Meteotsunami solibores and lone solitons on Atchafalaya shelf, LA

Alex Sheremet[1], Uriah Gravois[1], Victor Shrira[2]

1. University of Florida, USA; 2. Keele University, UK
Supported by the National Science Foundation and the Office of Naval Research

Order of Presentation

1. Motivation
2. Field observations
3. Knowledge and ignorance*
4. Numerical simulations
5. Summary

Motivation

Meteotsunamis (MT) are “small” tsunami (time scale 10-30 minutes) generated by atmospheric perturbations. Can be quite devastating (loss of life, $ millions in damage). Fairly common*: 100 events/year Great Lakes, Daytona Beach, Western Florida, on the NE Atlantic coast**. Frequent enough to have names: Risaga, Balearic Islands; Marubbio, Sicily; Abiki, Nagasaki Bay.

Meteotsunami awareness has increased in recent years, but they are is still poorly understood. Direct observations are scarce.

*) Rabinovich and Monserrat 1996, 1998; Monserrat et al. 2006,Rabinovich at al. 2009; Sepic et al 2012; **) Ewing et al. 1954; Bechle et al. 2015; Churchill et al. 1995; Paxton and Sobien 1998; Mercer et al. 2002; Vilibic et al. 2014;

Motivation

Meteotsunamis (MT) are “small” tsunami (time scale 10-30 minutes) generated by atmospheric perturbations. Can be quite devastating (loss of life, $ millions in damage). Fairly common*: 100 events/year Great Lakes, Daytona Beach, Western Florida, on the NE Atlantic coast**. Frequent enough to have names: Risaga, Balearic Islands; Marubbio, Sicily; Abiki, Nagasaki Bay.

Meteotsunami awareness has increased in recent years, but they are is still poorly understood. Direct observations are scarce.

Motivation: Lacunary understaning of the problem; we resolved to work toward solving some of outstanding questions...

*) Rabinovich and Monserrat 1996, 1998; Monserrat et al. 2006,Rabinovich at al. 2009; Sepic et al 2012; **) Ewing et al. 1954; Bechle et al. 2015; Churchill et al. 1995; Paxton and Sobien 1998; Mercer et al. 2002; Vilibic et al. 2014;

Motivation

Meteotsunamis (MT) are “small” tsunami (time scale 10-30 minutes) generated by atmospheric perturbations. Can be quite devastating (loss of life, $ millions in damage). Fairly common*: 100 events/year Great Lakes, Daytona Beach, Western Florida, on the NE Atlantic coast**. Frequent enough to have names: Risaga, Balearic Islands; Marubbio, Sicily; Abiki, Nagasaki Bay.

Meteotsunami awareness has increased in recent years, but they are is still poorly understood. Direct observations are scarce.

Motivation: a discovery of ignorance†: looking at data, scratching head, talking to one's betters.
†Harari, Sapiens: A short history of humankind.

*) Rabinovich and Monserrat 1996, 1998; Monserrat et al. 2006,Rabinovich at al. 2009; Sepic et al 2012; **) Ewing et al. 1954; Bechle et al. 2015; Churchill et al. 1995; Paxton and Sobien 1998; Mercer et al. 2002; Vilibic et al. 2014;

Experiment

2008 Experiment* Atchafalaya shelf

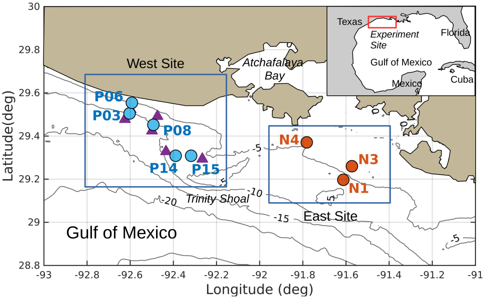
- Flat (slope ~ 10^{-3}), muddy, large;
- ~200 km covered.
- Sampling $\geq$ 2 Hz

West**: NPS, WHOI, UCSC,

- Chenier plain, Trinity Shoal.
- Complicated geometry.

East***: UF, Tulane, Atch. clinoform.

- Simpler geometry.



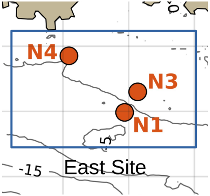
Atchafalaya, Northern Gulf of Mexico, 2008

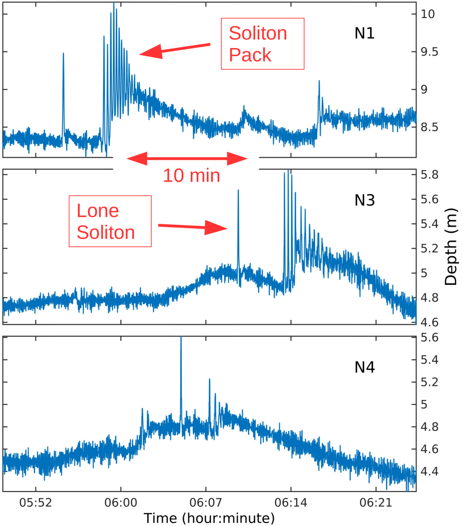
*) Dalrymple et al., http://www.ce.jhu.edu/dalrymple/MURI/; **) Engelstad et al.(2013); ***) Jaramillo et al. (2009); Safak et al.(2012), etc.

Observations: East

March 7, 2008, 5:00 - 6:00 LT;
Example pressure records
East site

- 10-15 min, 0.5 m waves;
- Lone solitons;
- Soliton train (solibore).

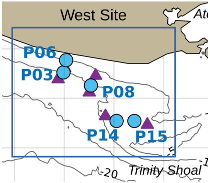


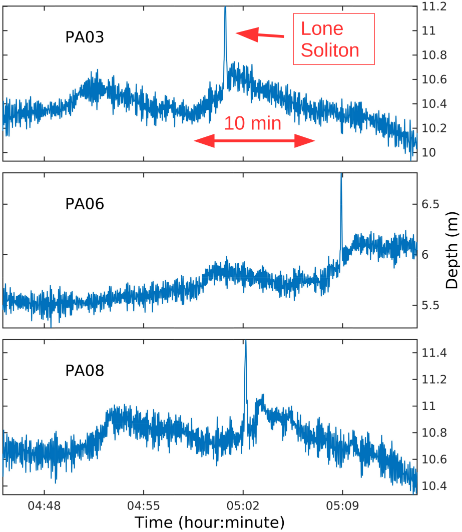


Observations: West

March 7, 2008, 5:00 - 6:00 LT;
Example pressure records
West site

- 10-15 min, 0.5-m waves;
- Lone solitons;
- No solibore.





Knowledge

- MT = “small tsunamis” (minutes to hours) generated by atmospheric perturbations;
- Amplified by shoaling
- Disintegrate into solibores.
- Number of solitons $\propto$ MT “excess” mass;

Squall line**
Meteotsunami Holland; weather.com/

Sumatra Tsunami (2004)*
Tohoku-Fukushima Tsunami; youtube.com

Meteotsunami: L~10 km.

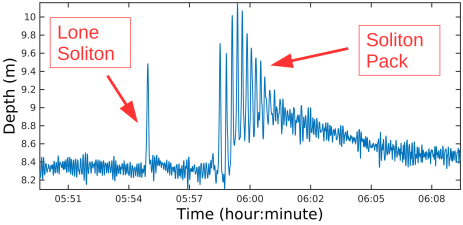
Tsunami: seismic, L~100 km.

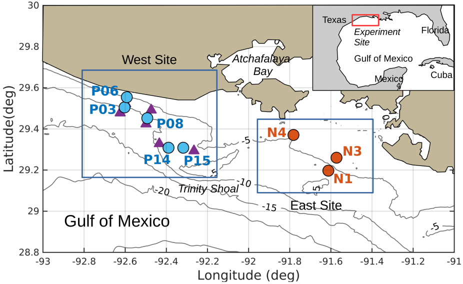
*) Copyright Anders Grawin, 2006. **) Dan Smeiska, 2014

Ignorance

Questions

- Generation mechanism?
- How many MT waves?
- Why solitons everywhere?
- Why lone soliton + solibore?
- How common is this?
- Interaction with waves?
- Interaction with mud?
- Anything else missing?

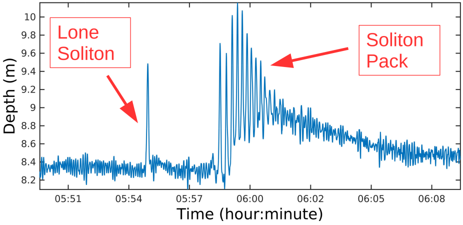


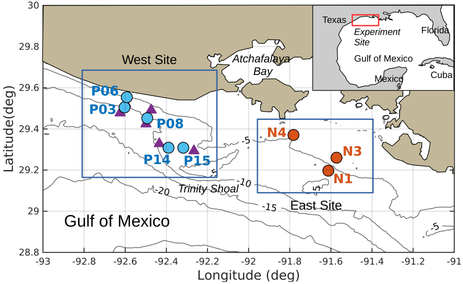


Ignorance

Questions

- Generation mechanism?
- How many MT waves?
- Why solitons everywhere?
- Why lone soliton + solibore?
- How common is this?
- Interaction with waves?
- Interaction with mud?
- Anything else missing?

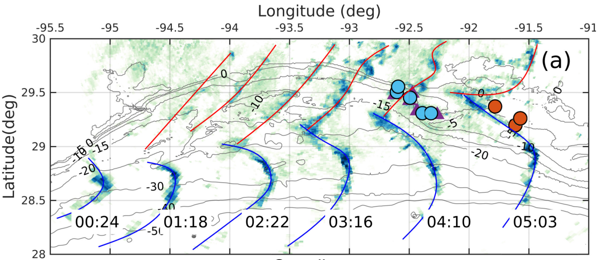




The storm: Radar reflectivity

Storm of March 7th 2008 studied over land*. No data over the ocean.
Best source for event: NOAA Level III NEXRAD, Lake Charles, LA.

- **bar** squall, weaker
- **bow** squall, strong
- kink $\longrightarrow$ tornado activity
- lines serve to estimate velocity



Squall

---

*) Rupert and Bosart (2014); **) http://www.ncdc.noaa.gov/.

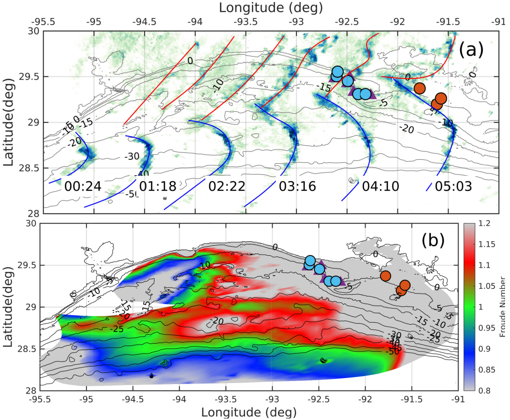
Hypothesis

Restricting to **East site:**

- Squall moved $\parallel$ isobaths.
- Strong refraction.
- East site hit by bow squall with two resonance bands:
  - North band strong (kink),
  - South band weak (tail).

Hypothesis:

- North $\rightarrow$ large MT, solibore
- South $\rightarrow$ weak MT, lone soliton
- Overlapped by refraction.

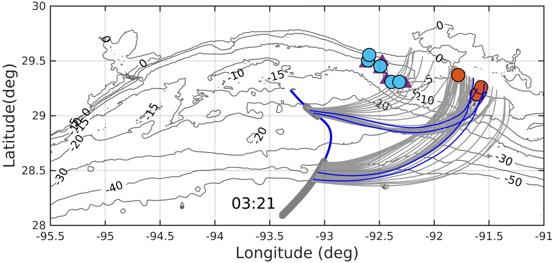


Froude number $U/\sqrt{gh}$

Numerical models

Looking for proof-of-concept. Using a 2-step inexpensive modeling. Poor man's inverse method.

1. **Ray tracing***

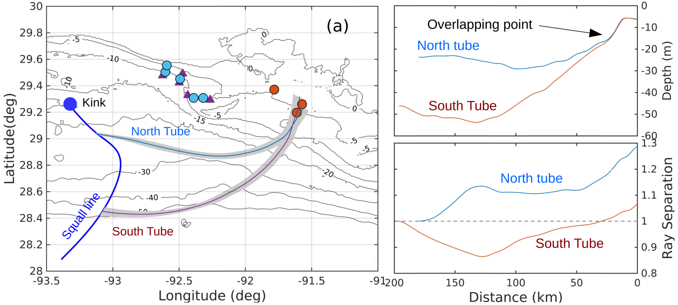


1. **The Variable-coefficient KdV**** applied to ray tubes,

$$u_x - \frac{1}{2}\left(u^2\right)_t - \frac{1}{\sigma^2}u_{ttt} = -\frac{1}{R}F\left(q\right)$$

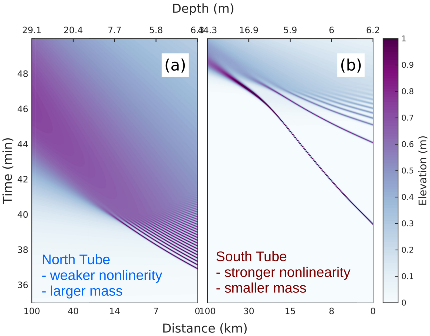
*) e.g., Chao (1972); many others; **) Ostrovsky and Pelinovsky (1975), Grimshaw (2007), many others;

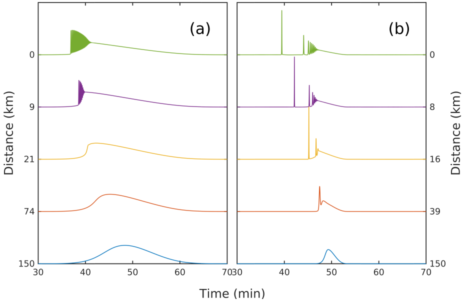
Ray Tracing



- Two perturbations arrive nearly simultaneously
  - North wave: shorter path, shallower, slower;
  - South wave: longer path, deeper, faster;
- Overlap point somewhere near 20-m isobath

vKdV simulations, invididual waves



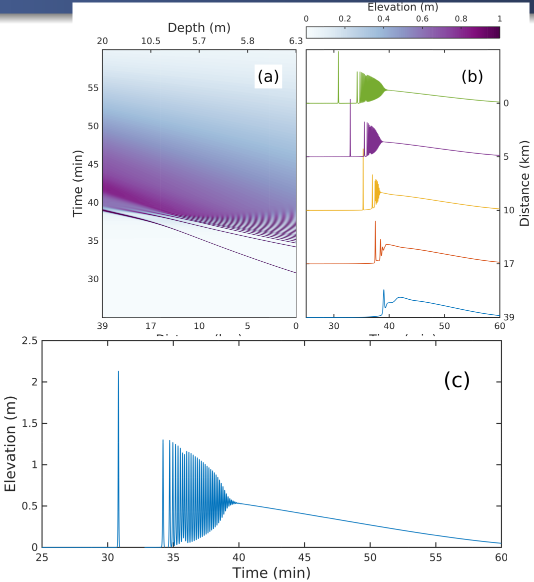


- Gaussian perturbations

- North tube: a = 0.8 m, T ~ 10 min
- South tube: a = 0.6 m, T ~ 3 min

vKdV combined waves

- Superposed ~20-m isobath
- Similar to the observations.



Summary

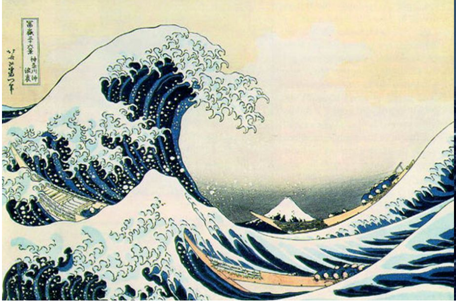
- The lone-soliton/solibore mix results from multiple MT waves + strong refraction
- Lone solitons are robust, propagte over large distances; should be common.

Remarks:

1. MTs are not “just long waves”;
   - large atmospheric perturbations can generate multiple MT waves;
   - complicated bathymetry can combine multiple MTs in complicated ways;
   - in NGoM propagation of MT is typically $\|$isobath: trapped MT are possible;
2. Existing observation arrays do not resolve the MT disintegration cascade. What is missed:
   - solitons/solibores are a hazard in themselves;
   - small-scale coherent structures and dynamics (e.g., wide-angle soliton collision);
   - small-scale processes - interaction with wave fields, currents, bed sediment;
3. Early warning and forecasting should be aware of these processes.

Paper: Sheremet et al. (2016), Nat. Hazards. pp. 1-22. ISSN 1573-0840

Questions?



Hokusai: Great wave off Kanagawa

Dudley et al. Notes Rec. R. Soc. 2013

The vKdV equation

vKdV equation in “signaling” coordinates*:

$$\eta_x + \frac{(c\Delta)_x}{2c\Delta}\eta + \frac{1}{c}\left(1 - \frac{3}{2h}\eta\right)\eta_t - \frac{h^2}{6c^3}\eta_{ttt} = -F(\eta).$$

$\Phi(t)$ = perturbation introduced at the left boundary into the still water domain $x > 0$, x = along-channel coordinate, η = free surface elevation, F = dissipation/growth forcing term, $c = \sqrt{gh}$, and Δ = channel width.

The “boundary” Cauchy problem is written as

$$\eta_x + \frac{1}{c}(1 - \alpha\eta)\eta_t - \beta\eta_{ttt} + \frac{1}{2}\frac{\delta_x}{\delta}\eta = -F(\eta),$$

$$\alpha = \frac{3}{2h}; \quad \beta = \frac{h^2}{6c^3}; \quad \delta = c\Delta,$$

with boundary and initial conditions

$$\begin{cases} \eta(x,t) = \Phi(t) & \text{at } x = 0 \\ \eta(x > 0, t = 0) = 0 & \text{at } t = 0 \text{ and } x > 0. \end{cases}$$

*)) Ostrovsky and Pelinovsky (1975), Osborne (1995); Caputo and Stepanyants (2003), Grimshaw (2007);

The vKdV equation

Several simple transformations* bring the equation to a standard normal form. Substitution a flux-like quantity

$$\zeta = \eta \delta^{1/2},\ \eta = \zeta \delta^{-1/2};$$

eliminates the inhomogeneous term; shifting the time axis to the linear arrival time $\bar{t}$

$$\bar{t} = t - \int_0^x \frac{dx'}{c},\ \bar{x} = x,$$

and using a scaling transformation based on the forcing in the initial condition

$$\Phi(\bar{t}) = A\phi\left(\frac{\bar{t}}{T}\right), \quad s = \frac{A}{T}\int_0^{\bar{x}} \frac{\alpha ds}{c\delta^{1/2}}, \quad \theta = \frac{\bar{t}}{T}, \quad \zeta = Aq,$$

*) Caputo and Stepanyants (2003), Grimshaw (2007);

The vKdV equation

obtains the non-dimensional form

$$q_s - \frac{1}{2}\left(q^2\right)_\theta - \frac{1}{U^2} q_{\theta\theta\theta} = -\frac{1}{R}\mathcal{F}\left(q\right)$$

$$\begin{cases} q(0,\theta) = \phi(\theta) \\ q(s>0,0) = 0 \end{cases} .$$

where

$$U^2 = \frac{\alpha A T^2}{9\beta c \delta^{1/2}}, \quad R = \frac{3\alpha A^2}{c\delta^{1/2} T}, \quad \mathcal{F}\left(q\right) = \delta^{1/2} F\left(\zeta\delta^{-1/2}\right),$$

where A is the amplitude and T is the time scale of the initial perturbationΦ; $L = cT$ is the spatial scale of the perturbation; U is the Ursell parameter; and θ is the normalized local time.

Used Rayleigh dissipation:

$$\mathcal{F}(q) = \frac{3}{4}\frac{\nu}{ch^2} q.$$

where $\nu = 10^{-2}\mathrm{m}^2/\mathrm{s}$. The equation was integrated using a simple method that combines the Fourier-transform in time with a symmetric split-step method of integration along the ray coordinate θ.