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 25 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 of 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 our first paper, **Tom Allan** [5] explains the need for, and potential of, a much larger constellation of low-cost microsatellites. 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 Ku-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. **Patrick Vincent and colleagues** [8] have now developed designs for a radar altimeter, Altika, operating at 35.75 GHz (Ka-band), enabling much smaller components and power requirements than for Ku-band altimeters. They discuss the advantages of using Ka-band rather than Ku-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 microsatellite 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 plans are being considered to construct a replacement.

A number of studies have looked at the backscatter strength, σ^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 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 last 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 ~0.5 mm / year. Second, **Faugerre 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.

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