

*Editorial*

## **Introduction to the Special Issue on "Satellite Altimetry: New Sensors and New Applications"**

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Spaceborne radar altimeters provide information on the Earth's surface by transmitting a series of radio-frequency pulses and recording their echoes. Although the beamwidth of the instrument is typically more than a degree, a finer ground footprint is achieved by only recording the return within a narrow window. Geophysical information on the sub-surface pixel is then derived from analysing the characteristics of the return signal, known as a 'waveform'. The delay in return of the signal indicates the mean height of the feature below the instrument (once a large number of corrections have been applied); the amplitude of the signal records the backscatter strength of the target, which is dependent upon the surface type and its roughness. Finally the shape of the waveform contains information on the variations in topography within the footprint. Further details about the principles of altimetry are given by Chelton et al. [1].

The first spaceborne test of the concept was on Skylab in 1973. This was followed by Geos-3 (1975 to 1978) and Seasat (1978), which, although it only lasted barely three months, marked such an advance in instrument performance and accuracy that it spawned many applications. Over the succeeding 30 years further radar altimeters have been built: Geosat (launched 1985), ERS-1 (1991), TOPEX/Poseidon (1992), ERS-2 (1995), GFO (1998), Jason-1 (2001) and Envisat (2002). Over this period there has been considerable advance in precise orbit determination, modelling of tidal and other corrections, and improvement in tracker algorithms to allow retrieval of information across rapidly-varying terrain. Together, these instruments have led to dozens of new applications spanning oceans, land, ice and atmosphere, and formed the basis of thousands of papers, including various journal special issues. An idea of the quantity of refereed papers, and the breadth of application can be found from the online catalogue [2] maintained by JPL. Altimetry data over the ocean have become so widely-used in oceanography that they are seen as essential for continued monitoring of our environment, including near real-time applications [3] and studies of long-term changes in global sea

level and wave height, as well as for forecasting of currents and wave conditions via assimilation into models. This has led to a strong push for maintaining our current altimetric capabilities, as exemplified by the support for Jason-2 by the operational agencies, NOAA and EUMETSAT.

However, many developments are being proposed to enhance the quality and coverage of data from altimeters. This special issue is dedicated to some of those new concepts, plus the efforts required to quality control and combine data from multiple missions.

For many oceanographic studies, it is found that one altimeter alone is insufficient to give the spatio-temporal sampling necessary for mapping the mesoscale variability. At various stages between 1992 and the present there have been between two and five altimeters in operation, but the only occasion that orbits have been deliberately configured for joint mapping is during the last few years of TOPEX when it was placed in an interleaved orbit with Jason. However, plans for a three-satellite mission, WITTEX, have been developed in some detail [4]. In one of the papers in our satellite altimetry special issue, **Allan** [5] explains the need for, and potential of, a much larger constellation of low-cost microsattellites. A particular emphasis of this article is how such a concept could provide better real-time detection of extreme events such as tsunamis.

Most altimeters to-date have relied on frequencies in the range 13.5-14 GHz in the  $K_u$ -band, which sets requirements on the size of antenna and the power and electronic circuits required to get useful radar echoes from ~1000 km above the surface. An exception is GLAS (on ICESat), which is a laser altimeter with a footprint only 65 m across and successive measurements 172 m apart [6]. Such an instrument can give high precision measurements over ice surfaces [7], but is only able to operate accurately in cloud-free conditions. **Vincent et al.** [8] have now developed designs for a radar altimeter, Altika, operating at 35.75 GHz ( $K_a$ -band), enabling much smaller components and power requirements than for  $K_u$ -band altimeters. They discuss the advantages of using  $K_a$ -band rather than  $K_u$ -band (minimal ionospheric correction, narrow beamwidth enabling altimetry near land, and higher number of independent pulses) as well as the disadvantages (greater sensitivity to clouds and rain). The relatively small size of the Altika concept means that it could provide the basic component of a microsattellite constellation.

An innovative solution to the problem of insufficient spatiotemporal sampling has been to develop plans for an altimeter with two receivers, enabling a swath of observations via interferometric techniques. A Wide-Swath Ocean Altimeter (WSOA) was proposed as part of the payload for the follow-on to Jason [9], but lack of funds forced this component to be cancelled. In this issue, **Enjolras et al.** [10] reappraise the WSOA concept, discussing the design and error budget. They point out that freeing such a project from the TOPEX/Jason orbit and moving to a sun-synchronous 14-day repeat orbit can significantly reduce drag and the need for frequent orbit manoeuvres, and consequently offer an improved performance.

Another revolutionary change to altimeter design has been the delay/Doppler altimeter [11]. Improved along-track resolution may be obtained if the on-board processing takes heed of a longer reception window for the radar returns, and makes use of the Doppler information that distinguishes echoes from before and behind the craft. The first spaceborne test of this was to have been SIRAL (on Cryosat), which had both delay/Doppler and interferometric capabilities [12]. Unfortunately failure of the launch rocket on 8th Oct. 2005 led to the loss of Cryosat, although ESA has promptly approved the construction of a replacement.

A number of studies have looked at the backscatter strength,  $\sigma^0$ . Initially it has just been related to wind speed, but later investigations determined effects due to intervening rain, wind stress and surface slicks. In this special issue, **Tran and Chapron** [13] demonstrate that wind direction has a subtle effect too, according to how the anisotropy of the short-scale waves is aligned with the polarization phase of the altimeter. The effect is different at Ku- and C-band, but in both cases is small for wind speeds of  $5 \text{ m s}^{-1}$ , but is more pronounced for high winds. The idea of directionality is explored further by **Karaev et al.** [14], who relate backscatter anisotropy to the dominant wind field. They develop plans for a "knife-beam" altimeter i.e. one with a much broader beamwidth in one direction than the other, allowing the reception of radar returns from points far from the nadir track. They propose that, by using a rotating knife beam to enable multiple looks at a portion of the sea surface, the direction of wave propagation may be retrieved.

The remaining three papers in this special issue deal with altimeters that are already operating. They look at the consistency within datasets and between them, which are key issues in the maintenance of long-term records for studying changes on interannual and decadal scales. First, **Fernandes et al.** [15] address the issue of long-term consistency within the 12-year TOPEX dataset. They show that the particular choices for certain instrument corrections can impact the estimation of sea level trend by  $\sim 0.5 \text{ mm / year}$ . Second, **Faugere et al.** [16] provide a thorough assessment of the first three years of Envisat data, showing that the proportions of data flagged and the r.m.s. uncertainties remained roughly constant over that period, and of a similar value to those for Jason. They also show that Envisat's trend in global mean sea level matches those derived from other datasets, provided that only data after August 2003 are considered. Finally, **Zhang and Chen** [17] consider maps of sea surface height anomaly produced separately for the four altimeters (Envisat, GFO, Jason-1 and TOPEX) flying during March 2004 to Feb 2005. They determine a small bias between their respective mean sea surfaces, and contrast their estimates of SSH variability: in each ocean basin Jason exhibits the least variability and TOPEX the most.

We hope that this special issue will serve as a timely and useful reference for the altimeter community, providing both thorough guides to some of the visionary thinking within sensor development, and also detailed examples of the analyses to optimise individual datasets and harmonise studies using multiple altimeters.

## References

1. Chelton, D.E.; Ries, J.C.; Haines, B.J.; Fu, L-L.; Callahan, P.S. Satellite altimetry. *Chapter 1 of 'Satellite Altimetry and Earth Sciences'* (ed. Fu, L-L. and A. Cazenave), Academic Press, 2001.
2. 'Ocean surface topography from space' literature database <http://sealevel-lit.jpl.nasa.gov/science/search-form.cfm>.
3. 'DEOS: Current velocities of the Gulf Stream' <http://rads.tudelft.nl/gulfstream/>.
4. Raney, R.K.; Porter, D.L. WITTEX: An Innovative Three-satellite Radar Altimeter Concept. *IEEE Trans. Geosci. Rem. Sens.* **1998**, *39*, 2387-2391.
5. Allan, T. The Story of GANDER. *Sensors* **2006**, *6*, 249-259.
6. Schutz, B.E.; Zwally, H.J.; Shuman, C.A.; Hancock, D.; DiMarzio, J.P. Overview of the ICESat Mission. *Geophys. Res. Lett.* **2005**, *32*, L21S01. doi: 10.1029/2005GL024009.

7. Abshire, J.B.; Sun, X.; Riris, H.; Sirota, J.M.; McGarry, J.F.; Palm, S.; Yi, D.; Liiva, P. Geoscience Laser Altimeter System (GLAS) on the ICESat Mission: On-orbit Measurement Performance. *Geophys. Res. Lett.* **2005**, *32*, L21S02. doi: 10.1029/2005GL024028.
8. Vincent, P.; Steunou, N.; Caubet, E.; Phalippou, L.; Rey, L.; Thouvenot, E.; Verron, J. AltiKa: A Ka-band Altimetry Payload and System for Operational Altimetry during the GMES Period. *Sensors* **2006**, *6*, 208-234.
9. Rodriguez, E.; Pollard, B. Centimetric Sea Surface Height Accuracy Using the Wide-Swath Ocean Altimeter. *Proc. IGARSS 2003*, **2003**, 3011-3013.
10. Enjolras, V.; Vincent, P.; Souyris, J.-C.; Rodriguez, E.; Phalippou, L.; Cazenave, A. Performances Study of Interferometric Radar Altimeters: From the Instrument to the Global Mission Definition. *Sensors* **2006**, *6*, 164-192.
11. Raney, R.K. Delay/Doppler Radar Altimeter. *IEEE Trans. Geosci. Rem. Sens.* **1998**, *36*, 1578-1588.
12. Phalippou, L., Rey, L.; De Château-Thierry, P.; Thouvenot, E.; Steunou, N.; Mavrocordatos, C.; Francis, R. Overview of the Performances and Tracking Design of the SIRAL Altimeter for the CryoSat Mission. *Proc. IGARSS 2001*. **2001**, 2025-2027.
13. Tran, N.; Chapron, B., Combined Wind Vector and Sea State Impact on Ocean Nadir-viewing Ku- and C-band Radar Cross-sections. *Sensors* **2006**, *6*, 193-207.
14. Karaev, V. Yu.; Kanevsky, M.B.; Balandina, G.N.; Meshkov, E.M.; Challenor, P.; Srokosz, M.; Gommenginger, C. A Rotating Knife-beam Altimeter for Wide-swath Remote Sensing of Ocean: Wind and Waves. *Sensors* **2006**, *6*, 620-642.
15. Fernandes, M.J.; Barbosa, S.; Lázaro, C. Impact of Altimeter Data Processing on Sea Level Studies. *Sensors* **2006**, *6*, 131-163.
16. Faugere, Y.; Dorandeu, J.; Lefevre, F.; Picot, N.; Femenias, P. Envisat Ocean Altimetry Performance Assessment and Cross-calibration. *Sensors* **2006**, *6*, 100-130.
17. Zhang, C.; Chen, G. A First Comparison of Simultaneous Sea Level Measurements from Envisat, GFO, Jason-1, and TOPEX/Poseidon. *Sensors* **2006**, *6*, 235-248.