STATISTICAL ANALYSIS OF HWRF ERRORS FOR ACCURACY ASSESSMENT OF COUPLED HYDRODYNAMIC MODELLING SYSTEMS

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OBJECTIVES

The US COASTAL Act of 2012 mandated coupled modelling of hurricanes, in order to ascribe building damages as caused by wind or water, at a high level of accuracy. The COASTAL Act modelling system consists of a hindcasted coupled atmosphere-ocean model providing the wind component (the Hurricane Weather and Research Forecasting model, HWRF), which then forces models of riverine flooding, ocean waves and surge (the water components). Conventionally, time series of observations at fixed in-situ locations such as meteorological stations, wave buoys and tide and stream gauges, and spatiotemporal data along satellite footprints are used to assess the accuracy of a given model. In this study, we statistically evaluate the outputs of deterministic simulations from the HWRF model and WAVEWATCH III (WW3) [1,2], an ocean wave model forced by HWRF. The evaluation is done at stationary observation locations and along satellite altimeter tracks for Hurricane Irma, 2017 (Fig. 1). The HWRF models' uncertainty is also determined via analysis of 40 ensemble members, corresponding to 40 sets of initial conditions of driving variables (Fig. 2). The high number of ensemble members allows to capture the spread of HWRF prediction errors, ensuring that hydrodynamic models are forced with a wide enough ensemble. From the spread of HWRF derived TC Vitals relative to National Hurricane Center (NHC) advisory (Fig. 3), 16 ensemble members for wind and pressure fields are generated to force downstream models. We analyze the statistical distributions of time series of model errors, for particular locations and important hurricane variables. We provide an exploratory method to assess the similarity between observations and HWRF/WW3 model estimates which is general enough to be useful across many geophysical variables. This is particularly important for minimizing the error propagation required by complicated coupled model systems, such as for the US COASTAL Act.

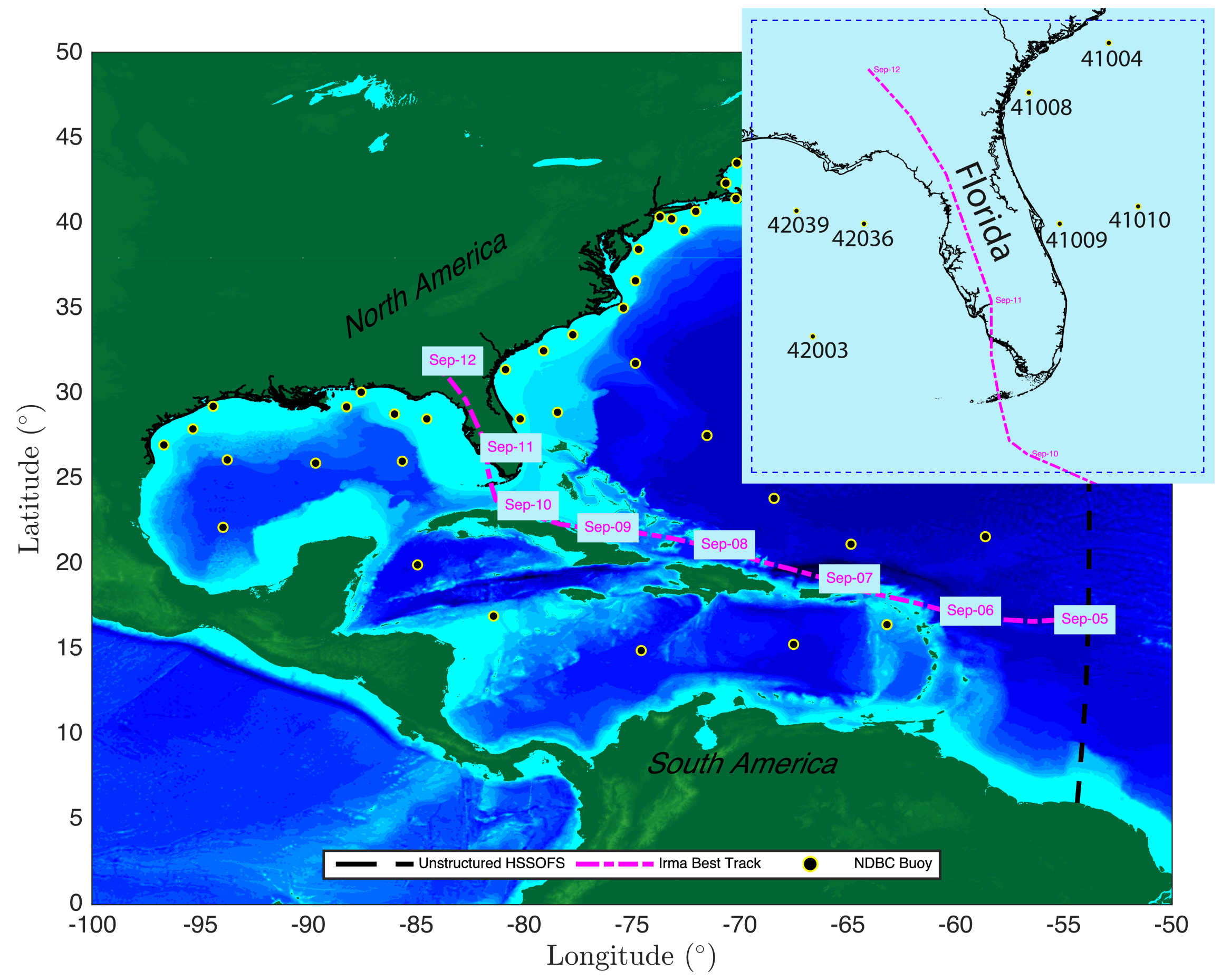


Figure 1: Hurricane Irma (2017) Best Track and NDBC buoy locations.

INTRODCUTION

The frequency and destructiveness of coastal storms have required improving the accuracy of numerical prediction models. The coupling of atmospheric, ocean wave and surge and hydrological models on high-resolution numerical domains has improved model accuracy by better representing nearshore/inland geometries and physics. But multiple sources of error remain, from instrument and processing noise in the observational data the models are built upon, to the physical parameterizations that are part of the models, accounting for the unresolved physics, to the stochasticity of the natural processes themselves. Determining the damage caused by hurricanes using such numerical models requires a statistical evaluation of uncertainty.

ATMOSPHERIC ENSEMBLES

We evaluate the spread of ensemble model results as an estimate of our model uncertainty. Such information is also used to evaluate the accuracy of model at observational locations (Figs. 5 & 6). The models' uncertainties are determined via analysis of TC Vitals from 40 discontinuous ensemble members, provided by perturbed atmospheric model every 6 hrs (Fig. 2). Based on the NHC best track information and the spread of HWRF ensemble, represented in term of Standard Deviation (σ), an adequate number of continuous wind and pressure fields are generated using Generalized Asymmetric Holland Model.

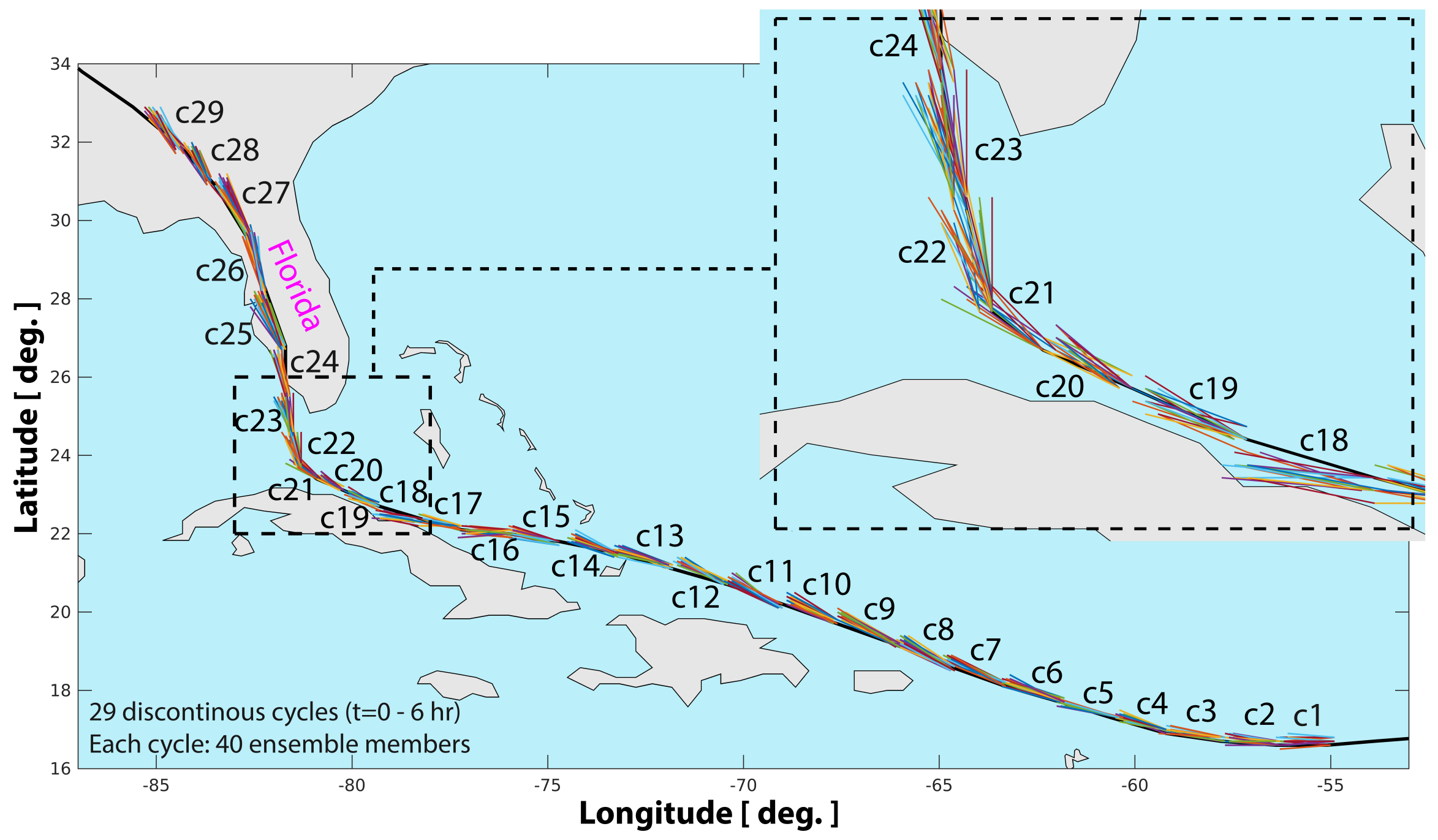
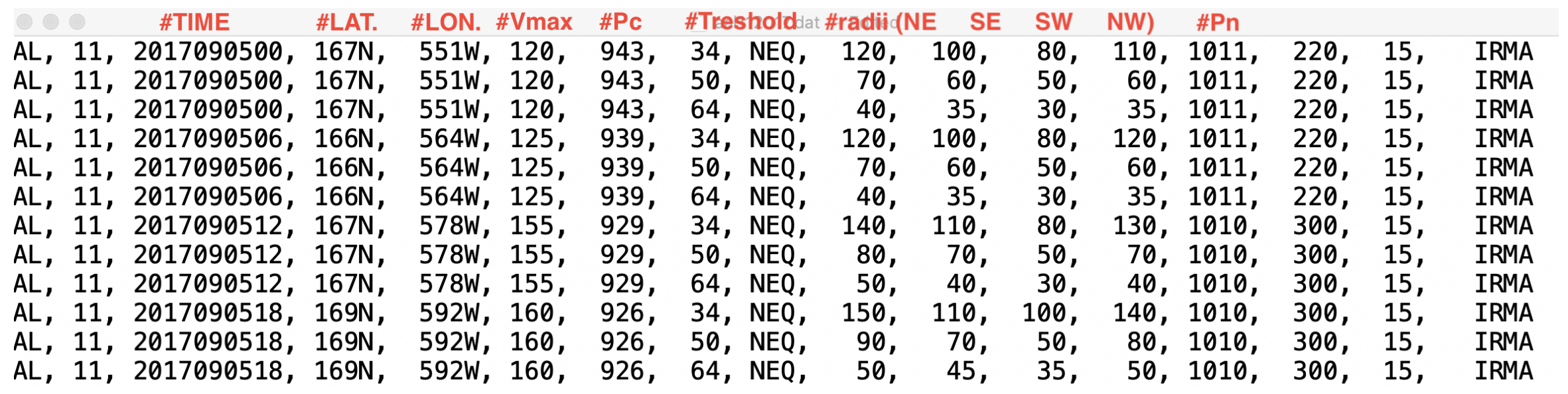


Figure 2: Hurricane Irma Tracks generated by HWRF ensembles (29 Discontinuous Cycles with $\Delta t = 6\ hr$).

HWRF Ensemble Members Statistics:

- Hurricane Best Track
- Maximum wind speed (V_{max})
- Pressure at MSL
- Maximum Wind Speed Radius (R_{max})
- radii for 34, 50 & 64 knots thresholds

The spread of this information is required to run the parametric model and generate adequate number of ensemble members to force hydrodynamic models (16 members).



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          #TIME        #LAT.  #LON. #Vmax  #Pc    #Treshold #radii (NE   SE    SW    NW)   #Pn
AL, 11, 2017090500, 167N,  551W, 120,  943,  34, NEQ,  120,  100,   80,  110, 1011,  220,  15,   IRMA
AL, 11, 2017090500, 167N,  551W, 120,  943,  50, NEQ,   70,   60,   50,   60, 1011,  220,  15,   IRMA
AL, 11, 2017090500, 167N,  551W, 120,  943,  64, NEQ,   40,   35,   30,   35, 1011,  220,  15,   IRMA
AL, 11, 2017090506, 166N,  564W, 125,  939,  34, NEQ,  120,  100,   80,  120, 1011,  220,  15,   IRMA
AL, 11, 2017090506, 166N,  564W, 125,  939,  50, NEQ,   70,   60,   50,   60, 1011,  220,  15,   IRMA
AL, 11, 2017090506, 166N,  564W, 125,  939,  64, NEQ,   40,   35,   30,   35, 1011,  220,  15,   IRMA
AL, 11, 2017090512, 167N,  578W, 155,  929,  34, NEQ,  140,  110,   80,  130, 1010,  300,  15,   IRMA
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AL, 11, 2017090512, 167N,  578W, 155,  929,  64, NEQ,   50,   40,   30,   40, 1010,  300,  15,   IRMA
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AL, 11, 2017090518, 169N,  592W, 160,  926,  64, NEQ,   50,   45,   35,   50, 1010,  300,  15,   IRMA
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Figure 3: NHC/HWRF Best Track Information (TC Vitals) for Hurricane Irma.

GENERALIZED ASYMMETRIC HOLLAND MODEL

A parametric representation of tropical cyclones for the gradient of wind speed and surface pressure fields, resembling a translating vortex is given by [3], and later extended by many other scholars. Here we use Generalized Asymmetric Holland Model (GAHM), introduced by [4] with two scaling parameters from original model. The gradient wind speed $V_g(r)$ at radius r is given by,

$$V_g(r)=\sqrt{V_{max}^2\left(1+\frac{1}{R_o}\right)e^{\phi\left(1-\left[\frac{R_{max}}{r}\right]^{B_g}\right)}\left[\frac{R_{max}}{r}\right]^{B_g}+\left(\frac{rf}{2}\right)^2}-\left[\frac{rf}{2}\right]$$

and surface pressure $P(r)$,

$$P(r)=P_c+(P_n-P_c)e^{-\phi\left[\frac{R_{max}}{r}\right]^{B_g}}$$

The Holland B factor (B_g) and intermediate factor (ϕ) are calculated iteratively to satisfy $\partial V_g(R_{max})/\partial r = 0$, $V_g(R_{max}) = V_{max}$, $V_g(r_{34}) = 34$, $V_g(r_{50}) = 50$ and $V_g(r_{64}) = 64$ knots constraints. R_o is Rossby number, f is Coriolis parameter, P_c and P_n are central and ambient background pressures respectively.

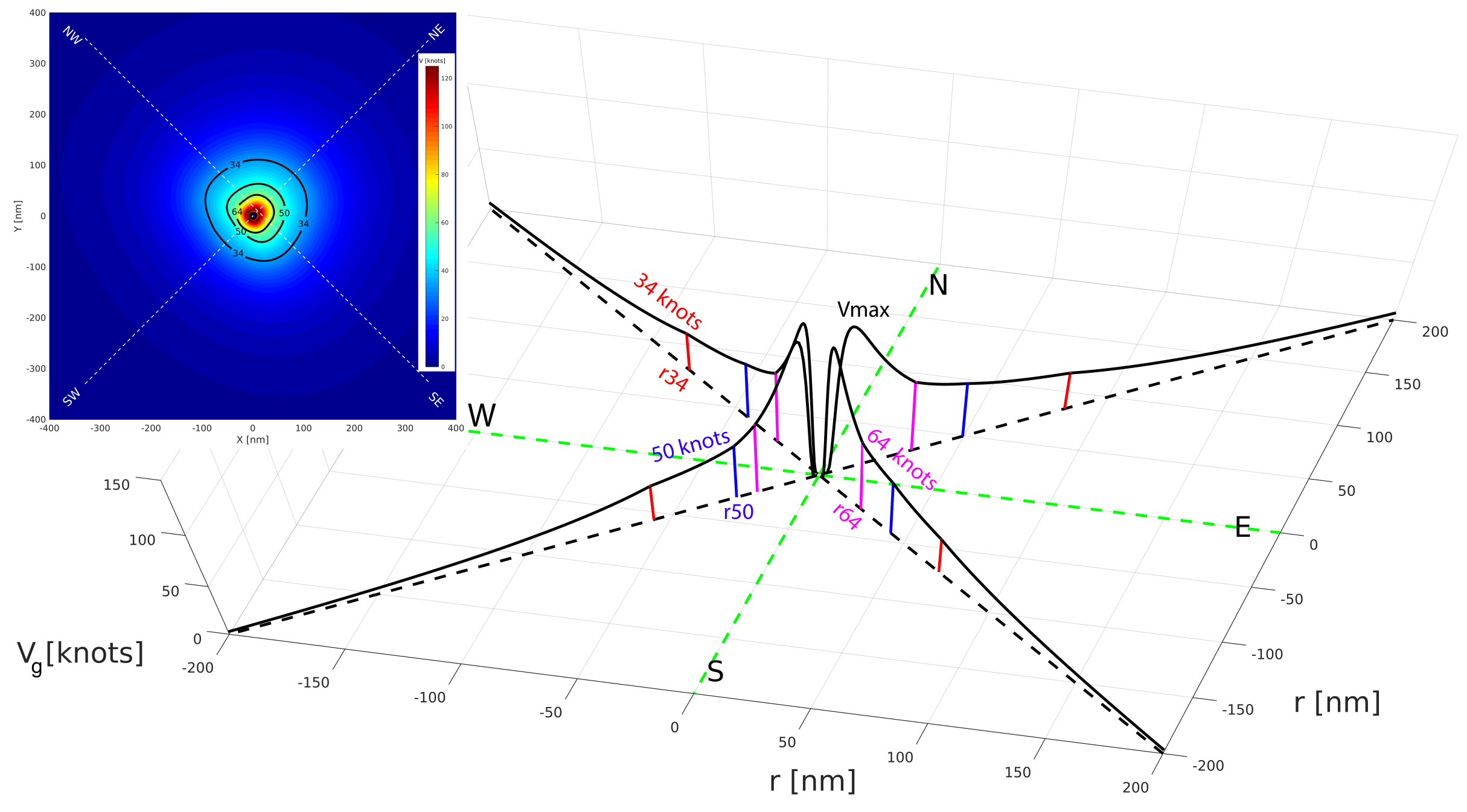

Figure 4: An schematic view of the gradient of wind speed for NE, NW, SE & SW quadrants calculated by GAHM. The interpolated wind field from quadrants is shown in upper left panel.

Four further steps are performed on the V_g:

- The wind velocity at the top of the atmospheric boundary layer to U_{10}.
- Sampling time adjustment from 1 min to 10 min winds.
- Adding the tapered translation velocity.
- Adding the atmospheric field out of hurricane cone from CFSR/GFS/HWRF models.

HURRICANE IRMA, SEPTEMBER 2017

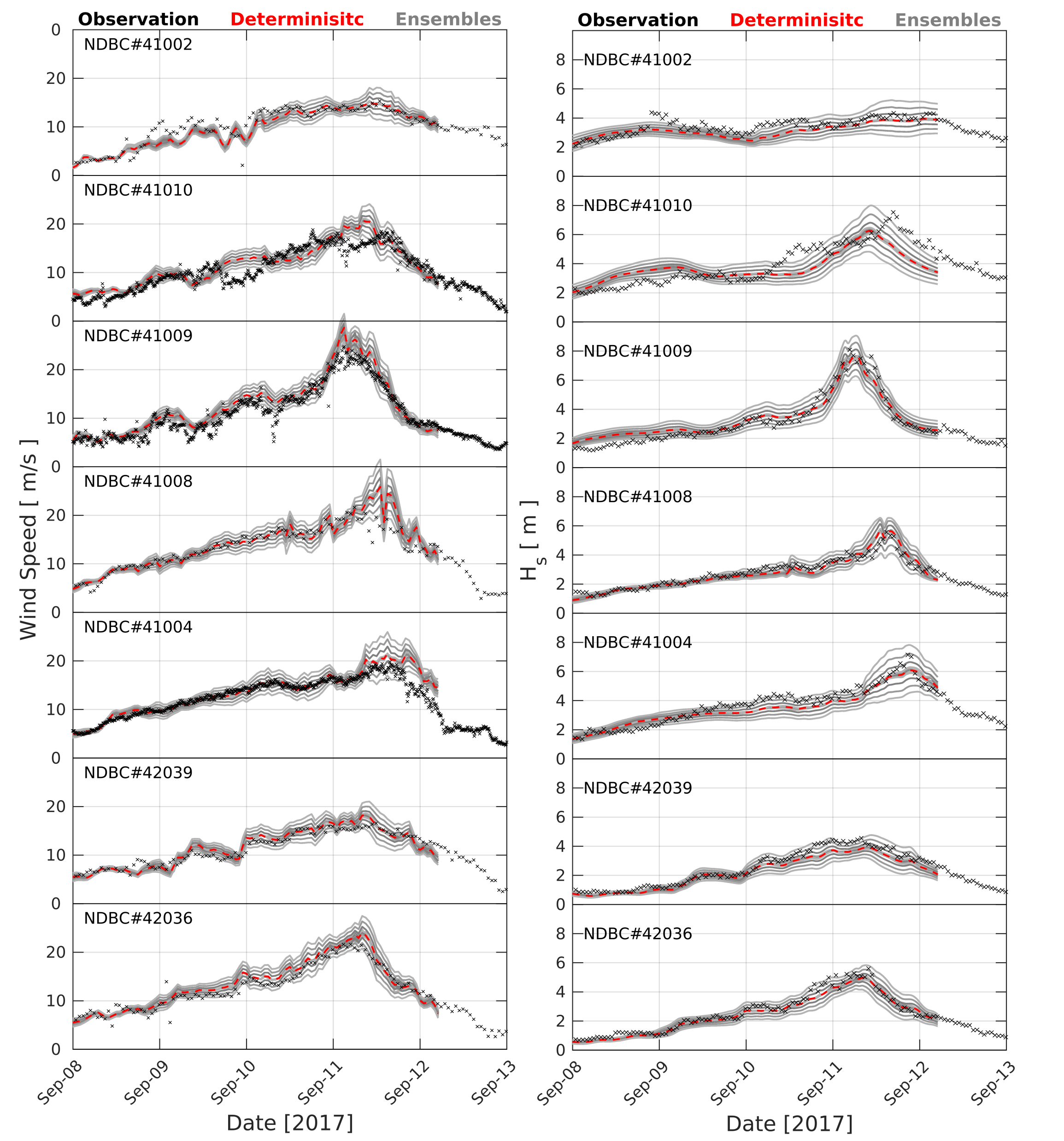

Figure 5: U_{10} and H_s time series at NDBC buoys (Fig. 1). The spread of gray lines relative to the deterministic simulation/observation represent error due to the perturbation in initiation of the upstream HWRF model (40 members) and spread of WW3 outputs forced by 16 ensemble members (generated by GAHM).

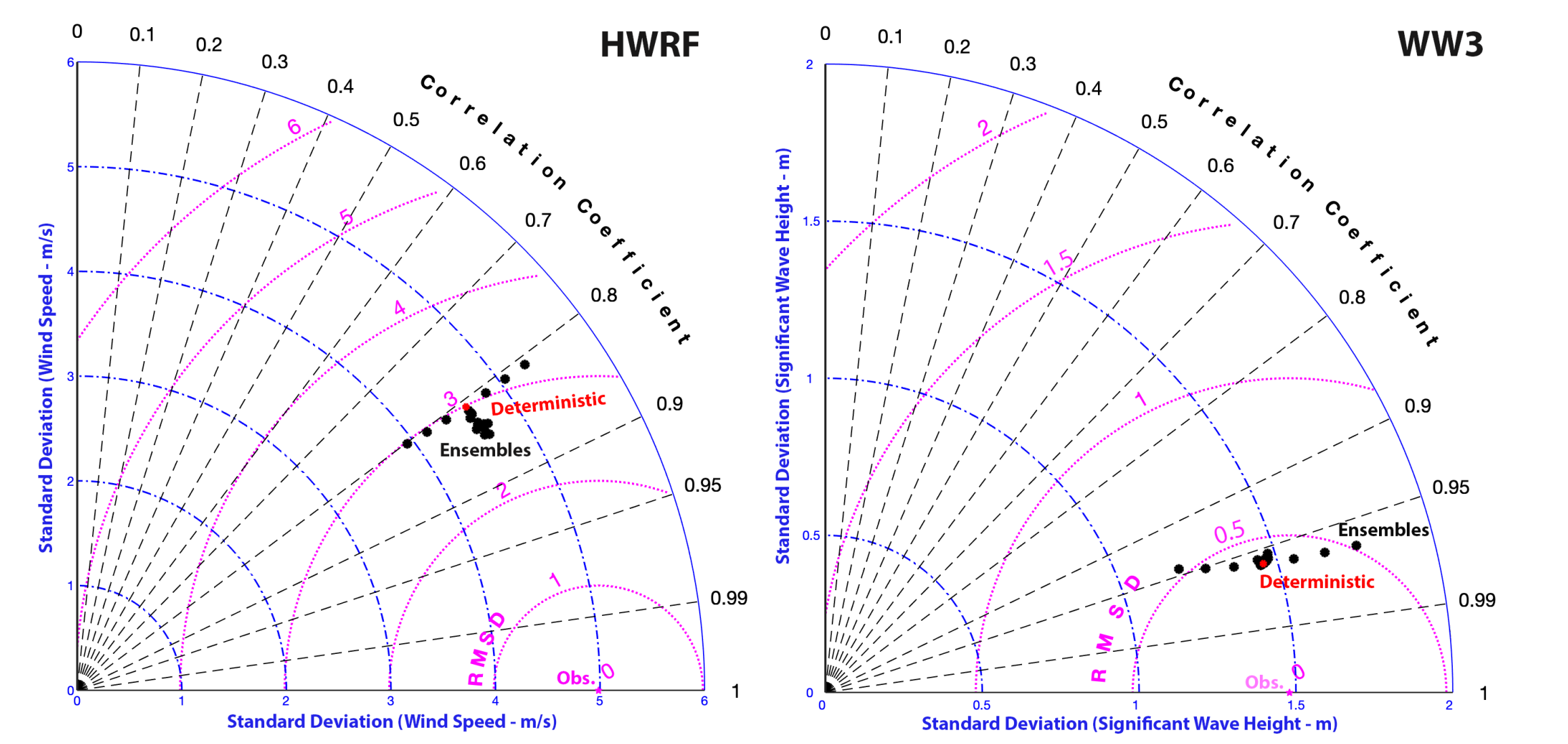

Figure 6: Models' performance in term of Standard Deviation, Correlation Coef. and RMSD, shown by Taylor diagram for deterministic and ensemble runs.

REFERENCES

[1] The WAVEWATCH III Development Group (WW3DG), 2019: User manual and system documentation of WAVEWATCH III version 6.07. *Tech. Note 333, NOAA/NWS/NCEP/MMAB*, College Park, MD, USA, 326 pp. + Appendices.

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