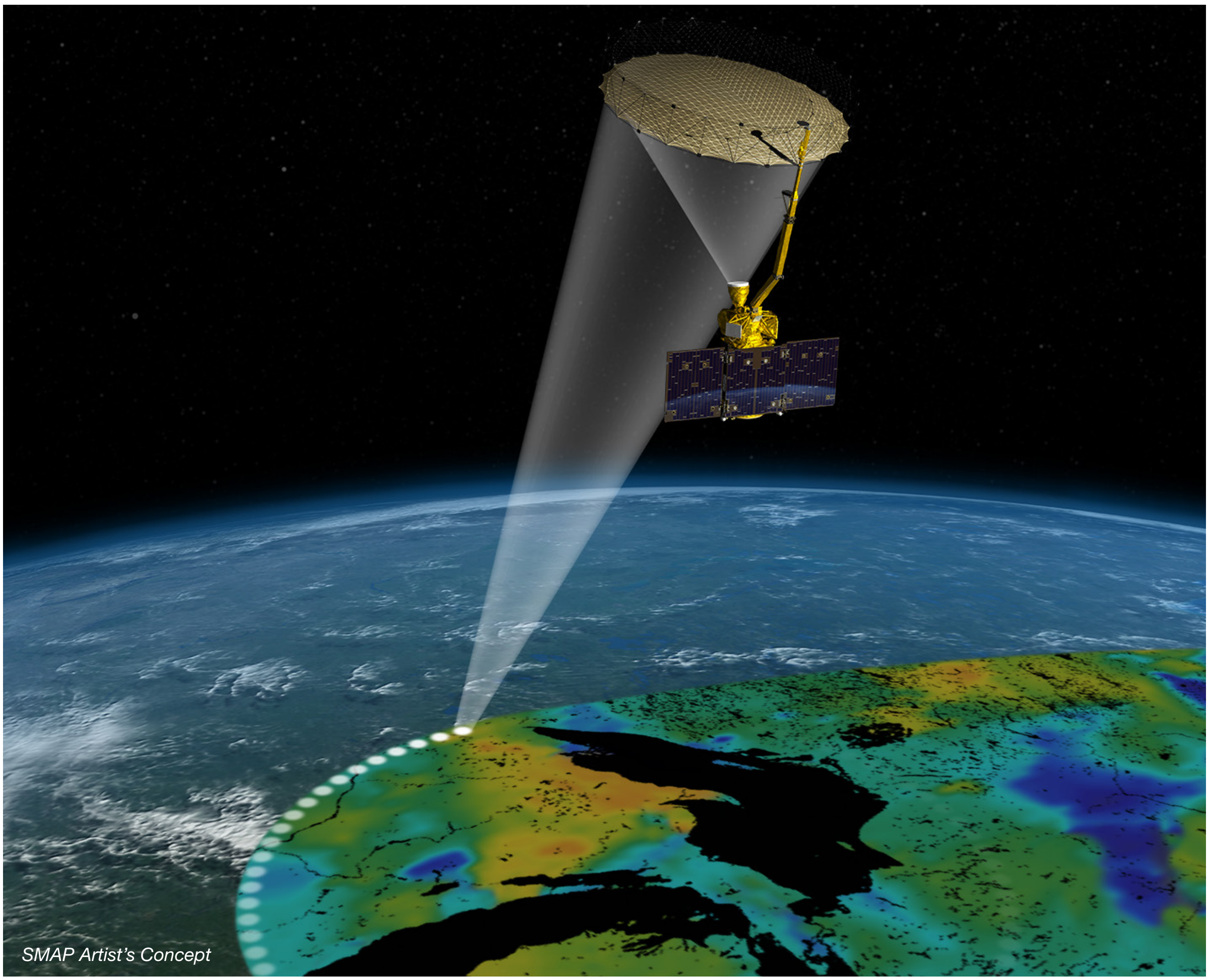
National Aeronautics and Space Administration

PRESS KIT/JANUARY 2015

# Soil Moisture Active Passive Launch



SMAP Artist's Concept

www.nasa.gov

# Media Contacts

| | | |
|---|---|---|
| Steve Cole<br>Headquarters,<br>Washington | Policy/Program<br>Management | 202-358-0918<br>stephen.e.cole@nasa.gov<br>202-657-2194 (cell) |
| Alan Buis<br>Jet Propulsion Laboratory,<br>Pasadena, Calif. | Soil Moisture<br>Active Passive Mission | 818-354-0474<br>alan.buis@jpl.nasa.gov |
| Rani Gran<br>Goddard Space Flight Center<br>Greenbelt, Maryland | Radiometer, GSFC Role | 301-286-2483<br>rani.c.gran@nasa.gov |
| Jessica Rye<br>United Launch Alliance<br>Cape Canaveral Air Force<br>Station, Florida | Launch Vehicle | 321-730-5646<br>jessica.f.rye@ulalaunch.com |
| George Diller<br>Kennedy Space Center,<br>Florida | Launch Operations | 321-867-2468<br>george.h.diller@nasa.gov |

# Contents

# Media Services Information

### NASA Television Transmission

NASA Television is available in continental North America, Alaska and Hawaii by C-band signal on AMC-18C, at 105 degrees west longitude, Transponder 3C, 3760 MHz, vertical polarization. A Digital Video Broadcast (DVB)-compliant Integrated Receiver Decoder is needed for reception. Transmission format is DVB-S, 4:2:0. Data rate is 38.80 Mbps; symbol rate 28.0681, modulation QPSK/DVB-S, FEC 3/4.

NASA TV Multichannel Broadcast includes: NTV-1 (formally the Public Channel) and NTV-3 (formally the Media Channel) in high definition, and NTV-2 (formally the Education Channel) in standard definition.

For digital downlink information for each NASA TV channel, access to all three channels online and a schedule of programming for Soil Moisture Active Passive mission activities, visit **http://www.nasa.gov/ntv** .

### Audio

Audio of the pre-launch news conferences two days before launch ("L minus 2") and launch coverage will be available on "V-circuits" that may be reached by dialing 321-867-1220, -1240, -1260 or -7135.

### Briefings

A mission, science and applied science overview news conference is scheduled for NASA Headquarters at 2 p.m. EST on Jan. 8, 2015. The news conference will be broadcast live on NASA Television. A pre-launch readiness briefing will be held at 1 p.m. PST (4 p.m. EST) two days before launch in the NASA Resident Office, Building 840, Vandenberg Air Force Base, California. Pre-launch science and applied science briefings will be held as part of NASA Social activities at Vandenberg Air Force Base one day before launch. These briefings will be carried live on NASA Television and on http://www.ustream.tv/nasajpl2 . Media advisories will be issued in advance, outlining details of these broadcasts.

### Launch Media Credentials

News media interested in attending the launch should contact TSgt Tyrona Lawson in writing at U.S. Air Force 30th Space Wing Public Affairs Office, Vandenberg Air Force Base, California, 93437; by phone at 805-606-3595; by fax at 805-606-4571; or by email at Tyrona.lawson@us.af.mil. Please include full legal name, date of birth, nationality, passport number and media affiliation. A valid legal form of photo identification will be required upon arrival at Vandenberg to cover the launch.

### News Center/Status Reports

The Soil Moisture Active Passive News Center at the NASA Vandenberg Resident Office will be staffed beginning four days before launch and may be reached at 805-605-3051. Recorded status reports will be available beginning three days before launch at 805-734-2693.

### Internet Information

More information on the mission, including an electronic copy of this press kit, news releases, fact sheets, status reports and images, can be found at **http://www.nasa.gov/smap** .

# Quick Facts

## Spacecraft

*Dimensions:* 4.9 by 3 by 3 feet (1.5 by 0.9 by 0.9 meters), spacecraft bus only; antenna 19.7-foot (6-meters) deployed, 1 foot by 4 feet (30 by 120 centimeters) stowed; spacecraft stowed configuration 15.8 by 5.6 by 6.3 feet (4.8 by 1.7 by 1.9 meters); deployed configuration without the reflector antenna 14.1 by 15.4 by 5.3 feet (4.3 by 4.7 by 1.6 meters); deployed with the reflector antenna 31.8 by 23.3 by 22.3 feet (9.7 by 7.1 by 6.8 meters)

*Weight:* 2,081 pounds (944 kilograms), including propellant and instruments

*Power:* 1,450 watts

*Primary Science Instruments:* L-band (non-imaging) 1.2- to 1.3-gigahertz synthetic aperture radar, L-band 1.4-gigahertz radiometer

*Instrument Dimensions:* 4.9 by 3 feet (1.5 by 0.9 meters) radar (mounted on anti-sun spacecraft panel); 3-feet (0.9-meter) radius by 2.6-feet (0.8-meter) height radiometer (swept volume of spun instrument assembly, including its integrated control electronics)

*Instrument Weights:* 108 pounds (49 kilograms) radar; 66 pounds (30 kilograms) radiometer

*Shared Antenna:* mesh deployable offset-fed reflector antenna, rotating at 13 to 14.6 rpm. Its 620-mile (1,000-kilometer) measurement swath allows SMAP to cover Earth's equatorial regions within three days and Earth's higher latitudes within two days. The boom and antenna together weigh 127 pounds (58 kilograms)

## Auxiliary Payloads

Educational Launch of Nanosatellite X (ELaNa X), consisting of three Poly Picosatellite Orbital Deployers containing four CubeSats (three CubeSat missions), mounted on the second stage of the Delta II launch vehicle:

ExoCube
GRIFEX
FIREBIRD-II (A and B)

## Mission

*Launch:* No earlier than Jan. 29, 2015, at 6:20:42 a.m. PST (9:20:42 a.m. EST) from Launch Complex 2 West (SLC-2W), Vandenberg Air Force Base, California

*Launch Vehicle:* United Launch Alliance Delta II 7320-10C

*Launch Window:* Three minutes daily

*Primary Mission:* Three years

*Orbit Path:* Near-polar, sun-synchronous, 426 miles (685 kilometers), with equator crossings at 6 a.m. and 6 p.m. local time. The spacecraft orbits Earth once every 98.5 minutes and repeats the same ground track every eight days.

*Orbital Inclination:* 98.1 degrees

*NASA Investment:* $916 million (design, development, launch and operations)

# Mission Overview

The Soil Moisture Active Passive mission is NASA's first Earth-observing satellite mission designed to collect global observations of surface soil moisture and its freeze/thaw state, data that have broad applications for science and society. High-resolution space-based measurements of soil moisture and whether the soil is frozen or thawed will give scientists a new capability to observe and predict natural hazards of extreme weather, climate change, floods and droughts, and will help reduce uncertainties in our understanding of Earth's water, energy and carbon cycles.

The mission will provide the most accurate and highest-resolution maps of soil moisture ever obtained, mapping the globe every two to three days from space for at least three years to help scientists better understand seasonal and year-to-year variations in soil moisture and its thawed and frozen states. The mission will validate a space-based measurement approach that could be used for future space missions to systematically monitor soil moisture.

The value of high-resolution measurements of soil moisture has been recognized for decades. But existing ground-based measurements of soil moisture are too sparse to show detailed variations. The Soil Moisture Active Passive mission will allow global mapping of soil moisture from space with about 6-mile (10-kilometer) resolution.

**What the Soil Moisture Active Passive Mission Will Do**

The Soil Moisture Active Passive mission will produce global maps of soil moisture that scientists and policymakers can use to track water movement around our planet.

The mission will allow scientists to better understand the processes that link Earth's water, energy and carbon cycles. Soil moisture controls the evaporation and transfer of water and heat from Earth's land surface and plants to the atmosphere. Just as perspiration helps maintain our body temperature, soil moisture and its evaporation help regulate Earth's surface temperature.

Climate change may have profound impacts on Earth's freshwater resources in the future. Understanding how climate change may affect water supplies and food production is crucial for policymakers. Current climate models produce widely differing estimates of how much water will be available regionally in the future. The SMAP mission will help bring these estimates into closer agreement, increasing our confidence in projections of regional future water availability.

The mission will improve the accuracy of short-term weather forecasts and long-term projections of climate change. Variations in soil moisture affect our weather by adding moisture to the atmosphere (or limiting water added to the atmosphere), thereby enabling cloud formation or intensifying dry spells during periods of drought. Improved soil moisture information from the mission will enhance the predictive capability of computer models used to forecast our weather. Over the longer term, the mission will improve our understanding of climate variability and change by improving the accuracy of models used to forecast seasonal climate outlooks. Better seasonal climate predictions benefit societal activities affected by climate.

The mission will advance our ability to monitor droughts and predict floods and mitigate their related impacts on people's lives. It will allow the monitoring of regional deficits in soil moisture and provide critical inputs into drought monitoring and early warning systems used by policymakers. The mission's high-resolution observations of soil moisture will improve flood warnings by providing information on ground saturation conditions before rainstorms. Hydrologists will be able to model water flow down to the scale of individual river basins.

The mission will allow us to improve the prediction of crop and vegetation growth on regional and global scales, permitting better estimates of agricultural productivity and potential yield. Its space-based observations will transform the accuracy and completeness of this critical driver of agriculture productivity. Improved seasonal soil moisture forecasts made possible by the mission will directly benefit global famine early warning systems. Regions of the world most susceptible to famine also tend to have sparse or no crop production information. It is in these areas especially that accurate information from satellites will likely have a strong impact.

Mission data on whether soils are frozen or thawed will allow scientists to detect variations in the timing of spring thaw and changes in the length of the growing season that have a major impact on vegetation productivity and whether high northern-latitude regions and their associated forests are generating or storing carbon. During the growing season, these boreal forests absorb large quantities of carbon. Data from the mission will help scientists determine how much carbon plants take up from the atmosphere each year, improving our understanding of the global carbon cycle and predictions of future climate change.

The SMAP team is engaged with “early adopters” — groups and individuals that foresee immediate uses for its data. Through workshops and tutorials, the SMAP Applications Working Group is partnering with these early adopters to test and integrate the mission’s data products into many different types of operations and decision support situations. Early adopters include weather forecasters from several nations and researchers and planners from the U.S. Department of Agriculture, U.S. Geological Survey, U.S. Centers for Disease Control and Prevention, U.N. World Food Programme and other organizations.

To obtain a measurement with both high resolution and high accuracy, the observatory will combine data from two instruments, an L-band radar and an L-band radiometer, in a way that takes advantage of the best features of each while working around their individual limitations. The instruments can peer into the top 2 inches (5 centimeters) of the soil, through clouds and moderate vegetation cover, both day and night.

“Active Passive” in the mission name refers to the two types of instruments used by the mission, which operate in the microwave frequency. The synthetic aperture radar instrument actively emits a signal and measures the backscatter that returns from Earth, whereas the radiometer instrument passively records Earth’s own naturally emitted microwave signal. Variations in these signals contain information on soil moisture changes. The instrument’s radar observations have high resolution of about 1.9 miles (3 kilometers) but lower accuracy than the radiometer observations. The radiometer observations have higher accuracy but lower resolution than the radar, with a spatial resolution of about 25 miles (40 kilometers). The combined processed measurements have intermediate resolution and high accuracy, and provide greater accuracy and spatial resolution in measuring soil moisture than is possible using either instrument alone. The mission will estimate soil moisture over Earth’s global land areas, excluding regions of snow and ice, frozen ground, mountainous topography, open water, urban areas and vegetation with high water content. It will estimate soil freeze/thaw states in regions north of 45 degrees north latitude, which includes Earth’s boreal forests.

The radar and radiometer instruments share a rotating 19.7-foot (6-meter) scanning reflector antenna made of a lightweight mesh that can be folded into a small package for launch and then unfurled in space. The width of the region scanned on Earth’s surface during each orbit is about 620 miles (1,000 kilometers). This allows the observatory to completely map Earth’s equatorial regions every three days and Earth’s higher latitudes every two days.

The SMAP observatory will fly at an altitude of 426 miles (685 kilometers), completing one near-polar Earth orbit every 98.5 minutes. The nearly north–south orbit track repeats exactly every eight days.

**Program History**

The SMAP mission is based on the Hydrosphere State (Hydros) soil moisture and freeze/thaw mission project that was proposed to the NASA Earth System Science Pathfinder Competed Missions Program in 2001. Hydros was led by Principal Investigator Dara Entekhabi of the Massachusetts Institute of Technology in Cambridge, who now serves as the SMAP Science Team leader. Hydros completed a series of risk reduction studies before being canceled in 2005 due to NASA budget constraints. In 2007, a successor mission now named Soil Moisture Active Passive was one of four Tier 1 missions recommended by the National Research Council’s Committee on Earth Science and Applications from Space.

The new mission retains much of the Hydros objectives and science leadership. Its instrument, performance requirements, lead and supporting NASA centers and key science personnel have been retained. The new mission is designed to fly at least three years versus two years for Hydros.

Following a successful mission concept review in June 2008, the Soil Moisture Active Passive mission entered its formulation phase in September of that year. The project completed its critical design review in July 2012 and proceeded into system integration and test in May 2013.

**Launch Site and Vehicle**

The Soil Moisture Active Passive observatory will be launched from Space Launch Complex 2 West (SLC-2W) at Vandenberg Air Force Base, California, on a United Launch Alliance Delta II 7320-10C launch vehicle, provided under the NASA Launch Services II contract. The Delta II 7320 rocket offers a reliable means of launching satellites up to 13,440 pounds (6,100 kilograms) into low-Earth orbit. Since its debut flight, there have been 150 successful Delta II launches, carrying satellites for government and commercial customers. It has a greater than 98 percent success rate.

The Delta II is an expendable launch vehicle, which means it can only be used once. The Delta II was originally used to launch the Global Positioning System Block II series of navigation satellites in 1989. Since that time, however, the Delta II has successfully launched a number of NASA payloads/missions into space, including Mars Pathfinder, CloudSat, Jason-2 and the Orbiting Carbon Observatory-2.

The Delta II family uses a four-digit reference designation system. The first digit designates the current Delta II design, the 7000 series. The second digit indicates the number of solid-propellant boosters attached to the first stage. The third digit is a 2, denoting a second stage. The last digit denotes the third stage. The number 0 indicates that there is no third stage. Sometimes, the four-digit number includes an extension indicating the payload fairing diameter in feet. Therefore, the Delta II 7320-10C launch vehicle for the Soil Moisture Active Passive mission is a 7000 series vehicle, with three boosters, a second stage, no third stage and a 10-foot-(3-meter)-diameter composite payload fairing.

The first stage of the Delta II uses an Aerojet Rocketdyne RS-27A main engine (12:1 expansion ratio) burning RP-1 fuel, a thermally-stable kerosene, and liquid oxygen. In addition to its main engine, the RS-27A includes two LR101-NA-11 vernier engines to provide vehicle roll control during main engine thrusting and pointing control during a brief coast period between main engine cutoff and separation from the second stage. The total thrust is approximately a 237,000-pound force (1,054,000 newtons). The first stage will be augmented with three boosters, specifically, Alliant Graphite Epoxy Motors using hydroxyl-terminated polybutadiene solid propellant. The thrust of each solid rocket-fueled booster is approximately a 109,135-pound force (486,458 newtons).

The second stage of the Delta II uses a restartable Aerojet Rocketdyne AJ10-118K engine burning Aerozine 50, which is a mixture of hydrazine and dimethyl hydrazine, reacting with nitrogen tetroxide as an oxidizer. The total thrust is estimated at a 9,750-pound force (43,370 newtons). Pointing control during coast periods and roll control during thrusting is provided by nitrogen gas thrusters. The second stage contains the vehicle's avionics suite — a combined inertial platform and guidance system that controls all flight events. The avionics suite uses a single fault-tolerant guidance system that includes a redundant inertial flight control assembly and integrated software.

The observatory will be contained inside the vehicle's composite payload fairing, which has a diameter of 10 feet (3 meters). The fairing protects the observatory and upper stage guidance equipment during flight in the lower atmosphere. It separates in two sections at a time set by payload heating constraints during powered flight on the second stage.

The launch vehicle uses an A937 payload adapter and separation system. A mission-unique forward separation ring design is used to attach the observatory to the separation system.

At launch, the Delta II will stand approximately 126.6 feet (38.6 meters) tall and weigh approximately 165.5 tons (150,173 kilograms).

**Launch Timing**

The Soil Moisture Active Passive observatory will be launched at a specific time and trajectory needed to achieve the required initial injection orbit and eventual science orbit. Unlike spacecraft sent to other planets, comets or asteroids, the launches of Earth-orbiting satellites do not need to be timed based on the alignment of the planets. Earth-orbiting satellites do, however, need to be launched during particular windows within any given 24-hour day in order to get into the proper orbit around Earth. The Soil Moisture Active Passive will assume what is called a "sun-synchronous" orbit, flying within eight degrees of Earth's north and south poles with a Mean Local Time of the Ascending Node

(MLTAN) of approximately 6 p.m. This terminator orbit optimizes the time of day for the observatory's science measurements and simplifies the design of the spacecraft power and thermal control systems.

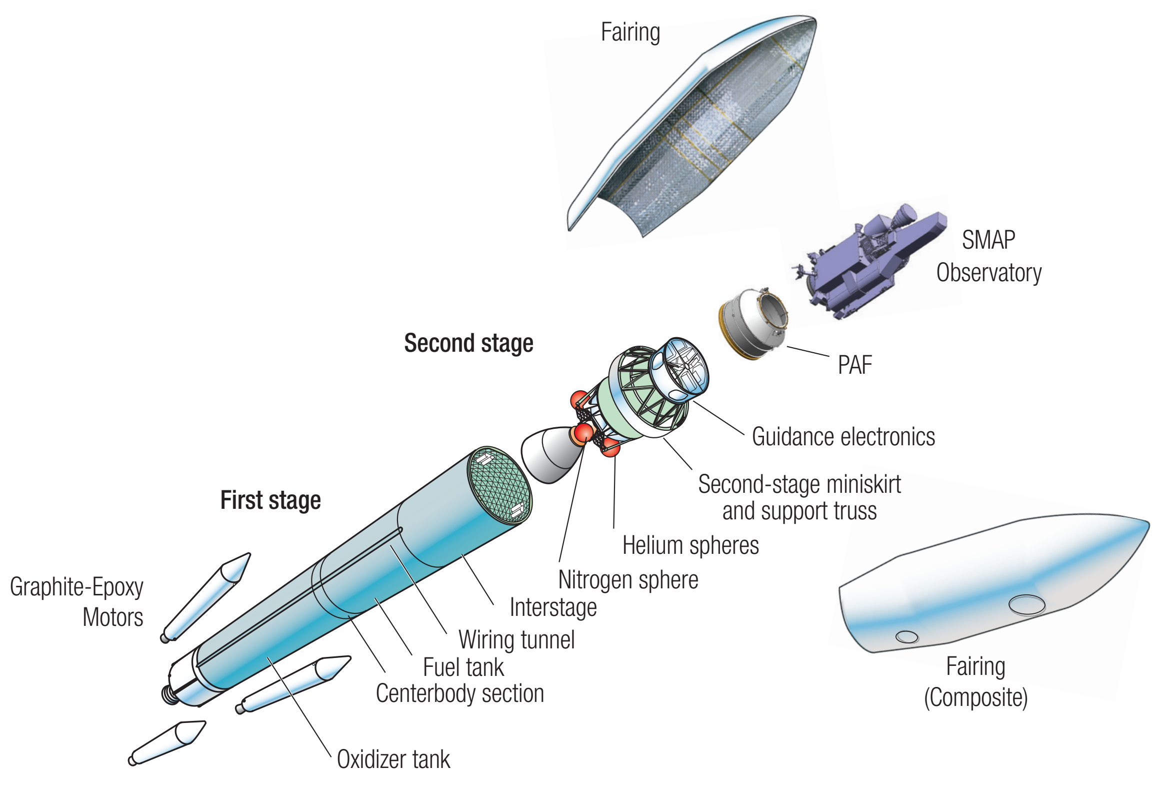
The launch date is based on the readiness of the observatory, the Delta II 7320-10C launch vehicle, and the Western Range at Vandenberg Air Force Base. Launch is currently scheduled for no earlier than 6:20:42 a.m. PST (9:20:42 a.m. EST) Jan. 29, 2015. The launch window is three minutes each day.

**Launch Sequence**

The Delta II will launch the Soil Moisture Active Passive observatory from Space Launch Complex 2 West down an initial flight azimuth of 196 degrees from true north (south-southwest). The boost phase trajectory is designed to place the observatory into the proper intermediate orbit (115 by 440 miles, or 185 by 709 kilometers) by the time of the first cutoff of the Delta II Second Stage (SECO-1). Three graphite epoxy solid motors are ignited 0.2 seconds prior to liftoff once the first-stage engine reaches its required thrust level. The three solid rocket motors burn for approximately 65 seconds but are not jettisoned until 99 seconds into flight in order to satisfy range safety constraints.

During the first 100 to 140 seconds of the boost phase, the vehicle steers the trajectory so that it achieves the required orbital inclination. Main Engine Cutoff (MECO) occurs approximately 262 seconds into flight, followed six seconds later by Stage I-II separation. After Stage I-II separation, the second stage ignites and burns until reaching the intermediate orbit. During this second stage burn, the payload fairing, or launch vehicle nose cone, will separate into two halves, like a clamshell, and fall away at approximately 295 seconds after liftoff when the free molecular heating rate has dropped to the required level. SECO-1 (Second-Stage Engine Cutoff #1) occurs at about 644 seconds after liftoff, after the intermediate orbit conditions are reached.

After SECO-1, the Soil Moisture Active Passive observatory and the second stage will coast in the intermediate orbit before the 12-second restart burn, which begins at 3,098 seconds after liftoff and places the observatory into the desired orbit. During most of the coast period, the observatory is angled to shade its spacecraft bus from the sun. During ascent, launch vehicle telemetry is received via S-band link through ground stations and Tracking and Data Relay Satellite links. Observatory telemetry cannot be received until after observatory separation. After cutoff of the second stage at SECO-2, the second stage will coast and orient for separation by



pointing the observatory's S-band low-gain antenna toward a Tracking and Data Relay satellite over the Indian Ocean and the observatory solar array generally toward the sun. Separation occurs off the east coast of Africa within view of a tracking station at Hartebeesthoek, South Africa (HBK) and will be monitored by a video camera attached to the second stage, with the video signal being sent down to HBK and transmitted back to NASA's Kennedy Space Center in Florida in near-real-time.

Separation of the Soil Moisture Active Passive observatory occurs approximately 56 minutes and 51 seconds after liftoff, with the vehicle in a 411- by 425-mile (661- by 685-kilometer) injection orbit, from which the spacecraft will subsequently maneuver over the course of several weeks and adjust its orbit until it reaches its final operational orbit of 426 miles (685 kilometers at the equator crossings). Separation is triggered by firing pyros on the separation system to release the clampband holding the forward and aft separation rings together. Push-off springs move the observatory away from the Delta II upper stage at a relative speed of less than 1.6 feet (0.5 meters) per second.

After spacecraft separation, the Delta II second stage will carefully move away from the observatory, first using nitrogen gas thrusters and then its main engine in an eight-second burn (SECO-3 at about 1 hour, 40 minutes after liftoff) to lower the orbit for deployment of the CubeSat missions. Following cutoff of the second stage at SECO-3, during another coast phase, three auxiliary payload CubeSat missions containing a total of four CubeSats will be deployed at SECO-3 plus 2,700, 2,800 and 2,900 seconds. The second stage will then perform one final 48-second restart burn to deplete residual propellants, beginning at 1 hour, 52 minutes, 30 seconds after liftoff. This final depletion burn targets the second stage for reentry over the southern Pacific Ocean to comply with NASA policy for limiting orbital debris and to ensure that any surviving debris falls into the ocean. Reentry will occur at about 2 hours and 10 minutes after liftoff.

Following separation, the observatory begins a series of autonomous initialization steps designed to place it into a safe, ground-commandable state. Its inertial reference unit and thruster catalyst bed heaters are turned on, and it begins establishing two-way communications with the ground to report its condition via its S-band downlink. Propellant lines below its latch valves are vented by opening and closing thruster valves, and a latch valve is opened to release hydrazine down to the thrusters. The observatory then fires thrusters to eliminate any tumbling induced during its separation from the launch vehicle. About a minute after separation, the observatory will begin deploying its three-panel solar array, a process that takes less than seven minutes. The observatory then turns to find the sun and point the solar array in that direction. It then performs a slow "rotisserie" roll at an effective rate relative to the ground of 1.5 revolutions per orbit. This is done to ensure that if the S-band low-gain antenna pointing is unfavorable to a ground station on one orbit, it will be more likely to be favorable on the next orbit.

In order to assess the health of the observatory and respond to any anomalies, it is vitally important to establish communications as soon as possible after separation from the Delta II. Injection and separation take place with the observatory headed north over eastern Africa, and the first opportunity for acquisition of the S-band telemetry is through Tracking and Data Relay Satellites (TDRS) over the Atlantic and Indian Oceans. Initial acquisition of the telemetry can occur within minutes after separation, depending on the attitude. The first opportunity for contact with a ground station occurs about 19 minutes after separation at the Svalbard Satellite Station in Norway, followed quickly by a pass at the Alaska Satellite Facility in Fairbanks. An uplink signal will be applied at all ground station passes to allow commanding and two-way Doppler measurements to update the observatory flight path. After the first orbit, a Tracking and Data Relay Satellite uplink signal will be applied between the ground station passes.

Once it is determined that the observatory is healthy and stable, the observatory's positioning and rotational phasing in the rotisserie attitude will be accurately determined, the commandability of the observatory will be established through NASA's Near-Earth Network, the launch restraints on the observatory's reflector boom antenna will be released and data recorded during launch will be played back.

The commissioning phase of the mission then begins, extending from the end of the launch phase until the observatory and mission system are fully functional and have demonstrated the required performance to begin routine science data collection. These activities are planned to be completed within 78 days of launch and not later than 90 days after launch.

During the spacecraft checkout subphase, spacecraft bus subsystems are brought up to full functionality. This includes transitioning the observatory to point directly at the ground (nadir); any initial tests and calibrations of the observatory systems, including initial post-launch tests of the health of the radiometer and radar instruments on days 11 and 12 of the mission.

Next comes the instrument deployment subphase, in which the instrument boom and reflector antenna are deployed from their stowed launch configuration and spun up in two stages to the rate of up to 14.6 revolutions per minute that is planned for data collection. This subphase is scheduled to begin on day 15 of the mission. The reflector boom assembly, produced by Northrop Grumman Aerospace Systems Astro Aerospace in Carpinteria, California, is deployed on day 16 in a two-step process. A pyro cable cutter releases the boom cradle, and then preloaded tension in the boom moves it away from the satellite bus. A motor then winds a cable that pulls the two-hinged boom to its full extension. The total boom deployment takes about 16 minutes. Ground commands can be sent to stop deployment if any anomalous behavior is observed.

The reflector antenna is then deployed on day 20, again in a two-step process. The furled reflector antenna is first released by firing a pyro to open restraints, and stored energy springs it partially open. A second motor then winds a cable to pull the reflector to its fully opened circular configuration, a process expected to take about 27 minutes. The total duration of the reflector antenna deployment procedure is about 33 minutes.

After this deployment, a test of the reflector antenna geometry is conducted by operating the radar in a non-spin test (days 26 and 27).

After successful deployment of the instrument reflector, activities in the main maneuver subphase focus on executing the major maneuvers to raise the spacecraft from its initial orbit to its final science orbit. A small calibration maneuver is executed on day 32 and the main maneuvers on days 38, 42 and 46 of the mission. During this subphase, tests are conducted to characterize the observatory's mass properties in order to precisely control the momentum of the system (days 33, 35 and 36).

When the boom and reflector deployments are judged to be successful and after achieving the final science orbit, the spin-up subphase begins. On day 49, the pyro harness connecting the observatory's spun instrument assembly (the part of the observatory that spins) to the spacecraft bus is cut and retracted and launch locks that protect the spin mechanism are released. The reflector antenna and hardware on the spinning side of the observatory are then spun up to a rate of up to 14.6 revolutions per minute in two steps, planned on days 52 and 55 of the mission.

During the first step, the spun instrument assembly is spun up to a rate of five revolutions per minute, a process that takes less than two minutes. During this initial spin-up, the reaction wheels on the observatory are not capable of generating enough counter torque, and the spacecraft bus spins in the opposite direction, reaching an estimated rate of up to 15 degrees per second. Once the spun instrument assembly rate stops accelerating at five revolutions per minute, the observatory's reaction wheels begin to reduce the rotation rate of the spacecraft bus. Once the bus spin rate is sufficiently slowed, flight software turns the observatory back to its science-gathering orientation, with the spin axis pointing straight down to the ground and the solar array toward the sun. This first step is expected to be completed in less than 25 minutes.

Following ground analysis of the first spin-up step, the second step begins on day 55. Guidance, navigation and control software manage the increments in the spin rate to keep the spun instrument assembly acceleration at a level that allows the observatory's reaction wheels to maintain the spacecraft's Earth-pointing (nadir) attitude. This process is expected to take less than 80 minutes. Analysis of the spin-up process and the stability of the observatory at the final spin rate is scheduled to be conducted on day 56.

The final step is the observatory checkout subphase, in which the radar and radiometer instruments are turned on during day 60 and tested, and any final calibrations or adjustments are made to bring the observatory up to its full operational capability and final maneuvers executed to precisely establish the science orbit. This subphase is scheduled to last no longer than 20 days.

Routine science operations then begin.

### Satellite Operations

The SMAP mission system includes all the assets needed to operate the satellite; acquire the data that it transmits to the ground; and process, distribute and archive science data products. It is composed of the mission operations system, ground data system and science data system.

The mission operations system consists of the people and processes needed to operate the observatory after launch and acquire instrument and engineering data. It is located at the JPL mission operations center and is organized into a flight operations team, responsible for planning and executing all processes necessary to operate the observatory; and a mission data operations team, responsible for operating and maintaining the ground data system and science data system communications networks and hardware.

The ground data system consists of the facilities, communications networks, hardware and software used by the mission operations system. Operations are centered at the mission operations center at JPL. Communications with the observatory are handled through the ground and space assets of the Near-Earth Network and Space Network. Scheduling and pass reporting for Near-Earth Network and Space Network assets are handled through the Data Services Management Center at the White Sands Complex in New Mexico, where the primary Tracking and Data Relay Satellite ground terminals are located. Science telemetry from the Near-Earth Network stations flows to the Earth Observing System Data and Operations System Level Zero Processing Facility at NASA's Goddard Space Flight Center in Greenbelt, Maryland, which formats the data into files and passes the radar and radiometer data to the Science Data System. Engineering data from the Near-Earth Network and Space Network stations flow to the mission operations center at JPL, which generates displays and other products to support both mission operations and science processing.

SMAP commanding and data return is accomplished through frequent contacts with ground stations of NASA's Near-Earth Network, with commanding and engineering data return at S-band and instrument data return at X-band. For early commissioning activities and critical mission events, including launch and instrument deployment, engineering data is also returned at S-band through the Space Network through the Tracking and Data Relay Satellites, which can provide coverage over most of the observatory's orbit. The primary path for commanding the observatory and returning science and engineering data is through three Northern Hemisphere tracking stations — in Wallops, Virginia; Fairbanks, Alaska; and Svalbard Island, Norway — and two Southern Hemisphere stations at the U.S. McMurdo Station, Antarctica and at the Norwegian research station (TrollSat) in Antarctica.

Once the spacecraft reaches orbit and begins transmitting data, the SMAP Science Data System will convert telemetry downlinked from the observatory into science data products provided to the science community for research and applications. Designed to process data products in a timely manner, the Science Data System facility includes computer hardware dedicated to operational data production as well as hardware for use by the Soil Moisture Active Passive science algorithm development team to enhance algorithm accuracy and performance.

The Science Data System is housed primarily at JPL, but with components at GSFC. Specifically, JPL is responsible for implementation of software to generate Level 1 instrument data products (both radar and radiometer) as well as Level 2 and Level 3 geophysical data products. GSFC is responsible for the Level 1 radiometer algorithms and for implementation of software to generate the value-added Level 4 geophysical data products produced by the GSFC Global Modeling and Assimilation Office.

SMAP baseline data products will be generated within the project's Science Data System and will be made available publicly through two NASA Distributed Active Archive Centers: the Alaska Satellite Facility in Fairbanks for Level 1 radar products and the National Snow and Ice Data Center in Boulder, Colorado, for all other products.

The SMAP team will coordinate the release of data product versions with the data centers and will ensure the completeness and accuracy of quality control information and validation status of the data products.

**Data Products**

Data products will include:

- The combined radar and radiometer processed measurements of soil moisture with 6.2 mile (10 kilometer) resolution and high accuracy

- The landscape freeze/thaw state detection

By combining SMAP observations with other available data such as precipitation and solar radiation in a land hydrology model, the mission team will also generate two additional products: an estimate of moisture in the top 3 feet (1 meter) of soil, known as the root zone; and an estimate of the exchange of carbon between the atmosphere and the land surface.

### Calibration and Validation

During the first year of science acquisition, a period of calibration and validation of the science data products is conducted to ensure that the data received from the observatory instruments are converted into accurate, scientifically useful measurements. This includes special field campaigns and intensive ground-based and airborne data acquisitions, data analysis and performance evaluations of the science algorithms and data product quality. These activities continue at a lower level for the remainder of the science observation phase, but primarily for the purpose of monitoring and fine-tuning the quality of the science data products. The observatory continues its normal data collection during calibration and validation activities.

### Science Team

An international, competitively selected science team is led by Dara Entekhabi of the Massachusetts Institute of Technology. Among its responsibilities, the science team will advise the project on aspects of the mission that influence the scientific usefulness of the data. The team has formulated a mission science plan and will oversee mission operations activities.

### Mission Phases

After mission development, the SMAP mission is divided into four primary phases:

The **launch phase** begins with the start of the launch countdown six hours before liftoff of the Delta II launch vehicle and takes the observatory from the ground, encapsulated in the fairing of the launch vehicle, to its initial free flight in a preliminary orbit known as the injection orbit. The phase ends 18 hours after launch, allowing time for ground controllers to establish regular and predictable ground station contacts before the start of observatory commissioning activities. Following ascent and separation from the launch vehicle upper stage, flight software aboard the observatory establishes telemetry links with the ground, stabilizes the observatory, deploys its solar array and points the spacecraft toward the sun. Ground controllers monitor the health of the observatory, collect data to establish its initial orbit, command the release of launch restraints on the observatory's stowed instrument boom and reflector antenna, and command the playback of launch telemetry data.

The **commissioning phase**, also known as the in-orbit checkout phase, includes checkout of the spacecraft's subsystems, up to eight orbital maneuvers to place the observatory into its final science orbit, deployment and spin-up of the instrument boom and reflector antenna, and checkout of the full observatory. It ends when both the ground project elements and the spacecraft and instrument subsystems are fully functional and have demonstrated the required on-orbit performance to begin routine science data collection. This phase is expected to be completed by 90 days after launch.

The **science observation phase** is the period of near-continuous instrument data collection and return, extending three years from the end of the commissioning phase. During this phase the observatory is pointed straight toward the ground with the solar array toward the sun, except for brief periods when propulsive maneuvers are needed to maintain its orbit and for periodic calibrations of the observatory's radiometer instrument. The first year of the science observation phase will include calibration and validation activities.

At the end of the observatory's useful life, it is maneuvered to a lower "disposal" orbit and is **decommissioned**, placing it in a state where it cannot interfere with other missions. This will be done in such a way as to mitigate the risks of creating an orbital debris hazard to other spacecraft in low-Earth orbit and of any observatory materials surviving reentry into Earth's atmosphere. During this phase, onboard propellants will be depleted to the maximum extent possible to reduce the risk of frozen propellants surviving reentry. The observatory components have been designed to minimize the risk of fragments reaching the ground. The disposal orbit is designed to ensure that the observatory reenters Earth's atmosphere within 15.5 years. Up to 30 days are allocated for this phase. During this phase, a final reprocessing of the mission's science data products will be completed.

## Auxiliary Payloads

In addition to the SMAP observatory, the Delta II launch vehicle will carry an auxiliary payload called Educational Launch of Nanosatellite X (ELaNa X), which consists of three Poly Picosatellite Orbital Deployers containing a total of four CubeSats (representing three CubeSat missions). The missions were selected as part of NASA's CubeSat Launch Initiative (CSLI), which enables the launch of CubeSat projects designed, built and operated by students, teachers and faculty to obtain hands-on flight hardware development experience. CSLI also provides access to space for CubeSats developed by the U.S. government and nonprofit organizations, giving all these CubeSat developers a low-cost pathway to conduct research in the areas of science, exploration, technology development, education or operations. Since its inception in 2010, the initiative has selected more than 100 CubeSats from primarily educational and government institutions around the United States.

This is the second Poly Picosatellite Orbital Deployer flight on a Delta II launch vehicle. The first was the ELaNa III payload that flew as an auxiliary payload on the NPP mission in October 2011.

The three CubeSat projects on ELaNa X include:

- **ExoCube**, a space weather satellite developed by California Polytechnic State University, San Luis Obispo, and sponsored by the National Science Foundation. Cal Poly designed the core satellite bus, while the scientific payload is supplied by NASA's Goddard Space Flight Center. The University of Wisconsin, Madison, and Scientific Solutions, Inc. (SSI) are developing the scientific objectives and providing guidance for instrument development. ExoCube will measure the density of hydrogen, oxygen, helium and nitrogen in Earth's upper atmosphere (exosphere and thermosphere) using direct mass spectroscopy measurements. The size of ExoCube is three CubeSat units, or 11.8 by 3.9 by 3.9 inches (30 by 10 by 10 centimeters).

- **The GEO-CAPE ROIC In-Flight Performance Experiment (GRIFEX)**, developed by the University of Michigan's Michigan Exploration Laboratory in partnership with NASA's Earth Science Technology Office and NASA's Jet Propulsion Laboratory. This is a technology validation mission that will perform an engineering assessment of a JPL-developed all digital high-performance focal plane array consisting of an innovative in-pixel analog-to-digital readout integrated circuit. Its high throughput capacity will enable the proposed Geostationary Coastal and Air Pollution Events (GEO-CAPE) satellite mission concept to make hourly high spatial and spectral resolution measurements of rapidly changing atmospheric chemistry and pollution with the Panchromatic Fourier Transform Spectrometer (PanFTS) instrument in development. GRIFEX will advance the technology required for future space-borne measurements of atmospheric composition from geostationary orbit that are relevant to climate change, as well as future missions that require advanced detectors in support of the Earth Science Decadal Survey. The size of GRIFEX is three CubeSat units, or 11.8 by 3.9 by 3.9 inches (30 by 10 by 10 centimeters).

- **FIREBIRD-II (A and B)**, developed by the University of New Hampshire, Montana State University, Los Alamos National Laboratory and the Aerospace Corporation. FIREBIRD-II is a two-CubeSat space weather project to resolve the spatial scale, size and energy dependence of electron microbursts in the Van Allen radiation belts. Relativistic electron microbursts appear as short periods of intense electron precipitation measured by particle detectors on low-altitude spacecraft, seen when their orbits cross magnetic field lines that thread the outer radiation belt. FIREBIRD-II will provide dual point radiation belt measurements that will offer insight into electron acceleration and loss processes in the outer Van Allen radiation belt. Each of the FIREBIRD CubeSats is 1.5 CubeSat units in size, or 5.9 by 3.9 by 3.9 inches (15 by 10 by 10 centimeters).

The CubeSat projects will be deployed at a minimum of 2,896 seconds after separation of the Soil Moisture Active Passive observatory, into a 273- by 416-mile (440- by 670-kilometer), 99.12-degree inclination orbit.

# Why Study Soil Moisture?

At any given time, very little of Earth's water is lodged in the top few feet of soil — only about one-thousandth of one percent of the total. Even leaving out the saltwater oceans, soil moisture is still only 0.05 percent of fresh water. Life could not exist on Earth without water, of course. But why send a mission to space to study this tiny fraction?

Soil is where our food grows, and new measurements from the Soil Moisture Active Passive mission have the potential to improve forecasts of upcoming growing seasons. Beyond that, better knowledge of soil moisture can improve our forecasts of how prone a region is to flooding or whether a drought might persist. Changes in future water resources are a critical societal impact of climate change, and a scientific understanding of how these changes may affect water supply and food production is helpful for policy makers.

These practical benefits, however, are not the main motivation for SMAP. There are basic scientific questions that turn on knowing more accurately how this tiny percentage of water is distributed on Earth and how it changes throughout the year. A better knowledge of soil moisture is a skeleton key to unlock an improved understanding of three of Earth's important cycles: the cycling of water between the surface and the atmosphere, the cycling of energy from the sun down to Earth and back up into the atmosphere, and the cycling of carbon among plants, the atmosphere and the soil. Soil moisture plays a critical role linking these three cycles. If we can better understand and model these building blocks of the Earth system, we can better forecast how our changing climate will affect them and better prepare for the changes already in store.

Another important question about moisture in soil is whether it is in solid or liquid form, that is, whether the soil is frozen or thawed. The freeze/thaw state of soil is the on/off switch that controls when plants are active and when they are dormant. Because most of Earth's land surfaces are covered by vegetation, the huge global flows of water, energy and carbon from land to the air mostly begin with a minuscule transfer of water from soil into the roots of a plant. Knowing exactly when and where plants are taking up water is an important part of understanding the global cycles.

**Linking Earth's Cycles**

Although each of these three intertwined cycles — water, energy and carbon — can be studied individually, nothing that happens on Earth is truly isolated. A process or component may appear to play a major role in one cycle and a bit part in another, but that small role could be just as important for keeping the second cycle stable. Global climate change has taught us that changes to any part of the Earth system can set off a chain reaction that reverberates across many cycles, and that small changes sometimes have unexpectedly large impacts.

Soil moisture is an important participant in the three cycles. Without it, the cycles would have evolved very differently. Understanding the role of soil moisture in each cycle is a critical part of understanding future climate change and preparing to deal with it.

You probably learned about the water cycle in a school science class: Water cycles from the air to the land or ocean surface mainly by rain and snow, and it cycles back from the surface to the air mainly by evaporation. Your teacher may not have mentioned that evaporation cycles not only water but also energy in the form of heat. As cooks know, it takes heat to change water from a liquid to a gas — to bring a pot of water to a boil, for example. That means evaporation is important in Earth's energy cycle as well as its water cycle.

Evaporation, both from bare ground and from plants growing in the ground, is the predominant way that land sheds the solar energy it receives every day. It is the first process to kick in when the ground starts heating up, and it continues as long as there is moisture in soil that can evaporate. Evaporation from soil uses up to half of the total solar energy that falls on land surfaces.

Soil moisture evaporation builds clouds, which temper and moderate Earth's weather and climate. The heat energy that changed soil moisture into water vapor does not disappear. It is what keeps the water molecules moving fast enough that the water stays in a gaseous state. You might say that the energy is "stored" in the water vapor. When the rising water vapor encounters colder air at high altitudes, it condenses back into liquid water to form clouds. During that process, the water throws off the stored heat energy into the surrounding air. The energy warms the high-altitude air and may add to the cloud-building process.

By contrast, in deserts and other places where there is no soil moisture to evaporate, the Earth's surface gets hotter and hotter until it heats the air above it solely by contact, just as your hands get warmer when you hold a cup of hot coffee. The desert air becomes very turbulent, creating high winds and other weather extremes. However, its temperature plummets as soon as the sun goes down. Thus the evaporation of soil moisture protects Earth and makes our home planet more comfortable.

Because most land surfaces are covered with vegetation, most soil moisture evaporation comes not from bare soil but through plants. In photosynthesis, plants use sunlight to synthesize foods from carbon dioxide gas in the air and water that they have absorbed from the soil through their roots. Some water is given off by plant leaves during the process. Scientists call this evaporation from plant leaves ***transpiration***.

For tens of thousands of years, photosynthesis kept Earth's carbon cycle spinning smoothly: animals exhaled carbon dioxide, and plants used it to grow. When humans started burning fossil fuels, however, we began force feeding more and more carbon dioxide into the air. Plants are able to absorb about half of our carbon dioxide emissions through photosynthesis, but we do not know whether they can continue to do so indefinitely. Because water is as essential as carbon for plant growth, understanding its availability is critical to understanding and preparing for our high-carbon future.

## Understanding the Role of Northern Forests

The immense northern forests of Alaska, Canada and Siberia are warming at a faster pace than the mid-latitudes and tropics. Trees take in carbon dioxide in photosynthesis and store it in their leaves and wood, so healthy and undisturbed forests generally remove carbon from the atmosphere. That makes them what scientists call a carbon sink. Global climate change has brought longer growing seasons and higher atmospheric carbon dioxide to the northern forests, and these changes promote faster and more widespread growth. More plant growth of any kind means more carbon dioxide removed from the air, so greening is one of the rare benevolent effects of our warming climate. However, decaying leaves and wood on the ground and in the soil release carbon back into the atmosphere. Droughts and wildfires can also release enormous amounts of carbon into the atmosphere from dead and burned vegetation. Climate change has also increased the frequency and extent of these events in the high northern latitudes.

It's an open question whether the increasing output of carbon will outpace the increased rate of plant growth, and carbon absorption, over the long term. In that case, the forests will become a source of carbon to the atmosphere rather than a sink.

There are also huge stores of carbon from dead plants and animals locked in permafrost soils — ground that remains frozen for at least two continuous years. Much permafrost has been frozen for thousands of years. But with Arctic warming, more and more permafrost is thawing. Carbon in unfrozen soil can decompose and be released into the atmosphere in the form of the greenhouse gases carbon dioxide and methane. The release could happen slowly or in a giant burst that would further accelerate the pace of climate change.

Knowing the length of time each year that soils remain unfrozen would help scientists understand which of these climate-change-induced shifts will prevail. But the vast extent of the boreal forests has few permanent settlements or even roads, so measurements are very sparse and mostly come from dedicated field campaigns. Ongoing, regular measurements are virtually nonexistent. SMAP's space-based measurement will create a higher-resolution and more complete data set than has ever been available of the timing of the winter freeze and spring thaw.

## Improving Weather and Climate Forecasts

SMAP's goal is not only to improve understanding of the role of soil moisture in the Earth system, but to estimate the quantities of water and energy that are exchanged between the land surface and the atmosphere. These exchanges are critical components for weather and climate models.

Soil moisture's importance in weather forecasting has to do with its persistence. Precipitation and temperature do not linger, limiting their value as indicators of future weather. In other words, if it is raining today, it may or may not rain tomorrow, and a hot day can follow a cold day. By comparison, soil moisture is long-lived. On top of the importance of soil moisture in controlling heating and cooling in the atmosphere through evaporation, its persistence makes it a factor in weather and climate models.

Weather forecasting models all over the world use soil moisture in calculating their forecasts. However, data are so sparse that soil moisture is estimated from other, better quantified data such as temperature and precipitation. This workaround is only moderately accurate. Experiments comparing forecasts made with real soil moisture measurements and with estimates have shown that more accurate soil moisture leads to a more realistic forecast. Similar experiments have shown that soil moisture is also important in forecasting climate for next season and further into the future. Climate models set up with observed soil moisture in the top few feet of soil have proven that the resulting predictions are more accurate than those with less realistic soil moisture.

One intriguing possibility is that soil moisture in one region and season may influence the next season's weather hundreds of miles away. A modeling study has uncovered a possible correlation between rainy Aprils in the Pacific Northwest and dry Julys in the Great Plains. Ongoing, global measurements will help clarify this and other possible links.

There is a third, intermediate kind of modeling that falls between short-term weather forecasts and long-range climate predictions: seasonal outlooks of specific quantities such as water availability and drought or flooding potential. Soil moisture measurements will have considerable impact on these outlooks.

**Improving Flood Prediction and Drought Monitoring**

Increasingly, scientists say we are in for more, and more extreme, floods and droughts as average global temperatures rise. However, it is hard enough to predict accurately where and how much rain will fall next week. Forecasting next season's rainfall is even harder. A data set that can improve the prediction of floods and droughts offers tremendous societal and economic value. SMAP's measurements have the potential to do just that.

We think of floods as the result of too much rain, but that is only part of the story. If soil is dry, it can soak up a heavy rain like a sponge. Soil that is already saturated, however, cannot absorb more moisture. Frozen ground also is unable to absorb much water from rain or snowmelt. A rainstorm that would cause no problem falling on dry soil will create a devastating flood if it falls on sodden or frozen terrain.

When, where or whether a flood occurs depends on weather conditions that cannot be known very far in advance. For this reason, hydrologists forecast an area's long-range flood potential rather than forecasting specific floods. SMAP's measurements of freeze/thaw timing and soil moisture will increase their understanding of flood potential, enabling them to make better-informed decisions about matters such as the amount of water to retain in reservoirs.

Moving to the opposite end of the water availability spectrum, SMAP's measurements can also help with monitoring droughts. Agricultural drought — the lack of adequate soil moisture where plant roots need it — can occur even in the absence of a widespread, ongoing shortfall in precipitation, and because of the persistence factor mentioned above, it can linger long after regional rainfall returns to normal. An improvement in our ability to monitor and forecast agricultural drought could help improve famine early warnings in the most food-insecure countries of the world.

# The Applications Program

The SMAP Applications Program was created in 2007 — seven years before the mission's scheduled launch — to locate and engage groups that were likely to find innovative ways to use the mission's data for societal benefit. The program now has more than 300 partners. Its extensive pre-launch activities over the years have set a new standard for engaging users during the development of a NASA mission.

The SMAP Applications Working Group, with a wide and inclusive membership, develops plans for SMAP applications and identifies future potential users of SMAP data. One important set of data users is the SMAP Early Adopters: individuals and organizations that are already aware of a clearly defined need for the kind of data SMAP will provide. Early Adopters use their own resources (funding, personnel, facilities, etc.) to conduct research with simulated SMAP data provided by the mission. The research is aimed at preparing them to integrate the real data into their own programs quickly, once it is available, and also at helping SMAP mission staff assure that the mission's data products meet user needs. Early Adopters work closely with SMAP team members, interacting in workshops, tutorials and other events.

There are currently 38 Early Adopter groups with participants at regional, national and international levels in the public and private sectors. SMAP's many and varied applications fall into six broad categories. Below are a sampling of Early Adopter groups in each category.

**Agricultural Productivity**

- Soil moisture monitoring in U.S. croplands — U.S. Department of Agriculture (USDA) National Agricultural Statistical Service
- Water modeling in rangeland and forest ecosystems — Boise State University, Idaho
- Downscaling SMAP data to assess water availability in a local river basin — U.S. Geological Survey (USGS) South Atlantic Water Science Center-Georgia, Norcross, Georgia
- Using SMAP data in a system to monitor global crop production — USDA Foreign Agricultural Service

**Droughts and Wildfires**

- Incorporating SMAP data into a famine early warning system — USGS and University of California, Santa Barbara
- Monitoring drought — University of Nebraska-Lincoln Center for Advanced Land Management Technologies and National Drought Mitigation Center
- Improving understanding of air quality risks from fires — University of North Carolina at Chapel Hill Institute for the Environment

**Floods and Landslides**

- Improving decision-making systems in emergency response operations — StormCenter
- Communications, Halethorpe, Maryland
- Flood forecasting in data-poor regions — U.N. World Food Programme, Rome, Italy
- Predicting power outages in hurricanes — Texas A&M University, College Station, Texas

**Human Health**

- Mapping the extent of Saharan dust emissions — Masdar Institute, Abu Dhabi, United Arab Emirates
- Supporting management of New York City's drinking water supply — City University of New York and New York City Department of Environmental Protection

**National Security**

- Assessing mobility for the U.S. Army and Marine Corps — U.S. Army Corps of Engineers Cold Regions Research and Engineering Laboratory, Hanover, New Hampshire
- Sea ice studies — University of Bremen Institute of Environmental Physics, Bremen, Germany
- Improving weather forecasting for the U.S. Air Force and Army — U.S. Air Force Weather Agency

### Weather and Climate Forecasting

- Assimilating SMAP data into national weather forecasting models — separate projects at the National Oceanic and Atmospheric Administration, Silver Spring, Maryland; Environment Canada's Meteorological Research Division, Dorval, Quebec; and the European Centre for Medium-Range Weather Forecasts, Reading, U.K.
- Using SMAP data in quantifying greenhouse gas emissions — Atmospheric and Environmental Research, Lexington, Massachusetts

# Science Goals and Objectives

The science objectives of the SMAP mission are captured by five specific goals.

1. **Understand processes that link Earth's water, energy and carbon cycles on land.** Soil moisture links the water and energy cycles through evaporation, as described in the preceding section, and links the water and carbon cycles through the plant processes of photosynthesis and transpiration. Better measurements of soil moisture are likely to increase scientists' understanding of how these basic Earth system cycles link together.

2. **Estimate flows of water and energy between the atmosphere and land globally.** SMAP's high-resolution measurements will improve the accuracy of estimates of these important exchanges.

3. **Quantify the net transfer of carbon between the boreal forests and atmosphere.** The overall role of northern forests in the carbon cycle, and their future role, remain unanswered questions. SMAP's measurements will provide new data on how carbon enters, leaves and is stored in these data-sparse landscapes.

4. **Enhance weather and climate forecasting accuracy.** The patterns of soil moisture affect heating at Earth's surface and the development of severe weather. With realistic soil moisture inputs into weather prediction models, the forecasts will improve where most needed: over land.

5. **Develop improved flood prediction and drought-monitoring capability.** Knowing soil moisture will allow hydrologists to make better decisions related to the risk of flooding or drought, such as how much water to retain in reservoirs.

# Observatory

Built in Pasadena, California, by NASA's Jet Propulsion Laboratory, Soil Moisture Active Passive is the latest in a long line of scientific spacecraft that JPL has built, or is in the process of building, for NASA. The spacecraft leverages avionics, software, power and instrument electronics derived from previous Earth observing and planetary missions. It is designed to accommodate the unique needs of a large spinning instrument in a compact package that can fit within a small launch vehicle fairing.

The SMAP observatory is defined as all of the hardware elements released into orbit from the Delta II launch vehicle. It consists of the spacecraft bus, which houses all the engineering subsystems necessary to maintain and support operation of the science investigations; the instrument, which consists of all the radar and radiometer processing electronics and hardware, the reflector antenna and its supporting structure and the deployment and spin mechanisms (see next section); and a cylindrical launch vehicle adapter (launch system hardware that attaches the bus to the launch vehicle). A portion of the adapter remains attached to the spacecraft bus after separation from the launch vehicle's upper stage.

When fully deployed in orbit and spinning, the SMAP observatory is about the size of a school bus. The observatory's spacecraft bus is made up of a rectangular-shaped, aluminum spacecraft structure that measures about 4.9 by 3 by 3 feet (1.5 by 0.9 by 0.9 meters). The three-axis stabilized spacecraft bus houses most components of the radar instrument and all the spacecraft's engineering subsystems. These subsystems provide power, receive and process commands from the ground and receive, store and downlink the science data collected by the instruments,. At the top of the bus is a spinning instrument platform that includes the radiometer instrument and the reflector antenna, along with the antenna's deployment structure and spin mechanism and instrument control electronics. A three-panel solar array is part of the spacecraft bus and is folded against the bus during launch. The spacecraft bus structure is oriented vertically at launch, as it is when in orbit.

The observatory, including the spacecraft, science instruments and onboard propellant, weighs 2,081 pounds (944 kilograms) at launch.

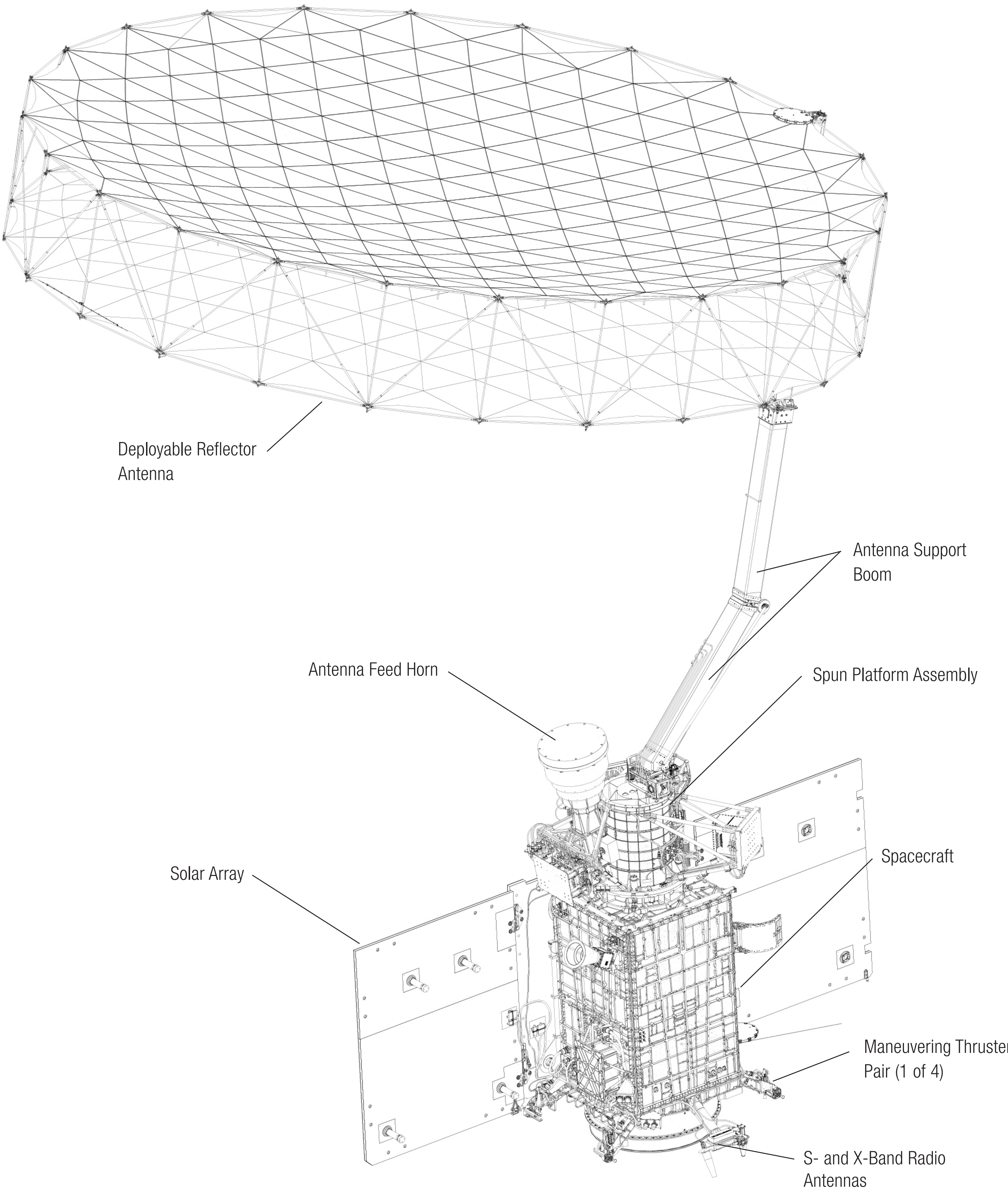
While the observatory is designed to last at least three years its resistance to radiation at its orbiting altitude of 426 miles (685 kilometers) and the 179 pounds (81 kilograms) of propellant that it carries should allow the mission to operate well beyond its design lifetime.

The observatory transitions through three main configurations during its mission. For launch, the solar array and reflector boom antenna assembly are folded against the spacecraft bus to fit within the fairing of the Delta II launch vehicle. After separation from the Delta II second stage, the solar array is deployed and the observatory remains in this configuration for about two weeks while the initial engineering checkout is performed. Then, starting about two weeks after launch, the instrument reflector boom assembly is deployed. Following deployment, maneuvers are executed to place the observatory in its final science orbit. About two months after launch, the instrument and antenna are spun up to a rate of up to 14.6 revolutions per minute for science data collection. Following spin-up, the science instruments are checked out, completing the planned post-launch on-orbit checkout phase and allowing science calibration and validation to begin.

**Thermal Subsystem**

The thermal subsystem maintains satellite equipment at proper temperatures. It uses a combination of active and passive components. Passive thermal control is used wherever possible and includes thermal paints on the observatory's external surfaces; multi-layer insulation blankets; radiators, which remove excess heat from the observatory electronics; and thermal doublers. Electronic boxes are attached to the outside structural panels, which function as radiating surfaces. Active heating controlled by mechanical thermostats is used where it is necessary to maintain components at operating temperatures, such as the propulsion tank, propellant lines and thrusters. Active heating is also used where needed to maintain components above minimum flight allowable temperatures, such as during eclipses, or survival heaters for the radar electronics should they be powered off if the satellite goes into a safe hold condition. Temperatures are measured and reported from many locations on the observatory using platinum resistance thermometers.

The thermal environment encountered by the observatory during most of its mission is relatively uniform, though significant variations must be accommodated during regular tracking passes for S- and X-band communications downlinks, seasonal eclipse periods of up to 19 minutes per orbit, propulsive maneuvers, and safe hold events when the instruments are powered off and survival heating is in use.



### Power and Pyro Subsystem

The observatory's power is generated, stored and distributed by the power and pyro subsystem. The power required to run the entire observatory is 1,450 watts, equivalent to about 18 common 80-watt household light bulbs. The major components of the subsystem are the three-panel solar array, four lithium-ion batteries, a single power bus, the power control assembly, the power distribution assembly and the pyro firing assembly.

The solar array uses gallium-arsenide solar cells with a cell area of about 75 square feet (7 square meters). It produces a beginning-of-mission output of about 2 kilowatts when directly pointing at the sun.

The batteries provide energy during eclipses, during launch and during infrequent propulsive maneuvers where the solar array cannot be pointed at the sun. The main spacecraft battery has a capacity of 50 Amp-hours. Three smaller batteries with a total capacity of 28 Amp-hours at the beginning of the mission are located inside the launch vehicle adapter and ensure sufficient energy at launch.

The power control assembly selectively switches among the nine solar array circuits to maintain the bus voltage between 24 to 36 volts, with the normal operating range between 29 and 33 volts. To maintain a positive energy balance on the observatory, flight software and subsystem hardware can autonomously switch off non-essential power loads if undervoltage thresholds are crossed.

Switches in the power distribution assembly distribute energy to the instruments and spacecraft loads.

The pyro-firing assembly contains the pyro-firing circuitry.

The subsystem is fully functional after solar array deployment within minutes after the observatory separates from the Delta II's upper stage.

### Flight Software

The observatory uses stored commands of its flight software to perform its normal operations and also receives commands and sequences from Earth. The software on the flight computer, part of the avionics subsystem, translates stored and ground commands into actions for various spacecraft subsystems. The flight software also gathers science data as well as engineering telemetry for all parts of the spacecraft and continuously monitors the health and safety of the observatory.

Hosted in the command and data handling spaceflight computer board, the software uses the WindRiver VxWorks operating system. Portions of the code are inherited from the JPL multimission system architecture platform and the Mars Science Laboratory project. The remainder of the software was developed to meet unique Soil Moisture Active Passive mission requirements, including functionality required for commanding, monitoring and data handling of the observatory's radar and radiometer instruments, along with associated power control, thermal control, spin mechanism control and fault protection functions to support specific instrument needs.

The flight software can perform a number of autonomous functions, such as attitude control and fault protection, which involve frequent internal checks to determine whether a problem has occurred. If the software senses a problem, it will automatically perform a number of preset actions to resolve the problem or put the spacecraft in a safe mode until ground controllers can respond.

### Command and Data Handling

Part of the avionics subsystem, the command and data handling design provides the hardware for the satellite's computing functions and for the storage of science and engineering data. It also provides hardware for the necessary interfaces to receive commands and data from the ground, to receive sensor data on the state of the observatory, to send actuation commands that modify the state of the observatory, to receive and store instrument data, and to format science and engineering data for transmission to Earth.

The hardware is packaged in a single assembly that contains the system flight computer, a RAD750 radiation-hardened single board computer that hosts the observatory flight software and controls various other parts of the satellite.

### Telecommunications Subsystem

The telecommunications subsystem provides telemetry links in two frequency bands to return observatory engineering and instrument data, and to receive commands and data to control the observatory activities. The observatory's radio system operates in both the S-band and the X-band ranges of the microwave spectrum. Science data will be downlinked at a rate of 130 megabits per second through the X-band transmitter. The S-band side of the subsystem is used to return engineering telemetry at lower data rates of 2 and 513.737 kilobits per second and to receive commands at uplink rates of 2 and 64 kilobits per second. The S-band transponder will also accommodate ground-based Doppler tracking for orbit determination since the spacecraft does not use GPS for navigation.

Data return at both frequencies is typically scheduled once or twice on most orbits of the science observation phase through ground stations of NASA's Near-Earth Network. Ground station contacts typically last between five and 11 minutes. For major events early in the mission, including the launch phase and the instrument deployment activities, and for anomaly situations, the S-band 2-kilobits per second engineering data are also returned through the NASA Space Network using Tracking and Data Relay Satellites, which allow coverage over most of the observatory's orbit. Commanding through the Tracking and Data Relay Satellites is also a backup capability. Tracking and Data Relay Satellite communication uses the S-band single-access capability, and data rates are limited to 2 kilobits per second for both uplink and downlink due to the increased range.

The S-band telecommunications hardware includes redundant S-band transponders (5-watt output), a single S-band low-gain antenna and a coaxial switch to select the active transponder. The X-band telecommnications hardware includes redundant X-band transmitters (8-watt output), a single X-band low-gain antenna, a bandpass filter and a coaxial switch to select the active transmitter.

### Guidance, Navigation and Control Subsystem

The guidance, navigation and control subsystem provides high stability for the spacecraft during science operations and points the instruments for science and calibration observations. It provides spacecraft attitude estimates, three- or two-axis attitude control, momentum management (including for the large spinning instrument and antenna), thruster control for propulsive maneuvers and control modes for instrument spin-up.

The attitude sensors include two coarse sun sensor units, which provide a relatively coarse measure of the sun's direction, primarily after separation from the launch vehicle and in the event the satellite enters a safe hold mode. There are sun sensors on various parts of the observatory such that more than one sensor is pointing toward the sun regardless of the orientation of the observatory.

The satellite's orientation is sensed and verified by a star tracker, while its rotation rates are sensed by an onboard inertial measurement system consisting of two inertial measurement units. The star tracker views the sky and processes the images gathered to recognize star patterns as they pass through the tracker's field of view. These sensors feed data to the flight software responsible for guidance, navigation and control, which determines the current attitude and commands actuators to maintain the desired attitude.

Pointing control over most of the mission is accomplished by four reaction wheels, which use the momentum of spinning wheels to nudge the satellite in one direction or another. Periodically the reaction wheels accumulate too much momentum, which requires the use of three devices called magnetic torque rods — somewhat like large electromagnets — to push against Earth's magnetic field and cancel out some of the momentum in the wheels. The torque rods use information from a device called a three-axis magnetometer that senses the orientation of Earth's magnetic field.

Eight hydrazine-powered thrusters of the propulsion subsystem provide pointing control immediately after separation from the launch vehicle, during propulsive maneuvers and during anomaly situations.

Three-axis stabilization means that the spacecraft can be held in any orientation in relation to space. The stabilization system is fully autonomous, relying on onboard systems to control the satellite orientation with no intervention required from ground controllers.

In addition to pointing the instruments, the spacecraft must know the precise location on Earth that the instruments are viewing. The observatory does not have an onboard Global Positioning System receiver because the large instrument reflector antenna obscures GPS visibility. For this reason, Doppler ground tracking with frequent data uploads to the observatory are used to maintain pointing accuracy.

## Propulsion Subsystem

SMAP requires onboard propulsion to finalize its orbit after launch vehicle separation and provide thrusting for orbit correction maneuvers. The onboard propulsion also provides attitude control, primarily to begin and maintain a sun-pointed attitude following separation from the launch vehicle and to provide greater control in the event of anomalies. The propulsion subsystem features a single pressurized propellant tank carrying 179 pounds (81 kilograms) of hydrazine. The observatory adjusts its orbit by firing any combination of its eight onboard thrusters, each of which provides about 1 pound (4.5 Newtons) of thrust. The subsystem is fully activated immediately after separation from the launch vehicle.

## Physical and Functional Redundancies

SMAP is a single-string spacecraft. This means that most spacecraft subsystems do not have backups. However, physical functional redundancies have been incorporated whenever possible. Some subsystems do have redundant units, including the inertial reference unit, S-band transponder, X-band transmitter, thrusters, latch valves, and most heaters and thermostats. There are other subsystems whose functionality can be accomplished by other units. Examples of functional redundancy include the ability to use the coarse sun sensors to provide spacecraft attitude instead of the star tracker.

# Science Instruments

The Soil Moisture Active Passive observatory carries two instruments, a radar and a radiometer. Both types of sensors have a long history of use from space. Combining their measurements allows the SMAP mission to capitalize on the strengths of each and work around their weaknesses.

The radar alone can produce a soil moisture measurement with a spatial resolution of about a mile and a half (3 kilometers), but the measurement itself is less accurate than one made by radiometer. The radiometer alone achieves a highly accurate observation of soil moisture but with a much poorer spatial resolution of about 25 miles (40 kilometers). Through advanced data processing, SMAP will provide the user community with a combined soil moisture measurement that has high accuracy and a resolution of 6 miles (10 kilometers). SMAP also offers the individual radar and radiometer data, among other data products.

Making the best use of both instruments required major advances in signal processing and in antenna design and fabrication. SMAP's radar was designed and built at NASA's Jet Propulsion Laboratory, Pasadena, California. The radiometer and its signal processing were developed and built at NASA's Goddard Space Flight Center (GSFC), Greenbelt, Maryland. The antenna was designed and built by Northrop Grumman Astro Aerospace, Carpinteria, CA.

**The Radar and Radiometer**

SMAP's radar uses a microwave frequency of 1215 to 1300 megahertz (MHz) in a part of the electromagnetic spectrum known as the L-band. The radar transmits almost 3,000 pulses of microwaves a second and receives the signals that bounce back from Earth, called backscatter. Microwaves at this frequency are able to penetrate a few inches or more into the soil before they rebound.

Water — including water in soil — responds differently than dry soil does to microwaves. Water changes the strength of backscatter and microwaves' polarization (the orientation of the electrical field of the microwaves). Therefore, backscatter from moister soil is stronger and is polarized differently than backscatter from dryer soil. The extent of the difference allows scientists to distinguish the amount of soil moisture. SMAP's radar emits pulses with two different polarizations, horizontal and vertical, to make a more complete measurement of this effect.

The radar achieves the mission's high resolution requirements by a technique called synthetic aperture radar (SAR) processing. SAR "synthesizes" a virtual antenna many kilometers long through complex signal processing of Doppler shifts in the backscatter. The Doppler shifts occur because returning microwaves from a target in front of the spacecraft appear to be compressed by the spacecraft's movement toward them, whereas returns from a target receding behind SMAP appear to be spread out.

SAR processing is commonly used in scientific research and space missions to produce topographic-like maps of terrain; however SMAP's SAR lacks the capability to produce these types of images. Instead, it produces "maps" of backscatter at high spatial resolution. SMAP is the first mission to use a SAR in connection with a rotating mesh antenna.

Besides providing soil moisture measurements, the radar data will also provide information on whether the soil is frozen or thawed — another key science objective. When water in soil freezes, radar backscatter is greatly reduced, making the change of state readily observable from space.

Like the radar, SMAP's radiometer detects differences in microwaves that are caused by water in soil; but the radiometer measures Earth's natural microwave emissions at the frequency of 1.4 gigahertz, in the L-band. Around the globe, the most striking difference in these natural emissions is between water and land surfaces. A desert emits microwaves at about three times the rate that a lake does. Because the difference is so large, even a small amount of moisture in soil causes a change that a radiometer can measure accurately.

**Mitigating Radio Frequency Interference**

Two other missions have used radiometers to measure soil moisture, although at a lower accuracy and/or resolution than SMAP. These missions have shown that radio frequency interference (RFI) is a growing problem for science missions that use the lower microwave region like L-band for their measurement. SMAP's measurements are especially vulnerable because most RFI occurs over land — where SMAP's measurements must be made. The L-band frequencies where SMAP's radiometer operates are reserved for passive remote sensing (that is, for "listening" but not transmitting) and other passive scientific uses by the International Telecommunication Union in Geneva, Switzerland, the body that allocates the global radio spectrum. However, this band is sandwiched between other L-band frequencies that are heavily used by air traffic controllers, the Global Positioning System, cell phone providers and others. These commercial signals can spill over randomly and unpredictably into SMAP's operating band and degrade SMAP's science measurements. The situation in the radar spectrum is even more acute because the spectrum is shared with other radar users.

The signal-processing technique used by earlier spaceborne radiometers has a wide field of view and averages the signal over a long period. Even a short burst of interference from a single source may contaminate a large area.

SMAP's radiometer engineers at GSFC have devised innovative ways to identify intruding the signals and delete only the small segments of data they contaminate. The radiometer collects almost 1,000 times more measurements than are conventionally considered necessary, and it sends its information in time periods of many different lengths so that the ground processing can detect harmful interference and remove it with the least possible data loss. SMAP is the first mission to use these complex RFI detection and mitigation techniques in the ground processing software.

SMAP's radar engineers at JPL incorporated the ability to tune SMAP's radar operating frequency to avoid RFI. The radar frequency can be changed as a function of the antennas rotational position or the observatory's location in its orbit, providing a high degree of dexterity to avoid other radars that might interfere with SMAP's measurements.

**The Antenna**

To enable the mission to meet its accuracy and resolution needs while covering the globe every three days or less, SMAP's rotating antenna is about 20 feet (6 meters) in diameter. SMAP's Reflector Boom Assembly (RBA) is an advanced, low-mass, deployable reflector system — the first spinning and precision mass-balanced mesh reflector with an ultracompact stowage volume and a precision surface. It is the first use of such a system in a spaceborne instrument that jointly supports radar and radiometric measurements for Earth science. It is also the first use of a deployable mesh antenna in a rotating spaceborne instrument, rotating at 14.6 revolutions per minute, or one rotation in fewer than four seconds. The RBA enables SMAP to meet its measurement requirements for high accuracy and spatial resolution and to achieve global coverage every two or three days while still using only a single small observatory that weighs just over a U.S. ton (1,000 kilograms).

The designers chose a flexible mesh antenna because it must fold into a very compact stowed volume of 1 foot by 4 feet (30 by 120 centimeters) for launch. The mesh is edged with a ring of lightweight graphite supports called a perimeter truss, which open like a camp chair when deployed. The antenna is attached to the observatory by a 16-foot (5-meter) deployable boom. When the antenna is deployed, the surface shape of the mesh must be accurate within about an eighth of an inch (a few millimeters). The antenna dish was provided by Northrop Grumman Astro Aerospace in Carpinteria, California. The boom and antenna together weigh 127 pounds (58 kilograms).

Confidently deploying large, low-mass structures in the microgravity environment of space is one of the larger engineering challenges that NASA missions can confront in development. The low mass of SMAP's antenna, coupled with its large deployed size, require the use of special equipment for ground testing to compensate for the effects of gravity, which will not be felt in space. The ground testing environment can pose more difficulties than space itself will pose because of the unavoidable limitations of this specialized equipment and the procedures that must be used. For this reason, ground testing is supplemented with sophisticated analysis, and large design margins must be included to insure the antenna will deploy in the space environment.

The antenna and boom are mounted on a spinning platform that also supports the radiometer. The motor and its control electronics that spins the antenna were provided by the Boeing Company in El Segundo, California. The antenna beam has a footprint of about

25 miles (40 kilometers) on Earth's surface, but the conical scanning pattern creates a swath of 621 miles (1,000 kilometers).

Because the antenna is shared by the radar and radiometer, the signals from Earth must be separated into the radar and radiometer bands by devices called frequency diplexers. The diplexers route each signal to the appropriate electronics for detection.

The antenna's incidence angle is 40 degrees, meaning that its dish is tilted at about a 20-degree angle from horizontal.

**Instrument Coverage**

The instrument will be placed in a near-polar, sun-synchronous orbit at an altitude of about 425 miles (685 kilometers). It will complete an orbit every 98.5 minutes, crossing the equator at 6 a.m. and 6 p.m. This orbit allows near-global coverage of Earth to be obtained every three days (44 orbits). It will repeat each orbit track exactly after eight days (117 orbits). The instrument will revisit each area every two days at high latitudes or three days nearer the equator.

By combining the radar and radiometer measurements, scientists will be able to provide estimates of soil moisture in the top two inches (five centimeters) of soil at a spatial resolution of about six miles (10 kilometers), excluding mountainous regions, open water, urban areas and tropical forests and other dense, humid vegetation with a water content greater than about 11 pounds of water in each square yard (5 kilograms in a square meter).

The radar data will provide the freeze/thaw measurement with 1.8-mile (3-kilometer) spatial resolution at an interval of every two days for each location north of 45 degrees north latitude — about the latitude of Minneapolis.

# Program/Project Management

The Soil Moisture Active Passive mission is managed for NASA's Science Mission Directorate, Washington, by NASA's Jet Propulsion Laboratory (JPL), Pasadena, California.

At NASA Headquarters, John Grunsfeld is the associate administrator for the Science Mission Directorate. Geoff Yoder is deputy associate administrator for the Science Mission Directorate. Mike Freilich is the Earth Science Division director within the Science Mission Directorate. Jack Kaye is associate director for research within the Earth Science Division. Christine Bonniksen is the SMAP program executive. Jared Entin is the SMAP program scientist. Brad Doorn is the program manager for water resources in the Applied Science Program of NASA's Earth Science Division. Lawrence Friedl is the associate director for the Applied Science Program.

The mission is managed programmatically for NASA Headquarters by the Earth Systematic Missions Program Office at NASA's Goddard Space Flight Center (GSFC), Greenbelt, Maryland. Tom McCarthy is program manager for the Earth Systematic Missions Program. Chris Savinell is the mission manager responsible for the SMAP mission within the project office.

At JPL, Kent Kellogg is the SMAP project manager, and Sam Thurman is the deputy project manager. The project scientist is Simon Yueh. JPL is responsible for project management, system engineering, instrument management, the radar instrument, mission operations and the ground data system. Together with GSFC, JPL is responsible for science data processing and delivery of science data products to the Alaska Satellite Facility and to the National Snow and Ice Data Center for archiving and public distribution. The California Institute of Technology, Pasadena, California, manages JPL for NASA.

At GSFC, Peggy O'Neill is the SMAP deputy project scientist. GSFC is responsible for the radiometer instrument. Along with JPL, it is also responsible for science data processing and delivery of science data products to the Alaska Satellite Facility and to the National Snow and Ice Data Center for archiving and public distribution.

The SMAP Science Team is led by Dara Entekhabi of the Massachusetts Institute of Technology, Cambridge, who guides the selected science team members.

At NASA's Kennedy Space Center, the NASA Launch Services Program is responsible for government oversight of launch vehicle preparations at Vandenberg; the engineering, certification and testing of the Delta II launch vehicle; spacecraft ground support and integration with the Delta II; the Space Launch Complex 2W pad facilities; countdown management; launch vehicle tracking; data acquisition; and telemetry monitoring. Choung Nguyen is the NASA Launch Services Program mission manager responsible for coordinating launch services for the SMAP mission.