Hurricanes and offshore wind farms

Mark Powell NOAA-AOML-HRD

NOAA's Atlantic Oceanographic and Meteorological Laboratories

AOML Virginia Key, Miami FL

CIMAS Cooperative Institute for Marine and Atmospheric Studies

MIAMI FIU FAU NSU

UF THE FLORIDA STATE UNIVERSITY USF

Center for Ocean-Atmospheric Prediction Studies

Hurricane Research
Physical Oceanography
Ocean Chemistry

Outline:

- Impacts on wind farms
- Risk Modeling
- Design conditions
- Field Program

Super Typhoons have damaged wind farms in China and Japan

Saomai 2006

Maemi 2003

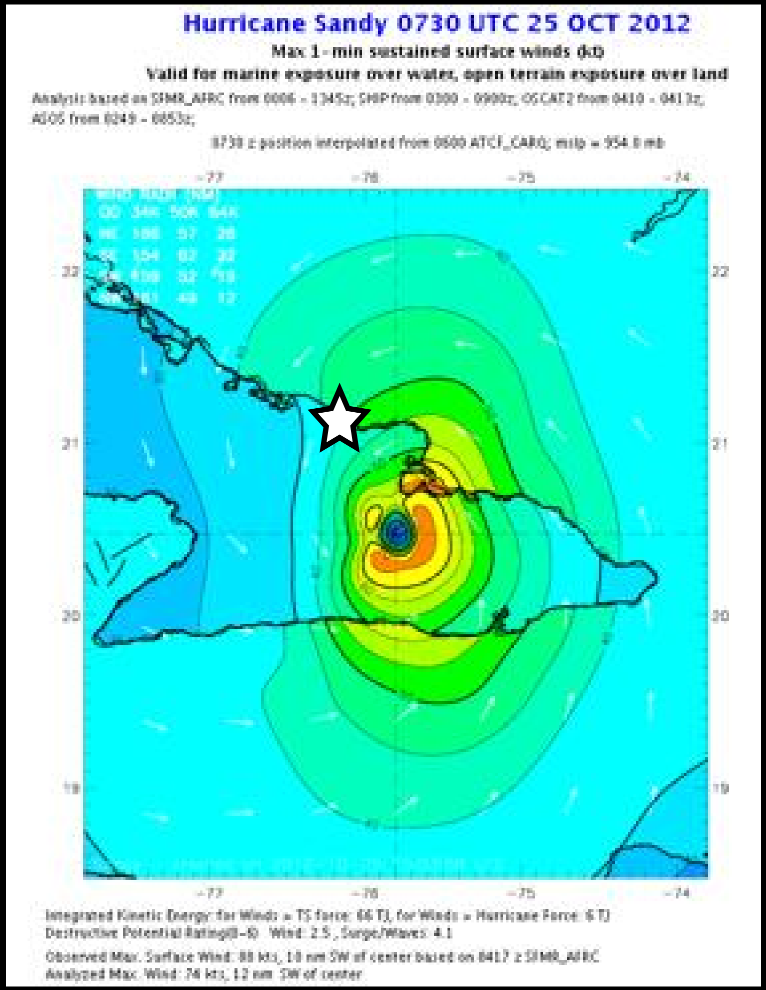
Photo: Ishisaki (From Eqecat Brochure)

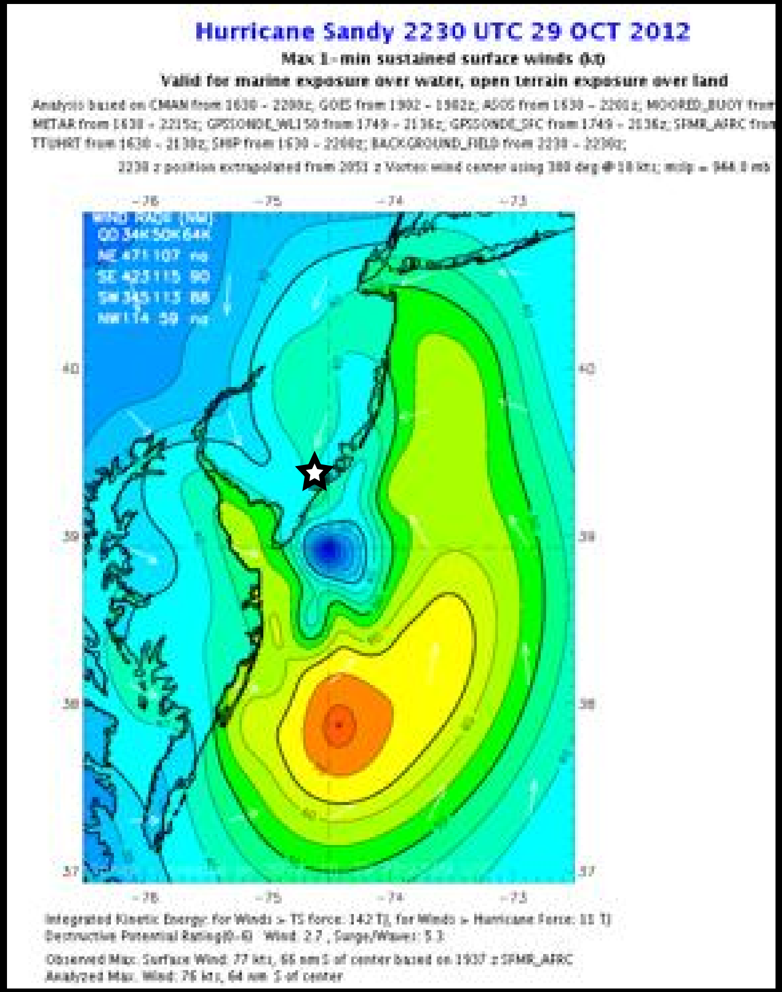
Active yaw controls failed or could not keep up with turbulence from complex terrain

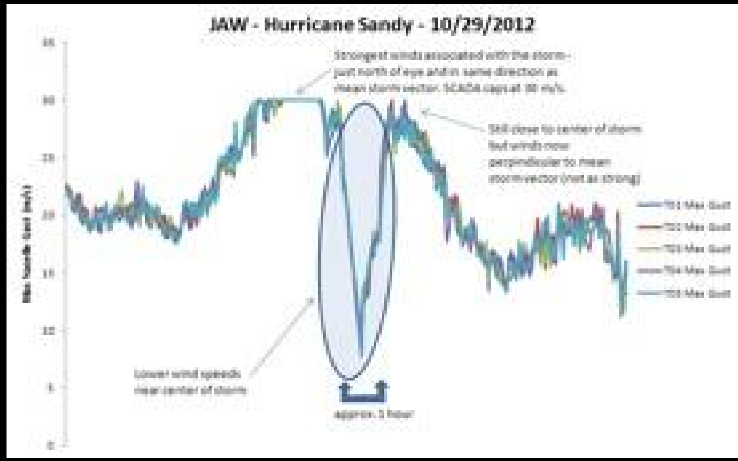
Hurricane Sandy

Gibara wind farm in Holguin Cuba

Jersey Atlantic wind Farm (Five 1.5 MW turbines)







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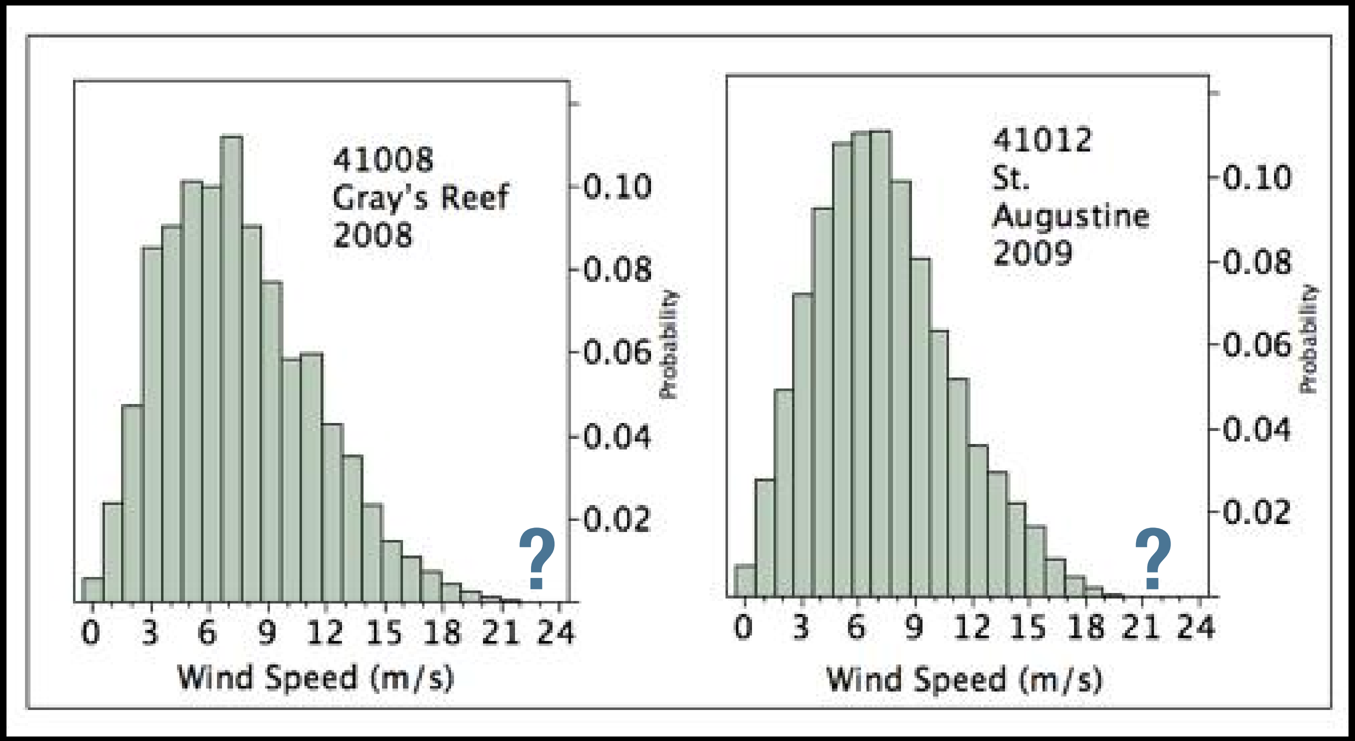
Impacts

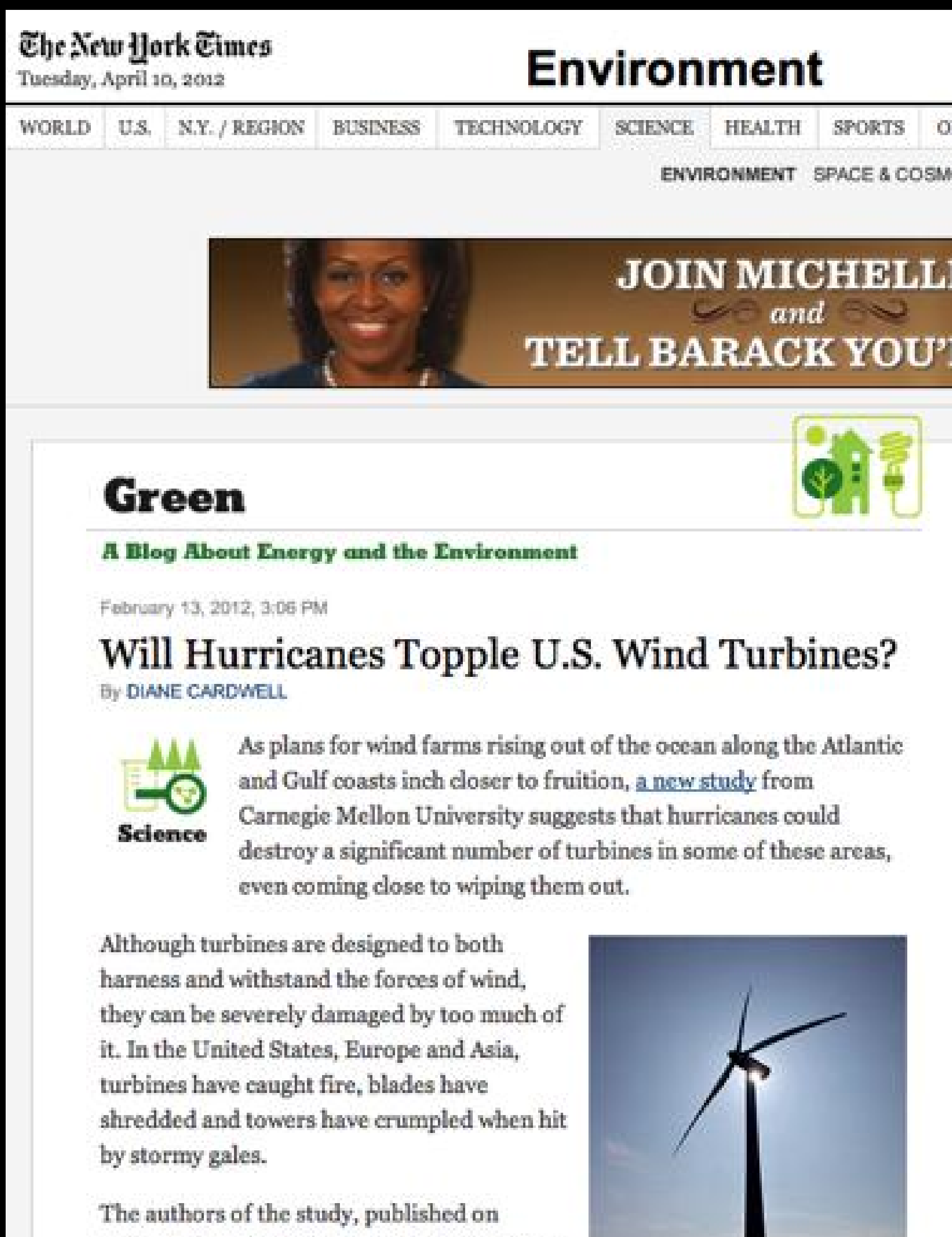
- Wind farms can withstand hurricanes provided yaw controls remain active
- Turbine resistance to hurricanes based on risk and design conditions

• Risk

- **Return Period Winds**
    - On site station data not sufficient to determine return periods
    - Short records and gaps in historical data prevent extreme wind climate assessment
    - Modeling needed to simulate longer period wind records



"In the most vulnerable areas now being considered by developers, nearly half the turbines in a farm are likely to be destroyed in a 20-y period"



The New York Times
Tuesday, April 10, 2012

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Green

A Blog About Energy and the Environment

February 13, 2012, 3:06 PM

Will Hurricanes Topple U.S. Wind Turbines?

By DIANE CARDWELL

Science

As plans for wind farms rising out of the ocean along the Atlantic and Gulf coasts inch closer to fruition, a new study from Carnegie Mellon University suggests that hurricanes could destroy a significant number of turbines in some of these areas, even coming close to wiping them out.

Although turbines are designed to both harness and withstand the forces of wind, they can be severely damaged by too much of it. In the United States, Europe and Asia, turbines have caught fire, blades have shredded and towers have crumpled when hit by stormy gales.

The authors of the study, published on

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BREAKING NEWS:
Rick Santorum suspends campaign for GOP n

Hurricanes pose risk to offshore wind farms

By Doyle Rice, USA TODAY

When an oncoming hurricane curves offshore — as most do — we usually breathe a sigh of relief. But soon, those offshore storms might give us so about.

Find a Forecast

Enter ZIP or city

Offshore hurricanes could proposed wind farms just according to a study out M the National Academy of S

"We find that hurricanes po turbines off the U.S. Gulf a are designed to the most s authors from Carnegie Me write.

Engineer Stephen Rose ar study in response to a 200 Department of Energy, wh should ideally provide one USA by 2030. The enginee

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Will Hurricanes Wipe Out Offshore Wind Farms?

A new study says that the high winds of severe storms could wreck nearly half of U.S. offshore wind turbines within a 20-year period. Can turbine builders make hurricane-resistant wind farms?

By Stephanie Warren

Lillgrund offshore wind farm, Sweden.

February 14, 2012 4:00 PM

TEXT SIZE: A . A . A

The future of wind energy is out to sea. For the United States to reach ambitious goals for tapping the energy—the Department of Energy estimates that wind could provide 20 percent of American energy by 2030—wind farms may need to go places where the wind blows steadily —and where there are no people to complain about turbines ruining the view from their veranda.

Offshore wind farms are already popular in Europe, and they're garnering major interest by

Exaggerating?

~~Quantifying~~ the hurricane risk to offshore wind turbines

Stephen Rose[a], Paulina Jaramillo[a,1], Mitchell J. Small[a,b], Iris Grossmann[a], and Jay Apt[a,c]

[a]Department of Engineering and Public Policy; [b]Department of Civil and Environmental Engineering; and [c]Tepper School of Business, Carnegie Mellon University, 5000 Forbes Avenue, Pittsburgh, PA 15213

Edited by William C. Clark, Harvard University, Cambridge, MA, and approved January 10, 2012 (received for review July 19, 2011)

VS

Mark D. Powell[a,1] and Steven Cocke[b]
[a]*National Oceanic and Atmospheric Administration, Atlantic Oceanographic and Meteorological Laboratories, Hurricane Research Division, Miami, FL 33149; and* [b]*Center for Ocean-Atmospheric Prediction Studies, Florida State University, Tallahassee, FL 32310*

LETTER

Hurricane wind fields needed to assess risk to offshore wind farms

In their paper in PNAS, Rose et al. (1) applied a statistical model to estimate hurricane wind losses to wind turbines over a 20-y typical wind farm lifetime. They combined a county annual landfall frequency probability density function with a generalized extreme value (GEV) fit of maximum wind speeds to model the expected 20-y losses attributable to hurricane activity at four hypothetical offshore wind farm sites.

We found one error and three major flaws in this approach, which lead to an order of magnitude overestimation of risk:

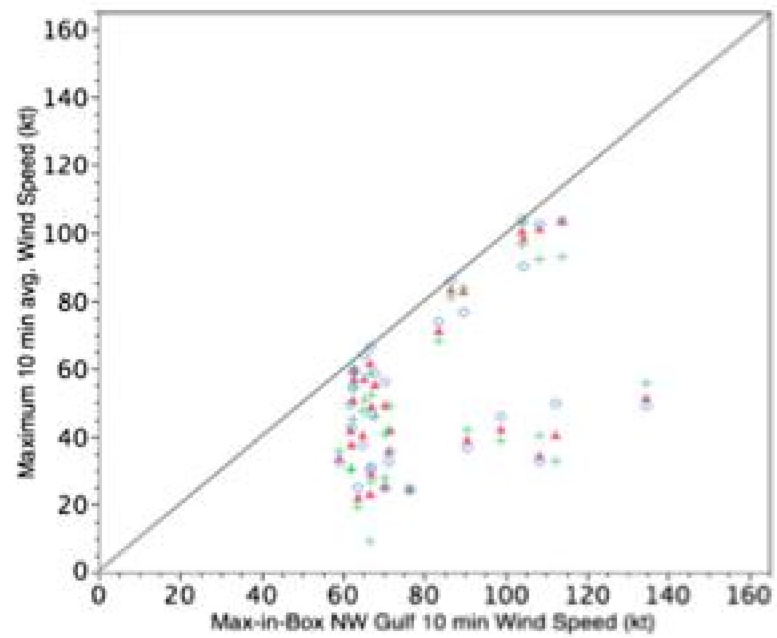
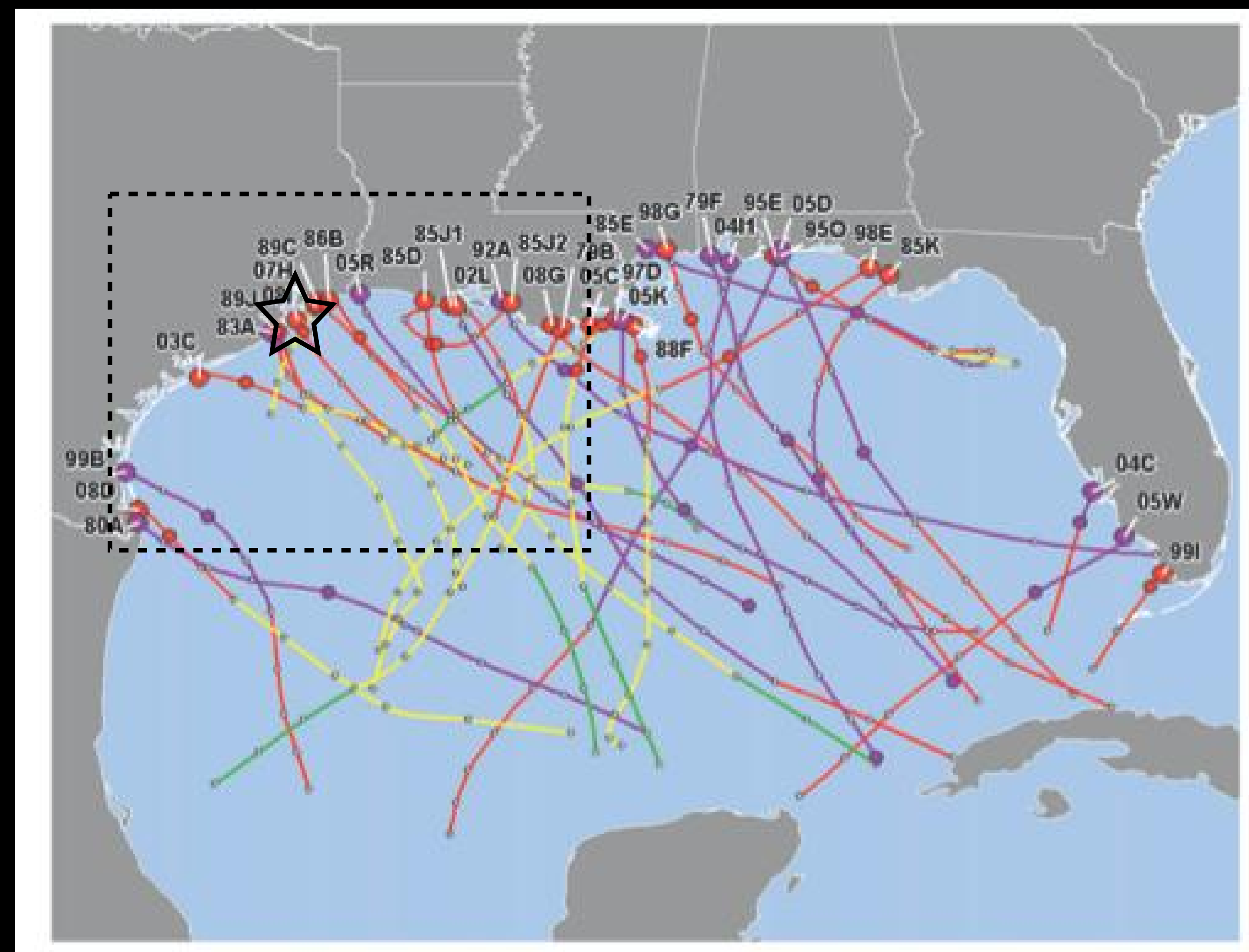


Fig. 2. Scatterplot of maximum landfall winds at wind farm locations (*y* axis) compared with the peak life cycle wind speed for the same hurricane while in the northwest Gulf of Mexico.

- Rose et al approach:
  - Collect **peak** intensity of every hurricane in box 1851-2008
  - fit peak intensity data to Generalized Extreme Value distribution
  - Fit annual GLS landfall frequency distribution with Poisson distribution
  - Simulate thousands of years of activity
  - Each landfall strikes entire (county sized) wind farm with peak intensity

50 Turbine farm offshore Galveston
(no yaw control):
“Likely” (30% chance) loss of 24
turbines over 20 years



An engineering model computes the wind loading on a turbine mast and whether it buckles or not

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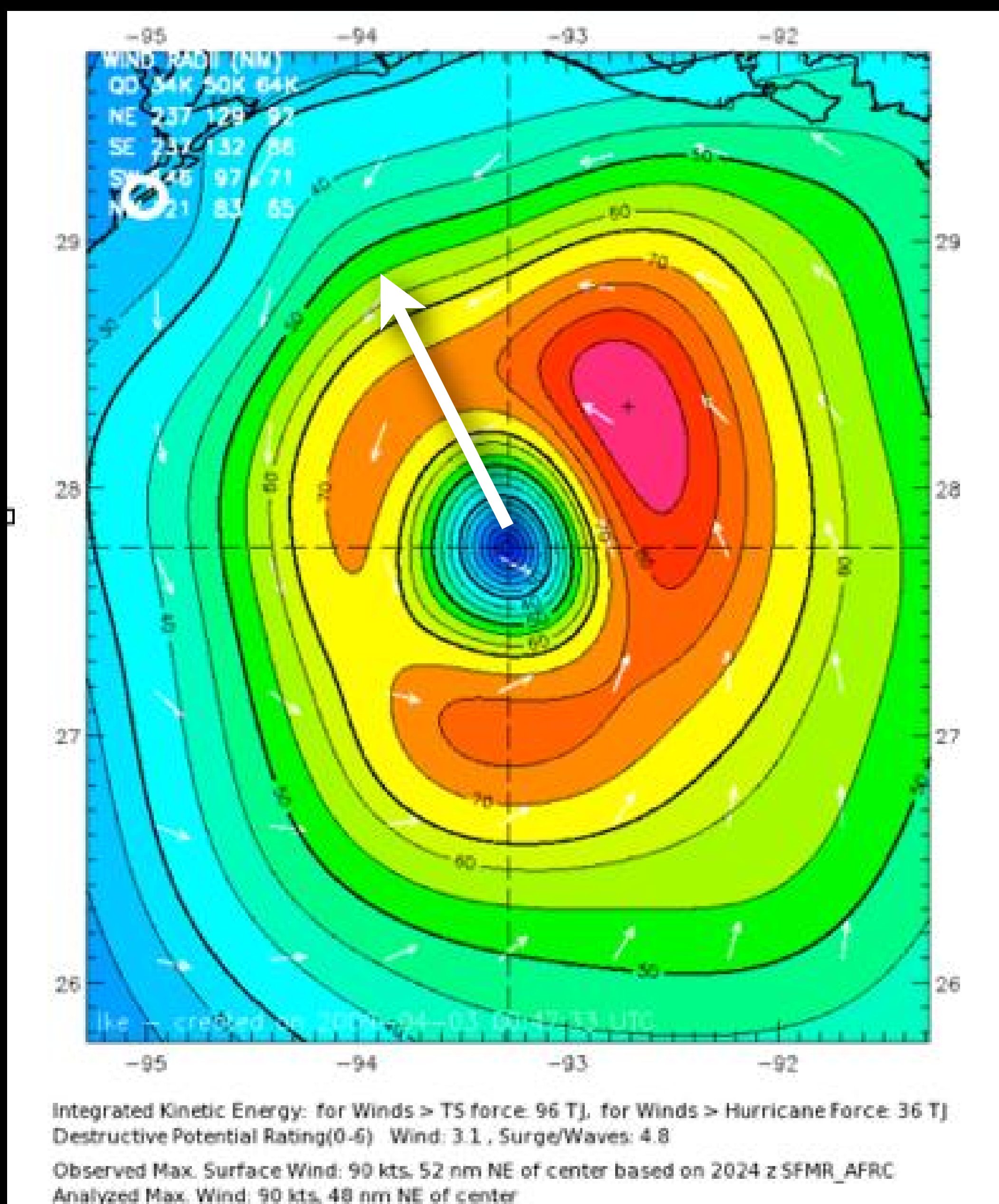
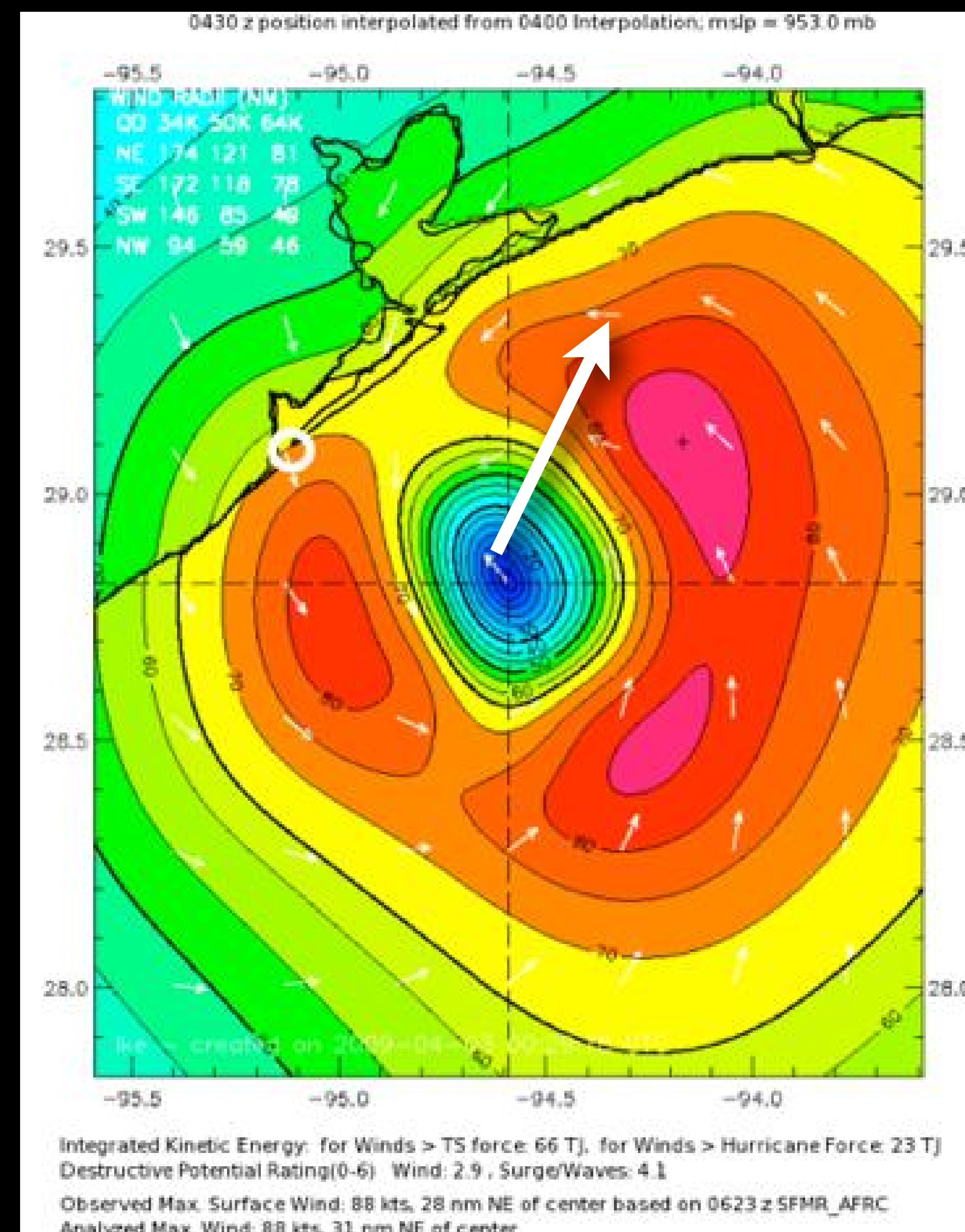
Powell and Cocke:

- Replaying all storms affecting Galveston1900-2010:
  - Loss of two turbines per 20 years (no yaw control)





- Stochastic models are available to assess risk

Florida's
Public
Hurricane
Loss
Model

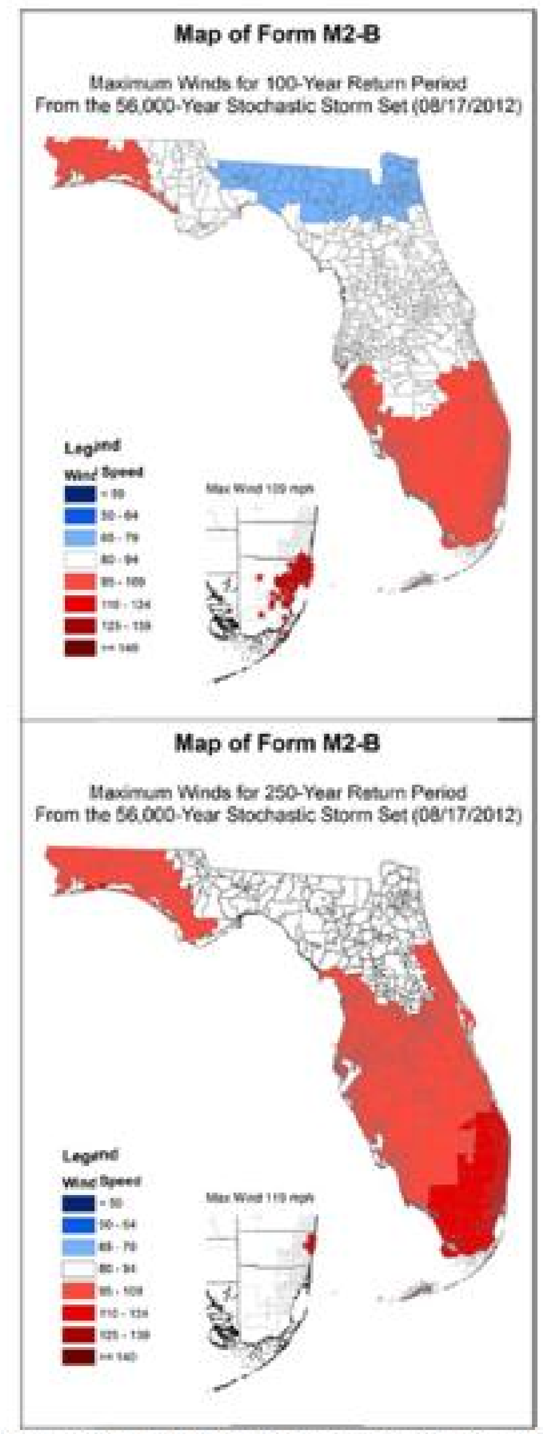


Figure 39. 100- and 250-year return period wind speeds at Florida ZIP Codes for open terrain wind exposure.

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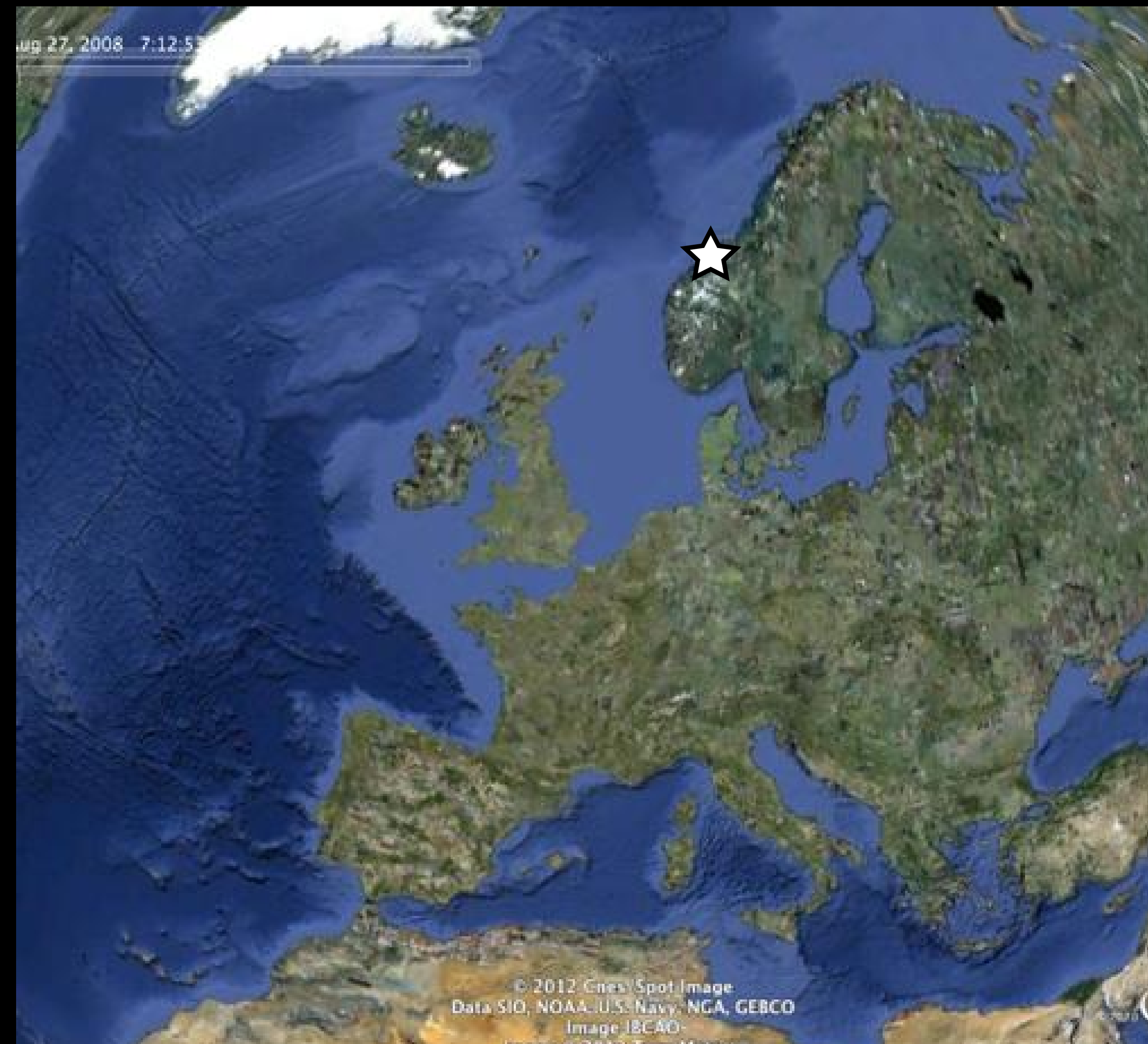
Risk

- Stochastic modeling based on observed tropical cyclone climate
- Lifecycle of each hurricane modeled
- Thousands of years simulated
- Winds from each event used to estimate return periods and losses

- Design Conditions
  - Current Standards
    - IEC 61400-3
    - DNV-RP-C205
    - API RP 2A-WSD

- Wind and Oil/Gas-based standards
    - Reference Norwegian sea data for wind profile and turbulence assessments
    - Froya location (63 N) data applicable to hurricane areas?
    - Winds in Froya study did not reach hurricane conditions



Standards

- IEC 61400-3 12.3 Assessment of wind conditions, DNV-RP-C205
  - IEC: "The roughness of the sea surface increases with wind speed and thus the turbulence intensity will increase as a function of wind speed."
- ABS: Offshore Wind Turbine Installations, API RP 2A-WSD
  - Profile Power law (Alpha 0.14) implies constant roughness with wind speed (equivalent to open terrain over land),
  - ***"For strong wind conditions, such as a hurricane"*** Profile log law (Froya) has no roughness dependence
  - Turbulence intensity increase with wind speed, no roughness dependence

Design Conditions: What's a hurricane really like?

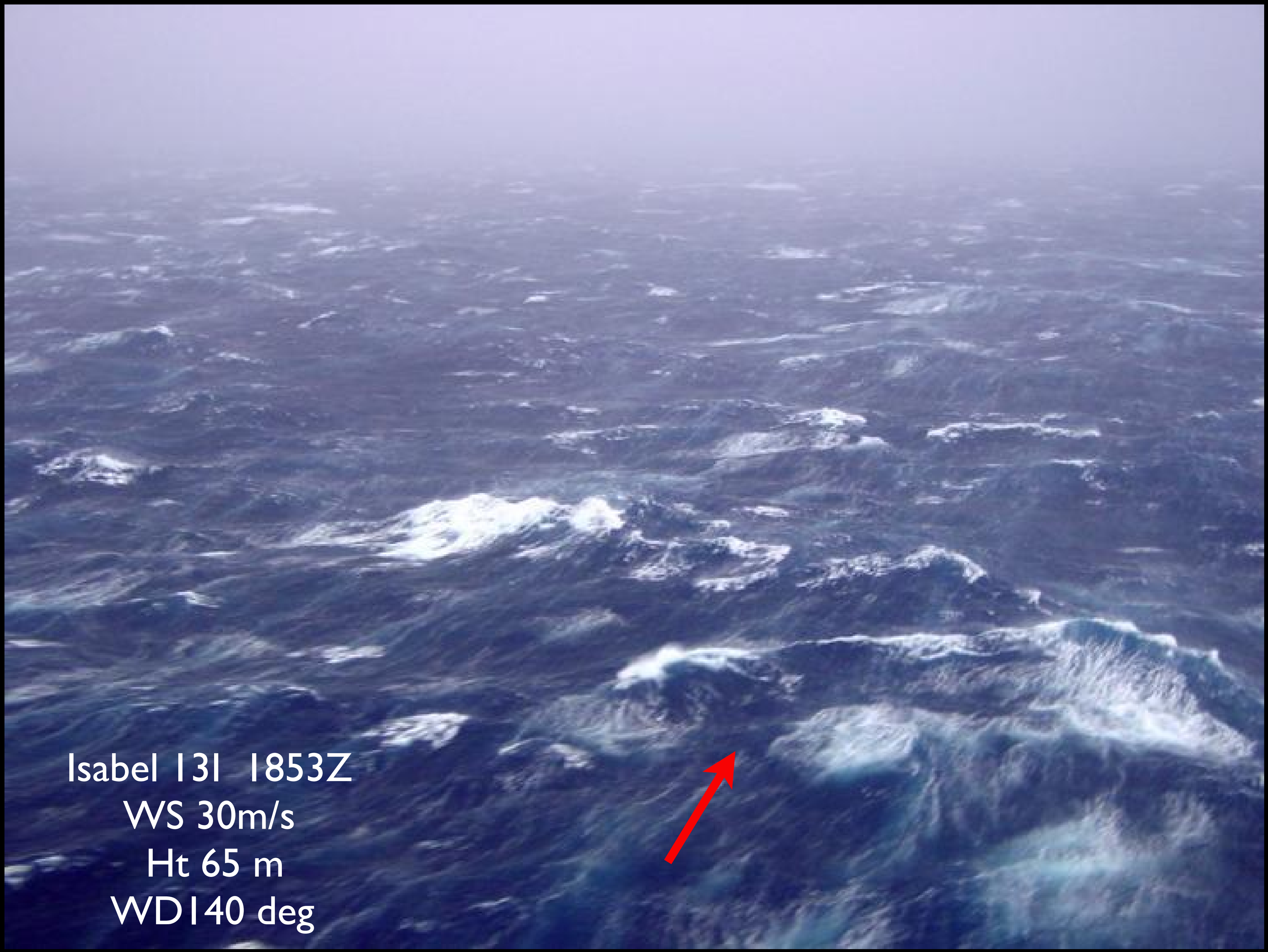


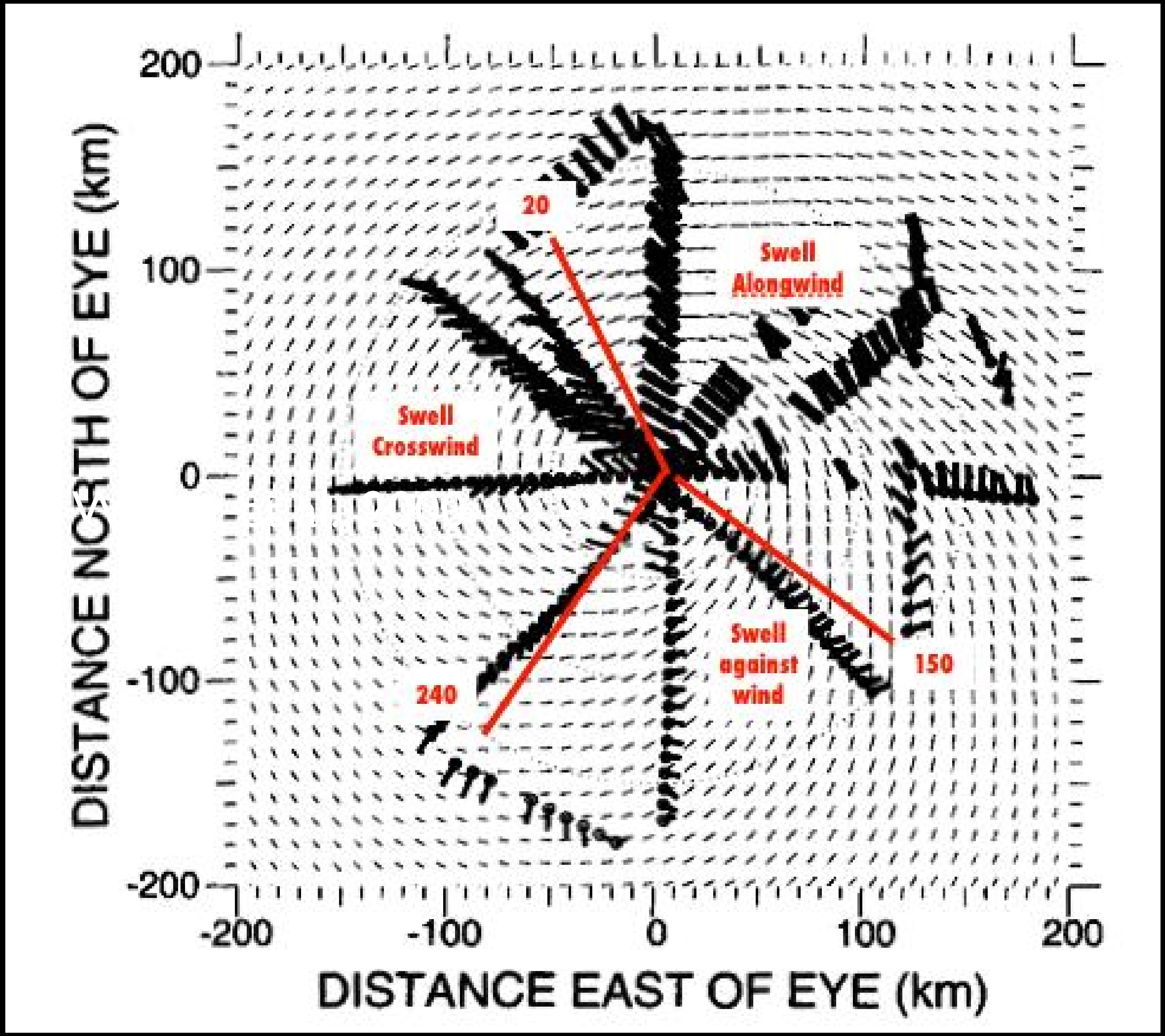
Photo provided by Michael Black, AOML

Hurricane Bonnie Waves

Scanning radar
Altimeter

Storm moving NW

Bold lines are wave direction,
length: wave length
width: sig. wave ht.



Wright et al., 2000

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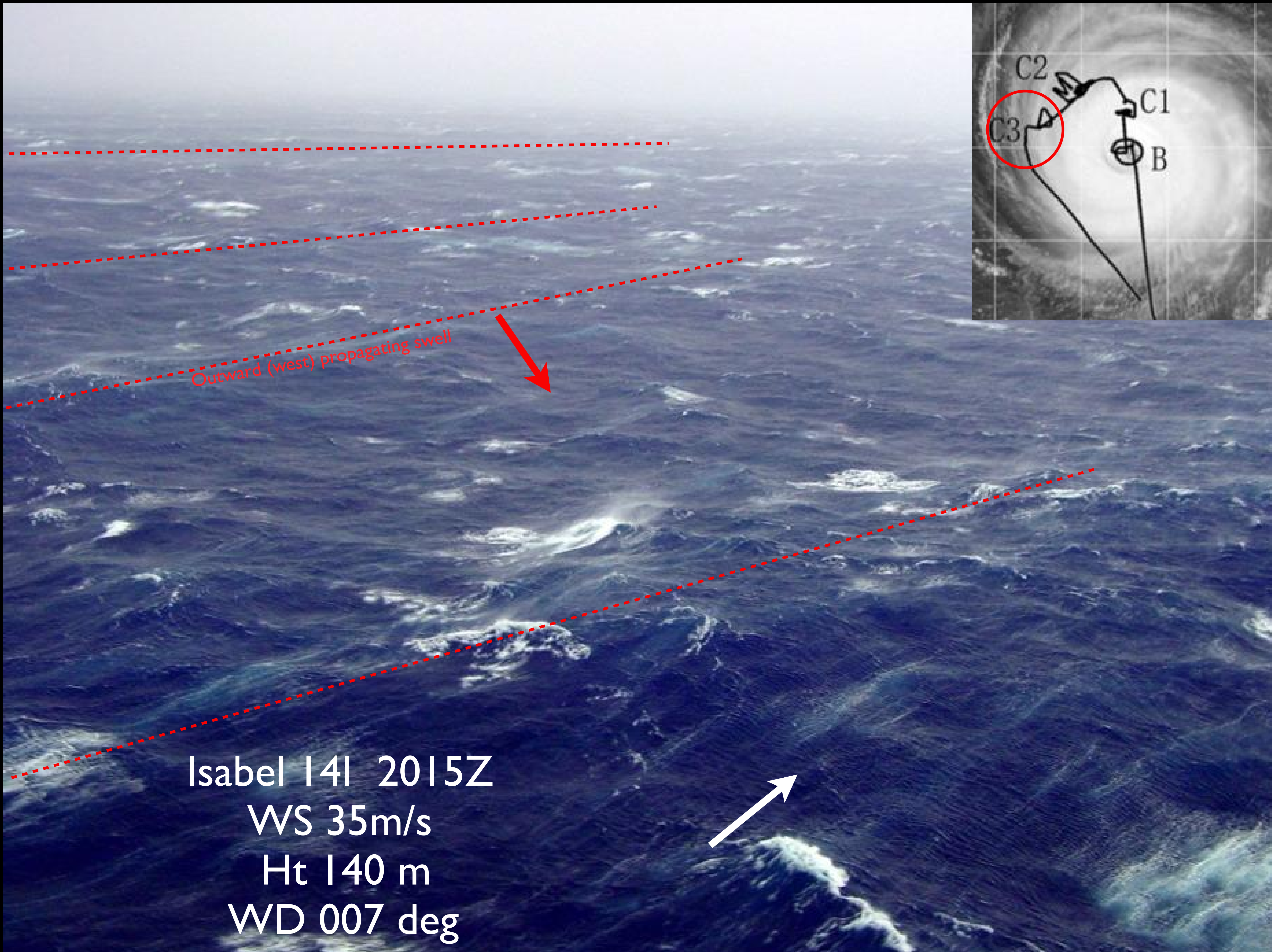
Photo provided by Michael Black, AOML



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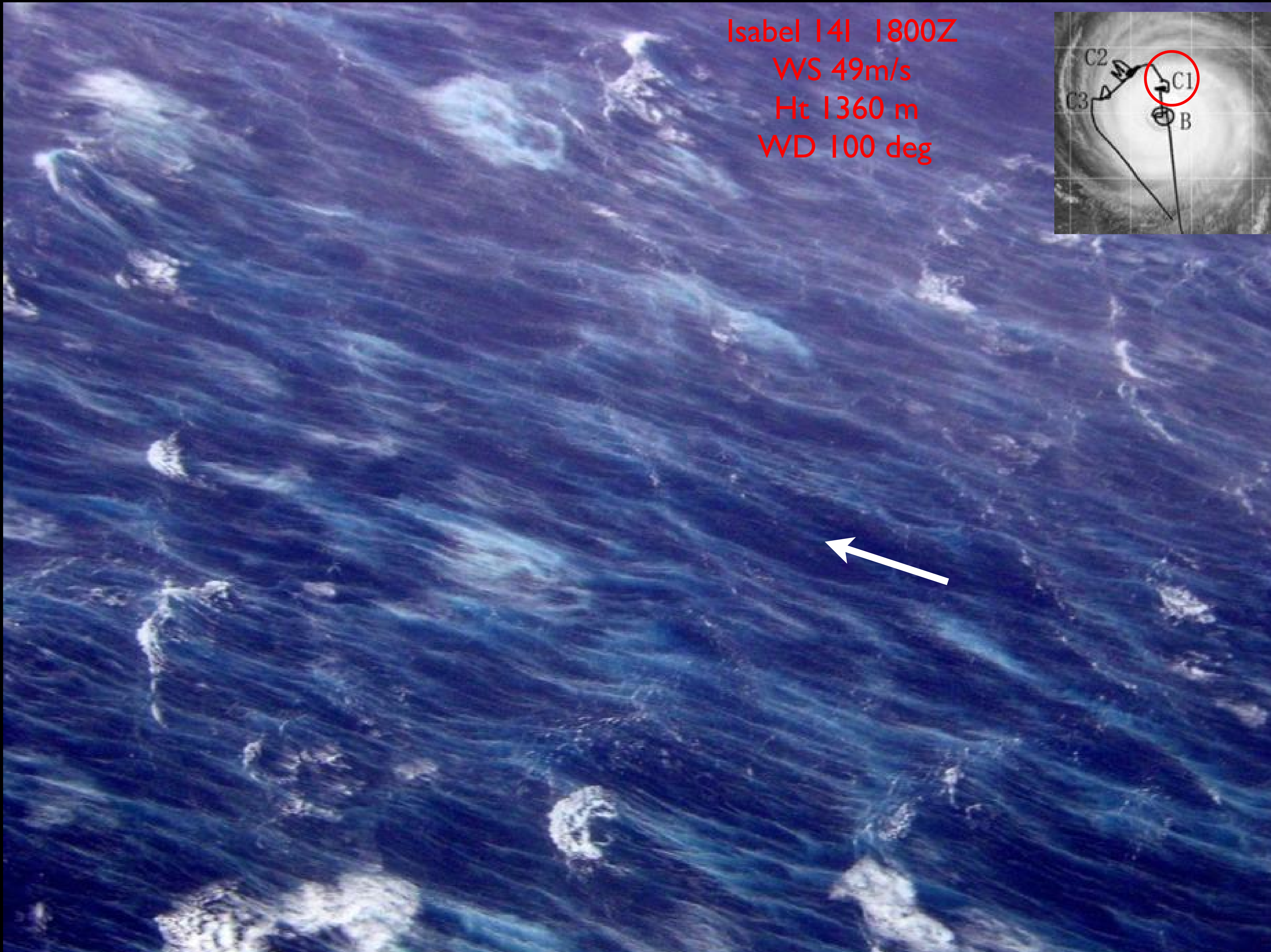
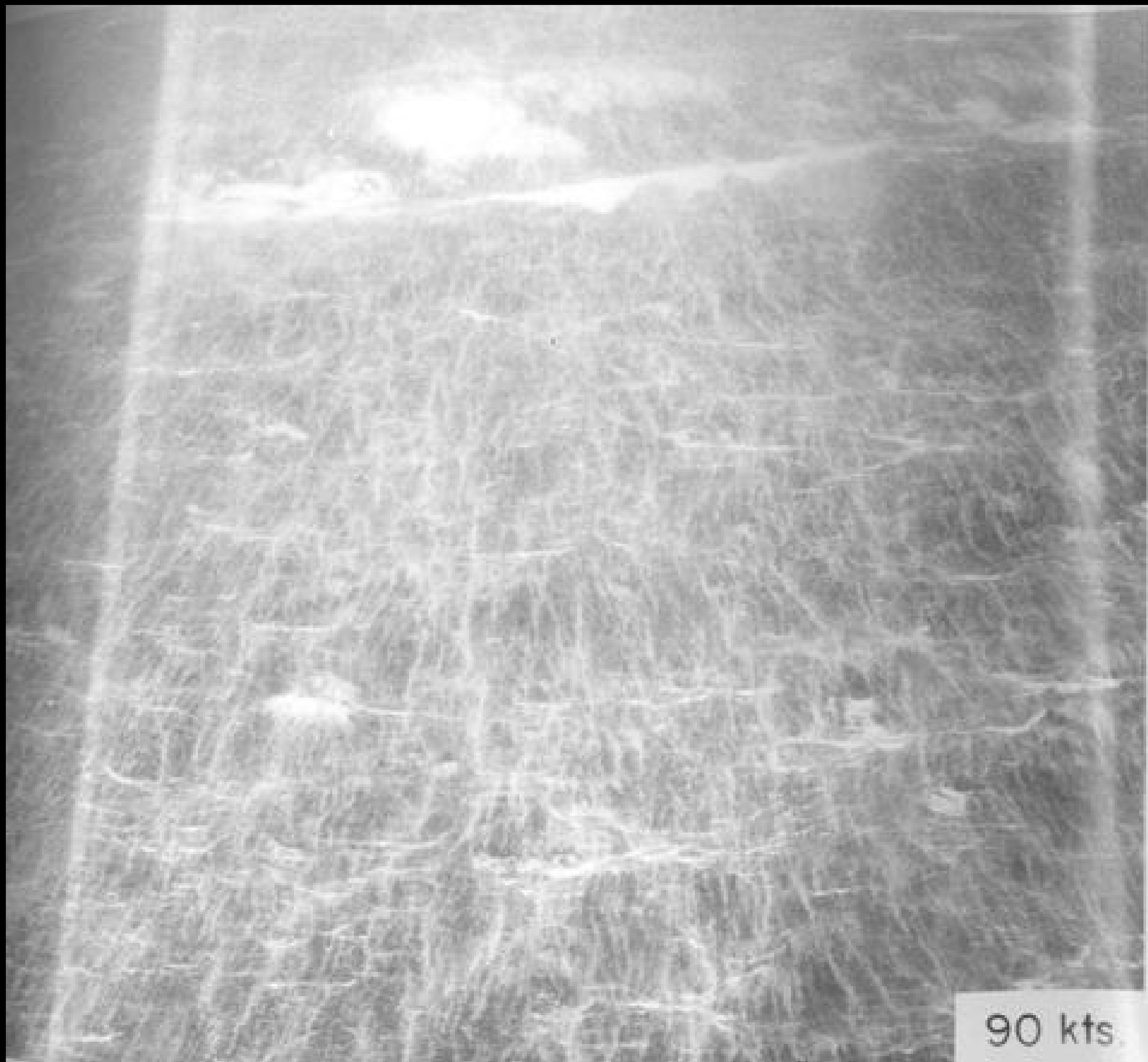
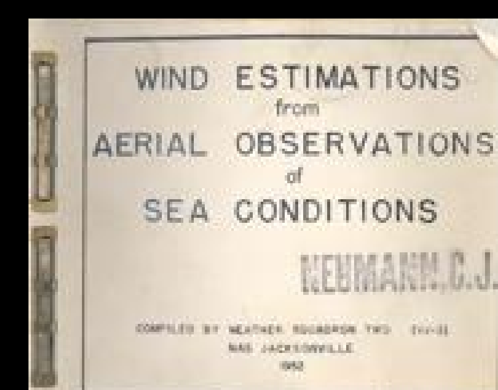




In extreme winds the sea state completely changes:
an emulsion (sea in air and air in sea)

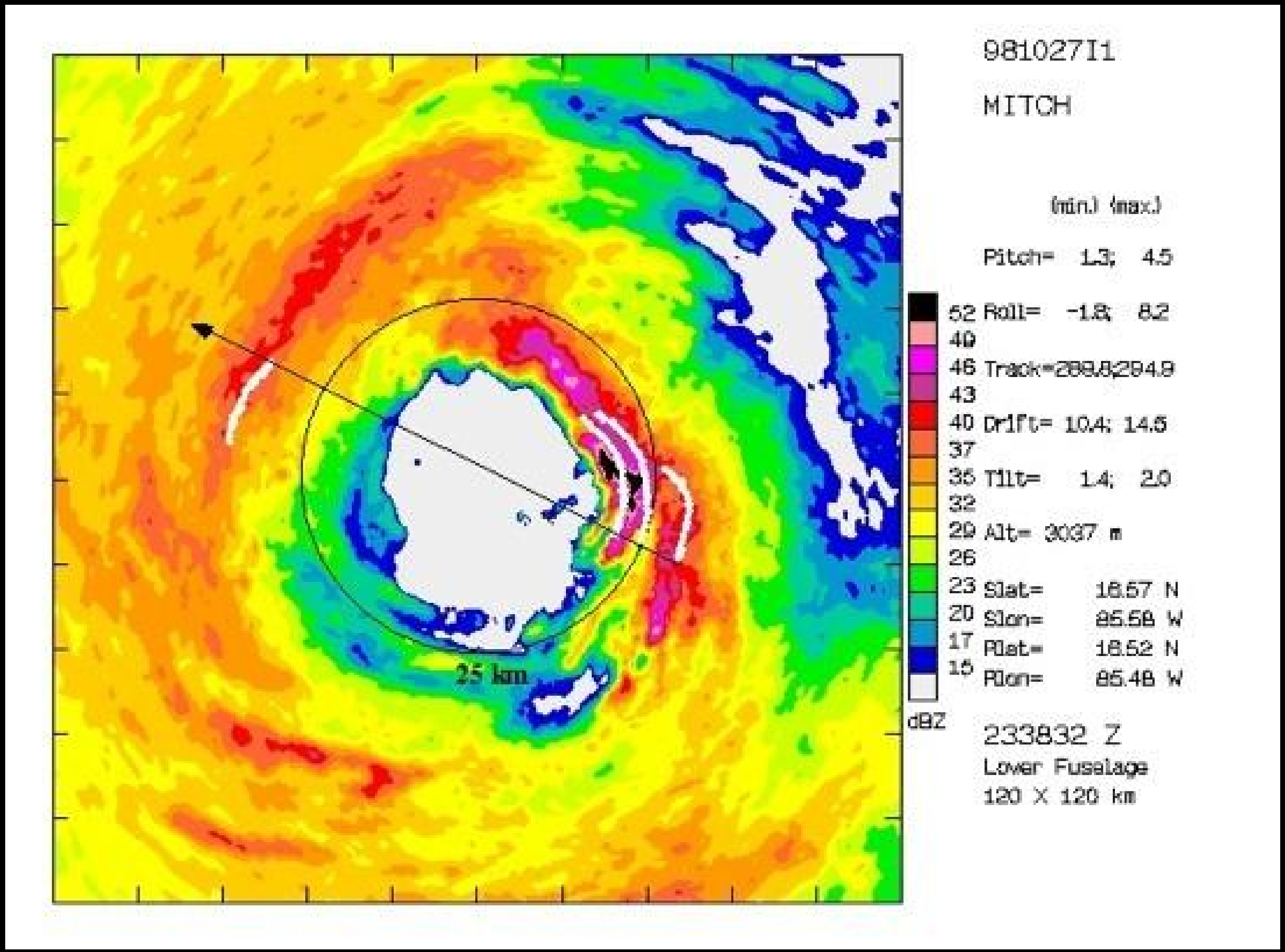
Roughness (friction) properties change

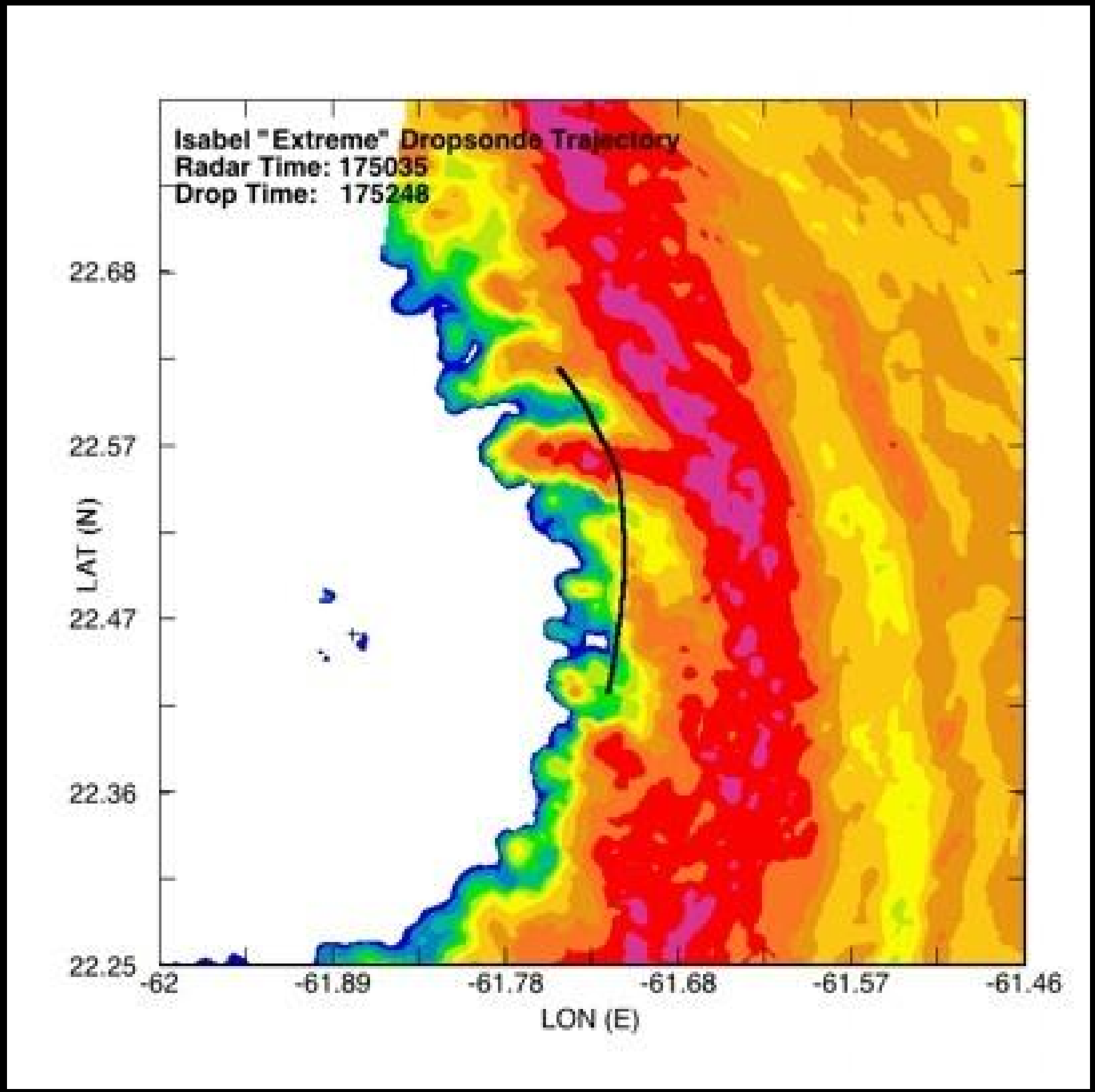
Turbines designs need to be based on actual hurricane conditions



GPS sonde probes sample near-surface wind conditions

GPS Sonde Trajectories



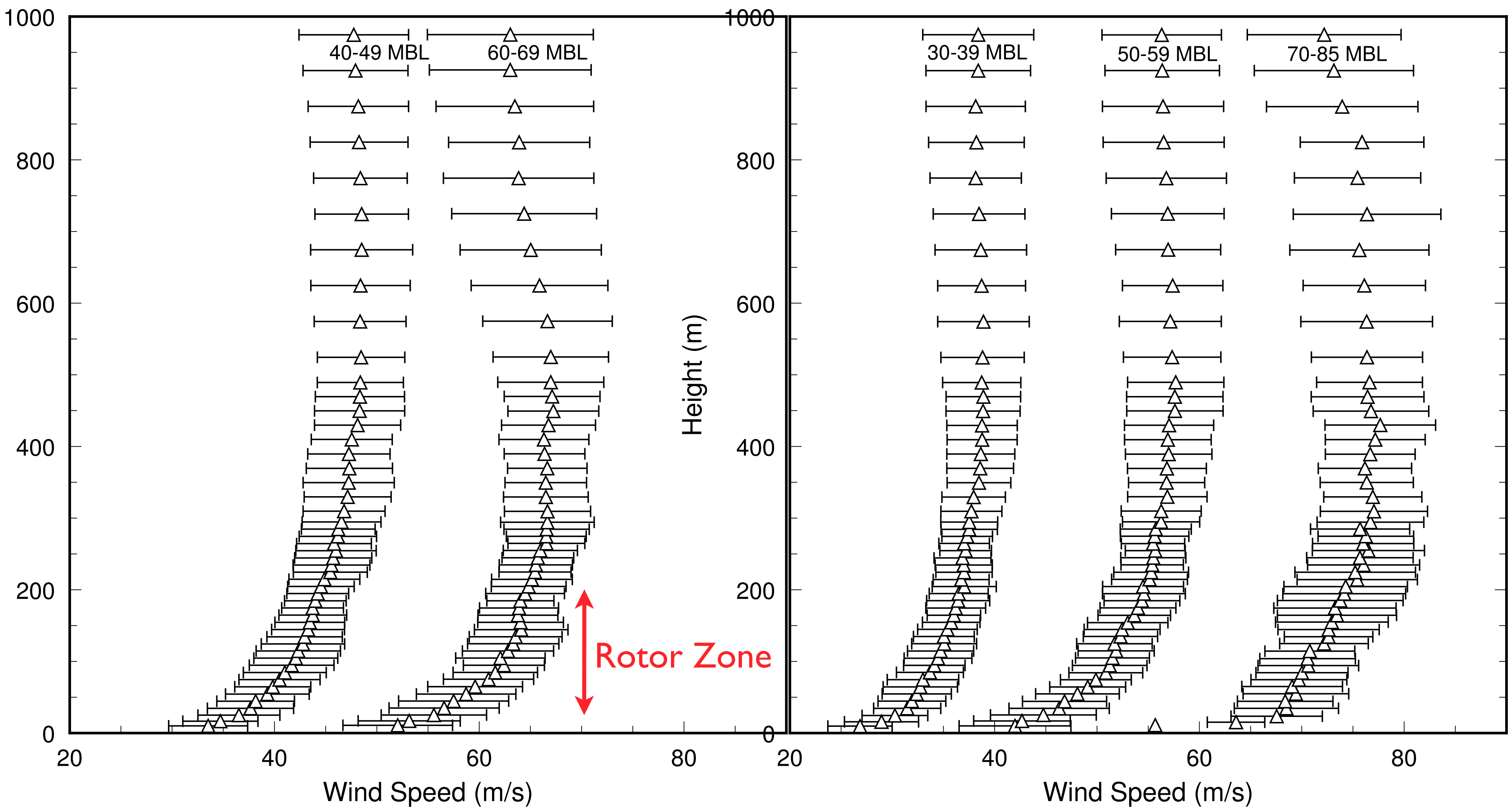


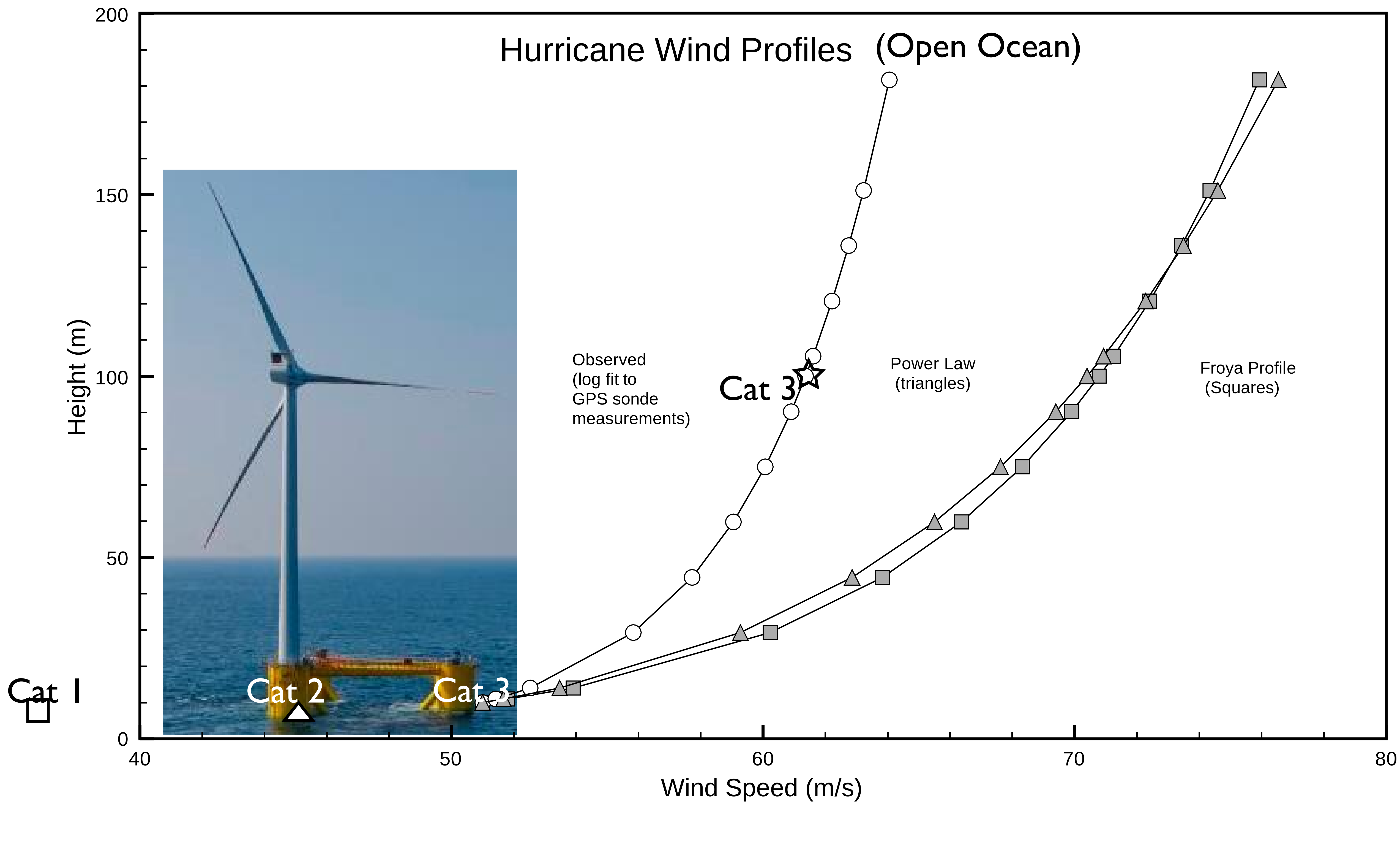
Radar images courtesy of Michael Black, AOML

Thousands of sondes in hurricanes over the past decade

Open ocean mean wind profiles

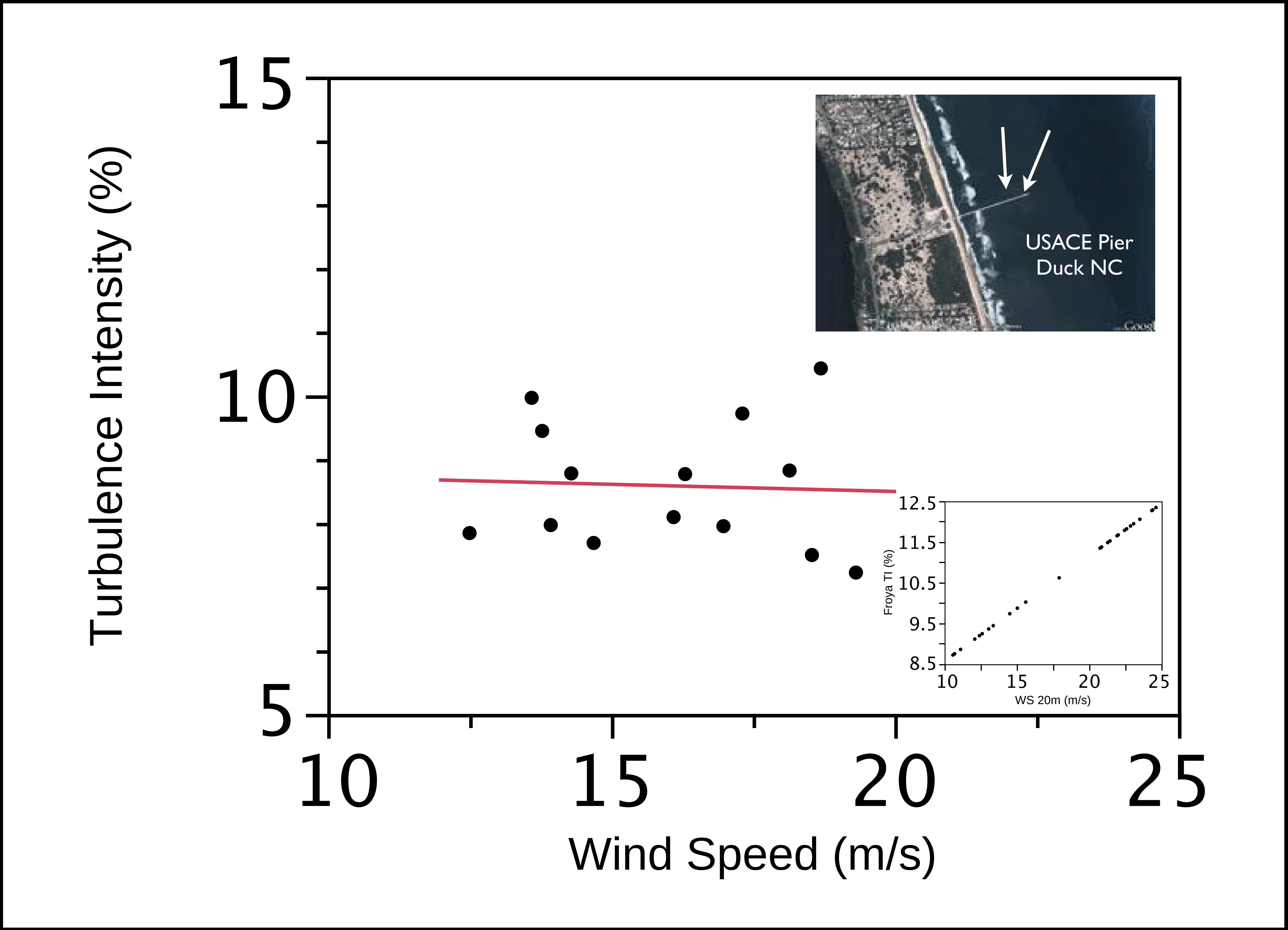
Wind profiles exhibit less shear in extreme winds
Roughness levels off and then decreases with wind speed



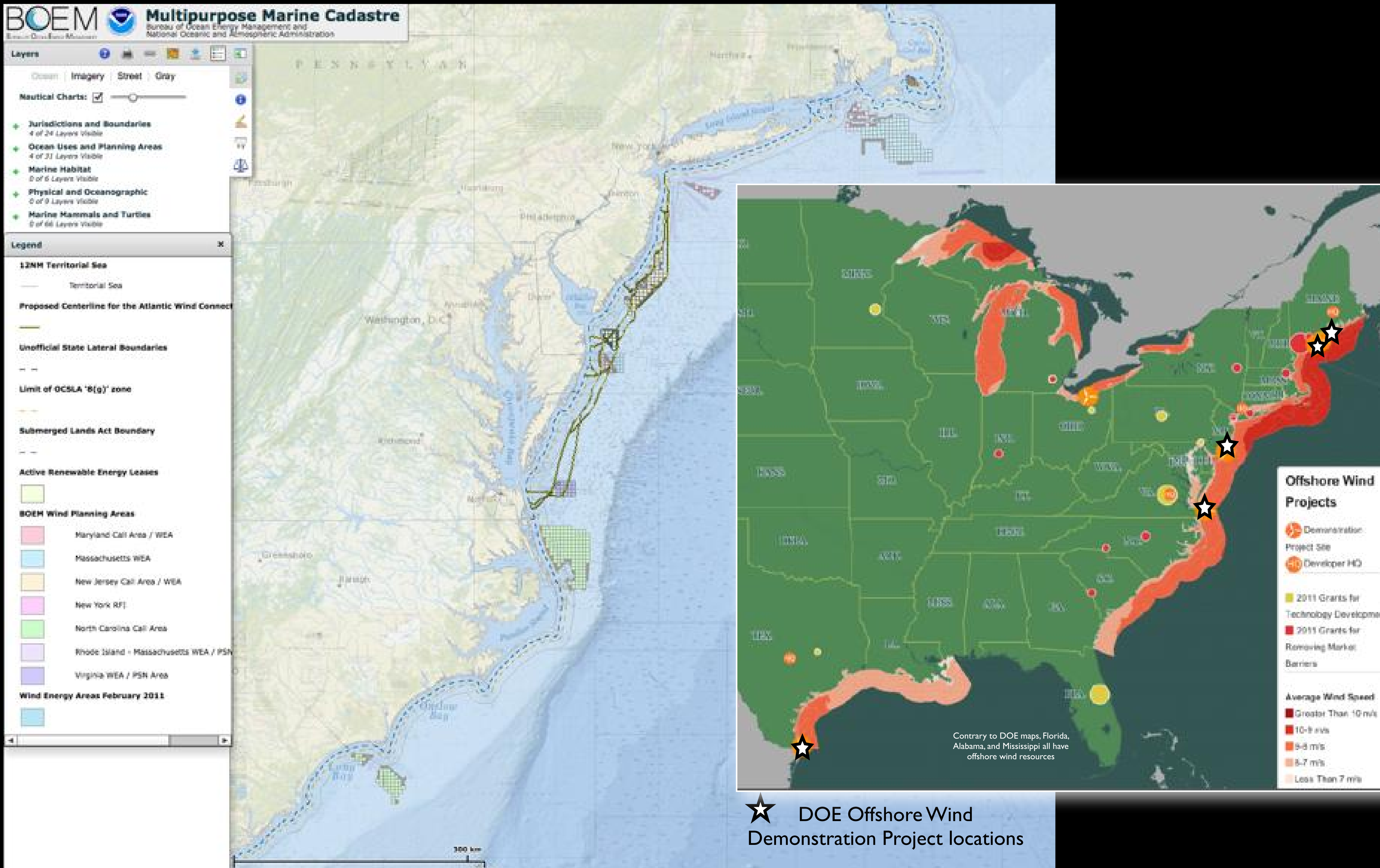


Extrapolate from Surface: winds 14% too high
Extrapolate from 100 m downward, Power law 13%, Froya 30% too low

Turbulence intensity in Hurricane Bob (1991)



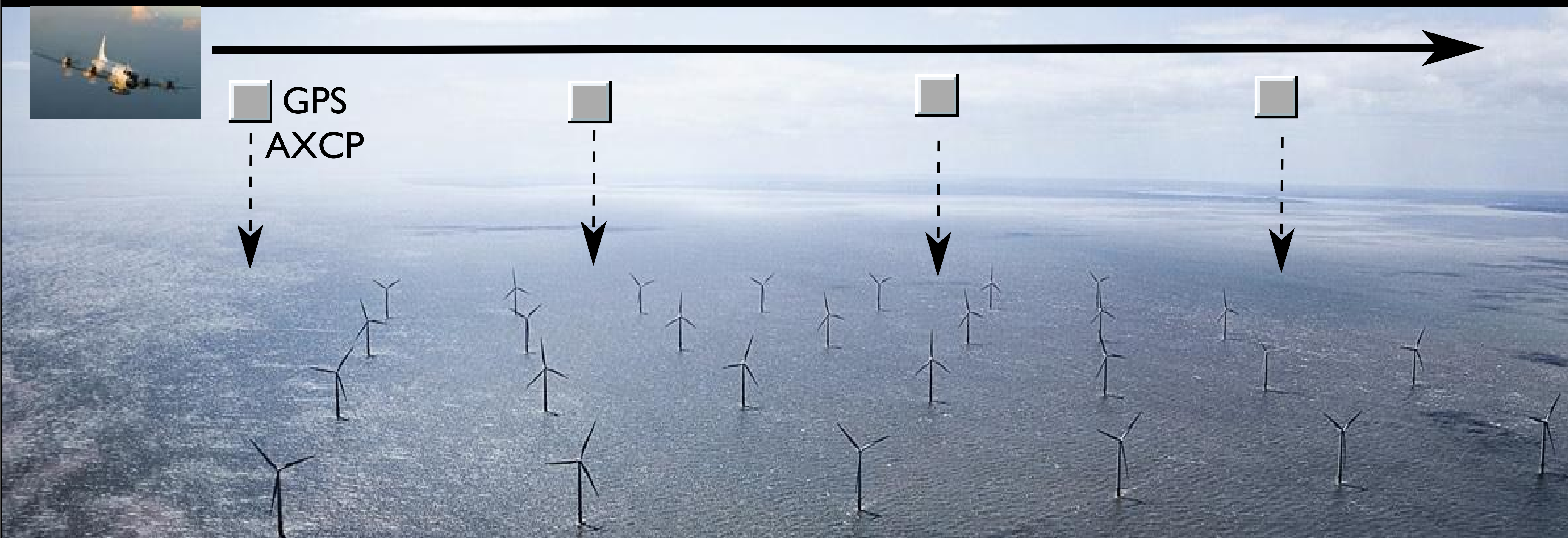
Wind farms will be in coastal waters
Do open ocean conditions still apply?



Offshore Wind Farm	Location	State or Federal
Baronyx	Offshore Cameron County near Port Isabel, TX (Rio Grande N and S)	State
Fisherman's Energy	Atlantic City, NJ (3 miles offshore)	State
Dominion Virginia Power	Virginia Beach	Federal
Statoil North America (Hywind Maine)	Boothbay Harbor	State
University of Maine (DeepCwind)	Monhegan Island	State
Deepwater Wind	Block Island (5 mi SE)	State
Cape Wind	Nantucket Sound (Horseshoe shoal)	State
Maryland Wind Energy Area	See Fig. 1	Federal
Rhode Island Wind Energy Area	See Fig. 1	Federal
New Jersey Wind Energy area	See Fig. 1	Federal
Maryland Wind Energy Area	See Fig. 1	Federal
Virginia Wind Energy Area	See Fig. 1	Federal
Delaware	See Fig. 1	Federal
North Carolina	See Fig. 1	Federal
South Carolina	See Fig. 1	Federal
Georgia	Lease request for a MET mast off Tybee Island	Federal

Listing of DOE funded demonstration projects and other offshore wind developments planned or projected in state and federal waters

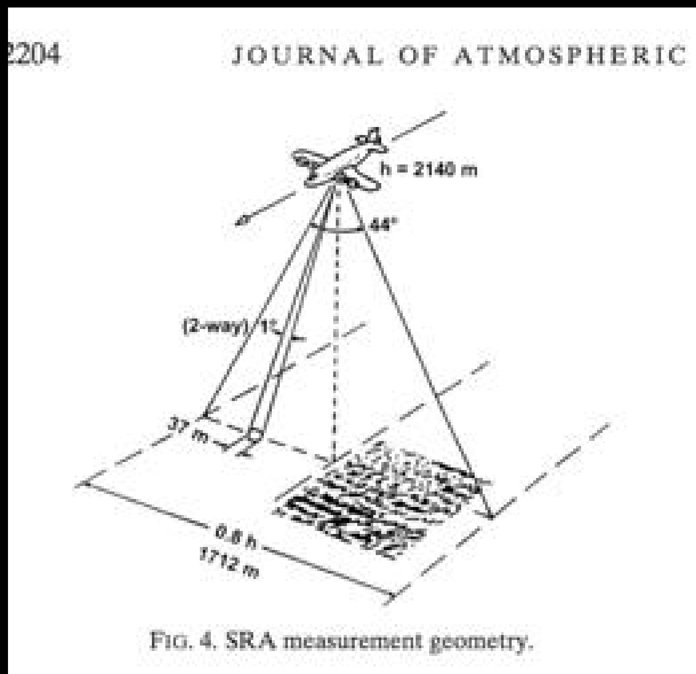
DOE-NOAA partnership to Collect data on coastal hurricane design conditions



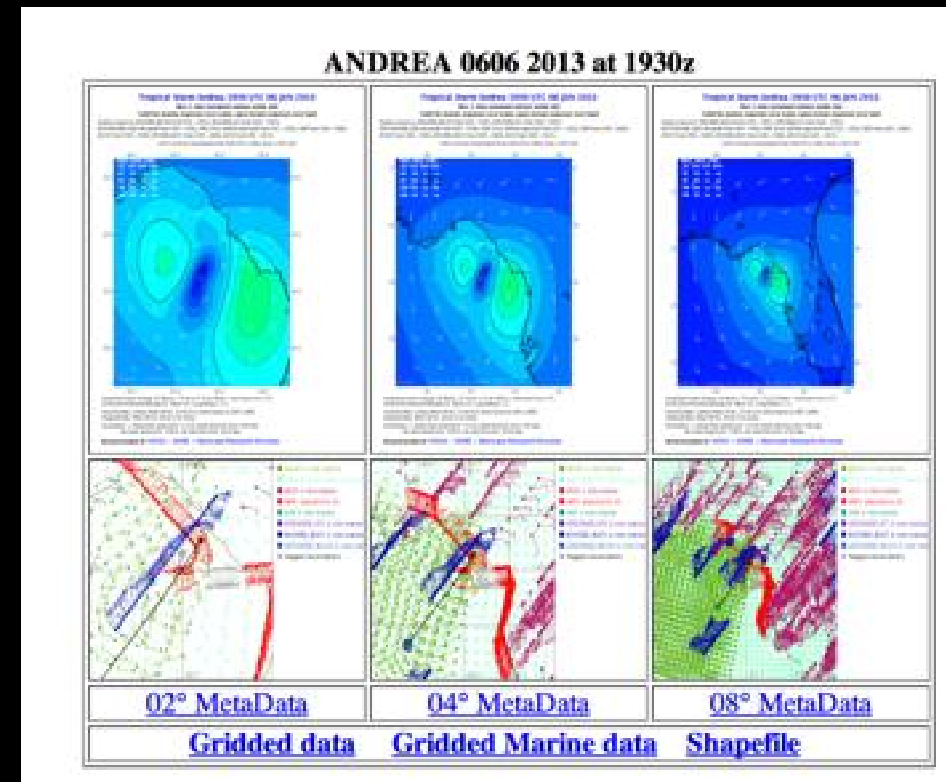
Schematic of NOAA P3 “piggyback” flight pattern showing hypothetical wind farm fly-by with expendable launches at a 2 km interval for 20 km.

Photo: Dong Energy “Gunfleet Sands 1” farm off SE England.

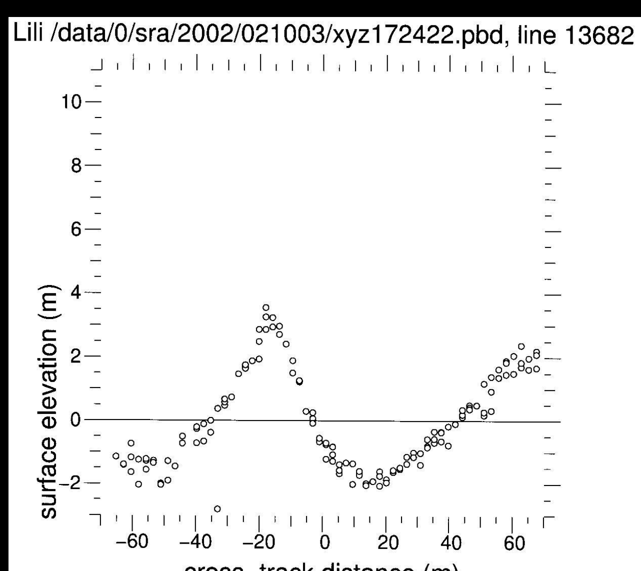
Collect wave, wind field, and oceanic data

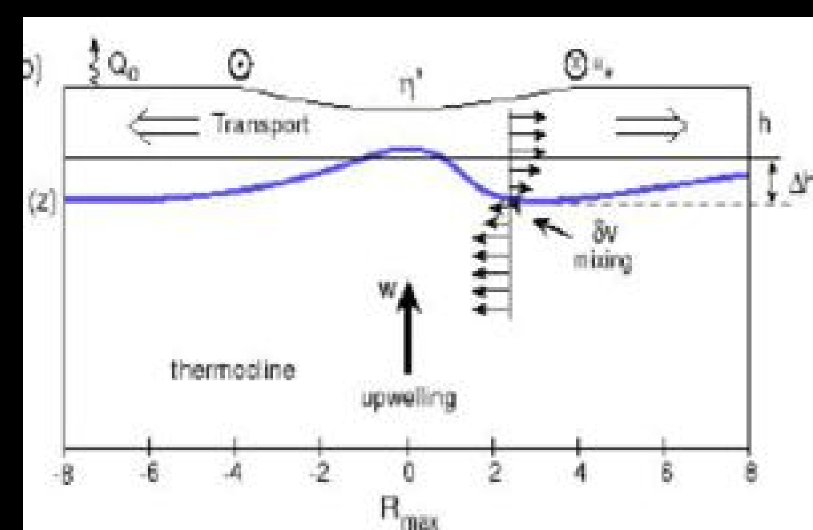


Scanning radar altimeter: Directional wave spectrum, significant wave height, individual wave imaging



H*Wind wind fields from real-time measurements





Subsurface current profiles from AXCPs

Expendables (Ex) and aircraft (A/C) measurement systems required for conducting offshore wind farm experiment

Observing system	Measurement	Number	Type
GPS sonde	Pressure, Temperature, Humidity, Velocity	4-10	Ex
AXBT	Ocean temperature profile	2-4	Ex
AXCP	Ocean current profile	2-4	Ex
Stepped Frequency Microwave Radiometer (SFMR)	Surface wind speed rain rate	8-10 hour missions	A/C
NOAA wide-swath radar altimeter	wave height and directional wave spectrum	8-10 hour missions	A/C
Airborne Doppler radar	3D wind velocity, rain rate	8-10 hour missions	A/C
Lower fuselage radar	reflectivity	8-10 hour missions	A/C
H*Wind	Analysis of surface wind field	8-10 hour missions	All available observations

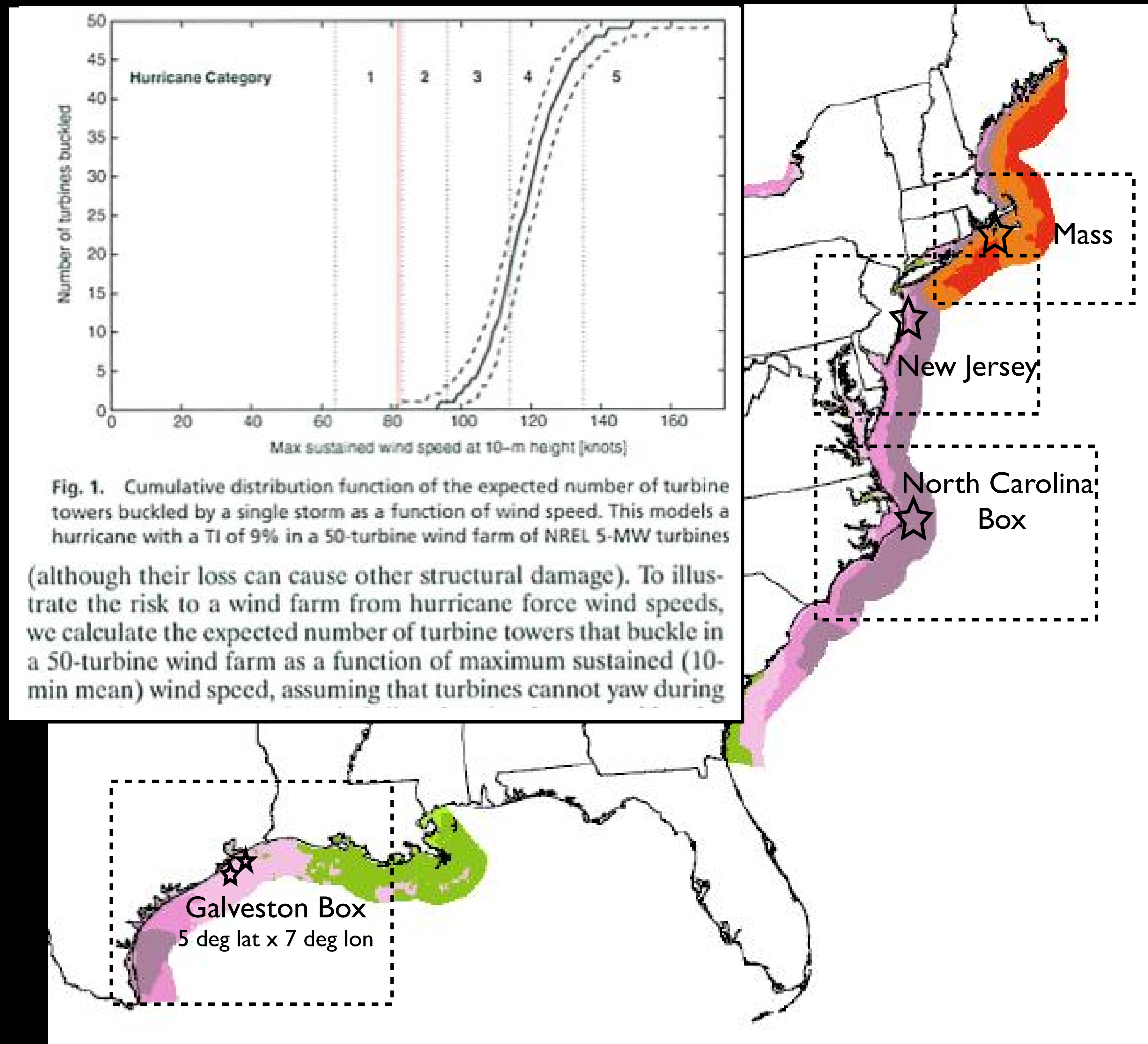
A comprehensive observational framework will help inform design conditions to help make sure offshore wind farms withstand hurricanes

Thanks!

Photo: Eranti Engineering Oy http://www.erantiengineering.fi/pilot-wind-turbine.htm

Extra Slides

- Sites: Galveston, NC, NJ, MA
- We examine Galveston
- Reproduce their results
- Run a simple wind model on all 1900-2010 Hurdat tracks within 200 km of GLS
- Record max wind at each location for each storm
- Compute losses using damage curve from PNAS paper



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- Gulf of Mexico hurricane landfall intensities 1979-2008

- More realistic than max box intensities since offshore wind farms will be close to shore

Tropical Cyclone Intensity Change before U.S. Gulf Coast Landfall

EDWARD N. RAPPAPORT AND JAMES L. FRANKLIN
NOAA/National Weather Service/National Hurricane Center, Miami, Florida

ANDREA B. SCHUMACHER
Colorado State University/CIRA, Fort Collins, Colorado

MARK DEMARIA
NOAA/NESDIS/Center for Satellite Applications and Research, Fort Collins, Colorado

LYNN K. SHAY
RSMAS/MPO, University of Miami, Miami, Florida

ETHAN J. GIBNEY
I. M. Systems Group, NOAA/National Climatic Data Center, Asheville, North Carolina

(Manuscript received 21 October 2009, in final form 28 May 2010)

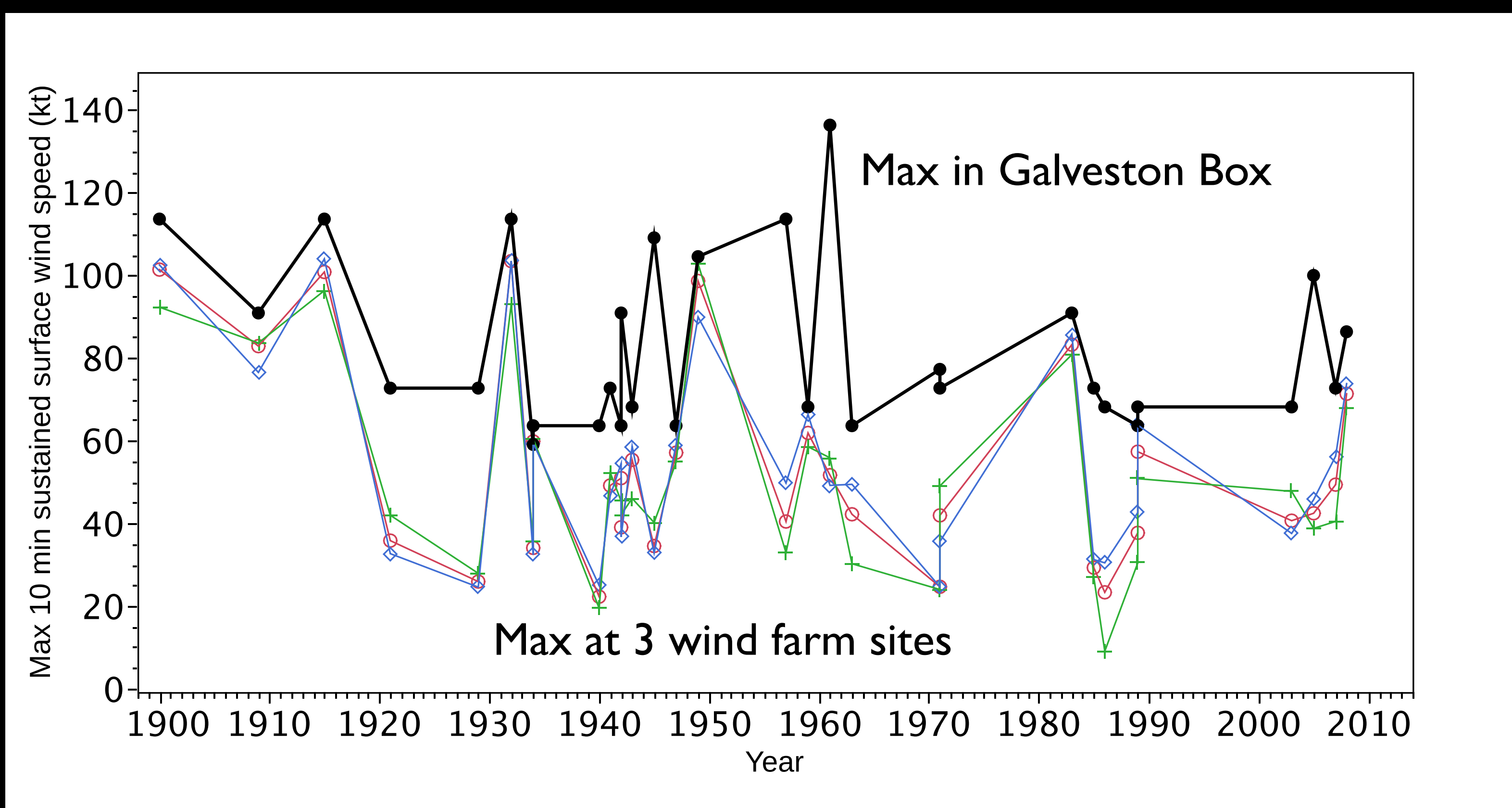
Result: 8% chance Hurricanes would collapse 25 or more turbines over a 20 year period avg. 6 per year

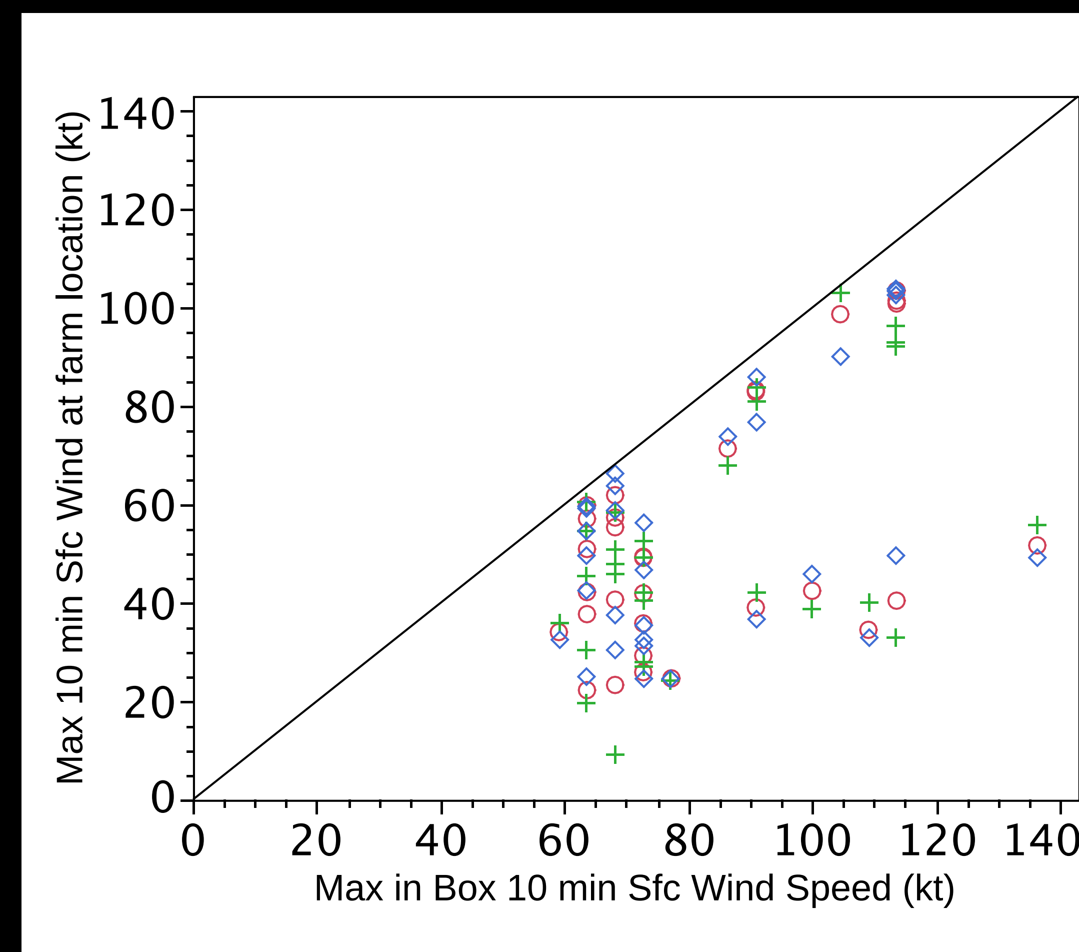
But this is still an overestimate!

TABLE 1. Intensity data (kt) for U.S. Gulf coast landfalling hurricanes (1979–2008). NA indicates that the system did not continuously have a tropical cyclone center over the Gulf from that time until landfall.

Hurricane	Landfall time and date	Intensity at landfall	Intensity 12 h before landfall	Intensity 24 h before landfall	Intensity 36 h before landfall	Intensity 48 h before landfall
Ike	0700 UTC 13 Sep 2008	95	91	90	85	85
Gustav	1500 UTC 1 Sep 2008	90	95	98	115	NA
Dolly	1820 UTC 23 Jul 2008	75	71	60	46	45
Humberto	0700 UTC 13 Sep 2007	80	47	NA	NA	NA
Wilma	1030 UTC 24 Oct 2005	105	94	85	NA	NA
Rita	0740 UTC 24 Sep 2005	100	109	115	124	151
Katrina	1110 UTC 29 Aug 2005	110	142	142	100	99
Dennis	1930 UTC 10 Jul 2005	105	124	94	76	NA
Cindy	0300 UTC 6 Jul 2005	65	53	33	28	NA
Ivan1	0650 UTC 16 Sep 2004	105	114	119	120	138
Charley	1945 UTC 13 Aug 2004	130	102	NA	NA	NA
Claudette	1530 UTC 15 Jul 2003	80	63	58	55	50
Lili	1300 UTC 3 Oct 2002	80	122	112	92	NA
Irene	2000 UTC 15 Oct 1999	70	65	60	60	NA
Bret	0000 UTC 23 Aug 1999	100	125	120	80	65
Georges	1130 UTC 28 Sep 1998	90	95	95	90	90
Earl	0600 UTC 3 Sep 1998	70	85	50	50	40
Danny	0900 UTC 18 Jul 1997	65	53	35	30	NA
Opal	2200 UTC 4 Oct 1995	100	130	95	78	68
Erin	1600 UTC 3 Aug 1995	75	68	NA	NA	NA
Andrew	0830 UTC 26 Aug 1992	105	120	115	115	NA
Jerry	0030 UTC 16 Oct 1989	75	60	55	55	55
Chantal	1300 UTC 1 Aug 1989	70	66	51	31	21
Florence	0200 UTC 10 Sep 1988	70	58	50	45	45
Bonnie	1000 UTC 26 Jun 1986	75	68	53	43	28
Kate	2230 UTC 21 Nov 1985	85	96	105	103	84
Juan2	1130 UTC 29 Oct 1985	65	75	NA	NA	NA
Juan1	1430 UTC 28 Oct 1985	75	67	57	47	37
Elena	1300 UTC 2 Sep 1985	100	109	106	96	90
Danny	1630 UTC 15 Aug 1985	80	74	58	43	30
Alicia	0700 UTC 18 Aug 1983	100	91	71	61	51
Allen	0600 UTC 10 Aug 1980	100	125	155	130	130
Frederic	0300 UTC 13 Sep 1979	115	115	108	90	75
Bob	1200 UTC 11 Jul 1979	65	65	50	30	20

- Results: PNAS paper overestimated hurricane risk by an order of magnitude
  - Wind farm site peak wind speeds are ~ 64% of "peak-in-box" intensity
  - For historical storms 1900-2010: Two turbines destroyed per 20 y compared to 24/20y if storms landfall at "peak-in-box" intensity





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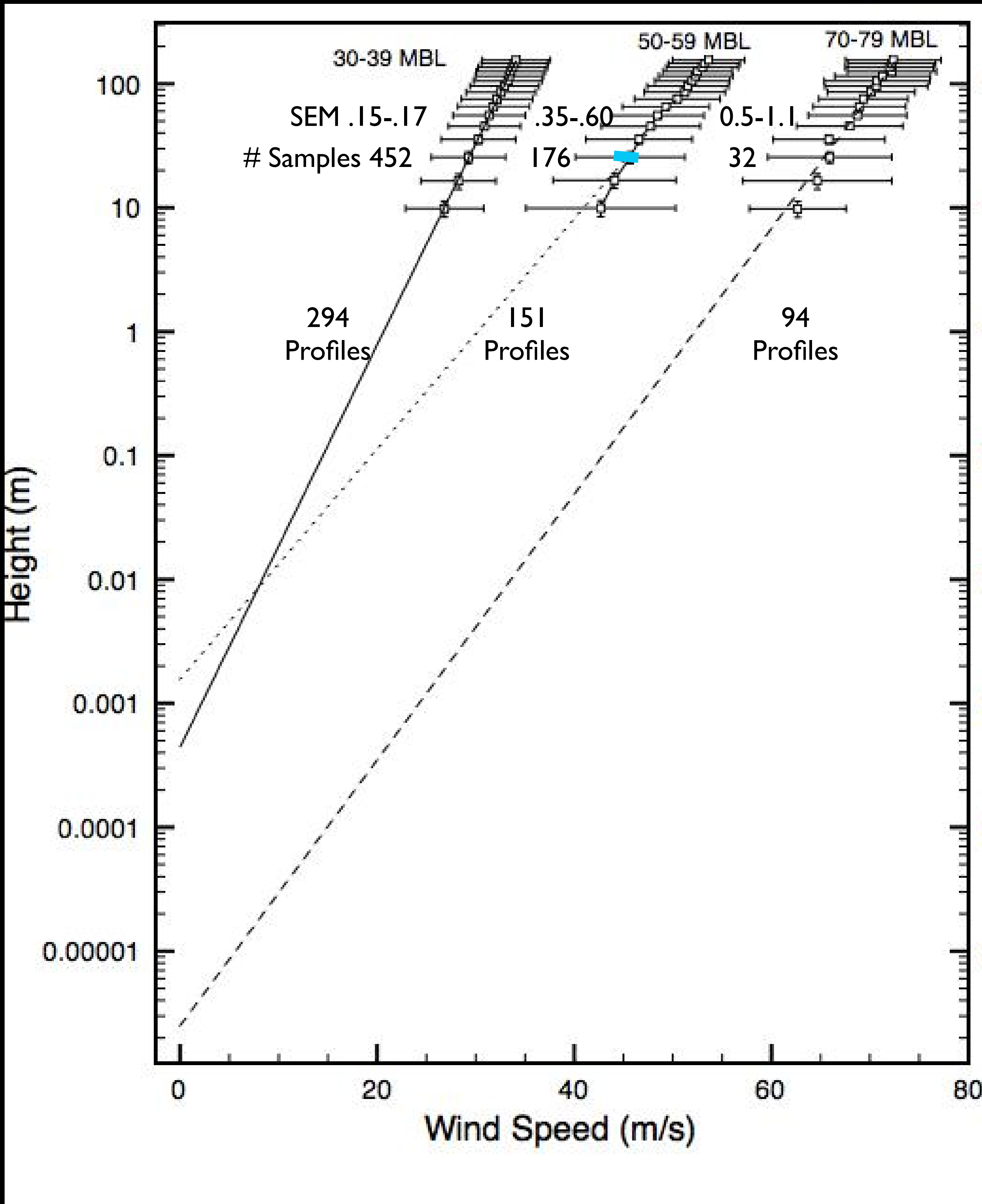
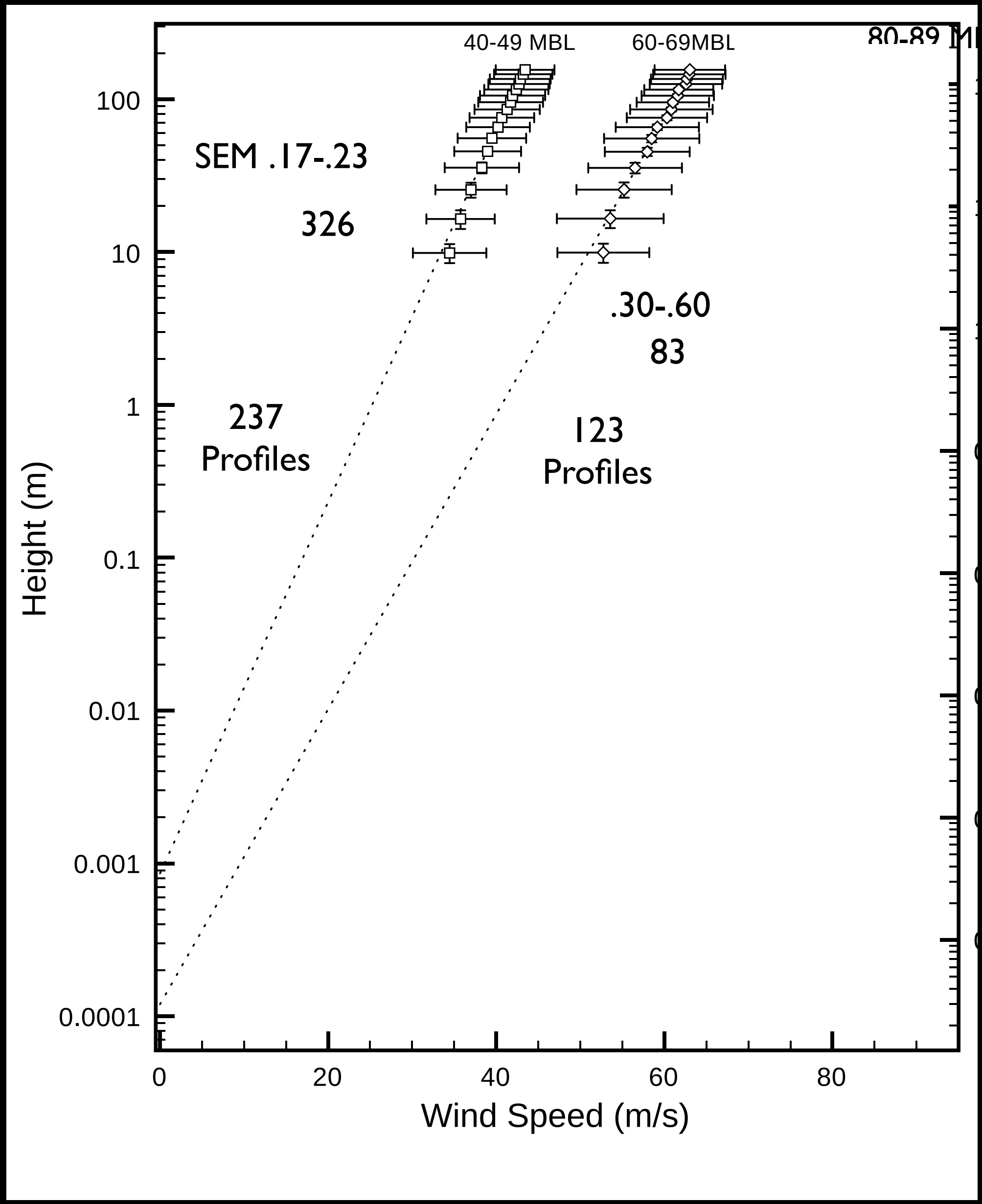
- Limitations
  - Error in their GEV fit (10 min vs 1 min)
  - Assume each storm landfalls at peak “box” intensity
  - Pre 1900 data (and GEV fits) are generally not used for risk modeling (e.g FL Commission)
  - Did not consider that hurricane winds vary spatially

Charlie Neumann, 1952 Hurricane season
Navy recon squadron, JAX
400-600 ft (120-180 m)





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Profile Method:

Log Law for neutral stability

$$U = U_* / k \quad Ln\,(Z / Zo)$$

$$Ln\,(Z) = (k / U_*)\, U + Ln\,(Zo)$$

slope intercept

$$\tau = \rho\, U_*^{\,2} = \rho\, C_d\, U_{10}^{\,2}$$

$$Cd = \left(\frac{.4}{Ln\left(\frac{Zo}{10}\right)} \right)^2$$