Summary Report
SWOT Science Working Group Meeting
October 17, 2011, San Diego, California

Introduction

Lee-Lueng Fu of JPL opened the meeting by providing a summary of the key mission development activities of the past year, the key milestones in the next year, and an overview of the agenda. The main purpose of the meeting is to keep the SWG updated on the development of the science requirements, informed of the key trades in mission design, and engaged in the upcoming Mission Concept Review (MCR), scheduled for late March/early April next year, followed by NASA's Key Decision Point (KDP)-A for starting Phase A for the SWOT Mission.

Agency Program Status

Eric Lindstrom of NASA made a presentation (with inputs from Selma Cherchali of CNES) on perspectives on mission science coordination. Emphasis was placed on the commitment from France's General Investment Commission of 170 M Euros towards the total French contribution of 211 M Euros to the SWOT Mission. To maintain a healthy margin for the funding entails consideration of potential descoping the nadir altimeter.

Two categories of distinct yet related science activities were addressed in Lindstrom's presentation: remote sensing (or "methodological") science and natural science (or "thematic") science. At NASA much of the former is contracted by the flight mission to ensure mission success, including algorithms, cal/val, data products, remote sensing science (e.g. RFI, signal corrections), etc. The latter is commonly solicited from the science community (e.g., via ROSES) using grants are the best vehicle. Coupling these different kinds of studies under one science team approach is the formula for success in the altimetry and scatterometer teams. The plan going forward is to use the various mechanisms of NASA and CNES to build ONE TEAM for SWOT. A coordinated announcement from NASA (ROSES) and CNES (TOSCA) is being planned for release in February, 2012.

Flight Project Status

Parag Vaze of JPL made a presentation (with inputs from Theirry Lafon of CNES) on the status of mission development. Based upon workshare agreement (September 2010), both NASA and CNES teams have been working closely to prepare a consolidated design and development plan. NASA, CNES & CSA (Canadian Space Agency) teams have regularly held fruitful telecons, meetings leading to significant progress, including converging on overall mission configuration in preparation for creation of a mission development plan and in preparation for NASA phase A studies. An overview of the science element of the MCR was presented.

CSA Science Participation

Guoqi Han of Fisheries and Oceans Canada made a presentation on behalf of Robert Saint-Jean of CSA on an overview of Canada's perspectives on science participation in SWOT. Highlights include science and application in both oceanography and hydrology with emphasis on key environmental issues of Canada.

Science Requirements and Mission Threshold Requirements

Ernesto Rodriguez of JPL reviewed the most recent release of the Mission Science Requirement Document. The emphasis was placed on the mission's threshold science requirements, which specify the minimum amount of science that the mission has to accomplish in order to have a successful mission. In Science Requirement Document v1.0, these had been called "Minimum Mission Requirements". These requirements provide criteria for judging the success of the mission when certain key functions of the mission are compromised unexpectedly. They are not basis for descope options.

Mission life – A minimum of one year of science data collection is required to cover the seasonal change and fulfill calibration and validation requirements.

Mission performance – In case of the failure of the so-called "ping-pong" mode involving coherent operation of the two KaRIN antennae, a maximum increase of the water elevation measurement noise level by a factor of two will incur, leading to degradation of oceanic resolution of a factor of two and 10% degradation of measurement accuracy over land water. This minimum performance level represents the threshold requirement.

Data coverage - In case of the failure of the onboard processor for processing and reduction of the ocean data in flight, significant loss of data collection capacity will be the consequence. A minimum of 45% of the global coverage of land water and ocean is required for achieving the threshold science objectives.

Data Downlink and Coverage

Vincent Albouys of CNES presented (with inputs from Brian Pollard of JPL) the mission's data downlink scenarios and data coverage capacity. The SWOT payload / KaRIN instrument will have two separate data-taking modes:

- High rate, presum-only data downlinked as raw samples for later full-resolution processing. Rate is estimated at 262 Mbps

- Low rate, onboard processed data (ocean-only) downlinked as complex interferograms. Rate is estimated at 0.2 Mbps.

The mission engineering team evaluates the capability of the flight and mission systems with respect to the amount of high rate data per cycle that can be downlinked for a given architecture. The science team can then assign the geographical locations for collection of high-rate data. The observatory can switch between the two modes driven by a tabular mask. The masks could be changed seasonally, after cal/val, or as requested.

Current design can support between 24-26% high rate data coverage from each cycle and maintain healthy margins for the mission design. The mission team can release more margin and increase area coverage as the fidelity of the design improves. The released margin can be applied to synergistic science (sea ice, coastal, etc.) as decided by the science team.

Hydrology Data Products

Doug Alsdorf of the Ohio State University made a presentation on the essence of the river discharge product recently formulated as part of the mission's science requirements. River discharge is a fundamental part of the terrestrial water balance, which is the key hydrologic science driver of the mission. Both research and application communities are not suited for handling terrabytes of data per day. Even after sub-sampling to rivers only, the gigabytes per day are still beyond the reach of a science team. A discharge product should thus be created by the project and made available to everyone. It is likely a hybrid between a project level and a science team level. Science team will create the algorithms whereas the project will implement the algorithms. Discharge will be provided for all measured rivers, not a subset. SWOT is a global mission. We need work breakdown structure by MCR that shows how mission will produce the product. This is not straightforward because of the lack of heritage for the algorithms.

Mission Fast Sampling Phase

Lee-Lueng Fu made a brief presentation on the overall requirement of a fast sampling phase for up to 3-month duration after launch to (1) enable the calibration of radar system parameters in the shortest time, resulting in the fastest transition to the nominal phase with a fully calibrated system, and to (2) study the temporal variability of the mesoscale and sub-mesoscale ocean circulation that has decorrelation time scales shorter than the repeat sampling interval. This will allow the design of data assimilative models for reconstructing the poorly sampled temporal evolution of ocean current systems. A 1 or 3-day repeat orbit represents a compromise between the required temporal sampling and adequate spatial coverage.

Doug Alsdorf presented the benefits of a fast sampling phase to hydrological studies. The fast-sampling phase should occur over regions of known fast temporal variations in hydrology, e.g., the spring time in the Arctic, April rainy seasons in the mid-latitudes, India's monsoons, etc. Hydrologic science includes surface water response to rainfall or snow melt. Rainfall-runoff is a key variable in the terrestrial water balance. The fast-sampling phase would allow mapping of stream flows along river reaches and thus open new opportunities for understanding model parameterizations and physics. Downstream flood wave propagation can be measured during the fast-sampling phase. Understanding flood wave interactions with rainfall-runoff, with groundwater, and floodplains are important science opportunities. This phase also allows rapid testing of discharge algorithms and related bathymetry estimates.

Steve Nerem of the University of Colorado presented a study of the tidal aliasing properties of the 1-day fast sampling phase and made the following comments:

- At the Scripps SWG meeting in 2008, preliminary selection was made of a 78 inclination, 970 km altitude 22-day repeat with a 3-day subcycle (allowed maneuvering into a 3-day repeat fast sampling orbit).
- SWOT Project has recently indicated that 1-day fast sampling orbit may present some advantages
- 22-day repeat orbits with a 1-day subcycle occur at lower altitudes (842 km and 873 km).
- The lower altitude may be advantageous for the mission design.
- The tidal aliasing properties for the lower altitude orbit are similar to the 970-km orbit, making the 1-day fast sampling phase acceptable for oceanography.
- In addition, analysis has indicated that an orbit with a slightly lower inclination would have better tidal aliasing characteristics for the MS4 compound tide.

During discussions Richard Ray of GSFC indicated that the MS4 tides are only relevant for certain shelf regions (~ 10 cm) and negligible (a few mm) in the open ocean.

Nadir Altimeter

Lee-Lueng Fu discussed the subject in light of the potential descope of the nadir altimeter. He stated that SWOT would demonstrate a transition from conventional pulse-limited nadir altimetry to interferometric wide-swath altimetry and that simultaneous measurements of the sea surface by both techniques will provide cross calibration and validation. He then illustrated that observations from conventional altimetry had exhibited unexplained SSH features at wavelengths shorter than 100 km. The two independent measurements might shed light on these features that are of great importance to the SWOT oceanographic objectives.

Rosemary Morrow of CNES discussed the advantages for cal/val. The availability of a conventional nadir altimeter will make the calibration/checkout of SWOT feasible over a time period of a few months rather than years for missions with new technology such as CR2 and SMOS. Another key point is that the wave height and wind speed measurement from the nadir altimeter are required for the EM bias correction to the SWOT height measurement over the ocean.

Cross-track Variability of Water Vapor Over the Ocean

Shannon Brown of JPL made a presentation on the issue of the residual errors from wet-tropospheric corrections from a conventional nadir-looking microwave radiometer. The presentation summarized independent JPL and CNES/CLS studies which produced similar conclusions. While SWOT will measure SSH over a finite swath, the radiometer will make only a one-dimensional profile measurement of the water vapor content, leaving the cross-track variability of the water vapor unaccounted for in making corrections. Using the AMSR-E wide-swath measurement of water vapor, Brown demonstrated that, although the wavenumber spectrum of the residual errors meets the mission requirement, there are significant "outliers" with magnitude larger than 1 cm at eddy scales. These "outliers" often occur in regions of significant interests to oceanography such as swift currents and energetic frontal and coastal zones. He demonstrated that by adding additional feeds to the radiometer would reduce these outliers to less than 1 cm and greatly enhanced the value of the SWOT observations.

Application Issues

Margaret Srinivasan of JPL presented a summary of a recent NASA workshop on applications. NASA Earth Science Application Program has emphasized a focus on early phase Decadal Survey missions including SWOT and stressed the importance of early recognition of application values in mission formulation phase (Phase A). Margaret Srinivasan and Craig Peterson of Stennis Center have been appointed as SWOT representatives for applications.

Doug Alsdorf then made remarks on the potential of hydrological applications which might be one of the most visible outcomes from SWOT but has not been adequately addressed. The following are potential applications:

– Water management: reservoirs, floods, ecology
– International rivers: flood and drought management
– Insurance: hydrodynamics and flood risks
– Transportation: shipping, barges
– Agriculture: irrigation
– Energy: water availability in new regions
– Spills and pollution: mapping of potential spill pathways

Development of Science Algorithms and Data Products

Phil Callahan of JPL presented a summary of the approach to science algorithms and data products. The following key points were made:

- Science processing algorithms will be developed primarily by supplier of each instrument
- Algorithm flow will be specified and iterated within entire development team, reviewed by the Science Team
- Initial data product definitions will be iterated with the Science Team
    - Multiple algorithms, data items for some quantities may be implemented
- Algorithm testbed will be set up and prototype processing developed
    - Testbed will read and write defined products
    - Test data will be (or emulate) defined products

- After initial development cycle, detailed algorithm specifications will be written for review by system engineering team and selected subset of the Science Team.

The following algorithms are examples of those needing significant Science Team input for approaches and, in some cases, operational parameters, models

- Global DEM for phase unwrapping
- Global a priori water mask
- Wet Troposphere and Ionosphere over land: Model selection and possible other approaches
- Vegetation detection, correction: Approaches, parameters
- Snow, ice flagging: Approaches, parameters
- Discharge: Parameters for Manning Equation – nominal/a priori and solutions from data during mission
- Flood plain topography: Approaches, support of solutions
- Mean Sea Surface, Geoid, Bathymetry to include in SSH product
- Tide models to include in SSH product : Open ocean, Internal, TBD [wind-forced]
- EM Bias: Models including variation across swath
- Wind Speed: Ka-band model function

The following is a preliminary list of data products:

Data Product	Key Characteristics (Archived, unless otherwise noted)	Daily Vol (GB)
L0b (Cleaned telemetry)	Telemetry separated by instrument, rev	**900**
L1a Ocean	Onboard interferograms	**3**
L1a High Rate	Single Look Complex images for each swath	**5500**
L1b Ocean	Combined onboard interferograms with corrections (Not archived)	**4**
L1b High Rate	Phase flattened interferograms (Not archived)	**2800**
L2b Nadir Altimeter	Jason-like SGDR produced by CNES	**0.5**
L2b Ocean	Sea Surface Height in fixed swath grid	**3**
L2b Hydrology	Triangular height networks. Derived: Surface water shape files separated by continent, rev; discharge product.	**TBD [~1 ?]**
Other Hydrology	Annual estimate of flood plain; Manning coefficients.	**TBD [~10 ?]**

AirSWOT Status and Plans

Ernesto Rodriguez presented a summary of the status and characteristics of AirSWOT:

What is AirSWOT?

- AirSWOT is a Ka-band radar interferometric sensor, currently under development under NASA ESTO and SBIR funding, will be the calibration/validation platform for the NASA SWOT mission.
- AirSWOT will be able to:
  - Measure sea surface height (SSH) to unprecedented precision, providing unique measurements of the ocean mesoscale and submesoscale circulation.
  - Measure river stage, slope, and width, key variables in understanding and predicting river discharge.
  - Simultaneously measure water surface radial velocity, Ka-band near-nadir cross section, and provide near-infrared imagery.
- These capabilities are not currently available from any other airborne or spaceborne sensor.

AirSWOT Status

- Currently funded up to instrument check-out by NASA Earth Science and Technology Office (ESTO)
- After checkout, AirSWOT will be managed by the SWOT project
- Near-term schedule:
  - Instrument system level I&T in fall/winter 2011
  - Initial check-out flights targeted for spring 2012
  - Science/remote sensing data collections to meet project priorities (and additional science and applications goals) nominally planned for fall 2012 (primary target, Pacific coast) and summer/winter 2013 in France (hydrology and ocean targets). Plans to be finalized by fall 2011.

Mission priority tasks for AirSWOT

- Demonstrate the capability to image surface water over the SWOT swath and separate water from land.
- Quantify the ability of SWOT to resolve “small” water bodies (e.g., rivers of 50m vs 100m width)
- Demonstrate the capability of AirSWOT to serve as the Cal/Val platform for the SWOT mission.
- Demonstrate the ability to estimate river bathymetry and Manning's constant to achieve reasonable discharge accuracy. Validate model results.
- Characterize ocean submesoscale correlation time and aid in the selection between 1 and 3-day repeat periods for the fast sampling phase
- Characterize the ocean spectrum from 100km to 10km
- Determine the impact of layover due to topography or vegetation on river and lake heights.
- Determine at what scales is SSH diagnostic of circulation

- Determine what is the impact of waves on the interferometric heights and on the estimated currents

Yi Chao of JPL presented a plan for an experiment to be conducted off the coast of Southern California in the fall of 2012. The primary goal of the experiment is to validate the key assumptions for the basis of SWOT science requirements for oceanography. In particular the following:

- Characterize the spatial and temporal de-correlation scales of ocean variability
- Validate numerical ocean models (e.g., ROMS) at the submesoscales
- Assess the ability of ocean models (e.g., ROMS) in assimilating the data for dynamical interpolation of sub-sampled data
- Investigate optimal design of the fast-sampling phase of the SWOT mission

This experiment will be a collaborative effort involving several academic institutions in the region: USC, UCLA, Caltech, and CalPoly. The site selection will take into consideration of existing observation network from coastal HF radar and CalCOFI spray gliders. Additional in-situ sensors include a sea glider, two slocum gliders, and a REMUS AUV. An existing modeling and data assimilation system will aid the experiment design and interpretation of the observations. There is also potential synergy with a planned/NASA-funded UCLA/JPL/UCSB experiment on submesoscale processes (SubEx-III) off the Southern California coast.

Rosemary Morrow presented a plan for an oceanographic experiment to be conducted in the Mediterranean Sea in 2013.

- Daily repeat flights over 2-4 week period over coastal and offshore eddies and filaments
- Complementary data from in-situ observations and other satellite analyses
- In-situ observations (HYMEX / MOOSE / DoWEX2013) : Gliders, surface drifters, Argo floats, meteo buoys, CTDs, tracer studies, ToYos?
- Possibility of a shared airborne platform with HyMex ATER
- Data assimilative models including wave effects.

Tamlin Palvesky of the University of North Carolina presented a plan of a hydrological experiment to be conducted in 2014 in Alaska in the region of the Yukon Flats and Tanana River. The following are the remote sensing science goals:

<u>Rivers</u>

§ Install 10 pressure transducer water level loggers on portions of the Tanana River near Fairbanks to measure *h*, *dh/dx*, and *dh/dt.*

§ With the help of the USGS, conduct Acoustic Doppler Current Profiler (ADCP) measurements at multiple cross-sections in the Tanana to measure *d, v, Q* coincident with AirSWOT overflights.

§ Track land surface type and inundation extent from high-resolution Digital Cirrus Camera and field surveys to validate *w* and *A*.

§ Combine measurements of *w*, *h, Q* to validate AirSWOT *dQ/dt* (and *Q*, if possible) in a range of river forms.

Lakes

- § Install 20 pressure transducer water level loggers in lakes within the Yukon Flats to measure *h, dh/dt,* and *dh/dx*.
- § Conduct surveys of open water and inundation extent using airborne imagery and field measurements to validate *A*.
- § Combine measurements of *A, h* to validate AirSWOT storage change in complex lake and wetland environments.

The following are the natural science questions for the experiment:

- How do complex systems of Arctic floodplain lakes interact with changing main-stem water levels in the associated river?
- Can coarse-resolution remotely sensed datasets be used to track channel width variations in braided rivers where channels are narrower than the native sensor resolution?

Stephane Calmant of Institut de Recherche pour le Developpement (France) presented plans of hydrological experiments to be conducted in France and French Guyana during April-June 2013. Main tasks to be performed during the experiments will address the following issues identified as key mission priorities:

- Ka-band sigma0 over water and land (function of incidence angle, classification of river/lake and land cover, surface roughness, …)
- Determine the impact of topography or vegetation on height determination (layover, data loss, mis-estimates…).
- Measure surface water correlation time.
- Demonstrate the ability to estimate river bathymetry and Manning's constant to assess the discharge accuracy using Manning's equation and validate the data for improving existing hydrological models.

Discussion Points

Before closing the meeting, ***Lee-Lueng Fu*** addressed the following issues:

Science requirements- A final version of the document is required for the MCR. ***The SWG should take a close look at the current version and provide comments as soon as possible.***

Mission Science Description Document - This document will be released to the public as a companion document for the announcement of the opportunity of the SDT. A fully vetted version should be ready by the end of November for the production of a formal release to the public. ***Authors who are still working on assignments should provide final versions to Lee-Lueng Fu by mid November.***

***Fast-sampling phase* –** The baseline mission design for the MCR is based on the orbit with 78- deg inclination, 970 km altitude, 22-day repeat with a 3-day sub-cycle for the fast-sampling phase. The exact geographic coverage of the 3-day orbit (specified by the ascending node) will be determined during Phase A with inputs from the future SDT.

The option of a lower orbit (22-day repeat at 840-870 km altitude, 76.7-78 deg inclination) with a 1-day subcycle for the fast-sampling phase will be carried for further study during Phase A.

45 % threshold science strategy* –** A preliminary plan for data collection to meet the mission's threshold science requirement is required for MCR. How should the 45% data collection be planned for meeting the threshold objectives of hydrology and oceanography? ***The SWG should take action on this question and provide an answer in January 2012.

***Cross-track wet tropo correction* –** The mission baseline for MCR is based on one-feed microwave radiometer for wet-tropo correction. The option for multiple-feeds is being carried as an open trade for Phase-A study.

***Nadir altimeter* –** In light of the potential descope of the nadir altimeter, the SWG made the following recommendation:

Because SWOT will demonstrate a transition from conventional pulse-limited nadir altimeter to interferometric wide-swath altimeter, and because simultaneous measurements of the sea surface by the conventional nadir altimeter and by SWOT will provide effective cross calibration and validation and provide a seamless transition, the nadir altimeter is essential for demonstrating SWOT as the future operational altimetry system.