*A White Paper submitted in response to the Request for Information for the*

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Title: Long-term Low Frequency Microwave Observations for Environmental Applications

and Climate Assessment

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***Key Question: How can knowledge of water availability be improved at various scales across both natural and managed landscapes, and how will water availability at these scales change in the future?***

***Introduction.*** In a likely future of changing climatic conditions, the availability of water resources (or lack thereof) at a specific location or across regions of interest becomes a key factor leading to economic and societal stress. Yet knowledge of future water availability remains largely unknown, with many climate model predictions disagreeing on both the amount and sign of moisture change in different regions [IPCC AR4, 2007]. Given that the Earth’s population lives overwhelmingly on land, information about the components of the terrestrial water cycle is particularly important in addressing the question of future water availability, and of these components, soil moisture is the primary state variable in land surface hydrology. Although NASA’s SMAP and ESA’s SMOS missions are currently using L-band microwave technology for accurate soil moisture determination in all-weather conditions, no enhanced replacement missions (new missions that will exploit new technologies for enhancing the temporal and spatial resolution of products) are planned once these missions end their useful life in orbit in the coming years. Thus, continuation of the observational record of critical microwave measurements (either follow-on or enhanced measurements) into the timeframe covered by the upcoming Decadal Survey is very uncertain. At the time of this white paper submittal, the National Research Council has just released a recommendation that NASA determine the value and implementation priorities for data continuity [National Academies, 2015].

***Need for Long Time Series Data Record.*** The scientific value of terrestrial L-band observations will grow non-linearly as the length of the historical dataset is enhanced. For example, prior to the ingestion of microwave brightness temperature observations, all land data assimilation systems require a climatological context for the ingestion – a multi-year (~decadal) record of equivalent measurements. The current lack of such information severely hinders the performance of such modeling systems [Reichle and Koster, 2004]. Climatological soil moisture information is also required to utilize L-band datasets for applications (like agricultural drought monitoring) that are based on the detection of relative inter-annual variability in soil moisture. In the specific case of agricultural drought, this requires the comparison of existing root-zone soil moisture conditions with past drought events with known end-to-season yield results. The characterization by month or season of the statistics of soil moisture (and any associated derived product, such as evaporation rates or flooding potential) simply cannot be achieved with only a few years of data, and these statistics have direct impact on numerous applications (e.g., trafficability) and scientific analyses (e.g., characterizing the variability of the surface energy budget). Long records are particularly needed for statistical or modeling studies of soil moisture impacts on weather because these impacts, while potentially important, can be subtle. Finally, trend analysis must be conducted over decadal time scales given that trends are necessarily superposed on unrelated inter-annual variations. Simply put, the value of L-band observations will compound as the datasets are lengthened.

While some soil moisture datasets do exist, their value is badly compromised by a lack of consistency between sensor types (e.g., transitions between passive and active-based sensors) and inconsistencies in the microwave frequencies utilized for retrieval [Loew et al., 2013]. In contrast, the recent success of Aquarius, SMOS, and SMAP cross-calibration efforts highlights the potential for consistency in L-band radiometry datasets acquired from different missions and different antenna designs, but all operating at the most appropriate low microwave frequency for accurate soil moisture determination.

***Societal Benefit Example.*** Agricultural drought monitoring has emerged as a major application for L-band terrestrial radiometry [Bolten and Crow, 2012]. In particular, recent evidence suggests that the relatively shallow penetration depth of microwave radiometers does not pose as serious a limitation as previously supposed [Qiu et al., 2014]. The relatively coarse spatial resolution of microwave sensors is not a large impediment to large-scale drought monitoring activities. However, it does represent a serious limitation when considering drought mitigation. Mitigation requires the resolution of individual agricultural/rangeland units (i.e., the scale at which discrete land management decisions are made). Such efforts cannot be reliably-supported by coarse-scale retrievals reflecting average conditions across an array of managed and non-managed portions of the broader landscape. The resolution issue is especially acute for irrigation agriculture where all relevant management information is spatially-restricted to a specific irrigation application unit. As a result, a sharp increase in the value of L-band radiometry for food security applications can be expected as the resolution of satellite sensors starts to approach the typical management scales of dry-land and irrigation-based agriculture. While such scales vary widely across the globe, 1 km is commonly assumed to represent the upper (i.e., coarser) edge of the management unit size distribution, and therefore is an aggressive resolution target for future L-band radiometry missions.

***Needed New Technology Investments.*** Achievement of finer spatial resolution with new L-band radiometer missions generally requires increased antenna aperture size. Mechanical structure and dynamics technology innovation and engineering are needed to increase instrument antenna size 5 to 10-fold beyond the large 6-m antenna used by SMAP. Both reflector (SMAP) and interferometer antenna technology (SMOS) need continued advancement to enable geophysical products (e.g. soil moisture) with greater resolution and accuracy in the future. Dealing effectively with an environment of worsening radio frequency interference (RFI) is an ongoing challenge of increasing complexity, particularly at low frequencies (< 5 GHz) due to proliferation of broadband wireless communications. On-board digital signal processing innovation is needed to keep pace with telecommunications advancements in order to provide on-board RFI detection and filtering and to manage the subsequent data downlink burden.

***Links to Other Observations.*** Accurate estimation of soil moisture from L-band brightness temperature measurements from space requires knowledge of other surface conditions, primarily soil temperature and overlying vegetation. Determination of soil moisture would greatly benefit from simultaneous measurement of the scene temperature under clear/cloudy and all-weather conditions, such as achieved using a 37 GHz microwave radiometer, to complement the all-sky, all-weather capabilities of L-band sensors. In addition, any improvements in visible/infrared and/or radar-based vegetation information at the spatial scale of new L-band missions would likely lead to associated improvements in soil moisture estimation.

***Communities Involved.*** Generation of a longer time series data record of L band-derived soil moisture measurements from follow-on or enhanced missions has obvious relevance to weather and climate assessments as already mentioned and to a wide variety of societal applications beyond the agricultural drought example given. It is anticipated that such a data record would be supported and heavily utilized by the weather/climate, land surface hydrology, and agricultural communities, as well as the range of application users represented by the SMAP Early Adopter Program.

***References***

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