SUMMARY AND RECOMMENDATIONS

WORLD OCEAN CIRCULATION
USER CONSULTATION MEETING

21–22 February 2019 | ESA–ESRIN | Frascati (Rome), Italy

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European Space Agency
Lumpkin presented recent efforts extending Lagrangian observations to study high-frequency and submesoscale processes and illustrated them with preliminary results.

Le Sommer et al. Overviewed the current state of surface currents in numerical models (good at >100km) and discussed how the progress (toward a km scale) will depend on application needs and sufficiency of observations.

Johannessen et al. Overviewed the current state of Globcurrent project and discussed ongoing and future efforts that will improve description of dynamical balances by refining to smaller scales, using prospective satellite missions and expanding applications.

Morrow overviewed how the SWOT mission (coming in 2021) will improve existing ocean current products (in WBC, near the equator, etc.) by resolving submesocale (SSH at 20 km effective resolution and 250m backscatter pixel) and also how it will study other such processes as tides in coastal areas, internal tide, currents is sea ice lead and freeboard.

Ardhuin overviewed physical principles and currents status of the SKIM (the first candidate mission to measure “directly” surface currents and their interaction with waves). If successful, the mission will provide data on a 30km and will dramatically improve applications addressing dynamics of the ecosystem, weather, and climate.
Chairs: Gus Jeans and Anton Ellenbroeck

- **Defining user needs and priorities:**
  What are the key user needs that ESA should address?
  What are the short term development priorities from a user perspective?

- **Linking Research activities to downstream users needs:**
  How do we effectively focus research on the future needs of the ocean economy?
  How to effectively deliver information to downstream consumers?

- **Involving new users**
  How to enlarge the user communities?
  How can Ocean Current Data assist countries with achieving their Sustainable Development Goals (SDGs, in particular SDG 7 (Clean Energy), SDG 13 (Climate Action) and SDG 14 (Life below water)?)
Session 2 User Needs for Downstream Applications – DISCUSSION SUMMARY

Recommended ESA Priorities

- Further improve rapid delivery
- Support for SKIM and related concepts
- Improve reliability in near shore areas with many users
- Provide high quality data for intermediate users to serve end users
- Data portals to improve and expand user access
- Highlight contributions to the UN Decade of Ocean Science and SDGs
Further User Engagement

- Promote two way communication and partnership
- Highlight mutual benefits of data sharing for validation
- Build on success of Future Earth forums
- Develop user case study library
- What uncertainty is acceptable and how should it be quantified?
- What is industry best practice?
What are key gaps in our understanding that can be addressed with surface velocity data?

What is needed in term of ocean surface velocity to advance our knowledge on global energy budget including momentum transfer and heat fluxes?

How can we advance the quantitative insight on how processes influence energy pathways, buoyancy budgets, vertical motions and physical-biology interactions in the upper ocean?

What controls the structuring and concentration of floating material?

How can we best combine ocean color and physical products in a useful way?

Which temporal and spatial domains should we prioritize? Resolution, coverage, regions, etc.
Session 3 Ocean Currents needs for Scientific studies – DISCUSSION SUMMARY

- Wide range of applications including biogeochemistry and ecosystem dynamics, microplastic litter/debris, equatorial dynamics, ice drift, near-coastal processes, mesoscale and submesoscale dynamics, frontal processes, vertical shear

- Discussion focused on importance of velocity data to improve process understanding with emphasis on
  - Separation into geostrophic, ageostrophic (Ekman, tide, inertial ...) velocity and Stokes drift
  - Equatorial velocity and equatorial waves and their role in climate
  - Surface velocity gradients (divergent and rotational component), frontal dynamics, water mass pathways
  - Heat, salt and tracer budgets in the mixed layer, near surface advection
  - Air-sea interactions (velocity wind feedback)

- Validation of numerical models and assimilation products
- Development/improvement of 3D velocity fields including vertical velocity by using additional information
- Combination of different satellite data and using synergies (SSH, SST, SSS, color etc.)
- Importance of reliable error estimates for user application
- Importance of validation campaign for SKIM, better use of Lagrangian velocities; relevant processes should be simulated in a single consistent model
To what extent do existing satellite ocean current products provide the information needed for the modelling community? What developments are needed to stimulate and develop the exploitation of satellite products by modelling communities?

How can surface velocity be used to validate models or to improve reanalysis products (on which time and space scales)? What are current limitations?

How do satellite-derived ocean current products relate to in model representations of the 3D structure of the upper ocean circulation? How mature are today’s methods to combine satellite and model data, or to assimilate new ocean surface data types into models?

Are we ready to assimilate surface currents? What are the possible improvements/drawbacks in adding the assimilation of surface current?

What is the impact of assimilation on the vertical velocity? It is shown to be higher the day after assimilation due to inconsistency between increments and model dynamics.
Satellite current products can provide information to both Ocean Modelling and Data Assimilation communities

- Assess the realism of non-assimilated ocean models, especially at scales <100km (obs. requirement depends on the process to assess (e.g. energy fluxes, vertical motions, high frequency wave motions)
- Assess the quality of assimilated systems a posteriori (obs. requirement depends on the targeted operational system - a possible rationale is for instance to match the spatial resolution of the future global CMEMS system)

Assimilation of surface current: are data assimilation methods ready for the direct assimilation of ocean surface currents (vector variable, divergence, frequency content)? Which improvement do we expect in representing the surface and upper layer dynamics?

Further investigations are needed in order to know the status of existing methods and to prepare the assimilation of surface currents.

Spatial resolution, frequency and quality / 3D velocity structure of in the upper layer or deeper, vertical velocity / global vs. regional applications (Ekman, geostrophy, tides, waves, etc.)
**SEED QUESTIONS**

- How well can we quantify the contributions to ocean circulation by ageostrophic processes such as tides, winds, Stokes, submesoscales, etc, in the open ocean, shelf seas and the coastal zone? Which of these are most critical to users, where and why?

- How are existing ocean surface current products impacted by unresolved small scale processes within the observation cells e.g. submesoscale fronts, filaments, sharp current gradients and changes in surface waves? How are these affecting our understanding of atmosphere-ocean coupling? What types of ocean observations are needed to fully characterise air-sea interactions?

- How to fully benefit from novel ocean wave measurements (unprecedented spectral and spatial coverage) and how to combine them with other data (sea level, circulation)?

- How to best improve ocean circulation forecasts (especially at regional or coastal scales): by assimilation data (applying novel DA techniques) or advancing in understanding and implementing novel waves-current interaction processes? How can Earth Observation data help in this process?
Strong impact of surface currents on winds at large scales, particularly in Equatorial regions
- Identified need to get new high-resolution data to study wave-ice-current interactions in ice-covered seas
  - Cryosat-2 altimeter wave data quality in sea ice regions affected by presence of ice

Ocean currents important for ocean waves on global and small scales
- E.g. areas of strong currents, also affecting predictability of rogue waves
- Critical importance of timeliness for operations!

Develop internal wave crest feature recognition products for various satellite sensors
- Value of developing atlas of internal waves? And perhaps other small scale processes too

Multi-sensor comparisons become more difficult for small scales because of sensors increasingly flying on different platforms (acquisition time separation becomes important factor)
- New validation methods and assessment approaches are needed to exploit high-resolution satellite data
Need to develop confidence flag about dominant processes in different regions (recommendations for users)
- Develop added-value products e.g. statistics to add to existing visualisation tools (e.g. from GlobCurrent)
- Example: S1 crossing sea index could be of interest for shipping industry

Recommendations that ESA should **urgently** re-process Sentinel-1 Doppler Centroid data (RVL, Radial velocity information containing both the ocean current and sea state contributions)

There are a lot of high-resolution data acquired (e.g. S1) but, in reality, products are not available to users
- E.g. no S1 wave data products in European Seas
- L2 processing algorithms exist. They should be applied and products distributed
What is the status and the main challenges of the synergetic use of SSH, SST, SSS, OC for ocean currents retrieval?

To what extent can we still improve current retrievals from present observations? Which effort is prioritary/more relevant?

Several ocean current retrieval algorithms rely on classical statistical (interpolation/regression) techniques. What is the status and potential of exploiting Machine Learning/Artificial Intelligence algorithms for current retrievals and/or synergistic approaches?

At scales below 200 km, the ocean SSH has a non negligible contribution from high frequency motions (internal waves, internal tides), which affect different scales in different regions, but are not predictable today. How should the new mapped altimetric geostrophic currents be calculated to minimise these high-frequency motions?

Which efforts are more relevant to fill the present knowledge gap in key ingredients of coastal altimetry (barotropic and baroclinic tides, mean sea surface, sea state bias)?

How can the synergetic use of EO techniques (including SST, SSS and currents from SAR images) help the validation and interpretation of 2D SWOT data for spatial scales below 150km?

Future/proposed new satellite sensors (e.g. SWOT, SKIM, STEREOID...) will provide unexplored observation capabilities but also pose new challenges: which processes will be key to consider to allow accurate retrievals?
FINE-SCALE OCEAN CURRENTS, INCLUDING THE COASTAL ZONE

While progress has been made on the quality of along-track altimeter sea surface heights and geostrophic currents offshore and in the coastal zones:

- **Better and dedicated gridding is needed for the small, fast movements**, together with a clear description of the procedure and the corrections applied to produce the gridded product.
- Consistent processing techniques are needed for a smooth transition from offshore to the coastal region.
- **Improved bathymetry** is needed to improve the knowledge of barotropic tides at the coast.
- **Internal tides** need to be corrected or filtered before calculating geostrophic currents.
FUTURE MISSIONS

- SKIM and SWOT will have improved 2D spatial resolution but will not describe the rapid temporal evolution. **The time resolution therefore remains an issue.** Combining multiple along-track altimeter missions with other satellite SAR/SST/SSS data is one solution, but efforts should be coordinated at agency level in order to achieve **optimum space-time coverage.** In addition, it is necessary to take full benefit of existing coastal HF-radar operations, which offer diurnal sampling.

- From SWOT and SKIM great challenges arise, at the limit of our understanding of the ocean physics. However, there are **ample possibilities to improve our understanding of fine-scale upper ocean dynamics at mesoscale to submesoscale with synergetic use of multiple data.**

- A **strong support for the EE9 candidate SKIM mission** (selection meeting in July 2019) has been expressed by the World Ocean Circulation User community. In addition, NOC welcomed support for the SEASTAR mission.
Session 6: Ocean Currents retrieval

DISCUSSION SUMMARY

FOCUS OF FUTURE PROJECTS

- The community recognizes the future need of measuring the total surface current, but also the fact that we currently differentiate between the ageostrophic from the geostrophic components. **Limits of geostrophic (but also Ekman) approximations need to be better assessed** especially when going to the fine-scales, considering the possible presence of both fast and slow unbalanced motion and complex interactions in the upper boundary layer and at the air-sea interface. Adapting our retrievals to the proper approximation depending on the scale considered is a key challenge.

- Surface currents detected from different satellite sensors (Doppler currents, altimetry, SAR fronts) represent different processes in the vertical – we also **need to better understand the vertical structure, with colocated in-situ currents at different levels**. In this respect it will be highly important to secure reprocessing of the Sentinel-1 A/B range Doppler from 2014.

- A point was raised to understand whether future funding efforts should privilege regional or global approach. **Global observations are the force of this community and should remain central**. Turnout for the ESA member states must be guaranteed, but our interests are often global too. A possible solution could be to keep a global perspective while finding specific high-interest locations to be used as testbeds to compare different approached.

- Further points include the requests to encourage the transition from research projects to operational use of data (e.g. GlobCurrent near real time products now within CMEMS) and to **provide error estimates and the description of the methodology used to estimate the signal and errors**.
BIG DATA

- Virtual research environments allow science users to directly work on data stored at agencies or data centres, allowing exchanges of programs and routines in open source. This is also the way to coordinate the interdisciplinary efforts that characterize this community. The use of a virtual data lab avoids the need to download huge amount of data. Access to advanced visualization platforms, such as ODL Virtual Laboratory, with overlay and colocation capabilities of satellite and in-situ data as well as model fields are also highly valuable.

- The Community needs to exploit the potential of new computing capabilities, in particular AI or machine learning, without forgetting that it is fundamental to understand the kind of data we use to feed these methods.