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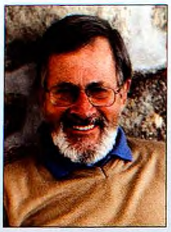

Hydrography and Disaster Management

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By Adam J. Kerr

Abstract

Several recent major natural disasters have raised the question of the part hydrography plays in their management. Hydrography provides the basic knowledge of the seafloor topography that is needed in predicting the dynamics of tsunamis. The monitoring of the sea level also provides important information. Topographic information, both above and under water, is needed to understand the effects of inundation of the shoreline following both tsunamis and hurricanes. A particular problem is faced in the coastal areas due to different vertical datums used by land surveyors and hydrographers but this matter is now being addressed.

Résumé

Plusieurs récentes catastrophes naturelles majeures ont soulevé la question du rôle que joue l'hydrographie dans leur gestion. L'hydrographie fournit les connaissances de base de la topographie du fond qui sont nécessaires pour la prédiction de la dynamique des tsunamis. Le contrôle du niveau de la mer fournit également d'importantes informations. Les informations topographiques importantes, à la fois au-dessus et au-dessous de l'eau, sont nécessaires pour comprendre les effets de l'inondation du littoral qui suit les tsunamis et les ouragans. L'on rencontre un problème spécifique dans les zones côtières en raison des différents niveaux de référence verticale utilisés par les géomètres et les hydrographes, toutefois ce problème est actuellement en cours de résolution.

Resumen

Varios desastres naturales importantes acaecidos recientemente han evocado la cuestión del rol que representa la hidrografía en su gestión. La hidrografía proporciona los conocimientos básicos de la topografía del fondo marino, que se requieren para la predicción de la dinámica de los tsunamis. El control del nivel del mar proporciona también una información importante. Se requieren ambas informaciones topográficas, la de la superficie del agua y la submarina, para comprender los efectos de la inundación de la línea de costa tras los tsunamis y los huracanes. Se hace frente a un problema particular en las zonas costeras, debido a diferentes dátums verticales utilizados por los topógrafos e hidrógrafos, pero este asunto está tratándose en la actualidad.

Introduction

In recent years several major disasters have occurred in worldwide coastal areas. The most recent has been hurricane Katrina and its disastrous effects on the city of New Orleans. On 26 December 2004 there was the major Asian tsunami that seriously affected the countries around the Indian Ocean and in which nearly 300,000 people died. Earthquakes and their sometimes associated tsunamis are a relatively frequent event in many parts of the world that are subject to seismic activity. A short list of some recent major tsunami events is provided by the USA NOAA Environmental Laboratory (www.pmel.noaa.gov/tsunami/database_devel.html) as follows:

28 March 2005 Indonesia.
26 December 2004 Indonesia (Sumatra).
25 September 2003 Hokkaido.
23 June 2001 Peru.
13 January 2001 El Salvador.
26 November 1999 Vanuatu.
17 July 1998 Papua New Guinea.

While major disasters in coastal areas are normally due to tsunamis, tropical cyclones or hurricanes, other disasters may occur in the form of ship grounding and major oil pollution and flooding caused by a combination of unusually heavy precipitation, sometimes linked with abnormally high tides. Such an event may be recalled when in 1956 a major storm caused extensive flooding in several countries surrounding the southern North Sea. That resulted in a major programme of public works, with dykes being built in the Netherlands and a Flood Barrier being built on the Thames in 1986 to prevent flooding in the city of London, at a cost of £ 370 million.

While the response to these disasters is initially in the hands of emergency measures personnel, such as firemen, policemen and medical staff, the longer term activity, directed at their future prediction and ideally their prevention, falls more into the hands of scientists and engineers from a variety of backgrounds. Whether the forces causing the disasters are meteorological or geological there is an urgent need to be able to predict more precisely just when and where they will occur. When they do occur we need to be able to predict the locations where remedial measures should be taken to minimise the damage to property and human beings. It is plainly evident that in most cases the worst damage occurs to low lying flat areas and these unfortunately are the sites where it has been found most convenient and economic to build our urban areas. Political response sometimes results in engineering studies and major public works to minimize future destruction. No doubt, this will be one of the outcomes of studies following the Katrina hurricane disaster.

Hydrography has an important part to play in both the prediction and response to emergencies, although in most cases, it will take place as part of a multi-disciplined approach. Basic mapping of several parameters is fundamental to successful modelling and prediction. Fortunately, in recent years new instruments have become available, which allow hydrographers to carry out their work more quickly and thoroughly and instruments such as multibeam acoustic systems and airborne laser systems (LIDAR) provide very effective tools for the task.

Figure 1: HMS Scott (photograph by courtesy of the UK Royal Navy and Hydrographic Office).

Hydrography in Prediction

Seismic disturbances in, or close to, marine areas are the cause of most tsunamis. While seismic disturbances occur in all of the world's oceans, the Pacific Ocean, which is surrounded by a ring of volcanic activity, and mainly due to the subduction of tectonic plates, has long been recognised as an area where tsunamis occur frequently. It has been noted that the number of significant tsunamis in the Indian Ocean, the site of the disastrous 2004 tsunami, is less than a dozen in the last 100 years, compared with the one hundred or more in the Pacific Ocean during the same period. (Gupta H.K., 2005). The actual study of seismic activity in a general sense is clearly in the hands of geologists and seismologists. In countries such as Japan, their research is fundamental to the economic prosperity as well as the safety of the people. The translation of this seismic activity into tsunami distribution and propagation involves work of a more multi-disciplinary nature. Once the seismic activity has taken place on the seafloor, subseafloor or nearby land we need to determine just how the tsunami will propagate in terms of direction and speed. We will also need to predict such matters as wave length and amplitude as it approaches a vulnerable coastline. Here hydrographers have a role, as has been shown recently in the surveys carried out by the UK Hydrographic Office, aboard HMS *Scott*, in the waters off Sumatra (UKHO, 2005).

Using a mutltibeam acoustic echo sounder (MBES) the surveyors were able to accurately map an area of the seafloor in the vicinity of the epicentre of the seismic disturbance that caused the major Asian tsunami on 26 December 2004. Working together with geologists and geophysicists, who used seismic instruments and conducted coring, they were able to provide information that permitted a better understanding of the trigger that set off the disturbance. While this type of research is undoubtedly helpful in making future predictions, the difficulty is in the immensity of the task. Subduction occurs over huge ocean areas and it represents an overwhelming survey task for hydrographers.

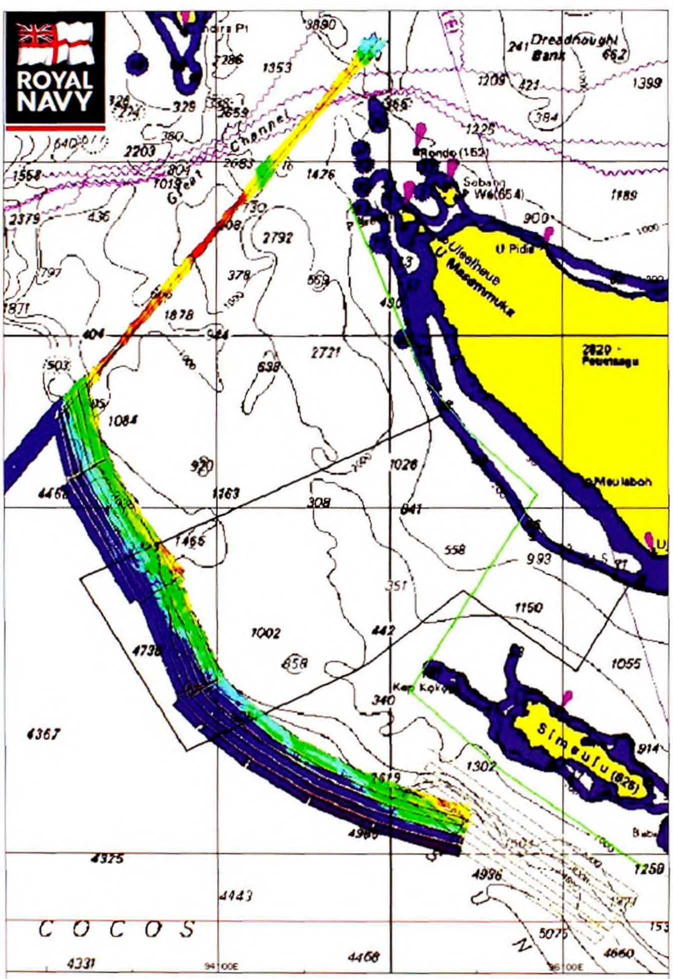

Figure 2: Survey area off West Sumatra (Graphic by courtesy of the UK Royal Navy and Hydrographic Office).

Even with the advantages of MBES the precise systematic surveying of the oceans is a huge task. It has been noted (Yeh, 1995) that for tsunami computations, in depths of water greater than 200 metres, it may not be necessary to resolve depth measurements on a grid finer than 2km. However if there is a narrow canyon or ridge approximately 2km. wide in water depths of 1,000 metres a higher resolution grid of about 500 metre spacing will be needed. Other ocean survey tasks demand the interest and limited resources of the hydrographers and submarine geologists. The best that can be done at present is to obtain sufficient data for generalised modelling and to understand the basic mechanisms which set off a tsunami.

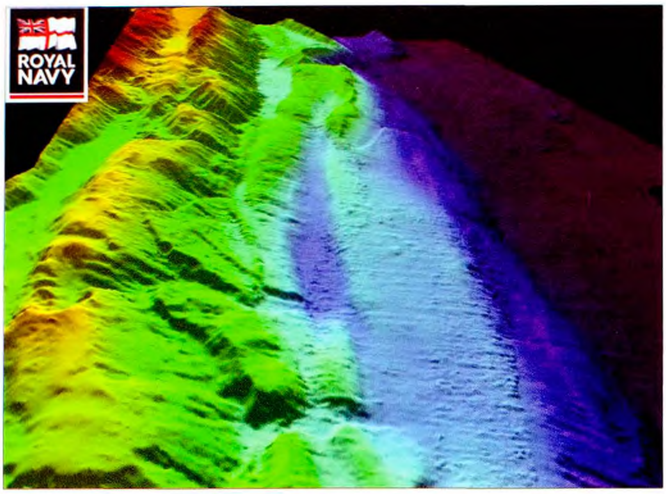

Figure 3: Multibeam acoustic imagery near epicentre (Graphic by courtesy of the UK Royal Navy and Hydrographic Office).

Most tsunamis are caused by a rapid vertical movement along a break in the earth's crust. Typically this mechanism only occurs in large subduction zones. Subduction occurs around most of the Pacific, with the exception of the western coast of North America, where movement along the faults is largely strike-slip (Lander, Lockbridge and Chinnery, 1989). While most current research is directed at seismicity as the trigger mechanism, some research is investigating the possibilities of landslides and underwater slippage as being the trigger. This has caused locally destructive tsunamis in Alaska and the subsequent cause of considerable re-charting of the area. Research has also been carried out in recent years by the National Oceanographic Centre in the UK, which has been examining such possibilities in the Canary Islands. The importance of obtaining detailed bathymetry has been made clear in this work (Wynn, 2003). Limited earlier bathymetric surveys did not show that slumping and landslides occurred however more recent detailed surveys have shown these features. From this it may be speculated that a trigger mechanism for tsunamis does exist in this area of the Atlantic Ocean. While media reports have tended to exaggerate this danger it is seen as less critical by scientists but nevertheless provides an interesting model to study the possible mechanism of tsunamis caused by landslides. (www.noc.soton.ac.uk/ CHD/ Research/topics/canaries_ slides. html).

An important method of monitoring and predicting tsunami activity is the monitoring of sea level change around ocean areas (Rabinovich and Stephenson, 2004). This has been a prime focus of activity for countries bordering the Pacific for many years. An International Tsunami Warning System for the Pacific was initially established at Honolulu, Hawaii in 1946, and the present organisation came into being in 1968. The organisation's task is to co-ordinate the national monitoring activities, and with a knowledge of tsunami characteristics and tools such as tsunami models and historical tsunami databases, advise countries of the possible occurrence of a tsunami. Water level gauges operated by most hydrographic offices, whose main task is to provide data for the analysis and prediction of tides, can provide this secondary important task of detecting anomalies in the form of a change of water level height caused by a tsunami. Research in some of the national offices that are involved in this enterprise includes the difficult task of distinguishing the seismically induced long waves from those pro-

Figure 4: Water level monitoring station, British Columbia, Canada. (Photograph by courtesy of the Canadian Hydrographic Service).

duced by meteorological forces, termed seiche oscillations. In recent years, and it may be noted, prior to the 2004 Asian tsunami, the network and technology of the water level monitoring stations was considerably improved.

Advantage has been taken of the availability of digital measuring devices which provide much higher precision than the earlier analogue devices. They can record water level heights at one minute intervals. Modern satellite communications contribute immeasurably to the networking of information and monitoring the progression of tsunami waves. The monitoring of tsunamis for providing advice and warning when damaging tsunamis are likely to occur, but also to determine if they will or will not cause damage is most important. It is important to determine if a false alarm has been set off.

Measurement of sea level heights in the open ocean by means of buoys, connected to pressure sensors located on the sea floor, supplement the terrestrially based, water level observation stations along the shoreline. As part of the US National Tsunami Mitigation Program deep ocean tsunameters have been developed and are now distributed across parts of the Pacific Ocean under a programme called DART (Deep-ocean Assessment and Reporting of Tsunamis) (www.pmel.noaa.gov/ tsunami/Dart/ dart_pbl.html). These devices are bottom mounted and transmit data acoustically to surface buoys equipped with satellite transmitters. It may be noted that this extension of the activity tends to take it out of the hands of the hydrographic community. At a workshop held in Paris in March 2005, a monitoring system for the Indian Ocean was discussed. It was suggested that 10 monitoring buoys should be commissioned for the Bay of Bengal without delay (Johnson, 2005). The importance of using existing buoy networks, of which there are several in the Indian Ocean, was emphasised at the meeting.

The study of the propagation of tsunamis across the deep oceans has been a source of much scientific interest and has resulted in numerous papers being written on modelling and forecasting of tsunami wave scattering, e.g. the MOST model discussed by Titov and Gonzalez (Titov and Gonzalez, 1997). Essentially the propagation of the tsunami wave is dependent upon the depth of the ocean but may be deflected by changes in the sea floor topography. In deep ocean depths the tsunami waves move at a speed of more than 1,000km. per hour and can cross oceans within a day. Because the speed of the tsunami depends on the depth of the ocean basins, the waves decrease in speed as they reach shallower water. The wave length is shortened and the energy within each wave is crowded into progressively less water, increasing the height of the Wave. (Lander, Lockbridge and Chinnery, 1989). Depending upon the direction in which the wave approaches shallow water, either perpendicularly or obliquely, it may be deflected in direction. In addition, offshore bathymetric features such as seamounts or submerged ridges focus the wave energy and produce extremely large waves at some coastal locations. The importance of this knowledge was only too apparent in assessing the devastation caused by the Asian tsunami. Generally speaking this area of research falls more to the physicist and mathematician rather than the hydrographer, although the bathymetry that hydrographers collect and compile will be fundamental to the modelling activity. Here again bathymetric knowledge is a pre-requisite for the modelling. Given the overall limitations of present models the current knowledge of ocean bathymetry may be sufficient for this research.

Problems of the Coastal Zone

It may be noted that most disasters occur in the coastal zone, the area where land and sea meet. Undoubtedly a mariner meeting a hurricane in the open sea may be fearful for his safety, but he needs to be much more so when the hurricane, having gained all its strength from the warm sea, actually makes contact with the land. At that point the hurricane will begin to lose strength, however it may cause heavy rainfall and consequent flooding for some distance inland. As noted above, the tsunami wave increases in amplitude as it approaches shallow water and consequently it will be at its most destructive as it reaches the shore, although other side effects caused by the storm surge, with its associated rise in sea level and consequent flooding, may in the end cause just as much damage. Basic, yet detailed, mapping of the coastal zone is essential for effective modelling (Yeh, 1995). It is essential in making a risk assessment of potential damage which could be caused by these events and as a means to support action taken to recover from these events. Yeh has stated that a 100 metre grid is needed for depths less than 10m. and a 50 metre grid is needed where depths are less than 2.5m. Research on the process of inundation caused by tsunamis has been carried out in the area of Juan de Juan Strait in northwestern USA (Venturato et al, 2004). Detailed and accurate information on both the underwater and dry land topography of an area are fundamental to the success of the models. It has only been in recent years that any priority has been given to the mapping of the interface between land and sea. Hydrographers have been mainly concerned with the area where ships float, not where they do not. Land surveyors have often seen the mud flats, that often border the dry land, as useless for development and consequently of little interest to map. An increase in environmental concern has caused several hydrographic offices to conduct surveys of the coastal zone as a matter of urgency. Hydrography has taken on a broader mandate of not just surveying for navigational reasons but to provide data for a variety of purposes, including engineering design and the modelling of various dynamic processes. There are a number of administrative difficulties which exist relating to the acquisition of data; one such issue is the matter of national copyright making it difficult for researchers to obtain the data. To remedy this an international pool of inshore data has been suggested (Yeh, 1995).

There are also some technical reasons for the neglect in surveying the coastal zone. Historically hydrographers, in order to provide a margin of safety to navigators, have used low water as a vertical datum to which all depth measurements were reduced. Land surveyors, on the other hand have preferred to use mean sea level as their vertical reference. These differences have resulted in a step along the shoreline that has made it difficult to ensure a smooth transition between marine and land data. There is now considerable interest in developing a common vertical reference frame, so that the mapping and charting of land and sea can be seamless. (Parker, 2002). A particular difficulty of surveying the coastal zone has been its hostility in many places. Invariably there is either heavy wave action and surf, making it difficult for survey boats to work in an area or the area may be large, flat and muddy which is also very difficult to survey. However help is at hand and there is now increasing use of airborne LIDAR which allows large areas of coastal zone to be surveyed precisely and rapidly. Such surveys have now been carried out over extensive lengths of the coastline of the USA.(Lillycrop,2005). Interferometric sidescan or other forms of wide swath sonar also promise to expedite shallow water bathymetric surveying.

Research has been carried out into the inundation of coastal areas as a result of flooding by tsunamis (Venturato et al, 2004) which may also have an application to flooding by hurricanes and other causes. Whether this information will be used by city planners in the coastal zone and planners that still seem to allow houses to be built on flood plains remains to be seen.

Hydrography in the Aftermath

Institutionally, the aftermath of a disaster brings much hand ringing and people expressing "what if!" It was noted earlier that in the first stages much of the work falls on the emergency measures teams. However, these teams must first reach the stricken areas and this will require a replacement of the infrastructure. In the marine sense this means that ships carrying relief supplies or moving refugees should be able to enter an area. Immediately after the Asian Tsunami disaster, on 12 January in London, a number of maritime organisations, headed by the International Maritime Organisation (IMO) met Their remit was to assess what action had to be taken (IMO, 2005). This group included the International Hydrographic Organisation (IHO). It was critical that the promulgation of maritime safety information was updated and dispatched as soon as possible. That task fell on the national hydrographic offices. Major changes in the topography and particularly the existence of objects that had been washed into the navigable channels, had to be surveyed with dispatch. An action plan developed at the IMO meeting contained the following elements:

Short term

- Assess the extent of damage to navigational aids in the affected areas, in cooperation with the national authorities.
- Assess and undertake preliminary re-survey for any reported changes in depths in the affected areas particularly ports, restricted navigational areas, the Malacca Straits and other areas as needed.
- Issue advice to shipping as appropriate, through existing networks.

Medium/long term

- Technical co-operation activities including needs' assessment missions; mobilizing and co-ordinating resources accordingly
- Assess and define new charting requirements
- Marking of new dangers, if necessary
- Participate in establishing an appropriate tsunami early warning system for the Indian Ocean, in co-operation with UNESCO/IOC and others

Consider and incorporate consequential amendments to the Organisation's basic documents as appropriate.

Regionally, UNESCO arranged a Workshop to discuss the development of a Tsunami Warning and Mitigation System for the Indian Ocean within a Global Network in 2005 (UNESCO, 2005).

At a national level the US Government also set out a plan for an improved tsunami detection and warning system. This included a promise of $ 37.5 million over the next two years to expand US detection and monitoring capabilities. Its elements include much of the research touched on in this paper.

The above type of work has taken a more direct and practical shape in the aftermath of the hurricane Katrina disaster. The US Coast Survey of NOAA has moved in directly with its Navigation Response Teams (NRTs) to coordinate the activities of several survey vessels working the area of New Orleans and the coast of Louisana (http://chartmaker.ncd.noaa.gov/nsd/katrina.htm). This work will no doubt be carried out in close co-operation with other US national agencies, such as the US Army Corps of Engineers, the US Naval Oceanographic Office and the US Coast Guard. It has been noted that these emergency services include performing side scan sonar surveying for updating US Government Navigational Charts, conducting hazardous obstruction surveys (utilising diving operations), electronic navigation capture, data collection and mapping support activities.

The Future

It is a certainty that other disasters will occur in the future. Considerable political speculation exists on the extent and type of future man-induced disasters but other major natural disasters remain inevitable. Hydrographers have a part to play, both in their capacity as providers of various types of marine data, particularly of the sea floor topography and the tides, but also as part of multi-disciplinary teams that work towards improving our ability to predict future maritime disasters, their consequences and minimization of their effects. Fortunately, recent developments in technology will aid them in their task. The broad and general use of satellite positioning will permit a common and precise geographic framework for any information. MBES permits sea floor mapping to be carried out quickly and precisely, although it should be recognised that when it comes to the oceans themselves the area still to be mapped is daunting. LIDAR is being increasingly used, although it must be borne in mind that it does not work well in turbid water and that this is the normal condition of water immediately following a disaster. Finally, due to advances in telecommunications and information technology, our ability to manage data has improved significantly in recent years.

It is typical following a disaster, be it a major shipwreck, a tsunami or a hurricane, for the political process to put in place various systems to try to alleviate the event happening again. Examples of this can be seen in the requirement for all ships to continually man their wirelesses, following the sinking of the *Titanic* or more recently, the development of a tsunami warning system for the Indian Ocean. However it is essential that once the political heat has passed, that ongoing support for marine science, in its broadest sense, continues to be provided because it is from the sea that most of these disasters develop.

Conclusions

Hydrography plays an important role in marine disaster management, both in its prediction and in the aftermath. Increasingly marine sciences are becoming multi-disciplinary and hydrography has an important part to play both in the scientific research and in engineering work that may anticipate or follow a disaster. Traditionally hydrographic surveys were mainly directed towards providing data for the production and maintenance of nautical charts but today hydrography has a much broader mandate and provides data for a great range of environmental and engineering studies.

Basic mapping of the bathymetry is fundamental to monitoring tsunamis in both the deep oceans and in the coastal zone. Modern technology in the form of multi beam and interferometric systems are being employed to provide the dense data sets for much of the modelling. The systematic measurement of water levels in many countries provides an important method detecting tsunami dynamics. The measuring stations are linked by communications to provide important warning systems. To date this activity has been mainly centred in the Pacific Ocean but the recent disastrous tsunami in the Indian Ocean has brought about the political will to extend the network internationally. It is important that such political will extends beyond the period immediately after the disasters to provide ongoing funds of a substantial nature for future scientific research into prediction and risk analysis and to the construction of reliable engineering defences.

References

1. US Marine Environmental Laboratory. NOAA. www.pmel.noaa.gov/tsunami/database devel.html
2. UKHO (2005) Indian Ocean Tsunami Briefing
3. H. Yeh (1995) The Tsunami Perspective. IOC Technical Series No. 63 pp 45-47
4. H. Yeh (1998) Tsunami researchers outline steps for better data. EOS. Trans.Amer.Geophys Union 79, 480 and 484
5. Gupta H./K.(2005) Early Warning Systems for Tsunamis and Storm Surges: The Indian Initiative. UNESCO Workshop Report. No. 196
6. Wynn R.B. and Masson D.G. (2003) Canary Islands landslides and tsunami general Symposium on Submarine mass movements and their consequences (Ed. By J.Mienert, Dortrecht, 325-332
7. Wynn R.B.(2003) www.noc.soton.ac.uk/CHD/Research/topics/canaries slides.html
8. Rabinovich A.B. and F.E. Stephenson (2004) Longwave measurement for the coast of British Columbia and Improvements to Tsunami Warning capability. Natural Hazards 32: 313-343
9. NOAA (2005) Deep Ocean Assessment and Reporting of Tsunamis. The DART program. http://www.pmel.noaa.gov/tsunami/DART/dart pbl.html. Lander J.F., P.A. Lockbridge and M.A. Chinnery (1989) United States Tsunamis (including US Possessions) 1690- 1988. pp.2-4
10. Titov V.V. and F.I. Gonzales (1997). Implementation and Testing of the Method of Tsunami Splitting (MOST). NOAA Technical Memorandum ERL PMEL – 112. November
11. Parker B. (2002) The Integration of Bathymetry, Topography and Shoreline and the Vertical Datum behind it. I H Review 3 # 3 November. pp 14-26
12. Lillycrop J. (2005) Status Report on the Joint Airborne LIDAR Bathymetry Technical Center of Expertise and CHARTS First Year of Operation. Proc. US Hydro 2005. March 29-31. San Diego, USA
13. Venturato A.J., V.V. Titov, H. Mojfeld and F.I. Gonzalez (2004) NOAA TIME Eastern Strait of Juan de Fuca, Washington, Mapping Project, NOAA Technical Memorandum OAR, MEL Contribution 2713
14. International Maritime Organisation (2005) IMO, IHO and IALA meet to coordinate Tsunami Responses. Briefing 04/2005. 12 January UNESCO (2005) International Coordination Meeting for the Development of a Tsunami Warning and Mitigation System for the Indian Ocean within a Global Framework. IOC Workshop Report No. 196 p 35

Biography

The author has previously been a Director of the International Hydrographic Organisation. He is now Editor of the International Hydrographic Review.

E-mail: adam.j.kerr@btinternet.com