



Surface Water and Ocean Topography (SWOT) Mission

Science Team Meeting

Pasadena, June 13-16, 2016

Algorithm Development Overview

Data Products

Phil Callahan, JPL

Algorithm Project Representative

Roger Fjørtoft, CNES

Algorithm Project Representative

SWOT DocuShare Collection: <https://charlie-lib.jpl.nasa.gov/docushare/xxx>



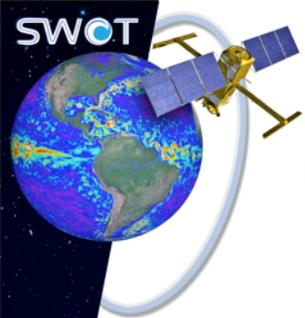
Algorithm and SDS Development Principles

- Project-level agreements on joint (JPL/CNES) development of Algorithm and Science Data System (SDS)
 - Joint JPL/CNES/ST Algorithm Development Team (ADT) defines content of data products, develops Algorithms (ATBD's), Science Algorithm Software (SAS) and auxiliary data (DEM, etc.)
 - Delivers and maintains SAS and auxiliary data
 - Supports integration into SDS Product Generation Executables (PGE)
 - JPL, CNES negotiated work-share for SAS, PGE implementation
 - JPL & CNES SDS exchange, use same PGEs to produce same data products
 - JPL & CNES develop and operate separate SDS based on previous project experience
 - CNES will process Eurasia region of the KaRIn high-rate data
 - JPL will process Non-Eurasia region of the KaRIn high-rate data and all low-rate data
 - Both sides can produce additional data products offline



ADT Charter and Deliverables

- 1. Develop a detailed algorithm development and validation plan and associated schedule.** Once the schedules are baselined the status will be reported periodically to the NASA/JPL and CNES project offices.
- 2. Develop algorithms for the processing of SWOT data from raw telemetry to the science data products** specified by the SWOT Science Requirement Document. These algorithms shall satisfy the accuracy and data specification requirements allocated by the SWOT project to this element.
- 3. Document the algorithm theoretical basis for each algorithm,** and provide the algorithm expected performance. The algorithm expected performance shall include expected accuracy and requirements in terms of computational resources (memory, throughput).
- 4. Provide working code,** in a computer language, or languages, agreed to with the project, that implements the algorithms **with agreed-to interfaces with the project mission system elements** (ground data system and science data systems).
- 5. Provide test cases** for the complete validation of the algorithm implementation.
6. Develop or gather, in coordination with the SWOT science team, **auxiliary data** required for the processing of the SWOT data to its final data products. These data shall include, but not be limited to, Digital Elevation Models (DEM's) for phase unwrapping, QA, and floodplain topography; *in situ* variables (e.g., bathymetry or Manning's coefficient) required for estimation of river discharge; satellite or Numerical Weather Prediction (NWP) data for geophysical corrections.
- 7. Support independent reviews** of the theoretical basis, validation, and implementation of the algorithms. These independent reviews would allow **feedback from the SWOT science team** and the science and user communities.

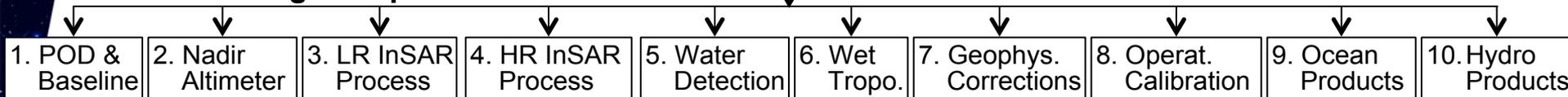


SWOT Algorithm Development Team (1/2)

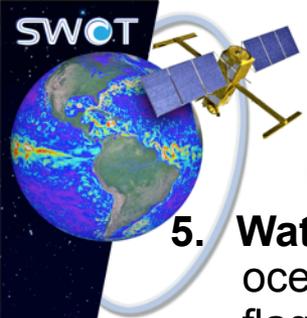
Steering Committee

- JPL Algorithm Lead
- JPL project representative
- US SDT hydro representative
- US SDT ocean representative
- CNES Deputy Algorithm Lead
- CNES project representative
- Fr SDT hydro representative
- Fr SDT ocean representative

Working Groups

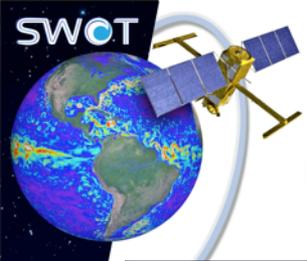


- 1. POD & Baseline Estimation** (TBD, Alexandre Couhert): Determine the location of reference points for all instruments, coordinate transformations between them, and provide an estimate of the interferometric baseline, including spacecraft attitude and geometric baseline deformations.
- 2. Nadir Altimeter Processing** (TBD, Francois Boy): Ku/C altimeter processing, cf. Jason series, KaRIn Nadir Channel (KNC) SAR nadir altimeter mode processing.
- 3. LR InSAR Processing** (Eva Peral+Curtis Chen, Damien Desroches): OBP algorithm validation and data product optimization. Ground processing of OBP output including instrument correction, σ_0 calibration, combination of beams, phase-to-height conversion and geolocation algorithms. Implementation of Ocean Products group specifications for interpolation, slopes, flagging, SWH, and wind speed.
- 4. HR InSAR Processing** (Xiaoqing Wu, Damien Desroches): HR data presuming, SAR processing, interferogram formation, instrument corrections, σ_0 calibration, phase flattening, multilooking, phase-to-height conversion, geolocation.



SWOT Algorithm Development Team (2/2)

5. **Water Detection** (Brent Williams, Roger Fjortoft): Water surface detection (land & ocean), layover flagging and mitigation (HR), shape-adaptive averaging (HR), rain/ice flags, coastal/ice contamination flagging/mitigation.
6. **Wet Troposphere** (Shannon Brown, Bruno Picard): Radiometer processing to calibrated brightness temperatures, wet troposphere correction over ocean and land. Selection/procurement, interpolation of wet troposphere models (NWP) (HR/LR).
7. **Geophysical Corrections** (TBD, Nicolas Picot [acting]): Land tides. Atmospheric pressure forcing (IB and DAC). Dry troposphere and ionosphere. EM bias. Geoid procurement and interpolation.
8. **Operational Calibration** (Curtis Chen, Nicolas Picot): Generate corrections from KaRIn-KaRIn and KaRIn-Altimeter ocean crossovers for roll-mitigation, range drift, and phase screen changes. Propagation of corrections over ocean and continents.
9. **Oceanography Products** (Sarah Gille (SIO), Nathalie Steunou): Ocean data product definition, including SSH, slope, wind speed, wave height. Definition/specification of slope, wind speed and wave height algorithms, interpolation and gridding. MSS, ocean tide model(s) definition and implementation.
10. **Hydrology Products** (Mike Durand (OSU), Claire Pottier): Hydrology data product definition and implementation, including reach averaged slope, discharge, storage change, cycle-based lake/wetland product, conversion to L2 product representation. Responsibility for ancillary data including global reference DEM with water levels, initial water mask, discharge coefficients.

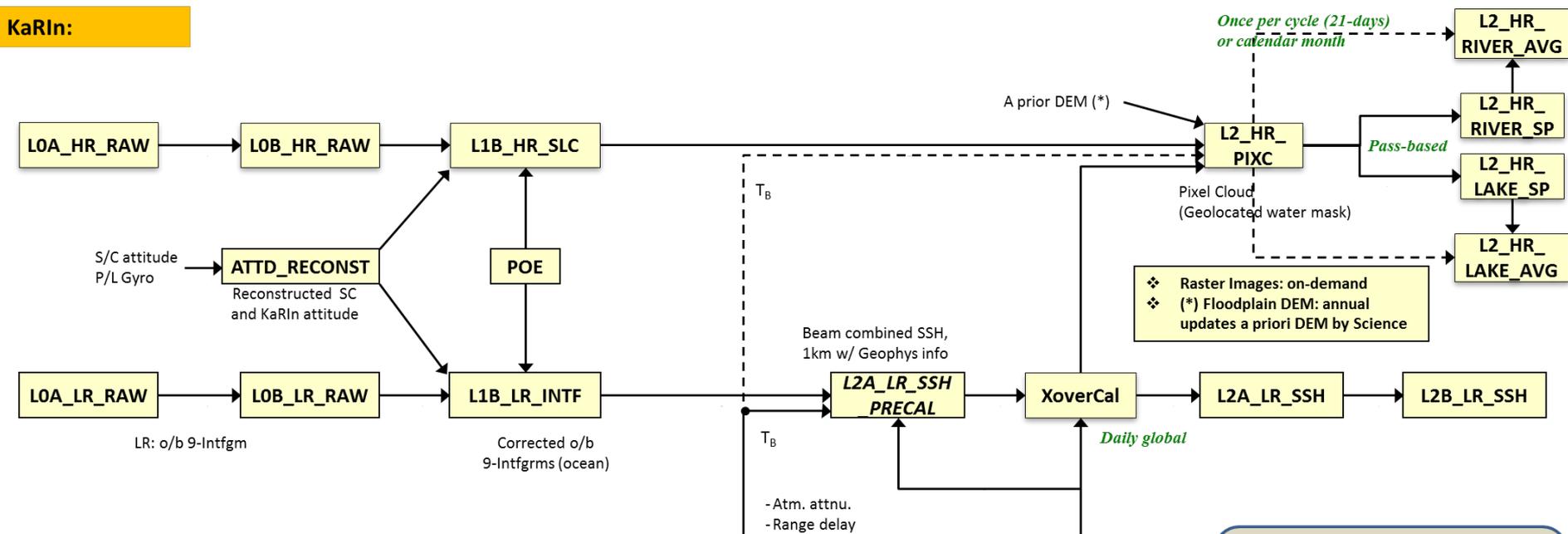


Key Science Data Products

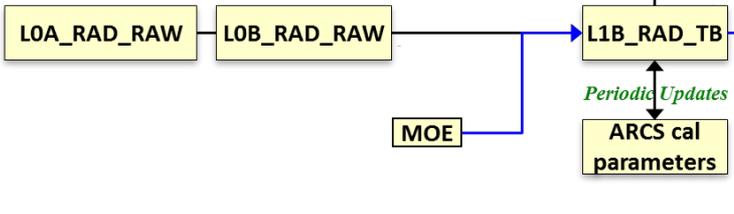
Products for Public Distribution	
L1B_LR_INTF	KaRIn low-rate Earth located ocean interferogram in 9 beams and robustness products
L2A_LR_SSH	KaRIn low-rate calibrated beam-averaged sea surface height in swath grid
L2B_LR_SSH	KaRIn low-rate calibrated beam-averaged sea surface height in Earth-fixed grid
L1B_HR_SLC	KaRIn high-rate single look complex data, in radar coordinates (request/selected distribution)
L2_HR_PIXC	KaRIn water mask pixel cloud
L2_HR_RIVER_SP	KaRIn river single-pass vector product
L2_HR_LAKE_SP	KaRIn lake single-pass vector product
L2_HR_RIVER_AVG	KaRIn river averaged vector product
L2_HR_LAKE_AVG	KaRIn lake averaged vector product
L2_HR_RASTER	KaRIn water mask raster image (on demand)
L2_HR_FP_DEM	KaRIn floodplain DEM
L1B_RAD_TB	Radiometer brightness temperatures
L2_NALT_IGDR	Interim geophysical data record with waveforms
L2_NALT_GDR	Geophysical data record with waveforms

SWOT Science Product Flow

KaRIn:



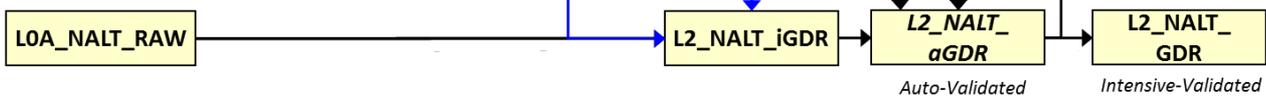
Radiometer:



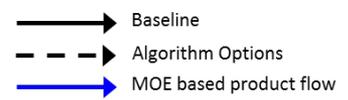
DORIS/GPSP:

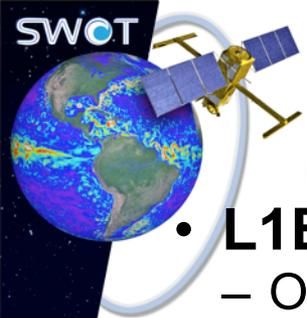


Nadir Altimeter:



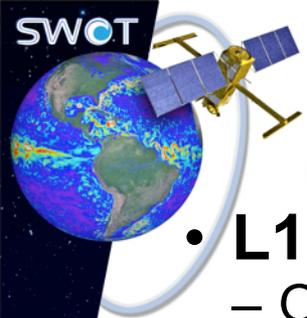
- Auxiliary data for Product Generation:
- *A priori* data (static): DEM, Static water mask, river DB/Lake DB, Geophysical Model Fct, etc.
 - Quasi-static data: Radiometer calibr. Parameters (ARCS), etc.
 - Dynamic data: ECMWF, Ionospheric data (IGNSS), etc.





Ocean Products

- **L1B_LR_Intf**
 - OBP interferograms and images (9 beams, 250m samples, 500m average) with geometry information, phase corrections and secondary OBP products – 250m average power and variance; along track averaged Doppler centroid, cross-track interferogram (along-track avg; can give wave spectrum) (Details from OBP presentation in Backup)
- **L2A_LR_SSH**
 - Earth-located, SSH from combining 9 beams in 1 (or 2) km grid based on instrument sampling with uncertainties, geophysical corrections, and fields
- **L2B_LR_SSH**
 - Earth-located, SSH from combining 9 beams in 1 (or 2) km fixed grid with uncertainties, geophysical corrections, and fields
 - “Lighter” (fewer items). Possibly averaged from L2A
- **L1B_RAD**
 - Radiometer Tb, calibration, geophysical retrievals at instrument sampling
- **L2_NALT_(I)GDR**
 - Traditional altimeter along-track GDR



LR/Ocean Product Issues

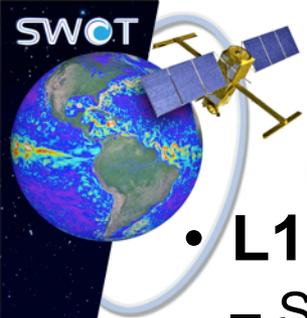
- **L1B_LR_Intf**

- Optimal use of 250m power data for flagging, gridding
- Details and use of additional OBP products (interferogram – wave spectra, Doppler)
- ATBD timeline given in OBP presentation

- **L2_LR_SSH**

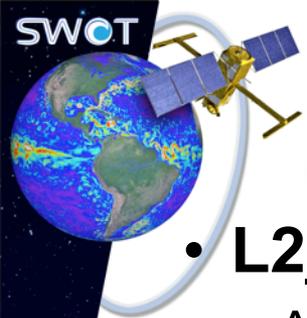
- Optimal gridding from high resolution (250m) to data products needs further definition and assessment.
 - Plan: Develop simulated ocean data products with different interpolation methods and grids and interact with the science team to choose interpolation for native grid and fixed grid. Include findings from AirSWOT in simulation.
- Need for 9-beam SSH in L2A product (standard or special)
- Details of L2B fixed grid product: grid, items, averaging – approach, from L2A or L1B

- Discussion during Ocean Splinter



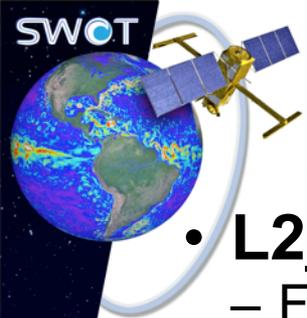
HR/Hydrology Products (1/2)

- **L1B_SLC**
 - Single look complex radar images with geometry information, radiometric calibration, instrument phase corrections
- **L2_HR_PIXC**
 - Geolocated heights of water mask (prior and detected with border) with uncertainties, geophysical corrections, and flags
 - Various levels of averaging for geolocation and height accuracy
- **L2_HR_River_SP**
 - Vector product (shapefile) based on river database for each pass
 - Includes height, slope, discharge with uncertainties for reaches
- **L2_HR_Lake_SP**
 - Vector product (shapefile) based on lake database for each pass
 - Includes average height, uncertainties, bounding points



HR/Hydrology Products (2/2)

- **L2_HR_River_Avg**
 - Average vector product (shapefile) based on river database for reaches
- **L2_HR_Lake_Avg**
 - Average vector product (shapefile) based on lake database
 - Includes average height, bounding points (assumed closed)
- **L2_HR_Raster**
 - Selected area of PIXC data as raster of heights, uncertainties, flags
- **L2_HR_FP_DEM (Flood Plain DEM)**
 - Annual update of DEM for areas near water bodies
 - Off line generation by selected investigators



HR/Hydrology Product Issues

- **L2_HR_PIXC**
 - Flagging, especially layover, ice/frozen
 - Details of averaging for geolocation and height accuracy
 - Updating of prior water mask
- **L2_HR_..._Avg**
 - Cycle or month?
 - Details of method, product for rivers
- **L2_HR_Raster**
 - Fixed set of areas as well as on-demand ?
 - Pass or Average – selectable in on-demand? Average method
 - Resolution, Area selection
- **Flood Plain DEM**
 - Proposed as off-line, Science Team product
 - Two methods need further exploration: bathtub, average interferograms
- **Discussion during Hydrology splinter**



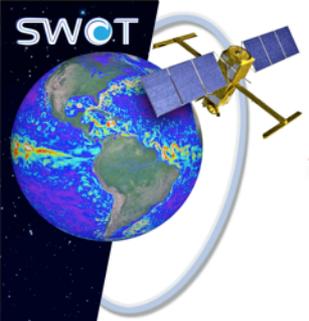
Algorithm Work for Next Phase (PDR–CDR)

- Ocean Issues
 - Use of 250m data in processing and products. OBP ATBD deadline
 - Characterization of measurement physics found in AirSWOT data
 - Testing of gridding schemes and errors in products
- Hydrology Issues
 - Water Detection robustness (dark water, flooded vegetation...)
 - Layover (vegetated/non-vegetated impact estimation, impact flagging, correction...)
 - Phase unwrapping (robustness, dependency on DEM accuracy...)
 - Use of priors and multi-temporal data; dynamic update of priors
 - Generation of hydrology products: lake vectors, cycle averages, raster, discharge algorithms, storage change, floodplain DEMs
- More realistic simulated data for algorithm testing
 - Validate and/or improve SWOT models and simulators to reflect realistic conditions. Use AirSWOT data that captures physics and phenomenology.
 - Use AirSWOT and simulated data to test prototype algorithms.

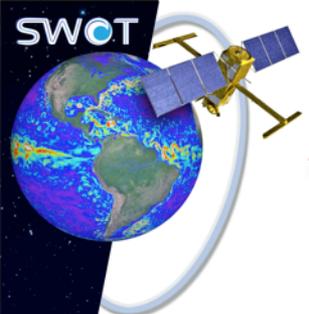


Algorithm Work – Science Team Contributions

- Product Definitions
 - LR/Ocean
 - HR/Hydrology, especially average and raster
- Algorithm Issues resolution for processor design
- Auxiliary models and fields
 - Reference surfaces: DEM, MSS, Geoid
 - Tide Models: “Standard”, Coastal, Internal
 - Dynamic Atmospheric Correction (updates)
- Key Milestones
 - Note: Ground system schedule will not be changed in the near term for launch delay
 - Full descriptions of all products and preliminary designs of all processors by December 2016
 - SDS Design Review – spring 2017. System Interface Rev #2 – Nov 2017
 - ATBD input and review (early 2018)



Backup



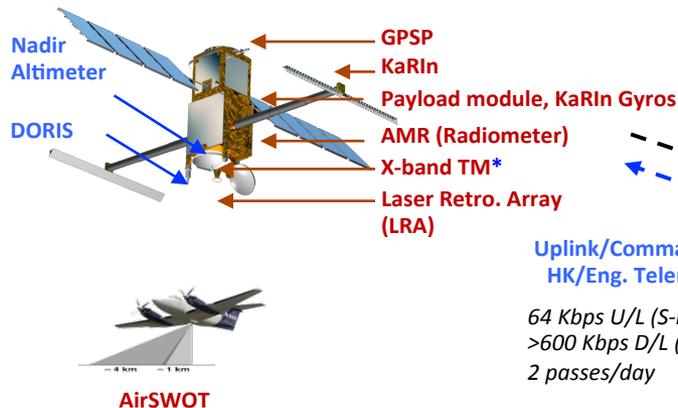
Mission Architecture

CNES Elements
NASA Elements
Joint Elements

*CNES ops



NASA – KSC/LSP Launch Vehicle (TBD)

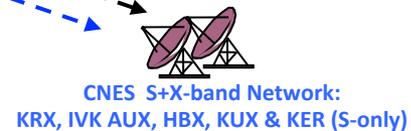


Uplink/Commanding, HK/Eng. Telemetry

64 Kbps U/L (S-band)
>600 Kbps D/L (S-band)
2 passes/day

Science Downlink

711 Mb/s (X-band); ~ 21 passes/day
(Info rate: ~620 Mb/s; ~7.9 Tbits/day)



To JPL POC:
S/C Telemetry (stored & RT), Payload R/T Engineering

S/C Control Center (SCC)

To SCC: S/C & P/L telemetry

To NOC: Commands

S-band
Cmd & Tlm

CNES Network Ops Center (NOC/COR)

X-band
Telemetry
Files

To CNES SCC: Payload commands

X-Band Telemetry Files

JPL Payload Operations Center

JPL Science Data Processing Center

NASA Science Data Archiving and Distribution PO. DAAC

AirSWOT, Instrumented Cal/Val Ground Sites

Altimeter, KaRIn (Eurasia), POD & Cal/Val data

KaRIn (non-Eurasia, Ocean), Cal/Val data

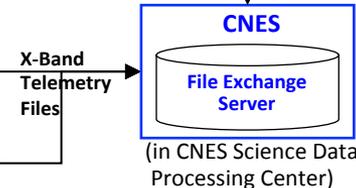
Auxiliary Data:

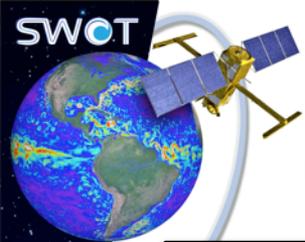
Tropo model(s), Iono info, Tide model(s), Mean Sea Surface, Digital elevation models

CNES Payload Operations Center

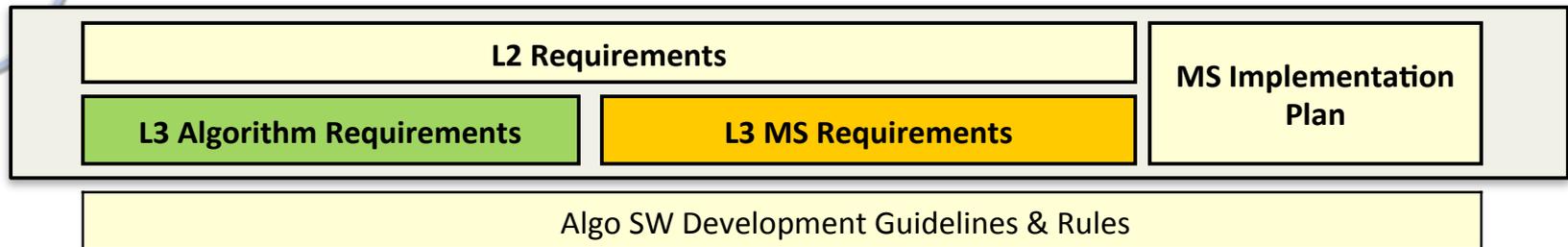
CNES Science Data Processing Center

CNES Science Data Archiving and Distribution



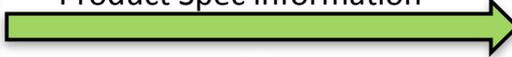


ADT—SDS Implementation Strategy



Define	<ul style="list-style-type: none"> Algorithm Development Plan ATBD Algorithm Software Design Doc
Design	<ul style="list-style-type: none"> Product Spec - Science fields Provide PGE-SAS I/F design input Provide WorkFlow design input Provide Control design input Select Ancil/Auxiliary data source
Implement	<ul style="list-style-type: none"> Science Algorithm SW Simulate Instrument Data & develop Gold Standard Test Data Algorithm Specification Doc

- SAS & Delivery documents
- Ancil/Aux data source selection
- Gold Standard Test Data
- Product Spec information



- PGE, Test Data, & Release documents
- Product Spec information

Define	<ul style="list-style-type: none"> SDS L4 Requirements SDS Ops Concept SDS SW Management Plan
Design	<ul style="list-style-type: none"> Prod Spec structure & Metadata PGE SAS-PGE-Data System I/F Data System Architecture Product Generation WorkFlow
Implement	<ul style="list-style-type: none"> PGE & Data System Integrate PGE & SAS SDS I&T & Validate Products





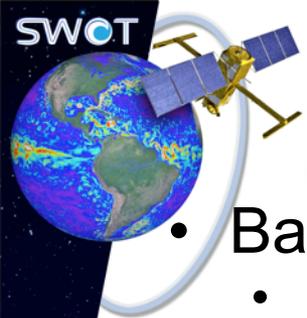
NASA Data Product Definitions

- L0: Telemetry data (“Raw”). L0B: Clean, time-ordered instrument frames
- L1: Partially processed including sensor position, geometry, calibrations generated. Reversible.
- L2: Earth-located, calibrated measurements in geophysical units
- L3: Spatially and/or temporally averaged geophysical data
- Ancillary: Data other project systems needed to process instrument data (orbit, attitude, engineering). Mainly dynamic/synchronized
- Auxiliary: External data needed in processing (DEM, weather/atmospheric model, tides, etc.). Static or dynamic

Data Products List

Products for Public Distribution	
L1B_LR_INTF	KaRIn low-rate Earth located ocean interferogram in 9 beams
L2A_LR_SSH	KaRIn low-rate calibrated beam-averaged sea surface height in swath grid
L2B_LR_SSH	KaRIn low-rate calibrated beam-averaged sea surface height in Earth-fixed grid
L1B_HR_SLC	KaRIn high-rate single look complex data, in radar coordinates
L2_HR_PIXC	KaRIn water mask pixel cloud
L2_HR_RIVER_SP	KaRIn river single-pass vector product
L2_HR_LAKE_SP	KaRIn lake single-pass vector product
L2_HR_RIVER_AVG	KaRIn river averaged vector product
L2_HR_LAKE_AVG	KaRIn lake averaged vector product
L2_HR_RASTER	KaRIn water mask raster image
L2_HR_FP_DEM	KaRIn floodplain DEM
L1B_RAD_TB	Radiometer brightness temperatures
L2_NALT_IGDR	Interim geophysical data record with waveforms
L2_NALT_GDR	Geophysical data record with waveforms
DORIS_RINEX	DORIS measurement RINEX1.0 format products
GPS_RINEX	GPS measurement RINEX1.0 format products

Internal Products for Archive-Only or Temporary	
L0A_LR_RAW	KaRIn low-rate packets in downlink unit
L0B_LR_RAW	KaRIn low-rate frames of raw 9-beam interferograms in half-orbit unit
L2A_LR_SSH_PreCal	KaRIn low-rate uncalibrated beam-averaged sea surface height in swath grid
XoverCal	KaRIn daily global crossover calibration parameters
L0A_HR_RAW	KaRIn high-rate packets in downlink unit
L0B_HR_RAW	KaRIn high-rate frames in half-swath scene
L0A_RAD_RAW	Radiometer raw packets in downlink unit
L0B_RAD_RAW	Radiometer raw data in time order in half orbit
L0A_NALT_RAW	Nadir altimeter raw packets in downlink unit
L0A_DORIS_RAW	DORIS raw packets in downlink unit
L0A_GPSP_RAW	Raw GPSP data in downlink unit
MOE	Medium accuracy orbit ephemeris
POE	Precision orbit ephemeris
ATTD_RECONST	Reconstructed S/C and KaRIn attitudes



OBP Ocean Products

(after July'15 SDT, CR pending)

From E. Peral OBP presentation

- **Baseline products:**
 - 9 complex interferogram and +/- SAR images at 500m x 500m pixels and 250m posting
- **Additional products:**
 - Average power and power variance at 250m x 250m pixels and 250m posting for the center beam for each swath (rectangular averaging)
 - Enables ground algorithms to detect/flag anomalous pixels (rain/ships/coastal and ice boundaries, etc.) and stress cases over the oceans at higher resolution than the interferograms, where detection may not be possible.
 - Doppler centroid image for each swath (from range compressed data)
 - Enables ground algorithms to extract ocean velocities with the potential to improve science return beyond current performance requirements.
 - High resolution cross-track interferogram (averaged in along track)
 - Enables ground algorithms to extract wave spectra with the potential to improve science return beyond current performance requirements.



Pixel Cloud Summary

The pixel cloud is a compact representation of the results of water detection, layover, rain and ice flagging, instrument and geophysical corrections, and estimation of geolocated heights

Posting kept close to full resolution ~4 looks to be able to accurately represent rivers > 50 m, lakes > 100 × 100 m², and to perform only minimal averaging of information

- phase-flattened interferogram, phase corrections
- water mask with layover/rain/ice flags, estimated water fraction
- slant range pixel coordinates, ground-projected pixel size
- Not computed, but would give noisy heights (~ 1-2 m); lat, lon (~ 10-100 m)

[rare]
~4 looks

[medium]
~50 looks

Additional interferogram adaptive averaging ~50 looks prior to phase-to-height conversion to optimize precision

- computed lat, lon, height and associated uncertainties (location not yet sub-pixel)

[well-done]
>>100 looks

Further adaptive averaging >> 100 looks to improve geolocation



Algorithm Plan to CDR (1)

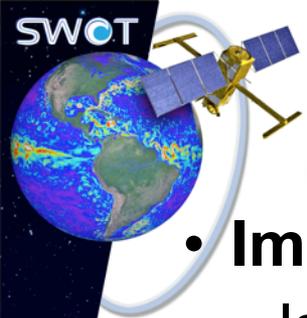
- **Maturing Algorithms for Discharge, Storage Change, Floodplain DEMs**

- Issue:

1. Discharge algorithms need maturing and validation beyond phase B activities to include river diversity, layover, and slope changes.
2. Lake storage algorithms need to account for partial observations, coupling to rivers, and vectorization algorithms.
3. Floodplain DEMs are a mission data product, but no prototype algorithms exist.

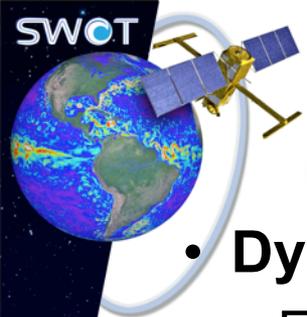
- Plan:

1. Continue joint activities between the ADT and Science Team discharge working groups to analyze data collected by AirSWOT over the Sacramento, Willamette, Tanana, and Mississippi rivers. Evaluate the merits of simple assimilation vs Manning discharge estimates.
2. Adapt existing optical lake algorithms to SWOT data.
3. Adapt optical and SAR “bathtub” floodplain estimates to SWOT. Build hybrid “bathtub” and average interferogram DEM estimation algorithms.



Algorithm Plan to CDR (2)

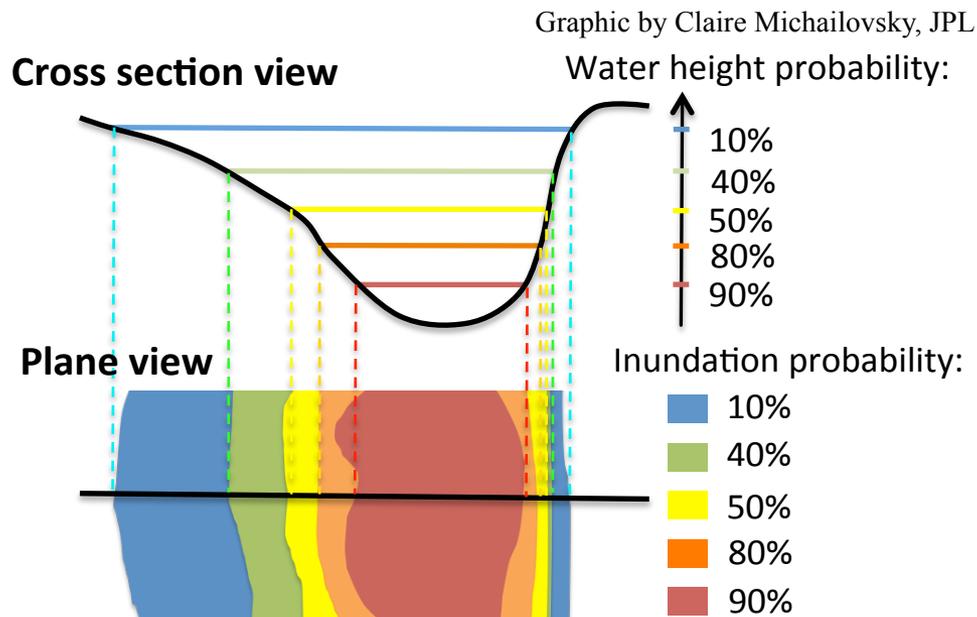
- **Improved Simulation for Algorithm Development**
 - Issue: Algorithms have been tested with relatively simple test cases, which may not capture the full measurement complexity.
 - Plan:
 1. Use existing AirSWOT data, and, when necessary, collect additional AirSWOT data, that captures realistic physics and phenomenology (vegetation, sigma-0 variability, layover, surface waves and velocity).
 2. Validate and/or improve SWOT models and simulators to reflect realistic conditions.
 3. Use AirSWOT and simulated data to test prototype algorithms.

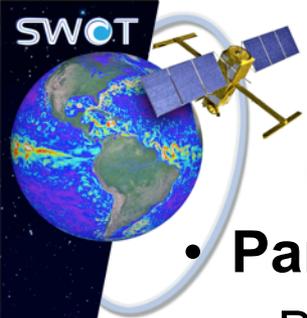


Hydrology Phenomenology Issues (1 of 2)

- **Dynamics**

- Extent variation is prime goal, BUT it means that prior water masks may need adjustment for water detection, identification
- Extent/Height co-variation: probability of inundation as a function of height (Pekel et al., ESA/Google, 2015)
- Variation in identification as bodies coalesce/separate
- Updating of prior water mask, weighting of recent vs long term





Hydrology Phenomenology Issues (2 of 2)

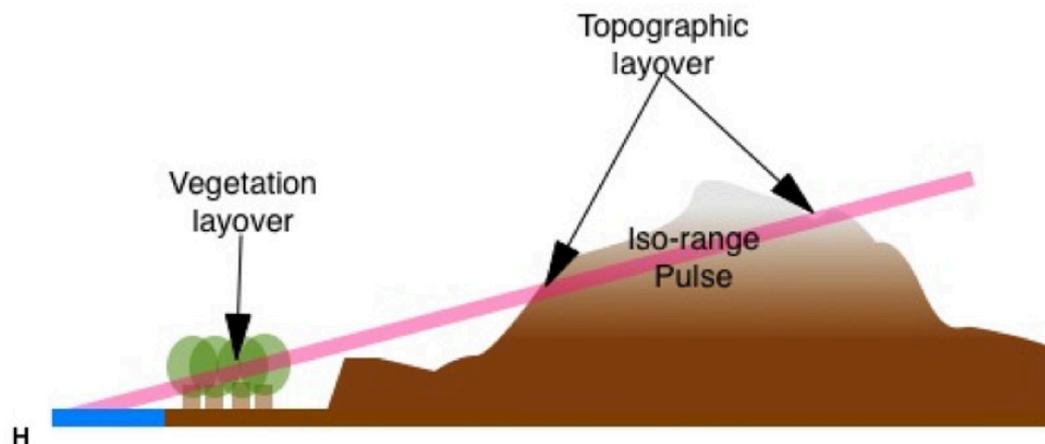
- **Partial Converge**

- Bodies may be only partly observed in one pass
- Temporal sampling is highly irregular in space/time

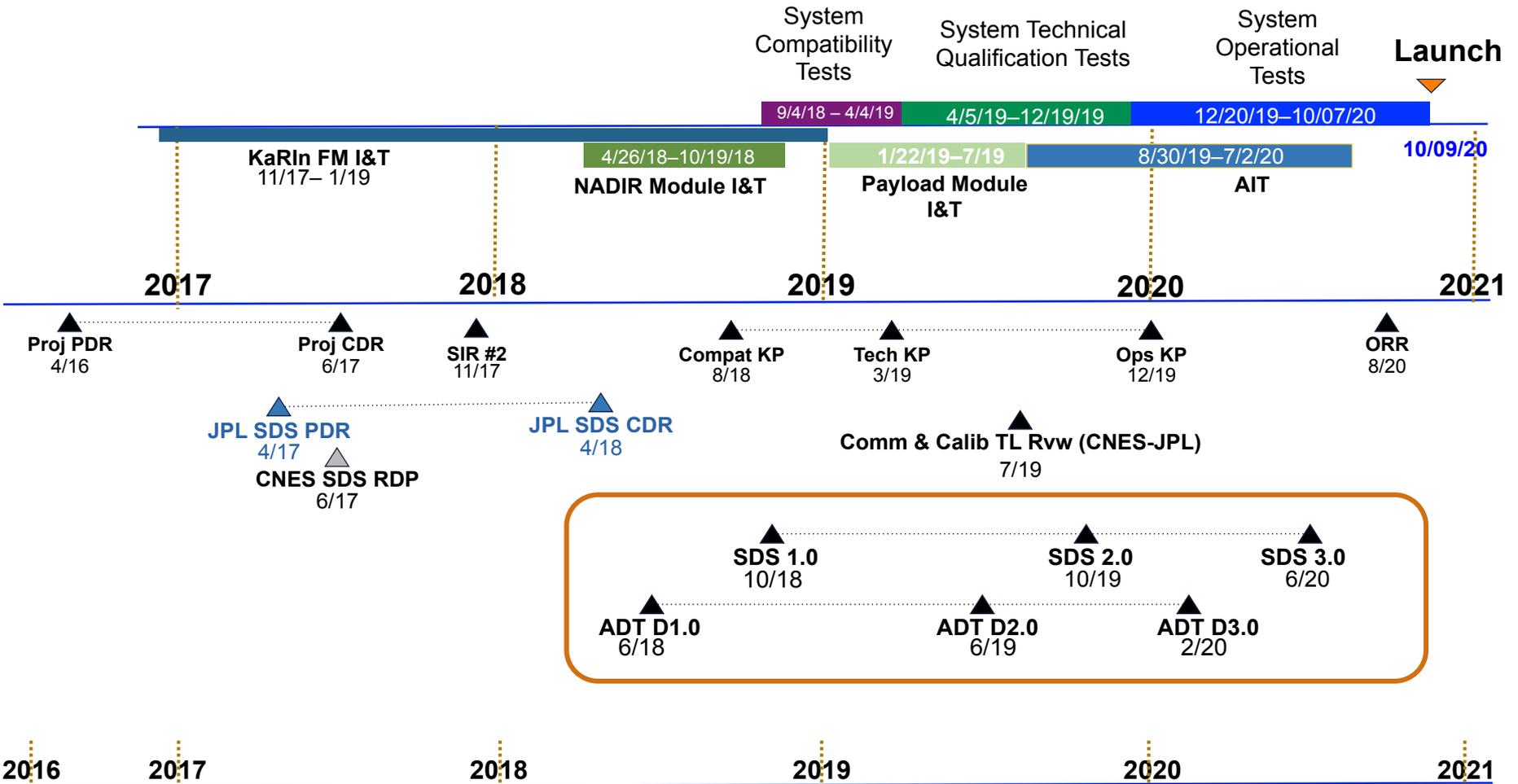
- **Layover effects**

- Geometric effect will depend on height, extent
- Vegetation effect may vary seasonally (as may height, extent)

Layover figure from SWOT Mission Science Document



SWOT MS, SDS, ADT Key Dates



Not yet updated to reflect new launch date (Apr 2021)