A.12 SURFACE WATER AND OCEAN TOPOGRAPHY (SWOT) SCIENCE TEAM

Amended August 22, 2019. This amendment releases the final text for this program element. Notices of intent to propose are requested by October 17, 2019, and the due date for proposals is November 21, 2019. The Data Management Plan (DMP) is not requested on the NSPIRES cover page. Instead, the DMP is to be included in the proposal PDF after the page limited S/T/M section, see Section 3.1 of this program element. A mandatory template is provided for the Summary Table of Work Effort and Current And Pending Support, see Section 3.2.

1. Introduction

Surface Water and Ocean Topography (SWOT) is a satellite mission being jointly developed by NASA and CNES (Centre National d'Etudes Spatiales), the French space agency, with contributions from the Canadian Space Agency (CSA) and the United Kingdom Space Agency (UKSA) and is currently scheduled for launch in 2021. Information on the SWOT mission and its capability to fulfill the objectives laid out for it can be found at the SWOT web site https://swot.jpl.nasa.gov/.

SWOT mission will be NASA's first global survey of Earth's surface water to observe ocean surface topography, major lakes, rivers, and wetlands with unprecendented resolution. Technical and scientific challenges include reducing measurement noise by two orders of magnitude below that of conventional altimetry missions like Ocean TOPography EXperiment (TOPEX)/Poseidon and Jason series. The systematic measurement errors (e.g., baseline roll and metrology, water-vapor induced range errors, etc.) must also be reduced at oceanic mesoscales to more than one order of magnitude below the signal levels. Mesoscale tidal errors caused by coastal and internal tides must be corrected for. The effects of vegetation, target layover, and water mask accuracy over land are challenges to be met by the mission’s measurement system.

The SWOT mission will use Ka-band radar interferometry to produce a swath of elevation measurements collected over land surface waters and over the ocean water surface. These elevation measurements are necessary for studying changes in the amount of water stored and flowing through the world’s rivers, lakes, wetlands, reservoirs, etc. The measurements are fundamental for studying ocean surface topography and mesoscale and submesoscale processes in the ocean. On land, the SWOT mission will make the first high-resolution mapping of the height and area variations of water bodies such as lakes, reservoirs, and wetlands. SWOT will also provide measurements necessary for estimating river discharge. All of these elements are of key importance to monitoring and understanding the shifting freshwater resources. Over the ocean, the SWOT mission will extend the capability of existing nadir profiling altimeters to two-dimensional mapping at higher resolution enabling the study of energetic ocean currents, eddies, and fronts that contain most of the kinetic energy of the ocean.

The objective of this announcement is to select a Science Team to assist with prelaunch planning and immediate post-launch scientific exploitation of the SWOT mission. The selection will be conducted in coordination with CNES, CSA, and UKSA. The Science Team will function for the period 2020 through 2024. Its role, along with relevant scientific research, will be to provide expert guidance to the SWOT project in the areas of measurement requirements, product definition, geophysical error sources, algorithm development, calibration, validation, and liaison with the broader science and applications communities.

2. Primary Research Priorities for the Science Team

2.1 Oceanography

The oceanography science goals of SWOT are to observe the sea surface height (SSH) in two dimensions at scales not resolved by conventional altimetry for studying the role of ocean circulation in exchange of heat and ocean properties between the upper and deep ocean. The SSH measurement is to be made by the technique of radar interferometry that is fundamentally different from conventional altimetry. The observations are also expected to advance the understanding of the processes of the coastal oceans and interactions with the estuaries.

The mission's science requirements were developed with the participation of the mission's Science Definition Team during 2013 – 2016. As the thrust of SWOT is to make SSH observations at previously unresolved scales, the observational requirements were specified in terms of wavenumber spectrum. Based on the prediction of signal strength and measurement errors, the spatial along-track resolution of SWOT is estimated to be 15 km for 2 m significant wave height. However, both signal strength and measurement errors are dependent on seasonal conditions, the actual resolved wavelengths vary from 15 km in the tropics to 30-50 km at high latitudes with the largest values in the Southern Ocean.

The mission's Science Team (2016 – 2019) has continued preparing the algorithms for open ocean and coastal processing, and contributed to the scientific understanding of the SWOT ocean signal, errors and applications. The mission has two phases with a 1-day repeat Validation orbit, and a 21-day repeat Science orbit. To aid in the preparation of ocean science studies, a SWOT ocean simulator has been developed to simulate the realistic SWOT swath, ground track and errors. The simulator can be applied to most high-resolution model formats, and is freely available at SWOT simulator GitHub.

The specific objectives for proposers addressing mission's Oceanographic priorities have been identified in the following subsections.

2.1.1 *Mesoscale ocean dynamics*

The oceanic mesoscale eddy field, which has not been adequately resolved by the conventional altimeters, is a central focus of SWOT oceanography. After mapping to two-dimensional gridded fields, the resolution of conventional altimeters is about 150 km in wavelength with on-going improvement owing to the increased number of altimeters on orbit. SWOT will also carry a nadir-looking conventional altimeter. With the constellation of conventional altimeters providing the global mesoscale field down to

150 km, the new high-resolution observations of SWOT will provide opportunities to study the interaction of the mesoscale variability within its wide range of scales from hundreds to tens of kilometers. The fine-scale swath observations will allow a better characterization of the anisotropic structure of the mesoscale field, its strain and vorticity, and local 2D energy fluxes. Studies are encouraged that will further our understanding of these smaller mesoscale processes, and their observability with SWOT. In addition, synergistic applications with other observations capable of revealing mesoscale variability such as in situ or airborne data, or satellite sea surface temperature and salinity, ocean color and SAR images, are also encouraged.

2.1.2 *Tides and high-frequency motions*

SWOT's orbits have been specifically designed to resolve the major tidal constituents during its lifetime. SWOT is expected to provide unprecedented observations of the barotropic tides, especially in the coastal and high-latitude regions where current tidal models have the largest errors. The development of high-resolution barotropic tide models will be a high priority for SWOT, and these should be progressively improved during the mission lifetime. Science studies addressing the barotropic tide, its modification due to the baroclinic tide, and improved tidal models will be encouraged.

Internal tides and low-mode internal gravity waves have SSH signals comparable to mesoscale geostrophic motions. How to separate them is a challenge of the SWOT mission. Investigations addressing the development of predictive models for the internal tides are encouraged, including those incorporating the SWOT data. The swath observations of SWOT will provide new opportunities to validate and improve the internal tide models. Understanding and improving the non-phase-locked, incoherent part of the internal tide is a big challenge for SWOT, but also an important scientific opportunity to learn more on this pathway to ocean mixing and dissipation.

Internal gravity waves are not deterministic processes amenable to prediction. Their potential presence in the SWOT observations presents an unprecedented challenge and an opportunity for studying the interaction of these waves with the mesoscale geostrophic motions.

2.1.3 *Ocean fronts and air-sea interactions*

Horizontal gradients in SWOT's 2D SSH data can reveal the larger ocean fronts, with scales of tens of kilometers. SWOT will also provide collocated Synthetic Aperature Radar (SAR) images at 250 m resolution including power and variance, as well as SAR Doppler Centroid products providing higher resolution observations of the surface roughness changes across fronts. Studies are encouraged that use the collocated SSH and SAR images and other data and models to investigate frontal dynamics and upper-ocean wind-wave interactions across ocean fronts.

2.1.4 *Geophysical Corrections and Algorithms*

There are anticipated contributions from the Science Team to better understanding of the measurement physics and the mission's algorithm development. Particular challenges include the correction for the electromagnetic bias at the Ka-band frequency and its spatial variability across the measurement swath; the estimation of wind speed and significant wave height across the swath; the use of radar imagery to estimate

surface current features; the detection of land, ice, and rain contamination; and, finally, the removal of errors due to the presence of ocean waves.

2.1.5 *Ocean state estimation*

The challenge of the separation of tides/waves from geostrophic motions is exacerbated by the deficiency of temporal sampling by SWOT. Owing to the limitation of near-nadir look angles to minimize the measurement errors, the swath of the observation is only 120 km wide with a 20-km nadir gap. It will take 21 days to complete the coverage of the world's oceans, with the revisit time varying from 10 days at the equator to two days at the poles. Apart from high latitudes, the repeat observations are most likely incoherent, presenting a challenge for estimating the continuously evolving state of the ocean. It is anticipated this challenge will motivate the development of creative approaches, including but not limited to the application of high-resolution assimilative models.

2.1.6 *High-level data products*

The number of observations at a given location in a repeat cycle ranges from two near the equator to more than ten at the highest latitudes. To reconstruct regular two dimensional SSH fields from the irregularly sampled observations, with complex error characteristics, will pose a significant challenge for advancing the study of ocean circulation from this new type of observation. Development of a methodology for producing optimally estimated products on regular space and time grids on both global and regional basis will be an important activity of the Science Team. The capacity to calculate derivatives of the SWOT gridded data (reconstruction of vorticity, strain, vertical velocities, and detection of fronts and filaments) must also be addressed.

2.1.7 *Calibration and Validation (Cal/Val)*

The interferometry measurement of SSH is fundamentally different from conventional altimetry. The approach to CalVal requires innovation and planning. First, the SWOT project needs to validate the measurement in terms of wavenumber spectrum, as opposed to previous point-wise validation. Second, the project must validate the utility of the SSH observations to the study of ocean circulation to meet the science goals. Cal/Val for SWOT will be orchestrated and conducted by the SWOT project at JPL. NASA is not seeking Cal/Val proposals with this program element. However, all members of the Science Team may involve themselves in analysis of the Cal/Val data.

2.2 Hydrology

The primary objective of SWOT hydrology, described in the Science Requirements Document, is to "characterize the spatial and temporal variations in surface waters, globally." In particular, SWOT aims to measure variations in lake and wetland water storage and river height, slope and discharge at sub-monthly, seasonal, and annual timescales. SWOT will provide these measurements for rivers wider than 100 m, globally, and for lakes larger than 250 m^2. These measurements will constitute the first globally consistent database of surface water storage and fluxes from space. They are expected to substantially advance hydrologic science in several areas, as specified in

the Science Description Document. The following specific objectives for proposers address the mission's Hydrologic priorities have been identified:

2.2.1 *River, lake, and wetland science*

The storage of water in lakes and reservoirs, fluxes through rivers, and interactions with inland and coastal floodplains and wetlands are critical to understanding a broad range of science questions focused on hydrology, hydraulics, biogeochemistry, water resources engineering, etc. For example, the SWOT Science Definition Team identified the following core SWOT hydrology science questions:

- What is the spatial distribution of freshwater storages and runoff through rivers, lakes, and reservoirs? Does inclusion of the knowledge "close" water budgets of regional/global hydrology and climate models?
- What are the impacts of water impoundments in reservoirs and natural lakes, human water withdrawals, and trans-boundary rivers on the global water cycle, societal water supply, and global sea level rise?
- What are the regional-to-global-scale responses of lake volumes and river flows to climatic phenomena, e.g. droughts, floods, and a warming Arctic?
- What are the three-dimensional forms of waves propagating through natural river channels, and how may these be used to improve hydrodynamic models of flood hazard and risk?
- What are the spatial and temporal dynamics of water storage in millions of unmapped lakes and river floodplains, and how do they impact biogeochemical fluxes of carbon, nutrients, and greenhouse gases, waterborne diseases/public health, sediment transport, and ecosystem functioning?

There are also many other fruitful science questions related to SWOT hydrology, including in the areas of remote sensing science (e.g., radar phenomenology), the terrestrial cryosphere (e.g., snow processes), and the science of deltas and estuaries.

The SWOT Science Team projects focused in this category will finalize development of ways to address science questions before launch and then use the first SWOT data post-launch to begin addressing them. Science investigations may focus exclusively on SWOT data or may use a combination of SWOT measurements, other satellite or in situ data, and/or numerical models. All projects should make clear their plans for both pre-launch and post-launch activities.

2.2.2 *SWOT algorithms and hydrologic data products*

In order to effectively address science questions using SWOT, robust algorithms and high-quality data products are essential. The SWOT Science Team is integrally involved in development of such algorithms and data products. Key areas that are solicited here include:

- Development and implementation of algorithms to produce river discharge estimates from SWOT data globally. These may be based on so-called mass-conserved flow law inversion algorithms or other novel or established algorithms. Emphasis should be on global-scale implementation of algorithms rather than in only a few rivers. Proposals on discharge may also seek to integrate multiple existing or novel discharge algorithms into multi-model ensembles.

- Development and implementation of algorithms and data products based on assimilation of SWOT river, lake, and/or wetland data into hydrologic or hydrodynamic models
- Development of data products, led by the Science Team, that combine SWOT data with other remote sensing or in situ datasets to aid in addressing key SWOT science questions. Examples of other current and future satellite instruments providing data that could be used in combination with SWOT data include nadir altimeters such as the JASON series, GRACE-FO, various Sentinel satellites, BIOMASS, ICE-Sat 2, MODIS/VIIRS, the Landsat suite, and NISAR.

All proposals in this category should demonstrate that it is possible to fully develop and distribute any proposed data products using proposed resources.

As for Oceanography, Cal/Val in hydrology is being conducted by the SWOT Project so proposals for Cal/Val sites and Cal/Val-related field activities are not sought.

2.3. Synergistic Sciences

2.3.1 *Coastal and estuarine processes*

The limitation of land contamination of conventional altimeter observations near coasts will be alleviated by the radar interferometry measurement. This improvement, plus the availability of high-resolution data (~ 50 m) in the region where river meets the ocean, or the estuarine regions, will provide unprecedented opportunities to advance understanding of the complex water flow and its effects on this important environment.

Understanding coastal and estuarine processes, as well as removing tidal signals, will be aided by using the improved knowledge of coastal bathymetry, which will be derived from SWOT measurements of deviations from the vertical, for the development of better coastal tides and circulation models.

2.3.2 *Cryosphere*

SWOT is required to identify water covered by floating ice. Additionally, it is possible that SWOT will provide useful measurements of snow surface elevation, especially during snowmelt when liquid water is present within the snowpack. Similarly, SWOT may provide some information on variations in elevation of glaciers and ice sheets, especially in low-slope regions. These measurements may provide useful information on variations in the cryosphere of importance to understanding of the terrestrial water cycle.

SWOT measurement will be useful to determine the freeboard of sea ice to allow an estimate of the sea ice volume. The high-resolution observation, at 1-km everywhere with limited data at resolution ~100 m, will allow better determination of ocean surface topography in the polar ocean in the midst of sea ice. SWOT will also be useful to determine the height of ice sheets and thus provide all-weather information for studying the evolution of polar ice sheet topography. Water cycles involving melting of glaciers and ice sheets are a potentially fruitful subject of investigation.

2.3.3 *Marine geophysics*

The SSH slope accuracy achieved by conventional altimetry is about 2 microradians, equivalent to 2 miliigals in gravity anomaly. Every SWOT measurement promises to achieve 1 microradian slope accuracy at 15 km wavelength over two dimensions as opposed to one-dimensional measurement by conventional altimetry. Over the lifetime of the mission, the precision of the measurement, as well as contamination due to mesoscale eddy slopes, will improve by an order of magnitude due to temporal averaging. Such global measurement is anticipated to result in an order of magnitude improvement in the accuracy of estimating seafloor depth at small scales. This would reveal the currently hidden abyssal hill fabric of the slow-spreading rate seafloor, as well as perhaps 10-20 thousand uncharted seamounts taller than 1000 m.

3. Programmatic Information

3.1 Data and Software Policy

Data, model results, and other information created under this announcement are subject to NASA's Earth Science Data policy. Proposals to develop products and software must provide a Data Management Plan (see below) and open source software development plan, identifying an open source software license and stating an open source software release milestones. Appropriate deliverables will be archived by ESDS at NASA Physical Oceanography Distributed Active Archive Center (PO.DAAC) in formats that can be readily used for a range of research needs. All data products must meet applicable U.S. Government-mandated standards adhering to requirements by NASA Earth Science Data Products. All software along with source code for the web portal development element must be released by the grantee to the NASA GitHub per the NASA Open Source Software policy and is subject to the NASA Earth Science Alternate Data Rights language to be included into award agreements. This includes all software developed with ESDS Program funding used in the production of data products, as well as software developed to discover, access, analyze, visualize, and transform NASA data. Open Source Software is defined as software that can be accessed, used, modified, and shared by anyone, and is often distributed under licenses that comply with the definition of "Open Source" provided by the Open Source Initiative or meet the definition of "Free Software" provided by the Free Software Foundation.

Proposed Data Management Plan (DMP) must provide information on how data will be managed and shared throughout its lifecycle in compliance with NASA's Earth Science data policy. Example information to consider for inclusion in a DMP are provided below. Additional information about data management best practices is available at PO.DAAC website that lists file formats and metadata models, with recommended metadata attributes. Specifically, each DMP must include the following information:

1) Data and formats produced by proposer, including information on
   a) data sources, e.g., satellites, in situ, airborne, model output, etc.
   b) data packaging, e.g., discrete points such as trajectory or fixed location, irregular grids of orbital or airborne swaths, regular grids of Level 3 or Level 4 products, time series, etc.;

c) file format, such as NetCDF, HDF, GeoTIFF, ASCII, shapefile, etc. NetCDF or HDF are the preferred PO.DAAC file format as they are both self-describing and platform/software interoperable;
d) metadata model conventions, such as Climate Forecast and Attribute Convention for Data Discovery, which are the preferred PO.DAAC metadata conventions for NetCDF and HDF file formats;
e) expected data latency, i.e., the time lag between the last observation in the data file and when data is fully processed and packaged for that data file.
f) total expected data volume for the life of the project; and
g) data reprocessing or new versions expected as part of the proposed project.

2) The timeline for the full cycle of data product delivery; starting from measurement, through production, review, and distribution. The timeline for re-processed versions of datasets.
3) Strategy for regularly documenting data product characteristics, including spatial, temporal, measurements characteristics, and data structure.
4) A plan to document data validation and uncertainty.

Consistent with a DMP, costs for all data management activities, including quality assessment, documentation, data and product sharing, data/metadata formatting, and preparation for long-term archive, must be included in the budget presented in the proposal. The DMP section must be inserted immediately after the 15-page S/T/M section. The DMP section does not have a page limit.

3.2 Budgetary and Programmatic Guidance

Total funds available for work selected under this program element are approximately $3.0M per year for four years.

Proposers must budget for mandatory project representation at annual Science Team meetings (odd years in Europe and even years in North America). Moreover, proposers are encouraged to include travel funding for one domestic or foreign trip per year to support participation in a relevant SWOT mission activity, workshop or scientific meeting.

ROSES requires that all proposals include a Summary Table of Work Effort and a list of Current And Pending Support. This program element mandates the use of the templates from the SARA web page.

Programmatic priority will be given to those proposals making the strongest scientific links to SWOT and address technical contributions to the overall SWOT mission and data products. Based on the quality of proposals received, awards will be distributed across the three research themes identified in Section 2 (~40% Oceanography, ~40% Hydrology, and ~20% Synergistic Science). Proposals outside these research themes may be considered but must be highly meritorious.

4. Summary of Key Information

Expected program budget	~$3M/year
Number of new awards pending adequate proposals of merit	~14-18

Maximum duration of awards	4 years
Due date for Notice of Intent to propose (NOI)	See Tables 2 and 3 of this ROSES NRA
Due date for proposals	See Tables 2 and 3 of this ROSES NRA
Planning date for start of investigation	June 2020
Page limit for the central technical section of the proposal	15 pp; See also Chapter 3 of the NASA Guidebook for Proposers
Relevance to NASA	Proposals that are relevant to this program are, by definition, relevant to NASA
General requirements for content of proposals	See Section 3 of the *NASA Guidebook for Proposers* and Section IV and Table 1 of *the ROSES Summary of Solicitation*.
Detailed instructions for the submission of proposals	See https://nspires.nasaprs.com/tutorials/ Sections 3.22-4.4 of the *NASA Guidebook for Proposers* and Section IV(b) of *the ROSES Summary of Solicitation*.
Documenting Work Effort and Current and Pending Support	Work Effort and Funding Support for PIs and Co-Is must be documented using the templates available on the SARA webpage
Submission medium	Electronic proposal submission is required; no hard copy is required or permitted.
Web site for submission of proposal via NSPIRES	http://nspires.nasaprs.com/ (help desk available at nspires-help@nasaprs.com or (202) 479-9376)
Web site for submission of proposal via Grants.gov	http://grants.gov (help desk available at support@grants.gov or (800) 518-4726)
Funding opportunity number for downloading an application package from Grants.gov	NNH19ZDA001N-SWOTST
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