Offshore Mesoscale Modeling Challenges And Observations

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and Mesoscale to Microscale Coupling project team

Atmospheric Science Challenges for the Wind Energy Industry
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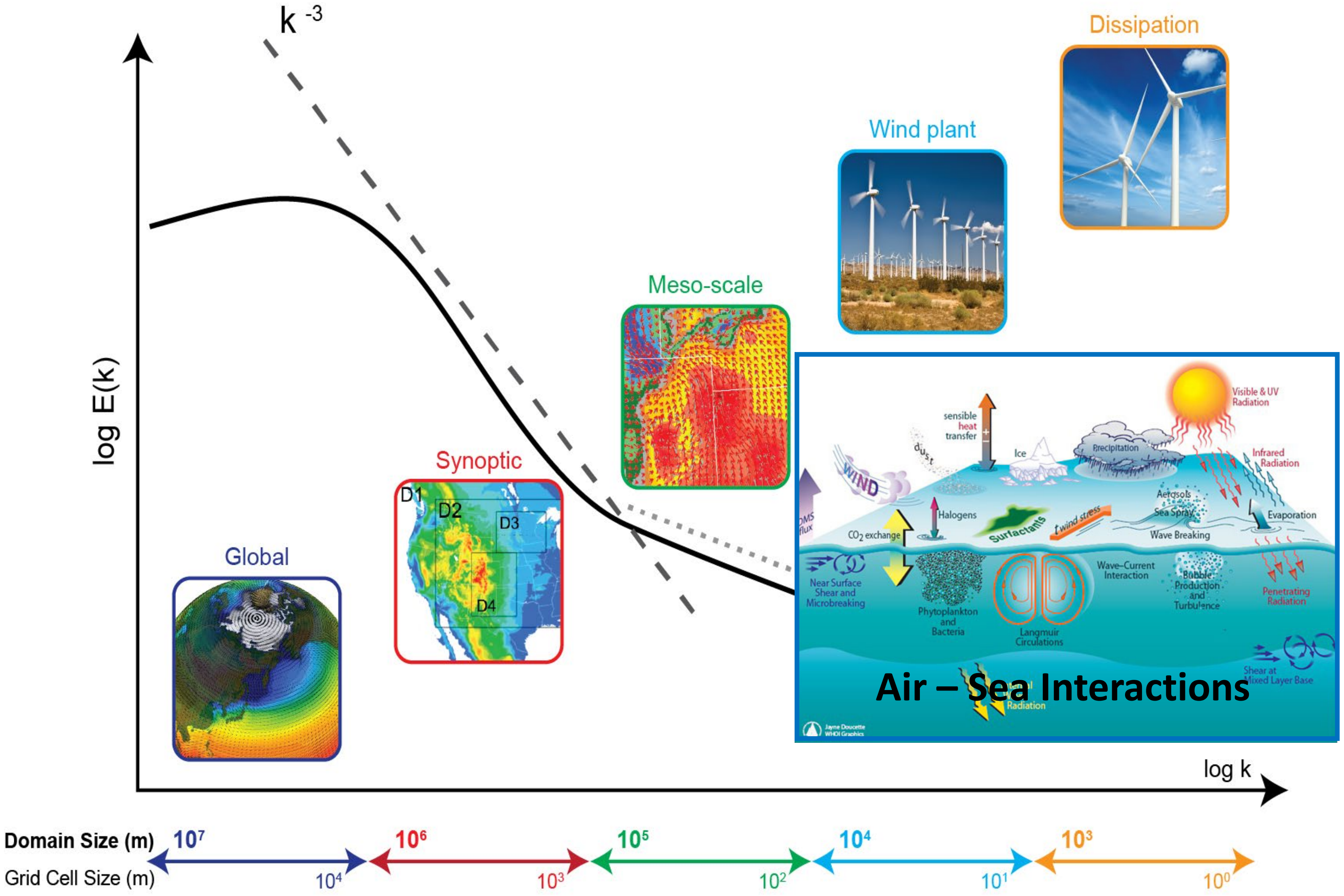
For offshore wind energy applications, atmospheric boundary layer cannot be isolated from the larger scale flows

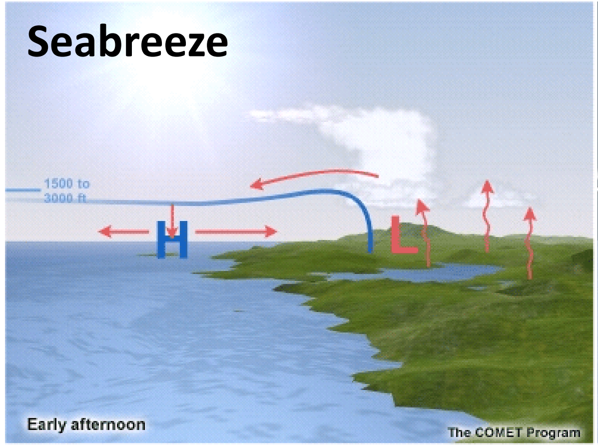


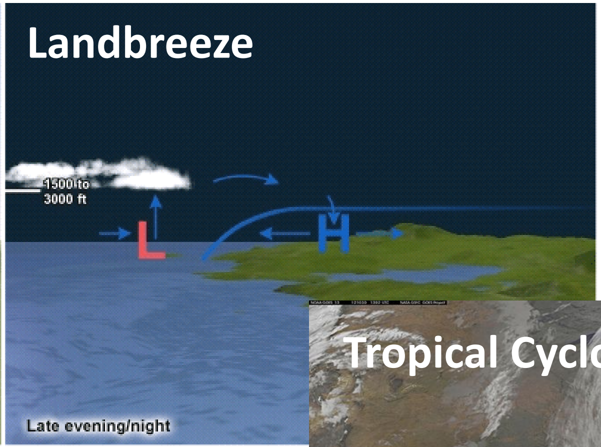
Effective coupling of mesoscale and microscale simulations requires:

- codes (mesoscale and microscale),
- boundary conditions (surface and lateral),
- turbulence development,
- **parameterizations,**
- etc.

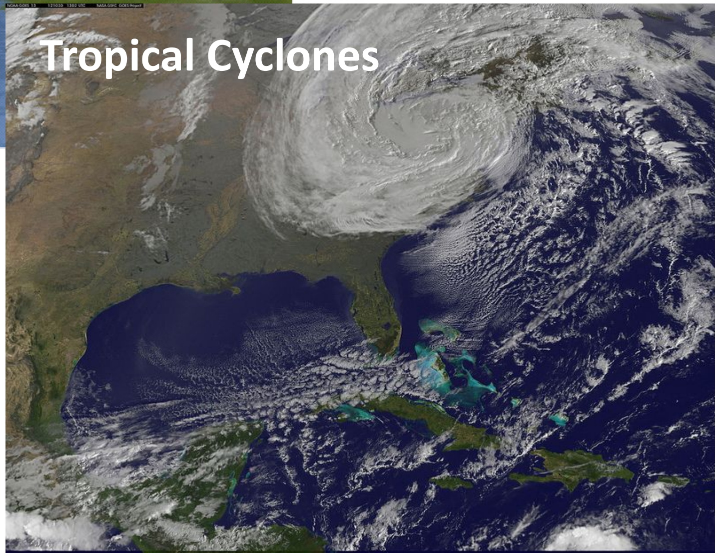
We will focus on **PBL** and **surface layer** parameterizations.

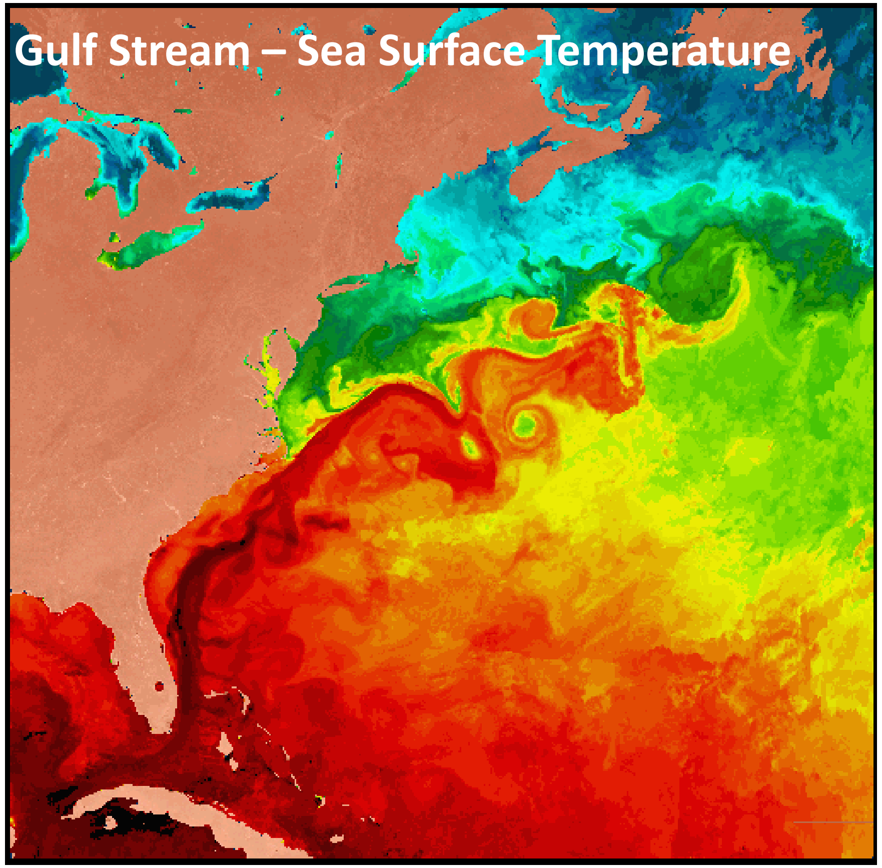
Offshore environment presents new challenges to mesoscale modeling and parameterization of physical processes

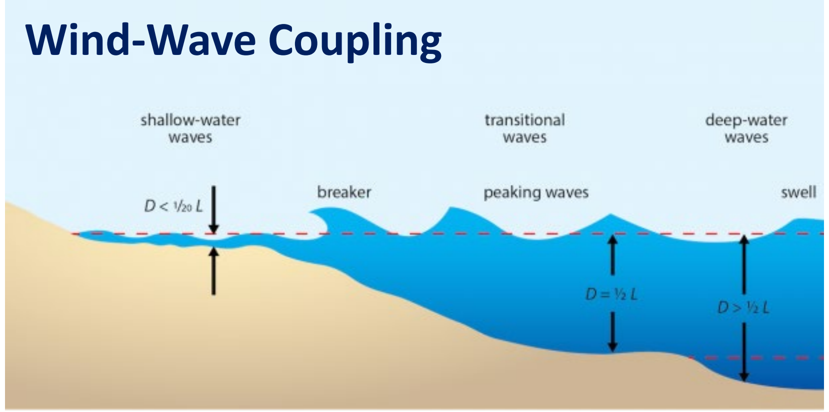


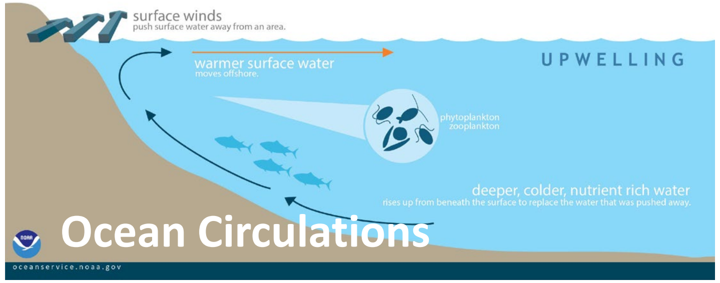


Although compared to land surface ocean surface can be considered flat the flows over it cannot necessarily considered horizontally homogeneous due to proximity of land or ocean surface state.







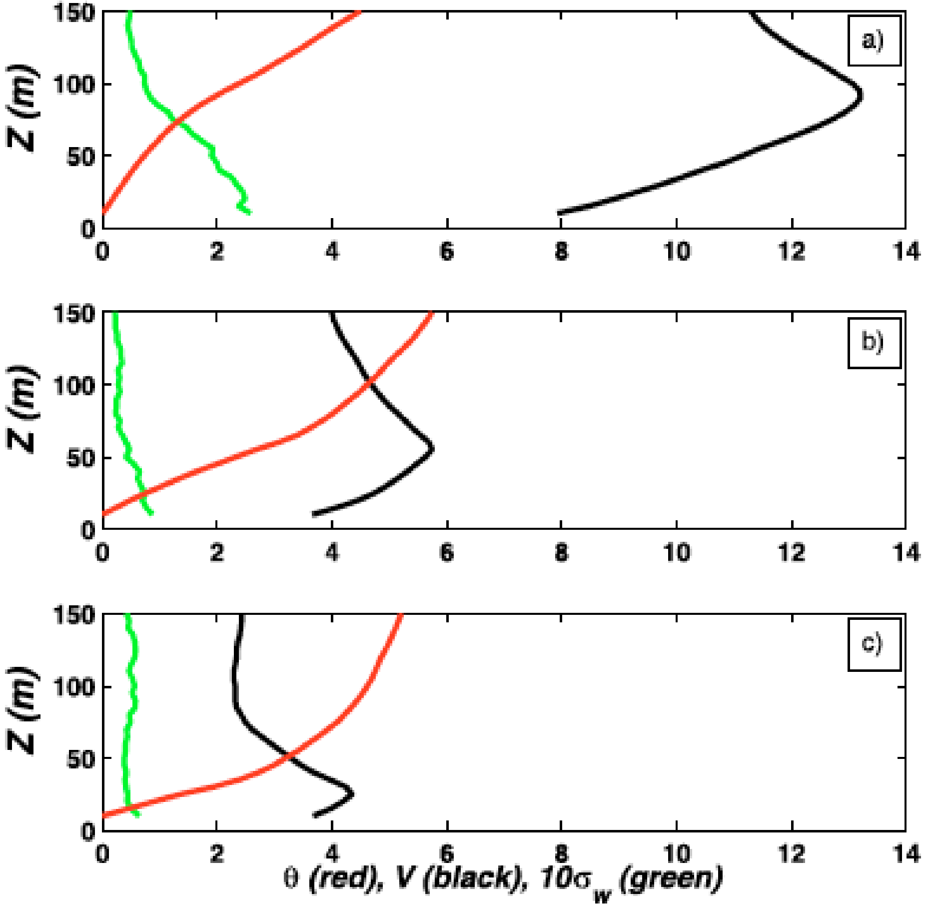


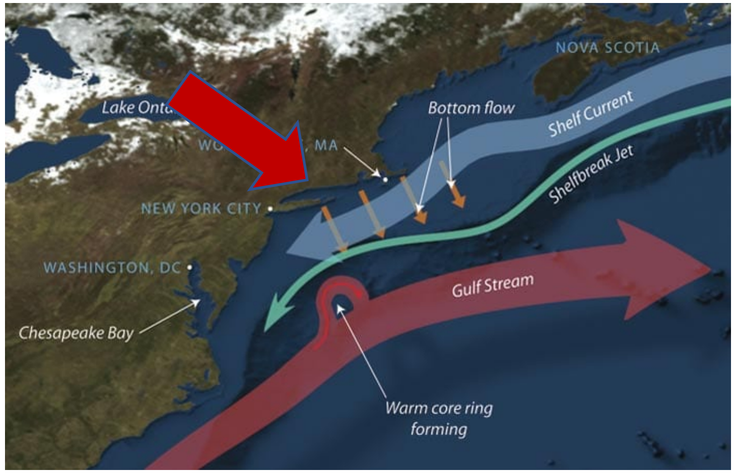
For offshore wind applications do we need:
coupled mesoscale and wave models,
coupled mesoscale and ocean model,
coupled mesoscale, wave, and ocean models?

Low-level jet is common not only in the Midwest but also along the East Coast

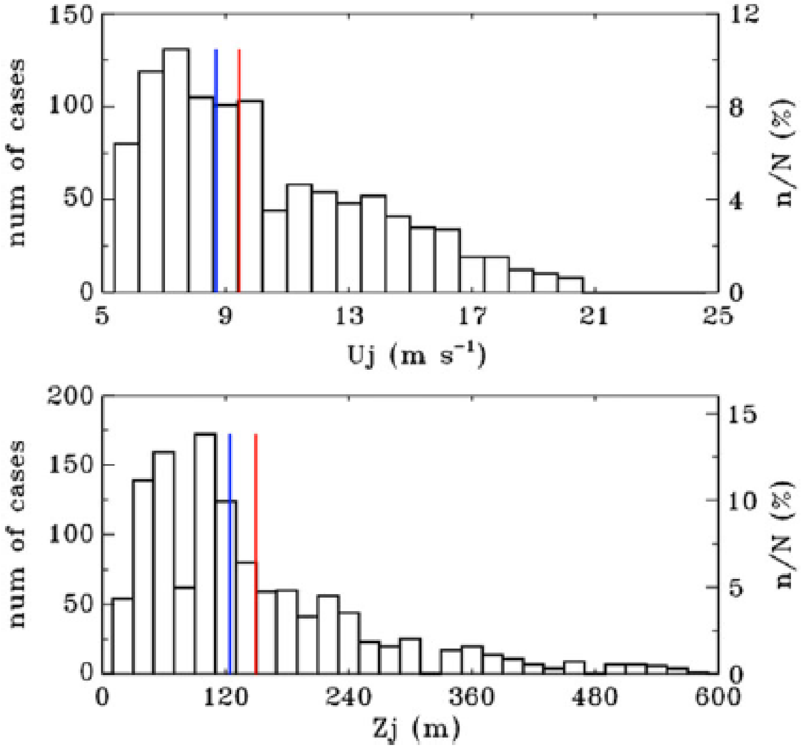
On the East Coast of United States in summertime shallow stably stratified marine boundary layer can persist for days.
Mesoscale models still do not capture LLJs accurately.

CBLAST August 7-8, 2001 (Mahrt et al. 2014)

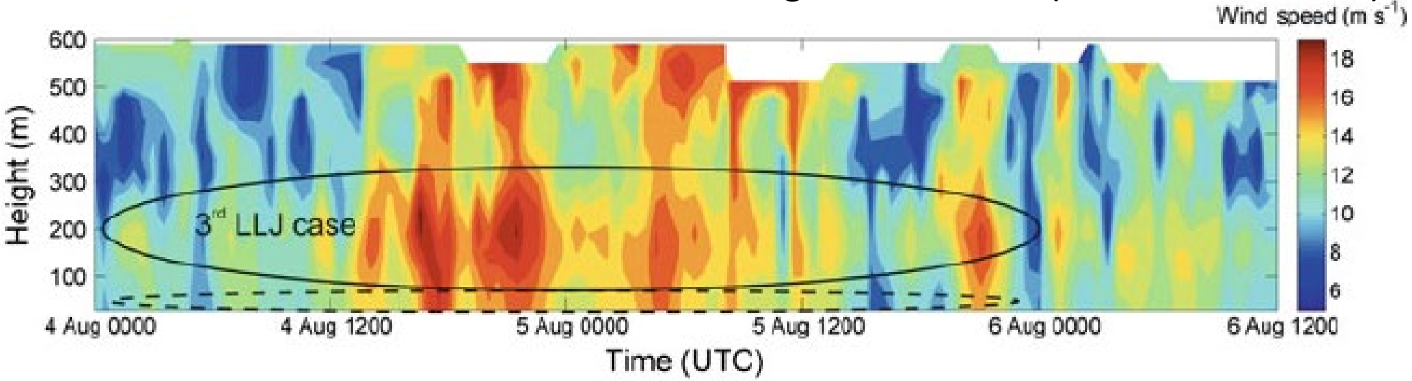




Ship-base LIDAR observations (Pichugina et al. 2017)

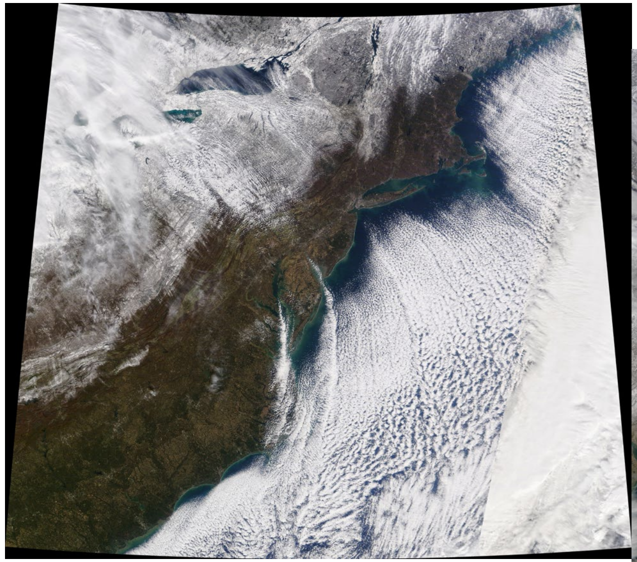


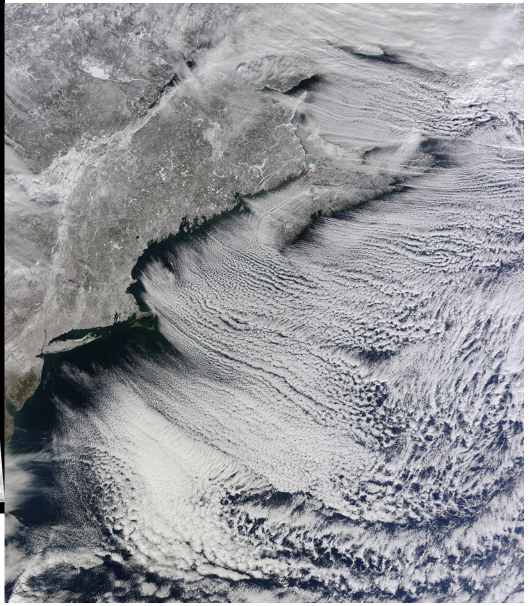
Sodar measurements at Nantucket during CBLAST 2003 (Helmis et al. 2013)



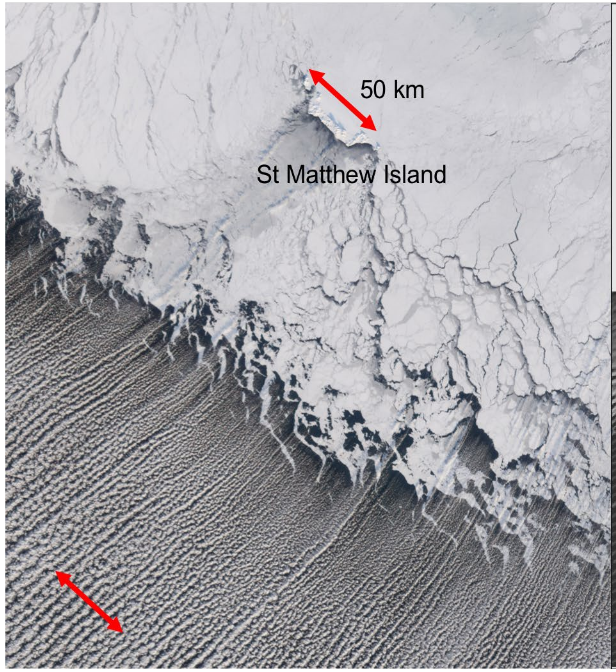
Cold air outbreaks result in offshore convective conditions

- One-dimensional planetary boundary layer parameterizations cannot represent convective structures accurately.
- These structures are observed over the areas where offshore wind deployment is planned.
- St. Matthews Island example demonstrates that while the model captures cold air outbreak well the helical convective rolls do not widen as observed.

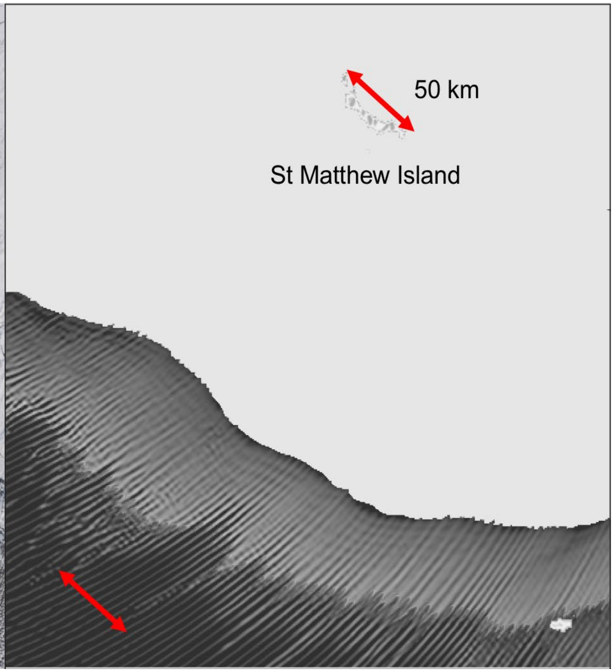




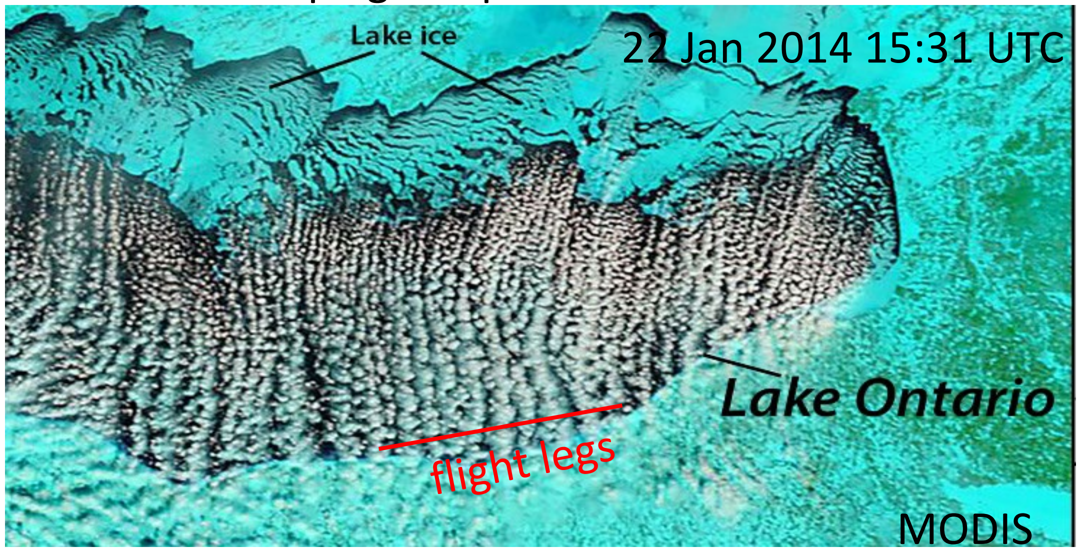
MODIS



WRF with 1D PBL



OWLeS campaign – “polar vortex” conditions



Currently numerical weather prediction models use 1D PBL schemes, which are inappropriate for grid cell sizes finer than 2 km

Conservation equation for the velocity components:

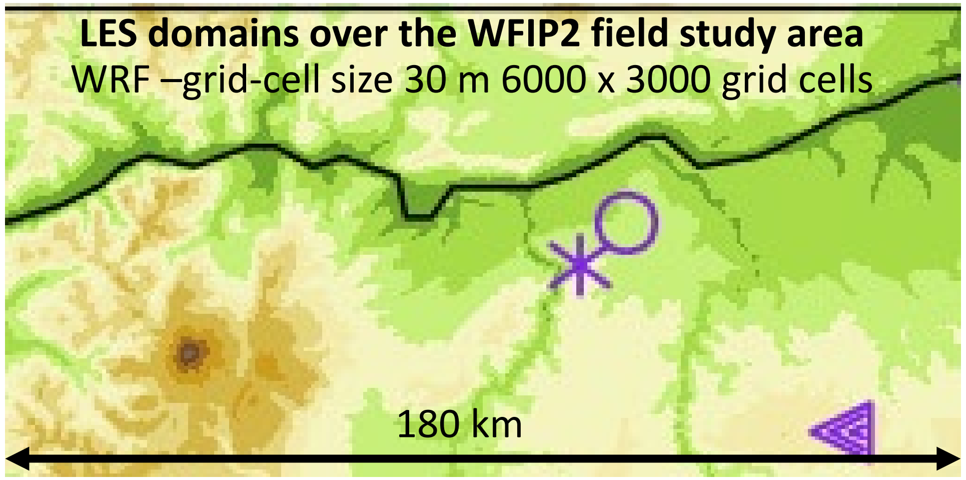
3D PBL

$$\frac{\partial U_i}{\partial t} + U_j\frac{\partial U_i}{\partial x_j} = -\frac{1}{\rho}\frac{\partial P}{\partial x_i} + 2\epsilon_{ijk}\Omega_j U_k - \frac{\partial \langle u_i u_j\rangle}{\partial x_j}$$

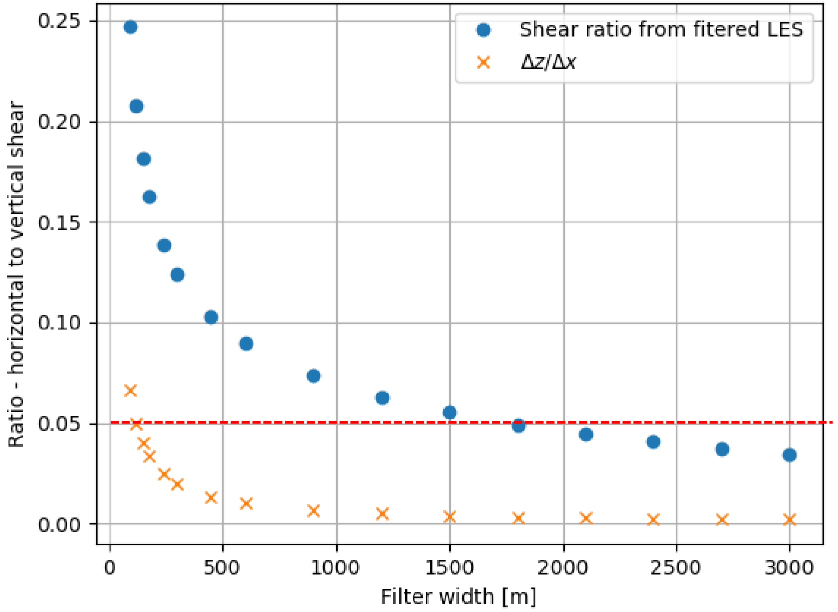
- 3D PBL scheme includes (diagnostic) parameterization of all six turbulent stress components and computation of stress divergence (Mellor and Yamada 1974,1982; Yamada and Mellor 1975)
- Consistent closure assumption for all stress components

Relative importance of horizontal shear in comparison to vertical shear is computed as:

$$R = \left[\frac{\left(\frac{\partial u}{\partial x}\right)^2 + \left(\frac{\partial u}{\partial y}\right)^2 + \left(\frac{\partial v}{\partial x}\right)^2 + \left(\frac{\partial v}{\partial y}\right)^2}{\left(\frac{\partial u}{\partial z}\right)^2 + \left(\frac{\partial v}{\partial z}\right)^2}\right]^{\frac{1}{2}}$$



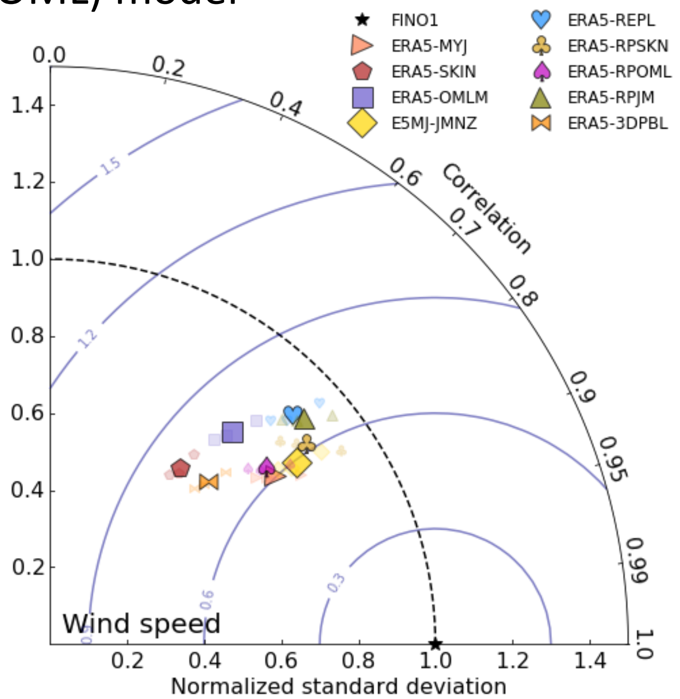
Filtered LES results at different scales
to demonstrate relative importance of horizontal shear

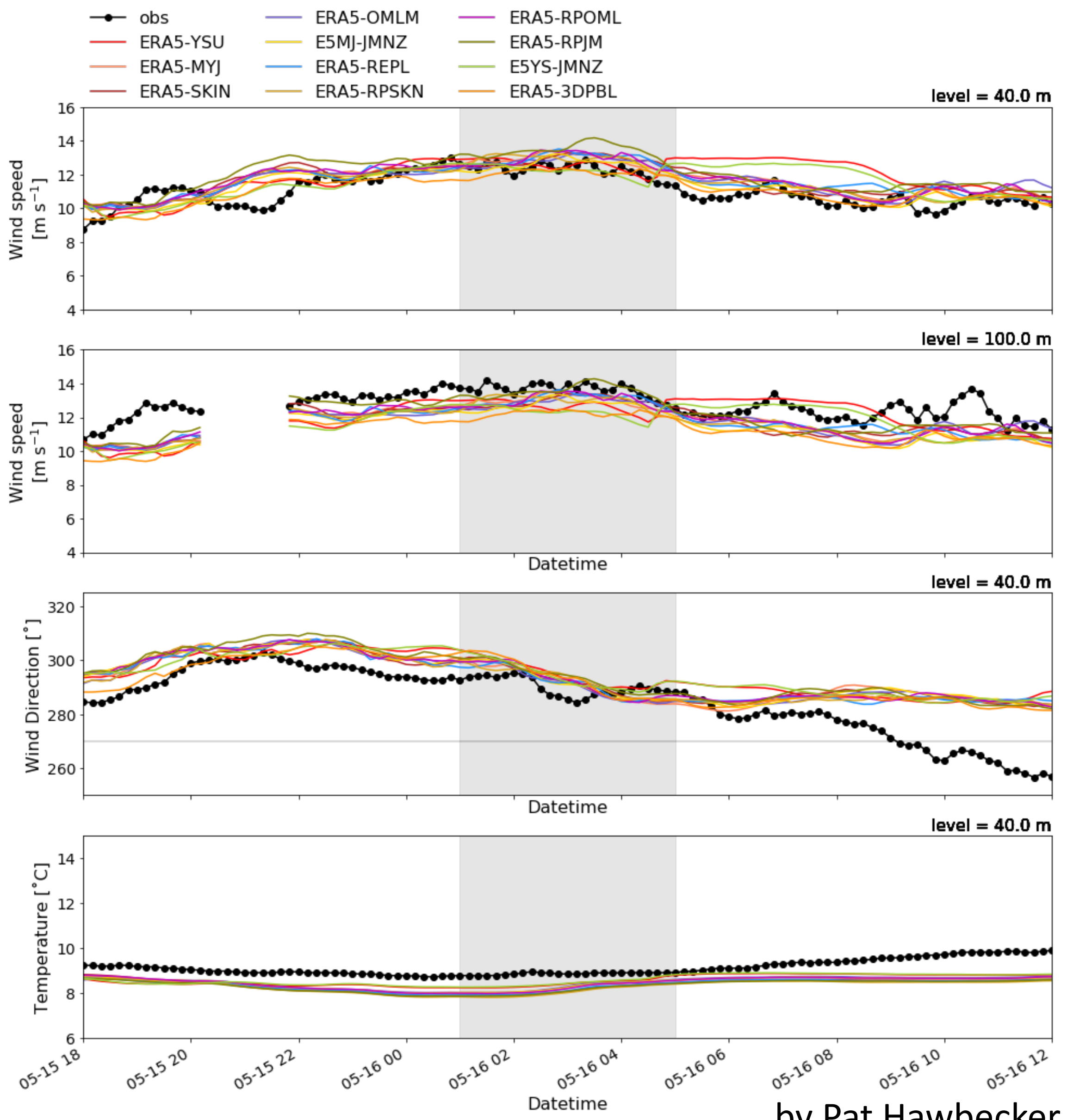


We used FINO1 observations to verify mesoscale simulations that will be used for coupling with microscale

- PBL: YSU, MYJ, 3DPBL
- Sea surface roughness: Charnock,
  - Charnock (default)
  - Jiménez depth-dependent roughness
- Sea surface temperature
  - Replacing SST (daily) w/ skin temperature (hourly)
  - SST_SKIN - skin temperature formulation within WRF
  - 1D Ocean Mixed Layer (OML) model

Taylor diagram represents a way to graphically summarize several performance measures (Pearson correlation coefficient, RMSE, and standard deviation).





by Pat Hawbecker

Offshore environment represents significant challenges for observations

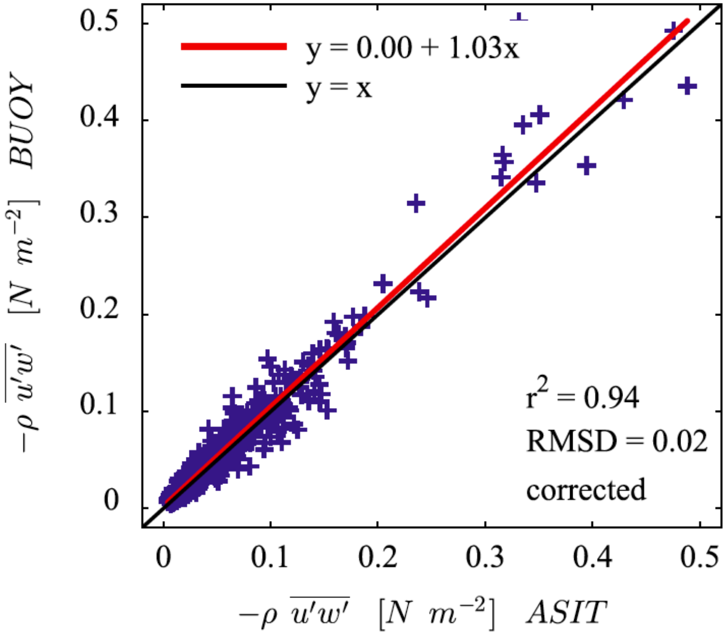
To improve planetary boundary layer and surface layer parameterizations we need collocated atmosphere, wave, and ocean state observations

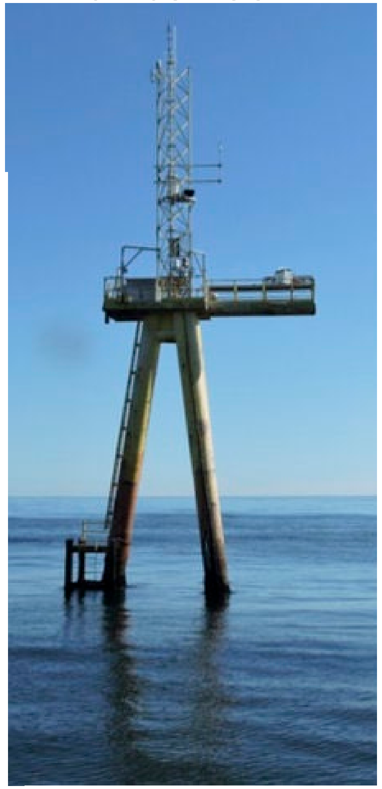
NOAA's buoy network provides information about winds and wave state:

- wind speed and direction,
- significant wave height, wave direction, and wave period

https://www.nrel.gov/wind/nwtc/metocean-data.html

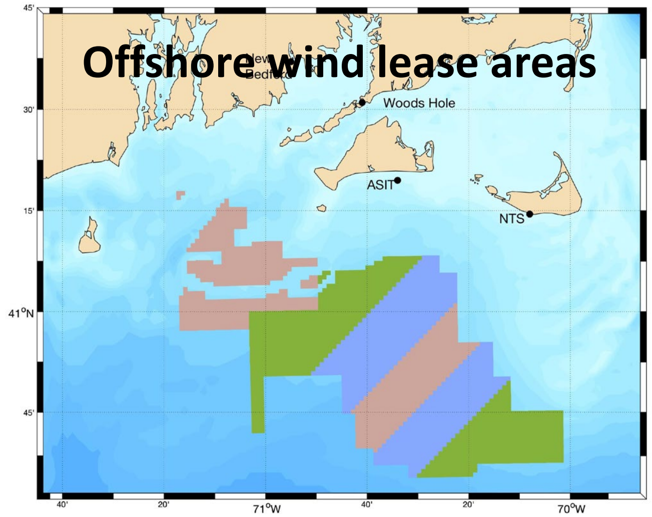
Flügge et al. (2016)





ASIT since 2002

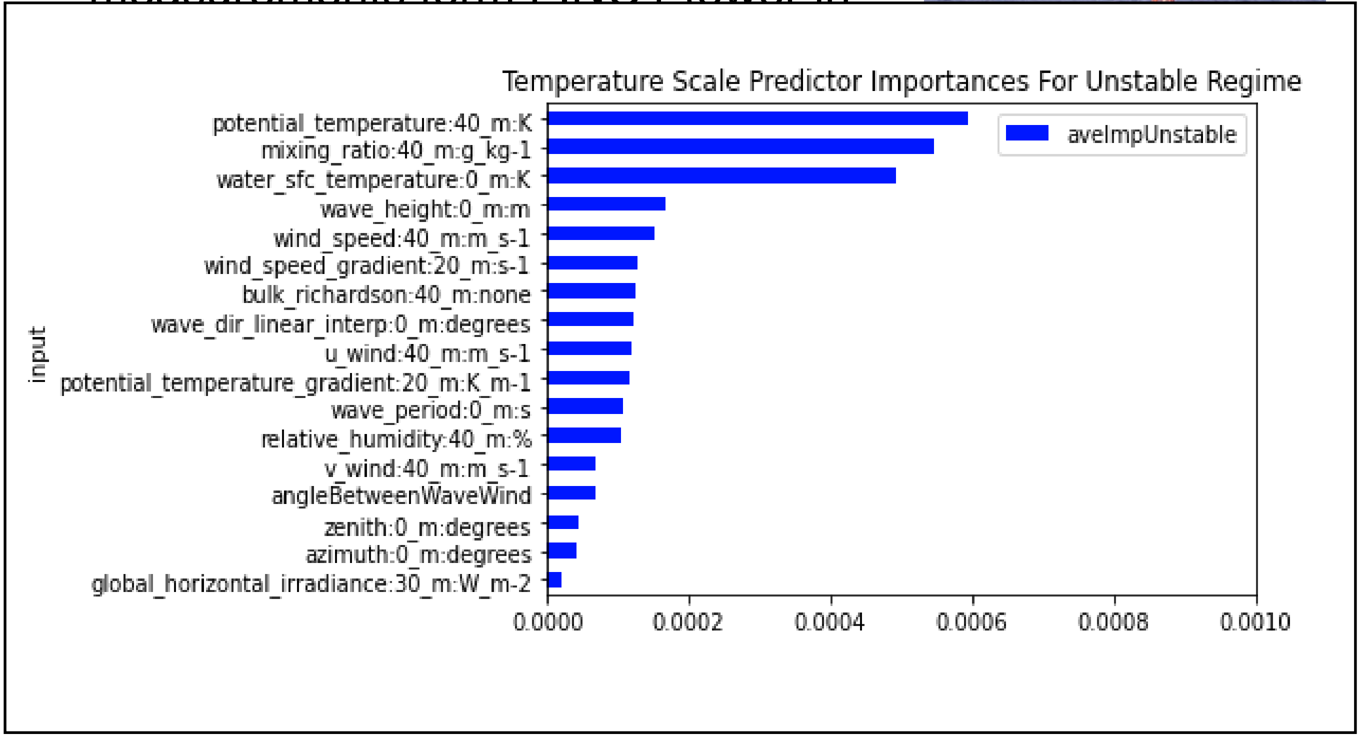
Cape Wind 2003 - 2011



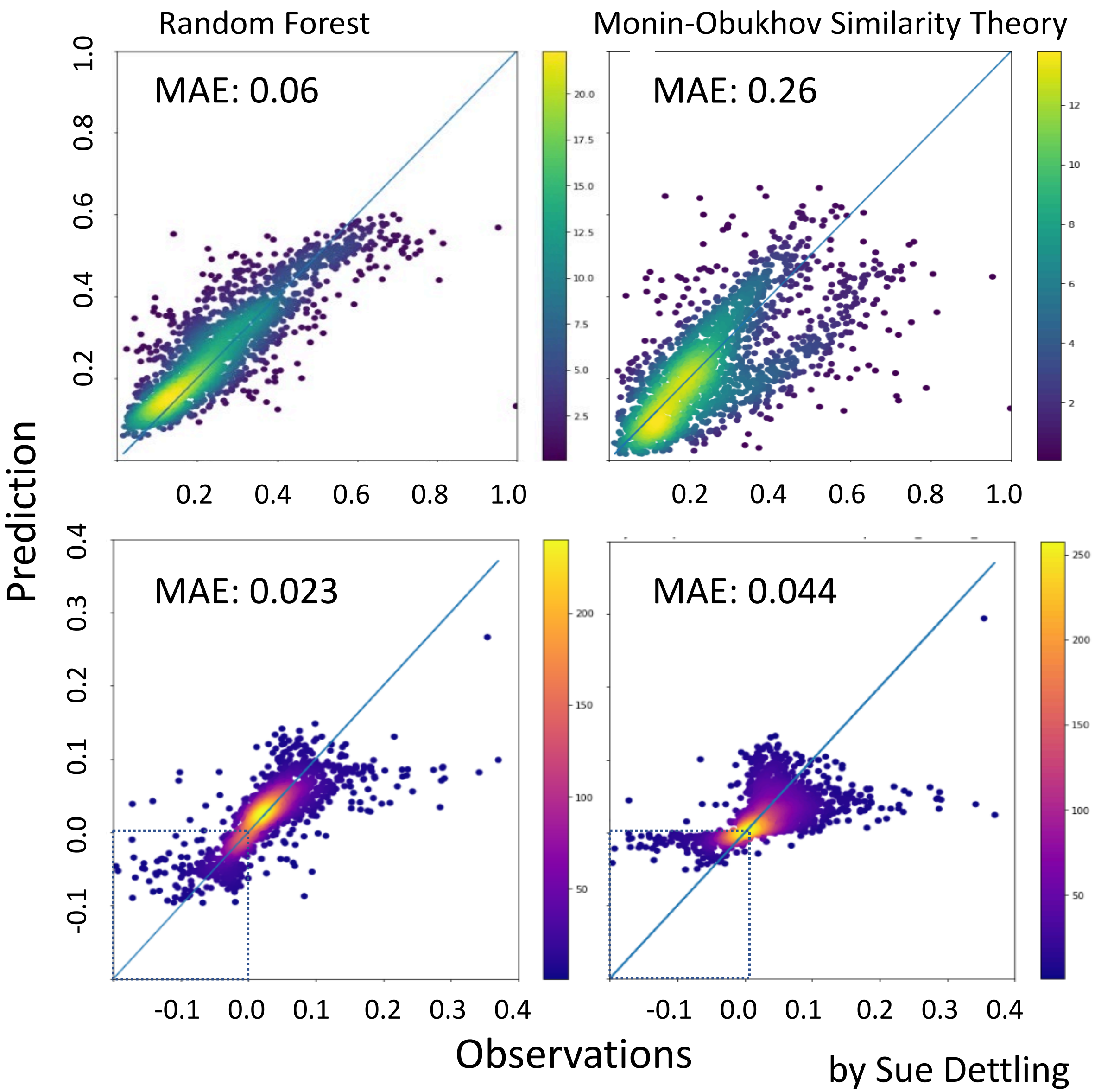
Preliminary resulst of applying machine learning for surface layer parameterization are encouraging

- Flux measurements in offshore environments are limited and not readily available (i.e. commonly shared).
- We developed a machine learning model using wind, wave, and flux measurements form FINO1 tower in

FINO1



Surface Friction Velocity and Temperature Scale (obs. 2010)



by Sue Dettling

A few final thoughts…

To address how marine boundary layer conditions impact offshore wind resource and performance we need to:

- build on what was learned in offshore environments in Europe and elsewhere where wind turbines have already been deployed,
- recognize special characteristics and related physical processes in different offshore environments,
- recognize that offshore environment is not necessarily homogeneous due to:
  - near shore effects of land and sea breezes, coastal jets,
  - effects of sea surface temperature gradients due to currents, and
  - effects of ocean circulations in general (e.g. upwelling), in addition we need to consider
  - wave effects on hub height winds
- explore machine learning is a promising approach for tackling parameterizations where theoretical assumptions are not satisfied and large, complete, and quality controlled data sets are available, and
- more data for model development and validation.