COMPARISON OF SATELLITE DERIVED OCEAN SURFACE WIND SPEEDS AND THEIR ERROR DUE TO PRECIPITATION

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ABSTRACT

The combination of passive and active microwave satellite data products should give new and improved insight into the structure and development of sub-synoptic scale circulation systems in the Earth's atmosphere, as e.g. polar lows, comma clouds and tropical cyclones. The present study focuses on wind speeds in severe storm systems derived from microwave radiometers and altimeters in comparison with related products from the Envisat mission. Especially, the influence of precipitation on the accuracy of wind speed estimates is analysed through this combination technique. Preliminary results suggest only minor errors through undetected signal contamination by precipitation.

Key words: Ocean surface wind speeds; rain attenuation; sensor intercomparison.

1. INTRODUCTION

The weather and climate of the extratropical latitudes are dominated by synoptic scale cyclones. Also mesoscale cyclonic systems of various dimensions and intensity are observed over the extratropical oceans, some of which are of large impact on the weather and climate of the European coastal regions and even continental Europe. These systems include small and short-lived cyclones, known as polar lows, which form poleward of the main baroclinic zone over high latitude oceans. Polar lows are often associated with strong winds and heavy precipitation, posing a serious danger to ships and coastal facilities. Because of their short life times and the remoteness of the genesis regions, not much is known about their phenomenology, origin and life cycle. Due to the lack of meteorological in-situ data, it can be argued that the most reasonable approach for studies about sub-synoptic scale systems is one that makes use of different satellite sensors. Especially the combination of passive and active microwave satellite data products should give new and improved insight not only into the structure and development of these systems, but also into the accuracy of satellite retrieved meteorological parameters in extreme weather situations. The focus of this study is on colocated wind speeds (u_{10}) in severe storm systems including polar lows, atmospheric fronts and comma-clouds over the eastern North Atlantic Ocean derived from QuikSCAT, Jason-1, Envisat and HOAPS (Hamburg Ocean Atmosphere Parameters and Fluxes from Satellite Data). The retrieval of satellite wind speeds in the presence of precipitation is crucial and will be evaluated through this combination techique. Satellite based wind speeds and colocation methods are described in section 2, followed by the results in section 3. First comparisons with Envisat ASAR wind speeds are given in section 4.

2. SATELLITE WIND SPEEDS AND COLOCATION METHODS

2.1. HOAPS-3

The Hamburg Ocean Atmosphere Parameters and Fluxes from Satellite Data (HOAPS, http://www.hoaps.org) is a completely satellite based climatology of precipitation, evaporation and all basic state variables needed for the derivation of these fluxes over the global ice free oceans. Except for the SST, all variables are derived from SSM/I passive microwave radiometers. The HOAPS-3 wind speed algorithm uses a neural network to derive wind speeds at 10 m height above the sea surface. It consists of 3 layers: an input layer with 5 neurons (19V, 19H, 22V, 37V, 37H), a hidden layer with 3 neurons and an output layer with one neuron (wind speed). The network was trained with a composite dataset of buoy measurements and radiative transfer simulations. The HOAPS-S dataset, which is used in this study, contains all retrieved physical parameters in the original SSM/I scan resolution (that is 50 km for wind speed) for every individual satellite. Horizontally polarized channels are more sensitive to the wind speed signal than vertically polarized channels, particulary at the SSM/I incidence angle [1]. Since surface roughness increases brightness temperatures, any phenomenon that roughens the ocean surface can result in erroneous wind speeds. Therefore wind speed is not accurate in heavy rain, and even light rain can degrade the signal. Additionally, virga and cloud water affect the SSM/I signal. Pixels containing substantial atmospheric contamination (rain) are filtered in HOAPS-3 to avoid misdetection of wind speeds. The detection is

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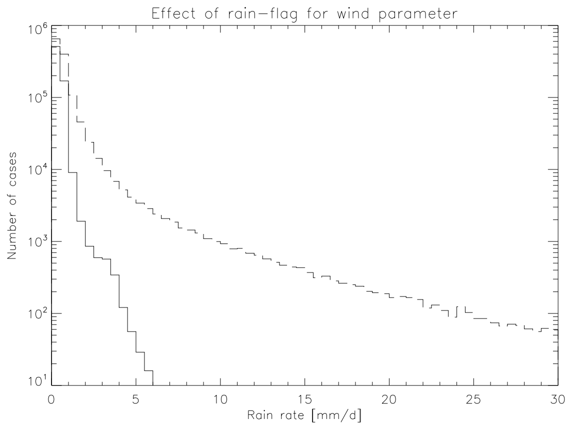

Figure 1. Number of pixels in bins of 0.5 mm/d width against rain rate resulting from 15 randomly selected days of scan data of all different SSM/I radiometers. The dashed line shows the number of all pixels containing rain rates greater 0. The solid line shows the number of pixels in which atmospheric contamination is detected and which are flagged.

done by brightness temperature thresholds for 19 and 37 GHz channels. If one of these thresholds is exceeded the corresponding pixel is flagged and wind values are not calculated. Fig. 1 shows the efficiency of this procedure. The number of pixels in which atmospheric contamination is detected and which are flagged is decreasing very fast by several orders of magnitude with increasing rain rates, indicating the performance of the filter. For rain rates above 6 mm/h all pixels are flagged.

2.2. Dual frequency altimeters

The Jason-1 and Envisat altimeters are two out of three most recent dual-frequency altimeters which are currently in space (the third one is TOPEX/Poseidon). The second frequency is aimed at the determination of the ionospheric electron content, which affects the radar signal path delay. Launched by the end of 2001, Jason-1 is the first follow-on to the TOPEX/Poseidon mission. The primary instrument is the Poseidon-2 altimeter which operates at 13.6 GHz (Ku band) and 5.3 GHz (C band). The second generation radar altimeter (RA-2), launched in March 2002 onboard Envisat, emits pulses at Ku band and S band (3.2 GHz). The Envisat and Jason-1 satellites carry microwave radiometers to correct the atmospheric path delay due to water vapor. Altimeter measurements are limited to nadir observations and are primarily dedicated to ocean topography. However, wind speeds are also estimated through relationships with the Ku band backscatter coefficient. Additionally, significant wave height is included in the wind speed model function for Poseidon-2. The main effect of rain on altimeter data is the attenuation of the pulse through absorbing rain drops which increases with frequency [2]. Additionally, rain roughens the sea surface and changes its radar cross section. To identify pixels contaminated by rain, rain flags are assessed from a combination of microwave radiometer liquid water and the difference between the backscatter derived from the altimeter frequencies. Altimeters provide high-resolution information of several kilometers. Regarding the colocation of altimeter and HOAPS wind speeds every HOAPS pixel that lies within a circle of 22.5 km radius from the center of the altimeter footprint is compared to the altimeter pixel. As for all other comparisons of satellite wind speeds presented in this study the maximum time difference between colocated values is not larger than two hours.

2.3. QuikSCAT

The SeaWinds scatterometer was launched in June 1999 on board the QuikSCAT satellite. SeaWinds collects backscattered power at Ku band via dual pencil beam scans at 46° and 55° incidence angles. Like the Envisat and Jason-1 altimeter, the SeaWinds scatterometer retrieves wind speeds through a relation with the Ku band backscatter coefficient. The influence of rain on QuikSCAT wind speeds is comparable to that on altimeter data. However, the integration path through the atmosphere is longer since QuikSCAT incidence angles are greater than 45°. This implies that atmospheric effects to the Ku backscatter due to rain are more significant [3]. For colocation with HOAPS wind speeds every HOAPS pixel that lies within a circle of 22.5 km radius from the center of the QuikSCAT footprint is compared to the QuikSCAT pixel.

3. COMPARISON OF SATELLITE DERIVED WIND SPEEDS

Scatterplots of satellite derived ocean surface winds for a region over the North Atlantic (40°W to 20°E longitude and 20°N to 80°N latitude) are calculated including several comma cloud, atmospheric front and polar low cases. A two-dimensional linear regression is applied to quantify the coherence between the different datasets. The correlation coefficient is calculated and a t-test is applied based on a level of significance of α=0.05. The t-test shows that the results are significant in all cases presented.

Fig. 2 shows wind speed from the Envisat altimeter against that from HOAPS. There is a good agreement between both datasets resulting in a high correlation of 0.949 ± 0.005. The root mean squared error (rms) is 1.63 m/s and the bias 0.804 m/s. Wind speeds reach values greater than 15 m/s in most of the raining cases. For those wind speeds the agreement between HOAPS and the Envisat altimeter is very good. The main result is that the rms and bias are smaller for the raining cases than for the the non-raining cases. The datapoints are much more spread for lower wind speeds, especially between 7 m/s to 15 m/s. A closer look at the data indicates that

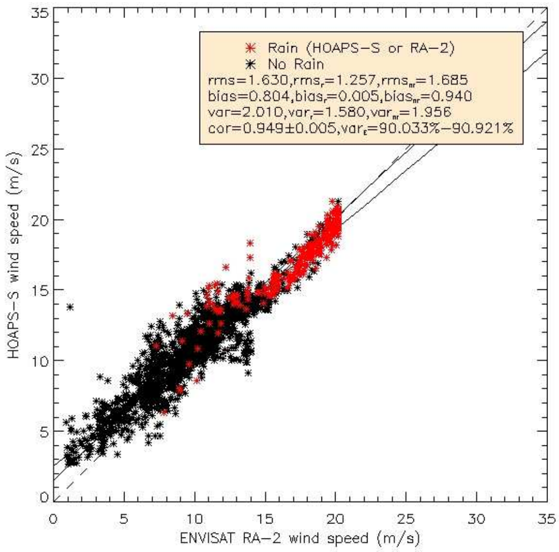

Figure 2. Envisat altimeter against HOAPS wind speed for 1752 colocated wind speeds over the eastern North Atlantic Ocean. Cases with HOAPS rain rates greater than 0 mm/hr or Envisat altimeter rain flag eq 1 are marked with red color. The dashed line is the refernce line (f(x)=x). The other two black lines result from a two-dimensional linear regression. The root mean squared error (rms), the bias and variance of the error (var) are given for all datapoints, for the red datapoints (subscript r) and the black datapoints (subscript nr). The correlation coefficient (cor) and the variance explained by the two-dimensional linear regression (var_ϵ) are also given.

these are cases where the altimeter crossed atmospheric fronts, passed an ice-edge or has been close to the coast. The time difference between the HOAPS and the altimeter satellite passes may lead to differences in wind speeds especially in those cases. Additionally, the different resolutions of the remote sensing systems leads to deviations in wind speeds. The sharp cut at 15 m/s may physically be related to the effect of sea foam which becomes dominant for values greater than 15 m/s. The two lines resulting from a two-dimensional linear regression show that HOAPS seems to overestimate low and underestimate high wind speeds. This is also the case for the wind speed comparisons given below.

The Jason-1 altimeter against HOAPS wind speed is shown in Fig. 3. The correlation between HOAPS and Jason-1 altimeter wind speeds is 0.912 $\pm$ 0.007, which is smaller than the correlation between HOAPS and the Envisat altimeter wind speeds. The rms is 2.119 m/s and the bias 1.013 m/s. The rms is larger for the raining than for the non-raining cases but the opposite is the case for the bias. The agreement between the different datasets is better for wind speeds lower than 5 m/s than for higher ones. In most of the raining cases the wind speed reaches values above 10 m/s. The largest deviations seem to be associated with rain. But since those are only very few

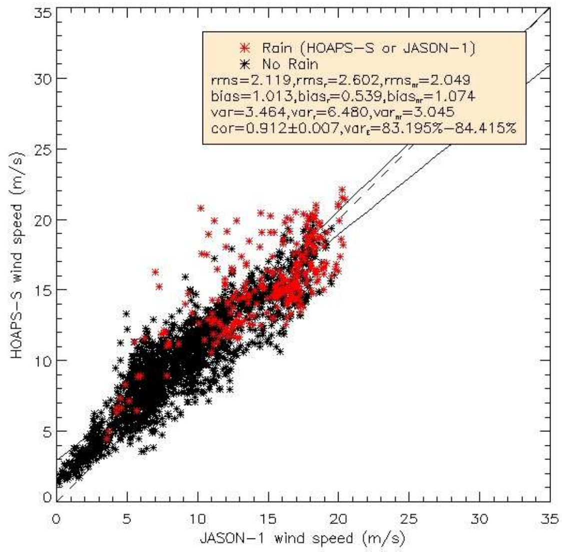

Figure 3. Colocated wind speeds as in Fig. 2, but for Jason-1 altimeter against HOAPS wind speed (2445 cases).

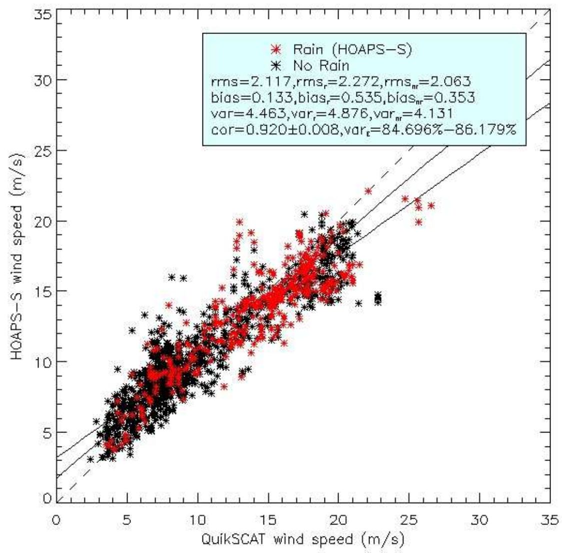

Figure 4. Colocated wind speeds as in Fig. 2, but for QuikSCAT against HOAPS wind speed (1399 cases).

cases, the error due to contamination of the signal by precipitation does not seem to be significant.

The QuikSCAT versus HOAPS wind speed is presented in Fig. 4. The correlation between HOAPS and QuikSCAT wind speeds is 0.920 $\pm$ 0.008. The wind speeds have a rms of 2.117 m/s and a bias of 0.133 m/s. The raining cases are spread almost equally over all wind speed values, although there is a tendency towards winds peeds above 10 m/s like in the comparison between HOAPS and the Jason-1 altimeter wind speeds. The rms and bias are higher in raining than in non-raining cases. Some of the largest deviations between HOAPS and QuikSCAT wind speed are again associated with rain but these are also few compared to the remaining cases.

4. FIRST COMPARISONS WITH ENVISAT ASAR WIND SPEEDS

In the following colocated satellite wind speeds from a dual polar low event, which is also included in the wind speed comparisons above, will be presented. In the morning of 15 March 2005 two comma-shaped polar lows developed near the Norwegian coast (see Fig. 5). The southern polar low propagated eastwards and reached the Norwegian coast in the evening of 15 March 2005. For this time an Envisat ASAR image is available allowing the verification of the position of the cyclone center and the determination of high resolution wind speeds (see Fig. 6). HOAPS and Jason-1 altimeter wind speeds are overlaid on the Envisat ASAR wind speed. The time difference between HOAPS and Envisat is about one and a half hour, but inspections of AVHRR images show that the polar low remained nearly stationary between the two satellite observation times. The time difference between the Jason-1 altimeter and the ASAR wind speeds is about 10 minutes and therefore negligible. There is a high level of agreement bewteen the several wind speed estimations. The increase in wind speed around the center of the polar low is detected by all sensors.

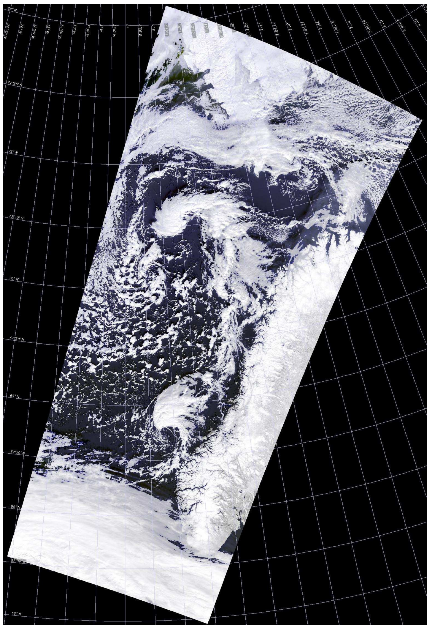

Figure 5. MERIS true-color image showing two polar lows on 15 March 2005 at 10:55 UTC near Norway.

Fig. 7 shows HOAPS precipitation overlaid on ASAR wind speed. This allows the detection of patterns in the ASAR image that might result from rain. According to [4] the ASAR radar return can be affected by raindrops impinging on the ocean surface and generating roughness that dampens the wind-generated capillary waves. Additionally, rain can affect the radar signal propagation path through the atmosphere. The highest precipitation rates of about 3 mm/h occur to the west of the eye of the polar low. Since some of the HOAPS wind speed pixels at and near the eye were flagged as being contaminated by atmospheric effects, there might be an influence on the ASAR data as well. This question must further be evaluated in future research.

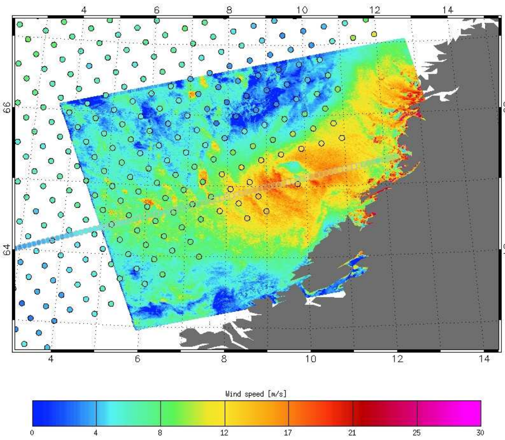

Figure 6. Wind speed calculated from an Envisat ASAR WS image with the CMOD-IFR2 algorithm for 15 March 2005 at 20:45 UTC. The resolution of the ASAR wind speeds is 300 m. Overlaid are HOAPS wind speeds (black encircled dots) and Jason-1 altimeter wind speeds (grey encircled dots).

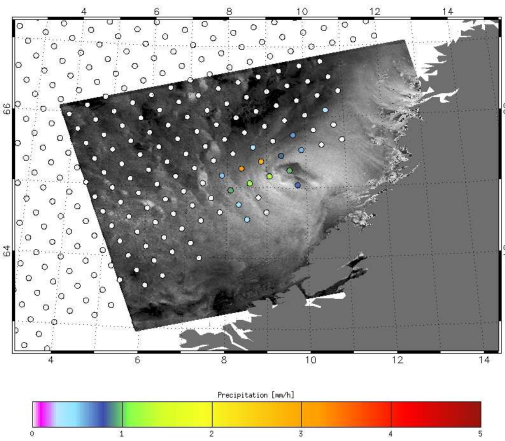

Figure 7. Wind speed calculated from Envisat ASAR as in Fig. 6 but now shown in shades of grey. Overlaid are HOAPS precipitation rates (black encircled dots).

5. CONCLUSIONS

Wind speeds from active remote sensing systems have been compared to passive microwave data from HOAPS for several comma cloud, atmospheric front and polar low cases over the eastern North Atlantic Ocean. The analysis has shown that HOAPS overestimates low and underestimates high wind speeds compared to the wind speeds derived from active remote sensors. Satellite derived wind speeds in high latitude severe storm systems in the eastern North Atlantic Ocean are associated with a rms of about 2 m/s. The best agreement was found between HOAPS and Envisat altimeter wind speeds with a correlation of 0.949 ± 0.005 and an rms of 1.630 m/s. Although undetected signal contamination by precipitation may result in large deviations between colocated wind speeds, the influence of precipitation on HOAPS wind speed does not seem to be significant since those cases are only few compared to the remaining cases. Deviations in wind speeds basically result due to different satellite observation times and different resolutions of the remote sensors. The different frequencies and algorithms used for the derivation of wind speed and different viewing angles further contribute to the wind speed deviations. First comparisons with Envisat ASAR wind speeds for a polar low event near Norway show a high level of agreement between the different data sets. HOAPS data may help to identify rain contaminated pixels in ASAR images.

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