Soil Moisture Active-Passive (SMAP) Breakout Session

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(Approximately 40 people in attendance)

SMAP Mission Overview

The Soil Moisture Active-Passive (SMAP) mission is one of the four first-tier missions recommended by the NRC Earth Science Decadal Survey Report. The objective of SMAP is to provide global measurements of Earth's soil moisture at 10-km resolution with two- to three-days revisit and land-surface freeze/thaw conditions at 3-km resolution with one- to two-days revisit. SMAP builds on the heritage of ground-based and airborne passive and active low-frequency microwave measurements that have demonstrated and validated the effectiveness of the measurements and associated algorithms for estimating the amount and phase (frozen or thawed) of surface soil moisture. The instrument design benefits significantly from heritage established by NASA Instrument Incubator Program (IIP) and Earth System Science Pathfinder Program (ESSP) activities, including the Hydrosphere State Mission (Hydros, Entekhabi et al 2004). The mission data will enable advances in weather and climate prediction and in mapping processes that link the water, energy, and carbon cycles. The SMAP instrument is a combined radar and radiometer system operating at 1.26 GHz (with VV, HH, and HV polarizations) and 1.41 GHz (with H, V, and U polarizations), respectively. The radar and the radiometer share the aperture of a 6-m lightweight deployable mesh antenna which rotated at 14.6 rpm to provide a constant look-angle scan across a swath width of 1000 km. The radiometer measurements allow retrieval of soil moisture in diverse (nonforested) landscapes with a resolution of 40 km. The radar measurements allow the retrieval of surface freeze-thaw state at relatively high resolution (3 km) while also enabling derivation of combined radar/radiometer data products that will include a 10 km soil moisture field.

Priority science products of SMAP measurements

Baseline mission and standard science products planned for delivery by the SMAP mission include (1) surface soil moisture (approximately the top 1-5cm of the ground surface) for low vegetation biomass areas and (2) landscape frozen/non-frozen status for regions where frozen seasons are significantly influence vegetation growth. The standard suite of deliverables includes an passive-only 40 km resolution surface soil moisture product derived from the L-band radiometer, and a 10 km resolution surface soil moisture product derived from the combined active-passive radar-radiometer instrument suite. The soil moisture products will be provided with a nominal 3-day global revisit. The SMAP landscape freeze-thaw product is to be derived from the L-band radar. It will be provided with 1-3 km spatial resolution and 2-day revisit for vegetated regions above 40 degrees north latitude. The freeze/thaw state variable constitutes the predominant frozen or non-

frozen condition of the integrated soil-snow-vegetation continuum and does not distinguish differences in freeze/thaw state among these various landscape elements.

The following uses of SMAP measurements were articulated by the NRC Decadal Survey:

- Estimate global water and energy fluxes at the land surface.
- Define low temperature and moisture constraints to land/atmosphere carbon/water/energy exchanges.
- Extend weather and climate forecast skill.
- Develop improved flood/drought prediction capability.

Members of the breakout session generally confirmed the importance of baseline mission and standard products, as well as NRC designated priority uses of these data. However, members also provided additional suggestions for other potential uses of SMAP data, as summarized below.

Other uses of SMAP measurements*:*

The breakout session participants identified a number of potential research/exploration, products, applications and studies that could be enabled by the SMAP mission, including:

- Trace gas emissions (CH_4, CO_2, N_2O);
- Snowpack water storage/dynamics;
- Wetlands classification and surface water dynamics;
- Woody biomass (magnitude/change) for autotrophic respiration assessment (repeat: annual);
- Soil freeze/thaw and root zone soil moisture;
- Soil active layer depth;
- Soil temperature;
- Fire danger index (duff moisture; 1-3km);
- Fire weather (soil moisture inputs);
- Ensemble closing of water/energy balance.

Trace gas emissions: Soil moisture and temperature are the primary environmental controls on soil heterotrophic respiration. SMAP would provide spatially explicit and temporally dynamic measures of these parameters enabling improved regional assessment of soil respiration and associated CO_2, CH_4 and N_2O emissions. Soil heterotrophic respiration could be used with current satellite based measures of GPP to compute net ecosystem exchange of carbon (NEE) with 1-3 day temporal fidelity and at scales commensurate with surface observations from tower eddy flux networks. The NEE variable is critical for accurate determination of terrestrial source/sink status for atmospheric CO_2. Improved mapping of wetlands and soil moisture and temperature status would enable better assessment of CH_4 and N_2O emissions for comprehensive assessment of these important trace gases. These measurements would benefit planned missions to measure total column atmospheric CO_2 concentrations (e.g. OCO), by providing sub-grid scale estimates of land-

atmosphere CO_2 exchange and associated moisture/temperature environmental constraints (temperature, moisture) at the base of the troposphere.

Snowpack water storage/dynamics: The freeze/thaw variable from SMAP is sensitive to the timing of seasonal snowpack ripening and spring snowmelt and could benefit regional snowmelt assessment and flood prediction, and as a constraint on regional hydrologic model simulations of these processes, particularly for northern (>50N) areas with frequent cloud cover (a major constraint on satellite optical-IR snowcover observations) and where surface weather and stream gage measurement networks are sparse.

Wetlands classification and surface water dynamics: The SMAP L-band active/passive microwave instrument is sensitive to vegetation biomass and surface wetness and would be useful for wetlands classification and characterization of surface water dynamics and DOC export. The 3-day temporal repeat and insensitivity to solar illumination, clouds, smoke, and other atmospheric aerosols would enable repeat mapping of wetland biomass and surface moisture at spatial and temporal scales sufficient to characterize vegetation phenology and dynamic hydrologic responses to discrete wetting/drying weather events.

Woody biomass (magnitude/change) for autotrophic respiration assessment: The L-band radar sensor from SMAP is sensitive to vegetation woody biomass, unlike optical-IR sensors which are primarily responsive to photosynthetic biomass. SMAP would provide the means for more accurate determination of woody biomass and associated autotrophic growth/maintenance respiration over forests and shrublands. These biomass measurements could potentially be provided with 1-3 day temporal fidelity commensurate with SMAP retrievals, though annual sampling is probably sufficient to characterize woody biomass, which generally doesn't exhibit large seasonal changes.

Soil freeze/thaw, active layer depth and root zone soil moisture: It was recognized that SMAP soil moisture and freeze/thaw measurements would provide valuable inputs to model assimilation based estimation of soil freeze/thaw status, soil active layer depth and root zone soil moisture conditions. The baseline SMAP products will characterize freeze/thaw state dynamics of the aggregate soil-snow-vegetation conditions, and surface (~1-5cm depth) soil moisture. Model based simulations incorporating these inputs as major drivers of thermal and hydrologic processes can extend these measurements to deeper soil layers useful for ecosystem studies.

Soil temperature: Soil temperature is a fundamental constraint on ecosystem processes, including soil decomposition and respiration, soil freezing and thawing, and permafrost stability. The passive L-band measurement from SMAP is sensitive to soil moisture and temperature and can be used with relatively simple radiative transfer and emissivity models to determine surface soil temperature. Soil temperature is not a designated product from SMAP, but would enable improved regional assessments of soil decomposition and respiration, soil organic carbon and permafrost.

Fire danger index and fire weather: A fundamental input to national fire danger assessments is the moisture status of surface litter (duff). SMAP could provide a direct measure of surface soil wetness to enable improved regional estimates of duff moisture and potential fire danger.

Ensemble closing of water/energy balance: SMAP soil moisture and freeze/thaw products provide information about surface energy partitioning between sensible and latent energy and evapotranspiration that could be used with other satellite observations and surface measurement networks in the context of ensemble model assimilations for closing

the regional water/energy balance. Currently, this is difficult to do from any single information source such as tower eddy covariance flux measurement networks.

Crop yield forecast modeling: SMAP soil moisture and freeze/thaw state variables bound the vegetation growing season and provide information regarding plant-available moisture that could enable improved crop yield forecast modeling. This information would be particularly useful for agricultural regions composed of extensive monocultures and non-irrigated croplands such as wheat production of central Eurasia, Canada and the mid-west region of the USA.

Science preparatory activities for using SMAP measurements

The breakout session members identified a number of activities that could be initiated and supported by NASA to prepare the community for using SMAP measurements, including:

- *Better integration of field scale measurements/networks*: Field scale measurements provide potentially valuable information for SMAP instrument calibration and product validation. There are currently multiple national and international monitoring networks, but no clear plan for obtaining, organizing and synthesizing these data in the context of the SMAP mission. Efforts should be made to prepare international data use agreements (if necessary) and funding for data processing and cal/val activities. This should be done well before mission launch.
- *Construction/Utilization of existing/planned datasets (PALS, ALOS, SMOS) for SMAP science development*: There are currently a number of existing and planned satellite L-band active/passive remote sensing datasets that would be useful for SMAP algorithm development, testing and implementation prior to launch. Funding and organization should be provided to support activities to acquire and process these data to support SMAP. These activities would also involve securing data use agreements and funding to support the use of foreign datasets, including ALOS and SMOS, which are critical test beds for SMAP.
- *Assessment of soil moisture sub-grid scale variability and cal/val through intensive field based sampling*: There was some question about the potential meaning and utility of a 10km soil moisture product for ecosystem studies. The breakout members recognized the need to establish appropriate methods for appropriate spatial scaling between SMAP measurements and field based observations and studies. Past regional scaling experiments such as Bigfoot and BOREAS were recognized as successful examples of similar experiments that could be implemented for scaling and cal/val analysis under SMAP.
- *Regional Experiments*: Regional experiments were identified as critical for SMAP algorithm development and cal/val both prior to and after launch. Field measurement campaigns to test algorithms over regional ecosystem/biomass gradients (e.g. Canadian boreal-tundra zone) using available measurement networks (IPY, NEON), satellite (ALOS, SMOS, AMSR-E) and airborne (PALS, UAVSAR, VHF/UHF radars) remote sensing were identified as particularly useful in the context of implementing SMAP for ecosystem studies. A mid-continent intensive

field campaign was also identified to assess capabilities for regional monitoring of soil moisture and surface fluxes.

Major issues to be resolved to enable SMAP science

Members of the breakout session identified several issues that if resolved, would enhance SMAP science delivery, including:

- *Potential for soil moisture sensitivity/retrieval at higher biomass levels*: The baseline for SMAP soil moisture retrievals includes all land areas where the water content of vegetation biomass is less than ~5kg m^{-2}, due to relative insensitivity of the L-band signature to soil conditions at higher biomass levels. Surface soil moisture is to be obtained with an accuracy of 4% volumetric for baseline conditions. This may be appropriate for hydrological studies, but is too restrictive for ecosystem studies. Potentially useful information regarding temporal changes in surface moisture may be obtained under higher biomass levels with reasonable accuracy. These measurements would be useful for assessing ecologically important variables such as regional wetting/drying cycles, surface humidity and vegetation water stress and would enhance the global extent and value of the SMAP mission for ecosystem studies. Regional experiments should be conducted to explore the potential utility of SMAP across the full range of global biomass and climate conditions.
- *File formats, metadata and data projections of planned products*: Planning should be implemented as soon as possible to define geographic projections, file formats and metadata of the SMAP products. These should be designed to incorporate existing tools and EOS protocols as much as possible to facilitate the widest possible use of SMAP data.
- *Sub-grid scale heterogeneity (mixed pixels) on SMAP (soil moisture and F-T) retrievals*: Studies should be conducted to explore the effects of subgrid scale heterogeneity on SMAP soil moisture and freeze-thaw retrievals. These studies could be implemented in the context of regional field campaigns (above).
- *Ancillary data products definition and development (surface water, landcover, etc…)*: A number of potential datasets were recognized as being important to SMAP data product development and applications. These ancillary datasets include surface water features, land cover classifications, digital terrain information, and vegetation continuous fields. These products should be standardized as much as possible for production of SMAP soil moisture and freeze/thaw variables. These products should also be distributed if appropriate in conjunction SMAP products. Funding should be made available to identify and assemble these products (if needed) well in advance of launch.