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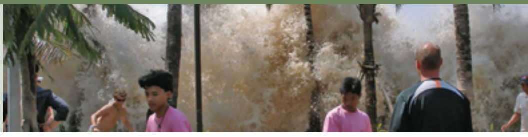
Modelling *answers tsunami questions*

New research will help emergency planners



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The Indian Ocean tsunami on 26 December 2004 demonstrated the potentially catastrophic consequences of natural hazards. In addition to humanitarian assistance, the Australian Government's response included the establishment of the Australian Tsunami Warning System (ATWS) and greater priority for research into hazard and risk modelling of tsunami impacts.

Determining tsunami risk

Geoscience Australia aims to define the economic and social threat posed to urban communities by natural hazards such as tsunamis. Predictions of the likely impacts of tsunamis can be made through the integration of earthquake and tsunami hazard research, community exposure and socioeconomic vulnerabilities. By modelling the likely impacts on urban communities as accurately as possible and building these estimates into land use planning and emergency management, we can better prepare communities to respond to tsunamis when they occur.

One critical component in understanding tsunami risk is being examined by the Risk Assessment Methods Project (RAMP) at Geoscience Australia which has been developing a hydrodynamic inundation modelling tool developed specifically to estimate the consequences of possible tsunami impacts on Australian communities.

Modelling methodology

Tsunami hazard models have been available for some time. They generally work by virtually converting the energy released by a subduction earthquake into a vertical displacement of the ocean surface. The resulting wave is then propagated across a sometimes vast stretch of ocean using a relatively coarse linear model based on bathymetries with a typical resolution of two arc minutes.

The maximal wave height at a fixed contour line near the coastline (say, 50 metres) is then reported as the hazard to communities ashore. Models such as Method of Splitting Tsunamis (MOST) (Titov & Gonzalez 1997) and the URS Corporation's Probabilistic Tsunami Hazard Analysis (Somerville et al 2005) follow this paradigm.

The severity of a hydrological disaster is critically dependent on complex bathymetric and topographic effects near the area of interest. For example, during the 1993 Okushiri Island tsunami, a very large run-up was observed at one specific location, whereas surrounding areas received much less inundation (Matsuyama et al 1999). Estimating the impact of a tsunami on a particular community therefore requires modelling of the nonlinear process by which waves are reflected and otherwise shaped by the local bathymetries and topographies. These complex effects generally require elevation data of much higher resolution than is used by the linear models, which typically use data resolutions in the order of hundreds of metres (sufficient to model long-wavelength tsunamis in open water). The data resolution used by nonlinear inundation models, by contrast, is typically in the tens of metres.

The ANUGA model (Nielsen et al 2005)—the result of collaboration between the Australian National University and Geoscience Australia—is suitable for this type of modelling. However, running a nonlinear model capable of resolving local bathymetric

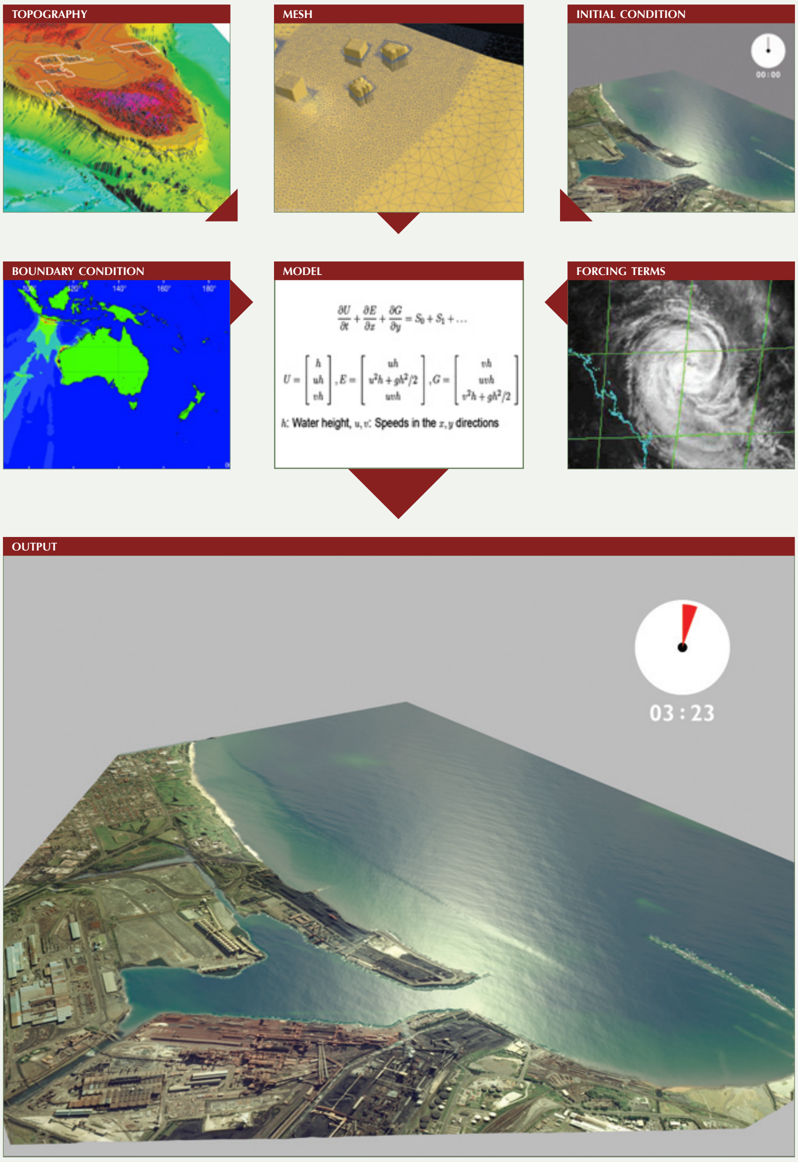

Figure 1. Data requirements for an ANUGA simulation include topography of the study area, a triangular mesh, definition of initial and boundary conditions, and any forcing terms, such as wind stress. Boundary conditions could capture incoming waves from a range of sources, such as output from other models, run-off or tidal variations.

effects and run-up using detailed elevation data requires more computational resources than the typical hazard model, making it inapplicable for complete end-to-end modelling of a tsunami event.

We have adopted a hybrid approach, in which the output from a hazard model such as MOST is used as input to ANUGA at the seaward boundary of its study area. The output of the hazard model thus serves as a boundary condition for the inundation model. In this way, we restrict the computationally intensive part to regions where detailed understanding of the inundation process is required.

Furthermore, to avoid unnecessary computations, ANUGA works with an unstructured triangular mesh rather than the rectangular grids typically used by hazard models. The advantage of an unstructured mesh is that different regions can have different resolutions, allowing computational resources to be directed where they are most needed. For example, one might use very high resolution near a community or in an estuary, whereas a coarser resolution might be enough for deeper water, where the bathymetric effects are less pronounced.

To implement a scenario, the modeller requires suitable initial conditions (such as a tidal height), boundary conditions (such as model data from a subduction zone earthquake), forcing terms (such as wind) and, importantly, bathymetric and topographic data for the study area (figure 1). The calculated run-up height and resulting inundation ashore is determined by these inputs, as well as the cell resolution.

The data should ideally capture all complex features of the underlying bathymetry and topography, and cell resolution should be commensurate with the underlying data. Any limitations in the resolution and accuracy of the data, including the cell resolution, will introduce errors to the inundation maps as well as to the range of model approximations.

Tsunami impact on the North West Shelf

Historical evidence of large tsunamigenic earthquakes off Sumatra with impacts on the Western Australian coastline suggests that communities and infrastructure along that coastline are at risk of tsunami inundation (Cummins & Burbidge 2004).

To better understand the risk, particularly for the significant petroleum production infrastructure off the North West Shelf and near the Sunda Arc trench, the Fire and Emergency Services Authority (FESA) in Western Australia struck a collaborative research agreement with Geoscience Australia. Initial priority areas are Onslow, Port Hedland, Karratha, Dampier, Broome, Busselton and Perth. The study has brought together a number of groups within Geoscience Australia to support the FESA project. The study areas for the first project milestone are Onslow and Port Hedland.

The boundary condition has been defined by the Earthquake and Tsunami Hazard Project model of an Mw 9 earthquake generated east of Java by the Sunda Arc trench (Mw is a logarithmic measure of earthquake size, similar to the Richter scale but better suited to very large events). This event is plausible, but the recurrence rate is not yet known. The earthquake and subsequent tsunami wave in deep water are simulated by MOST, which outputs water height and velocity in space and time. ANUGA then uses this information and propagates the wave through the shallow water and onshore.

The collation of data has proved to be a challenging task. Geoscience Australia's Petroleum and Marine Division has sourced available hydrographic charts ('fairsheets') for regions identified on the North West Shelf. Digitisation of some of these charts is needed, and matching the entire dataset requires suitable metadata to be available (which it seldom is, especially for older datasets). Thanks to the National Mapping and Information Group within Geoscience Australia's Geospatial and Earth Monitoring Division, offshore and onshore datasets for Onslow and Port Hedland have been delivered to RAMP for inundation modelling.

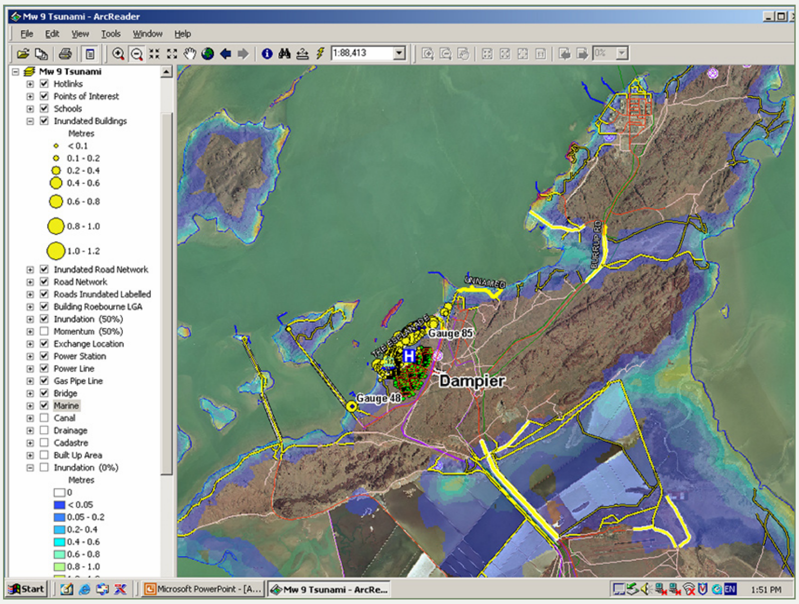

Figure 2. Example of inundation map provided to emergency managers. Here, the map is embedded in a GIS product, enabling emergency managers to use the output as a decision support tool.

Once the inundation modelling has been completed, structural damage and contents loss estimates can be made. RAMP engineering models and the national building exposure database (NBED) are brought together to develop a damage estimate for each simulation. The NBED contains information about residential buildings, people, infrastructure, structure value and building content, and has been created so that consistent risk assessments for a range of natural hazards can be conducted. The damage estimates use the NBED information and predict probability of collapse as a function of the building type, location and inundation depth at the building and floor levels.

Finally, the GIS team within RAMP develops the decision support tool (figure 2), which includes ANUGA outputs, inundation maps, time series for defined point locations, and damage estimates. These outputs are included as layers in the decision support tool, with aerial photography and overlays of critical infrastructure, such as roads. Visualisations developed from the ANUGA output (figure 3) are useful to modellers and planners alike for understanding the behaviour of the tsunami.

The outcome is a tactical decision support tool for use by operational emergency managers as they make decisions on how to mitigate risk to coastal communities. In particular, the tool will provide:

- a better understanding of national tsunami risk and resourcing requirements for particular communities and regions
- scenarios for a wide range of tsunami events for which casualty and infrastructure consequences are predicted, and against which emergency management capability can be assessed
- real-time consequence prediction tools for tactical use by emergency managers to obtain assessments of tsunami impact and expected consequences to guide initial resource deployment.

Further studies

The preliminary hazard modelling has identified communities most at risk from tsunamis generated by subduction zone earthquakes. More detailed modelling, which will be available by the end of 2006, will provide information on return periods so that tsunami risk can be determined. This is consistent with RAMP's objective of defining the national risk from a range of rapid-onset natural hazards in a standardised and consistent way.

The relative tsunami risk can be measured using the modelling techniques we have described, providing a strategic aid to emergency planning. In addition, the precomputed simulations and risk maps will form a library of scenarios for the ATWS, aiding mitigation, warning, response and community recovery in the event of a tsunami disaster.

The recent meeting of the Australian Tsunami Working Group acknowledged the utility of detailed impact modelling for mitigating the effects of tsunamis. However, the biggest barrier to such modelling is the unavailability of reliable, high-resolution bathymetry and elevation data. Geoscience Australia has developed a set of guidelines for state agencies, outlining the requirements for the collection of such data. These guidelines will assist the exchange of data between agencies and guide third parties in the collection of data.

Other state agencies have expressed interest in conducting studies similar to those being done for FESA. Geoscience Australia is committed to working with state emergency managers to understand tsunami risk, and will continue to conduct detailed studies in areas of national interest.

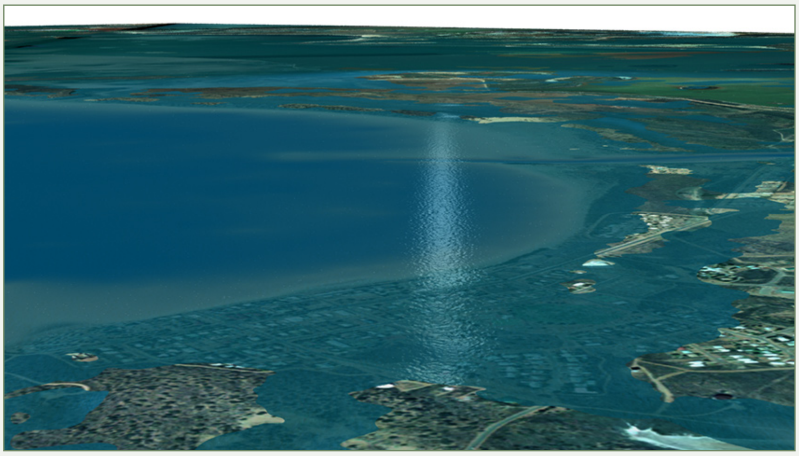

Figure 3. Snapshot of visualisation of tsunami inundation, North West Shelf (photograph courtesy of Department of Land Information, Western Australia).

More information

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References

Cummins P & Burbidge D. 2004. Small threat, but warning sounded for tsunami research. AusGeo News 75, 4–7.

Matsuyama M, Walsh J & Yeh H. 1999. The effect of bathymetry on tsunami characteristics at Sisano Lagoon, Papua New Guinea. Geophysical Research Letters 26(23):3513–3516.

Nielsen O, Roberts S, Gray D, McPherson A & Hitchman A. 2005. Hydrodynamic modelling of coastal inundation. MODSIM 2005 International Congress on Modelling and Simulation, Modelling and Simulation Society of Australian and New Zealand, 518–523. www.mssanz.org.au/modsim05/papers/nielsen.pdf

Somerville P, Thio H-K & Ichinose G. 2005. Probabilistic tsunami hazard analysis. Report to Geoscience Australia.

Titov V & Gonzalez F. 1997. Implementation and testing of the Method of Splitting Tsunami (MOST) model. NOAA Technical Memorandum ERL PMEL-112.

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Risk Assessment Methods Project www.ga.gov.au/urban/projects/ramp/inundation.jsp
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