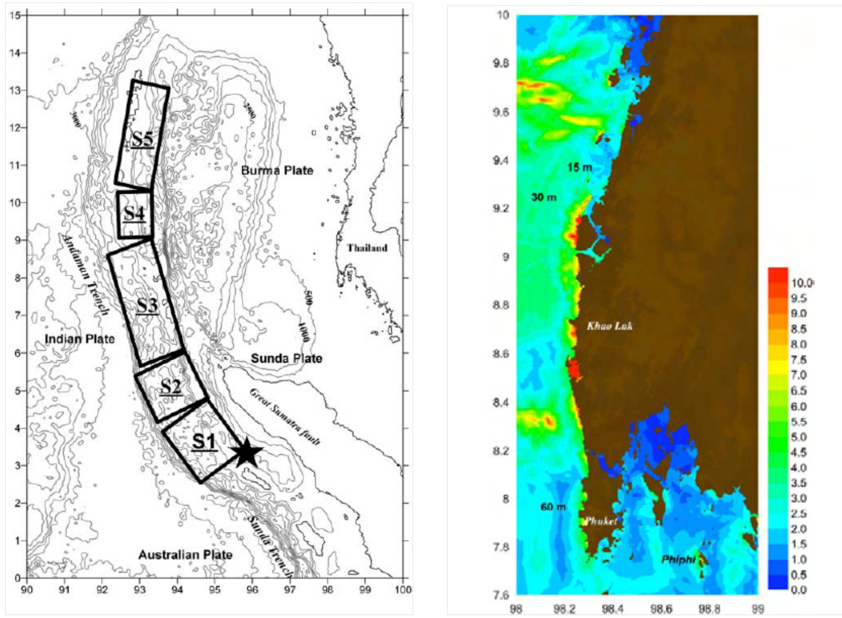
GEOWAVE

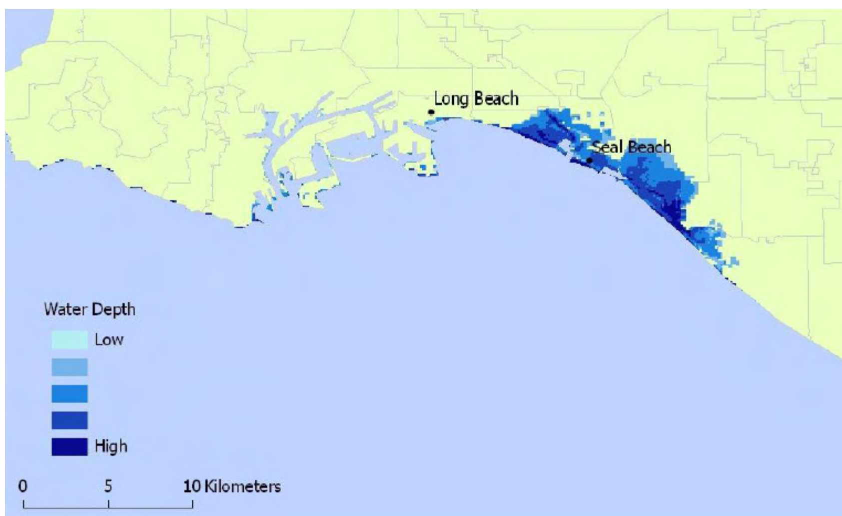
GEOWAVE simulates tsunami generation, propagation, and inundation using a 4th order fully nonlinear and fully dispersive Boussinesq wave model with multiple wave dissipation mechanisms, wave breaking, and dry land overflow.

GEOWAVE provides a programming architecture to generate multiple tsunami sources with TOPICS and insert these tsunami sources at the appropriate time into a simulation run in a modified version of FUNWAVE.

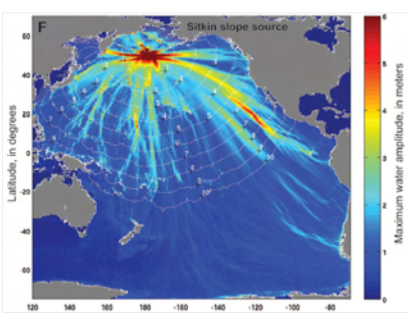
GEOWAVE has been distributed around the world to over 40 research groups in more than 10 nations as an open source community model under a GNU General Public License. It is one of the most validated and accurate tsunami models in the world. GEOWAVE 1.0 has been in continuous use since 2002, with an updated version GEOWAVE 1.1 issued in 2009.



Five co-seismic tsunami source segments (left panel) and maximum surface elevation simulation results (right panel) for Thailand that accurately reproduce tsunami measurements and observations from the 2004 Indonesia event (Ioualalen et al., 2007).



Risk assessment and loss estimates for a given tsunami scenario are based in part on local water depths from tsunami inundation, along a populated Southern California coastline (Grossi et al., 2008).



Example of volcano-induced tsunami hazard: Catastrophic failure of Sitkin volcano would produce a transoceanic tsunami impacting much of the Pacific Basin. Model results created using Spherical Boussinesq simulation. (Waythomas et al., 2009).

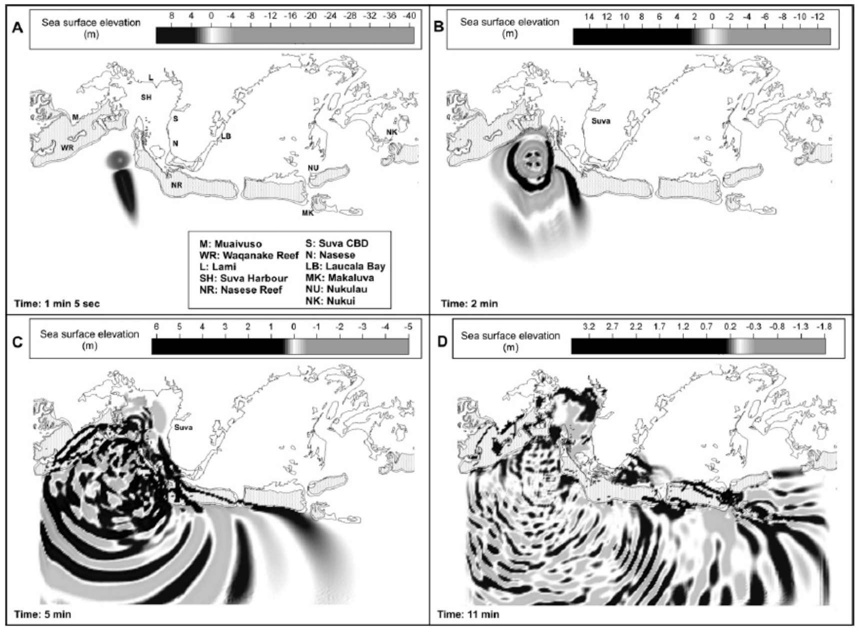
GEOWAVE produces tsunami hazard maps with a wide variety of outputs such as water depth, water velocity, water flux, wave breaking location, etc. as well as processed outputs such as sediment transport modes, forces on structures, floating object lateral displacements, boulder transport and emplacement, people and cars being swept away, etc. Scripts for Surfer and MATLAB software are available to plot these tsunami hazard maps.

TOPICS

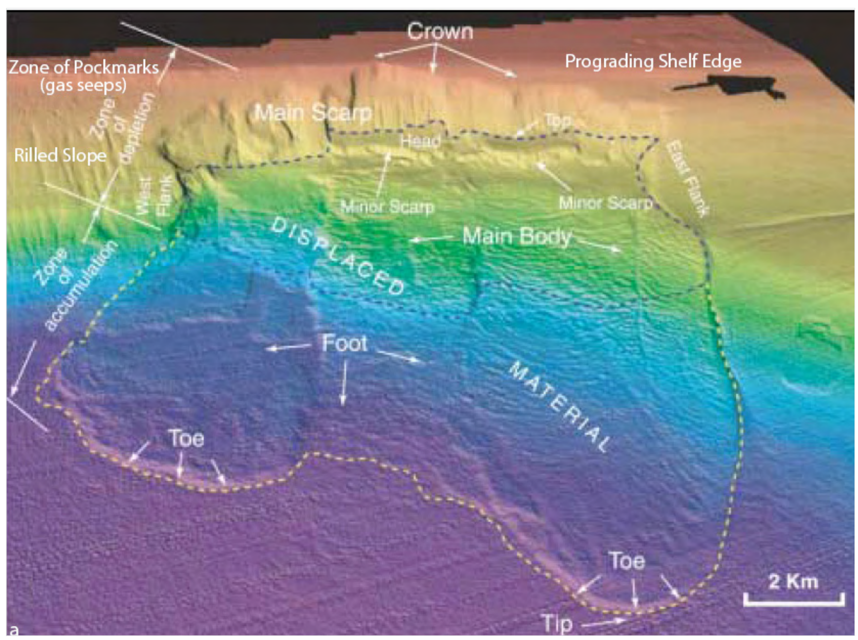
TOPICS produces 3D tsunami sources for tsunamis generated by earthquakes, subaerial landslides, rock slides, debris flows, pyroclastic flows, submarine slides, submarine slumps, and reef failures, among other available tsunami sources.

A 3D tsunami source comprises a free surface shape, as well as two horizontal water velocities for each grid point. Tsunami sources can be used as initial conditions, or introduced in the middle of a tsunami simulation, with timing appropriate for a given target seismic event.

Multiple tsunami sources can be used in any tsunami simulation, the description of complex fault structures, the propagation of a fault rupture, or earthquake/landslide combinations. TOPICS can capture the full complexity of geological events. TOPICS also enables the user to design an incoming periodic wave train, or input an arbitrary tsunami source derived from outside of TOPICS. TOPICS is sufficiently flexible to enable any of its tsunami sources to be introduced into GEOWAVE at any time.

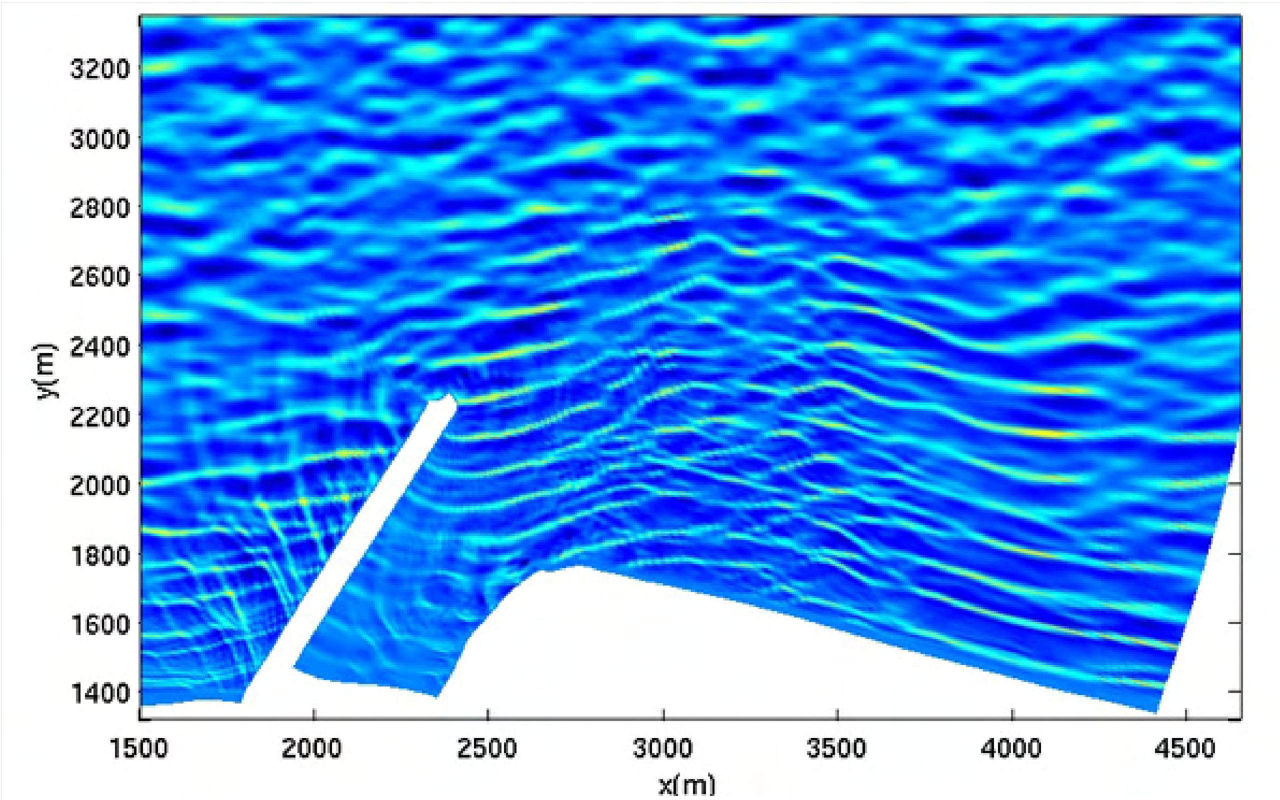


Four free surface snapshots of the 1953 Suva, Fiji tsunami generated by a reef failure just outside Suva harbor (Rahiman et al., 2007).



Sea floor representation and interpretation of an underwater mass flow with constrained motion and known tsunami impact (Greene et al., 2006).

FUNWAVE

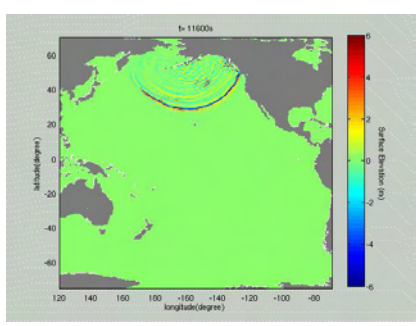


Instantaneous water surface snapshot from curvilinear Boussinesq model used for wave-structure interactions.

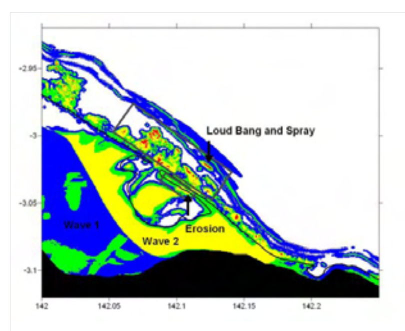
The wave propagation module in GEOWAVE is FUNWAVE, which is a phase-resolving, time-dependent Boussinesq model for ocean surface wave propagation. It is based on fully nonlinear and dispersive Boussinesq equations and takes into account wave breaking reflections from structures and bottom friction effects.

FUNWAVE has been available as an open source community model under a GNU General Public License since before 1998. FUNWAVE has more than 1400 registered users worldwide.

FUNWAVE was adapted for tsunami simulations within GEOWAVE by modifying the traditional beach algorithms, handling topography in a standard manner, introducing sponge layers to simulate open boundaries, and based on numerous case studies, using a specific set of simulation parameters optimized for tsunami simulations.



Instantaneous modeled surface elevation from GEOWAVE for a Pacific tsunami hazard.



Breaking wave eddy viscosity reproduces eyewitness observations at Papua New Guinea (Tappin et al., 2007).

Case Studies and Descriptions

Historical Case Studies

- Alika 2, Hawaii, US, volcano flank collapse
- Aniakchak, Alaska, US, pyroclastic flow
- 1755 Lisbon, Portugal, triple point earthquake
- 1800s Mt. Augustine, Alaska, US, debris flows
- 1908 Messina Strait, Italy, earthquake and landslide
- 1946 Unimak, Alaska, US, earthquake and landslide
- 1953 Suva, Fiji, earthquake and reef failure
- 1960 Chile, massive earthquake
- 1975 Kalapana, Hawaii, US, earthquake and slump
- 1994 Skagway, Alaska, US, spontaneous slide
- 1998 Sissano, Papua New Guinea, earthquake and slump
- 1999 Vanuatu, earthquake and landslide
- 2003 Montserrat, West Indies, pyroclastic flows
- 2004 Indian Ocean, massive earthquake

Unpublished GEOWAVE Studies

- Alika 2, Hawaii
- 1755 Lisbon, Portugal
- 1883 Krakatau, Indonesia
- 1908 Messina Strait, Italy
- 1929 Grand Banks, Canada
- 1977 Sumbawa, Indonesia
- 1979 Kitimat, B.C., Canada
- 1994 Java, Indonesia

Tsunami Scenarios Studied

- Santa Barbara Channel landslides
- Aleutian Arc Islands landslides
- Baker Lake, OR, debris flows
- San Pedro Bay tsunami risk
- Nicaraguan landslides
- Cascadia landslides

Consulting with GEOWAVE

- Offshore LNG structure, Woodside Energy, Ltd.
- Offshore mooring structure, Woodside Energy, Ltd.
- Onshore pier structure, Woodside Energy, Ltd.
- Guam tsunami hazards, USGS, U.S. Navy
- Pier 400, POLA, All American Pipelines, L. P.
- Baraldsness and Nyhamn Rock Slides, NGI Report 20001472-2
- Geiranger and Tafjorden Rock Slides, NGI Report 20011622-1

Applications of GEOWAVE to tsunami case studies and scenarios around the world.

Relevant Publications

1. Grilli, S. T., Dubosq, S., Pophet, N., Perignon, Y., Kirby, J. T. and Shi, F., 2010, *Numerical simulation of co-seismic tsunami impact on the North Shore of Puerto Rico and far-field impact on the US East Coast: a first-order hazard analysis, Nat. Haz. Earth Syst. Sci.*, In Press.
2. Abadie, S., Morichon, D., Grilli, S.T. and Glockner, S. 2010, *A three-fluid model to simulate waves generated by subaerial landslides*, Coastal Engineering, 57, 779-794, doi:10.1016/j.coastaleng.2010.03.003.
3. *Pacific Basin Tsunami Hazards Associated with Submarine Mass Flows in the Aleutian Islands of Alaska*, C. F. Waythomas, P. Watts, F. Shi, J. T. Kirby, Quaternary Science Reviews, 28, 1006-1019, 2009.
4. Grilli, S.T., Taylor, O.-D. S., Baxter, D.P. and S. Maretzki 2009, *Probabilistic approach for determining submarine landslide tsunami hazard along the upper East Coast of the United States*, Marine Geology, 264(1-2), 74-97, doi:10.1016/j.margeo.2009.02.010.
5. *Estimating Losses from Tsunami Risk: Focus on Southern Californi*a, P. Grossi, P. Watts, A. Boissonnade, R. Muir-Wood, Proc. 14th World Conference on Earthquake Engineering, Beijing, 8 pp, 2008.
6. Tappin, D.R., Watts, P., Grilli, S.T. 2008, *The Papua New Guinea tsunami of 1998: anatomy of a catastrophic event,* Natural Hazards and Earth System Sciences, 8, 243-266. www.nat-hazards-earth-syst-sci.net/8/243/2008/.
7. Abadie, S., Morichon, D., Grilli, S.T. and Glockner, S. 2008, *VOF/Navier-Stokes numerical modeling of surface waves generated by subaerial landslides*, La Houille Blanche, 1 (Feb. 2008), 21-26, doi:10.1051/lhb:2008001.
8. Enet, F. and Grilli, S.T. 2007, *Experimental Study of Tsunami Generation by Three-dimensional Rigid Underwater Landslides*, Journal of Waterway Port Coastal and Ocean Engineering, 133(6), 442-454, doi:10.1061/(ASCE)0733-950X(2007)133:6(442).
9. Ioualalen, M., Asavanant, J., Kaewbanjak, N., Grilli, S.T., Kirby, J.T. and P. Watts 2007, *Modeling the 26th December 2004 Indian Ocean tsunami: Case study of impact in Thailand*, Journal of Geophysical Research, 112, C07024, doi:10.1029/2006JC003850.
10. Grilli, S.T., Ioualalen, M, Asavanant, J., Shi, F., Kirby, J. and Watts, P. 2007, *Source Constraints and Model Simulation of the December 26, 2004 Indian Ocean Tsunami*, Journal of Waterway Port Coastal and Ocean Engineering, 133(6), 414-428, 10.1061/(ASCE)0733-950X(2007)133:6(414).
11. *The Source Mechanism and Numerical Modelling of the 1953 Suva Tsunami, Fiji*, T. I. H. Rahiman, J. R. Pettinga, P. Watts, Marine Geology, 237(2), 55-70, 2007
12. *Unique and Remarkable Dilatometer Measurements of Pyroclastic Flow–Generated Tsunamis,* G. S. Mattioli, B. Voight, A. T. Linde, P. Watts, C. Widiwijayanti, S. R. Young, D. Elsworth, P. E. Malin, E. Shalev, E. Van Boskirk, W. Johnston, R. S. J. Sparks, J. Neuberg, V. Bass, P. Dunkley, R. Herd, T. Syers, P. Williams, D. Williams, Geology, 35(1), 25-28, 2007
13. *Case Study: Mapping Tsunami Hazards Associated with Debris Flow Into a Reservoir*, J. S. Walder, P. Watts, C. F. Waythomas, J. Hydraulic Engineering, 132(1), 1-11, 2006
14. *Numerical Modeling of the 26th November 1999 Vanuatu Tsunami*, M. Ioualalen, B. Pelletier, M. Regnier, P. Watts, J. Geophysical Research, 111(C6), 2005JC003249, 2006.
15. *Numerical Simulation of Tsunami Generation by Cold Volcanic Mass Flows at Augustine Volcano, Alaska*, C. F. Waythomas, P. Watts, J. S. Walder, Natural Hazards and Earth System Sciences, 6, 671-685, 2006.
16. *Submarine Landslides in the Santa Barbara Channel as Potential Tsunami Sources*, H. G. Greene, L. Y. Murai, P. Watts, N. A. Maher, M. A. Fisher, C. E. Paull, P. Eichhubl, Natural Hazards and Earth System Sciences, 6, 63-88, 2006.

Relevant Publications

17. Dalrymple, R.A., Grilli, S.T. and J.T. Kirby 2006. *Tsunamis and challenges for accurate modeling, Oceanography*, 19(1), 142-151.
18. Day, S. J., P. Watts, S. T. Grilli and Kirby, J.T. 2005, *Mechanical Models of the 1975 Kalapana, Hawaii Earthquake and Tsunami*, Marine Geology, 215(1-2), 59-92, doi:10.1016/j.margeo.2004.11.008.
19. Grilli, S.T. and Watts, P. 2005, *Tsunami generation by submarine mass failure Part I: Modeling, experimental validation, and sensitivity analysis,* Journal of Waterway Port Coastal and Ocean Engineering, 131(6), 283-297, doi: 10.1061/(ASCE)0733-950X(2005)131:6(283).
20. Watts, P., Grilli, S.T., Tappin D., and Fryer, G.J. 2005, *Tsunami generation by submarine mass failure Part II: Predictive Equations and case studies*, Journal of Waterway Port Coastal and Ocean Engineering, 131(6), 298-310, doi:10.1061/(ASCE)0733-950X(2005)131:6(298).
21. *Giant Landslides, Mega-Tsunamis, and Paleo-Sea Level in the Hawaiian Islands*, G. M. McMurtry, P. Watts, G. J. Fryer, J. R. Smith, F. Imamura, Marine Geology, 203, 219-233, 2004.
22. *Megatsunami Deposits on Kohala Volcano, Hawaii from Flank Collapse of Mauna Loa*, G. M. McMurtry, G. J. Fryer, D. R. Tappin, I. P. Wilkinson, M. Williams, J. Fietzke, D. Garbe-Schoenberg, P. Watts, Geology, 32(9), 741-744, 2004.
23. *Probabilistic Predictions of Landslide Tsunamis off Southern California*, P. Watts, Marine Geology, 203, 281-301, 2004.
24. *Source of the Great Tsunami of 1 April 1946: A Landslide in the Upper Aleutian Forearc*, G. J. Fryer, P. Watts, L. F. Pratson, Marine Geology, 203, 201-218, 2004.
25. *Tsunami Hazard from Submarine Landslides on the Oregon Continental Slope*, B. G. McAdoo, P. Watts, Marine Geology, 203, 235-245, 2004.
26. *Tsunamigenic Slope Failure Along the Middle America Trench in Two Tectonic Settings*, R. von Huene, C. R. Ranero, P. Watts, Marine Geology, 203, 303-317, 2004.
27. Watts, S. T. Grilli, J. T. Kirby, G. J. Fryer, and Tappin, D. R. 2003, *Landslide tsunami case studies using a Boussinesq model and a fully nonlinear tsunami generation model*, Natural Hazards and Earth System Sciences, 3, 391-402.
28. *Numerical Simulation of Tsunami Generation by Pyroclastic Flow at Aniakchak Volcano, Alaska*, C. F. Waythomas, P. Watts, Geophys. Res. Letters, 30(14), 1751-1755, 2003.
29. Grilli, S.T., Vogelmann, S. and Watts, P. 2002, *Development of a 3D Numerical Wave Tank for modeling tsunami generation by underwater landslides*, Engineering Analysis with Boundary Elements, 26(4), 301-313.
30. Kennedy, A. B., Kirby, J. T. and Gobbi, M. F., 2002, *Simplified higher order Boussinesq equations. 1: Linear considerations*, Coastal Engineering, 44, 205-229.
31. Shi, F., Dalrymple, R. A., Kirby, J. T., Chen, Q. and Kennedy, A., 2001, *A fully nonlinear Boussinesq model in generalized curvilinear coordinates*, Coastal Engineering, 42, 337-358.
32. Kennedy, A. B., Kirby, J. T., Chen, Q. and Dalrymple, R. A., 2001, *Boussinesq-type equations with improved nonlinear behaviour*, Wave Motion, 33, 225-243.
33. *The Sissano, Papua New Guinea Tsunami of July 1998 - Offshore Evidence on the Source Mechanism*, D. R. Tappin, P. Watts, G. M. McMurtry, Y. Lafoy, T. Matsumoto, Marine Geology, 175, 1-23, 2001.
34. Gobbi, M. F., Kirby, J. T. and Wei, G., 2000, *A fully nonlinear Boussinesq model for surface waves. II. Extension to O(kh^4)*, Journal of Fluid Mechanics, 405, 181-210.
35. Kennedy, A. B, Chen, Q., Kirby, J. T., and Dalrymple, R. A., 2000, *Boussinesq modeling of wave transformation, breaking and runup. I: One dimension*, J. Waterway, Port, Coastal and Ocean Engrng., 126, 39-47.

Relevant Publications

36. Chen, Q., Kirby, J. T., Dalrymple, R. A., Kennedy, A. B. and Chawla, A., 2000, *Boussinesq modeling of wave transformation, breaking and runup. II: Two horizontal dimensions*, J. Waterway, Port, Coastal and Ocean Engrng., 126, 48-56.
37. Watts, P., Imamura, F., and Grilli, S.T. 2000, *Comparing Model Simulations of Three Benchmark Tsunami Generation Cases. Science of Tsunami Hazards*, 18(2), 107-123.
38. Kennedy, A. B., Dalrymple, R. A., Kirby, J. T. and Chen, Q., 2000, *Determination of inverse depths using direct Boussinesq modelling*, J. Waterway, Port, Coastal and Ocean Engrng., 126, 206-214.
39. *Super-Scale Failure of the Southern Oregon Cascadia Margin*, C. Goldfinger, L. D. Kulm, L. C. McNeill, P. Watts, Pure Appl. Geophys., 157, 1189-1226, 2000.
40. *Tsunami Features of Solid Block Underwater Landslides*, P. Watts, J. Waterway, Port, Coastal, and Ocean Engineering, 126(3), 144-152, 2000.
41. Chen, Q., Dalrymple, R. A., Kirby, J. T., Kennedy, A. and Haller, M. C., 1999, *Boussinesq modeling of a rip current system*, Journal of Geophysical Research, 104, 20, 617-20, 637.
42. Wei, G., Kirby, J. T. and Sinha, A., 1999, *Generation of waves in Boussinesq models using a source function method*, Coastal Engineering, 36, 271-299.
43. Grilli, S.T. and Watts, P. 1999, *Modeling of waves generated by a moving submerged body. Applications to underwater landslides*, Engineering Analysis with Boundary Elements, 23, 645-656.
44. Gobbi, M. F. and Kirby, J. T., 1999, *Wave evolution over submerged sills: Tests of a high-order Boussinesq model*, Coastal Engineering, 37, 57-96.
45. *Wavemaker Curves for Tsunamis Generated by Underwater Landslides*, P. Watts, J. Waterway, Port, Coastal, and Ocean Engineering, 124(3), 127-137, 1998.
46. Wei, G., Kirby, J. T., Grilli, S. T. and Subramanya, R., 1995, *A fully nonlinear Boussinesq model for surface waves. I. Highly nonlinear, unsteady waves*, Journal of Fluid Mechanics, 294, 71-92.
47. Wei, G. and Kirby, J. T., 1995, *A time-dependent numerical code for extended Boussinesq equation*s, Journal of Waterway, Port, Coastal and Ocean Engineering, 120, 251-261.