

## **TSUNAMI RESEARCHERS OUTLINE STEPS FOR BETTER DATA**

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A tsunami is a long wave. The length of the wave is much longer than its depth. A typical tsunami wave in deep water is several tens to hundreds of kilometers long. Hence even if such a wave propagated over a 4000-m-deep abyssal plain, its evolution would be strongly affected by the bottom bathymetry. This is not the case for storm-generated waves, which are typically less than 500 m long; waves whose length is less than twice their depth are not affected by the presence of the ocean bottom.

Once a tsunami approaches shore, its amplitude increases by shoaling, owing to the decrease in water depth. Unlike other ocean-related research, tsunami analyses therefore require one to integrate bathymetry data over the entire ocean basin that is in the path of the tsunami and then add the coastal topography information from areas on dry land that would possibly be inundated by the tsunami. Hence data may be needed from ocean trenches that are more than 10,000 m deep, from abyssal plains that are 4000 m deep, from continental shelves that are 200 m deep, and from coastal areas above sea level.

Accurate and high resolution data are important, and not just for numerical simulations. For example, bathymetry data are needed for placement of tsunami instruments, development of tsunami inundation mapping [e.g. BERNARD, 1998], assessment for submarine and supermarine landslides [e.g. RANEY and BUTLER, 1976], and hindcasts of earthquake source mechanisms [e.g. SHUTO, 1991; SATAKE and KANAMORI, 1991]. With this information, during an actual tsunami event, real-time tsunami-effect assessment and predictions could possibly be made by judgement calls based on graphical presentations of bathymetry and coastal topography data. No matter how sophisticated the prediction models are, unless the bathymetry and topography are sufficient, predictions from the models will be unreliable and might yield misleading information.

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In the past few years, the tsunami research community has discussed the importance of bathymetry and coastal topography data at several workshops: the International Tsunami Measurement Workshop in 1995; the Workshop on Tsunami Mitigation and Risk Assessment in 1996; a workshop at a joint meeting of the International Association for Physical Sciences of the Oceans and other groups in 1997; and a regional workshop at the Japan Oceanographic Data Center (JODC) in 1997. Earlier this year the International Workshop on Bathymetry and Coastal-Topography Data Management was held as an extension of the JODC workshop.

The most recent meeting took up the current status of deep water bathymetry data, including the General Bathymetric Chart of the Oceans (GEBCO), a world-wide digital bathymetric chart from the British Oceanographic Data Center (BODC). Also looked at were JODC data and the Geophysical Data System (GEODAS) of the National Geophysical Data Center (NGDC). Details can be found in the organizations' Web pages (<http://www.nbi.ac.uk/bodc/gebco.html>), (<http://www.jodc.jhd.go.jp/jodc.html>), and (<http://www.ngdc.noaa.gov/mgg/geodas/geodas.html>), respectively.

In addition, TOPEX input [e.g. SMITH and SANDWELL, 1994] was discussed. Also known as the Sandwell-Smith data, they are based on sparse sounding data augmented by bathymetry estimates from a wealth of gravity anomaly information supplied by the satellite ([http://topex.ucsd.edu/marine\\_topo/mar\\_topo.html](http://topex.ucsd.edu/marine_topo/mar_topo.html)).

Yuchiro TANIOKA compared the data around Japan with the SANDWELL-SMITH data and concluded that SANDWELL-SMITH give much shallower depths than the actual sounding data where water depth is less than 100 m. Where water depth is greater than 1000 m, the SANDWELL-SMITH data are in excellent agreement with the sounding data. This method yields poor predictions when marine sediments are present, but the technique is useful not only to compensate sounding data in deep water but also to discover previously unknown features in deep ocean bathymetry. For example, David SANDWELL demonstrated that a chain of seamounts in the South Pacific was discovered with this technique. Sounding data in the Southern Hemisphere are sparse in comparison with those in the Northern Hemisphere. The discovered seamount chain might be important for tsunami analyses since significant wave scattering and refraction may occur depending on the length scale of the features.

Resolution much finer than 1 minute ( $\approx 2$  km) may not be needed in deep water bathymetry for tsunami computations, so there is optimism. The data will be improved significantly in the next few years with close international cooperative efforts, especially among BODC, JODC, NGDC, and TOPEX, and the data will be continually improved, updated, and maintained by those groups. Nonetheless, the problem remains in shallow water bathymetry on continental shelves. Based on a simple model proposed by SHUTO *et al.* [1986], the grid size requirements for tsunami numerical simulations can be estimated. In order to satisfy the criteria of a minimum of 30 grid points for 1 tsunami wave length with a wave period of 5 minutes, the grid size should be less than 500 m where the depth is more than 250 m; a grid size of 100 m is needed where depth is more than 10 m; and a grid size of 50 m where depth is more than 2.5 m. These rule-of-thumb estimates show that a grid size smaller than 500 m is evidently required for tsunami computation on

a continental shelf; perhaps a 100-m grid size is desirable. Currently, the Japan Meteorological Agency (JMA) has the 1-minute (~ 2 km x 2 km) data covering the regions between the coast and ~200-400 km away from the coast around Japan (from latitude 20°N to 48°N and from longitude 120°E to 152°E); those data are used for tsunami warning by JMA. JODC also has a coastal dataset of 30"x45" grids (~ 1 km x 1 km), and plans to create a systematic and detailed bathymetry database for the vicinity around Japan, the 500-m grids for the coastal areas (from the coastline to 15 nautical miles offshore) and the 1-minute grids for the continental shelf regions. Russian 1-minute data around the Kamchatka Peninsula also were presented at the workshop (<http://omzg.sccc.ru/tsulab/kam1m.gif>), clearly demonstrating the recent trend for bathymetry data, which used to be totally classified, to become more and more accessible to the public.

Since shallow water bathymetry data are usually collected and managed by regional organizations for regional interest, dataset development is not as standardized or coordinated internationally as for deep-water bathymetry data. Furthermore, in most countries hydrographic charts are copyrighted and cannot be digitized without the approval of a country's national Hydrographic Office. As an initial international effort, GEBCO will ask member countries of the International Hydrographic Organization for shallow water bathymetry in digital form in order to construct a global shallow water database at 2-minute resolution. Evidently, the present status of shallow-water bathymetry data is far from adequate; much finer resolution (say 100 m) is needed for tsunami analyses. For tsunami run-up analyses, 30 m of vertical and 5 km of horizontal coastal topography data would be sufficient for most tsunami events. Extreme cases should be handled by individual investigators, workshop participants felt.

Currently, 30-second coastal topography data are available on the Web (<http://www1.gsi.mc.go.jp/gtopo30/gtopo30.html>) from the U.S. Geological Survey (USGS). The USGS also has three high-resolution datasets available on the Web site ([http://edcwww.cr.usgs.gov/glis/hyper/guide/usgs\\_dem](http://edcwww.cr.usgs.gov/glis/hyper/guide/usgs_dem)): a 10-m and 30-m resolution dataset, 2-second resolution grids, and 3-second resolution grids. The 10-m data are not widely available, but the 30-m data are generally available for U.S. coastal areas. The Japan Geographic Survey Institute plans to release 50-m resolution topography data on three CD-ROMs next year.

USGS also plans to release 1-second (30-m) resolution data for selected areas next year. Also, 30-m data for a limited number of estuaries are available in the United States from the National Oceanic and Atmospheric Administration's Office of Resource and Conservation Analysis.

One must be careful about topography data since coastal areas have much faster temporal variation than deep ocean areas, but available data, at least in Japan and the United States, appear to be adequate for tsunami run-up analyses in general, and such data will be much improved in the future. For example, coastal topography now can be measured from an aircraft with a new technology, which uses the Global Positioning System (GPS) (<http://www.csc.noaa.gov/text/beach.html>). It is capable of measuring elevation to an accuracy of 10 cm. It might also be able to help assess tsunami impact and damage in future tsunami surveys.

For U.S. coastal areas, 3-second (90 m x 90 m) integrated bathymetry and topography data are currently being developed by Lincoln PRATSON. The data

now cover only the east coast but will be expanded to include the Gulf coast, west coast, Alaska, and Hawaii. The work appears to be extremely useful for tsunami research.

Vertical measurements for both bathymetry and coastal topography are a serious concern. For example, USGS topography data are based on the North American Vertical Datums of 1929 (NAVD'29), but in some island areas, local mean sea level is used. Shorelines shown on USGS topographic maps are an estimate of the mean high water line. In general, topography data are often measured from the mean high high water (MHHW) level and bathymetry data are customarily measured from the mean low low water (MLLW) level. There are at least 66 different measurements around the world, such as MHHW, MLLW, highest astronomical tidal level, and lowest astronomical tidal level. This creates inconsistency and confusion.

Common measurements for both bathymetry and topography are needed, and workshop participants agreed that the most appropriate might be found in the mean-Earth ellipsoid of the World Geodetic System 84. A minor problem in this is that the actual sea surface may deviate up to 30 m above or below the ellipsoid surface. Hence such data would have to be converted for specific uses such as navigation or tsunami computations. Nonetheless, this measurement is time invariant and is directly related to present measurement practice using GPS. Once set up, with all bathymetry and coastal topography data in a single format (latitude, longitude, depth, or elevation), the measurements can be readily converted to other measurements. The conversion algorithm from the ellipsoid surface should be provided, as well as local tide information, so that local depths can be computed. For example, tsunami simulation calculations need to be performed based on the sea level at the time of the event. Bathymetry and coastal topography data based on the proposed common ellipsoid should be converted to data based on mean sea level and then adjusted for tidal levels. The data management system based on standardized measurements will provide simplified and consistent data conversion processes for both bathymetry and topography.

Even though emphasis is on digitized gridded and contour datasets, the raw information must be retrievable so that the accuracy and precision of the processed data can be estimated. The raw information for both marine tracking data in deep water and National Ocean Service hydrographic survey data in coastal waters is available through NGDC's GEODAS. U.S. Navy raw data are still classified but, even if the original raw data cannot be declassified, information about such data, such as measurement densities, would give some indication of the accuracy and precision of the processed data. One example is the JODC Bathymetry Integrated Random Data Set (J-BIRD), developed by JODC (<http://www.jodc.jhd.go.jp/inf/data/bathymetry/mesh-depth.html>). Within a given 30" x 45" mesh (~ 1 km x 1 km), provided in the coding are mesh location, average depth value, minimum depth, maximum depth, the number of raw data points, and standard deviation. Such coding will provide sufficient information without having to declassify the raw data. It is also desirable that the coding for unavailable raw data be standardized internationally. Any data update should be based on the original raw data; one should try to avoid altering previously modified data.

Workshop participants also attempted to identify areas deficient in data. Shallow water bathymetry data and topography data in remote areas are often

unavailable. Participants proposed that any scientific group collecting bathymetry or coastal topography data for its own use should be encouraged to share the data with the larger scientific community. For example, once finished with local bathymetry data collected in, say, Indonesia or Nicaragua, tsunami researchers could transmit the data to one of the following contact persons: Peter HUNTER at GEBCO (peter.hunter@soc.soton.ac.uk), Lt. W. Austin CRESWELL (acreswell@ngdc.noaa.gov), or David SANDWELL (sandwell@geosat.ucsd.edu). GEBCO and other organizations should also start digitizing all available shallow water sounding data from the existing charts and convert them to a standardized format (latitude, longitude, depth from the ellipsoid surface) for later processing.

The International Workshop on Bathymetry and Coastal Topography Data Management was held in Seattle, Washington, March 20-22, 1998.

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