# Summary of *The Future of Altimetry* Session

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## Introduction

The Future of Altimetry session was split in two parts. The first part, a symposium splinter session, chaired by Eric Lindstrom and Hans Bonekamp, consisted of several presentations on specific programmatic, scientific and technological developments. The second part, chaired by Jean-Louis Fellous and Stan Wilson, comprised a plenary session, initially with keynote speakers again highlighting the main themes for the future, and then concluding with a round table discussion – which resulted in the development of a set consensus recommendations concerning the future of altimetry.

## Summary of Part 1

The splinter session started with a summary of the recommendations of the European Community GAMBLE project conducted in 2002-2003 (see presentation given by T. Allan on behalf of D. Cotton). In brief, the GAMBLE project emphasised that single satellite coverage is not sufficient to meet both the operational and scientific user needs. Rather a constellation of at least 3 nadir looking altimeters is needed to provide the sampling required for many practical purposes. The GAMBLE project also particularly stressed the need for the demonstration of new technology such as wide-swath altimeters or larger constellations of altimeters on micro-satellites. The latter could prove to be also very effective in the timely deliverance of sea state information and in warning for natural hazards (see presentation by T. Allan).

An important topic for the future of altimetry is the ongoing transition towards operational services. In Europe, a leading initiative is the GMES program to develop a coordinated operational environmental information service, partly based on space infrastructure. For the GMES core marine services, the operational GMES Sentinel-3 mission will deliver key information on, as examples, sea surface topography, sea-surface temperature and water quality (see presentation by M. Drinkwater). The planned 20-year operational phase of GMES Sentinel-3 is currently foreseen to start in 2011 with the first of a series of 3 satellite launches. In the nearer future, the main planned operational mission is OSTM (or Jason-2); a mission conducted by space agencies NASA and CNES and the operational organizations, NOAA and EUMETSAT. OSTM prolongs the TOPEX/Poseidon and Jason-1 series and as such enhances the operational status of the current altimetric services for climate monitoring and operational oceanography. For the longer term, EUMETSAT as a leading European operational organization is offering its capacity for the operation of some of the proposed future operational missions, such as GMES Sentinel-3 and possibly OSTM follow-on for which, together with partners, funding has to be pursued (see presentation by H. Bonekamp).

Scientific developments were expressed in the Future of Altimetry splinter session, both in terms of both new technology and demonstrating missions. The splinter session gave a precise overview of the main altimeter developments and indicated the recent preference for Ka-band altimetry (see presentation by L. Phalippou). In particular, CNES is now proposing its first AltiKa mission with a foreseen launch mid 2009 aiming at filling the possible service gap after ENVISAT RA-2 and complementing OSTM for the resolution of ocean meso-scale variability (See presentation by J. Verron). The platform for AltiKa is still to be decided (possibly Oceansat-3). AltiKa, which is basically proven technology, will enhance accuracy and sampling capabilities in coastal regions and will improve continental ice-sheet monitoring, though possible loss of observing capacity under rain and some cloud conditions has been discussed as a concern.

Considerable scientific progress is expected from Wide Swath Interferometric Altimetry, not only by resolving smaller scale ocean variability, but also by providing a truly a two-dimensional sampling of hydrological systems. In August 2005, a consortium with over 150 participants of the wider hydrological science community has submitted the WatER proposal to ESA's living Planet program (see presentation by N. Mognard). The proposed mission (to be flown after 2010) will contribute to a fundamental understanding of the global water cycle by providing global measurements of terrestrial surface water storage changes and discharge. The main instrument of WatER mission is the Wide Swath Ka-band Radar INterferometric altimeter (KaRIN), which could map rivers, lakes and wetlands with a spatial resolution of ~100m and a height accuracy of 5-10 cm (see presentation by E. Rodriguez). The performances of interferometric radar altimeters have been extensively studied and a sun-synchronous orbit is favoured for wide-swath altimeters (see presentation by V. Enjolras). A point of further issue needing clarification in the near term is how well a single Wide–Swath altimeter could meet the requirements for both the oceanographic and hydrological communities.

Finally, higher resolution is needed not only for progress in mapping ocean meso-scale variability and hydrological systems, but also to make the next advances in geodetic and bathymetric mapping using space altimetry. Studies have shown that these advances could be realised in highly cost-effective manner with a delay-Doppler radar altimeter technique and a micro satellite mission (see presentation by W. Smith).

**Summary of Part 2**

The second part of the Future of Altimetry session, a plenary featuring a set of keynote speakers, began with a presentation by D. Alsdorf that identified a fundamental problem in understanding the global water cycle, namely, the measurement and prediction of fresh-water flows across floodplains and wetlands. The lack of a capability to measure water elevations and their changes over time and space is limiting our ability to model and hence predict the hydrologic, ecologic, and societal consequences of floods. Both point-based stream gauges and profiling satellite altimeters are not capable of providing the requisite broad areal coverage. Such a capability is being proposed by the (previously mentioned) WatER Mission, and a key feature of this mission is the Ka-band Radar INterferometer (KaRIN) which is capable of delivering the required high-resolution two-dimensional measurements.

The second presentation, by D. Sandwell noted that our current understanding of the topography and tectonics of the ocean basins is largely derived from dense satellite altimeter measurements of the marine gravity field combined with sparse geophysical measurements from research vessels. Data from ERS-1 and GeoSat have not only provided a confirmation of plate tectonics, but also partly revealed smaller-scale structures such as thousands of seamounts. Additionally, the dense gravity information has been combined with sparse ship soundings to construct global bathymetry maps at ~10 km resolution – a great improvement over hand-drawn maps but still far worse than our current maps of Mars, Venus, and the Moon. While these data have filled a huge gap in our understanding of the ocean basins, they also identified a need for an additional factor of 5 improvement in gravity accuracy that can only be achieved with third generation altimeters. Such an improvement would enable resolving the fine-scale tectonic structure of the deep ocean floor, measuring the roughness spectra of the global seafloor to better constrain models of tidal dissipation and mixing, and resolving the fine-scale gravity field for research and exploration.

The next presentation by D. Wingham concerned the use of satellite altimetry to study the cryosphere. With almost 80% of the Earth's fresh water locked up in its frozen state (i.e. snow, ice and permafrost), the cryosphere plays an important role in moderating the global climate – and as such, the consequences of receding ice cover due to global warming are far reaching and complex. The present ICESat (Ice, Cloud and land Elevation Satellite) and the forthcoming CryoSat-2 mission will, among other things, provide capabilities to monitor changes in the elevation of polar ice caps and thickness of sea ice – helping us determine whether our ice masses are thinning due to global warming. No other observational capability can provide the global coverage offered by satellites.

The presentation by P.-Y. Le Traon focused on the observational needs of operational oceanography, noting that a central objective for future altimeter missions will be to provide data to complement those from *in situ* systems. Such observations are required for assimilation into models to provide integrated analyses of the ocean and forecasts of how it will change. On the broad-scale, the unique contribution of satellite altimetry to provide observations of the surface pressure field, together with the upper-ocean density field from ARGO floats, is enabling the implementation of operational oceanography on a basin- and global-scale. However, meeting these needs requires continuation of the Jason-class series of satellite altimeters.

The next-to-last presentation was by L.-L. Fu who noted that, in spite of the revolutionary impact radar altimetry has achieved over the past quarter century, its sampling capability has always been a compromise between the spatial and temporal requirements. As a result, high spatial resolution can only be achieved in the along-track direction, leading to asymmetry in the radar's mapping capability. Given the new technology demonstrated by the Shuttle Radar Topography Mission for mapping land topography using radar interferometry, he proposes using the same technique with synthetic aperture radar to achieve spatially uniform high resolution for mapping the ocean surface topography. With such a technique, an intrinsic resolution in the range of tens of meters and, after spatial averaging, centimetric precision at 1 km resolution appear achievable. Thus, for the first time, ocean eddies which account for 90 % of the kinetic energy of the ocean could be fully resolved from space. This new measurement could enable the calculation of ocean surface currents and marine gravity anomalies with much improved accuracies. It could also be applied to mapping the elevation of water surface on land, as well as the free board of sea ice and elevation of land ice. The next step here would be assessing the extent to which this single observing system would be able to meet such a variety of user needs; and to the extent that it can, this could result in assembling a potentially powerful coalition of users to promote such a capability.

The final presentation by J.-M. Lefèvre concerned measuring waves on the surface of the oceans from space. As noted by P. Janssen in an earlier talk during the Symposium, ECMWF has been assimilating radar-derived observations of surface waves into its operational wave forecasting system since 1993. Radar altimetry has enabled wave forecasting to become one of the (if not the) first components of operational oceanography. Now, our challenge is to ensure that a continuing series of altimeters will fly, with no gaps in coverage, to sustain operational wave forecasting.

**Summary of Round Table Discussion**

Following these presentations, a round table discussion was held; it involved all keynote speakers (except that D. Anderson replaced J.-M. Lefèvre) plus Prof. Jean-François Minster as panellists, with J.-L. Fellous (ESA/CNES) and S. Wilson (NOAA) serving as moderators.

Introducing the round table discussion, the moderators highlighted some of the issues related to transitioning research to operations. Some[1] have compared the challenge of bridging the gap between research and operations to "crossing the Valley of Death", as it is perfectly illustrated by the recent story of satellite altimetry. Forthcoming data gaps seem unavoidable – between Jason-1 and Jason-2/OSTM, between Envisat and Sentinel-3, and beyond Jason-2 – as there is currently no approved plan for a *Jason-3*.

More generally, the ocean community is pursuing a series of major objectives with regard to observations:

- Establish a sustained, systematic global ocean observing, assimilation, analysis and forecasting capability ("Operational Oceanography"),
- Ensure the availability of "Fundamental Climate Data Records", in accordance with the GCOS Implementation Plan in support of the UNFCCC (and the GEO/GEOSS *Climate Societal Benefit Area* requirements),
- Demonstrate new concepts and fulfill observing needs for emerging applications, and
- Transition demonstrated observational capabilities from research to operational status.

The first objective – establish a sustained, systematic (*i.e.*, operational) capability for the oceans analogous to what has been available for the atmosphere for decades – represents a central challenge. Such a capability should be able to:

- Collect global observations of key ocean variables and boundary conditions from both satellite and *in situ* systems,
- Assimilate those observations into analyses and models, and
- Utilise those models to provide global forecasts, which in turn provide a context for detailed regional and local forecasts.

Our challenge is to justify such a capability in terms of the societal needs it serves and the benefits it provides. However sufficient justification for sustaining the observational components – particularly the satellites – has *not* yet been made.

The concept for a Global Ocean Observing System has been developed in detail; it should provide a basic physical framework spanning ocean basins for:

- Extending to ecosystem modeling – *i.e.*, adding the biogeochemistry,
- Nesting of high-resolution, place-based (*i.e.*, coastal) and event-based (*i.e.*, hurricanes), models, and
- Assessing the impact of the oceans on the atmosphere on short, intermediate and longer time scales.

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[1] "From Research to Operations in Weather Satellites and Numerical Weather Prediction: Crossing the Valley of Death", Board on Atmospheric Sciences and Climate, Commission on Geosciences, Environment, and Resources, National Research Council, National Academy Press, Washington, D.C. (2000).

While the U.S. has not yet established an organisational focus for such an *operational* global ocean capability, several European countries (including France, U.K., Italy, Norway, Greece…) have; and, with the European Commission and ESA, are engaged in a strategic approach to operational oceanography through the GMES initiative (MERSEA, GMES Marine Core Services).

The initial observational elements, as well as critical issues associated with each, are:

- Two *key state variables* for the oceans:
    - Upper-ocean density field – The global array of 3,000 Argo profiling floats (now over 80% in place), with full global coverage anticipated in 2007.
    - Surface pressure field – Following Jason-1 and Jason-2/OSTM, a new start in NOAA/EUMETSAT is needed for a Jason-3.
- A key boundary condition for the ocean:
    - Surface stress field – Following the ERS-2 wind scatterometer and QuikSCAT, ASCAT on METOP (launch 2006) and CMIS on NPOESS (launch 2013) are planned; how well will these techniques meet operational NWP and ocean forecasting needs?
- A key non-physical variable:
    - Near-surface chlorophyll-a – The central issue is how to implement the collection of scientific-quality data records spanning from SeaWiFS, MODIS and MERIS to the ocean colour sensor on Sentinel-3 and VIIRS on NPP/NPOESS.

Beyond the operational needs, the keynote speeches also highlighted the importance of emerging requirements, which include in particular, hydrology, geodesy/bathymetry, near-shore observations, and innovative concepts – including constellations of micro-satellites, wide swath/SAR altimeter, GNSS reflections, trade-offs to Jason reference orbit, etc.

These inputs triggered a lively discussion with the floor. Questions related to a number of topics, such as (among many others):

- Interfacing with the users: R. Stewart noted the absence of ship operators or fishermen. J.-F. Minster explained the European approach to implementing the GMES interface to users, through decomposition of the user base as a function of needs. It was suggested that researchers should attend users meetings. Continuity of service remains key in getting attention and support from users. However, one should recognise that even if (some) users are ready to buy a service, there is no way that they could cover the costs of infrastructure, which has to be paid by public funding.

- Improving awareness on our goals and objectives: D. Anderson observed that we have to learn from other communities (*e.g.*, ice community) and urged oceanographers to draft their goals so that they could write it in *three lines on a postcard*. It was said that our message is not heard because there are too many messages from a number of sources (GOOS, GCOS, GEO/GEOSS, CEOS), which makes it essential to ensure strict consistency. It was noted that even though planetary exploration (*e.g.*, Mars Rover) attracts much public interest, recent surveys show that people choose ocean by 2 to 1! However, we have better images from Mars than from the ocean floor. J.-L. Fellous objected to the noted *lack of money flow* and cited the recent decision of ESA member States and the European Commission to start the development of a family of operational satellites, the Sentinels, with an unprecedented over-subscription of the program proposal by 25%!

- The continuing need for high-precision altimetry with the same reference orbit: this does not matter for fishermen, but is still crucial for coupled models and climate. The case for denser coverage was also stressed. S. Wilson suggested that the best way to address the funding issue for the long term could involve looking for a combined satellite mission that met the needs of both continuity and denser coverage. Also it was repeated that no operational system can survive if it is not anchored to research, enabling an attack on new problems, a validation of observations and the development of future systems.

This Round Table discussion concluded and resulted in the development of the following *Statement*, which was unanimously adopted.

**Statement From**
***THE SYMPOSIUM ON 15 YEARS OF PROGRESS IN ALTIMETRY***
**Venice, 16 March 2006**

The past 15 years of satellite altimetry has enabled remarkable advances in a variety of disciplines. With these advances in mind, the 510 attendees from 30 countries at this Symposium offer the following consensus recommendations to sustain and advance our capabilities in satellite altimetry.

**Recommendations:**

1. Recognising the importance of monitoring climate change – as reflected in the GCOS requirements that have been endorsed by the UNFCCC and GEOSS, as well as new products and services enabled with the advent of operational oceanography – which underpin European GMES Core Services,

   (a) **Maintain continuity of the high-accuracy Jason altimetry time series** established by TOPEX/Poseidon and Jason-1, and being continued with OSTM/Jason-2, through implementation of a Jason-3; and at the same time,

   (b) **Maintain continuity with altimeters on at least two complementary, high-inclination satellites** – such as the present GFO and ENVISAT and the future Sentinel-3, AltiKa, and NPOESS, with the option to reactivate ERS-2 when needed.

2. Recognising the significant potential of emerging technologies required to facilitate new discoveries in geophysics, mesoscale and coastal oceanography, and terrestrial hydrology, **extend the capability of altimetry to denser observational coverage through the development of swath altimetry.**

3. Recognising the importance of data policy to the dramatic impact that TOPEX/Poseidon and Jason-1 continue to have in a variety of fields, **maintain an open data policy – with timely access, including near-real time data distribution for operational purposes –** to calibrated and quality controlled data for the benefit of all users.

4. Recognising the critical role that it plays, especially in satellite altimetry, **any operational system – must be well grounded in, and maintain a continuing partnership with, the scientific community.**

5. Recognising the benefits of joint efforts as exemplified by ERS-1 & -2, TOPEX/Poseidon, GFO, Jason-1, ENVISAT, and OSTM/Jason-2, **broad collaboration between engineering and science, research and operations, and international partners must be maintained** in future endeavours.

**Recommendation for a change of ERS-2 orbit**
**(following Venice Symposium round table discussion)**

**P.Y. Le Traon**
**March 20, 2006**

Over the past 5 years, major advances have been achieved to develop global operational oceanography, in particular, in Europe through GMES. Operational or pre-operational global and regional systems are now providing regular description and forecast of the ocean state. Such descriptions are needed for a wide range of applications (e.g. marine safety, pollution monitoring, offshore industry, fishery management) as well as for ocean, climate and ecosystem research. Operational systems critically depend on the availability of high quality altimeter data. Most applications require high resolution sea level observations to analyze and forecast surface currents (e.g. pollution monitoring). Over the past 3 years, the ocean was well observed with 4 altimeters flying simultaneously (Jason-1, ENVISAT, TOPEX/Poseidon and Geosat Follow On). Only three altimeters are now flying and Geosat Follow On will not last for very long. With only two altimeters (Jason-1 and ENVISAT), operational oceanography services will be severely degraded. Research on mesoscale variability (e.g. long term monitoring of ocean eddies) will also be hampered by the lack of resolution.

We are in a transition period where operational services are now being implemented as part of GMES Marine Core Services. There is a high risk to fail without an adequate altimeter observing system. We thus recommend using ERS-2 altimeter data over the next two years (e.g. up to Jason-2 launch) to provide together with Jason-1 and ENVISAT an adequate sampling of the mesocale variability. This could be done by shifting ERS-2 35-day orbit to ensure a time lag of 8 days with ENVISAT. Improved real time coverage (with additional ground stations) will also be required although the real time coverage of the North Atlantic is already acceptable.