Learning from the Experts Webinar Series

Offshore Wind Turbine Design for Extreme Weather Events

Dr. Bruce Bailey
Executive in Residence
Center of Excellence in Weather & Climate Analytics
University at Albany

November 7, 2024

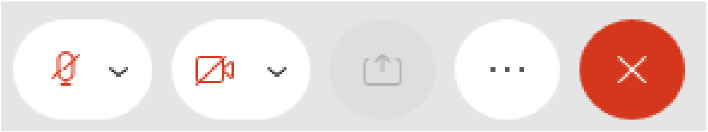
Meeting Procedures

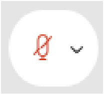
Webinar recordings and presentations will be available at:

www.nyserda.ny.gov/osw-webinar-series

Participation for Members of the Public:

> Members of the public will be muted upon entry.



You'll see  **when your microphone is muted**

> Questions and comments may be submitted in writing through the Q&A feature at any time during the event. Please submit to **All Panelists**.

> If technical problems arise, please contact Adam.Hauck@nyserda.ny.gov

Learning from the Experts

This webinar series is hosted by NYSERDA's offshore wind team and features experts in offshore wind technologies, development practices, and related research.

NEW YORK STATE | NYSERDA

Offshore Wind Turbine Design for Extreme Weather Events

Dr. Bruce Bailey
Executive in Residence
Center of Excellence for Weather & Climate Analytics
University at Albany

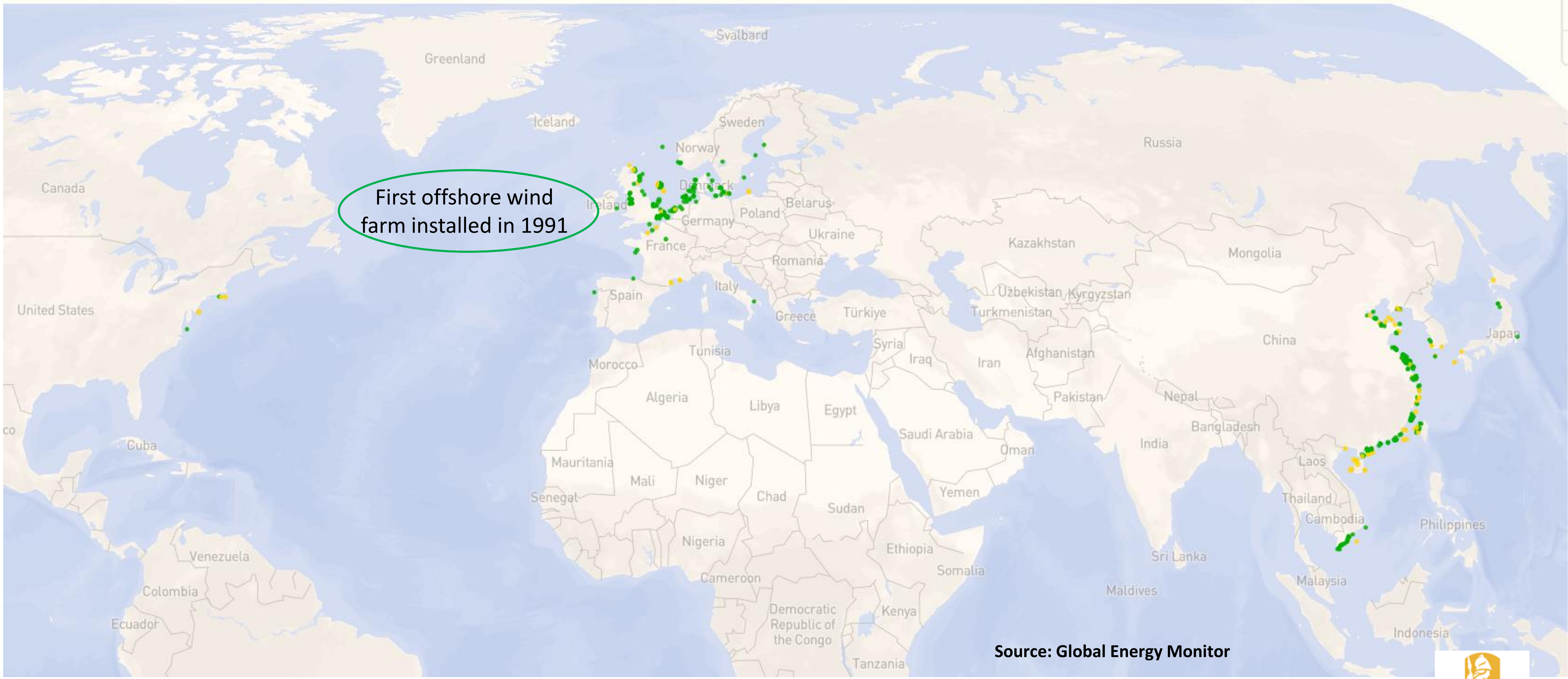
November 2024

Talking Points

- Global Perspective
- Extreme Event Types in the NE US
- The Metocean Environment
- Designing Projects for Norms & Extremes
- Estimating Extreme Probabilities
- East Coast Storm Risks
- Climate Change

University at Albany
State University of New York

Over 300 Offshore Wind Energy Projects Worldwide = 75 GW

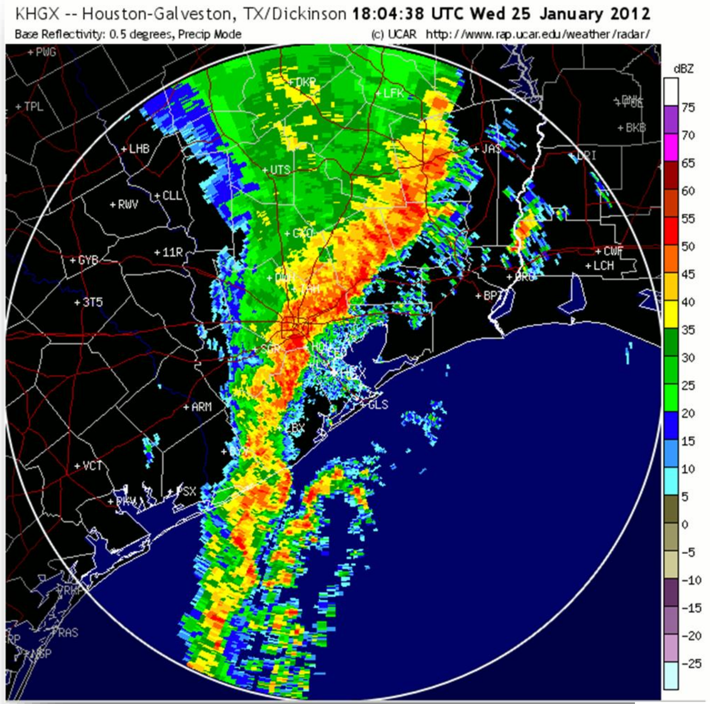


Source: Global Energy Monitor

Main Sources of Extreme Winds & Waves in Northeast US

Tropical Cyclones / Hurricanes

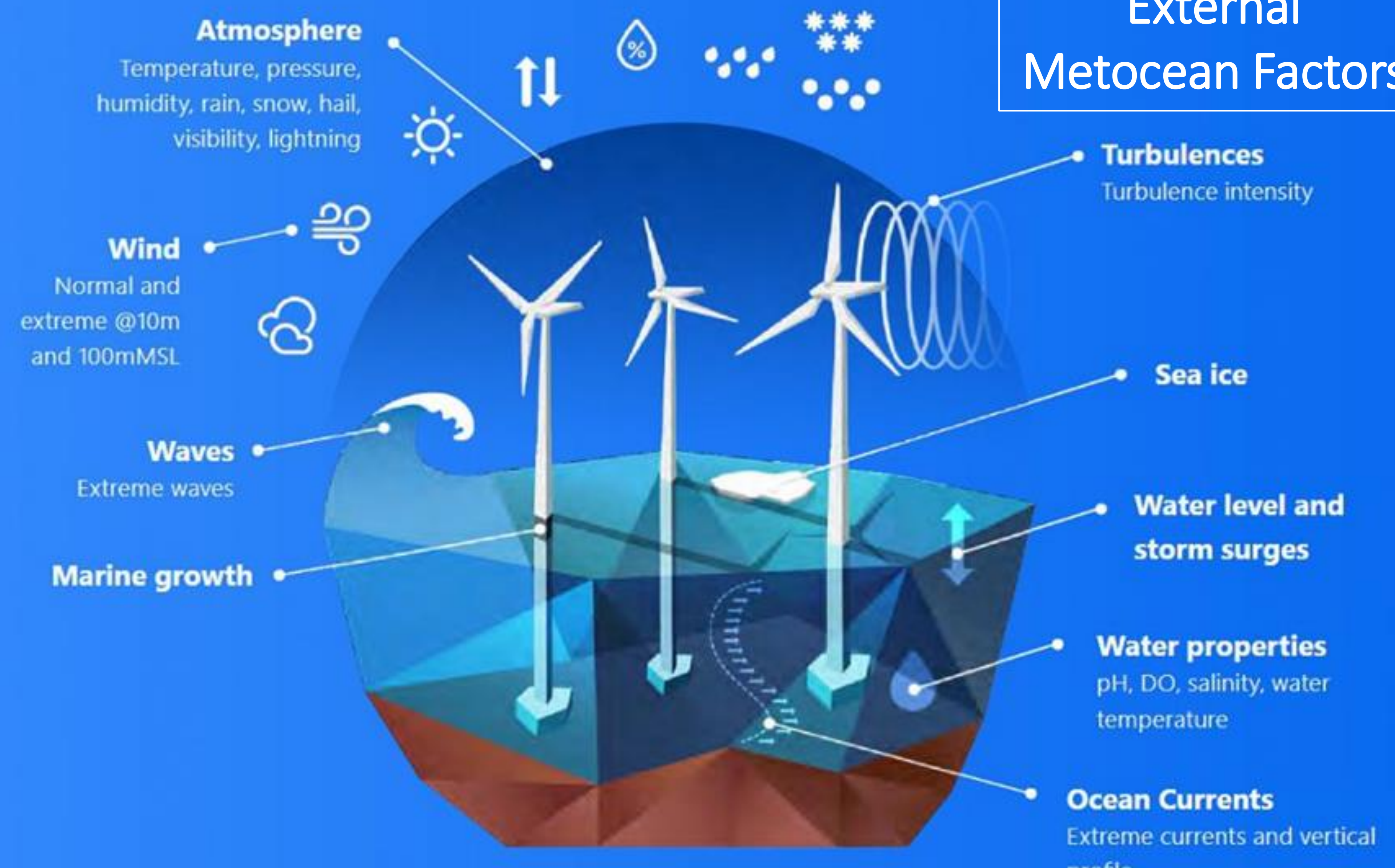
Squall Lines



Extratropical Cyclones / Nor'easters

UNIVERSITY AT ALBANY
STATE UNIVERSITY OF NEW YORK

External Metocean Factors



Source: DHI

Key Metocean Parameters

Atmosphere

Normals & Extremes

- Wind speed / direction
- Turbulence, Wind shear
- Temp., Pressure, Humidity
- Air Density
- Precipitation, icing, visibility

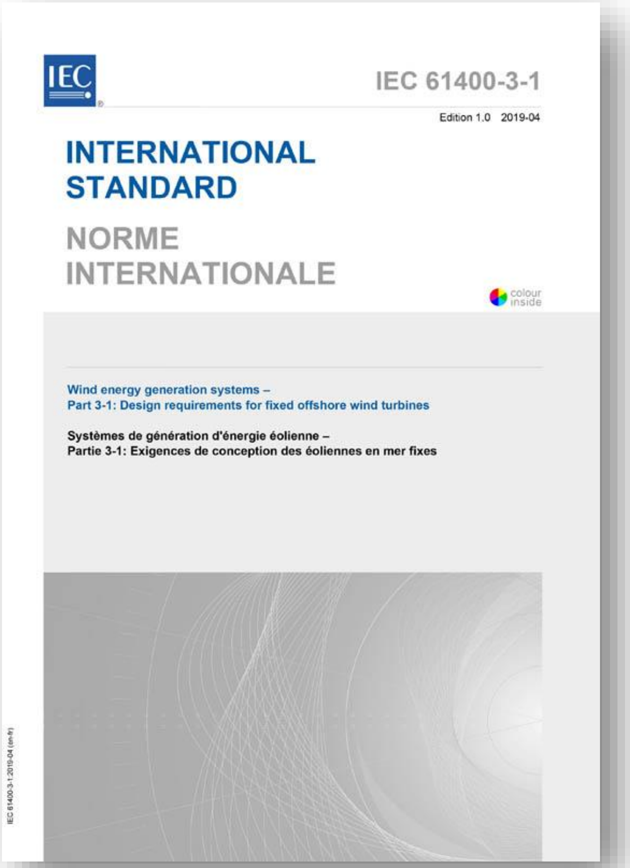
Ocean

Normals & Extremes

- Wave heights, periods, directions
- Significant wave and peak stats
- Water levels
- Currents, breaking waves
- Temp., salinity, etc.

Joint Distributions of Wind & Wave Stats for Normal & Extreme Conditions

Design Standards


IEC
IEC 61400-3-1
Edition 1.0 2019-04
INTERNATIONAL STANDARD
NORME INTERNATIONALE
colour inside
Wind energy generation systems –
Part 3-1: Design requirements for fixed offshore wind turbines
Systèmes de génération d'énergie éolienne –
Partie 3-1: Exigences de conception des éoliennes en mer fixes

Primary Standards for Wind Turbine Design Requirements:

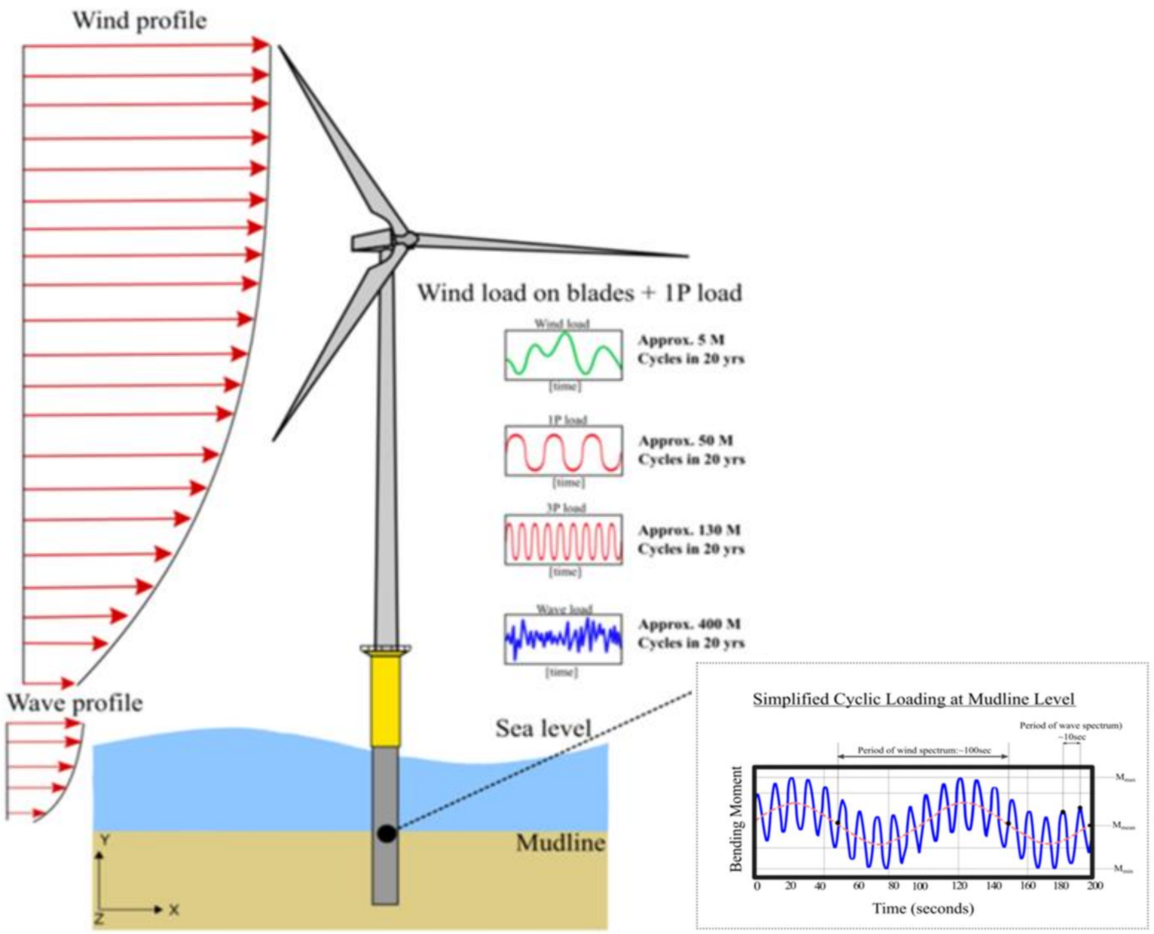
- IEC 61400-3-1: Fixed Offshore Wind Turbines
- IEC 61400-3-2: Floating Offshore Wind Turbines

Wind Turbine Class	I	II	III	S	T
V*avg* = Annual avg speed @ hub ht	10.0 m/s	8.5 m/s	7.5 m/s	Values specified by the designer	For tropical cyclone-prone regions
V*ref* = extreme 10-min speed; 50-yr recurrence	50 m/s	42.5 m/s	37.5 m/s		
V*ref* $_T$ = for tropical storm environment	57	57	57		
V*ext* = extreme 3-sec gust w/50-yr recurrence	70.0 m/s	59.5 m/s	52.5 m/s		

Turbine subclasses based on turbulence intensity.
All values assume standard air density = 1.225 kg/m3

University at Albany
State University of New York

IEC Design Load Requirements



IEC 61400-3 outlines >30 **design load cases** to analyze. They represent various operational modes of the wind turbine (start-up, operation, shut-down, parked, etc.).

- Fatigue load cases: normal & fault conditions
- Ultimate load cases: 50-yr extreme conditions

Software packages are available to run these design load cases (such as **openFAST**, available from NREL).

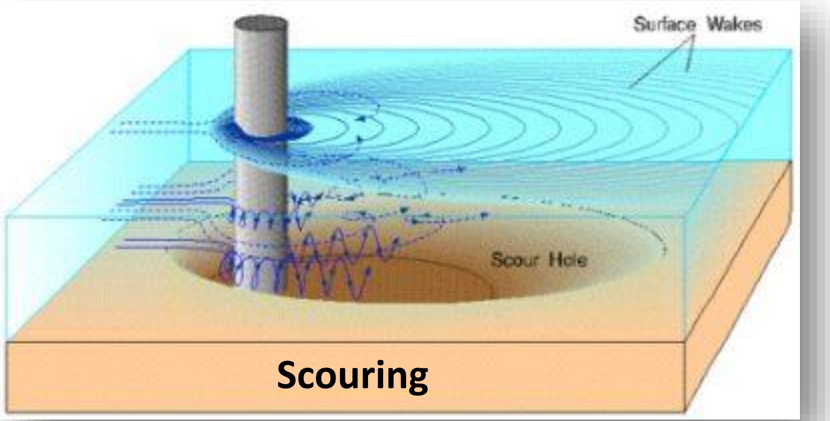
They couple modules for aerodynamics, hydrodynamics, structural dynamics, and electrical/control system dynamics.

Limitations of IEC Design Standard

- Applies to just the rotor & nacelle assembly; support structure designed for site-specific conditions follow other standards
- Not meant to encompass all offshore conditions
- Does not account for change of wind direction (veer) across the rotor plane
- Wind shear and turbulence within tropical cyclones may be more severe than assumed
- Some analysis methods, such as estimating 50-yr recurrence values, are not prescribed

University at Albany
State University of New York

Other Design Considerations



Other Applicable Standards & Guidance for Offshore Structures & Activities

- International Electrotechnical Commission (IEC)
- International Organization for Standardization (ISO)
- American Petroleum Institute (API)
- DNV GL
- American Bureau of Shipping (ABS)
- Bureau of Ocean Energy Management (BOEM)

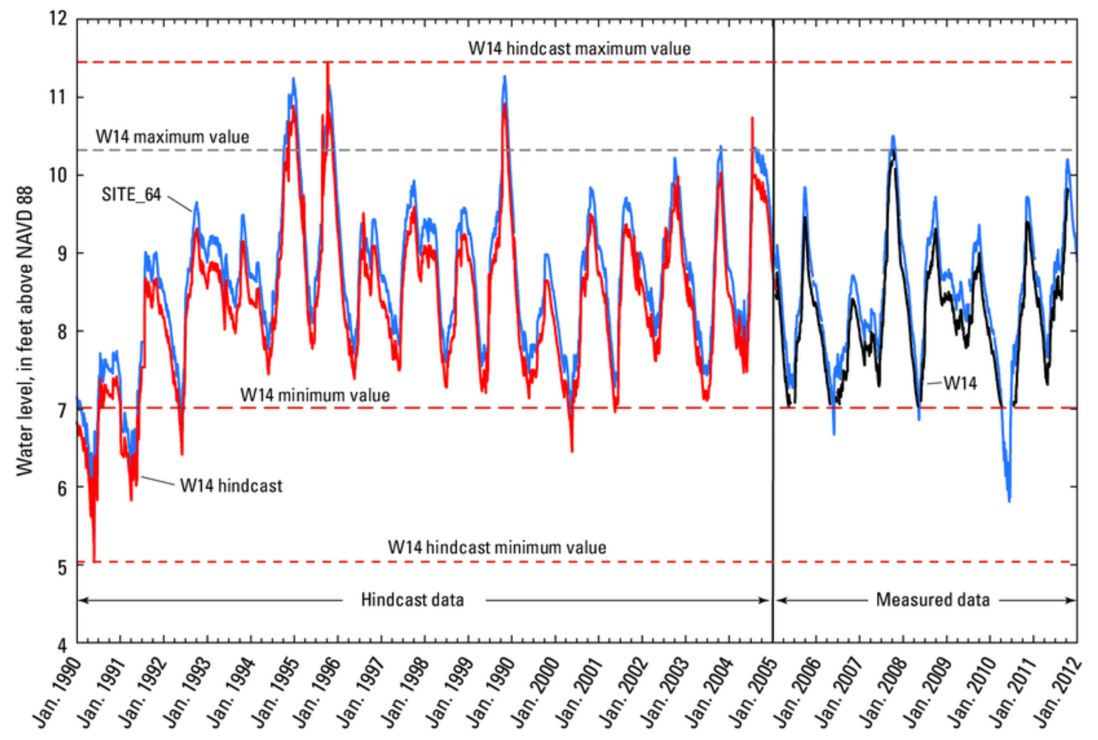
How Long-Term Metocean Conditions are Determined

Objective

- Derive Long-Term Typical and Extreme Metocean Conditions for Project Area

Approach

- On-site measurements for 2+ years
- Correlate with regional concurrent data sources that also possess a historical record
  - Reanalysis data (e.g. ERA5)
  - NDBC Buoys
- Reconstruct the project site's long-term conditions via numerical modeling (hindcasting) techniques
- Estimate extremes for different return year periods
- Quantify uncertainties

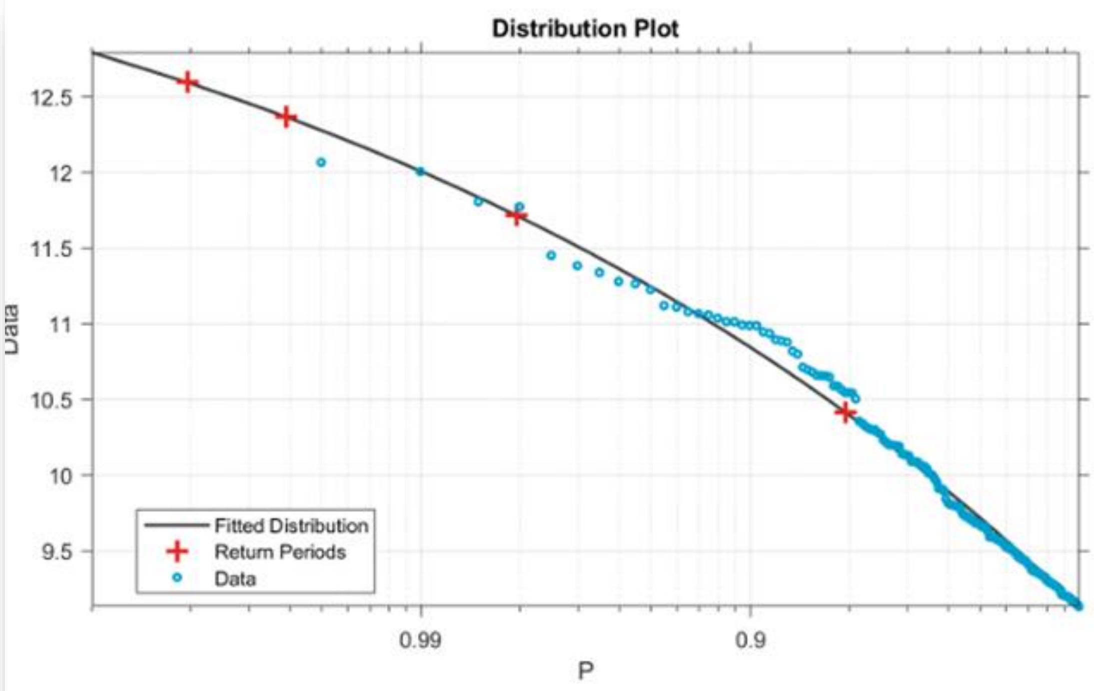


University at Albany
State University of New York

Extreme Value Analysis (EVA)

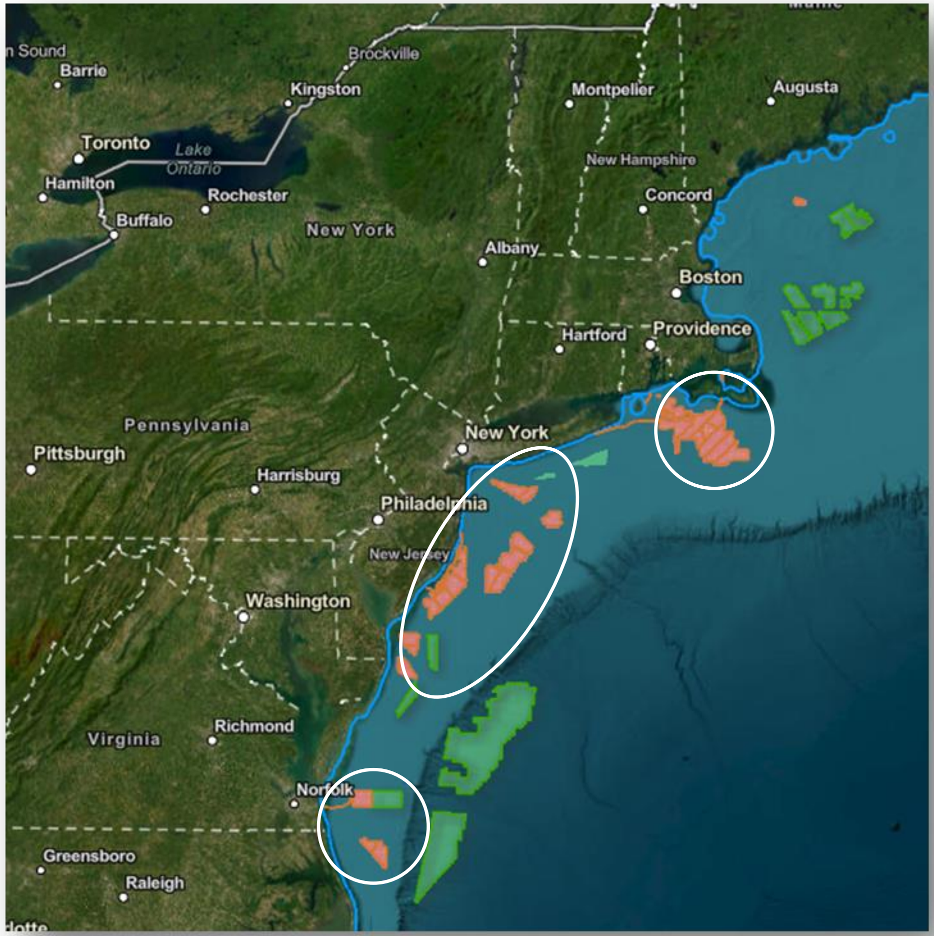
Deals with the statistical analysis of extreme events, focusing on the tail ends of the data distribution.

- Identifying Extreme Data Over a Sufficient Period
- Sorting Independent Data Populations
  - Hurricanes & Extratropical cyclones constitute a 'mixed climate'
- Modeling (e.g., Gumbell, Weibull, Pareto)
- Return Period Estimation



Return Period	Probability	Extreme Value
1	0.8050245266	10.41
10	0.9805024527	11.72
50	0.9961004905	12.37
100	0.9980502453	12.60

Estimated Maximum Winds & Waves For East Coast Areas



Region	50-yr Max 10-min Speed @ 100 m	50-yr Signif. Wave Ht.	50-yr Max Wave Ht.
MA-RI	39-44 m/s	9-11 m	16-19 m
NY-NJ-MD-DE	34-39 m/s	6-8 m	10-19 m
VA-NC	39-44 m/s	6-10 m	10-16 m

Data from **Barthelmie et al., 2021 (Energies)** based on 40-yrs of ERA5 reanalysis data and extreme value analysis techniques.

Same Regions	50-yr Max 10-min Speed @ 150 m ht	50-yr Signif. Wave Ht.
	45 - 49 m/s	6 – 11 m

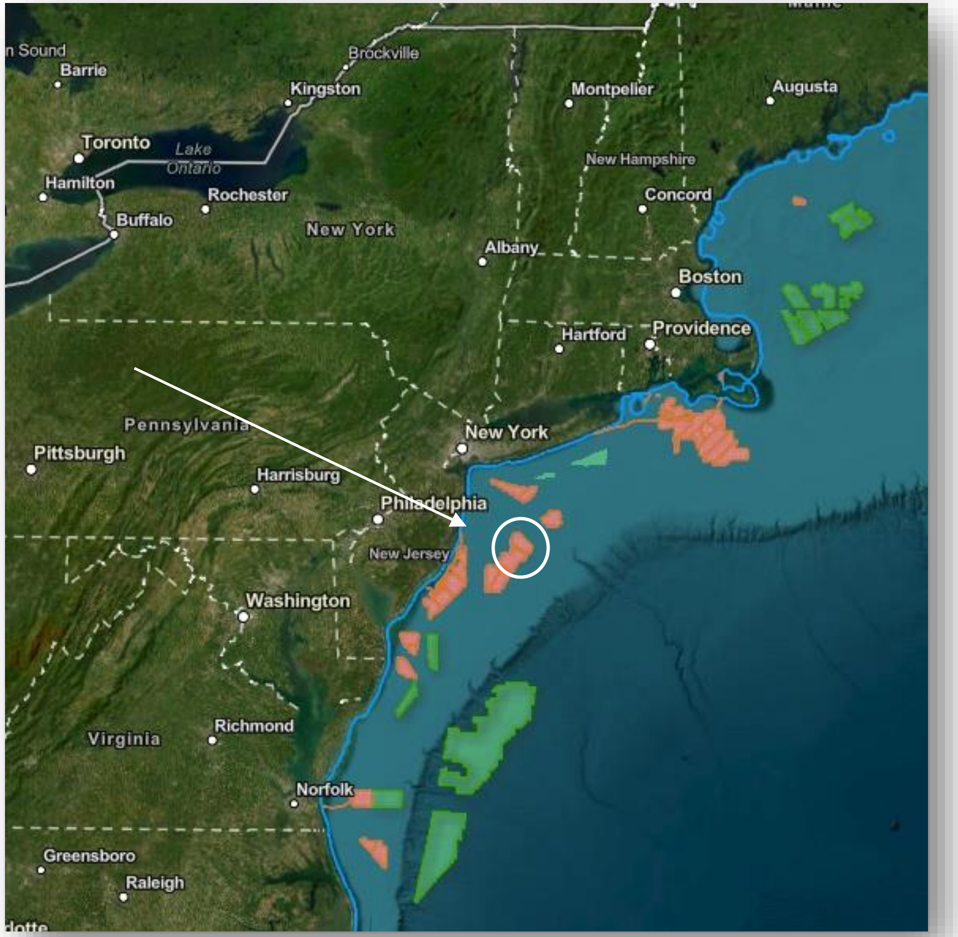
From **M. Mroczek et al., 2024 (Ocean Engineering)**

Top Max 1-Hr Speeds @ 150m, 1940-2023, ERA5 Data

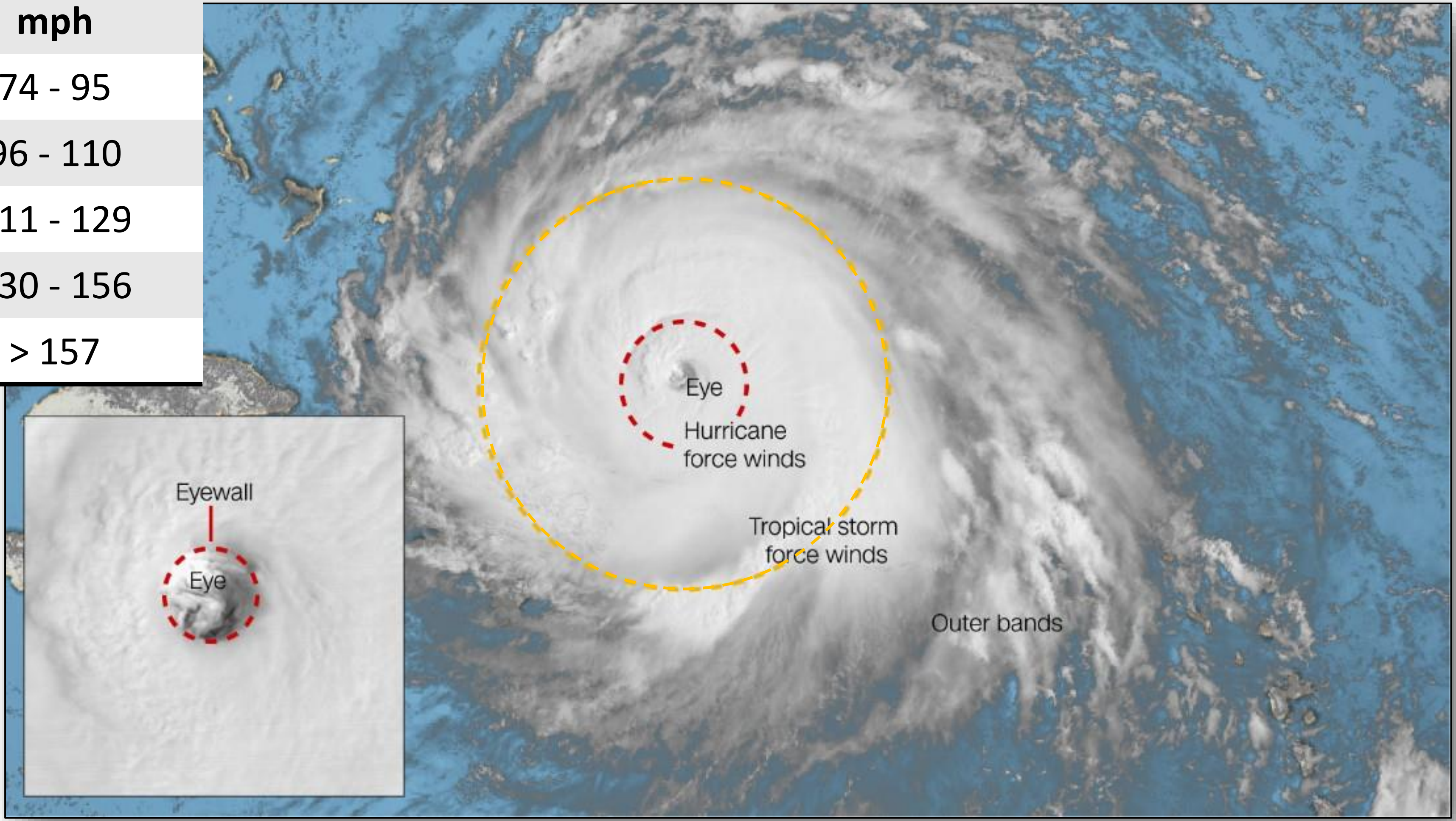
NY Bight

Rank	Max Speed m/s	Date	Event
1	43.9	**9/1954**	Hurricane Edna
2	39.7	8/1991	Hurricane Bob
3	39.7	9/1985	Hurricane Gloria
4	39.0	10/2012	Hurricane Sandy
5	39.0	**9/1960**	Hurricane Donna
6	36.9	**11/1950**	Great Appalachian Storm
7	36.3	**8/1954**	Hurricane Carol
8	34.8	2/1976	Groundhog Day Storm
9	34.3	**9/1961**	Hurricane Esther
10	33.3	8/2011	Hurricane Irene

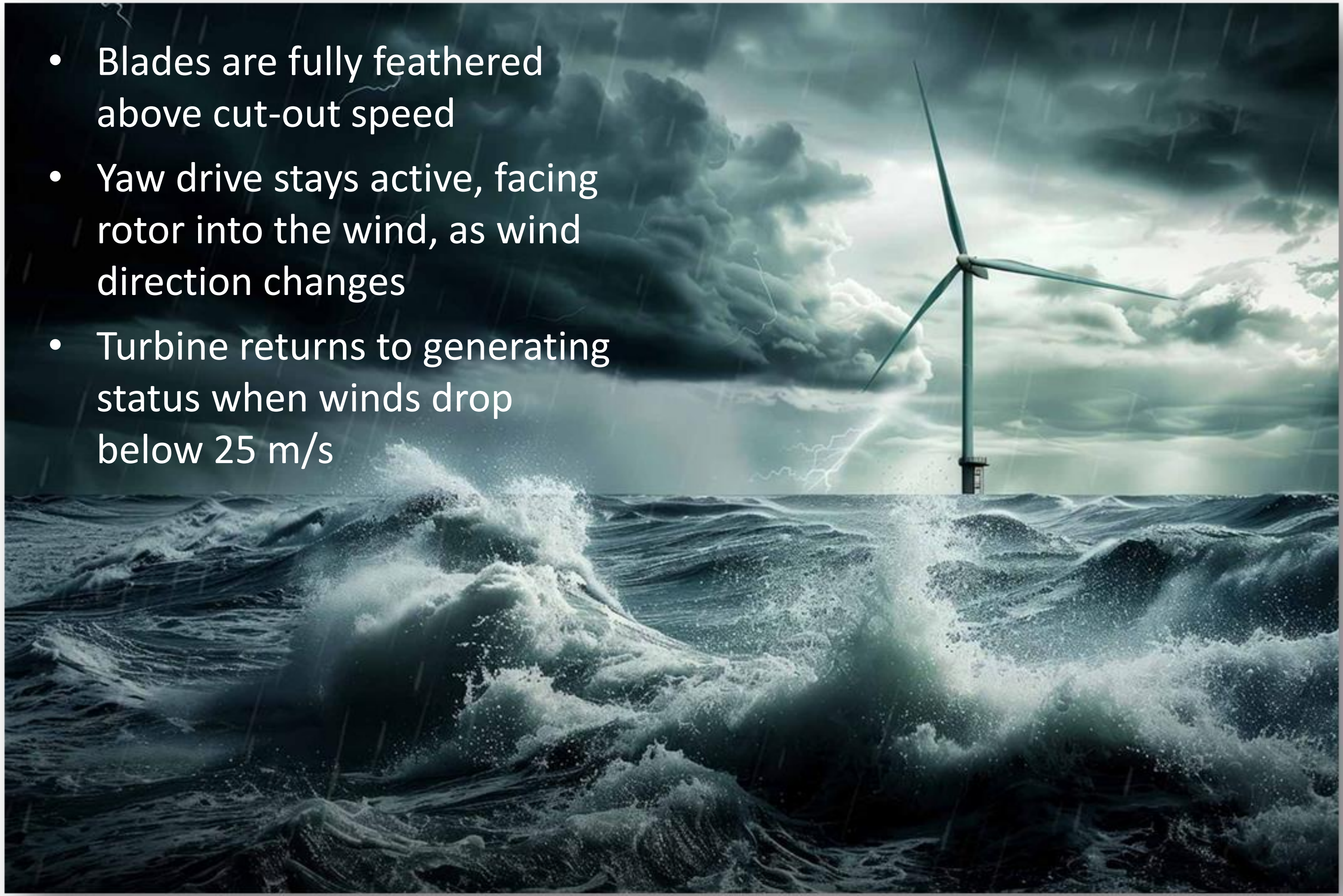
40 m/s = 90 mph



Hurricane Categories and Maximum Sustained Winds @ 10 m Height		
Category	**m/s**	**mph**
1	33 - 42	74 - 95
2	43 – 49	96 - 110
3	50 - 57	111 - 129
4	58 - 70	130 - 156
5	> 70	> 157



How Turbines Survive Extreme Winds

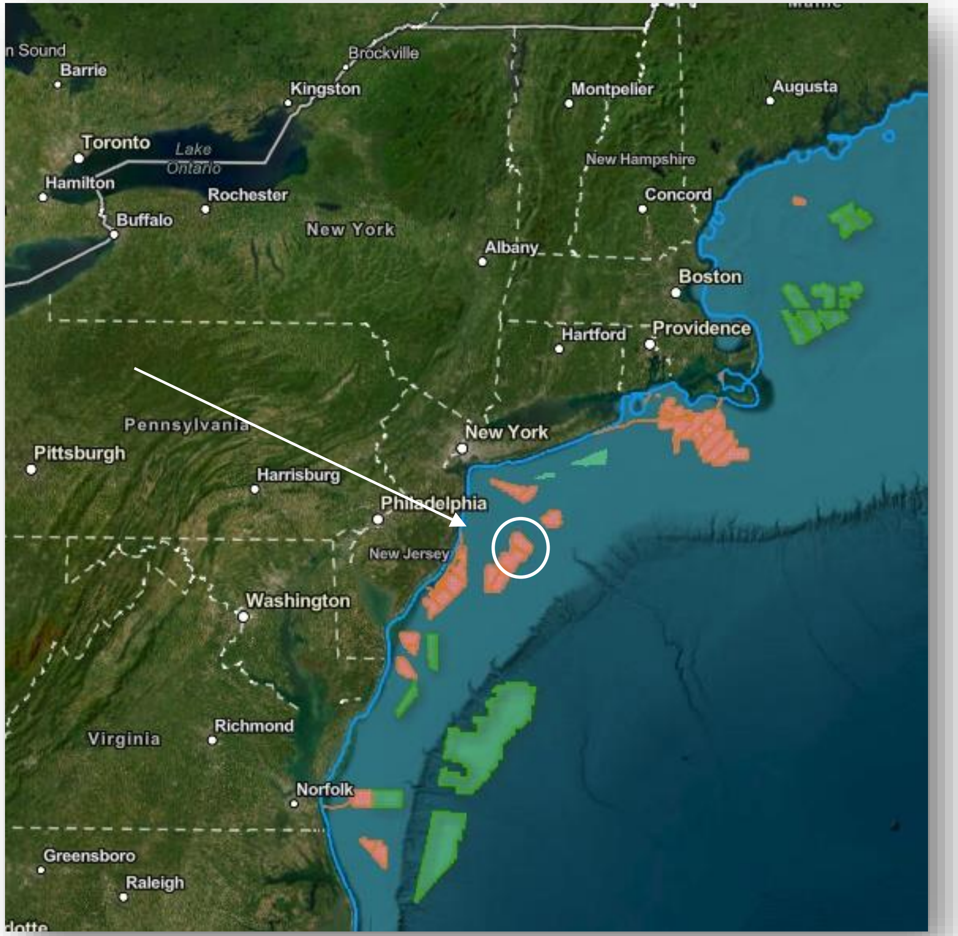


- Blades are fully feathered above cut-out speed
- Yaw drive stays active, facing rotor into the wind, as wind direction changes
- Turbine returns to generating status when winds drop below 25 m/s

Longest Duration High Wind Events @ 150m, 1940-2023

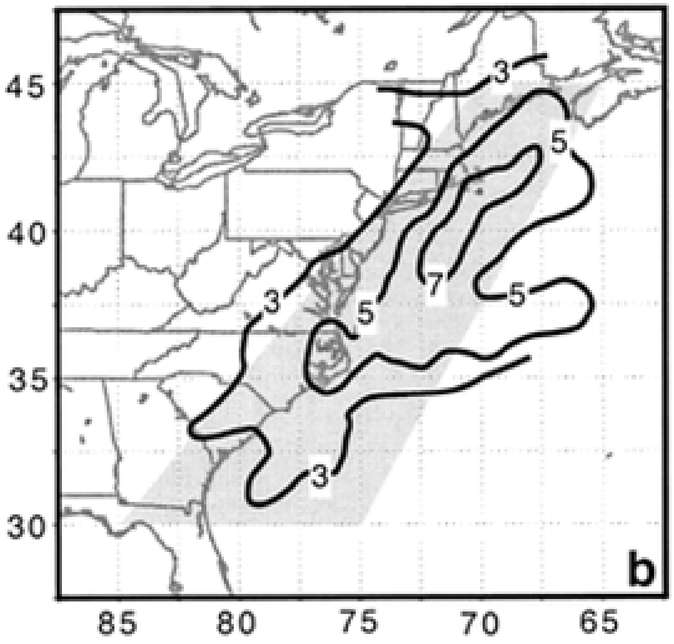
Threshold 22.5 m/s - NY Bight

Rank	Length - Hrs	Date	Event
1	45	3/1962	Ash Wednesday Storm
2	29	1/1944	Nor'easter
3	27	10/2012	Hurricane Sandy
4	27	2/1969	Nor'easter
5	27	1/1966	Nor'easter
6	26	2/1998	Nor'easter
7	25	3/1993	Nor'easter
8	25	12/1962	Nor'easter
9	24	9/1961	Hurricane Esther
10	24	3/1948	Nor'easter



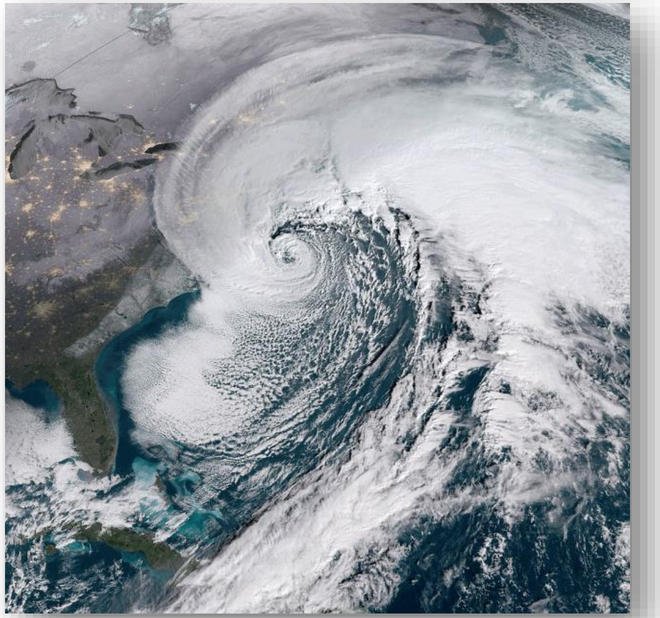
UNIVERSITY AT ALBANY
STATE UNIVERSITY OF NEW YORK

East Coast Winter Storms (Nor'easters)

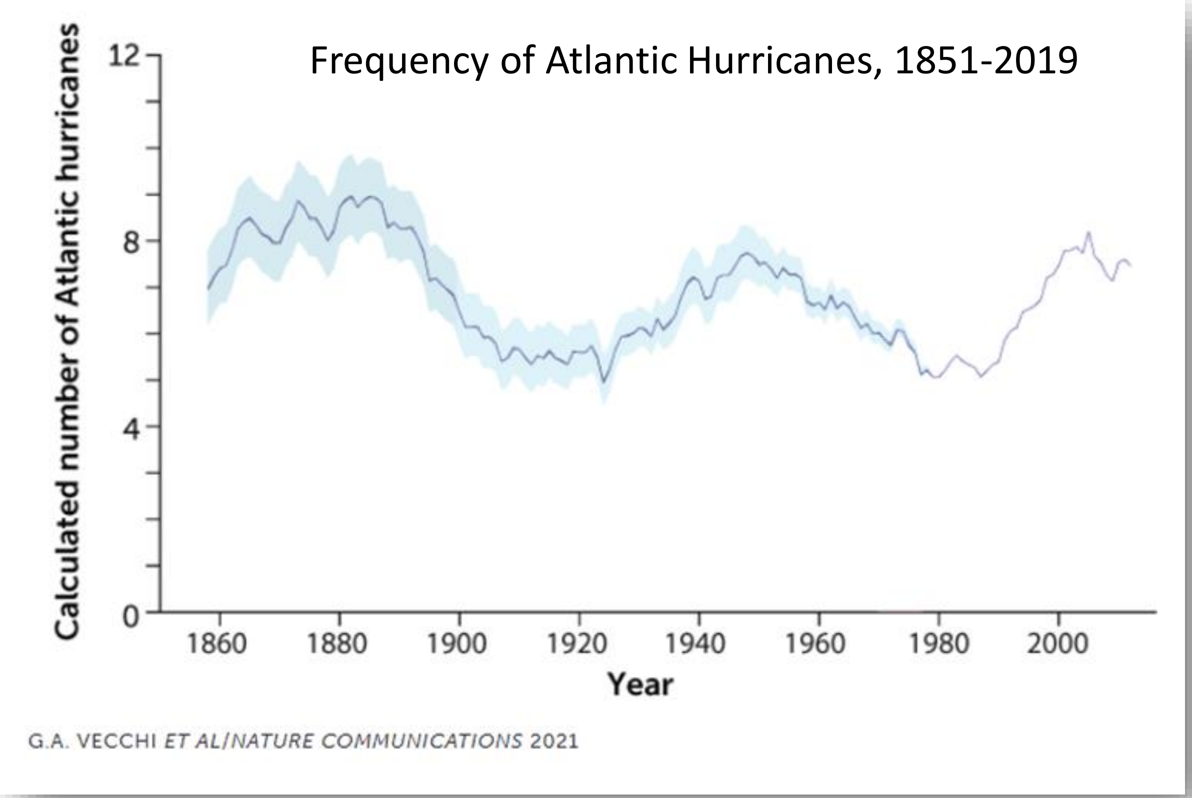


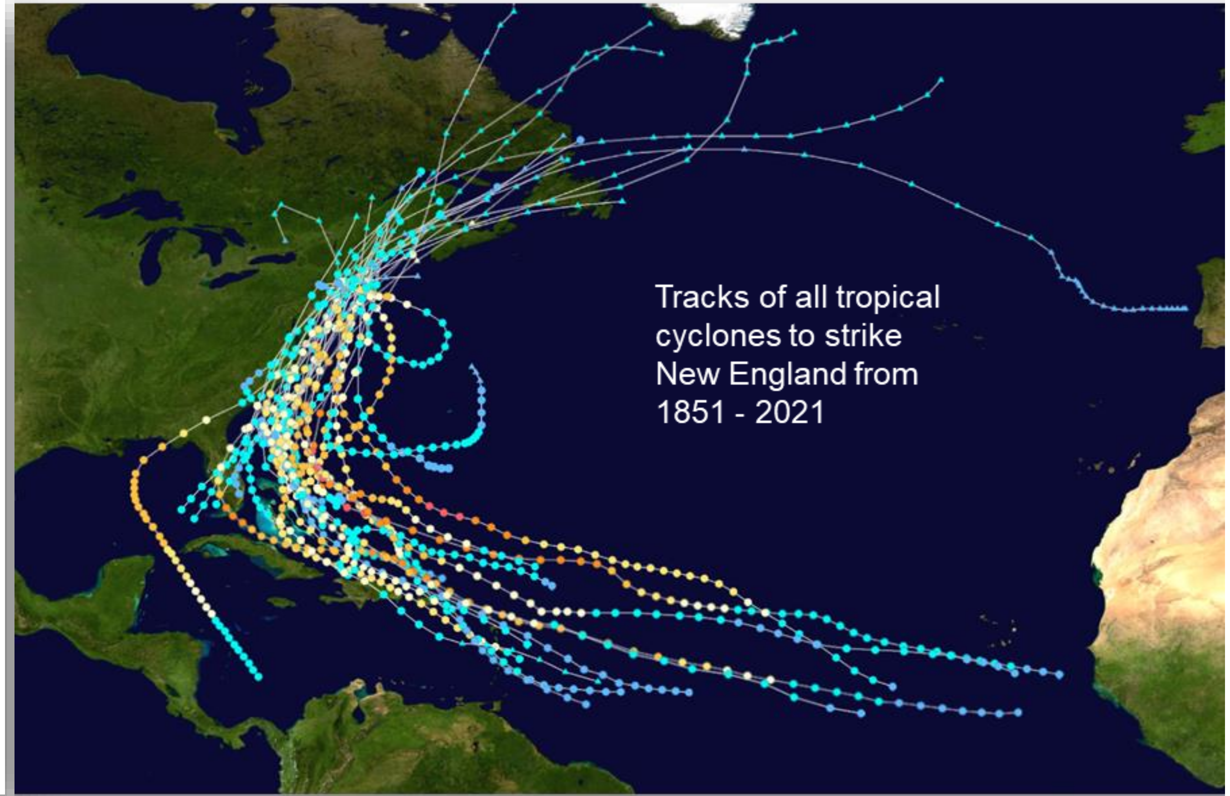
Favored Development Areas for Coastal Winter Storms; From Hirsch et al., 2001

- Average of 12 East Coast Winter Storms per year. 3 are 'strong'
- Peak occurrence in Jan-Feb
- Interdecadal variability
- Higher frequency of storms during El Nino periods
- Climate change modeling suggests fewer storms and more intense ones; more E-ward track



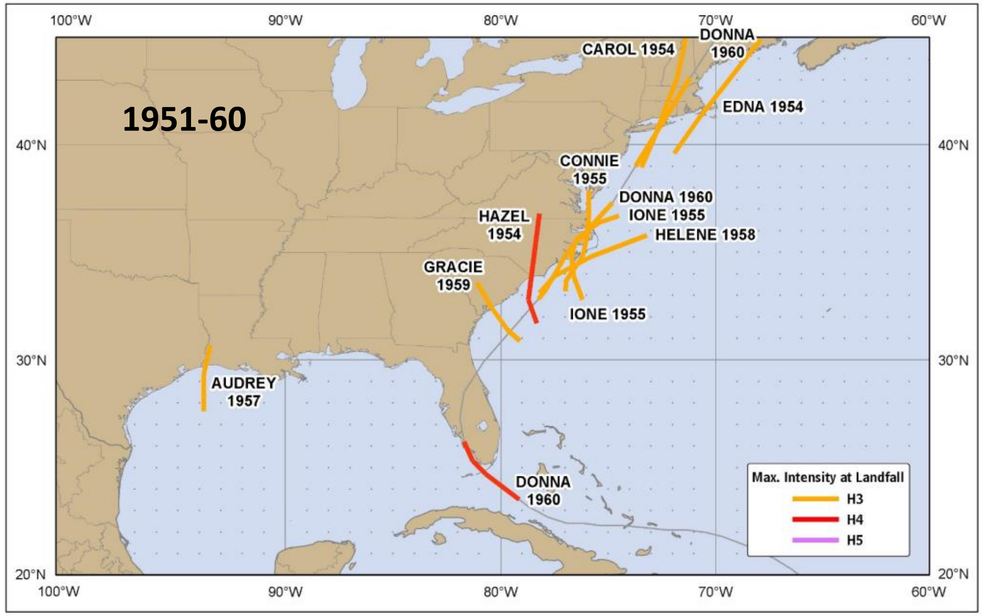
Trends in Atlantic Tropical Storms & Hurricanes

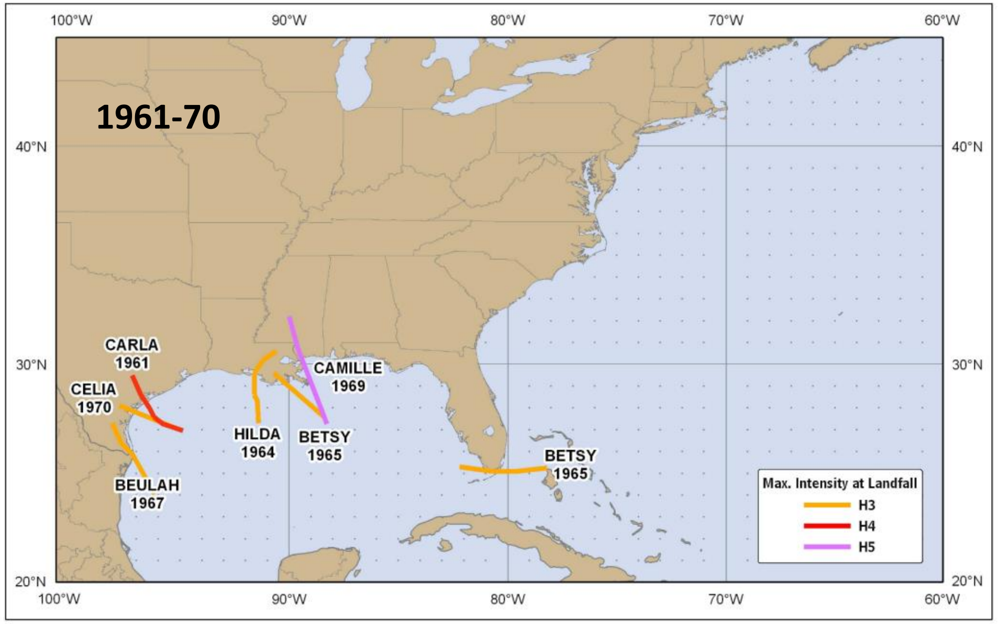


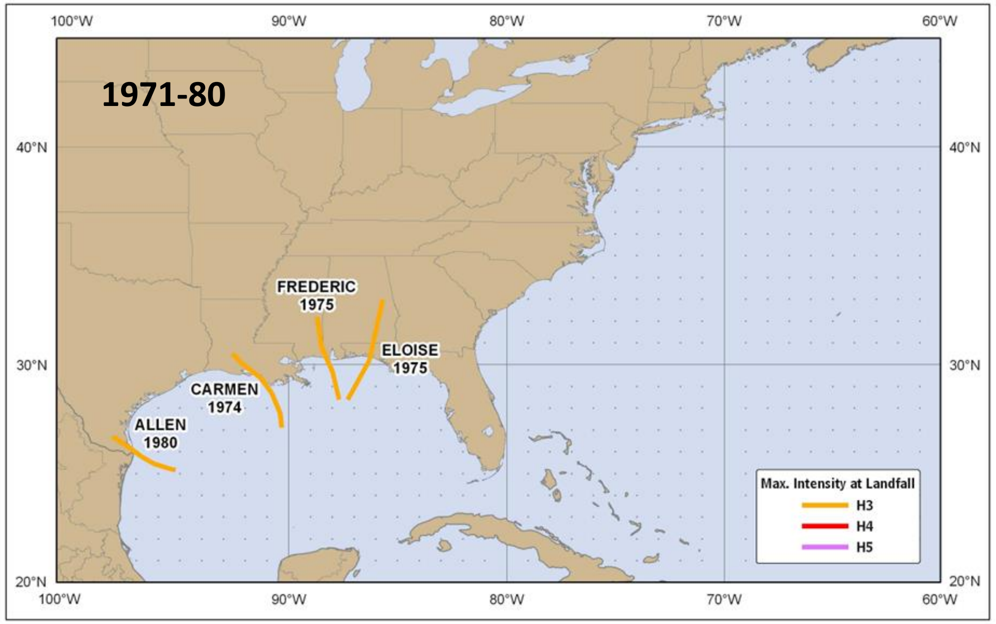


UNIVERSITY AT ALBANY
STATE UNIVERSITY OF NEW YORK

1950s East Coast Major Hurricane Activity Vs. Following Decades

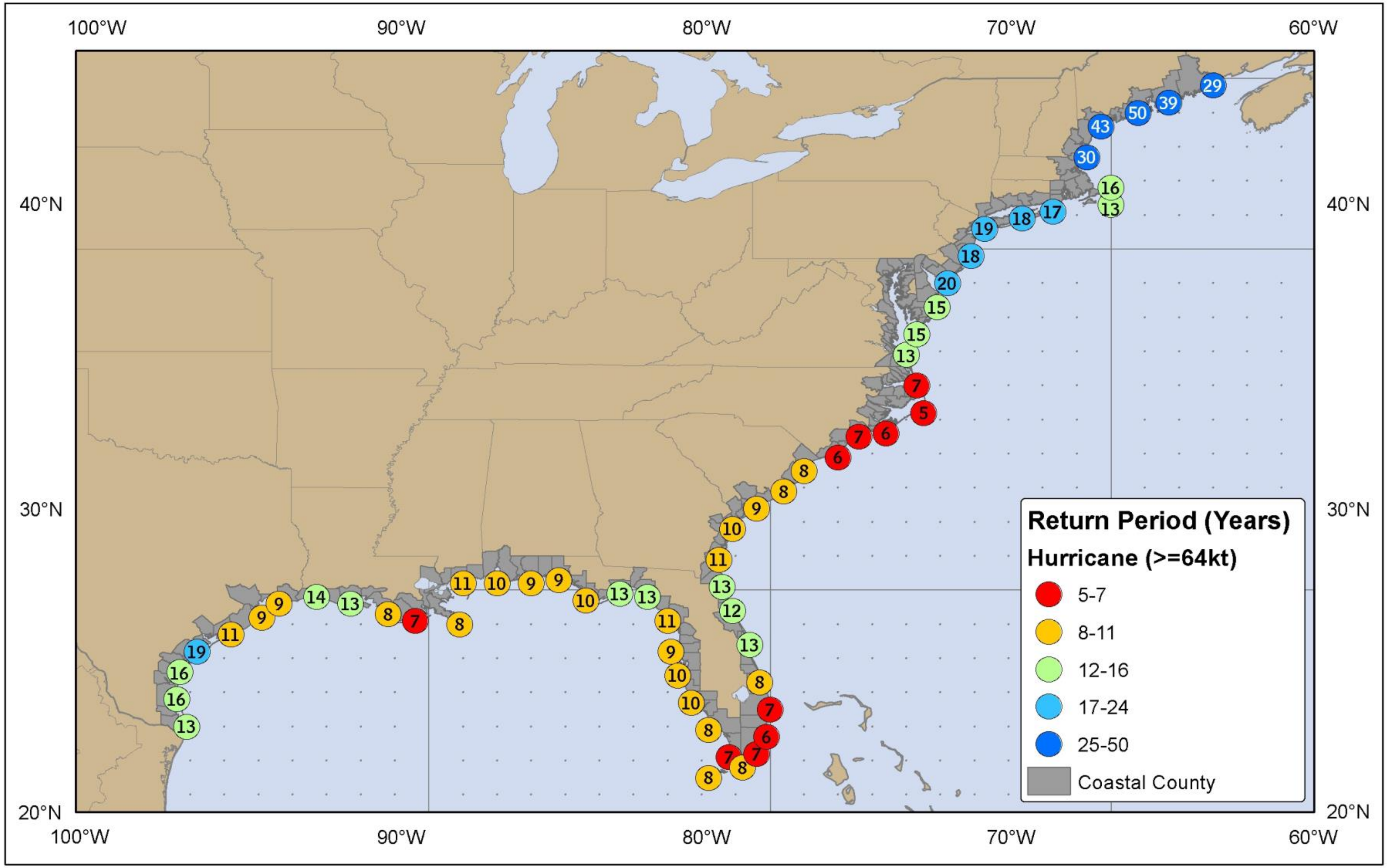






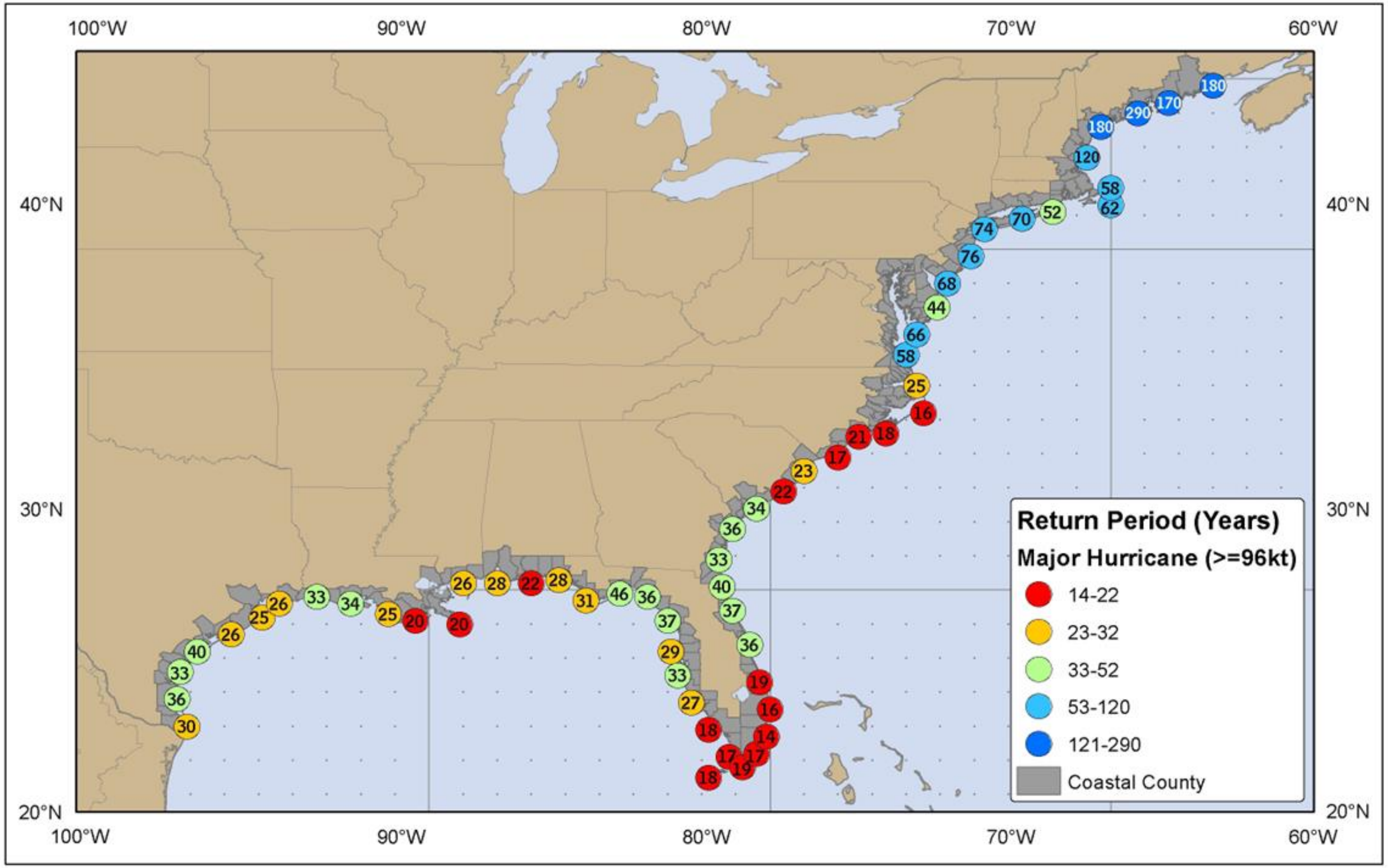
Hurricane Probability

Estimated return period (years) for hurricanes passing within 50 nautical miles of various locations on the U.S. Coast



Major Hurricane Probability

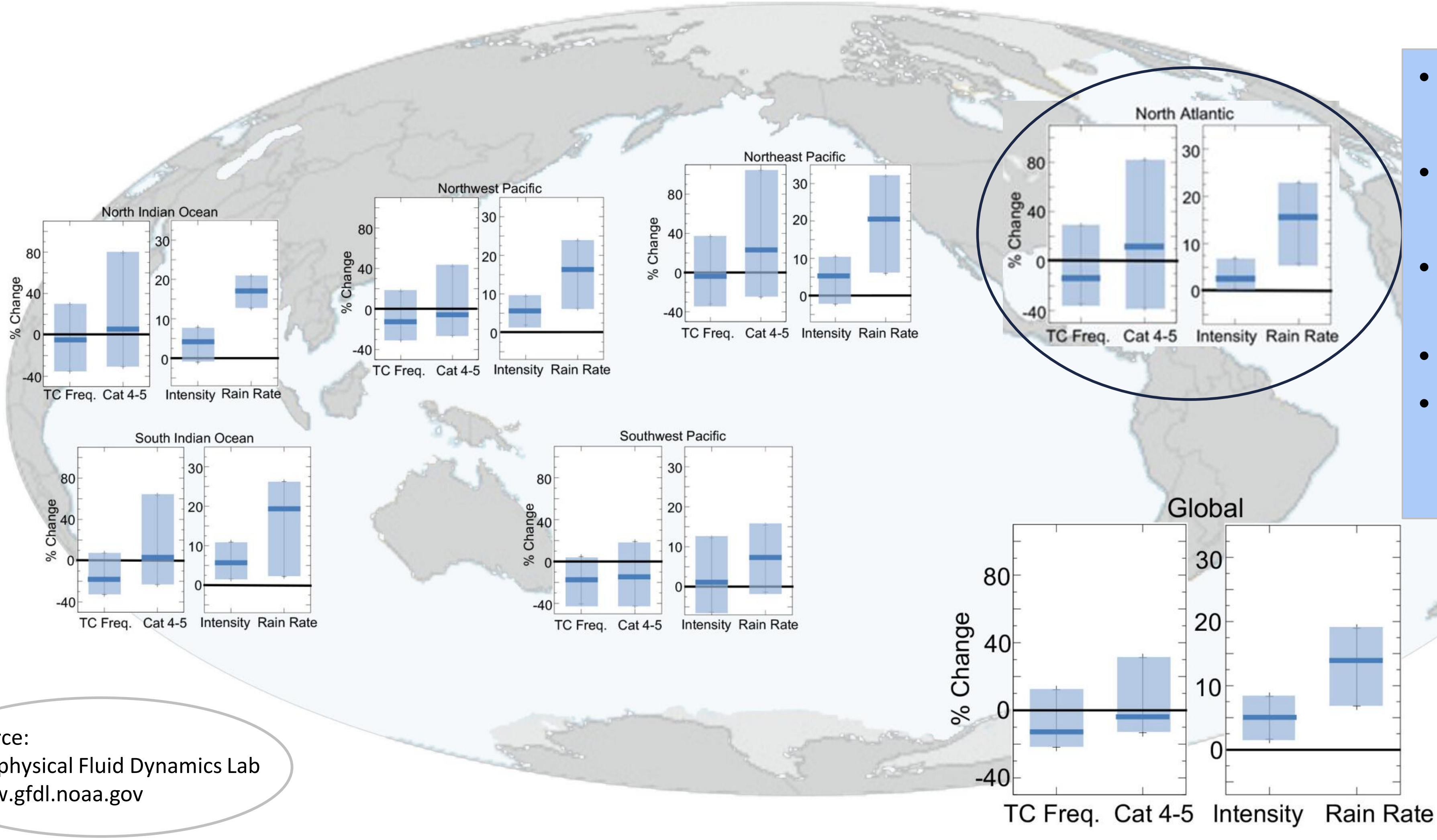
Estimated return period (years) for major hurricanes (Cat. 3-5) passing within 50 nautical miles of various locations on the U.S. Coast



Climate Change Considerations

- Ocean temps are warming & sea level is rising
- Port facilities & land-based substations should account for higher tides & storm surges
- To address climate change risk, some project designers choose longer extremes return periods or larger safety margins

Tropical Cyclone Projections – 2°C Global Warming



- **Total # of TS's & hurricanes decrease by ~15%**
- **# of Cat 4-5 hurricanes increase by 10%**
- **Strongest winds increase by 3%**
- **Rainfall rates increase 15%**
- **Storm inundation levels increase due to sea level rise (2-3 ft by 2100)**

Source:
Geophysical Fluid Dynamics Lab
www.gfdl.noaa.gov

Concluding Points

- Turbines are available as Class types; Towers & foundations are customized for site conditions.
- Commercially available Class I turbines are robust and suitable for northeast US conditions.
- Nor’easters and hurricanes produce the most extreme metocean conditions in this region.
- Changes in extreme weather due to climate change are factored into project planning.

UNIVERSITY AT ALBANY
STATE UNIVERSITY OF NEW YORK

Thank You

Bruce H. Bailey
bbailey2@albany.edu

University at Albany
State University of New York

Next Webinar

November 20, 1:00 p.m. ET

Scaling Offshore Wind Turbines

Walt Musial, National Renewable Energy Laboratory (NREL)

Visit wind.ny.gov to register

Check out over 40 past webinars, including:

- Assessing Offshore Wind Electromagnetic Fields in Our Communities
- Remote Technology to Support Offshore Wind Operations and Maintenance
- How Offshore Wind Farms are Installed
- The Commercial Sale of Offshore Wind Power Generation
- Innovations and Emerging Technologies in Offshore Wind

www.nyserda.ny.gov/osw-webinar-series

We want your feedback! Send suggestions for future webinar topics to offshorewind@nyserda.ny.gov

NEW YORK STATE | NYSERDA