Nearshore processes

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Outline

1. Shallow water source terms and their scaling
2. Depth-induced breaking
3. Bottom friction
4. Wave-current interaction, nonlinear corrections
5. Nonlinear three-wave interactions
6. Other processes and approaches
7. Multi-scale modeling
8. Conclusions

Action balance equation

$$\frac{\partial N}{\partial t} + \nabla_{\vec{x}} \cdot \left[\left(\vec{c}_g + \vec{U}\right)N\right] + \frac{\partial c_\sigma N}{\partial \sigma} + \frac{\partial c_\theta N}{\partial \theta} = \frac{S_{tot}}{\sigma} \quad , \quad N = E(\sigma,\theta)/\sigma$$

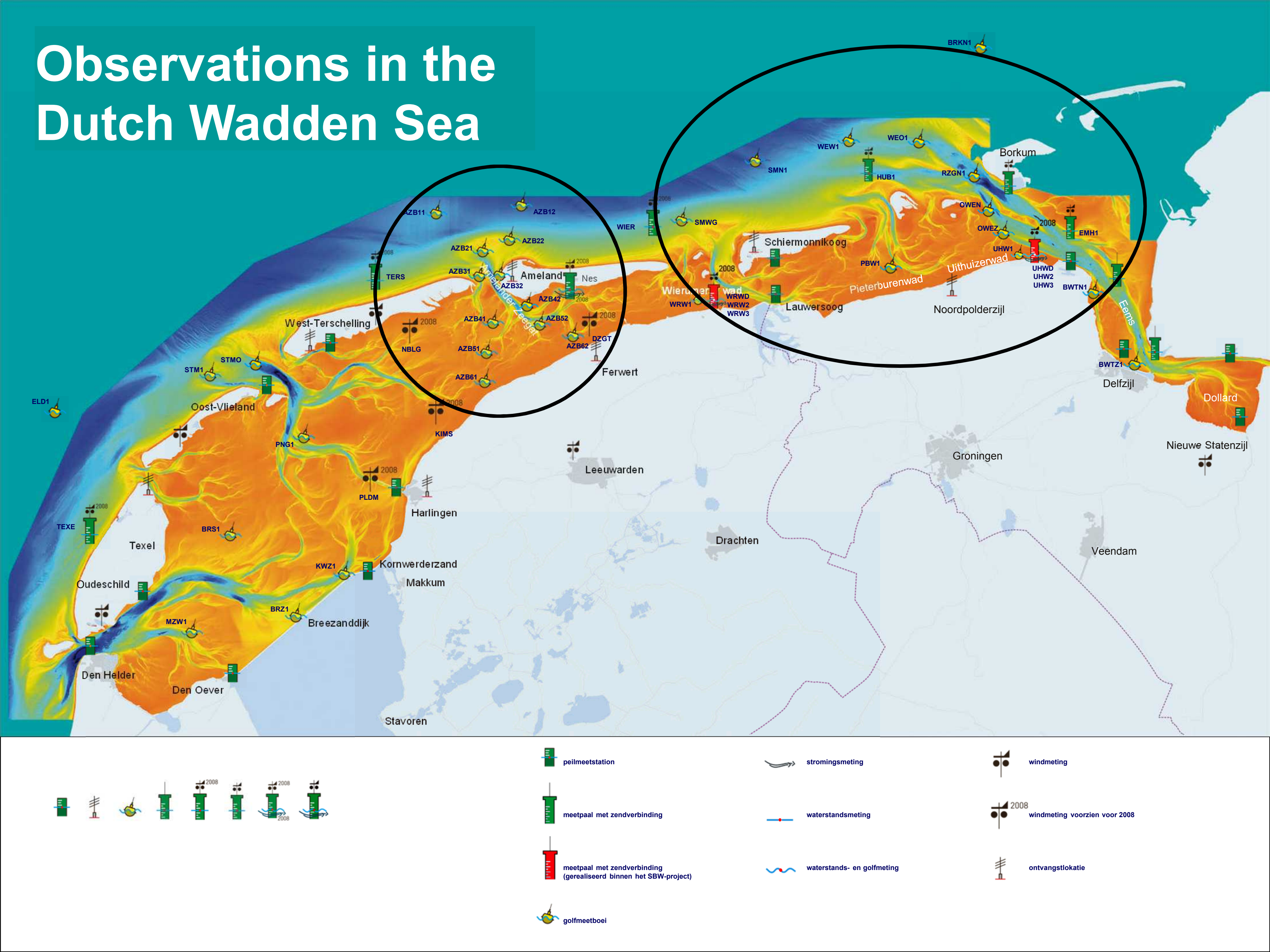
$$S_{tot} = S_{in} + S_{wc} + S_{nl4} + \boxed{S_{bot} + S_{brk} + S_{nl3} + S_{xx}}$$

$$\frac{d\vec{x}}{dt} = \vec{c}_g + \vec{U} = \frac{1}{2}\left[1 + \frac{2kd}{\sinh 2kd}\right]\frac{\sigma\vec{k}}{k^2} + \vec{U} \, ,$$

$$\frac{\partial \sigma}{\partial t} = c_\sigma = \frac{\partial \sigma}{\partial d}\left[\frac{\partial d}{\partial t} + \vec{U} \cdot \nabla d\right] - c_g \vec{k} \cdot \frac{\partial \vec{U}}{\partial s} \, ,$$

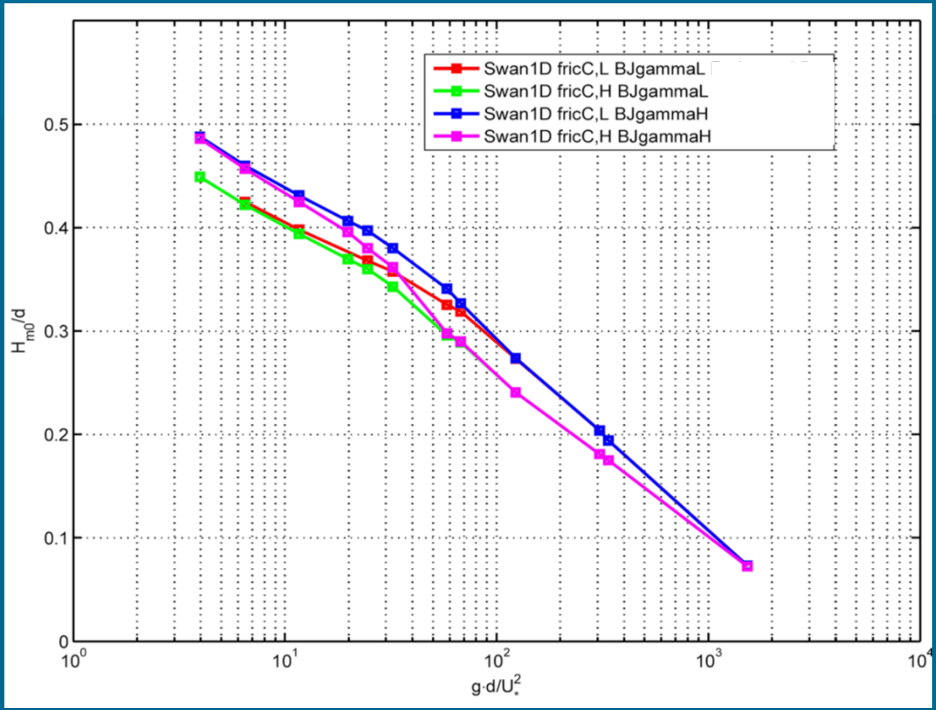
$$\frac{\partial \theta}{\partial t} = c_\theta = -\frac{1}{k}\left[\frac{\partial \sigma}{\partial d}\frac{\partial d}{\partial m} + \vec{k} \cdot \frac{\partial \vec{U}}{\partial m}\right]$$

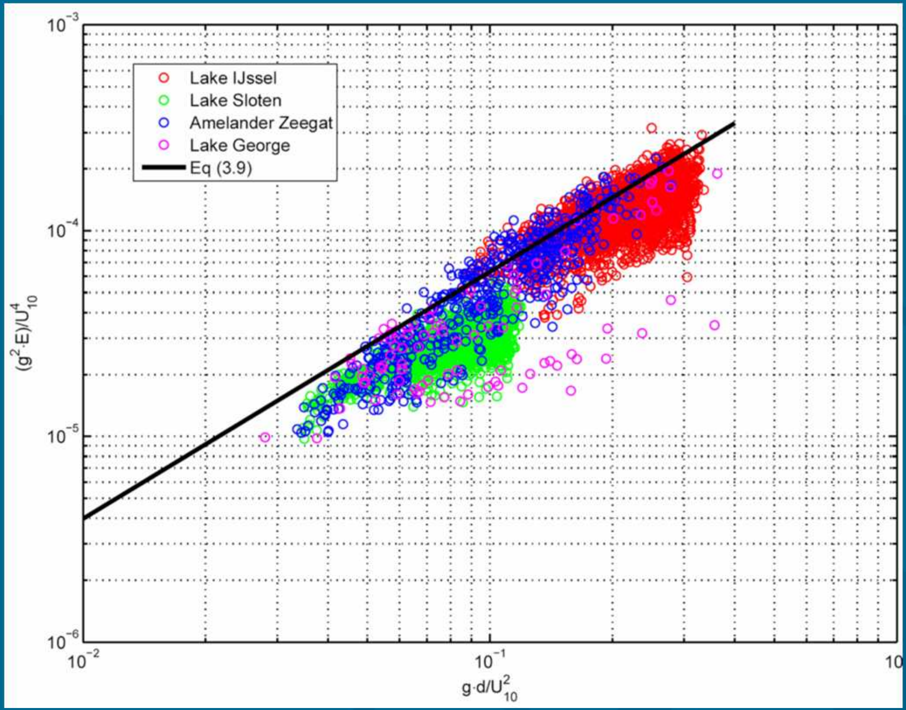
Observations in the Dutch Wadden Sea



Transition of dominance with depth

- Bottom friction dominant over intermediate depths. Depth-induced breaking dominant for smallest depths. H_{m0}/d ratio strongly dependent on value of breaker parameter.
- Wadden Sea interior comparable with conditions found in shallow lakes (Lake George, Lake IJssel, Lake Sloten)





Depth-induced breaking

From Thornton & Guza (1983):

$$D_{tot} = -\frac{B^3}{4}\frac{f_{m01}}{d}\int_0^\infty H^3 p_b(H)\,dH$$

$$p_b(H) = W(H)\,p(H)$$

Introduce a biphase-dependent weighting function on the pdf:

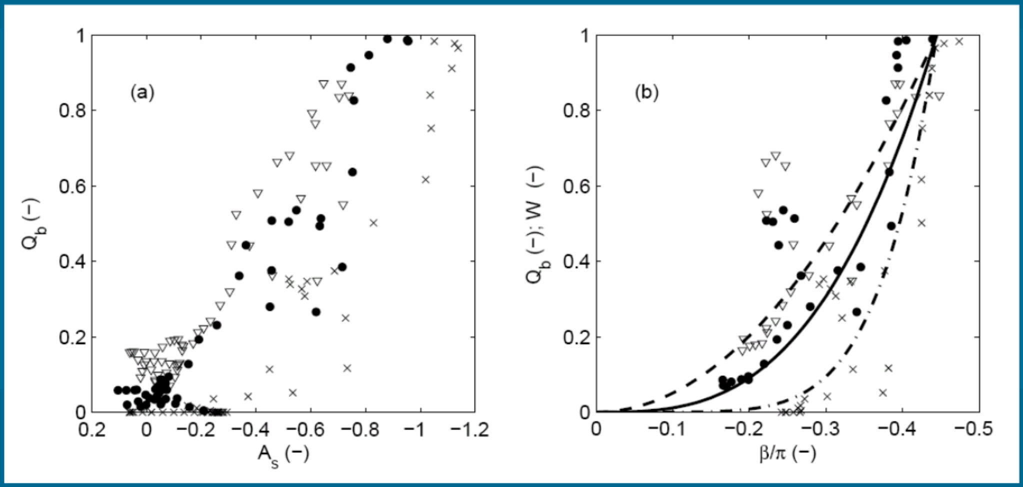
$$W(H) = \left(\frac{\beta}{\beta_{ref}}\right)^n \quad , \quad \beta_{ref} = -\frac{4\pi}{9}$$

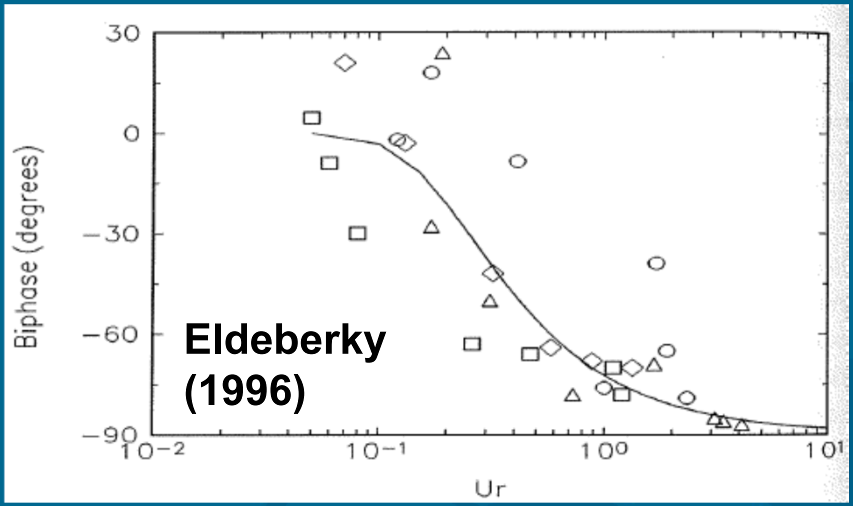
$$n = 4 - \frac{4}{\pi}\arctan\left[\nu\left(S_{\mathrm{loc}} - \tilde{S}_{\mathrm{loc}}\right)\right]$$

$$D_{tot} = \frac{3\sqrt{\pi}}{16}\frac{B^3 f_{m01}}{d}\left(\frac{\beta}{\beta_{ref}}\right)^n H_{rms}^{\ \ 3}$$

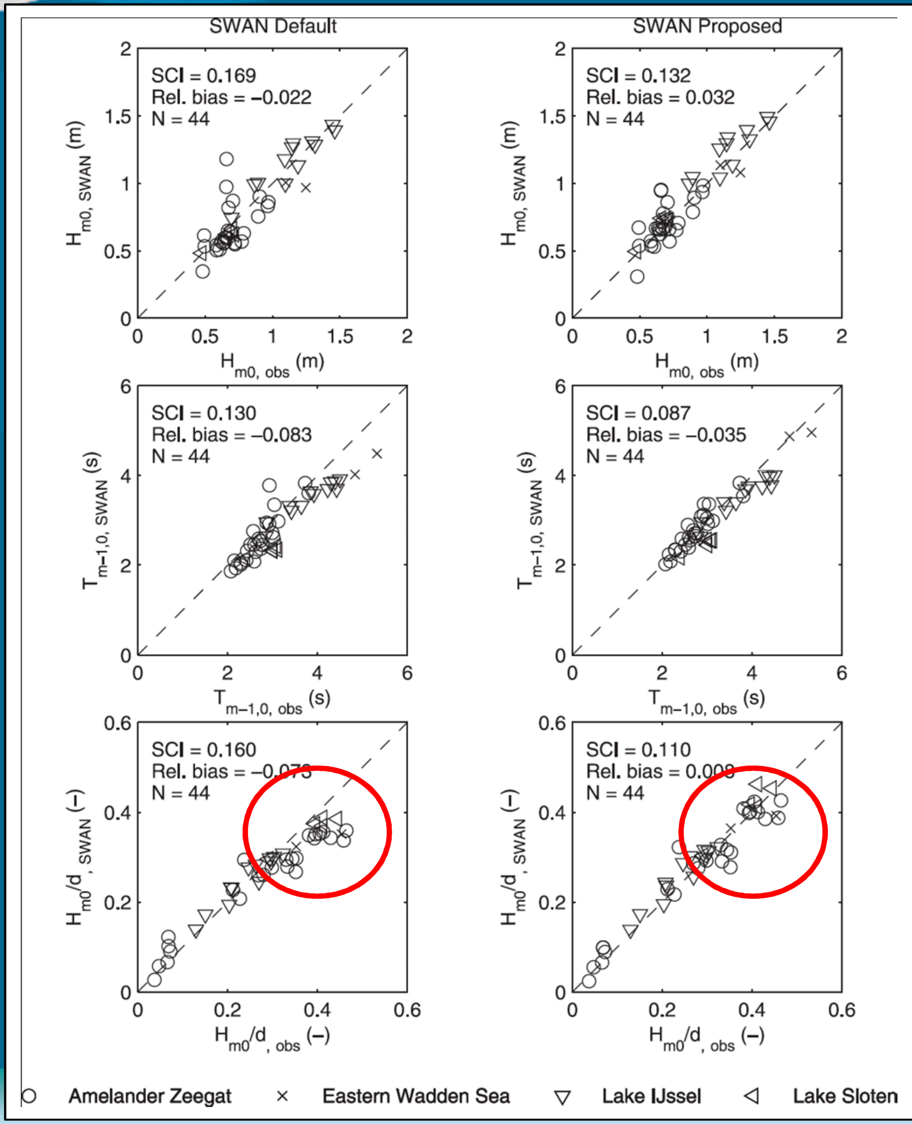
(Van der Westhuysen, 2009; 2010)

Boers (1996):

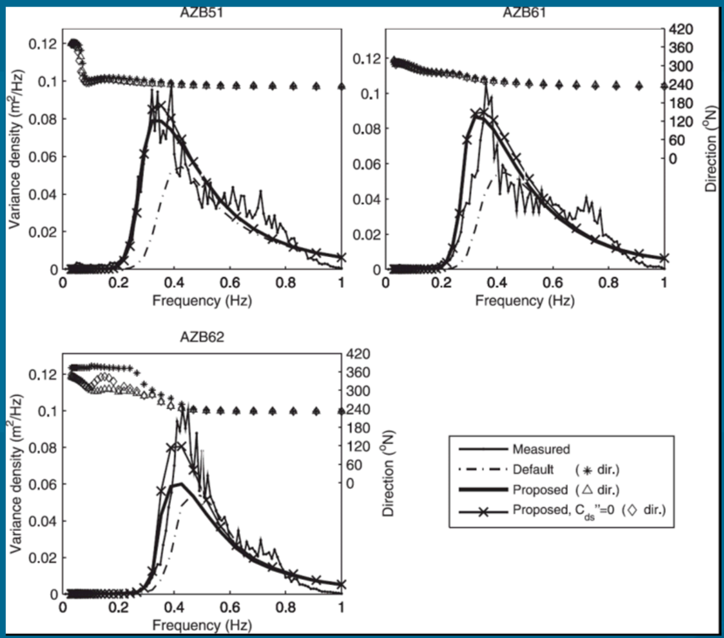


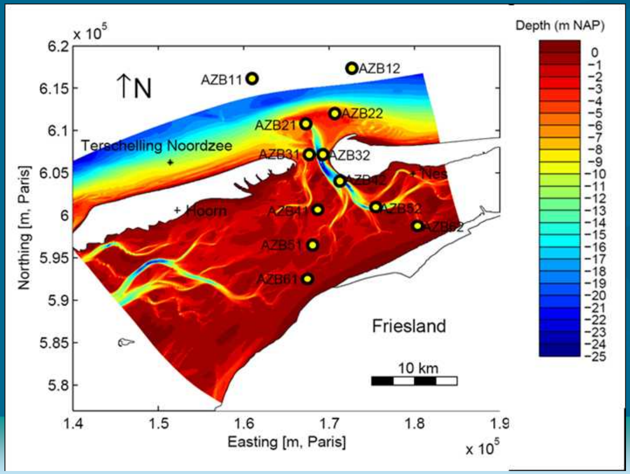


Depth-induced breaking (2)



Amelander Zeegat (18/01/07, 12:20)

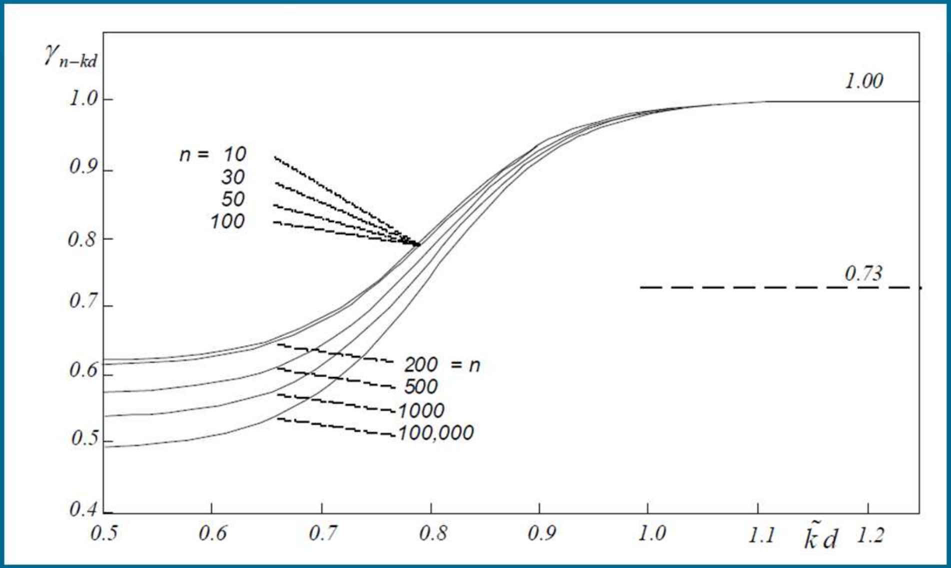




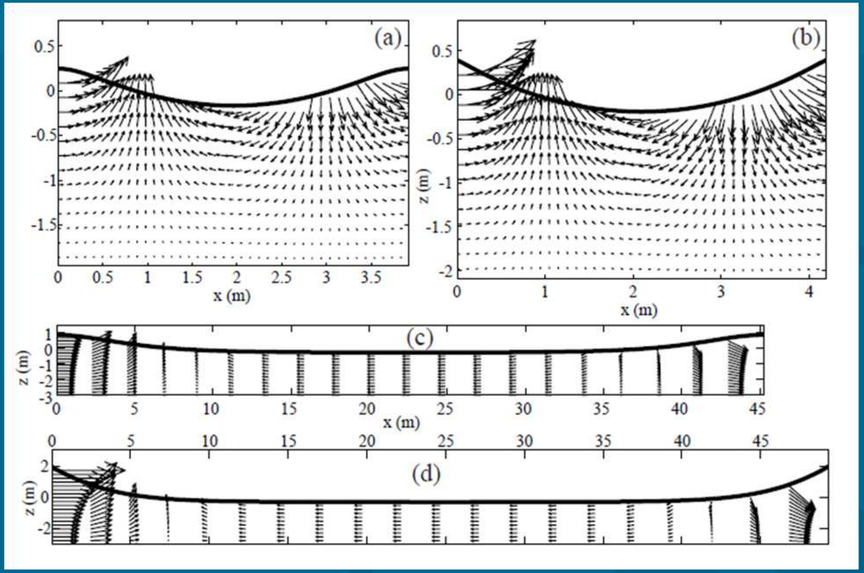
Depth-induced breaking (3)

1. Additional influence of mean bed slope, 1/n (Salmon and Holthuijsen 2011).

2. Unification of depth-induced and deep water breaking dissipation (whitecapping) terms, based on nonlinearity (Fillipot et al. 2010).



(Salmon and Holtuijsen, 2011)



(Fillipot et al., 2010)

Bottom friction

Hydrodynamic friction model:

$$S_{bot}(\sigma,\theta) = -C_{bottom}\frac{\sigma^2}{g^2\sinh^2(kd)}E(\sigma,\theta)$$

Empirical (e.g. Hasselmann et al. 1973):

$$C_{bottom} = \text{const}$$

Drag law (e.g. Hasselmann and Collins 1968; Collins 1972):

$$C_{bottom} = f_w g U_{rms}\,, \quad f_w = \text{const}$$

Eddy viscosity (e.g. Madsen et al. 1988):

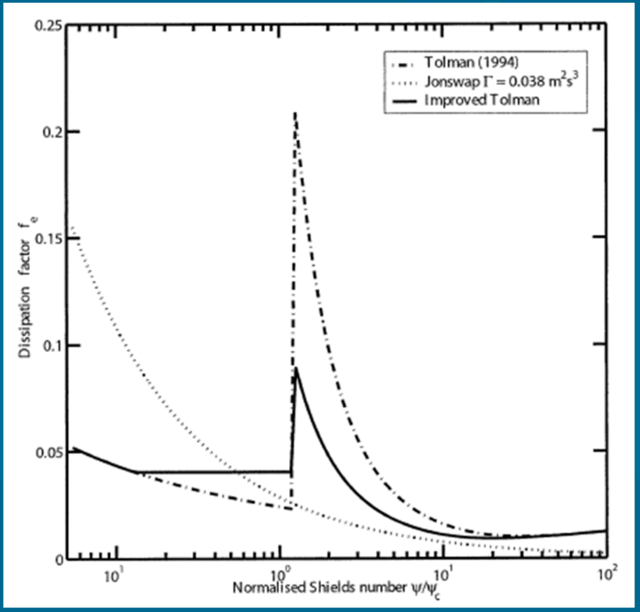
$$C_{bottom} = f_w g U_{rms}/\sqrt{2}\,, \quad f_w = f(k_N)$$

with $f_w = f(k_N, a_b)$ given by Jonsson (1966, 1980) and Jonsson and Carlsen (1976)

Bottom friction (2): movable bed

Movable bed roughness models:

- Shemdin et al. (1978): k_N can vary from sand grain roughness to ripple roughness
- Grant and Madsen (1982): ripple model for monochromatic waves
- Nielsen (1992) and Van Rijn (2007): ripple models for irregular waves

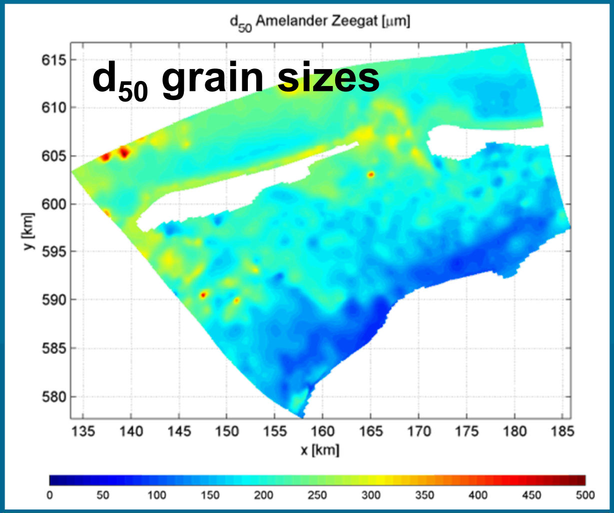


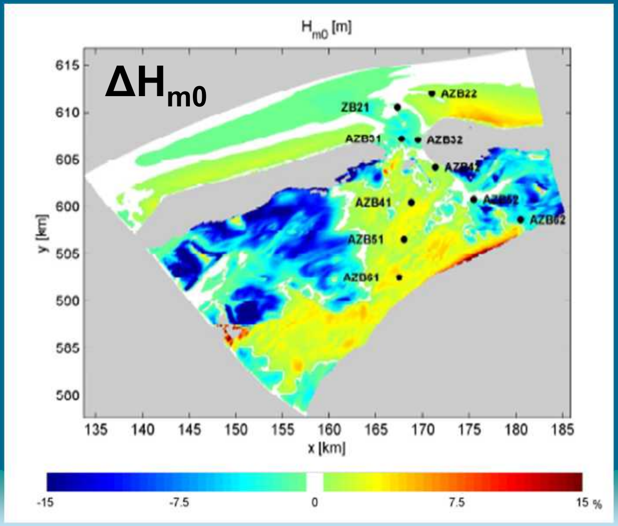
Ardhuin et al. (2003)

1. Graber and Madsen (1988): implementation of GM82 in monochromatic wave model
2. Tolman (1994, 1995): implementation of MPG88 + modified GM82 in WW2
3. Ardhuin et al. (2003a,b): implementation of modified T94 in CREST
4. Smith (2011): implementation of Nielsen in SWAN

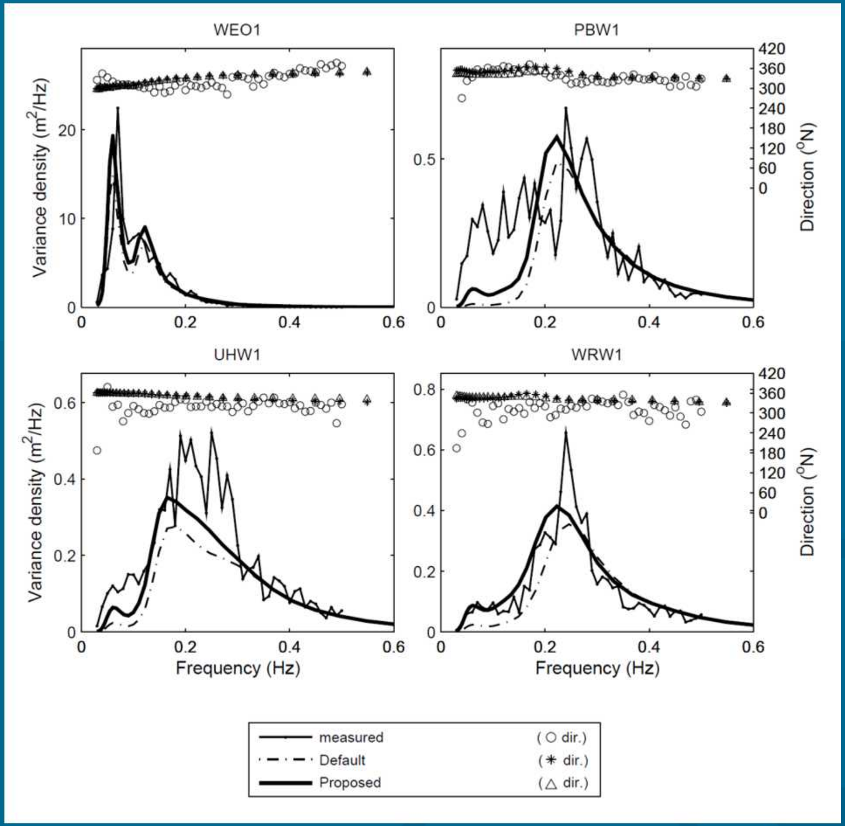
Bottom friction (3)

MPG88+V. Rijn (2007) vs. C_{bot} = 0.067 m^2/s^3





C_{bottom} = 0.038 m^2/s^3 vs. 0.067 m^2/s^3



(Van der Westhuysen et al. 2012; Zijlema et al. 2012)

Wave-current interaction

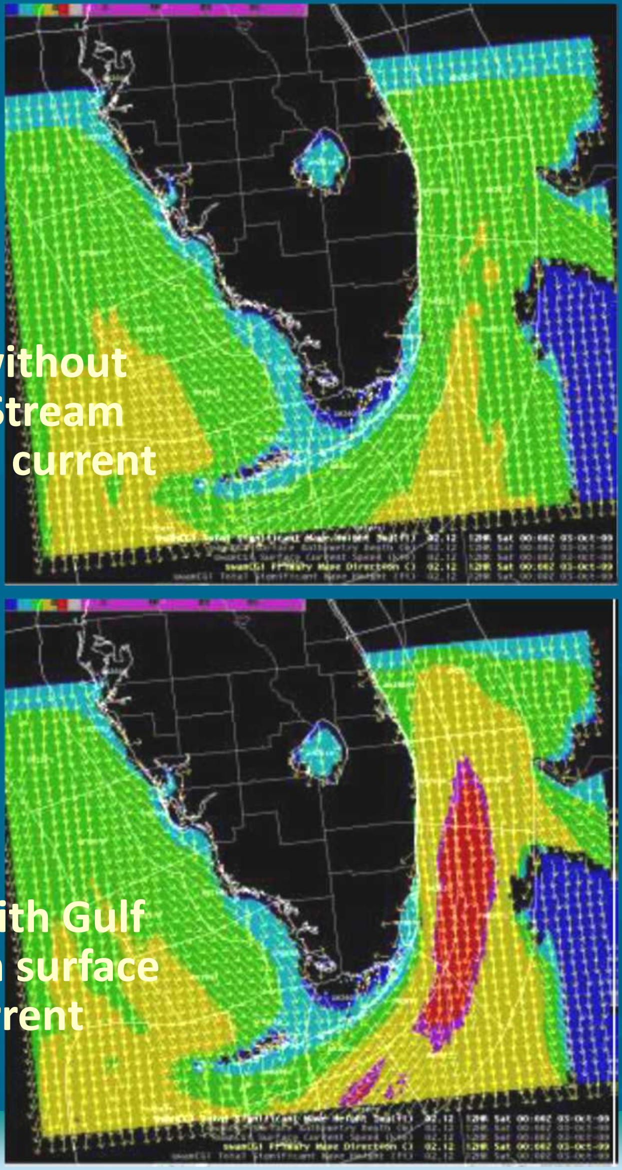
Wave kinematics (linear):

$$\frac{d\vec{x}}{dt} = \vec{c}_g + \vec{U} = \frac{1}{2}\left[1 + \frac{2kd}{\sinh 2kd}\right]\frac{\sigma\vec{k}}{k^2} + \vec{U}$$

$$\frac{d\theta}{dt} = c_\theta = -\frac{1}{k}\left[\frac{\partial\sigma}{\partial d}\frac{\partial d}{\partial m} + \vec{k}\cdot\frac{\partial\vec{U}}{\partial m}\right]$$

$$\frac{d\sigma}{dt} = c_\sigma = \frac{\partial\sigma}{\partial d}\left[\frac{\partial d}{\partial t} + \vec{U}\cdot\nabla d\right] - c_g\vec{k}\cdot\frac{\partial\vec{U}}{\partial s}$$

$$\omega = \pm\left[gk\tanh(kd)\right]^{\frac{1}{2}} + \vec{k}\cdot\vec{U}$$



H_{m0} without Gulf Stream surface current

H_{m0} with Gulf Stream surface current

Wave-current interaction (2)

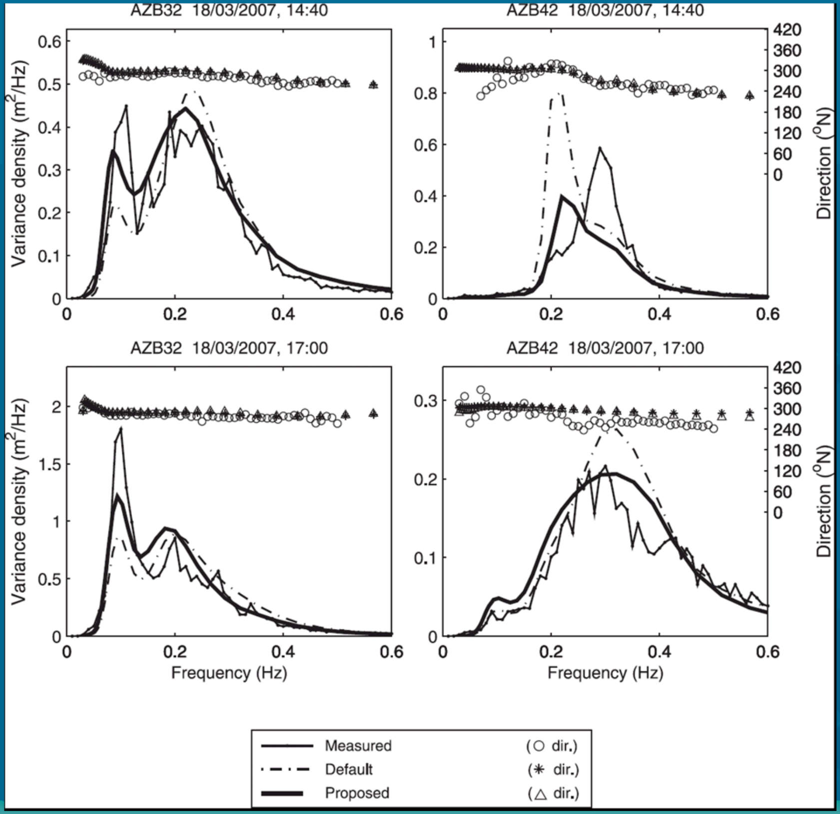
Enhanced dissipation under current gradients (partial blocking):

$$S_{diss,cur}(\sigma,\theta) = -C''_{ds} \boxed{\max\left[\frac{c_\sigma(\sigma,\theta)}{\sigma},0\right]} \left[\frac{B(k)}{B_r}\right]^{p/2} E(\sigma,\theta) \quad ,$$

$$\Rightarrow \quad S_{diss} = S_{wc} + S_{diss,cur}$$

$$\frac{dS^*}{dt} / S^* \propto \frac{d\sigma}{dt} / \sigma = \frac{c_\sigma}{\sigma}$$

- Isolates steepening effect due to currents
- Valid for partial blocking situations
- Negative gradients in both opposing and following currents. Observed by Babanin et al. (2011).

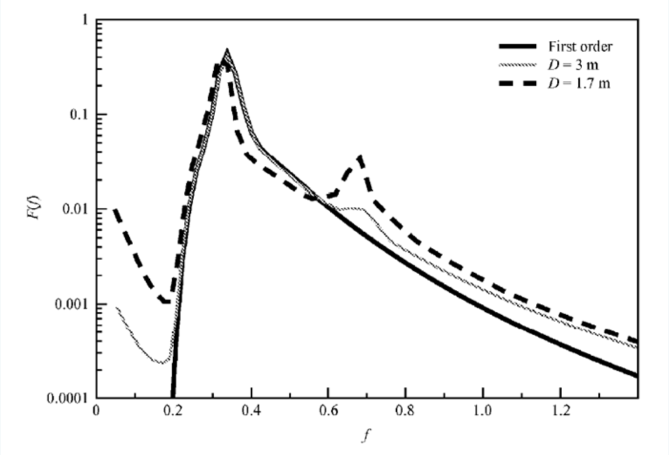


(Van der Westhuysen 2012)

Nonlinear corrections

1. Willebrand (1975): Nonlinear corrections to radiation transfer equation, including ambient current
   a) Generalization of group velocity for nonlinear waves
   b) Refraction due to wave field inhomogeneity
   c) Higher-order correction to radiation stress effects

2. Shyu and Phillips (1990): Blocking and reflection of gravity waves in ambient current
3. Janssen (2009): Second-order corrections to the linear wave spectrum, valid for kD>1
   a) Stokes frequency correction (as observed by Babanin et al. 2011)
   b) Forces subharmonic and first super-harmonic
   c) Tail level correction



Triad (three-wave) interaction

Cascade of stochastic equations:

$$\frac{d}{dx}\zeta_p = ik_p\zeta_p + i\sum_{n+m=p} W_{nm}\zeta_n\zeta_m$$

$$d_x\langle\zeta\zeta\rangle = \langle\zeta\zeta\rangle + \langle\zeta\zeta\zeta\rangle^C$$

$$d_x\langle\zeta\zeta\zeta\rangle = \langle\zeta\zeta\zeta\rangle + \langle\zeta\zeta\rangle\langle\zeta\zeta\rangle + \langle\zeta\zeta\zeta\zeta\rangle^C$$

$$\vdots$$

(T.T. Janssen 2006)

Distinctions:

- Deterministic equations used: Boussinesq, full dispersion, etc.
- Closure hypothesis: quasi-normal closure, relaxation to Gaussian
- Bispectral parameterization: one- and two-equation models

Triad (three-wave) interaction (2)

LTA (Eldeberky 1996) – local, collinear, self-sum model

$$S_{nl3}^{+}(\sigma,\theta)=\max\left(0,\alpha_{EB}2\pi c_{g,\sigma}J^{2}\left|\sin(\beta)\right|\left[\frac{\sigma}{k_{\sigma}}E^{2}(\sigma/2,\theta)-2\frac{\sigma/2}{k_{\sigma/2}}E(\sigma/2,\theta)E(\sigma,\theta)\right]\right) \quad ,$$

$$S_{nl3}^{-}(\sigma,\theta)=-2S_{nl3}^{+}(2\sigma,\theta)$$

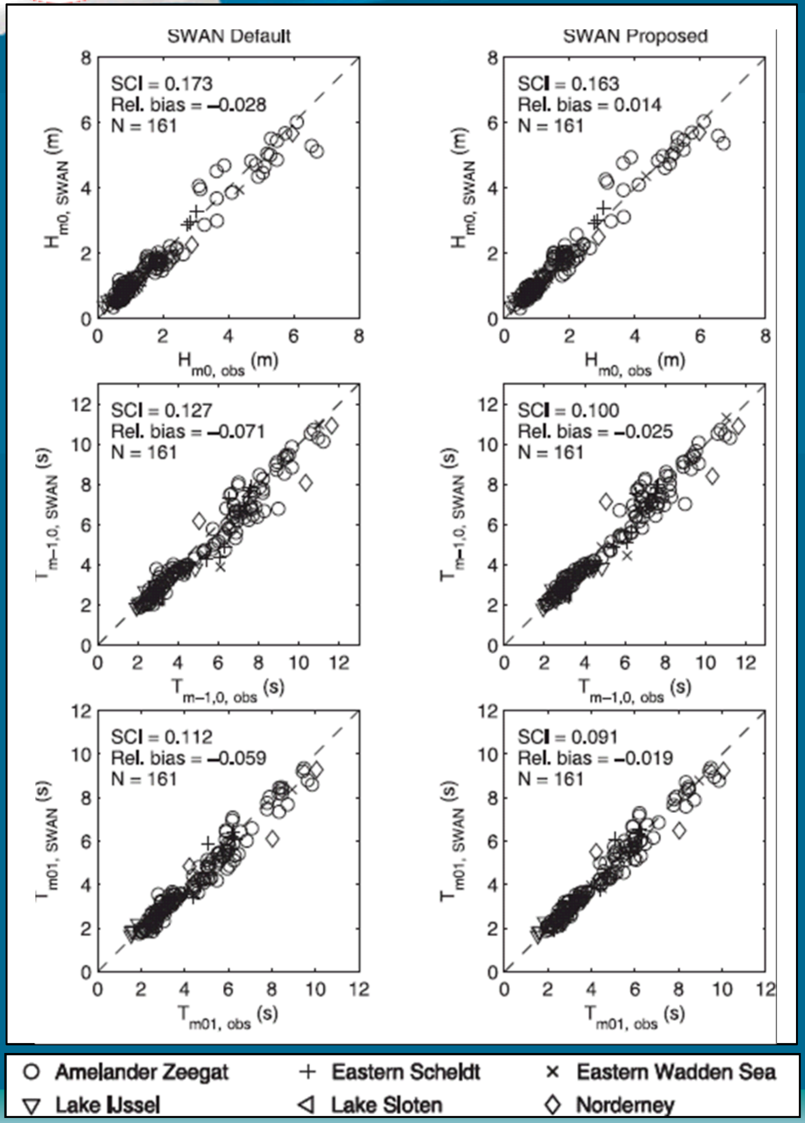
T.T. Janssen (2006) – two-equation model, parallel contours

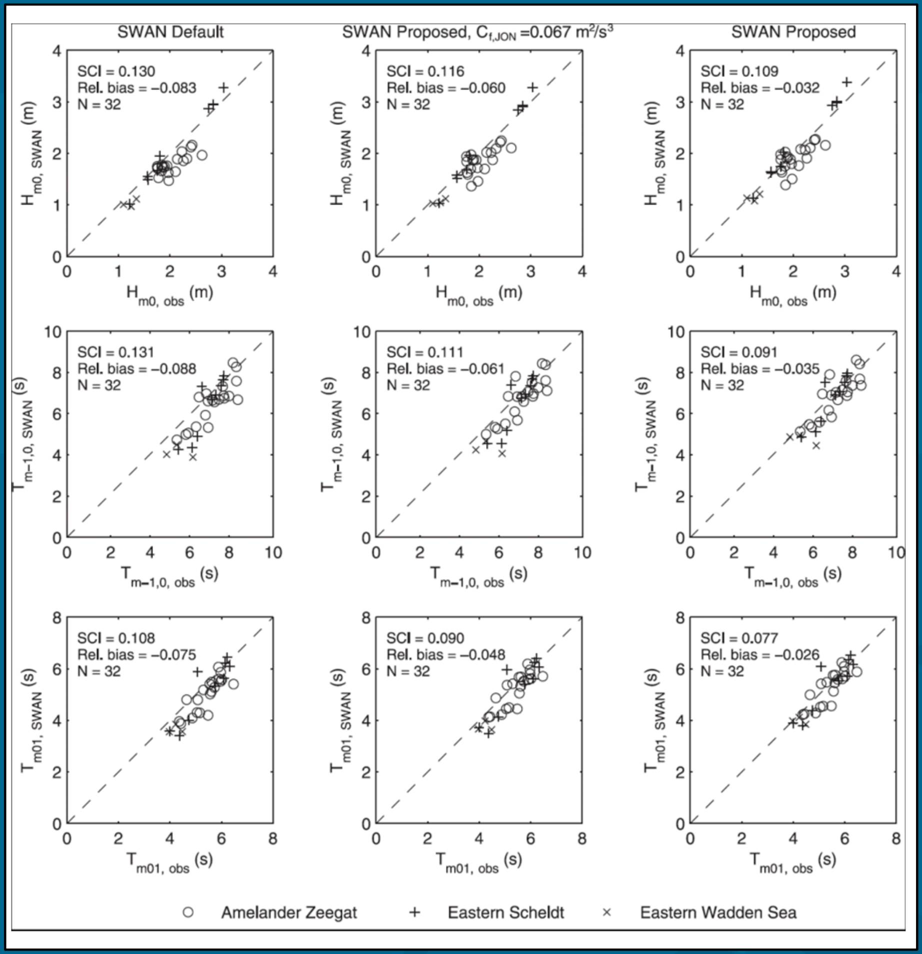
$$\frac{d\xi_{1}^{1}}{dx}=-D_{1}\xi_{1}^{1}-2\sum_{v2}W_{(1-2)2}^{(1-2)2}\,\mathrm{Im}\left[C_{(1-2)2}^{(1-2)2}\right]\Delta\sigma\Delta\lambda\,, \quad \text{where } \xi_{i}^{j}(x)=c_{g}^{lin}(\sigma_{i},x)E(\sigma_{i},\lambda_{j},x)$$

$$\frac{dC_{12}^{12}}{dx}=i\left(\Lambda_{12}^{12}+i\mu_{12}^{12}\right)C_{12}^{12}-\frac{1}{2}\left(D_{1}+D_{2}+D_{(1+2)}\right)C_{12}^{12}$$
$$+2i\left[W_{(1+2)(-2)}^{(1+2)(-2)}\xi_{2}^{2}\xi_{(1+2)}^{(1+2)}+W_{(1+2)(-1)}^{(1+2)(-1)}\xi_{1}^{1}\xi_{(1+2)}^{(1+2)}+W_{12}^{12}\xi_{1}^{1}\xi_{2}^{2}\right]$$

- Transport equation for the spatial cross-correlations in the wave field. Developed for inhomogenous Gaussian wave fields (Smit and Janssen 2011). To be extended to transport equation of three-wave correlations (bispectrum), see Waves NOPP.
- New one-point closure approximation under development, see Waves NOPP

Overall comparison



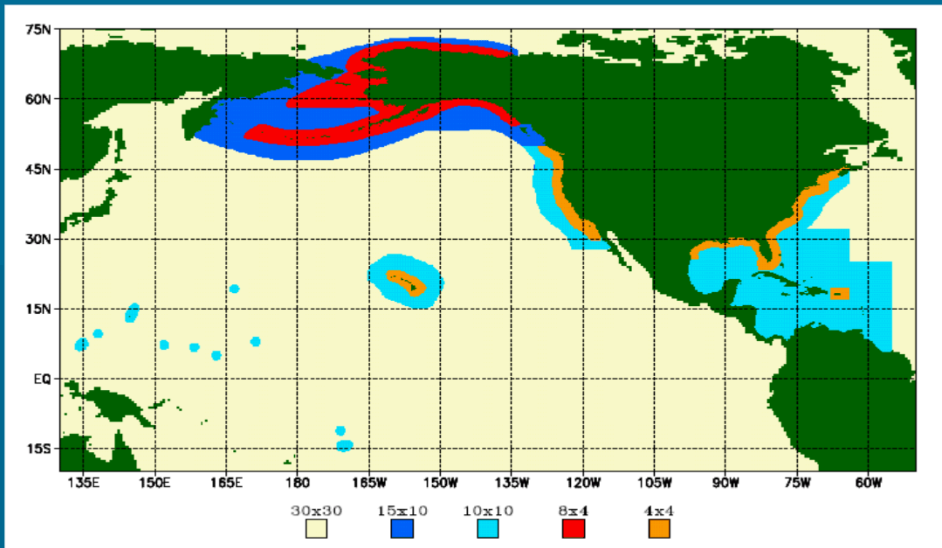


Other processes

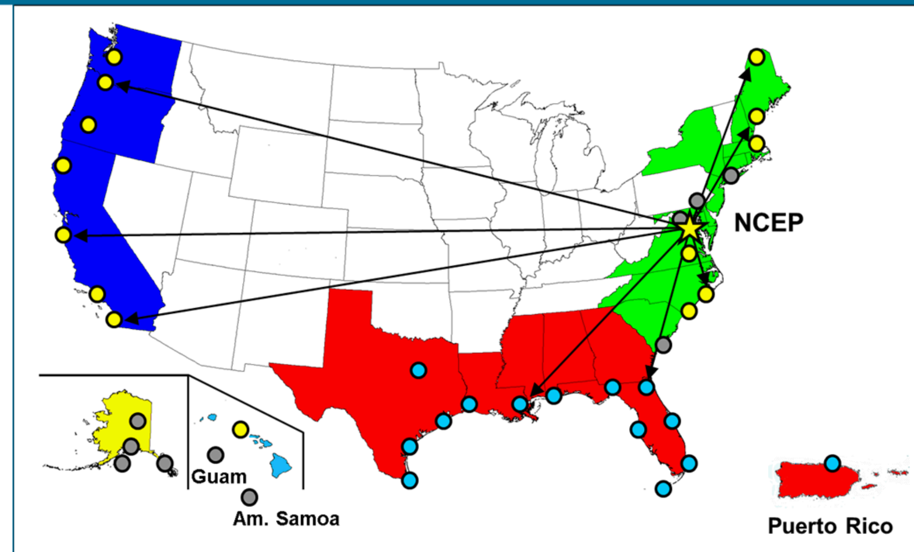
1. Coastal reflection (Benoit, 1996; Booij et al. 1999; Ardhuin et al. 2011; Ardhuin and Roland 2012)
2. Phase-decoupled diffraction (Holthuijsen et al. 2003; Liau et al. 2011; Toledo et al. 2012)
3. Topographic scattering (Bragg forward and back scattering): (Hasselmann 1966; Ardhuin and Herbers 2002).
4. Mud interaction (e.g. Gade 1958; Ng 2000; Kaihatu et al. 2007; Rogers and Holland 2008; Kranenburg et al. 2011)
5. Vegetation dissipation (e.g. Mendez and Losada 2004; Suzuki et al. 2011)
6. Phase resolving modeling (e.g. Boussinesq, non-hydrostatic, surf beat models)

Multi-scale modeling

Current WW3 global grid mosaic (max res = 4 arc-min)

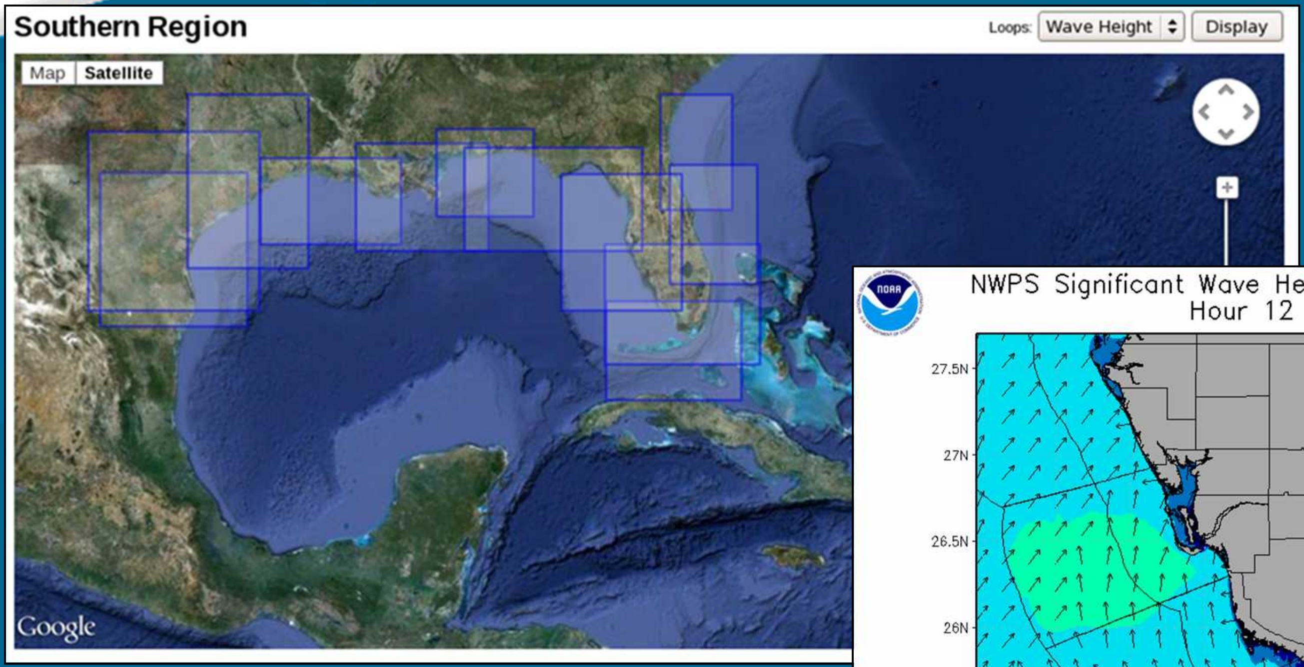


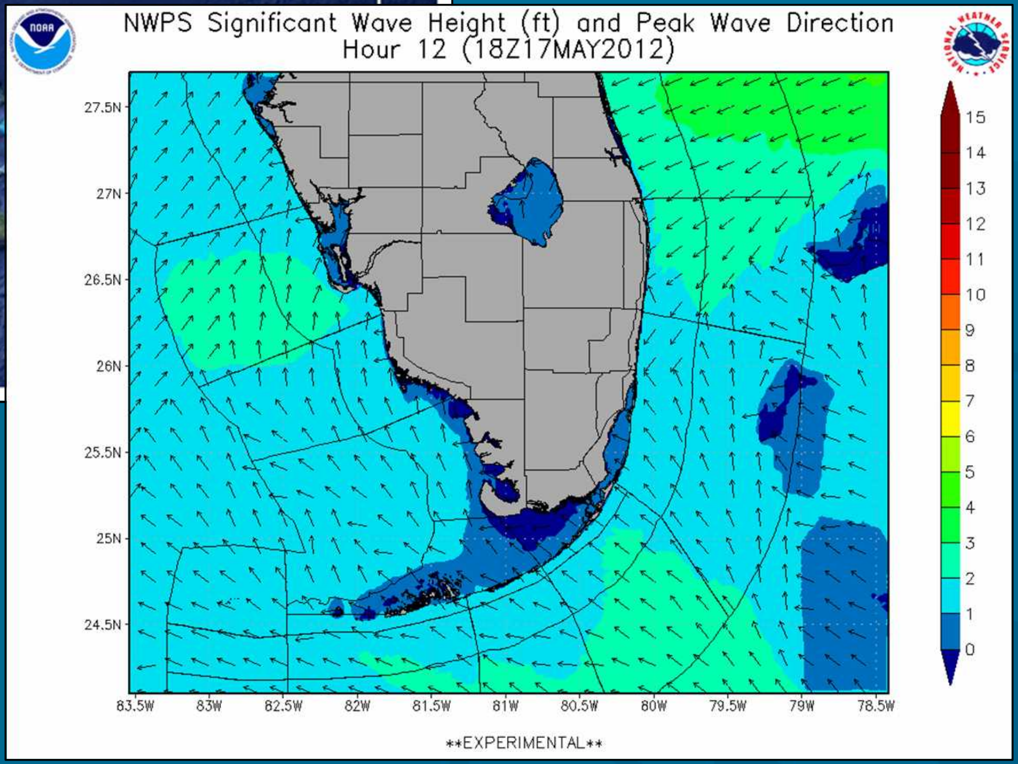
Distributed nearshore modeling



- Centrally supported by NCEP, but runs locally at WFOs.
- Produces high-resolution wave and inundation guidance in the nearshore.
- Driven by forecaster-developed winds from GFE, WW3 BCs and RTOFS/ESTOFS.
- To be included in the AWIPS II baseline -> National roll-out FY13Q4.

Nearshore Wave Prediction System (*NWS Southern Region domains)*

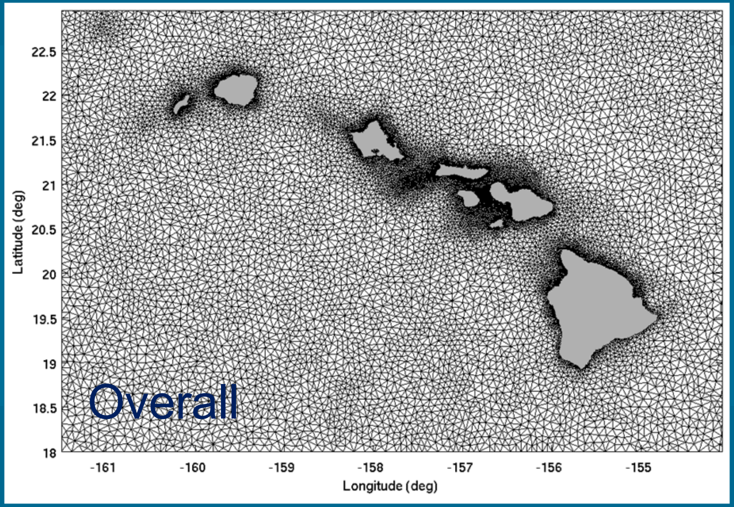


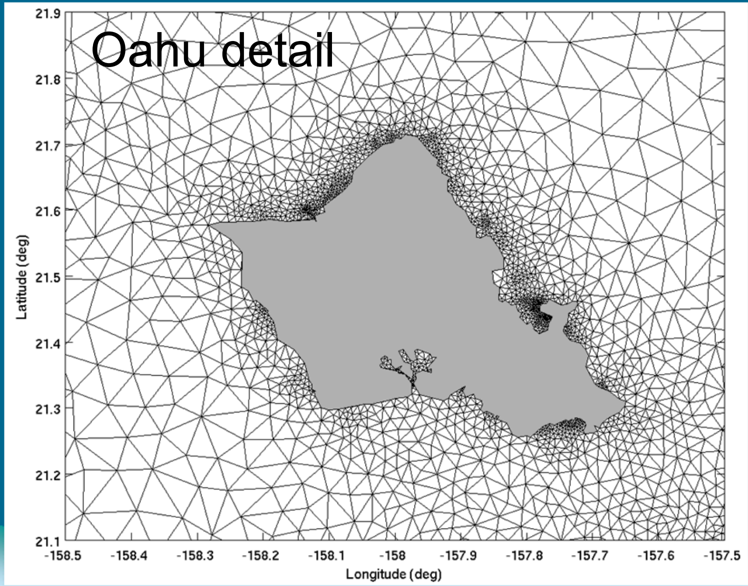


- WFO MFL Alpha testing site
- 1 arc-min grid, nesting down to 500 m
- 102 h forecast, 3 hourly

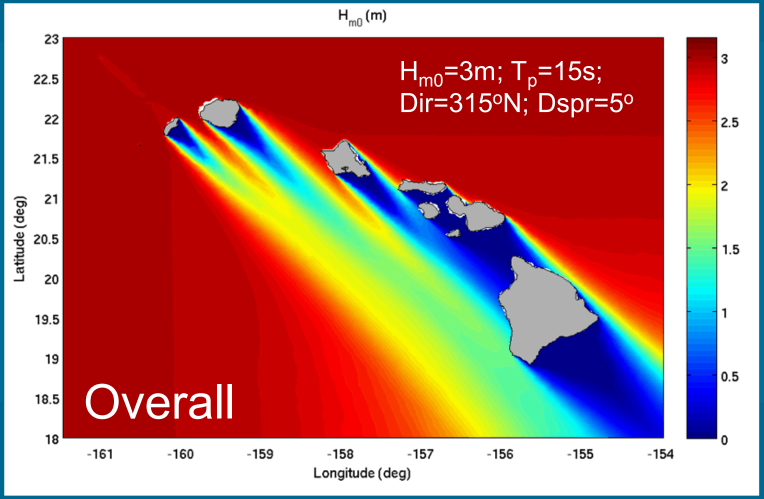
Unstructured grid domains: WFO-HNL

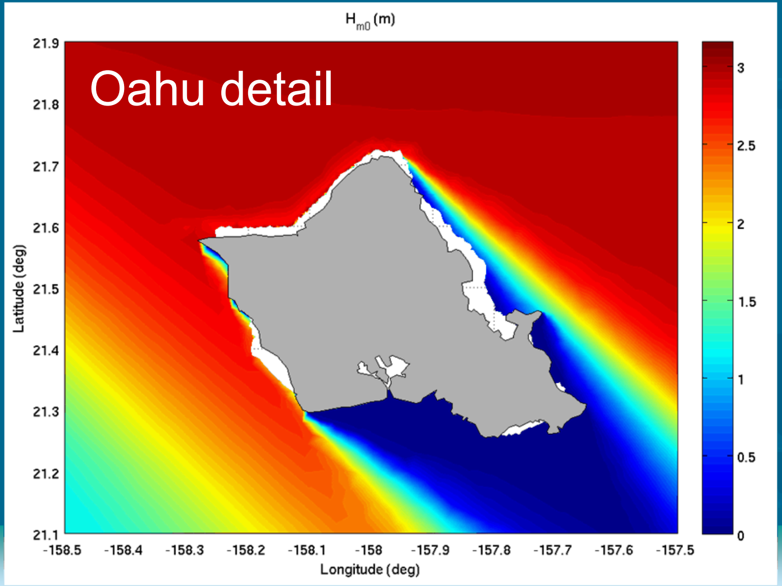
Unstructured mesh





Sign. wave height H_{m0}

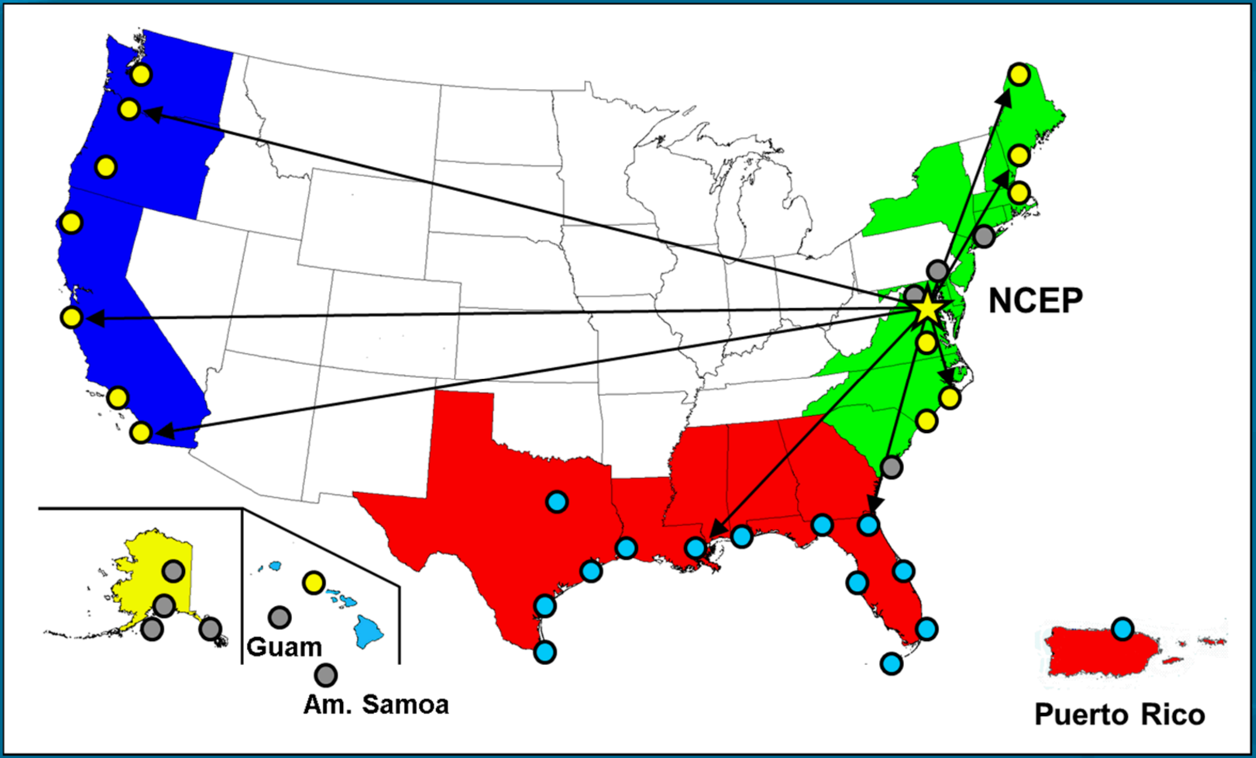




Conclusions

1. Depth-induced breaking: inclusion of nonlinearity and bed slope
2. Bottom friction and movable bed models
3. Wave-current interaction and nonlinear corrections
4. Three-wave interactions: one- and two-equation models
5. Other: coastal reflection, phase-decoupled diffraction, topographic scattering, mud, vegetation, phase-resolving approaches
6. Multi-scale modeling: high-resolution nearshore prediction systems

Nearshore Wave Prediction System (NWPS)



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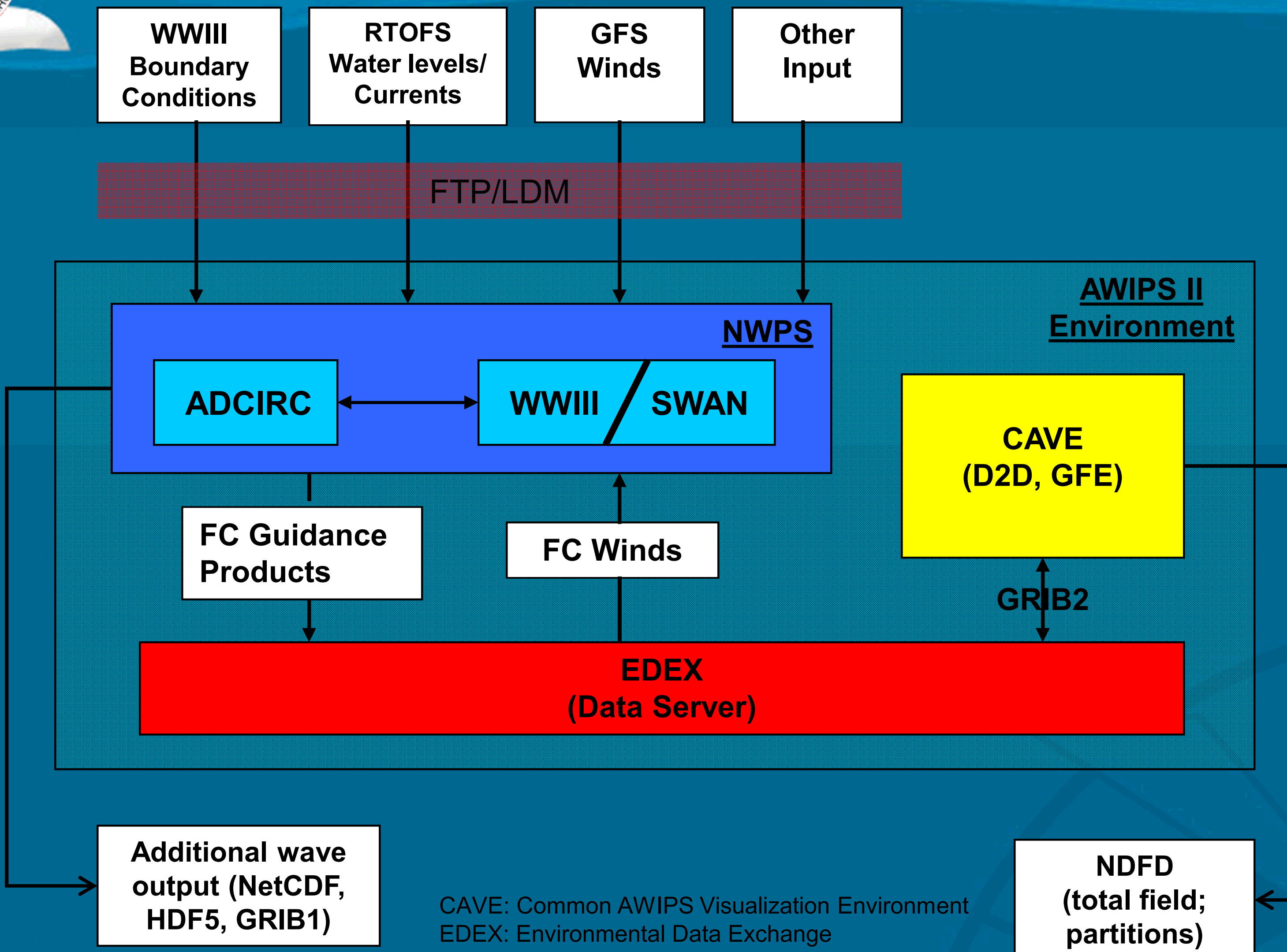
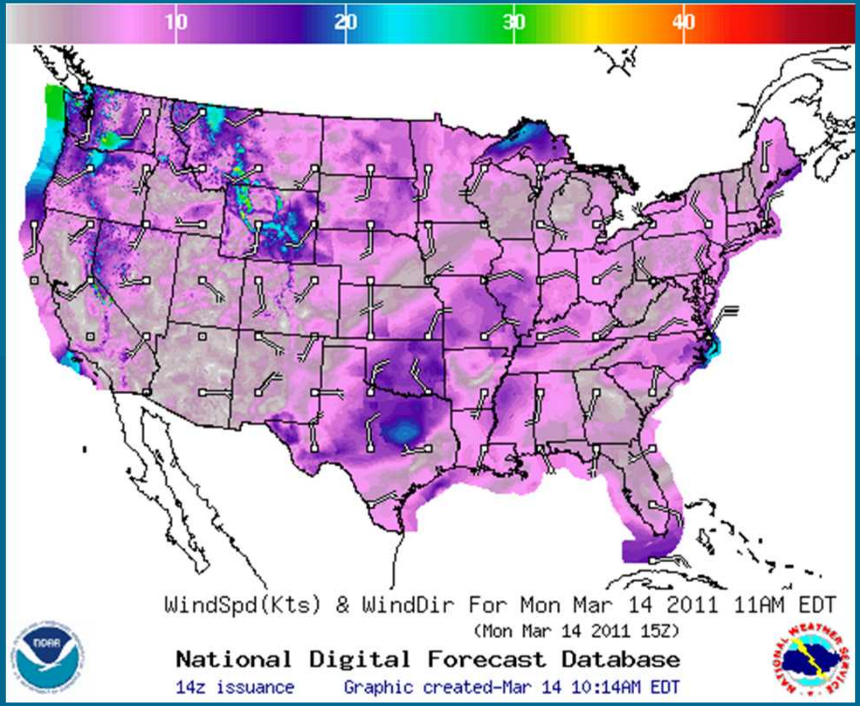
NWPS system architecture

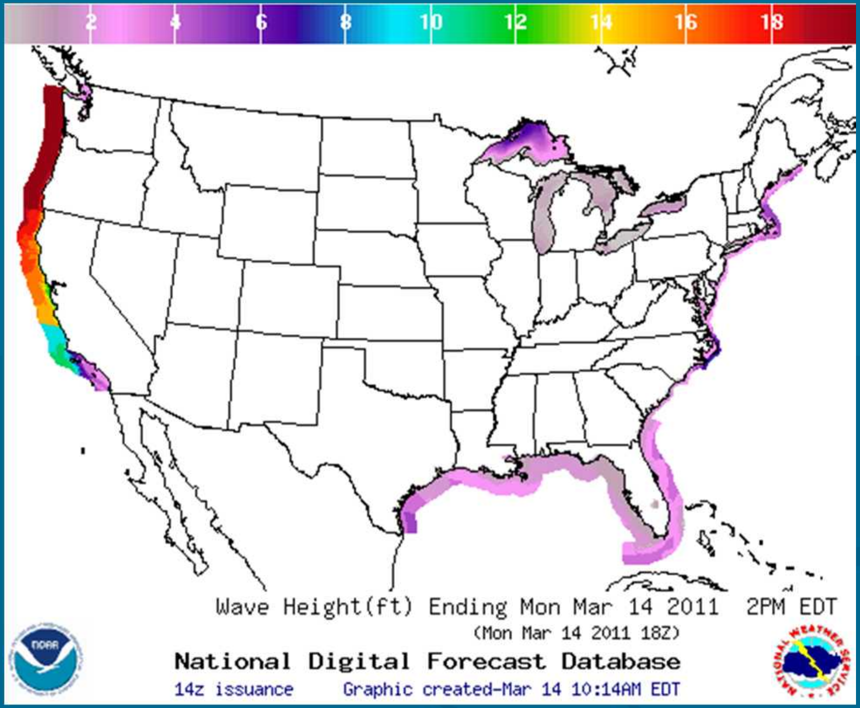


CAVE: Common AWIPS Visualization Environment
EDEX: Environmental Data Exchange
LDM: Local Data Manager

Wave field output to NDFD



Wind speed and direction (Kts) (CONUS region)



Significant wave height (ft)