisture product developed by NOAA and NESDIS as pre-processor to assimilate all available satellite soil moisture data products into the Global Forecast System.SMOPS ASCAT Satellite data is assimilated into the land surface model using EnKF. The final output is validated with ground-based sensor located at IIT-Kanpur, the data for which is acquired from ISMN portal.

RESULTS

The top layer soil moisture data is assimilated into Noah M.P model to reduce errors in soil moisture estimates. The final model is called India Water Model or IWM.

The montly variation for IWM soil moisture data assimilated product for year 2012 is shown in Fig 2.

[VIDEO] https://res.cloudinary.com/amuze-interactive/image/upload/f_auto,q_auto/v1638781111/agu-fm2021/05-48-84-71-03-a1-c8-91-7c-d4-65-b9-3b-c1-02-7e/image/surface_ychbrj.mp4

Fig 2: Soil moisture monthly variation

The soil moisture data from ISMN available at IIT Kanpur site is considered as ground truth and compared with soil moisture from IWM, ESA-CCI and GLDAS CLSM data. Fig 3 shows the variation of soil moisture at IIT-Kanpur station from January 2012 to November 2012 (The ESA-CCI data is linearly interpolated for unavailable dates).

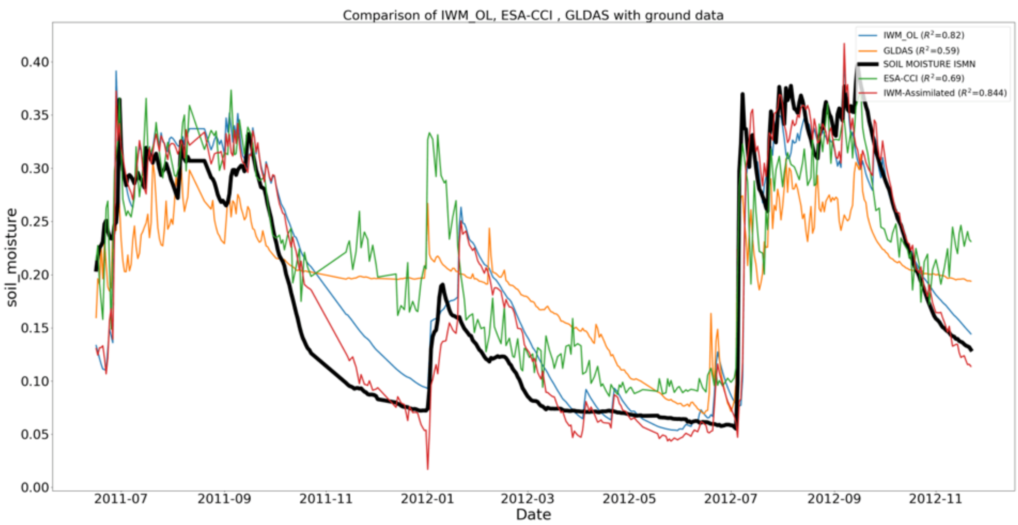

Fig 3: Intercomparison of soil moisture datasets

The performance of India Water model is compared to Satellite data as well as other Data assimilated products. IWM-DA has the best overall accuracy with R^2value of 0.844. The bias corrected GLDAS-CLSM has R^2 value of 0.59 while the satellite Soil moisture ESA-CCI has R^2 value of 0.63.The R^2 values for all datasets are shown in fig 4.

Dataset	R^2 value
IWM-OL	0.81
IWM-DA	0.844
ESA-CCI	0.63
GLDAS-CLSM	0.59

Fig 4: Accuracy of datasets used

CONCLUSION

Soil moisture is one of the essential parameters for earth systems study, the root zone soil moisture is extremely important for crop yield forecasting, agricultural drought monitoring. Soil moisture also plays a critical role as an antecedent condition in natural hazards like floods, droughts and landslides, therefore making accurate soil moisture representation very important. This study highlights that Data assimilated products not only produce more accurate datasets but also provide continous datasets at high spatio-temporal resolution which is not possible by satellite data.

ABSTRACT

Soil moisture is a vital climatic variable driving environmental and biological processes. Large scale soil moisture can be estimated using Land Surface Models or observed using active and passive microwave remote sensing. Increasing availability of remotely sensed soil moisture retrievals has allowed for constraining Land Surface Model (LSM) estimates. Though the accuracy of remote sensing datasets is constrained by soil roughness, vegetation, and surface temperature, combining them with LSMs allow us to reduce errors in soil moisture estimates. This study assimilates the SMOPs-ASCAT, ESA-CCI and SMAP soil moisture retrievals into a land surface model u sing an ensemble Kalman filter. The open-loop and data assimilated soil moisture outputs are evaluated against the ground-based sensor data. This demonstrates the establishment of an Indian Land Data Assimilation System (ILDAS) with the goal of providing accurate soil moisture products at high spatial and temporal resolution over India.

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