Quasi-stationary WAVEWATCH III

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Atmospheric and Oceanic Science

Covered in this lecture:

- Action balance equation and solution methods
- Quasi-stationary operation of WWIII
- Alternative QS approaches
- Field case: Hurricane Gustav

Action balance equation

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

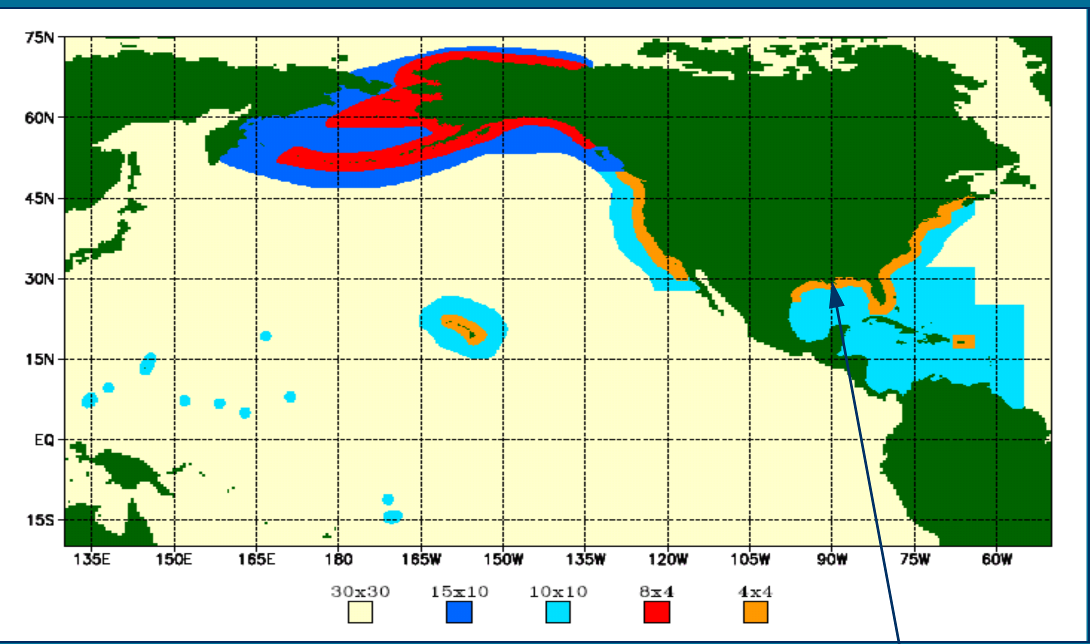
$$\dot{\mathbf{x}} = \mathbf{c}_g + \mathbf{U} \ ,$$

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

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

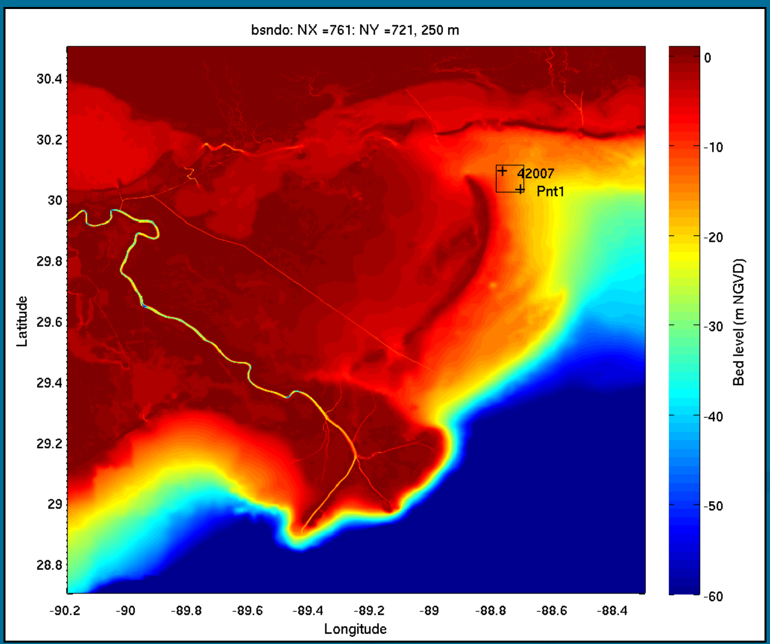
Resolving coastal scales

Current WWIII model grid mosaic



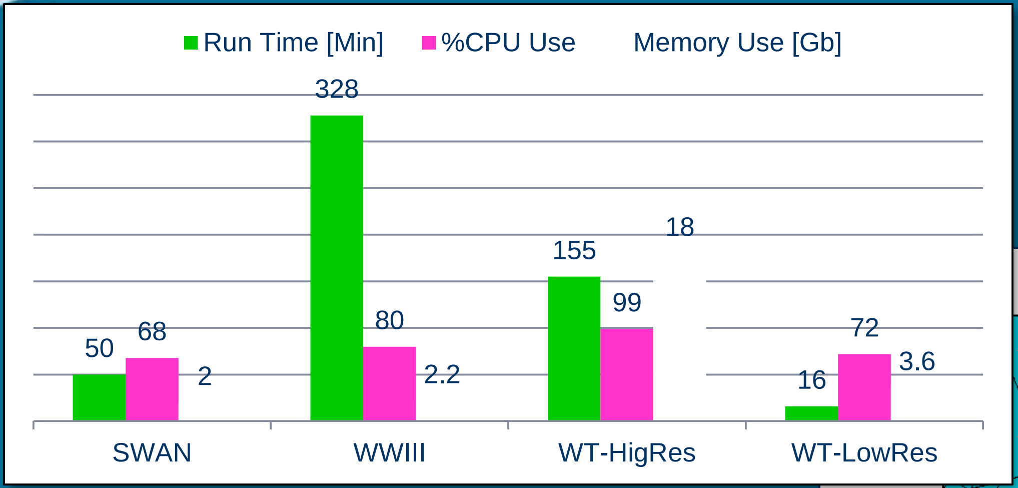
Max. coastal resolution = 4 arc min (7.5 km)

Desired nearshore application

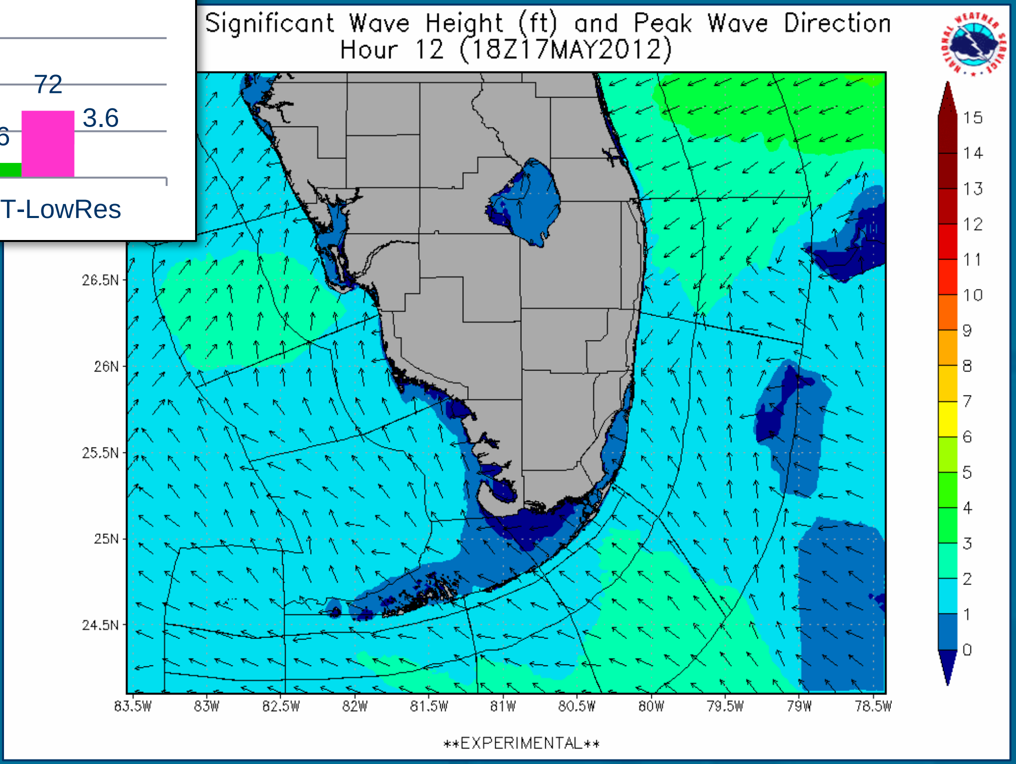


Nearshore resolution: < 100 m

Performance comparison: Explicit vs. Implicit



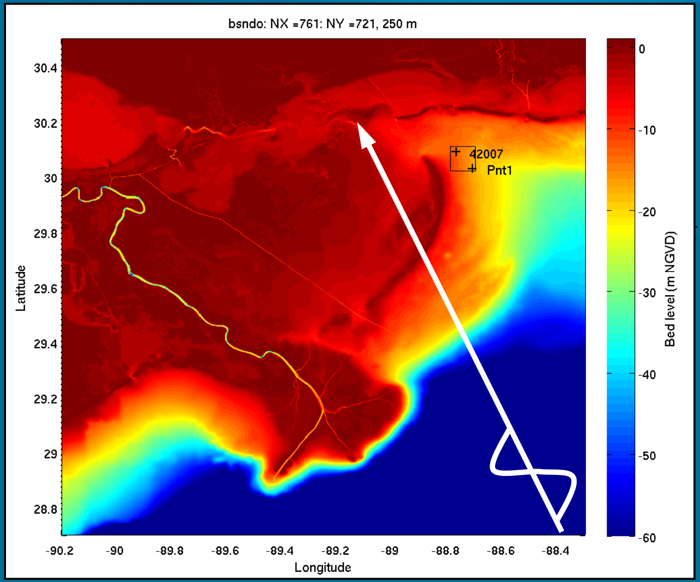
- WFO MFL Alpha testing site
- 1 arc-min grid
- 96 h forecast, dt – 600 s



Quasi-stationary operation of WWIII

$t_s \equiv$ Residence time

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



Quasi-stationary conditions

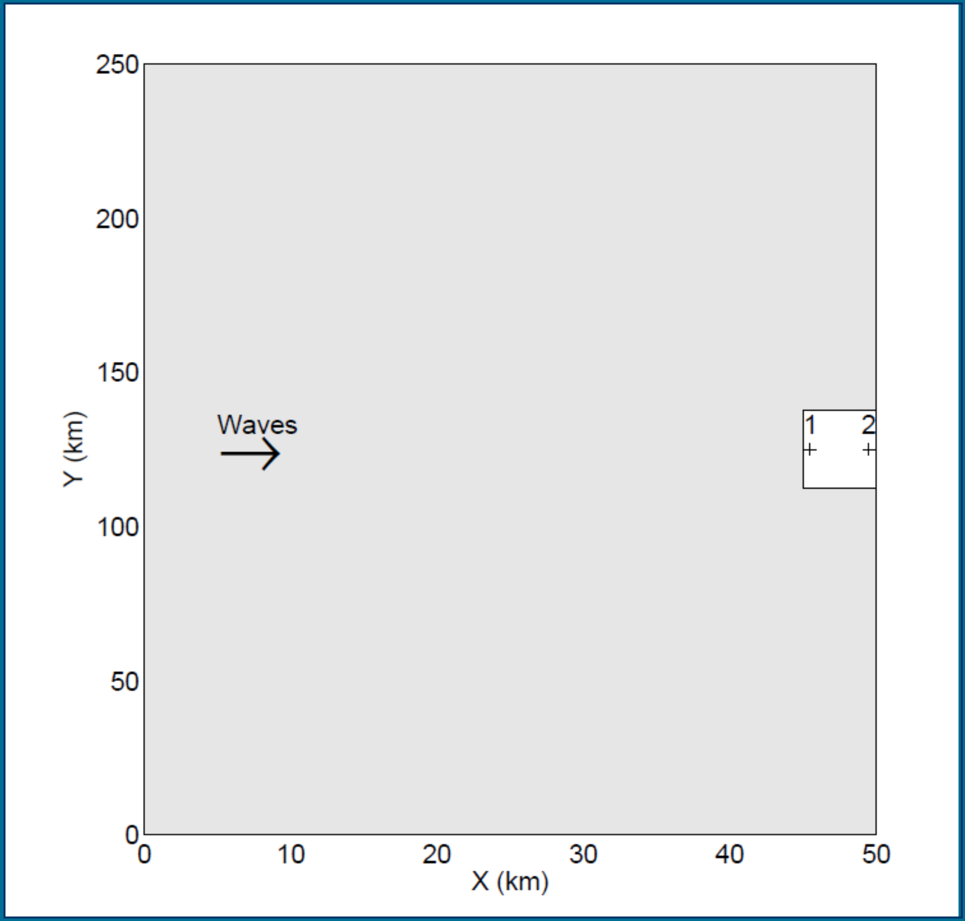
where: $$\gamma = \frac{\Delta t_s}{t_s} > 1$$

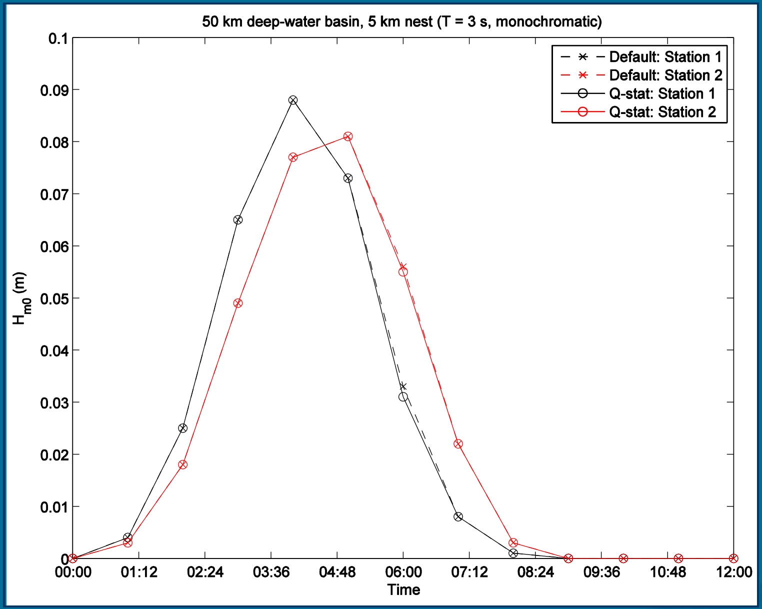
Time stepping can be accelerated: $$t_i = t_{i-1} + \gamma \Delta t_n$$

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

with α a constant = 1.2

Test case: Idealized wave propagation



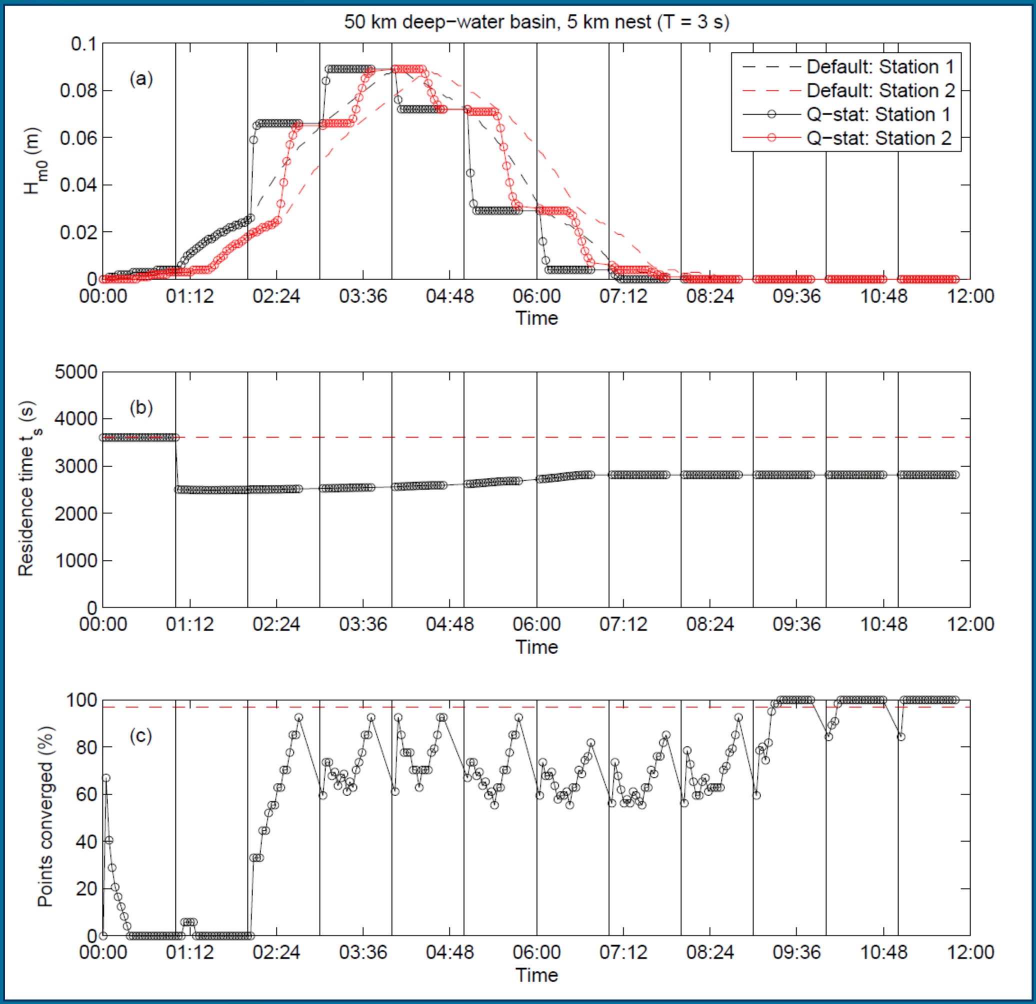


f_p = 0.33 Hz, Std dev. = 0.01 Hz

Dir = 270 ^{o}N, monochromatic,

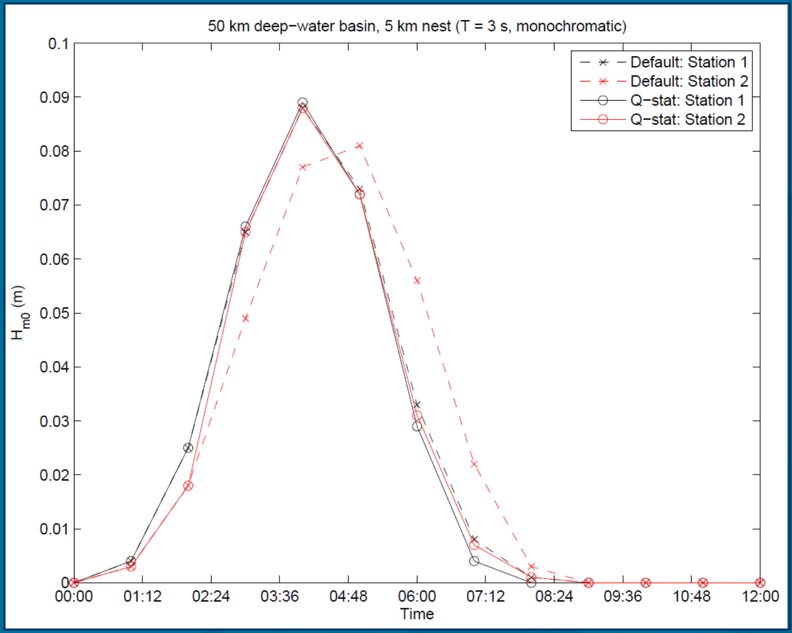
long-crested

Approach 1: Discontinuous time stepping, discontinuous stationary BC

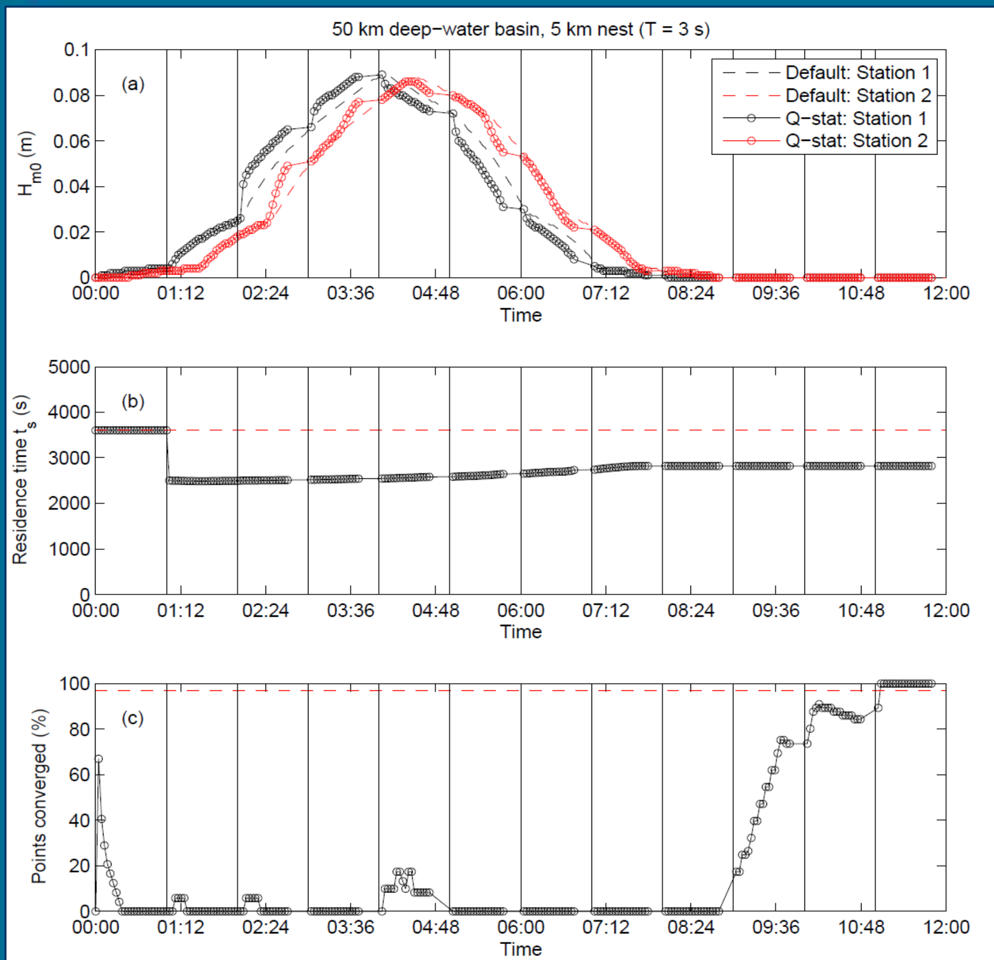


$$t_i = t_0 + \left[i + (n_m - n_i) \left\lfloor \frac{i}{n_i} \right\rfloor \right] \Delta t_n$$

$$\psi_i = \psi_1$$

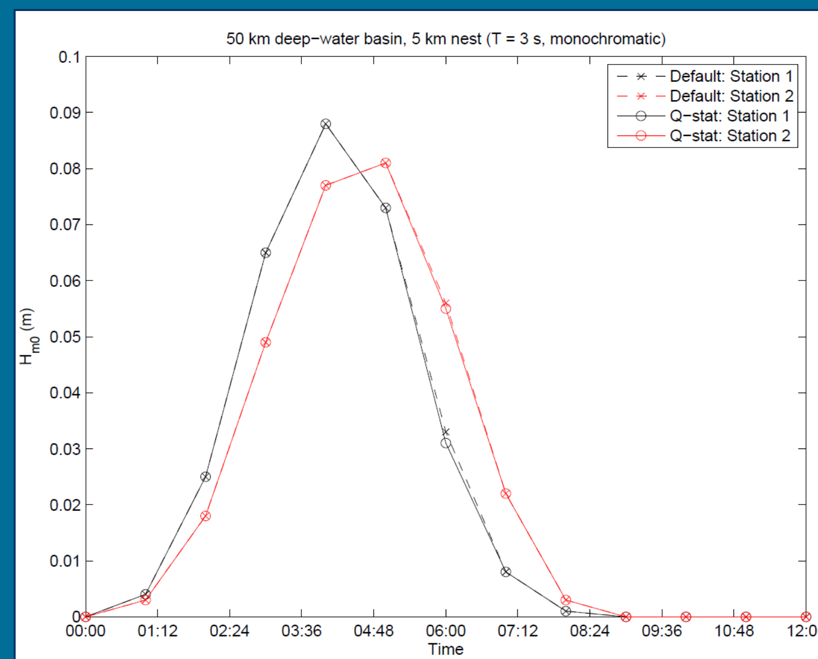


Approach 2: Discontinuous time stepping, discontinuous nonstationary, phase-shifted BC

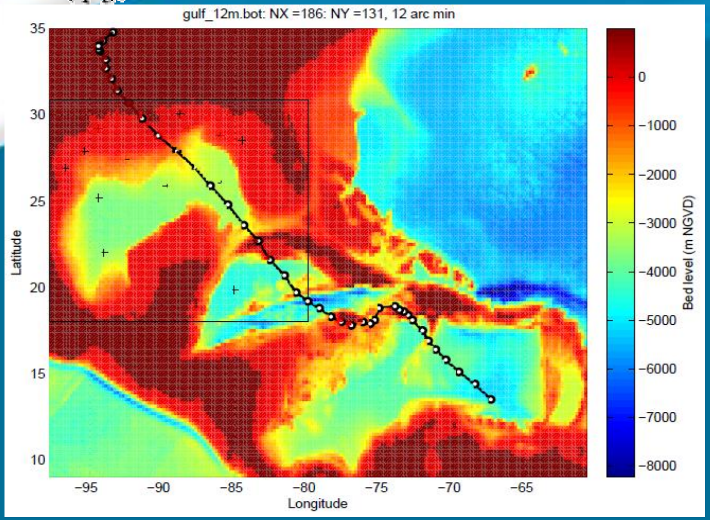


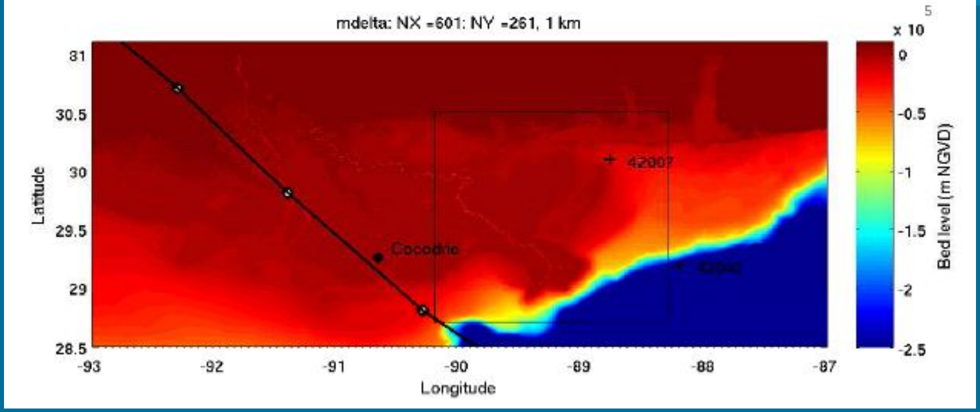
$$t_i = t_0 + \left[i + (n_m - n_i) \left\lfloor \frac{i}{n_i} \right\rfloor \right] \Delta t_n$$

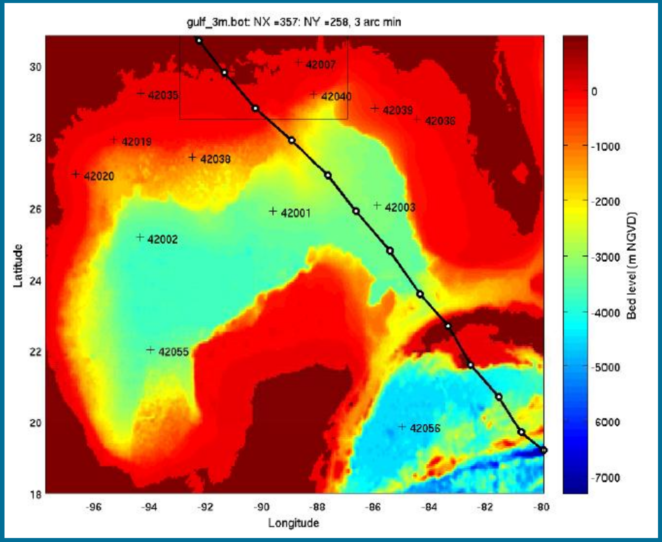
$$\psi_i = \psi\left(t_i + (\Delta t_s - t_s)\right) \quad , \quad \text{for } \gamma > 1$$

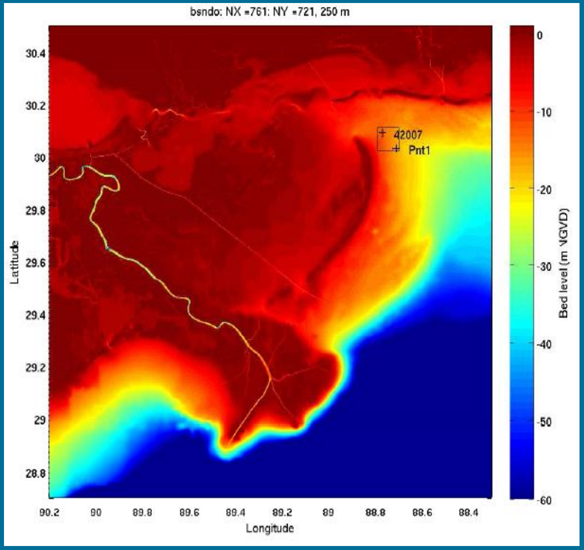


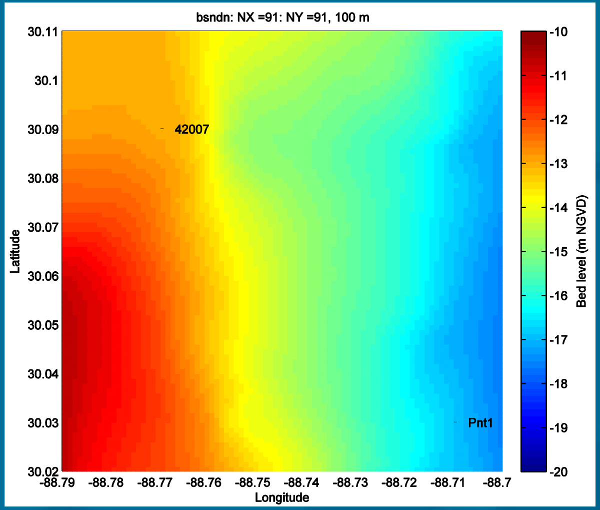
Field case: Hurricane Gustav (Aug-Sept 2008)





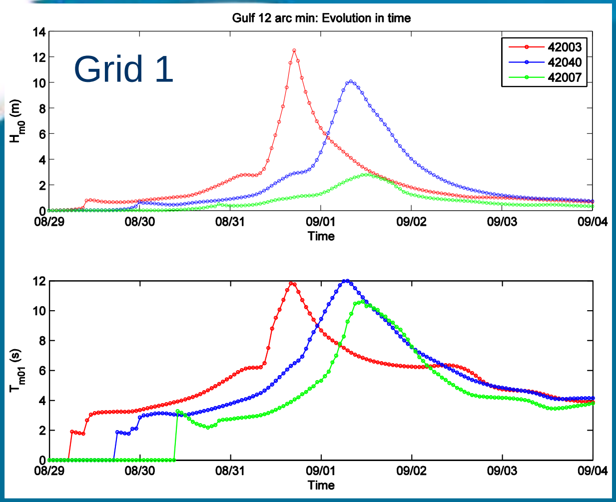


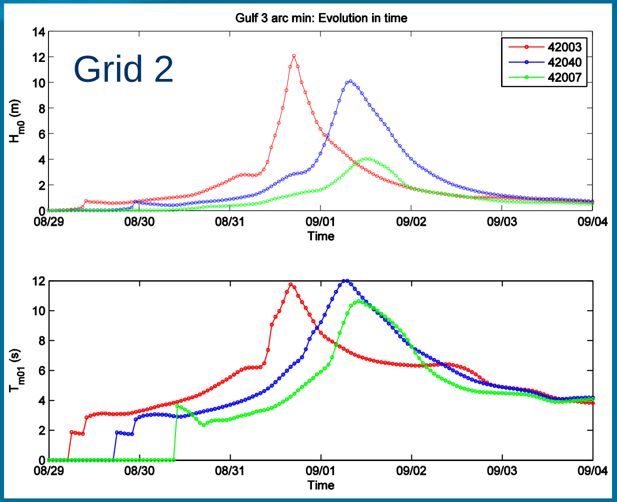


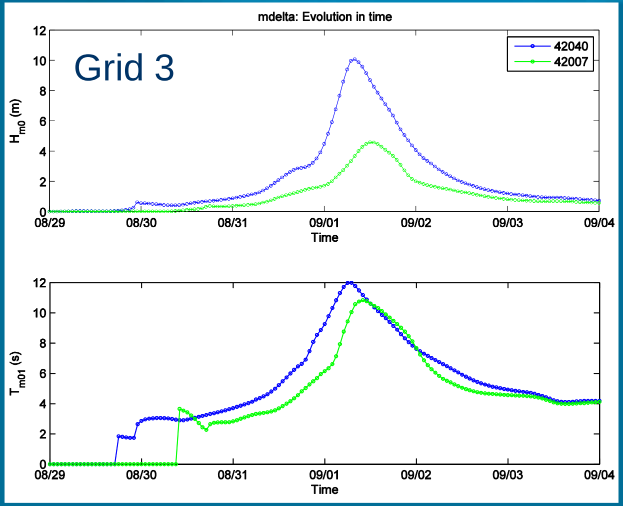


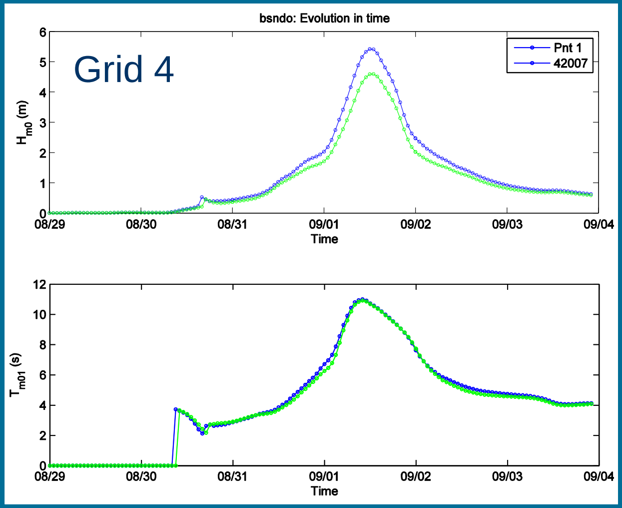
Data: Chen et al. (2010)

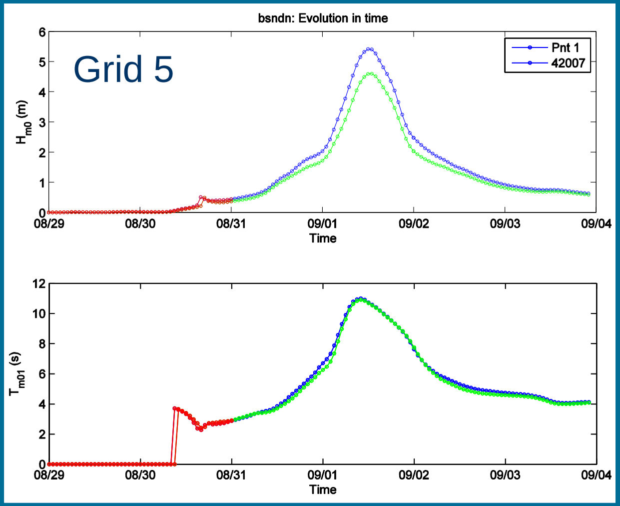
Results: H Gustav (Nonstationary WWIII)









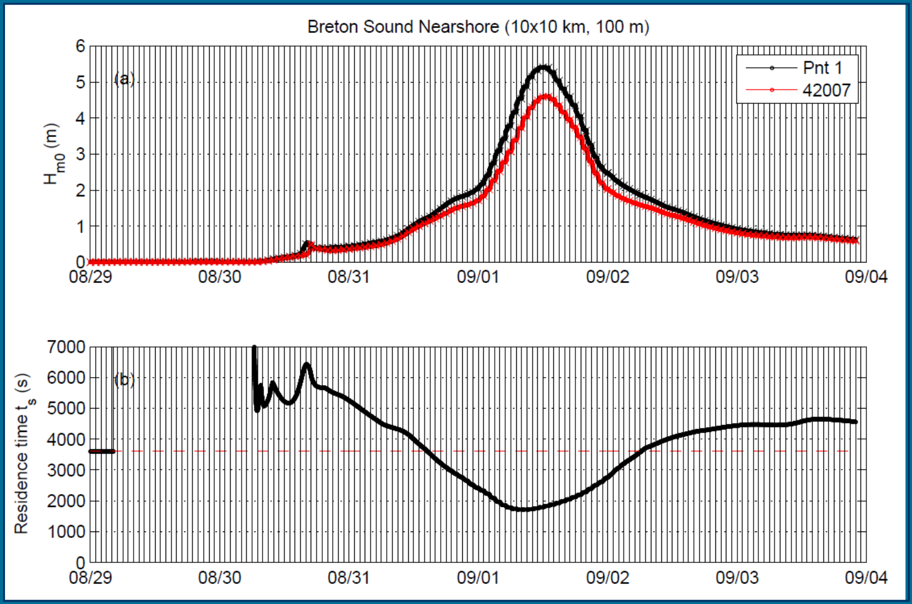


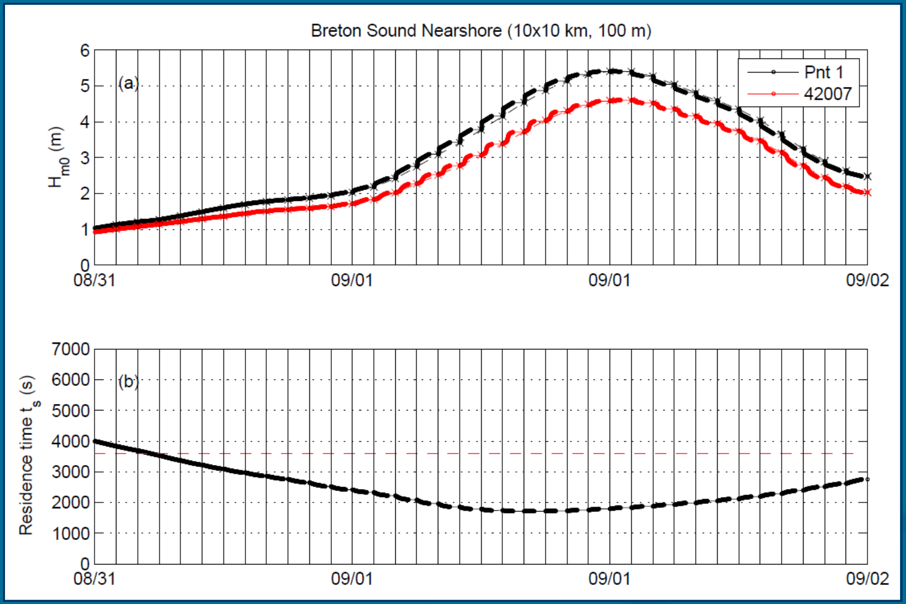
Grid 5: $\Delta t_n = 5$ s

Run time = 67 min

(512 cores on IBM Power6 Cluster)

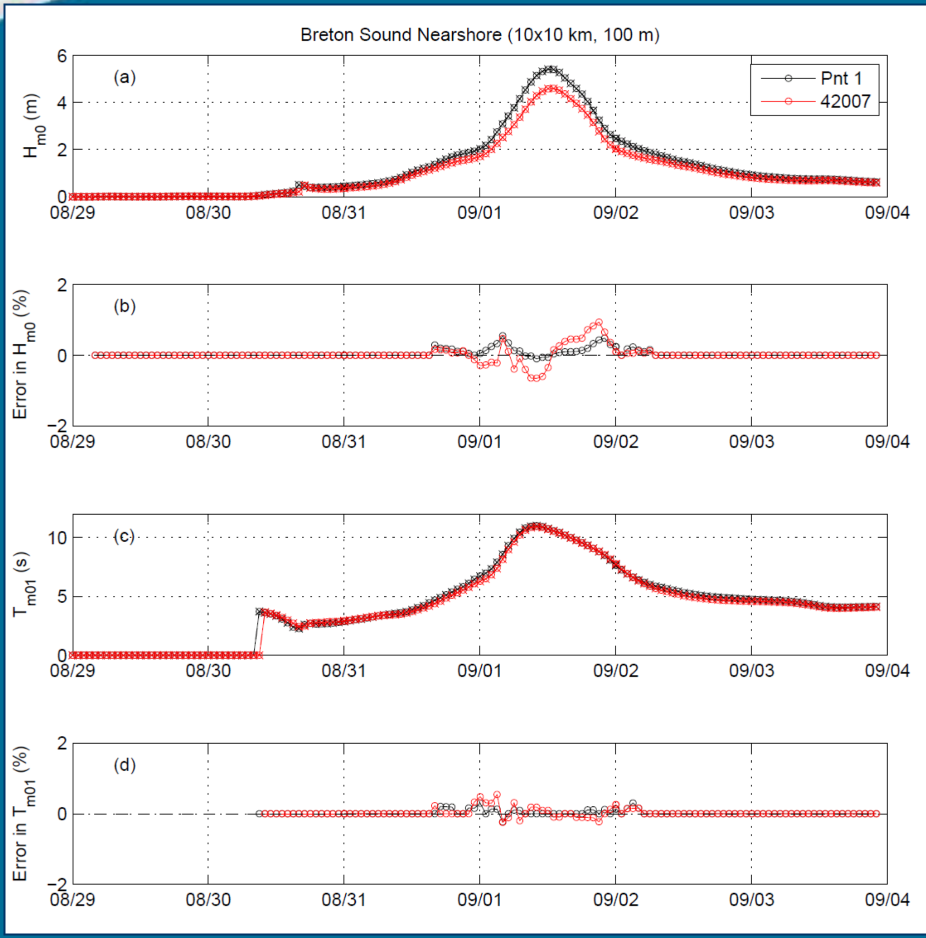
Results: Hurricane Gustav, QS WWIII



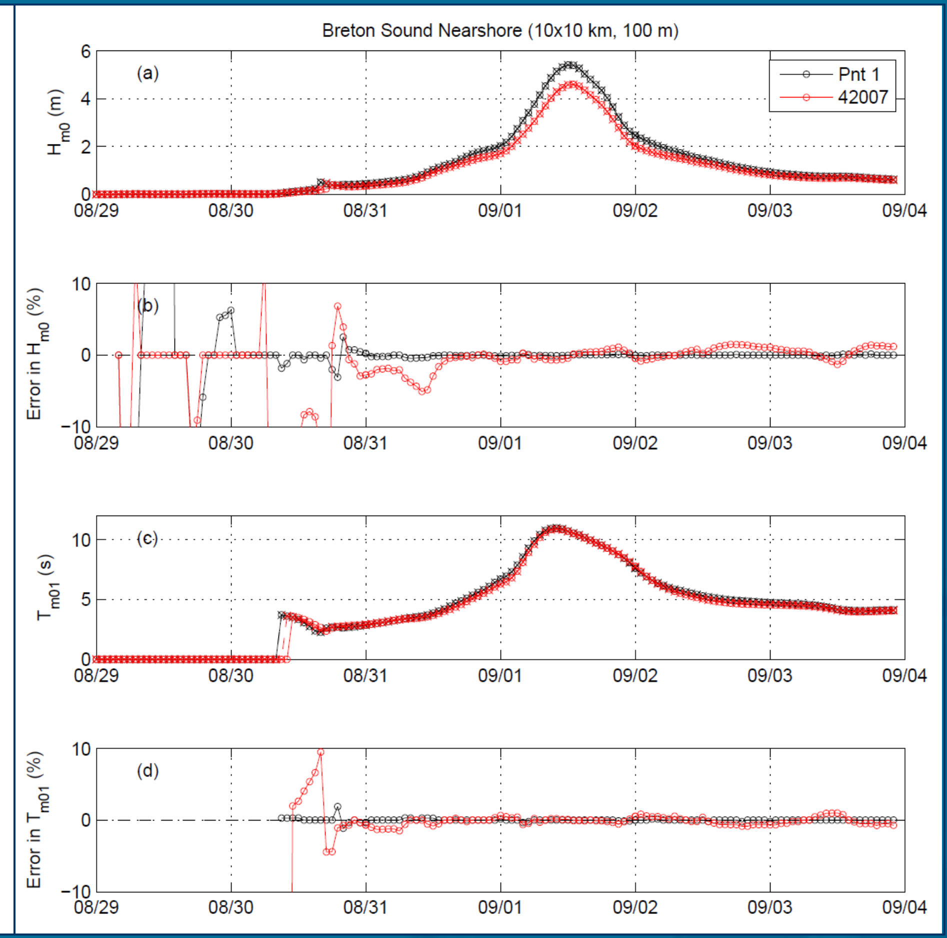


Results: Hurricane Gustav, QS WWIII

Wave-field dependent t_s



Constant t_s = 1800 s



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.

The end

End of lecture