National Aeronautics and Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

CNES

CSA ASC

UK SPACE AGENCY

Surface Water and Ocean Topography (SWOT) Mission

SWOT Science Team Meeting
January 13-15, 2016

Cal/Val Overview

SWOT Cal/Val Team

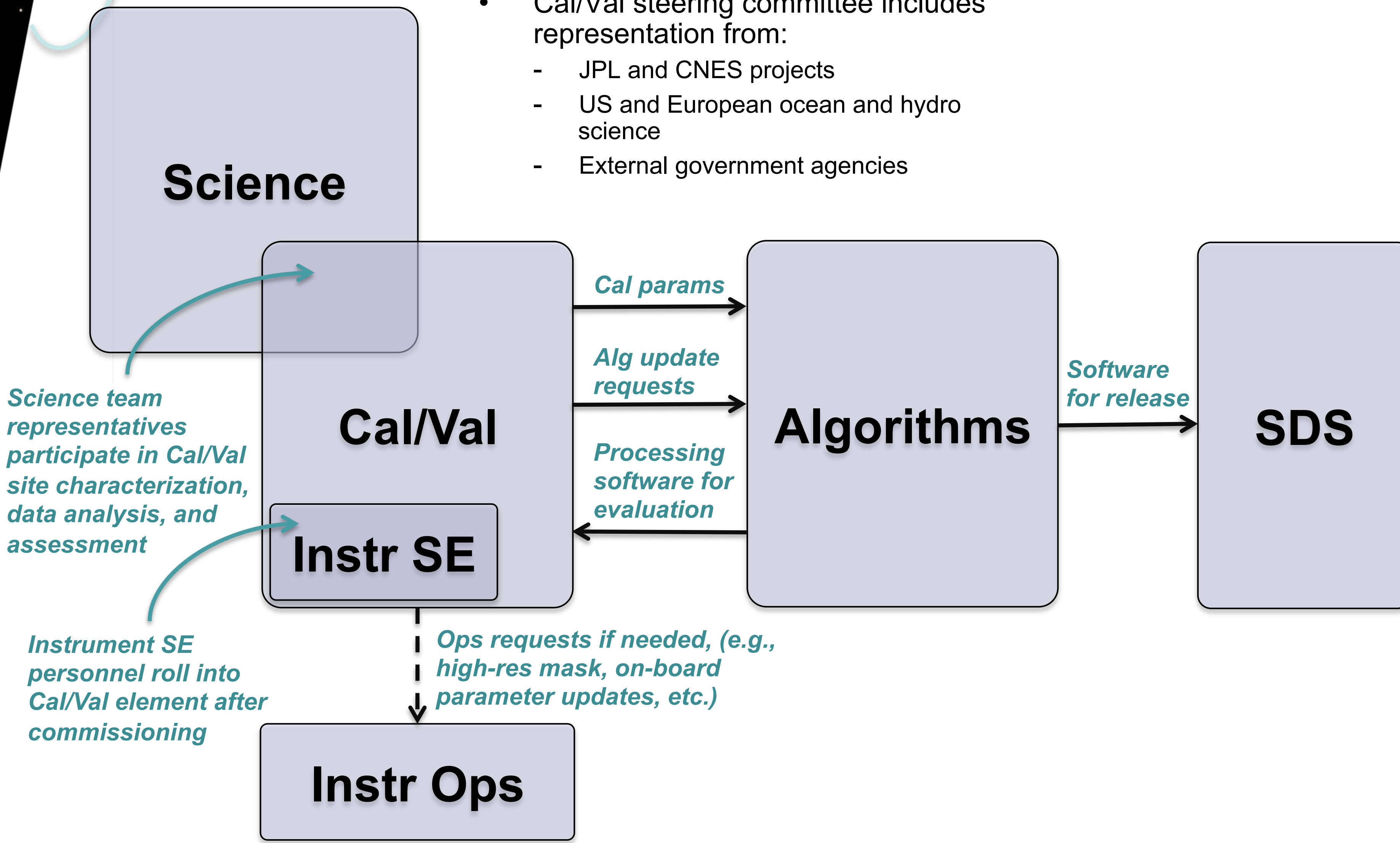
SWOT

Cal/Val Overview

- Basic objectives of Cal/Val:
  - Estimate calibration parameters for ground processing based on flight data
  - Validate measurement performance: Does system behave as expected, and if not, what can/should we do?
  - Validate the data products
  - Validate measurement with respect to high-level requirements: Does performance meet mission success criteria?
- Major activities:
  - Collect truth data at identified Cal/Val sites for comparison with SWOT measurements
  - Compare SWOT measurements to external truth data
  - Compare SWOT measurement characteristics to models and simulations
  - Resolve anomalies, coordinate with ADT for algorithm upgrades
  - Plan and coordinate above efforts
- CalVal plan is in final draft form and will be released soon by the project.
  - Contact ernesto.rodriguez@jpl.nasa.gov if you would like a draft version

Team Organization in Cal/Val Phase

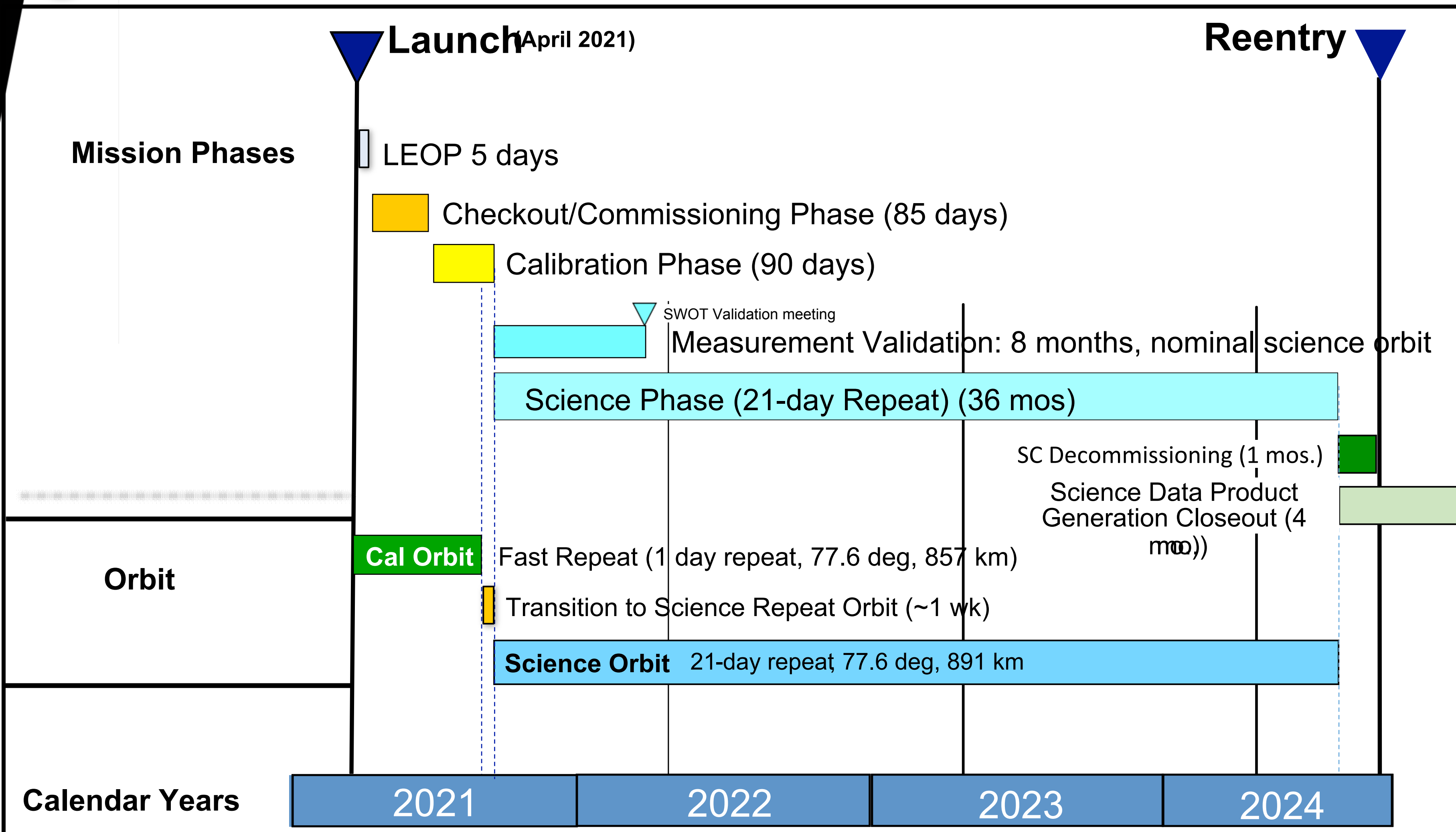
- Cal/Val steering committee includes representation from:
  - JPL and CNES projects
  - US and European ocean and hydro science
  - External government agencies



CalVal Steering Group

- Steering group leads:
  - Ernesto Rodríguez (JPL)
  - Stéphane Calmant (IRD)
- Project leads:
  - Curtis Chen (JPL)
  - Nicolas Picot (CNES)
- Hydrology Representatives
  - Tamlin Pavelsky (UNC)
  - Jean-François Crétaux (LEGOS/CNES)
  - Pascal Bonnefond (OCA)
  - Paul Bates (U Bristol)
- Ocean Representatives
  - Yi Chao (RSS)
  - Francesco d'Ovidio (LOCEAN-IPSL,CNRS),
  - Pascal Bonnefond (OCA)
- Government Agency Representatives
  - Justin (Toby) Minear (USGS)
  - Al Pietroniro (Environment Canada)

Mission Phases / Timeline (Proposed)



1-day Repeat Orbits for CalVal & Ocean Science

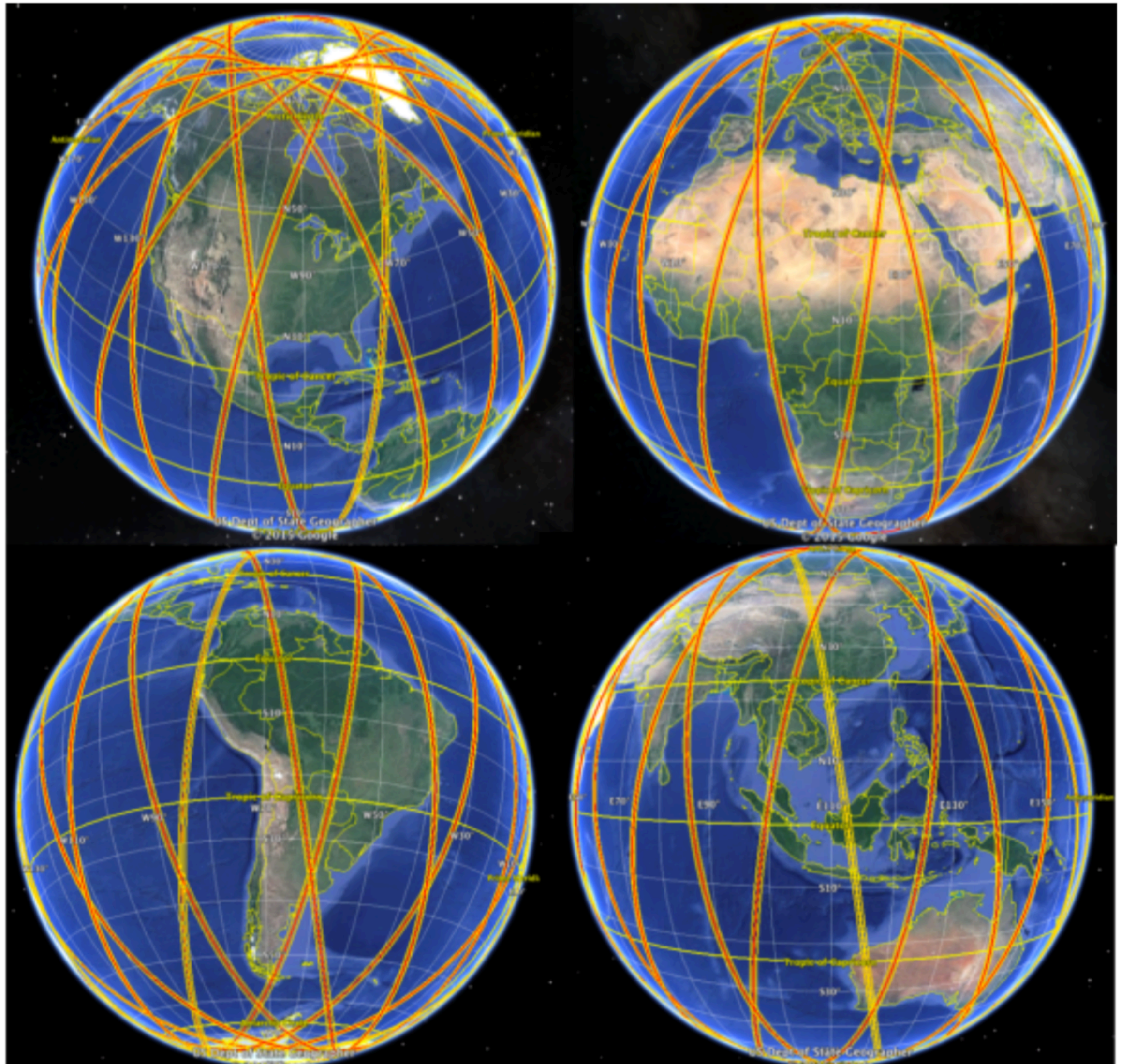


Figure 1: Fast sampling phase orbit coverage during the SWOT 1-day repeat phase.

Advantages/Disadvantages of 1-day Orbit

- Advantages
  - Revisits 1/day (2/day at cross-overs)
  - Ocean SSH correlated between repeats (except for smallest scales and internal waves)
  - Can sample fast dynamic variability for rivers
  - Experiment sites can be identified, characterized, and instrumented before launch
  - CalVal can be accomplished more quickly
- Disadvantages
  - Measurement accuracy degrades away from cross-over diamonds or from the ocean
    - ♦ Errors are long-wavelength, cross-track slope & height drift
    - ♦ Can be partially overcome with corner reflectors in the scene
  - Location of CalVal sites is limited over land for activities during the 1-day cycle phase
- CalVal does not end with 1-day orbit:
  - Ongoing instrument drift calibration
  - Global validation
  - ***Characterize*** discharge and wetland performance
  - Ongoing CalVal until CalVal meeting and beyond to correct for instrument drifts

SWOT CalVal Site Selection Philosophy

- Designate a relatively small number of Tier 1 "super-sites", that will be the focus of project funded calibration and validation activities.
- Encourage interested science team members to contribute and complement super-sites in collaboration with the project.
- Communication and coordination with science team members who have additional sites
- Leverage available data sets and sites (Tier 2) to improve global coverage
- Engage the scientific community to participate in SWOT by providing additional sites, data, and expertise
  - First meeting with South American hydrologists led to science team participation through CNES and identification of South American sites
  - Plan to reach out globally

Calibration

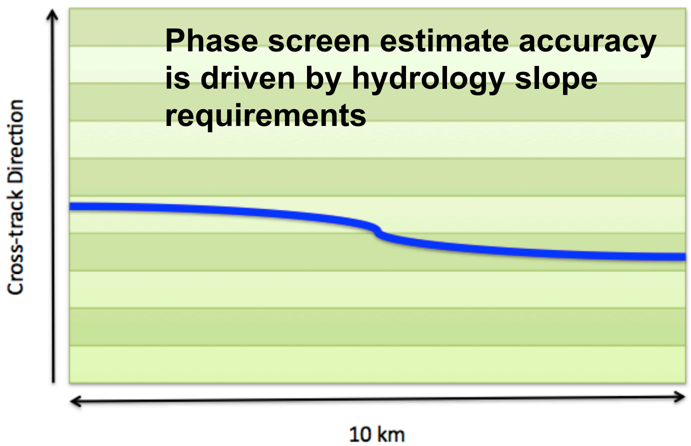
Key Calibration Parameter Overview

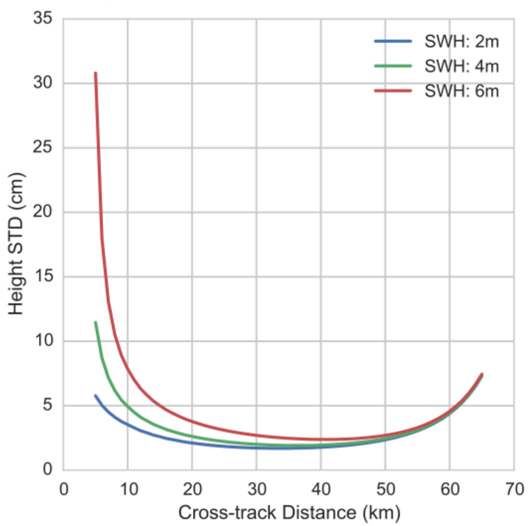
- Focus here on parameters that do not have heritage from Jason series
- Blue: does not require in-situ data
- Red: requires in situ or other data
- KaRIn:
  - Differential range delay
  - Phase screen
  - Static phase/roll bias
  - Static range bias
  - Absolute radiometric calibration factor
- Advanced Microwave Radiometer (AMR):
  - Inter-beam calibration

Phase Screens

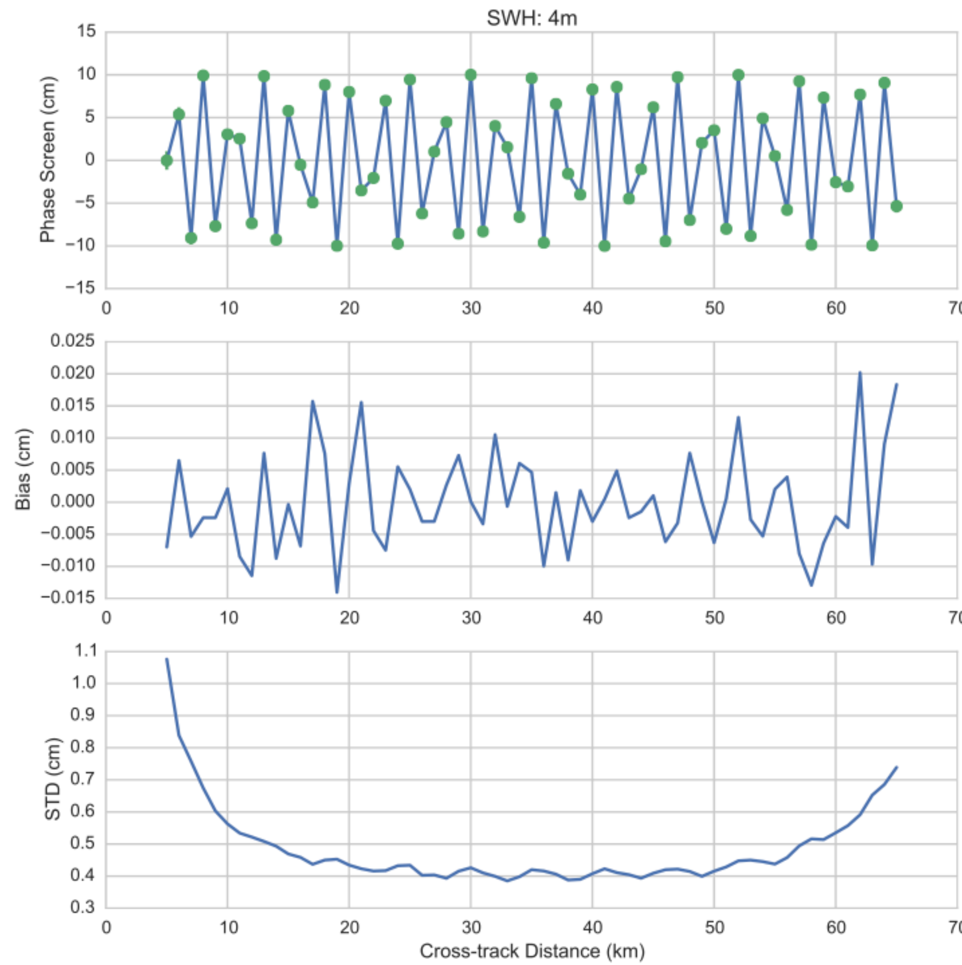
- The phase screen is a systematic distortion of measured heights that depends only in cross-track position
  - The cross-track frequency and magnitude of the phase screen is not known *a priori*
- There is no impact of phase screen on SWOT along-track spectra (OCEAN requirement)
  - There can be impacts on cross-track spectra
- The phase screen requirements come from cross-track slopes in hydrology
- Phase screens will be calibrated using
  - Airborne measurements
  - Cross-over measurements
  - Along-track measurements

Phase Screen Details



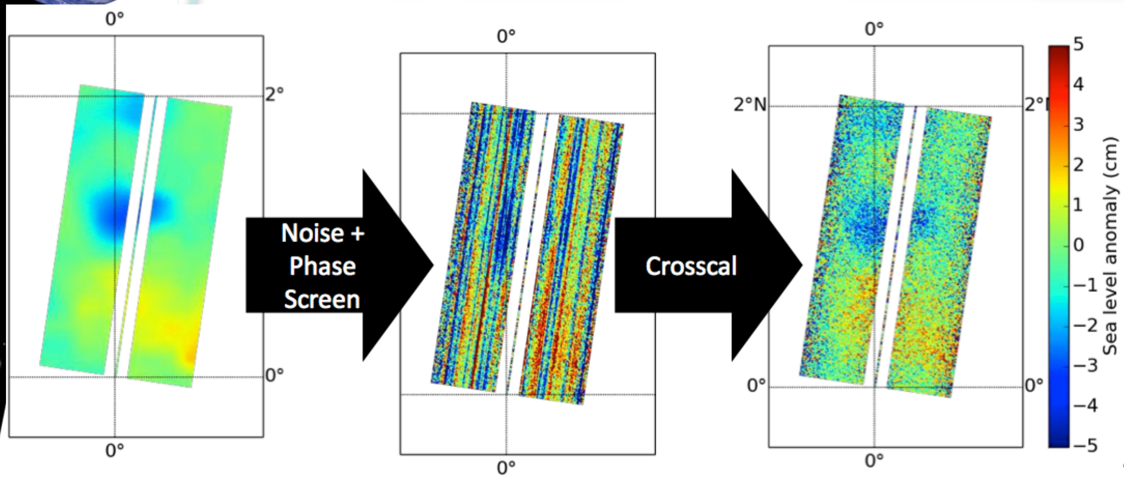


Along-track averaging extent is driven by need to beat down SWOT random error

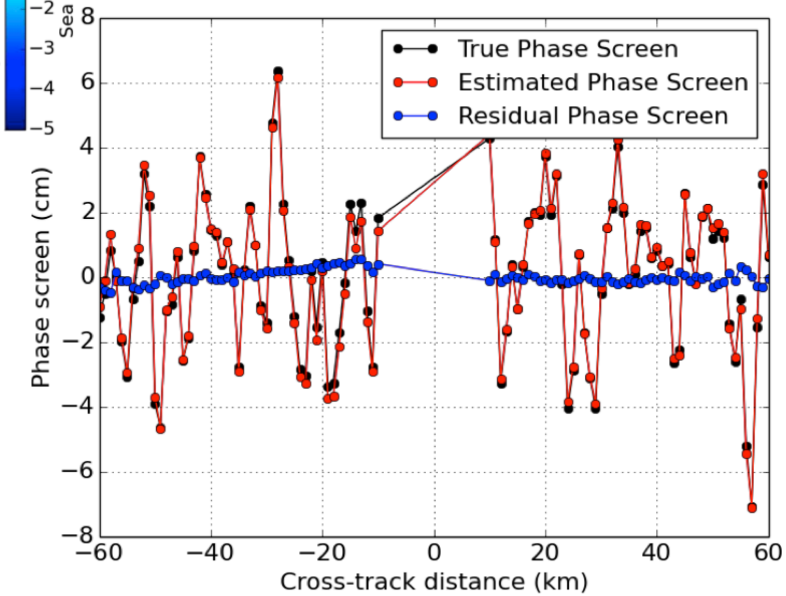


Crossover-based phase screen estimation accuracy in simple simulation

Phase Screen Estimation Simulation



Results courtesy Gerald Dibarboure

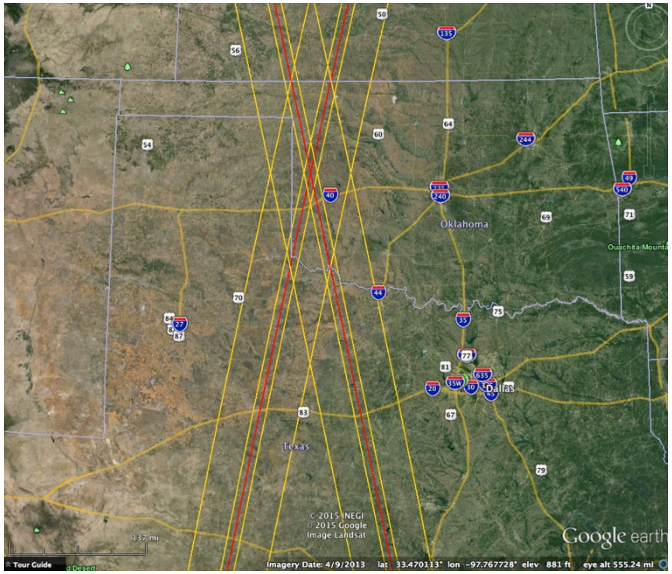


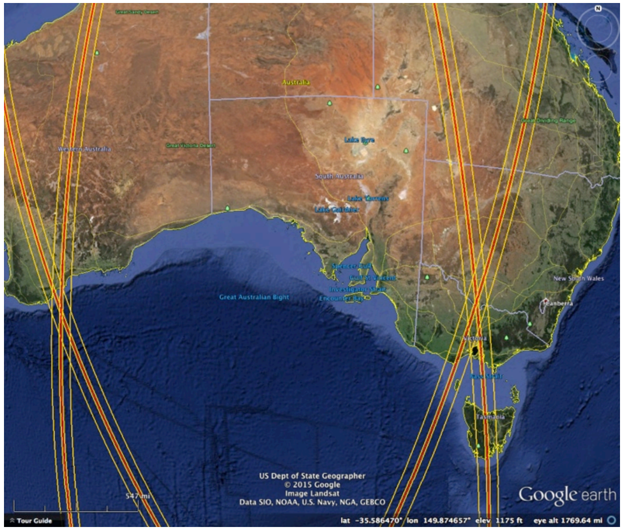
- Uncalibrated: 2.3 cm RMS ➡ Calibrated (one image): 0.21 cm RMS
- Estimation error from mesoscale and noise will average out (calibration one daily dataset should yield sub-millimetric residuals)

- Simulation of direct estimation approach including SSH variation, swath geometry, etc. demonstrates ability to estimate phase screen with SWOT data only
  - Submillimeter error with 1-3 days of data
  - Could be applicable beyond fast-repeat phase to monitor phase screen stability
- Assumes model-based removal of bulk signal variations and inversion for phase screen
- Phase screen is orthogonal to other parameters estimated by operational calibration algorithms

Corner Reflector Calibration & Sites

- Oklahoma/Kansas Site
  - US Project site
  - Primary corner reflector site
- Australia Site
  - US Project site
  - Secondary corner reflector site at alternate latitude (France could also deploy a corner reflector site)
- Corner reflector objectives:
  - SAR point target response validation
  - Approximate common-range calibration for on-board param during commissioning
  - Validate geolocation accuracy
  - Secondary phase screen validation
- Site characteristics
  - Seven reflectors per swath
  - Zenith pointed reflectors





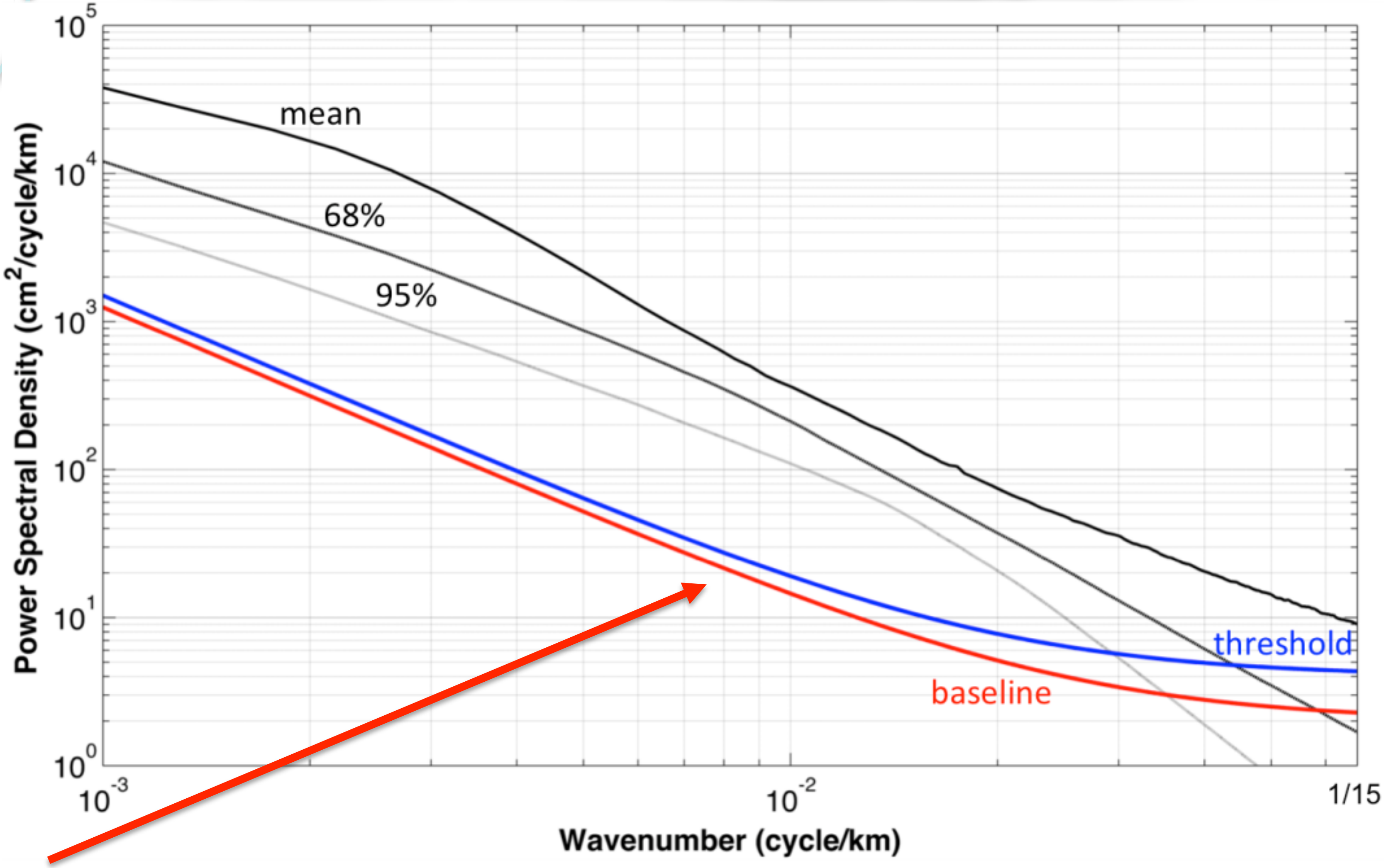
SWOT

Validation

Key Validation Challenges

- Ocean
  - How can the high-frequency spectrum be validated?
- Hydrology
  - How can the large variability of hydrology targets be sampled?
  - How can validation data be stored and distributed widely?

SSH Error PSD Requirement (D-61923)



The spectrum of the ***difference*** between measured and truth SSH needs to be characterized synoptically at scales between 15 km and ~150 km wavelengths

Three Spectral Validation Approaches Identified

- AirSWOT (JPL SWOT project instrument)
  - Interferometric airborne platform similar to KaRIN
  - Has not yet demonstrated ability to meet validation requirements
- MASS lidar (Scripps, K. Melville, L. Lenain)
  - Has demonstrated ability to reproduce Jason-scale SSH
  - Validation of performance for higher frequencies currently being funded by SWOT project
- In situ instrumentation
  - Challenges are in demonstrating synoptic performance and reaching required accuracy
  - SWOT measurement noise must be accounted for by averaging before comparing to in situ data
  - Multiple approaches being studied (Moorings, CTD’s, PIES, gliders, drifters, …)
  - Special workshop on Thursday as a follow-on to the science team meeting

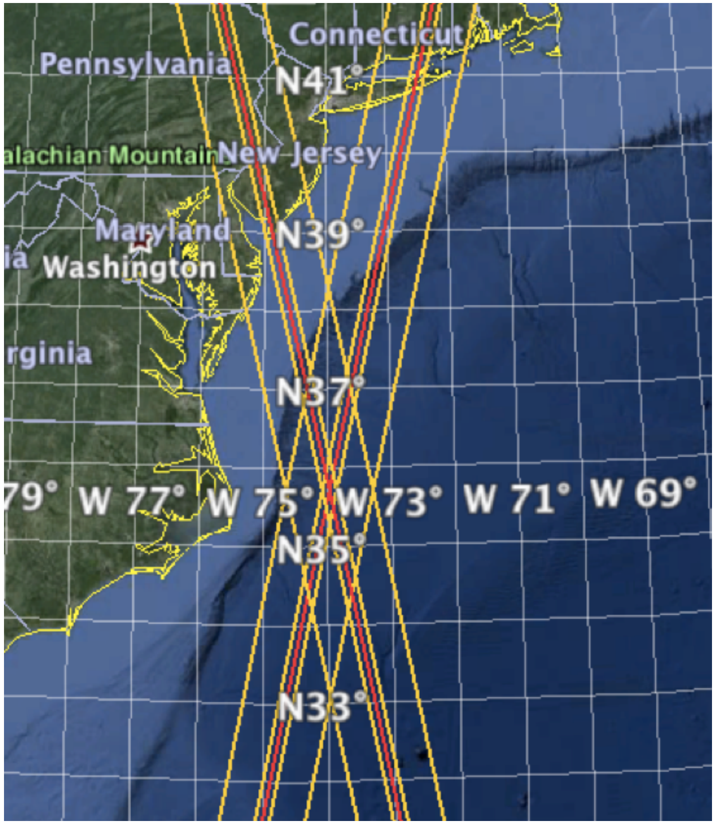
Hydrology Global Coverage

- Tier 1 project sites in North America and France
  - Sub-tropics to arctic
- Must be complemented with additional sites from science team, operational agencies, foreign partners
- Brazil is currently seriously examining validation activities in coordination with IRD (France)
- More work needs to be done coordination Tier 1 sites, coordinating with other science team sites, bringing in international partners

Rio Negro GPS survey for stage/slope in support of SWOT from IRD/Brazil partnership.

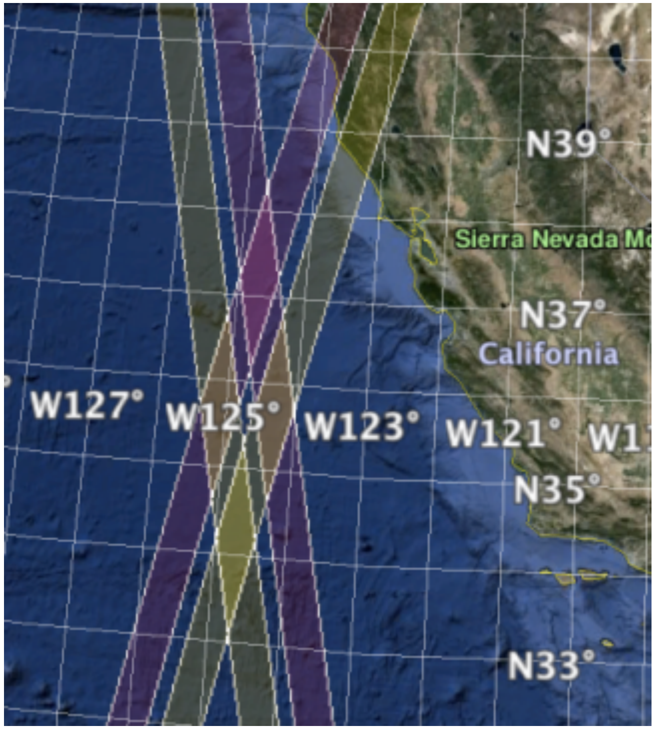
Primary 2-D SSH Validation Site

- Gulf Stream Validation Site will be used for primary 2-D SSH validation
  - Covered by crossover-diamond during 1-day orbit
  - Easier logistics for airborne mapping (e.g., AirSWOT)
  - More favorable weather for lidar (vs. fog off CA)
  - Long history of study
    - ♦ Existing instrumentation
    - ♦ Interesting features
- Primary site for validation of 10-100 km SSH error wavelengths



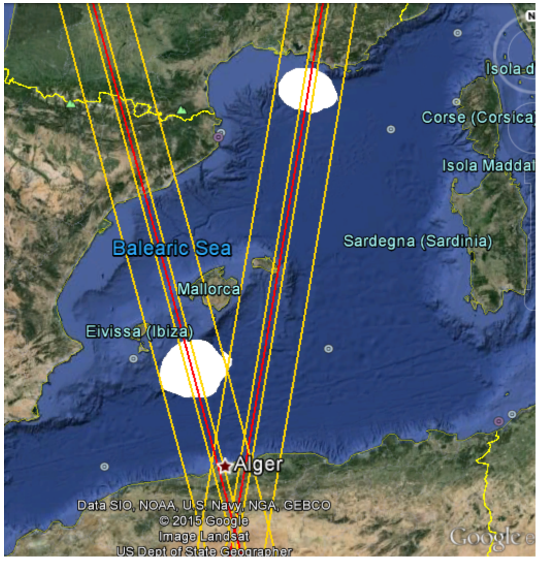
Backup 2-D SSH Validation Site

- California Current/Coast Validation Site will be backup for 2-D SSH validation
  - Covered by crossover-diamond during 1-day orbit
  - Easiest logistics for AirSWOT
  - Must contend with military warning zones
  - Fog may be problem for lidar
- Had previously been primary site for validation of 10-100 km SSH error wavelengths, now backup

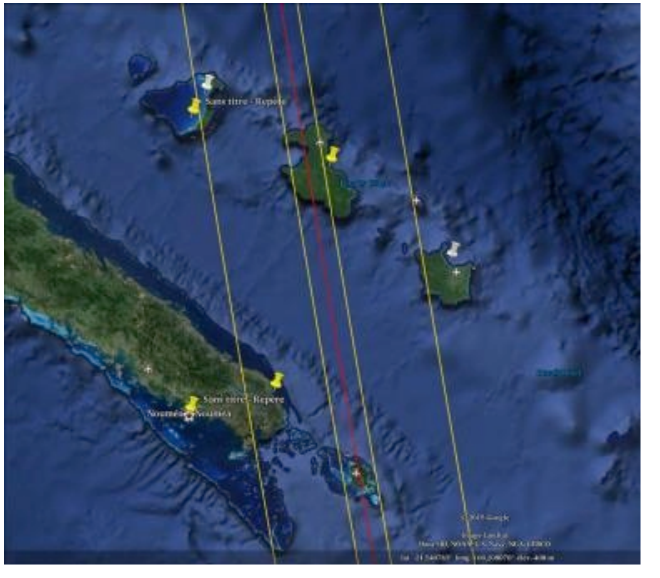


Other Potential Ocean Validation Sites

- Mediterranean Validation Site
  - Potential French project
  - Offers validation for characteristics of enclosed sea

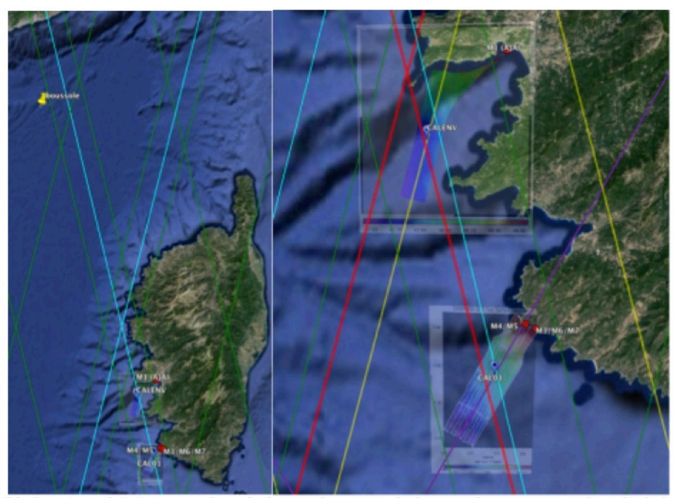


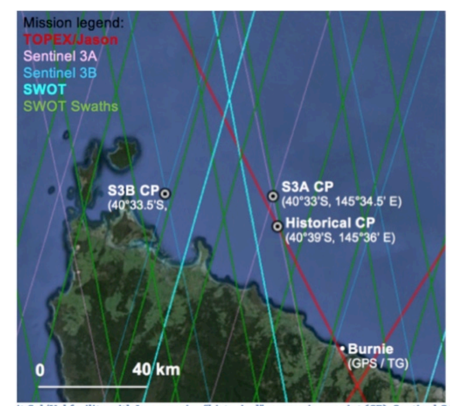
- Loyalty Validation Site
  - Potential support for site through ROSES/TOSCA
  - Subject of previous study, including AltiKa science characterization



Ocean Altimetry Cal/Val Sites

- SWOT leverages existing altimeter calibration sites for calibration of nadir altimeter and, by extension, absolute range calibration of KaRIn:
  - Harvest (Backup US Jason Site)
  - Corsica (French Jason and SARAL Site, Nominal SWOT site)
  - Bass Strait (Backup Australia Jason Site)
- Sites have extensive instrumentation and long history of data specifically for Cal/Val of ocean altimetry missions
- Nominal SWOT orbit passes very close to all three of above sites





Hydrology Tier 1 vs Tier 2 Sites

- Tier 1 sites involve direct field measurements by/for SWOT (10–20 sites)
  - Dense networks of GPS leveled pressure transducers or GPS buoys (every 6–20 river widths)
  - AirSWOT (not necessarily coincident with SWOT)
  - Other airborne measurements (lidar, NIR camera, L-band SAR) at some sites
  - Modeling/analysis work
  - Metrology stations
- Tier 2 sites leverage existing measurement assets to characterize SWOT spatial variability (~100 sites)
  - e.g., Data from existing gauges leveled by GPS that are freely available from USGS (or equivalent from other countries)
  - Not enough detail to troubleshoot potential SWOT issues or subtleties, but enough first order info to provide more comprehensive assessment/validation of performance

River Validation Sites

- Willamette River Site
  - US Project site
  - Single and multiple-threaded channels, typical of temperate climate rivers
  - Near SWOT 100 m baseline width requirement
- Garonne River Site
  - Potential French Project site (potentially others also: Rhone, Rhin, Loire,…)
  - Well defined channel along reaches covered by 1-day orbit
  - Can evaluate effects of layover
- Lower Mississippi Site
  - US Project site
  - Wide, low slope river
- Connecticut River Site
  - US Project site
  - Validation of ice flagging/performance
- Tanana River Site
  - US Project site
  - Large, complex, braided river with changing planform
  - Validation of ice flagging/performance
- Canadian Arctic Sites
  - Potential Canadian (Environment Canada) sites, some in cooperation with USGS
- South American Sites
  - Potential French/Foreign Partner sites

Lake Validation Sites

- Lake Issykkul Site
  - Potential French Project site (potentially other sites over French regions also)
  - Heritage validation site for satellite altimeters
  - Far from ocean, so good for validating crossover-based roll/phase corrections
- Lake Tahoe Site
  - US Project site
  - Large, high-altitude lake
- Prairie Potholes Site
  - US Project site
  - Validation of performance for small/ephemeral waterbodies
- Yukon Flats Lake and Wetlands Site
  - US Project site
  - Boreal wetland/lake complex
- South American Site
  - Potential French/Foreign Partner sites
  - Validation of lakes in mountainous area
- Exploring other sites in South America, Africa, South Asia

Wetland Validation Sites

- Lower Mississippi River Wetlands Site
  - US Project site
  - Range of vegetation types
- Yukon Flats Lake and Wetlands Site
  - US Project site
  - Validation of wetland lakes in boreal regions
- Everglades Wetland Site
  - US Project site
  - Mixed moderate height canopy typical of lowland wetlands
- Potential French Site (still under discussion)
- All US wetland sites to be characterized with some combination of
  - Lidar DEM
  - AirSWOT
  - Near IR imaging
  - L-band SAR (e.g., UAVSAR)
  - in situ instrumentation
  - Ground survey

Tidal/Estuary Validation Sites

- Severn Estuary and River Site
  - Potential UK Project site
  - Highly dynamic tidal estuary
  - Covered by 1-day orbit
- Connecticut River Tidal Site
  - US Project site
  - More moderate tidal action than Severn
  - General validation for near-shore coastal areas
  - Covered by 1-day orbit
- Potential French Site (still under discussion)

Summary

- The Science Definition Team (SDT) and CalVal Steering groups have developed a nominal CalVal plan
  - Your comments regarding this plan prior to official release are welcome!
- As we transition from the SDT to the ST, we need to coordinate with actual science team proposed activities to optimize the plan
- Ocean calibration of SSH is a major challenge
  - We are flying SWOT because these measurements are not easy in situ!
  - Science team participation in ocean CalVal workshop and follow-on are encouraged.
- Global hydrology calibration is a challenge of a different sort
  - Need to coordinate across project and science team activities
  - Need to continue outreach to foreign partners
  - Next step: meeting with South American hydrologists in Concepción, Chile, late November 2016 (follow up of 2015 Rio Meeting)
    - ♦ Opportunities for collaboration between SWOT science team members and South American hydrologists. Opportunity to bring in additional South American hydrologists into the science team.

Backup

Static Phase/Roll Biases

- Parameters: Static bias between estimated and true roll angle of baseline or differential phase (cannot readily distinguish roll knowledge error from differential phase error, so correct with same parameter)
  - Dynamic variations are not addressed by calibration; they must be removed by algorithms (estimated from crossovers) or residual errors accepted
- Estimation approach: Compare KaRIn ascending/ descending data at crossover diamonds
  - Need 1-day repeat orbit to make ocean variation between passes small
  - Average many repeats to account for dynamic roll/phase variations, ocean temporal variation, residual troposphere (not removed by radiometer), etc.
- Minimum site/instrumentation needs: Ocean crossover diamonds during fast repeat phase

Static Range Biases

- Parameter: Absolute range (height), to be made consistent with Topex/Jason series
- Estimation approach (multiple steps):
  - Calibrate nadir altimeter and/or cross calibrate nadir altimeter to current Jason series altimeter (heritage from Jason series)
  - Cross calibrate KaRIn to nadir altimeter by interpolating between KaRIn swaths and averaging long along-track spans to remove spatial variation
- Minimum site/instrumentation needs:
  - Long ocean swaths
  - Nadir altimeter calibration site

KaRIn Backscatter Radiometric Calibration

- Parameters: Gain (absolute, swath-to-swath) and antenna pattern corrections
  - Note: No requirement on radiometric accuracy
- Estimation approach: Cross calibrate to AirSWOT where incidence angles agree
- Minimum site/instrumentation needs:
  - Contemporaneous AirSWOT coverage with AirSWOT lines oriented to give coverage of SWOT look vectors
  - Comparison of KaRIn measurements to wind model functions
  - Corner reflector sites will contribute

AMR Calibration

- Radiometer internal reference, front end path loss, etc. are calibrated pre launch
  - Typically accurate to better than 3%
- Brightness temperature (TB) will be tuned in flight, following heritage approach of previous radiometers:
  - Vicarious Earth references (cold ocean, amazon)
  - TBs from weather models
  - Inter-satellite comparison with other microwave radiometers
  - 2.7 K cosmic microwave background during cold-sky maneuvers (not in baseline)
- Beam-to-beam calibration:
  - Compare global averages (spatial/temporal), which have zero mean difference on time scales longer than ~10 days
  - Consider 90 deg yaw maneuver to orient beams along nadir track so they both see same scene with slight time separation (not in baseline)

Calibration Parameters and Approaches

- Topics addressed in this subsection:
  - What are key calibration parameters?
  - What is approach for choosing values for these parameters?
- In this context, calibration parameters are parameters needed for ground processing that can only be selected based on flight observations
  - Parameters that are resident on spacecraft are set during commissioning activities before Cal/Val phase starts
    - ♦ Primary responsibility for setting on-board params lies with payload SE and Ops teams, not Cal/Val team
    - ♦ Cal/Val team should be cognizant of on-board params and may ultimately request changes, but baseline plan is that no changes will be made to on-board parameters after commissioning
  - Internal calibration data (e.g., KaRIn calibration loop, AMR reference load, etc.) are not included here (covered by instruments)

Differential Range Delay

- Parameter: Difference in starting range between channels comprising an interferogram
- Estimation approach: Find peak in cross-correlation between SAR images from individual channels
  - Oversampling of complex data gives sub-pixel precision
  - Averaging of many estimates gives fine accuracy
  - Extensive heritage in airborne and spaceborne interferometry contexts
- Minimum site/instrumentation needs: None
  - Just need to have scene with enough SNR
  - Scene contrast not needed since correlated speckle between images gives good cross-correlation peak by itself

Ocean Flag Validation

- Rain and ice flags
  - Plausibility of statistics, maps, time series
  - Comparison to other spaceborne sensors
  - Compare SSH statistics with and without flags
- Land flags
  - Comparison to high-resolution land mask
  - Comparison to changes in statistics of sigma0, phase, coherence near known land boundaries

Surface Water Flag Validation

- Rain flag:
  - Comparison to local meteorology stations
  - Commercial Doppler radar maps
  - Satellite products (e.g., GPM)
- Ice flag:
  - Satellite optical imagery to monitor ice breakup
  - Airborne optical imagery contemporaneous with SWOT at time of ice breakup at Tanana River Cal/Val site
- Land flag:
  - Basically inverse of water mask; see inundated surface area
- Layover flag:
  - Still under development

Ocean Error Budget Validation

Ocean Error Budget Validation

- Topics addressed in this subsection:
  - What observables need to be validated to convince ourselves that system is performing as expected?
    - Corollary: If system is not performing as expected, how do we fix it and/or make the best of it?
    - Need to ensure that we understand measurement in order to make proper science interpretations of the data
  - What is approach for validating these observables?
- Generally, Cal/Val will validate error budget terms that can be uniquely separated in order to identify problem areas, facilitate understanding and interpretation of data, etc.
  - Validation is loosely defined here as showing that system is doing the right thing
  - Separate from formal requirement verification that must be closed out before launch

Key Ocean Error Budget Terms for Validation

- Random height error (Nadir Altimeter, KaRIn)
- Roll/phase drift
- Precise orbit determination (POD)
- Media effects:
  - Wet troposphere delay
  - Dry troposphere delay
  - Ionosphere delay
- Electromagnetic bias/wave effects
- Flags (addressed in backup)

Random Height Error

- Nadir altimeter:
  - Look for floor in along-track PSD and compare to expected level
- KaRIn
  - Look for floor in along-track and cross-track PSDs and compare to expected level
  - Include analysis of swell effects on PSDs using models (e.g., WaveWatch3)
  - Examine differences at crossover diamonds during 1-day repeat orbit to eliminate high-spatial-frequency, low-temporal-frequency components of sea surface anomaly

Roll/Phase Drift

- Unknown roll of interferometric baseline cannot be distinguished from unknown channel-to-channel phase drift, so lump these terms together
- High-resolution processing chain relies on crossover data for estimation and removal of roll/phase drifts over land
- Compare magnitudes and statistics of estimated roll/phase drifts between crossovers to expected levels

Precise Orbit Determination

- POD approach and validation are largely inherited from previous altimeter missions
- Validation approaches:
  - Data residuals
  - DORIS, GPS, laser consistency
  - Altimeter crossover residuals
  - Comparisons of solutions between groups

Media Effects

- Validation of path delay effects follows previous altimeter missions:
  - Wet troposphere:
    - ♦ Beam-to-beam AMR comparisons to validate individual beams
    - ♦ Under flights with airborne radiometers (eg, HAMMR) and upward looking WVRs to validate high frequency error spectrum
    - ♦ Comparisons to models and coincident observations from other satellite radiometers
    - ♦ Data self consistency (e.g., crossovers) and spatial/temporal plausibility
  - Dry troposphere
    - ♦ Cross-model comparisons
    - ♦ Data self consistency (e.g., crossovers) and spatial/temporal plausibility
  - Ionosphere
    - ♦ Data self consistency (e.g., crossovers) and spatial/temporal plausibility
    - ♦ Comparison to GPS-based models

SWOT

EM Bias

- Nadir EM bias approach and validation inherited from previous altimeter missions:
  - Data self consistency (e.g., crossovers)
  - Comparisons to other models
- Off-nadir EM bias
  - Comparison to nadir altimetry
  - Comparison to coincident lidar data
- Fast sampling phase presents unique opportunity for determining the EM bias
  - 1-time/day (or 2-times/day at the cross-overs) SSH differences will be caused mainly by EM bias changes due to changing sea state conditions (although a smaller sub-mesoscale signature is also expected)
  - During the fast sampling period, it will be possible to process high resolution data over the ocean to fully characterize the wave spectrum, including SWH and wave direction.
  - We expect that traditional methods of determining the EM bias will yield results quickly given the short temporal revisits and enhanced wave information collected during this phase.

Ocean Data Product Validation

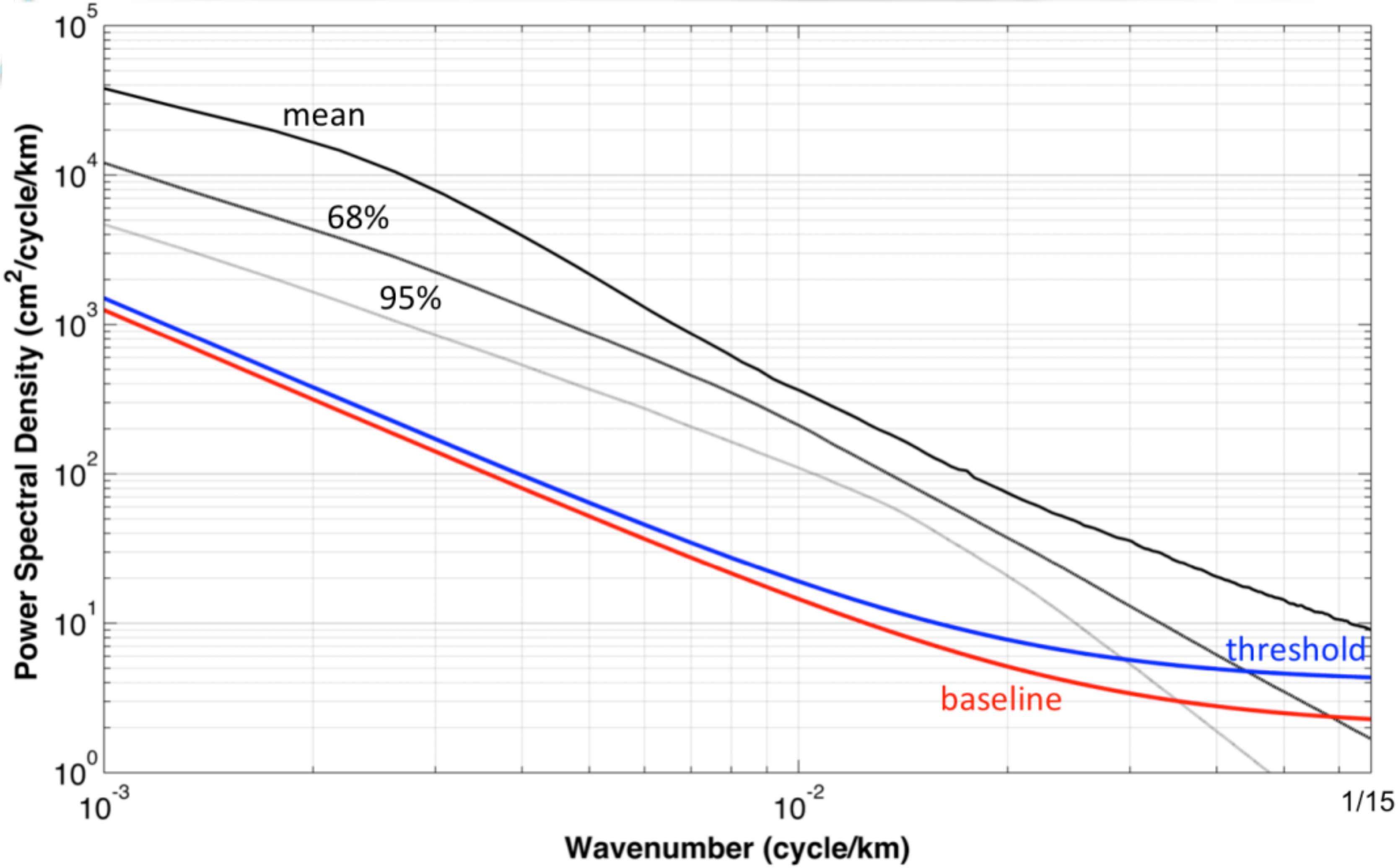
Ocean Data Product Validation

- Topics addressed in this subsection:
  - What is approach for validating primary data products of mission?
- Data products must be compared to independent data to show that end-to-end measurement performance meets L1/L2 requirements

Ocean Data Products for Validation

- Sea surface height (SSH)
  - 10–100 km
  - 100–1000 km
- Significant wave height (SWH)
- sigma0
- Wind speed

SSH Error PSD Requirement (D-61923)



SSH from 10–100 km

- Validation of 10–100 km wavelengths of SSH error PSD requirement is based primarily on comparison to AirSWOT data
  - Collect AirSWOT data along lines parallel to SWOT tracks
  - Compute differences of SSH (corrected for tides, etc.)
  - Average across track
  - Compute spectra along track
- Additional validation can be done piecewise
  - 40–100 km wavelengths can be validated by comparison to other spaceborne nadir altimeters
  - 10–40 km wavelengths can be validated by comparison to airborne (AirSWOT, lidar) or in situ assets, which may have more difficulty covering longer length scales
  - Ocean models can also provide valuable info and we may also use other spaceborne data (color, SST, SAR, …)

SSH 100–1000 km

- Validation of 100–1000 km wavelengths of SSH error PSD requirement is based primarily on comparison of KaRIn and Nadir Altimeter
  - Average KaRIn data into bins in cross track direction
  - Compute SSH height difference between KaRIn and Nadir Altimeter
  - Compute spectra along track
- Additional validation can also be achieved by comparison to other spaceborne altimeters

Significant Wave Height

- Nadir altimeter SWH approach and validation inherited from previous altimeter missions
- Off-nadir SWH validation uses similar approach as nadir SWH:
  - Statistical and spatial/temporal analyses for plausibility
  - Comparisons of crossovers with short temporal separations (during 1-day orbit)
  - Comparison to buoy data
  - Comparison to other satellite data (e.g., CFOSAT)
  - Cross comparison of KaRIn and Nadir Altimeter SWH

sigma0 and Wind Speed

- Nadir altimeter approach and validation inherited from previous altimeter missions
- KaRIn (*No requirement on radiometric accuracy or wind speed*):
  - Similar statistical and spatial/temporal analyses as for Nadir Altimeter
  - Cross comparison of Nadir Altimeter and KaRIn sigma0
  - Comparison to external data (e.g., GPM/TRMM)
  - Comparison of different wind speed inversion algorithms

Surface Water Error Budget Validation

Surface Water Error Budget Validation

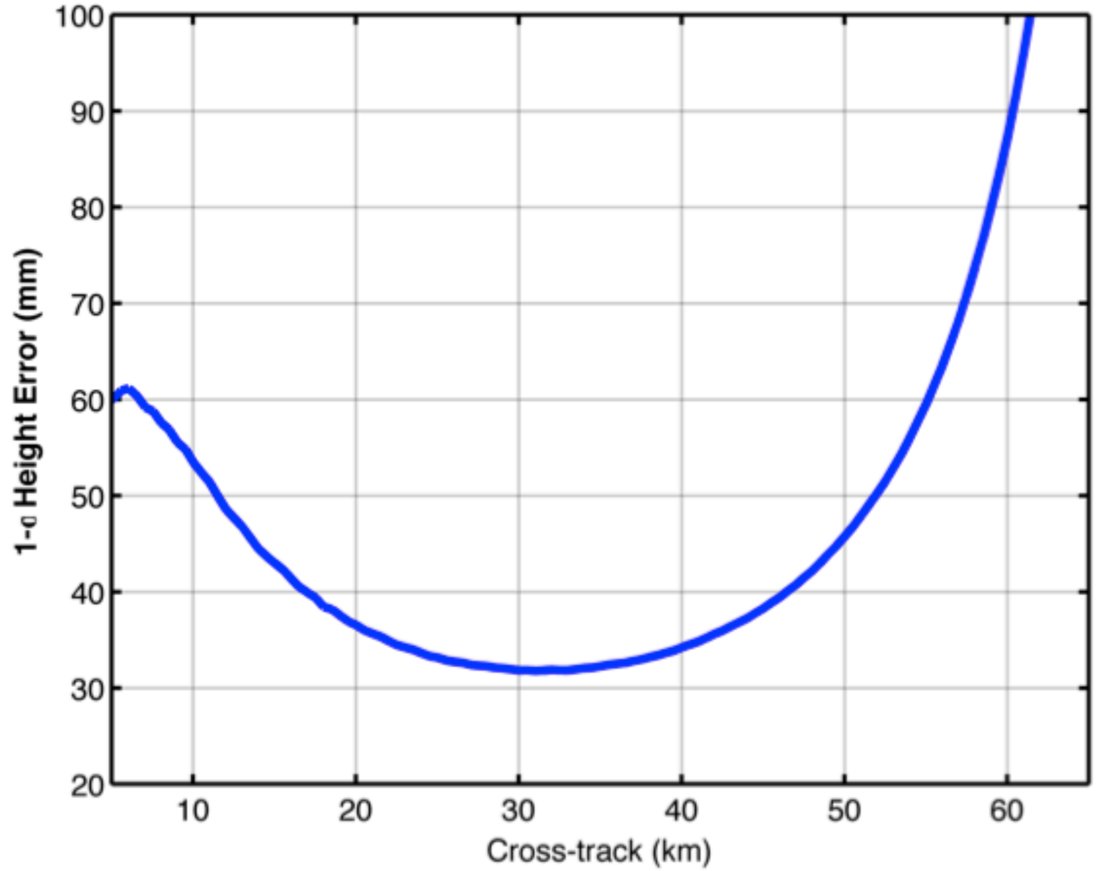
- Topics addressed in this subsection:
  - What observables need to be validated to convince ourselves that system is performing as expected?
    - ♦ Corollary: If system is not performing as expected, how do we fix it and/or make the best of it?
    - ♦ Need to ensure that we understand measurement in order to make proper science interpretations of the data
  - What is approach for validating these observables?
- Generally, Cal/Val will validate error budget terms that can be uniquely separated in order to identify problem areas, facilitate understanding and interpretation of data, etc.
  - Validation is loosely defined here as showing that system is doing the right thing
  - Separate from formal requirement verification that must be closed out before launch

Key Surface Water Error Budget Terms for Validation

- Random height error
- Absolute height error
- Inundated surface area
- Roll/phase drift
- Propagation delay
- Slope
- Geolocation
- Flags (addressed in backup)

Random Height Error

- Validate random error by examining high-frequency variations over large lakes, examining correlation, backscatter, etc.

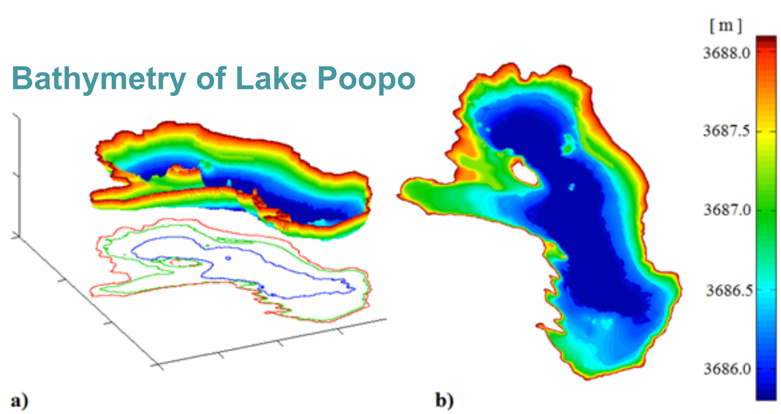


Absolute Height Error

- Validate SWOT height measurements by comparison to field measurements at Cal/Val sites:
  - Dense networks of GNSS-leveled pressure transducers and GPS buoys
    - ♦ Impact of cross-channel water surface curvature to be characterized before launch
  - Direct measurement of free surface height at time of SWOT overpasses using GPS floats
  - External validation from nadir altimeter products for large lakes
  - Heritage from AirSWOT experiments in CA, OR, LA, AK

Inundated Surface Area

- Inundated surface area validation achieved at Cal/Val sites by comparison of SWOT measurement to:
  - Direct observation with nearly contemporaneous airborne near/mid-infrared camera images
  - Indirect estimate of inundation extent computed from high-quality DEM/ bathymetry and field measurement of surface water elevation
  - Direct measurement of river widths by field teams walking along water/ land boundaries (Particularly for challenging areas such as where wet sand bars are adjacent to sediment-laden rivers--difficult to distinguish in NIR imagery)
  - Satellite imagery (SPOT, Landsat, MODIS) for large lakes
  - UAVSAR, lidar collections over wetland sites



Roll/Phase Drift

- Compare SWOT height measurements over large lakes whose surfaces shapes are stable and well characterized and validate that residual tilts are small
- Examine statistics of crossover roll estimates over ocean in nominal orbit (see ocean error budget validation slides)

Propagation Delay Validation

- Propagation delay corrections over land are based on models, not direct SWOT measurement
  - External models will have been validated already to varying degrees
- Compare SWOT model corrections to independent measurements:
  - Ground-based GPS wet troposphere and ionosphere estimates
  - Upward-looking radiometer and/or radiosonde data where available

Slope

- Validate SWOT slope measurements by comparison to field measurements at Cal/Val sites:
  - Dense networks of leveled pressure transducers or GPS buoys
    - ♦ Pre-launch characterization of cross-channel elevation changes to compensate for such effects
  - Direct measurement of free surface height at time of SWOT overpasses using GPS floats
  - AirSWOT measurements during SWOT Cal/Val phase to measure slopes over long river reaches
  - Pairs of accurately leveled gauges at Tier-2 Cal/Val sites

Geolocation

- Validate by comparing geolocated corner reflector responses to surveyed positions
- Compare gelocations of identifiable features at Cal/Val sites to GPS surveyed positions or gelocations from airborne data

Surface Water Data Product Validation

Surface Water Data Product Validation

- Topics addressed in this subsection:
  - What is approach for validating primary data products of mission?
- Data products must be compared to independent data to show that end-to-end measurement performance meets L1/L2 requirements

Surface Water Data Products for Validation

- Pixel cloud
- River vector products
- Lake vector products
- Raster product

- Discharge characterization (no accuracy requirement)

Pixel Cloud

- Pixel cloud includes height, geolocation, classification, etc.
  - Validate properties of pixel cloud product using approaches described in previous subsection

River and Lake Vector Products

- Pass-based vector products are derived from pixel cloud for single SWOT overpass to give reach-scale or whole-lake height, slope, width/inundation extent, and discharge
  - Validate properties of pass-based vector product using approaches described in previous subsection
- Cycle-based vector products incorporate data from 21 day orbit cycle*
  - Validate height and slope with time-series data from continuously logging gauges/pressure transducers
  - Validate inundation extent using rating curves from high-quality bathymetric DEMs and field measured water elevation

** Possibly monthly instead, but Cal/Val approach is unaffected*

Discharge Characterization

- Characterization of derived bathymetry
  - Comparison to actual cross sections from ADCP
  - Comparison to external database of virtual river bed elevations
- Characterization of derived discharge
  - Comparison to in situ discharge measured directly by acoustic Doppler current profilers (ADCPs) at times of SWOT overflights
  - Comparison to existing and upcoming stream gauges and rating curves (e.g., USGS)
    - ♦ Rating curves will be built during pre-launch Cal/Val site characterization
  - Comparison to hydraulic models of selected Cal/Val sites
  - Statistical/morphological estimates of discharge at global scale

Cal/Val Sites