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The Story of GANDER

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Abstract: GANDER – for Global Altimeter Network Designed to Evaluate Risk – was an idea that was probably ahead of its time. Conceived at a time when ocean observing satellites were sometimes 10 years in the planning stage, the concept of affordable faster sampling through the use of altimeter-carrying microsats was primarily advanced as a way of detecting and tracking storms at sea on a daily basis. But, of course, a radar altimeter monitors changes in sea-level as well as surface wave height and wind speed. Here then is a system which, flown with more precise missions such as JASON 2, could meet the needs of ocean modellers by providing the greater detail required for tracking mesoscale eddies, whilst servicing forecasting centres and units at sea with near real-time sea state information. A tsunami mode, instantly activated when an undersea earthquake is detected by the global network of seismic stations, could also be incorporated.

Keywords: microsats, constellation, sea state, ocean topography, global climate

1. Introduction

Of all the sensors developed by NASA in the 1970's for monitoring the sea surface from polar-orbiting satellites, the radar altimeter has arguably contributed most to our understanding of marine physics and, by association, to global climate change. The detection of quasi-continuous changes in sea level has revealed in remarkable detail the presence and dynamics of mesoscale eddies, western boundary currents, general circulation patterns, ocean tides and Rossby waves around the globe.

Seasat had led the way in 1978 and when it failed after no more than 3 months of operation, the US Navy launched a radar altimeter on Geosat in 1985 to map the geoid to a high spatial resolution. The

design of the European Space Agency's, ERS-1 closely paralleled Seasat, and by the time of its launch in 1991 it was virtually guaranteed that its payload would include a radar altimeter. ERS-1 was closely followed by the US/French Topex/Poseidon mission which concentrated exclusively on altimetry and included in its payload a dual-frequency instrument and other supporting sensors to estimate the atmospheric and ionospheric variability that contributed to the sea height measurement.

Such a dedicated mission as Topex/Poseidon firmly established the altimeter as a 'must have' in the physical oceanographic armoury. Topex/Poseidon still flies today, now joined of course by its successor, JASON-1. Plans for JASON-2 with contributions from Eumetsat and NOAA were finally approved in 2004. At the same time the NASA/JPL plan to fly a wide-swath altimeter on JASON-2, that would partially resolve the sampling problem of the pencil-beam sensors, was shelved.

Today there are 5 altimeters in operation – Envisat, ERS-2, Geosat Follow-on, Topex/Poseidon and JASON. Another type of altimeter, designed to monitor the properties of polar ice, was to be carried on ESA's Cryosat mission but that spacecraft failed on launch.

Against this brief historical background, what exactly is GANDER and where, if at all, does it fit into the schemes of future programmes?

2. The development of the GANDER concept

The community of altimeter users around the globe is largely drawn from the marine research community. Their main interest is in detecting and tracking ocean surface features that produce very small changes in surface height. The one sensor capable of monitoring the changes in global sea level that feature prominently in the media reporting of global warming effects has detected a rise of the order of 2-3mm p.a. [10], over the last decade and a half which, of course, climate models predict should increase due to global warming.

The point that needs to be stressed to political decision-makers is that whatever differences of opinion may exist over the human effect on a changing climate, it is imperative to maintain a continuous global watch on key environmental features that can be detected from satellites.

The altimeter also provides estimates of wave height and wind speed which may also act as significant indicators of climate change. Successive calibration campaigns plus a steady improvement in technology has brought the accuracy of these measurements down to better than 30cm in wave height and <2m/s in wind speed [2], [4]. The multi-year archive of these measurements has provided wave climate statistics to reveal decadal trends in observed winter wave height that may be correlated to ocean basin pressure fluctuations such as the North Atlantic Oscillation [1], [11].

Notwithstanding this not negligible contribution to understanding and predicting climate change, the greater use of a continuous stream of wave height measurements has been their contribution to meteorological forecasts. The resolution of wave models has substantially improved with the increasing power of computers and although some forecasting centres can, and do, insert altimeter observations directly into their models, their greater value probably lies in checking the accuracy of forecasts.

A major problem with altimeter observations is the relatively poor sampling. As a very narrow swath instrument – unlike colour, temperature and even radar imagery – successive passes of the altimeter can leave gaps of over 3,000km unsampled. Equally constraining for daily operations is the

fact that of the 5 altimeters presently in orbit only 3 deliver data in near real-time. This is not enough to have a significant impact on day-to-day marine operations.

It was this realisation that prompted SOS, one of a few satellite ‘value-added’ companies working in the marine market, to suggest faster sampling that would serve to improve not only the forecasts, but could provide a service - particularly useful in times of bad weather - transmitting direct observations of surface winds and waves to ships at sea at regular intervals.

Large multi-sensor satellites such as Envisat are not cheap. The realisation of a constellation to provide faster sampling very much depends on finding a much more economic approach. Fortunately, one was at hand. The Engineering faculty at the University of Surrey had been so successful in developing very small satellites that a private, non-profit making company, Surrey Satellite Technology Ltd (SSTL), had been formed. They started piggy-backing other satellite missions and had come to acknowledge the potential of economic launches from Russia. At the time of writing 24 of their small satellites have been placed in orbit around the Earth.

SOS and SSTL teamed up to launch the idea of GANDER – A Global Altimeter Network Designed to Evaluate Risk. The combination of simple radar altimeters carried on microsats weighing no more than 80kg (as opposed, for example, to Envisat’s 8,000kg) held out the promise of sampling global wave heights and wind speed at the frequency required for day-to-day marine operations – at an affordable cost.

The British National Space Centre announced a programme called MOSAIC that would part-fund the development of a small satellite and payload if it showed real market potential to the extent of attracting 50% external funding. In the event it proved difficult to convince a private company to invest up to £5m in the development of a GANDER prototype. That contract was won by TopSat in which the UK Ministry of Defence subscribed the 50% development cost.

With support from the British National Space Centre, a Technical Study and Business Plan were completed to investigate:

- a) How a constellation might achieve the goals set for it within the constraints of a limited payload;
- b) The development of a business that would aim to equip each vessel that carried GPS with a GANDER receiver to display in real-time the observed sea-state in the sea area around the vessel. A brochure was prepared to demonstrate how a constellation of small satellites could be launched and operated.

The GANDER concept is illustrated in Figures 1, 2 and 3.

3. Shared benefits to science and operations

Ever since the launch of Europe’s ERS-1 in 1991 there has been a concerted effort to derive *operational* benefits from payloads designed largely for longer-term ocean research. To further this aim, a fast-delivery service was incorporated in the design of later satellites. As noted, this allowed meteorological forecasting centres to enjoy near real-time access to actual observations of surface winds and wave conditions. As a result, forecasts improved but the degree of improvement introduced by the observations from a single platform, where successive orbits were separated by some 3,000km, was relatively modest.

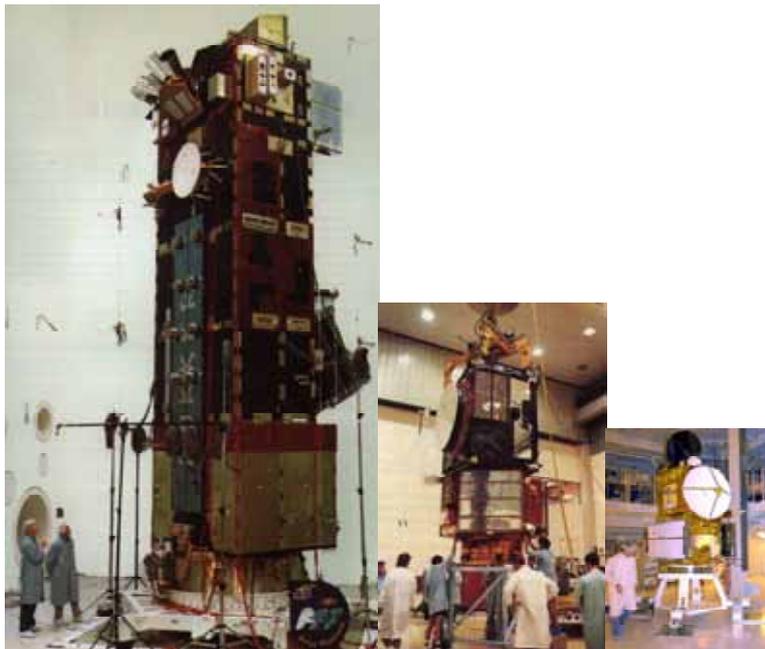


Figure 1. Comparison of platforms for carrying an altimeter – Envisat, Topex/Poseidon, JASON and GANDER. The humans are shown approximately the same size in each image.

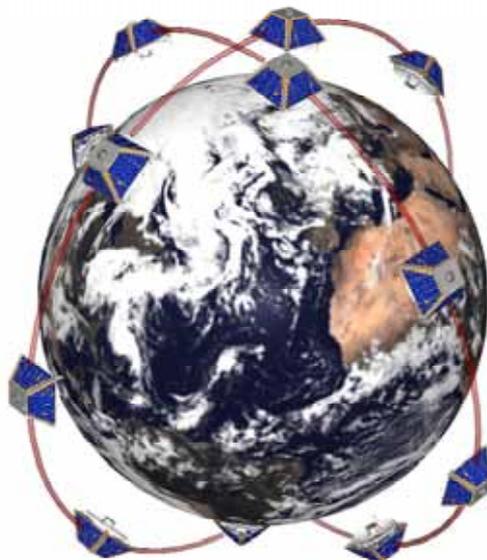


Figure 2. A GANDER constellation of microsats in 2 orbit planes.

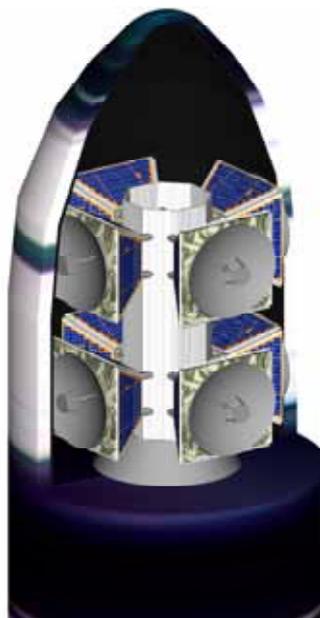


Figure 3. A single rocket could launch 8 micros into orbit.

Envisat was the prime example of a multi-sensor platform which, with its advanced synthetic aperture radar plus a range of other sensors, was designed to demonstrate potential operational as well as scientific benefits. The main thrust remained nevertheless the gathering of global environmental information reflecting the long-term state of planet Earth. Inevitably with any multi-sensor mission, compromises have to be made regarding sensor duty cycles, revisit times, and data transmission.

Topex/Poseidon and its successor JASON-1 demonstrated the value of concentrating on a single sensor, the radar altimeter, with all of the necessary supporting instrumentation required to achieve the best performance [7]. The fact that this single instrument could simultaneously deliver precise measurements of sea surface height together with reliable estimates of surface wind and wave parameters, coupled to the GANDER technical study which demonstrated that an altimeter could be fitted into an 80kg microsat [6], led to the conclusion that the faster sampling required by day-to-day marine operations could really be achieved at an affordable price.

The next question was, would the measurements of surface height required by ocean modelers be unacceptably compromised by the constraints of a small platform? For the measurement of waves and winds the exact location of the satellite is not important; for the measurement of surface height it is crucial. It was considerations such as these that led several people to propose a comprehensive investigation to the European Commission.

4. GAMBLE

As altimeter sea surface height data from JASON, Envisat and Topex/Poseidon were combined, the greater complexity revealed in the depiction of mesoscale eddies confirmed what oceanographers had long suspected – that the sampling of those fields with a single altimeter mission fell short of what was required to understand and predict the transport of heat, a key element of global climate models [8]. Such confirmation begged the question, however, of how many platforms are ultimately required to

match the ocean's spatial and temporal scales of variability. The oceanographic community appeared to be moving towards a similar conclusion as the marine operators and forecasters who required more frequent updates of surface wave and wind conditions especially when storms at sea were threatened [5].

When the two communities came together to propose a Thematic Network programme to the European Commission, the name given to the programme was GAMBLE, for Global Altimeter Measurements By Leading Europeans.

From the outset the GAMBLE team encouraged a mix of research scientists, forecasting centres and marine operators to participate in a series of 6 Workshops centred on the themes listed below (with the lead organization shown in parenthesis). In the event over 40 organisations took part in these discussions.

Whereas the original GANDER concept had been driven by the perceived needs of marine operators for frequent updates of sea-state information, the GAMBLE study took full account of the requirements for marine climate research and looked for a common denominator.

The emergence of dedicated altimeter-carrying microsats opened up the possibility of frequent sampling. It was no longer unrealistic to plan for a greater number of polar-orbiting altimeters on the grounds of expense. Could the GAMBLE investigators find arguments to convince the paymasters of EO satellites that radar altimeters held the greatest promise of achieving that long-sought goal of extracting operational benefits from research missions?

The Working Groups participating in GAMBLE were as follows:

WG1 - Project Definition (Centre National D'Etudes Spatiales)

WG2 - Sea surface height error budget (Collecte Localisation Satellites)

WG3 - Sea-state error budgets (Istituto Per Lo Studio Della Dinamica Delle Grandi Masse, now Istituto di Scienze Marine)

WG4 - Orbit determination and tracks (Technical University of Delft)

WG5 - Operational requirements (Satellite Observing Systems)

WG6 - Research requirements for both SSH and sea-state (Southampton Oceanography Centre, now National Oceanography Centre, Southampton)

Over the 18 months of the project each Working Group produced a report of its findings based on issues raised at the individual Workshops. A Final Report [3] was submitted to Brussels in February 2004.

4.1. Orbit determination

The main issues concerning the possible utilization of small satellites in support of a larger, dedicated altimeter research mission such as JASON-2 were identified and discussed. The Working Group led by the Technical University of Delft was asked to consider the problem of orbit determination. Much of the success of the TOPEX/Poseidon and JASON missions could be attributed to the support measurements put in place to achieve a very precise determination of the satellite's orbit. Microsatellites would be unable to accommodate the same level of instrumentation and, in those circumstances, could not deliver the same order of precision.

This was the problem faced by the Delft team. If less strict hardware specifications must be accepted for microsattellites, what alternative solutions presented themselves, and at what cost in loss of precision?

Precise Orbit Determination (POD) is traditionally based on a combination of force modeling and high-accuracy tracking data. There are currently three tracking systems available for cm-level orbit determination – satellite laser ranging (SLR), DORIS, and geodetic GPS [9].

SLR is the only system providing a direct and unambiguously accurate range measurement. The SLR community is organized under the International Laser Ranging Service and puts a high priority on measurements from altimeter-carrying spacecraft. These measurements are usually combined with the French DORIS system, which with 60 beacons evenly distributed around the globe, gives excellent coverage.

The GPS system was originally designed for ground-based navigation but special techniques have evolved for satellite positioning. A special receiver developed by JPL now achieves cm-level POD. (At the time of the study, not enough was known of the proposed Galileo system).

The use of force models allows the restitution of accurate orbits even when the tracking data contains gaps. Conversely uncertainties in the force model have been solved using good tracking data. Over the last decade the combination of systems to achieve the highest-accuracy – each system (including using the altimeter-record itself) has brought about a dramatic improvement. Constellations of micros may present a different set of problems. Although small retro-reflectors for laser tracking may be fitted, a high number of satellites might prove too much of a burden to the network of tracking stations.

One powerful technique which could evolve is to minimize discrepancies at the many track intersections that would occur daily. In this way much of the accuracy achieved by the ‘master’ satellite (e.g. JASON-2) could be passed on to the less well-controlled suite of micros.

There is, of course, no POD requirement for the wind/wave part of the mission.

4.2. Dual benefits – research and operations

What could not be decided within the scope of a limited-period investigation was the preferred number of platforms to ensure adequate coverage for the detection and tracking of mesoscale eddies. That number was almost certainly less than the number required to track and deliver information on the development of storms at sea at a frequency that would make a significant impact. It was felt that to try to define a specific number at this stage invited comment on whether that number was too large or too small according to the main priorities set. What was concluded and written into the Final Report was the following:

‘. . . by one means or another the sampling of the ocean’s surface by altimeters needs to be increased so that operational requirements are met for both ocean dynamics and sea-state forecasts.’

The opinion of the team was that the most important thing to get decision-makers to accept was the concept of thinking imaginatively about the cost-effectiveness of introducing micro-platforms that would reduce the high number of casualties suffered each year in extreme sea conditions, while simultaneously making a valuable contribution to our knowledge of the dynamics of mesoscale eddies.

5. Altimeters as a tool in disaster monitoring

In their final report, the Working Group on Research made the following observation:

‘There are other phenomena, for example tsunamis and storm surges, where the sampling of one or two altimeters is not sufficient to detect the signal at the sea surface. Large constellations offer the promise of detecting such signals. Operationally this could be very important as both tsunamis and storm surges cause considerable amounts of damage and loss of life, particularly in the developing countries.’

Ten months after submitting this Report, the biggest marine disaster in living memory struck in the Indian Ocean.

Even as the idea of using altimeters to detect tsunami waves in the open ocean was being advanced, there remained some doubt on an altimeter’s ability to detect a surface wave no more than a metre high travelling at speeds of up to 800km/hour across the surface of the ocean. These doubts were removed on December 26th when first JASON, followed by Topex/Poseidon, recorded the wave on its way to wreak havoc along the coasts of Sri Lanka, SE India and Indonesia (Figure 4). In the event, the signal was clear. The two waves recorded are shown, each with peak-to-trough heights less than 1 metre.

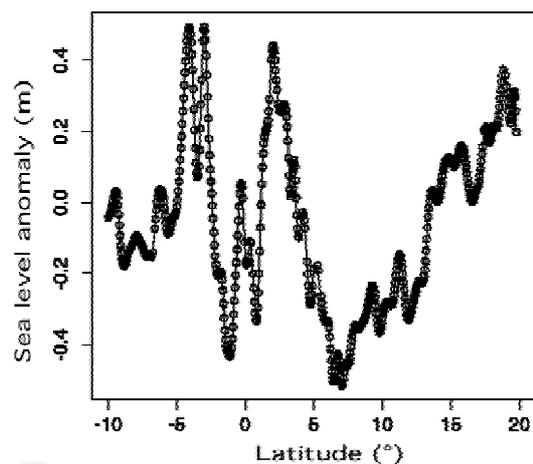


Figure 4. a) Track of JASON across the Indian Ocean on December 26th 2005
b) The double tsunami wave measured by the altimeter.

Having established that a GANDER constellation of altimeters could contribute to a tsunami early warning system the question now arises about the willingness of space agencies to collaborate in creating a global surveillance system. If any single event could move these agencies to collaborate in implementing an operational system of dedicated, polar-orbiting altimeters, surely the loss of some 240,000 lives should concentrate minds.

At the time of writing, more than a year after that terrible event, this is not the case. UNESCO’s Intergovernmental Oceanographic Commission (IOC) is coordinating the installation of a global network of surface buoys attached to pressure sensors placed on the sea-floor. It is expected that these will detect the wave’s passage as it moves over the surface at high speed. These buoys will, of course,

have to be moored many hundreds or thousands of kilometers from vulnerable coastlines to give sufficient warning of the impending threat.

An important consideration when identifying the merits and demerits of buoys and satellites is maintenance. It has been argued that it is unrealistic to contemplate building a constellation of satellites for an event that may not recur in 50 years. This argument, of course, is true for satellites and buoys alike, but there is an important difference. Whereas the only function of the buoys would be the detection of the tsunami wave passing overhead, the normal operational mode of the satellites would be issuing daily warnings on the progress of threatening storms across the global oceans. The instant an underwater earthquake was detected, the altimeters would be switched to tsunami mode. And as soon as an altimeter crossed the advancing tsunami wave front other altimeters would be programmed to track and report on its progress. Computer simulations demonstrate that a constellation of 8 satellites in each of 3 inclined orbit planes would normally detect a tsunami wave front around 30 minutes after the initial quake (varying from 0 to 60 minutes) and thereafter a contact would be made at roughly 15 minute intervals.

Unlike the buoys which may have to withstand monster waves and fierce winds year after year, satellites operate above the weather and require little maintenance. Topex/Poseidon, for example, was launched in 1992.

Satellites also offer unrivalled uniform and global coverage. As has been demonstrated on previous missions, observations can be made immediately available to everyone.

It appears that one approach to increase the chances of providing warning of the next tsunami could be a mix of 'in situ' buoys and polar-orbiting GANDER micros. The number of platforms may then be reduced. Halving the number to 12 would double the interval between successive hits but in conjunction with buoys operating independently, could provide a timely warning.

In Figure 5 we demonstrate a familiar scenario whereby a landslide in the Canaries triggers a tsunami traveling westwards towards the eastern seaboard of America. Even with only 12 satellites in orbit a 'hit' would be made at roughly 1/2 hourly intervals which could still provide a timely warning.

6. Conclusion

We have demonstrated how radar altimeters could be deployed in a more imaginative way at a small fraction of the cost of a single, multi-sensor research platform. If a constellation of 24 micros were planned – 8 satellites (say) in 3 inclined orbit planes and if 3 space agencies agreed to share the cost by assuming responsibility for a single plane, then at current prices the cost to each agency would be in the order of €100 million. Envisat cost €3,000 million.

The clinching argument ought to be the versatility of such a monitoring arrangement. Bulletins on the location and development of storms at sea – based on actual observations – would be distributed globally several times a day. The added value to climate change programmes of more frequent sampling of ocean currents and mesoscale eddies has been discussed and agreed by leading oceanographers in the European Commission's GAMBLE programme. That a GANDER constellation could instantly be triggered to act (at the very least) as a complement to any 'in situ' tsunami warning system is surely a concept worth further investigation.



Figure 5. A slide from a volcano on the Canaries could trigger a tsunami wave across the Atlantic.
Taken from 'Tsunami' published by Carlton Books

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