Using data assimilation in mesoscale numerical modeling to map offshore wind resource

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Abstract – Observational surface wind data from QuikSCAT (QS) satellite and sea surface temperature (SST) data from GHRSST Level 4 analysis have been ingested to an atmospheric mesoscale numerical model using a Newtonian relaxation assimilation technique. The mesoscale model WRF was used to map the wind resource at 90 m a.g.l. for the North Sea area. A model domain with a spatial resolution of 20x20 km was used to simulate a winter and a summer month, November 2008 and July 2009. The modeled wind results have been validated against observational data from the anemometric mast FINO1. A spatial improvement of the average wind field at 90 m a.g.l. from the observational data has been assessed. Each assimilated data source has shown a distinct impact. The QS assimilation had higher impact during the summer period while the SST assimilation during the winter period. Improvements of 5% and more were obtained from using data assimilation on the overall domain. Validation with the FINO1 anemometric mast shows improvements on the average vertical wind profile while error statistical parameters were only slightly improved.

1. Introduction

The offshore wind resource assessment is one of the primary key tools used by offshore wind farm promoters for decision making investments in offshore wind parks. In Europe, due to the renewable energy policies recently established by the European Commission (EU) for the wind sector, it is expected an interesting growth of offshore wind parks along the European coasts. To support the expected investments, wind research and industry partners in collaboration with the EU have created the FP7 NORSEWInD project *(Norsewind, 2008)* with the main purpose of delivering to the North, Baltic and Irish Sea areas high quality wind atlases for offshore wind resource assessment.

A Newtonian relaxation assimilation technique *(Stauffer and Seaman, 1990)* has been set up with the Weather Research and Forecasting (WRF) *(Skamarock and Klemp, 2008)* mesoscale model. The aim is to improve the regional wind atlases to be constructed for the areas of the NORSEWInD project. A model domain with a spatial resolution of 20x20 km was used to simulate a winter and a summer month, namely, November 2008 and July 2009. The QuikSCAT (QS) satellite surface wind data *(Perry et. al., 1995)* and the sea surface temperature (SST) data from GHRSST level 4 analyses *(Donlon C. et al.,* 2007*)* were the observational sources ingested into the numerical model simulations.

The observational data from FINO1 anemometric mast, whose location is displayed in Figure 1, was used to perform point validation at 90 m a.g.l. The average vertical wind profile was computed for levels 33, 50, 60 and 90 m a.g.l.. An assessment of the spatial improvement of the average wind field at 90 m a.g.l. from the observational data was then performed.

2. Methodology

The WRF model was configured using 2 nested domains, a coarser (D1) with grid spacing of 100x100 km and a nested domain (D2) with 20x20 km using the parameterizations described in Table 1. The coverage area is displayed in Figure 1 which also points the location of FINO1 anemometric mast. Initial and boundary conditions were ingested into D1 from NCAR Reanalysis datasets (Kalnay *et. al.*, 1996) at a frequency of 4 times per day. These conditions were objective interpolated into D1 grid from the 2.5°x2.5° reanalysis grid spacing.

Table 1: WRF parameterization setup.

	D1	D2
Horiz. Res [km]	100	20
NX x NY	18x21	36x51
Vert. Levels	28	28
Micro-physics	WSM6	WSM6
LW radt.	RRTM	RRTM
SW radt.	Dudhia	Dudhia
Land-Surface	Noah	Noah
Surface	Eta	Eta
PBL	MYJ	MYJ
Cumulus	KF	KF

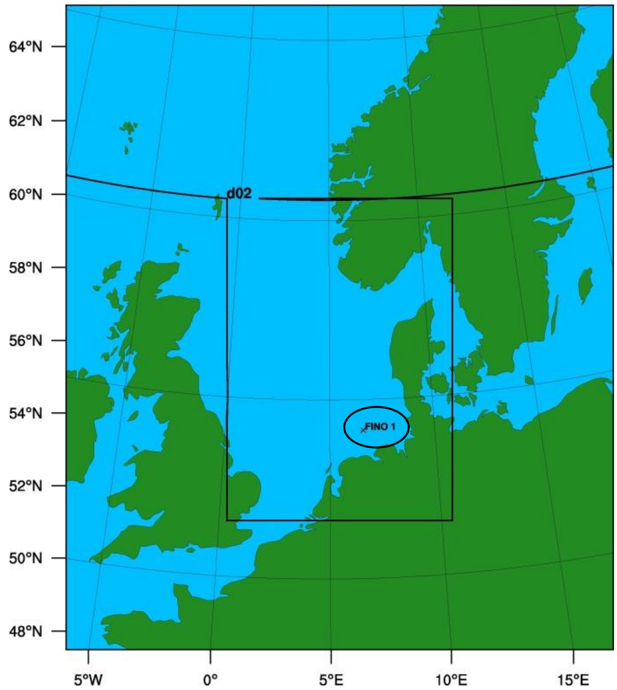

Figure 1: WRF domains setup and location of FINO1 anemometric station.

Three experimental runs were performed, a control run without data assimilation departing from a "cold" start via Reanalysis, a second run almost equal to the first but "warm" started with QS data assimilation and a third one "warm" started with SST data assimilation. The QS dataset is configured with a 0.25° gridded ocean surface wind vector field from daily ascending and descending satellite passes. It is a level 3 processed product and is nowadays freely available from PODACC-NASA's website[1]. A contour plot of the averaged QS sea wind speed and direction for each of the months under analysis is displayed in Figure 2.

The SST data used is a product from the Group for High Resolution Sea Surface Temperature (GHRSST) Level 4 analysis produced daily on an operational basis but refined by the Danish Meteorological Institute for the North Sea area. This product is usually produced only once a day at 00h UTC. Figure 3 displays a plot of the monthly averaged SST for the study area.

[1] http://podaac.jpl.nasa.gov/

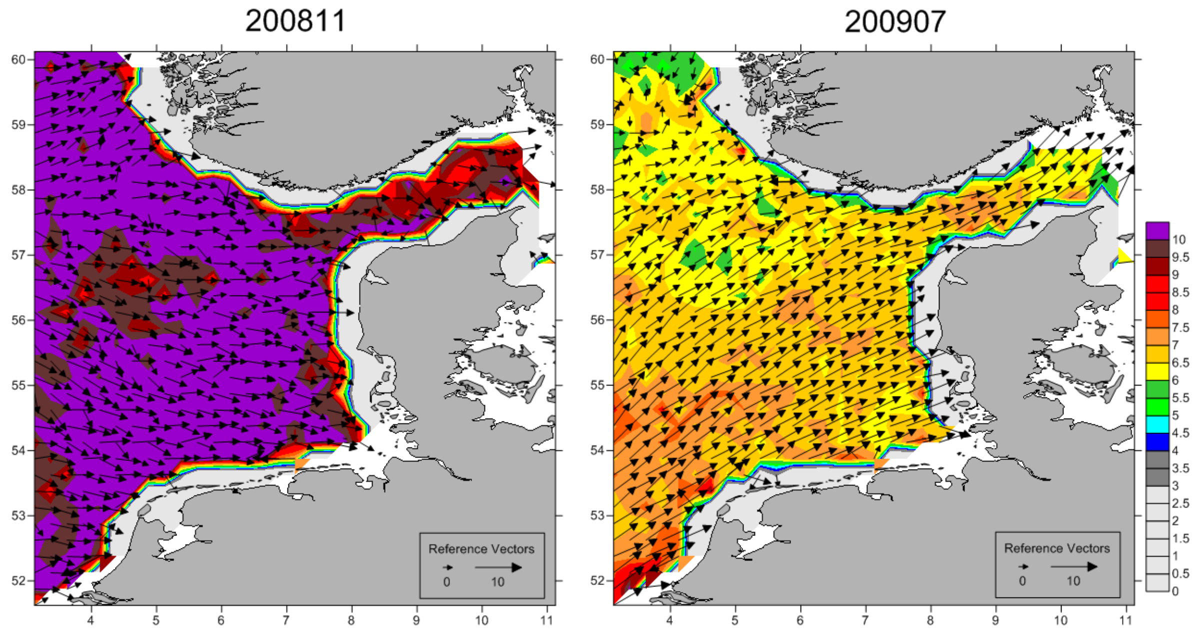

Figure 2: QuikSCAT monthly average wind speed and direction for the study area.

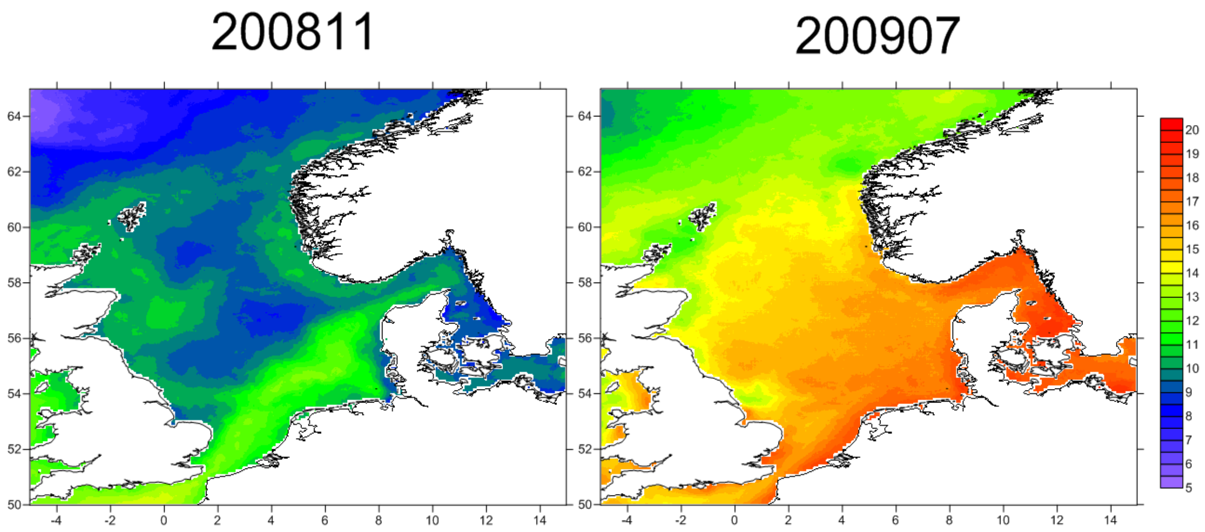

Figure 3: Averaged SST for November 2008 (on the left) and July 2009 (on the right) for the study area.

The FINO1 anemometric mast was chosen for point validation since it is one of the few offshore wind stations with available data at the study area for both months under analysis. A spatial improvement assessment (I_{WIND}) of the average wind speeds at 90 m a.g.l. was measured at each grid point by calculating the proximity of the assimilation run (*AS*) versus control run (*CR*) compared with QuikSCAT (*QS*) observations following equation (1).

$$I_{WIND}\,(\%) = 100 \times \frac{\|CR - QS\| - \|AS - QS\|}{\|CR - QS\|} \qquad (1)$$

For the SST assimilation improvement (I_{SST}), only the comparison between the control

(*CR*) and the assimilation run (AS_{SST}) was assessed. For this case, the SST improvement is expressed by the following equation:

$$I_{SST}\ (\%) = 100\ \times \frac{\|CR\| - \|AS_{SST}\|}{\|CR\|} \quad (2)$$

3. Results

3.1 Validation against anemometric mast

Time series of wind data at ten-minute intervals were produced from WRF model at FINO1 to be comparable with wind data ten-minute averaged from the met mast. The main wind statistical parameters for both time series at 90m (a.g.l.) were processed. Results for November 2008 month are presented in Table 2, where OBS means FINO1 observational time series, WRF_NN is the control run, WRF_QS is QS assimilation run and WRF_SST is the SST assimilation run.

Table 2: Statistics for FINO1 point validation for November 2008.

			90 m a.g.l.		
		OBS	WRF_CR	WRF_QS	WRF_SST
WBL	AVG [m/s]	11.23	12.00	12.02	11.83
WBL	STDEV [m/s]	4.53	4.43	4.20	4.40
WBL	A [m/s]	12.62	13.46	13.45	13.20
WBL	k	2.7	2.96	3.14	2.84
	CORREL	-	0.83	0.83	0.84
WSPD	MAE [m/s]	-	2.07	1.99	1.95
WSPD	RMSE [m/s]	-	2.82	2.65	2.62
WDIR	MAE [°]	-	12.39	12.96	11.83
WDIR	RMSE [°]	-	17.14	18.10	16.48

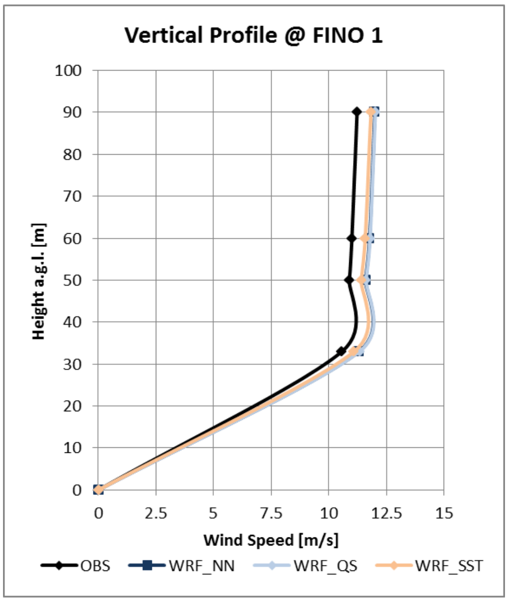

Figure 4: Average vertical wind profile at FINO1 for November 2008.

During the winter month, a correlation of 83% was obtained for all simulations with the WRF model predicting stronger winds than the observed, meaning that WRF for the winter period overestimated the winds from the common atmospheric transient weather circulation patterns that usually occurred at this time of the year. The assimilation of QS sea winds had a low impact on improving the simulated wind field at 90 m a.g.l. with slight improvements on both mean wind speed absolute error (MAE) and root mean square error (RMSE). With the assimilation of SST data, the wind flow errors have diminished allowing a closer approximation with the observational FINO 1 wind data. This impact was observed at all levels of analysis as displayed in the vertical profile in Figure 4.

Figure 5 displays a plot of the time series for November 2008 month. The overestimation of wind speed by WRF model can be observed on several occasions. For wind direction, almost no changes can be observed between the three WRF simulation types. All of them were able to reproduce with success the observed wind direction.

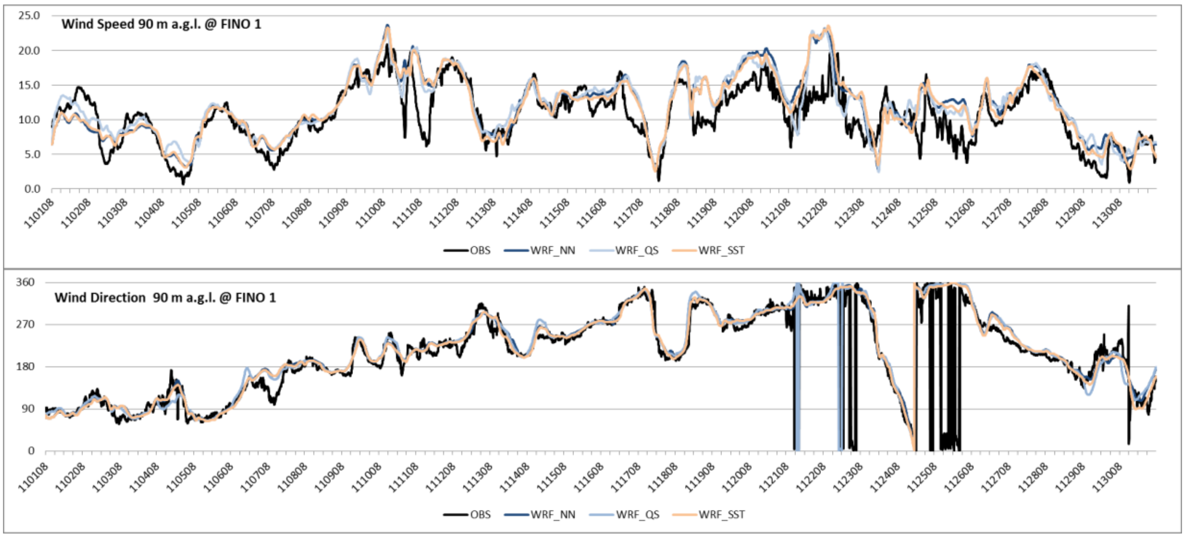

Figure 5: Time series of wind speed (above) and direction (below) for November 2008 at FINO1. Times series of observations (OBS), control run (WRF_NN), QS assimilation (WRF_QS) and SST assimilation (WRF_SST).

A different behavior of the WRF model was observed for the summer month where the model has underestimated the wind speeds. Table 3 presents the same statistical validation parameters calculated for FINO1 local point.

Table 3: Statistics for FINO1 point validation for July 2009.

			90 m a.g.l.		
		OBS	WRF_CR	WRF_QS	WRF_SST
WBL	AVG [m/s]	8.60	8.46	8.40	8.44
	STDEV [m/s]	3.36	3.08	3.05	3.25
	A [m/s]	9.65	9.47	9.38	9.60
	k	2.71	2.99	3.02	2.66
	CORREL	-	0.67	0.68	0.69
WSPD	MAE [m/s]	-	2.07	2.05	2.00
	RMSE [m/s]	-	2.62	2.59	2.63
WDIR	MAE [°]	-	19.98	23.93	19.35
	RMSE [°]	-	31.28	37.55	30.94

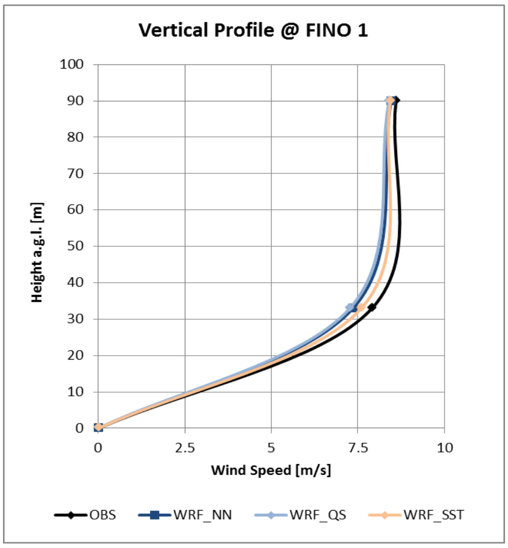

Figure 6: Average vertical wind profile at FINO1 for July 2009.

From Table 3, a correlation of about 68% was achieved by WRF model. The lower correlation value means that WRF running at 20x20km spatial resolution could not represent well the thermal stratification phenomena activity in the North Sea area occurring in the summer months. Both assimilation runs and also the control run allowed approximately 1% of improvement on correlation when compared with observational values.

The average vertical profile displayed in Figure 6 (right side of Table 3) was only calculated for levels 33m and 90m (a.g.l.) due to inconsistencies on observations founded in levels 50m and 60m (a.g.l.). Simulation results with and without assimilating data has underestimated wind speeds on both levels. Nevertheless, this difference has diminished from the 33m to the 90m level.

Figure 7 presents the plots of the wind speed and direction time series for July 2009. There are several wind speed local maximums associated with episodes of strong transient stratification atmospheric phenomena coupled with local sea-breezes that WRF model was not able to reproduce with 20x20km spatial resolution, reflecting this way the lower averages obtained. In an opposite case, the wind direction is generally well reproduced therefore reflecting the higher direction MAE and RMSE but with some exceptions by the QS assimilation run on some occasions due to the stratification phenomena.

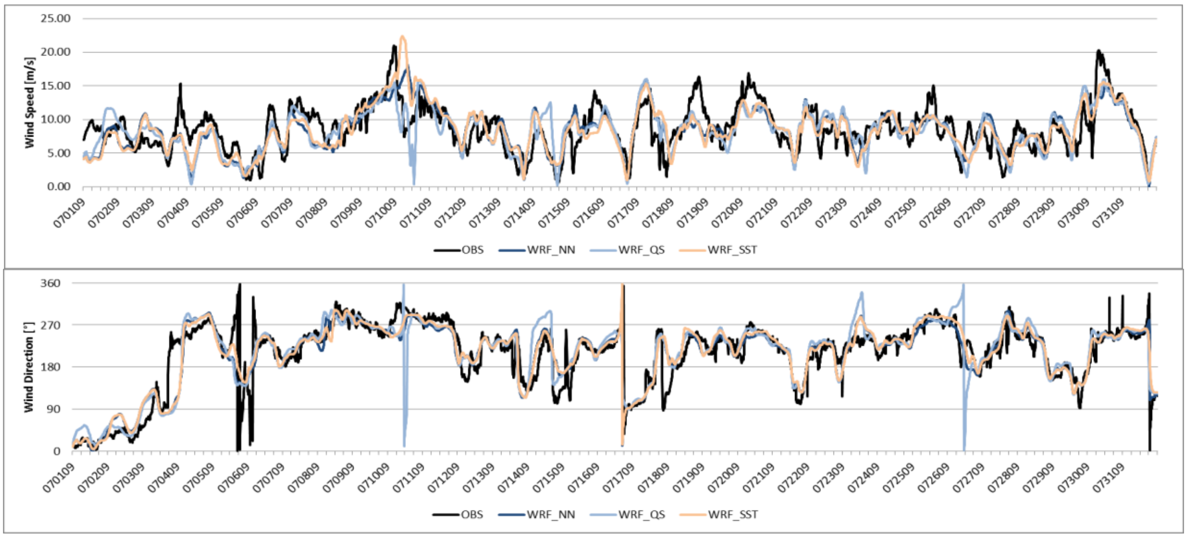

Figure 7: Time series of wind speed (above) and wind direction (below) for July 2009 at FINO1. Time series of observations (OBS), control run (WRF_NN), QS assimilation (WRF_QS) and SST assimilation (WRF_SST).

3.2 Spatial Improvement

A spatial analysis to assess a positive or negative impact of data assimilation when compared with the control run on the overall domain was assessed. Equation (1) was used to obtain the QS assimilation run performance and Equation (2) for the SST assimilation performance. Figure 8 displays the spatial performance for November 2008 month (winter) and Figure 9 for July 2009 (summer).

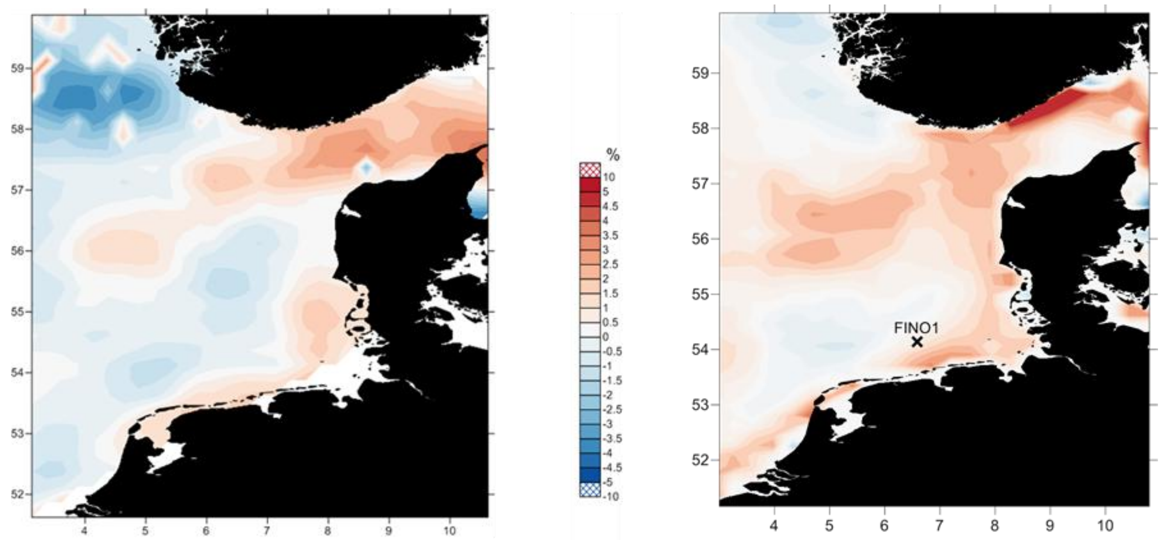

Figure 8: Spatial improvement for November 2008. QS assimilation performance on the left and SST assimilation performance on the right.

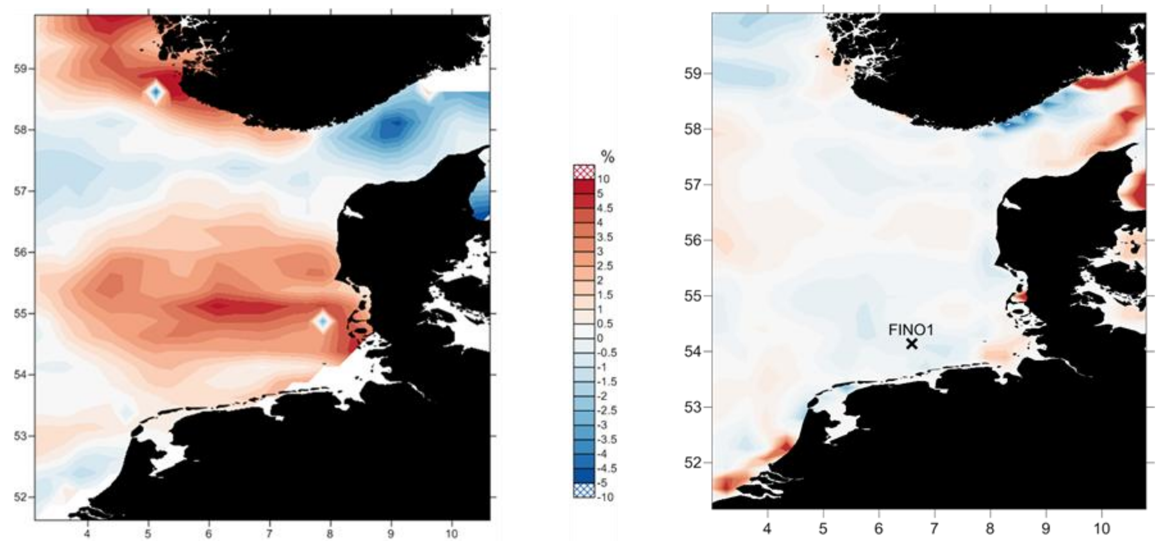

Figure 9: Spatial improvement for July 2009. QS assimilation performance on the left and SST assimilation on the right.

The QS assimilation had higher positive impacts during the summer month with large areas obtaining an improvement between 5 and 10%. The SST assimilation showed a higher positive impact during the winter month where large areas showed a positive impact, especially near the coast.

4. Conclusions

The Newtonian relaxation scheme used to assimilate the winds from the QuikSCAT and the SST from the GHRSST databases has allowed improvements in the range of 5 to 10% for the summer period and from 3 to 5 % for the winter period.

During the winter, the SST data assimilated showed a higher positive impact while the QS assimilated data showed better results during the summer.

The point validation using met mast FINO 1 did not reflect the improvements displayed by the spatial analysis. This can be explained by the fact that FINO 1 dataset is part of the NCAR Reanalysis project assimilation cycles and therefore in a certain way this data is already "present" on the initial and boundary conditions ingested into the WRF model domain. Nevertheless, slight improvements on the MAE and RMSE were obtained due to the fact that QuikSCAT and GHRSST databases have a better spatial resolution than NCAR's Reanalysis project data. It should be noticed that the SST data assimilation has demonstrated ability to correct the vertical wind profile on both occasions, during the summer and winter cases.

Better results could be achieved if they were performed on better spatial resolutions. This work is currently being done for the purposes of the FP7 NORSEWInD project.

5. Acknowledgements

The results and the met mast data presented in this work are part of the EU FP7 NORSEWInD project from which the authors are partners. The authors would also like to acknowledge project FCT ROADMAP.

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