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METEOROLOGY

Impact of the ASCAT scatterometer winds on the quality of HIRLAM analysis in case of severe storms

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Abstract. The impact of the Advanced Scatterometer (ASCAT) data assimilation on the quality of HIRLAM analysis is assessed in cases of rapidly developing severe storms of 2013. The HIRLAM quality is analysed for two observing system experiments: with and without the ASCAT data assimilation. Mainly impact on the model analysis output is evaluated. Marine observations of 10-m wind speed and mean sea level pressure are used as measures of quality. The results show that depending on ASCAT data coverage in the HIRLAM domain and temporal availability of the data at the assimilation time moment, the impact may be either more or less accurate. It is also detected that some narrow places of the Baltic Sea (Bothnian Bay, Gulf of Finland) are not affected by the ASCAT data assimilation. According to the ASCAT Wind Product specification, ASCAT measurements near the shoreline are usually flagged as land contaminated. The ASCAT winds in these areas are not admitted to the analysis after the procedure of the HIRLAM quality control, most likely due to the proximity to the land. The use of the ASCAT Coastal Wind Product in the future may enlarge the ASCAT data coverage in these areas. In addition, some weaknesses of the ASCAT data assimilation were detected in the study raising the question of the optimal ASCAT data usage. Further attempts to improve the quality of the HIRLAM analyses are expected in the ASCAT data thinning before assimilation or by reducing time differences between the HIRLAM analyses.

Key words: ASCAT, marine winds, storm, HIRLAM, data assimilation, experiments.

List of acronyms and abbreviations

3DVAR – Three-Dimensional Variational data assimilation
AIREP – AIRcraft REPorts
AMO – Assimilated Marine Observations
ASCAT – Advanced Scatterometer
ASCEXP – Experiments with ASCAT data assimilation
BSH – Federal Maritime and Hydrographic Agency of Germany
C-band – 4.0–8.0 GHz electromagnetic spectrum frequency range
DRIBU – DRIfting BUoys
EARS – EUMETSAT Advanced Retransmission Service
ECMWF – European Centre for Medium-Range Weather Forecasts
EUMETSAT – European Organization for the Exploitation of Meteorological Satellites
FGAT – First Guess at Appropriate Time
HARMONIE – Hirlam Aladin Regional/Mesoscale Operational NWP in Europe
HIRLAM – HIgh Resolution Limited Area Model
IMO – Independent Marine Observation
KNMI – Royal Netherlands Meteorological Institute
MARNET – MARine Environmental Monitoring NETwork in the North Sea and the Baltic Sea
MET Norway – Norwegian Meteorological Institute
Met Office – UK's national weather service
MetOp – Meteorological Operational satellite
MSLP – Mean Sea Level Pressure
NWP – Numerical Weather Prediction
O–A – Surface-based Observation minus HIRLAM Analysis
O–B – ASCAT Observation minus HIRLAM Background
OSCAT – Oceansat-2 scatterometer
OSE – Observing System Experiments
OSI SAF – Ocean and Sea Ice Satellite Application Facility
PILOT – Pilot-balloon stations
QuikSCAT – Quick Scatterometer
REFEXP – Experiments without ASCAT data assimilation
RMSE – Root Mean Square Error
SHIP – Synoptic observations from ships
SD – Standard Deviation
SYNOP – Surface synoptic stations
TEMP – Upper air soundings
UTC – Coordinated Universal Time
WVC – Wind Vector Cell

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1. INTRODUCTION

The Advanced Scatterometer (ASCAT) on the Meteorological Operational satellite (MetOp) of the European Organization for the Exploitation of Meteorological Satellites (EUMETSAT) is a C-band (5.255 GHz) radar, whose primary objective is to determine the wind field at the ocean surface (Figa-Saldaña et al., 2002). Scatterometers uniquely define the mesoscale wind vector field at the sea surface by measuring the radar backscatter signal (σ^0) from wind-generated cm-sized, so-called gravity-capillary sea waves (Stoffelen et al., 2006). It was found experimentally that the sensitivity to wind speed and direction describes well the changes in backscatter over the ocean at moderate incidence angles due to changes in surface roughness (OSI-SAF Project Team, 2013).

The ASCAT mission has been primarily designed to provide global ocean wind vectors operationally. The main applications are in the use of the high-resolution ASCAT winds in operational nowcasting and assimilation of marine winds into Numerical Weather Prediction (NWP) models (Figa-Saldaña et al., 2002; Stoffelen et al., 2013).

Most general weather centres such as ECMWF (European Centre for Medium-Range Weather Forecasts), Met Office (UK's national weather service), Japan Meteorological Agency, and Environment Canada already use the ASCAT data in the data assimilation process. The ECMWF was the first centre that assimilated the ASCAT winds into the global NWP model in 2007 and showed a positive effect on forecast skills, especially over the southern hemisphere where the number of marine observations is limited. In addition, for ocean waves a significant positive impact was observed in the tropics (Hersbach and Janssen, 2007).

The impact of the ASCAT data assimilation into numerical models is mainly analysed for global models and in general, the impact is neutral to positive (Hersbach and Jannsen, 2007; Bi et al., 2010; Payan, 2010; Takahashi, 2010). More recent studies of the ASCAT-A and ASCAT-B (ASCAT measurements from MetOp-A and MetOp-B) data assimilation into the ECMWF by De Chiara et al. (2014) also show a positive effect when either or both the ASCAT data sets are assimilated together with Indian Oceansat-2 scatterometer (OSCAT) data. The impact of scatterometer observation results for severe storms such as tropical cyclones was also evaluated by De Chiara et al. (2014) showing generally the benefit into the model analyses and forecasts. Cotton (2013) evaluated the impact of the ASCAT-A and ASCAT-B scatterometer data assimilation into the global model of Met Office. To better exploit data from parallel ASCAT-A and ASCAT-B operations a new thinning scheme is proposed.

For limited area models the Master's Thesis by Ollinaho (2010) indicated a positive to neutral impact on the forecasts of the High Resolution Limited Area Model (HIRLAM) (Undén et al., 2002), which serves as the main NWP platform for short-term (up to three days) operational weather forecasting and NWP applications in many European countries. However, the impact of ASCAT assimilation was assessed only by means of station data over land. De Valk (2013) in his paper compared HIRLAM experiments with assimilated ASCAT winds and without ASCAT assimilation with data from moored buoys, ships, and coastal stations. The results showed that over land there is no significant difference between analyses minus first guess for both experiments, the same as for wind forecasts differences (3-hour forecast, 6-hour forecast); over sea the patterns remain only partly visible. Both De Valk (2013) and De Haan et al. (2013) analysed the impact of the ASCAT data assimilation into the HIRLAM (during a period of 10 weeks and shorter) and reported positive results. Valkonen and Schyberg (2015) assessed the impact of the ASCAT assimilation into the Hirlam Aladin Regional/Mesoscale Operational NWP In Europe (HARMONIE) model in case of severe storms and showed a slightly positive impact on forecasts in comparison with observations over land.

The general aim of our work was to assess the impact of the ASCAT data assimilation into the HIRLAM analysis in case of extreme events such as severe storms. The study is concentrated on the Observing System Experiments (OSEs) to inspect the analysis output quality and differences in the analysis output with ASCAT data assimilation and without it. The wind speed at 10-m height and the Mean Sea Level Pressure (MSLP) are compared with observations over marine areas. It is slightly different from the study by Valkonen and Schyberg (2015) where the impact of ASCAT data assimilation on the forecasts over land was assessed. In addition, the differences between the ASCAT observations and model background (O–B) and also between the model analysis after ASCAT assimilation (O–A) are inspected to assess how well the system is set for ASCAT winds.

The synoptic situations of severe storms can develop dramatically and accurate calculations of model analysis may improve the quality of forecasts of severe weather. As HIRLAM is the operational weather prediction model used in the Estonian Weather Service it is relevant to check if any significant differences arise from the assimilation of ASCAT winds and which approach could be more accurate.

The structure of this paper is as follows. Section 2 presents the data and methods of the current study and consists of four subsections. First, an overview of severe storm cases is given, then observational data (ASCAT ocean surface wind product and marine surface-based measurements) are described. Next, an overview of the HIRLAM model and the data assimilation system applied in the Estonian Weather Service is presented. Section 3 shows the results: analyses of the model experiments are compared with surface-based measurements in three different case studies and then the differences ASCAT O–B and O–A are analysed. Finally, Section 4 summarizes the results of the study and draws conclusions.

2. DATA AND METHODS

2.1. Severe storm cases

In the current study three different cases of severe storms in 2013 were selected to investigate the impact of satellite-based measurements on the HIRLAM analysis output with the emphasis of the ASCAT data impact on the storm initialization accuracy. The storm cases were chosen to contain the highest possible density of the ASCAT stormy wind measurements (over 15 m s^{-1}) in the marine areas of the HIRLAM modelling domain (Fig. 1), where the impact of the ASCAT data is expected to be visible.

The first study case is the strong storm on 28 October 2013, named in Germany Christian, in Denmark Allan, and in the UK St Jude. The storm moved across northern Europe and caused massive damages and disruptions. The impact of the storm was considerable. At least 15 people perished, a large number of trees were blown down, power supply broke down, train connections were interrupted, streets were impassable, and the Øresund Bridge between Denmark and Sweden had to be closed (Storch et al., 2014). In Germany, peak wind speeds ranking 11 (28.5–32.6 m s^{-1}) and 12 ($\geq$32.7 m s^{-1}) on the Beaufort scale were observed at many stations along the coasts of the North and Baltic seas as well as further inland, with a maximum of 47.7 m s^{-1} at St Peter Ording, a location facing the North Sea (Storch et al., 2014).

The second stormy wind case of 1 December 2013 observed in the current study was not so dramatic as the event in October. However, as the storm took place in the Baltic Sea region it was possible to analyse the impact of the ASCAT winds for the closed marine area near the Baltic countries.

The third interesting case is the severe storm Xaver (05.12.2013), where the ASCAT measured widely winds over 20 m s^{-1}, indicating the high power of the storm. The storm moved across northern Europe and caused severe winds with gusts of hurricane force across northern Germany and at higher sites. Shipping and rail traffic were shut down in several places and flights were cancelled. In addition, dangerous street conditions and road accidents affected by the storm Xaver were reported in other European countries. More than 10 people died Europe-wide due to the storm (Deutschländer et al., 2013).

2.2. The ASCAT ocean surface winds

The ASCAT ocean surface winds provided by the EUMETSAT as the ASCAT Wind Product give information about the equivalent-neutral wind speed and direction at 10 m above the sea surface. Scatterometer data are organized into the so-called Wind Vector Cells (WVCs), the averaged wind solution in the centre of a defined grid box. Two types of the ASCAT wind products are generally processed: with a grid spacing of 12.5 km at a spatial resolution of 25 km or with a grid spacing of 25 km at a 50 km resolution across and along two 550-km wide swaths on both sides of the nadir track. The radar backscatter measurements (σ^0) are provided in three azimuth directions: fore, mid, and aft pointing respectively 45°, 90°, and 135° away from the satellite propagation vector, to resolve the wind direction and speed (OSI-SAF Project Team, 2013). The translation of the radar backscatter measurements from the sea surface into the wind speed and direction is performed by a geophysical model function (Stoffelen, 1998). In addition, this model links the dependences of the backscatter signal from the frequency, polarization, and incidence angle of the emitted and returned microwave, as well as from the local wind direction, relative to the satellite azimuth look direction (Hersbach et al., 2007).

For each backscatter measurement the wind speed solution as a function of all possible wind directions is shown. Given the basic harmonic wind direction dependence of the backscatter signal, four solutions exist in this general case (Stoffelen, 1998). Each wind ambiguity is characterized by a solution probability that is determined based on the distance-to-cone residual in the wind inversion. The wind ambiguities, solution probabilities, and prior information from the ECMWF model (10-m background winds) are used in a two-dimensional variational ambiguity removal (2DVAR) procedure (Vogelzang et al., 2009) to produce the surface wind field. Most of the quality control and ambiguity removal procedure of the ASCAT data are carried out during the retrieval process.

The ASCAT Level 2 winds obtained for the current study were processed in near real-time by the Koninklijk Nederlands Meteorologisch Instituut (KNMI) (see http://www.knmi.nl/scatterometer) and afterwards disseminated to the users by EUMETSAT. Processing and further dissemination of operational ASCAT are performed in both global and regional frame. The regional product known as the EARS (EUMETSAT Advanced Retransmission Service) ASCAT Wind Product is acquired locally by the network of Advanced High Resolution Picture Transmission receiving stations, which helps to provide European countries with the ASCAT winds within 25 min after data acquisition. The ASCAT Level 2 Wind Product includes information on the backscatter measurements, selected wind solution from

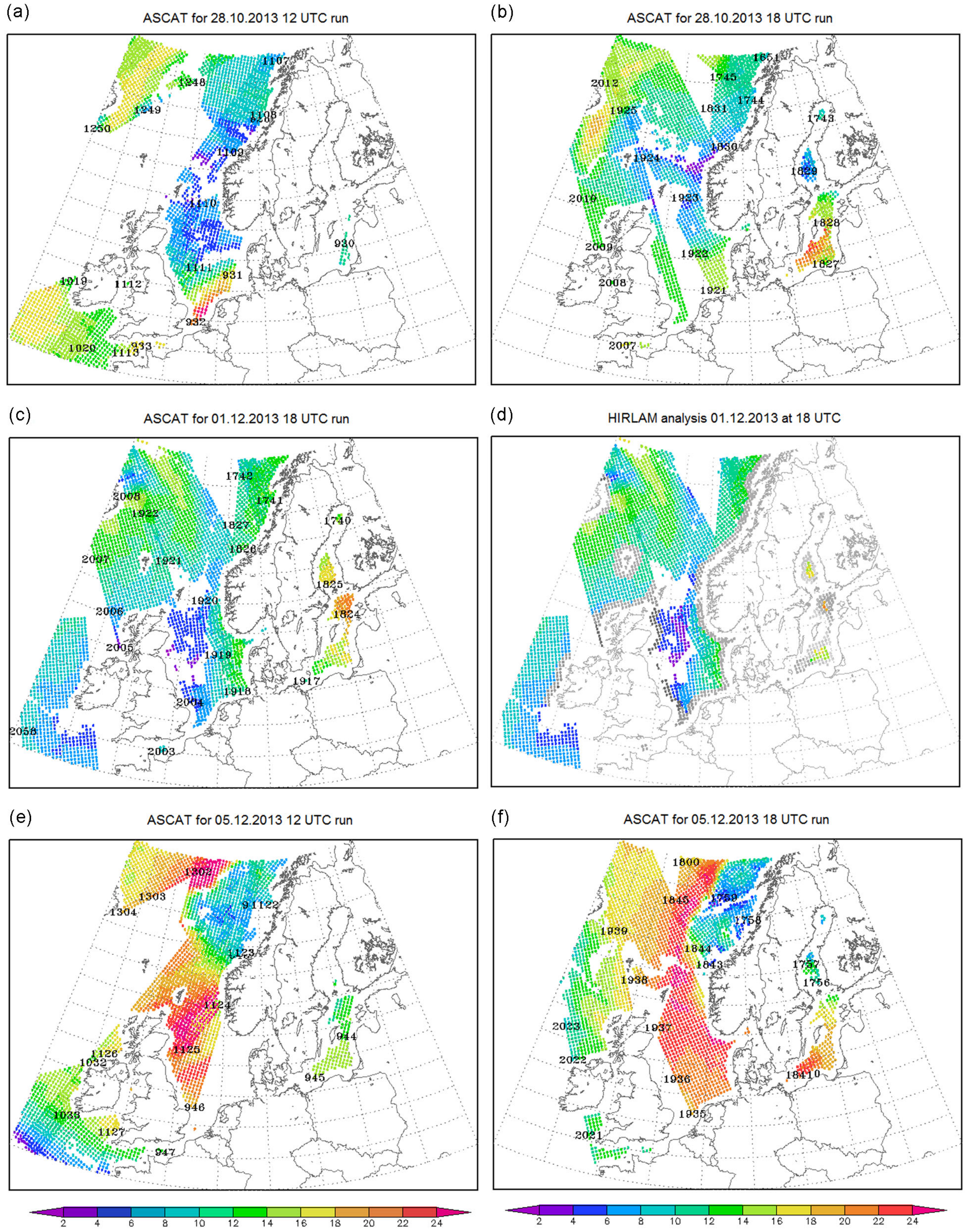


Fig. 1. Coverage of the EARS ASCAT overpasses in HIRLAM assimilation windows at 12 UTC and 18 UTC on 28.10.2013 (a, b), 01.12.2013 (c, d), and 05.12.2013 (e, f). HIRLAM analysis winds after ASCAT data assimilation at 18 UTC on 01.12.2013 (d): grey dots represent the ASCAT measurements rejected after quality control, probably due to proximity to the land. Three and/or four digit numbers in the figures show the ASCAT overpass time in UTC.

calculated ambiguous (up to four) wind solutions, scanning geometry, and the WVC quality flag in case of poor data quality (too large inversion residual, or too high noise value in the input product such as sea-ice or land contamination) among others. The procedure and improvements of the quality control performed at the KNMI are described in more detail by Portabella et al. (2012).

The coverage of the EARS ASCAT Level 2 data used in the HIRLAM assimilation window is not uniform during the day. The overpasses are quite sparse for HIRLAM 00 UTC and 06 UTC analyses while for HIRLAM analyses at 12 UTC and 18 UTC the HIRLAM domain is more densely filled with the ASCAT data (Fig. 1).

The accuracy of the ASCAT winds is validated against in situ wind measurements from buoys, platforms, or ships and against NWP data. Even better, the errors of all NWP model winds, in situ data, and scatterometer winds are computed in a triple collocation exercise. The performance is rather constant over the globe and depends mainly on the sub-footprint wind variability. The performance of the products issued by the Ocean and Sea Ice Satellite Application Facilities (OSI SAF) and EARS is characterized by a wind component RMS error smaller than 2 m s^{-1} and a bias of less than 0.5 m s^{-1} in wind speed (OSI-SAF Project Team, 2013).

In April 2013 the EUMETSAT began to disseminate operationally the ASCAT measurements from MetOp-B, which enlarged the coverage of the ASCAT measurements. As reported in the ASCAT Wind Product User Manual (OSI-SAF Project Team, 2013), both MetOp-A and MetOp-B ASCAT winds have the expected accuracy (compared with buoy data), the wind speed bias of –0.02 m s^{-1} for MetOp-A and 0.05 m s^{-1} for MetOp-B, the standard deviation is 1.78 m s^{-1} for MetOp-A and 1.80 m s^{-1} for MetOp-B. Buoy collocations and a triple collocation study made by Verspeek et al. (2013a) show also that there are no significant differences in wind quality between the ASCAT-A and ASCAT-B wind products; therefore ASCAT data from both satellites can be successfully used in operational work or in the data assimilation procedure. Verspeek et al. (2013b) used the so-called NWP Ocean Calibration (NOC) method to assess the errors of the ASCAT-A and ASCAT-B winds; data from the global oceans between latitudes 55°N and 65°S (sea ice-free areas) are used for this purpose. The error variances of the buoy data, ASCAT-A and ASCAT-B 25-km wind product, and ECMWF background winds showed standard deviations in line with the expected accuracy defined by OSI-SAF Project Team (2013). In our study both the ASCAT-A and ASCAT-B data are used for assimilation into HIRLAM.

2.3. Surface-based measurements

As the most significant impact of scatterometer observations on NWP forecasts is expected over sea and near-coastal regions, close to where the observations are made (De Valk, 2013), it is important to find out observations in marine areas on the HIRLAM domain. Two different types of observations are used for this purpose.

In our study we used two types of surface-based measurements: Independent Marine Observation (denoted here as IMO), which is not used in the HIRLAM data assimilation cycle, and Assimilated Marine Observations (denoted here as AMO), which belong to conventional data assimilated operationally into the HIRLAM. The IMO data are collected from moored buoys, lighthouses, lightships, oil platforms, and marine stations while the AMO data are collected mainly from islands or stations near the shoreline. The historical IMO data from UK Met Office buoys, lightships, and private industry oil platforms were obtained manually from the webpage http://www.wunderground.com/MAR/ukm.html. The measurements from Väderoärna buoy were provided by the Swedish Meteorological and Hydrological Institute; wind data from Vaindloo Island came from the Estonian Weather Service; marine data from some German buoys, lighthouses, and lightships were obtained via the Marine Environmental Monitoring Network in the North Sea and the Baltic Sea (MARNET) (http://www.bsh.de/en/Marine_data/Observations/MARNET_monitoring_network/index.jsp) and received from the Bundesamt für Seeschifffahrt und Hydrographie – Federal Maritime and Hydrographic Agency of Germany (BSH). In addition, it was a good opportunity to use the free access climate database http://eklima.met.no/ for marine data from the Norwegian Meteorological Institute (MET Norway). All surface-based measurements used in the analysis were carried out mainly at 12:00 UTC and 18:00 UTC, except measurements on the Kiel lighthouse with 09-min delay (at 12:09 UTC, 18:09 UTC).

An overview of IMO data is presented in Table 1. To adjust the wind speed to 10 m from buoys, lighthouses, and lightships, the method described by Hsu et al. (1994) was used:

$$u_2 = u_1 \left(z_2 / z_1 \right)^P , \tag{1}$$

where u_2 is the wind speed at the desired reference height z_2, u_1 is the wind speed measured at height z_1, P is an empirically derived coefficient that varies dependent upon the stability of the atmosphere. For neutral stability conditions P is equal to 0.11, which is more appropriate for open water surfaces (Hsu et al., 1994). As reported by Ingleby (2009), all selected here private industry oil platforms report the wind

Table 1. Overview of independent marine observational (IMO) data points. WMO is World Meteorological Organization, HEIGHT means the actual height of the anemometer or the level to which the wind measurements are adjusted, MSLP shows the availability of data for MSLP data verification

WMO ID	Name	Lat, deg	Lon, deg	Type	HEIGHT, m	Owned and maintained by	MSLP
	Vaindloo	59.8	26.4	Station	10	Estonian Weather Service	No
	Väderoärna	58.5	10.9	Buoy	3	SMHI Sweden	Yes
62105	K4	55.0	−13.2	Buoy	3	Met Office UK	Yes
62029	K1	48.7	−12.4	Buoy	3	Met Office UK	Yes
62103	Channel	49.9	−2.9	Lightship	14	Met Office UK	Yes
62107	Seven Stones	50.1	−6.1	Lightship	14	Met Office UK	Yes
62304	Sandettie	51.2	1.8	Lightship	14	Met Office UK	Yes
62142	North Sea	53.0	2.1	Oil platform	10	Private industry	Yes
62145	North Sea	53.1	2.8	Oil platform	10	Private industry	Yes
62144	North Sea	53.4	1.7	Oil platform	10	Private industry	Yes
62301	Aberporth	52.4	−4.7	Buoy	3	Met Office UK	Yes
62081	K2	51.0	−13.4	Buoy	3	Met Office UK	Yes
62120	E Scotland	56.4	2.1	Oil platform	10		Yes
62164	North Sea	57.2	0.8	Oil platform	10	Private industry	Yes
64046	K7	60.5	−4.2	Buoy	3	Met Office UK	Yes
63117	North Sea	61.3	1.1	Oil platform	10	Private industry	Yes
63110	North Sea	59.5	1.5	Oil platform	10	Private industry	Yes
63113	North Sea	61.0	1.7	Oil platform	10	Private industry	Yes
62095	M6	53.0	−15.9	Buoy	4.5	Met Office UK & Met Eireann	Yes
62303	Pembroke	51.6	−5.1	Buoy	3	Met Office UK	Yes
64045	K5	59.1	−11.7	Buoy	3	Met Office UK	Yes
1300	Gullfaks C	61.2	2.3	Oil platform	10	MET Norway	No
1402	Sleipner A	58.4	1.9	Oil platform	10	MET Norway	No
1309	Troll A	60.6	3.7	Oil platform	10	MET Norway	No
1404	Heimdal	59.6	2.2	Oil platform	10	MET Norway	No
1202	Draugen	64.4	7.8	Oil platform	10	MET Norway	No
1201	Heidrun	65.3	7.3	Oil platform	10	MET Norway	No
1200	Norne	66.0	8.1	Oil platform	10	MET Norway	No
66021	Arkona Becken	54.9	13.9	Buoy	10	BSH Germany	Yes
66022	Oder Bank	54.1	14.2	Buoy	9	BSH Germany	Yes
66024	Darsser Schwelle	54.7	12.7	Buoy	9	BSH Germany	Yes
	Kiel	54.5	10.3	Lighthouse	34	BSH Germany	Yes

measurements adjusted to 10-m height. In addition, marine winds measured in the Norwegian Sea are also adjusted to 10 m. Figure 2 shows the geographical location of IMO and AMO observations. The AMO measurements are carried out mainly on islands and chosen manually depending on the location from the shoreline or in case it has been established that the measurements can represent marine winds. However, the effects of slowing down the wind speed and wind turning caused by land friction have to be taken into account.

In addition to statistical calculations, a visual comparison of the wind speed and the MSLP analysis was made for both OSEs. The number values in figures represent the difference between observational data and analysis (O–A). Some data points with close locations were eliminated from figures for clarity's sake.

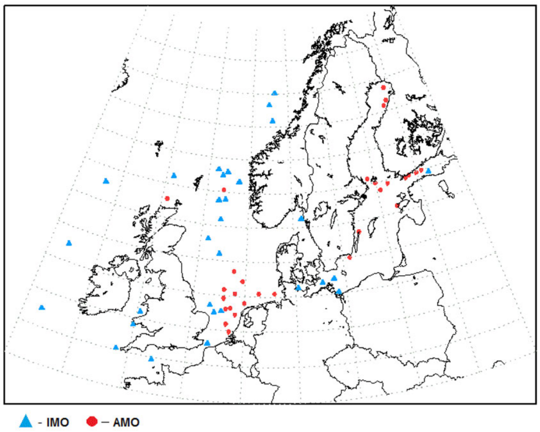


Fig. 2. Geographical location of the marine wind observations. The IMO datapoints are marked by blue colour, AMO datapoints are red.

2.4. HIRLAM and data assimilation

The HIRLAM is a hydrostatic grid-point model whose dynamics is based on a semi-implicit semi-Lagrangian discretization using hybrid vertical coordinates. The model equations and their numerical aspects are described in more detail by Undén et al. (2002). At present, the Estonian Weather Service uses the HIRLAM 7.4 version. The HIRLAM ETA domain, which covers with a horizontal resolution of 11.1 km the northern area of European countries, is used for OSEs. A more detailed overview of the HIRLAM environment in Estonia is presented by Männik et al. (2014).

The boundary fields for the HIRLAM operational model are provided by the ECMWF model. The 54-h forecasts of the HIRLAM are calculated four times a day with forecast starting-points at 00, 06, 12, and 18 UTC. Besides its usual application as the weather prediction model, the HIRLAM acts as the driving model for the local High Resolution Operational Model for the Baltic marine modelling system, which is currently used for storm surge warnings (Služenikina and Männik, 2011). In case of a positive impact of the ASCAT data assimilation on the HIRLAM, it may improve the quality of marine forecasts.

The current data assimilation system in the HIRLAM is Three-Dimensional Variational (3DVAR), the assimilation window is 06 h, −03 h from the analysis time, and +03 h ahead. Some conventional observations are generally assimilated into the local HIRLAM. The surface observations include the observations from synoptic stations (SYNOP), ships (SHIP), and from drifting buoys (DRIBU). The upper air observations include the measurements from radiosoundings (TEMP), aircraft reports (AIREP), and from pilot-balloon stations (PILOT). An overview of meteorological parameters assimilated into the HIRLAM is given in Table 2.

The First Guess at Appropriate Time (FGAT) is applied for both the conventional and ASCAT data assimilation in the operational HIRLAM. Traditionally, 3DVAR uses only a short-range forecast valid at the analysis time to compute the innovations (observations minus background); however, in the FGAT option all short-range forecasts are taken into account in the assimilation time window, and for each observation the closest forecast is selected (Huang et al., 2002). This option helps to approximate the model analysis time with observational data sampled at asynoptic time and to improve the accuracy of the model analysis output. However, in the HIRLAM 3DVAR this scheme is not used for in situ observations such as SYNOP, TEMP, and PILOT to avoid data redundancy associated with the assumption about a static observation increment (HIRLAM System Documentation, www.hirlam.org).

Table 2. Conventional observations assimilated into the HIRLAM 3DVAR system, where z is geopotential height, u is zonal wind component, v is meridional wind component, T is temperature, and q is specific humidity

	Observation type	Parameters assimilated
Surface	SYNOP	z
	SHIP	z
	DRIBU	z
Upper air	TEMP	u, v, T, q
	AIREP	u, v, T
	PILOT	u, v

The algorithm of the ASCAT data assimilation in the HIRLAM 7.4 is written by De Valk (2013) with John De Vries and is optional for calculations. The principle of SeaWinds Quick Scatterometer (QuikSCAT) satellite data assimilation is applied for the ASCAT. As the ASCAT and SeaWinds have different data structures, the reading routines had to be adapted. Once the wind vector cell information is ingested, the consecutive steps for the ASCAT and SeaWinds data assimilation are similar (De Valk, 2013). A more detailed description of the SeaWinds 3DVAR assimilation algorithm is given by Tveter (2006).

The spatial and temporal screening procedure of the ASCAT observations is performed before the admission of the ASCAT data into the HIRLAM analysis: location of each WVC is compared with the HIRLAM domain and the ASCAT observational time should fit into the time window of a given assimilation cycle. Then, the WVC quality flag from the ASCAT wind product is used to ensure the high quality of the backscatter measurements and successful inversion. The ASCAT data that are land or sea-ice contaminated as well as the data with the wind speeds exceeding 30 m s^{-1} are rejected during the quality control. In addition, the HIRLAM checks the number of ambiguities calculated for each WVC and takes the wind solutions only from the WVCs where up to two ambiguities exist. As the ASCAT wind information consists of wind ambiguities, no first-guess check is carried out and in the analysis variational quality control is not active for ASCAT (De Valk, 2013). The wind vector ambiguous solutions at each WVC are compared with the HIRLAM background winds, and the closest solution is finally selected, other wind solutions are rejected in the HIRLAM analysis.

It is well known that global models lack variance on scales below 200 km. As a consequence, the representativeness error of closely spaced observations (separated by less than 200 km) is correlated. However, nowadays assimilation systems assume uncorrelated observations. To account for this inconsistency, NWP centres apply data thinning and/or inflate the observation error variances to reduce the weight of the observations in the analysis (De Haan et al., 2013). In our study observational error for both wind components is 1.8 m s^{-1}, no data thinning or error inflation was applied for the ASCAT 25-km data assimilation as it is done by De Haan et al. (2013) and De Valk (2013); so more weight is given to the ASCAT observations.

In this paper two different OSEs are carried out: with ASCAT data (named 'ASCEXP') and without ASCAT data assimilation (named 'REFEXP'). As mentioned above, three different case studies are analysed:

- 28.10.2013 at 12 UTC and 18 UTC
- 01.12.2013 at 18 UTC
- 05.12.2013 at 12 UTC and 18 UTC.

The experiments are recalculated for the selected cases in the past using the backgrounds from the operational HIRLAM archive. For each case the calculations are started with the backgrounds one day before the cases at 06 UTC to avoid the 'cold start' of the model and the ASCEXP analyses are recalculated with the same method adding the ASCAT measurements in each analysis cycle. In the current study only results of OSEs analyses are compared with observations to investigate, first of all, the impact of the assimilation of the ASCAT winds into the model in case of a stormy wind situation. The bias, Root Mean Square Error (RMSE), and correlation coefficients calculated for both parameters are analysed. In addition, the differences between the ASCAT winds and model background winds (O–B) as well as model analysis after ASCAT assimilation (O–A) are calculated.

3. RESULTS

3.1. Storm Christian (St Jude, Allan) 28.10.2013

The case of the storm Christian is evaluated for two assimilation cycles at 12 and 18 UTC. The highest wind speeds measured by ASCAT for 12 UTC assimilation window were across the Belgian coast, the Netherlands, and Germany (max 25.8 m s^{-1}) and for 18 UTC assimilation window over the southern part of the Baltic Sea (max 23.9 m s^{-1}) (see Figs 1a and 1b).

The fields of the wind speed and the MSLP analysis at 12 UTC mainly differ in the centre of the storm Christian, as it is shown in Figs 3 and 4. The REFEXP calculated stormy winds in the larger marine area, while in the ASCEXP stormy winds are pressed together and shifted more to the east, and the area of weak winds has already developed in the tail of the rapidly moving storm. In addition, slightly stronger winds are calculated across the coastline of Belgium and the Netherlands in ASCEXP.

Verification with surface-based observations (O–A) detected wind speed underestimation in the tail of the storm, in some points even up to 7–8 m s^{-1}. The ASCAT measurements were significantly lower than the HIRLAM background winds before assimilation, but after data assimilation HIRLAM winds decreased (Fig. 3). What could be the reason that the ASCAT winds were lower than the actual winds? Haeseler and Lefebvre (2013) analysed the storm Christian in more detail and report that with the forward speed of 1200 km in 12 h, Christian was a rapidly moving low. On 28 October at 07 UTC

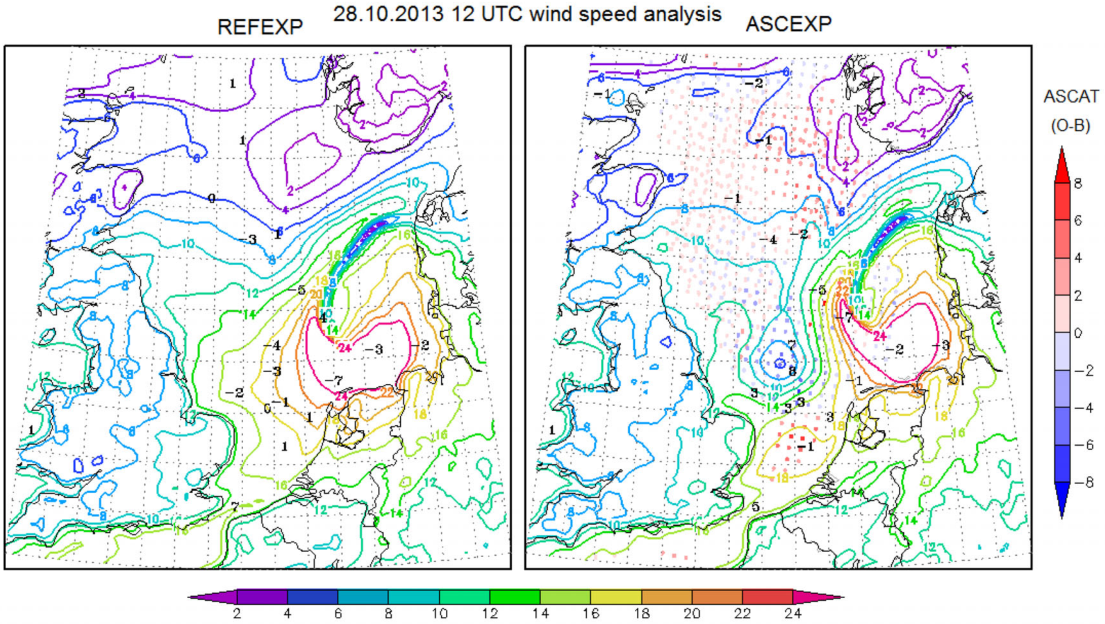


Fig. 3. The HIRLAM 10-m wind speed analyses 28.10.2013 at 12 UTC: REFEXP (left), ASCEXP (right). The number values: surface-based observation minus analysis (O–A); colour dots: ASCAT observation minus HIRLAM background (O–B) before assimilation.

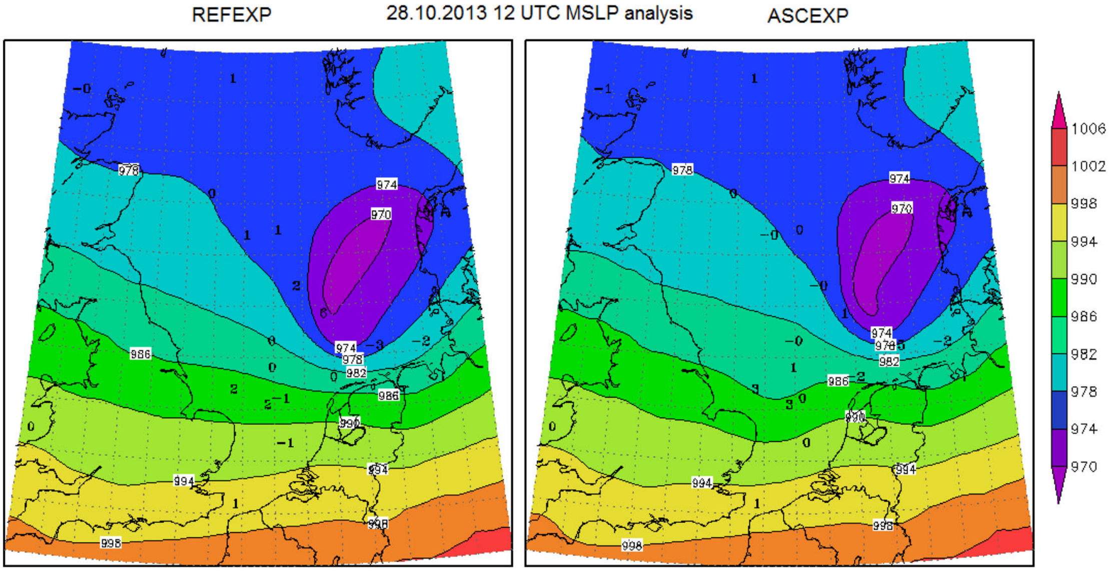


Fig. 4. The HIRLAM MSLP analyses 28.10.2013 at 12 UTC: REFEXP (left), ASCEXP (right). The number values: surface-based observation minus analysis (O–A).

the centre of the storm with a pressure of 977 hPa was located over the East Midlands, UK. Inspection of the ASCAT overpasses in the same area reveals that the ASCAT measurements were made at 09:31–09:32 UTC. This fact confirms that the centre of the low had moved slightly in two hours and that the ASCAT still gave accurate measurements. The problem lies in the fact that the ASCAT measured weaker winds in the tail of the moving storm in this time moment and the analysis at 12 UTC follows the ASCAT measurements made about two hours before the analysis time moment.

The statistics for wind speed and MSLP for 28.10.2013 at 12 UTC (Table 3) shows that the results of OSEs are either more or less accurate depending on the area of inspection. The most notable in the MSLP analysis is that the isobars between the UK and the Netherlands (Fig. 4) shifted slightly to the south in the ASCEXP. Deepening of the low in this region probably is related with the strong winds registered there by the ASCAT. In spite of this fact, the field of the lowest pressure is more accurate in ASCEXP, which is moved more to the east unlike the REFEXP.

The visual comparison of OSEs analyses for 28.10.2013 at 18 UTC (Fig. 5) does not show significant differences. In the ASCEXP the area of stronger winds is extended more to the southern part of the Baltic Sea and

Table 3. The HIRLAM REFEXP and ASCEXP bias, RMSE, and correlation (CORR) with observed values of the 10-m wind speed and MSLP 28.10.2013 at 12 UTC (left) and 18 UTC (right)

10-m wind speed					10-m wind speed				
20131028 12 UTC		BIAS	RMSE	CORR	20131028 18 UTC		BIAS	RMSE	CORR
ASCEXP	IMO	0.00	2.17	0.95	ASCEXP	IMO	−0.63	2.11	0.91
REFEXP		0.45	2.25	0.94	REFEXP		−0.08	1.68	0.94
ASCEXP	AMO	0.56	3.24	0.81	ASCEXP	AMO	0.37	2.13	0.89
REFEXP		−0.36	3.11	0.87	REFEXP		0.53	2.12	0.89
ASCEXP	ALL	0.29	2.77	0.88	ASCEXP	ALL	−0.23	2.11	0.88
REFEXP		0.03	2.73	0.90	REFEXP		0.16	1.87	0.92
MSLP					MSLP				
ASCEXP	IMO	−0.08	2.07	0.98	ASCEXP	IMO	−0.20	0.98	1.00
REFEXP		−0.28	1.57	0.99	REFEXP		−0.15	0.98	1.00
ASCEXP	AMO	−0.50	1.26	0.98	ASCEXP	AMO	−0.71	0.77	1.00
REFEXP		−0.02	1.49	0.97	REFEXP		−0.78	0.83	1.00
ASCEXP	ALL	−0.31	1.67	0.98	ASCEXP	ALL	−0.41	0.90	1.00
REFEXP		−0.13	1.52	0.98	REFEXP		−0.41	0.92	1.00

the winds are stronger in the northern part of the Norwegian Sea. In this case we have two ASCAT overpasses across the Baltic Sea region starting at 17:43 UTC and 18:27 UTC, both showing strong winds in the Baltic Sea region. Unfortunately, the southern part of the Baltic Sea is not covered enough with observational data and we cannot check model accuracy sufficiently.

Statistical parameters for 28.10.2015 at 18 UTC are worse in the ASCEXP in the wind speed analysis compared with IMO data. The differences from IMO data points can be clearly observed near the coast of the Norwegian Sea, where the ASCEXP values follow the ASCAT wind speed values registered in this assimilation window. Unfortunately, the comparison with IMO data points detects overestimation. This overestimation stems from the stronger ASCAT wind measurements in comparison with IMO (Fig. 1b and Fig. 5, right). The model assimilates ASCAT winds and becomes 'incorrect' in respect to IMO. It is difficult to assess to which observations should be given priority here.

The MSLP statistics is more accurate in AMO data points in ASCEXP analysis and takes into account all marine MSLP observations. The visual comparison of the MSLP 28.10.2013 at 18 UTC is represented only by REFEXP analysis and the difference between the OSEs analyses (Fig. 6), as the output in MSLP for both OSEs,

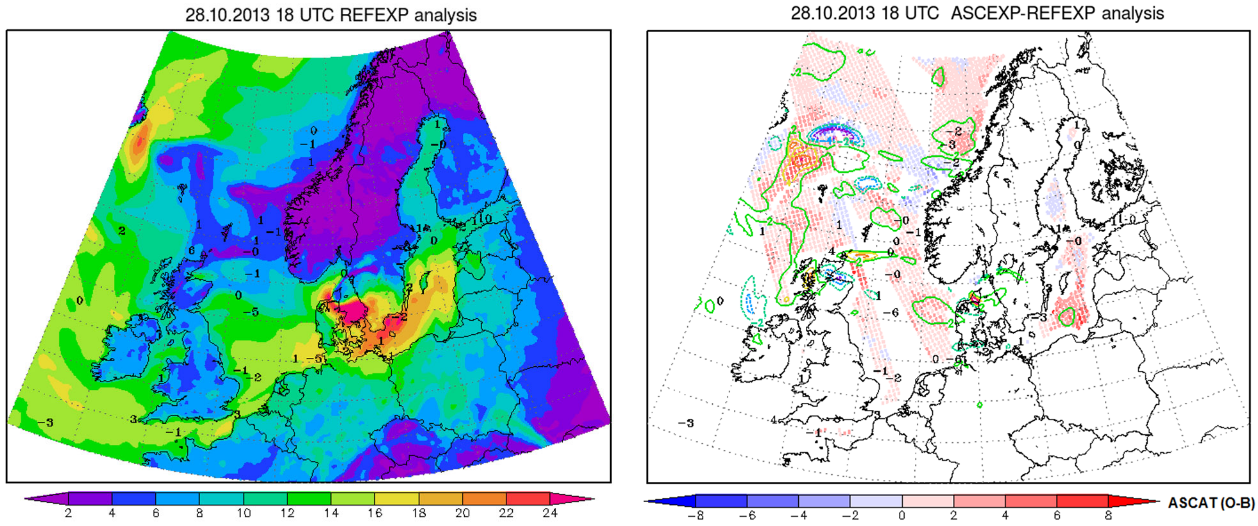


Fig. 5. HIRLAM 10-m wind speed analyses 28.10.2013 at 18 UTC: REFEXP (left), ASCEXP–REFEXP (right). The number values: surface-based observation minus analysis (O–A); colour dots: ASCAT observation minus HIRLAM background (O–B) before assimilation; colour contours (2 m s^{-1} step) represent wind speed analyses difference (ASCEXP–REFEXP).

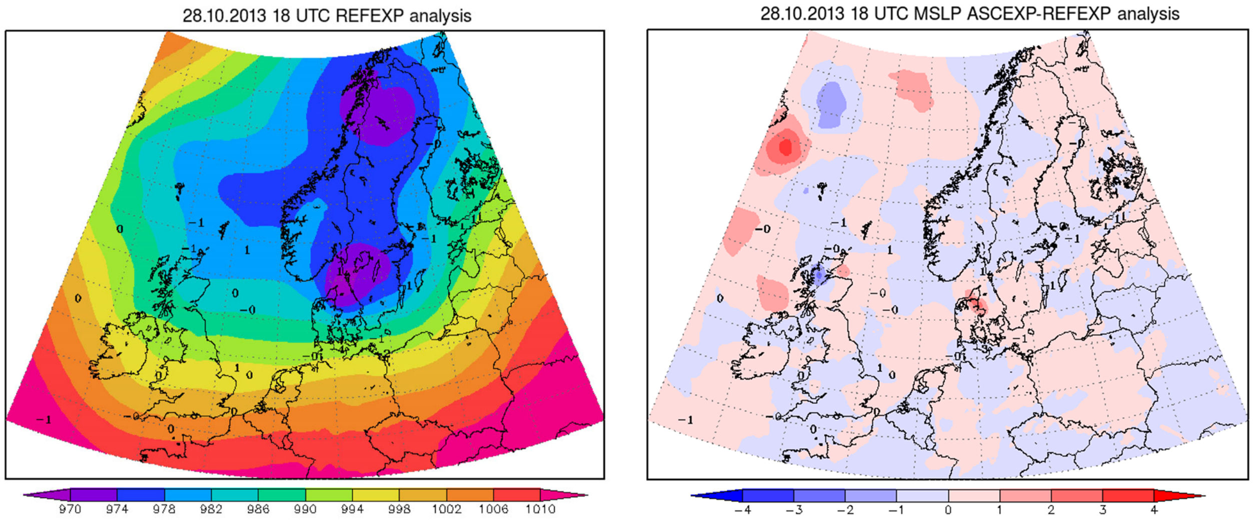


Fig. 6. The HIRLAM MSLP analyses 28.10.2013 at 18 UTC: REFEXP (left), ASCEXP–REFEXP MSLP analysis difference (right). The number values: surface-based observation minus analysis (O–A).

is very similar. Some differences were detected in the area where the accuracy cannot be checked by marine observations.

3.2. Stormy winds over the Baltic Sea 01.12.2013 at 18 UTC

In this case study we omit the OSE for 01.12.2013 at 12 UTC because of relatively sparse coverage of the ASCAT data in the HIRLAM domain, with missing measurements in the Baltic Sea. Fortunately, for 18 UTC run we have the ASCAT overpasses in the Baltic Sea region starting at 17:40 UTC and 18:24 UTC providing a good coverage of ASCAT measurements (Fig. 1c).

Two HIRLAM wind speed analyses of 01.12.2013 at 18 UTC are shown in Fig. 7. The main OSEs differences appear over the Baltic Sea, over the North Sea, and in the northwestern part of the HIRLAM domain. In all these areas the ASCEXP calculates stronger winds. Unfortunately, the most distinctive difference features appear in places that are not verifiable with independent data.

In both OSEs strong underestimation of the wind speed is detected in the Gulf of Bothnia (7 m s^{-1}) and widely in the Gulf of Finland (4 m s^{-1}). It is well known that the ASCAT wind product with the grid spacing of 25 km measures the winds about 70 km away from the coastline, the WVCs closer than ~70 km from the coast are flagged because of land contamination (Verhoef et al., 2012). The ASCAT winds in these areas are not admitted, most likely due to their proximity to the land (Fig. 1d), although they were full of ASCAT measurements. Unfortunately, the ASCAT measurements could not improve the analysis of the storm over the Baltic Sea.

The results of statistical comparison with marine observations are presented in Table 4. The RMSEs in the ASCEXP are slightly lower in both the wind speed and the MSLP compared with IMO data; however, the RMSEs of AMO data in both parameters are higher than

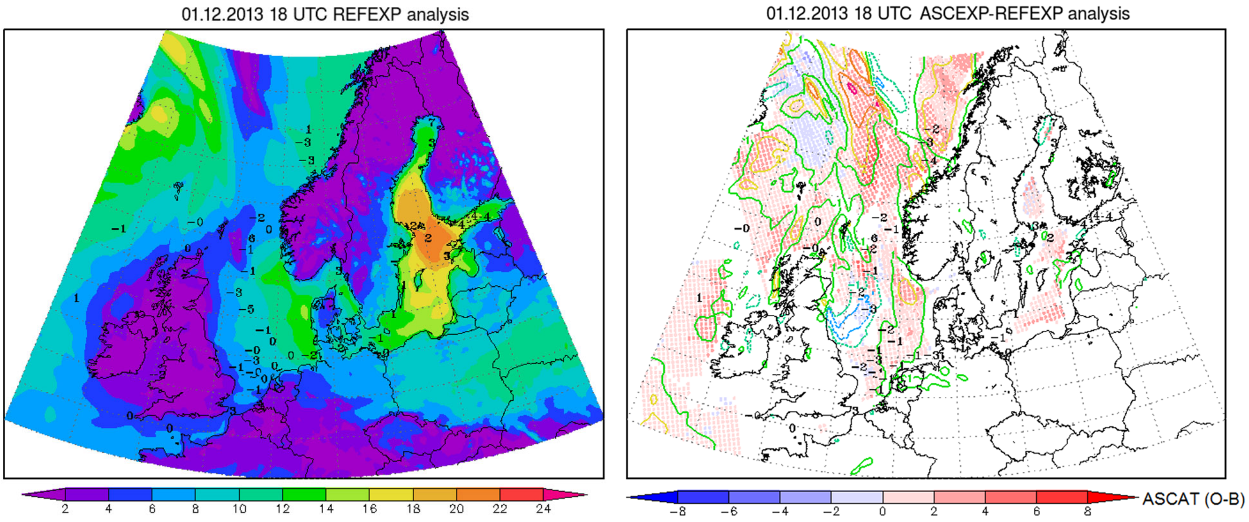


Fig. 7. HIRLAM 10-m wind speed analyses 01.12.2013 at 18 UTC: REFEXP (left), ASCEXP–REFEXP analyses difference (right). The number values: surface-based observation minus analysis (O–A); colour dots: ASCAT observation minus HIRLAM background (O–B) before assimilation; colour contours (1 m s^{-1} step) represent wind speed analyses difference (ASCEXP–REFEXP).

Table 4. The HIRLAM REFEXP and ASCEXP bias, RMSE, and correlation coefficients (CORR) of 10-m wind speed and MSLP on 01.12.2013 at 18 UTC

10-m wind speed					MSLP				
20131201 18 UTC		BIAS	RMSE	CORR	20131201 18 UTC		BIAS	RMSE	CORR
ASCEXP	IMO	−1.10	2.13	0.79	ASCEXP	IMO	−0.27	0.84	0.99
REFEXP		−0.96	2.18	0.75	REFEXP		−0.16	0.89	0.99
ASCEXP	AMO	0.48	2.82	0.86	ASCEXP	AMO	−0.65	0.85	1.00
REFEXP		0.87	2.72	0.88	REFEXP		−0.45	0.75	1.00
ASCEXP	ALL	−0.34	2.49	0.88	ASCEXP	ALL	−0.47	0.85	1.00
REFEXP		−0.08	2.46	0.88	REFEXP		−0.31	0.82	1.00

in REFEXP. An overestimation of the wind speed can be detected (Fig. 7, right) in the ASCEXP, which shows higher differences from AMO data points over the North Sea. The ASCAT overpasses after 19 UTC over the North Sea and in the northwestern part of the HIRLAM domain may cause wind speed overestimations in these regions. The cause of wind speed overestimations over the Norwegian Sea is not known, the ASCAT measurements are quite close to the assimilation moment.

The visual comparison of the MSLP shows similar results except the difference over the Norwegian Sea; here the isobars of the ASCEXP are more extended to the north and shifted slightly to the east (Fig. 8).

3.3. Storm Xaver 05.12.2013

The storm Xaver brought very high wind speeds over a large marine area of Europe; ASCAT registered the maximum for 12 UTC HIRLAM run with 28.6 m s^{-1} and for 18 UTC run 25.5 m s^{-1}. Here we evaluate two HIRLAM runs: at 12 UTC and 18 UTC. The results of the two experiments at 12 UTC (Fig. 9) differ considerably for the Norwegian Sea but show only small differences in other marine areas. The statistical output in this case (Table 5) shows more accurate wind speed analysis in REFEXP compared with IMO data. Here we observe a very strong wind speed overestimation over

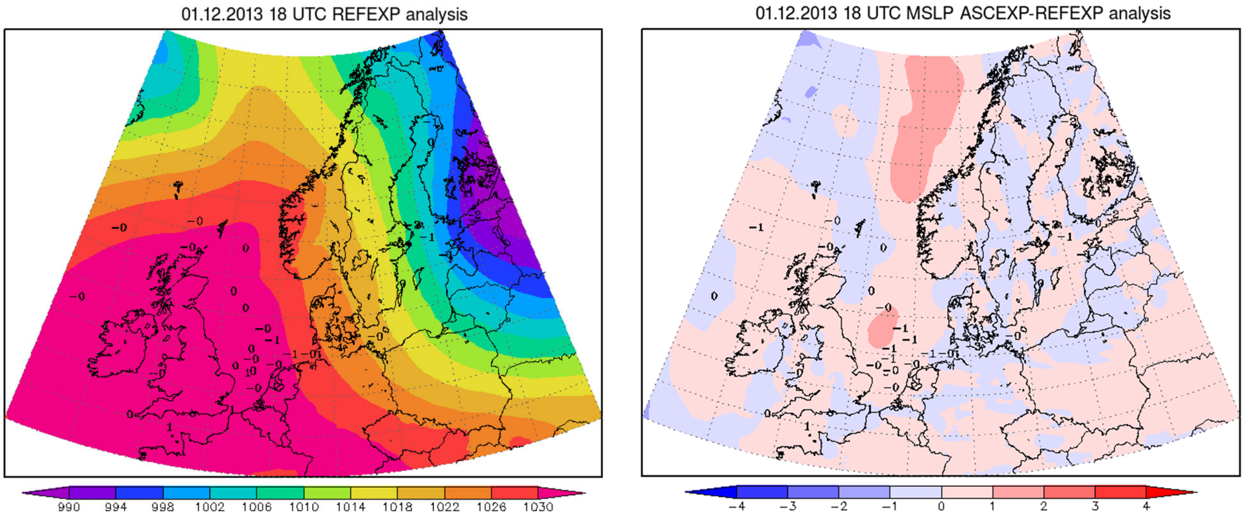


Fig. 8. The HIRLAM MSLP analyses 01.12.2013 at 18 UTC: REFEXP (left), ASCEXP–REFEXP MSLP analyses difference (right). The number values: surface-based observation minus analysis (O–A).

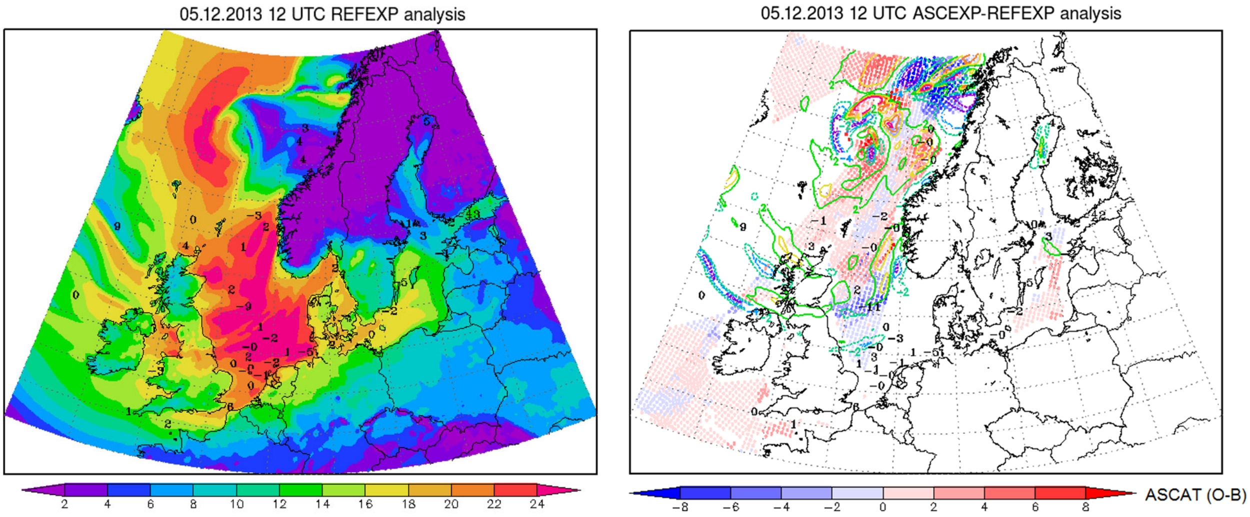


Fig. 9. HIRLAM 10-m wind speed analyses 05.12.2013 at 12 UTC: REFEXP (left), ASCEXP–REFEXP analyses difference (right). The number values: surface-based observation minus analysis (O–A); colour dots: ASCAT observation minus HIRLAM background (O–B) before assimilation; colour contours (2 m s^{-1} step) represent wind speed analyses difference (ASCEXP–REFEXP).

Table 5. The HIRLAM REFEXP and ASCEXP bias, RMSE, and correlation (CORR) with observed values of 10-m wind speed and MSLP on 05.12.2013 at 12 UTC (left) and 18 UTC (right)

10-m wind speed					10-m wind speed				
20131205 12 UTC		BIAS	RMSE	CORR	20131205 18 UTC		BIAS	RMSE	CORR
ASCEXP	IMO	0.20	3.35	0.82	ASCEXP	IMO	−1.77	4.12	0.81
REFEXP		0.90	3.27	0.86	REFEXP		−0.73	3.46	0.86
ASCEXP	AMO	−0.45	4.06	0.84	ASCEXP	AMO	0.42	3.41	0.80
REFEXP		−0.33	4.10	0.84	REFEXP		0.55	2.89	0.85
ASCEXP	ALL	−0.12	3.71	0.83	ASCEXP	ALL	−0.67	3.78	0.79
REFEXP		0.30	3.70	0.85	REFEXP		−0.09	3.19	0.85
MSLP					MSLP				
ASCEXP	IMO	−0.45	1.53	1.00	ASCEXP	IMO	−0.03	1.42	1.00
REFEXP		−0.45	1.54	1.00	REFEXP		0.10	1.35	1.00
ASCEXP	AMO	−0.91	1.16	1.00	ASCEXP	AMO	−0.61	0.86	1.00
REFEXP		−0.99	1.29	1.00	REFEXP		−0.72	0.99	1.00
ASCEXP	ALL	−0.69	1.35	1.00	ASCEXP	ALL	−0.34	1.16	1.00
REFEXP		−0.73	1.42	1.00	REFEXP		−0.34	1.17	1.00

the North Sea (–11 m s^{-1}). This overestimation is caused again by differences in the measurement time: the ASCAT measurements in this area were carried out at 09:45 UTC. However, over the Norwegian Sea the ASCEXP analysis is very accurate and fits with IMO data points because of the more appropriate time of measurement (11:23 UTC).

An important fact in this case is that about 2.0% of all ASCAT measurements used in the current assimilation window are winds over 25 m s^{-1}. Although the ASCAT Wind Product User Manual (OSI-SAF Project Team, 2013) gives the data range of the ASCAT winds 0–50 m s^{-1}, the wind speeds over 25 m s^{-1} are generally known to be less reliable. At strong winds wave breaking will further intensify, causing air bubbles, foam, and spray at the ocean surface, and a more and more complicated ocean topography (Verhoef and Stoffelen, 2014). The buoy measurements in high wind/wave conditions may also show underestimated wind due to the flow disturbance extending beyond the anemometer height (Ingleby, 2009). It is also known that the model calculations may not be perfectly fitted for severe weather conditions. All these facts may lead to large variations between observed and analysed wind speed differences, especially in closely located observational data points.

In the case of 05.12.2013 at 12 UTC the ASCAT measurements over 25 m s^{-1} are used in the assimilation cycle, but in general the analysis winds are reduced to be closer to the background winds. However, at 09:42 UTC the analysis winds strengthened and were closer to the ASCAT measurements (Fig. 10). Unfortu-

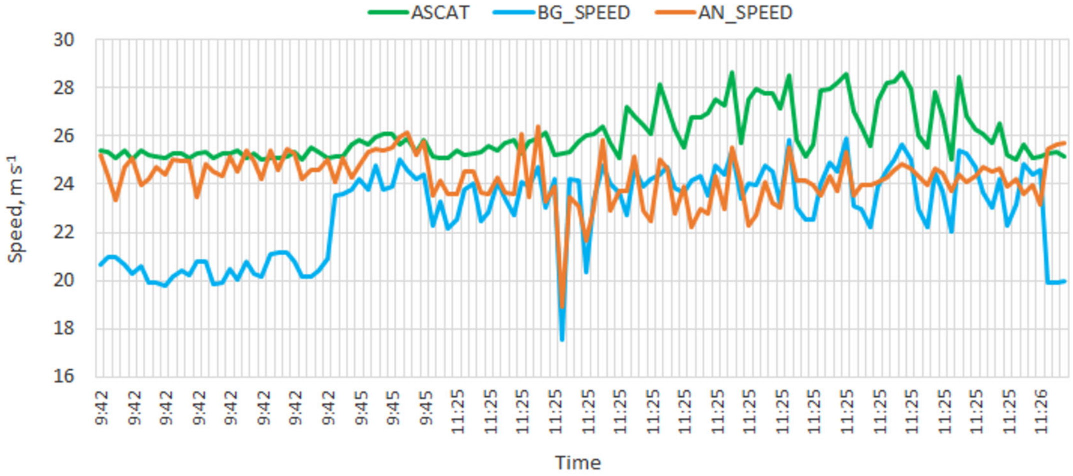


Fig. 10. The ASCAT winds over 25 m s^{-1} assimilated into the HIRLAM (ASCAT), analysis winds after assimilation (AN_SPEED), and the background winds (BG_SPEED) on 05.12.2013 at 12 UTC.

nately, as this area is located in the northern part of the Norwegian Sea, the accuracy of the analysis cannot be checked by surface-based marine observations.

The storm Xaver on 05.12.2013 at 18 UTC intensified and winds were very strong already in the southern part of the Baltic Sea (Fig. 11). The ASCEXP calculates stronger winds across the Norwegian coast and in the southern part of the Norwegian Sea, and the differences from marine observations may reach –12 m s^{-1}. Here again we observe a strong variation of the wind speed measurements in closely located data points inside the storm. At 18 UTC the wind speed statistics is more accurate in the REFEXP for all marine observations (Table 5), which is most likely caused by wind speed overestimations in the ASCEXP analysis. The wind speed analyses in the Baltic Sea region are very similar in both OSEs.

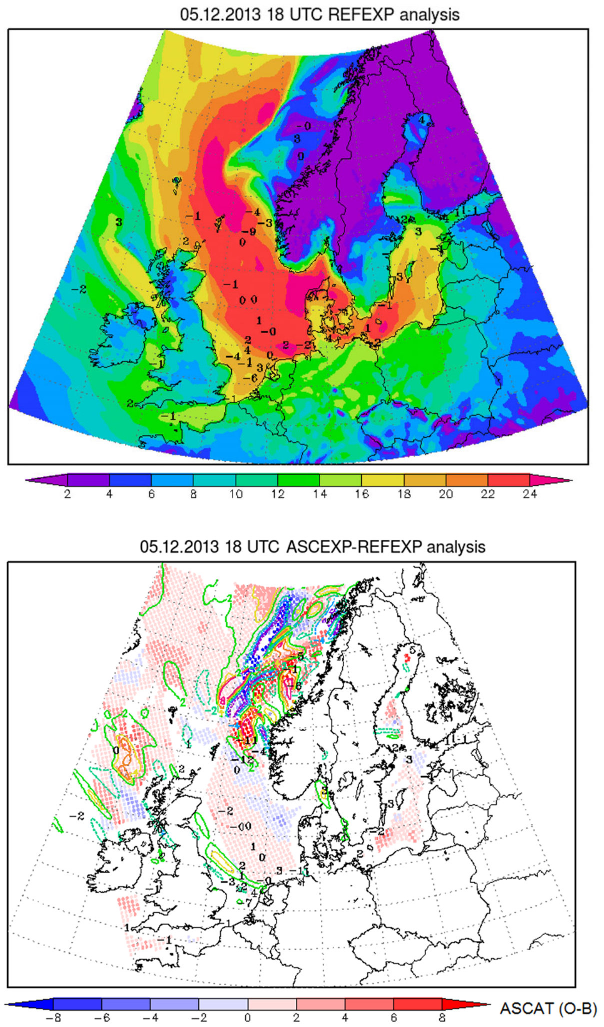


Fig. 11. HIRLAM 10-m wind speed analyses 05.12.2013 at 18 UTC: REFEXP (top), ASCEXP–REFEXP analyses difference (bottom). The number values: surface-based observation minus analysis (O–A); colour dots: ASCAT observation minus HIRLAM background (O–B) before assimilation; colour contours (2 m s^{-1} step) represent wind speed analyses difference (ASCEXP–REFEXP).

Visual comparison of the MSLP in both analysis cycles shows significant differences over the Norwegian Sea (Fig. 12). Most likely, the strong ASCAT winds and their assimilation in this area (Fig. 1f) deepen the low-pressure system in comparison to the REFEXP. Unfortunately, the accuracy of OSEs output cannot be checked with observational data in these areas because of the missing MSLP measurements. Here we omit the ASCEXP analyses showing only REFEXP analyses and the ASCEXP–REFEXP differences.

The statistics of the MSLP 05.12.2013 at 12 UTC (Table 5) give smaller errors in the ASCEXP for all types of marine observations and, in general, show a better fit with observed MSLP than the statistics for 18 UTC. The MSLP statistics at 18 UTC are rather similar for both experiments.

3.4. ASCAT winds and HIRLAM

To study how the model backgrounds in severe storm cases fit with scatterometer observations, the ASCAT winds admitted into the HIRLAM analysis were compared with the model background (O–B) and with the analysis winds after assimilation (O–A). In all severe storm cases the mean O–B is more than 1 m s^{-1} (Fig. 13), which indicates that the ASCAT instrument measured stronger winds than the HIRLAM forecasts calculate. After the ASCAT data assimilation the mean O–A is less than 0.5 m s^{-1} and the mean standard deviation of the wind speed is less than 2 m s^{-1}, as it should be expected for the background winds. However, such general statistics hide the details of phase shifts by including effects that cancel each other.

It should be useful to analyse a longer period of ASCAT data for the evaluation of the O–B biases. In case the biases are systematic, the bias correction before the ASCAT assimilation should be undertaken. Presently no bias correction is applied in the HIRLAM.

The O–B scatterplot against time difference between the ASCAT observation time and analysis time (Fig. 14) detects that in case of the storm Xaver (05.12.2013) the wind speed deviations are the highest and occur even at the assimilation time moment. If we consider other cases, the ASCAT consistency with HIRLAM background winds is better when the ASCAT measurements are closer to the assimilation time moment. This means that in case of extremely strong storms such as the storm Xaver, higher discrepancy with the HIRLAM background winds may be expected. First, the ASCAT winds over 25 m s^{-1} are generally known to be less reliable, but they are taken into assimilation and then the limited area model calculations may not be perfectly fitted for extreme weather conditions.

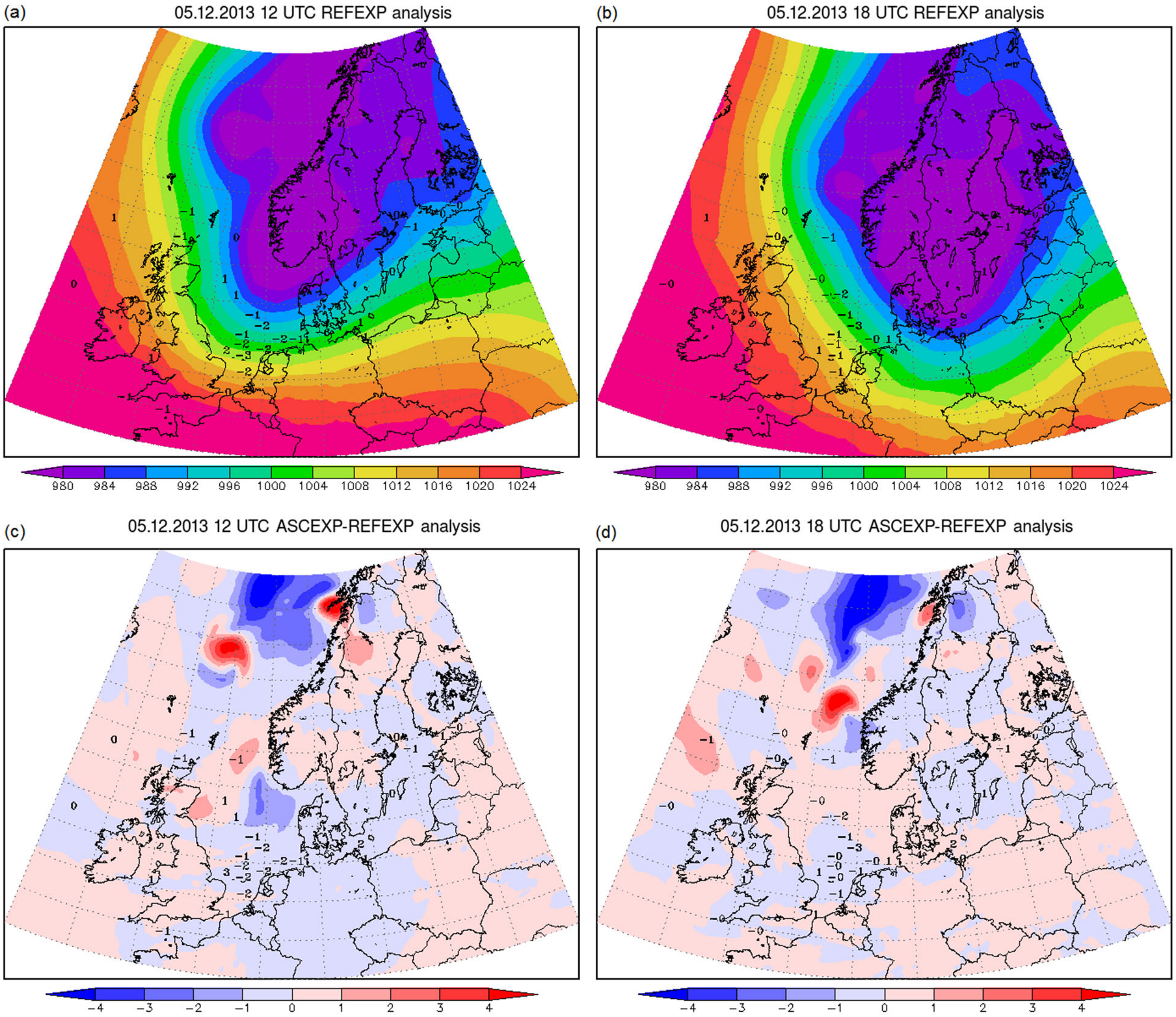
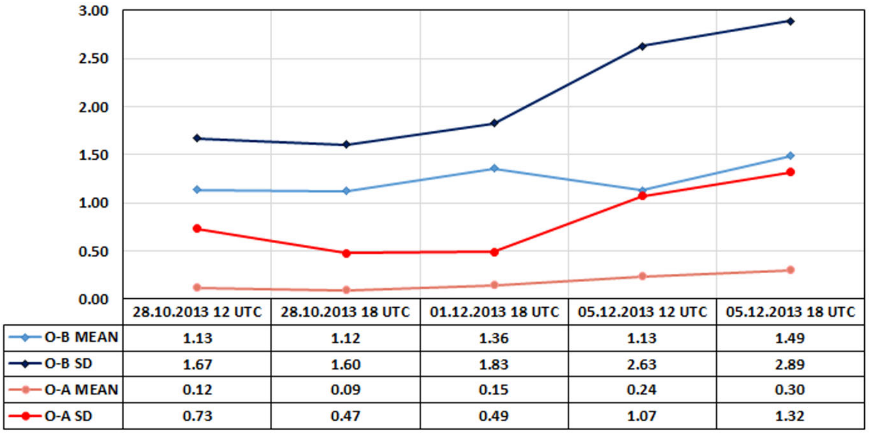


Fig. 12. HIRLAM MSLP analyses of the reference experiment REFEXP at 12 UTC (a) and 18 UTC (b), and ASCAT data containing analyses difference from the reference ASCEXP–REFEXP at 12 UTC (c) and 18 UTC (d) on 05.12.2013.



	28.10.2013 12 UTC	28.10.2013 18 UTC	01.12.2013 18 UTC	05.12.2013 12 UTC	05.12.2013 18 UTC
O-B MEAN	1.13	1.12	1.36	1.13	1.49
O-B SD	1.67	1.60	1.83	2.63	2.89
O-A MEAN	0.12	0.09	0.15	0.24	0.30
O-A SD	0.73	0.47	0.49	1.07	1.32

Fig. 13. The mean and standard deviation (SD) of ASCAT and HIRLAM wind speed differences (m s^{-1}) before assimilation (O–B) and after ASCAT assimilation (O–A), severe storm cases in 2013.

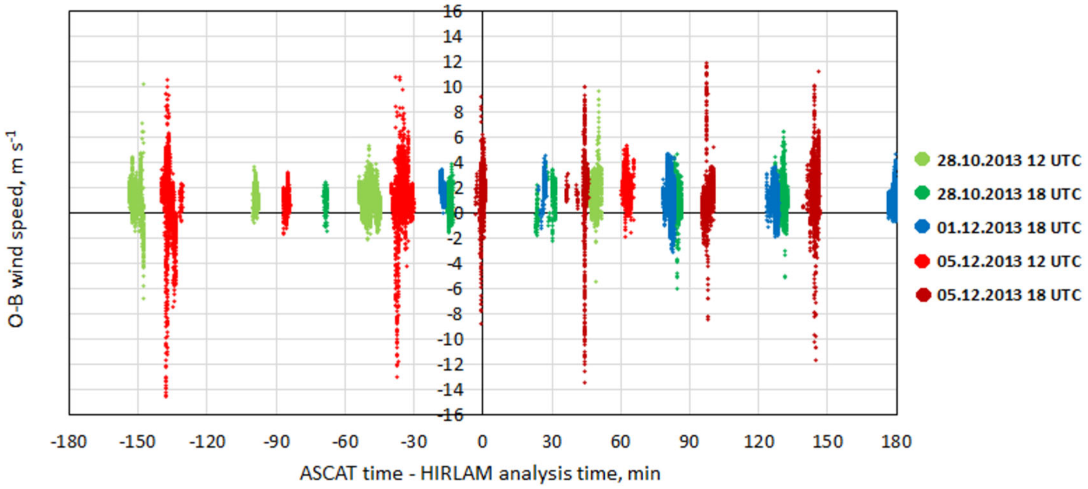


Fig. 14. Scatterplot of O–B wind speed difference versus ASCAT time minus HIRLAM analysis time for all severe storm cases.

4. CONCLUSIONS

In this paper the impact of the ASCAT measurements on the HIRLAM data assimilation quality is assessed in cases of severe storms caused by fast moving mid-latitude cyclones. The quality of the assimilation is examined in marine areas of the HIRLAM domain against in situ observations (10-m wind speed and MSLP) and the ASCAT measurements.

The results of verification show that sometimes the ASCAT data assimilation improves the analysis, but in some cases the REFEXP gives more accurate results. It is clear that case studies provide fewer statistics for the overall quality assessment of the ASCAT data assimilation in comparison with statistics collected over longer periods. On the other hand, the case studies may give more information about the model behaviour in specific synoptic situations. Valkonen and Schyberg (2015) also demonstrated strong day-to-day variations in the standard deviations of the ASCAT data compared to the model background (O–B) and the analysis (O–A). Such variations show how the model fits with instantaneous ASCAT measurements performed in the assimilation time window.

Verification of the OSEs in this study was performed separately for each case. The smallest RMSE of the wind speed appeared in the storm Christian (2.11 m s^{-1}) and the highest in the storm Xaver (3.78 m s^{-1}). De Valk (2013) analysed the impact of the ASCAT 25-km wind data asssimilation on the HIRLAM during one-week experiments in wintertime and showed similar results: the mean standard deviation of the model initial state (00 length forecast) from marine observations was about 3.5 m s^{-1}. Statistical calculations of the MSLP showed also that the ASCAT data assimilation has an impact on the changes in the MSLP and in locations of the low-pressure systems.

Areas of no impact after the ASCAT data assimilation were detected as well. It was found that the HIRLAM rejected most of the ASCAT observations located close to the shoreline after the procedure of quality control. As a result, in the Baltic Sea storm of 01.12.2013 at 18 UTC (Fig. 7) the wind speeds were significantly underestimated in both OSEs, the same was detected in the storm Xaver 05.12.2013 at 12 UTC. It would be of interest to investigate possibilities of the application of the ASCAT Coastal Wind Product, which may increase the impact of the ASCAT data assimilation in these areas.

Assimilation of extremely strong ASCAT winds is also highlighted in this study. In the storm Xaver HIRLAM assimilated the ASCAT winds over 25 m s^{-1}. The analysis winds mainly followed HIRLAM background winds, which are weaker than the ASCAT measurements (Fig. 10). This result is contrary to the study by Valkonen and Schyberg (2015), which showed that in the case of the strong ASCAT winds (over 23 m s^{-1}) HARMONIE background winds were always higher than ASCAT. This may be attributed to the different tunings or systematic differences of HIRLAM and HARMONIE background forecast models. Some large differences in case of extremely strong ASCAT winds were detected between the ASCAT and HIRLAM background winds observed in our study as well. Unfortunately, the lack of independent marine observations in the area where large departures occurred does not allow comprehensive evaluation of the impact on the data assimilation quality.

Results from case studies of severe storms show that the impact of the ASCAT data assimilation into HIRLAM is considerable and well visible in both the wind and MSLP analyses. However, we demonstrate that strong winds measured by ASCAT may affect adversely the analysis quality and can create significant phase errors in case of relatively fast moving severe storms. No adjustments in the system such as data thinning or observation error setting were made in the study, similar to the studies by De Valk (2013) and De Haan et al. (2013), which gave more weight to the ASCAT measurements. Some negative results detected in the study raise the question about the optimal use of the ASCAT data. Probably, the ASCAT observations should be thinned to get better results, especially in areas where measurements are performed simultaneously from both satellites. Such technique was applied by Valkonen and Schyberg (2015), De Chiara et al. (2014), and Ollinaho (2010) and shows positive to neutral results. Another approach that could improve the quality of the HIRLAM analyses is to shorten the time interval between the analyses. In our studies the FGAT is applied, but it still seems to be insufficient to avoid large differences in observations and backround in the assimilation cycle. As improving the quality of severe storm forecasting is very important for society, further research is necessary to improve the data assimilation methods for ASCAT winds to avoid such negative impacts.

ACKNOWLEDGEMENTS

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Skatteromeetri ASCAT tuuleandmete assimileerimise mõju HIRLAM-i analüüsi kvaliteedile tugevate tormide puhul

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On hinnatud skatteromeetri ASCAT andmete assimileerimise mõju ilmaennustustarkvara HIRLAM väljundi kvaliteedile 2013. aasta kiiresti arenevate tormide ajal. Seda on tehtud kahe vaatlussüsteemi eksperimendi kaudu: ühel juhul toimub ASCAT-i andmete assimileerimine ja teisel mitte. Mudeli väljundi kvaliteedi hindamiseks on kasutatud kümne meetri kõrgusel mere kohal registreeritud tuule ja keskmise õhurõhu andmeid. Tulemused näitavad, et olenevalt uuritava ala kaetusest ASCAT-i andmetega ja assimilatsiooni hetkel saadaolevast andmehulgast võib tulemus olla enam või vähem täpne. On ka leitud, et mõnede kitsamate alade puhul Läänemeres (Botnia ja Soome laht) ei mõjuta ASCAT-i andmete assimileerimine oluliselt tulemusi. Tuuleprodukti spetsifikatsiooni käigus näitavad ASCAT-i mõõtmised rannikualade lähedal tavaliselt maismaaga saastumist. Nendel aladel ei analüüsita ASCAT-i tuuli pärast HIRLAM-i kvaliteedikontrolli, põhjuseks on tõenäoliselt ranniku lähedus. Tulevikus võiks neil aladel ASCAT-i avameretuule produkti täiendada rannikutuule produktiga. Lisaks avastati mõned ASCAT-i andmeassimilatsiooni nõrgad kohad, mis tõstatab küsimuse ASCAT-i andmete optimaalsest kasutamisest. On leitud, et tulemuste edasiseks parendamiseks on vaja proovida ASCAT-i mõõtmisi hõrendada enne assimileerimist või vähendada ajalist vahemikku HIRLAM-i analüüsides.