RECENT PROGRESS IN THE MODELING AND DETECTION OF METEOTSUNAMIS

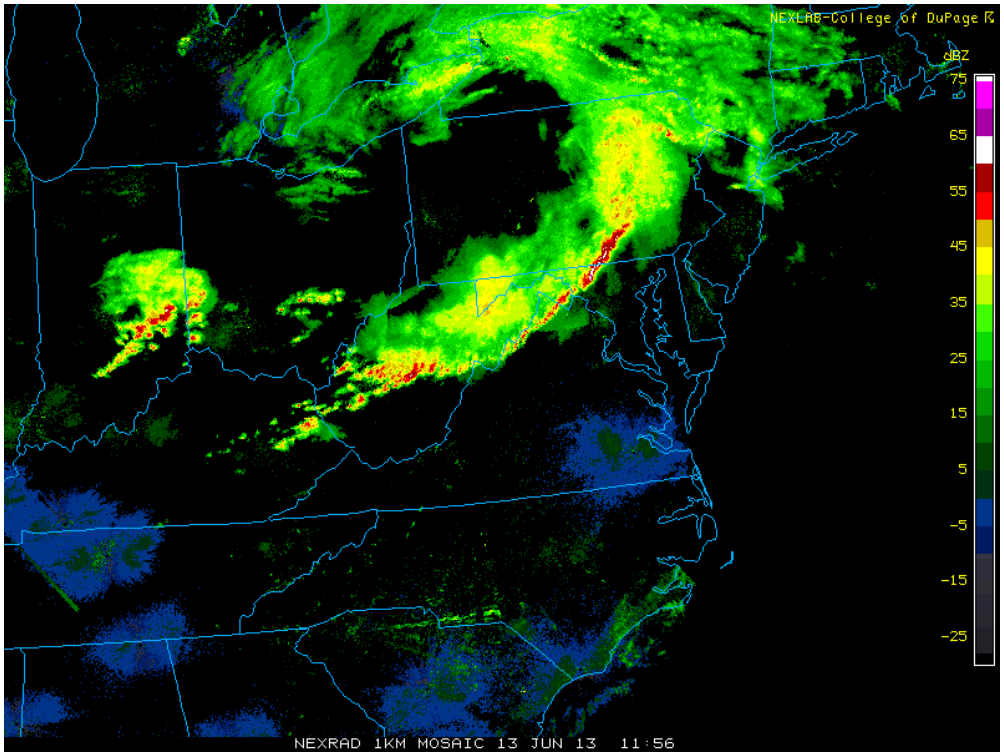
Stephan T. Grilli[1], James T. Kirby[2], India Woodruff[2], C.A. Guérin[3]

1. Department of Ocean Engineering, University of Rhode Island
2. Center for Applied Coastal Research, University of Delaware
3. Mediterranean Institute of Oceanography, University of Toulon

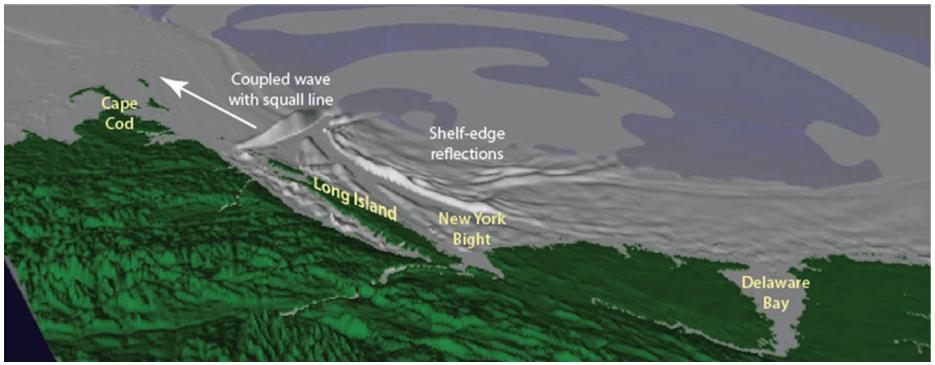
NTHMP Winter Meeting 2019

East-Coast Meteotsunami hazard

- Mostly caused by *squall lines and derechos* moving onto the shelf, towards the E-SE sector
- Frequent in *summer* (Bluestein, 1993)
- Ex: *Radar* for June 13, 2013 EC meteotsunami => **2 m waves** off of NJ

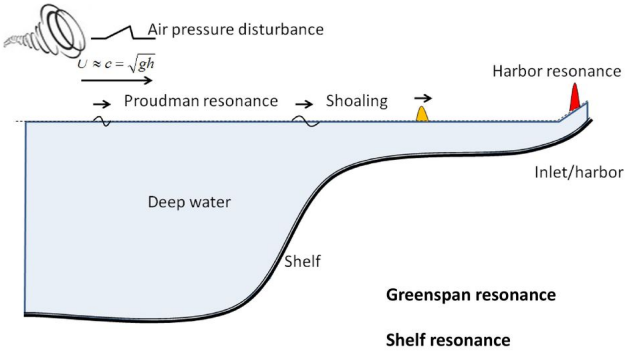


East-Coast Meteotsunami hazard



[Geist et al., 2014: June 13, 2013 MT modeling]

- **<u>MT generation mechanisms:</u>**
  - *Proudman* (1929) *resonance* ($U \sim (gh)^{1/2}$)
  - *Edge waves* (Greenspan, 1956; like SMFs)
  - *Shelf resonance* (Monserrat et al., 2006)
  - *Shelf edge reflection* (Rabinovitch, 2003)
  - *Harbor resonance* (20+ for 06/13/18 MT)



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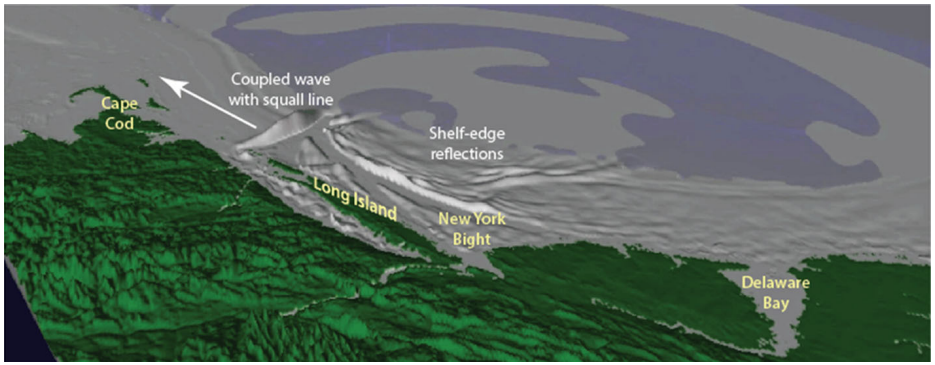
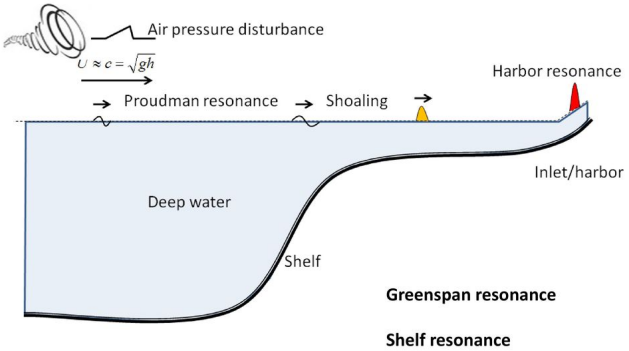


[Geist et al., 2014: June 13, 2013 MT modeling]

- **<u>MT generation mechanisms:</u>**
  - Proudman (1929) resonance ($U \sim (gh)^{1/2}$):

    $\Delta\eta \sim \Delta p\ U\ t/w$

    with Δp the pressure discontinuity and w the pressure front width (Hibiya et al., 1982)



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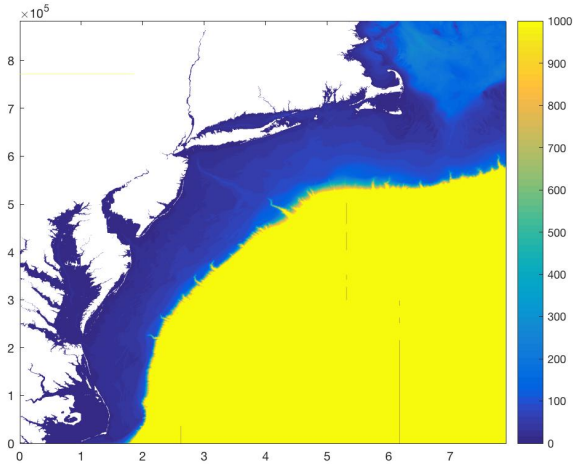

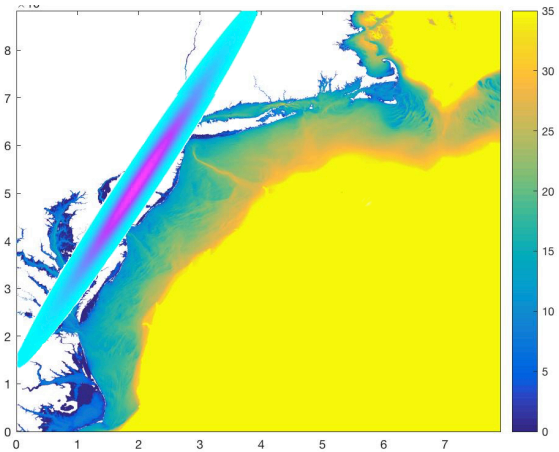

- **<u>MT generation mechanisms:</u>**
  - Proudman (1929) resonance ($U \sim (gh)^{1/2}$):

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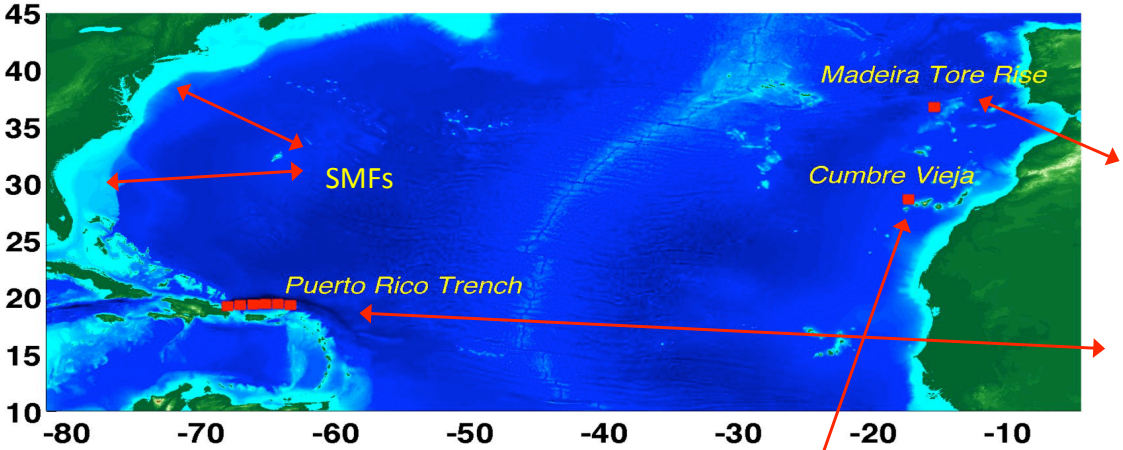
=> *Depth h* (meter) and *celerity c* (m/s)

=> *Typical U* ≈ [7.2 – 29.6] (m/s) (95% CL)

Typical Δp ≈ [0 – 5.2] (hPa) (95% CL)

[Geist et al., 2014]

East-Coast tsunami hazard assessment (NTHMP)



Extreme sources (PMTs) (2010-…):

-> LSB-M9 far-field *seismic source* : repeat of Lisbon 1755 [Barkan et al., 2008]

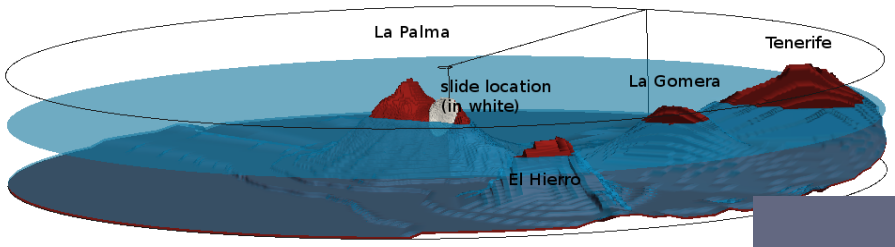
-> PRT-M9 far-field *seismic source* in PRT: 600 x 150 km (12 SIFT sources; 12 m slip; 600 yr of full (orthogonal) convergence) [Knight, 2006; Grilli et al., 2010]

-> CVV Far-field *flank collapse* of CVV (80 to 450 km^3 volume; return period (?) perhaps 1,000-100,000 yrs.

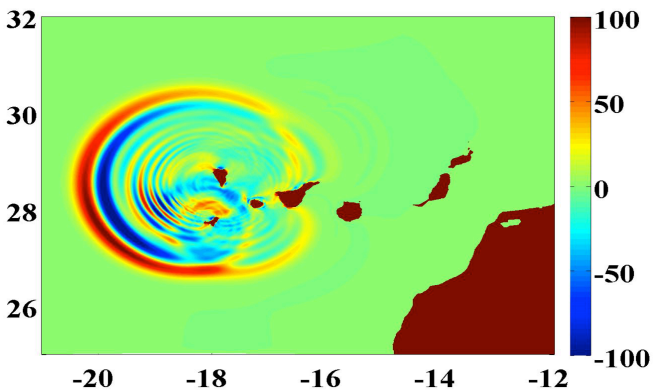
[Abadie et al., 2012; Tehranirad et al., 2015]

-> near-field **SMFs** on continental slope/margin: assumed to be rigid slumps with Currituck slide characteristics (***proxies***; 165 km^3 volume) [Grilli et al., 2015, 2017; Schambach et al., 2018]

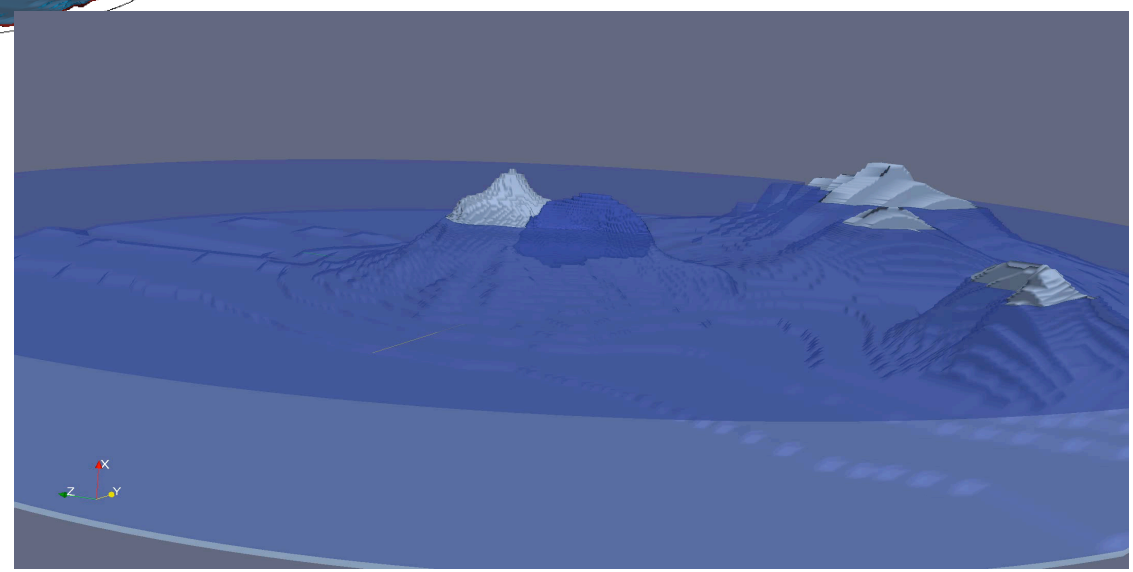
Far-field: Cumbre Vieja 450 km^3 flank collapse (NTHMP)



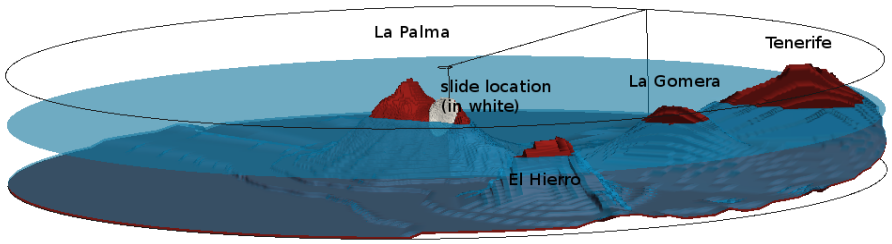
[Abadie et al., 2012; Tehranirad et al., 2015]



-> 3D-NS simulation up o 20 min (m)



Cumbre Vieja 450 km^3 flank collapse source (NTHMP)



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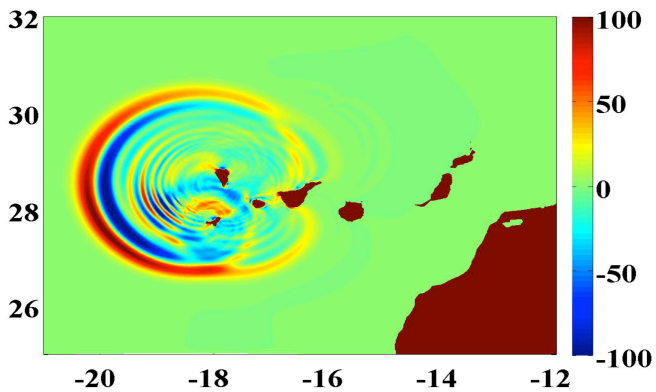


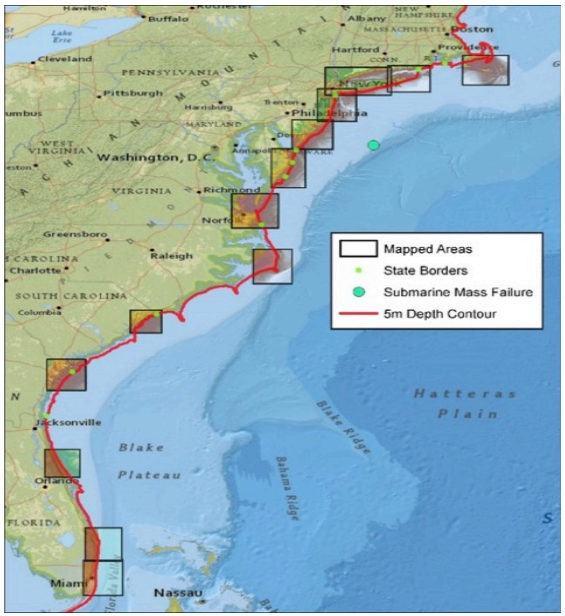
-> 2D-FUNWAVE-TVD transoceanic simulations in nested grids (m)

Near-field: Hudson River Canyon 165 km^3 SMF

[Grilli et al., 2015, 2017; Schambach et al., 2018]

East-Coast tsunami hazard assessment (NTHMP; 2010-…)

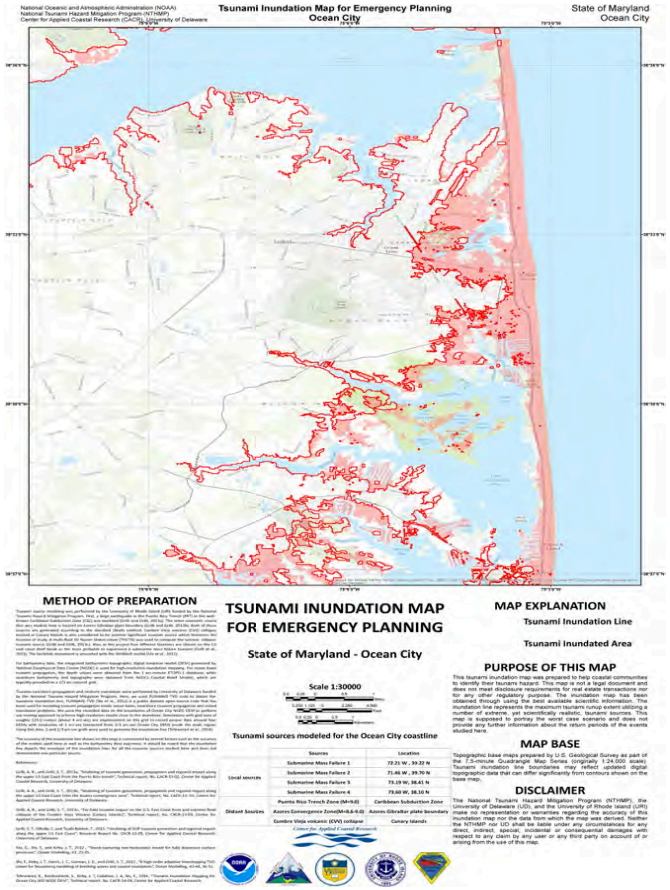
- **Inundation mapping from PMT sources in Atlantic Ocean:**



=> *Volcanic collapse* (La Palma CVV)
=> *Submarine Mass Failures* (SMFs; off the continental shelf)
=> *Coseismic* (LSB, PRT)

[Bare earth DEM, no erosion]

- *No return periods* for maps
- Only *extreme hazard* is mapped
- At 100 y return, ***MT may dominate EC tsunami hazard***



East-Coast Meteotsunami hazard for NTHMP mapping

- Geist et al. (2014):
  - Statistics of 2000-2013 EC events caused by squall lines/derechos
  - Validation of modeling for 06/13/13 MT (a few max. elevations at tide gages)
  - Monte Carlo simulations => hazard curves: $\eta_{max} = f(T_r)$ at tide gages
- Here, based on Dusek et al.'s (2018) EC tide gage analysis from 1996-2018:
  - Select *10 squall lines/derechos* events with $\Delta p > 0.9$ hPa at at least 4 tide gages
  - Use radar/tide gages to infer squall *geometry, direction and speed* [Vilibic et al., 2008]
  - *Parameterize* as moving *Gaussian pressure dist.* **=> modeling with FUNWAVE-TVD**

	Date	Max Pressure Jump (mb)	Number of Gauges	Storm Length(kilometers)	Storm Velocity(meters/sec)	Max Wave Height (meters)	Area
1	06/13/2013	3.7	16	515	26	0.58	Mid-Atlantic Coast
2	06/30/2012	4.1	7	500	23	0.41	Mid-Atlantic Coast
3	12/08/2011	3.6	20	400	23	0.79	Mid-Atlantic Coast
4	3/02/2009	4.9	8	1042	31	0.75	East Coast
5	07/02/2012	4.5	7	900	17	0.51	South Atlantic Coast
6	04/11/2013	3.8	7	561	23	0.42	Mid-Atlantic Coast
7	02/05/2016	3.6	4	1521	29	0.59	East Coast
8	01/16/2016	3.5	5	270	22	0.41	Mid-Atlantic Coast
9	06/09/2011	3.3	6	750	22	0.31	New England
10	02/03/2015	2.5	7	514	8	0.46	East Coast

East-Coast Meteotsunami hazard for NTHMP mapping

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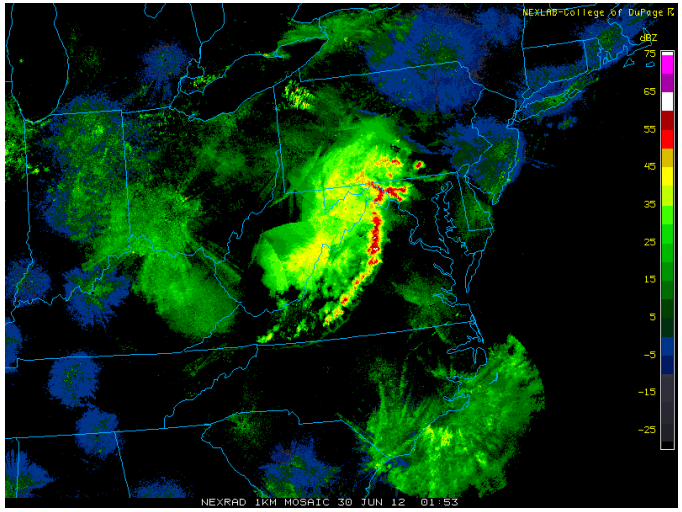
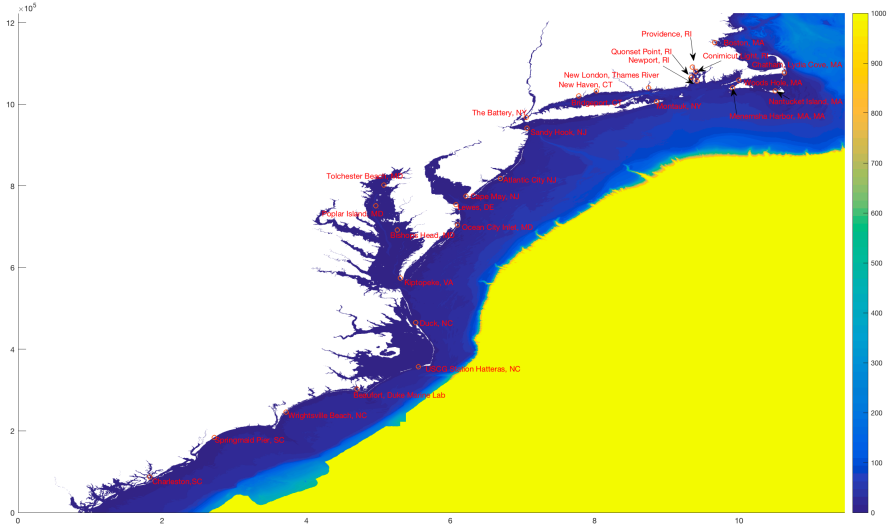


=> use Δp from gauge records



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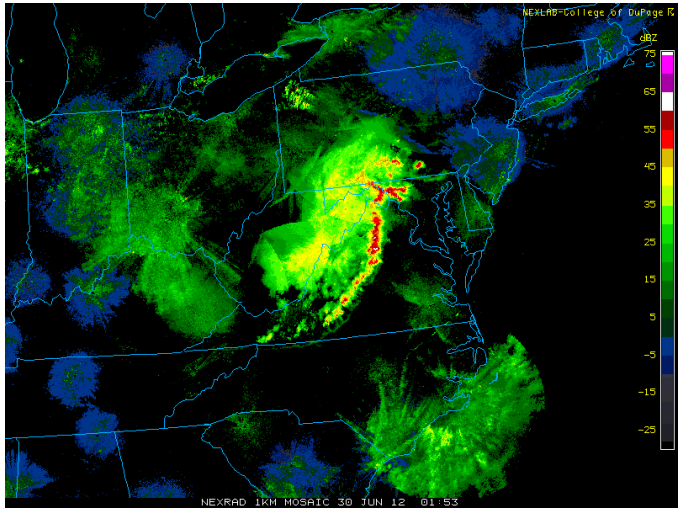

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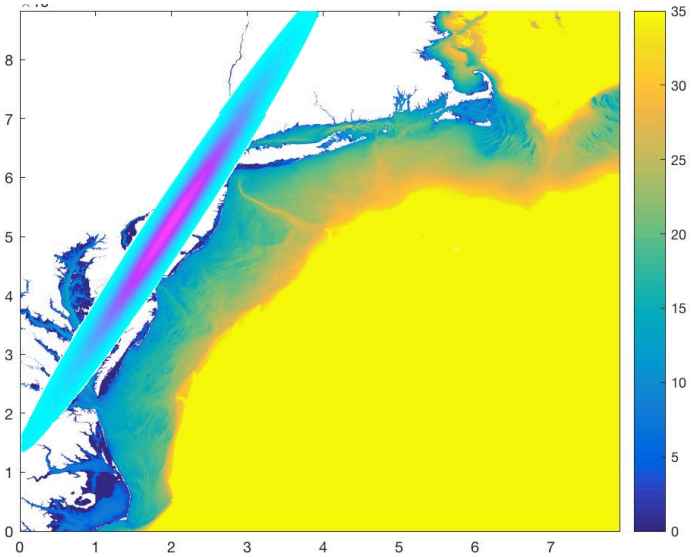
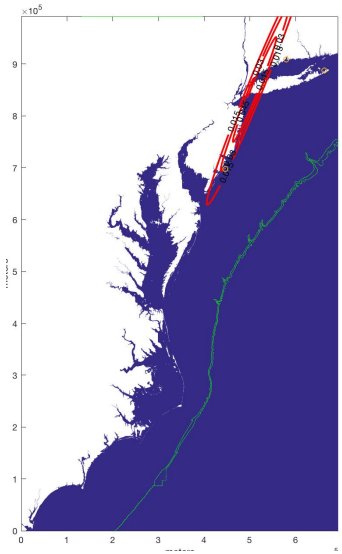
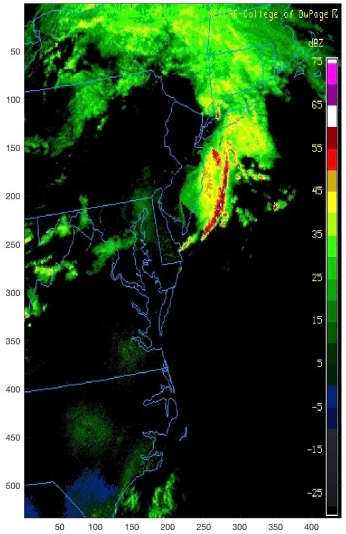


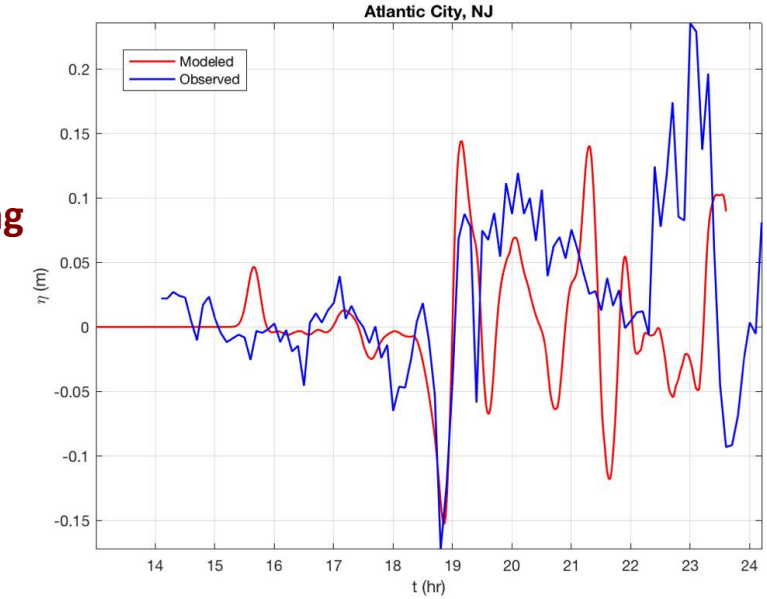
East-Coast Meteotsunami hazard for NTHMP mapping

- Example of 06/13/13 MT:
  - Δp = 6 hPa (10 by 463 km), U = 26 m/s, dir. 25 deg.
  - *modeling with FUNWAVE-TVD* : 500x500 m grid, with dispersion, 11h





=> modeling



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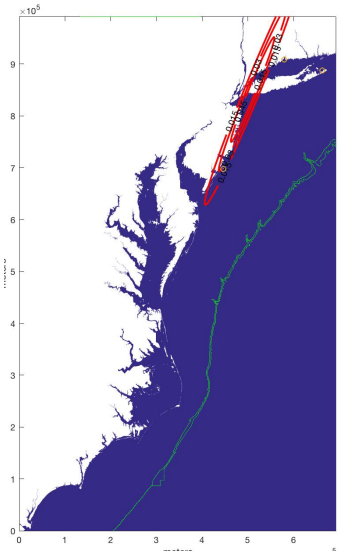

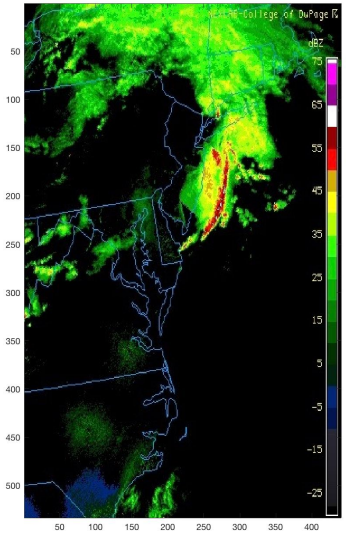

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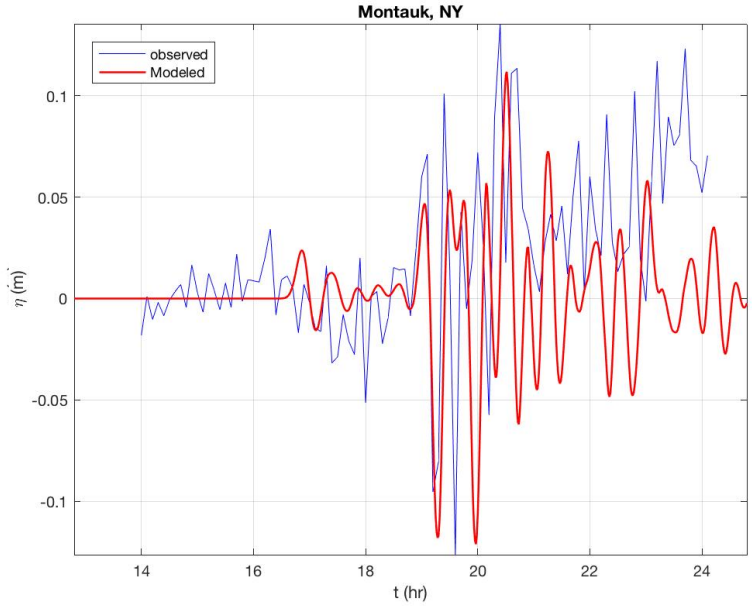

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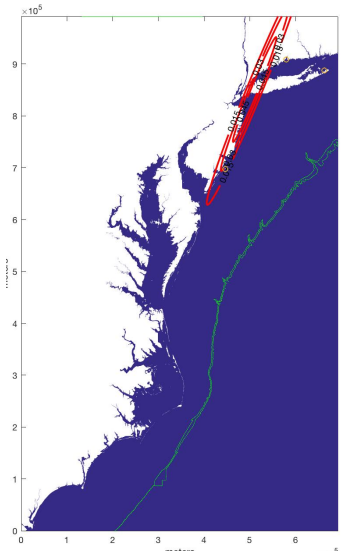
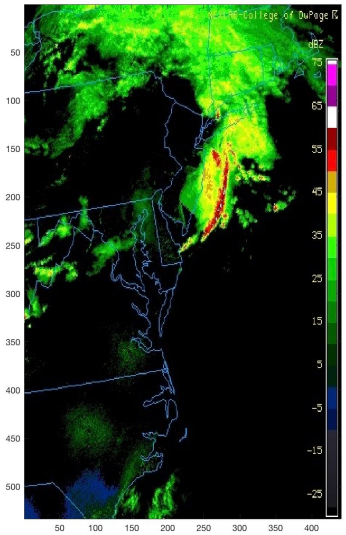
  - *modeling with FUNWAVE-TVD* : 500x500 m grid, with dispersion, 11h





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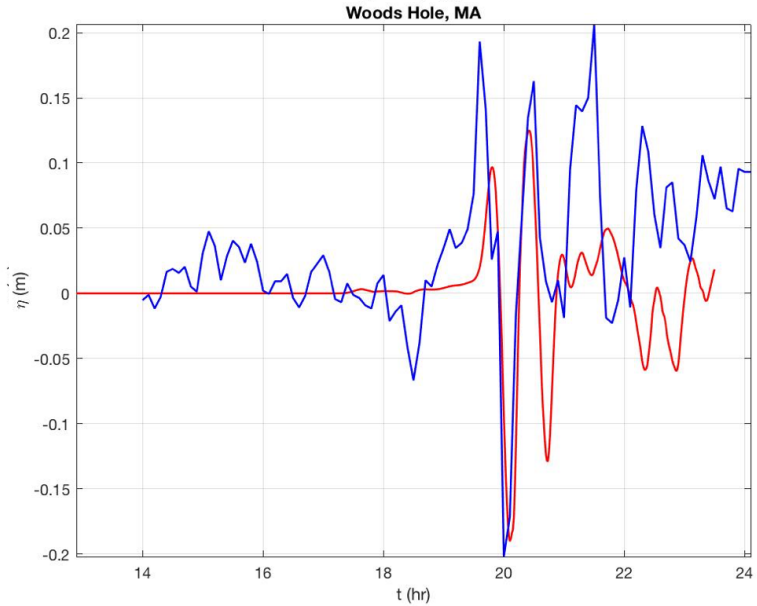
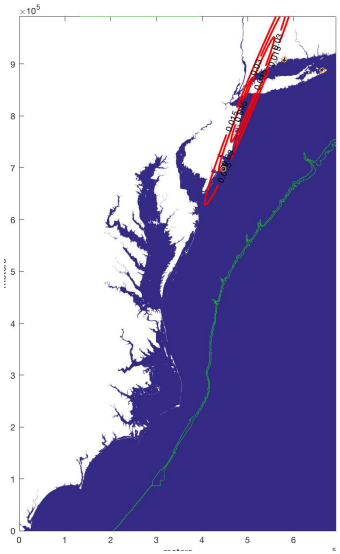
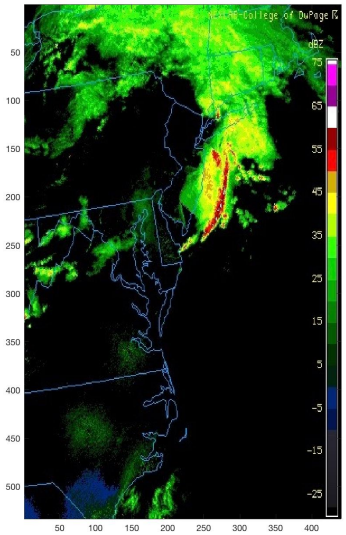


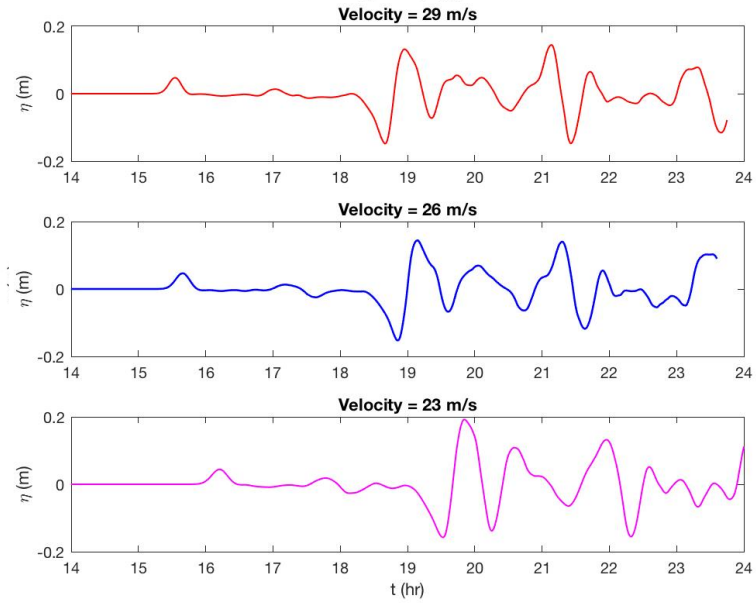
East-Coast Meteotsunami hazard for NTHMP mapping

- Example of 06/13/13 MT:
  - Δp = 6 hPa (10 by 463 km), *sensitivity*: *U* = 23-29 m/s, dir. 25 deg.
  - *Modeling with FUNWAVE-TVD* : 500x500 m grid, with dispersion, 11h



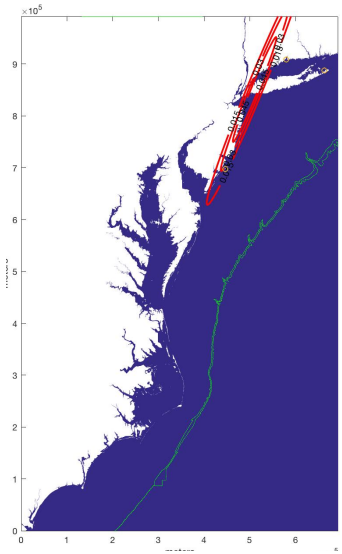


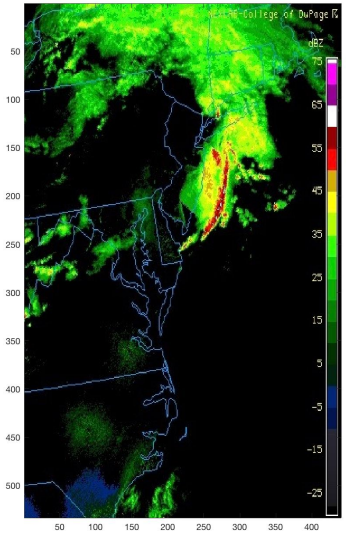
=> Atlantic City Gauge



East-Coast Meteotsunami hazard for NTHMP mapping

- Example of 06/13/13 MT:
  - Δp = 6 hPa (10 by 463 km), *sensitivity*: U = 26 m/s, dir. 335, 0, 25 deg.
  - *Modeling with FUNWAVE-TVD* : 500x500 m grid, with dispersion, 11h





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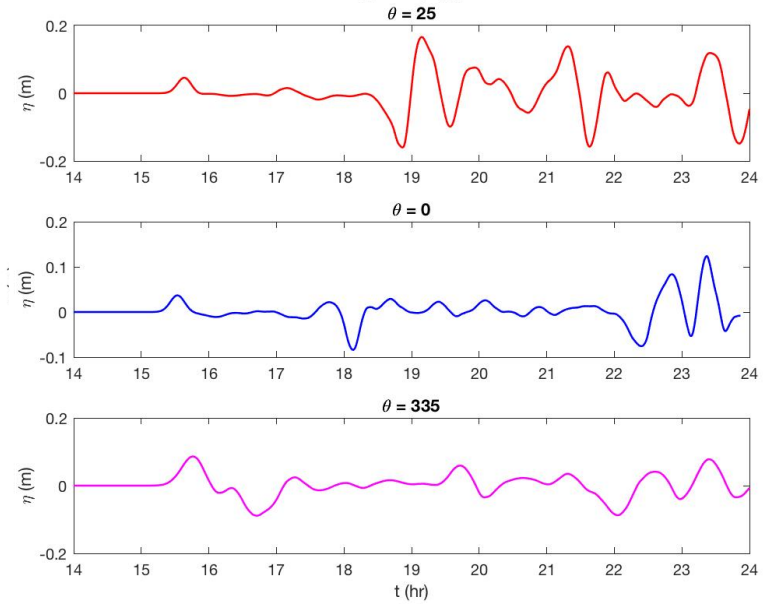
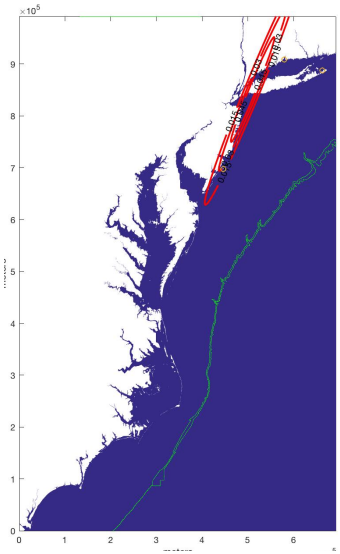
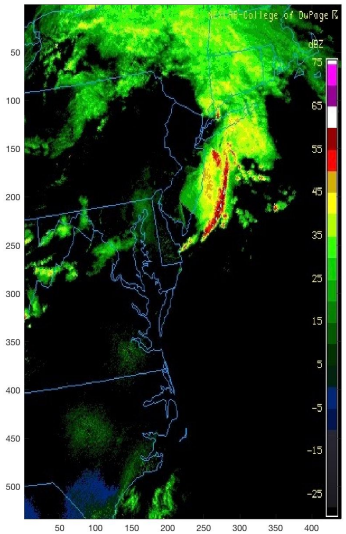


East-Coast Meteotsunami hazard for NTHMP mapping

- <u>Example of 06/13/13 MT:</u>
  - Δp = 6 hPa (10 by 463 km), *sensitivity*: U = 26 m/s, dir. 25 deg.
  - *Modeling with FUNWAVE-TVD* : 500x500 m grid, with/without dispersion, 11h





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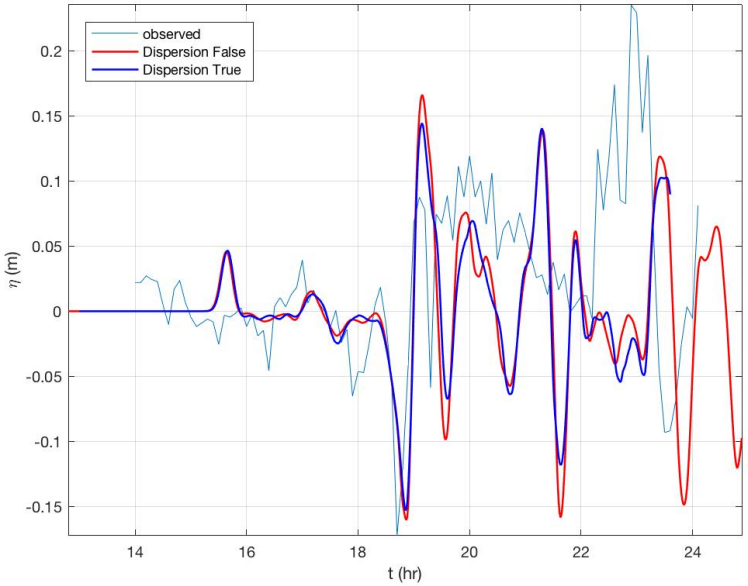


East-Coast Meteotsunami hazard conclusions

- *Similar simulations* were performed for 10 selected MT (Woodruff, 2018; MS)
- *Overall good agreement* at tide gages similar to 06/13/13 event
- *Main features are well captured* (height and period) with small underprediction of elevations likely due to the *coarse nearshore grid*

- *Frequency dispersion does not matter for MT generation*
- *Elevations are very sensitive to U and storm direction*
- *Important source of error: Δp* is based on gauge records at *6 min interval*

- Range of *parameters* for all EC MT
- *MC simulations* will be performed
- *MT hazard* will be included in *NTHMP mapping*

Minimum Storm Length (km)	300
Max Storm Lenth (km)	1100
Minimum Pressure Field Velocity (m/s)	15
Max Pressure Field Velocity (m/s)	31
Minimum Pressure Jump(mb)	0.9
Max Pressure Jump(mb)	4.1

Meteotsunami detection and warning

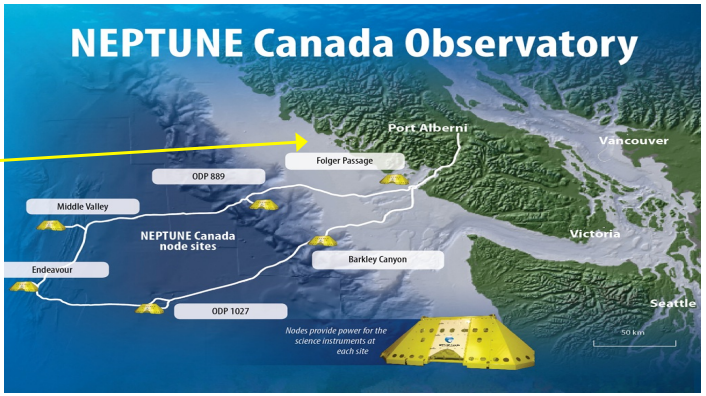
- *Detection of MT* is important as large events can cause loss of life and property damage (enhanced by resonance in harbors) (Geist et al., 2014)
- *Detection of MT* is difficult as there is no natural warning (e.g., EQ) and they can occur over a large area => *point measurements (gauges) are not sufficient*

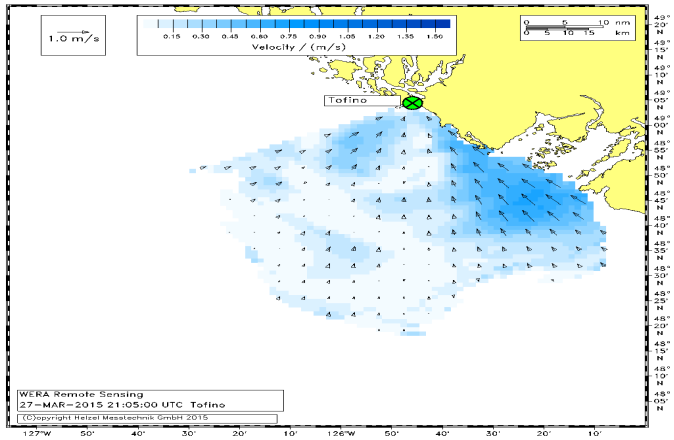
- *Detection of squalls/derechos* with parameters in the critical range could be made and hence risk of MT identified before it even happen (e.g., Titov, 2018; PMEL-NOAA).
- *Detection of the MT itself* can be made using *HF radars*. Surface currents of the 06/13/13 event were identified *a posteriori* in Codar data (Lipa et al., 2014)
  => *Spatially dense measurements* that can more easily detect MT events

- Guérin et al. (2017, 2018) developed new *tsunami detection algorithms* for HF radar, which are implemented in the Tofino, BC Wera radar.
  => a strong "meteotsunami-like" event (1 m elevation) was detected in real time on 10/14/16 that occurred off Tofino *in the wake of Typhoon Songda*

MT Detection with the Tofino WERA radar

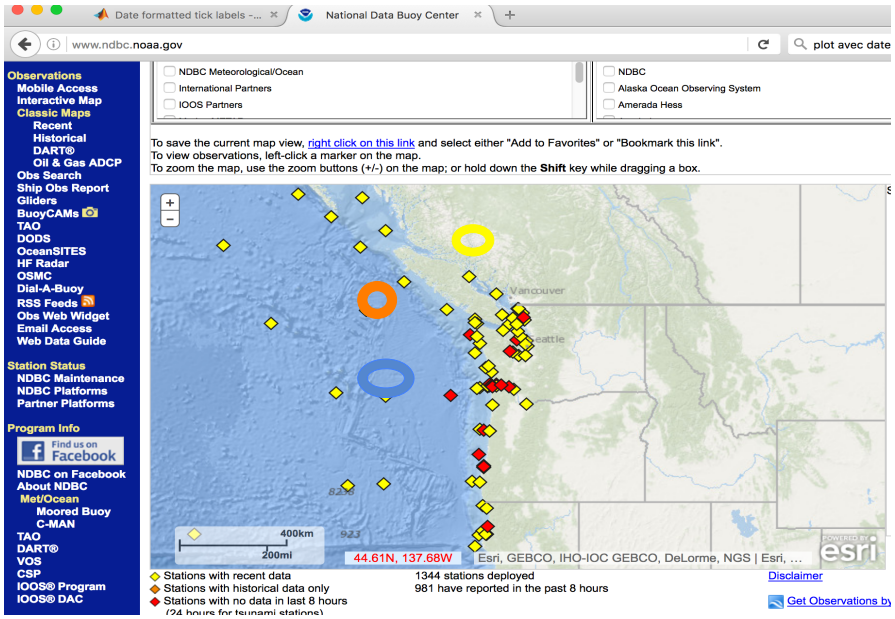
- *WERA HF radar* installed in 2015 in Tofino (Vancouver Island) for tsunami detection
- Part of « *Neptune Observatory* » maintained by ONC on the Pacific side of BC
- *Radial currents measured* up to 85-100 km range, 1.5 km range resolution and ~10 deg azimuthal resolution

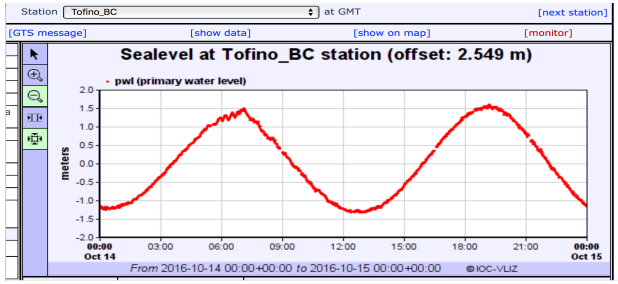


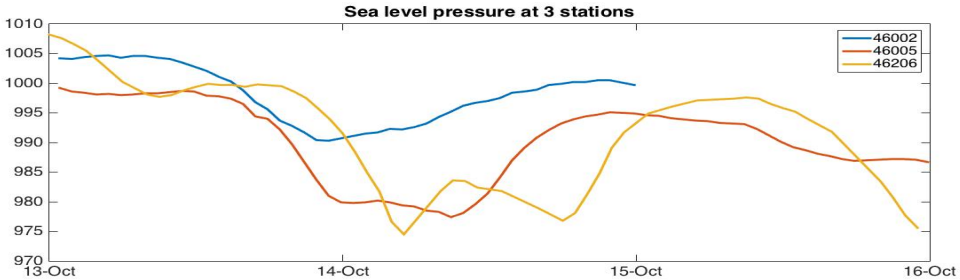


Tsunami alert triggered at Tofino WERA radar

- *Tsunami alert triggered* at the Tofino HF radar on October 14th, 2016, at 6.06 am
- *Remnants of Typhoon Songda* were moving up the coast

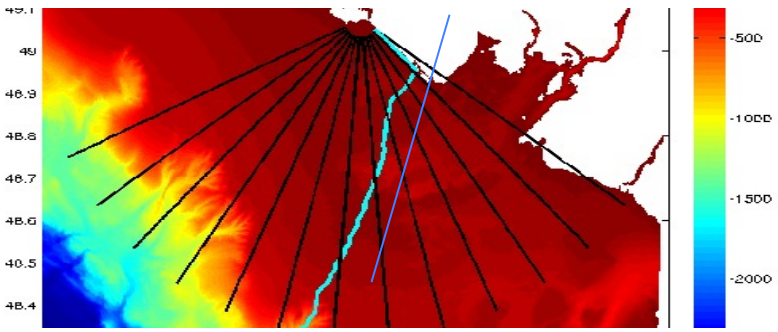


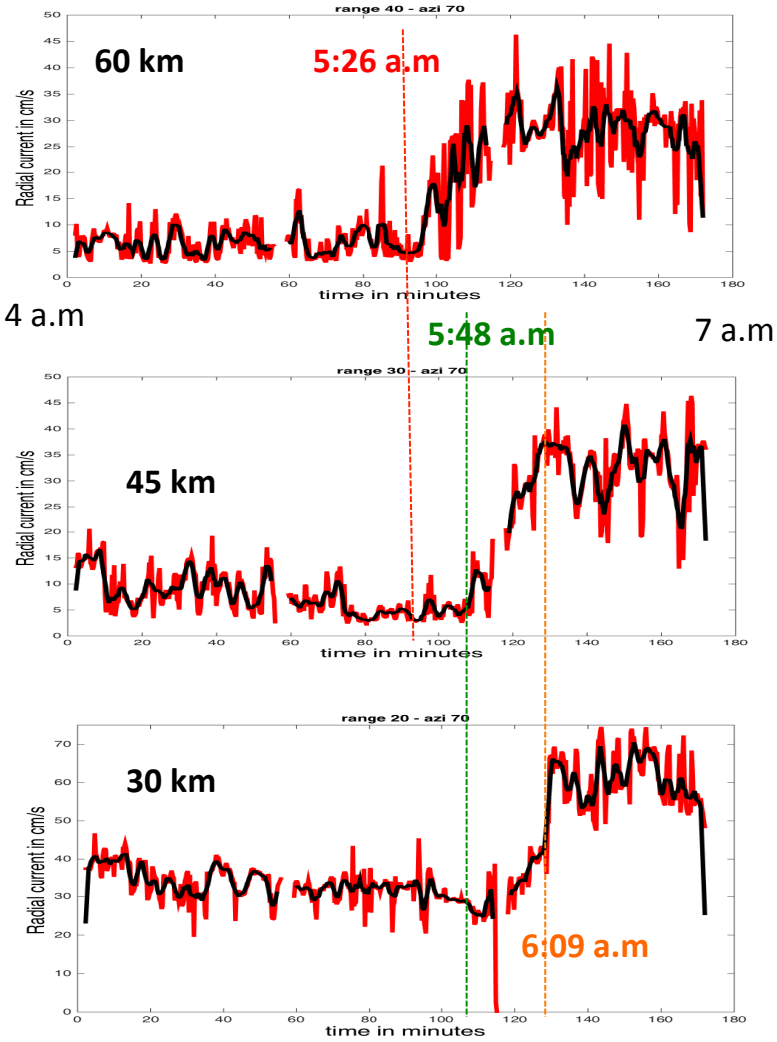




- *Low pressure front* propagates at about U = 26.4 m/s
- *Tide gage oscillations* of 10 cm, with 20 min period
- No seismic activity => possible **meteo-tsunami ?**

Inverted current time series



- *Currents inverted* from HF radar along azimuth #70 at ranges of 30, 45 and 60 km
- *Step in current speed* with 25 cm/s jump
- Speed of front *consistent with shelf long wave celerity*

  => possible Proudman resonance
- Details in Guérin et al. (2017, 2018)