Assessment and Calibration of an Operational Wave Forecast for the Brazilian Coast

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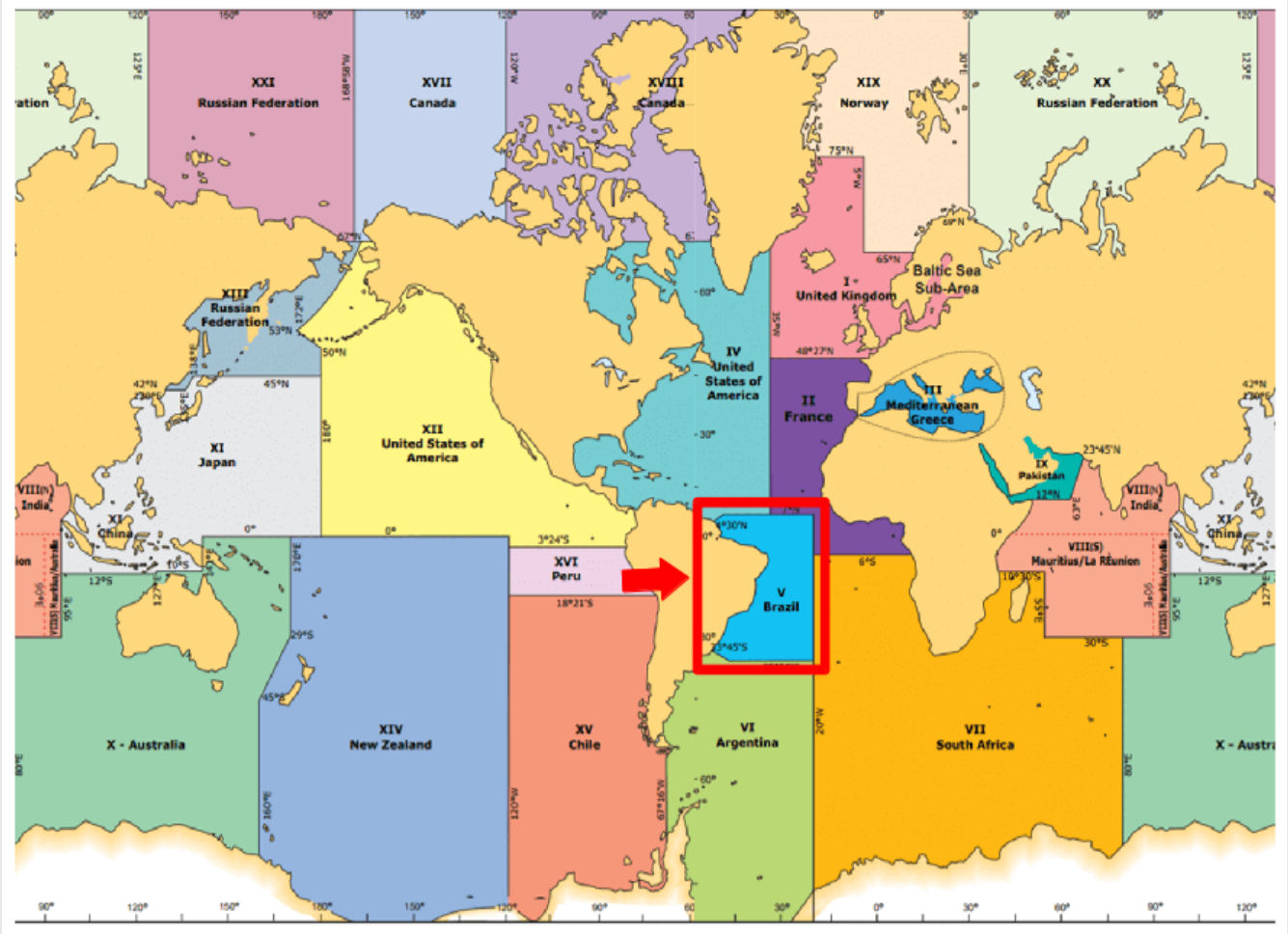
2nd International Workshop on Waves, Storm Surges and Coastal Hazards

Brazilian Forecast and responsibilities

International Convention for the Safety of Life at Sea (SOLAS)

- 21 areas, 19 Countries
- Coordinating and promulgating meteorological warnings and forecasts for METAREA V
- Operational Forecast & “Programa Nacional de Boias” (PNBOIA)



The Operational Forecast of 10m Winds and Waves

Wave Model	**WAVEWATCH III – version 4.18, 6.07**
Forecat Cycle	00Z /12Z, 5-Days, Field and Point ouputs (1h)
Bathymetry	ETOPO-1 + CHM/Brazilian Navy
Ice Conc.	NCEP/NOAA
Wind Input	**NCEP-GFS: (7') ~ 12.8 km** **DWD-ICON: (7.5') ~ 13.7 km** **COSMO: 7km**
Multi-Grid	GLOBAL (30') ~ 55km METAREA V / South Atlantic (6') ~10km ANTARCTIC (6') ~10km
WW3 ST	ST4, Bmax = 1.33 (Global) , 1.5 (subgrids)

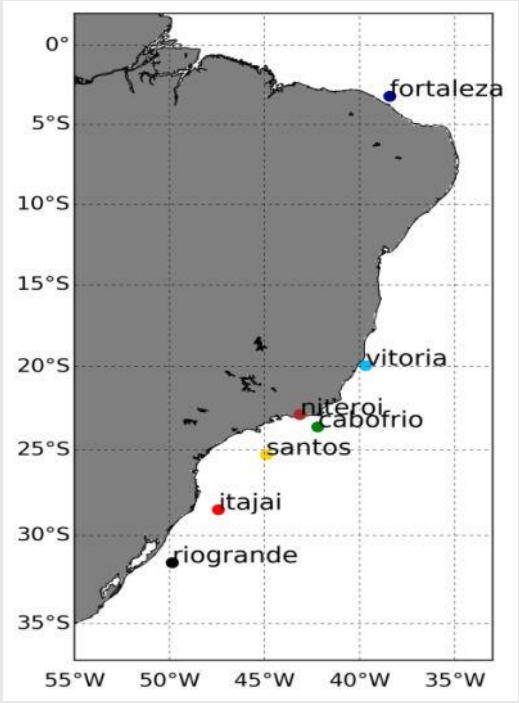
$$S_{in}(k,\theta) = \frac{\rho_a}{\rho_w}\frac{\beta_{max}}{\kappa^2} e^Z Z^4 \left(\frac{u_*}{C}\right)^2 \times max[cos(\theta-\theta_u),0]^2 \sigma F(k,\theta)$$

Forecast Assessment

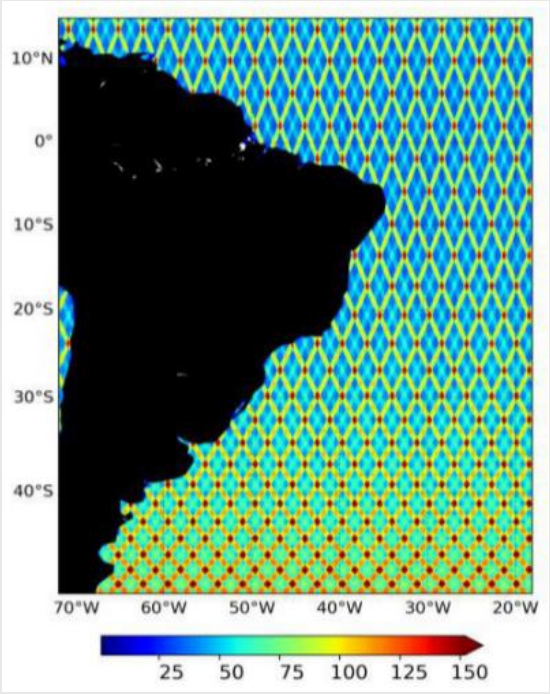
Multivariate distribution of forecast error. Period 04/2017 – 02/2018

- Metocean Buoys (AXYS-3M PNBOIA)
- Altimeters (JASON2, JASON3, SARAL, CRYOSAT2)
  - Multivariate assessment: $\mathcal{E}_M(F_t, T, P_v, L_{xy}, V, \ldots)$

Buoys: 34,238 matchups



Altimeters: 4,477,863 matchups



Altimeter/Model: max dist 25km and 30min

Gaussian Weighted Average of sat records. Kd-tree (python)

Min Wdepth: 80m
DistCoast: 30km

Forecast Assessment

Error Metrics: scatter and systematic components (Mentaschi et al., 2013), where x is the model and y the observations

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

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

$$SCrmse = \sqrt{\frac{\sum_{i=1}^{n}\left[(x_i - \bar{x}) - (y_i - \bar{y})\right]^2}{n}}$$

$$SI = \sqrt{\frac{\sum_{i=1}^{n}\left[(x_i - \bar{x}) - (y_i - \bar{y})\right]^2}{\sum_{i=1}^{n} {y_i}^2}}$$

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

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

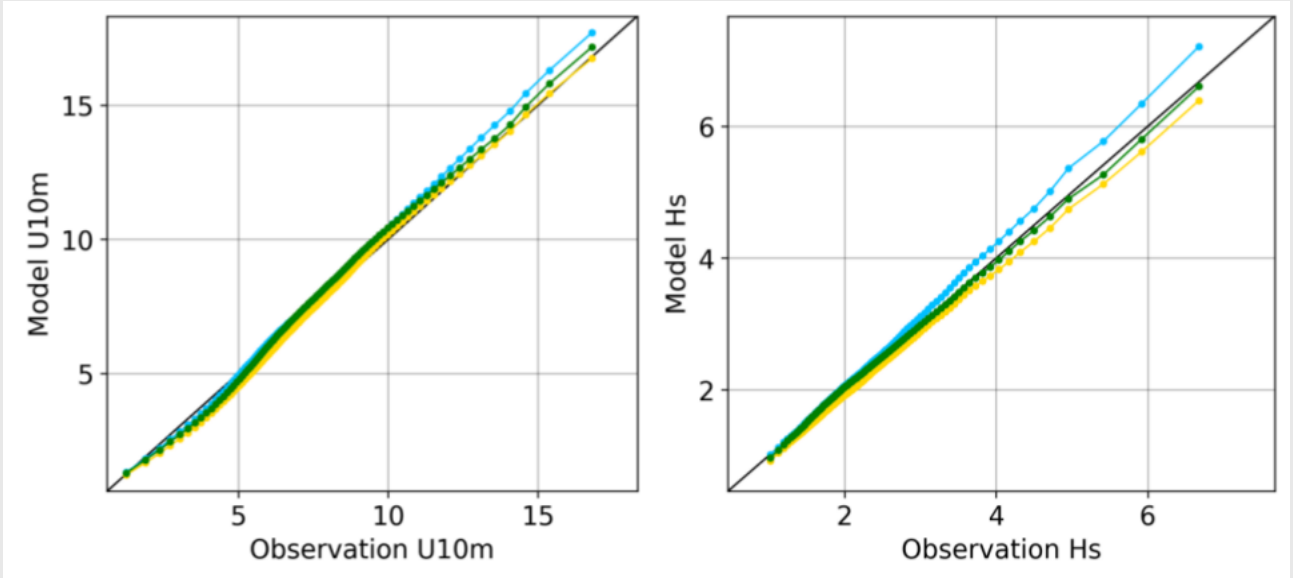
$$CC = \frac{1}{n}\frac{\sum_{i=1}^{n}(x_i - \bar{x}) - (y_i - \bar{y})}{\sigma_x \sigma_y}$$

Results, QQ-Plots

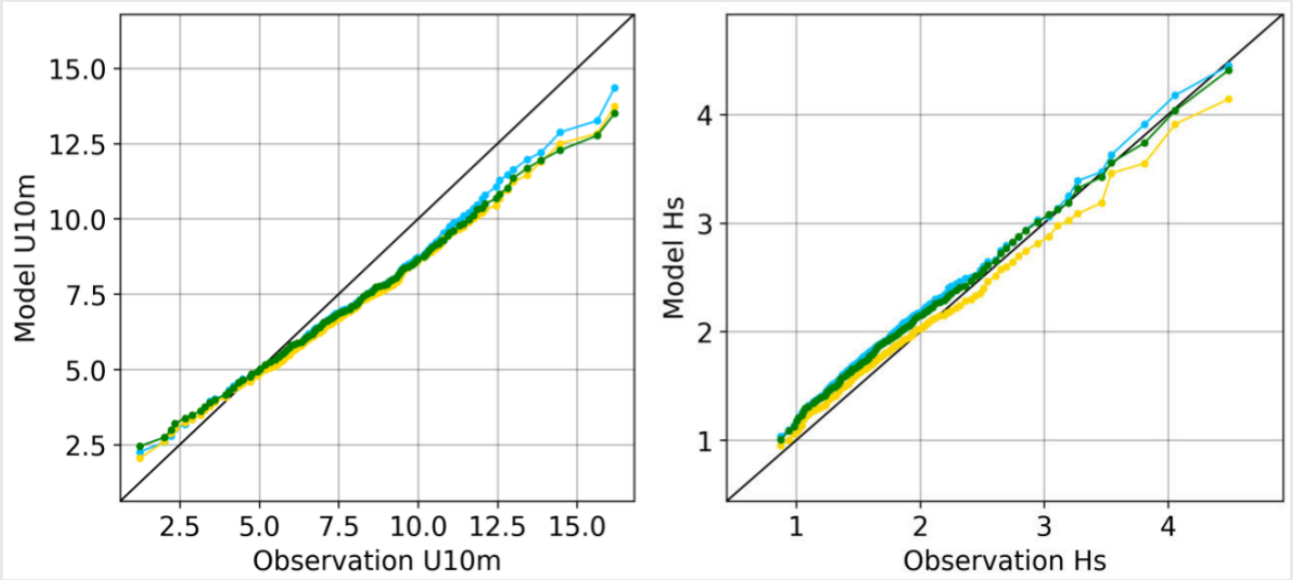
GFS ICON COSMO

$\mathcal{E}_M(F_t, T, \boldsymbol{P_v}, L_{xy}, V, \dots)$

Altimeters



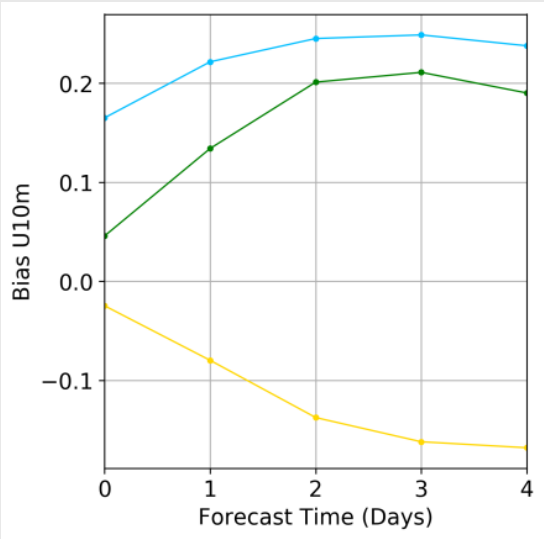
Buoys

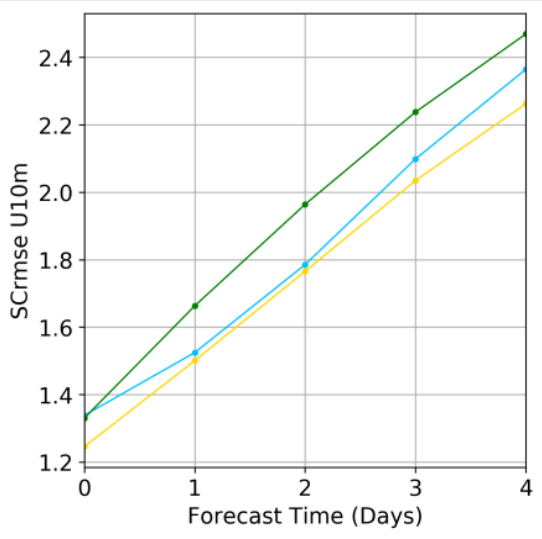


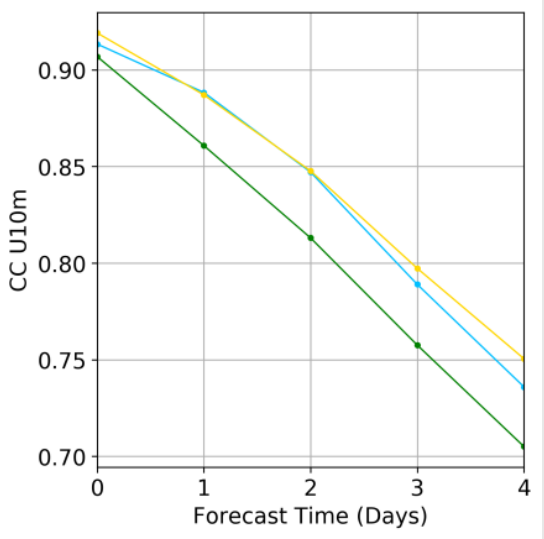
Results, forecast lead time

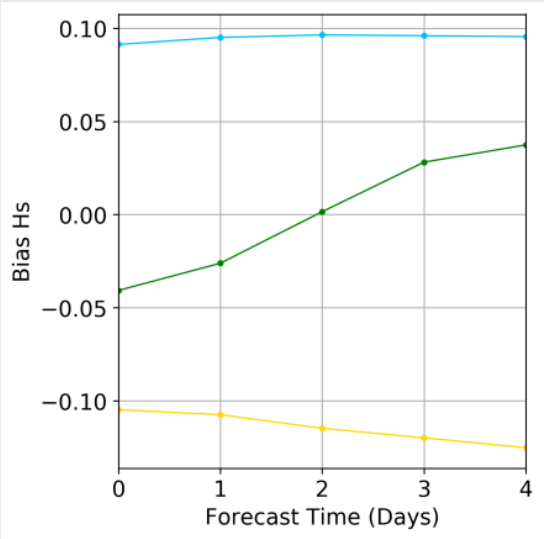
GFS ICON COSMO

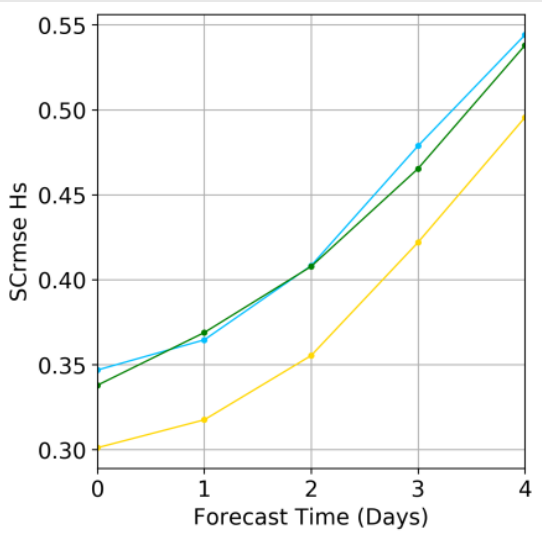
$\mathcal{E}_M(\boldsymbol{F_t}, T, P_v, L_{xy}, \boldsymbol{V}, \dots)$

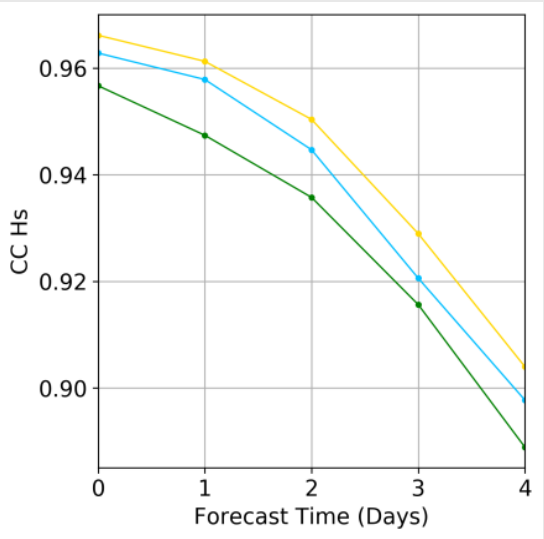










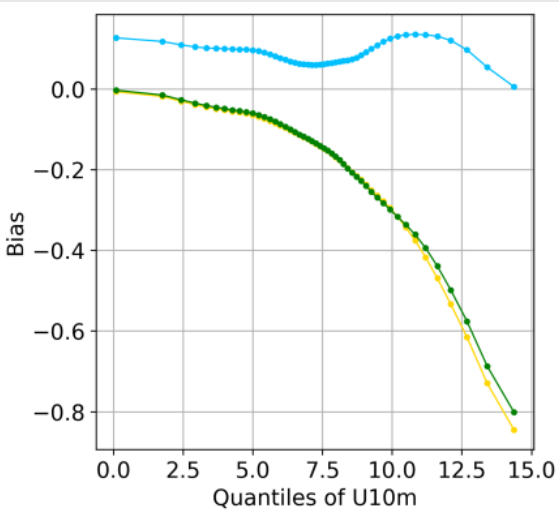


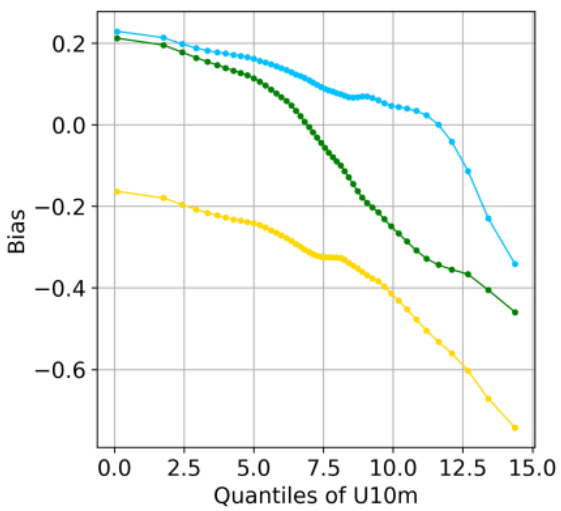
Results, percentiles

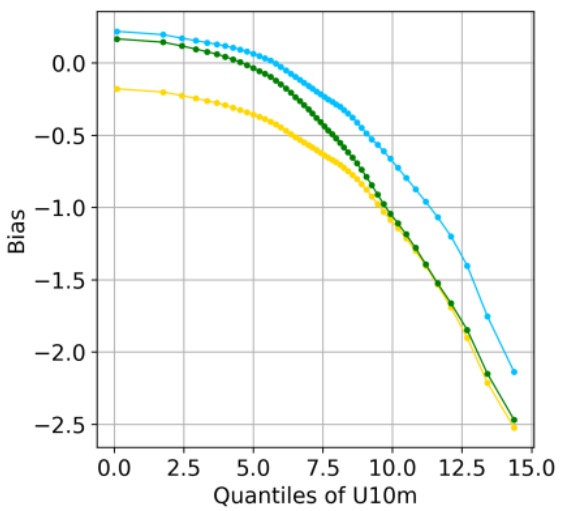
GFS ICON COSMO

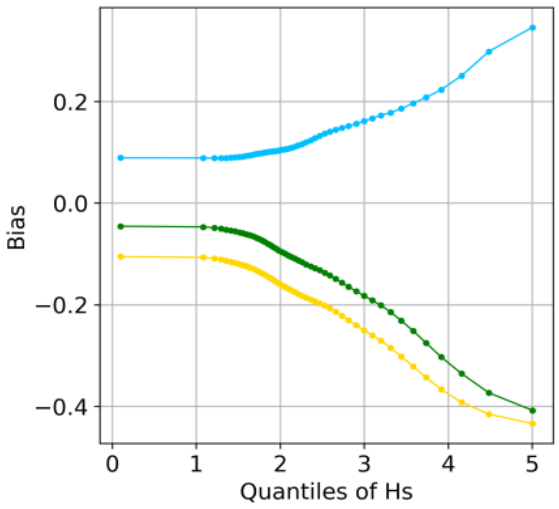
$\mathcal{E}_M(\boldsymbol{F_t}, T, \boldsymbol{P_v}, L_{xy}, \boldsymbol{V}, \dots)$

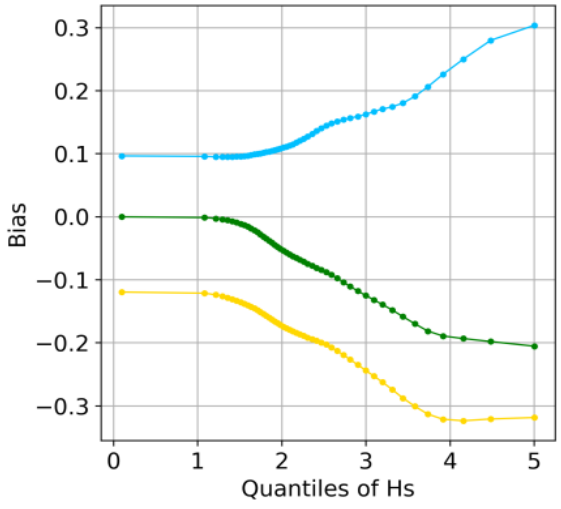
0h (nowcast) 48h 96h

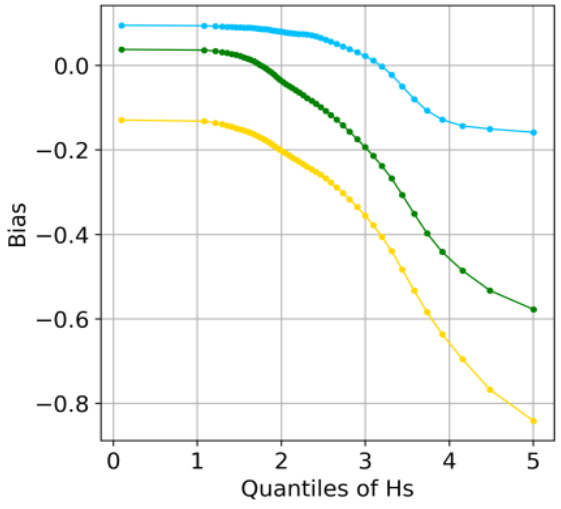










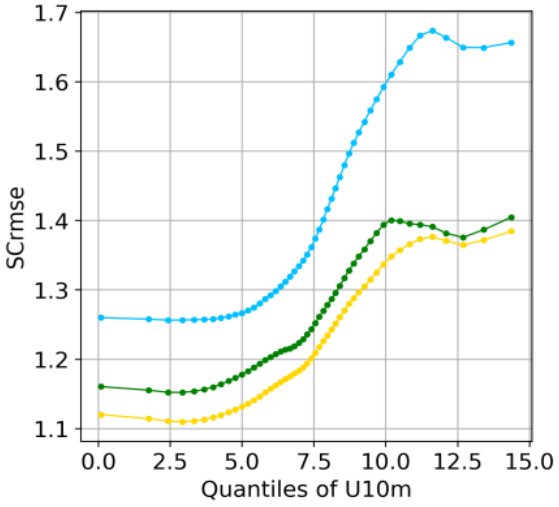


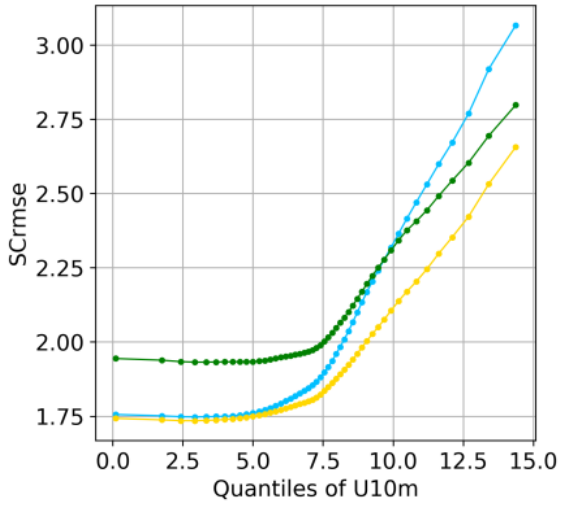
Results, percentiles

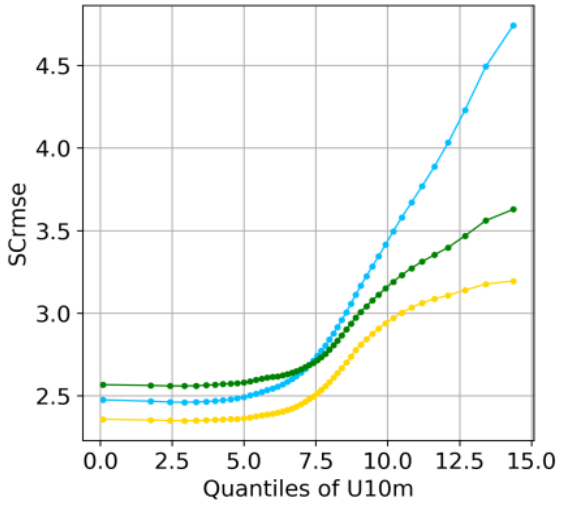
GFS ICON COSMO

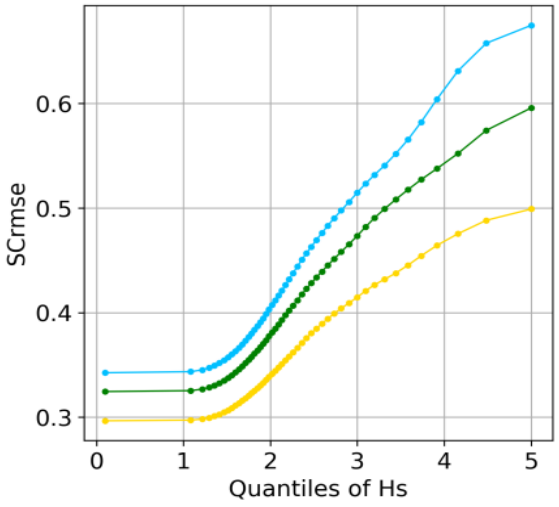
$$\mathcal{E}_M(\boldsymbol{F_t}, T, \boldsymbol{P_v}, L_{xy}, V, \dots)$$

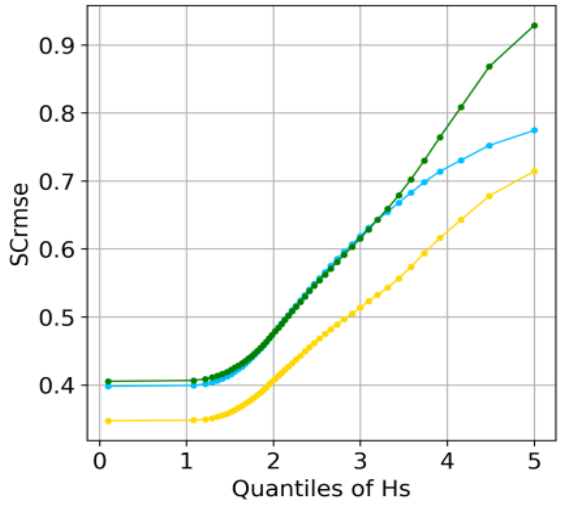
0h (nowcast) 48h 96h

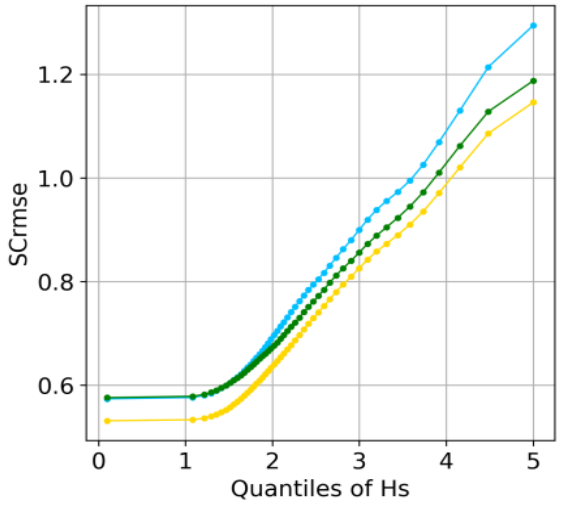












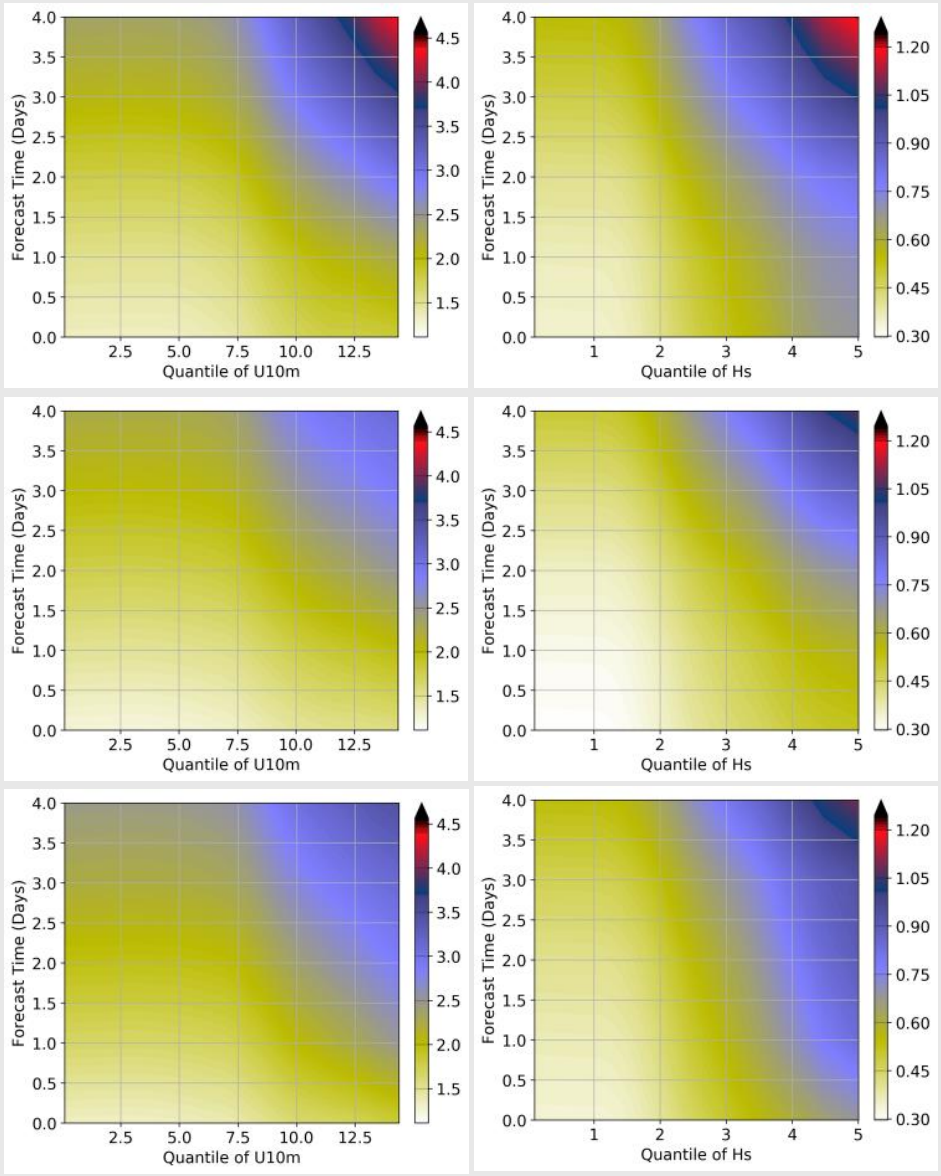
Results, combination of percentiles and forecast lead time

$$\mathcal{E}_M(\boldsymbol{F_t}, T, \boldsymbol{P_v}, L_{xy}, \boldsymbol{V}, \dots)$$

GFS

ICON

COSMO

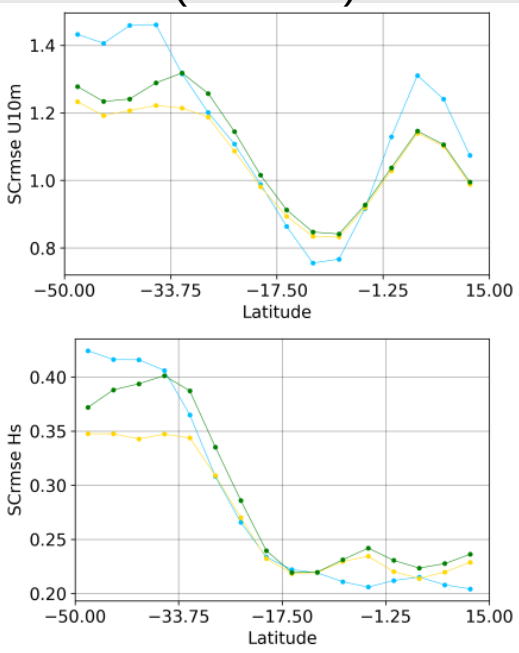


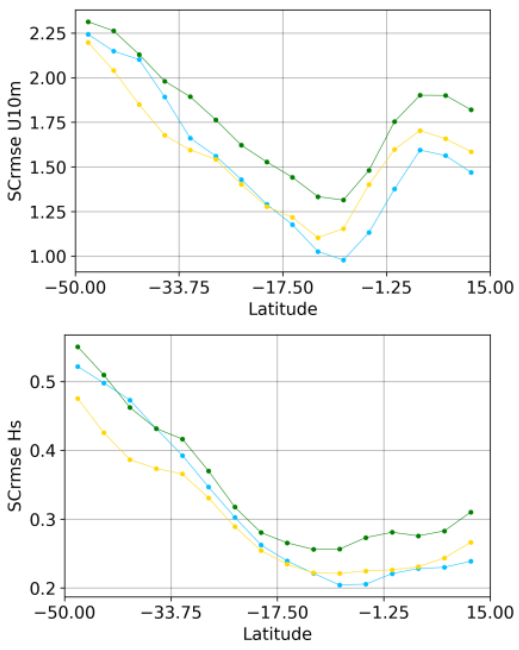
Results, space

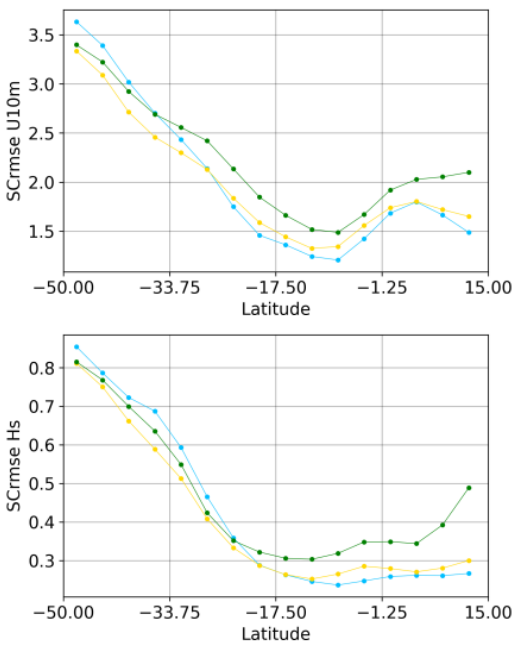
GFS ICON COSMO

$$\mathcal{E}_M(\boldsymbol{F_t}, T, P_v, \boldsymbol{L_{xy}}, V, \dots)$$

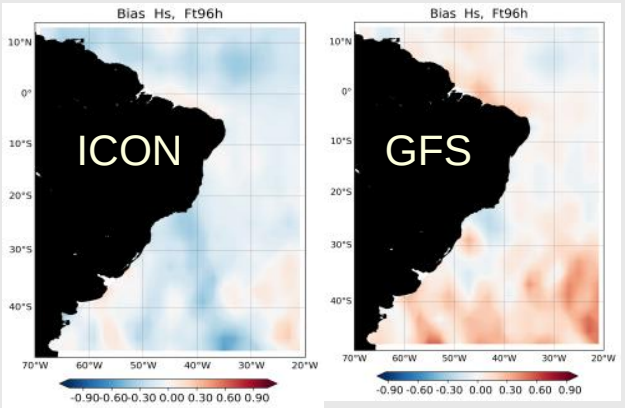
0h (nowcast) 48h 96h







- Increasing underestimation of ICON and overestimation of GFS with $\boldsymbol{F_t}$



New Implementation – First test

Tests with: compilation and parallelizaion (MPI), space-time resolution, spectral resolution, time-steps, calibration of ST4 (Bmax)

Critical balance between: run time, reliability/stability of simulation, accuracy (bulk metrics), and accuracy under extreme events (subtropical cyclones).

Spectral resolutions considered:

- Number of Frequencies (25, 29, 32)
- Number of Directions (24, 36, 48)

Spatial resolutions considered :

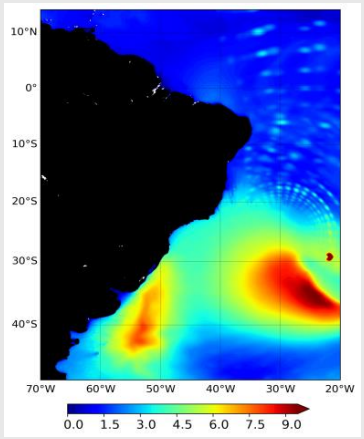
- Global (30', 25', 18', 15')
- Antarctic and South Atlantic (9', 6', 5', 3')

Wind inputs: ICON and GFS

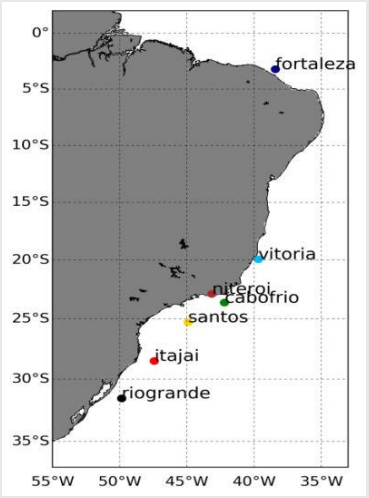
✓ 60 short tests for the period 08/08/2017 a 13/08/2017
follow by a few 1-year of simulation

Initial 5-day test (08/08/2017 a 13/08/2017)

Spatial Resolution (arc-min)		Spectral Resolution		
global	regional	Freq(glo/reg)	Dir(glo/reg)	**C-Time (h)**
15'	3'	29/35	36/48	18.2
15'	3'	25/29	24/36	14.3
15'	*3'*	*25*	*24*	*6.7 (GSE)*
15'	3'	25	36	9.0
25'	**5'**	**25**	**36**	**2.9**



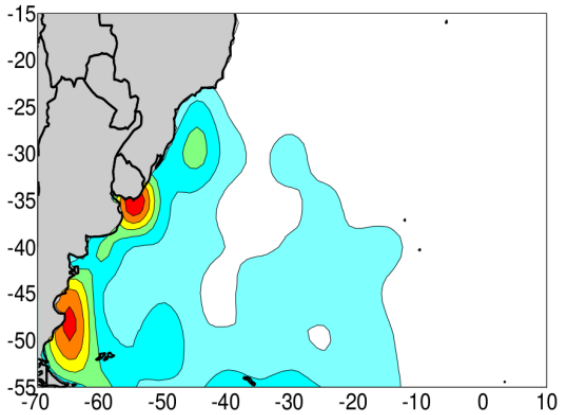
			Buoy Santos				Buoy Fortaleza			
		C-Time	Bias	RMSE	SI	CC	Bias	RMSE	SI	CC
High-Res	15‘ / 3‘ (29x36) (35x48)	18h	-0.14	0.26	0.06	0.819	0.03	0.10	0.05	0.885
“Low” -Res	25‘ / 5‘ (25x36) (25x36)	2.9h	-0.17	0.28	0.06	0.806	-0.01	0.09	0.05	0.878

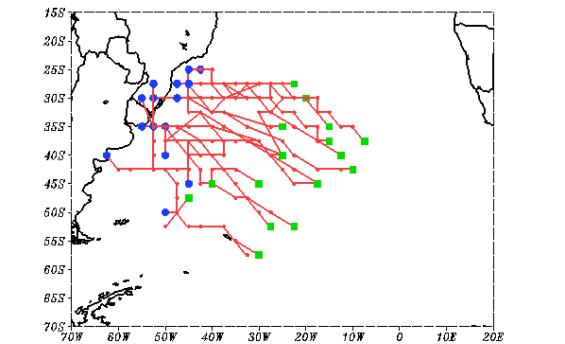


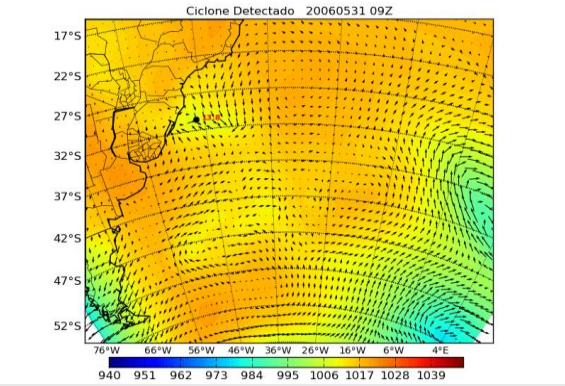
	Buoy Santos				Buoy Fortaleza			
Wind	Bias	RMSE	SI	CC	Bias	RMSE	SI	CC
ICON	-0.44	0.52	0.07	0.706	-0.13	0.18	0.07	0.760
GFS	-0.17	0.28	0.06	0.806	-0.01	0.09	0.05	0.878

	Buoy Santos				Buoy Fortaleza			
WW3 ST4	Bias	RMSE	SI	CC	Bias	RMSE	SI	CC
T471	-0.03	0.23	0.06	0.813	0.03	0.10	0.05	0.879
T405	-0.36	0.42	0.06	0.813	-0.22	0.24	0.05	0.894

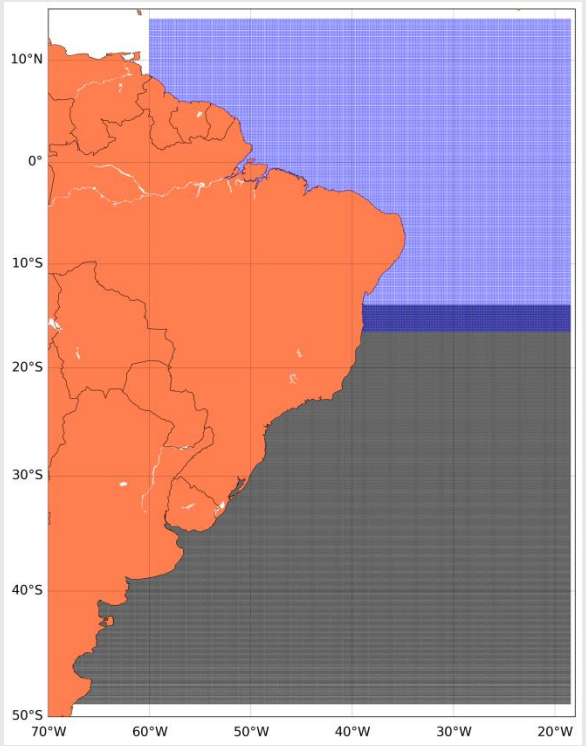
New WW3 multi-grid

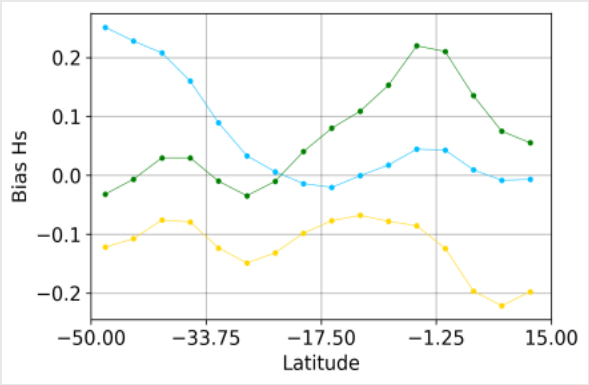


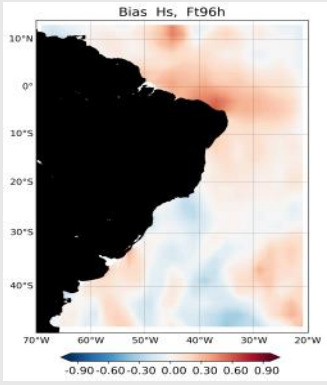




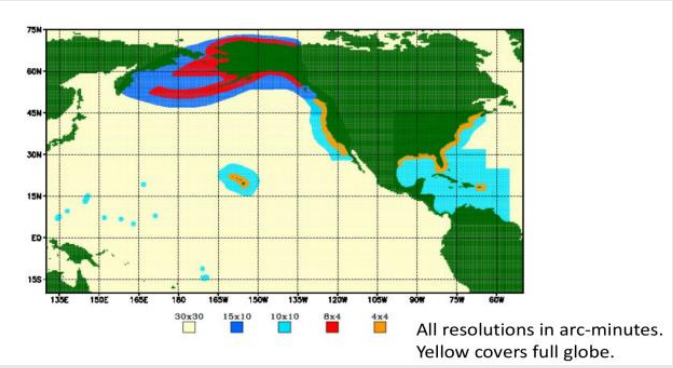
New mosaic and configuration (6' and 9')

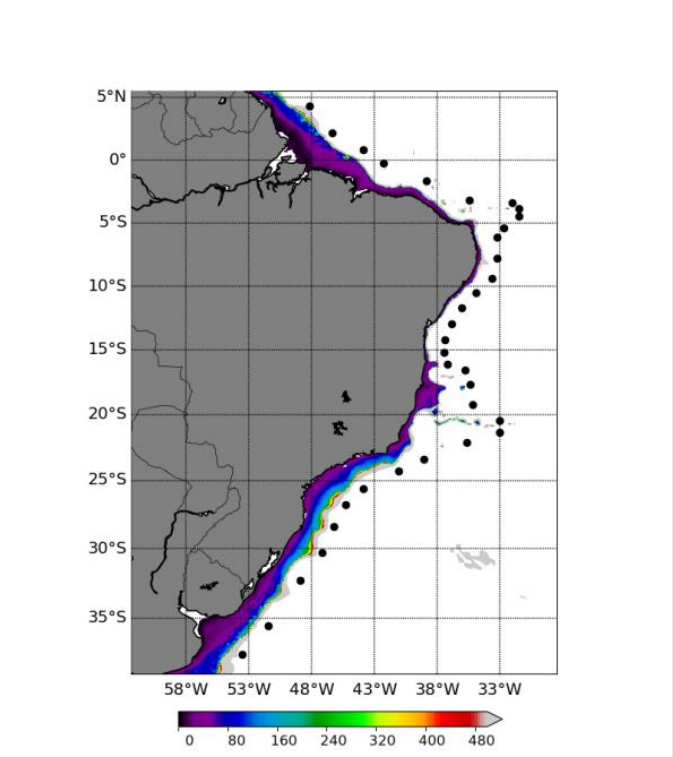


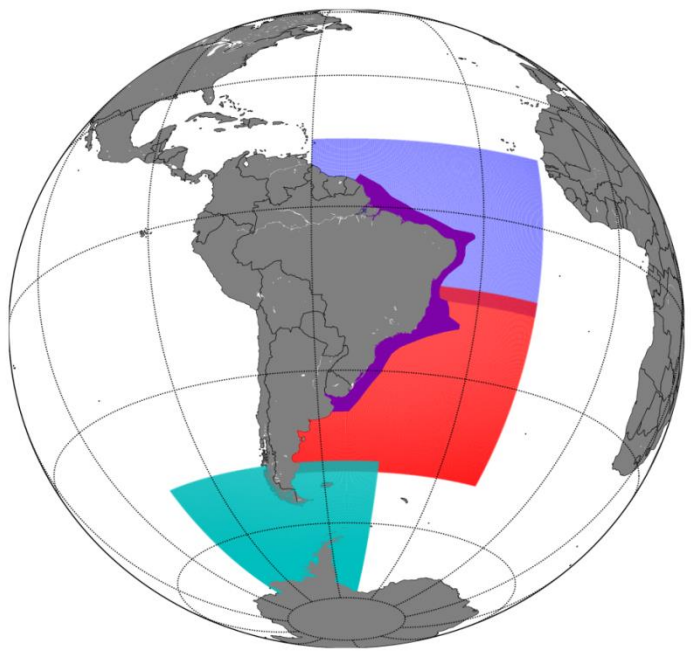




New WW3 multi-grid mosaic







- **Spectral Resolution (32x36),** *1.1 0.0373 32 36 0.*

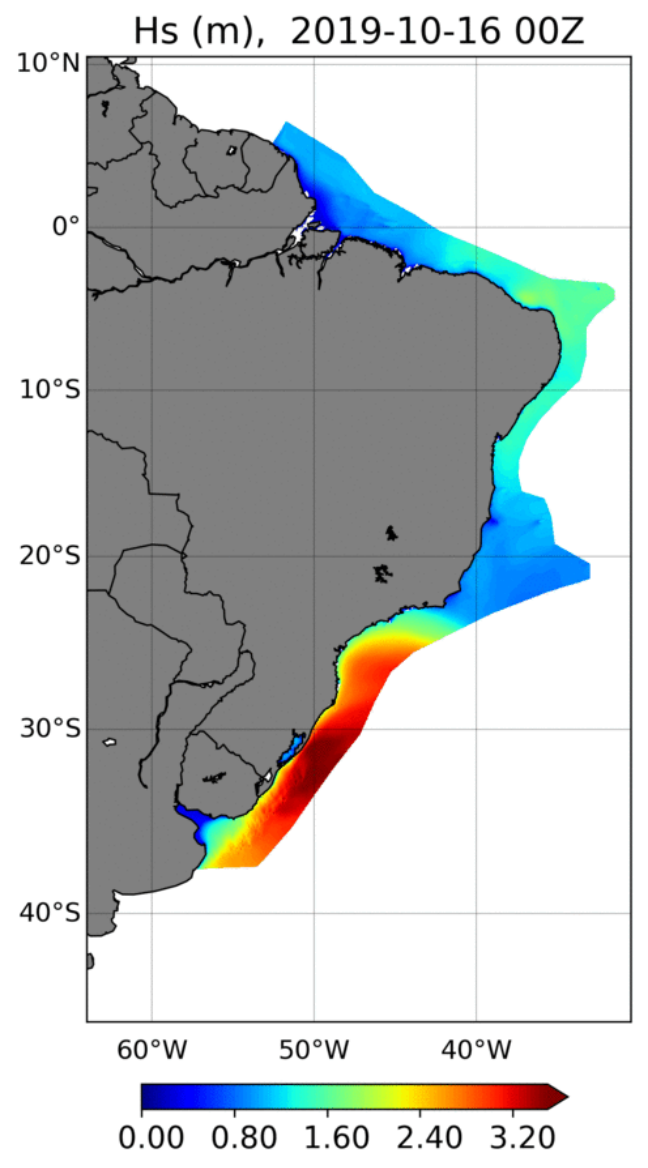
- **Global (18')**
- **Antactic (6')**
- **Atl-Meta-S (6'), Atl-Meta-N (9')**
- **Brazil Coastal (2')**

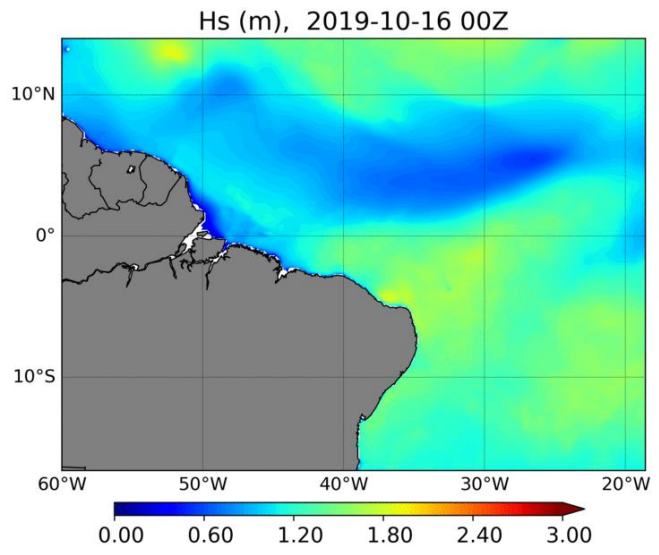
ST4 Betamax, ICON and GFS
G (1.33), AMS (1.45), AMN (1.40), ANT (1.45)
G (1.43), AMS (1.55), AMN (1.50), ANT (1.55)

C-time: 50 minutes (288 cores)

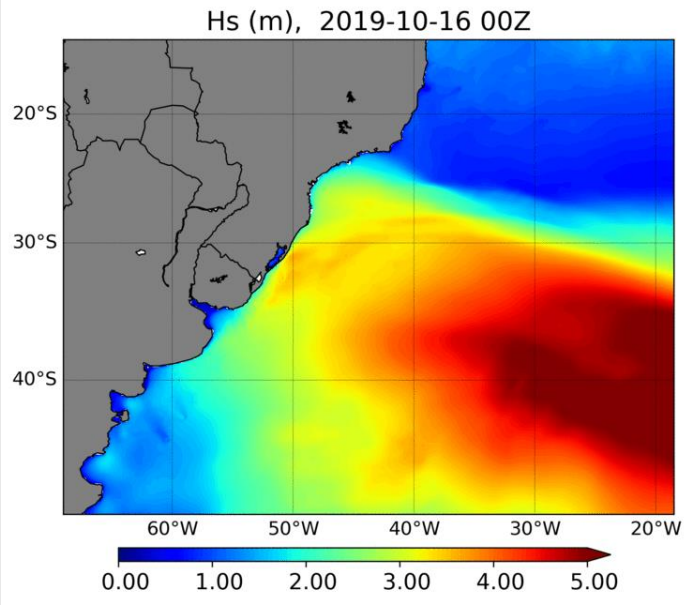
New WW3 multi-grid mosaic

Brazil Coast 0.03 (2')





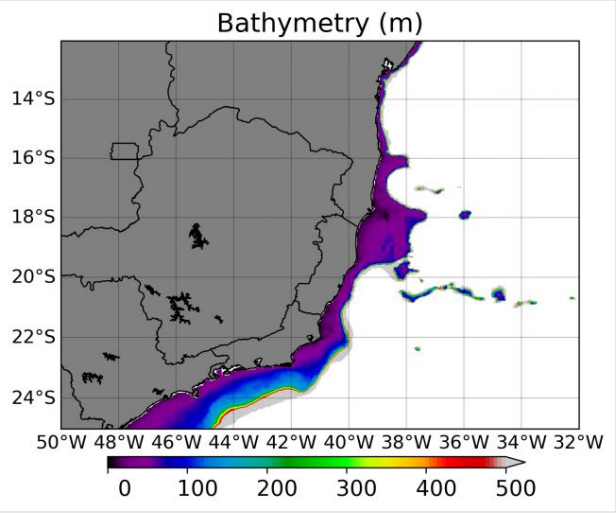
Atl-Meta-N 0.15 (9')

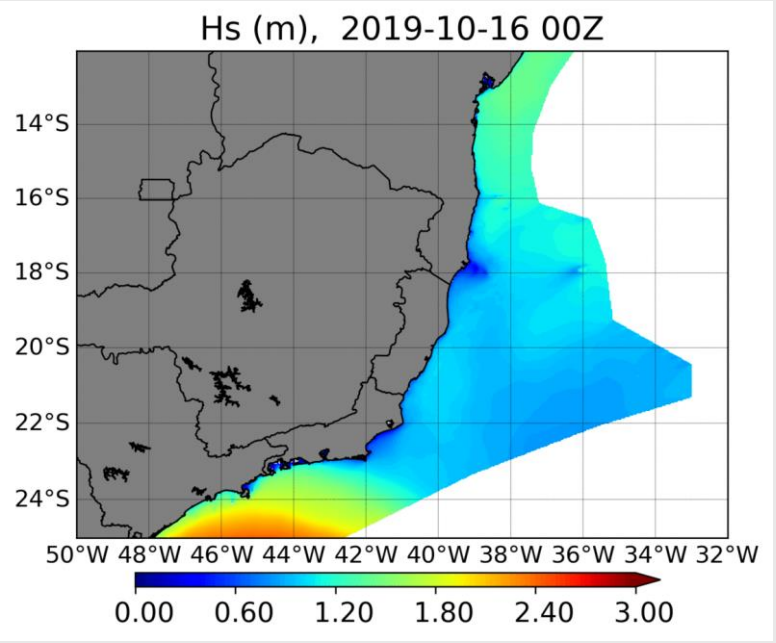


Atl-Meta-S 0.1 (6')

Ongoing and future developments

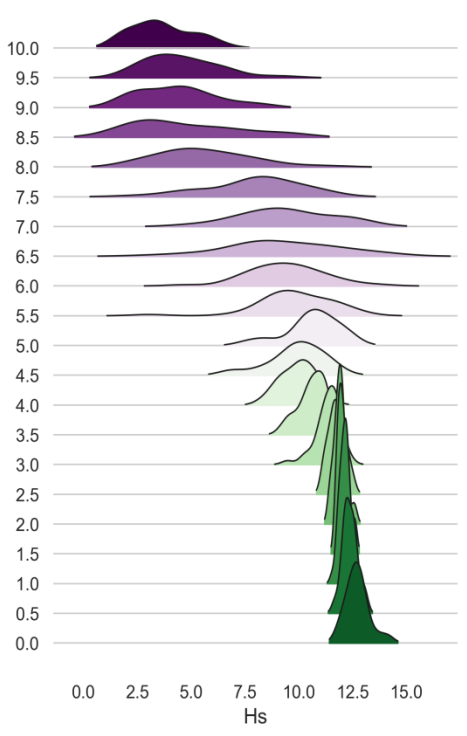
- **New simulation starting in June-2019**
- **New WW3 calibration with recent winds (GFS-FV3)**
- **Include scatterometer winds in the model assessments**
- **Assessment of additional variables and wave spectra from buoys**
- **Include space-time extremes, Hmax**
- **Surface currents (mercator/noaa-hycom)**
- **GMD**
- **Polar/Curviliniar grid**
- **Calibration of coastal grid (**swell/islands are good enough?**)**
- **Unstructured grids**
- **Shallow water grids (ADCIRC)**

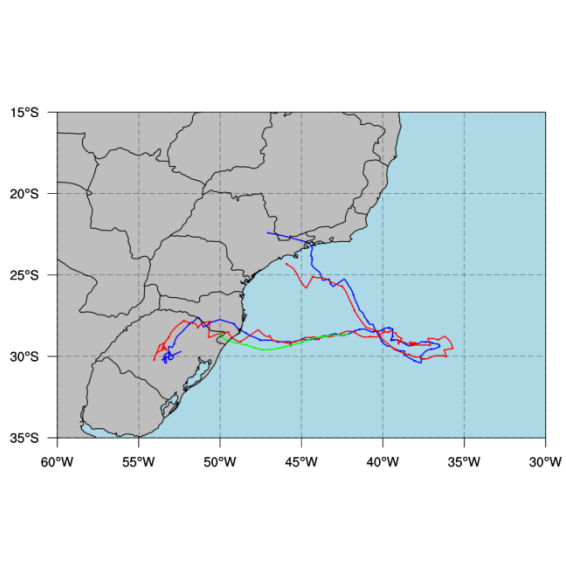




Ongoing and future developments

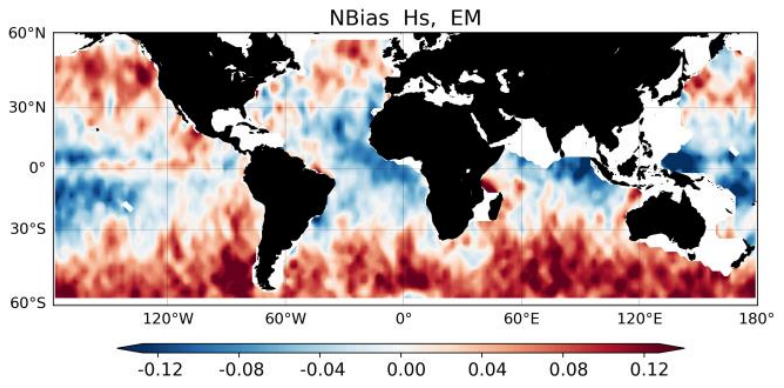
- **Expand the forecast horizon**
- **Multi-model deterministic and Ensemble forecast (CMC-EnvCanada, FNMOC-USnavy, NCEP/NOAA, DWD/ICON, etc)**
- **Cyclone tracking**

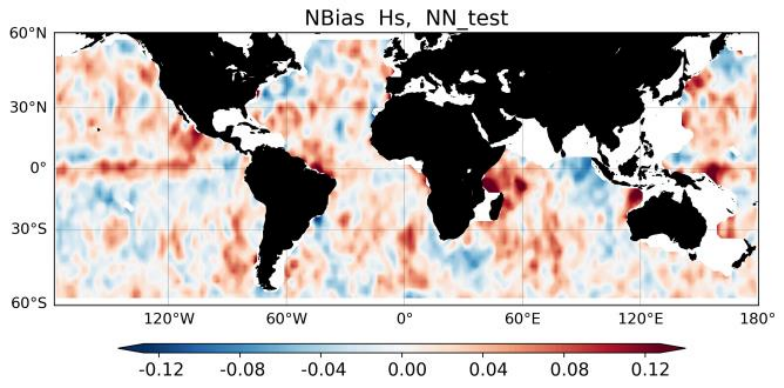


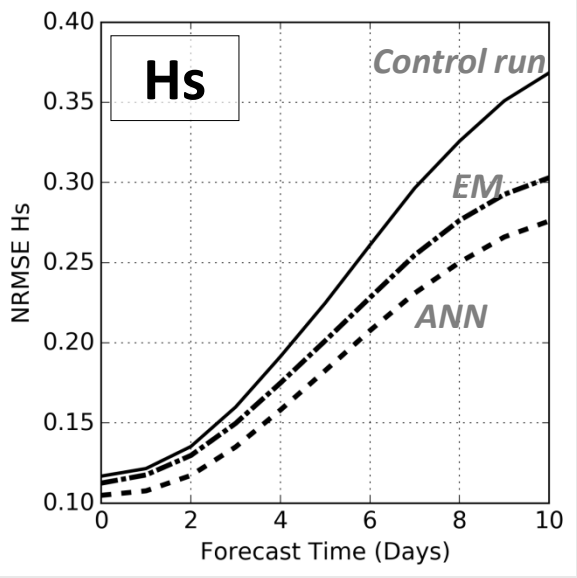


Ongoing and future developments

- **Post-processing models using neural networks**







Thank you !

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