Quasi-stationary WAVEWATCH III® for the nearshore

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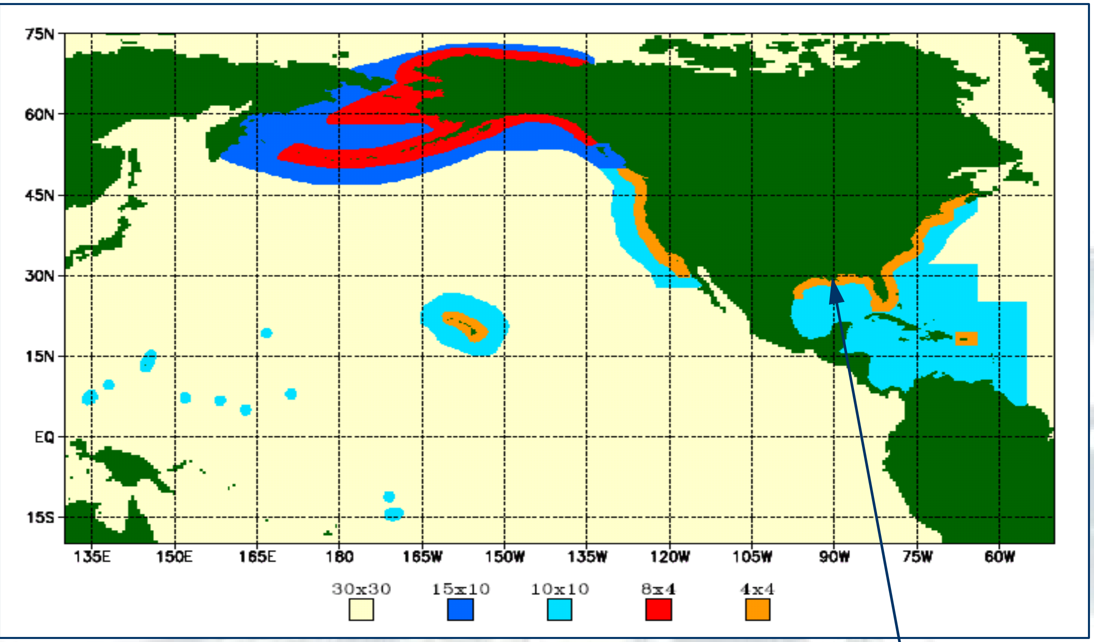
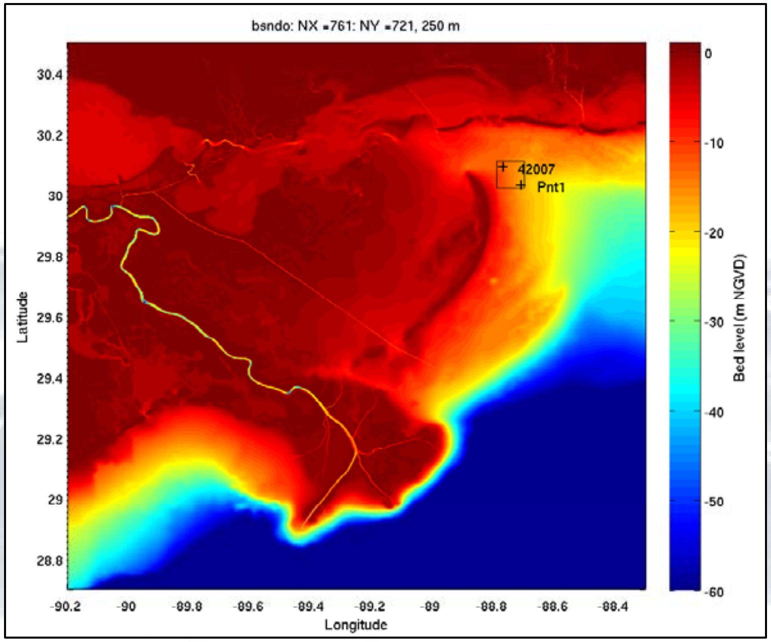
WHERE AMERICA'S CLIMATE WEATHER AND OCEAN SERVICES BEGIN

Motivation

Current WWIII model grid mosaic

Desired nearshore application





Max. coastal resolution = 4 arc min (7.5 km)

Nearshore resolution: < 100 m

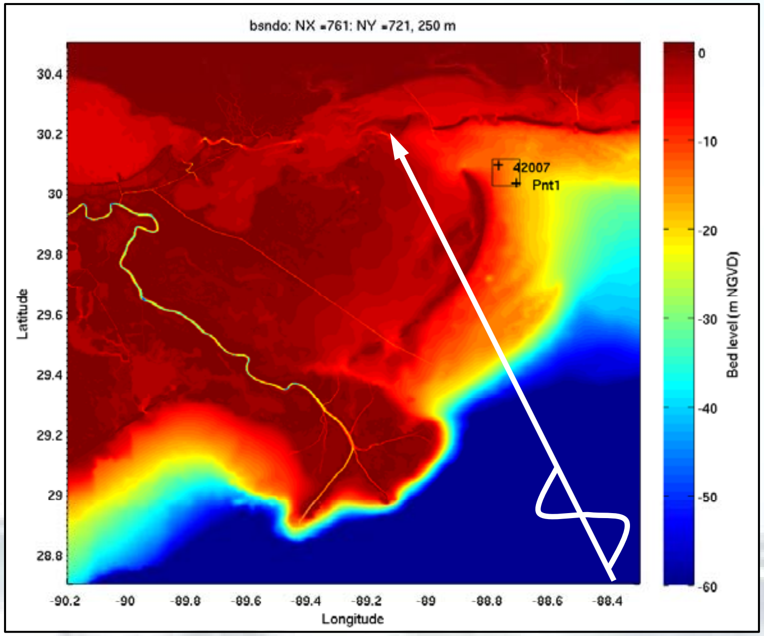
Method

$t_s \equiv$ Residence time

$\Delta t_s \equiv$ Global input/output interval

Quasi-stationary conditions

where: $\gamma = \dfrac{\Delta t_s}{t_s} > 1$



Time stepping can be accelerated: $t_i = t_{i-1} + \gamma \Delta t_n$

where $t_s = \alpha \dfrac{\text{Distance}}{\text{Group velocity}} = \alpha \dfrac{X}{c_{g,\tilde{T}m01}}$,

with α a constant = 1.2

Conclusions

- If the residence time t_s in nearshore domains is shorter than the input/output interval, quasi-stationary conditions develop, and a saving in computational time of the explicit model is possible.
- Quasi-stationary approach is proposed with (i) discontinuous time stepping, and (ii) nonstationary, discontinuous, phase-shifted BCs.
- With variable t_s computed from wave field: Local computational time savings of up to 50% (depending on domain and wave condition), with errors below 1% and no spurious phase lag.
- With constant t_s: Greater constant savings in computational time (50% total), but with greater error (H_{m0} < 5%; T_{m01} < 2%).
- Run time is about 20 times longer than an equivalent nonstationary SWAN run (with Δt = 10 min, no. iter = 3), but CFL condition is adhered to, and error can be controlled.
- Future: QS implementation for WWIII Multigrid.

Outline

1. Action balance equation and solution methods
2. Quasi-stationary operation of WWIII
3. Alternative QS approaches
4. Field case: Hurricane Gustav
5. Conclusions

Action balance equation

$$\frac{\partial N}{\partial t} + \nabla_x \cdot \dot{\mathbf{x}} N + \frac{\partial}{\partial k} \dot{k} N + \frac{\partial}{\partial \theta} \dot{\theta} N = \frac{S}{\sigma}$$

$$\dot{\mathbf{x}} = \mathbf{c}_g + \mathbf{U} \, ,$$

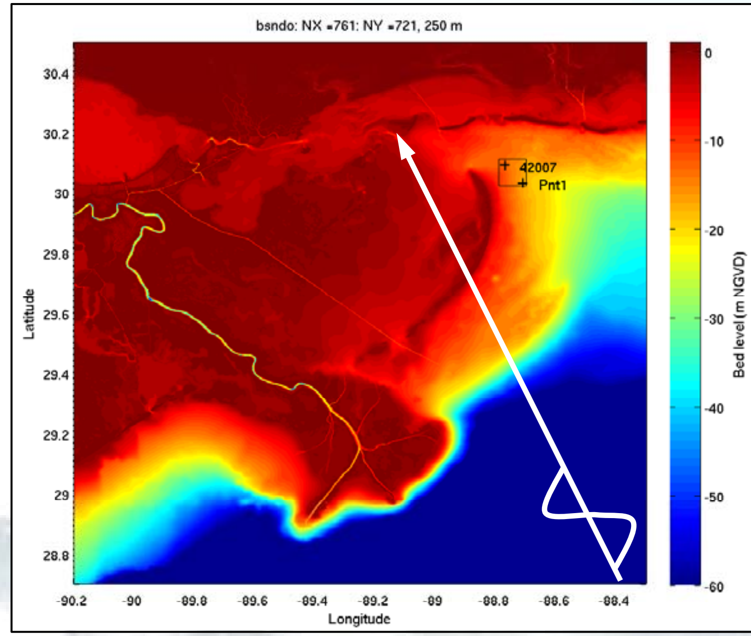
$$\dot{\mathbf{k}} = -\frac{\partial \sigma}{\partial d} \frac{\partial d}{\partial s} - \mathbf{k} \cdot \frac{\partial \mathbf{U}}{\partial s} , \quad \dot{\boldsymbol{\theta}} = -\frac{1}{k} \left[\frac{\partial \sigma}{\partial d} \frac{\partial d}{\partial m} - \mathbf{k} \cdot \frac{\partial \mathbf{U}}{\partial m} \right]$$

- Required physics for nearshore application already present
- Eulerian approach on rectangular, curvilinear or unstructured grids
- Explicit vs. Implicit implementations
- CFL constraints and nearshore application

Quasi-stationary operation of WWIII

$t_s \equiv$ Residence time

$\Delta t_s \equiv$ Global input/output interval



Quasi-stationary conditions

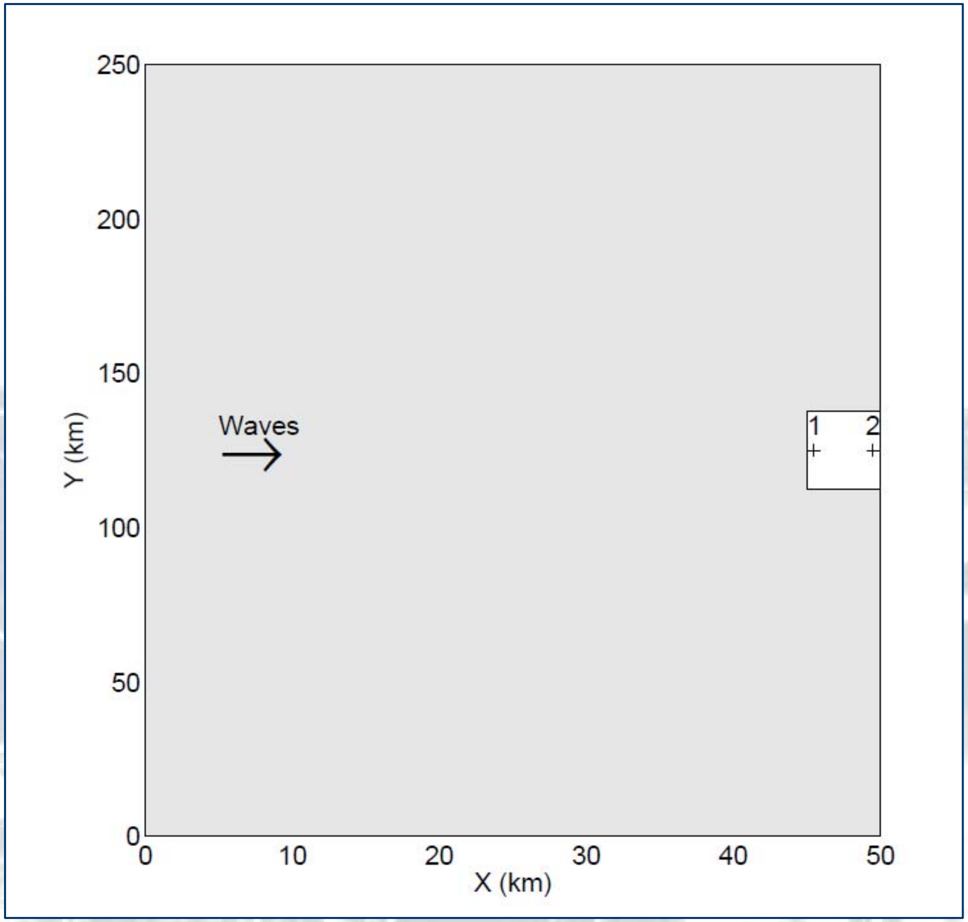
where: $\gamma = \dfrac{\Delta t_s}{t_s} > 1$

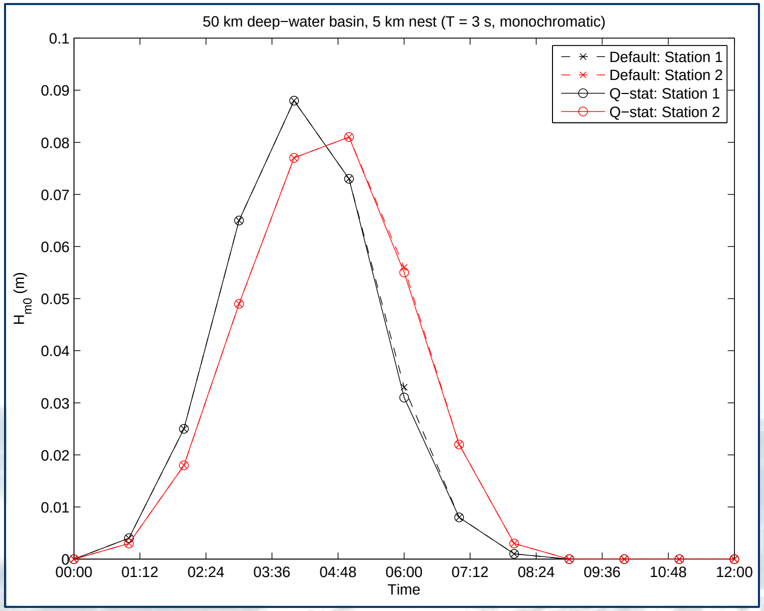
Time stepping can be accelerated: $t_i = t_{i-1} + \gamma \Delta t_n$

where $t_s = \alpha \dfrac{\text{Distance}}{\text{Group velocity}} = \alpha \dfrac{X}{c_{g,\tilde{T}m01}}$,

with α a constant = 1.2

Test case: Idealized wave propagation

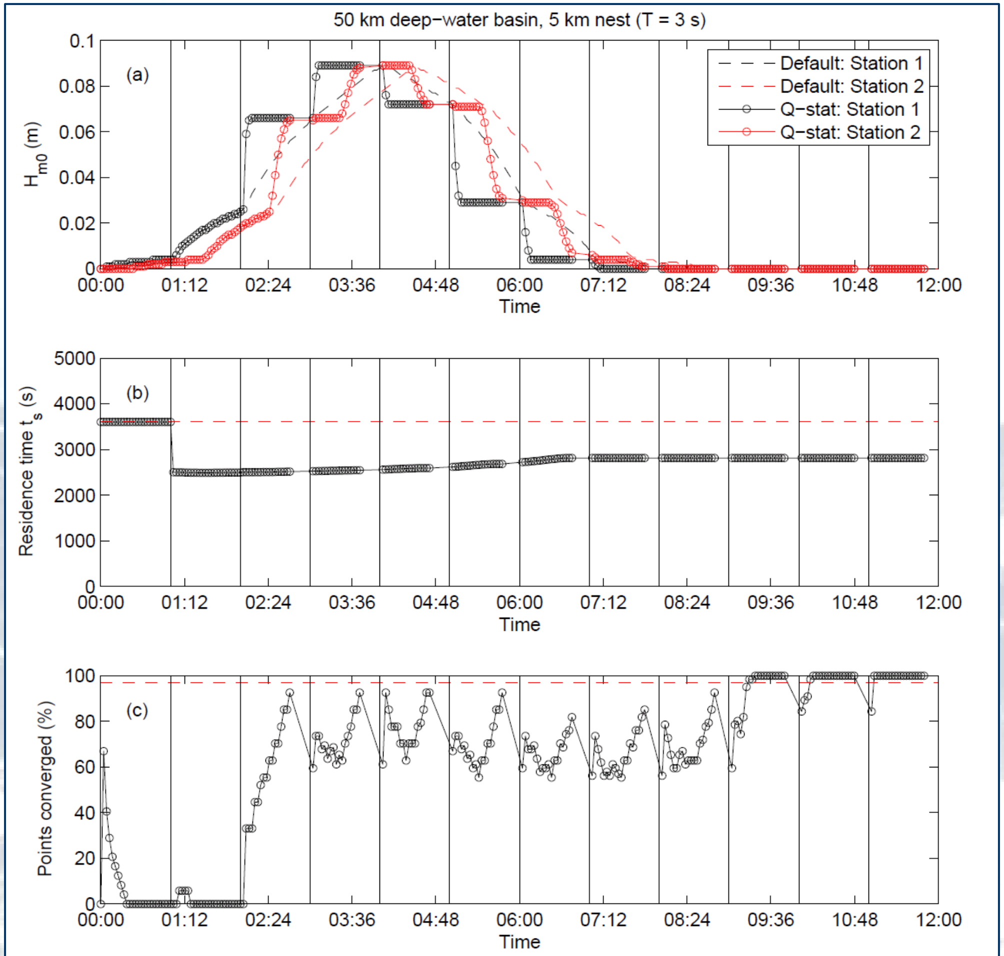




f_p = 0.33 Hz, Std dev. = 0.01 Hz

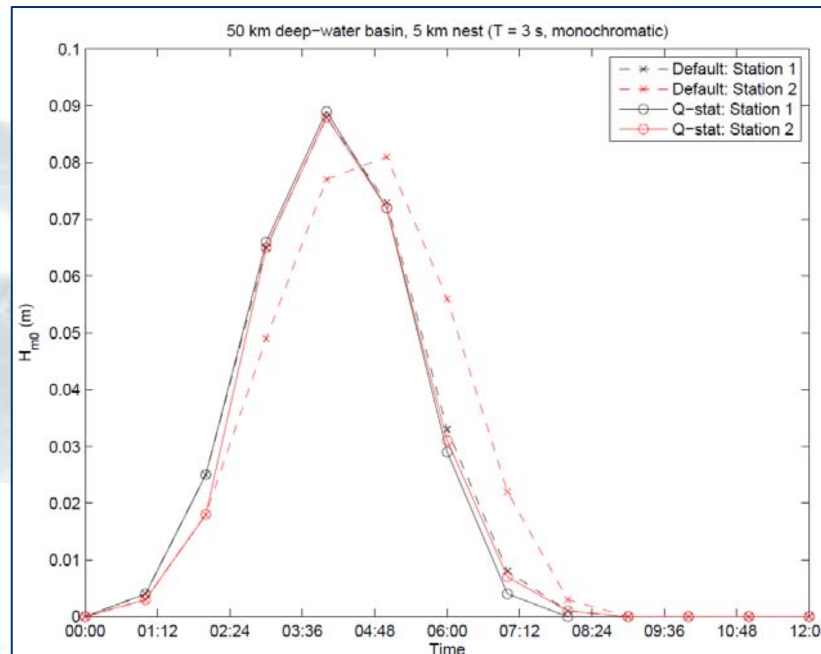
Dir = 270 °N, monochromatic, long-crested

Approach 1: Discontinuous time stepping, discontinuous stationary BC

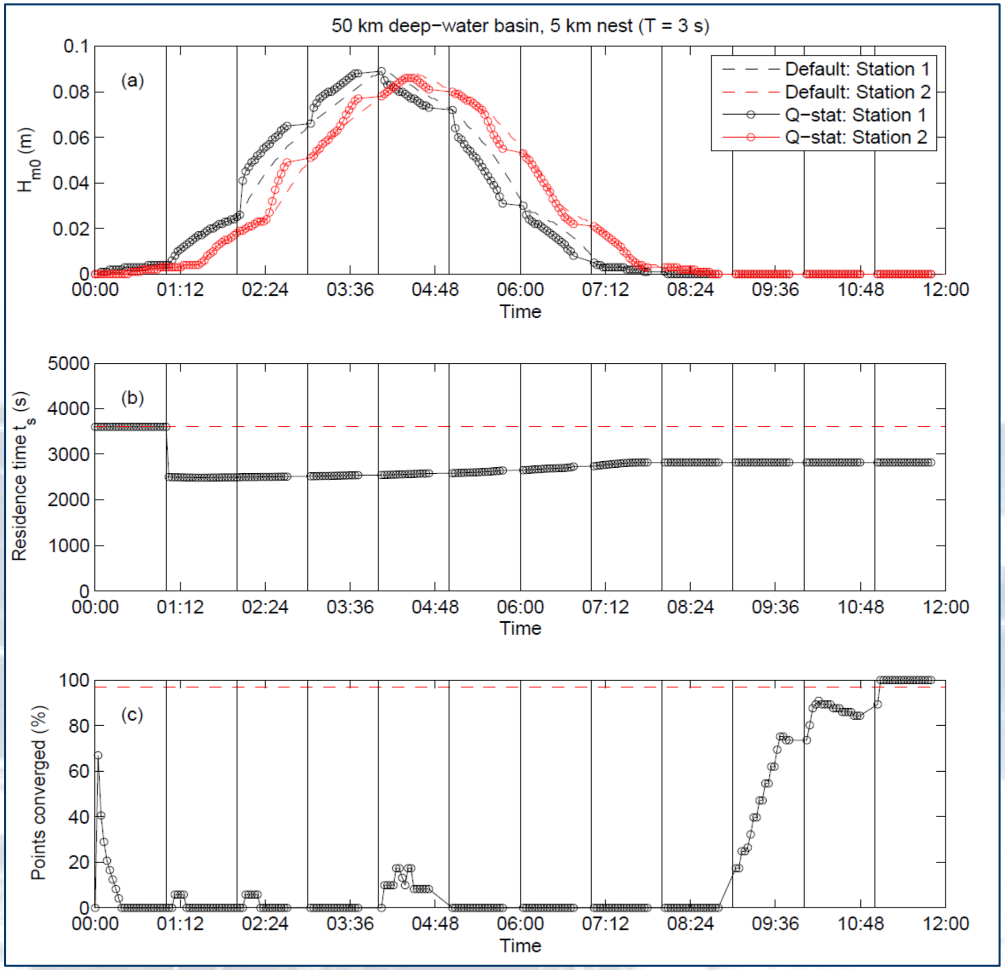


$$t_i = t_0 + \left[i + (n_m - n_i) \left\lfloor \frac{i}{n_i} \right\rfloor \right] \Delta t_n$$

$$\psi_i = \psi_1$$

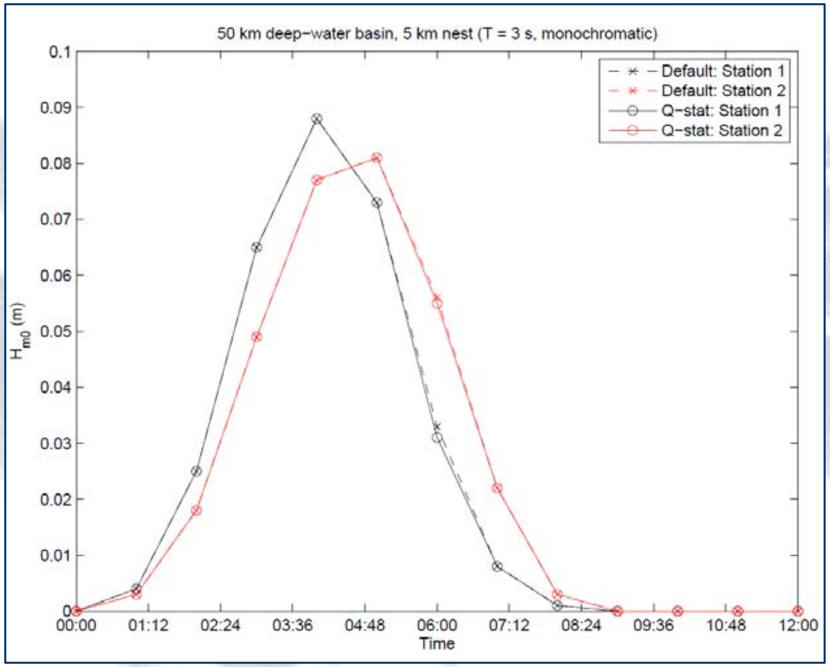


Approach 2: Discontinuous time stepping, discontinuous nonstationary, phase-shifted BC

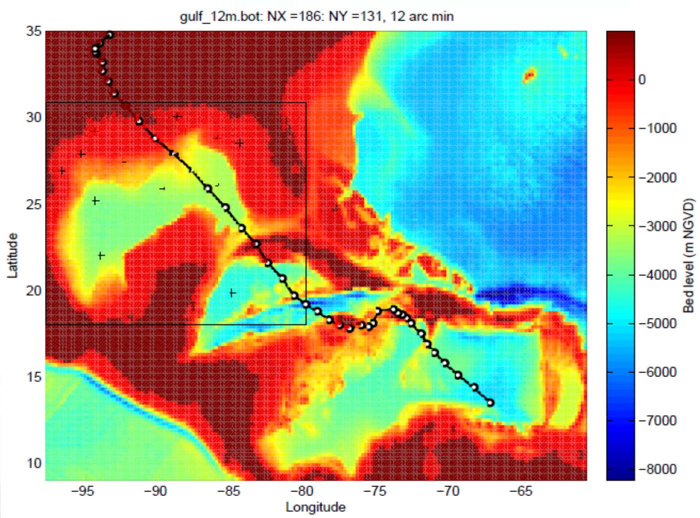


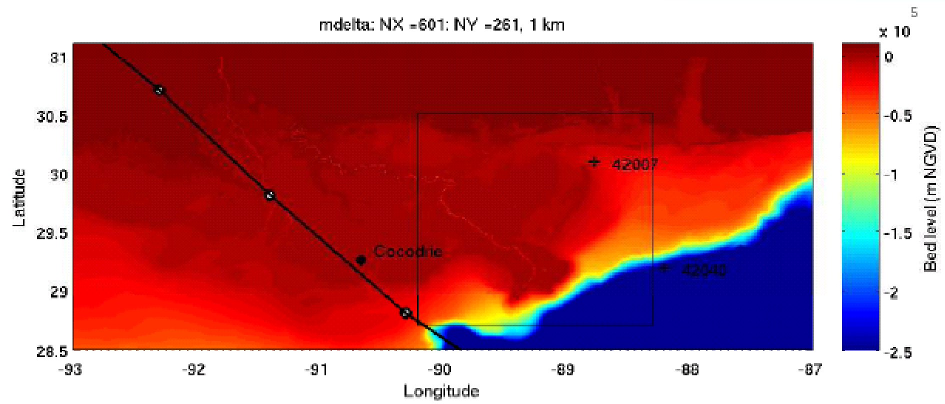
$$t_i = t_0 + \left[i + (n_m - n_i) \left\lfloor \frac{i}{n_i} \right\rfloor \right] \Delta t_n$$

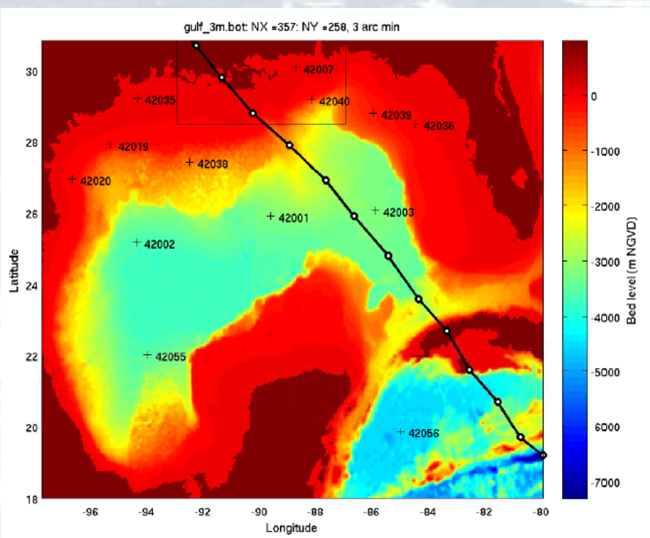
$$\psi_i = \psi(t_i + (\Delta t_s - t_s)) \quad , \quad \text{for } \gamma > 1$$

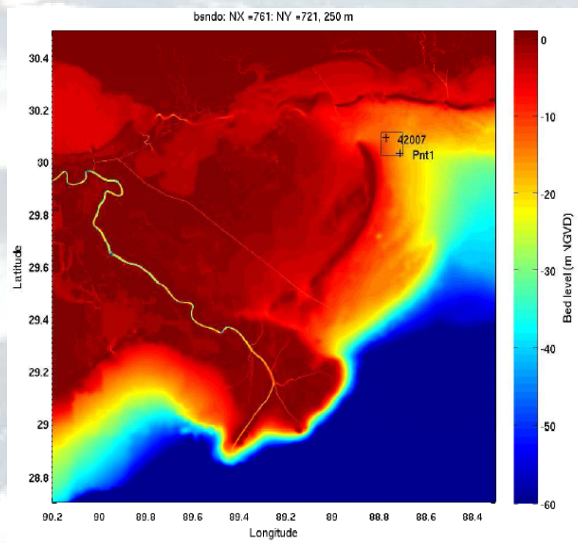


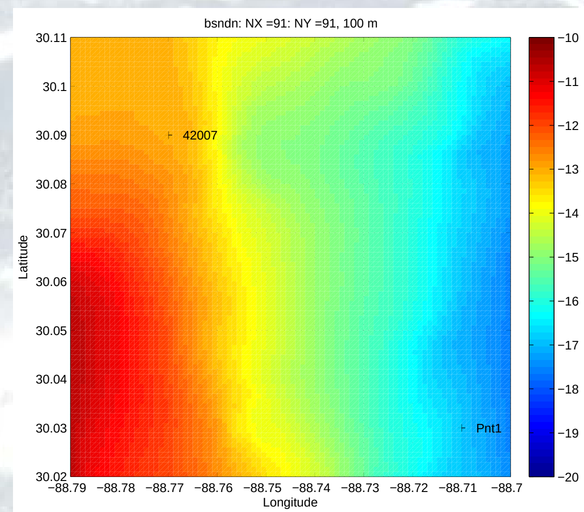
Field case: Hurricane Gustav (Aug-Sept 2008)





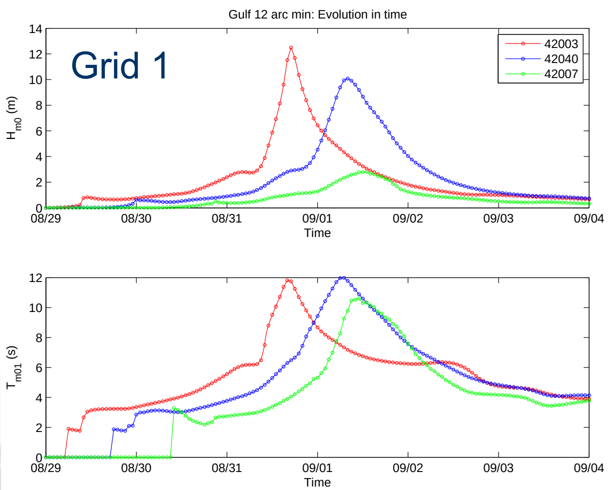


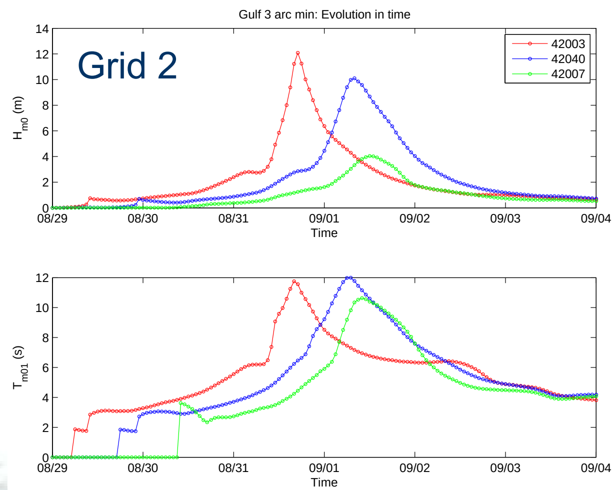


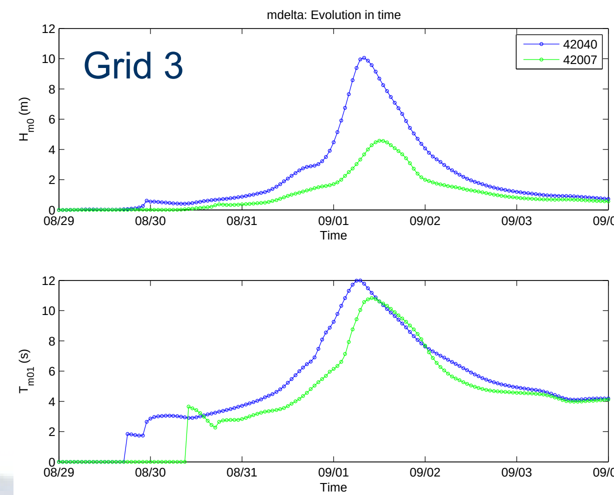


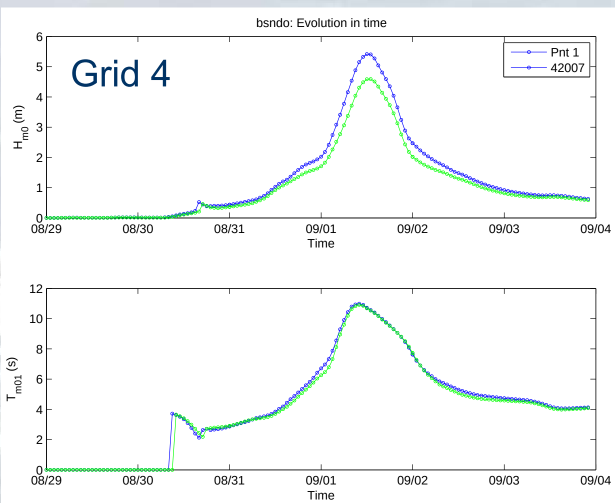
Data: Chen et al. (2010)

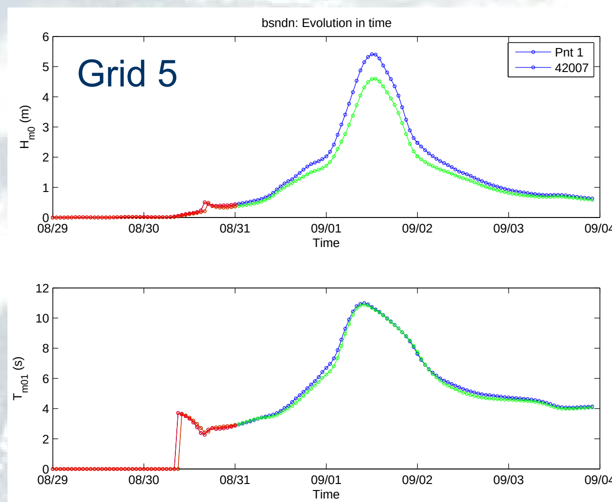
Results: H Gustav (Nonstationary WWIII)









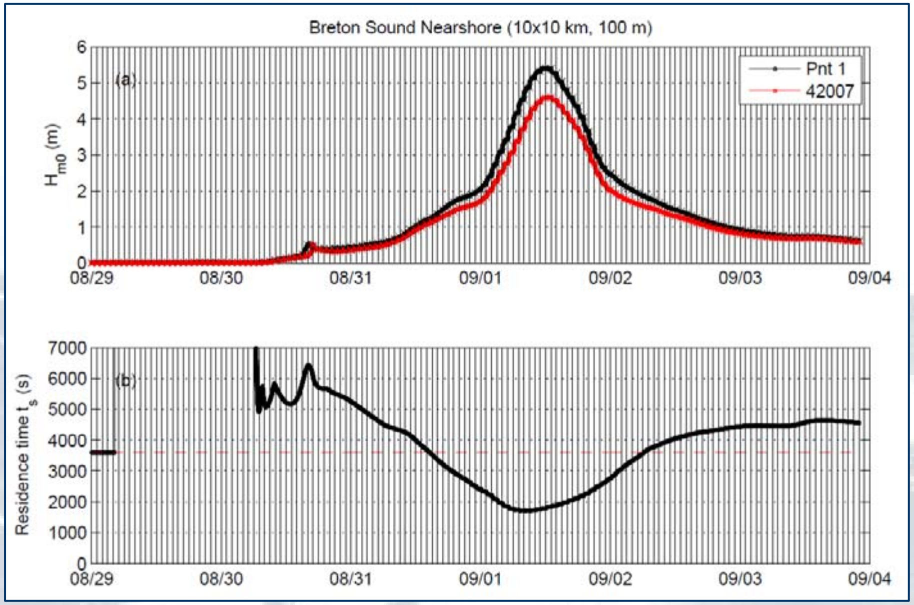


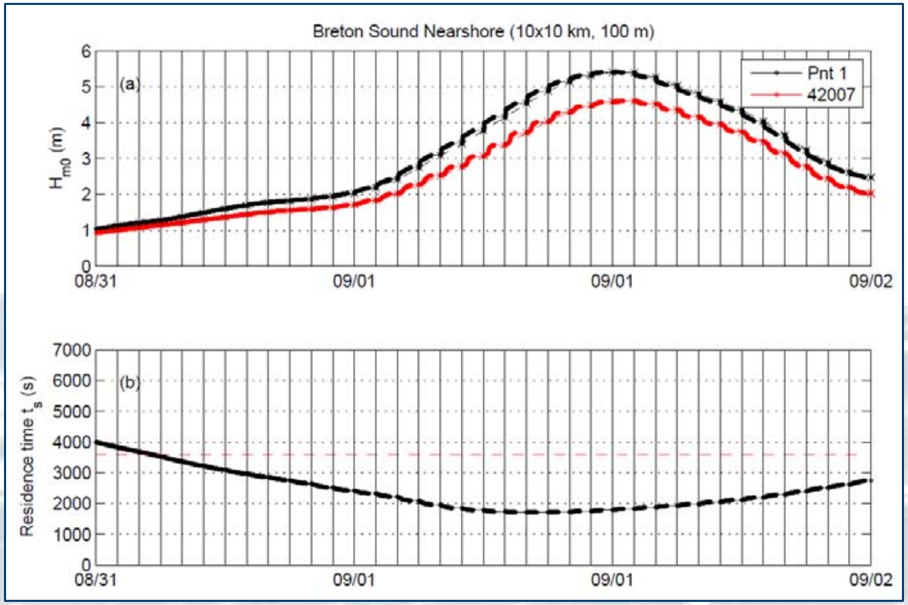
Grid 5: Δt_n = 5 s

Run time = 67 min

(512 cores on IBM Power6 Cluster)

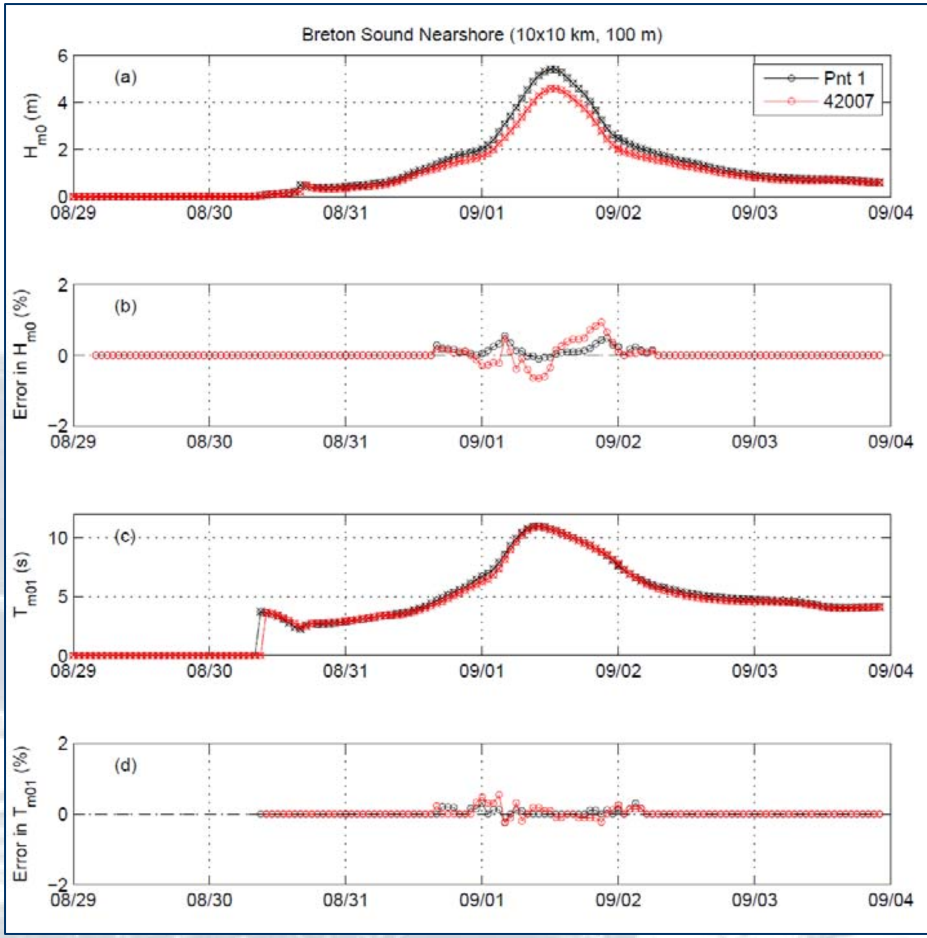
Results: Hurricane Gustav, QS WWIII



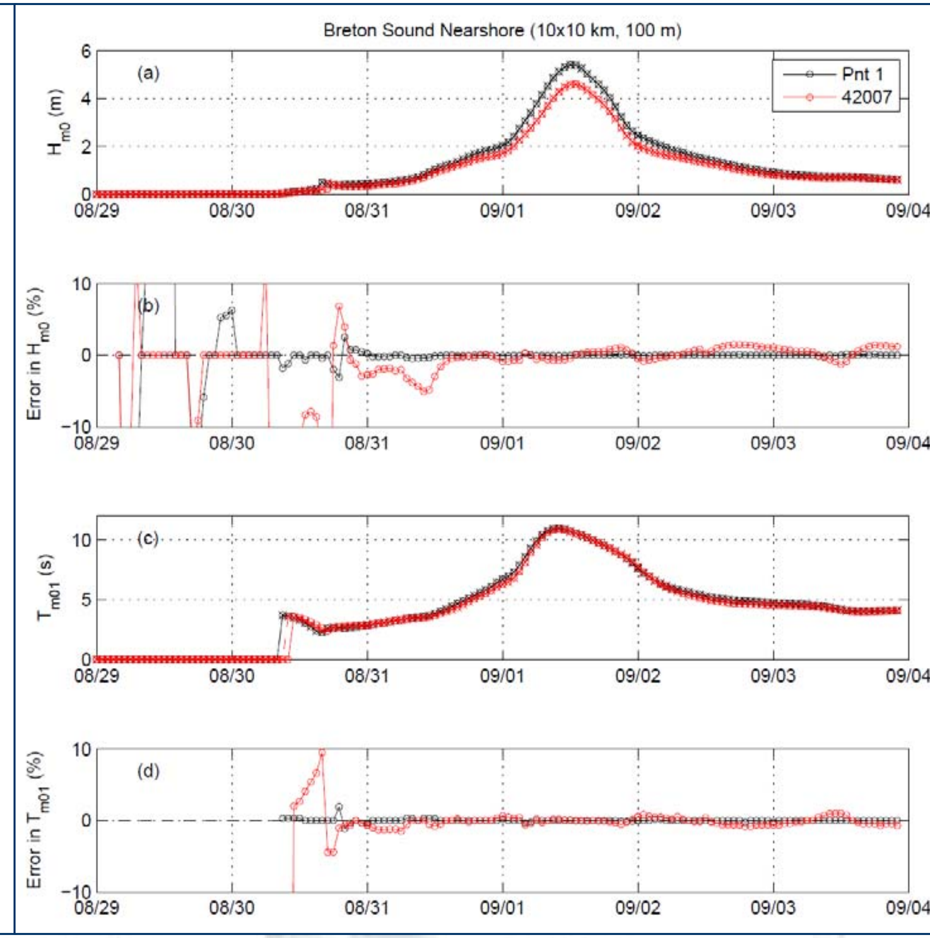


Results: Hurricane Gustav, QS WWIII

Wave-field dependent t_s



Constant t_s = 1800 s



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Questions?

Convergence criteria

Alternative way to identify stationarity:

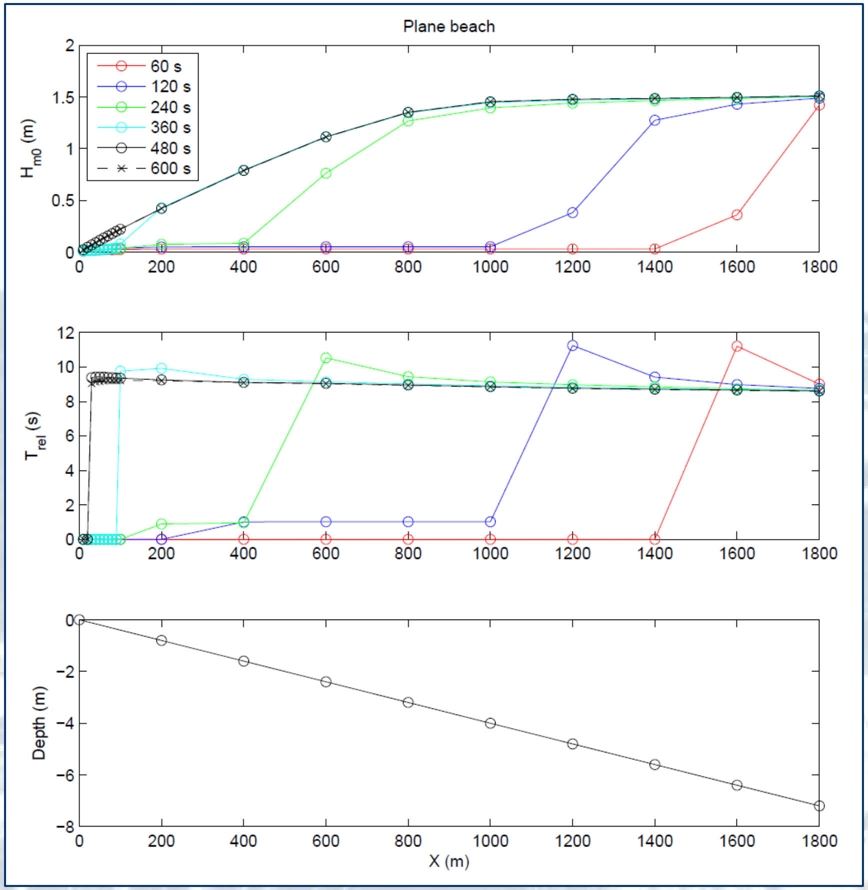
$$100.\frac{H_{m0,t_i} - H_{m0,t_{i-1}}}{H_{m0,t_{i-1}}} = \Delta H_{m0}\% = 5\% \text{ / hour}$$

$$100.\frac{T_{m01,t_i} - T_{m01,t_{i-1}}}{T_{m01,t_{i-1}}} = \Delta T_{m01}\% = 5\% \text{ / hour}$$

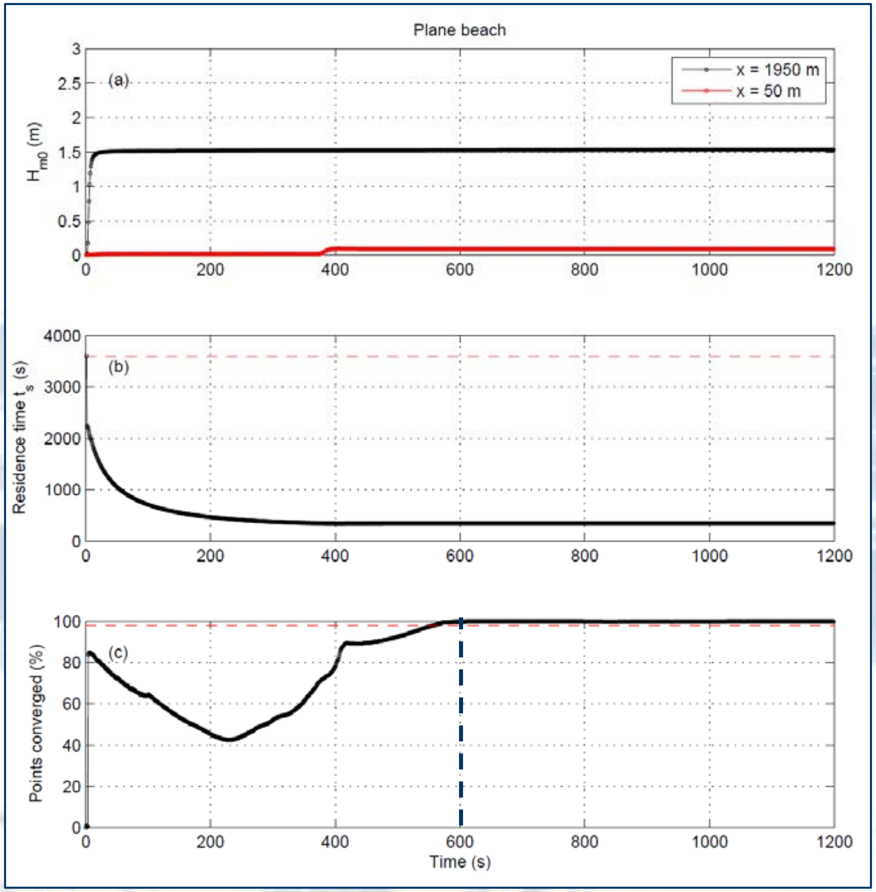
… met at 95% of wet grid points.

Results: Plane beach surf zone, QS WWIII

Conv. behavior in space



Conv. behaviour in time



H_{m0} = 1.5 m, T_p = 10 s, slope = 1:25, Δx = 10 m; Δt = 1 s