Estimating offshore wind energy potential

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Working Group on Space-based Lidar Winds
May 14, 2014, Boulder, CO

Development & deployment of offshore WE

US offshore WE Goal:
54 GW of wind generating capacity by 2030, at a cost of energy of $0.07/ kWh.

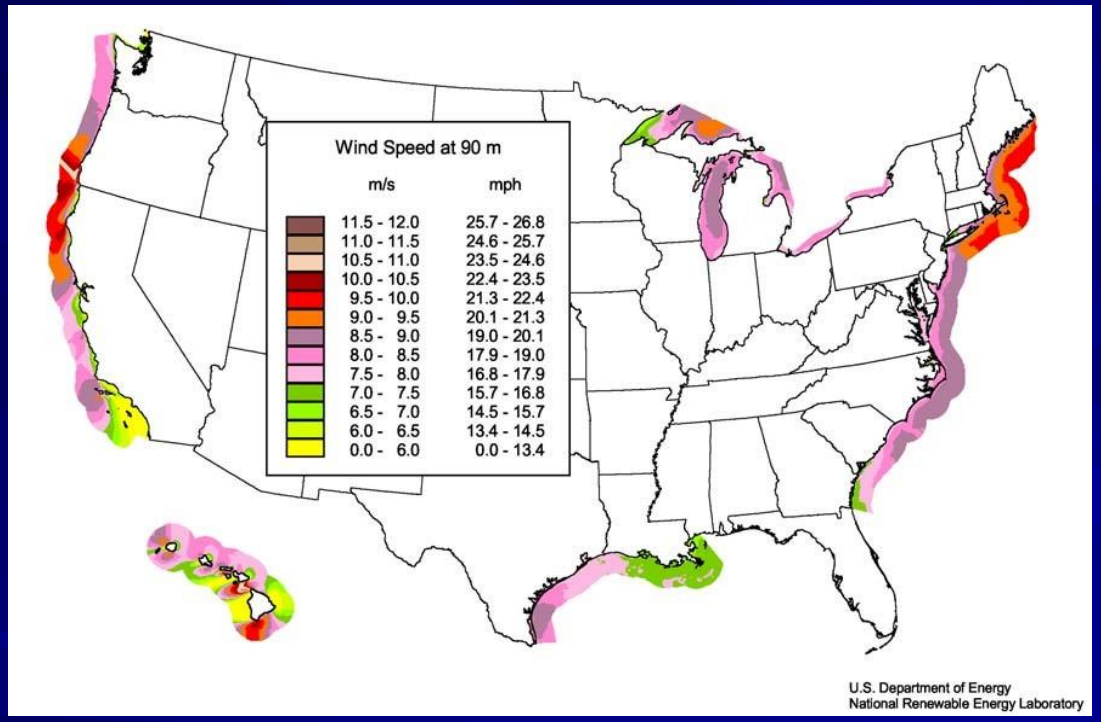
<u>Shortage of data</u>

on the wind flow at turbine rotor heights drives up the costs of the installation, operations, and maintenance of wind projects

Models are potentially important tools in providing offshore winds

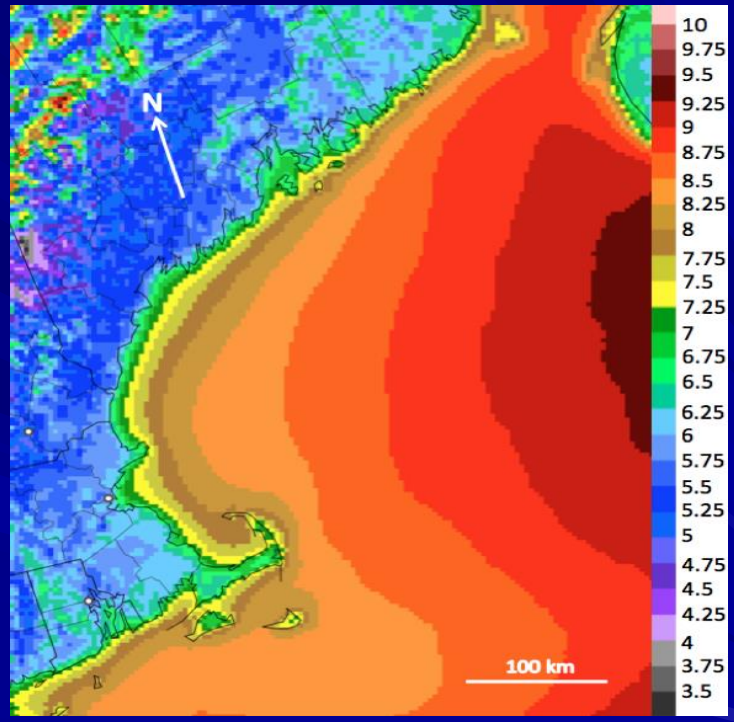
Modeled wind resources

In the absence of measurements at turbine levels, the accuracy and fidelity of model output is unknown



U.S. offshore wind speed estimates at 90-m height

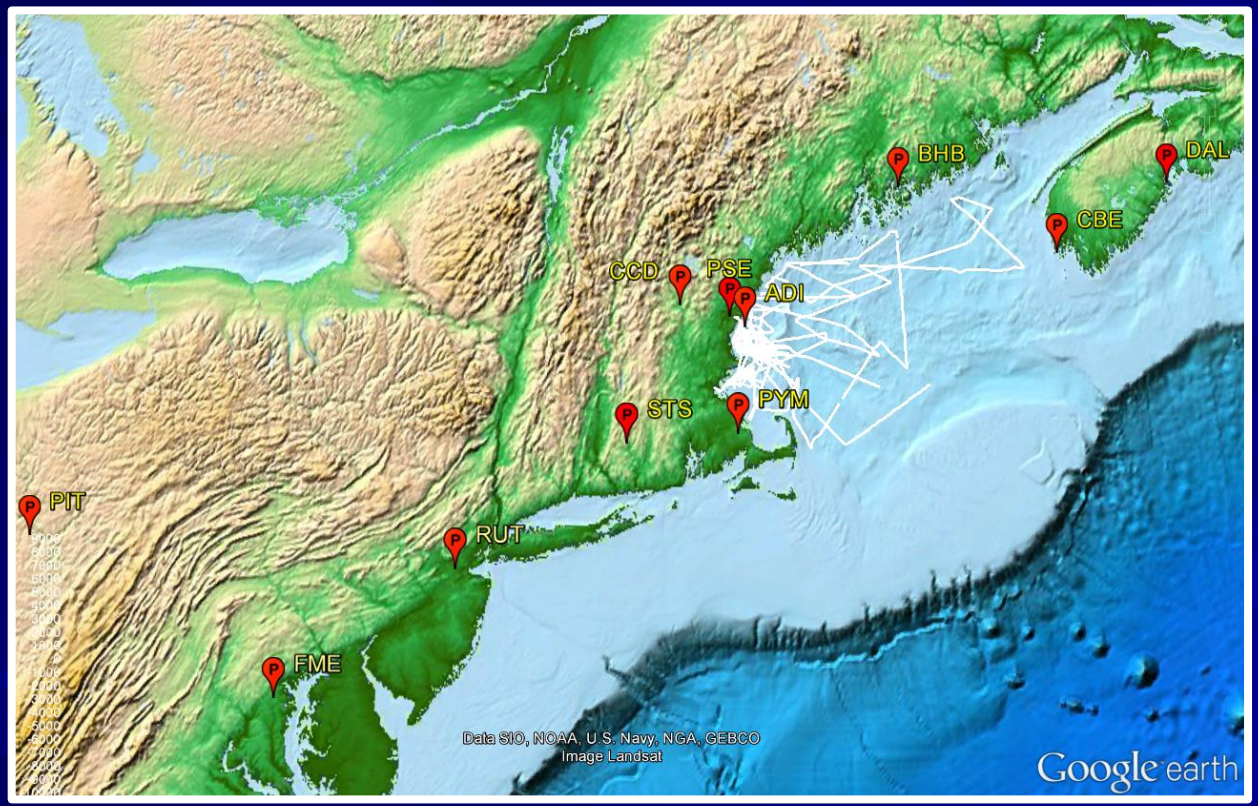
(DOE Report, 02/2011)



Average 80-m wind speed over the Gulf of Maine in 2012 – 2013

(DOE Report, 04/2014)

Prediction of Offshore Wind Energy Resources (POWER) - 2013



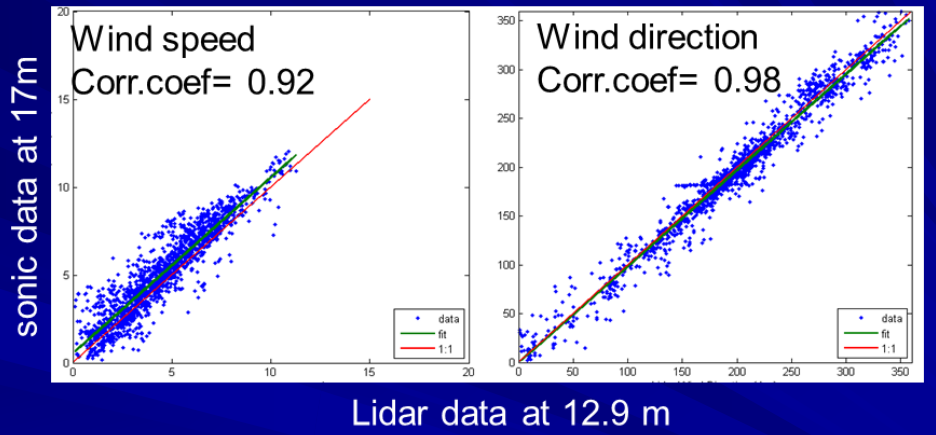
Objectives

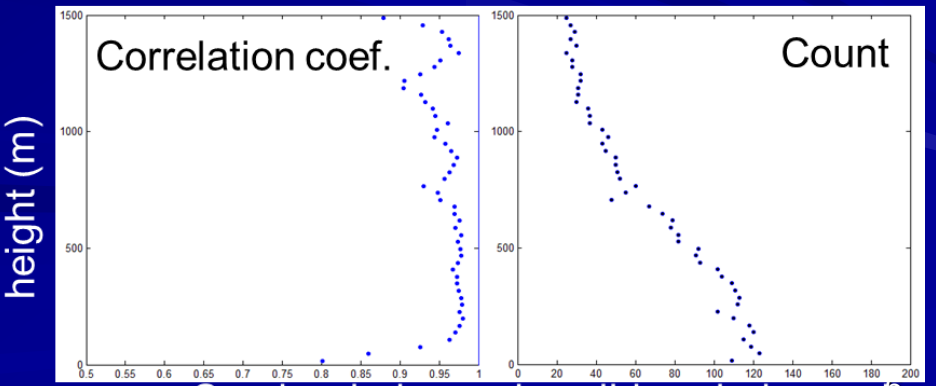
- Use ship-borne lidar measurements to evaluate NOAA/NCEP forecast model skill in predicting boundary-layer winds
- Assess the impact of inland wind profiler data assimilation on the accuracy of hourly updated weather model forecasts
- Determine spatial variability of marine winds

The High Resolution Doppler Lidar

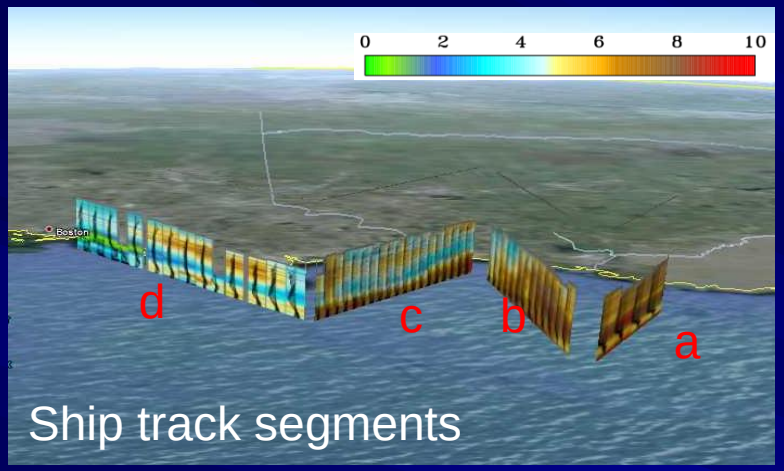
Characteristics	HRDL
Wavelength	2.02 μm
Pulse energy	2.0 mJ
Pulse rate	200 Hz
Range resolution	30 m
Velocity precision	~10 cm s^{-1}
Time resolution	0.5 s
Minimum range	189 m
Maximum range	3-8 km

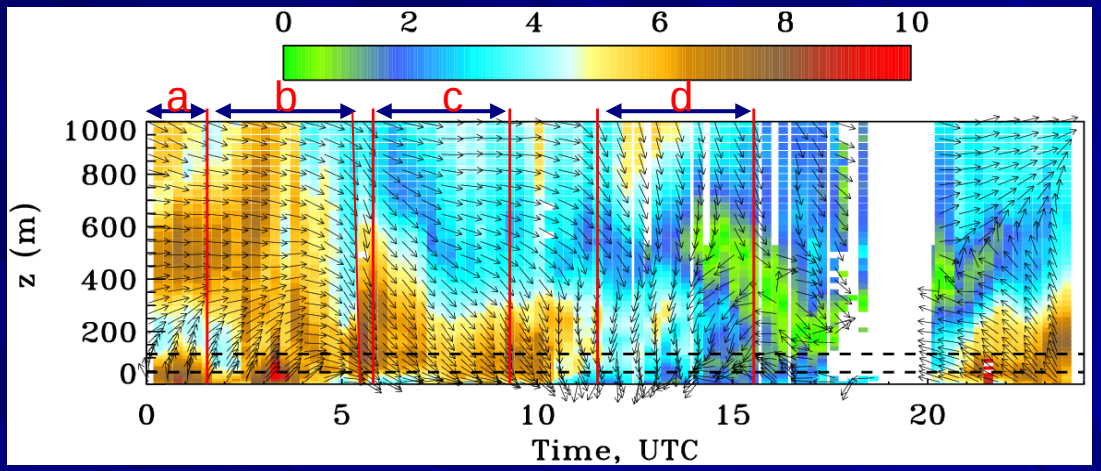
Pointing angle error
< 0.5° - normal sea
< 1° - rough sea



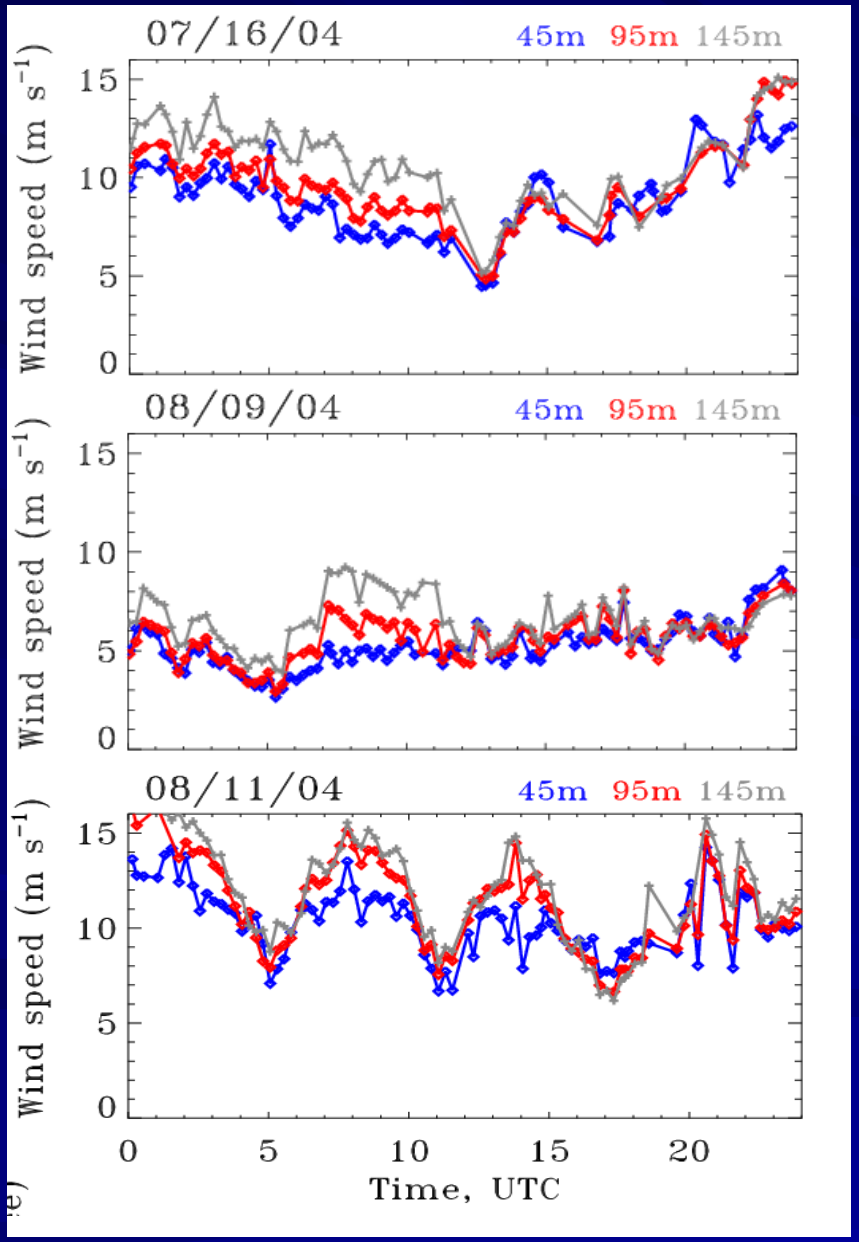


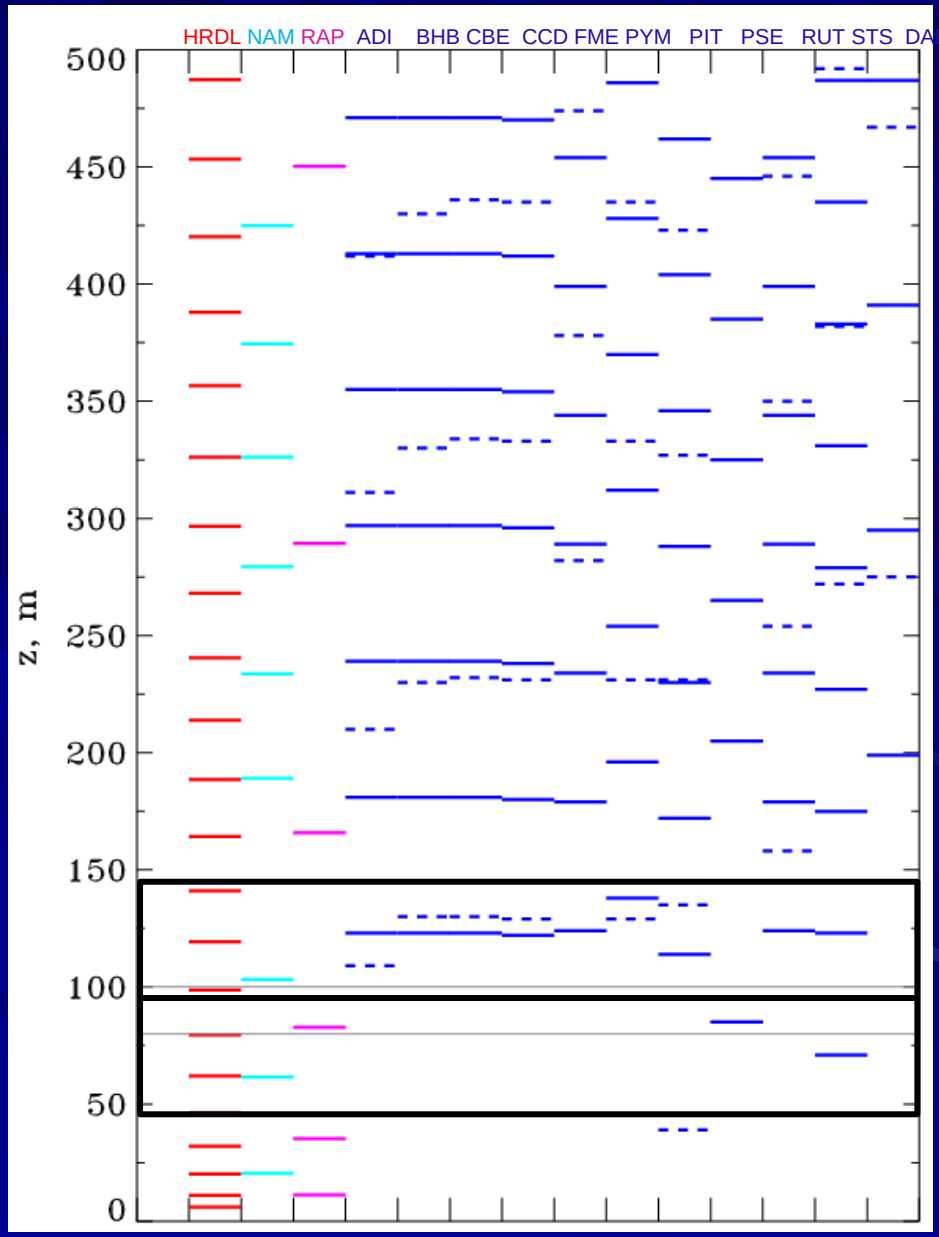
Spatial and temporal variability of lidar-measured winds





Heights of measurements and model outputs

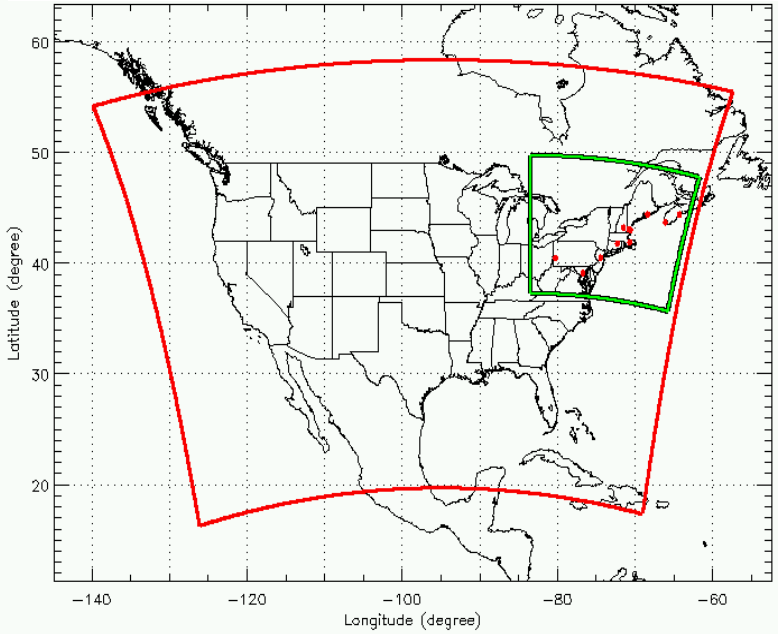




Models used in the study

High Resolution Rapid Refresh	**HRRR**	3 km	NOAA/ESRL
Rapid Refresh	**RAP**	13 km	NOAA/ESRL
Contiguous United States	**NAM conus**	4 km	NOAA/NCEP
North American Mesoscale	**NAM parent**	12 km	NOAA/NCEP

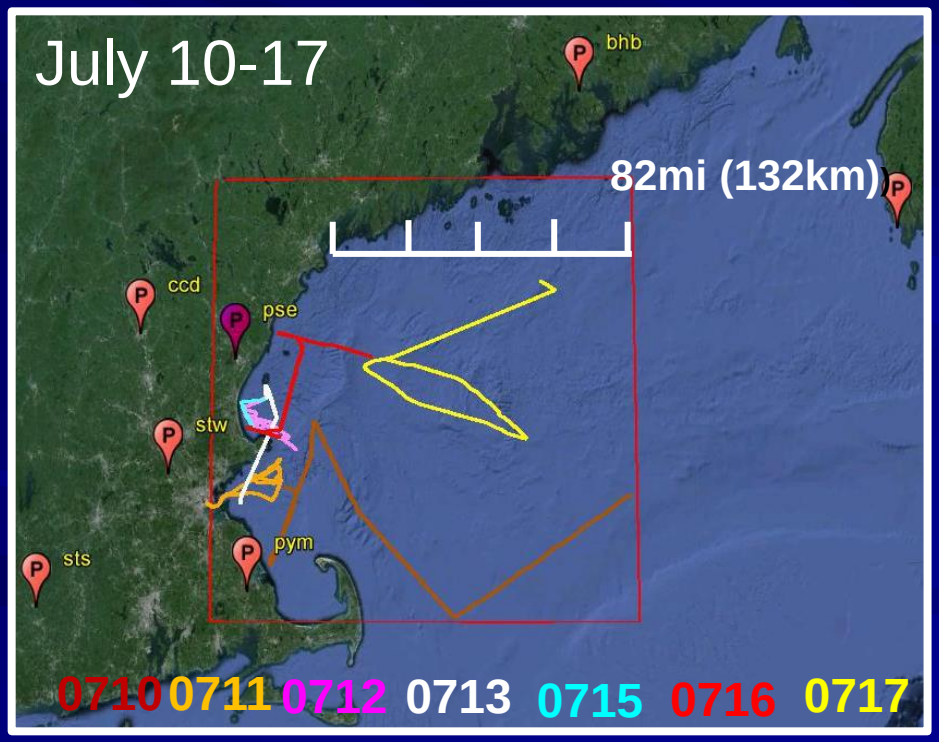
RAP domain **HRRR domain**

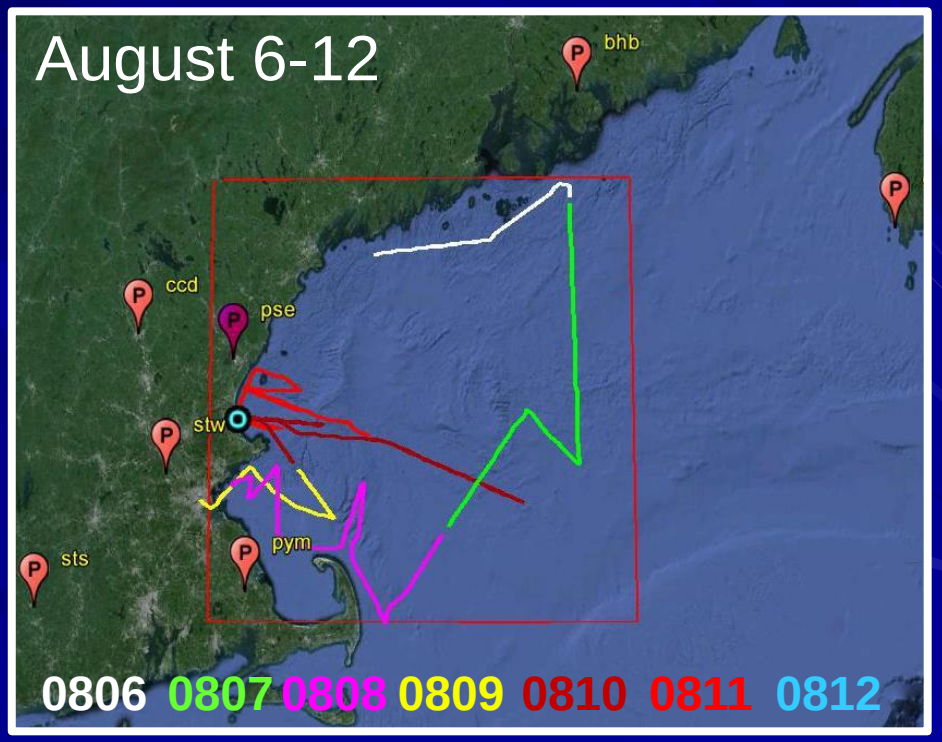


NAM parent domain **NAM conus domain**

Study periods: July 10-17 and August 6-12

- Possibly in the same area
  - NEAQS 2004 was designed to track urban pollution plumes
- Broad coverage
  - close to the shore and farther out in the ocean
- Variety of atmospheric conditions
  - strong and weak winds, ramps, LLJ, fog, and rain



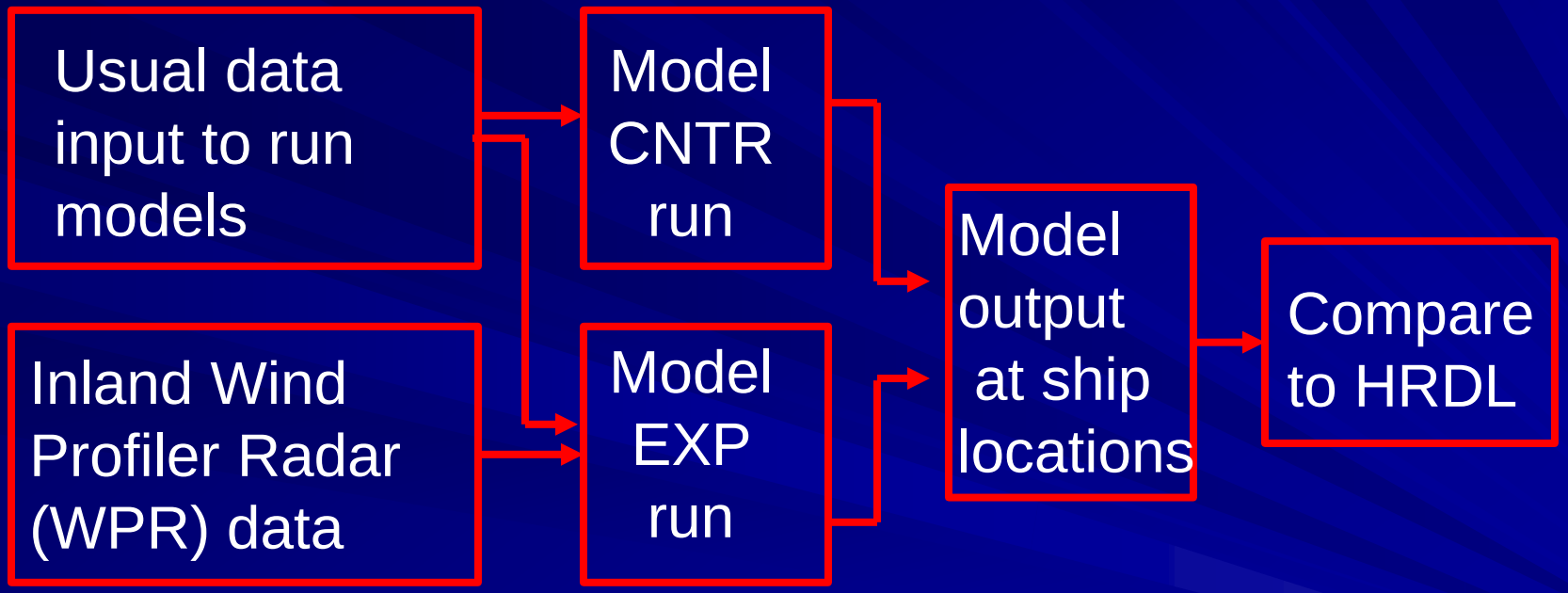


Ship tracks during two study periods

The model verification

Control run - *without* wind profiler data assimilation

Experimental run - *with* wind profiler data assimilation



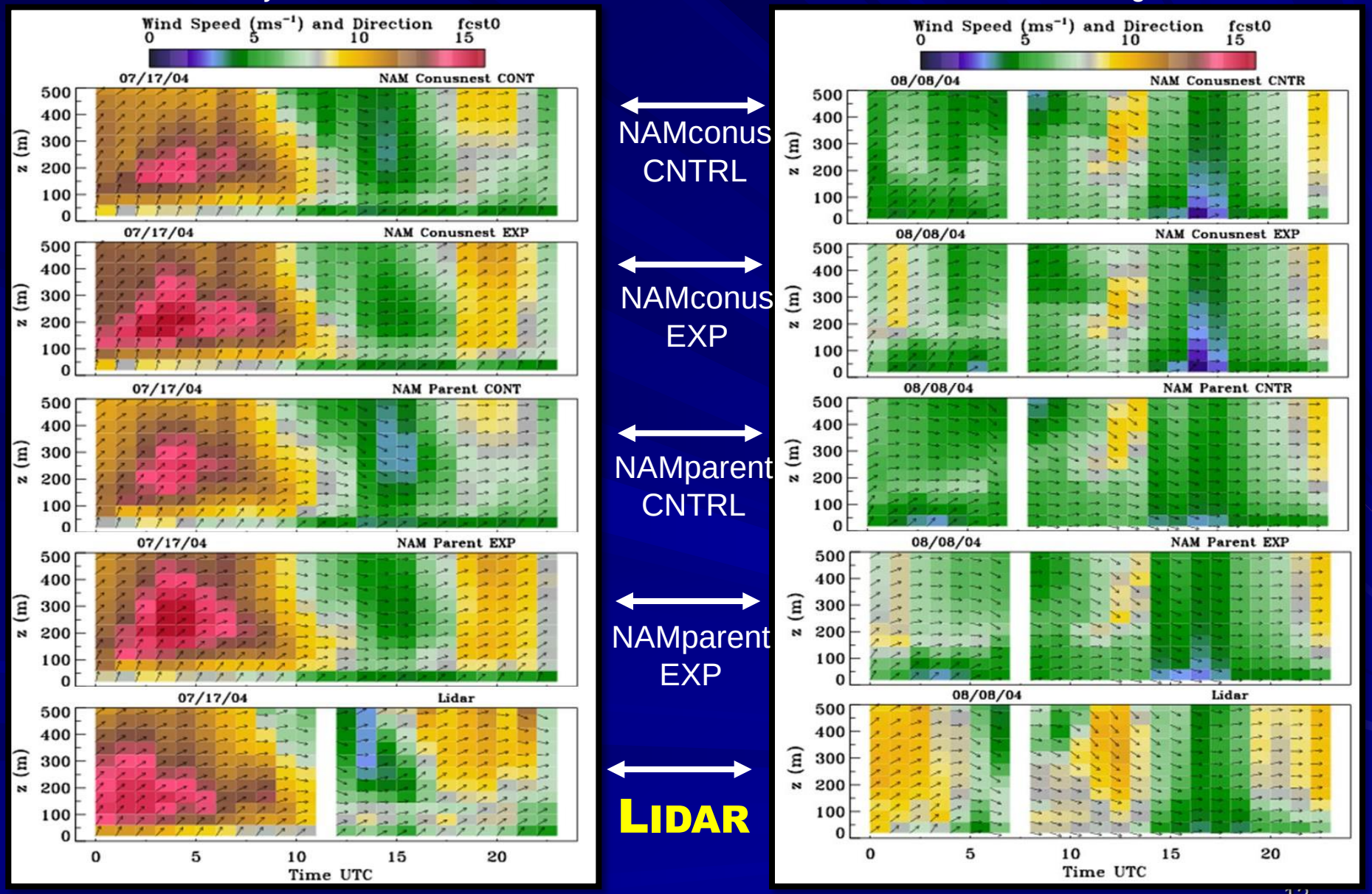
16 configurations (4 models x 2 runs x 2 periods) were used to evaluate model skill in predicting scalar and vector winds

Observed and modeled wind field

Sample of visual comparison

July 17

August 8



NAMconus CNTRL

NAMconus EXP

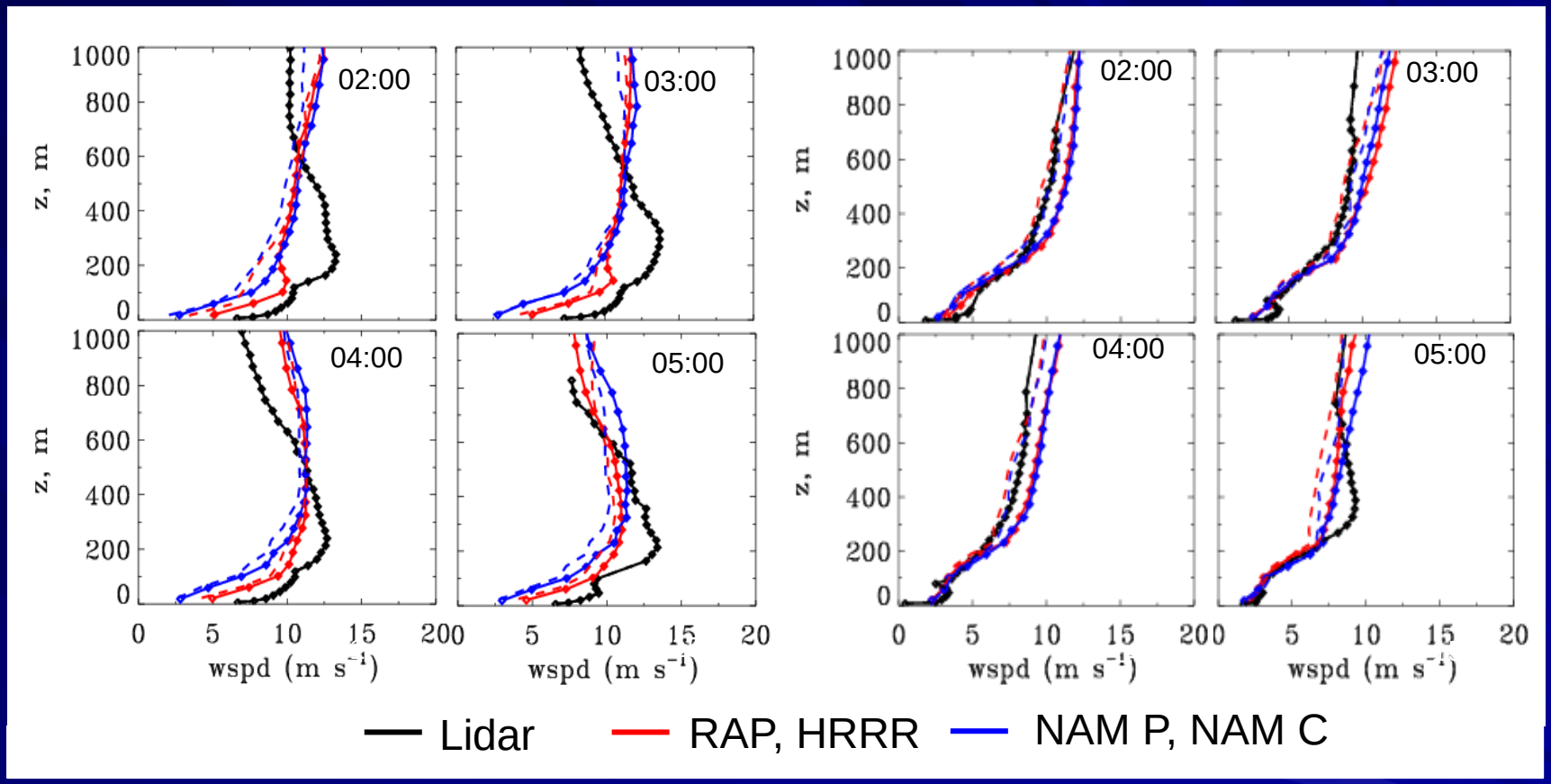
NAMparent CNTRL

NAMparent EXP

LIDAR

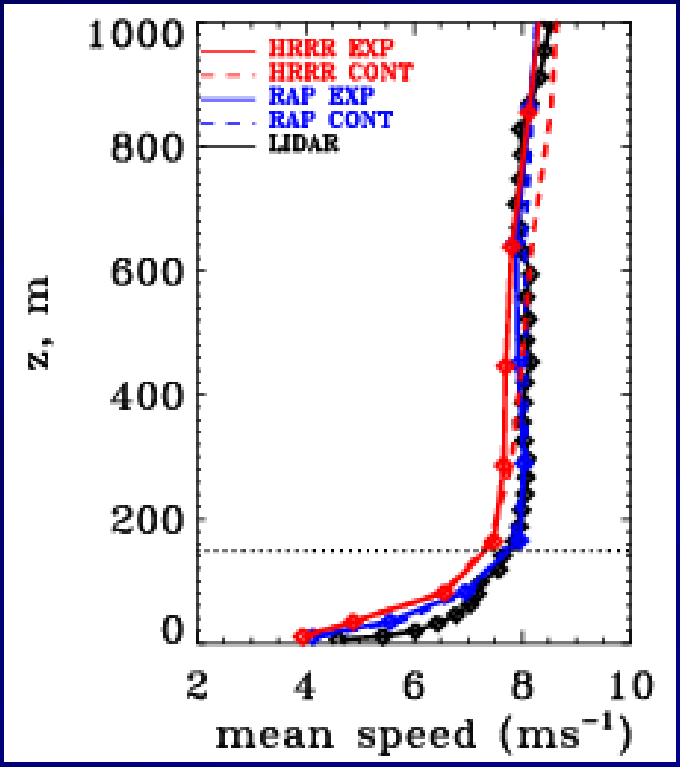
Examples of lidar-measured and modeled wind

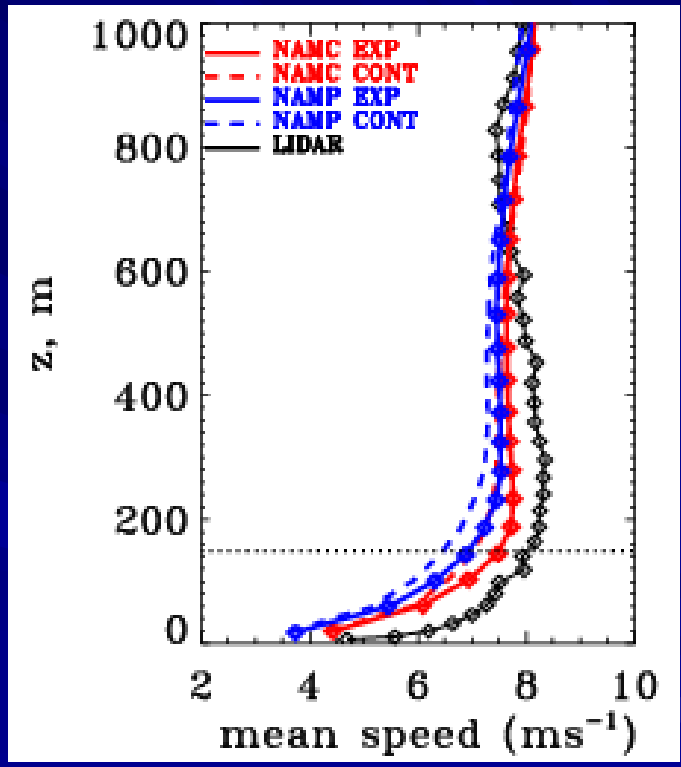
July 16 August 9



Greater discrepancies - for LLJ-like profiles

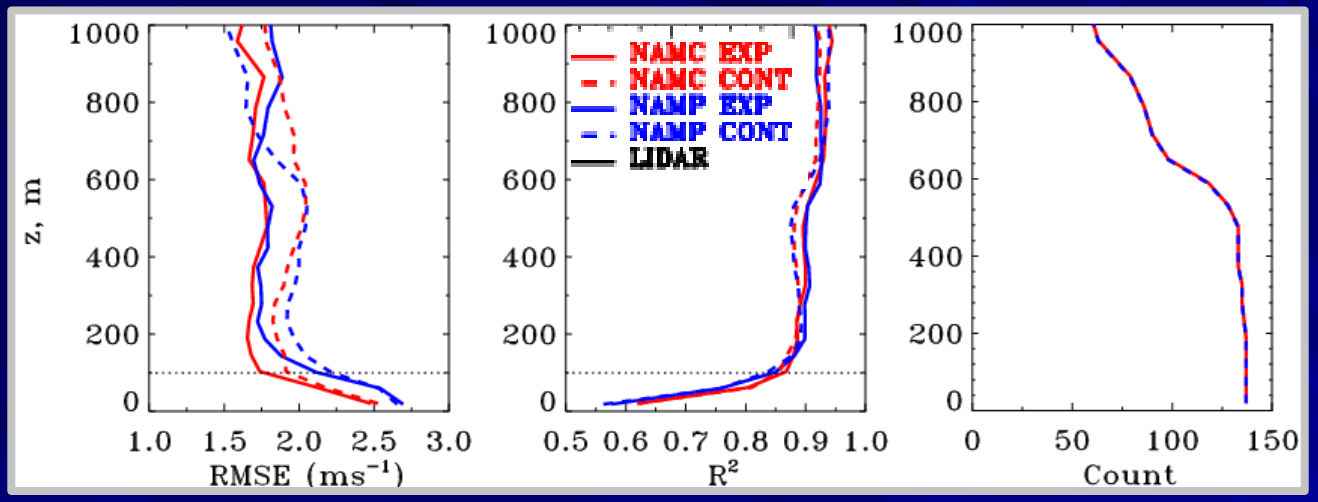
Observed and modeled period-mean wind profiles (August 6-12)



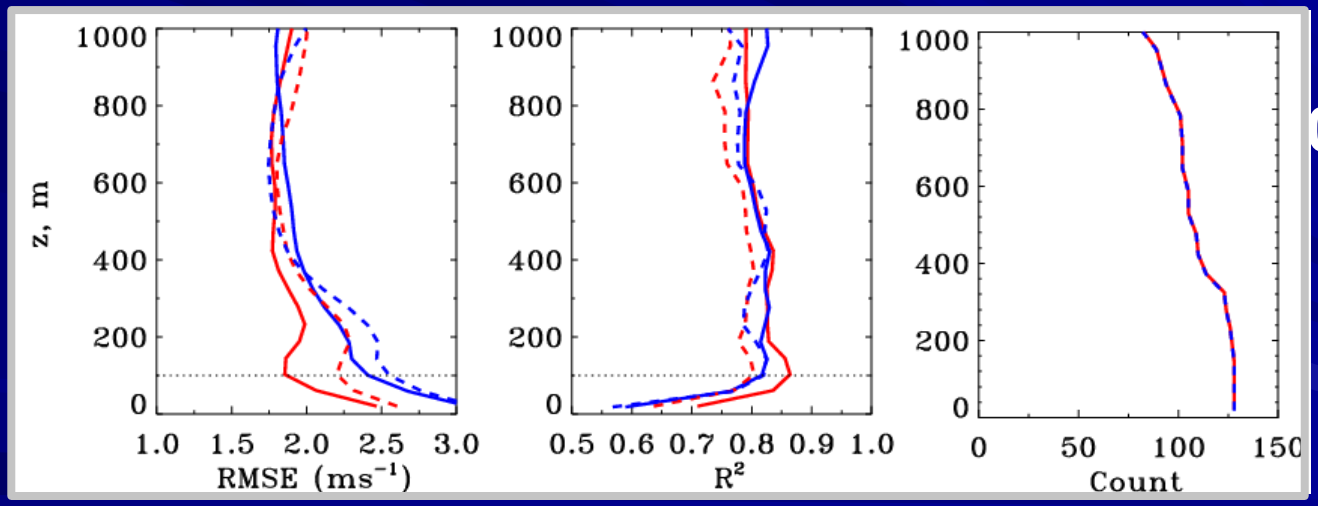


Profiles of scalar wind statistics

Initial conditions



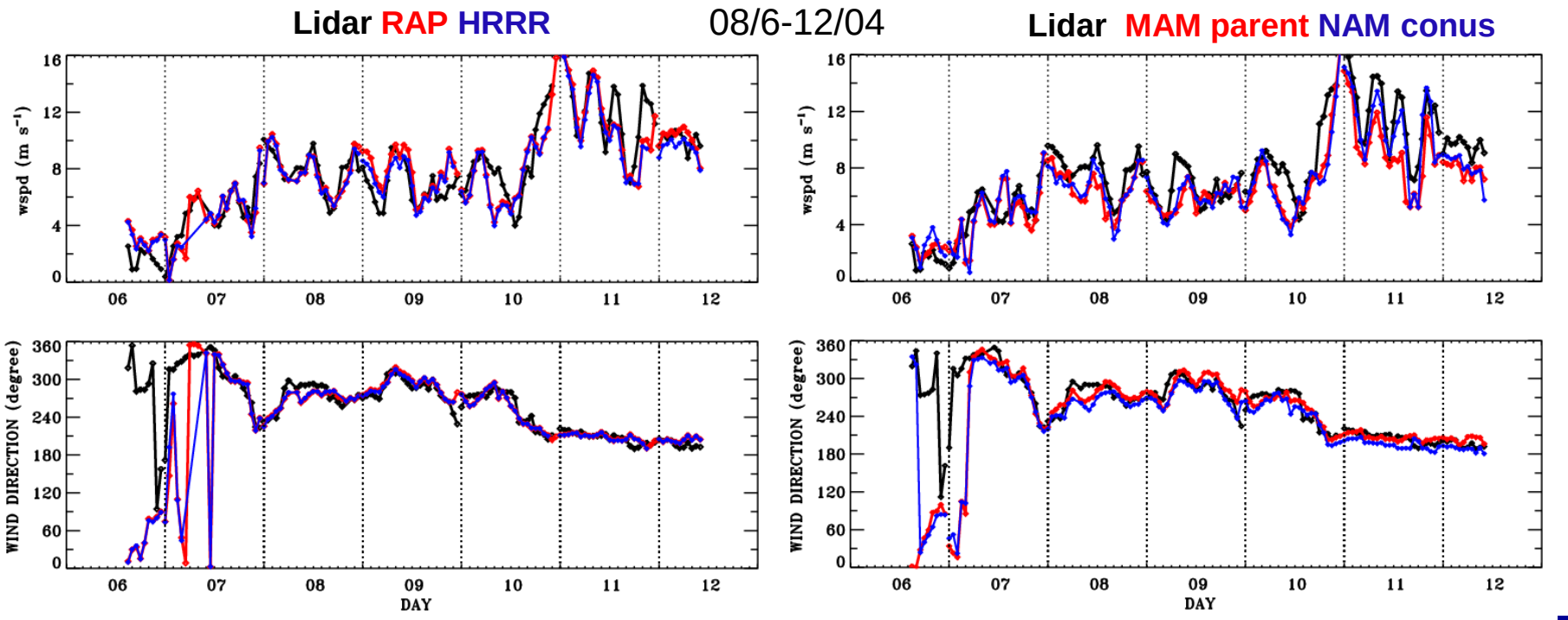
08/ 6-12



07/10-17

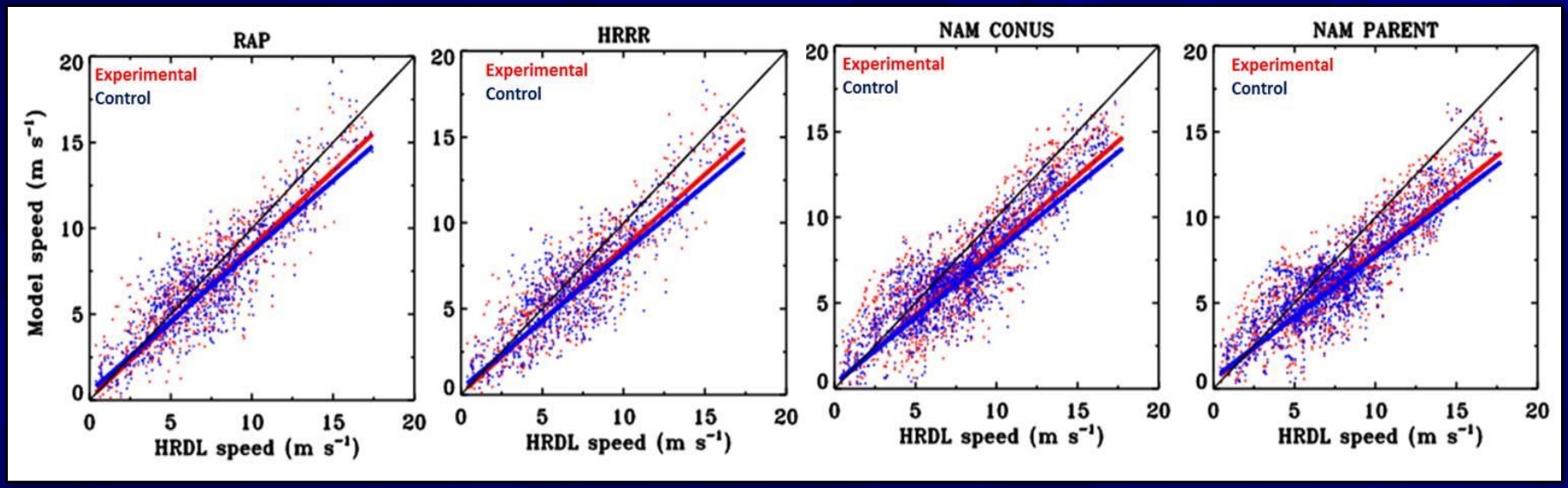
Greater discrepancies below 100 m

Hub-height wind
Initial conditions



Observed and modeled winds

August 6-12

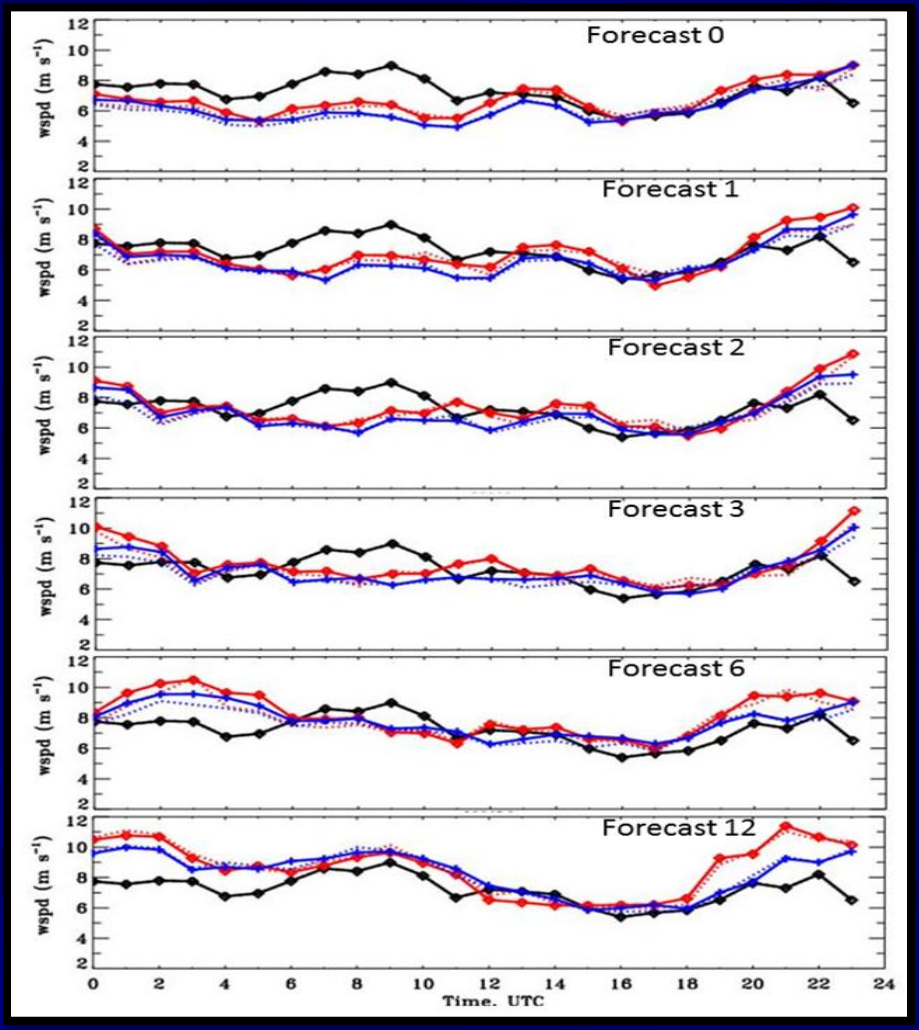


Correlation statistics between measured and modeled wind speed

Model	COUNT	R^2	Bias	Slope
RAP EXP	810	0.88	0.11 ± 0.14	0.88 ± 0.02
RAP CONT	810	0.87	0.49 ± 0.16	0.82 ± 0.02
HRRR EXP	750	0.88	0.09 ± 0.15	0.85 ± 0.02
HRRR CONT	804	0.86	0.36 ± 0.15	0.79 ± 0.02
NAM CONUS EXP	1479	0.88	0.25 ± 0.12	0.81 ± 0.02
NAMRR CONUS CONT	1476	0.88	0.29 ± 0.12	0.77 ± 0.01
NAMRR EXP	1479	0.88	0.49 ± 0.12	0.74 ± 0.01
NAMRR CONT	1479	0.87	0.62 ± 0.12	0.71 ± 0.01

Greater discrepancies for stronger winds

Time-series of measured and observed wind at 80 m for several lead times

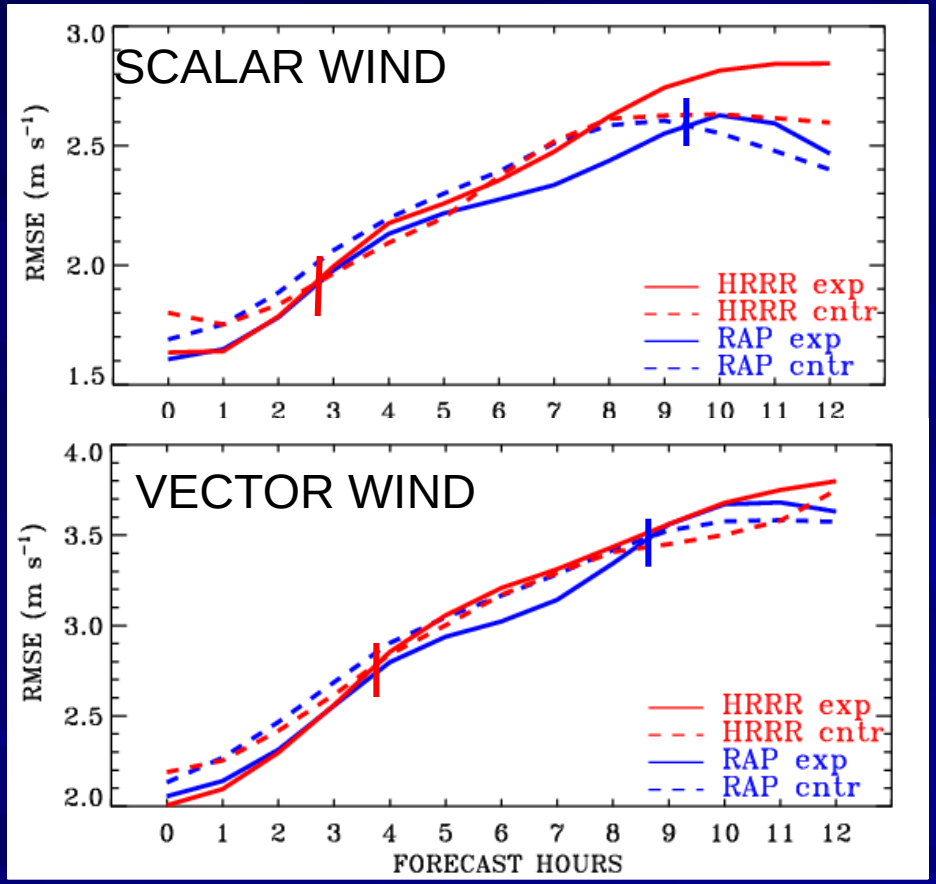


Note under prediction of nocturnal winds (03-04 UTC) for the 0-3 hr lead-time forecasts, and over prediction of the late afternoon winds (18-06 UTC) for the 6 and 12-hr forecasts.

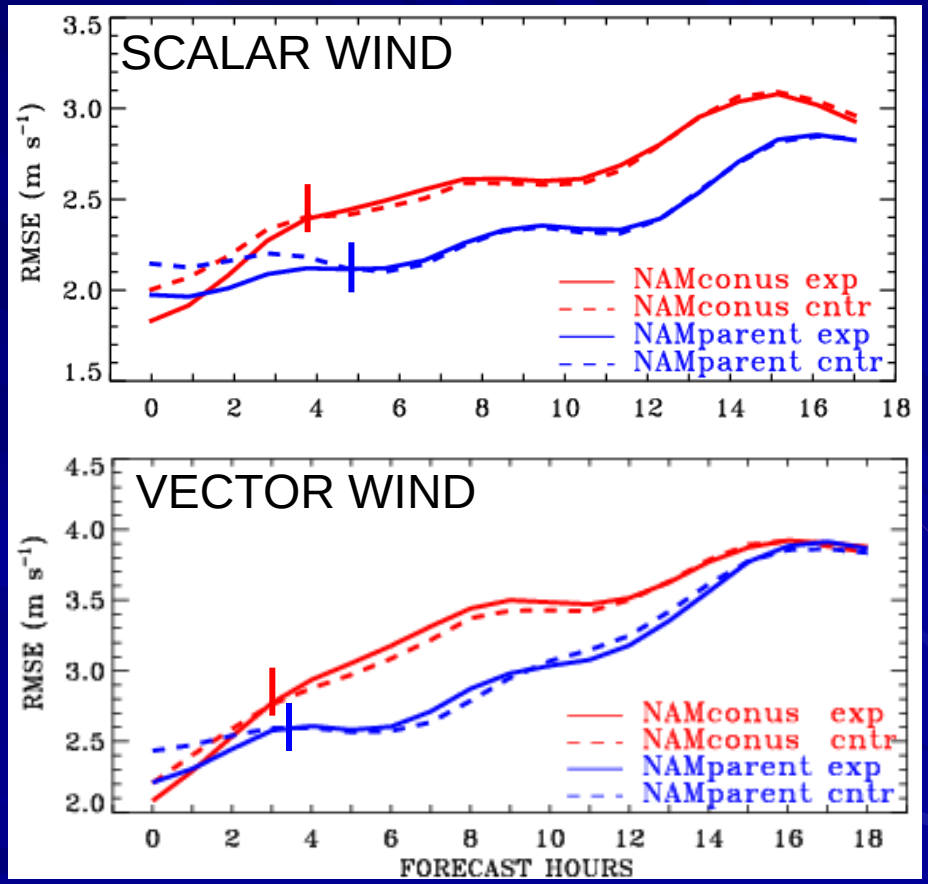
RMSE between observed and modeled wind

Study period - August 6-12
up to 500 m layer

ESRL models



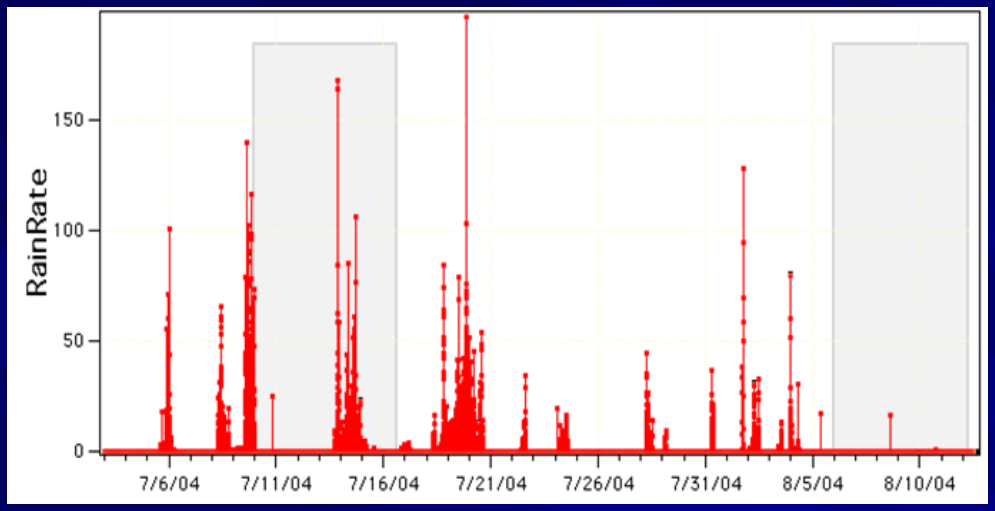
NCEP models

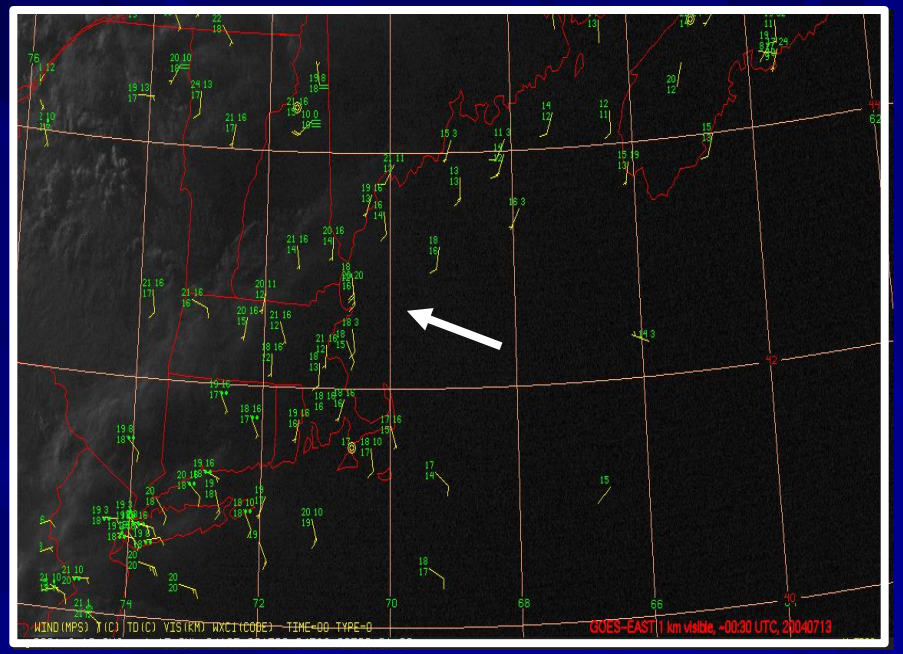


All models show an improvement for 3-5 lead hours

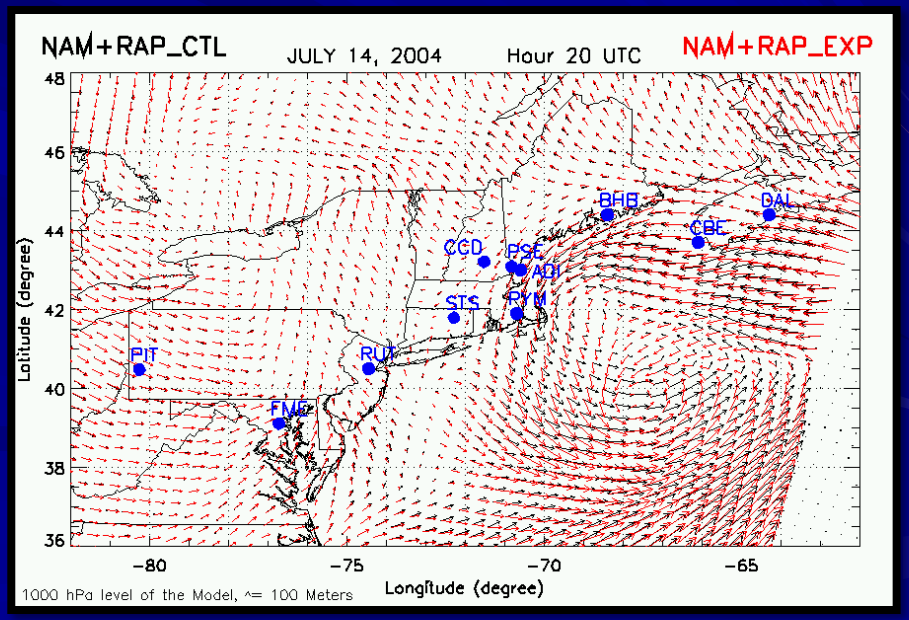
ERSL RAP shows an improvement up to 9 lead hours

July 13-15 atmospheric conditions

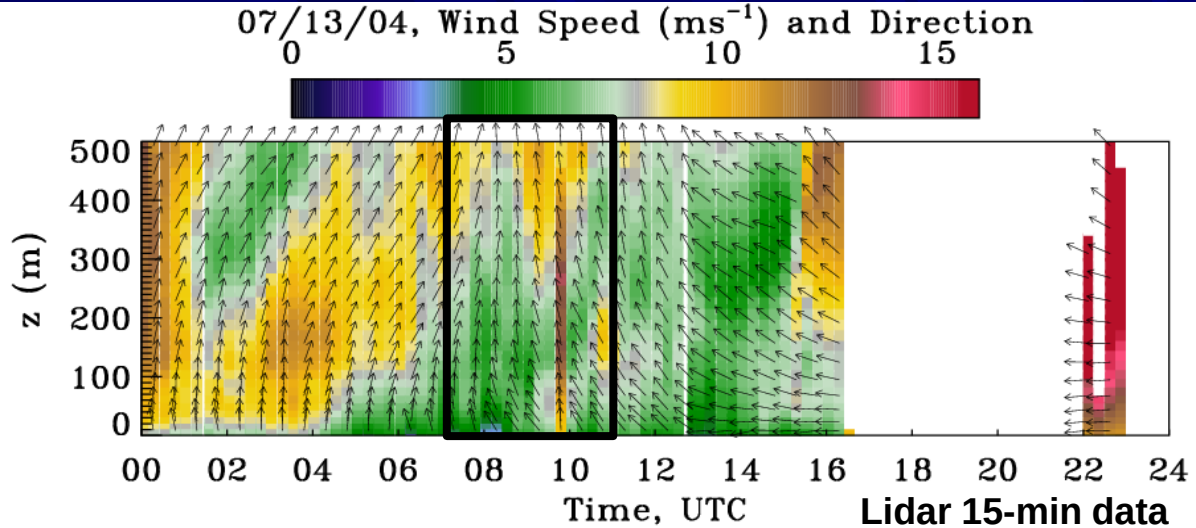


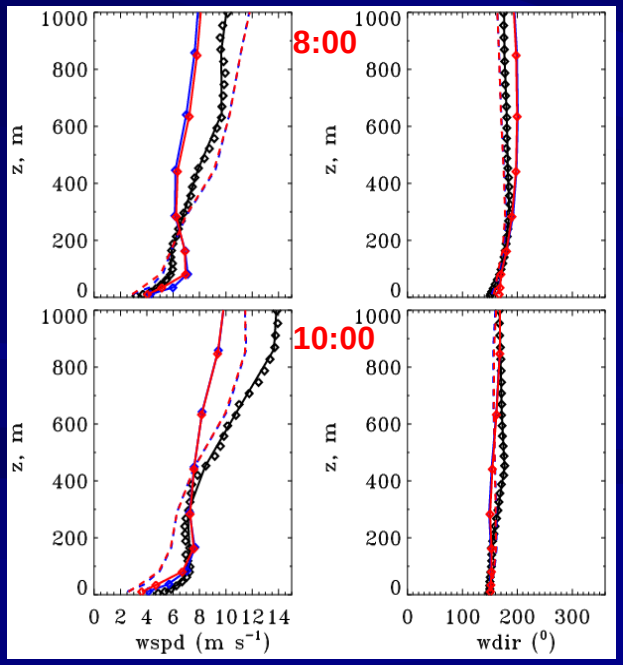


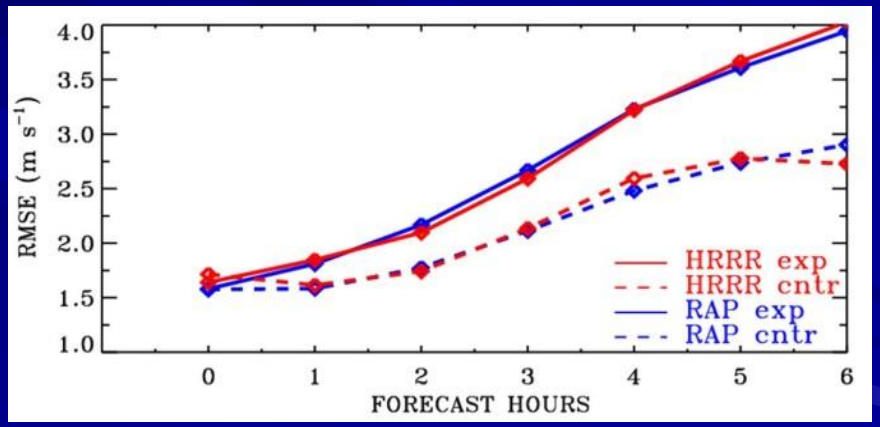
- Fog and rain
- Change of wind direction
- Mesoscale low-pressure vortex



Case study: July 13 atmospheric conditions

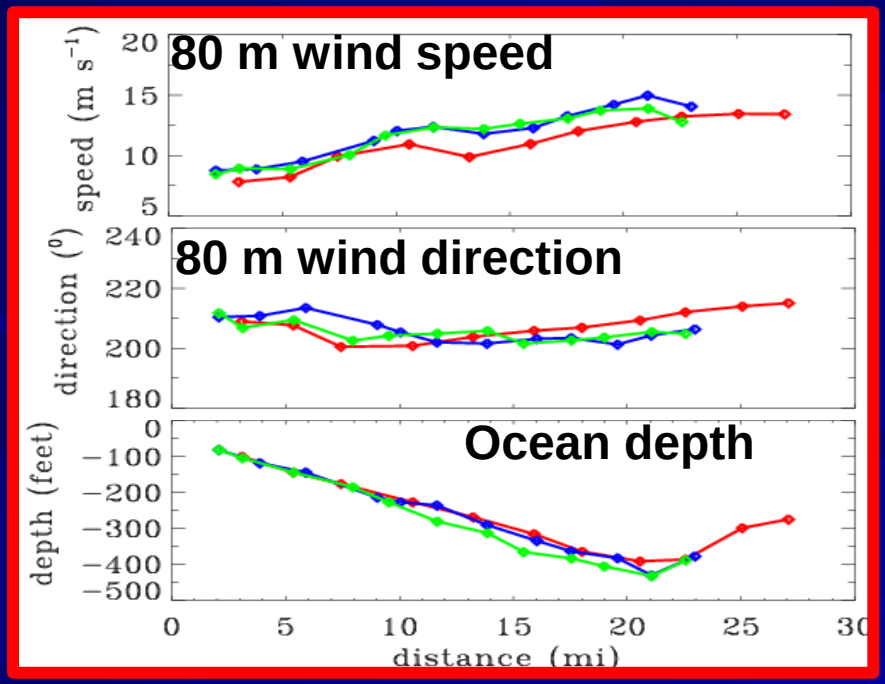


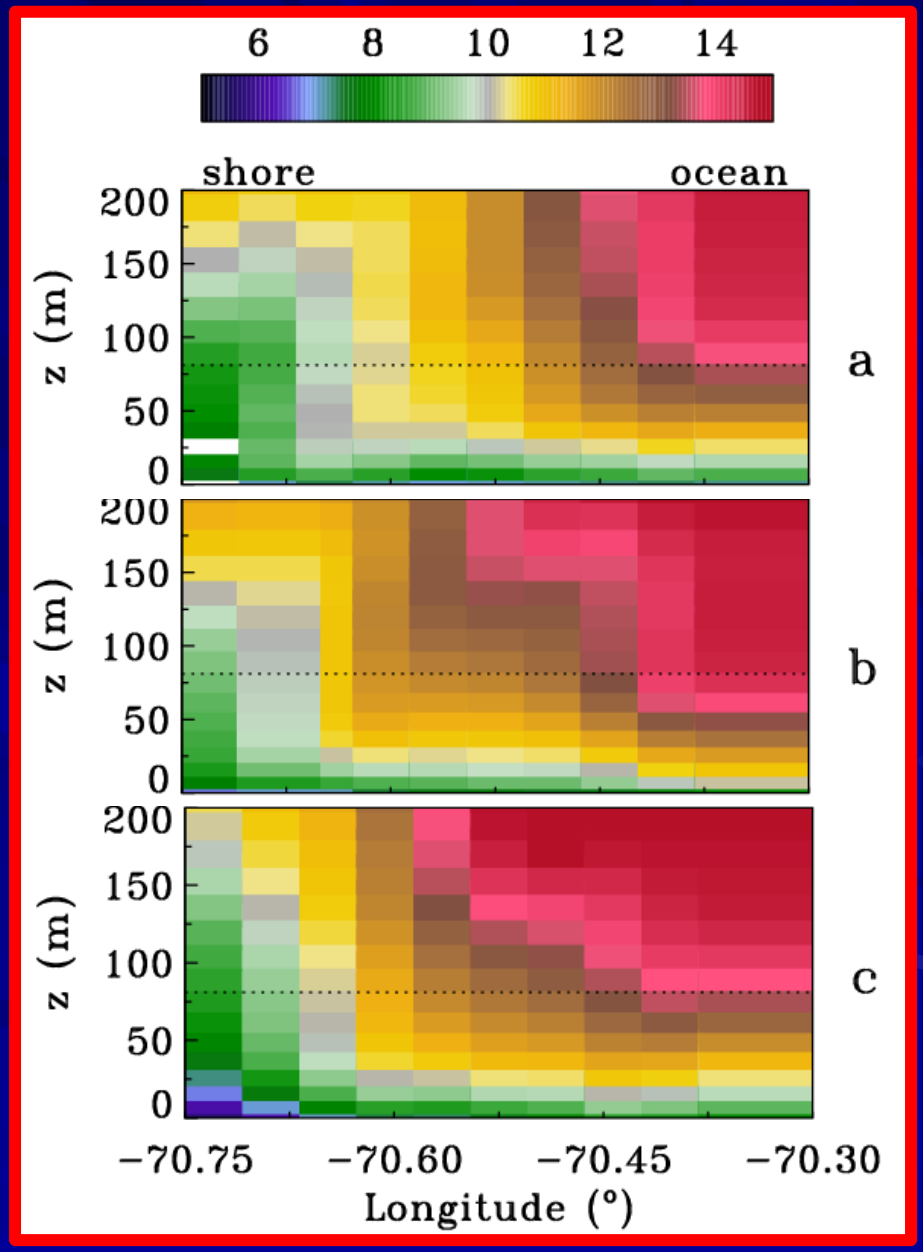




RMSE between HRDL-measured and modeled winds averaged in the first 500-m

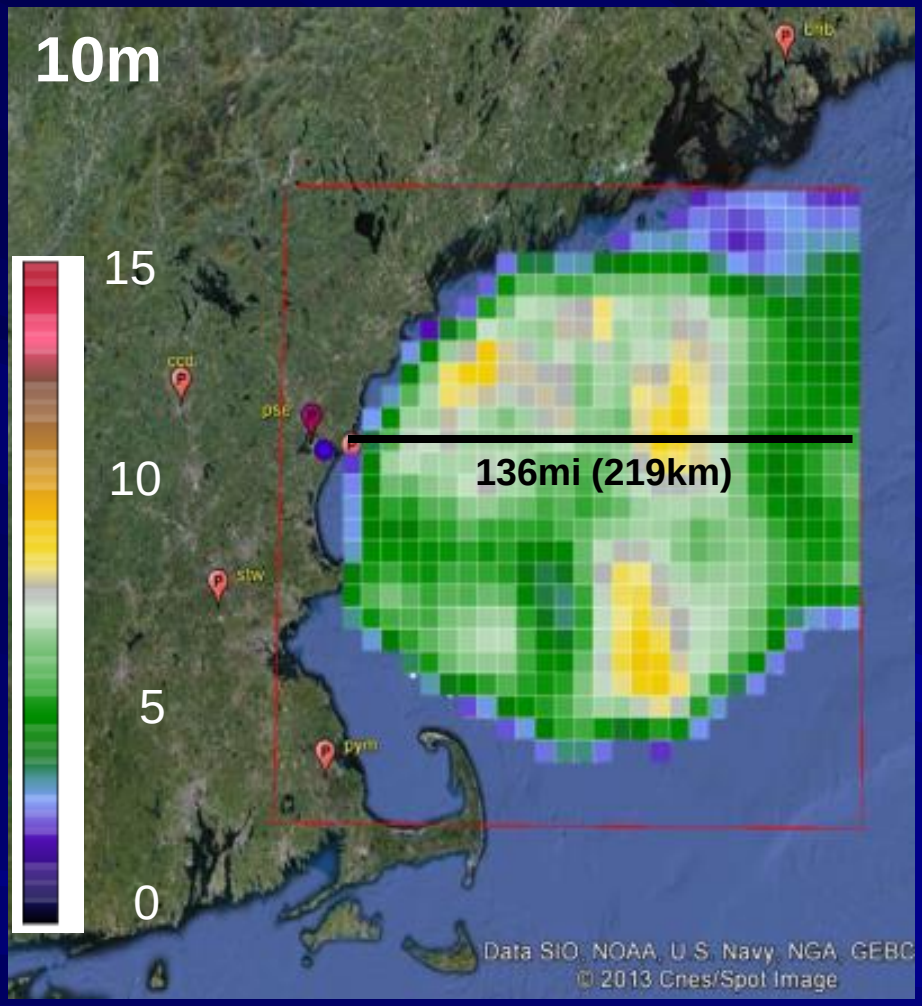
Spatial Variability (August 11, **8 hours**)

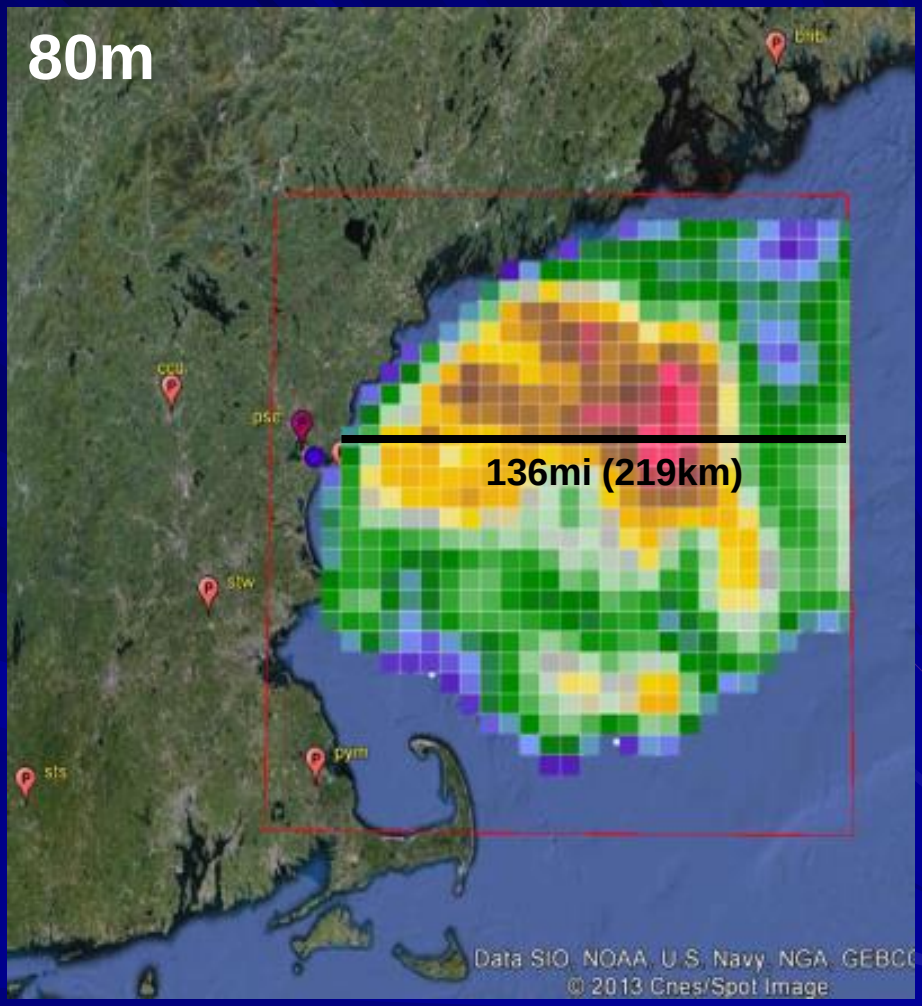




Could surface data **represent hub-height winds?**

July 9 - August 12, 2004





Spatial distribution of winds at surface differs from distribution at hub-height

Conclusions

- All models capture major trends in wind field
- Larger discrepancies in observed and modeled winds were found below 100-200m
- Assimilation of wind profilers data show up to 10% improvement in all models for the first 2-4 forecast hours
- All models show better agreement with lidar data for August period compared to July, when 3 days of fog, rain, and directional ramps were observed
  - Assimilation of wind profilers data for these days leads to greater RMSE.
- Short-term experiments provide insight on wind variability:
  - spatial, vertical, diurnal

WE-oriented, long-term measurements are needed to answer all questions !

Thank You!

Projected US offshore wind farms

- **Cape Wind** - off the coast of Massachusetts
  130-turbines, ~ 420 MW

- **Long Island** Offshore Wind Park
  off the coast of Long Island, New York
  40 turbines, 140 MW

- **Off the Galveston**, Texas coast 50 turbines

Wind turbines projected for offshore installation will be larger than inland turbines

↓

More wind Power Production

$P \sim D\ V^3$

Cape Wind 3.6 MW turbine:

79 m hub, 111 m D, 134.5 m above water

Proposed 10 MW turbine:

162 m hub, 145 m D, 234.5 m above water

(~30 story building)

Motion compensation

Stabilize the pointing of the beam

- Low elevation angle scans
- Vertical staring

Remove platform motion from

LOS velocity measurements

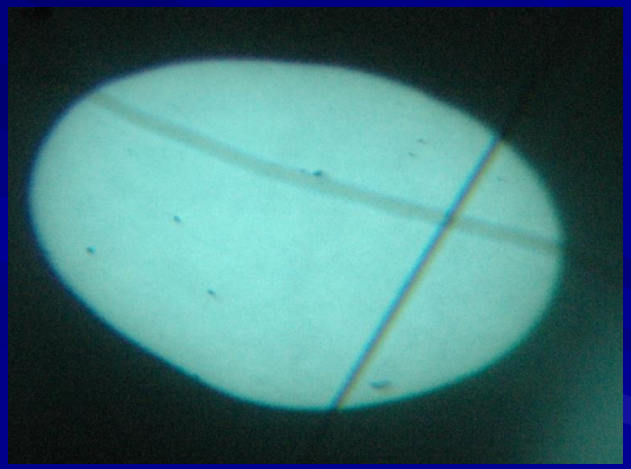
- Linear
- Rotational (ω x r)

Maintain “world frame” scan parameters

Pointing-angle accuracy tests

Land-based (in this building) Triple-swiveling motorized platform to simulate roll, pitch, and yaw from ship motions, wave activity

2 tests on ship at sea:
1) Horizontal (0º elevation) azimuth scans (see horizon)
2) Track sun

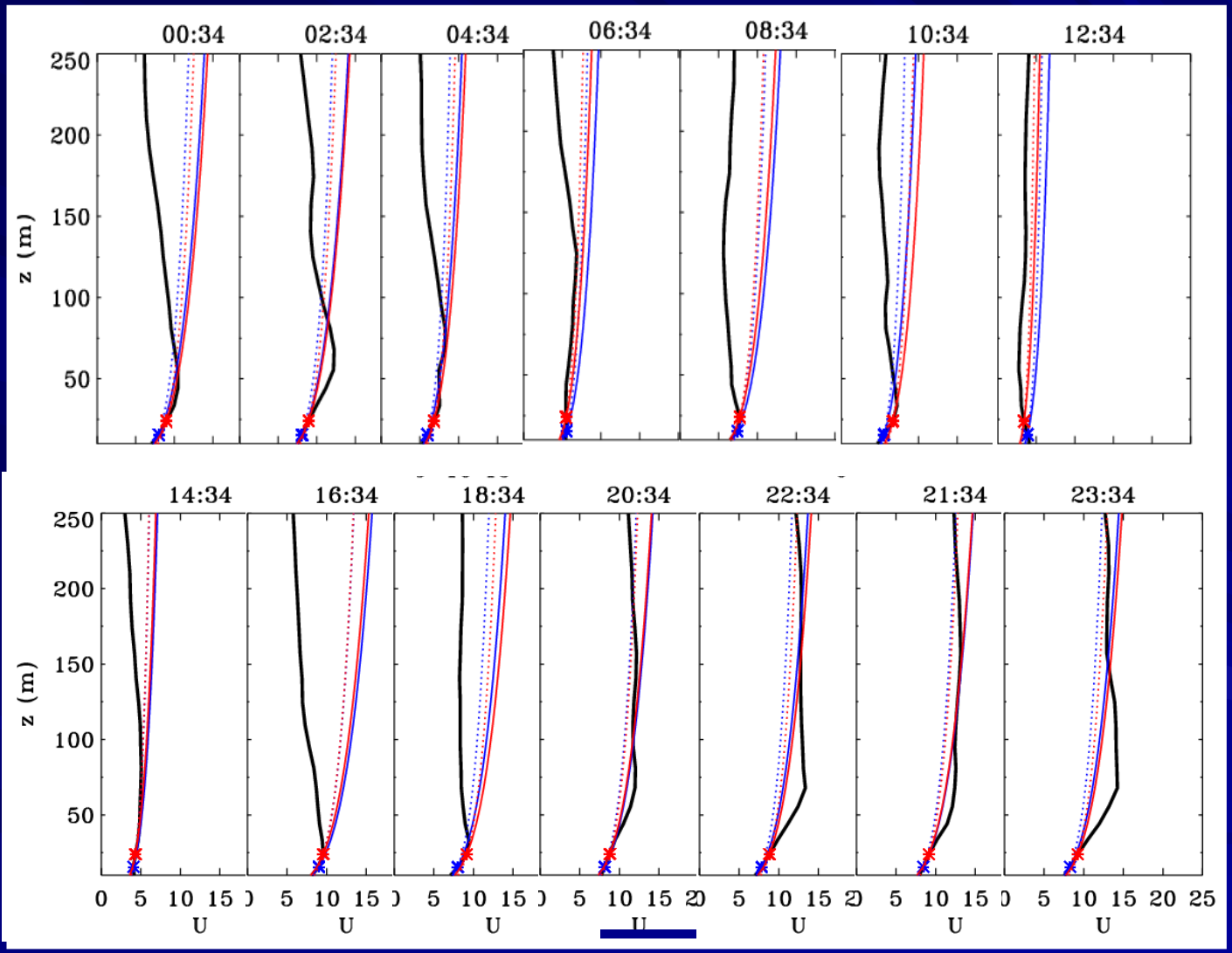


Solar disk and cross hairs

***Conclusion*: Scanner maintains desired pointing angle to <u>less than 0.5</u>º under normal conditions, less than 1º in very rough seas**

Power-law wind speed profile vs. measured

$$U=U_0\,(Z/Z_0)^{\alpha}$$

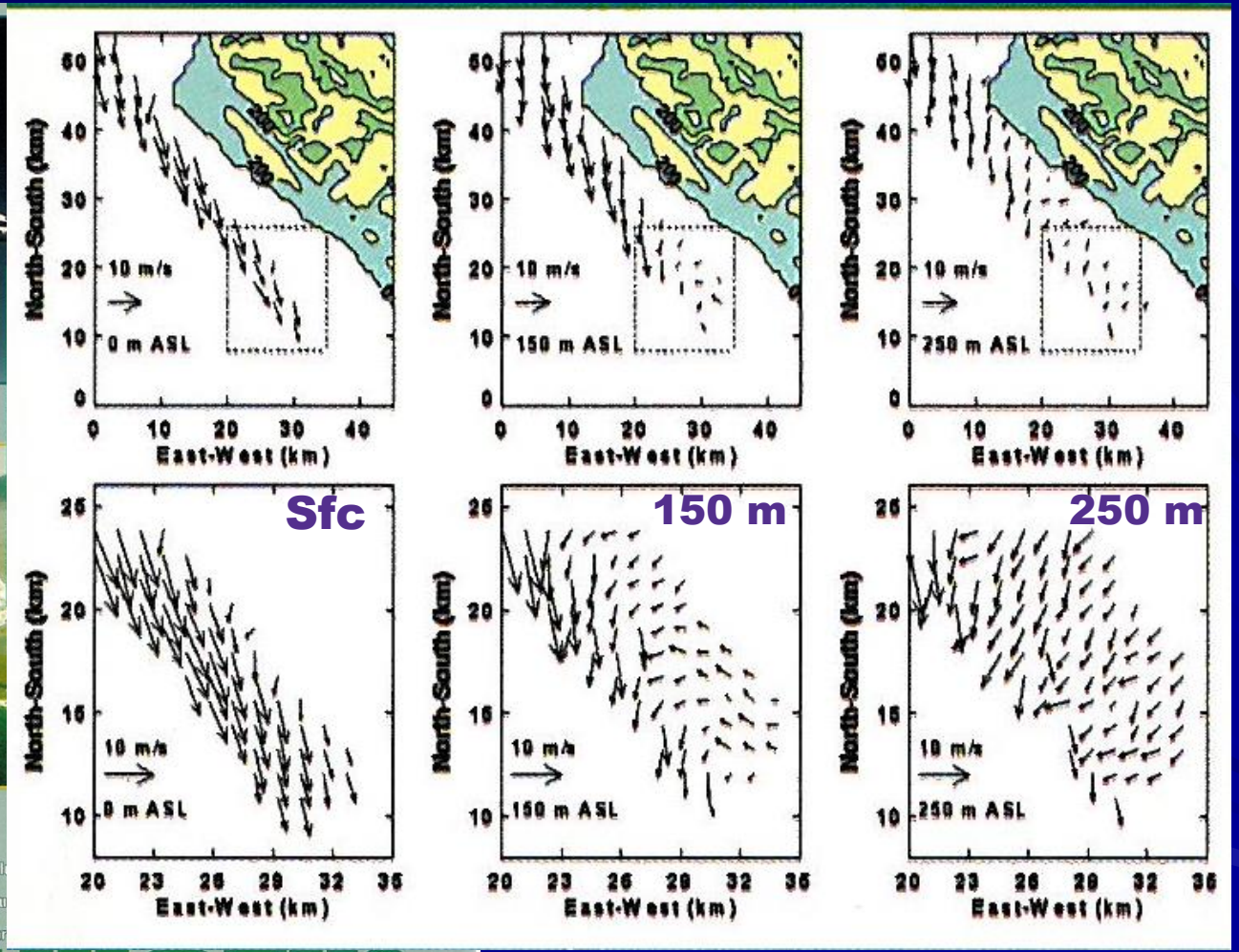


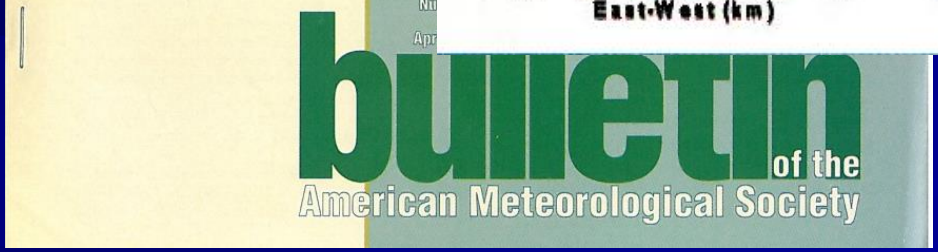
07/30/04

Black - lidar
dotted - α=1/7
solid - α=0.34
blue – Z_0=15m
red – Z_0=25 m

Wind-speed variability
– *horizontal and vertical*

Off the US West coast
30 June 1996

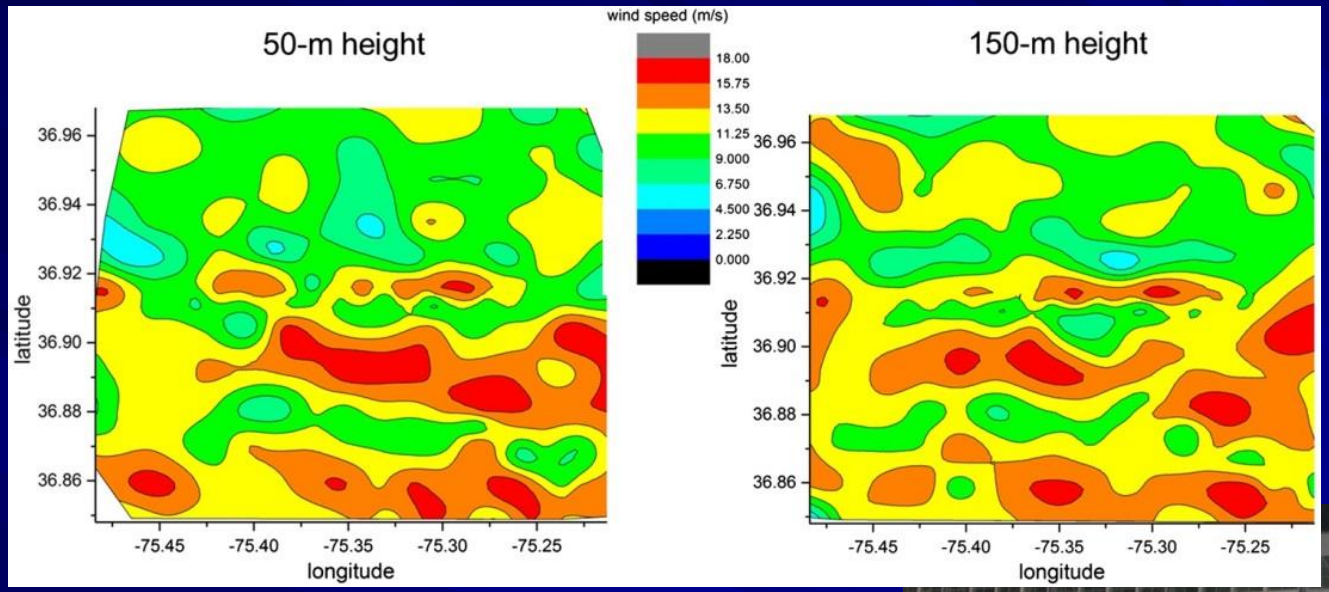


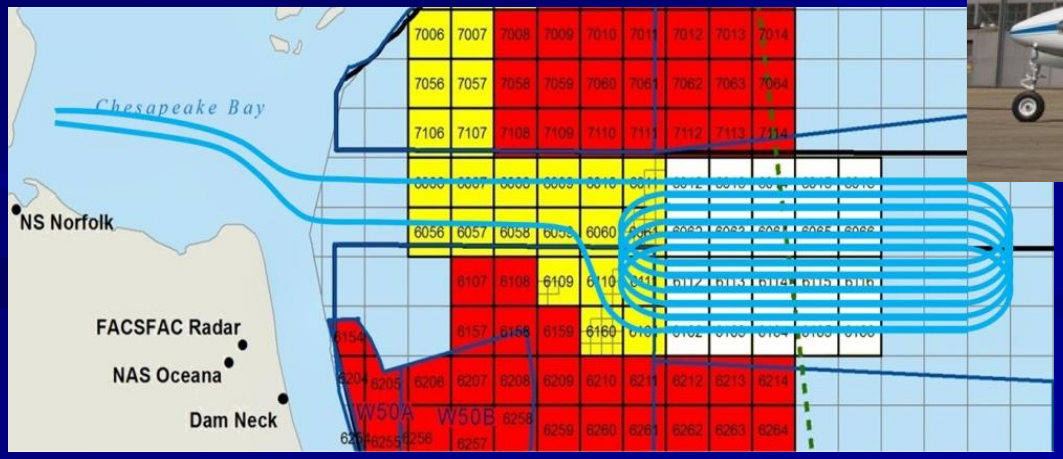


J. Rothermel & all., The Multi-center Airborne Coherent Atmospheric Wind Sensor. *BAMS*. **April 1998**

Wind-speed variability – *horizontal and vertical*

Off the US East coast
November 2, 2012.





Three-dimensional wind profiling of offshore wind energy areas with airborne Doppler lidar G. J. Koch&all DOI: 10.1117/1.JRS.8.083662]

http://spiedl.org/terms