Forecasting Hurricane-Generated Wind Waves at NOAA/NCEP

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With HL Tolman and YY Chao.

Outline

- NOAA/NCEP's operational forecasts of hurricane-generated waves, performance in 2002 & 2003:
  - Isidore and Lili (2002)
  - Isabel (2004)
- Moving grid version of WAVEWATCH III:
  - Space-time wind resolution in hurricane wave models.
  - Waves during hurricane Lili (2002)
- Forecasts of maximum hurricane wave heights:
  - Revisiting Young (1988) model.

NOAA/NCEP's Specialized Models for Hurricane-Generated Waves

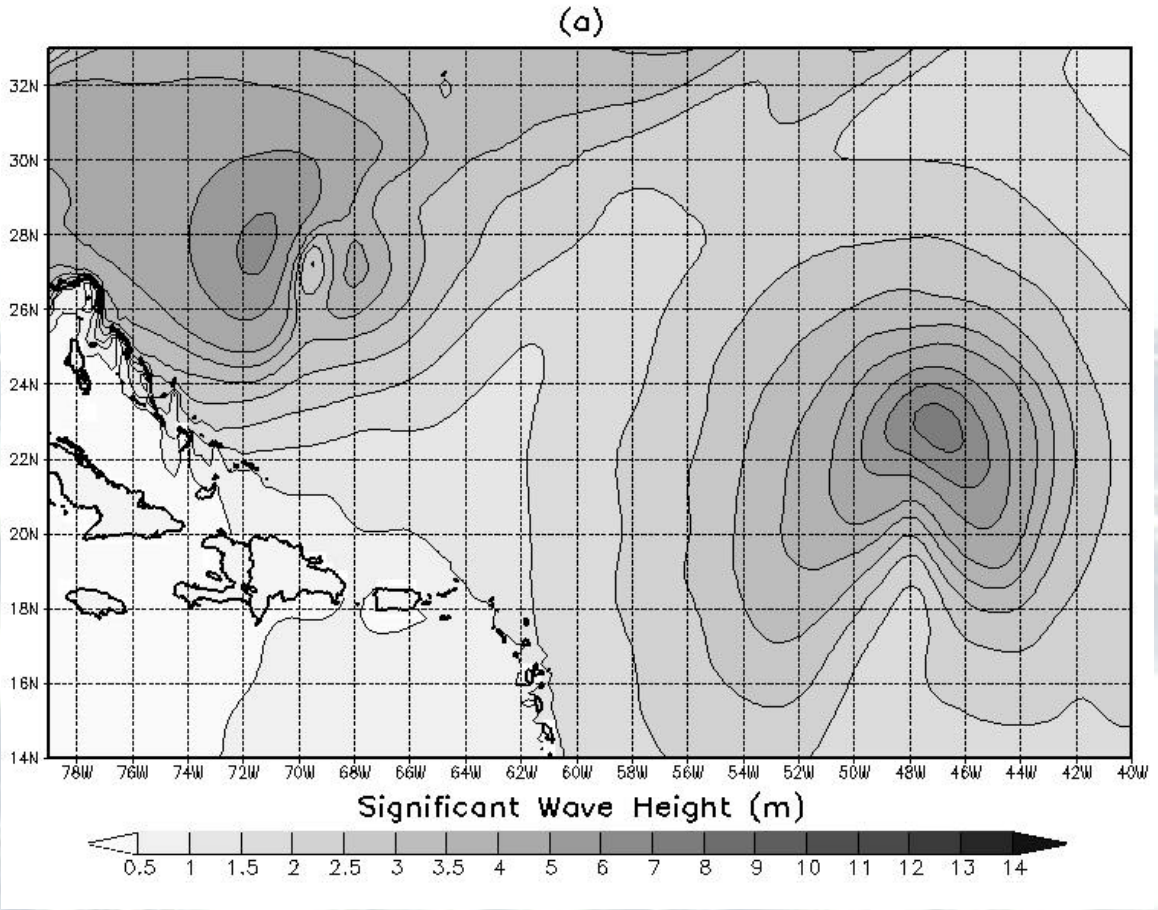
- NOAA WAVEWATCH III, Version 2.22:
  - NWW3: Global, 1.25x1º, 180h, 3-hourly GFS winds
  - WNA: W North Atlantic, 0.25x0.25º, 180h, 3h GFS winds
  - NAH: Hurricane version of WNA, 0.25x0.25º, 126h, 1h GFS+GFDL winds
  - ENP: E North Pacific, 0.25x0.25º, 180h, 3h GFS winds
  - NPH: Hurricane version of ENP, 0.25x0.25º, 126h, 1h GFS+GFDL winds
  - AKW: Alaskan Waters, 0.5x0.25º, 180h, 3h GFS winds

GFDL

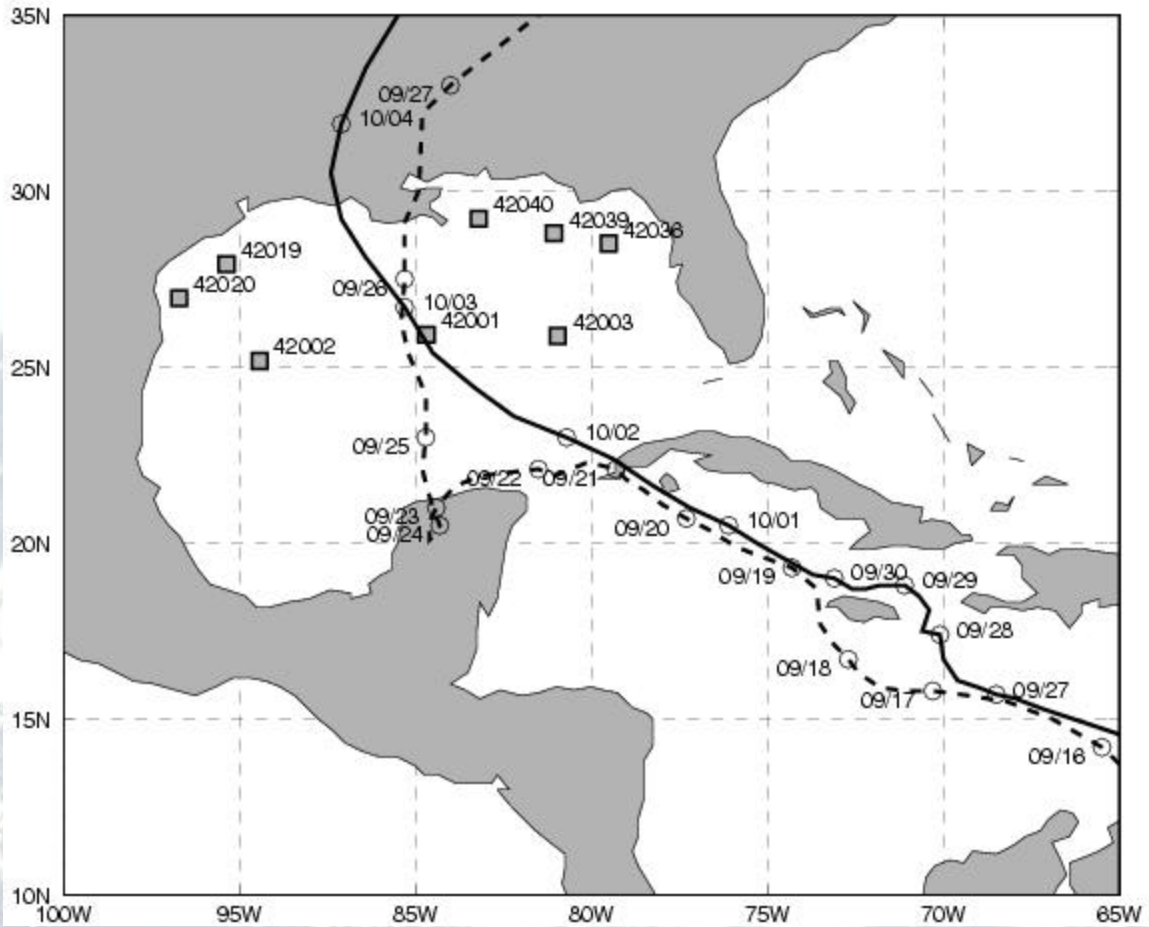
- All models: 24 directions, 25 frequencies, 4 daily cycles (00z, 06z, 12z, 18z) with 6h hindcasts for continuity

Why Specialized Hurricane Wave Models?

- Wave models: as good as wind models.
- NCEP's GFS: low resolution.
- High res winds: NCEP's GFDL model.
- Domain mismatch.
- Hurricane wave models blend GFS and GFDL winds.



NCEP Guidance:
NAH vs. WNA during Lili and Isidore (2002)



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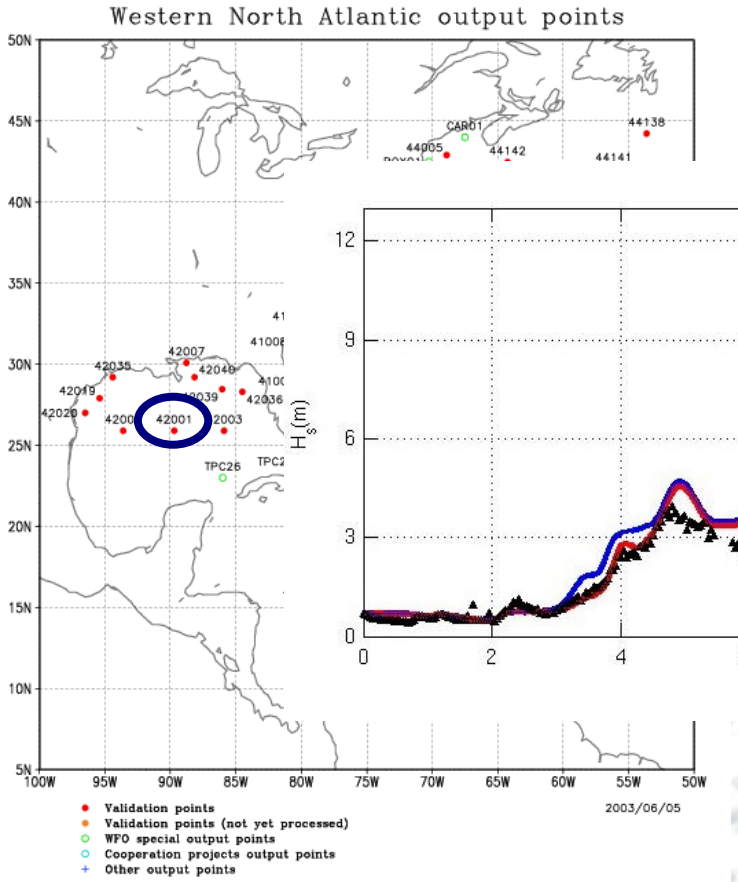
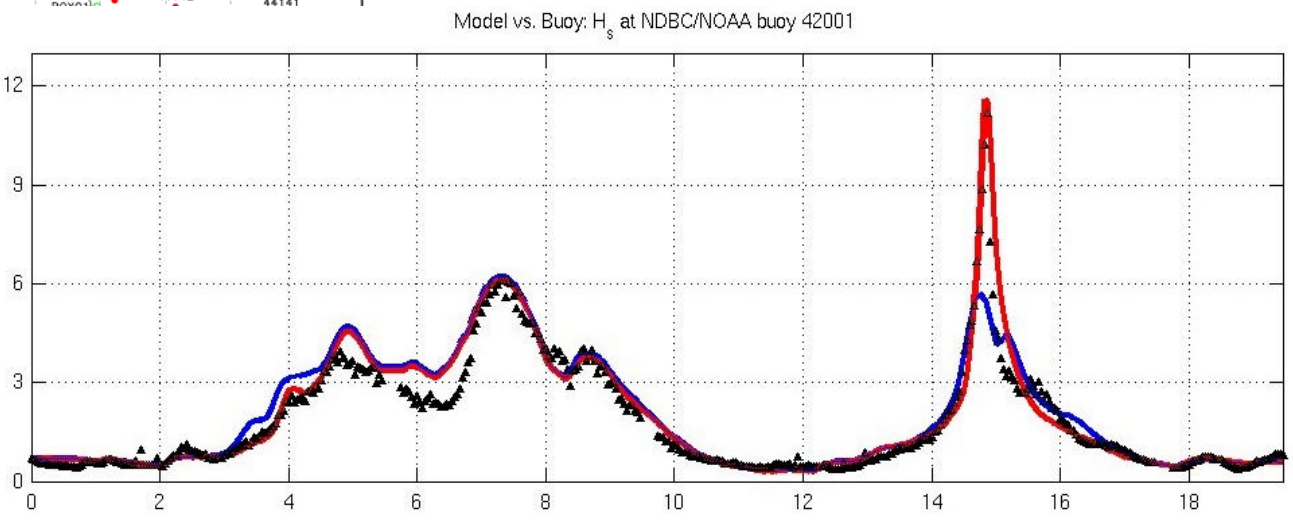
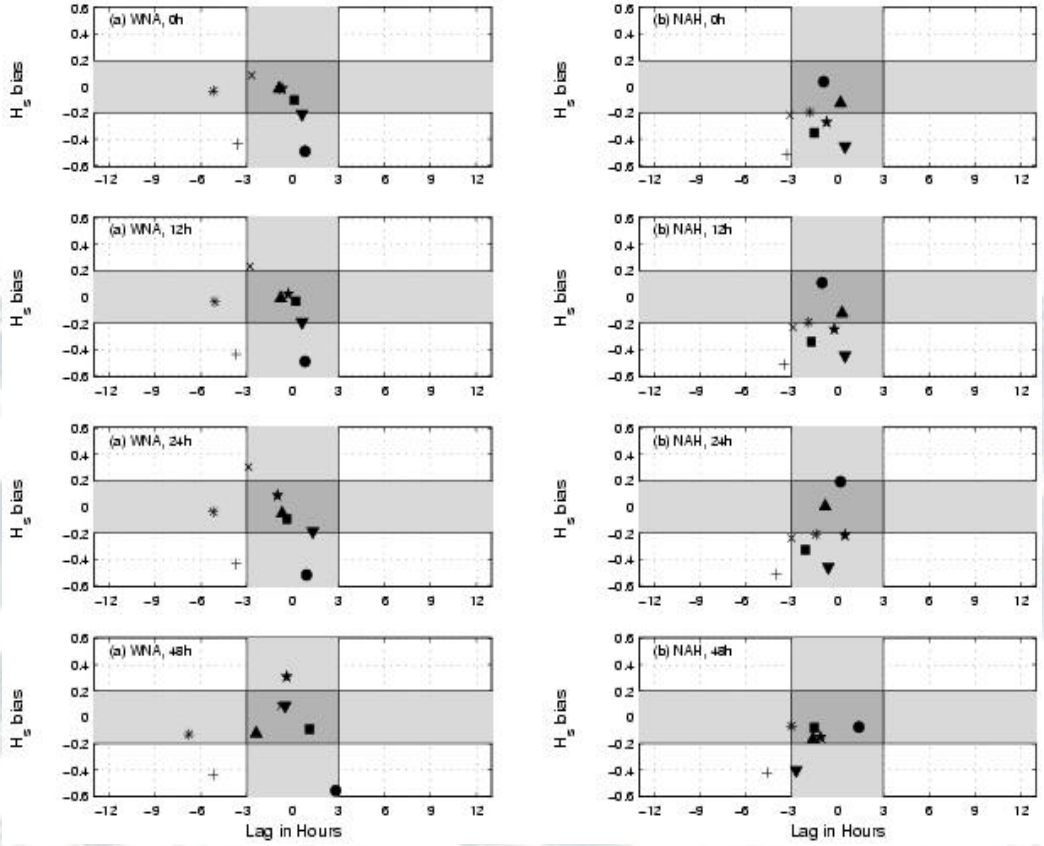


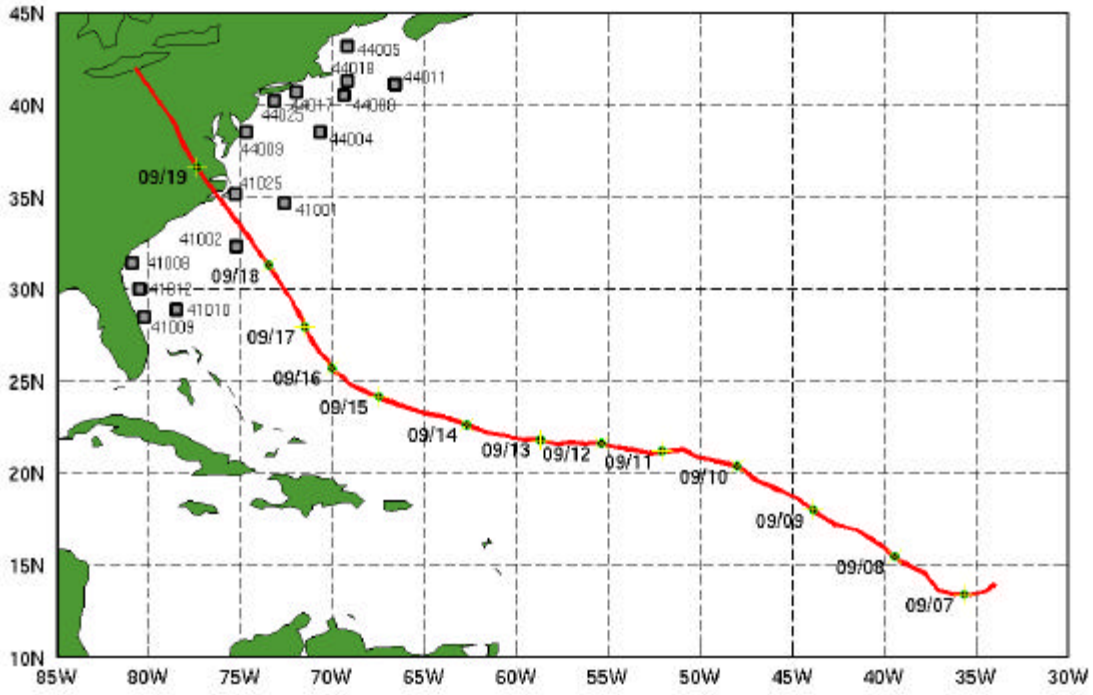


NCEP Guidance: NAH vs. WNA during Lili and Isidore (2002)

- Max Hs at other buoys.
- Target plots
  - Relative bias
  - Time lag
- Timing generally better: NAH.
- Height somewhat better: WNA.
  - Swell fields.
  - GFDL problem: adjusted.



NCEP Guidance:
NAH vs. WNA during Hurricane Isabel (2003)

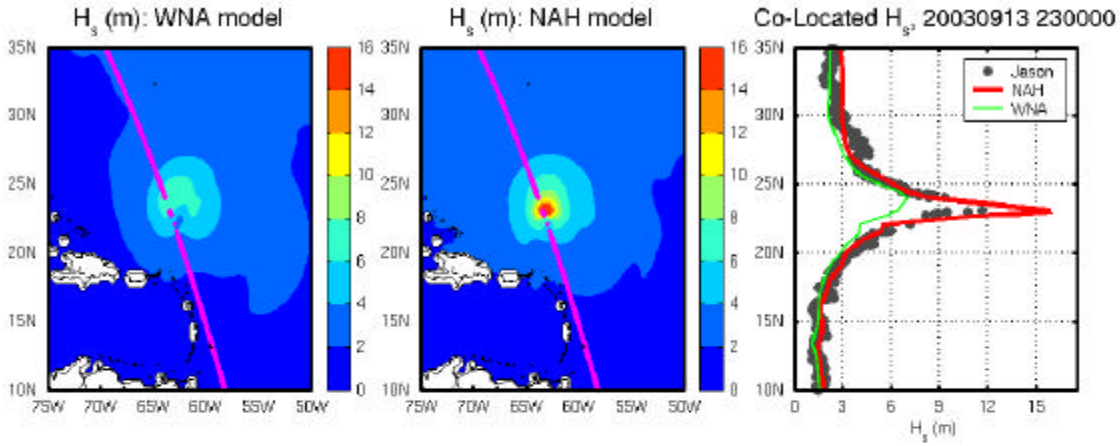


Isabel's track and locations with buoy observations

NCEP Guidance:
NAH vs. WNA during Hurricane Isabel (2003)

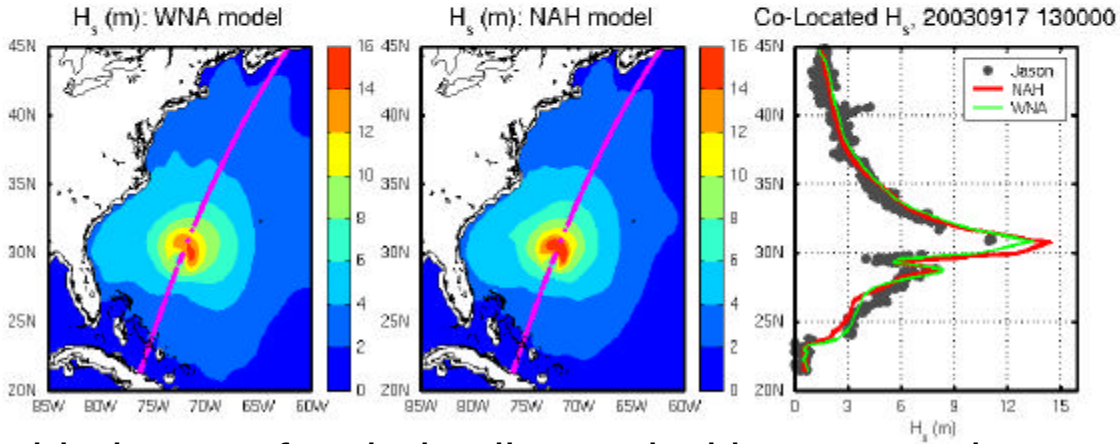
9/13/2003:

Isabel is small and poorly resolved by GFS



9/17/2003:

Isabel is larger and well resolved by GFS

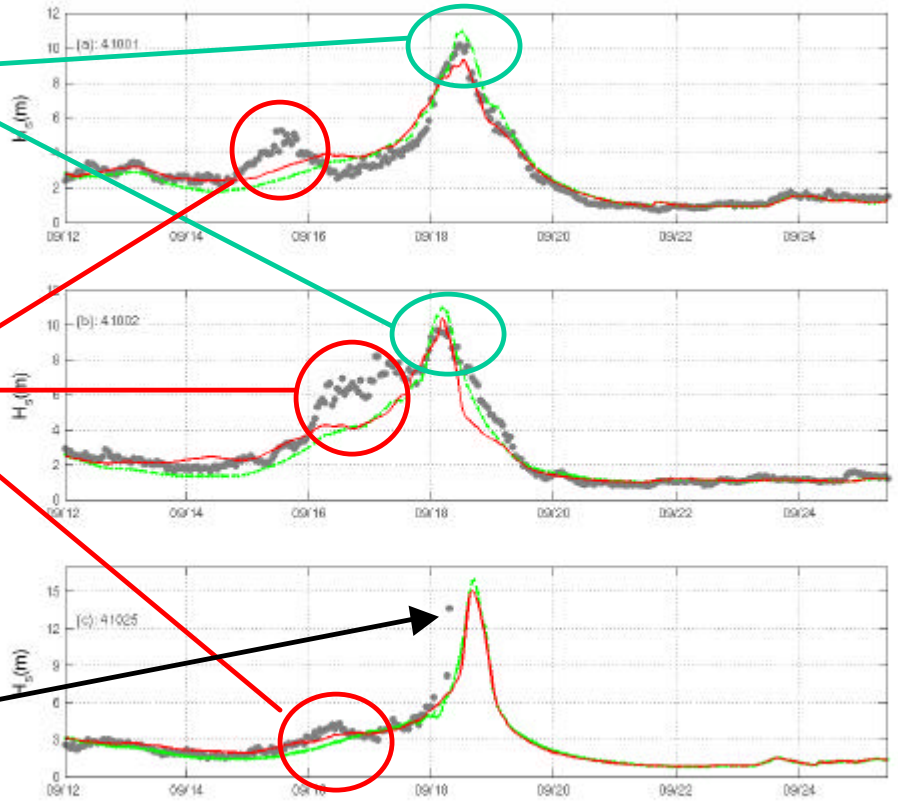


WNA and NAH hindcasts of Isabel collocated with Jason-1 data.

NCEP Guidance:
NAH vs. WNA during Hurricane Isabel (2003)

- Maximum wave heights very well represented.
- Initial swell arrivals underestimated. Swells generated when Isabel was cat. 5 hurricane (wind errors).
- Do we believe last observation of 41025. Buoy in surf zone !

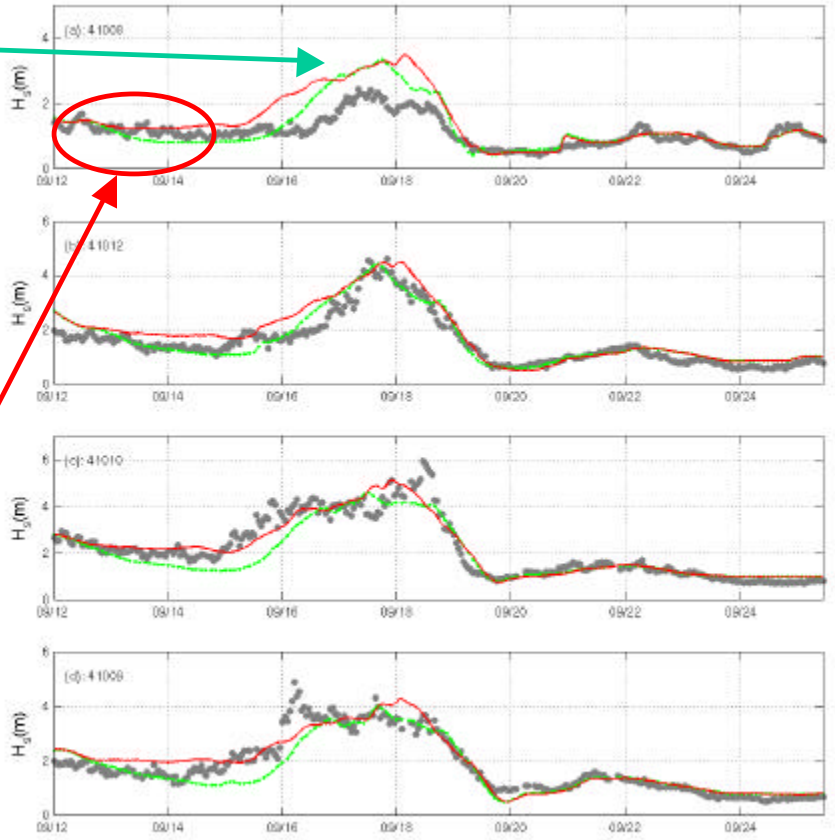
Hindcast at buoys near track



NCEP Guidance:
NAH vs. WNA during Hurricane Isabel (2003)

- For buoys at the Atlantic seaboard in shallow water, swells are overdone, most likely because shallow water processes are not well resolved yet.
- Some tidal influence to be seen in data (not in model yet).

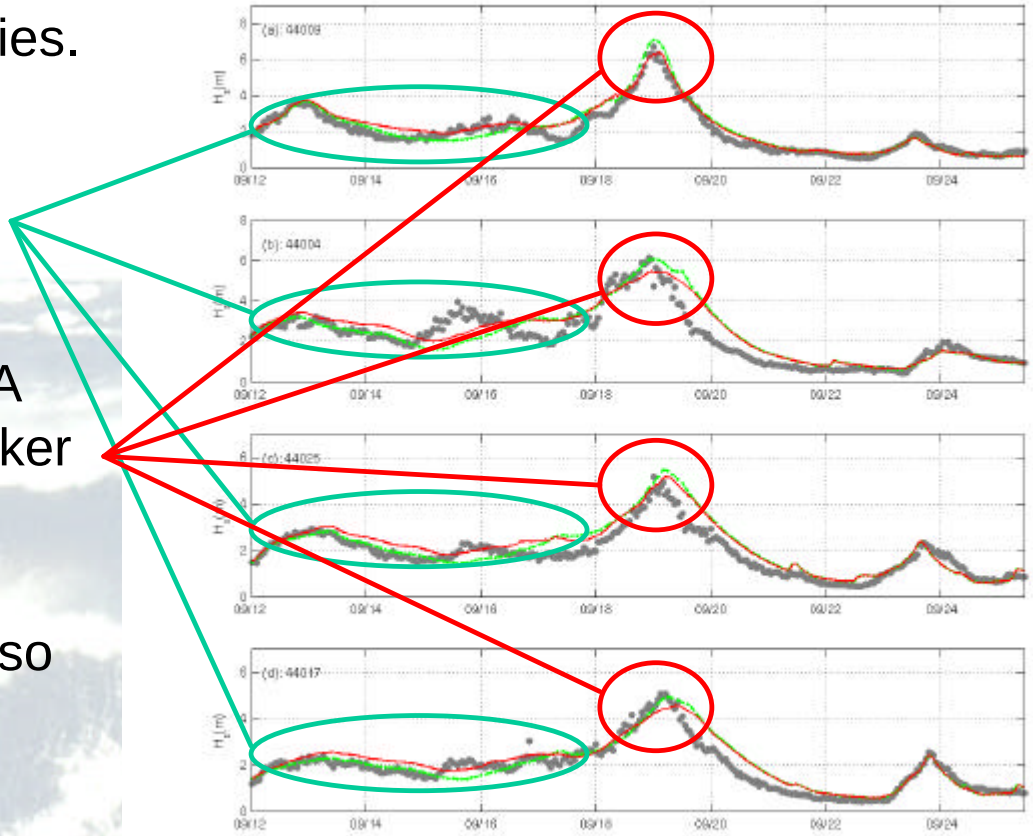
Hindcast at buoys south of track



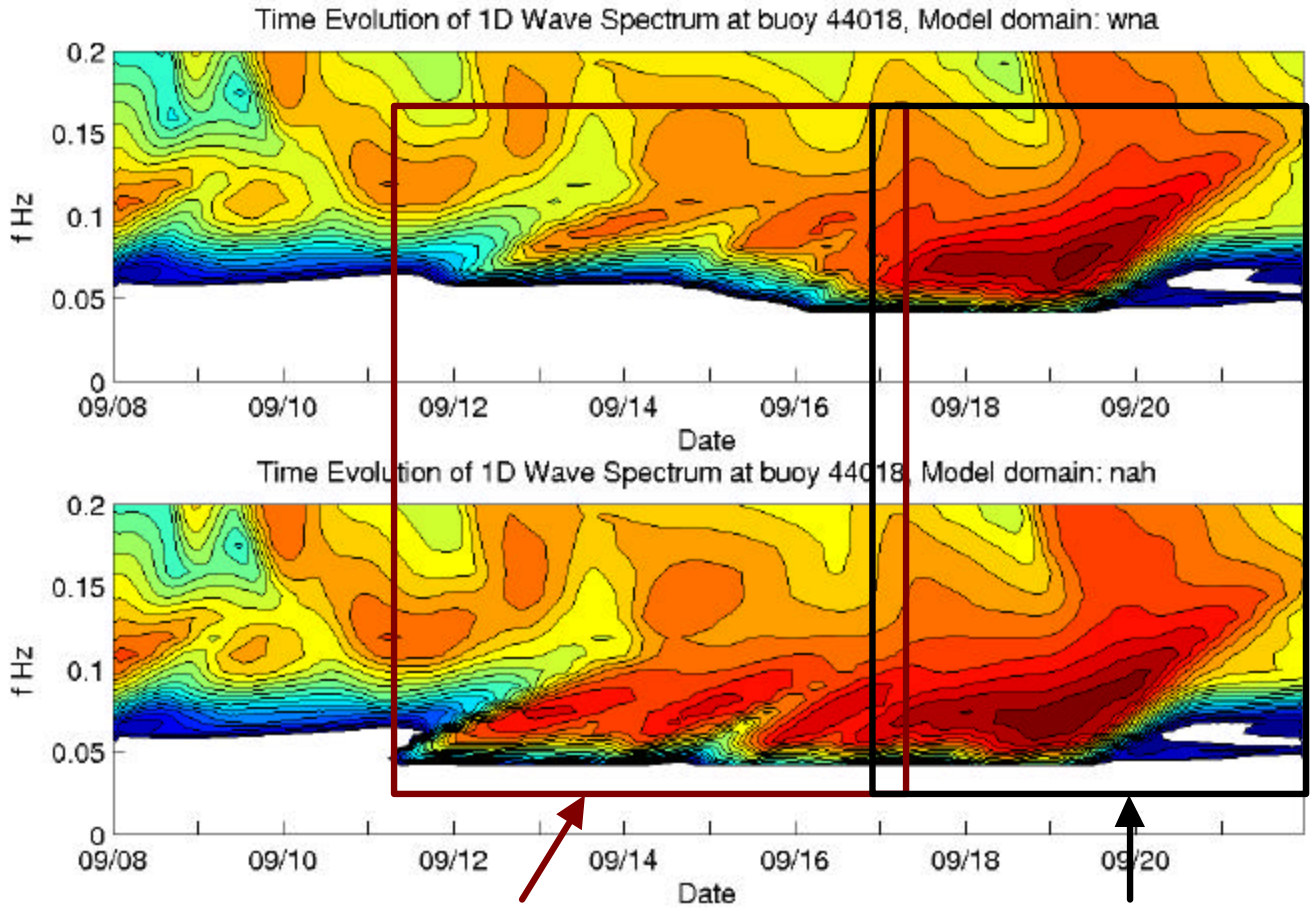
NCEP Guidance:
NAH vs. WNA during Hurricane Isabel (2003)

- Many features as in previous time series.
- Swells from NAH systematically higher.
- Highest wave heights from WNA larger due to weaker winds over larger areas
- Last two points also clear in previous slides.

Hindcast at buoys north of track



NCEP Guidance:
NAH vs. WNA during Hurricane Isabel (2003)



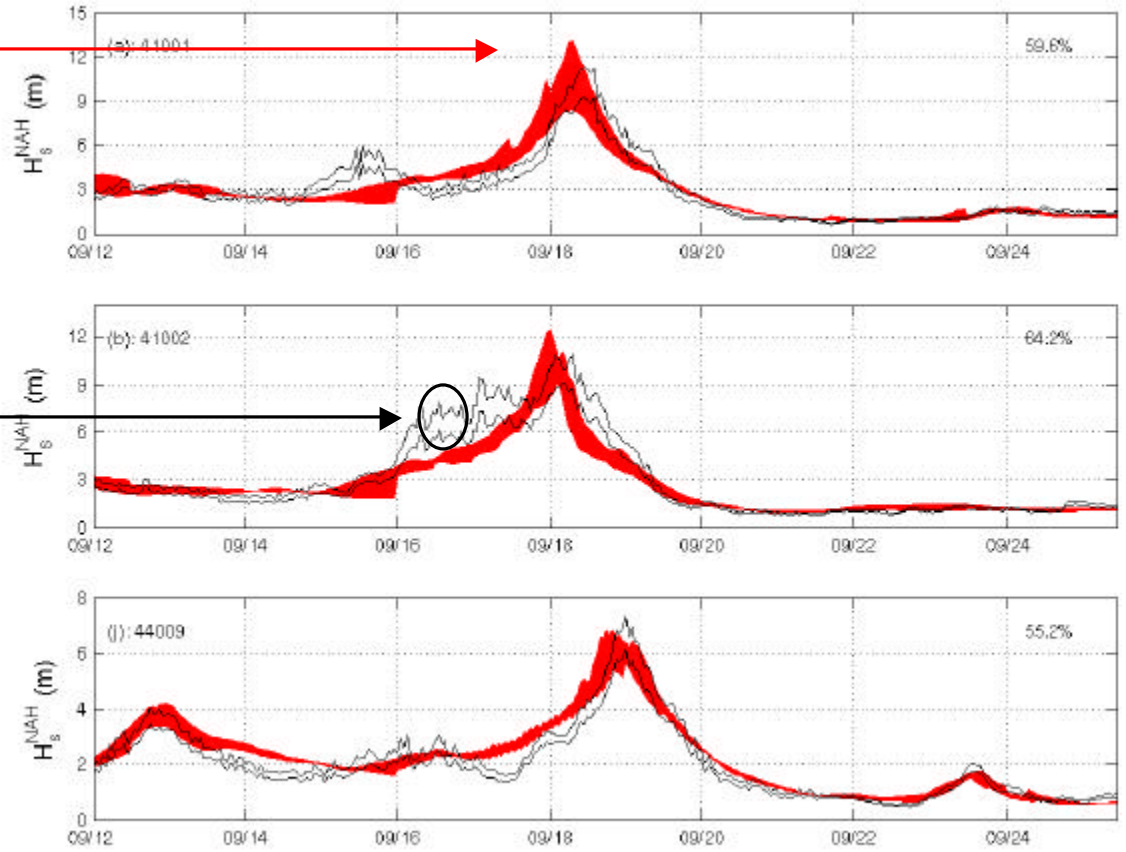
WNA misses Isabel, swells

WNA and NAH similar

NCEP Guidance:
NAH vs. WNA during Hurricane Isabel (2003)

NAH forecast envelope

Buoy 95% confidence interval

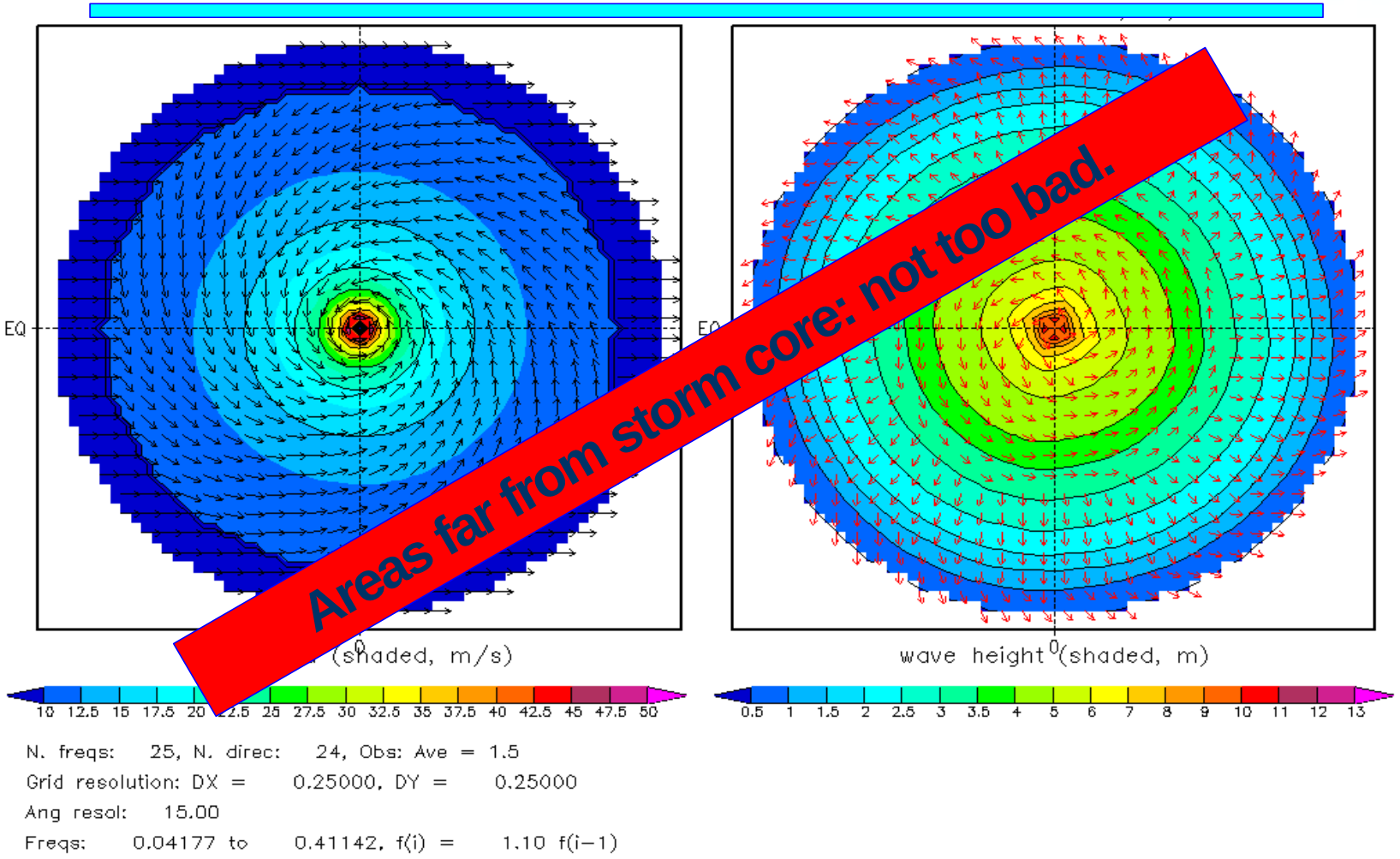


Ranges of wave heights in 72h forecasts

Wind resolution in hurricane wave models

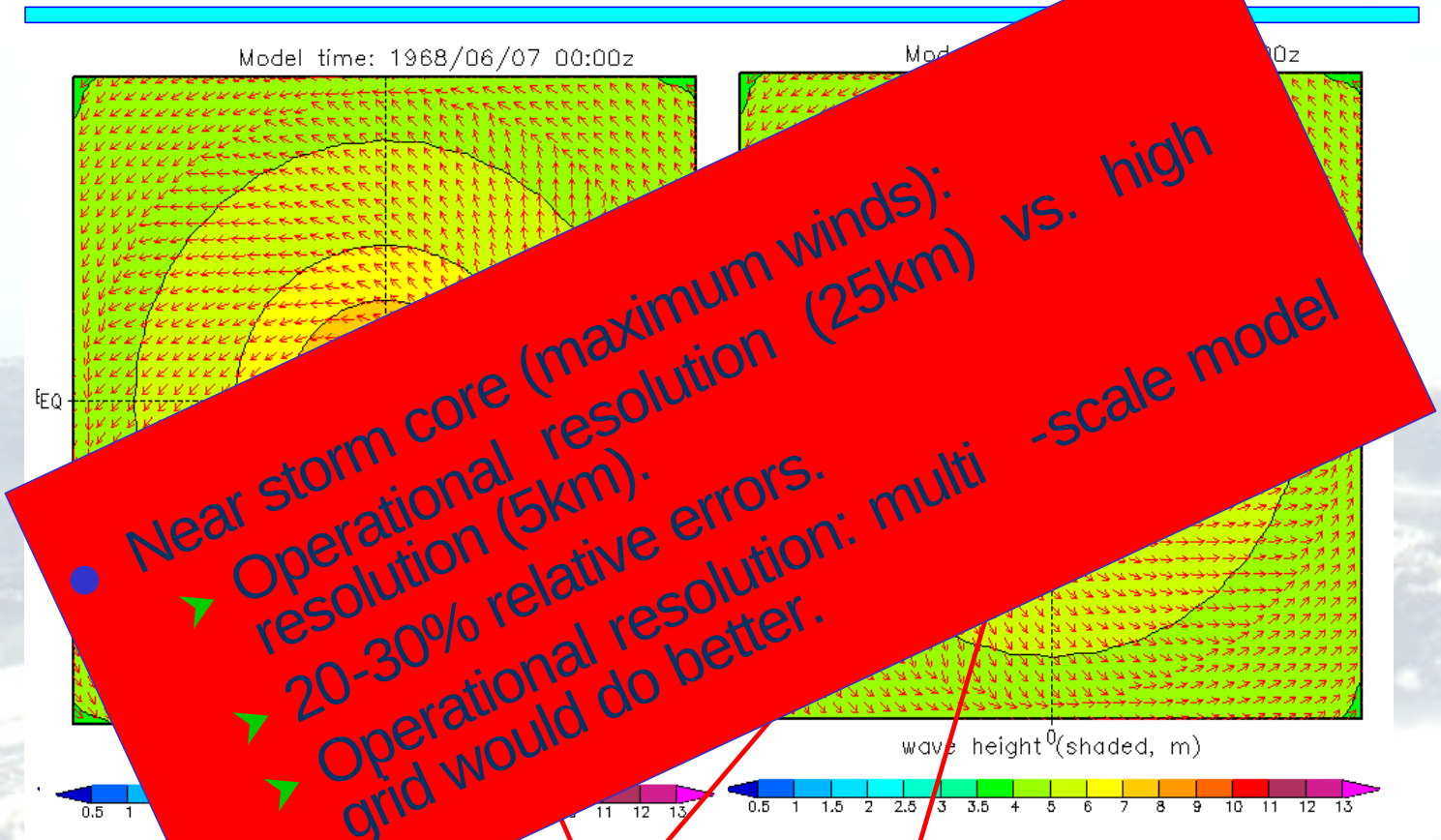
- Investigate optimal space and time resolution for modeling hurricane-generated waves.
- Initial tests, spatial resolution:
  - Simulations with fixed Rankine vortex.
  - Several resolutions (0.05, 0.1, 0.25)

Wind resolution in hurricane wave models



Areas far from storm core: not too bad.

Wind resolution in hurricane wave models

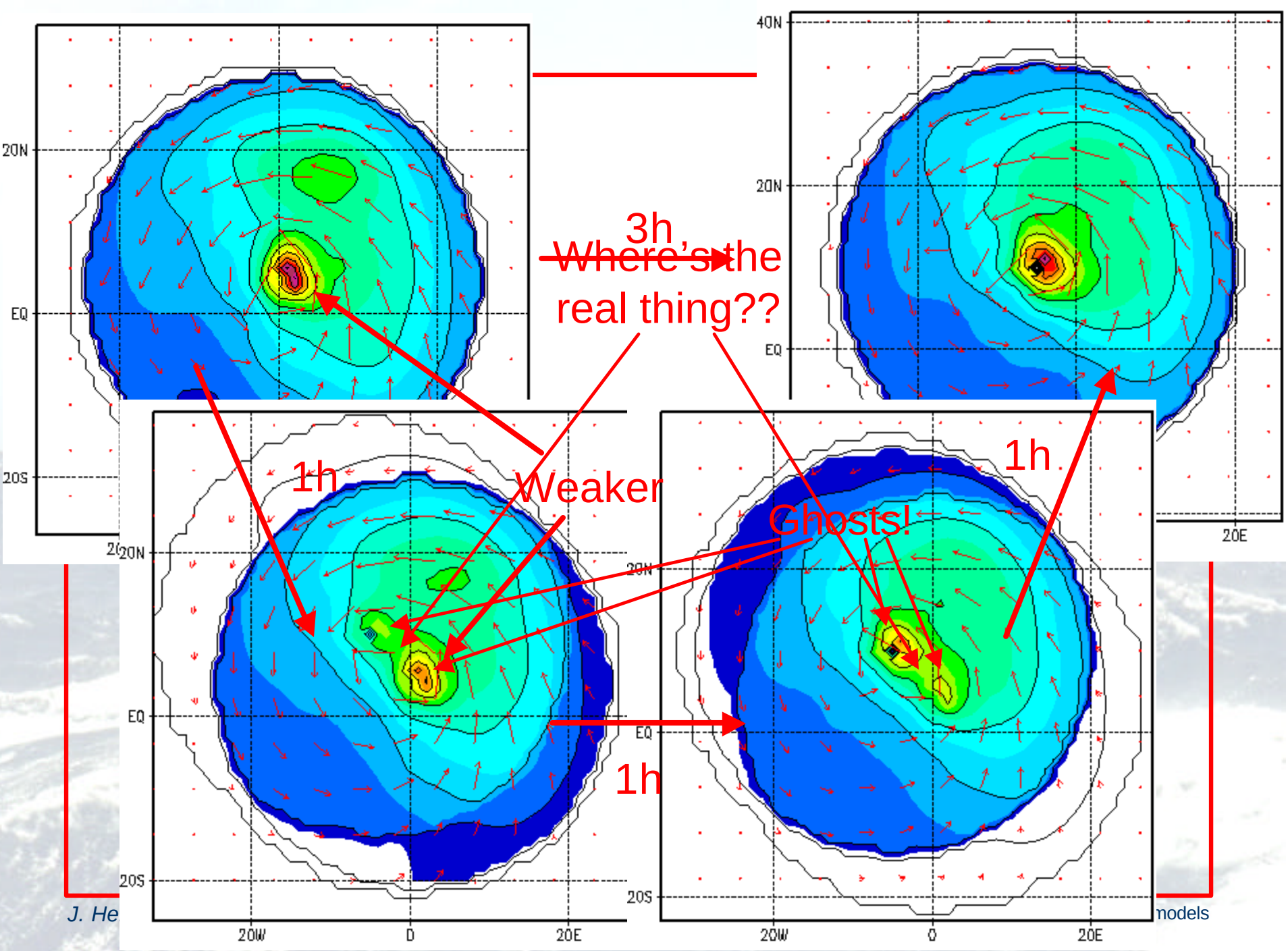


- Near storm core (maximum winds):
  - Operational resolution (25km) vs. high resolution (5km).
  - 20-30% relative errors.
  - Operational resolution: multi -scale model grid would do better.

Fine structure + Accuracy max location

Wind resolution in hurricane wave models

- Wind's time interval, first problems:
  - Initially, hurricane wave model was forced with 3h winds (standard output from GFDL).
  - Problems: 3h too large period, hurricane moving too fast.
  - Time-space interpolation led to "ghost" fields.


20N
EQ
20S
40N
20N
EQ
20E
3h
Where's the
real thing??
1h
Weaker
Ghosts!
1h
20N
EQ
20S
20W
0
20E
1h
20N
EQ
20S
20W
0
20E

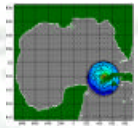
J. He models

Wind resolution in hurricane wave models

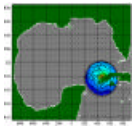
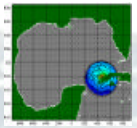
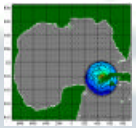
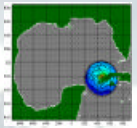
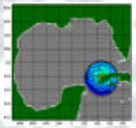
- How far should one go?
  - At NCEP hurricane wave model, 0.25º resolution ⟶ 5min internal time step.
  - Ideal intake: 5min wind fields.
  - Too large files, busy I/O.
- Solutions:
  - Coupled atmosphere-wave model.
  - Best compromise: how far should stretch time resolution of winds in hurricanes?

Wind resolution in hurricane wave models

- Sensitivity tests:
  - Hurricane Lili (Sep/Oct 2002).
  - NOAA/HRD winds at 5min resolution.
  - WAVEWATCH III, grid covering the Gulf of Mexico, at ≈10km resolution.
- Storm-centered winds re-sampled at:
  - 15min.
  - 1h.
  - 3h.
  - 6h.
- Winds set to 0 outside hurricane (r=300km).

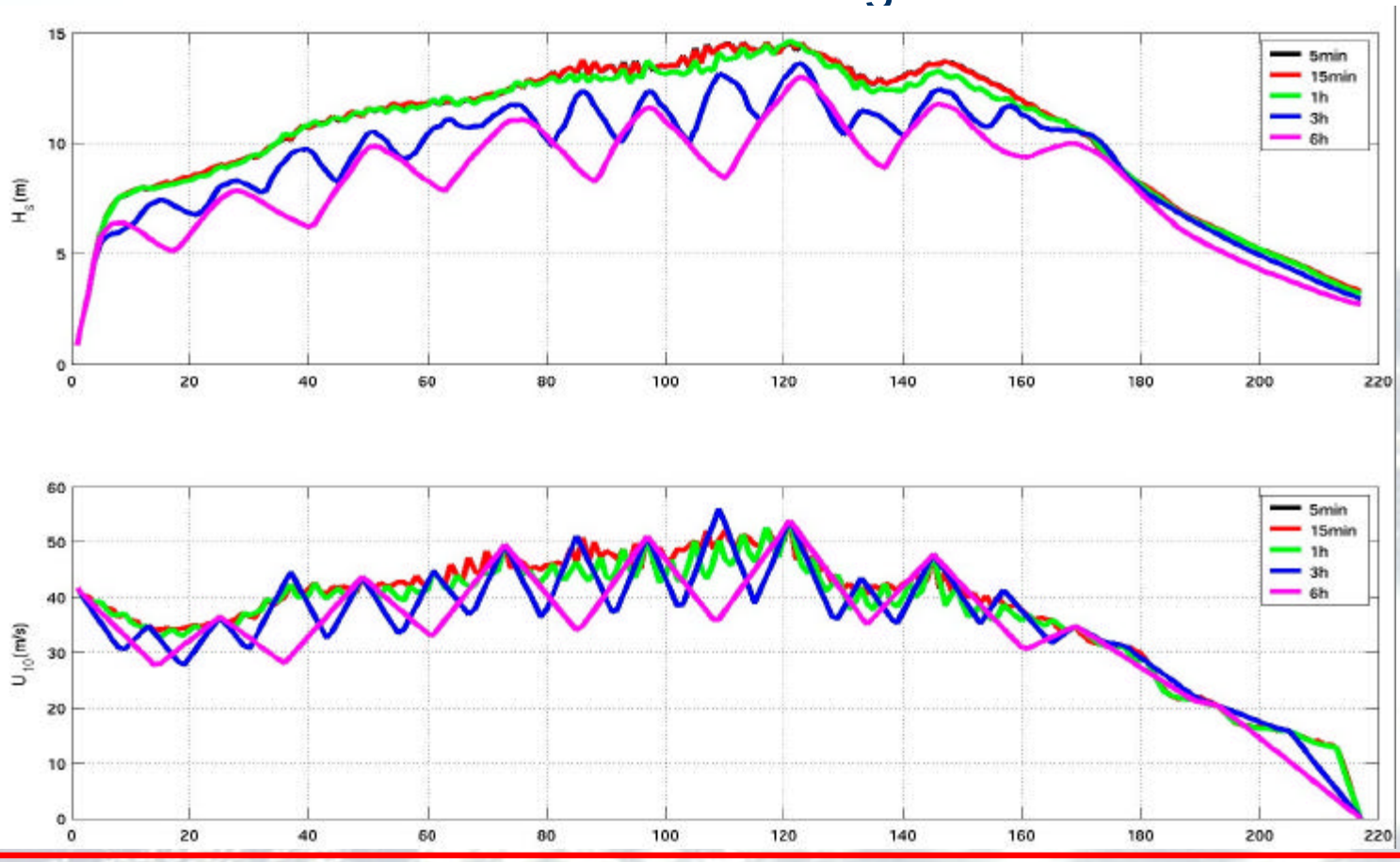


Wind resolution in hurricane wave models

- Zooming onto a frame following hurricane:
  - 5min. 
  - 15min. 
  - 1h. 
  - 3h. 
  - 6h. 

Wind resolution in hurricane wave models

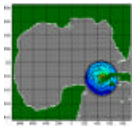
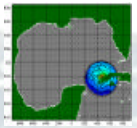
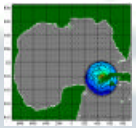
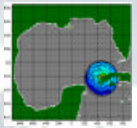
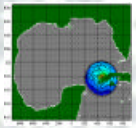
- Maximum wind and wave heights.



Wind resolution in hurricane wave models

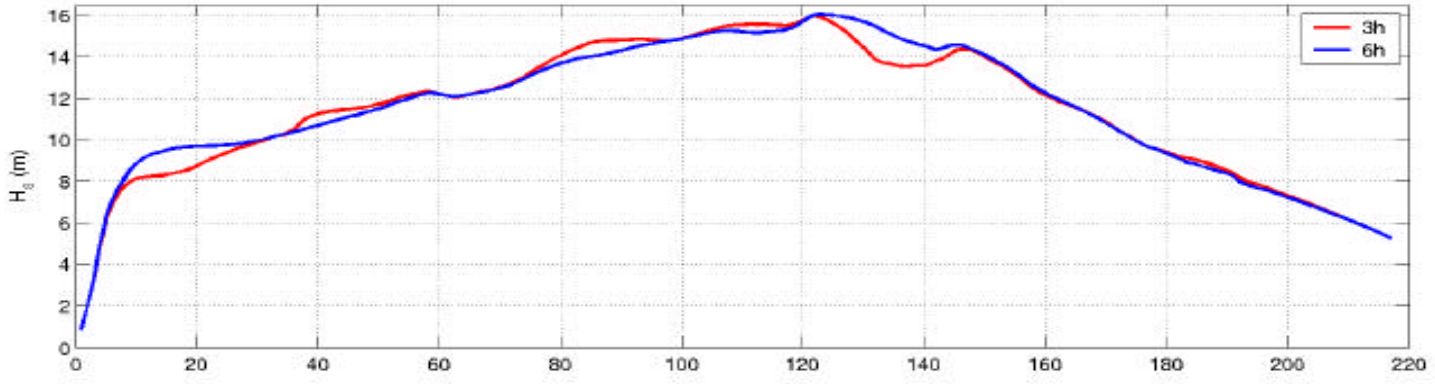
- What if you don’t have:
  - Coupled atmosphere-wave model?
  - Wind fields with hourly resolution?
- Investigation to find alternatives.
- Experiments with moving grid version of WAVEWATCH III:
  - Same resolutions as fixed grid seen before.
  - Grid 600km x 600km.
  - Following (centered at) hurricane’s eye.

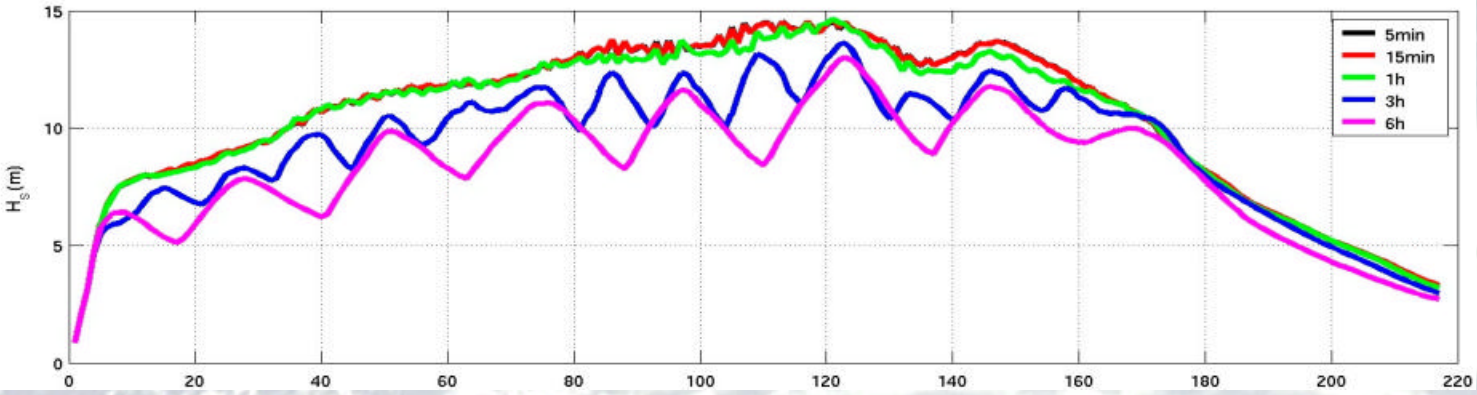
Wind resolution in hurricane wave models

- Moving grid wave height fields.
  - 5min. 
  - 15min. 
  - 1h. 
  - 3h. 
  - 6h. 

Wind resolution in hurricane wave models

- Maximum wind and wave heights, moving grid.

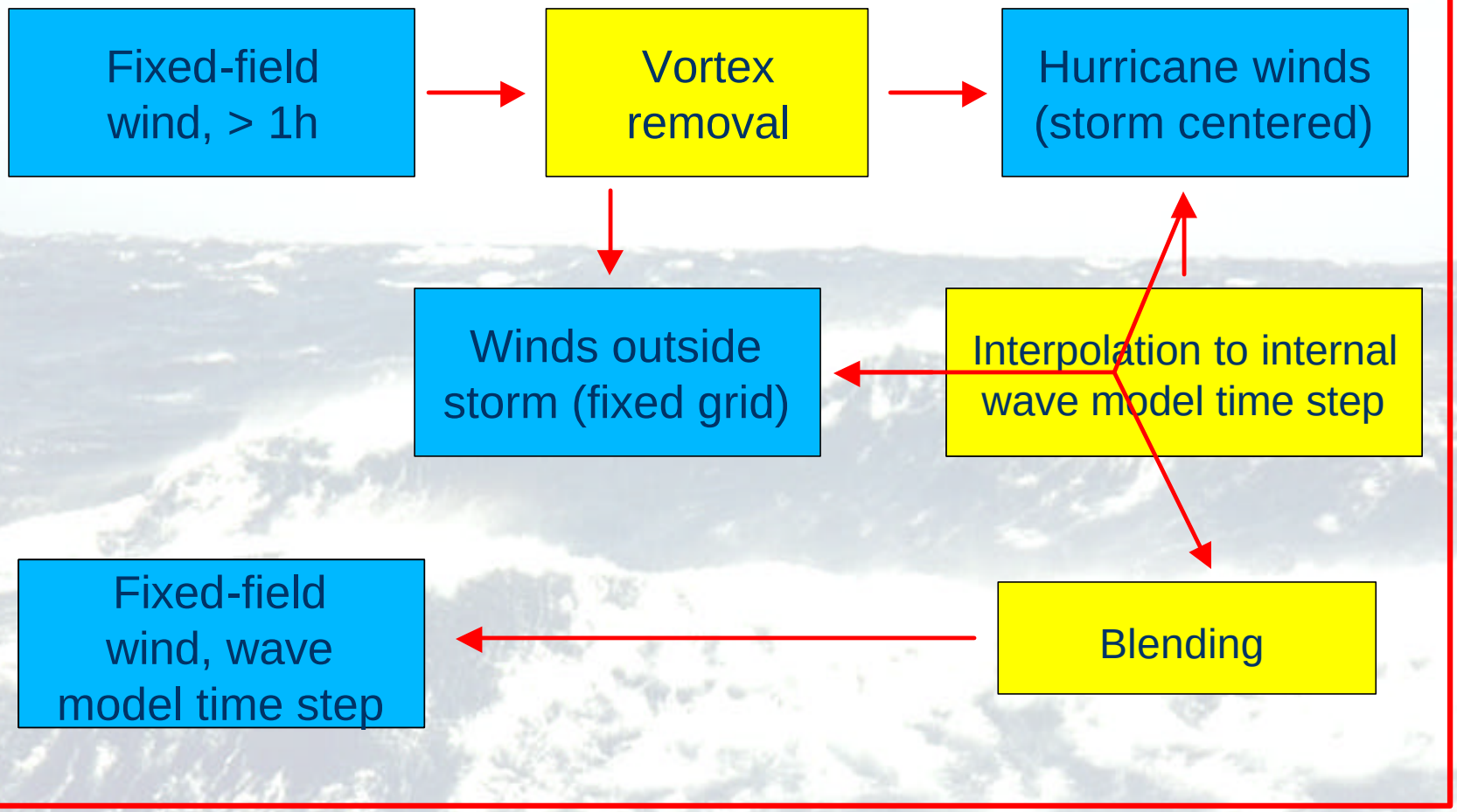




Wind resolution in hurricane wave models

- No coupling, no hrly winds, you can get away if:
  - Map storm winds to frame centered at hurricane's eye (vortex removal).
  - Interpolate to wave model internal time step.
  - Map back into fixed frame of reference.
- Advantages:
  - Accepts wind fields at irregularly spaced times (HRD analyses).
  - Applicable also to other intense storms.
  - No ghosts!!

Wind resolution in hurricane wave models



Practical Forecasts of Maximum Height

- Parametric model: estimates of Hs max.
  - Based on JONSWAP relation.
  - X_{eq}: function of R_{max}, V_f and U_{max}.
  - Young (1988) model:

$$\frac{gH_s^{max}}{U_{max}^2} = \alpha \left(\frac{gX_{eq}}{U_{max}^2} \right)^{\beta}.$$

$$\frac{X_{eq}}{R'} = a_f U_{max}^2 + b_f U_{max} V_{fm} + c_f V_{fm}^2 + d_f U_{max} + e_f V_{fm} + f_f,$$

$$\frac{X_{eq}}{X_{eq}^{ref}} = \alpha \log \left(\frac{R_{max}}{R_{max}^{ref}} \right) + 1,$$

$$a_r = \alpha R_{max}^{ref}$$

$$b_r = R_{max}^{ref} \left(\alpha \log R_{max}^{ref} - 1 \right).$$

$$R' = a_r \log R - b_r.$$

  - X_{eq} depends directly on V_f and U_{max}.
  - R_{max} is a scaling parameter.

Practical Forecasts of Maximum Height

- Alternative approach:
  - Ross (1976), max H_s depends only on R_{max}.
  - Strong evidence, also on V_f and U_{max}.
  - Young (1988), present study:
    - ⇨ Effective cumulative fetch, on c_g (peak).

$$\frac{gH_s^{max}}{U_{max}^2} = \alpha \left(\frac{gX_{eq}}{U_{max}^2} \right)^{\beta}.$$

$$\chi = \left[R_{max} \left(1 + \gamma V_f / c_g^{max} \right) \right]^{\lambda},$$

$$X_{eq} = a\chi^{b},$$

$$f_p = \frac{g}{U_{max} 0.123}$$

$$2\pi f_p = \frac{g}{U_{max} \alpha_J X_{eq}^{\beta_J}}.$$

Practical Forecasts of Maximum Height

- Objectives:
  - Revisit Young's parameterization.
    - Used 2G model, now 3G: WAVEWATCH III.
  - Verify alternative parameterization.
- 200+ Experiments with moving Rankine vortex.
  - R_{max}, 20, 30, 50 and 80km.
  - V_f, 0 to 10m/s, 2.5m/s increments.
  - U_{max}, 20 to 60m/s, 10m/s increments.
- WWIII, 25 frequencies (0.04-0.41Hz), 36 directions.
- Moving grid, storm centered, 0.1deg resolution.
- Max winds in front and rear quadrant.

Practical Forecasts of Maximum Height

- Preliminary results, only front quad.
- Green: Y88.
  - 5% RMSE.
- Red: new data.
  - 12% RMSE.
- New data: doesn't support Y88 model as strongly as Y88 data.

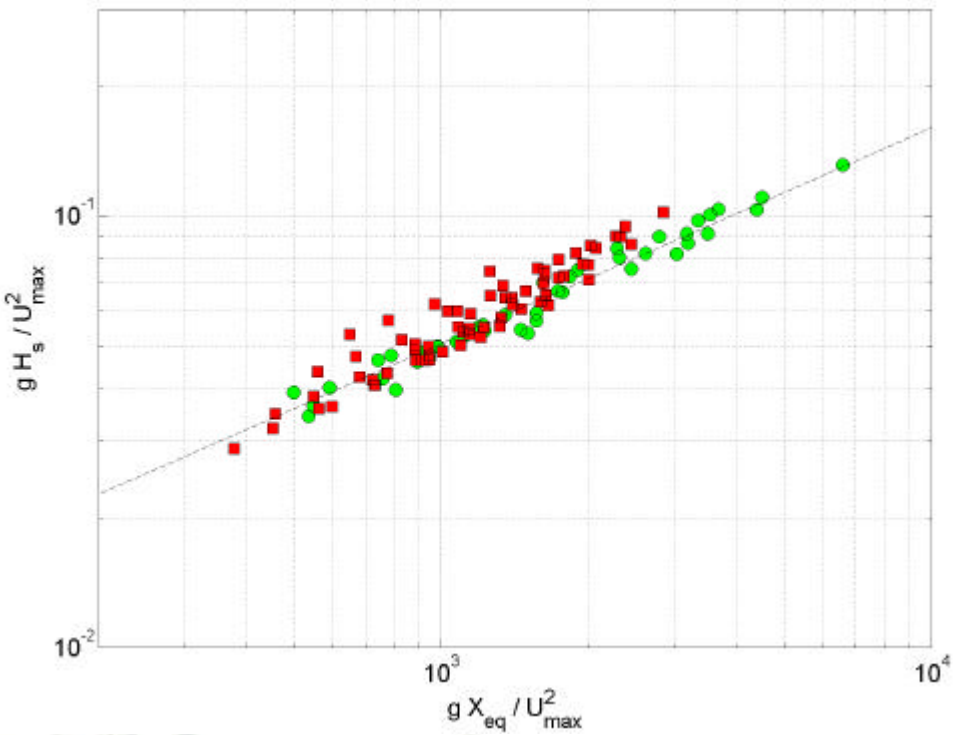


Table 2: Parameter values for equation (5) and (6) obtained from FQS and Y88 data.

Run	a_f	b_f	c_f	d_f	e_f	f_f	a_r	b_r
Y88	-2.175×10^{-3}	1.506×10^{-2}	-1.223×10^{-1}	2.190×10^{-1}	6.737×10^{-1}	7.980×10^{-1}	22.5×10^{3}	70.8×10^{3}
FQS	5.936×10^{-5}	1.719×10^{-2}	-3.479×10^{-2}	8.555×10^{-2}	1.319×10^{-1}	-5.340×10^{-1}	29.7×10^{3}	103.7×10^{3}

Practical Forecasts of Maximum Height

- Verification of alternative model:
- New data, red.
  - 2.5% RMSE.
- Y88, green.
  - 3.9% RMSE.
- Which to choose?
  - Real data.

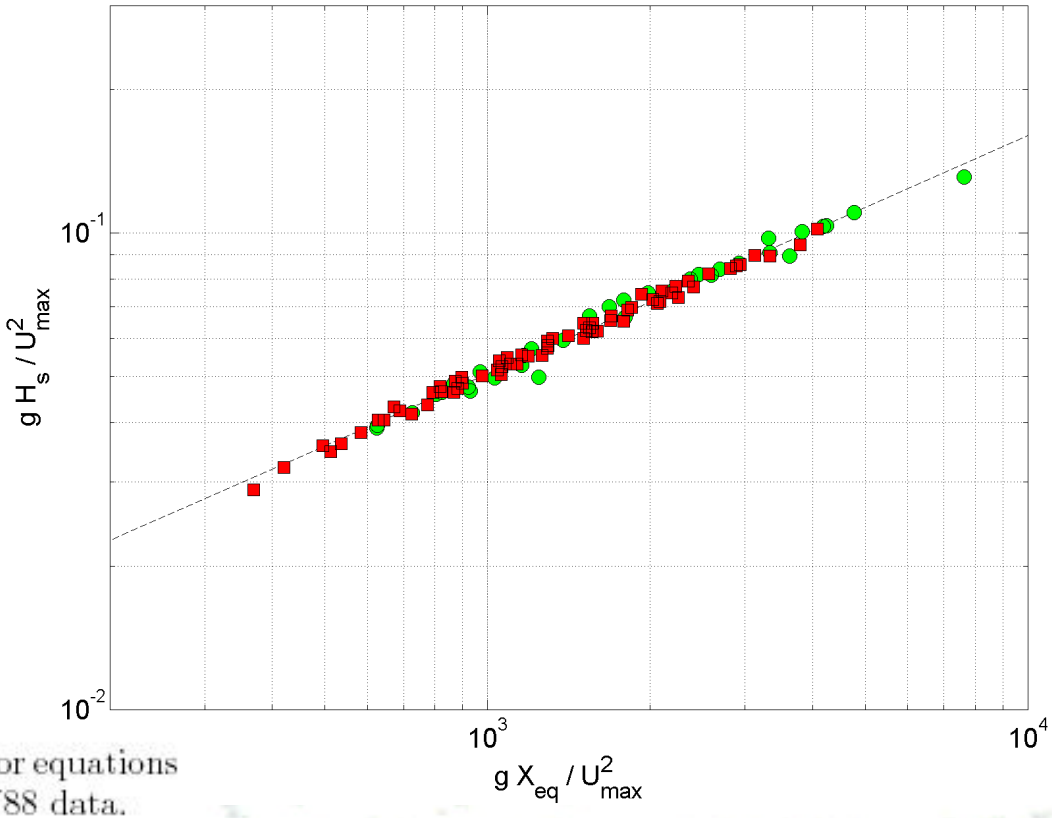


Table 3: Preliminary parameter values for equations (9) and (10) obtained from FQS and Y88 data.

Run	γ	λ	a	b
Y88	2.3	0.5	1106.1	0.76
FQS	2.1	2.8	0.6	0.29

QUESTIONS?

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