Using Data Assimilation and State Estimation in Marine Boundary Layer Paramaterizations to Improve Offshore Wind Energy Prediction

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Motivation

- Offshore wind energy generation is a growing energy sector
- The marine atmospheric boundary layer (ABL) environment is not well studied or modeled
  - Very few instrumented tall towers offshore worldwide
  - ABL schemes generally tuned for performance over land
- Improvements in marine ABL schemes in NWP models can help offshore wind resource assessment, management, and short-term prediction

Middlegrunden wind farm near Copenhagen

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Modifications to WRF-SCM

- Current distribution version of WRF-Single Column Model (SCM) hard-coded for use over land only
- Some modifications were necessary for use of WRF-SCM over water:
  - Values for XLAND and LANDMASK now set appropriately for land or water according to '&scm' namelist value of scm_lu_index
- Other modifications to WRF-SCM:
  - If provided, SCM now uses user-specified eta levels in namelist, instead of only model-calculated eta levels
  - Allows for higher model resolution over depth of tower
- Plan to submit these modifications to WRF development team for future public release

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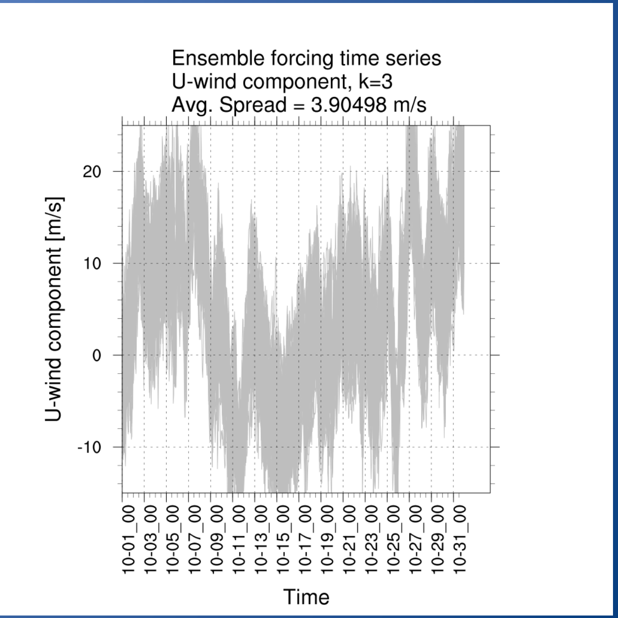
Ensemble Forcing Methodology

- Previously, SCM forcings built by random draws from "climatology" of met_em files
- New methodology builds SCM ensemble forcings from EOFs of 3D wrfout files over the period of interest
  - Mean forcing taken directly from 3D wrfout files
  - Modes calculated for each variable and each hour/ time of day separately
  - Perturbation ε is a linear combination of leading N modes (eigenvalue λ * eigenvector **e**)
  - Random coefficients α drawn from normal distribution with mean of 0.0 and std. dev. tuned so that forcing spread approximates mean forcing (3D WRF) RMSE averaged over the period of interest
  - AR(1) process applied to α's for temporal consistency (auto-regression coefficient 0.95)
  - Unique α's for each ensemble member, and therefore, unique perturbations ε as well

$$\varepsilon = \sum_{n=1}^{N} \alpha_n \lambda_n \mathbf{e}_n$$



Ensemble forcing for U-wind for Oct 2006

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Research Plan

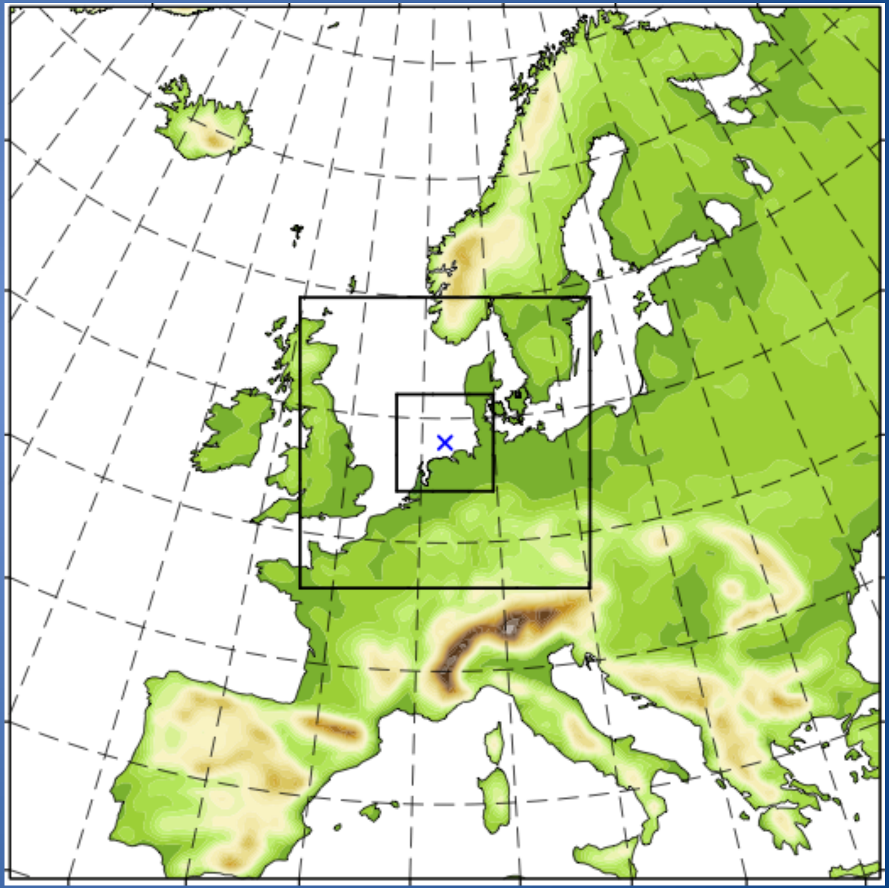
a) Location of the FINO 1 platform in the North Sea

FINO1 research platform

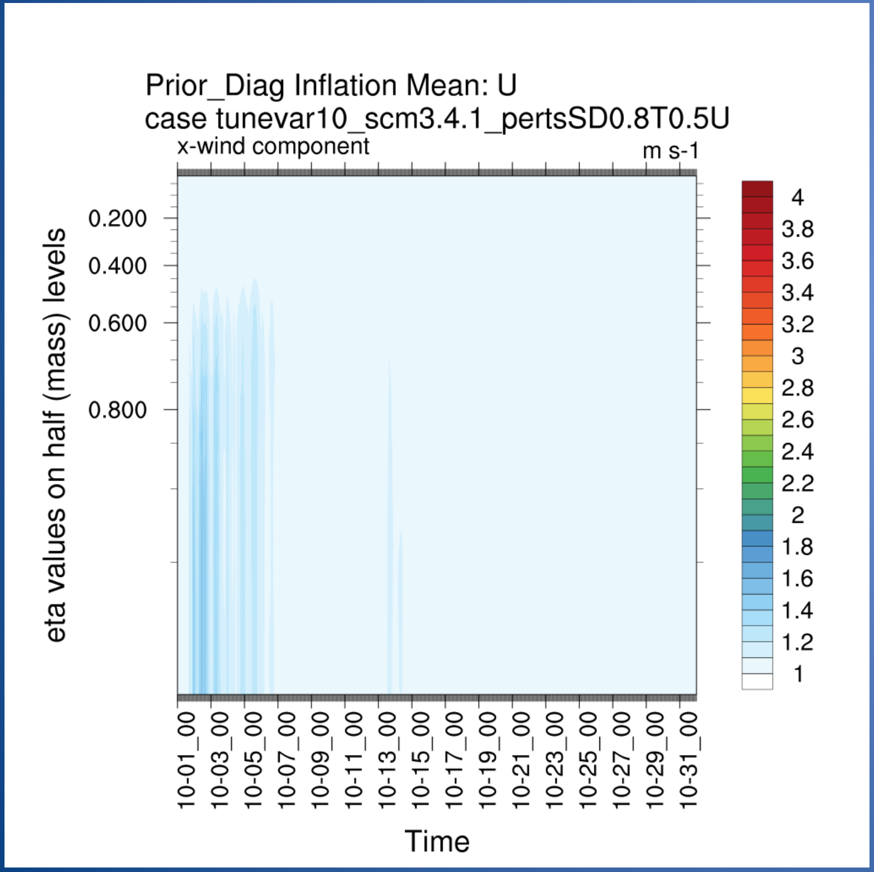
- Couple Data Assimilation Research Testbed (DART) with WRF-SCM first to explore estimation of several parameters
  - MYNN-2.5 PBL scheme
  - MYNN surface layer scheme
  - Eventually move to 3D WRF
- Assimilate data from 100-m FINO1 tower in North Sea
  - 7 anemometers/wind vanes
  - 5 thermometers
  - Oct-Dec 2006, prior to construction of adjacent Alpha Ventus wind farm

3D WRF Setup

- WRF-ARW v3.4.1, 3 domains
  - 30/10/3.3 km
  - First levels 15, 45, 75, 100, 130, 195, 315, 490 m
- Thompson MP, MYNN PBL, Kain-Fritsch Cumulus (D1 & D2 only), Noah LSM, RRTM/ Dudhia radiation
- ICs & LBCs from Climate Forecast Reanalysis System (0.5°)
- SST from NCEP RTG (0.083°) and DMI (0.03°)



SCM-DART Setup

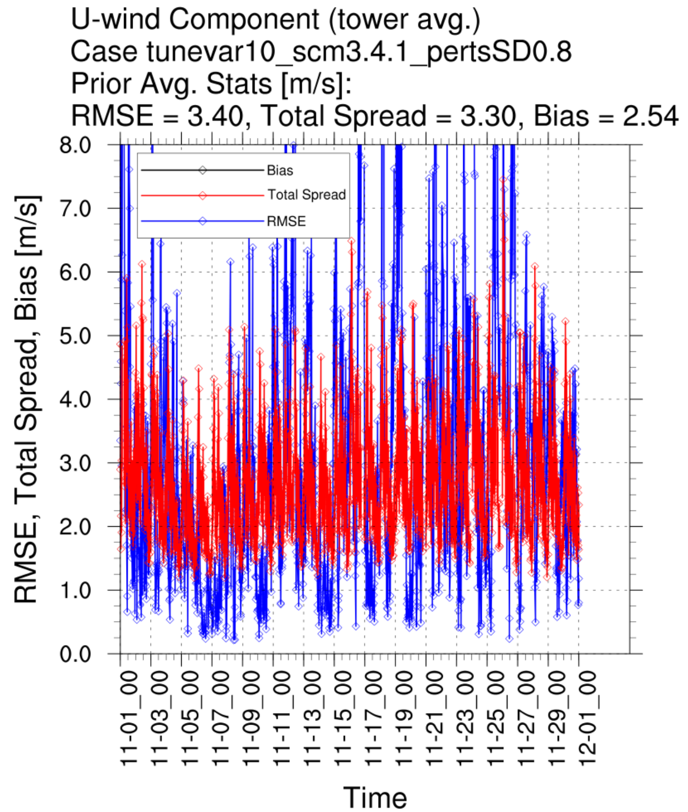


- WRF-SCM v3.4.1
  - Vertical advection on
  - All other advection off
  - 60 eta levels
    - Bottom 10 levels spaced every ~20 m from 30-210 m
  - SST updated daily via auxinput8
- DART
  - Ensemble adjustment Kalman filter (EAKF)
  - Vertical localization 4 km
  - 1-h assimilation cycles
  - Assimilating T, Td, U, V
  - Tuned observation errors to improve match between average RMSE and Total Spread
    - T = 1.0 K, Td = 1.5 K, U,V = 1.0 m/s

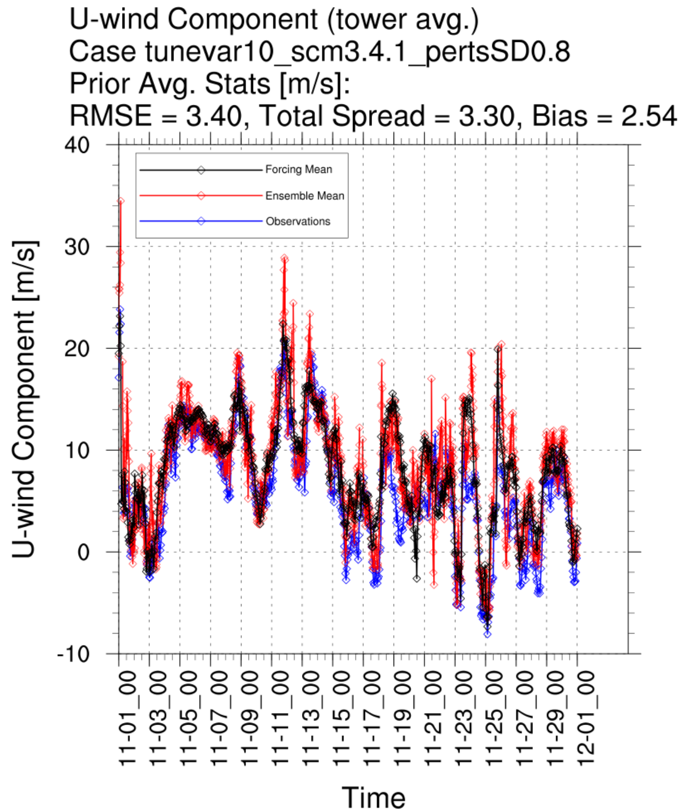
Preliminary SCM-DART Results

Nov 2006 – U-wind component

RMSE and Total Spread



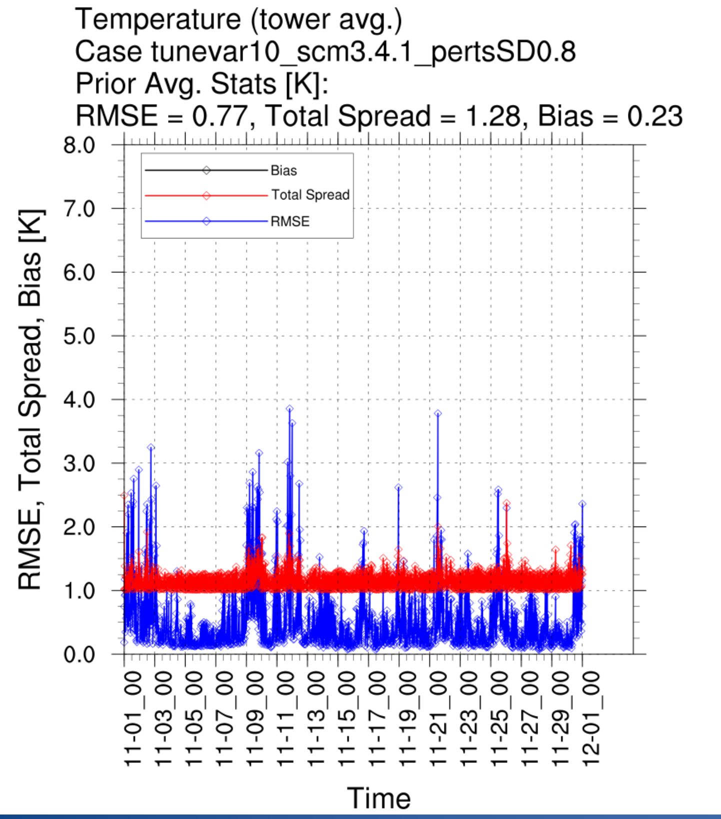
Obs., Ens. Mean, Mean Forcing



Preliminary SCM-DART Results

Nov 2006 – Temperature

RMSE and Total Spread



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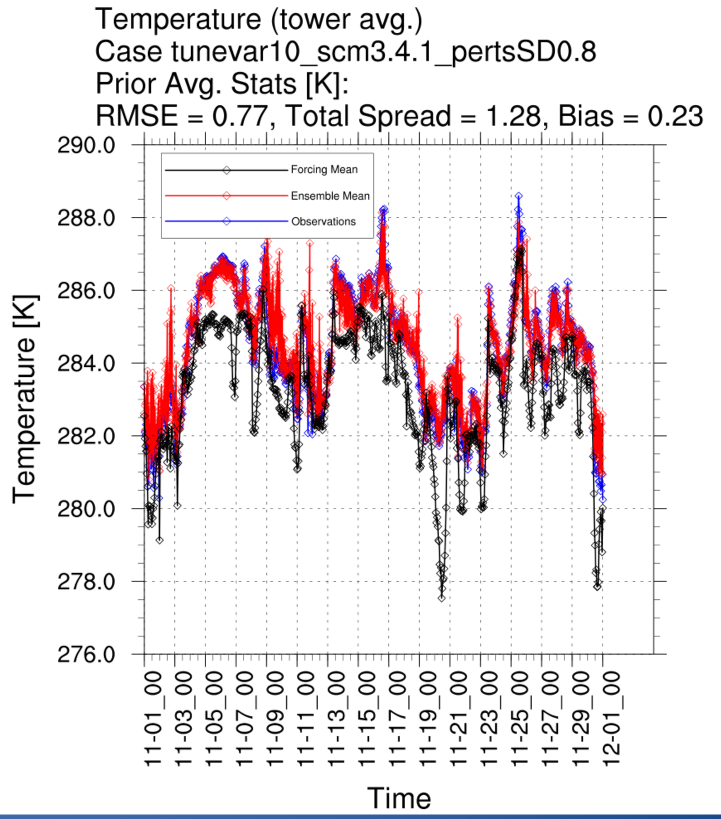

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Preliminary SCM-DART Results

RMSE	Oct 2006		Nov 2006	
	Mean Forcing	SCM-DART	Mean Forcing	SCM-DART
Temperature (K)	1.48	0.62	1.44	0.77
U-wind (m/s)	3.32	3.16	3.32	3.40
V-wind (m/s)	5.14	2.72	5.14	3.04

- SCM-DART prior (1-h) forecasts generally have lower monthly average RMSE compared to the mean forcing (3D WRF) monthly average RMSE over the depth of the FINO1 tower
- Further improvements are expected with parameter estimation and improved WRF ICs (coming soon)

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Summary

- Modified WRF-SCM for use over water
- Created new SCM ensemble forcing methodology that only requires 3D wrfout files for period of interest
- Initial SCM-DART results promising, yielding comparable average RMSE & total spread
- Priors (1-h forecasts) generally closer to observations than mean forcing, so assimilation is working well

Ongoing/Future Work

- Investigate sensitivity of WRF to roughness parameter, use SCM-DART to estimate it
- Compare SCM-DART performance with different 3D WRF initial conditions
  - Baseline (no DA) ← Used for this presentation
  - WRF w/ nudging DA
  - WRF coupled with WaveWatch III (WWIII)
  - Roughness parameter estimation without WRF-WWIII coupling
- Demonstrate wind resource assessment capability
- Move from SCM-DART to 3D WRF-DART parameter estimation experiments

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Thanks for listening!

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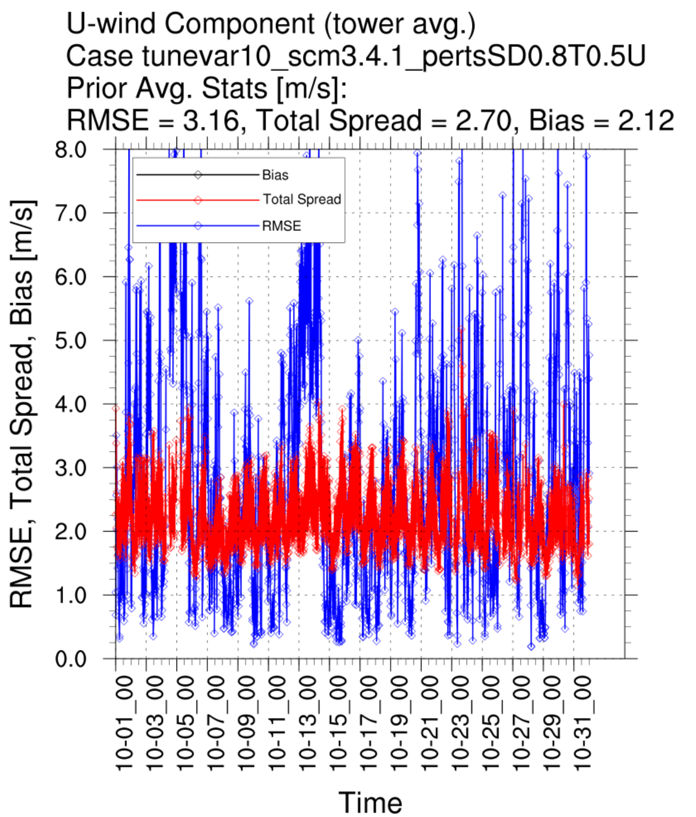
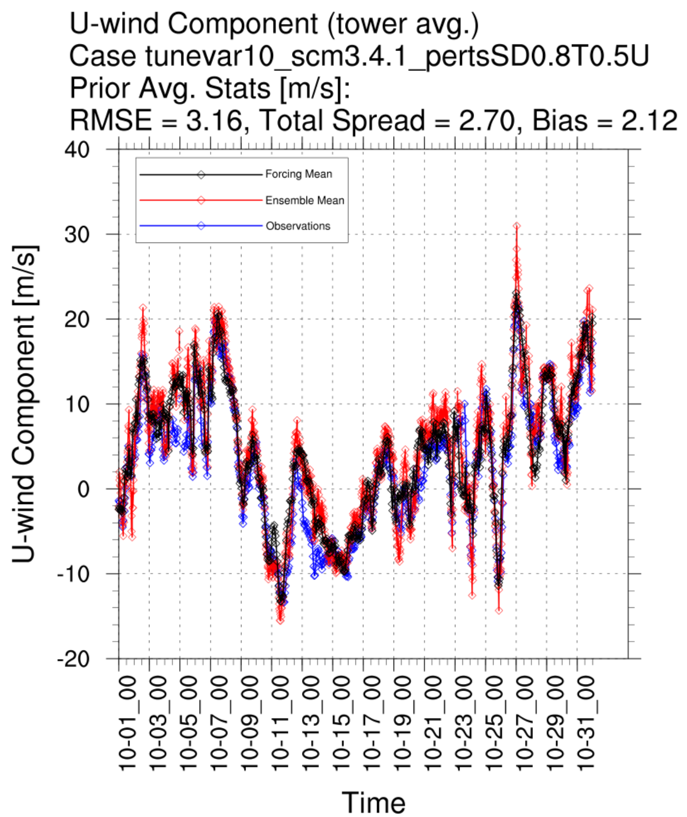
Preliminary SCM-DART Results

Oct 2006 – U-wind component

RMSE and Total Spread



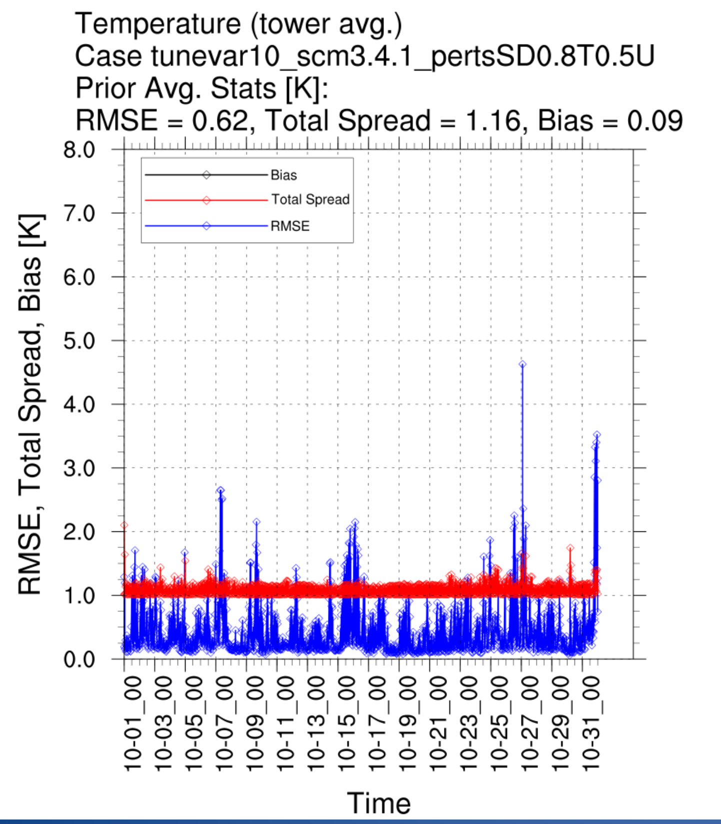
Obs., Ens. Mean, Mean Forcing



Preliminary SCM-DART Results

Oct 2006 – Temperature

RMSE and Total Spread



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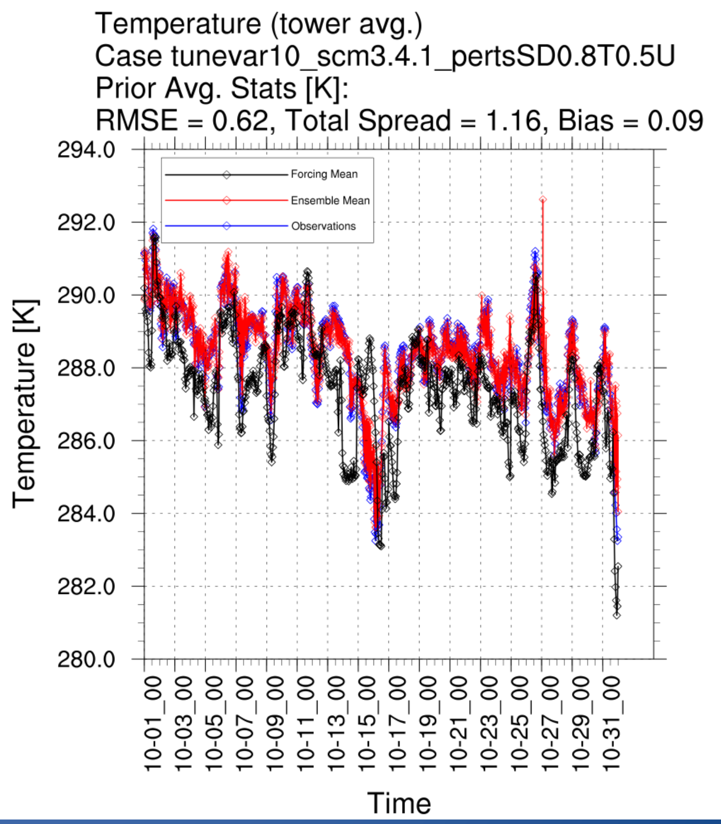
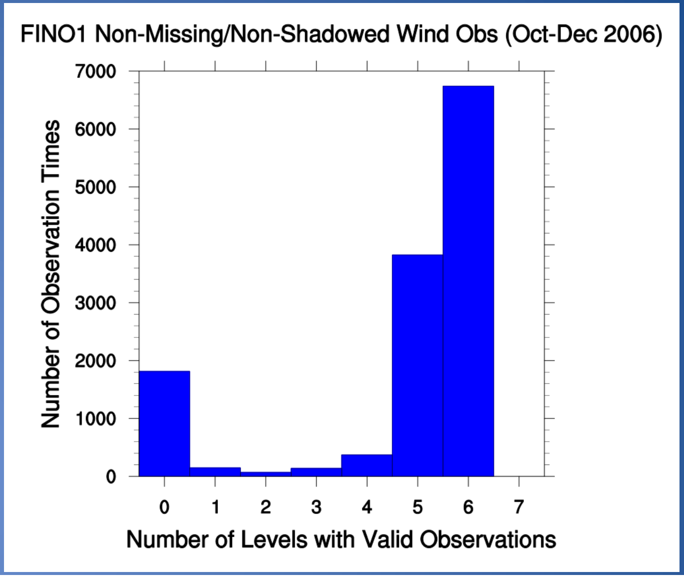


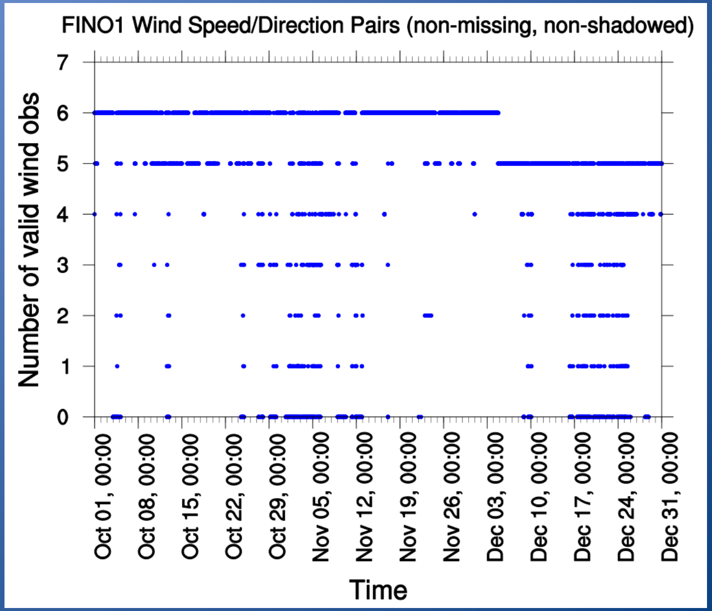
FINO1 Wind Observations

- How to deal with wind observations that are shadowed by the mast?
- Define mast shadow as winds from the direction:

  (boom angle)+180° +/- 30°

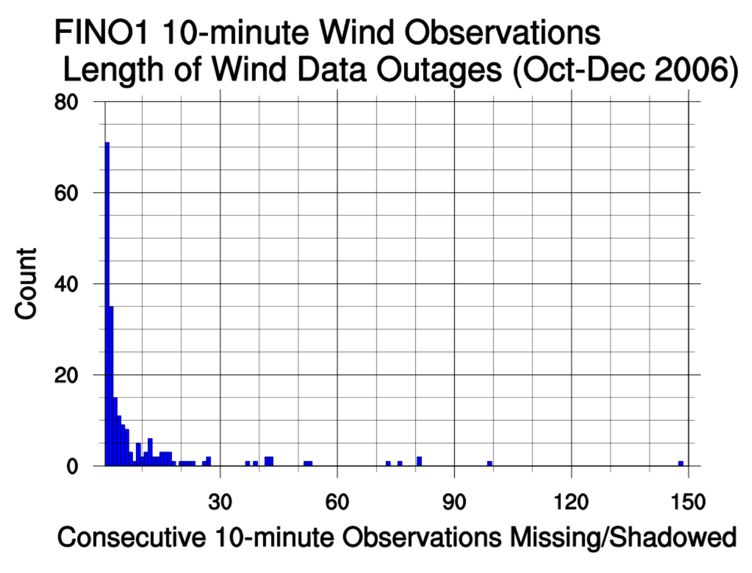
- How prevalent are shadowed obs?
  - 13.7% of obs times have no valid wind obs
  - Over 80% of obs times have 5 or 6 valid wind obs

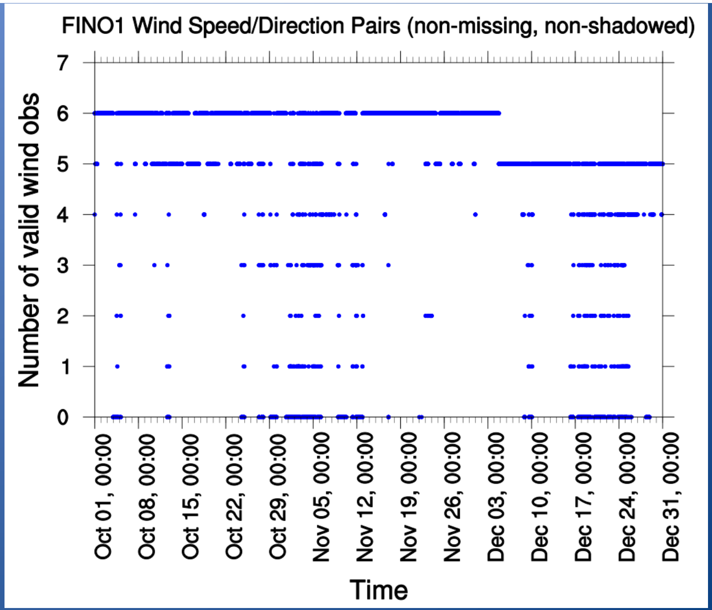




FINO1 Wind Observations

- Vast majority of wind data "outages" due to shadowing are an hour or less in duration
- Because of this and wind data "outages" only occurring for under 14% of all obs times, for now we are throwing out all shadowed wind obs





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State Augmentation Motivation

- NWP models have deficiencies in surface and boundary layer parameterization schemes
- Structural and physical model deficiencies are often poorly understood
- Uncertainty in model parameters
  - Constant or variable?
  - Often cannot measure "correct" value
- Data assimilation can be used to estimate parameter values
  - Reduced forecast (background) error shows the parameter is accounting for some related model error
- DART updates WRF state vector of T, Td, U, V
- Parameter array appended to state vector