Impacts of forcing details on wave models using the NCEP global wind wave model setup of WAVEWATCH III ®

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Background

Wind is important for wind waves (dah !)

- Bauer et al. (1996), update wind rather than waves for DA
- View from meteorological perspective :
  - Accurate description of mesoscale features
- Competing view points ?
  - Wave height scales quadratic with wind speed
  - Waves as low-pass filter of forcing
- Systematic assessment of impact of wind perturbations should be very insightful

Background (history, scales)

- Gustiness, e.g.,
  - Kahma and Calkoen (1992, 1994)
  - Abdalla, Cavaleri, Bidlot, Janssen 2002 and 2003
- Resolved scales, e.g.
  - Shuyi Chen et al (2013), high-resolution hurricane work
- Propagating wind perturbations (dynamic fetch), e.g.
  - Tolman & Alves (2005), Xu et al. (2007), Chen et al (2013)
- Perturbing ensembles
  - Spread in wave ensembles is directly related to time scales of perturbation of wind field (not just amplitude) (NCEP)

Experiments

Systematic perturbation study with wind wave model

- WAVEWATCH III, set up as for NCEP global models
- Time limited growth starting with flat surface and $U_{10,b}$ = 20 ms^{-1}
- Systematically perturbed wind speed

$$U_{10}(t) = U_{10,b}\,[1 + \Delta\widehat{U} \sin(\,2\pi\, T_\delta^{-1} + \phi_0)\,]$$

- Gives (systematic ?) wave height perturbation

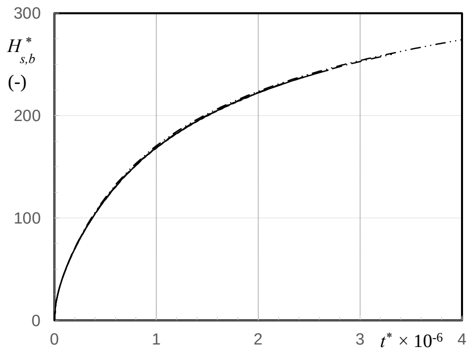
$$\Delta H_s(t) = H_s\left(\Delta\widehat{U}, T_\delta, \phi_0, t\right) - H_{s,base}(t)$$

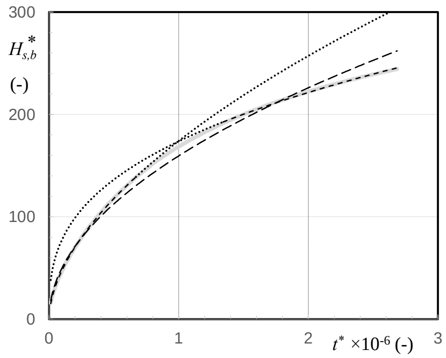
- Ideally described with $\Delta H_{s,avg}$ and std σ_H, in principle as $f(t)$

Before actual experiments

To make sure results are reliable

- Test convergence / set time steps
- Test scaling behavior
  - Universal u_* scaling for baseline run
    - Two distinct scaling ranges
  - Not for U_{10} scaling
  - How do you scale with perturbed wind ?
- Sensitivity to perturbations
  - Generally good above $\Delta\widehat{U} = 10\%$
  - Noise introduced due to parametric tail transition skips

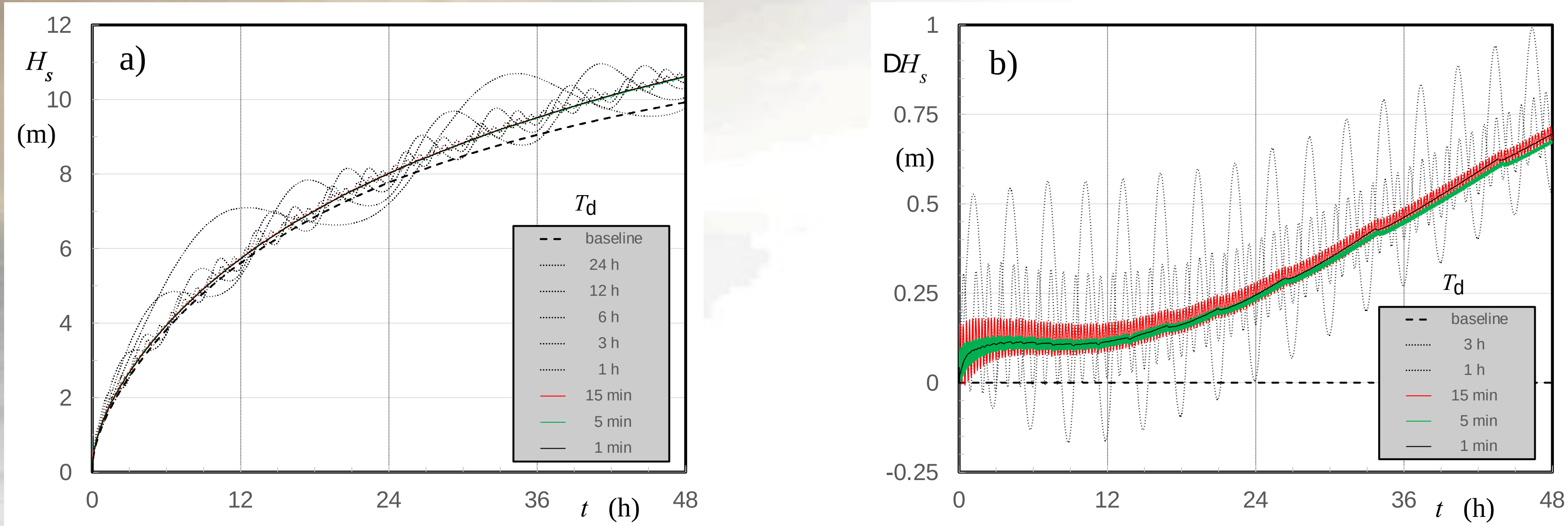




A first look

$\Delta\widehat{U} = 30\%$ and $\phi_0 = 0$, with a large range of T_δ

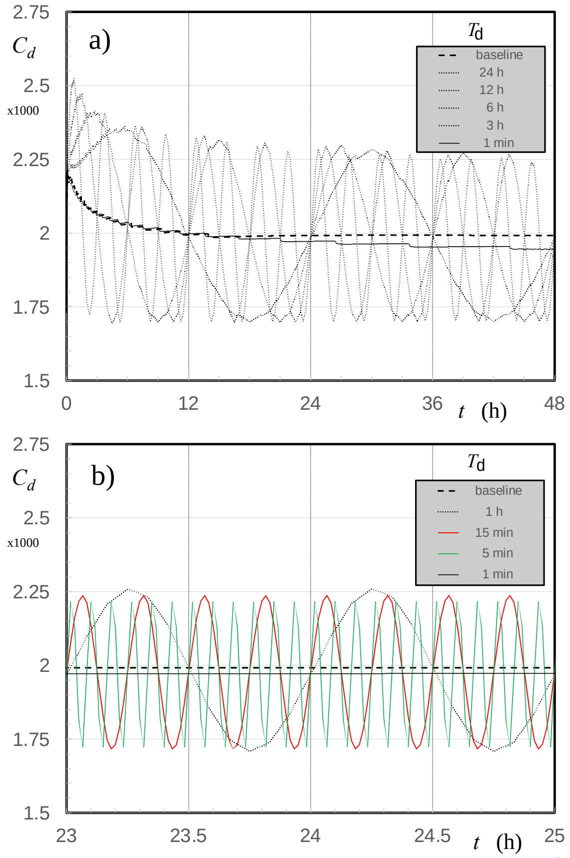
- Clear mean impact, clear low pass filtering even for T_δ = 24h!



A first look (extended)

Additional observations from the first look:

- Wave height good proxy for most mean parameters (not σ_d or f_p)
- Wind direction variability has small impact
- Air-sea temperature difference has small impact
- Note that drag coefficient reacts near instantaneous, without low pass filter behavior

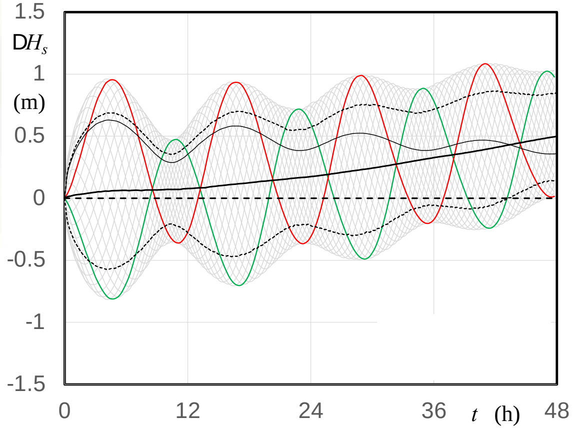


A first look (phase averaging)

For each ($\Delta\widehat{U}$,T_δ), 24 ϕ_0 are used

- The amplitude of ΔH_s is f(ϕ_0)
- This can be removed with running box filter with width T_δ
- This is directly related to cumulative effects of nonlinear initial growth
  - Physically sound
  - Not relevant in nature ?

All following results are phase ϕ_0 averaged and filtered as needed



Example with $\Delta U_{10} = 20\%$ and $T_\delta = 12$h.

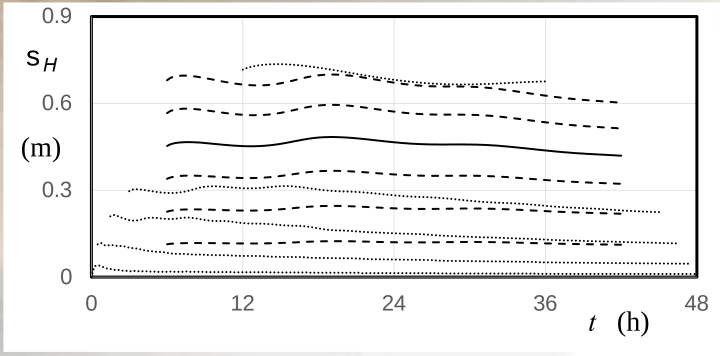
Red, green and grey lines are results with all initial phases

Black lines are mean parameters

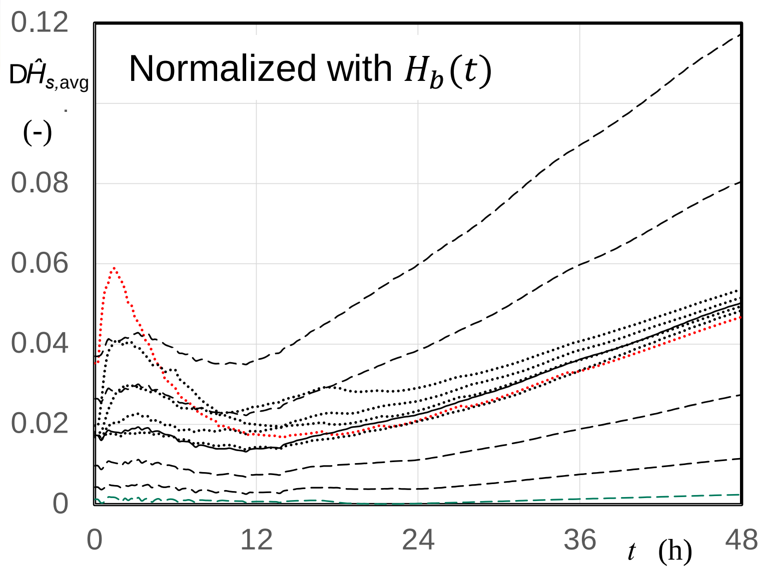
Evolution in time

Is the impact of perturbations on average a function of *t* ?

- Variability σ_H is nearly constant over time (0-48h)



- Perturbation mean $\Delta H_{s,avg}$ is $f(t)$
  - ➤ Initial growth (3-9h) range vs.
  - ➤ mature growth (24-48h) range

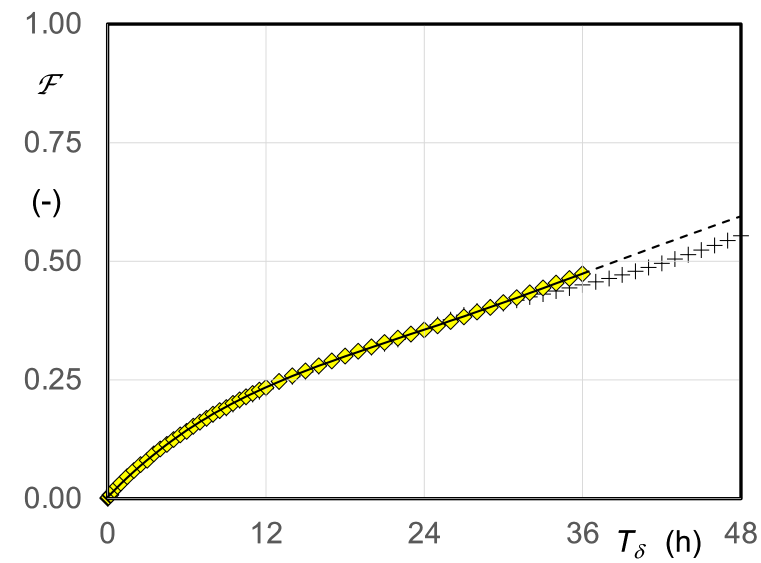


Low pass filtering

Amplitude of wave perturbation relative to wind perturbation

- σ_H constants in time
- Non-dimensional (u_*)
- Filter function $\mathcal{F}(T_\delta)$
- $\mathcal{F}(\infty) \equiv 1$
  - Form from scaling
  - Asymptote defines $\mathcal{C}$

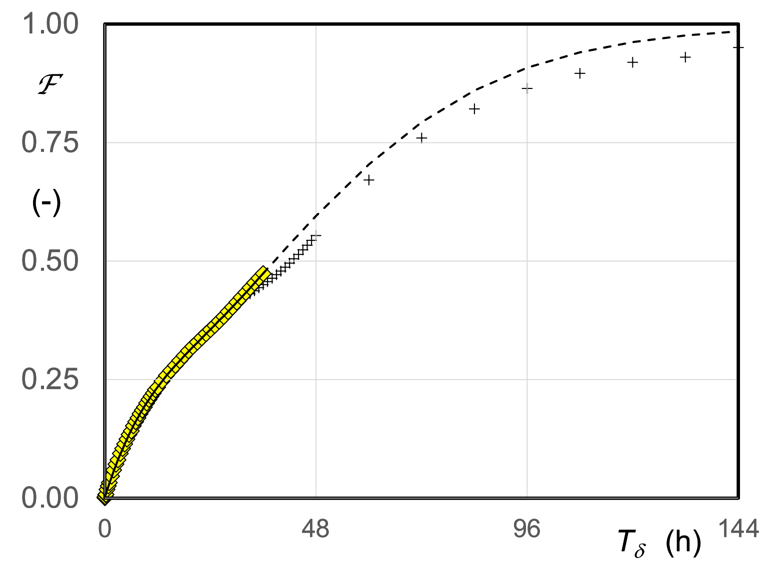
$$\frac{g\sigma_H}{u_*^2} \propto \mathcal{C} \; \mathcal{F}(T_\delta)\, \Delta\hat{U}$$



Low pass filtering

Low pass filtering dominates scaling behavior

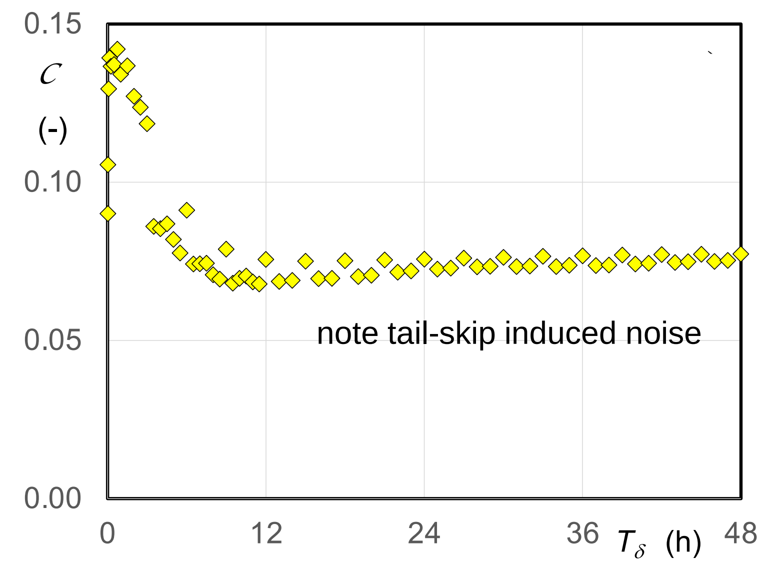
- Extended exp for $T_\delta \rightarrow \infty$
- Impact for
  - Error propagation
  - Wind resolution
  - Wave ensembles
    - T_δ versus $\Delta\hat{U}$



Mean change, initial growth

Mean change relative to wind perturbation

- Assume ΔH_s constant for t = 3-9h
- Non-dimensional (u_*)
- Form from scaling
- Constant $\mathcal{C}$ from experiment
- $\mathcal{C}$ asymptotes for $T_\delta > 24$h
- $\mathcal{C}$ enhancement for $T_\delta < 12$h

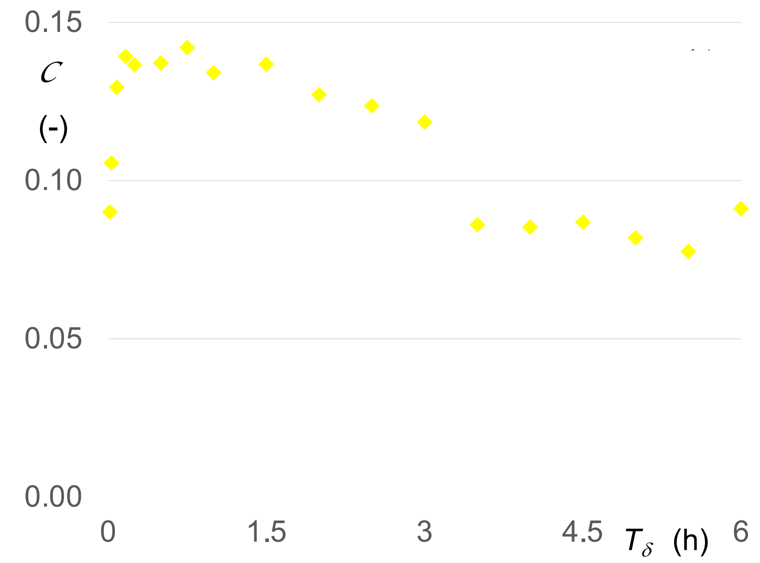


$$\frac{g\Delta H_{s,init}}{u_*^2} \propto \mathcal{C}\,\Delta\hat{U}^2$$

Mean change, initial growth

Constant behavior with enhancement area

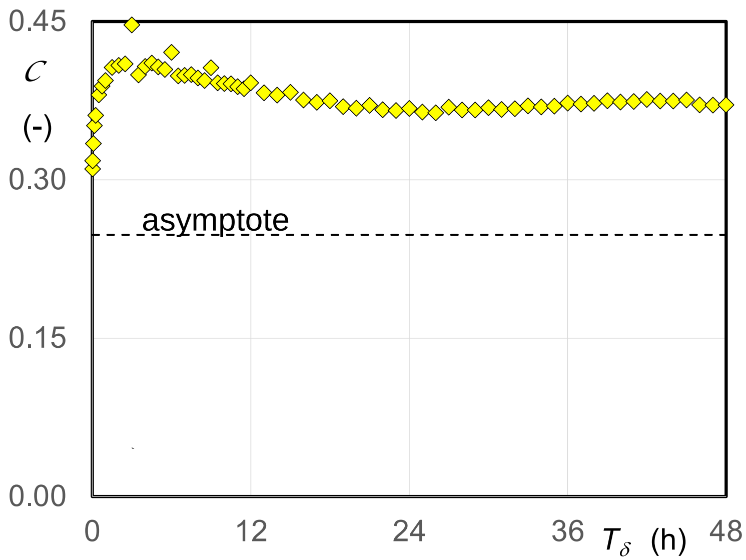
- Results for $T_\delta \downarrow 0$ like asymptote
  - ➤ Consistent with expectation
- Enhanced impact range
  - ➤ Nonlinear feedback ?
- Impact for
  - ➤ Gustiness
  - ➤ Scale-aware physics
  - ➤ Wind resolution



Mean change, mature growth

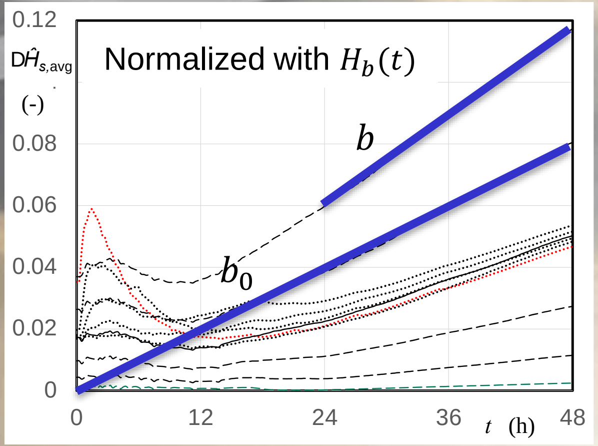
Mean change relative to wind perturbation

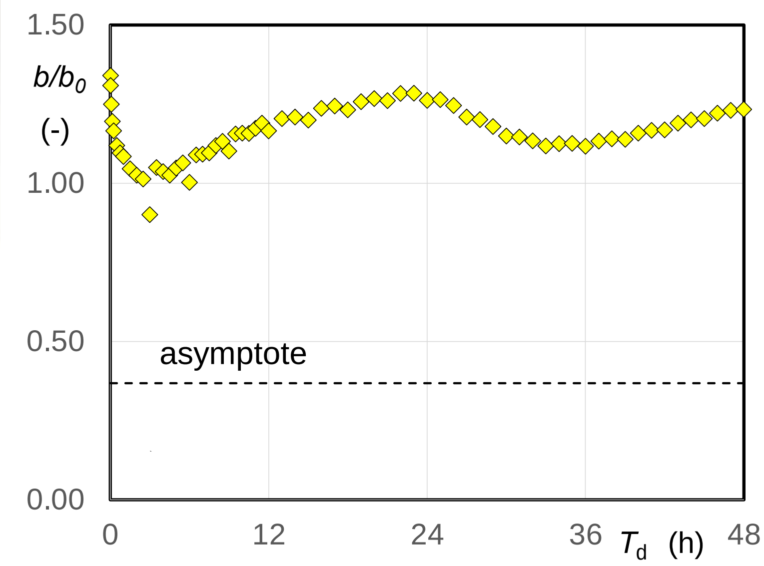
- Increases for t = 24-48h
- Same formulation as $\Delta H_{s,init}$
- Tail-fit noise less evident
- $\mathcal{C}$ asymptote for $T_\delta \gg 48$h
- $\mathcal{C}$ enhancement for most T_δ
- Bigger impact than for $\Delta H_{s,init}$



$$\frac{g\Delta H_{s,mat}}{u_*^2} \propto \mathcal{C}\, \Delta \widehat{U}^2$$

$\Delta H_s(t)$, mature growth





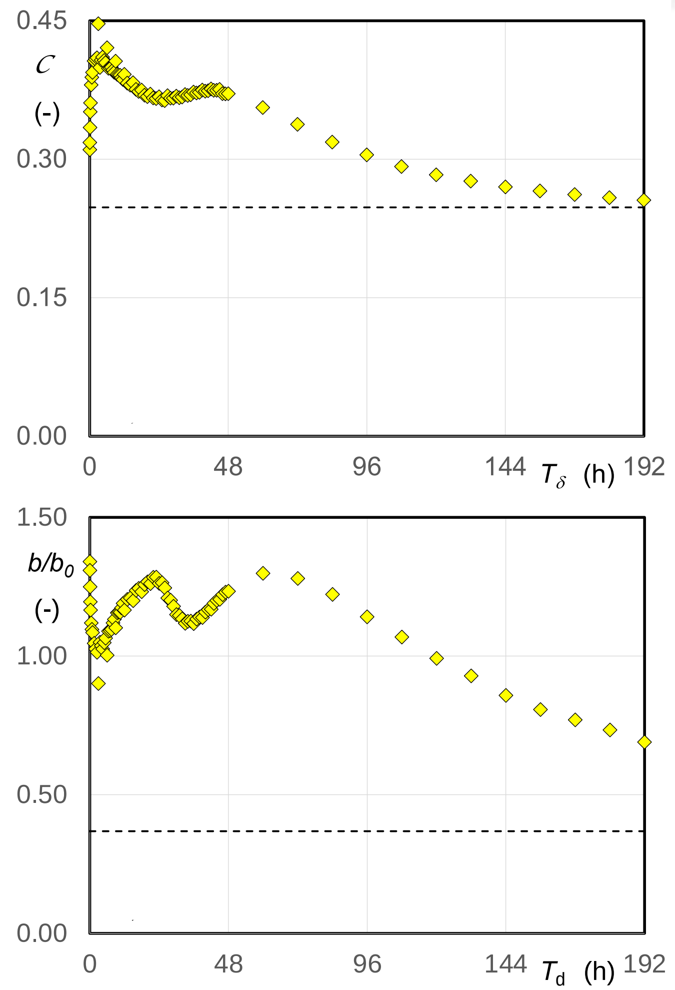
Linear growth with time

- Normalized slope b/b_0
- Fit for t = 24-48h
  - $\Delta H_s = a + b\,t$, $\Delta H_s = b_0\,t$

Mature growth

Enhancement throughout (vs. asymptote)

- Impact for
  - Gustiness
  - Wind resolution
  - Scale aware physics



Sooooo ....

Interesting results for

- Low pass filter behavior
  - Impacts ensemble building
  - Impacts DA, will Bauer et al. (1996) work?
  - Impacts for coupling time scales (including C_d results)
- Enhanced mean impacts, but ....
  - Including previously unseen secondary feedback
  - Do we need scale-aware physics?
    - Can approaches with “effective wind” work?

But ....

Thank You!

Limitations:

- A specific WW3 configuration
- In highly idealized conditions

Possible next steps:

- Nondimensional growth time and time scales assessments from operational models
- Similar assessments in fetch-limited conditions
- Similar assessment in moving storm conditions