SMAP Data Products and Applications _001

A tutorial slide presentation with notes, that can be adapted as needed for specific audiences.

Outline _002

The goal of this tutorial is to familiarize SMAP data users with the SMAP mission, its objectives, instruments, algorithms, data products, calibration and validation, and applications.

Comprehensive summaries of these aspects of SMAP are provided in the 182-page SMAP Handbook document available free for download from the SMAP website.

Specific details of the algorithms, calibration and validation plan, and applications plan are also available in separate documents referenced in a slide at the end of the presentation.

What Is SMAP? _003

SMAP stands for **S**oil **M**oisture **A**ctive **P**assive. "Active" refers to the SMAP radar, which is an active sensor, while "Passive" refers to the SMAP radiometer, which is a passive sensor.

SMAP radar and radiometer observations of the land surface are sensitive to changes in the near-surface water content of the soil (soil moisture), and to changes in the frozen or thawed state of the surface. Retrieval algorithms are used to process the radar and radiometer data to yield estimates of the soil moisture and the frozen or thawed state of the surface.

SMAP is one of a series of Earth science missions launched by NASA. SMAP has five key science themes within its overall science objective. SMAP also has a strong applications component with five applications thematic areas (described in subsequent slides).

NASA Earth Observing Satellite Fleet _004

This chart provides a graphic visualization of NASA's fleet of Earth Observing Satellites as of June 2015. The oldest satellite is Terra, launched in December 1999 and the newest is SMAP, launched in January 2015. Part of NASA's mission is studying Earth and being able to address key scientific questions, which require satellite observations.

In 2007 the National Research Council (NRC) published its first Earth Science Decadal Survey Report which relied on the science community to identify and prioritize leading-edge scientific questions, the observations required to answer them, and notional missions to make those observations. It was intended to guide the agencies' (NASA, NOAA, USGS) space-based Earth observation programs in the coming decade.

The report recognized the need for a global soil moisture and surface freeze/thaw observations and recommended SMAP as one of four Tier-1 missions, which are the highest priority missions. The SMAP mission was especially ripe to move forward because it leveraged work done under two earlier missions. One was Hydros, which was the predecessor to SMAP but was cancelled due to budget constraints and never launched. The other was Aquarius which did launch, and lessons learned were leveraged from its L-band radiometer and radar instruments. There were therefore no technology issues and SMAP could be implemented on a fast-track.

The SMAP mission was initiated in February 2008 and launched on January 31, 2015.

Why Soil Moisture? _005

Soil moisture information is useful in a number of societal benefit applications, which for SMAP are grouped into five main thematic focus areas.

(1) Soil moisture variations affect the evolution of weather and climate over continental regions. Initialization of numerical weather prediction and seasonal climate models with accurate soil moisture information enhances their prediction skills and extends their skillful lead times.

(2) SMAP soil moisture observations will provide information on water availability and environmental stress for estimating plant productivity and potential yield. This will enable significant improvements in operational crop productivity and water stress information systems, providing crucial information for decision makers.

(3) Currently there is no global in situ network for soil moisture monitoring hence drought monitoring and prediction is highly dependent on models. Model predictions can be greatly enhanced through assimilation of space-based soil moisture observations leading to improved ability to monitor agricultural drought (lack of root-zone soil moisture) and improved famine early warning in the most food-insecure regions of the world.

(4) The surface soil moisture state is key to the partitioning of precipitation into infiltration and runoff and thus is one of the major pieces of information that drives flood prediction modeling.

(5) SMAP will benefit the emerging field of landscape epidemiology, aimed at identifying and mapping vector habitats for human diseases such as malaria, where direct observations of soil moisture and freeze/thaw status can provide valuable information on vector population dynamics.

Why Measure From Space? _006

The primary objective of SMAP is to provide high-resolution and frequent-revisit global maps of soil moisture and surface freeze/thaw state. A current limitation in measuring soil moisture and freeze/thaw globally and with good spatial representation is that there are few automated in situ measurement stations around the world, and these only provide point measurements. Point measurements are often not representative of the surrounding landscape because they do not capture heterogeneity.

The map on the right shows one U.S. network of in situ soil moisture stations, which are few and far between in most places. The U.S. is the region in the world with the most comprehensive in situ network of soil moisture stations. Other regions such as large parts of Africa are totally lacking. Some areas are so vast and remote that it is not possible to obtain measurements of soil moisture or freeze/thaw state on a continuous basis.

There are a number of precursor satellite instruments that have been used in the past to provide some soil moisture information but these instruments have lower sensitivity, coarser spatial resolution, or much less spatial coverage than what SMAP will provide. The SMAP radiometer is designed to detect and filter out contaminating interference from man-made radiation sources (known as RFI) and hence the global coverage by SMAP of high quality measurements is much higher than with any previous satellites.

SMAP will provide observation of all the land surface every three days or less. This high frequency of temporal sampling is essential for accurate tracking of the dynamics of surface wetting and drying caused by precipitation.

Why Active and Passive? _007

Passive remote sensors (radiometers) measure either thermally emitted radiation from a medium, or scattered radiation from a natural source such as the sun, to determine the emissivity or albedo of the surface.

Active remote sensors (or radars, operating in the microwave region of the electromagnetic spectrum) provide their own illumination source, sending out a transmitted wave and measuring the received reflection back from the target to determine its backscatter cross-section.

Measurements of emissivity (or albedo) and backscatter cross-section (sometimes simply called backscatter) provide complementary information on the soil moisture, roughness and vegetation characteristics of the land surface.

The radiometer measures the power of the received radiation, while the radar measures both the amplitude and phase of the received signal relative to the transmitted signal. The spatial resolution of the radiometer and radar measurements depends on the ratio of the antenna aperture size (linear dimension) to the wavelength of the measured radiation. These are known as real aperture observations.

In the case of the radar, special processing (synthetic aperture processing) can be performed that uses the amplitude and phase information of the radar measurements along with information on the forward motion of the radar relative to the surface to obtain enhanced spatial resolution. Radars that employ synthetic aperture processing are known as synthetic aperture radars or SARs. SARs provide higher spatial resolution, allowing finer-scale features of the surface to be observed.

The SMAP radar is a special type of SAR called an unfocused SAR, as a result of its unique antenna scanning geometry and processing method.

Measurement Frequency _008

Remote sensors are designed to operate at specific regions of the electromagnetic spectrum according to their intended application.

Sensors intended for surface observation operate at “atmospheric window” frequencies where attenuation and emission by atmospheric gases is low. Sensors intended for global soil moisture sensing must also operate where attenuation by vegetation is low which implies sensing at low microwave frequencies since vegetation attenuation decreases with frequency.

Attenuation by clouds and rain is also less at lower frequencies. The sensitivity of microwave radiation to soil moisture is governed by the dielectric constant of water, which is highest at frequencies below about 5-7 GHz.

For the above reasons, soil moisture sensors are designed to operate at microwave frequencies below ~7 GHz (C-band), and preferably as low as ~1 GHz (L-band) for highest accuracy. At frequencies below about 1 GHz Faraday rotation by the ionosphere becomes a significant problem and there is increased threat from radio frequency interference (RFI) from man-made emitting sources. In fact, RFI is a problem throughout the L- to C-band region, except for a few bands that have been protected by international regulation for use in radio astronomy and remote sensing (protected bands).

The SMAP radiometer operates at a frequency of 1.41 GHz, and the radar operates at adjustable frequencies in a small range near 1.26 GHz. At these frequencies (corresponding to wavelengths of 21-24 cm) the soil emission and backscatter measured by SMAP is sensitive to water in the top approximately 5 cm of the soil. Higher frequencies (shorter wavelength) would not penetrate as deeply into the soil therefore the long wavelength at L-band is optimum for SMAP in terms of instrument design.

A final consideration is that wavelengths longer than L-band would present limitations in spatial resolution of the instrument (coarser resolution) because the resolving power of the instrument is related to the ratio of the antenna size (linear dimension) to the wavelength.

Retrieval of Soil Moisture _009

Emission (radiometer) and backscatter (radar) equations are used to model the interactions between microwaves and the vegetation and soil for a typical vegetation-covered landscape. The radiometer measures the emitted radiation intensity or brightness temperature (in units of Kelvin) and the radar measures the backscatter or sigma naught of the transmitted signal (in units of dB).

Each equation models three components of the radiation-surface interaction. Emissions that reach the radiometer come from: (1) the soil directly, (2) the vegetation directly, and (3) from the vegetation bouncing off the soil and to the receiver. Similarly, backscattering interactions from the radar signal come from: (1) the soil, (2) the vegetation, and (3) the vegetation-soil or the soil-vegetation. The radar interactions are more complex because the scattering interactions are more dependent (than emission) on the relative sizes and orientations of the vegetation components. The backscatter signal is also more sensitive (than emission) to the roughness of the soil. The theoretical modeling and experimental verification of the three terms in each of the equations is therefore more complex and difficult for the radar than for the radiometer.

The figure on the right depicts how the brightness temperature of a bare, smooth soil (vertical axis) depends on soil moisture (horizontal axis) for an L-band, horizontal polarization radiometer. The soil moisture can range from close to 0% or very dry, to about 40% which is near saturation. As the soil moisture increases the brightness temperature decreases, changing by about 100 Kelvins over the full range of soil moisture. Details of theoretical modeling and experimental verification for radiometer and radar measurements of vegetation-covered soils can be found in the literature (e.g., Ulaby, F. and D. Long (2014): Microwave Radar and Radiometric Remote Sensing, University of Michigan Press, 1016pp.)

The emission and backscatter equations are inverted and computer-coded as soil moisture retrieval algorithms to extract the soil moisture information from the radiometer and radar measurements.

SMAP Mission Design _010

The SMAP mission design encompasses: the instrument and spacecraft (together called the observatory); the launch vehicle that places the observatory in the required orbit; the mission operations and ground data system used to control the observatory and get the raw data from the spacecraft to the ground; the science data processing facility to generate the science data products; and the delivery to the designated archives where the general public can access the SMAP science data products. This slide presents an overview of these mission design components.

SMAP Instrument and Operating Characteristics _011

SMAP uses two microwave sensors, a radar and a radiometer, both operating at L-band (low-frequency microwave range). L-band measurements are directly sensitive to the moisture and freeze/thaw conditions of the land surface and can observe the surface regardless of day or night conditions and most weather conditions.

The radar operates at 1.26 GHz and is processed on a 1 km Earth-fixed grid. It has variable spatial resolution across the swath, providing 1-3 km resolution over the outer 70% of the swath. The radiometer operates at 1.41 GHz and is processed on a 36 km Earth-fixed grid. It has uniform resolution of about 40 km across the swath. Both sensors share a parabolic reflector antenna that is 6 meters in diameter. The reflector viewing direction or boresight is offset from nadir and the reflector rotates about the nadir axis at 14.6 revolutions/minute, creating a swath 1000 km wide on the ground.

The orbit is polar sun-synchronous at 685 km altitude with a 6am/6pm equatorial crossing. The swath coverage from successive orbits provides for global coverage in 2-3 days depending on latitude. The orbit track repeats exactly every 8-days.

The SMAP mission is designed to last for a minimum of three years, however it is expected to last much longer since most NASA satellites have exceeded their design life by many years. The uniqueness of SMAP is that it will provide soil moisture measurements by combining data from the radar and the radiometer to produce a 9 km soil moisture product that covers the globe every 2-3 days.

SMAP Data Products _012

SMAP generates fifteen distributable data products representing four levels of data processing. Level 1 (L1) data are the instrument data (radar and radiometer). L2 data are geophysical retrievals on half orbit segments (ascending and/or descending paths). L3 data are global composites of L2 geophysical retrievals for an entire UTC day (1 file contains all ascending and/or descending paths for each day). L4 data are model-derived products of root zone soil moisture and carbon net ecosystem exchange. The L4 products are value-added products derived by assimilating SMAP observations into hydrologic/ecosystem.

<u>Half-orbit data</u>: refers to data from either the ascending or the descending portion of the orbit for a single orbit. The northernmost and southernmost orbit locations demarcate the half-orbit boundaries. <u>Time order</u>: the spatial locations in the data product follow the time-sequential scanning motion of the antenna and the orbital motion of the spacecraft. <u>Daily composite</u>: aggregation of either the ascending or descending paths, separately, for a single day, gridded onto a global projection. <u>Swath Grid</u>: the grid is oriented in swath coordinates centered along the nadir ground track. <u>Grid (Resolution)</u>: the L1C radar product uses a swath grid, however all other gridded products use an Earth-fixed grid called EASE-grid.

The dimensions shown for the gridded products refer to the grid spacing not the inherent spatial resolution of the instruments. The L1B products are provided at the inherent spatial resolutions of the radar and radiometer instrument measurements, which are shown in parentheses. <u>TB</u> refers to brightness temperature (radiometer measurement), <u>S0</u> refers to sigma naught (radar measurement), SM is soil moisture FT is freeze/thaw state, C is carbon, A is active, P is passive, AP is active/passive.

NASA has a free and open data policy, hence all SMAP data will be freely available to the public online through two data centers: (1) the Alaska Satellite Facility, for L1 radar data, and (2) the National Snow and Ice Data Center, for L1 radiometer data and all higher level derived products.

Data Delivery Schedule _013

SMAP was launched on January 31, 2015. Orbit adjustments and observatory (spacecraft and instrument) checkout took place during the first three months after launch, after which routine science data transmission and processing began. This marked the formal start of the nominal three-year science mission. During the first six months of the science mission the quality of the radar and radiometer data was assessed as part of the SMAP calibration and validation activity focusing on L1 products. The L1 product validation was completed for a release to the public of validated L1 products by the end of October 2015. Partially validated "beta" L1 products were released to the public after three months (end of July 2015). The beta products were considered good enough quality to be used for scientific analyses and early release to the public but had the caveat or caution to the user that they had not been fully validated and could still contain some anomalies.

During the first year of the science mission, and in parallel with the L1 product assessments, the quality of the higher-level geophysical products was assessed as part of the SMAP calibration and validation activity focusing on the L2-L4 products. The target was to have the L2-L4 product validation completed for a release to the public of validated L2-L4 products by the end of April 2016. Partially validated "beta" L2-L4 products were released to the public after six months (end of October 2015). The beta products are considered good enough quality to be used for scientific analyses and early release to the public but had the caveat that they had not been fully validated and could still contain some anomalies.

Current Status _014

The current status of the SMAP science mission and data product delivery are summarized in these milestones, which provide an update to earlier planned mission targets. A key anomaly occurred on July 7, 2015 when the SMAP radar unexpectedly ceased transmission. After an in-depth analysis of available engineering data and fault-tracing it was concluded by review teams that the anomaly was apparently caused by a failure in the low-voltage power supply of the radar amplifier. All attempts to restart the radar have been unsuccessful and NASA officially declared the radar lost on September 2, 2015. Thus, only radar data from April 13 to July 7 (just under three months of data) are available from the SMAP mission. The radiometer continues to operate normally and is providing excellent data.

Data Product Descriptions _015

The thirteen SMAP data products from Level 1B (calibrated instrument data) through Level 4 (value-added assimilation products) are of most interest to the science and applications communities. These data products are available from the ASF and NSIDC distributed active archive centers (DAACs), which were designated by NASA as the distribution centers for SMAP data.

The product data files are formatted as HDF files that include metadata descriptions of the file contents. In addition, the DAACs provide documentation along with the data that describe the data spatial resolution, projections, gridding, quality flags, and ancillary information needed to interpret the data.

Browse examples of the data products are provided as separate slides.

Level 1B Radar Product _016

The level 1B radar product (L1B_S0_LoRes) contains low-resolution real-aperture normalized radar backscatter cross sections (σ_0) in time order. The SMAP mission distributes this data product in half orbit files. L1A data are the primary input to the L1B processor that generates the L1B files.

The L1B files contain an array of floating point indices that specify either the center of the instrument instantaneous field of view (IFOV) or the center of the cells in an instrument swath grid. The data are geolocated. The product contains radar backscatter for co-pol (hh, vv) and cross-pol (hv or vh, but not both). Kp is also provided which is a measure of error defined as the normalized standard deviation of the radar cross section measurement. Orbit and attitude information are available, as well as short term and external calibration.

Finally, the data are organized relative to the footprints acquired for each instantaneous field of view (IFOV). For each footprint, the product lists σ_0 values for the co-pol and cross-pol channels. The processor subdivides each footprint into a set of 5-km slices, and provides σ_0 values for co-pol and cross-pol channels for each slice. Descending orbits provide data at approximately 6:00 am local solar time Equator crossing, while ascending orbits provide data at approximately 6:00 pm local solar time.

Level 1C Radar Product _017

The level 1C radar product (L1C_S0_HiRes) contains calibrated synthetic aperture radar (SAR) normalized radar backscatter cross sections (σ_0) that are multi-looked onto a 1 km x 1 km instrument swath grid. The SAR-processed single-look spatial resolution (before multi-looking) varies from about 400 m to 1.2 km in the outer 70% region of the swath, but in the center 30% region of the swath the resolution degrades significantly. The data product files are organized as half orbit granules. Forward and aft looking data are stored separately. Ancillary data elements in the product provide measures of data acquisition time and geometry as well as data quality. The product is restricted to land and coastal water.

Level 1B Radiometer Product _018

The level 1B radiometer product (Level 1B_TB) contains time-ordered, geolocated and calibrated brightness temperatures at vertical and horizontal polarizations and third and fourth Stokes parameters. The 3-dB effective footprint (EFOV) spatial resolution is a 39 km x 47 km ellipse. The data product files contain half orbit granules. The brightness temperatures include RFI filtering and corrections for Faraday rotation, galactic, solar, lunar and atmospheric radiation, and antenna pattern corrections for radiation entering from outside the main beam region (2.5 x the 3-dB beamwidth). Antenna temperatures referenced to the feedhorn are also included. Forward and aft looking data are stored separately.

Level 1C Radiometer Product _019

The level 1C radiometer product (L1C_TB) is a gridded version of the L1B_TB product sharing the same major output data fields and data granularity (i.e., one half orbit per file). The data in the L1C_TB product are presented in three 36 km EASE-grid projections: a global cylindrical projection, a north polar projection and a south polar projection. Within each projection, the fore- and aft-view data in each antenna scan are gridded and stored separately. For each projection and view, the product contains TB observations, instrument viewing geometry information, and data quality flags. The higher-level products that use radiometer data use this product as their referential starting product.

Level 2 Passive Soil Moisture Product _020

There are three SMAP level 2 soil moisture products. One is derived from radiometer data, one is derived from radar data (considered an experimental product), and a third is derived from combined radiometer and radar data. The radiometer level 2 soil moisture product described here (L2_SM_P) uses radiometer L1C_TB data as input. The processing software ingests 6 am descending half-orbit granules of the L1C_TB. (Data from the 6 pm ascending half-orbit granules are not currently used but this could change in the future.) The ingested data are inspected for retrievability criteria according to input data quality, ancillary data availability, and land cover conditions. When these criteria are met the software invokes the retrieval algorithm to generate soil moisture values.

The output L2_SM_P product contains the soil moisture values, and includes water body-corrected brightness temperatures, ancillary data, and quality-assessment flags on the global 36-km EASE grid. The data are formatted as one-dimensional arrays such that only EASE grid cells that are associated with the half-orbit swath are in the product. The SMAP mission accuracy requirements specify that soil moisture should be retrieved with 0.04 m^3/m^3 volumetric accuracy in low or moderately vegetated areas. The threshold for defining areas where retrievals will meet mission accuracy is defined as vegetation water content less than 5 kg/m^2. Water body and freeze/thaw flag information is provided by the SMAP high-resolution radar data. Ancillary data are used to generate flags for urban areas, mountainous terrain, dense vegetation, precipitation, snow and ice. Some of these flags are used to prevent retrieval of soil moisture, others are used as quality indicators to let the user know that the soil moisture retrieval accuracy may not meet the target mission requirements.

Level 2 Active Soil Moisture Product _021

The high-resolution (3 km) radar level 2 soil moisture product (L2_SM_A) is considered an experimental product. Radar backscatter is more influenced by vegetation characteristics than radiometric brightness temperature, hence it is challenging to retrieve accurate soil moisture using the radar only in the presence of the diversity of vegetation cover found globally.

The L2_SM_A product is derived from SMAP L1C_S0_HiRes input data and is output in half-orbit granules on a 3 km cylindrical EASE grid. The processing software ingests half orbit granules of the 1-km swath grid L1C_S0_HiRes data and averages them onto a 3 km Earth-fixed grid to reduce noise in the data. The gridded data are then inspected for retrievability criteria according to input data quality, ancillary data availability, and land cover conditions. When the criteria are met, the software invokes the retrieval algorithm to generate soil moisture. Vegetation influences the retrieval hence the algorithm uses a landcover map to determine which vegetation-type data cube to use in the retrieval. There are also freeze/thaw, urban area, and transient water body masks. The data are in a 1-dimensional array. Only cells that are covered by the actual swath for a given projection are written in the product.

Level 2 Active-Passive Soil Moisture Product _022

The L2_SM_AP soil moisture product is a combined radar and radiometer product on a 9 km grid. It uses L2_SM_A and L2_SM_P data as inputs, which provide radar backscatter and radiometer brightness temperatures (corrected to remove influence of water bodies), as well as ancillary data, and quality-assessment flags. To generate the L2_SM_AP product the processing software ingests the 6 am descending half-orbit granules of the L2_SM_A and L2_SM_P products. The ingested data are inspected for retrievability criteria according to input data quality, ancillary data availability, and land cover conditions. When the criteria are met, the software invokes the retrieval algorithm to generate the soil moisture.

The high-resolution radar data are used to disaggregate the coarse resolution radiometer data and then a radiometer-based retrieval algorithm is applied to retrieve soil moisture at 9 km. The output L2_SM_AP product contains half-orbit gridded data of soil moisture, ancillary data, and quality-assessment flags on the global 9-km EASE grid. The data are provided in a 1 dimensional grid. Note that in the mid-swath area the radar resolution, and hence the combined product resolution, are degraded.

Level 3 Passive Soil Moisture Product _023

The level 3 radiometer soil moisture product (L3_SM_P) is a daily global composite of the level 2 (L2_SM_P) product. It represents gridded data of the radiometer-based soil moisture retrieval, ancillary data, and quality assessment flags on the global 36-km EASE grid. To generate the L3_SM_P product the processing software ingests one day's worth of L2_SM_P granules and creates global composites as two-dimensional arrays for each output parameter defined in the L2_SM_P product. Because the input L2_SM_P granules are available only for descending (6 am) passes the resulting L3_SM_P granules are also available only for descending passes. In high latitudes where swaths of the individual half-orbit granules overlap the data point with acquisition time closest to 6 am local solar time is used.

Level 3 Active Soil Moisture Product _024

The level 3 radar soil moisture product (L3_SM_A) is a daily global composite of the level 2 (L2_SM_A) product. It represents gridded data of radar-based soil moisture retrieval, ancillary data, and quality-assessment flags on the global 3-km EASE grid. To generate the L3_SM_A product the processing software ingests one day's worth of L2_SM_A granules and creates global composites as two-dimensional arrays for each output parameter defined in the L2_SM_A product. Because the input L2_SM_A granules are available only for descending (6 am) passes the resulting L3_SM_A granules are also available only for descending passes. In high latitudes where swaths of the individual half-orbit granules overlap the data point with acquisition time closest to 6 am local solar time is used. This product is considered experimental.

Level 3 Active-Passive Soil Moisture Product _025

The level 3 active/passive soil moisture product (L3_SM_AP) is a daily global composite of the level 2 (L2_SM_AP) product. It represents gridded data of active-passive soil moisture retrieval, ancillary data, and quality assessment flags on the global 9-km EASE grid. To generate the L3_SM_AP product the processing software ingests one day's worth of L2_SM_AP granules and creates global composites as two-dimensional arrays for each output parameter defined in the L2_SM_AP product. Because the input L2_SM_AP granules are available only for descending (6 am) passes the resulting L3_SM_AP granules are also available only for descending passes. In high latitudes where swaths of the individual half-orbit granules overlap the data point with acquisition time closest to 6 am local solar time is used.

Level 3 Freeze/Thaw Product _026

The level 3 freeze/thaw (L3_FT_A) product (L3_FT_A) is a daily global composite of the AM and PM radar data for areas pole-ward of 45 degrees north latitude. This product contains freeze-thaw states along with gridded SMAP radar backscatter data, ancillary data, and quality-assessment flags on a north polar 3-km EASE grid. To generate the L3_FT_A product the processing software ingests one day's worth of L2_FT_A pre-processed half-orbit granules and creates global composites as two-dimensional arrays for each output parameter defined in the L2_FT_A product.

Because the input L2_FT_A granules are available both for descending (6 am) and ascending (6 pm) passes in the boreal zone north of 45 N latitude, the resulting L3_FT_A granules contain data for both AM and PM data, maintained as separate two-dimensional layers. Where data overlap occurs at high latitudes the data point whose acquisition time is closest to 6 am or 6 pm local solar time is used (according to which array is being filled).

Level 4 Surface and Root-Zone Soil Moisture Product _027

The level 4 surface and root-zone soil moisture data product (L4_SM) contains estimates of land surface conditions including surface (5 cm) and root zone soil moisture (1 meter depth). The retrievals are based on the assimilation of (downscaled) SMAP brightness temperatures and freeze-thaw retrievals using a customized version of the NASA Goddard Earth Observing System version 5 (GEOS-5) land data assimilation system (LDAS). The L4_SM data product is output on a 9 km global EASE grid.

The L4_SM data product consists of two collections of data granules (or files): (1) gph - a series of 3-hourly time average geophysical land surface fields that are output by the L4_SM algorithm (this collection will be of primary interest to most users; and (2) aup - provides diagnostics from the land surface analysis updates and consists of a series of 3-hourly instantaneous (or snapshot) files that contain the assimilated SMAP observations, the corresponding land model predictions and analysis estimates, and additional data assimilation diagnostics.

Level 4 Carbon Product _028

The level 4 carbon data product (L4_C) contains daily estimates of global ecosystem productivity (NEE), Gross Primary Productivity (GPP), heterotrophic respiration (Rh), and soil organic carbon (SOC) along with quality control metrics. The net ecosystem exchange (NEE) of CO_2 with the atmosphere is a fundamental measure of the balance between carbon uptake by vegetation gross primary production (GPP) and carbon losses through autotrophic (R_a) and heterotrophic (R_h) respiration. The sum of R_a and R_h defines the total ecosystem respiration rate (R_{tot}), which encompasses most of the annual terrestrial CO_2 efflux to the atmosphere. NEE, GPP, and R_h are expressed in units of g C m^{-2} yr^{-1}, and SOC is expressed in units of kg C m^{-2}. The L4_C data product is output on a global 9 km EASE grid.

SMAP Resources at the ASF DAAC _029

The Alaska Satellite Facility (ASF), located at the University of Alaska, Fairbanks, is the NASA-designated distributed active archive center (DAAC) for synthetic aperture radar (SAR) data from a variety of satellites, including SMAP. The ASF DAAC hosts a number of documents and tools along with the SMAP level 1 radar data to facilitate use of the data. These can be found at https://www.asf.alaska.edu/smap/documents-tools/.

Vertex is the ASF's data portal for remotely sensed imagery of the Earth including SMAP. It provides a capability to search and download SMAP data, https://vertex.daac.asf.alaska.edu.

There is also an applications programming interface (API) for searching, visualizing and downloading data, https://portal.asf.alaska.edu/get-data/api.

SMAP Resources at the NSIDC DAAC _030

The National Snow and Ice Data Center (NSIDC), located at the University of Colorado, Boulder, is the NASA-designated distributed active archive center (DAAC) for cryospheric and microwave radiometer data products.

The NSIDC DAAC distributes level 1 (L1) radiometer data and higher level (L2-L4) geophysical data products for the SMAP mission. NSIDC also maintains validation campaign data sets for SMAP.

The NSIDC DAAC hosts a number of documents and tools along with the SMAP radar data to facilitate use of the SMAP data. These can be found at https://nsidc.org/data/smap/smap-data.html and https://nsidc.org/data/smap/tools.

SMAP Portal at the ASF DAAC _031

The SMAP data portal at the ASF DAAC is (https://www.asf.alaska.edu/smap/). This portal has links to the SMAP data portal at NSIDC (https://nsidc.org/data/smap) and the NASA Earth Science Data and Information System (ESDIS) project (https://earthdata.nasa.gov/about/esdis-project), which coordinates NASA data holdings at the NSIDC and ASF DAACs and provides access to other Earth science data resources.

SMAP Portal at the NSIDC DAAC _032

The SMAP data portal at the NSIDC DAAC is https://nsidc.org/data/smap. This portal has links to the SMAP data portal at ASF (https://www.asf.alaska.edu/smap/) and the NASA Earth Science Data and Information System (ESDIS) project (https://earthdata.nasa.gov/about/esdis-project), which coordinates NASA data holdings at the NSIDC and ASF DAACs and provides access to other Earth science data resources.

SMAP on Worldview _033

The Worldview tool from NASA's EOSDIS (https://earthdata.nasa.gov/worldview) provides the capability to interactively browse global, full-resolution satellite imagery and then download the underlying data. Most of the 100+ available products are updated within three hours of observation, essentially showing the entire Earth as it looks "right now". This supports time-critical application areas such as wildfire management, air quality measurements, and flood monitoring. Browsing on tablet and smartphone devices is generally supported for mobile access to the imagery.

Worldview uses the Global Imagery Browse Services (GIBS) (https://earthdata.nasa.gov/about/science-system-description/eosdis-components/global-imagery-browse-services-gibs) to rapidly retrieve its imagery for an interactive browsing experience.

Soil Moisture – Observed Changes _034

Multiple level 2 radiometer (L2_SM_P) or level 3 radiometer (L3_SM_P) product files can be composited into 3-day images to show global coverage soil moisture (no gaps between swaths). Two such 3-day images centered on April 5 and April 14, 2015, are shown here to illustrate temporal changes in soil moisture. Changing soil moisture patterns due to precipitation and drying are evident in India, Bangladesh, Australia Argentina.

Soil Moisture – Expected Accuracy _035

The accuracy of SMAP soil moisture retrievals is impacted by various factors, including vegetation water content, fractions of urban areas and open water within the viewing footprint of the instrument, and variance of surface topography within the footprint. Thresholds for these factors are used to develop a mask (flags are included within the product files) indicating estimated data quality. These thresholds may be changed as experience is gained during calibration and validation of the data.

Value of Soil Moisture Data to Weather and Climate _036

SMAP data can be used to improve forecasts of local storms and seasonal climate anomalies. Accuracies of such forecasts can be illustrated by model predictions with and without assimilated soil moisture observations.

Flood and Drought Applications _037

U.S. operational flood and drought products include the National Weather Service Flash Flood Guidance (http://www.srh.noaa.gov/rfcshare/ffg.php) and the U.S. Drought Monitor (http://droughtmonitor.unl.edu). SMAP data can be used as direct soil moisture observations to improve the quality of these products, both in spatial resolution and accuracy.

A Flood Example _038

Soil moisture is a key factor in determining flood potential. End-users such as the United Nations World Food Programme are investigating the use of SMAP soil moisture condition information combined with rainfall forecasts from the European Centre for Medium-range Weather Forecats (ECMWF) to produce flood indices.

A Flood Example – Results _039

The study shown uses hydrologic models (VIC and LISFLOOD-FP) with archived historical observations to generate a regression model for prediction.

Crop Yield Modeling _040

SMAP can enable significant improvements in operational crop productivity and water stress information systems by providing realistic soil moisture and freeze/thaw observations as inputs for agricultural prediction models. Improved models will provide crucial information for decision-makers managing water and other resources, especially in data-sparse regions. A better grasp of the impact of agricultural drought on crop yield provides better crop supply and demand information for use by producers, commodity markets, traders, and policy makers.

Agricultural Crop Yield and Food Security Applications _041

Data from satellite observations, including soil moisture, precipitation and other environmental observations can be assimilated into crop models to derive improved crop yield estimates. This study is one of a number of such investigations in progress.

SMAP Applications Development Approach _042

SMAP initiated an applications program to engage SMAP end users and build broad support for SMAP applications. The accuracy, resolution, and global coverage of SMAP soil moisture and freeze/thaw measurements are invaluable across many science and applications disciplines including hydrology, climate, carbon cycle, and the meteorological, environmental and ecology applications communities. Key aspects of this approach include:

- Establish a SMAP Applications Working Group (AppWG) and SMAP Applications Plan
- Promote the use of SMAP products to a community of end-users and decision-makers (SMAP Early Adopters) that understand SMAP capabilities and are interested in using SMAP products in their applications
- Provide information, documentation and communication strategies to reach out to these new communities, including those of precipitation, drought detection, agriculture, and ecosystem modeling, among others
- Foster and facilitate relationships between mission Early Adopter research and the SMAP mission

SMAP Applications Early Adopters _043

The Early Adopters are a subset of the SMAP Application Working Group. The goal of SMAP's Early Adopter program is to provide specific support to Early Adopters in applied research using SMAP data and to accelerate the use of SMAP products. The full list of SMAP Early Adopters, projects, and contact information is provided on the SMAP web site http://smap.jpl.nasa.gov/science/early-adopters/.

Early Adopters Video _044

The SMAP Early Adopters are a diverse group representing a cross-section of end-users. End-users from key applications areas of SMAP discuss their research and potential use of SMAP data in a short video that can be accessed at the SMAP website. Users include the U.S. Forest Service, the UN World Food Programme, and the U.S. Department of Agriculture.

SMAP Documents _045

A list of the key SMAP mission science and data documents available to the public, and where to access them.