

Observing Ocean Surface Topography at High Resolution :

Surface Water and Ocean Topography (SWOT)



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With input from SWOT Ocean Working Group Leads







SWOT : Observing Ocean Surface Topography at High Resolution :

Opportunities and Challenges

Today's altimetric 2D sea surface height (SSH) observations resolve scales of 150-200 km => SWOT aims to extend that to 15 km resolution

Ocean Opportunities :

- Observing the ocean's 2D SSH energy cascade at finer scales
- Observing the dynamical interaction between ocean eddies / jets with internal tides => instabilities & mixing
- Extending 2D SSH/currents into coastal/estuary regions

Challenges :

- SWOT has v good spatial resolution, weaker temporal resolution
- New techniques needed to reconstruct 2D/3D balanced velocity fields
- In-situ validation of rapidly evolving processes









SSH of Internal Tides





SWOT Science Team 2020-2023 : New Ocean Science Team : Working groups

HR Modelling – ocean, air-sea, waves P. Klein, B. Arbic, J. Le Sommer, L. Renault 3 Projects

US (1), FR (2)

SWOT Instrument processing : oceans & marine gravity

F. Ardhuin, D. Sandwell, C. Ubelmann, D. Vandemark

5 Projects US (3), FR (1), Denmark

Tides & Internal Tides

B. Arbic, F. Lyard, R. Ray, E. Zaron

> **3 Projects** US (2), FR (1)



Coastal & Estuarine Studies N. Ayoub, B. Laignel, M. Simard 6 Projects

International Teams :

Australia (4), Canada, Denmark, Germany, Greece, India, Japan, UK, Portugal, Spain

SWOT Data Inversion & Assimilation

E. Cosme, S. Gille, PY Le Traon

8 Projects US (3), FR (3), Aust (2)

Regional Science Validation studies

K. Drushka, F. D'Ovidio, A. Pascual

9 Projects US (1), FR (4), Aust, UK, Japan, Spain

SWOT Geodetic CalVal

P. <u>Bonnefond, C. Watson,</u> B. Haines, S. Mertikas

4 Projects US (1), FR (1), Aust, Greece

High-Resolution Ocean Modeling Working Group

P. Klein, B. Arbic, J. Le Sommer, L. Renault

2021-01-26/28: Zoom Teleconferences, about 40 participants, Focus on polling to determine interests of various groups and modes of interaction, some time for discussion



High-Resolution Ocean Modeling Working Group

Major science themes from the polling and discussions:

How to optimally use our existing ocean models for preparing SWOT (inc. SWOT Cal/Val, and SWOT Adopt a Crossover)?

- Model data as pseudo-observations, planning field campaigns, etc.
- In particular for developing interpolation algorithms for L4 products
- Key : access to model data, SWOT data, SWOT science simulator

What are the key questions that we should be able to address with our models in combination with SWOT?

- Air-sea interactions at fine scale
- Interaction between wave and non-waves
- Cross scale interactions, energy budgets and cascades
- Drivers for vertical exchanges
- Key : effective resolution of SWOT ocean data ? how to prepare the analysis of SWOT data ?

How SWOT could help improve our ocean model in the future ?

- Fostering model/model comparisons
- A wealth of data for model/observation comparisons
- Improve our understanding of the missing physics in the current generation of ocean models (air-sea exchanges at fine scale, interaction with waves and their impact in the resolved currents)

SWOT Fast Sampling Phase will be key for addressing the above challenges

Practical organisation of the group's activity

- Monthly 1h meeting with a clear main focus, a small number of presentations and ample time for discussions
- Possible topics : wave/non-wave, air-sea interactions, data sharing, CalVal/AdAC...
- A shared folder for sharing presentation material and notes
- Need for a communication platform to foster our exchanges (ideally a restricted discourse forum)
- This platform should probably be organized at the SWOT Science Team level (to foster exchanges across groups) => AVISO+ SWOT Forum

A key aspect : improving the reproducibility of our studies

Discussion emphasized the need to improve how we could better

- share information about our model simulations and set-up
- share information on how to assess our models
- share model data itself

Example solution : targeted PANGEO deployments, cf on-going study \rightarrow



Synergies with other groups

Our discussions emphasized the need for cross-cutting activities among the working groups, before and after SWOT launch

CalVal group

- OSSE
- data access

Coastal / estuarine group

- BC for coastal models
- Model assessment metrics

Ocean data inversion and assimilation

- OSSEs, data access
- Hi-res forecasting systems

Tides, internal tides and IGW

- Hires tides models
- wave/non-waves interaction

Regional ocean science validation studies

- OSSEs, data access
- Model / data comparisons

OSSEs : Observing System Simulated Experiments

SWOT ocean instrument processing

- Data access
- Surface waves
- Hi-res geoids

...

Tides and Inertia-Gravity Waves Working Group

B. Arbic, F. Lyard, R. Ray, E. Zaron

2021-01-27: Zoom Teleconference, about 30 participants, 11 brief presentations

Propose to have a monthly meeting via Zoom for ongoing discussion and coordination.



Stammer et al., 2014

Model : HYCOM 1/12° Arbic et al., 2012

Tides and Inertia-Gravity Waves Working Group

Major themes from the presentations:

Field programs are planning to observe internal tides, their generation, and interactions with non-tidal flow and stratification; coastal and river tides are also being studied with the view of exploiting future SWOT data.

Numerical modeling with both idealized and realistic models will be used to complement field programs and study processes of interaction between tides and low-frequency motion, and interactions of coastal processes and deep ocean.

Data analysis with existing altimetry and other data is aimed at developing better descriptions of the signals we expect to see with SWOT data, so that we can identify surprises when the data become available; flow decompositions are being compared to define their utility for data assimilation and process studies.

Improving tide predictions is the goal of refined barotropic tide models in highlatitude and coastal regions; HYCOM/NEMO baroclinic tides are being assessed; next version of HRET baroclinic model is coming; improvements to prediction of minor tides are being implemented.

HRET : High Resolution Empirical Tide model

Field Programs and Numerical Modeling

Several projects involving extensive fieldwork and modeling were presented.

Example (at right) is from Cravatte and Gordeaux is shown.

Projects across the Science Team recognize the significance of baroclinic tidal signals anticipated in SWOT data.

In situ experiment: SWOTALIS (2022)



Discussion points

(1) Further **improvements to barotropic tide models** are increasingly costly to implement in terms of manpower, computer cycles, and new data (e.g., bathymetry) needed to achieve gains. Collaboration on improving coastal tide predictions is important.

(2) Our knowledge of the **spectrum of internal tide variability** needs to be put into a form which can be used by the community. This information is useful for designing data assimilation systems, for example.

(3) What is the **relationship of this WG to the SWOT Project Office**? When is the deadline for the selection of final BT/IT models for the initial GDR's? We want to coordinate our activities to insure that the tides-related products meet the expectations of the SWOT Project Office and the Science Team.

Near-Term Activities re: Tides

Barotropic Tides :

- Latest TPXO9.4 is being compared with FES2014 by Ray and Boy; overtides are greatly improved on the European Shelf.
- Zaron and Elipot published comparison of TPXO9.3 and FES2014. More minor tides will be included TPXO and GOT in the future.
- Development of FES2022 has begun, and GOT5 is in the works.
- Improvements at high-latitude with CryoSat-2 and ICEsat-2 are being studied.
- Exercise the capability of combining models from multiple groups into forthcoming TPXO Atlas solutions.

Baroclinic (stationary or phase-locked component):

- Carrere et al evaluation of baroclinic models was published in Ocean Science.
- A new version of HRET is coming which will incorporate GM data and surface drifter data.
- HYCOM tides skill assessment is ongoing by Arbic and Nelson.
- New study of dual-satellite crossovers by Zaron to quantify non-phase-locked tides.
- Several groups are evaluating approaches to estimating the baroclinic tides from SWOT-like data with both empirical approaches and models.

Model analyses:

• Arbic and collaborators, Rainville, Kelly, and Zaron are working on separate analyses of nonphase-locked tides in different numerical model outputs.

SWOT Data Inversion and Assimilation Working Group

Status and Plans February 2021

Emmanuel Cosme, Sarah Gille, Shane Keating, Pierre-Yves Le Traon

Challenges :

- SWOT has v good spatial resolution, weaker temporal resolution
- New techniques needed to reconstruct 2D SSH fields & maintain fine-scales / 3D balanced velocity fields



Working Group Status

Two one hour sessions in January 2021 :

- Session 1 (~30 participants): 13 lightning talks to inventory research activities:
 - Dynamic interpolation
 - 3D Variational assimilation
 - Machine learning techniques to separate signals (balanced/wave) & noise
 - Vertical projections from theory (eg sQG, omega equation)
 - 4D Data assimilation
- Session 2 (~25 participants): Discussion to identify common interests and opportunities for collaboration

2-line summary:

- +++: A large diversity of scientific questions, study regions, approaches, tools
- ---: Difficult to reach session 2 objectives in a plenary zoom format (and due to diversity).

Main work priorities over the next few months

- Form an exhaustive mapping of scientific questions, study regions, approaches, tools of interest to ST members
- Try to identify common interests and opportunities for collaborations with an incremental approach.
 - Example: sharing metrics and OSSE protocols & plans
- Collate interests by contacting ST members individually, and establish a few targeted activities.
- Activate communication channels: forum, regular zoom meetings.
- Connect with other Working Groups to coordinate efforts
 - Example: OSSEs and reconstructions on Xovers

Opportunities

Targeted regions (for example):

- Adopt-a-crossover locations (with Regional Validation Working Group?)
- California Current pre-calval and calval
- Other (in response to community interests)

Specific activities (possibilities):

- Address specific problems (mapping, BM/IT separation, etc) through data challenge framework
 - (e.g. <u>https://zenodo.org/record/4045400#.YBpTbOClbOQ</u>)



- Agree on structure of HYCOM and MITgcm fields for targeted regions
- OSSEs (e.g. to plan field work); using in-situ datasets on Xovers shared within SWOT-ST.
- Common diagnostics to intercompare different methods and different regions
- Common domains for specified regions to facilitate intercomparisons



SWOT Regional Ocean Science Validation Working Group

Kyla Drushka, Francesco d'Ovidio, Ananda Pascual and ~30 Working Group members

Join the listserv: email kdrushka@apl.uw.edu

Jan 26 2021 Working Group meeting

Discussion & presentations:

 State estimates, forward modeling, and pre-launch campaign:

Matt Mazloff, SIO (USA)

 BIOSWOT-Med, finescale physical--biogeochem. coupling:

Andrea Dogioli , MIO (France)

- Multi-platform sampling and 3D reconstruction: Ananda Pascual, IMEDEA (Spain)
- Geodetic validation in Bass Strait, Australia: Christopher Watson, U. Tasmania (Australia)
- SWOT-ACC validation site South of Tasmania: Benoit Legresy, CSIRO (Australia)
- SWOT field campaign around New Caledonia: Sophie Cravatte, LEGOS (France)
- OSSEs for Adopt-a-Crossover: Kyla Drushka, APL-UW (USA)



-1 1 3 5 7 9 11 13 15 17 19 21 23 25 Ocean Surface Temperature (degC) 06/11/2018



Adopt-a-Crossover (AdAC): a related activity

- Coordinated field campaigns are planned for the fast-sampling phase
- 11 experiments confirmed, led by different teams
- Unifying goal: quantify ocean dynamics on SWOT scales: O(1-100) km
- AdAC Consortium: a separate, international group to facilitate coordination, endorsed by CLIVAR
- Ongoing activities:
 - website (coming soon),
 - paper refining science objectives
 - model analysis and OSSEs

SWOT fast-sampling orbit and "adopted" sites with planned field campaigns



Working Group goals & priorities

- Liaise between the SWOT ST and the Adopt-a-Crossover Consortium
 - Provide information and relevant tools, models and data to the AdAC teams planning field campaigns
 - Ensure that AdAC experiments are relevant for SWOT
- Share model output and code in crossover regions
 - Collaboration with High-Resolution Modeling and Data Assimilation & Inversion Working Groups
- Identify in situ measurements needed by the SWOT
 ST (e.g., surface waves) and modeling community

Regional Ocean Science Validation WG plans for 2021

- Meetings every two months
- Form sub-groups to promote collaboration on:
 - 1. Regional field campaigns. Specific topics:
 - Science objectives
 - Key measurements
 - Sampling strategies
 - Data sharing

Contact: francesco.dovidio@locean.ipsl.fr

- 2. Regional model analysis. Specific topics:
 - Sharing high-res regional model output
 - Developing metrics and OSSEs
 - Sharing code

Contact: kdrushka@apl.uw.edu

SWOT Instrument processing : oceans & marine gravity

F. Ardhuin, F. Nougieur, D. Sandwell, C. Ubelmann, D. Vandemark

3 sub-groups ... SWOT processing and wind wave working group Mean Sea Surface (MSS) preparation Estimating and reducing errors

Zoom meeting, 02/02/2021 & 02/03/2021 (**bold:** speakers, slides are online, see link below)

Fabrice Ardhuin (LOPS), Lotfi Aouf (Meteo France), Alex Ayet (CERFACS), Laiba Amarouche (CLS), Jean Bergeron(CSA), **Bia Villas Boas** (JPL), Bertrand Chapron (LOPS), Bruce Cornuelle (SIO), Salvatore Dinardo (CLS), **Pierre Dubois** (CLS), Alejandro Egido (NOAA), Yannice Faugere (CLS), Luciana Fenoglio (U. Bonn), Lucile Gaultier (ODL), Sarah Gille (SIO), Christine Gommenginger (NOC), Adrien Martin (NOC), **Rosemary Morrow** (LEGOS), **Fred Nouguier** (LOPS), Ernesto Rodriguez (JPL), **David Sandwell** (SIO), Ngan Tran (CLS), **Clement Ubelmann** (OceanNext), Doug Vandemark (UNH), Yao Yu

Working group activities, google drive: <u>http://tiny.cc/SWOTW3G</u>

1) Mean Sea Surface (MSS):

MSS: Sub working group dedicated to improved MSS from altimetry (incl SWOT)

CLS/CNES, DTU, NOAA, SIO.

Figure : SSH Slope Error

The L-1 norm of the slope data w.r.t. to the mean slope model (5 m by 3 m cell) divided by the square root of the number of points.

Q. When is the deadline for the selection of MSS for the ⁻ initial GDR's?

Q. At SWOT launch, do we provide a long-term 30-year MSS to the Project or a more recent MSS (3-year)?



2) Significant wave height variability issues



For SWOT, **SWH** is derived from the **volumetric decorrelation** between the interferometric channels, or the height noise due to surface waves. We currently make 1 SWH estimate in the middle of each swath (+ nadir).

Wave models show small-scale variability. Globally, SSH error is small (within Project requirements). But locally?

What is the real number (3% is an order of magnitude, WW3 underestimates gradients ...)? If needed, what other wave proxy can we use? (e.g. cross-track grid of Doppler centroid) ?

Planned activities related to this question: Cal-Val with wave measurements (Lenain et al.), coupled numerical modelling with assimilation (SIO + JPL), interpretation of Doppler centroid & NRCS gradients (LOPS) ... Slide #24

3) Development of end-to-end ocean instrument simulations relevant to SWOT (talks by P. Dubois and F. Nouguier)

One goal is to adapt tools built for SAR, SKIM, CFOSAT, DDA applications for use on SWOT wave-impacted SSH and OBP data evaluations



4) Limited HR data over the ocean : phenomenology

High resolution data in the open ocean is VERY noisy for SSH measurements. However, there may be some need for checking assumptions on SSH-NRCS or SSH-SWH correlations. That will only make sense if dedicated effort is planned and organized.

As of today, expected HR data download sites during 1-day orbit (as presented in 2015!):



We intend to discuss short-scale ocean process reasons for collecting HR ocean data elsewhere during the 1-day & 21-day orbit phases.

Deadline : June 2021 HR mask decision date.

This will be one subject for March or April group meetings

Summary : SWOT processing and wind wave working group

New working group just started ... not yet discussed everything...

A wide range of issues:

- "Large scale" slopes (SSH) : mean sea surface to derive anomalies, SWOT-specific errors (eg roll/phase/random errors), alongtrack signal/noise estimates.
- **Small scales** : very few detailed instrument simulations over ocean, possible limitations due to hypotheses:
 - Group will be looking for more cross correlated information from field observation program and simulations in terms of surface waves, wind, currents, and SSH slope at scales of 100m to 100 km
 - SWH estimation or other wave proxy is a key part of the processing: group will review proposed L1 & L2 ATBDs.
 - Mitigation Algorithms : A cross-track grid of Doppler Centroid could be a very beneficial addition (linear trend proposed now mixes very different incidence angles with very different errors on DC, see Marie & al. 2020)
 - Consider internal waves / low winds as one target topic for short scale cross correlation analyses => could justify moving some HR acquisition location if dedicated analysis effort organized.



Moving Forward : New Ocean Science Team : Working groups

SWOT Ocean Working Groups are organising into 1-2 month virtual meetings

=> AVISO+ SWOT Forum

- A shared folder for sharing presentation material and notes
- a communication platform to foster exchanges (restricted discourse forum for SWOT ST members and associates)
- organized at the SWOT Science Team level (to foster exchanges across groups)

=> Exchanges with Project and Algorithm Development Team (ADT) advancement via the SWOT Subject Matter Experts (SMEs) and the Science Leads

SWOT Ocean science advancing in parallel – more science discussions at our next meeting – June 2021 !?

Ocean CalVal preparation : many strands, ocean in-situ campaigns need longer lead time –> presentation tomorrow







SWOT Ocean material

- Recent SWOT Ocean review articles :
 - Rodriguez et al 2017 : Wide-swath altimetry : a review. In "Satellite altimetry over oceans and land surfaces" CRC Press
 - Morrow et al., 2019. Global Observations of Fine-Scale Ocean Surface Topography With the Surface Water and Ocean Topography (SWOT) Mission. Frontiers in Mar Science
 - d'Ovidio et al., 2019. Frontiers in Fine-Scale in situ Studies:
 Opportunities During the SWOT Fast Sampling Phase. Frontiers in Mar Science
- SWOT publications may be found at <u>http://swot.jpl.nasa.gov/science/publications/</u>.
- Info : SWOT Mission, orbits, data products, Science Team : <u>http://swot.jpl.nasa.gov</u> & <u>www.aviso.altimetry.fr => swot</u>
- SWOT Ocean Simulator (orbits & errors) : https://github.com/SWOTsimulator

Key SWOT ST Ocean achievements 2016-2019

- Better regional, basin-scale, global **models of fine-scales** including highfrequencies : tides, internal tides & internal gravity waves
- Role of small/sub-mesoscales active in the deep winter mixed layers, feeding energy to larger summer mesoscales. Role in net upward heat fluxes below the mixed layer, driven by mesoscale strain.
- Estimating & reducing SWOT errors globally, regionally & seasonally
- Better understanding of alongtrack altimeter 1-D SSH observations to 30-50 km – compared to HR models. Transition scales between mesoscales, internal tide cascade, error levels
- Synergy of multi-satellite data to separate ocean dynamics, and understand interactions
- Unique SWOT observations of **wave-current interactions** at fronts
- Wide range of **reconstruction techniques** investigated to maintain finescales in 2D & 3D maps of SSH, velocity
- **CalVal preparation** pre-launch campaigns and CLIVAR-endorsed adopta-crossover initiative.





