ANALYSIS OF HIGH SPATIAL AND TEMPORAL SURFACE WINDS FROM ALADIN MODEL AND FROM REMOTELY SENSED DATA OVER THE CANARIAN UPWELLING REGION

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Abstract

The quality of surface wind speeds and directions derived from the regional model for weather forecasting "Aire limitée et adaptation dynamique" (ALADIN), in use at the Directorate of Meteorology (DOM) of Morocco, are examined by comparison with the 10-m wind speeds and directions observed by meteorological stations and with satellite wind analysis estimated from QuikSCAT, and new surface wind products, known as Blended wind products, which consist of merged satellite observations and numerical model estimates, over oceanic regions North-West of Africa during the period 2003-2006. Overall, the various surface wind sources exhibit good agreement. Highest correlations are found for ALADIN and Blended; however, ALADIN wind speeds and the associated variability tend to be underestimated in comparison with in-situ and satellite estimates. ALADIN wind speed biases are 1m/s, and the associated RMS difference values vary between 1,15m/s and 2,15m/s. Similar good agreements are found for wind direction comparisons. Indeed, for winds higher than 3m/s, the mean and the standard deviation difference values do not exceed 6° and 30°, respectively. However, some large discrepancies between ALADIN and the satellite wind estimates are found at some specific local areas such as Essaouira and the Canary Islands. The former are mainly associated with the impacts of orography.

Keywords: Upwelling; Ocean circulation forcing; Surface wind; ALADINmodel; QuiKSCAT; Blended wind product.

ANALYSE SPATIALE ET TEMPORELLE DES VENTS DE SURFACE DU MODELE ALADIN ET DES DONNEES DE TELEDETECTION SUR LA REGION D'UPWELLING DES CANARIES

Résumé

La qualité de la vitesse et la direction du vent de surface issu du modèle régional "Aire Limitée et adaptation dynamique» (ALADIN) pour la prévision météorologique, actuellement opérationnel à la Direction de la météorologie nationale du Maroc, sont étudiés par comparaison avec la vitesse du vent de 10 m et les directions observées par les stations météorologiques et à l'analyse du vent par satellite estimée à partir de QuikSCAT, à partir de nouveaux produits sur les vents de surface, les produits du vent Blended, fusionnant des observations satellitaires et les estimations du modèle numérique, sur les côtes du nord-ouest de l'Afrique au cours de la période 2003-2006. Sur l'ensemble, le

vent de surface des différentes sources présente un bon accord. Corrélations plus élevés se trouvent entre ALADIN et Blended, mais la vitesse du vent ALADIN et la variabilité associée ont tendance à être sous-estimée par rapport aux vents in-situ et les estimations par satellite ... le biais de la vitesse du vent ALADIN est de l'ordre de 1 m/s, et les valeurs associées des différences de RMS varient entre 1,15 m/s et 2,15 m/s. De bons accords similaires sont trouvés dans la comparaison des directions du vent. En effet, pour les vents de plus de 3m/s, la moyenne et les valeurs de la différence de l'écart type ne dépassent pas 6 ° et 30 °, respectivement. Toutefois, certains écarts élevés entre ALADIN et les estimations du vent par satellite sont trouvés sur certains domaines spécifiques locaux telles que Essaouira et les îles Canaries. Ces écarts sont essentiellement liés aux impacts de l'orographie.

Mots clefs: Upwelling ; forçage de la circulation océanique ; vent de surface ; modèle ALADIN ; QuikSCAT ; produit vent Blended.

1. INTRODUCTION

Surface wind speed and direction and the associated variables such as wind stress, curl, and divergence play an important role in many features of global, regional, and local oceanic areas. For instance upwelling regions are driven by wind stress curl and the wind stress (P. Marchesiello and al., 2002). Such regions and especially those located near coasts are of major interest. Even thoug their extent account for less than 1% of total global ocean surface, their economic impact at local and regional scales is very important. Indeed, more than 20% of fish catch occur in these regions (Pauly *et al*, 1995). One of the major coastal upwelling systems with respect to primary production is the Canary Current System located off the northwest African coasts (Figure 1). Generally speaking, surface wind blows equatorward along an eastern ocean boundary surface, waters are driven away from the coasts (Ekman transport) and replaced by denser water from below, which in general are rich in nutrients. Three types of atmospheric circulation characterizes the Northwest African region. Southeastward Circulation associated with polar cold airflow reaching 20°N to 15°N and exceptionally 10°N in case of heavy downstream cold air. Such atmospheric circulation remains seasonally dependent, and the related winds and heat fluxes are generally from the westerly direction. The latter are influenced by wind and pressure field disturbances in the middle and surface boundary layers. The second circulation type is associated with northeast and southeast winds (trade winds) blowing throughout the year over the Atlantic inter-tropical region. Between north and south regimes the convergence zone contributes to the northwest as well as southwest wind reinforcement, which in turn creates a strong atmosphere activity during summer. In winter, the contact between air masses brought by the north winds and warm air masses at the equator, creates the front of the trade winds which is a semi-permanent structure splitting the subtropical anticyclonic cells. Thus, a strong gradient wind exists in summer and winter over the Atlantic Ocean, and provides the remarkable phenomenon of upwelling. The third type of atmospheric circulation is associated with the southwest monsoon. These winds are caused by the difference between seasonal sea and land temperatures. The most favorable region for monsoon development is located in tropical western African area, where the weather elements are punctuated every year by the ebb and flow of the monsoon in the South-West. Upwelling can result from both a coastal divergence of the seaward Ekman current (forced by the alongshore stress at the coast) and an upward Ekman pumping associated with cyclonic stress curl (forced by nearshore wind drop-off)." (X.J. Capet et al, 2004). The importance of wind forcing in the ocean circulation has been widely studied. Early in the 20th century, it was demonstrated that wind stress is the main forcing component of the coastal upwelling; significant advances in understanding the structure of wind stress and its curl have directly caused the measurements of surface winds and wind stress using instrumented aircraft (Enriquez et al, 1995). Several previous studies pointed out the requirement of accurate winds for investigations of upwelling systems. The latter are mainly related to Benguela (Blank et al, 2005), and especially to California (Perlin et al, 2004) upwelling systems. A precise wind is particularly required in these specific regions where the changes of the atmospheric circulation off the coast are relted to the coastal topography generating a small-scale variability in the wind features (Choa et al, 2001).

To meet such requirements, it is important to investigate at first surface winds; wind stress and wind stress curl derived from numerical model with high spatial and temporal resolution and capable to reproduce the multi-scale patterns. One of the main models available over north-west African region is ALADIN (ALADIN Team, 1997) operational at present in Météo-Maroc. ALADIN 10-m winds are currently available at fine horizontal grid points of 16 km every 3 hours. To assess the quality of the numerical model estimates at various spatial and temporal scales, in-situ and remotely sensed data are used. Indeed, Previous studies (e.g.; Small, 2008; Chelton et al, 2005; Bentamy et al, 2007) suggested that scatterometer retrievals could be used to objectively assess the surface winds derived from numerical models. It was shown that the scatterometer wind observations capture fine features that can be used to investigate the spatial and temporal characteristics of surface wind speed and direction derived from the regional atmospheric model ALADIN.

This paper investigates how ALADIN estimates the 10-m wind in comparison with the surface winds retrieved from the NASA SeaWinds scatterometer onboard QuikSCAT satellite over the Northwest Atlantic region and during 2003–2006 period. To assess ALADIN and QuikSCAT comparisons, available in-situ data are also used. Comparisons are performed on the Regional *Ocean* Model System (ROMS) grid points. Indeed, the present study results will be used to assess the oceanic simulations based on ALADIN forcing experiments. The latter is out of scope of this paper. The present paper is organized as follows: the section 2 provides a description of ALADIN model, QuikScat, and in-situ

wind data. Section 3 gives the comparisons between the numerical model, the scatterometer, and the in situ data. Section 4, presents the comparisons spatial and seasonal basis. And section 5 summarizes and discusses the main results.

2. DATA

2.1 Model description

The Moroccan National Meteorology Center (Direction de la Météorologie Nationale (DMN)) uses for its operational numerical system for weather prediction based on the model ALADIN (Aire Limitée Adaptation dynamique Développement International) since 1996 (ALADIN TEAM, 1997). It is a cooperative project that started in 1990 and involved 15 European countries, Morocco and Tunisia. The application based on ALADIN and routinely used at DMN is called ALBACHIR. The project goal was to develop the limited area of the global Météo-France spectral model ARPEGE (Action de Recherche Petite Echelle Grande Echelle) and to have a tool for dynamic adaptation to the limit of the hydrostatic approximation. In this study, ALADIN is used in the hydrostatic mode with a horizontal resolution of 16 km and an integration of 675 s for the four years of simulation. The model spatial grid is interpolated at 0,08 ° horizontal grid spacing, yielding to the horizontal map of 119 x 160 grid points. The number of vertical levels is 37. The grid is used as a lambertian projection of the geographical area. The model is coupled with the global model ARPEGE and the pattern of relaxation of border areas is provided by the technique of Davies Kallberg (B. Ahrens et al, 2002). The initialization is done through the implementation of digital filters. The vertical discretization (hybrid coordinates introduced by Simmons and Burridge (1981)) and physical parameterizations are from the ARPEGE model without any change. The semi-implicit and semi-Lagrangian correction schemes are applied. The model performs its own analysis of data by various methods including the optimal interpolation and three-dimensional variational technique. The physical parameterizations included in the model are quite complex and are related to stratiform precipitation, the vertical turbulent diffusion, and the drag of gravity waves, radiation and convection deep. The quality of ALADIN data are routinely investigated (www.cnrm.meteo.fr/aladin/spip.php).

More specifically, ALADIN surface winds used in this study correspond to the zonal and meridional wind forecasts at 10 m based on the 00:00 UTC analysis time. Data are available every 3 hours (00h:00, 03h:00, 06h:00, 09h:00, 12h:00, 15h:00, 18h:00, 21h:00 UTC) on regular latitude-longitude grid of 0.1°. The missing ALADIN wind data during the study period (2003 -2006) are replaced by the forecasts based on the 12:00 UTC analysis time. The former are associated with the following days 05/01/2003, 09/03/2004, 10/03/2004, 23/06/2005, 06/01/2006, 18/11/2006, 28/12 / 2006 and 30/12/2006.

2.2 Scatterometer data

The remotely sensed wind data are derived from the SeaWinds scatterometer on board the NASA QuikSCAT satellite (JPL, 2006). More specifically, this study uses the gridded wind fields estimated from QuikSCAT retrievals over the global ocean (Bentamy et al, 2002) and available at:
(http://cersat.ifremer.fr/fr/data/discovery/by_product_type/gridded_products/mwf_quikscat)

Their spatial resolution is 0.5° in longitude and latitude, whereas three temporal resolutions are available: daily, weekly, and monthly. In this study, the daily and monthly data are used. They have been estimated from rain free QuikSCAT observations based on a geostatistical method assuming the knowledge of the spatial and temporal structure function of surface wind speed, zonal component, and meridional component. The accuracy of the resulting QuikSCAT gridded wind fields have been estimated through various comparisons with averaged buoy wind data. The latter are mainly derived from moored buoys located offshore of United States and European coasts, and in the Atlantic and Pacific tropical regions. For instance the comparisons of daily buoy and QuikSCAT winds performed in the European Seas (Sotillo et al, 2005) indicated that the scatterometer wind speed and direction field accuracies (buoy minus satellite difference rms) are less than 1,50m/s and 24°, respectively. Better accuracy results are obtained when only buoy wind data greater than 5m/s are considered. The rms differences are reduced to 1,20m/s and 18° for wind speed and direction. Hereafter, the daily scatterometer wind fields are mentioned as QuikSCAT data.

2.3 Blended data

To enhance the spatial and temporal resolutions of surface wind, the remotely sensed retrievals are blended to the operational ECMWF wind analyses over the global oceans. The blending method aims to provide 6-hourly gridded wind speed, zonal component, meridional component, wind stress and the corresponding components at global scale. The spatial resolution of the resulting wind fields is 0,25° in longitude and latitude. The remotely sensed wind observations are derived from near real time measurements performed by Seawinds scatterometer onboard QuikSCAT satellite and by the three Special Sensor Microwave Imager (SSM/I) onboard DMSP satellites F13, F14, and F15. ECMWF analyses are available at synoptic time (00h:00; 06h:00; 12h:00; 18h:00) on a regular latitude-longitude grid of size 0,5625°×0,5625°. ECMWF analyses are interpolated in space and time over each satellite swath occurring within 3 hours from the synoptic time. The differences are evaluated at each scatterometer and radiometer wind cell of about 0,25° resolution. The former are used through an objective method to estimate global wind fields retaining first

ECMWF-QuikSCAT wind differences in swath regions, and in the temporal and/or spatial QuikSCAT unsampled areas, available and valid observed differences between ECMWF and SSM/I are used. SSM/I retrieved surface wind speed is considered as a regional variable. It is related on average to QuikSCAT wind speed through a linear relationship determined on one hand from QuikSCAT and buoy and on the other hand from SSM/I and buoy comparison results (Bentamy *et al*, 2002). More details about data, objective method, and computation algorithm may be found in (Bentamy *et al*, 2007 and 2009). In this study, only Blended wind estimates, covering the period 2005–2006, are available and used.

2.4 In-situ data

In-situ observations are derived from the DMN coastal synoptic stations (Figure 1). The main topic of using in-situ data is to provide a baseline of ALADIN and QuikSCAT comparison interpretation. These data are the hourly wind direction and wind speed, measured by the vane and anemometer instruments, 10 m above the ground. Wind measurements are performed at the following stations: Essaouira (31°31'N, 9° 47'W) Laayoune (27°10'N, 13°13'W) and Dakhla (23°43'N, 15°56'W). The meteorological station of Essaouira is located on island near the seaside; it is in the extreme southwest of the Tensift basin, it is bounded by the ocean in the west, the Hadid Cap in the north, the Sim Cap in the south and mountains in the east. The area is characterized by a temperate climate, where prevailing wind blows from the north to the northeast throughout the year. However, in winter and spring southwest wind passages, related to weather disturbances, are often observed. Situated in a Saharan plain at 25 km from the coast, the meteorological station of Laayoune is located at the same latitude of the Canary Islands. The area is characterized by a Saharan climate, with a prevailing wind blowing from the northeast in May and September and from the southwest in October and February. Dakhla station is located in Dakhla Airport on a plain at 800 m from the coast, and at 1300 m from Oued Eddahab almost on an island, it is bounded in the south and the west by the Atlantic Ocean and in the east by Wadi Eddahab and by the road from Boujdour in the north. The black Cap is located in the south of the city. The area is characterized by a Saharan climate; the prevailing wind blows constantly and moderately from the northeast.

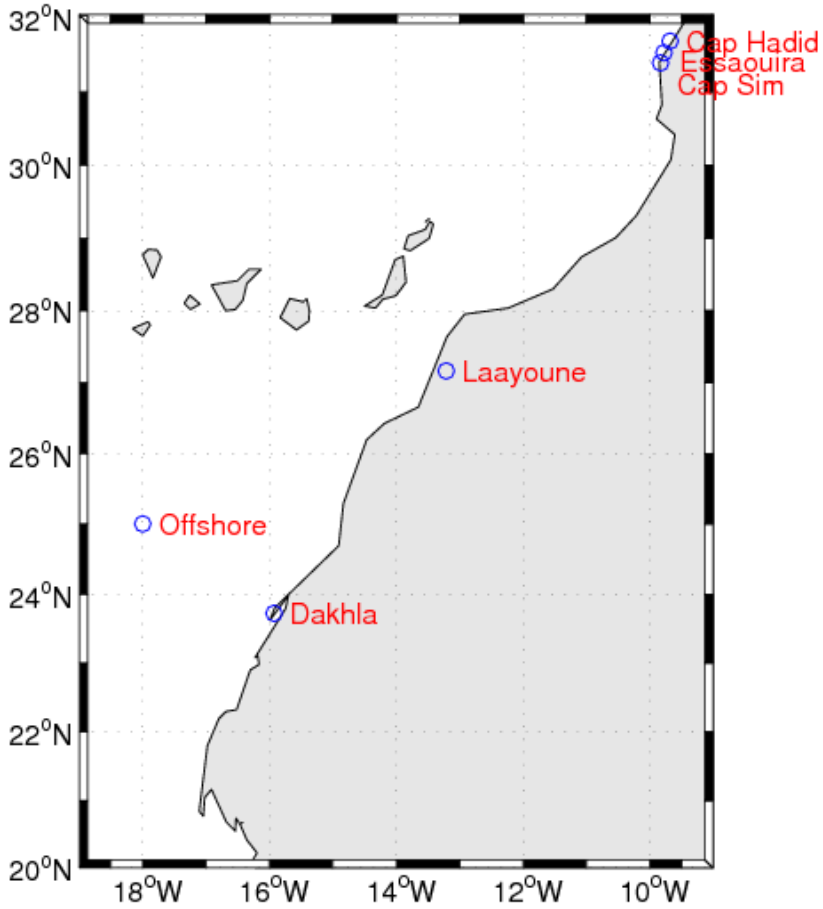


Figure 1: Northwest African study area. Circles indicate locations of ALADIN, in-situ and QuikSCAT comparisons.
La région d'étude Nord-Ouest africain. Les cercles indiquent les emplacements des comparaisons d'Aladin, in-situ et de QuikSCAT

3. LOCAL COMPARISONS

For comparison purposes, daily wind speed and components are calculated from ALADIN 3 hourly forecasts and from 6-hourly satellite Blended data. Numerical model and satellites are interpolated, using cubic spline procedure, on ROMS grid (32 °N, 20°N; 19°W, 9°W) which spatial resolution is 0,08° in longitude and latitude over the study oceanic basin. ALADIN model wind estimates have a spatial resolution close to the ROMS grid point. It is obvious that scatterometer data are over-sampled by the interpolation. To assess the impact of the spline cubic interpolation of scatterometer estimates, comparisons between the two interpolated data are performed for wind speed as well as for wind components. The mean differences are close to zero, and the associated standard deviation values do not exceed 0,5m/s.

Daily winds are also computed from the meteorological station measurements. The latter are collocated in space and time with the closest model, scatterometer, and Blended daily estimates. One should notice that the comparisons between the four sources involve data of different spatial and temporal structures. Table 1 and 2 summarises the wind speed and direction statistics estimated during the study period at the station sites. Overall, and based on the first and second statistical moments, the four sources provide quite similar wind vector characteristics. The winds at the three locations are mainly northeast to northwest with mean wind speeds close to the wind mean. Numerical model and in-situ, and especially scatterometer and in-situ wind comparison issues are challenging tasks. Indeed, the differences in spatial and temporal representiveness of each wind source may have significant impact on the comparisons. For instance, daily winds derived from scatterometer retrievals tend to be overestimated compared to in-situ data. Such results are associated with the differences between off- and near- coasts surface winds. In fact, daily scatterometer winds are estimated only from observations occurring at least 50 km off the coasts. We did an interpolation of satellite data on the grid for our study area. To fill the missing points in our data file, it was proceed for objective analysis (Package Roms_tools). However, QuikSCAT winds exhibit significant wind speed correlations, especially at Dakhla site. Even though the model wind speeds are closer to in-situ than scatterometer estimates; they are biased low against the three sites. More specifically, due to Essaouira station location, model as well as scatterometer exhibits significant biases versus in-situ. Model has a positive bias of 1m/s, whereas QuikSCAT has a negative bias exceeding 2,50m/s. One should notice that the difference between Essaouira station and model winds does not exhibit significant seasonal behaviour, whereas the in-situ and scatterometer departure is minimum and maximum during summer and winter seasons, respectively. High winds reported from coastal (in-situ) and off-shore (scatterometer) locations occurring during summer tend to be more consistent than low wind events. The best wind speed correlation, reaching 0,82, between in-situ and ALADIN is found at Dakhla site. Similar good agreement is obtained from Dakhla and QuikSCAT daily wind comparison, despite the DMN station location.

Table 1: Statistical parameters to those of In-situ, ALADIN, and QuikSCAT (QSCAT) daily wind speeds and their comparisons estimated at the meteorological stations Essaouira, Laayoune, and Dakhla, and the offshore location during 2005-2006 period. Std stands for standard deviation parameter.

Paramètres statistiques des données in-situ, ALADIN, et QuikSCAT (QSCAT) de la vitesse du vent journalier et leurs comparaisons estimé aux stations météorologiques Essaouira, Laâyoune, Dakhla et ainsi qu'au large pendant la période 2005-2006. Std pour le paramètre écart-type.

		Essaouira	**Laayoune**	**Dakhla**
Mean(Std)	In-situ	4,28(1.95)	6,47(2.64)	7,71(2,90)
	ALADIN	3,27(1.65)	5,17(1.94)	6,48(2,19)
	QSCAT	6,95(3,27)	6,93(2,59)	7,23(2,73)
	Blended	4,83(2,55)	6,58(2,32)	6,95(2,38)
Std Difference	Insitu/ALADIN	1,15	1,63	1,67
	Insitu/QSCAT	2,15	2,28	1,85
	Insitu/Blended	1,55	1,62	1,15
Correlation	Insitu/ALADIN	0,80	0,78	0,82
	Insitu/QSCAT	0,77	0,62	0,78
	Insitu/Blended	0,79	0,79	0,91

Table 2: Statistical parameters of In-situ, ALADIN, and QuikSCAT (QSCAT) daily wind directions and their comparisons estimated at the meteorological stations Essaouira, Laayoune, and Dakhla, and the offshore location and during 2005-2006 period. Std stands for standard deviation parameter.

Paramètres statistiques des données in-situ, ALADIN, et QuikSCAT (QSCAT) de la direction du vent journalier et leurs comparaisons estimé aux stations météorologiques Essaouira, Laâyoune, Dakhla et ainsi qu'au large pendant la période 2005-2006. Std pour le paramètre écart-type.

		Essaouira	**Laayoune**	**Dakhla**
Mean(Std)	In-situ	3(58)	26(48)	13(31)
	ALADIN	28(55)	13(43)	19(32)
	QSCAT	11(50)	22(39)	27(33)
	Blended	14(53)	16(40)	22(32)
Std Difference	Insitu/ALADIN	40	28	21
	Insitu/QSCAT	43	31	25
	Insitu/Blended	27	10	14
Correlation	Insitu/ALADIN	0,47	0,79	0,69
	Insitu/QSCAT	0,46	0,72	0,65
	Insitu/Blended	0,57	0,93	0,88

During the period 2005-2006, when Blended wind estimates are available for this study, the comparison of these data to in situ have the best statistics compared to ALADIN and QuikSCAT results. Indeed, the wind speed root mean square differences between in-situ and Blended daily data (*resp* in-situ/ALADIN and in-situ/QuikSCAT) are of 1,65m/s(*resp*. 1,63m/s and 3,37m/s), 1,67m/s(*resp*. 1,86m/s and 2,43m/s), and 1,33m/s(*resp*. 1,82m/s and 1,62m/s) at Essaouira, Laayoune, and Dakhla stations, *resp*ectively. The associated wind speed correlation coefficients are 0,79(*resp*. 0,77 and 0,75), 0,79(*resp*. 0,78 and 0,61), and 0,91(*resp*. 0,84 and 0,82)**.** Blended winds tend to improve both observed departure between in-situ and QuikSCAT, which is mainly related to the geographical locations, and the wind speed underestimation as found from in-situ and ALADIN comparisons.

Except at the Essaouira location, the statistics characterising the wind direction comparisons are comparable to the results obtained at different coastal and oceanic locations (e.g. Sotillo *et al*, 2005). The wind direction biases, estimated as mean differences between in-situ and model, and between in-situ and scatterometer, are relatively small. They vary between 2° and 14°. The associated standard deviation (Std) values are less than 31°. As for wind speed, the lowest differences of standard deviation (Std differences) are found at Dakhla station. The lowest agreement between in-situ and the two sources are found at Essaouira site. The Std values are about 40° while the correlations do not exceed 0,50. The main reason of such discrepancies is related to wind speed distribution associated with the station geographical location. Indeed, the in-situ daily wind speeds lower than 3m/s account for more than 28% of total time series, whereas it accounts for only 15% and 7% for Laayoune and Dakhla stations, respectively. Excluding station wind speeds lower than 3m/s lead to a reduction of the Std difference values to 29° for in-situ/ALADIN, and to 33° for in-situ/QuikSCAT. Furthermore, wind direction at the Essaouira station exhibits the highest variability among the three stations. Such wind behaviour may have an impact on the comparisons calculated from collocated data.

Despite of the geographical location and the surface wind representiveness, the Dakhla station is the only site among three where model and scatterometer exhibit quite similar results compared to in-situ data. Both have wind speed and wind direction standard deviation differences lower than 2m/s and 30°, which are particularly the QuikSCAT wind retrieval specifications. Even though ALADIN exhibits better results than QuikSCAT in terms of rms and correlation values, the associated bias value is high. It exceeds 1,20m/s, whereas the scatterometer bias is about 0,50m/s. ALADIN wind speed features are used as a baseline for the model and the scatterometer comparisons as shown in the next section.

4. REGIONAL COMPARISONS

This section aims to assess the comparisons of daily surface wind speed and direction derived from ALADIN, QuikSCAT, and Blended over the study region including coastal and open sea areas. In previous section, it was shown that the two sources (QuikSCAT, ALADIN) exhibit quite similar statistical results derived from comparisons with in-situ data. For instance at Dakhla location, the bias and standard deviation values of scatterometer minus ALADIN wind speeds (*resp*. wind direction) are about 0,70m/s (*resp*. 6°) and 1,70m/s (*resp*. 20°), respectively. The associated correlation coefficients are 0,77 and 0,76 for wind speed and direction, respectively.

Over the African northeast Atlantic region, the three wind fields exhibit similar large-scale spatial patterns (Figure 2). The annual highest winds occur in northeast open sea area and especially in its southern region. The lowest wind speed patterns are found along the Moroccan coasts between 28°N and 32°N on an annual basis. The spatial distributions of the correlation estimated between QuikSCAT/ALADIN (Figure 3) and between QuikSCAT/Blended (Figure 4) daily data (wind speed and components) at each grid point of the studied area show high and significant values. More than of 93% of correlation values exceed 0,80. The lowest correlations (about 0,50) are found at areas located between Canarian Islands and at the coastal area located between 28°N and 32°N. The main discrepancies between the three wind fields are found for the wind amplitudes and fine scale wind structures. Relative to QuikSCAT surface winds, the numerical model estimates are underestimated with a mean difference value of 1,70m/s. However, one should notice that very high differences are found near coast areas and at Canarian island lee sides due to the Venturi effect not captured by the radar. The former are mainly due to the extrapolation of daily 0,50°×0,50°degree resolution QuikSCAT data to ROMS grid point. Excluding these areas, the overall bias between QuikSCAT and ALADIN is reduced to 0,70m/s, the rms differences are quite low and do not exceed 1,50m/s, while the associated correlation coefficients are higher than 0,80. The rms differences of wind components indicate that the fluctuations have some preference for north-south orientation associated to the surface wind characteristics in this region (Figure 2). Blended winds tend to improve the comparisons with QuikSCAT estimates for wind speed as well as for wind components (Figure 4). Even though, Blended wind speeds are also underestimated compared to QuikScat data, the overall bias is about 0,40m/s. The corresponding rms and correlation values are about 0,56m/s and 0,97, respectively. Slight improvements are also depicted near coasts and at the islands lee side.

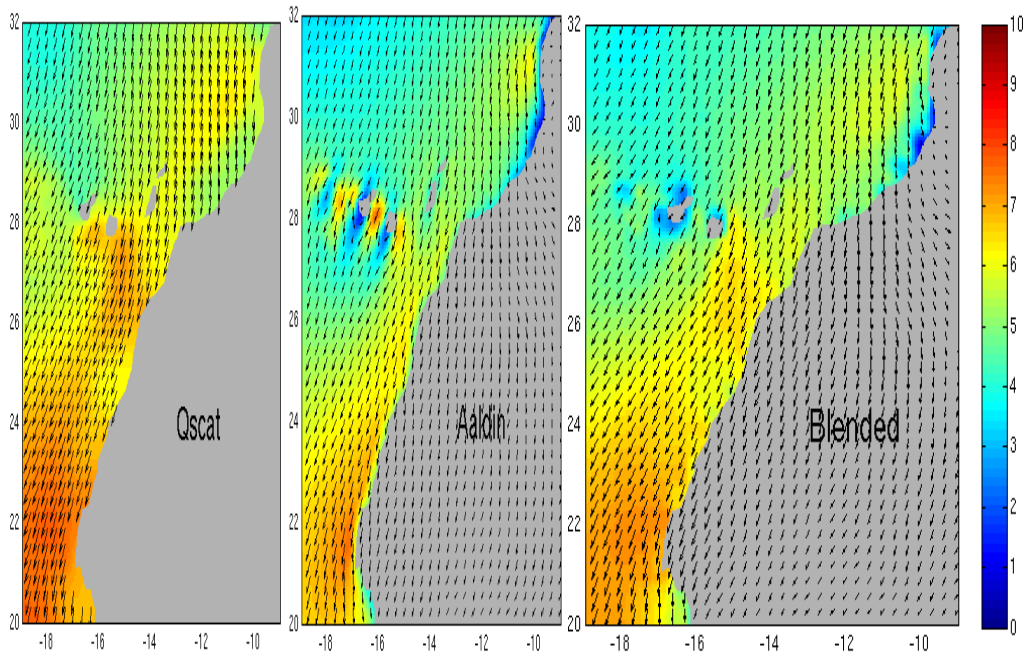


Figure 2: Mean wind speed (in color) and direction (arrows) calculated from daily QuikSCAT, and Aladin data during the period 2003–2006, and from Blended estimates during 2005-2006 over ROMS grid.
Vitesse moyenne du vent (en couleur) et la direction (en flèches) calculée à partir de QuikSCAT journalier, et les données Aladin au cours de la période 2003 2006, et à partir des données Blended au cours de 2005-2006 sur la grille ROMS.

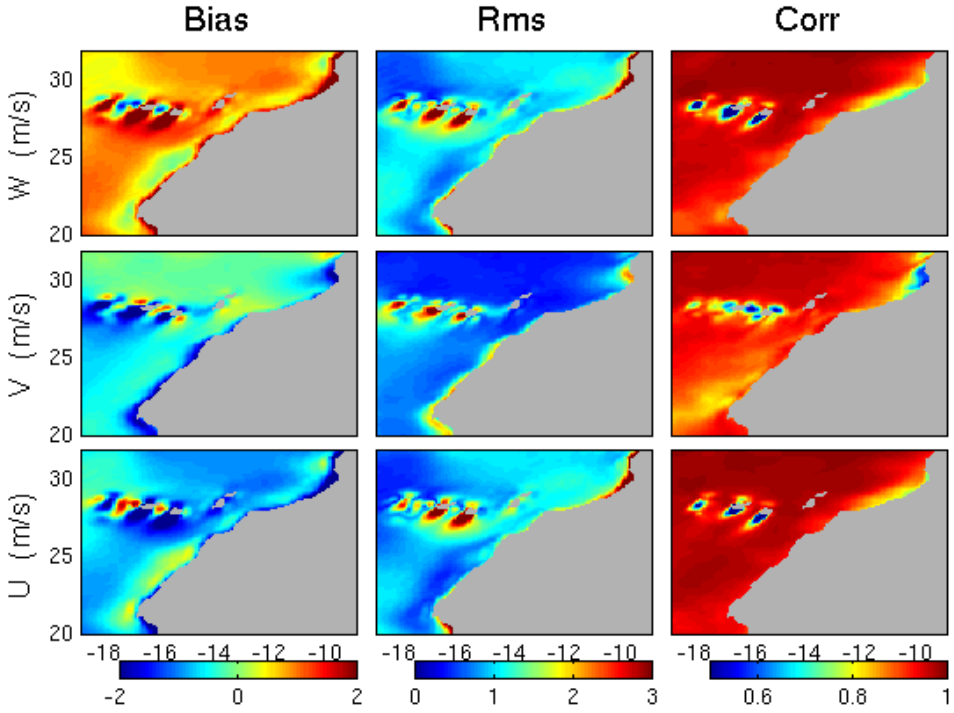


Figure 3: Spatial distribution of mean (1st column), rms (2nd column) differences between QuikSCAT and ALADIN, and of the associated correlation (3rd column) of wind speed (1st raw), zonal component (2nd raw), and of meridional component (3rd raw), estimated from daily data from 2003 to 2006.

Distribution spatiale de la moyenne (1re colonne), rms (2e colonne) et les différences entre QuikSCAT et ALADIN, et de la corrélation associées (3e colonne) de la vitesse du vent (1re ligne), composante zonale (2e ligne), et de la composante méridienne (3e ligne), estimé à partir des données journaliers de 2003 à 2006.

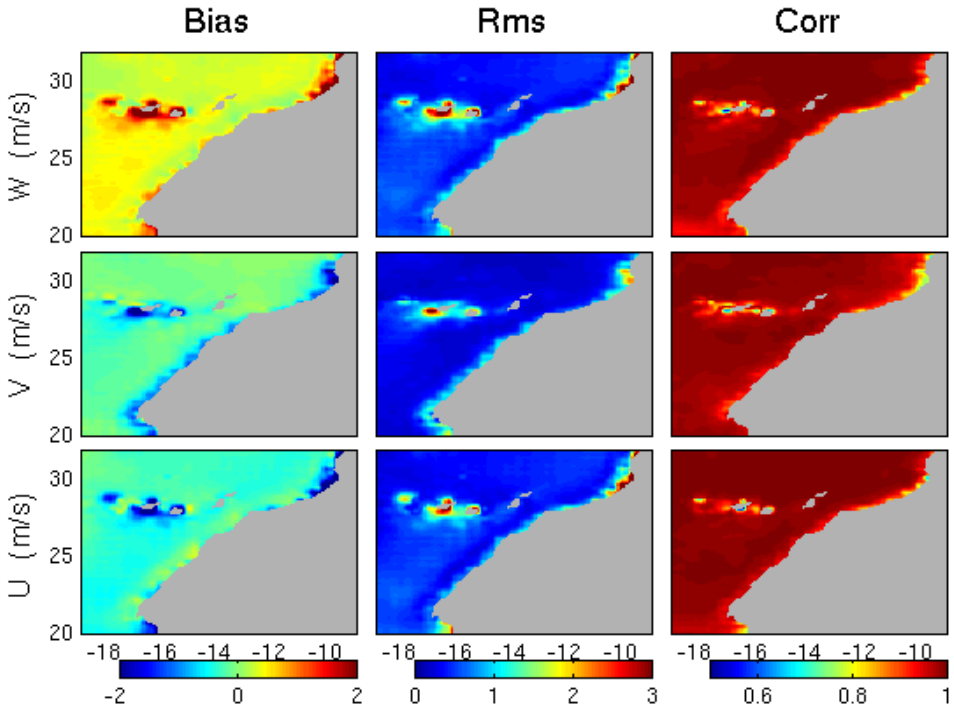


Figure 4: Spatial distribution of mean (1st column), rms (2nd column) differences between QuikSCAT and Blended and of the associated correlation (3rd column) of wind speed (1st raw), zonal component (2nd raw), and of meridional component (3rd raw), estimated from daily data from 2005 to 2006.

Distribution spatiale de la moyenne (1re colonne), rms (2e colonne) et les différences entre QuikSCAT et Blended, et de la corrélation associées (3e colonne) de la vitesse du vent (1re ligne), composante zonale (2e ligne), et de la composante méridienne (3e ligne), estimé à partir des données journaliers de 2005 à 2006.

Seasonal patterns (not shown) are also depicted in wind speed differences, especially between QuikSCAT and ALADIN. Maximum differences, reaching 1,50m/s, occur during fall and winter season. In contrast, differences are much smaller during spring and summer season; most of them do not exceed 0,50m/s. The last seasons are related to high wind periods. For instance, on July, both QuikSCAT and ALADIN provide the highest winds of the year, with a mean difference close to zero. In contrast, the difference between QuikSCAT and Blended data does not exhibit any significant seasonal patterns, even though its values are positive during the whole period 2005–2006 and vary between 0m/s and 0,60m/s

5. WIND STRESS VARIABILITY

The spatial and temporal patterns of wind stress and especially of the wind stress curl are essential to investigate the impact of the oceanic surface wind forcing in the study area. As shown in the previous section, the three wind sources exhibit uniform alongshore winds. Consequently, they push water offshore in surface Ekman layer due to the Earth's rotation. Previous studies (e.g. Pickett et al, 2003) stated that Ekman pumping from wind stress curl could be as important as Ekman transport from alongshore winds. Indeed, wind stress curl generates ocean-surface divergence (convergence), forcing upward (downward) water movements. Therefore, it is relevant to better quantify the relative importance of Ekman processes derived from ALADIN, QuikSCAT, and Blended winds. The results will be used to highlight difference sources in oceanic simulations related to wind forcing.

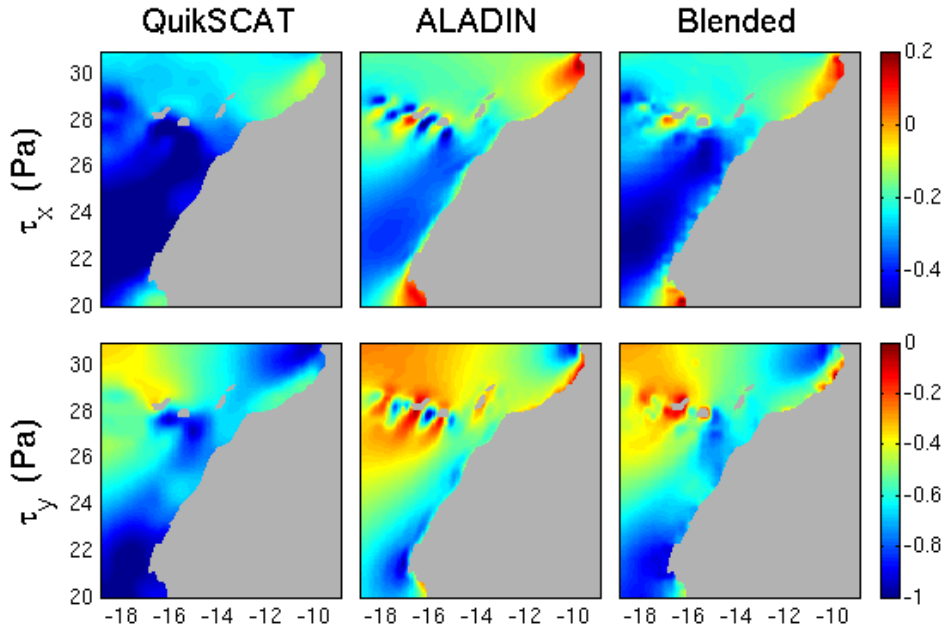


Figure 5: Averaged zonal (top) and meridional (bottom) wind stress component fields from QuikSCAT (1st column), ALADIN (2nd column), and Blended (3rd column), calculated over the period 2005–2006.
La moyenne zonale (en haut) et méridionale (en bas) de la composante du champ stress du vent de QuikSCAT (1re colonne), ALADIN (2e colonne) et Blended (3e colonne), calculé sur la période 2005-2006

Wind stress vectors are estimated from ALADIN daily wind vectors, interpolated over ROMS grid point, based on the Large and Pond parameterization (1981), generally used in atmospheric and ocean studies (Koraçin *et al*, 2004). QuikSCAT daily wind stress fields are objectively calculated from wind stress over swath (Bentamy *et al*, 2002). The latter are estimated from scatterometer wind observations using Smith model (1988). Blended daily wind stress fields are calculated as a mean of the 6-houly wind stress fields. The Blended wind stress is estimated based on Smith parameterization. Figure 5 shows averaged zonal and meridional wind stress component fields during the period 2005–2006. As expected (see Figure 2) the three sources exhibit quite similar large-scale patterns . The highest wind stress values coincide with the strongest winds, which are off Sim Cape and Hadid Cape near Essaouira, south of Dakhla and between the Canary Islands. A large area of low wind stress lies on the coast across the bay of Agadir. The coastal wind vector and wind stress spatial distributions are also similar. The main differences between the three wind stress vector fields are found in amplitudes highly related to wind speed differences (Figure 4) and amplified due to the bulk parameterizations which are different in the calculation of wind stress from satellite and from model data. The maximum differences are found near the coast of Essaouira and the Canary Islands, reaching a maximum of about 0,12 Pa. The lowest discrepancies are depicted in offshore areas of the studied region and on the southern coast of Essaouira across the bay of Agadir. Figure 6 points out the differences between the three wind stresses according to whether they occur in coastal and off-coast areas. They show the meridional behaviors of wind stress along Essaouira (Figure 6a), Laay-

oune (Figure 6b), and Dakhla (Figure 6c) locations, from ALADIN, QuikSCAT, and Blended data. They clearly illustrate and confirm the above results. At the latitude of Laayoune wind stress decreases slightly but remains quite close to QuikSCAT estimates, which is not in full agreement with the pattern results published by Koraçin *et al* (2003). The wind stress decreasing towards coasts is more valuable at Dakhla latitude, mainly for ALADIN and Blended data. Such pattern is not retrieved from QuikSCAT. The most remarkable wind stress decreasing towards coasts is found at Essaouira latitude. Such behavior is mainly retrieved from Blended and especially from ALADIN estimates. The model seems to involve the effect of the Cape Sim and Cape Hadid. The vicinity of the Canary Island in conjunction with continent may have significant impact on the observed wind stress decreasing at Laayoune latitude.

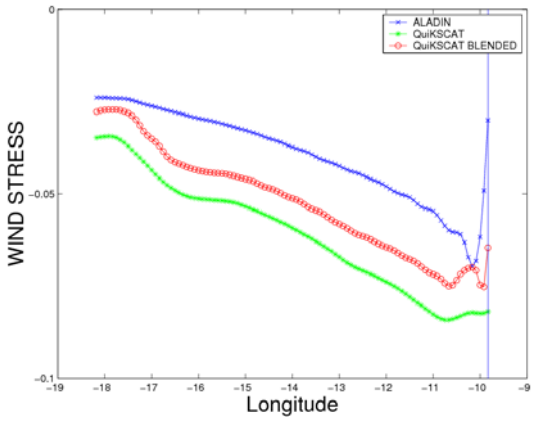


Figure 6a: The evolution of wind stress from the offshore to the coast in Essaouira over the period 2005-2006.
L'évolution du stress du vent du large à la côte d'Essaouira sur la période 2005-2006.

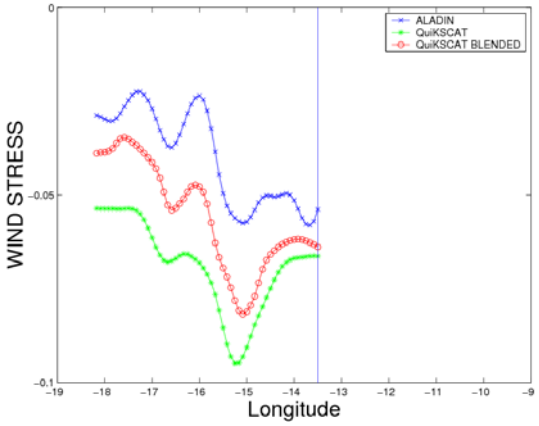


Figure 6b: The evolution of wind stress from the offshore to the coast in Laayoune over the period 2005-2006.
L'évolution du stress du vent du large à la côte de Laayoune sur la période 2005-2006.

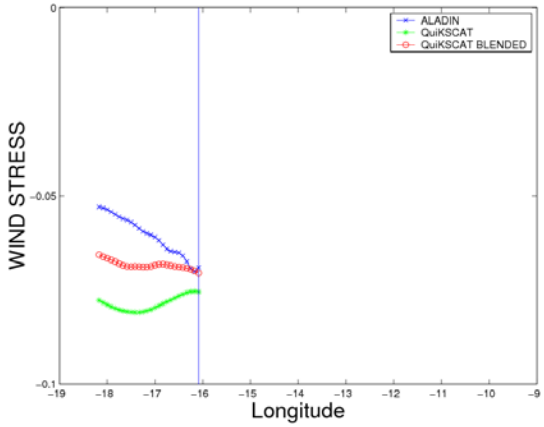


Figure 6c: The evolution of wind stress from the offshore to the coast in Dakhla over the period 2005-2006.
L'évolution du stress du vent du large à la côte de Dakhla sur la période 2005-2006.

As expected from the wind stress component agreement, the averaged wind stress curls have similar patterns at offshore areas (Figure 7). They indicate a maximum positive value near Essaouira, although confined to the coast and reaches 0,2 10^{-6} N/m^2 (ALADIN). This maximum may be due to the acceleration of winds associated with Cape Hadid. Generally speaking, wind stress curl calculated from ALADIN wind vectors exhibits higher values near the coast and in the Canary Island vicinity in comparison with QuikSCAT and Blended estimates. Such results are expected due to the scatterometer sampling scheme and to the interpolation over the ROMS grid map. One should notice that Blended wind stress tend to recover the numerical model coastal behaviors. In the areas located about 50 km to 100 km off North-West African coast, QuikSCAT provides the highest wind stress values of 0,5 10^{-6} N/m^2. Similar patterns are found in Blended data, whereas ALADIN wind stress curl estimates are seems to be realistic results.

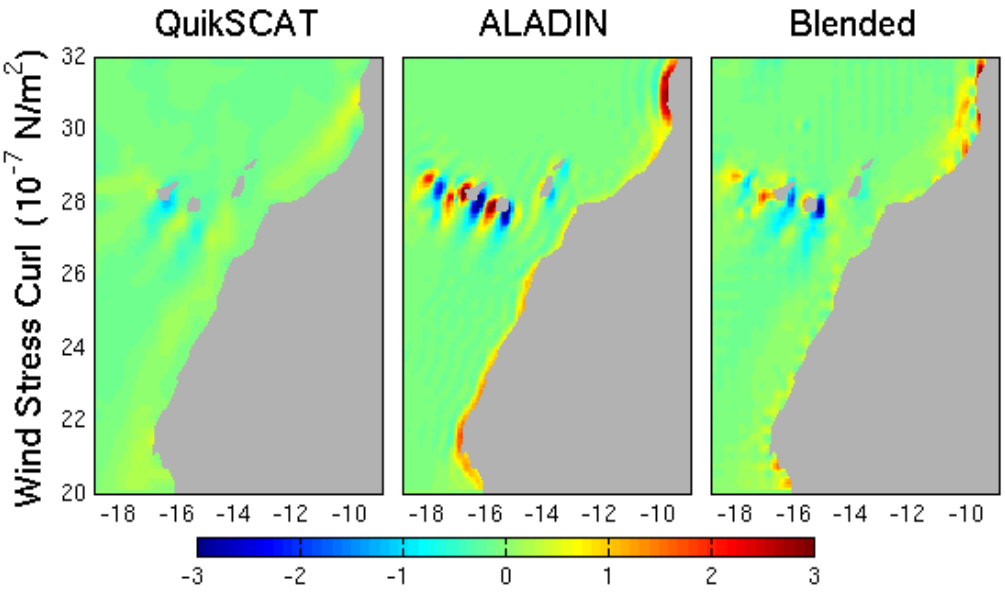


Figure 7: Averaged wind stress curl from QuikSCAT, ALADIN, and Blended, calculated over the period 2005–2006.
La moyenne du rotationnel de la tension du vent de QuikSCAT, ALADIN, et Blended, calculé sur la période 2005-2006

6. CONCLUSION

This paper presents a first assessment of the numerical description of 10 m winds forecast by the operational model ALADIN using QuikSCAT scatterometer and Blended wind data over the oceanic region located off-coats of the North West African continent. The latter is known as an important upwelling region. The main topic of this study is the investigation of the accuracy of the forecast model ALADIN in terms of surface wind speed and direction (or the zonal and meridional components) at 10-m. The relatively large amount of forecast and observed surface winds (4 years of data) allows a statistically adequate comparison. For instance, the derived comparison results underline the importance of the numerical modeling description of the orography and its impact on surface wind features.

The comparisons between ALADIN and QuikSCAT wind speeds performed at the meteorological stations indicate high correlation coefficients exceeding 0,70. The highest correlation value of 0,84 is found at Dakhla where orography impact is quite small. The correlation between in-situ and ALADIN model data (and also QuikSCAT) exhibits the lowest value at the Essaouira site. Possible reasons for this behavior are both the resolution of the model, which is not sufficient to resolve the details of the topographical effect over the coastal area; moreover the satellite cannot perform measurements near the coast; in addition there are effects of landforms: Cape Sim and Cape Hadid.

The comparisons performed over the whole study area indicate that QuikSCAT and Blended are highly correlated. Indeed the zonal wind component correlation coefficients exceed 0,90. Also, high variability of QuikSCAT is observed in comparison to ALADIN and Blended data during all seasons: it is about 2 ms^{-1} to 2,5 ms^{-1} with little difference observed between the three products for both components; this small difference is of the order of 0,5ms^{-1}. The topographical effect was noticed on variability, which is induced by the Capes, the bay and islands on the wind and thus on the phenomenon of upwelling. Some differences between the simulations and satellite estimates can be attributed to the nature of the QuikSCAT data that are given on daily basis, while the model data correspond to the daily average of the eight 3-hour outputs. The simulated wind field is in good agreement with in-situ, QuikSCAT and Blended data even though there are significant differences between the 3 types of data in term of the measurement techniques, calculation methods and resolution. This latter is of 0,17° for the model while it is 0,5° for QuikSCAT and 0,25° for Blended products. Note that the scatterometer data are contaminated by land in the satellite measurement near the coast with accuracy of 2 ms^{-1}.

Finally, QuikSCAT measurements, Blended data and ALADIN simulations give consistent spatial and temporal behavior over the oceanic regions west of the southern Morocco.

Acknowledgements

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