ABSTRACTS

Microwave remote sensing of the land surface processes has advantages over optical remote sensing such as least attenuation due to the atmosphere, and high temporal resolution among others. Soil moisture is an important land surface variable, which is present at land atmosphere interphase and influences the hydrologic, atmospheric, climate, agricultural, and carbon cycles.

Given the challenges involved in measuring the soil moisture at local scale (heterogeneous nature of the soil, financial constraints etc.), microwave remote sensing has assisted the researchers in obtaining the soil moisture at the global scales. This year marks the four decades of research on microwave remote sensing of soil moisture. The microwave sensors can be categorized into two kinds passive (where the Sun acts as the source of energy) and active (where the sensor sends a microwave signal and records the response) sensors. Each has their own pros and cons. This thesis comes under the purview of microwave remote sensing of hydrology. The thesis can be broadly divided into two parts.

In the first part, a synthesis of four decades of research and development on the passive and active microwave soil moisture retrieval algorithms is provided. The algorithms associated with passive sensors use the radiometer brightness temperatures, while active sensors use the radar backscatter measurements to retrieve soil moisture. The physics of both algorithm classes are since the microwave measurements at lower frequencies are influenced by the soil dielectric property, which acts as a proxy for the surface soil moisture content. In this review effort, the emphasis is laid on the physical models of the passive and the active retrieval algorithms. These algorithms facilitate to obtain the individual radiative contributions from soil, vegetation, and atmosphere that reach satellite sensors after mixing (roughness), scattering, and attenuation. In the process, the current research efforts to improve individual aspects of the algorithms, followed by a description of different retrieval procedures are investigated.

Following a comprehensive review of retrieval algorithms, an overview of how our knowledge in this field has improved in terms of the design of sensors and their accuracy for retrieving soil moisture is presented. The evolution of the products of various sensors over the last four decades is assessed in terms of daily coverage, temporal performance, and spatial performance, by comparing the products of eight passive sensors (Scanning Multichannel Microwave Radiometer – SMMR, Special Sensor Microwave Imager – SSM/I, Tropical Rainfall Measuring Mission (TRMM) Microwave Imager – TMI, Advanced Microwave Scanning Radiometer – Earth Observing System – AMSR-E, WinSAT, Advanced Microwave Scanning Radiometer 2 – AMSR2, Soil Moisture Ocean Salinity – SMOS and Soil Moisture Active Passive – SMAP), two active sensors (Active Microwave Instrument – Wind Scatter meter ERS, Advanced Scatter meter – ASCAT), and one active/passive merged soil moisture product (European Space Agency-Climate Change Initiative – ESA-CCI combined product) with the International Soil Moisture Network (ISMN) in-situ stations and the Variable Infiltration Capacity (VIC) land surface model simulations over the Contiguous United States (CONUS). In the process, the regional impacts of vegetation conditions on the spatial and temporal performance of soil moisture products are investigated. In addition, inter-satellite comparisons are carried out to study the roles of sensor design and algorithms on the retrieval accuracy. The analysis indicates that substantial improvements have been made over recent years in this field in terms of daily coverage, retrieval accuracy, and temporal dynamics. It is concluded that the microwave soil moisture products have significantly evolved in the last

four decades and will continue to make key contributions to the progress of hydro-meteorological and climate sciences.

In the second part of the thesis, the focus is primarily on passive microwave remote sensing of land surface variables. The passive microwave soil moisture retrieval algorithms are in general based on the zeroth order radiative transfer model. If a microwave sensor can measure the brightness temperatures in dual polarizations, they can be used in tandem with the radiative transfer equations to estimate another important land surface variable called the Vegetation Optical Depth (VOD), which closely relates to the water content in foliage and woody components of the above ground biomass. So, mathematically, the dual polarized radiative transfer equations can be inverted to derive the VOD, which in turn acts as an input in the soil moisture retrieval process. It is identified that there exist multiple ways – thus resulting in multiple analytical solutions – by which the radiative transfer equations can be inverted resulting in the problem of equifinality in soil moisture retrieval algorithm. In this thesis, a new analytical solution coined as the Karthikeyan's solution is proposed, which is used to derive a new set of VOD and soil moisture products based on the X-band (10.65 GHz) AMSR-E brightness temperature observations. The products thus obtained are compared with two products, which in turn are derived using two existing analytical solutions from the literature. Apart from the problem of equifinality, the results from the above work indicate that the VOD retrievals are influenced by high-frequency variability, which may dampen the true signal emitted from vegetation, rendering the VOD retrievals unusable for vegetation related research.

In addition to the VOD, specifying appropriately the soil surface roughness parameter is also important while retrieving the soil moisture. Until recently, this parameter was a global constant in the operational retrieval algorithms. With these challenges, the succeeding work in the thesis is designed wherein a new retrieval algorithm, coined as the Simultaneous Parameter Retrieval Algorithm (SPRA), is developed to simultaneously retrieve the VOD, the surface roughness parameter, and the soil moisture at global scale using the Level 3 0.25° X-band brightness temperatures of the AMSR-E sensor.

The methodology is based on the premise that the vegetation dynamics undergo slower temporal changes than the soil moisture, an assumption, which has previously been successfully used for microwave radiometric retrievals at lower frequencies. Results indicate that the SPRA produces the VOD retrievals with reduced high-frequency noise when compared to the baseline Land Parameter Retrieval Algorithm (LPRM) retrievals. This effect assisted in identifying the influence of precipitation and cropping patterns on the temporal dynamics of the VOD. The surface roughness parameter indicated a strong dependence on vegetation, followed by the topographic complexity. A precipitation-based validation of SPRA and LPRM soil moisture retrievals over India indicated a better skill of the SPRA product. The improvement in skill is a result of using the new VOD and spatially varying surface roughness retrievals.

Given the constraints associated with soil moisture, validating the satellite retrievals are still considered a challenging area of research. To validate the satellite soil moisture products at continental/global scales, a novel validation technique, which validates microwave soil moisture retrievals using precipitation data is proposed. It is based on the concept that the expectation of precipitation conditioned on soil moisture follows a sigmoidal convex-concave shaped curve, the characteristic of which was recently shown to be represented by mutual information estimated between soil moisture and precipitation. On this basis, with an emphasis on distribution free – non-parametric computations, a new measure coined as the

Copula–Kernel Density Estimator based Mutual Information (*CKDEMI*) is introduced. The validation approach is generic in nature and utilizes *CKDEMI* in tandem with a couple of proposed bootstrap strategies, to check the accuracy of any two-soil moisture products (here AMSR-E sensor's VUA-NASA and U. Montana products) over India using precipitation (IMD) data. The proposed technique yields a 'best-choice soil moisture product' map, which contains locations where any one of the two/none of the two/both the products have produced accurate retrievals. The results indicated that, in general, VUA-NASA product has performed better over U. Montana's product for India. The best-choice soil moisture map is then integrated with land use land cover and elevation information using a novel PDF based procedure to gain insight on conditions under which each of the products has performed well. Finally, the impact of using a different precipitation (APHRODITE) dataset over the best choice soil moisture product map is also analysed. The proposed methodology assists researchers and practitioners in selecting appropriate soil moisture product for various assimilation strategies at both basin and continental scales. The soil moisture products obtained from the Karthikeyan's solution and the SPRA are validated over India using the proposed method