Offshore Wind Resources and Forecasting

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Headquarters: Albany, NY

- Mapping
- Energy Assessment
- Project Engineering
- Performance Evaluation
- Forecasting

- Industry Leader & Consultant for 25 Years
- Full spectrum of wind plant design, development and evaluation services
- Project roles in over 60 countries
- Offices in Austin, TX and Barcelona, Spain; 100 employees

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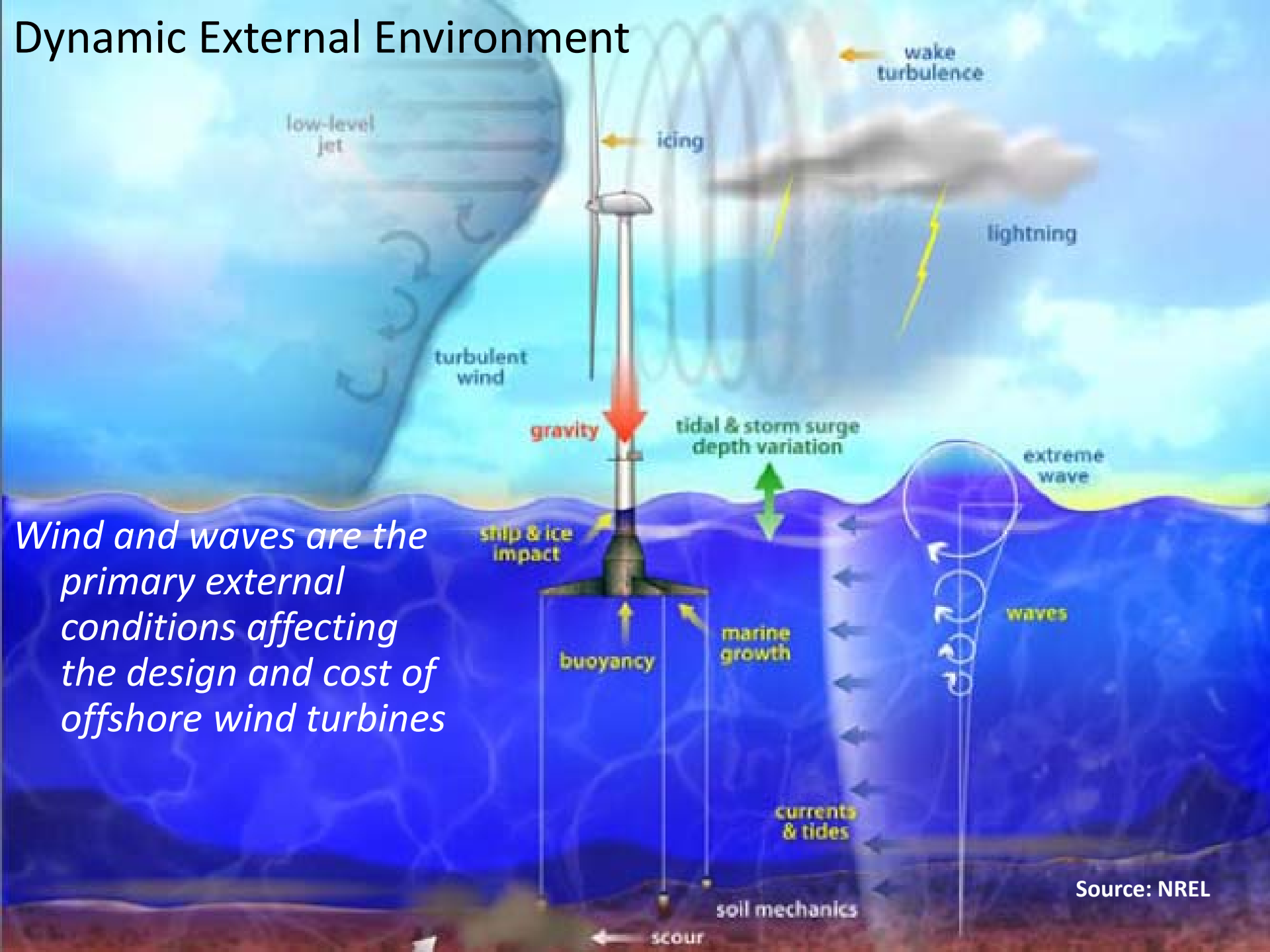
Topics

- Contrasting Land & Offshore Winds
- Extreme Winds
- Wind Measurement
- Wind Modeling
- Measurement Approaches for Wind Farms
- Wind Forecasting
- Future Needs & Trends

Dynamic External Environment



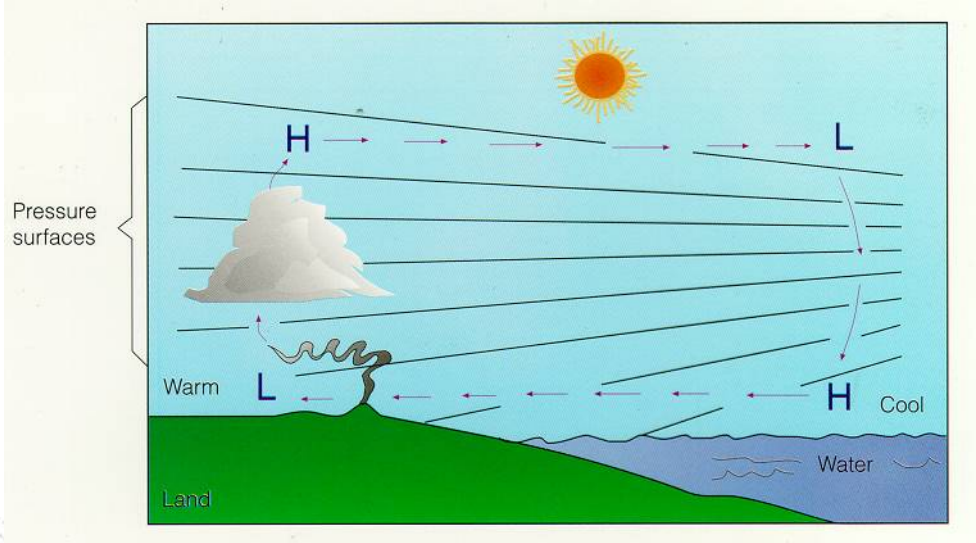
Wind and waves are the primary external conditions affecting the design and cost of offshore wind turbines

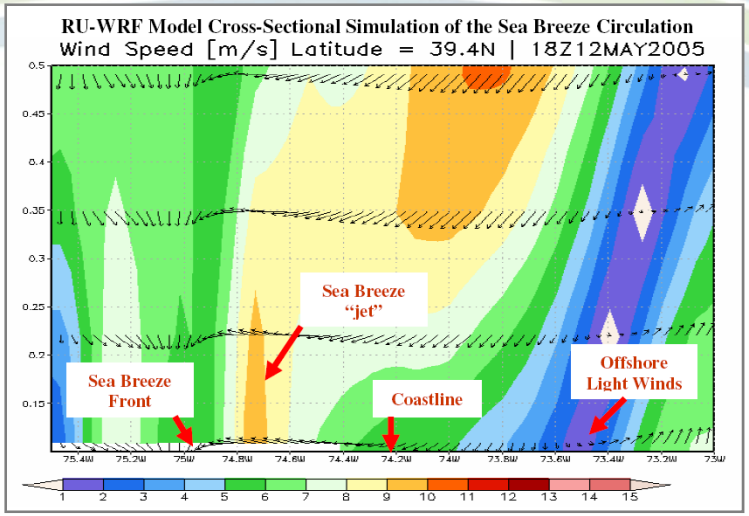
Source: NREL

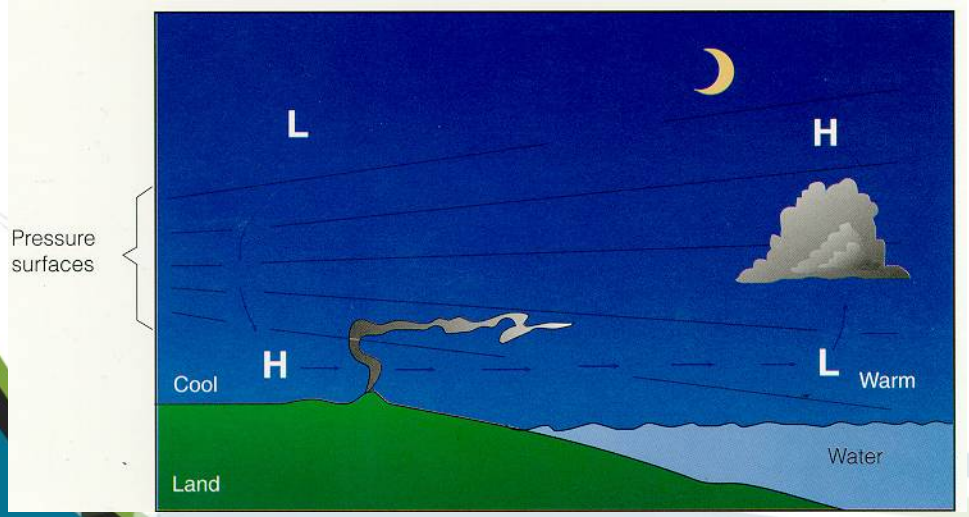
Offshore Contrasts With Land

- Stronger Winds:
  - Very little surface roughness
  - No terrain
  - Fetch dependent
- Spatially consistent
- Lower average wind shear (.08-.16 typical)
- Lower turbulence intensity (.05-.10 typical)
- Sea/lake breeze & stability issues

Sea/Lake Breezes



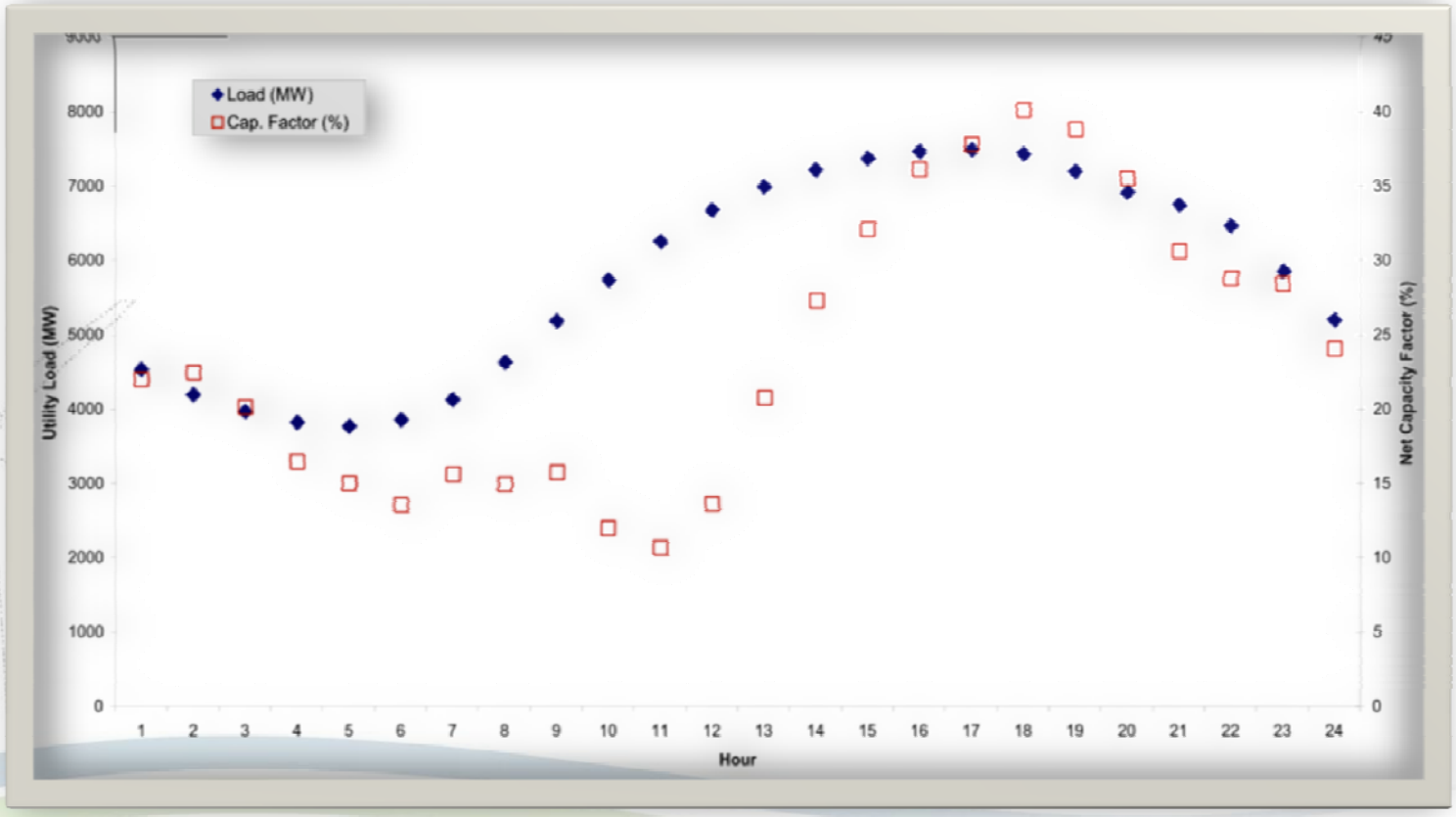




- Sea Breezes Are 3-Dimensional
- Favor Spring & Summer Seasons
- Offshore Extent Is Variable
- Wind Intensity is Variable

Sea Breezes & Load Matching

Avg. Peak Day:1999-2003
Coastal NJ Utility Load & Plant Net Capacity Factor

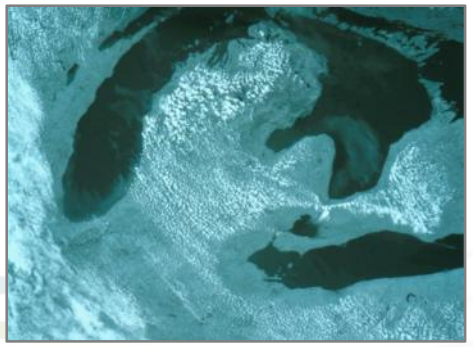


Based on Ambrose Light Station Wind Data

Role of Atmospheric Stability

- Fall-Winter
  - Water warmer than air ⇨ unstable atmosphere
  - Promotes vertical mixing and stronger surface winds
    - Lake effect snow squalls

- Spring-Summer
  - Water cooler than air ⇨ stable atmosphere
    - Lake/sea breezes
  - Suppresses mixing and winds



Stability Effects on Wind Shear

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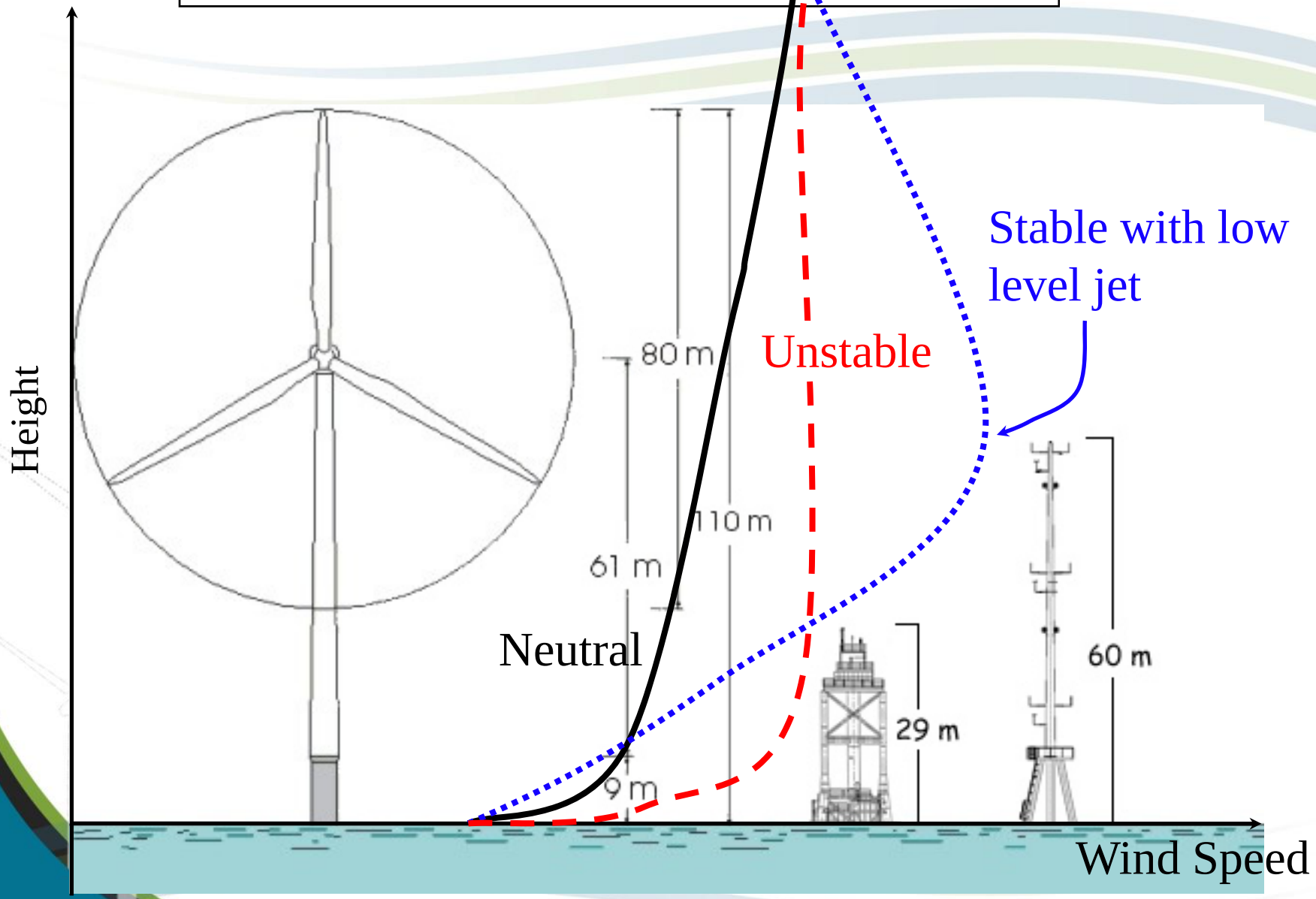
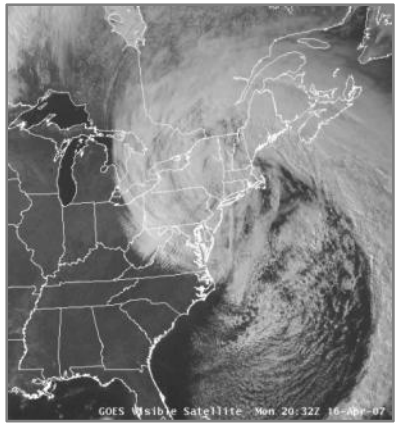


Extreme Winds

Strong Fronts/
Thunderstorm Lines



Slow Moving Intense Coastal Storms – Nor'easters
(large waves too)

Hurricanes
(large waves too)

Hurricane Risks

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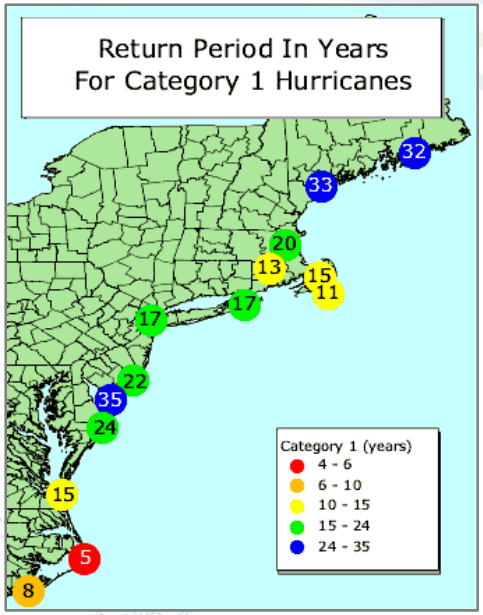


Saffir-Simpson Hurricane Scale

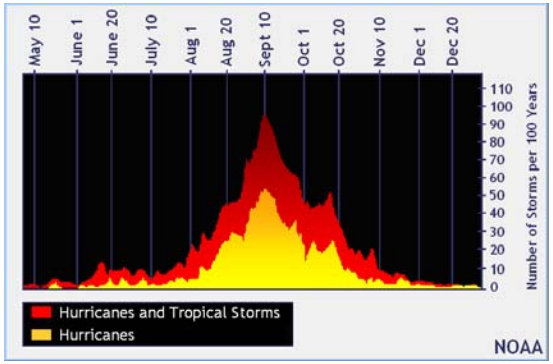
Category 1: 74-95 mph

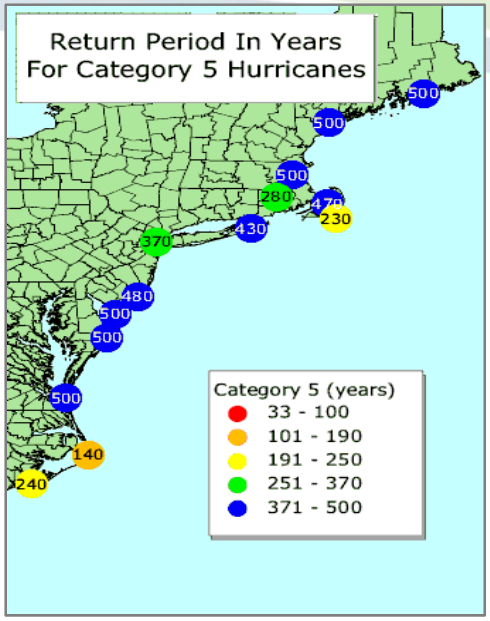
Category 2: 96-110 mph

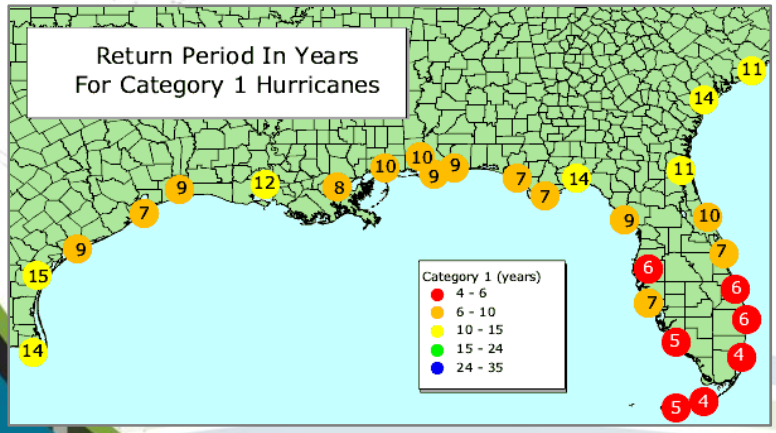
Category 3: 111-130 mph

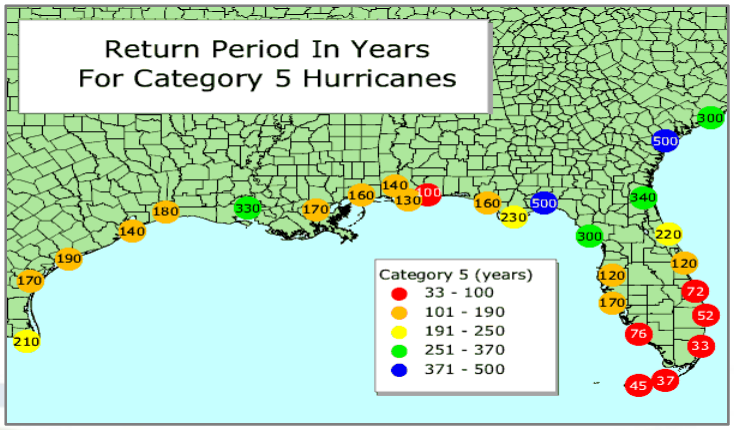
Category 4: 131-155 mph

Category 5: 156+ mph



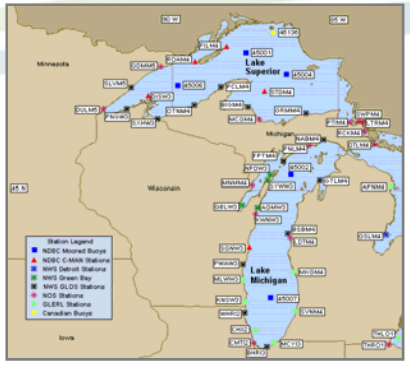


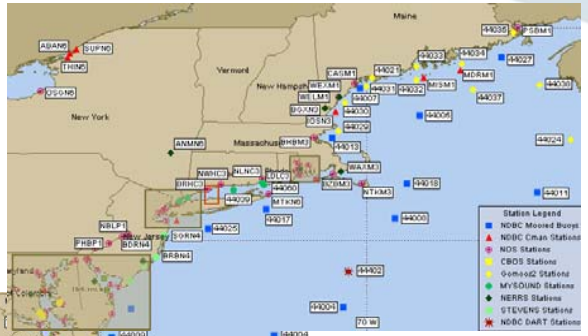


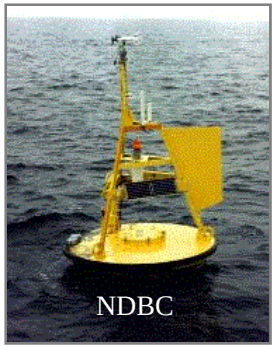


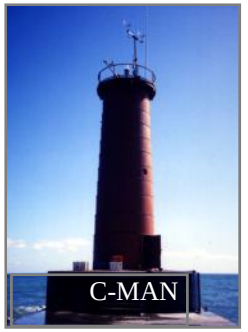
Conventional Sources of Wind Data

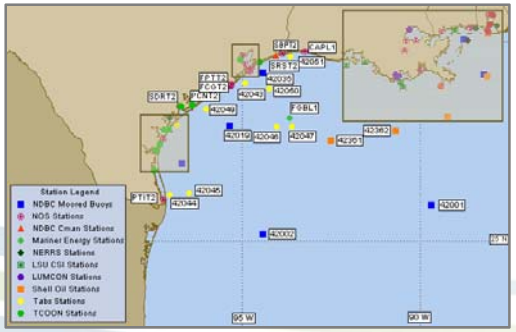
- **Surface**
  - Buoys and Coastal Marine Automated Network Stations (C-MAN) - NDBC
  - Coastal met. stations
  - Ships (seasonal, moving)
    - Voluntary observing ships
  - Commercial aircraft
- **Remote Sensing**
  - Weather balloons from land
  - Satellite (QSCAT, SAR)



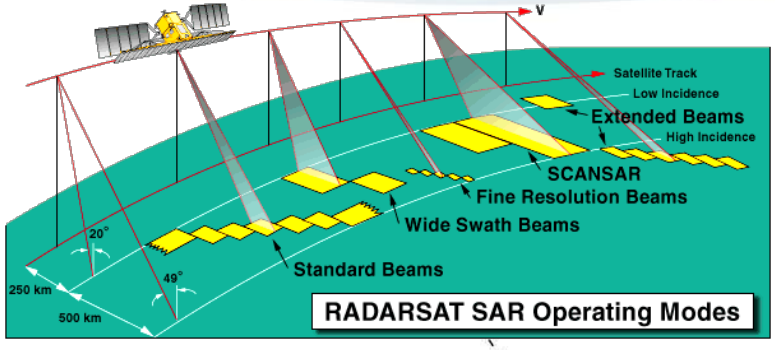


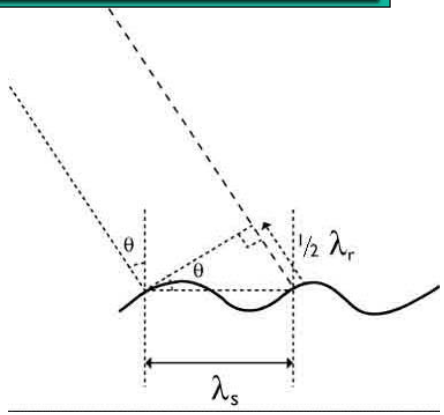






Satellite Imagery

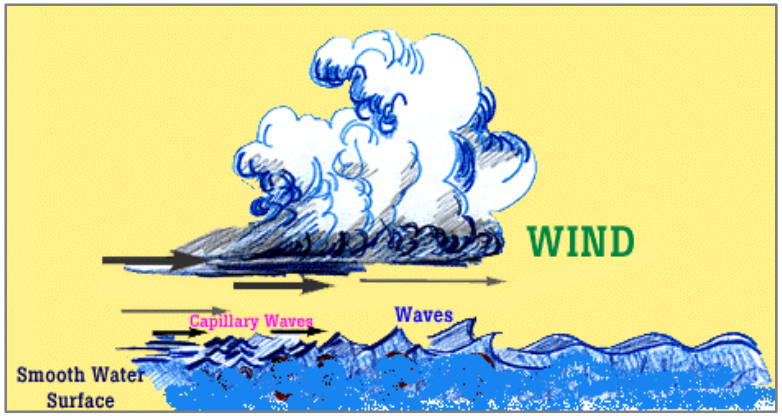




Radar signal is related to sea waves by Bragg resonant scattering

$\lambda_s = n\,\lambda_r / (2*\sin\theta)$

Wind friction over sea creates wavelets of few cm-scale when wind speed is several m/s.

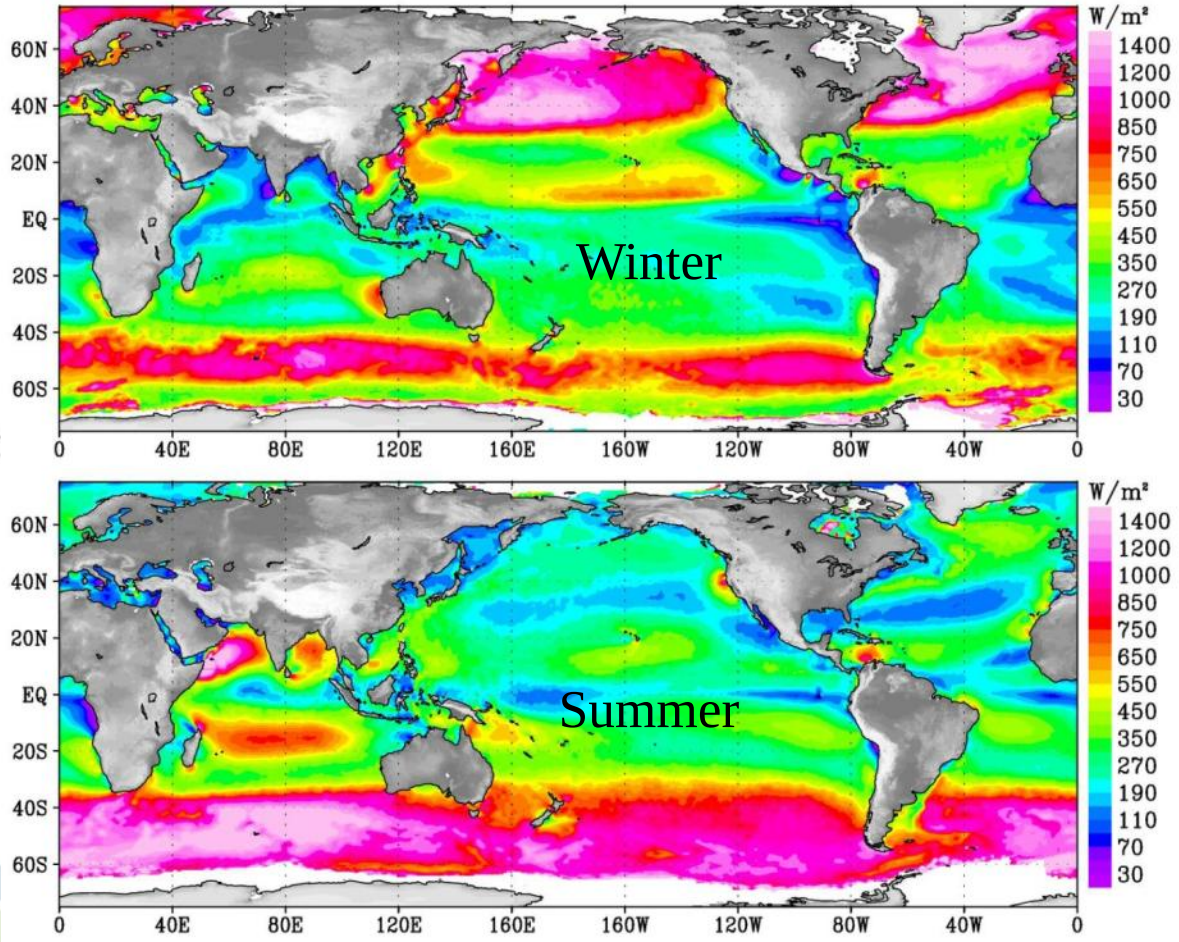


Speed Accuracy
~1.5-2.0 m/s

Source: P. Beaucage

QuikSCAT Wind Climatology

1999 - 2007



Source: NASA/JPL

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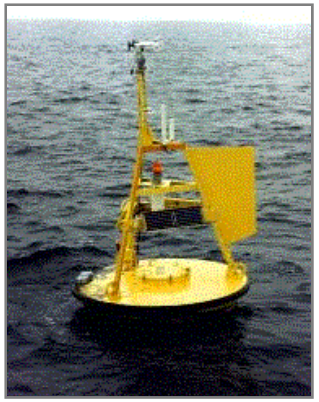
Weaknesses of Conventional Data

- Low elevation measurement (<10 m)
- Low number and density of stations
  - Some buoys removed in winter
- Ship data – limited value
- Balloon trajectory is wind dependent
- Satellite coastal resolution (QuikScat)
- Accuracy (typically 1-2 m/s)



Wind Modeling

- Wind maps developed from 3-D mesoscale numerical weather models (WRF, MM5, MASS)
- Combine boundary layer properties & atmospheric data to simulate all physics of the atmosphere
- Widely used for mapping & forecasting
- Key Inputs:
  - Global Reanalysis Data (NCEP/NCAR) - synthesis of data sources
  - NCEP or MODIS/Pathfinder Sea Surface Temperatures
  - Sea Ice
  - National Elevation Data; Landsat Land Cover
  - Differential Vegetation Index

Wind Resource Mapping

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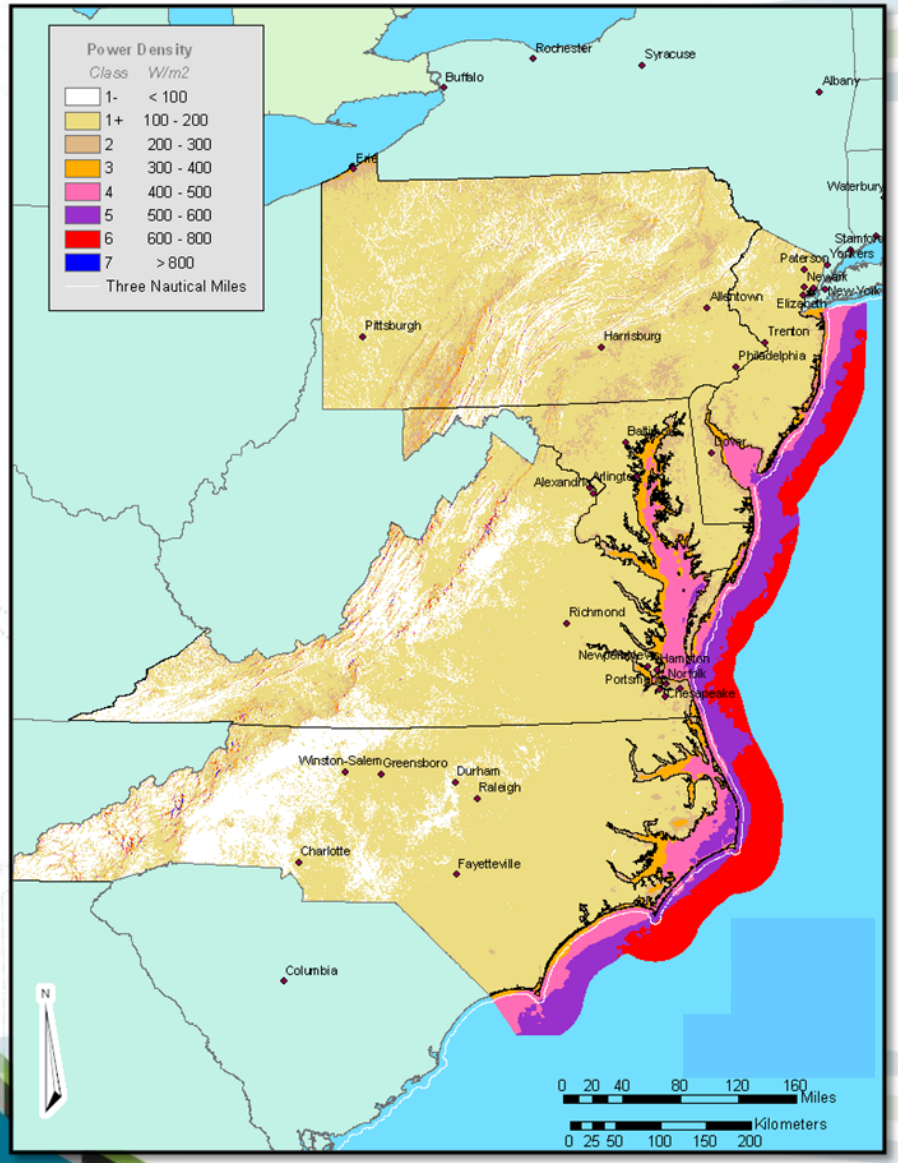
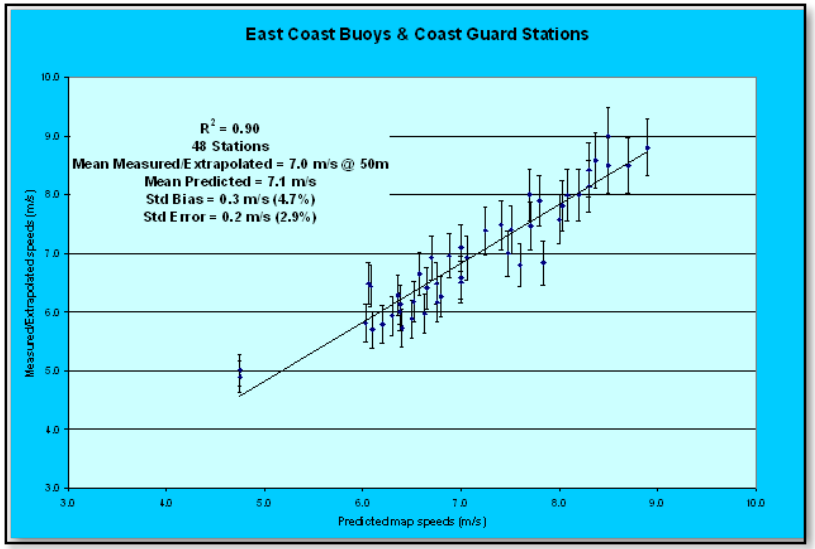


Validation Results



Regional Wind Maps

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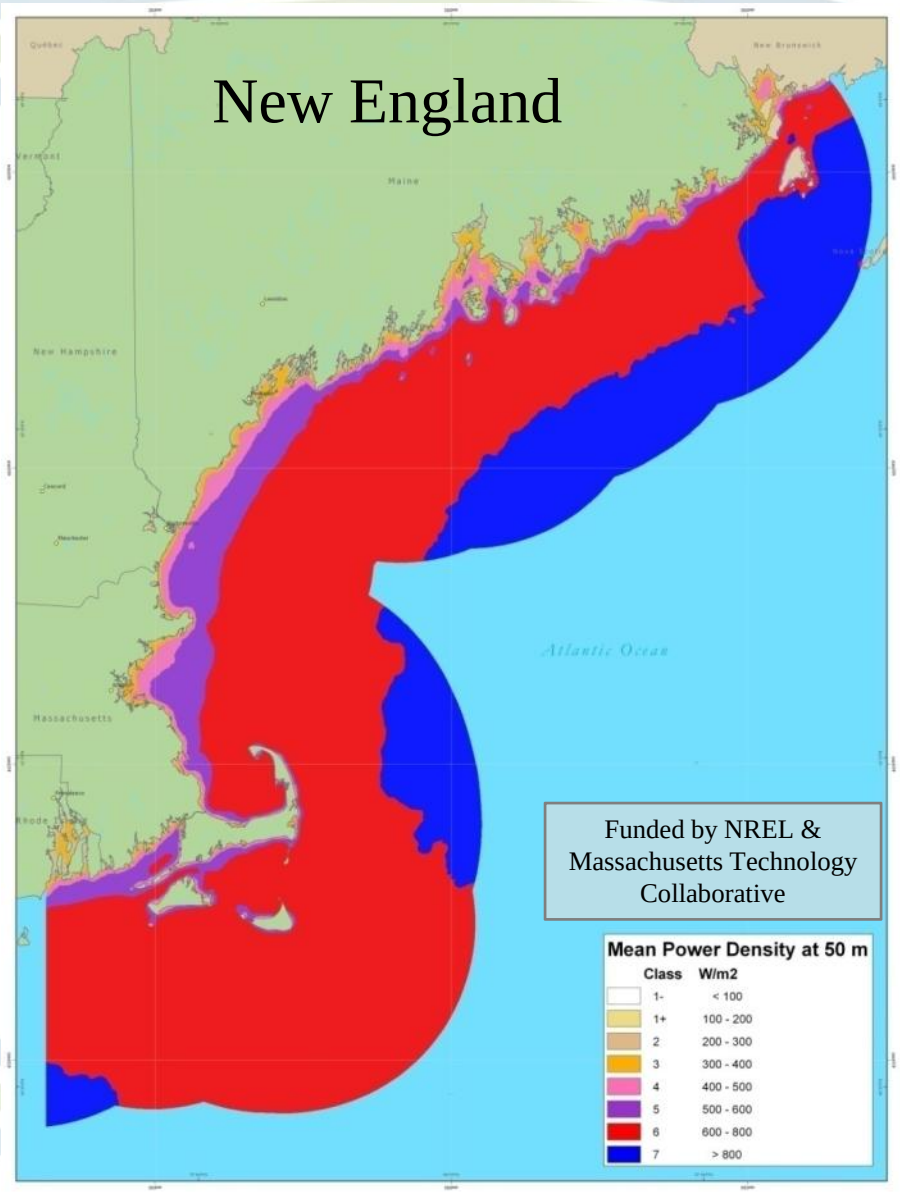
- Funded by NREL & States
- 50 nautical miles from shore
- Annual, monthly, diurnal
- Six heights: 10, 30, 50, 90, 150, 300 m
- Power density, speed averages & distributions, wind roses



Texas/Louisiana

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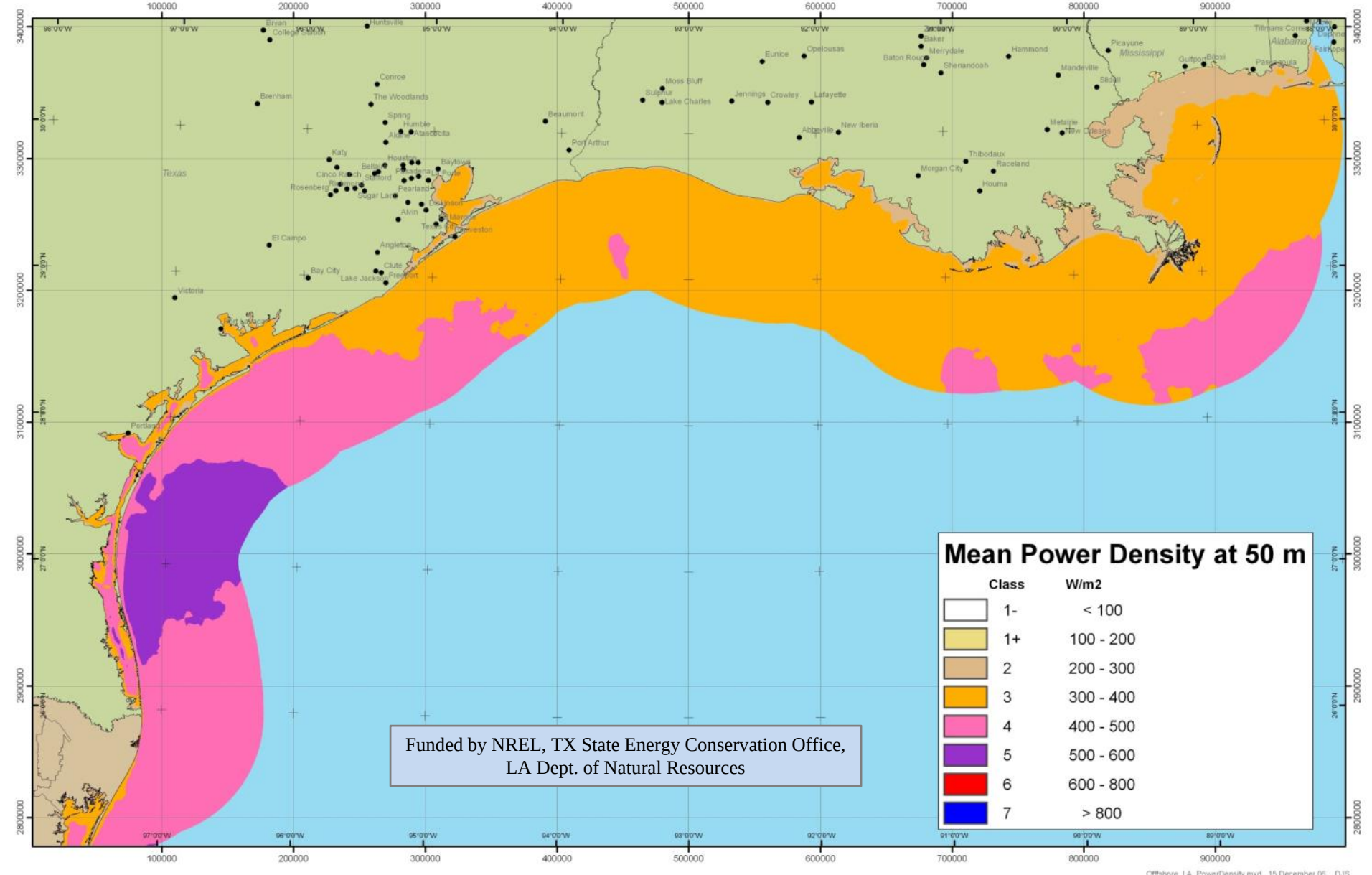
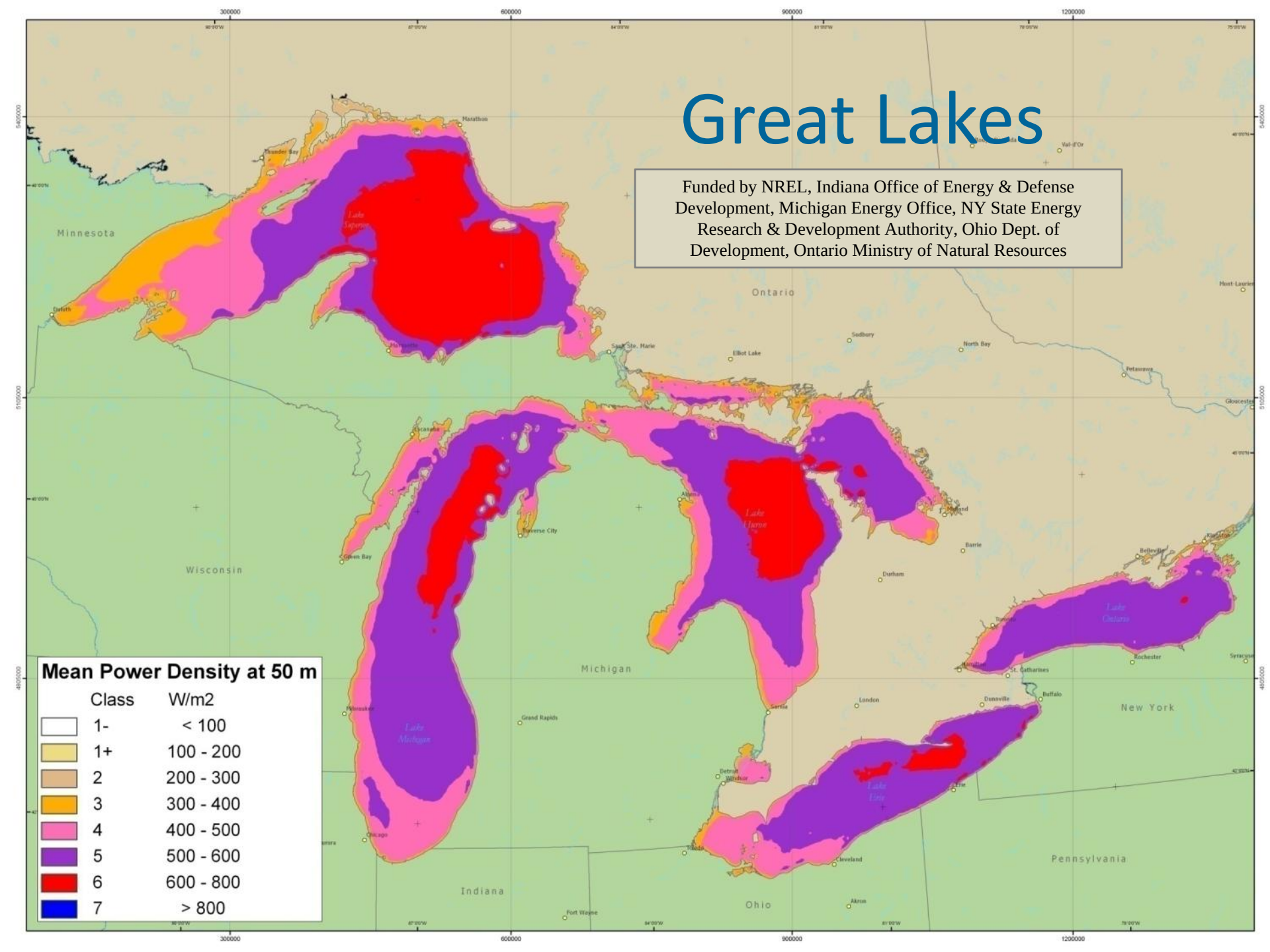


Great Lakes

Funded by NREL, Indiana Office of Energy & Defense Development, Michigan Energy Office, NY State Energy Research & Development Authority, Ohio Dept. of Development, Ontario Ministry of Natural Resources



Desired Data for Siting & Design of Offshore Wind Plants

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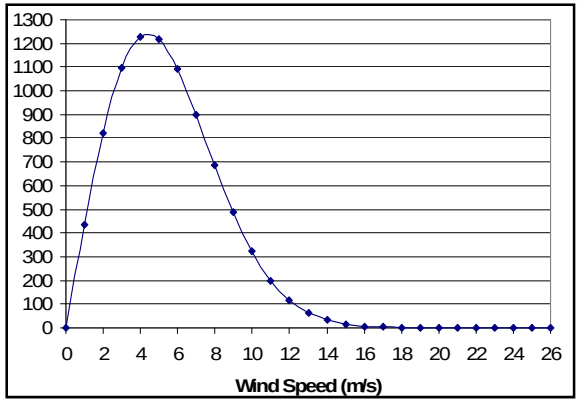
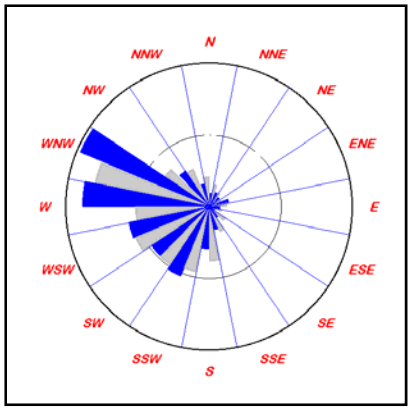
- Wind Speeds – annual, monthly, hourly, sub-hourly (including hub ht)
- Speed Frequency Distribution
- Wind Shear
- Turbulence Intensity
- Wind Direction Rose
- Extreme Gusts & Return Periods
- Air Temp., RH, Pressure, Density, Solar
- Coincident Sea-State Conditions
  - Including sea surface temp





Assessment Approaches

- Tall Met. Mast(s)
  - Most credible & widely accepted
  - Multiple heights; rugged sensors
- Complemented by:
  - Lidar/sodar
  - Project weather buoys
  - Ocean data (temp., waves)
- Regional Weather Obs
- Height & Climatological Adjustment (MCP)
- Mesoscale Modeling

FINO-1 Mast – Germany

Cape Wind Mast

NaiKun Mast – B.C.

Cleveland Crib

Energy Production Projections

- Application of Wind Statistics to Turbine Power Curves
- Assumptions for Loss Factors and Availability
- Wake Effects
- Hourly Production Statistics
  - Load matching and energy pricing
  - Sub-hourly variability & forecast-ability

Wind Forecasting

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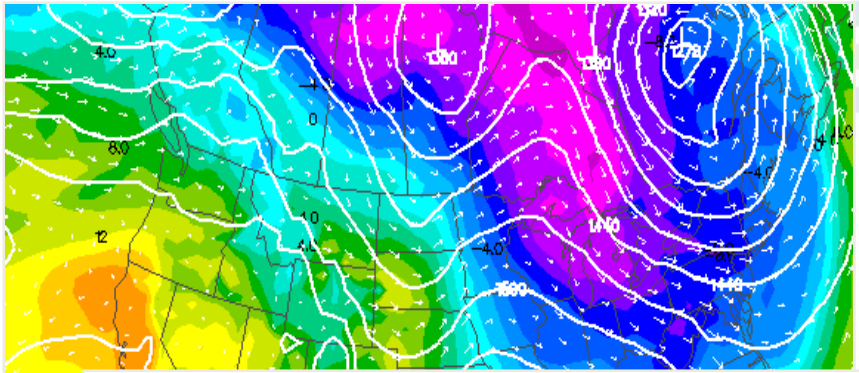
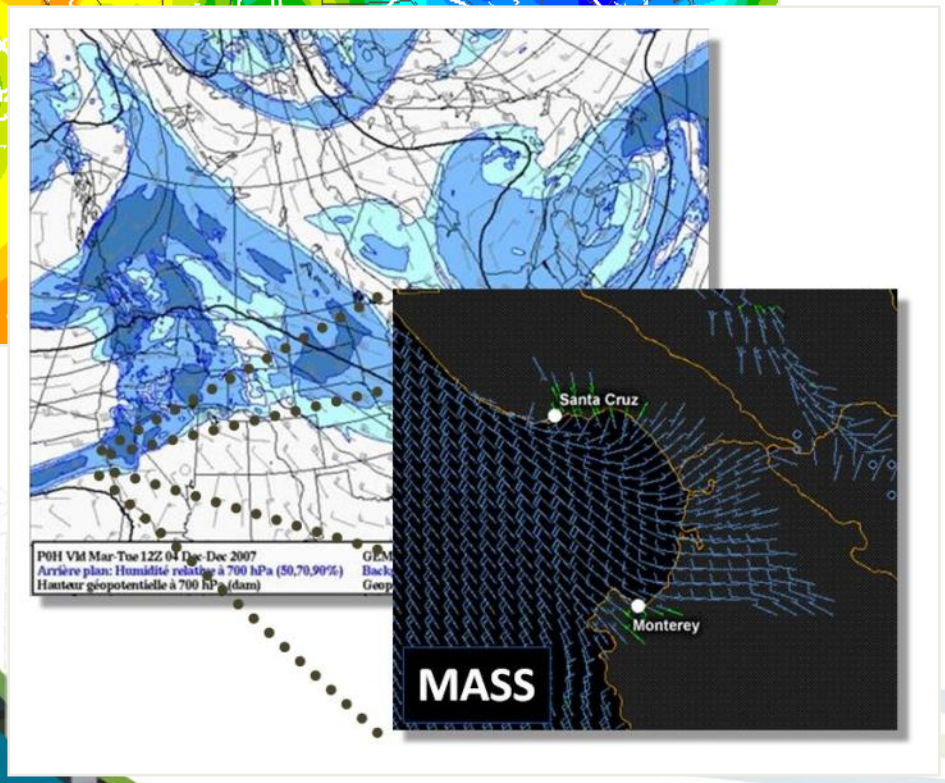
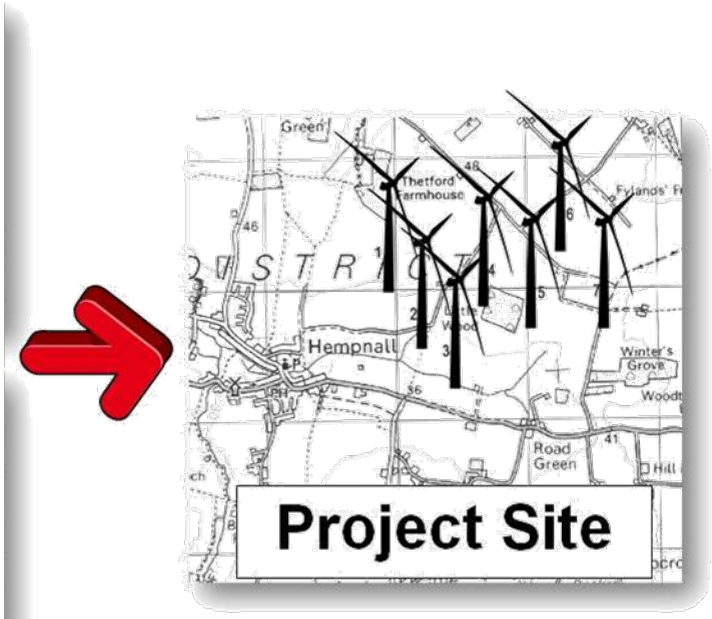
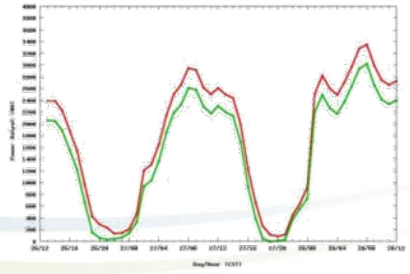




Minutes to Days in Advance





How Forecasts Are Produced

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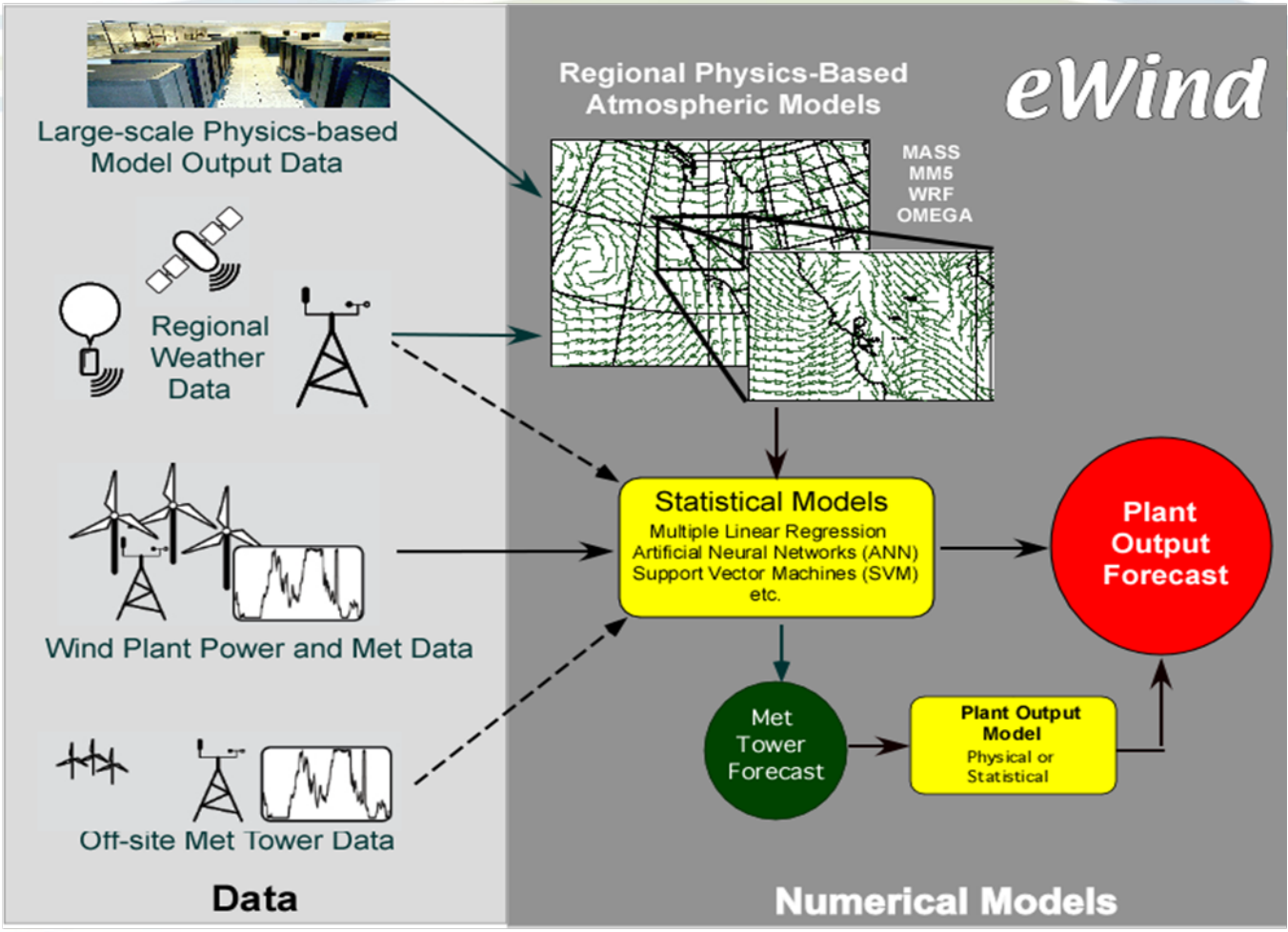
- **Physics-based models**
- **Statistical models**
- **Forecast ensembles**
- **Diverse set of input data with widely varying characteristics**
- **Importance of specific models and data types vary with look-ahead period**



Desired Outcome

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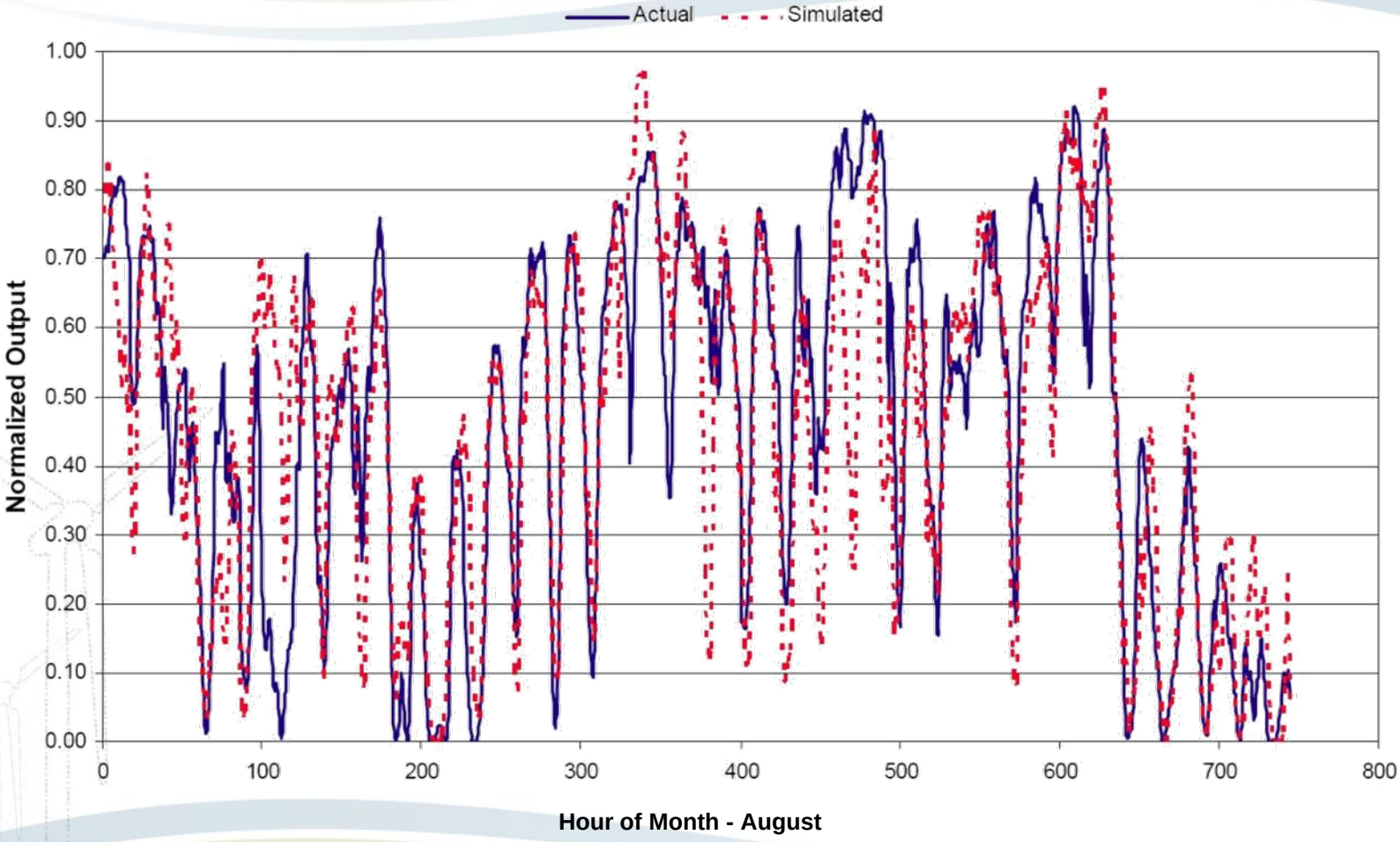

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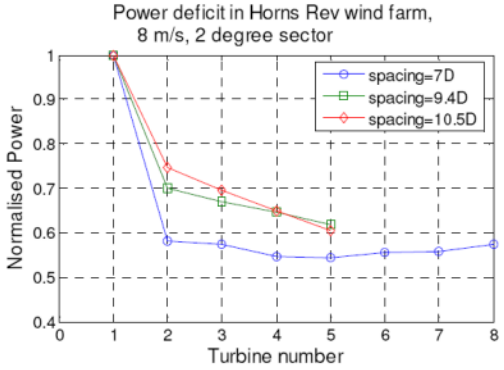
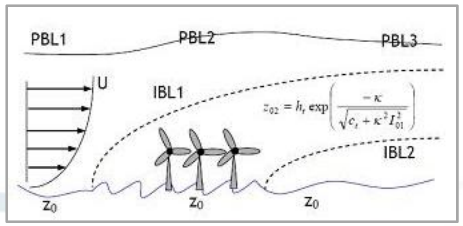
Modeling Turbine Wakes

- Perturbations in marine flow propagate long distances
- Turbine wakes take longer to decay than over land
  - Low TI and high stability reduce wake decay
- Traditional wind farm models over predict energy output for large arrays
- Model adjustments & refinements in progress





R. Barthelmie IU/UE

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Future Needs & Trends

- Special Purpose Offshore Monitoring Masts
  - Vertical wind structure and stability
  - Coincident sea state conditions
- Use of Lidar (vertical and side scan) or Sodar
  - Including units mounted on special spar buoys
- Reliance on Remote Sensing & Models
- Improved Wind Farm Modeling Tools
- Collaboration w/Government Agencies & Research Initiatives

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Thank You!