Visualization and Validation Methods Applied to Wave Modeling

Ricardo M. Campos[CIMAS], **Ali Abdolali**[IMSG/NCEP], **Matthew Masarik**[IMSG/NCEP], **Jessica Meixner**[NCEP], **Avichal Mehra**[NCEP]

[CIMAS] Cooperative Institute for Marine and Atmospheric Studies (CIMAS, NOAA/AOML)
[IMSG/NCEP] IMSG at Environmental Modeling Center, National Centers for Environmental Prediction, NOAA
[NCEP] Environmental Modeling Center, National Centers for Environmental Prediction, NOAA

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1. Introduction

- The third-generation spectral wave model which is actively used for operational wave forecasts, **WAVEWATCH III (WW3)**, is a **five-dimensional numerical model** covering: space (latitude, longitude), time, and spectrum (direction and frequency).
- The wave characteristics and extra dimensions require different types of validation and visualization tools compared to other modeling systems. The assessments against buoy and altimeter data, for hindcasting and forecasting simulations, also require special techniques and data structure.
- Our study presents the recently-developed **WW3-tools python package**, designed to facilitate the visualization and validation of WW3 results with easy-to-handle scripts and functions:

https://github.com/NOAA-EMC/WW3-tools

2. Methodology and Package Structure

✓ First part: visualization; where codes to plot *wave fields* and *point outputs* (time-series and spectrum) are included. Examples of "wave panels" are available, ideal for case-studies and direct comparisons of two WW3 simulations side-by-side, including buoy data.

✓ Second part: validation; including both WW3 against buoy data (NDBC and Copernicus) and satellite altimeter data (AODN). The flowchart illustrates the methodology for validation against altimeter data. The collocation of altimeter tracks and grid data follows Monaldo (1988), Augustinus & Ribal (2019), and Campos et al. (2020) – criteria of space/time and weighted average (distance) using scikit-learn kdtree.

✓ The validation with both altimeter and buoy data has a convenient data array structure, including the matchups of model/observation accompanied by the corresponding: water depth; distance to coast; latitude and longitude; cyclone information (from IBtracks); ocean names; offshore and marine zones; forecast lead time (if user enters a list of forecast files); and satellite or buoy IDs.

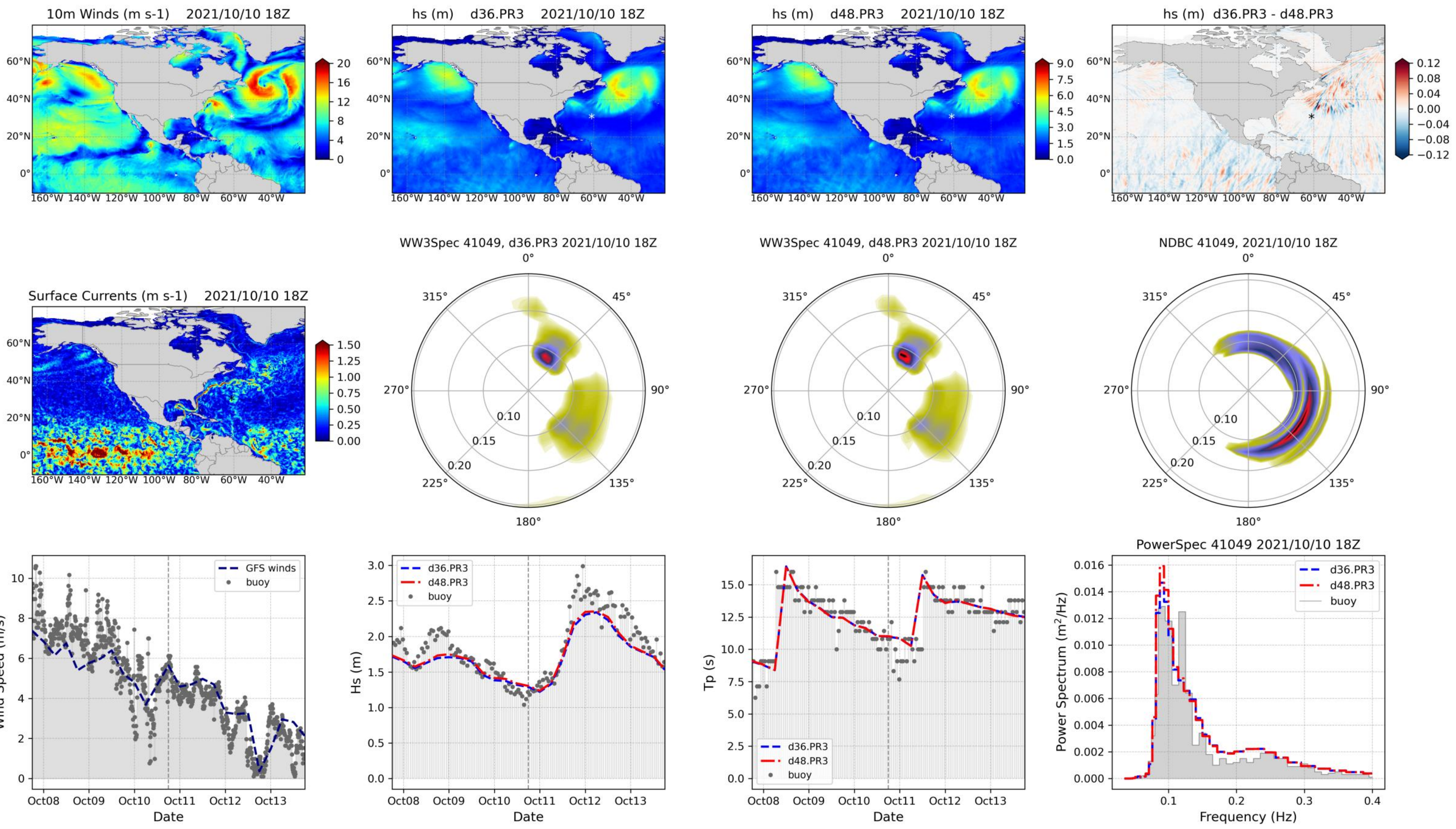
✓ Therefore, by subsampling the data array through the indexes, it is possible to calculate error metrics and evaluation plots for a variety of metocean conditions, locations, forecast ranges etc.

3. Validation of GEFSv12 Wave reforecast data

- 20-year GEFSv12 wave reforecast. WAVEWATCH III forced by GEFSv12 winds. Temporal and spatial resolution of 3 hours and 0.25°. Global domain with several wave parameters (including partitions), and spectrum at 658 point outputs.

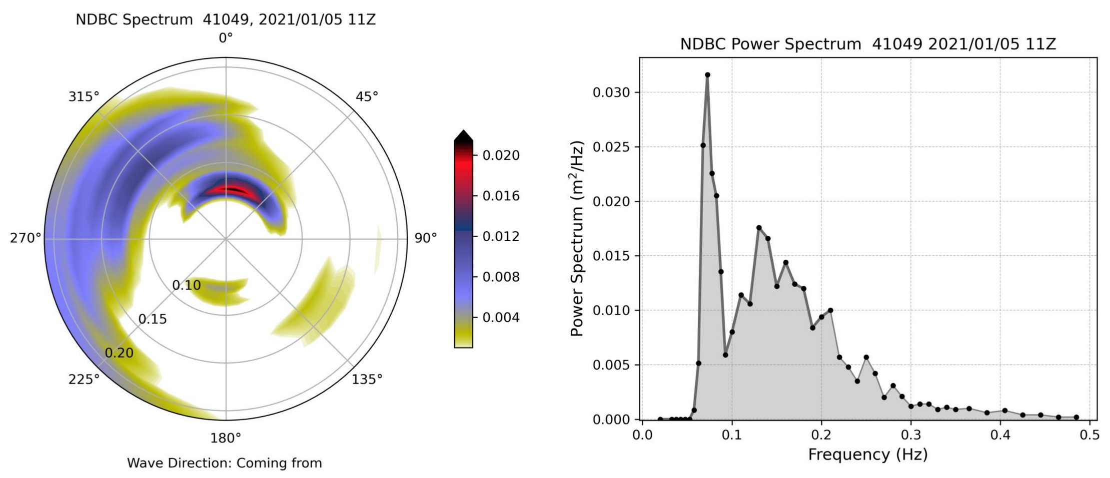
  https://noaa-gefs-retrospective.s3.amazonaws.com/index.html
  https://noaa-nws-gefswaves-reforecast-pds.s3.amazonaws.com/index.html

- Ensemble: 1 cycle per day and 5 members, forecast range of 16 days. Once a week expanded to 11 members, out to 35 days.
- First analysis for the period between 08/24/2016 to 10/18/2016: One extratropical cyclone in the North Pacific Ocean, and two hurricanes (Mathew and Nicole) in the Atlantic Ocean.
- Analyses using WW3-tools. Total of 7,158,315 model/buoy matchups and 30,621,735 model/satellite matchups. Especial attention to error metrics and statistics.



Example: Comparison of two WW3 GFS simulations, diff. spectral **d**iscretization (number of **d**irections)

Example of spectral plot: NDBC buoy 41049



Download Altimeter Data (get_AODN_AltData.sh) IMOS/AODN Quality-Controlled and Calibrated. Missions: CRYOSAT2, ENVISAT, ERS1, ERS2, GEOSAT, GFO, HY2, JASON1, JASON2, JASON3, SARAL, SENTINEL3A, SENTINEL3B, TOPEX. (1)

(2) **Grid Mask (prepGridMask.py)** ww3 grid information (lat/lon), water depth and distance to coast, ocean names, High Seas Marine Zones, Offshore Marine Zones. *A mask is build using max distance to coast and water depth, for satellite data processing*

(3) **Cyclone Map using Ibtracks (procyclmap.py)** Same grid domain and resolution as GridMask, identifying cyclonic areas (3h time resolution): 0(no cyclone); 1(Missing or not reported); 2(disturbance); 3(extratropical); 4(subtropical storm/cyclone); 5(tropical storm/cyclone)

Grid Satellite Tracks (gridSatGlobal_Altimeter.py) using AODN files with additional quality control, Grid Mask information. Pyresample.kd_tree is used. User-defined criteria for gridding (25km and 30min), weight function (by distance) (4)

Data Collocation and matchups Satellite and Model (modelSat_collocation.py). It builds pairs altimeter/ww3 for the same location/time, organized in columns. For these positions/time the data array also includes: satellite ID, water depth, distance to coast, ocean names, marine zones, and cyclonic/non-cyclonic information. Variables Hs and Wind Speed. (5)

(6) **Summary statistics and error metrics (mvalstats.py)**. *smrstat* function to calculate prob moments, percentiles, and compare the model results with observations. *metrics* function to calculate error metrics

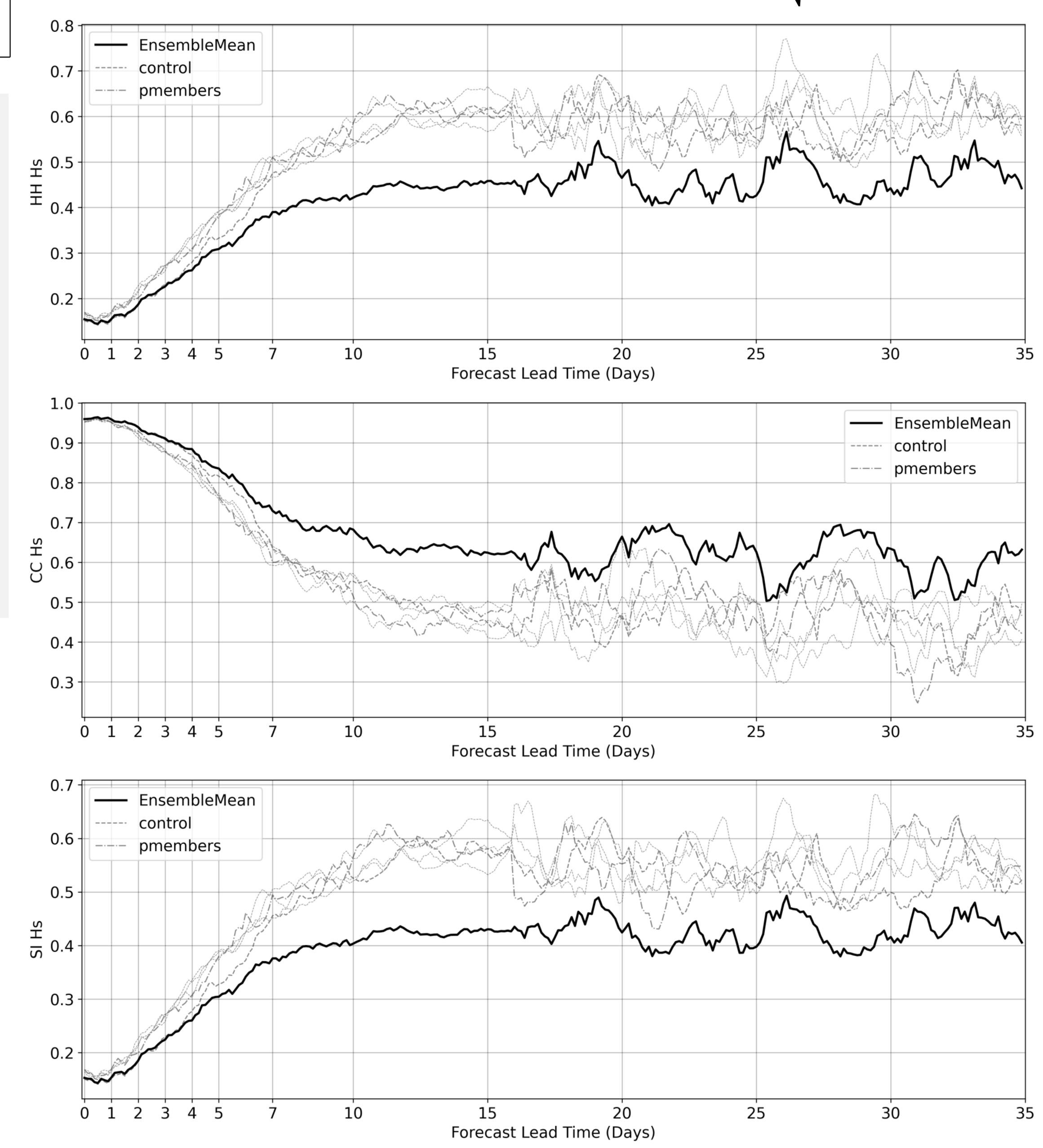
Visualization (pvalstats.py) including time-series, QQ-plots, scatter plots, Taylor Diagram, combined errors, PDF, error as a function of percentiles and latitudes. (7)

Validation using 107 buoys

Hs		Bias	RMSE	Nbias	NRMSE	Scrmse	SI	HH	CC
Day1	Ctrl	0.04	0.29	0.02	0.15	0.29	0.15	**0.15**	0.95
	EM	*0.17*	*0.24*	*0.13*	*0.17*	*0.17*	*0.12*	***0.17***	*0.91*
Week1	Ctrl	0.05	0.51	0.03	0.26	0.51	0.26	**0.26**	0.86
	EM	*0.13*	*0.26*	*0.09*	*0.18*	*0.23*	*0.16*	***0.18***	*0.87*
Week2	Ctrl	0.07	1.01	0.04	0.49	1.01	0.49	**0.51**	0.54
	EM	*0.16*	*0.51*	*0.11*	*0.32*	*0.48*	*0.30*	***0.31***	*0.54*
ByndW2	Ctrl	-0.02	1.14	-0.01	0.51	1.14	0.51	**0.55**	0.47
	EM	*0.04*	*0.66*	*0.03*	*0.36*	*0.66*	*0.36*	***0.38***	*0.52*

Importance of considering the limitations of RMSE and selecting additional metrics

$$HH = \sqrt{\frac{\sum_{i=1}^{n}(y_i - x_i)^2}{\sum_{i=1}^{n} y_i x_i}}$$

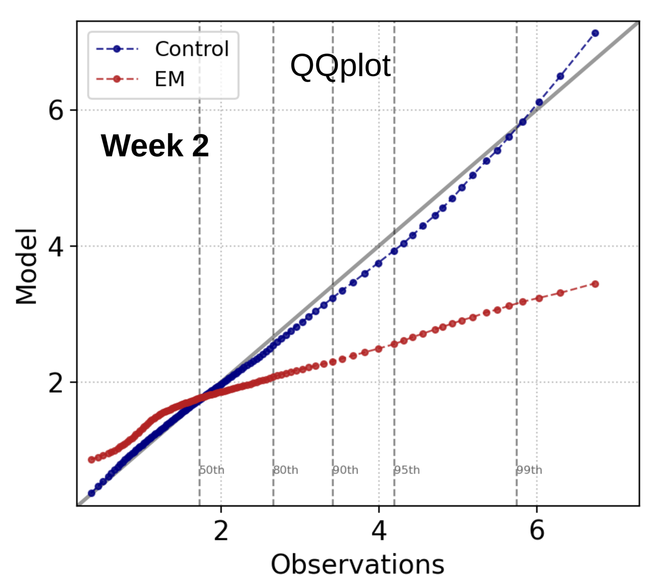


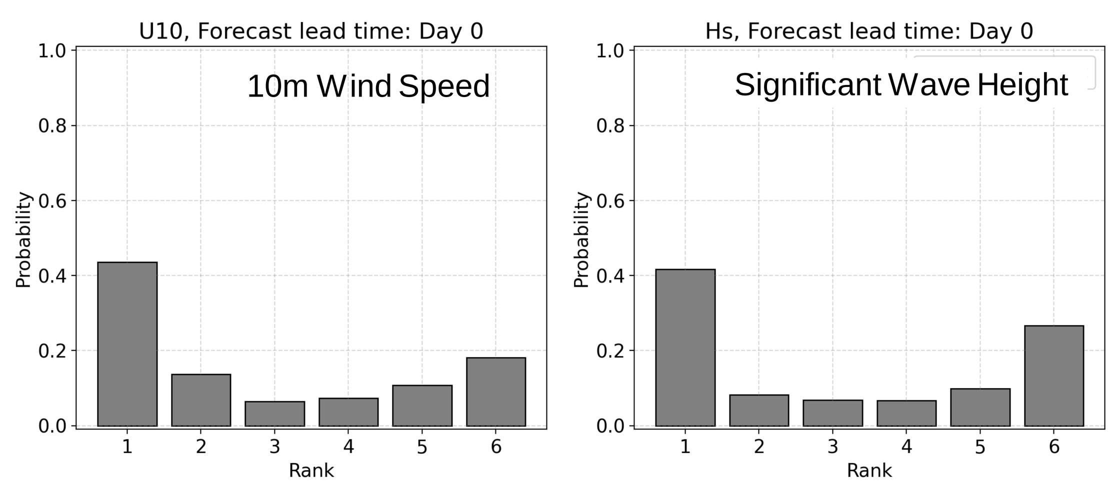
- Analysis of GEFSv12 error as a function of the forecast lead time, for a validation using buoy and altimeter data.

- High correlation coefficient in the first forecast days.

- Rapid increase of scatter errors in the first week.

- Better performance of EM compared to individual deterministic runs but the average introduces bias (positive and negative) varying with percentiles.





Rank Histogram: effect of the spread in the atmospheric ensemble (surface winds) and the direct impact on the wave ensemble (over-confident)