Design Conditions for the Hurricane Metocean Environment: White-Capping and Depth-Limited Wave Breaking

U.S. Department of Energy

WINDExchange Offshore Wind Webinar

http://apps2.eere.energy.gov/wind/windexchange

15 Jan 2015

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Combined Wind & Wave Loading Guidance

Both the IEC 61400-3 and the ABS BOWTI standards specify Design Load Cases (DLCs) for combined wind and wave loading by assuming that for a given design storm, the peak 3-second gust and the maximum individual wave height would not occur at the same instant at a given turbine location. They therefore specify two combined DLCs:

- ***Extreme wind with reduced wave*** *(e.g., DLC 6.1b): the peak 3-second gust at hub height is combined with a "reduced" individual wave height that is lower than the maximum individual wave*

  $V_{gust,\ max} = 1.4\ V_{ref\ 10\ min}$ $\qquad$ $H_{reduced} = 1.3\ H_s$

- ***Extreme wave with reduced wind*** *(e.g., DLC 6.1c): the maximum individual wave height is combined with a "reduced" 3-second gust speed that is slower than the peak gust*

  $V_{gust,\ reduced} = 1.1\ V_{ref\ 10\ min}$ $\qquad$ $H_{max} = 1.86\ H_s$

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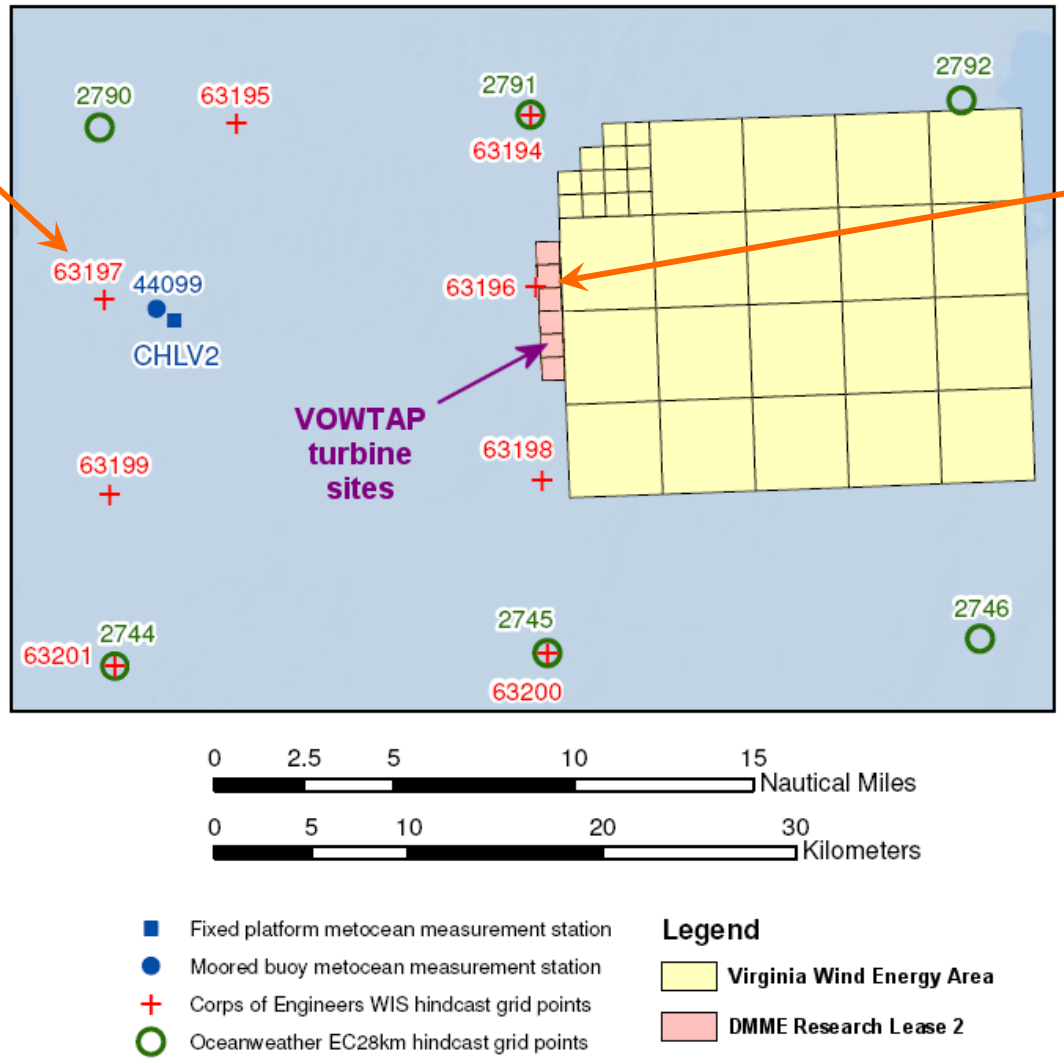
Is this the right multiplier and what kind of wave is it?

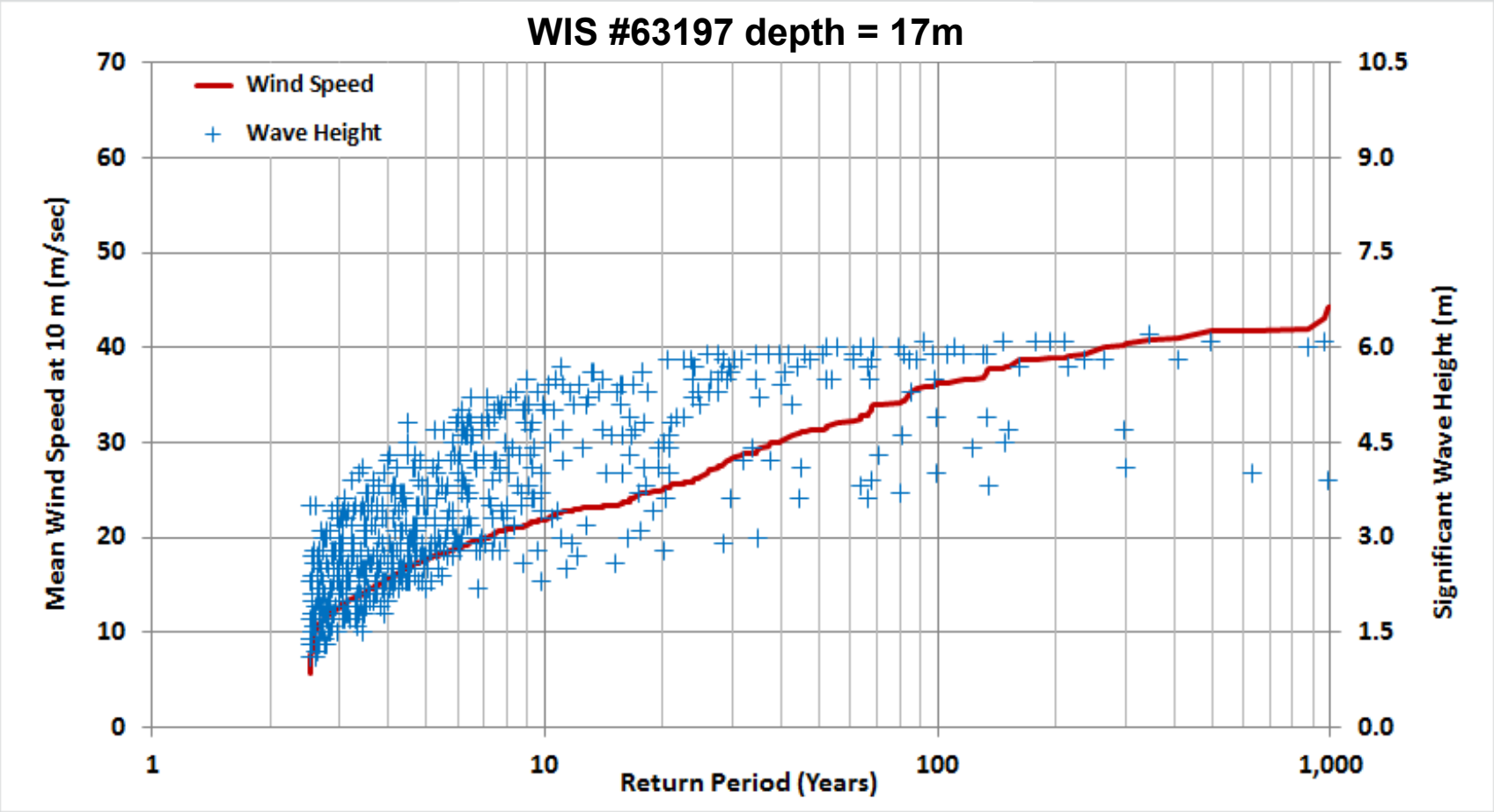
Comparing SHM-SWAN Wind & Wave Hazard Curves across Virginia Nearshore Shelf

WIS grid point nearest to wind and wave measurement validation stations



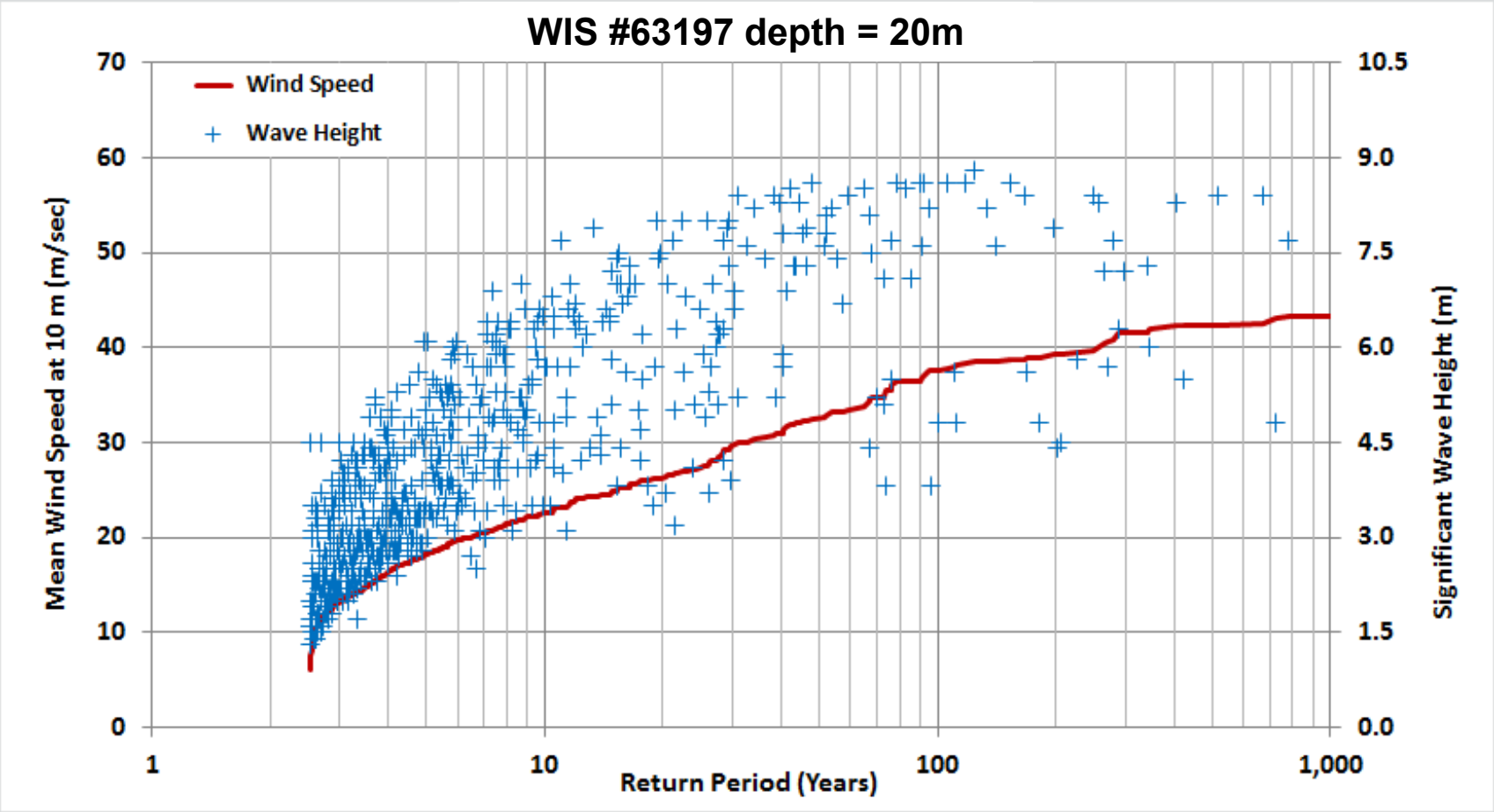
WIS grid point nearest to Virginia Offshore Wind Technology Advancement Project

Mean Surface Wind Speed Hazard Curve and Associated Significant Wave Heights at WIS 63197



Hagerman, G., M. Forte, J. Hanson, P. Vickery, S. Banik, J. Blanco, and L. Atkinson, 2014. *Development of an Integrated Extreme Wind, Wave, Current, and Water Level Climatology to Support Standards-Based Design of Mid-Atlantic Offshore Wind Projects*. Final Report for Technology Assessment Project #672. Herndon, VA: U.S. Bureau of Environmental Enforcement.

Mean Surface Wind Speed Hazard Curve and Associated Significant Wave Heights at WIS 63196



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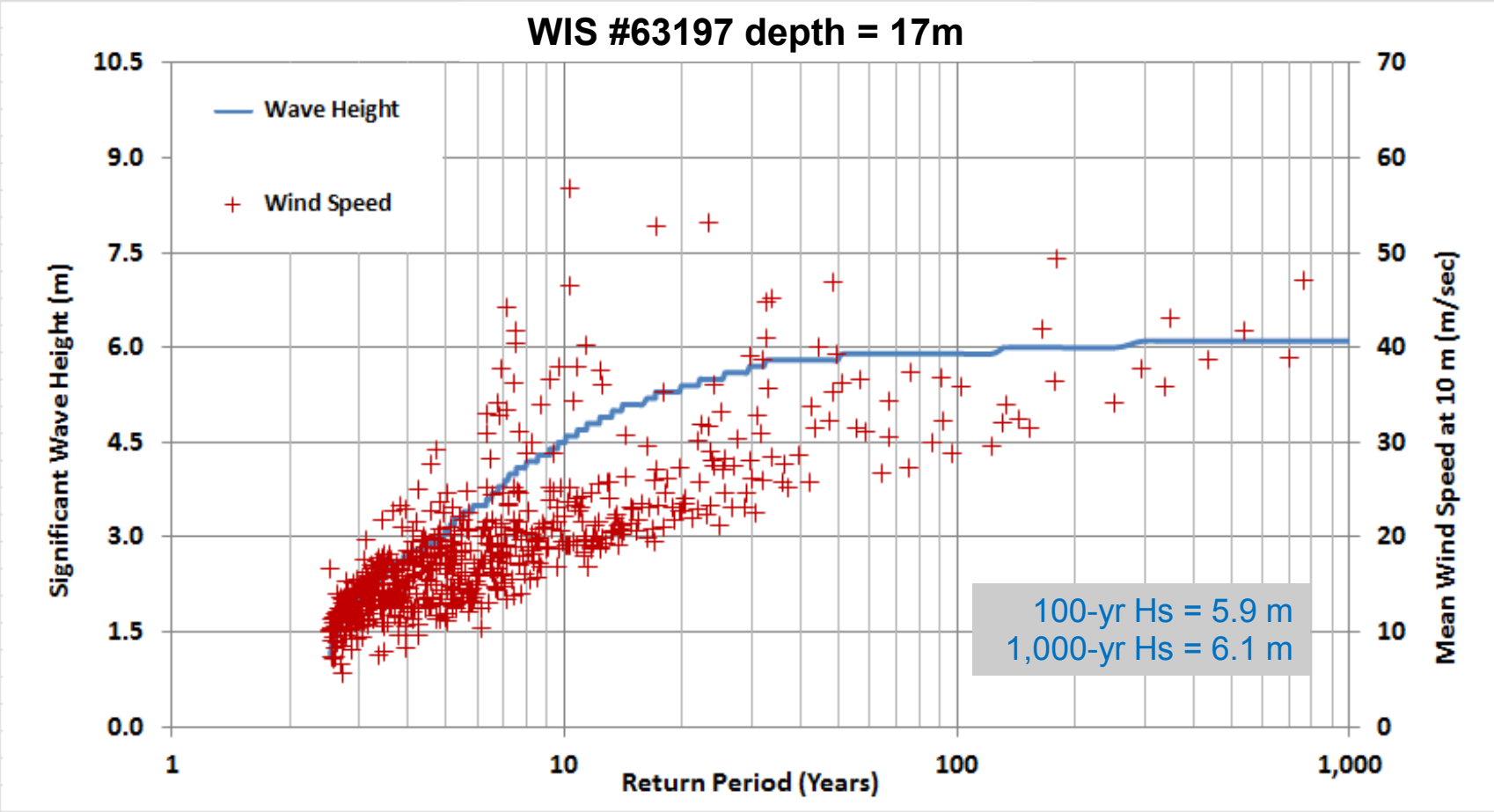
Significant Wave Height Hazard Curve and Associated Mean Surface Wind Speeds at WIS 63197



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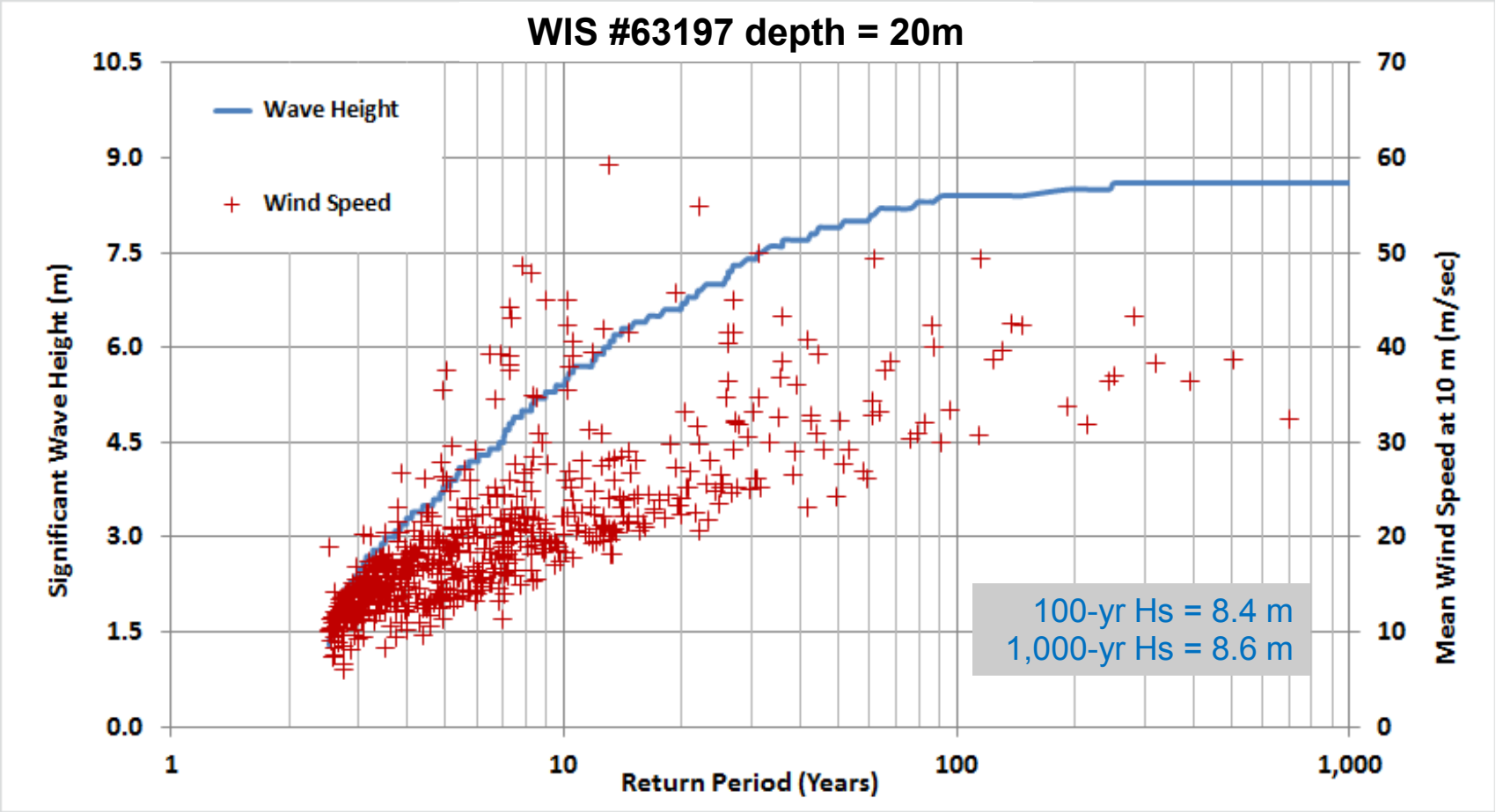

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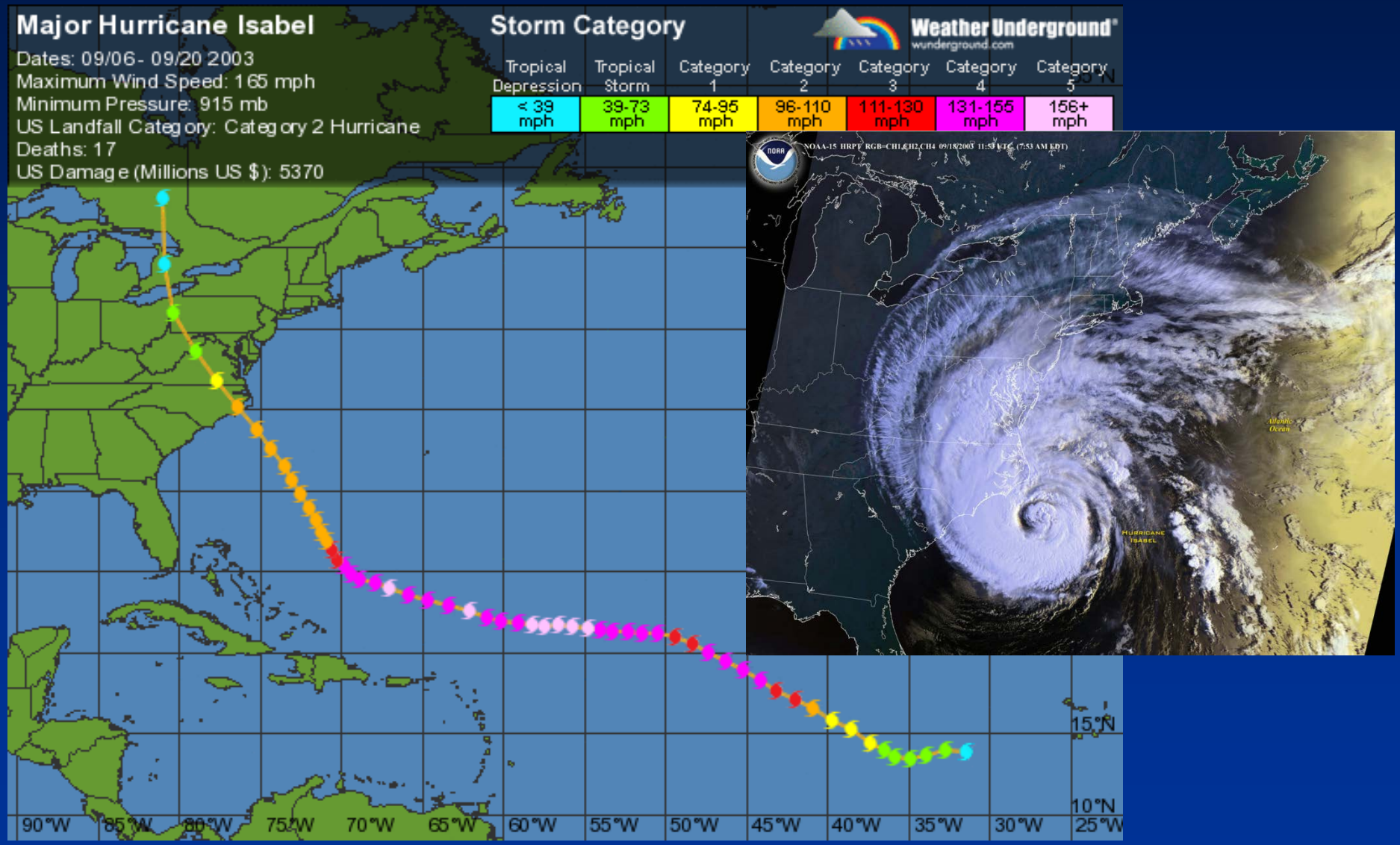
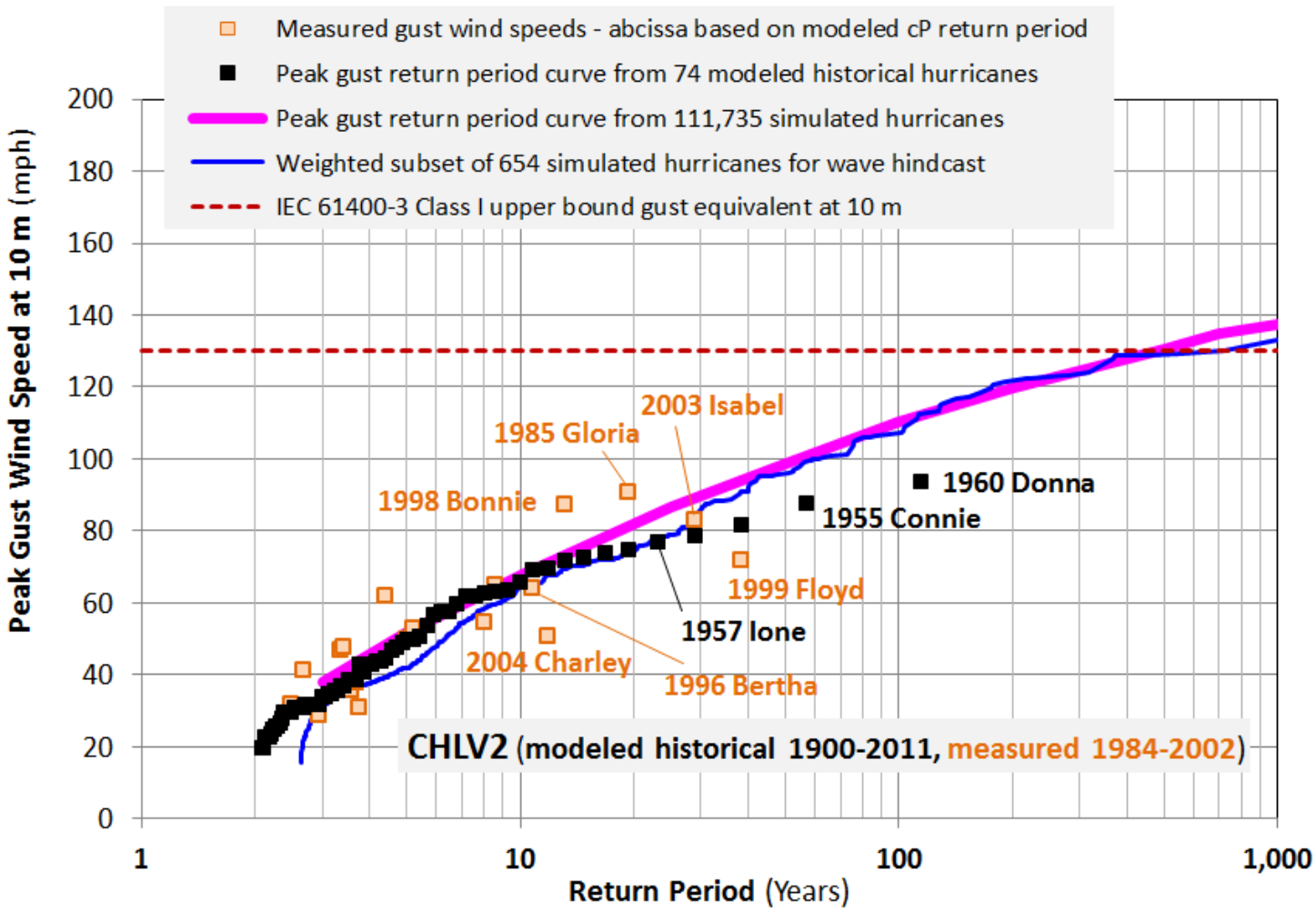
Sep 2003 Hurricane Isabel Track & Satellite Image



Sep 2003 Hurricane Isabel a ~30-year Wind Event



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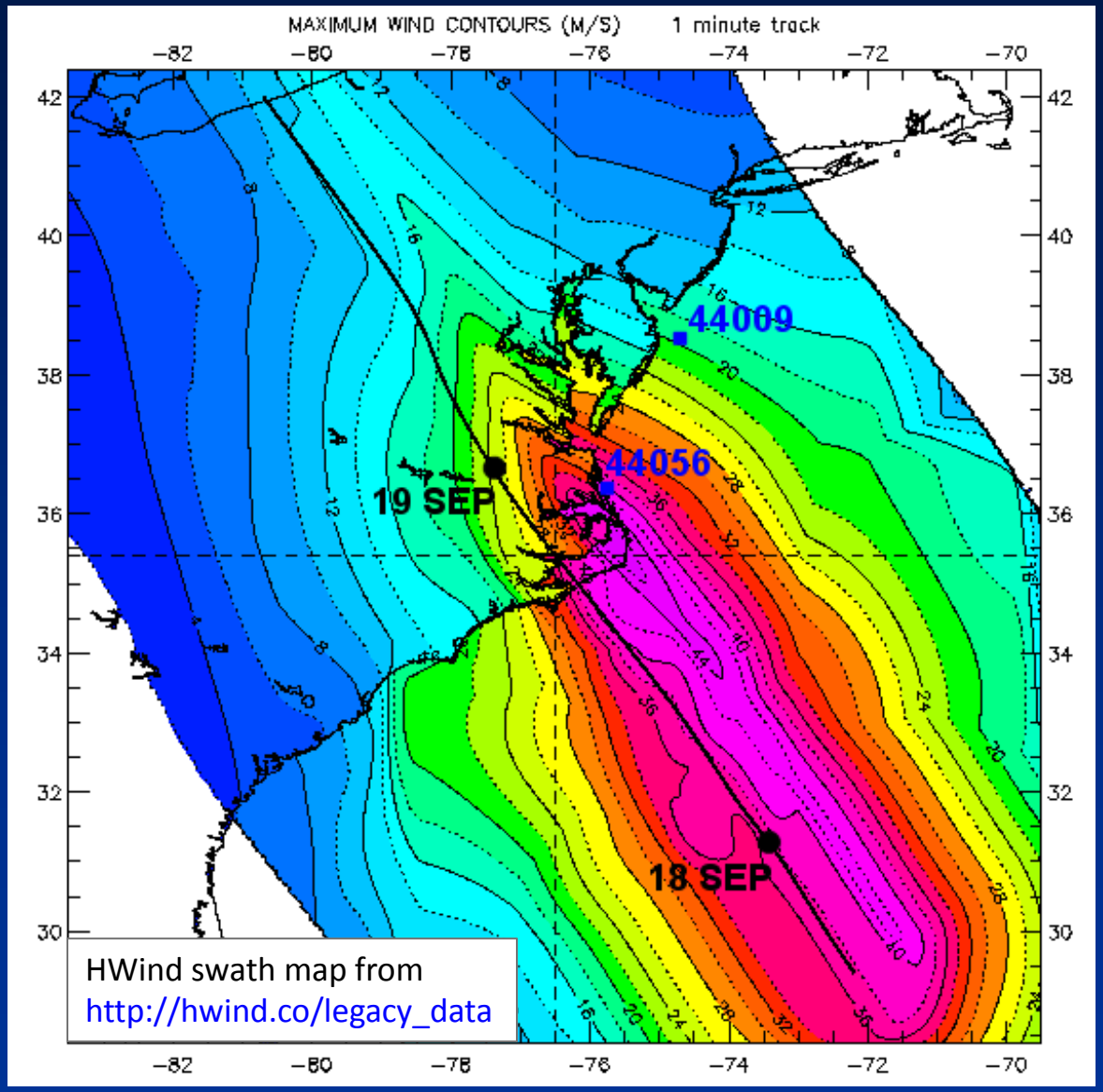
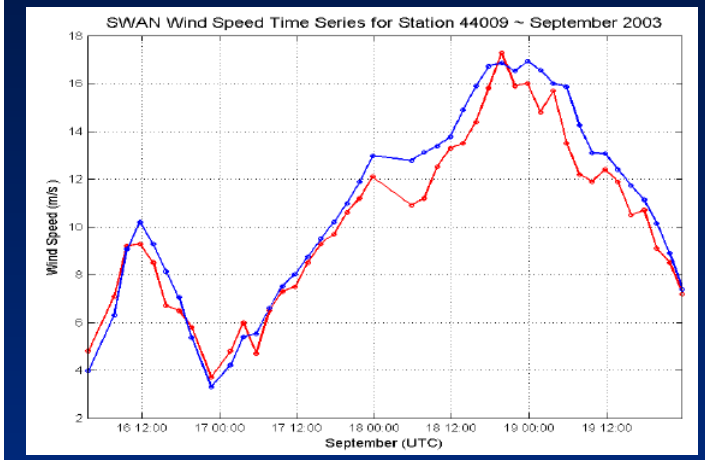
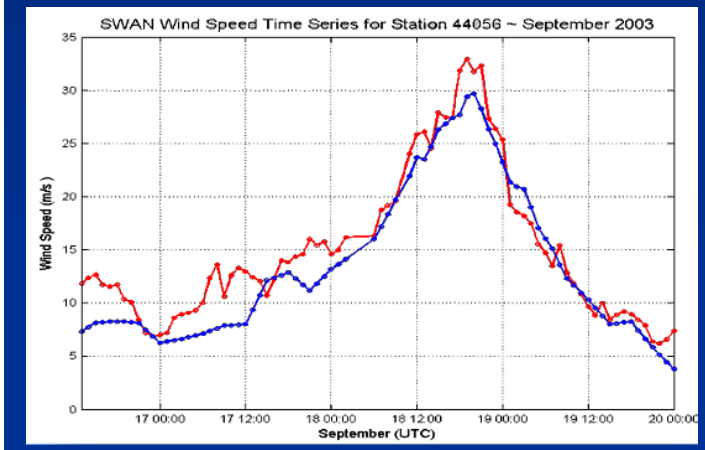
Sep 2003 Hurricane Isabel SWAN Modeling Wind Speed Validation (Jeff Hanson & colleagues)

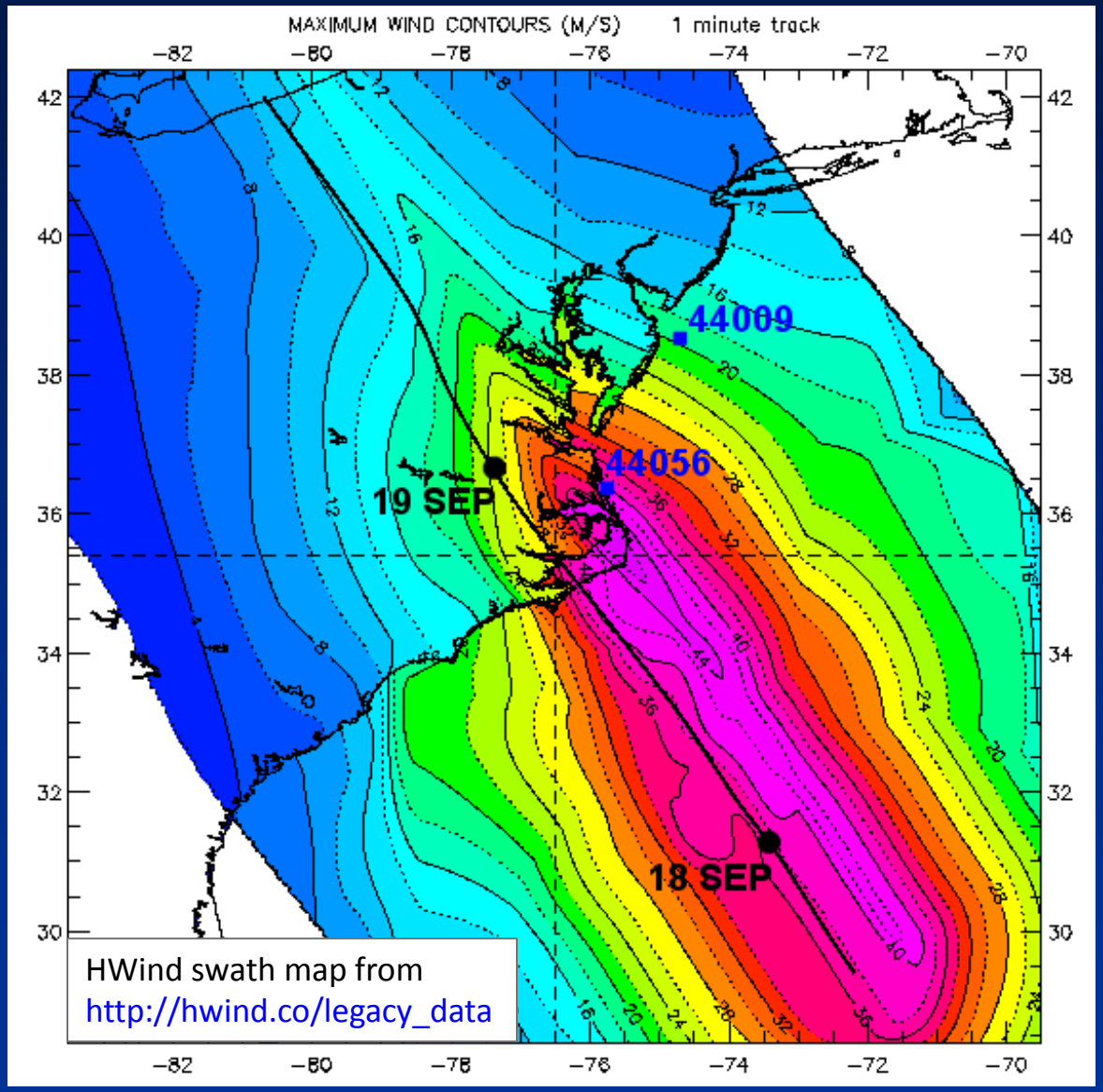


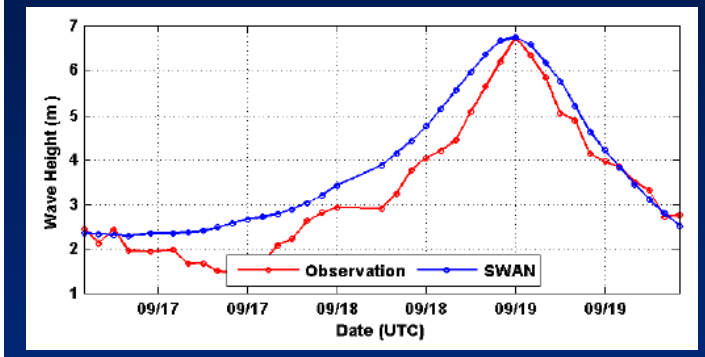


Observation
Model



Sep 2003 Hurricane Isabel SWAN Modeling Wave Height Validation (Jeff Hanson & colleagues)





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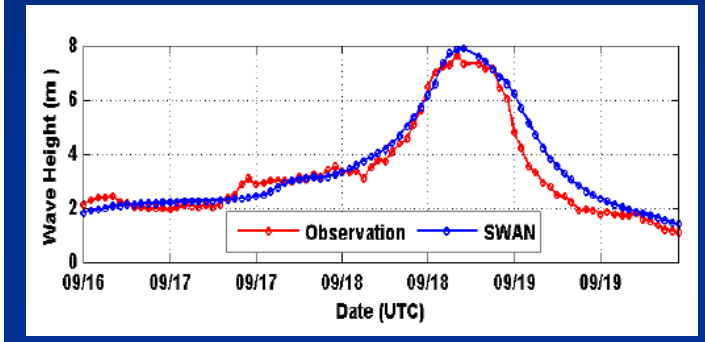
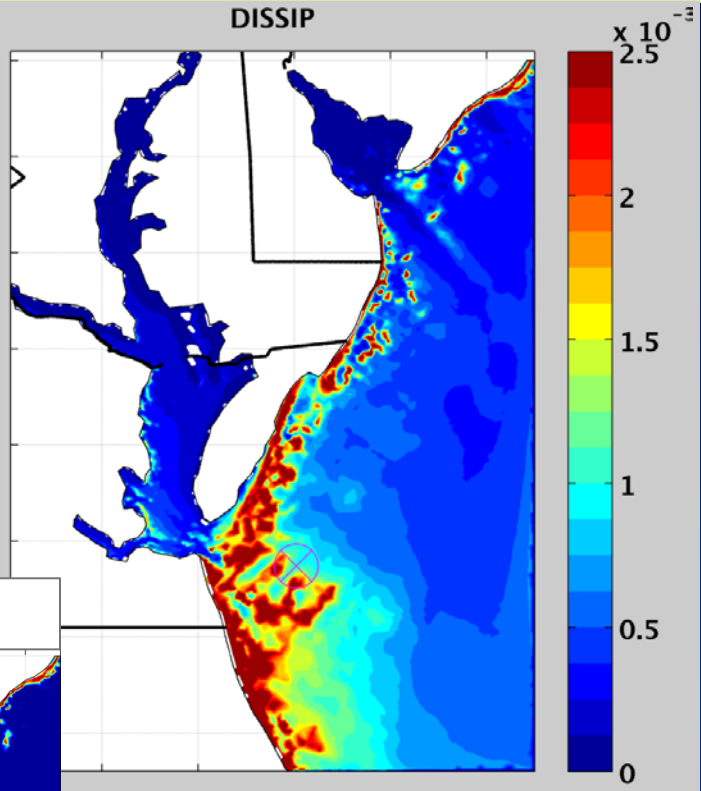


Sep 2003 Hurricane Isabel SWAN Modeling
Wave Dissipation over Shelf (Jeff Hanson & colleagues)

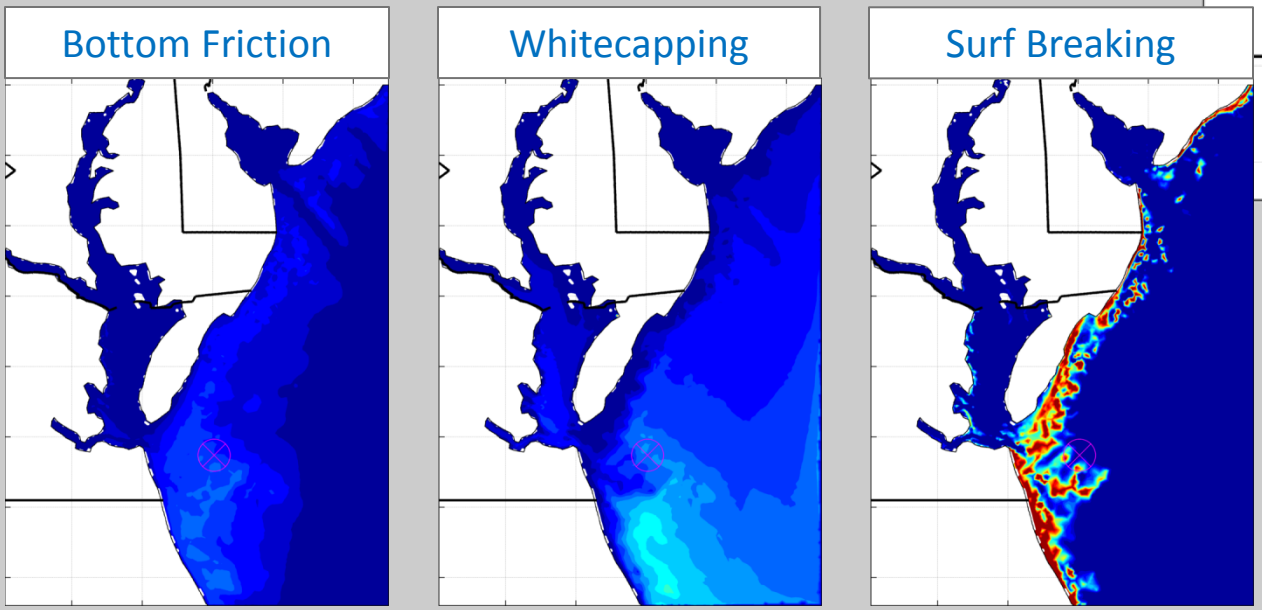
SWAN modeled wave dissipation during Sep 2003 Hurricane Isabel at storm peak Hs

- JONSWAP bottom friction, $CF_{JON} = 0.038$
- Westhuysen et al (2007)* whitecapping
- Surf breaking at $\gamma = H_{max}/d = 0.73$

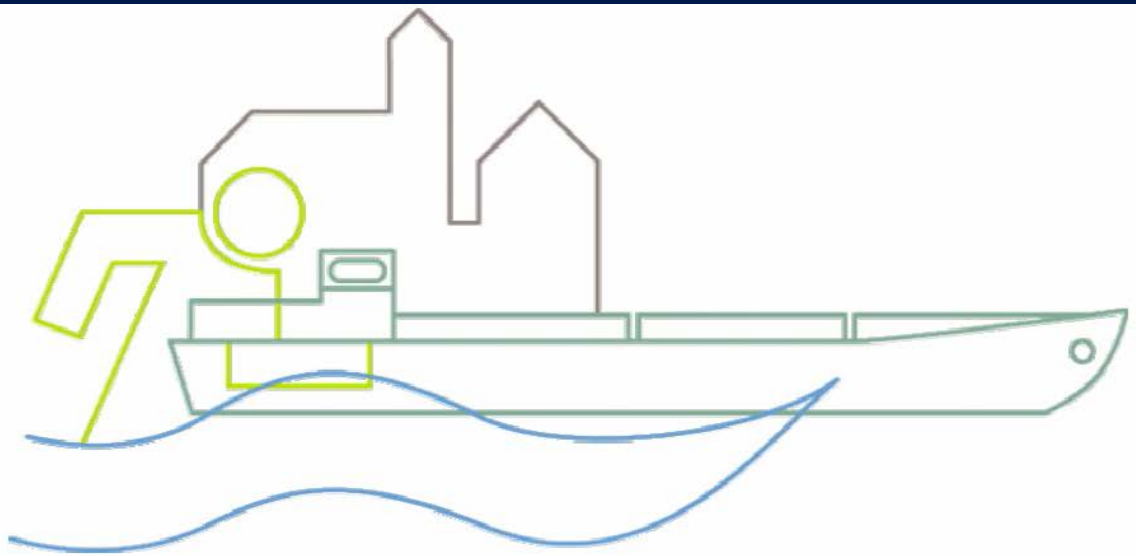
*van der Westhuysen, Zijlema and Battjes, 2007. *Coastal Engineering*, 54, pp.151-170



Comparison of Dissipation Source Terms at Common Scale



Down-Looking Wave Radar Results from German Federal Institute of Hydrology



bfg Bundesanstalt für Gewässerkunde

A Powerful Method of Measuring Sea Wave Spectra and Their Direction

C. Blasi, S. Mai, J. Wilhelmi, T. Zenz, U. Barjenbruch
Federal Institute of Hydrology (BfG)

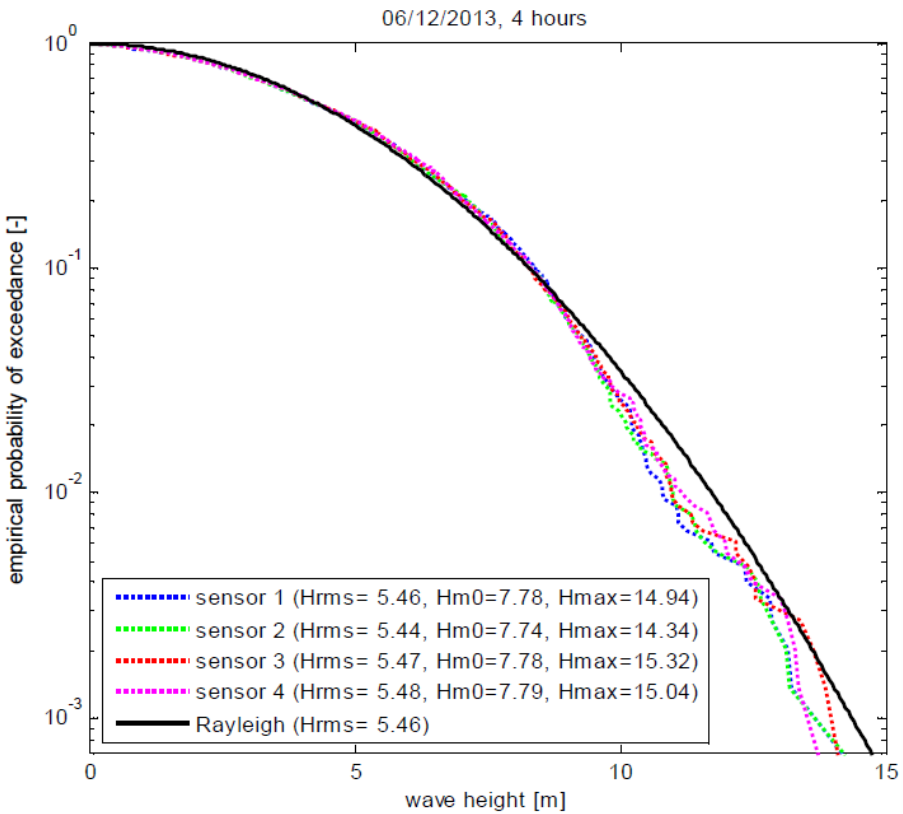
11th International Conference on Hydroscience & Engineering
Session T12 "Remote Sensing and Field Monitoring"

2 October 2014

Down-Looking Wave Radar Results from German Federal Institute of Hydrology

Interesting findings by using the radar array

wave conditions during "Xaver" - measured distribution vs. Rayleigh distribution



empirical distribution by Rayleigh

$$P(H) = \exp\left(-\left(\frac{H}{H_{rms}}\right)^2\right)$$

- the distribution proposed by Rayleigh overestimates the probability of higher waves during the storm 'Xaver'
- one reason may be the limited water depth of about 30 m causing wave breaking

several authors proposed alternative wave distributions to account for this deviation, e.g. *Forristall*, Glukhovskii / Klopman, Mendez et al., Battjes / Groenendijk

Down-Looking Wave Radar Results from German Federal Institute of Hydrology

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Conclusions / Summary

concerning wave height distributions

- Within the given measurement accuracy the wave height distributions of Mendez et al. and Mai (modifying Battjes / Groenendijk) are able to reproduce the wave height distributions measured during the extreme winter strom "Xaver" at the FINO 1 research station.

- The assumption of Rayleigh distribution for wave heights is not valid having "shallow" water depth ("shallow" in the meaning of $H_s/d = 1/3$ or $H_{max}/d = 1/2$).

- In the design of offshore constructions one should calculate "maximum" wave heights using depth dependent wave height distributions (to avoid too conservative designs).

Rayleigh distribution predicts the most probable maximum wave height (*Hs*) in a storm as:

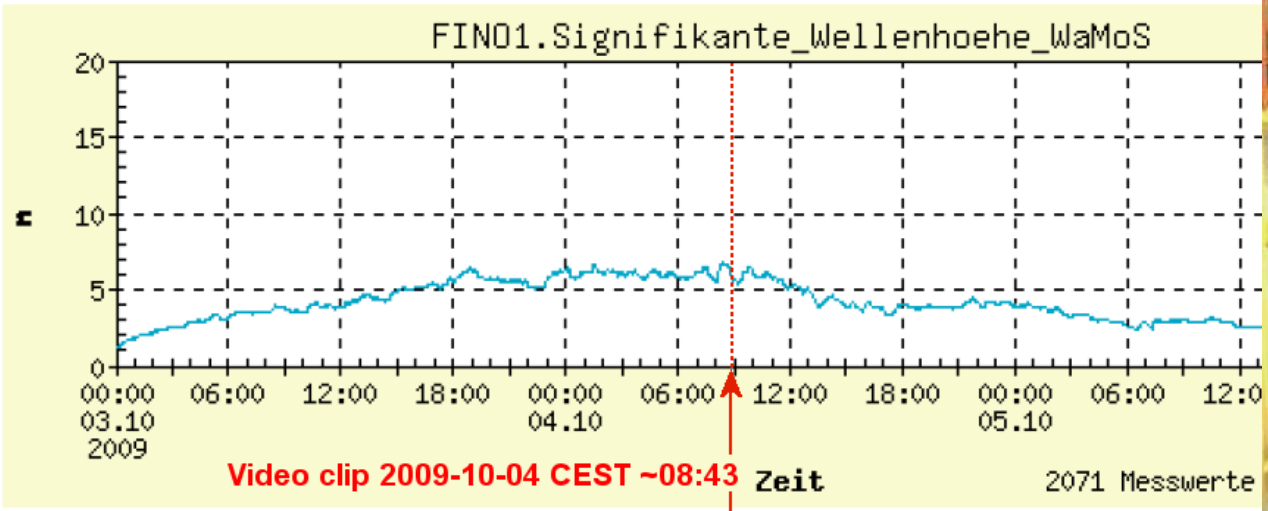
$$H_m = H_s \sqrt{\frac{\ln N}{2}}$$

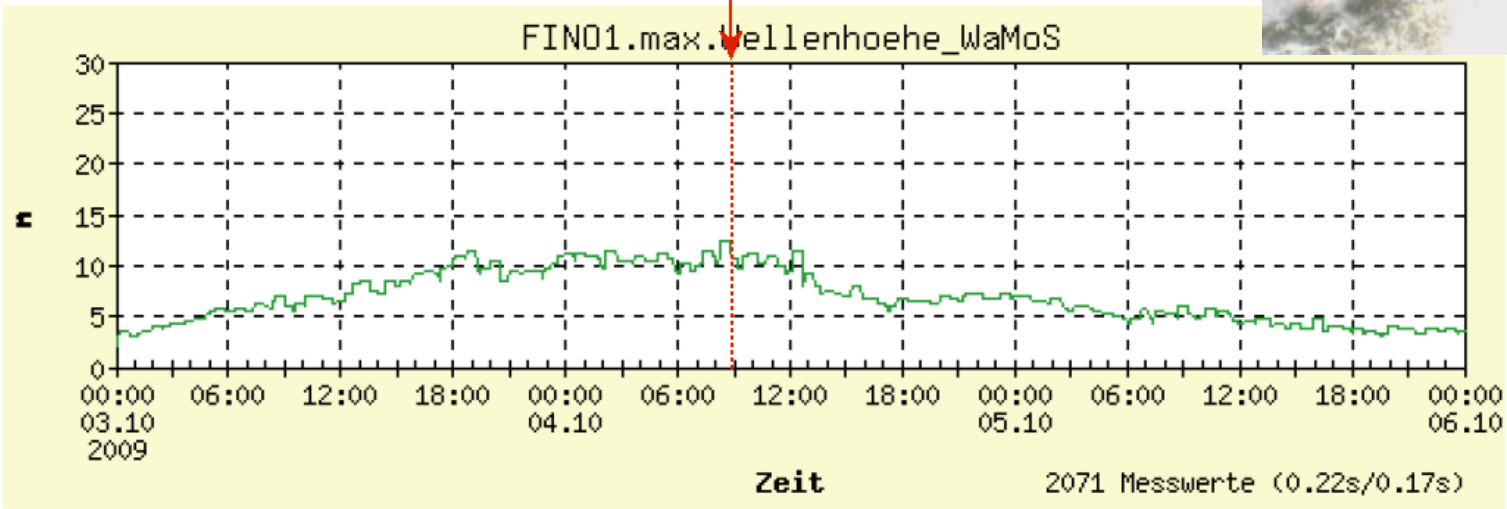
where:
Hm = most probable maximum wave height
N = Number of waves in storm time series

For *N*= 1,000 waves, *Hm* = 1.86 *Hs*

Instance of Wave Breaking at FINO-1

Storm Event October 2009





Time lapse of breaking wave in 28 m depth at FINO-1 platform in North Sea; significant wave height = 5.2 to 5.3 m

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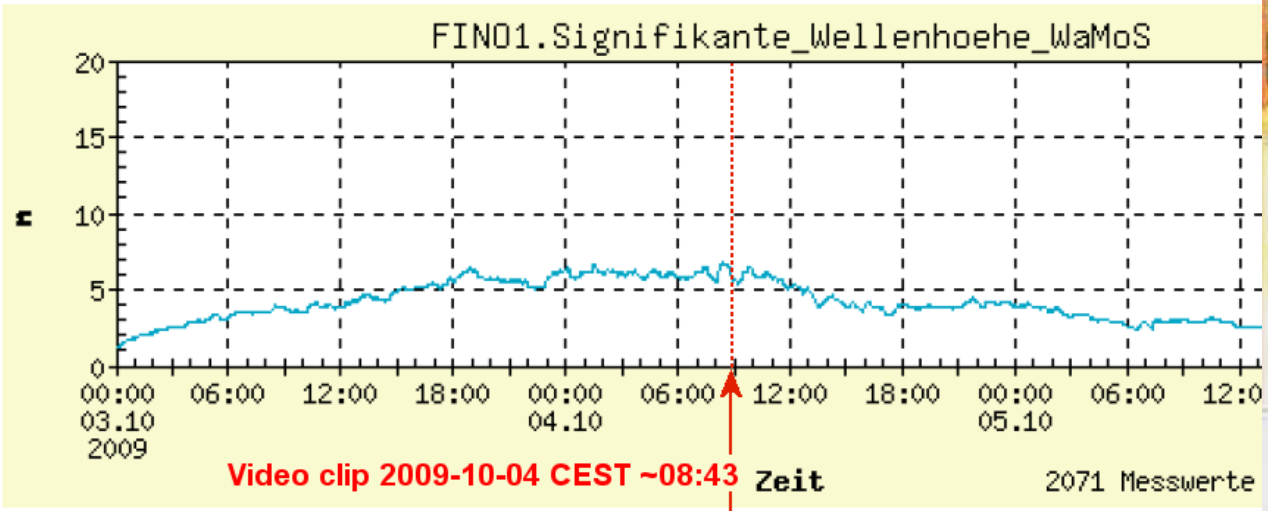
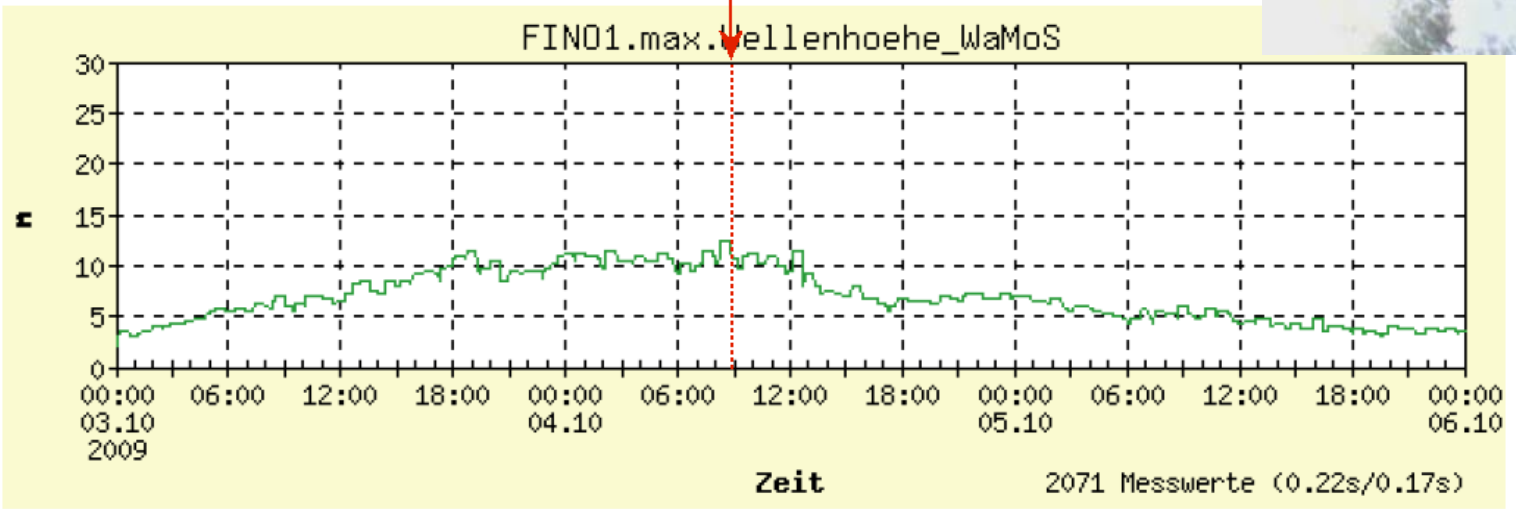
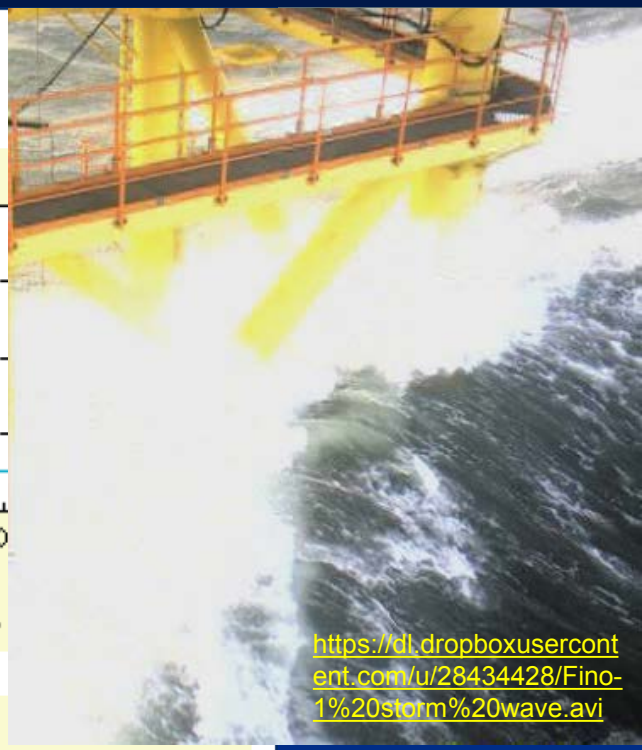






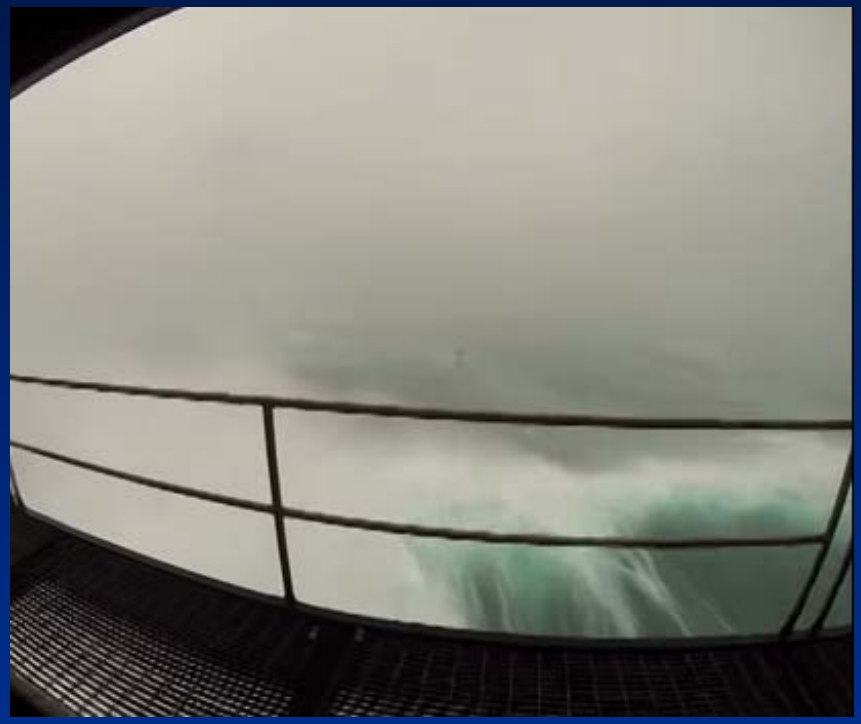
https://dl.dropboxusercontent.com/u/28434428/Fino-1%20storm%20wave.avi

Time lapse of breaking wave in 28 m depth at FINO-1 platform in North Sea; significant wave height = 5.2 to 5.3 m

July 2014 Hurricane Arthur at Frying Pan Tower Richard Neal Videos of Breaking Waves (Hs unknown)

www.youtube.com/watch?v=t40g_OBmdfs

Amazingly long-lived spilling breaker starts to break at 0:31 into video and continues breaking for ~25 seconds



www.youtube.com/watch?v=HoZ023o8y44

Watch breaker that appears from under the platform at 1:01 into video, and washes over buoy at 1:07

Thank You!

Email: hagerman@vt.edu