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Downscaling SMOS soil moisture data using geospatial technology

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Abstract
Downscaling of SMOS data using Geospatial Technology was carried out to develop a system to enhance the spatial resolution of soil moisture which otherwise is available at~ 40 Km, by incorporating various ancillary information, at a much higher spatial scale. The current spatial resolution of SMOS data has limited uses due to the coarse resolution. Two study sites one each in Udham Singh Nagar district (Rudrapur area) and Nainital District (Haldwani area) were selected for developing downscaling approach. Point wise soil moisture was interpolated in Quantum GIS software by employing Inverse Distance Weightage algorithm. LANDSAT 8 images were used to generate land use and land cover map of the study region. Soil information was retrieved from the earlier studies carried out in the department. Soil layer and land use map were merged in order to analyze the moisture regime of the area. Soil moisture at each polygon was extracted from interpolated soil moisture layer. Multivariate model was used to downscale the soil moisture values of SMOS at 1km spatial resolution by using the layers of LST and EVI as input. Results indicate that downscaled moisture exhibited quite good agreement with measured soil moisture (R^2, 0.924 RMSE 0.0487).

Keywords: landsat 8, MODIS, SMOS, soil moisture, NDVI, EVI

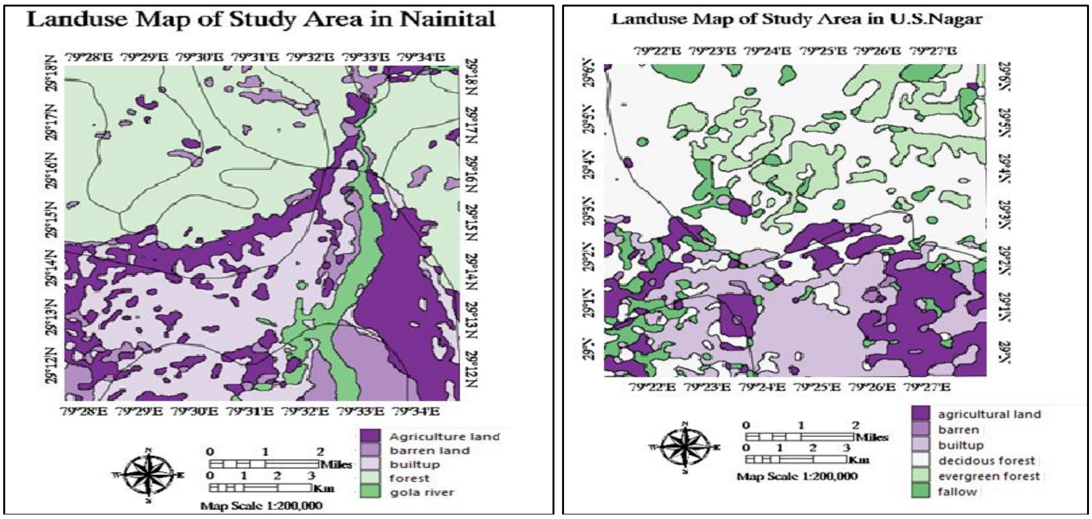
Introduction
Soil moisture plays a very important role for both on small agricultural scale and in large-scale modeling of land/atmosphere interaction. Soil moisture observations over large areas are increasingly required in a range of environmental applications including meteorology, hydrology, water resource management and climatology.
Various approaches have been developed over the past two decades to infer near- surface soil moisture from remote sensing measurements of surface temperature, radar backscatter and microwave brightness temperature Prigent *et al*., 2005; Crow and Zhan, 2007 [1]. The relative merit of these approaches depends on the strength of the physical link between the observable in the different spectral domains and soil water content the spatial/temporal resolution which is technically achievable by the different space borne remote sensing systems. The physical link between L-band brightness temperature and soil moisture profile (up to 5 cm) has been shown to be stronger than at higher frequency, and more direct than with radar backscatter and with thermal data.
The first satellite to make L-band observations specific to soil moisture retrieval will be the European Soil Moisture and Ocean Salinity (SMOS) mission was launched in 2009. The baseline SMOS payload is an L-band (1.4 GHz) two dimensional (2D) interferometric radiometer that aims at providing global maps of soil moisture with an accuracy better than 4% v/v every 3 days and with a resolution better than 50 km (Kerr *et al*., 2001) [3].

Materials and Methods
The study area chosen is comprised of Nainital and Udham Singh Nagar districts of Uttarakhand, India. Udham Singh Nagar is located between 28^0 58′ 4″N and 79^0 24′ 0″ to E. Nainital is located between 29^0 22′ 48″N to N and 79^0 27′ 0″ to E.SMOS, LANDSAT 8, and MODIS data were used. The SMOS data downloaded from the website https://earth.esa.int/web/guest/missions/esa-operational-eo missions/smos, Landsat8 and Modis data downloaded from the site http://earthexplorer.usgs.gov/.
The soil moisture data was in the form of pixels and took on the basis of area of interest. After the selection of pixel, subsetting of the places was done and values of soil moisture for Nainital and U.S Nagar for the different dates were drawn Point soil moisture data was interpolated in using inverse distance weightage method by keeping the cell size of 0.00036 and 0.00039. The interpolated soil moisture layer was assigned to World Geodetic System 84(WGS-84). Initially soil moisture has been interpolated in the percentages which was

converted into $m^3/\ m^3$ is comparable with soil moisture derived by SMOS. The land use/land cover map of the study area was generated using LANDSAT8 image (Fig.1).

Manually soil moisture was estimated from collected sample by the use of gravimetric method. The land use/land cover map of the study area was generated by using LANDSAT8 image. All bands were layer stacked to form a multiband image. Two subsets of study regions (part of Nainital and U.S Nagar) have been drawn from the image. The files of land use/land cover classification were then converted into vector format by using ENVI-4.8 software; the conversion was done by using the option raster to vector, which converted raster data into vector data. The vector which was generated in ENVI is transported to the QGIS 1.8.0 for developing the zonal statistics of each classified polygon. The land use polygons were also imported in Quantum GIS and were merged with soil polygons the attributes were updated by considering soil attributes as base layer.

The area of each polygon was computed using embedded algorithm in Quantum GIS. Polygons were thereafter superimposed on interpolated layer of soil moisture. The values of soil moisture at each polygon level were retrieved using zonal statistics function available in Quantum GIS. The polygons representing built up land were assigned zero (0) soil moisture. Thereafter area weighted soil moisture considering the area of each polygon has been computed for entire study region. Area weighted soil moisture was compared with SMOS soil moisture in order to analyse the accuracy of SMOS.



(A). (B).

Fig 1: Landuse Map of Study Areas **a)** Landuse Map of Study Area in Nainital **b)** Landuse Map of Study area in U.S. Nagar

Soil moisture and area was derived from the landuse, soil polygon, and interpolated image of both regions in QGIS 1.8.0 by using zonal statistics. Which gave all information releated to soil moisture and area.

Land surface temperature and EVI (Effective Vegetation Index) is good indicator of soil moisture and could prove to be useful in downscaling the soil moisture. LST increases when soils are deficient in moisture. On other hand LST decrease when sufficient soil moisture is available. LST derived through MODIS satellite is available every day.

Therefore MODIS LST images of derived dates were downloaded from USGS website and subsets of study region were prepared. MODIS images provide LST at approx. 10:30 A.M. with spatial resolution of 1 Km. For the analysis of EVI, MODIS NDVI images have been taken and these images are at 16 days interval. For displaying these images ENVI- 4.8 has been taken.

The images consist of three band reflectance NDVI and EVI. After displaying the images subset of area of study has been taken out and their values for EVI values shown in the EVI values of U.S. Nagar was more because of the more soil moisture in U.S. Nagar than in Nainital. SPSS software was used for the development of multivariate model considering soil moisture values as dependent variable and LST, Atm. Temp., NDVI, EVI, Dew point, wind speed, wind direction as independent variable. Stepwise variable selection approach by defining the probability value for inclusion of variable and exclusion of variable has been adopted. Multivariate model was thereafter used for downscaling soil moisture at scale of MODIS image i.e. 1Km.

Results and Discussion

Comparison of SMOS soil moisture and measured soil moisture

The data which was obtained from the subset of SMOS and the data provided by the zonal statistics being compared with each other and values found are as follows:

Table 1: Comparison of SMOS soil moisture and measured soil moisture

Date	Place	SMOS Moisture	Observed Moisture	Diff. in R^2
19 Dec, 2013	Haldwani	0.08	0.12	0.0016
26 Dec, 2013	Rudrapur	0.221	0.221	0
11 March, 2014	Rudrapur	0.148	0.23	0.006724
13 March, 2014	Haldwani	0.055	0.0891	0.001163
			Error	0.0487

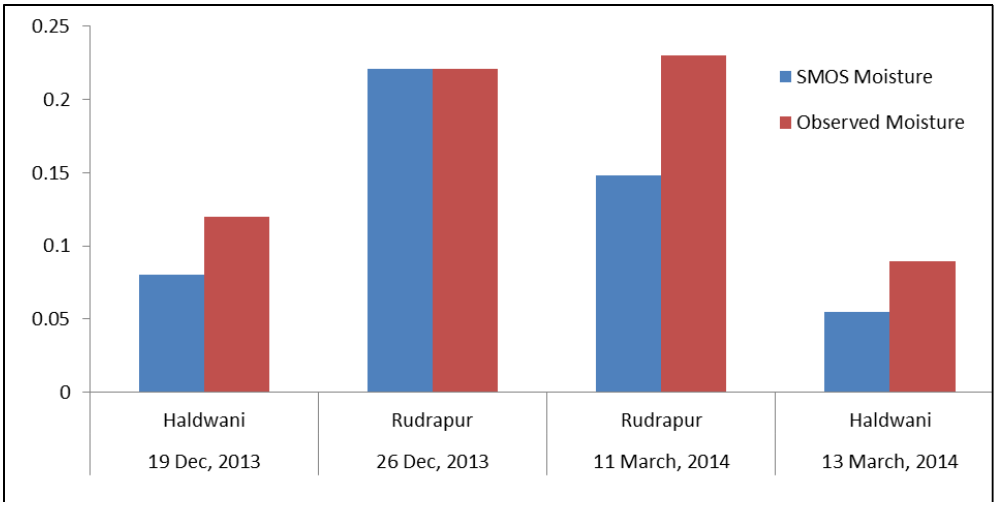


Fig 2: Bar graph showing the Comparison of SMOS data and Observed data

Development of multivariate model for soil moisture estimation parameter

SPSS software was used for the generation of multivariate model. The parameter which were taken in the SPSS for the development of equation was SMOS soil moisture data, Land surface temperature(LST), Atmospheric temperature(AT), Atmospheric temperature in Kelvin (ATk), NDVI values, EVI values, Dew point, Wind speed, Wind direction.

Table 2: Parameter used in SPSS

Moisture	LST	AT	ATK	LST-ATK	NDVI	EVI	Dew point	Wind speed	Wind direction
0.08	291.23	8.4	281.55	9.68	0.6358	0.329	0.8	3	160
0.221	290.54	17.5	290.65	-0.11	0.5797	0.31128	11.2	2	310
0.148	297.22	22.1	295.25	1.97	0.5874	0.3005	16.2	3	260
0.055	299.21	17.6	290.75	8.46	0.5493	0.2886	16.4	4	230

By running these parameters in SPSS (Table 2) there were two values of R^2 were found the value of second equation was greater than that of first equation the value first equation was 0.835 and value for second equation was 0.924. On the basis of R^2 values the coefficient of second equation for the development of downscaling model. The coefficients are as follows:

Table 3: Coefficients used in Multivariate model

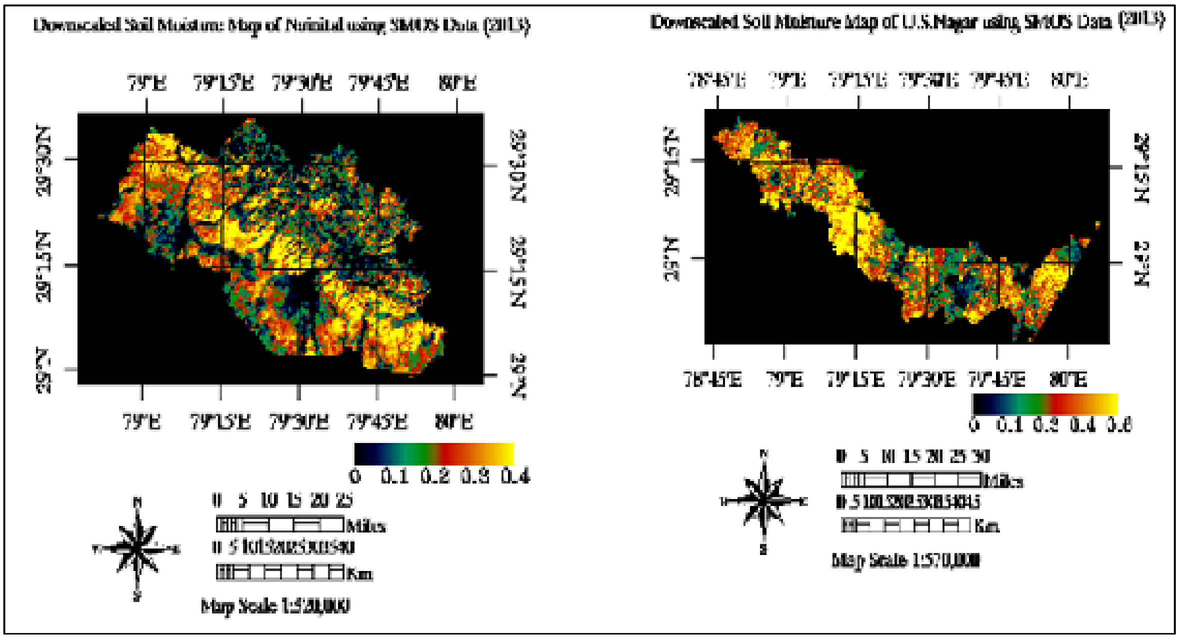
Coefficients[a]						
Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	.199	.024		8.427	.014
	LST_ATM_diff	-.015	.004	-.944	-4.029	.056
2	(Constant)	.302	.023		12.947	.049
	LST_ATM_diff	-.009	.002	-.599	-5.858	.108
	Wind speed	-.043	.009	-.473	-4.622	.136
3	(Constant)	.481	.000		.	.
	LST_ATM_diff	-.007	.000	-.464	.	.
	Wind speed	-.056	.000	-.614	.	.
	NDVI	-.257	.000	-.124	.	.

Downscaling of soil moisture using multivariate model

Downscaling algorithm was developed by the use of coefficients generated by the SPSS. The coefficients was applied in ENVI-4.8 software for the development downscaled image of district Nainital and U.S. Nagar. The developed algorithms were:

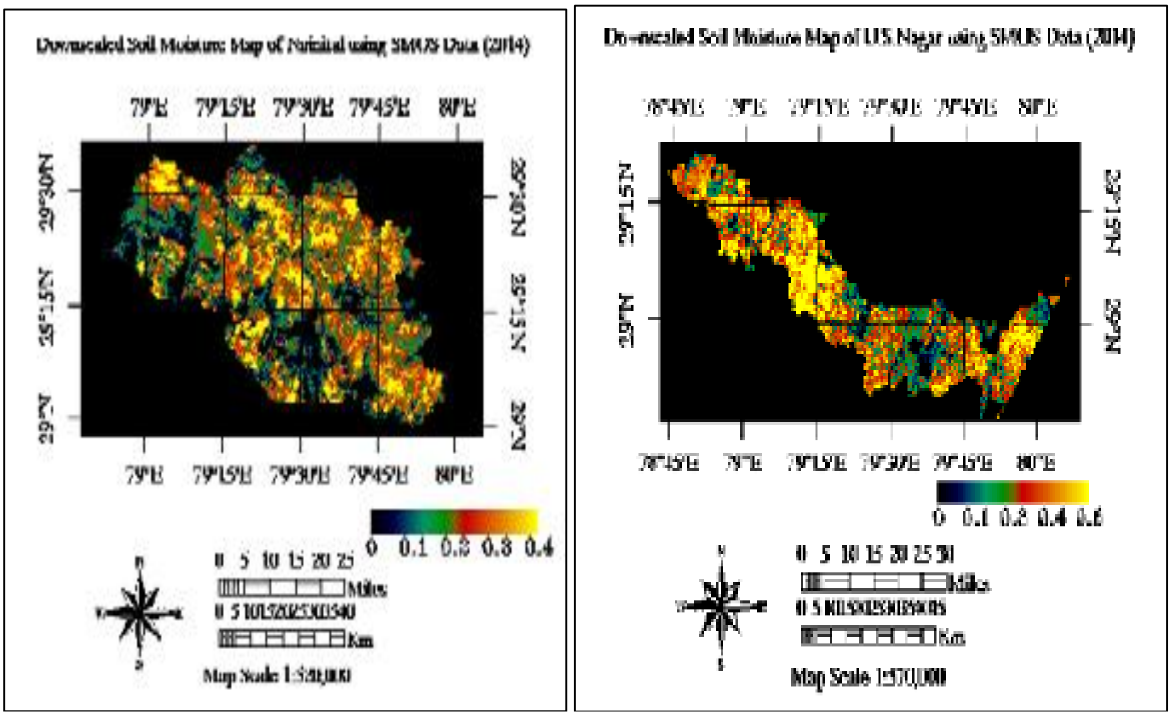
(-0.015* (Float (b1)-281.55)+1.277*float (b2))-0.190 (Haldwani)
(-0.015* (Float (b1)-290.65)+1.277*float (b2))-0.190 (Rudrapur)
(-0.015* (Float (b1)-295.25)+1.277*float (b2))-0.190 (Rudrapur)
(-0.015* (Float (b1)-290.75)+1.277*float (b2))-0.190 (Haldwani)

For the generation of downscaled images above equations were used in which b1 and b2 represent LST and EVI bands respectively. After the generation of downscaled image some negative values was there, they were removed by using masking option from ENVI-4.8. The downscaled soil moisture maps of Nainital and Udham Singh Nagar districts in Fig (3, 4) respectively.



(A) (B)

Fig 3: Downscaled Soil Moisture Maps 2013 **a)** Nainital **b)** U.S. Nagar



(A) (B)

Fig 4: Downscaled Soil Moisture Maps 2014 **a)** Nainital **b)** U. S. Nagar

Conclusion

The above study concludes that soil moisture estimation using remote sensing could be an important tool to find out the moisture condition of a very large place within a shorter period of time and will be cost effective. Soil moisture is also very important from the agriculture point of view for this a proper information regarding the soil moisture is required SMOS gives an idea about moisture condition at a very coarser resolution so by using downscaling technique soil moisture status comes to a comparatively good resolution and gives a proper scheme for scheduling irrigation.

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