GAMBLE

WP3 –Scientific/Technical theme 2 – sea-state error budgets, future detectability

Summary Report

December 2002

1. Introduction

This is a summary of discussions and contributions for GAMBLE WP3 (Sea State), and provides an overview of information that will be presented in the Work Package final report. The final report will summarise future requirements of altimeter sea state data from the user community, and provide input to discussions which will generate recommendations for future developments in terms of altimeter missions and data processing capabilities. Until the final reports is completed (due in April 2003) readers who desire further detail are directed to the WP3 interim report and Venice Workshop minutes.

WP3 contributions have been gained from a wide variety of sources (see Appendix). A GAMBLE workshop was held in Venice in September 2002 where many of the key issues were debated.

2. Key issues

Altimeter data, for both wind speed and wave height, have been collected for more than a decade, making available an unprecedented volume of data. Key advantages have been the capacity of providing data in areas where virtually no measurement was previously available, independently of the local wind and wave conditions. This wealth of data drastically improved the knowledge of the conditions to be expected in the sea, and boosted the publication of wind and wave atlases. The assimilation of these data into the numerical models operational at the major meteo-oceanographic centres resulted in a substantial improvement of their skill, both for analysis and forecast products.

However, problems still exist.

Sampling

Altimeter data are still relatively scarce on a global scale, with large gaps in space and time. An orbit with a return period of, e.g., ten days implies at each visited location less than forty data per year, with a gap of 2.5° between adjacent tracks.

Accuracy

The accuracy of measurements is still an issue, more for wind speed than for wave height. Both the parameters have strong uncertainties in extreme conditions. This is precisely the area in which users are posing their most pressing demands, particularly for offshore operations.

Assimilation into Models

In application to forecast models, the altimeter has been the basic instrument for supply of wave height information. However, the impact of altimeter data is appreciable only in a relatively narrow band on the sides of the ground track. The main drawback has been the inability to singularly correct, with data assimilation, the individual wave systems that compose the two-dimensional spectrum at a given location. SAR data have been useful in this respect, boosting the development of techniques for the assimilation of the

measured spectra. However, to date the assimilation of SAR data has required an a priori knowledge of the spectrum, itself obtained from the model in which the data are to be assimilated.

Understanding of Wave Processes

One of the key issues for the improvement of the numerical wave model is a better knowledge, hence formulation, of the physics of waves, and of their interaction with the atmosphere. Waves are the interface that controls the fluxes between the two large systems, ocean and atmosphere, that in turn control the earth climate. A better knowledge of the involved processes is highly desirable. However, the basic difficulty in studying the physics of waves, e.g. their generation by wind, is the characteristic of the processes of taking place as a sequence of single, highly concentrated, events, but sparse in space and time. A satellite can only detect the integrated effect, and be used as the verification tool of a numerical model trying to represent the physical truth. In addition it is also clear that the single knowledge of H_s is a rather crude information, and the availability of the two-dimensional spectrum is highly desirable.

3. Requirements

Improved Sampling

Improved sampling is recognised as a priority. Multi- (micro) Satellite constellations provide one option. Other options include bi-static altimetry or the use of reflections of GPS signals from the ocean surface. A number of questions must be answered:

What improved sampling rates in time and space are required to make a useful impact?

Features in Sea State in general vary more rapidly in time than features in sea surface height – though they may well cover larger areas.

The GANDER constellation (10 operational satellites) was designed to provide measurements every 6 hours within 200 km of every ocean location.

Météo France and ECMWF are carrying out simulation studies to investigate the impact on wave forecasts of increased sampling by 3,4,5 or more satellite altimeters.

What orbits are required?

Unlike the requirement for the precise measurement of ocean topography there was no requirement by the wave community to lay down repeat orbits. Neither was there the same requirement for precise position fixing. An approximately uniform distribution, in space and time, is a desirable characteristic.

Accuracy

Priorities are:

1. Improving or verifying the accuracy of altimeter measuments of high winds and waves.
2. New algorithms are required for measurements of winds greater than 15 ms^{-1}.

The accuracy achieved in the measurement of significant wave height by present-day altimeters is estimated to be ±25cm (or 6%) and this is generally considered sufficient if it can be achieved over the whole measured range. Altimeter measurements of high

waves (> 15m) are thought to be accurate, but there are few in-situ ground truth data to confirm this.
Wind speed algorithms are known to have (undesirable) environmental dependencies, and are not accurate above 15 ms^{-1} (the backscatter to wind speed relationship changes fundamentally at high winds).

Measurements of Other Sea State Parameters

After measurements of significant wave height, information on surface wave spectra are considered the most important requirement. Wave direction can be derived from purpose designed radar such as proposed by SWIMSAT, or (longer wavelengths only) from the wave mode of Envisat's ASAR (or ERS SAR).

Model Forecasts/Nowcasts

Extensive tests have clearly shown that when directional wave information is assimilated into operational wave models, the effect is much longer lasting than when only significant wave height is assimilated.

Wave Climatologies

Whilst it is clear that improved sampling would reduce errors in climatologies, and allow a reduction in the grid size, a higher priority was placed on the need for wave parameters in addition to significant wave height. Parameters could include wave period, wave direction, and swell parameters (height, period and direction), and joint distributions (e.g. of wave height / period, Hmax/Hs).
In addition it was felt that more use could be made of joint analyses of altimeter and SAR data - for climatologies of e.g. groupiness, expected maximum wave heights, crest length.

Event and Process Studies

Joint use of altimeter/SAR and perhaps altimeter/optical data sets could provide important information by allowing profiles of individual severe events.
For detailed studies of ocean wave processes it was suggested more sophisticated processing of the altimeter signal should be attempted. For instance

1. Analysis of the waveform shape (averaged if necessary) could provide estimates of: Kurtosis/skewness, pdf of surface elevation,
2. Estimate of steepness would be of use to offshore operators and also for better estimates of sea state bias.

Cryosat altimeter data over the ocean should be requested, to allow:

3. Analysis of phase information from the return waveform.
4. Analysis of returns from altimeter "sub-cells" (< km scale).

Air-Sea Flux Climatologies

Climatologies of air-sea fluxes (momentum, heat, gas, freshwater) are centrally important in climate studies. Altimeters offer a unique possibility for direct measurements of surface wind stress, and air-sea gas transfer velocities.
Presently available estimates of global mean air-sea gas transfer velocities vary by a factor of two. Any improvement on this resolution would be beneficial. An accuracy to

aim for (in a climatology) could be 50% (or 10 cm / hr) on a monthly averaged 2° x 2° grid.

Coastal Measurements

The spatial variability of the wind and wave conditions close to the coasts is such that no presently conceivable satellite system can supply the required data. On the other hand the narrow band of sea that borders the continents is where most of the economical and safety issues are concentrated.

The vision anticipated for the future is a continuous sequence of local scale high resolution models all along the coasts – complemented here and there, where necessary or required, with local measurements – and bounded by output from offshore models.

However, local models can provide correct results only when the input data are correct. Particularly in continental areas, U_{10} and H_s are often underestimated. Altimeter data are essential to provide a necessary reference for their correction and assimilation.

Continuity

The climatological use of altimetry requires continuity in the measurements. Given the limited time span of each mission (although ERS and especially T/P were successful beyond expectations), and to avoid multiple and complicated calibration campaigns, an overlap of the different missions is highly recommended. The almost twelve consecutive years provided by ERS1-2 and T/P have been taken over by ENVISAT and by Jason-1, a follow up of T/P. Jason-1 has a similar set of instruments as T/P, but with a much reduced weight and volume. It is planned to be followed by Jason-2 in 2005.

4. New Concepts

The new concepts act both on quantity, e.g. multi satellite constellations such as GANDER or AltiKa, and on innovative techniques.

Altika proposes a low cost Ka-band integrated altimeter/radiometer, with the capability of a noise reduction that would allow the detection on the ocean surface of shorter wavelengths than it is presently possible.

SWIMSAT has already been mentioned, and the availability of wave spectra would substantially improve the quality of the wave forecast. Delay doppler altimetry (the WITTEX proposal) would allow the capability of sampling small cells within the altimeter footprint combining the signal from two or three mini satellites flying with a short separation along closely parallel ground tracks. “Bistatic” altimetry allows altimeters to receive signals from a neighbouring satellites on a parallel ground track, so generating extra sampling.

More long term prospects are the inclined swath altimeter and the GPS altimetry. The latter would provide the same data of a conventional altimeter, but make use of the signals emitted by the GPS satellites and reflected by the sea surface. The echoes would be recorded by “parasitic” cheap satellites. The concepts are very promising, but still at the level of study, not feasible for a mission before 5-10 years from now. Present designs for swath altimetry will not provide off-nadir measurements of sea-state, and so for this purpose do not represent an improvement on nadir altimeters.

Appendix – Contributors to the GAMBLE Sea State Work Package

Contributor	Topic
Luigi Cavaleri (ISDGM, CNR, Italy)	Wave models, coastal applications (GAMBLE WP3 Leader)
David Woolf, et al (Southampton Oceanography Centre, UK)	Wave climate studies, altimeter algorithms for wind speed and wave period.
David Cotton (Satellite Observing Systems, UK)	Applications for offshore operations (wave climate statistics and near real time), GANDER (microsatellite borne wave measuring altimeters)
Daniele Hauser (CETP, France)	SWIMSAT – A satellite wave measuring radar (providing directional spectra).
Yves Menard (CNES, France)	JASON-1
Patrick Vincent (CNES, France)	Altika (Ka band altimeters)
Laurent Phallippou (ALCATEL Space)	New altimeter technology
Peter Janssen (ECMWF, EU)	Operational wave modelling, wave theory, sea state bias, errors.
Jean-Michel Lefevre (Méteo France)	Operational wave modelling, multi-satellite simulations.
Jim Gunson (UK Met. Office)	Operational wave modelling
Susanne Lehner (DLR, Germany)	SAR wave measurements, MAX wave.
Johannes Guddall (DNMI , Norway)	Impact of Tropical storms, MAXwave.
Francisco Ocampo-Torres, CICESE (Mexico)	Altimeter sea state data requirements from Mexican perspective.