LA-UR-05-1228

Modeling Tsunamis with ASC Codes

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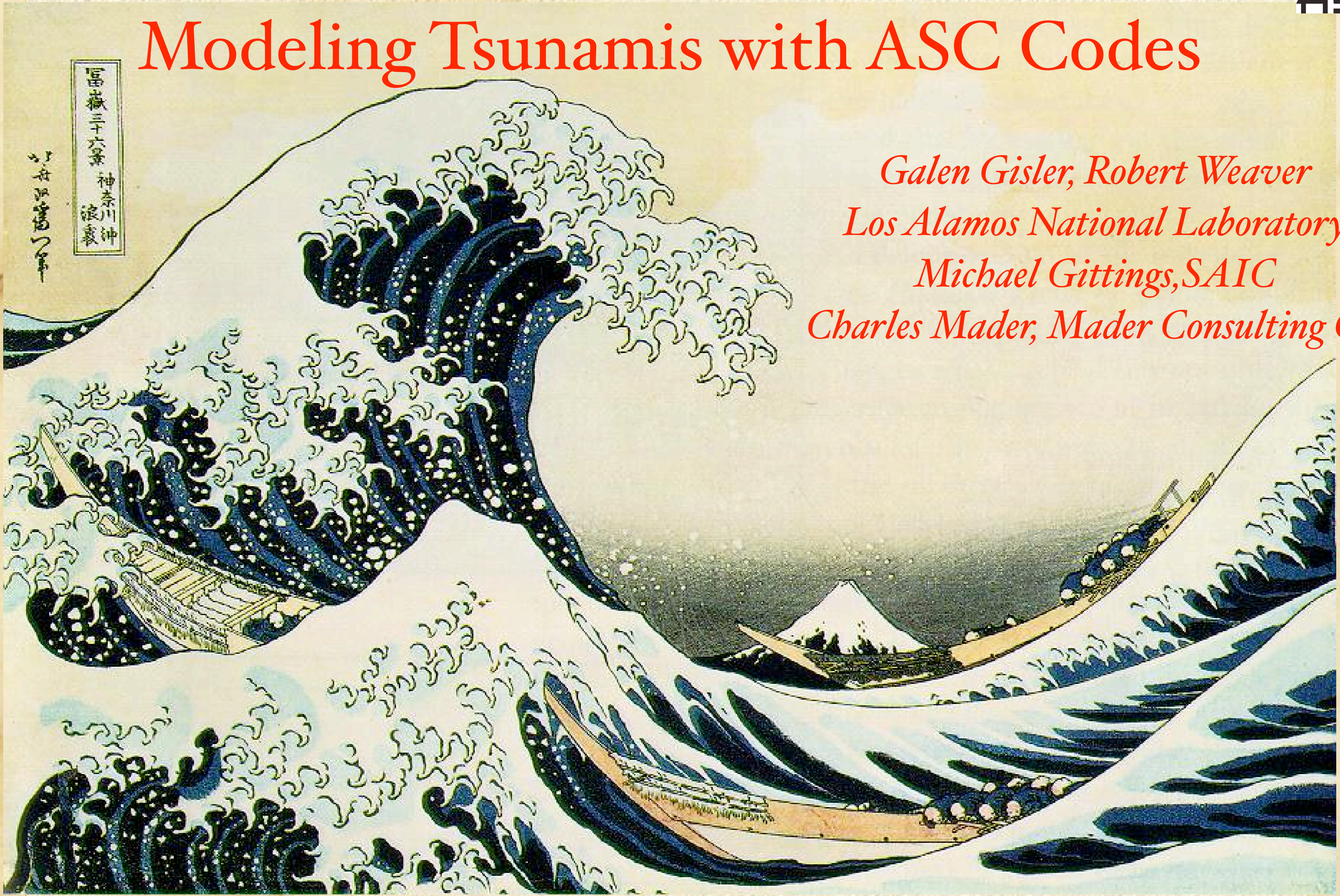


ASC PI Meeting 2005 Feb 24, San Antonio, TX

Original Motivation

- ASC has developed code capabilities that are of broad application and interest
- Valuable to apply these to studies of hazards to general populations, like tsunamis
- Validation data is available in a regime that is well beyond laboratory tests (e.g. Lituya Bay 1958)
- The SAIC equation of state for water in SAGE is the best in the world

Lituya Bay, Alaska: Validation Example

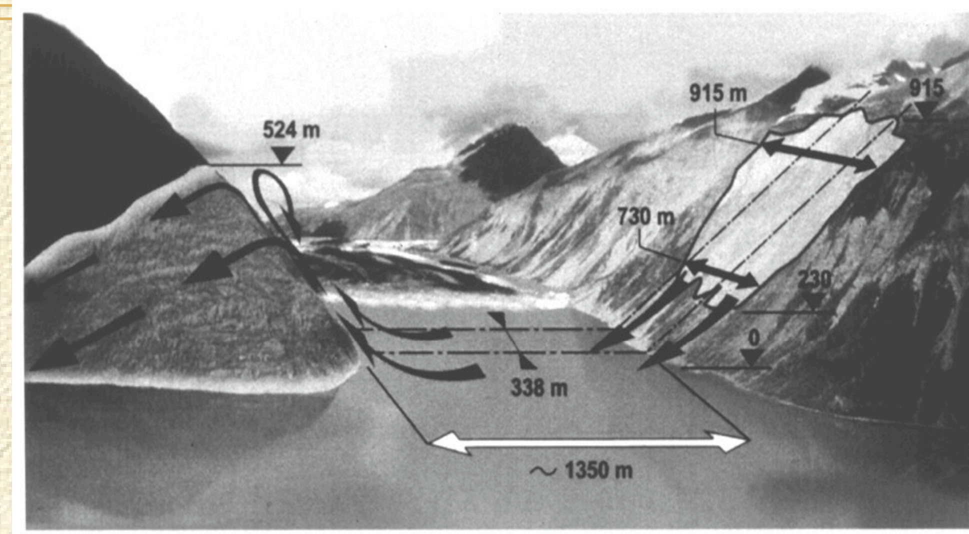


Fig. 3 **Gilbert Inlet illustration** showing rockslide dimensions, impact site and wave run-up to 524 m on spur ridge directly opposite to rockslide impact. Direction of view is North and the front of Lituya Glacier is set to 1958 post slide position. Illustration background is synthesized from two oblique images taken in 1997 (Photos: courtesy of Charles L. Mader).

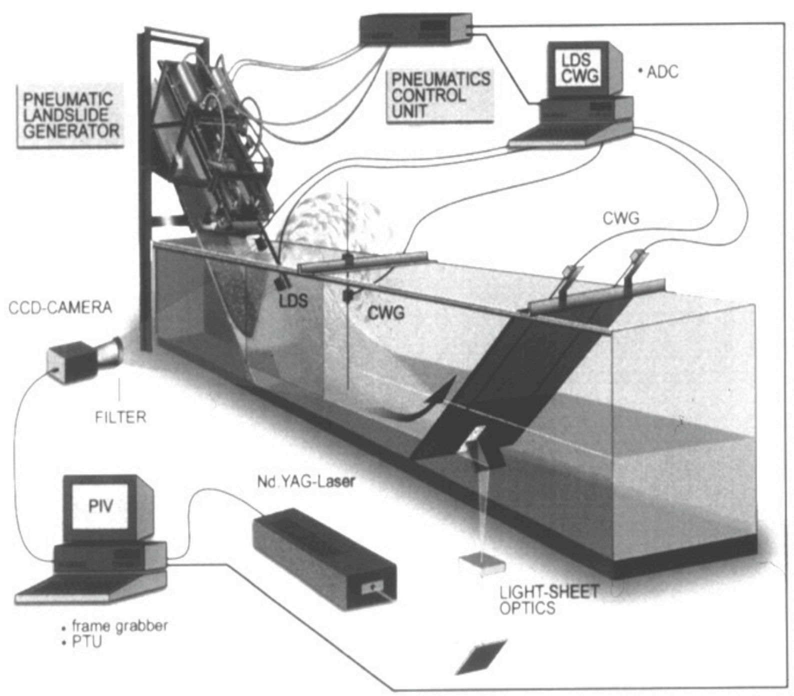
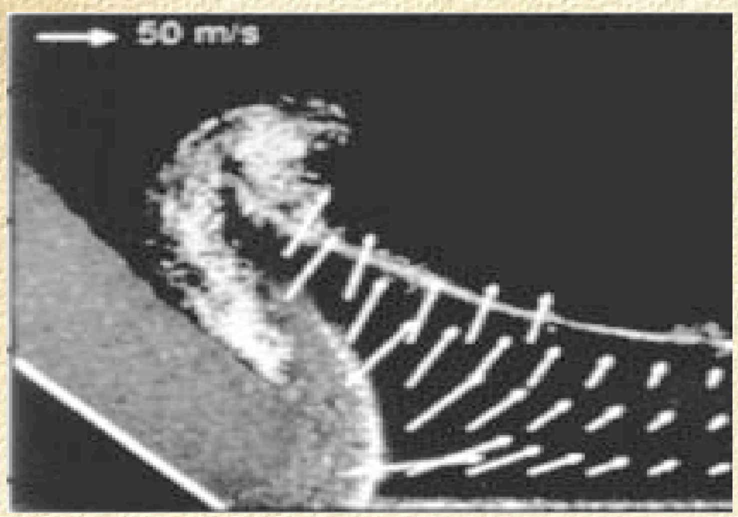


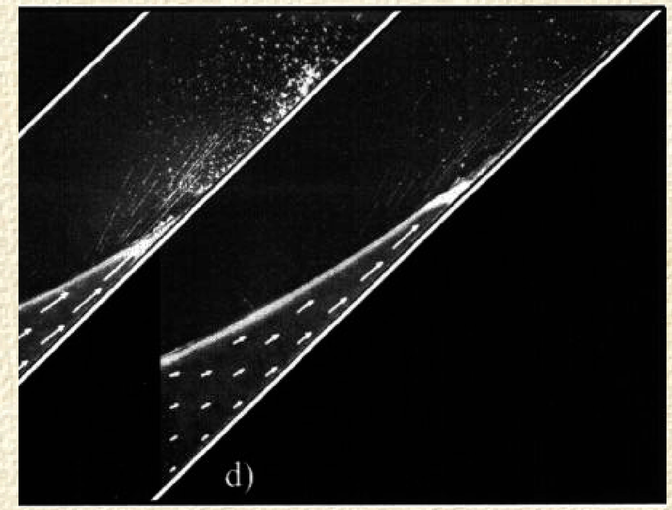
Fig. 8 **Experimental setup** with pneumatic installation and measurement systems: Laser distance sensors (LDS), capacitance wave gages (CWG) and particle image velocimetry (PIV). PIV-System with CCD-camera, twin Nd:YAG-laser, simplified light-sheet and beam guiding optics

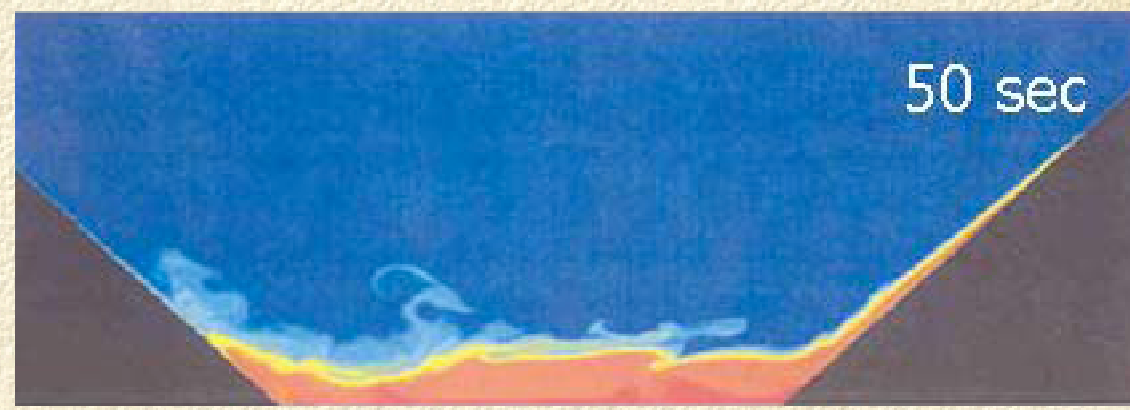
- 1958 July 8, a landslide generated a tsunami with a 524-meter run-up on the opposite side of the bay
- Modeled in lab experiment at 1:675 scale by Hermann Fritz, ETH Zürich
- Charles Mader simulated lab experiment and real tsunami using SAGE

Lituya Bay experiment and simulation



Photos and particle velocimetry courtesy of Hermann Fritz

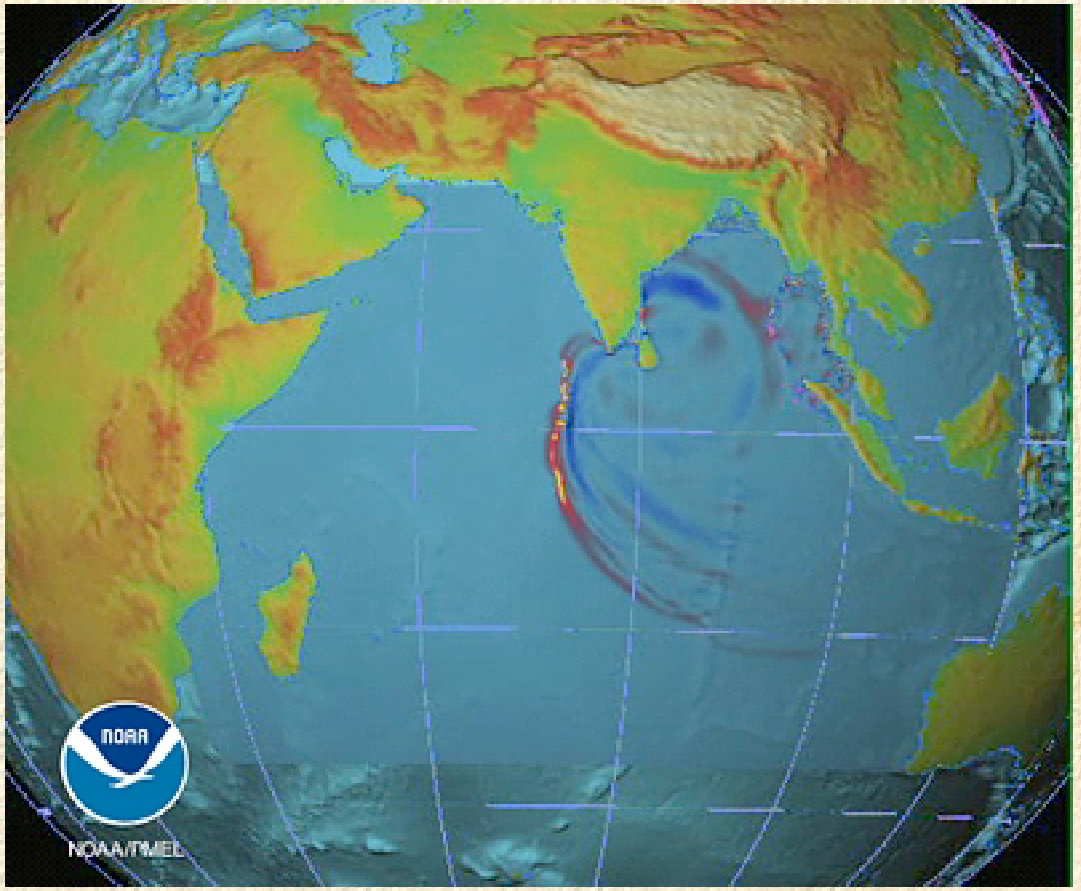




Simulation by Charles Mader

- The extent of run-up and reported time to maximum run-up are well replicated in both experiment and simulation

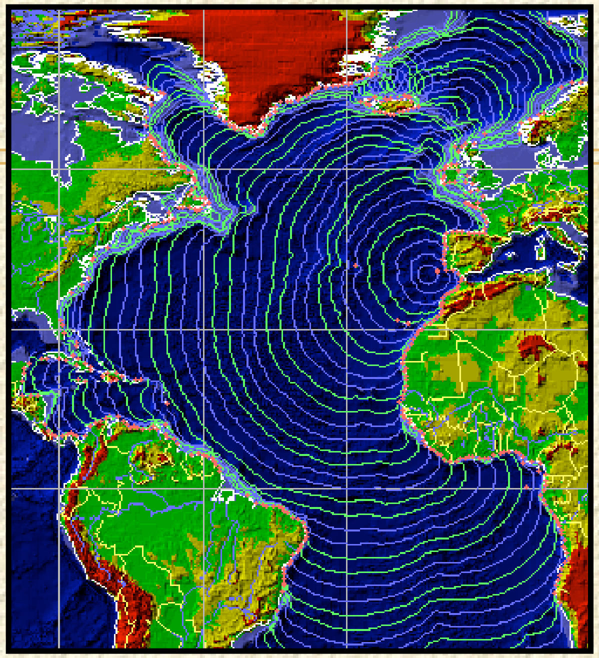
Compelling Recent Motivation — 26 Dec 2004



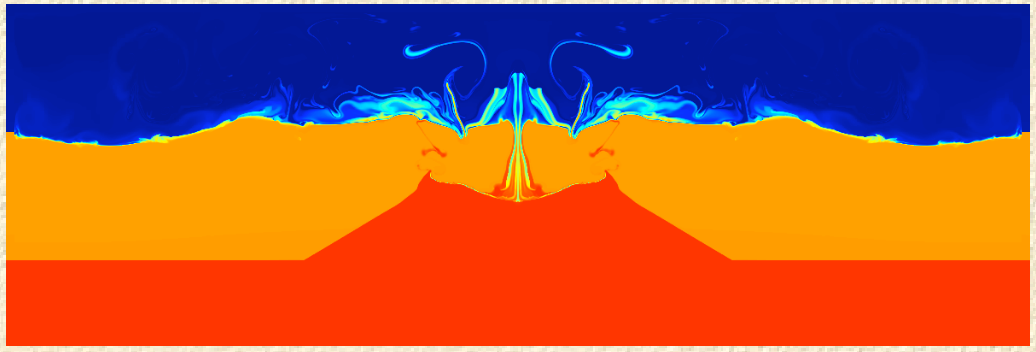
Titov Simulation of Sunda Trench Tsunami
nonlinear shallow water wave equations with dispersion

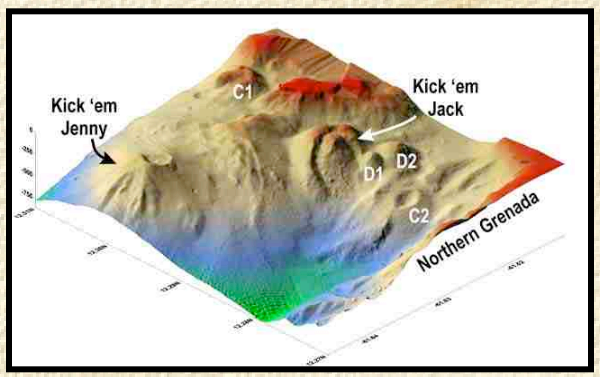
- Sunda Trench Earthquake/Tsunami
- Pacific Ocean has most Tsunamis, warning system
- Warning Systems for Other Oceans? Indian Ocean will be done!
- What about the Atlantic?
- The International Tsunami Information Center (a joint US-NOAA and UNESCO office) asked us to examine an Atlantic scenario with Navier-Stokes model

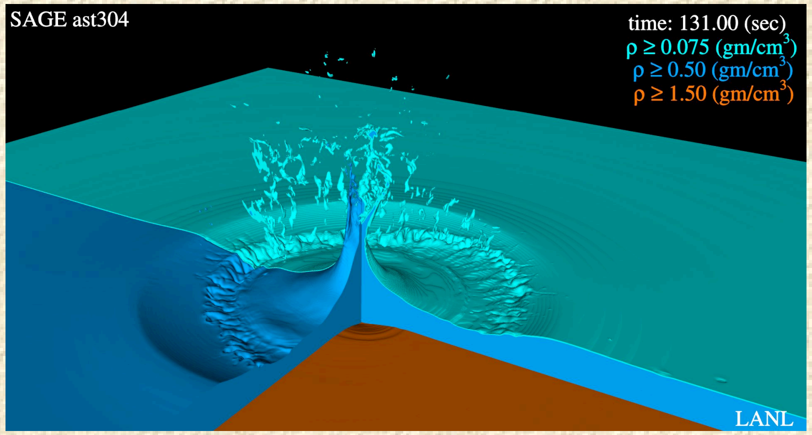
Tsunami Threats to the Atlantic



- Lisbon 1755 Earthquake & Tsunami
- Landslides
- Volcanos
  - Caribbean
  - Iceland
  - Canary Islands
- Asteroid Impacts??







La Palma, Canary Islands

- Ward & Day 2001, *GRL*: Threat to US East Coast from Cumbre Vieja lateral flank collapse
- Controversial from the start
    - Would the entire flank collapse at once?
    - Would a long-period wave result?
    - Would it propagate across the Atlantic?

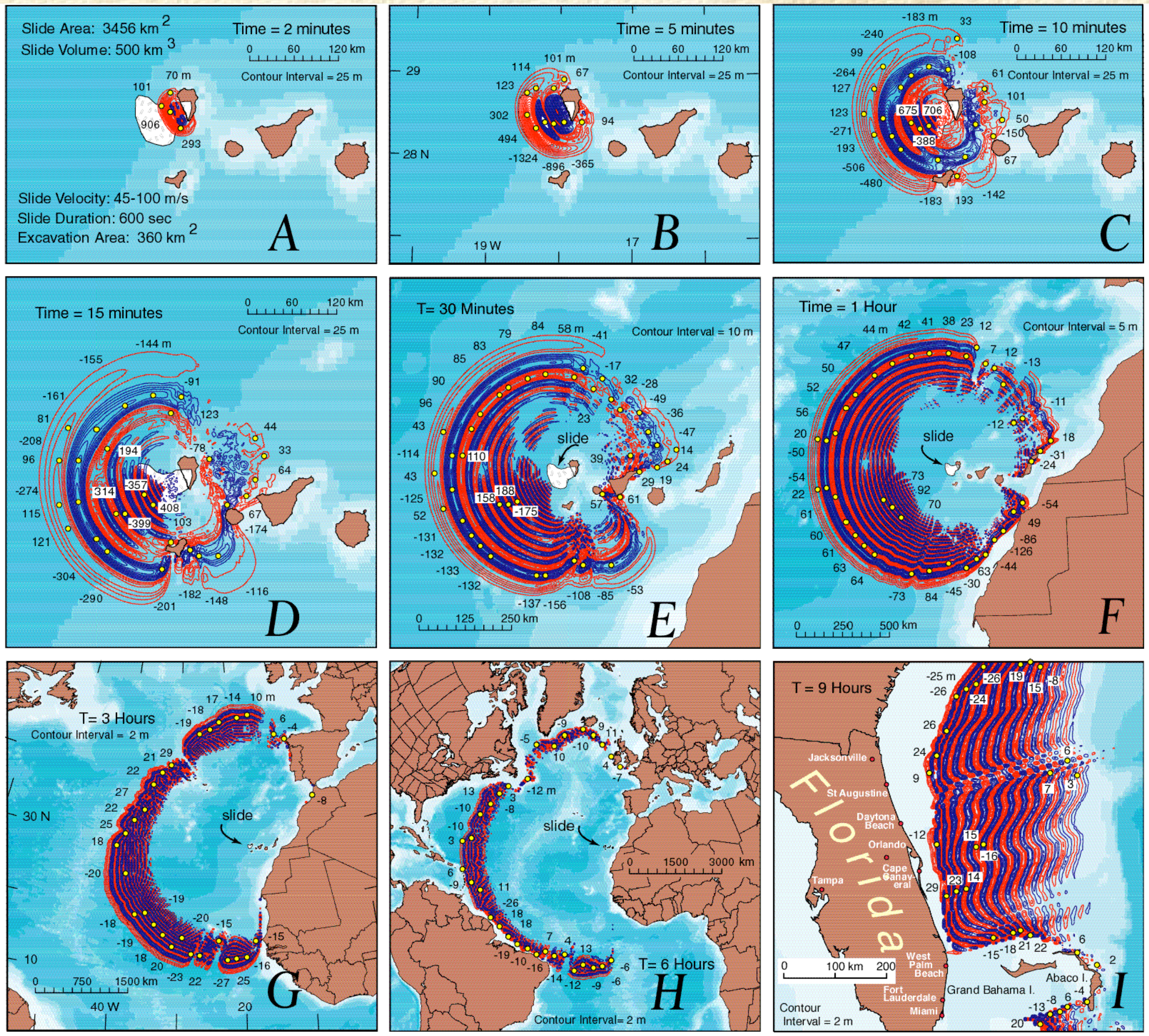
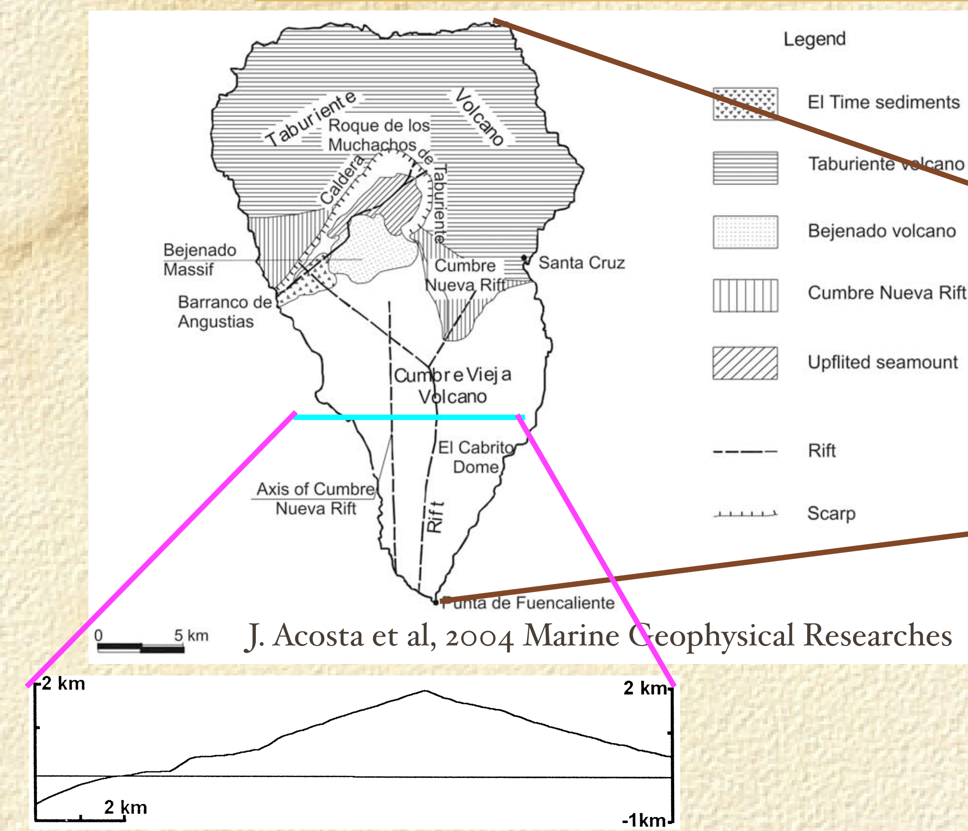
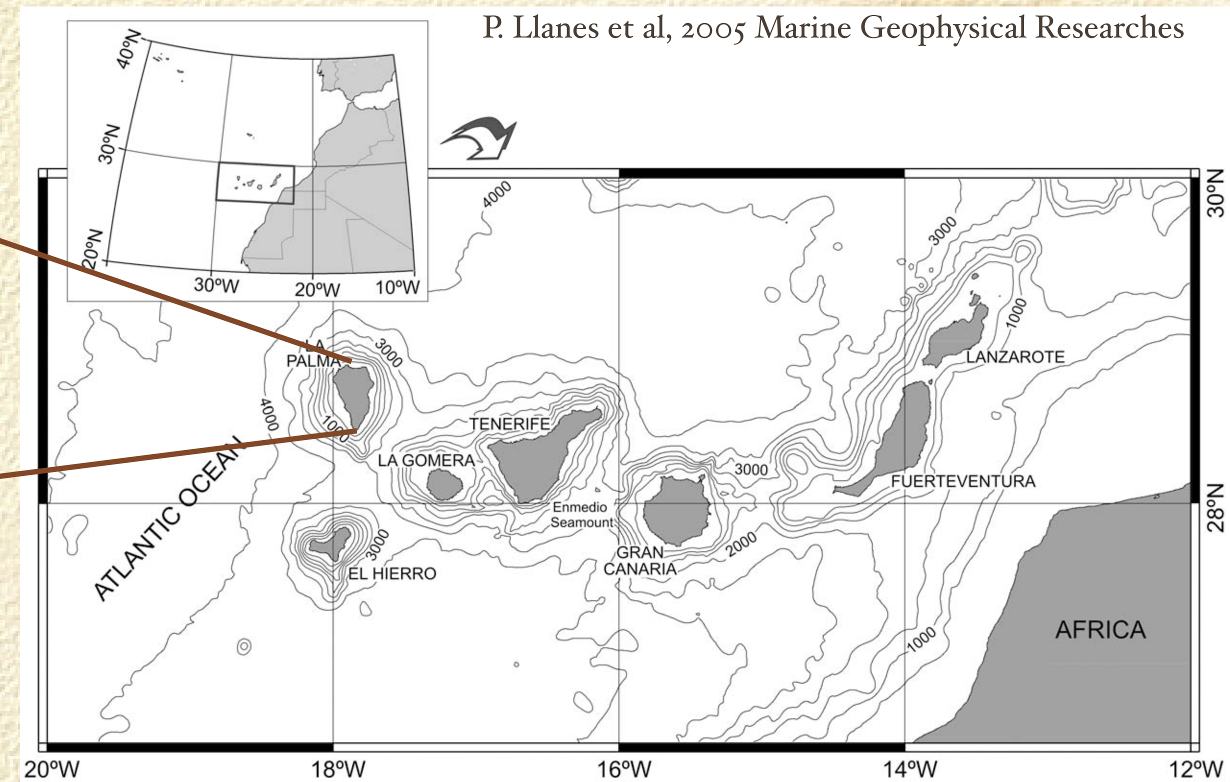


Figure 4. Evolution of the La Palma landslide tsunami from 2 minutes (a, upper left) to 9 hours (i, lower right). Red and blue contours cover elevated and depressed regions of the ocean respectively and the yellow dots and numbers sample the wave height, positive or negative, in meters. Note the strong influence of dispersion in spreading out an original impulse into a long series of waves of decreasing wavelength. See also that the peak amplitudes generally do not coincide with the first wave. Even after crossing the Atlantic, a lateral collapse of Cumbre Vieja volcano could impose a great sequence of waves of 10-25 m height on the shores of the Americas.

Cumbre Vieja Flank Collapse Scenario



J. Acosta et al, 2004 Marine Geophysical Researches



P. Llanes et al, 2005 Marine Geophysical Researches

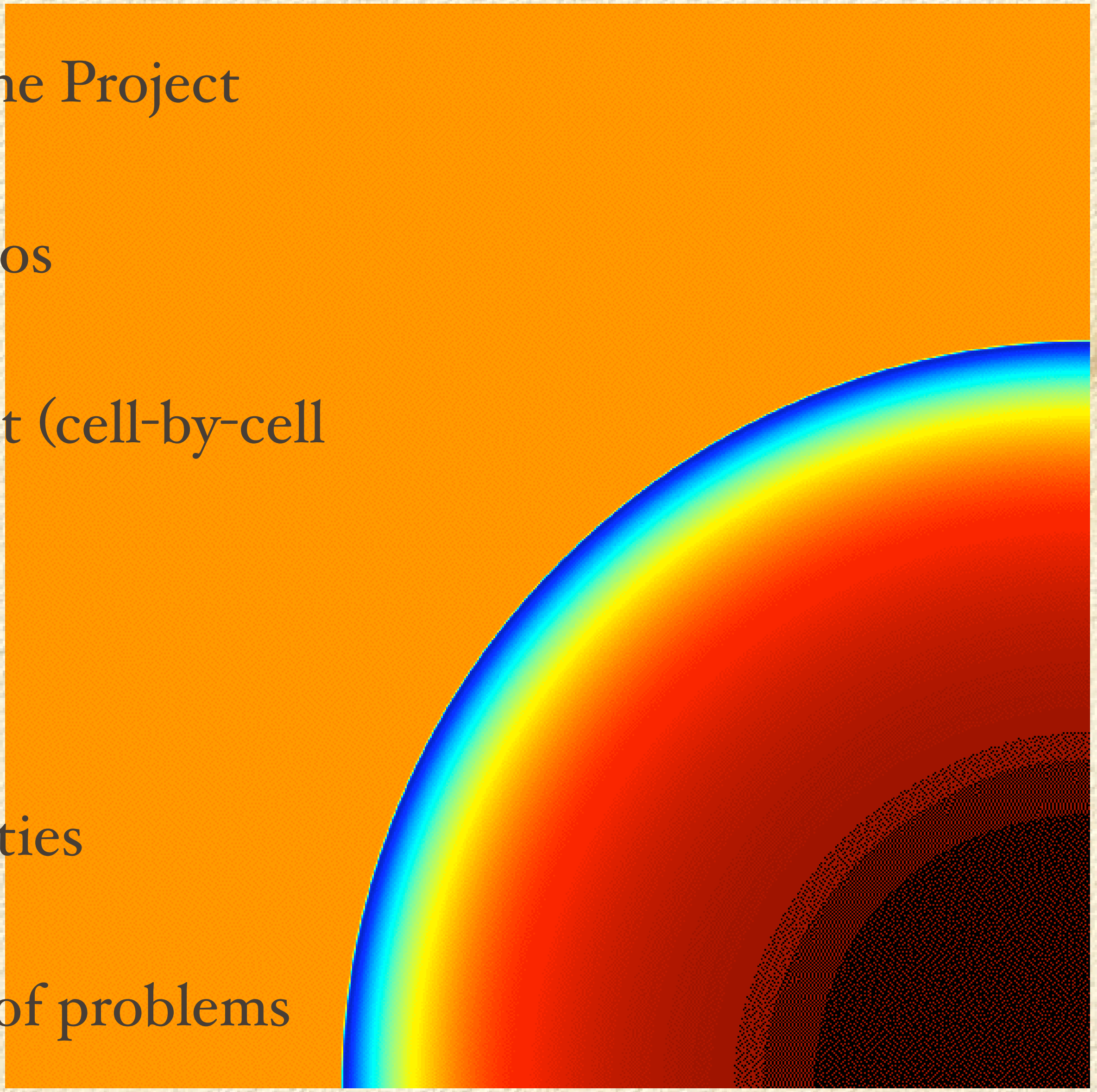
- The Cumbre Vieja volcano is the southern half of the island of La Palma, at the western end of the Canaries archipelago
- There are numerous vents along the ridge and to the west with a major rift trending N-S and echelon rifts trending E-W; the slope is steep: 20°
- A St Helens-like flank collapse of Cumbre Vieja could send 500 km^3 of rock sliding into the Atlantic ocean

Goals of Our Preliminary Simulations

- Understand coupling of rock motion to wave generation
  - energy balance, entrainment, turbidity
- What periods/wavelengths can result from a maximal Cumbre Vieja landslide?
  - two-dimensional calculations in schematic geometry
- What radiation patterns can be expected?
  - three-dimensional calculations, limited by available bathymetry
- Exercise CAD Design/Zoner interface for complex topography/ bathymetry
  - found and fixed a problem feature of OSO/Spica
- Shakedown of open Linux clusters Pink (Institutional Computing) and Flash (ASC/NW)

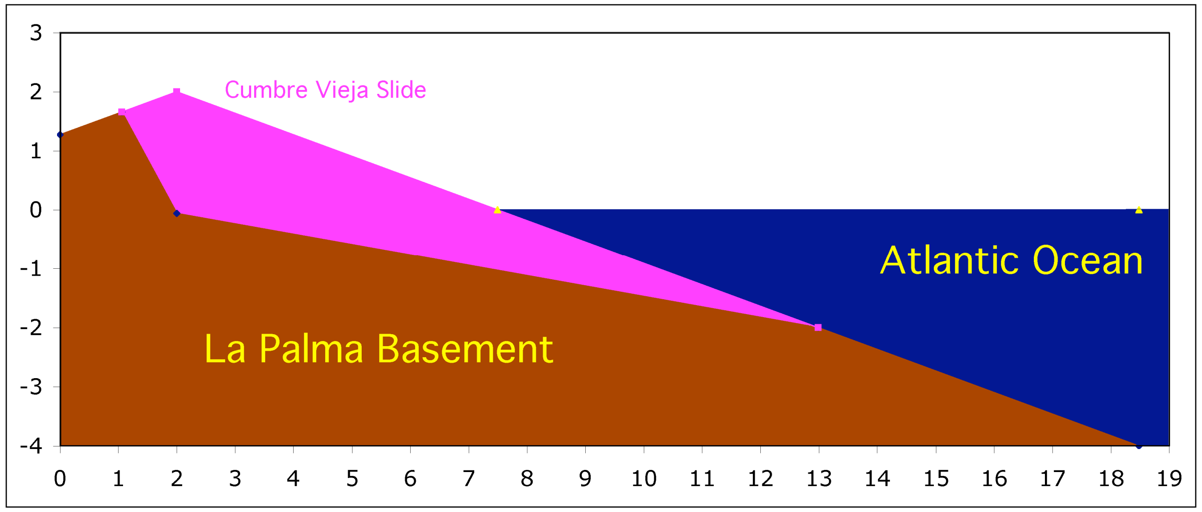
Simulating Tsunamis with SAGE

- SAGE hydrocode: DOE/ASC Crestone Project
- Joint development SAIC & Los Alamos
- Continuous adaptive mesh refinement (cell-by-cell and cycle-by-cycle)
- Multi-material EOS, strength
- Variety of geometries & dimensionalities
- Verified & validated on a broad suite of problems



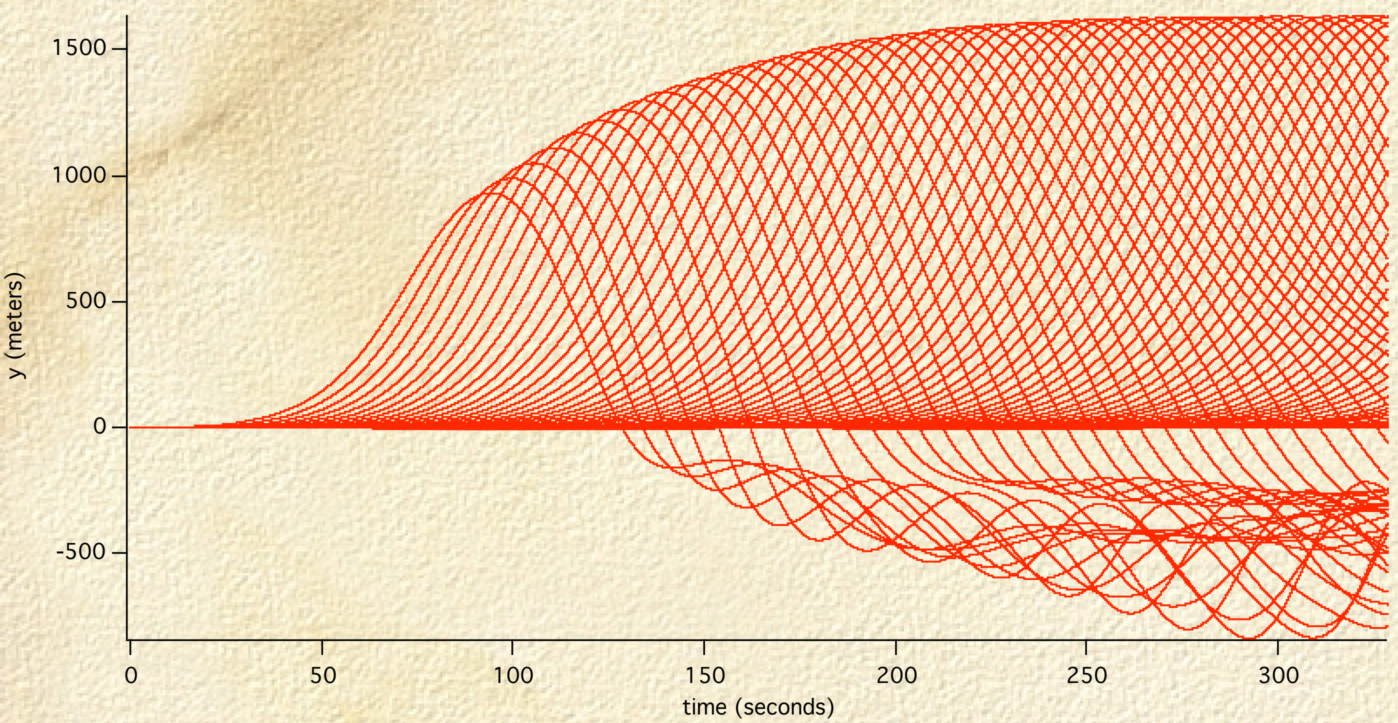
Example frame from Sedov verification problem

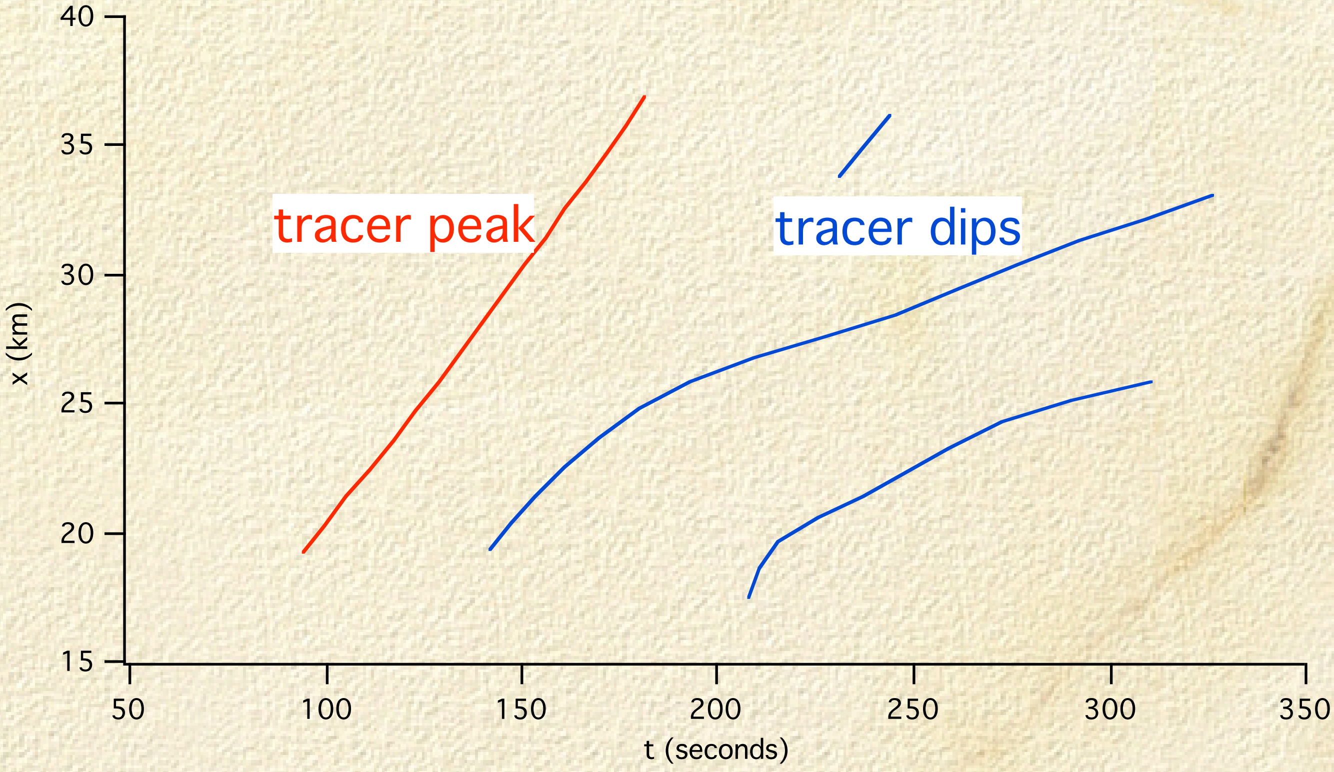
Two-Dimensional Simulations with SAGE



- Geometry of slide from S. Day — parameter study varied head offset & toe depth
- Movie (9 minutes real time) shows entrainment & turbidity currents
- Computational box 8 km high x 120 km long, resolution 15 meters, slide volume 500 km^3
- Short wavelength of principal wave, many high-frequency components
- Slide run-out to ~75 km in 9 minutes, *average* velocity ~140 m/s (inviscid fluid basalt)
- Maximum slide speed ~200 m/s occurs at ~2 minutes, close to shallow-water wave speed for enhanced pumping of wave

Tracer Particles give best indication of wave characteristics

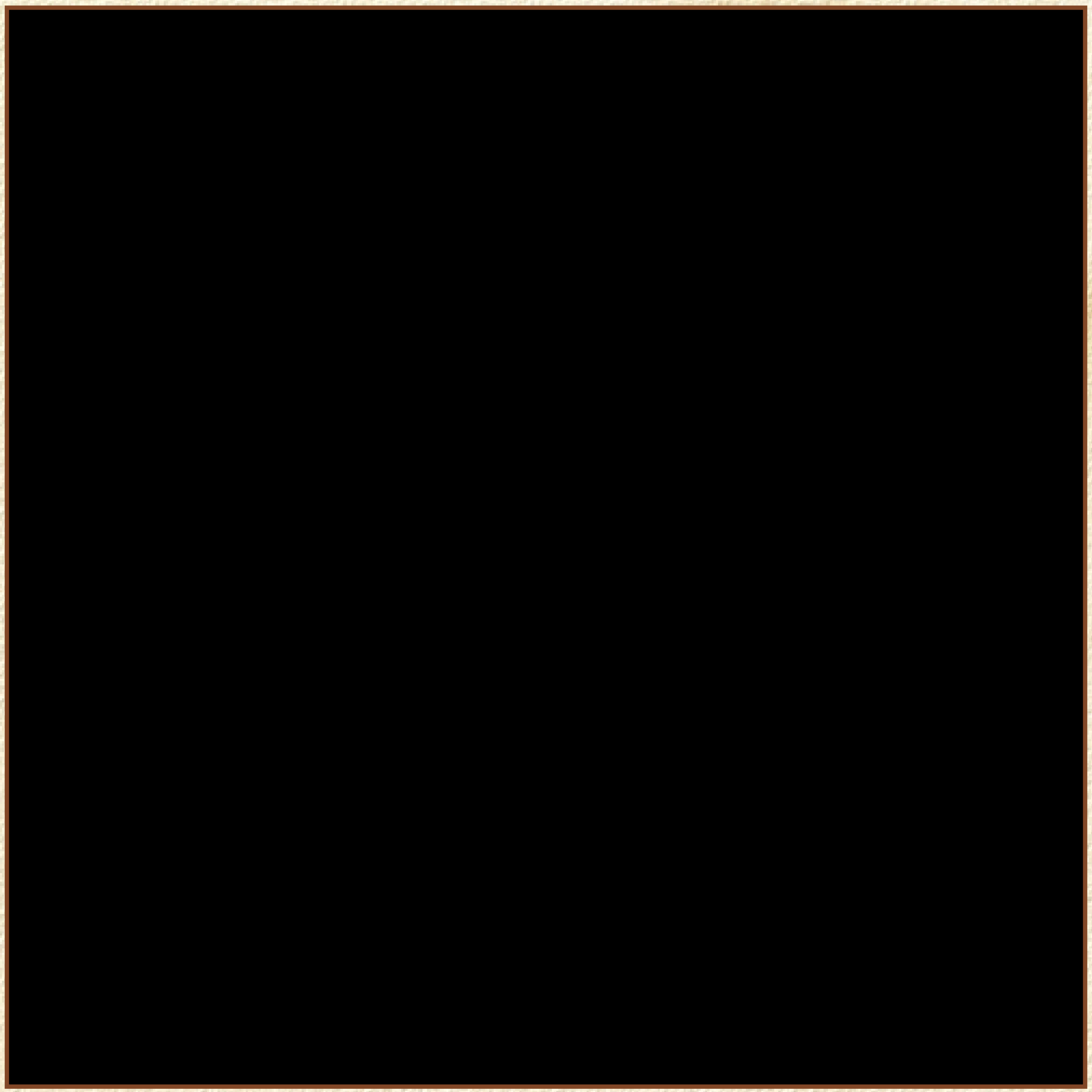




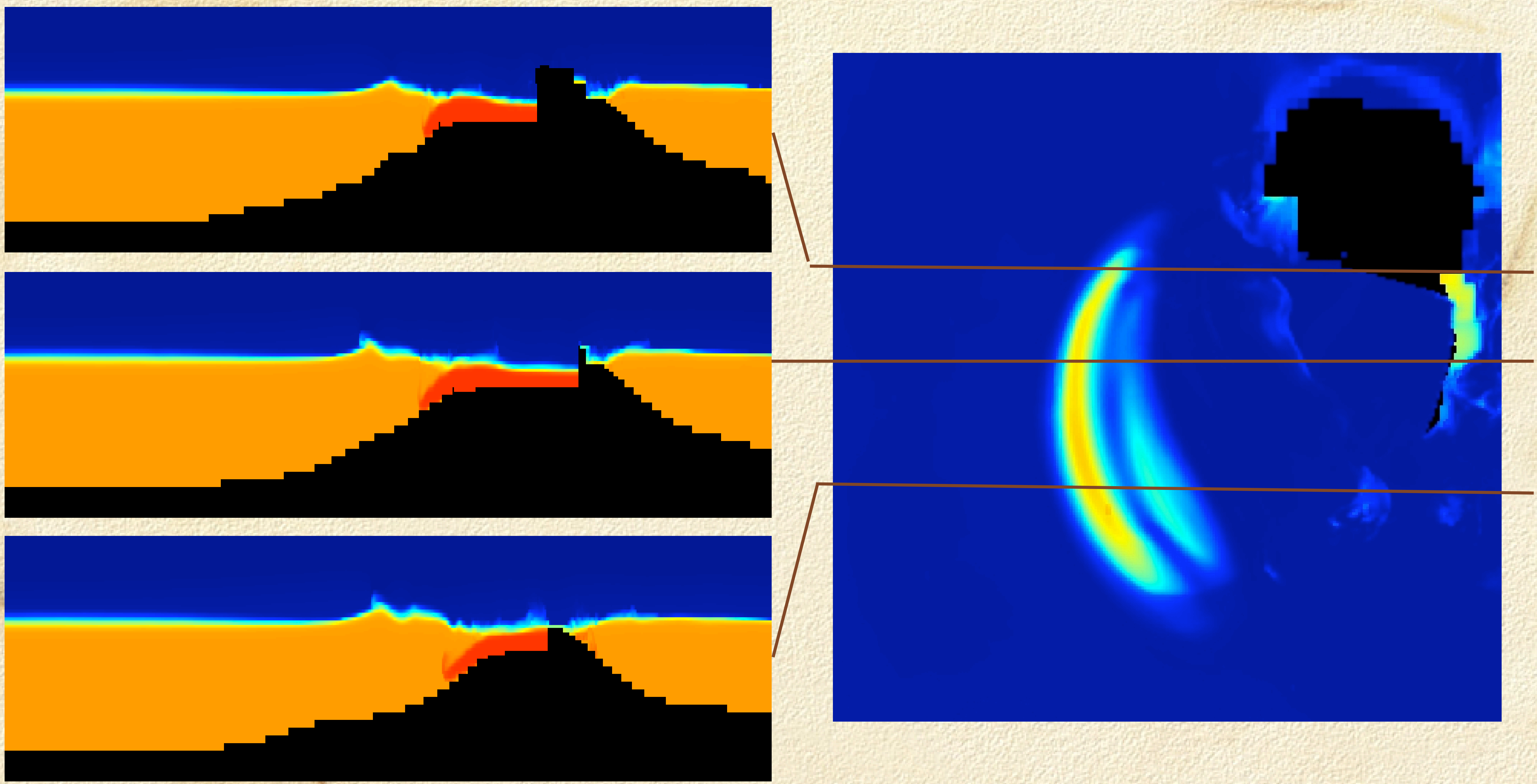
- Velocity ~200 m/s, period ~4 min, wavelength ~50 km
- Maximum wave height ~1.6 km (no lateral dispersion)
- Shallow-water wave speed in 4 km depth is 198 m/s

Three-Dimensional Simulations with SAGE

- Bathymetry/topography into CAD package for design (~4 km resolution with public data)
- Resolution of calculation 125 meters
- Volume of slide 375 km^3
- Movie of horizontal slice at 500 m altitude shows wave crests propagating toward SW
- Duration of movie 209 seconds real time



Vertical slices show higher wave to south

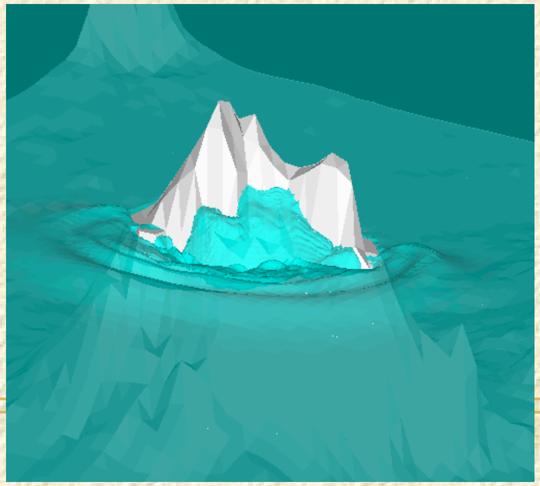


- 5x vertical exaggeration along lines indicated at 209 seconds after slide starts
- 6 km separation of wave crests, 700 m maximum height asl

Preliminary Indications

- Waves are too short in wavelength and period to propagate across the Atlantic
    - are there lower frequency components?
- Direction of strongest wave is toward the Western Caribbean
- There would be significant local damage in the Canaries, Morocco and Spain

Future Work



- Stanford ASC Center will participate in the continuation of this work with their CDP incompressible flow model (early sample above)
- Instituto Español de Oceanografía has promised us much better bathymetry for predicting the radiation pattern from a La Palma slide
- Other tsunami simulations in progress or planned — validation data exist:
  - The 1888 Ritter Island slide in Papua New Guinea (similar geometry to La Palma)
  - ***The Sunda Trench 2004 December 26 earthquake/tsunami event***
  - The Lisbon 1755 November 1 earthquake/tsunami event as a credible Atlantic threat
- This work to be reported at the International Tsunami Symposium in Crete, June 2005

Acknowledgments

- ASC V&V Program
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