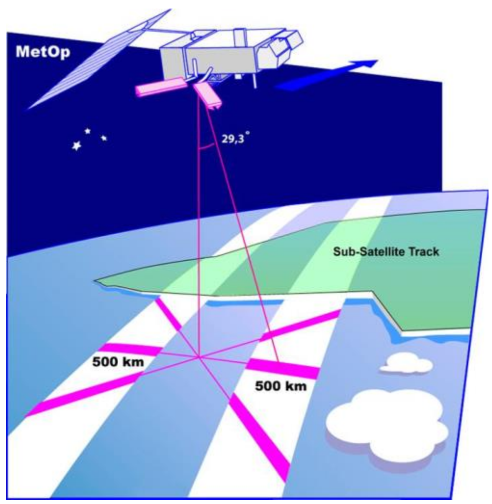
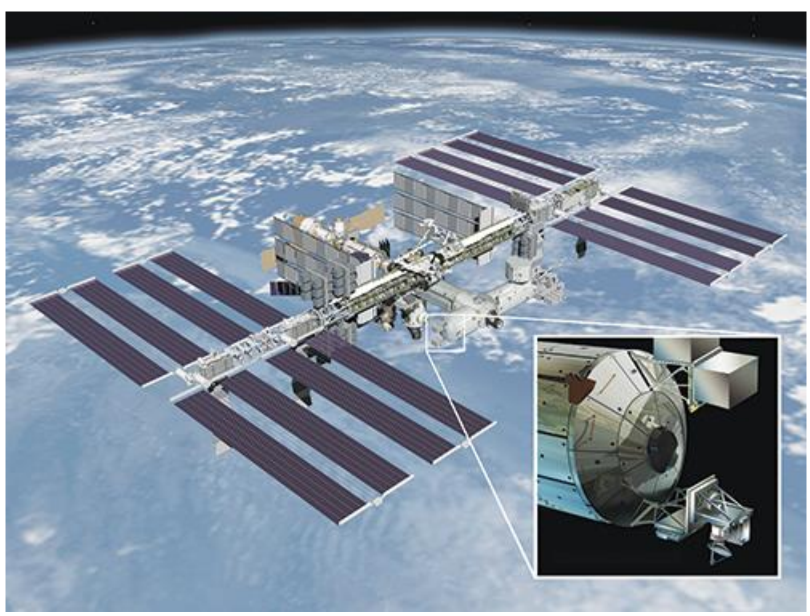
Environnement Canada
Centre météorologique canadien

Environment Canada
Canadian Meteorological Centre

Processing of KNMI's scatterometer wind vectors at the Meteorological Service of Canada





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Revision history			
Version	**Date**	**Author/changed by**	**Remarks**
1.0	2007/05	Jean-Marc Belanger	Original author – Quikscat data
2.0	2009/06	Judy St-James	Addition of ASCAT data
3.0	2016/05	Judy St-James	Addition of ASCAT data from MetOp-B and ISS RapidScat data

Table of contents

Introduction

Ocean surface scatterometer wind vector retrievals are assimilated in the 4DEnVar analysis operational system at MSC (Meteorological Service of Canada) since May 2008. This document gives a brief description of the data, its generation, local processing and quality control.

Generally speaking, datasets based on Scatterometer measurements provide two different physical quantities. The first one is called the Normalized Radar Cross-Section (NRCS), also referred to as sigma0. NRCS is a relative measure of the power returned to the radar by the earth surface. Over the ocean, scattering from wind-driven surface gravity-capillary waves is the main contributor of energy returning to the satellite. It is recognized that at the moderately high incidence angles of the Scatterometer beams, resonant Bragg scattering occurs for centimeter wavelengths (Valenzuela, 1978). While NRCS measurements over land are used to derive various kinds of geophysical parameters we limit ourselves to ocean measurements. Over the ocean, information on the atmospheric wind vector at 10 m above the surface has been empirically linked to NRCS since the U.S. sponsored SEASAT mission in the seventies.

The Advanced SCAtterometer (ASCAT) is one of the instruments carried on-board the Meteorological Operational (MetOp) polar-orbiter satellite launched by European Space Agency (ESA) and operated by the European organization for the exploitation of METeorological SATellites (EUMETSAT). MetOp-A (2) was launched on 19 October 2006, followed by MetOp-B (1) on 17 September 2012. ASCAT has two sets of three antennas to generate radar beams looking on both sides of the satellite ground track. ASCAT also provides equivalent neutral wind vectors over the ocean.

In late 2009, after ten years of successful operations, the NASA SeaWinds instrument on the QuikScat satellite stopped sending wind data, leaving a hole in the global collection of wind scatterometers. To mitigate the loss of QuikScat, NASA's Jet Propulsion Laboratory and the agency's station program came up with a solution that uses the framework of the International Space Station and reuses hardware originally built to test parts of QuikScat to create an instrument for a fraction of the cost and time it would take to build and launch a new satellite. The resulting instrument package measures ocean winds with accuracy similar to QuikSCAT, but with a measurement swath on the ground smaller by a factor of two due to the lower ISS orbit. This swath width is similar to the EUMETSAT ASCAT scatterometer, and the two data sets complement each other to achieve coverage similar to QuikSCAT. RapidScat was launched on 20 September 2014 and mounted on the International Space Station. The ISS-RapidScat observations provide the first near-global direct observations of how ocean winds vary over the course of the day, while adding extra eyes in the tropics and mid-latitudes to track the formation and movement of tropical cyclones.

Quikscat data was assimilated in the global and regional numerical weather prediction systems from May 2008 to 23 November 2009 when the satellite stopped collecting continuous swath-based wind data. In March 2009, ASCAT from MetOp-A data were added followed by ASCAT from MetOp-B in April 2013. On 16 March 2016, winds from ISS-RapidScat were included in the MSC’s 4DEnVar analyses.

Generalities on ASCAT scatterometer

ASCAT is a real aperture radar using vertically polarized antennas emitting at a frequency of 5.255 GHz (C-band). This frequency makes it rather insensitive to rain. Two sets of three antennas are used to generate radar beams looking 45 degrees forwards, sideways and 45 degrees backwards with respect to the satellite's flight direction on both sides of the satellite ground track. These beams illuminate 550 km-wide swaths separated by about 700 km (figure 1) and provide measurements of radar backscatter from the sea surface. Using three different viewing directions separated by a short time delay, three independent backscatter measurements can be obtained for each Wind Vector Cell (WVC). Since the backscatter depends on the sea surface roughness which in turn is a function of wind speed and direction, it is possible to calculate wind speed and direction at the sea surface with these triplets.

The backscatter measurements from each beam are spatially averaged by using a 2D hamming window in the along- and cross-track directions. Each node contains values corresponding to several adjacent nodes along and across track, thus adjacent nodes are correlated. Two smoothed products at different horizontal scale and spatial grids are generated: 50-km and 25-34-km on grids of 25-km and 12.5-km respectively. The 50-km spatial resolution product (25-km grid spacing) is used in our MSC's assimilation systems.

The 25-km grid spacing product is as follows.

Swath width: 525 km
1 row of data = 21 cross track 25-km size WVCs X 2 swaths = 42 WVCs

The mean Local Solar Time at

ascending pass is: 21h30
descending pass is: 9h30

The repeatability cycle is 29 days/412 orbits and is almost equivalent to 5 days/71 orbits repeat cycle.

The average daily coverage is about 70% of the global ocean between +- 60 degree latitude.

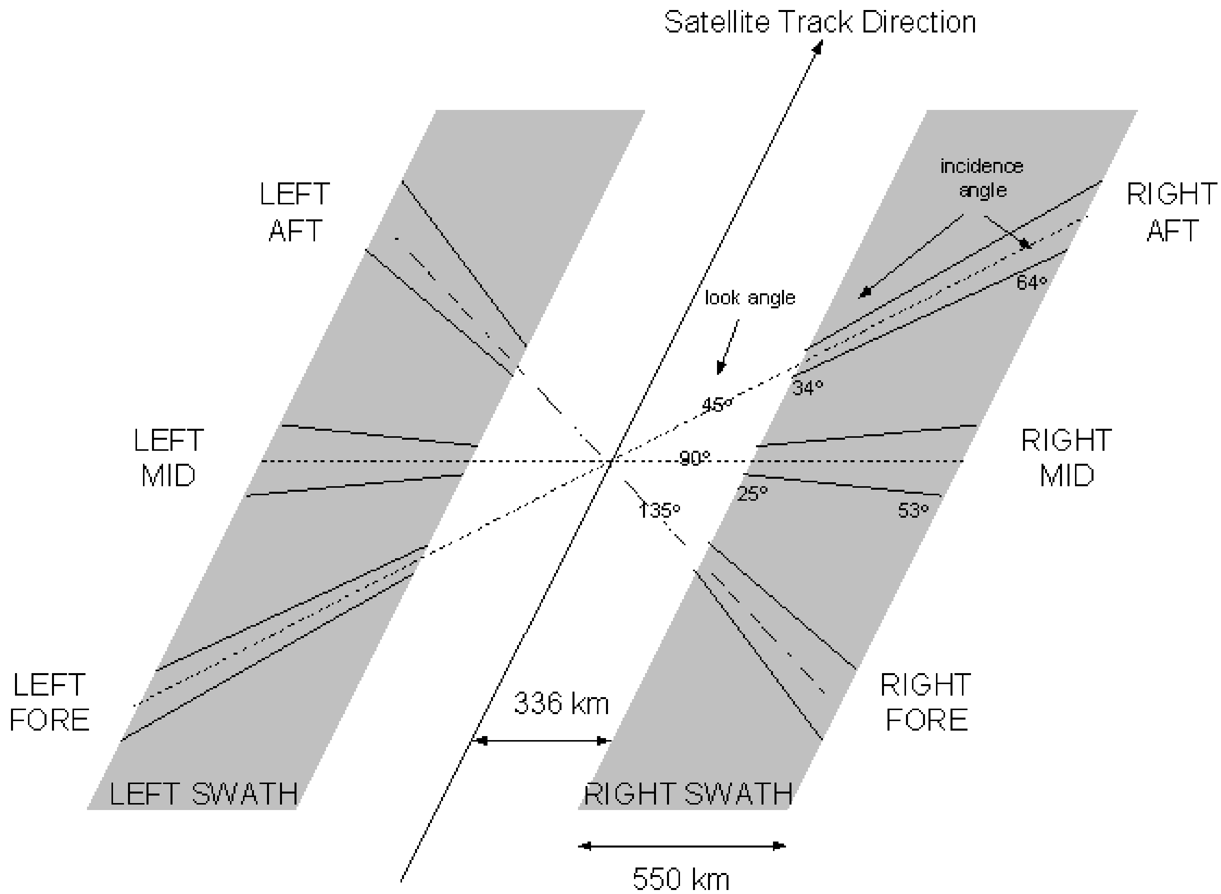

Figure 1: Illustration of ASCAT swath geometry for a Metop minimum orbit height (822 km). (from Eumetsat's tech note at http://oiswww.eumetsat.org/WEBOPS/eps-pg/ASCAT/ASCAT-PG-4ProdOverview.htm#TOC42).

Generalities on RapidScat scatterometer

RapidScat is mounted on the International Space station (ISS) and the data are acquired at several ground stations. The altitude of the space station's orbit changes, depending on the reboost schedule, between 375km and 435 km and will also vary over the course of the mission. The inclination of the space station is 51.6 degrees. Particularly, the pitch bias with which the ISS flies will vary depending on the combinations of visiting vehicles and their berthing sites. Both the altitude and altitude variations of the ISS require timing modifications to the engineering hardware that will be accomplished in day-to-day operations of the radar. Data loss due to various ISS activities such as vehicle dockings or astronaut/cosmonaut space walks, is also expected during the course of the mission. Also, data gaps appear in particular over the Indian Ocean due to interruptions in data transmission from ISS.

ISS's RapidScat is a microwave radar emitting at Ku band (at 13,4 GHz). This frequency is more sensitive to rain contamination but also more sensitive to surface wind effect on the ocean. RapidScat uses a dual pencil beam in a conical scanning fashion (figure 2). Its 0.75 meter parabolic dish rotates at 18 rpm emitting radiation pulses every ~6 ms while the International Space Station is flying at a ground speed of approximately 7 km/s, resulting in an over-sampling of the ocean surface. The two beams have different polarizations:

Inner beam: HH-polarized at 49 degree incidence angle (for and aft)
Outer beam: VV-polarized at 56 degree incidence angle (for and aft)

Outer beam: Swath width of 1100 km
Inner beam: Swath width of 900 km

2 beams x 2 looks = 4 beam flavours

In the 50km product from KNMI the swath is divided as follows

Swath width: 1100 km
1 row of data = 21 (42) cross track 50 (25) km size WVC (wind vector cell)
1 orbit = 1624 rows

RapidScat covers the majority of the ocean between 55 degree north and 55 degree south in 48 hours. The orbit is not sun-synchronous.

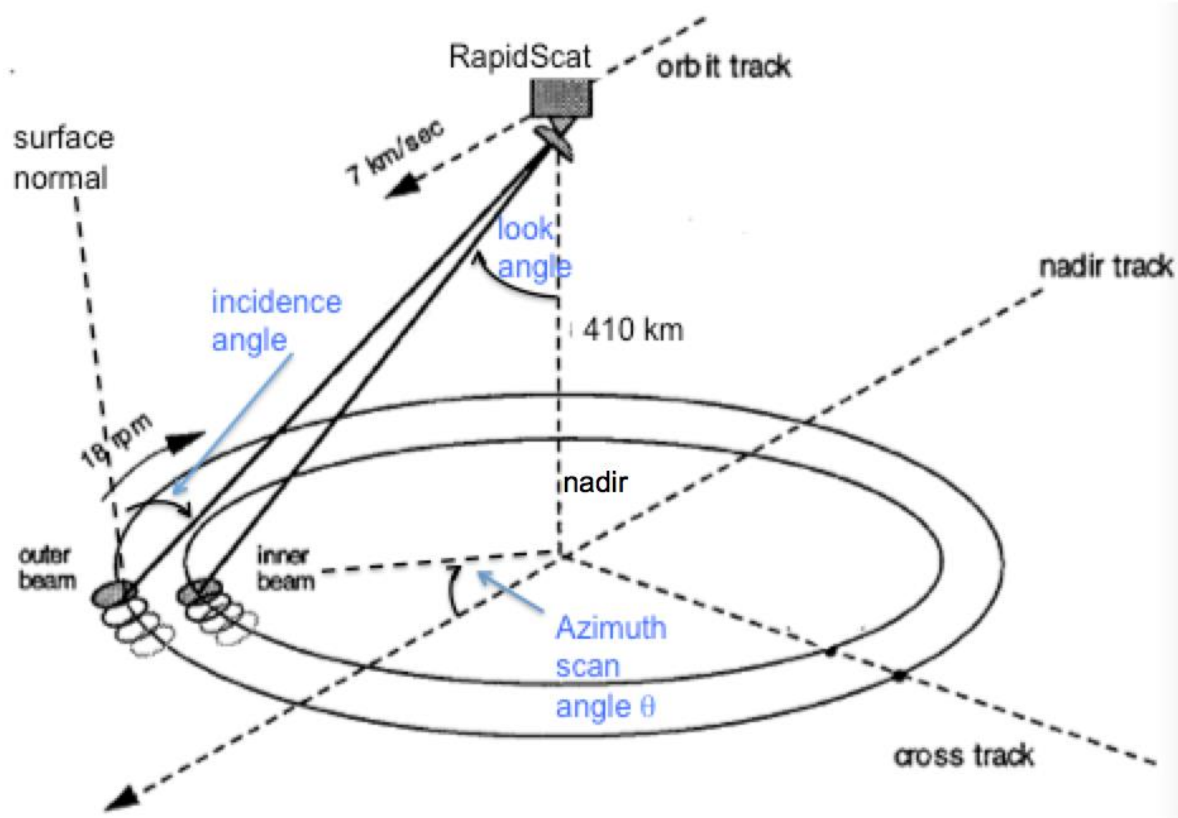

Figure 2: Illustration of RapidScat radar beam geometry and scanning operation.

Scatterometer data providers

Level 2 ASCAT and RapidScat 10m wind vector datasets are provided by the KNMI scatterometer team led by Ad Stoffelen. These products are distributed by the Ocean and Sea Ice Satellite Application Facility (OSI SAF) at KNMI. At MSC we have been retrieving BUFR files from the KNMI ftp site on a daily basis since 2008. It is felt that the KNMI Scatterometer wind vector products are less noisy and more suitable for our global low-resolution 4DEnVar system while being actively supported by a team of experts.

Overview of KNMI Scatterometry wind processing

We now give a brief overview of the main components of the wind retrieval algorithm. Figure 3 is based on figure 4 from the Theoretical Basis document for the OSI SAF wind products (2015).

Figure 3: Algorithm of the wind retrieval used to invert sigma0's.

Space-borne scatterometer measurements relates to the centimeter-scale waves generated on the ocean surface by wind stress. The observed scatterometer backscatter is transformed into wind products and more specifically represented by the equivalent-neutral (EN) wind at 10 meter height, independent of atmospheric stratification. The steps that lead to this EN wind product are described in the Theoretical Basis document for the OSI SAF wind products (2015). The Scatterometer documentation is available online on the KNMI website at http://www.knmi.nl/scatterometer/publications.

Additional information about the spatial averaging, the NWP collocation, the wind retrieval, the ambiguity removal and the monitoring steps are given in this document.

Spatial averaging

ASCAT data

This section is based on the ASCAT Wind Product User Manual v1.14 (2016) and the Eumetsat ASCAT Product Guide (2008).

Eumetsat generates the level 1b spatially-averaged normalized backscatter radar cross section values, known as σ_0 triplets. The following chart (Figure 4) illustrates the level 1 ground processing chain. As a first step, the ASCAT power echoes are subject to internal calibration and noise correction. The corrected measurement is then normalized to 256 σ_0 values along every antenna beam projection on the ground and localized on the surface of the Earth. Spatial averaging (smoothing) in the along- and across-track directions is further applied per beam over all available σ_0 values. Three σ_0 values (one for each beam) for each grid node of each swath at the desired resolution are obtained. The averaged σ_0 values at two different horizontal scales and spatial grids are generated: a 50km (25km grid spacing) and a 25-34km (12.5km grid spacing).

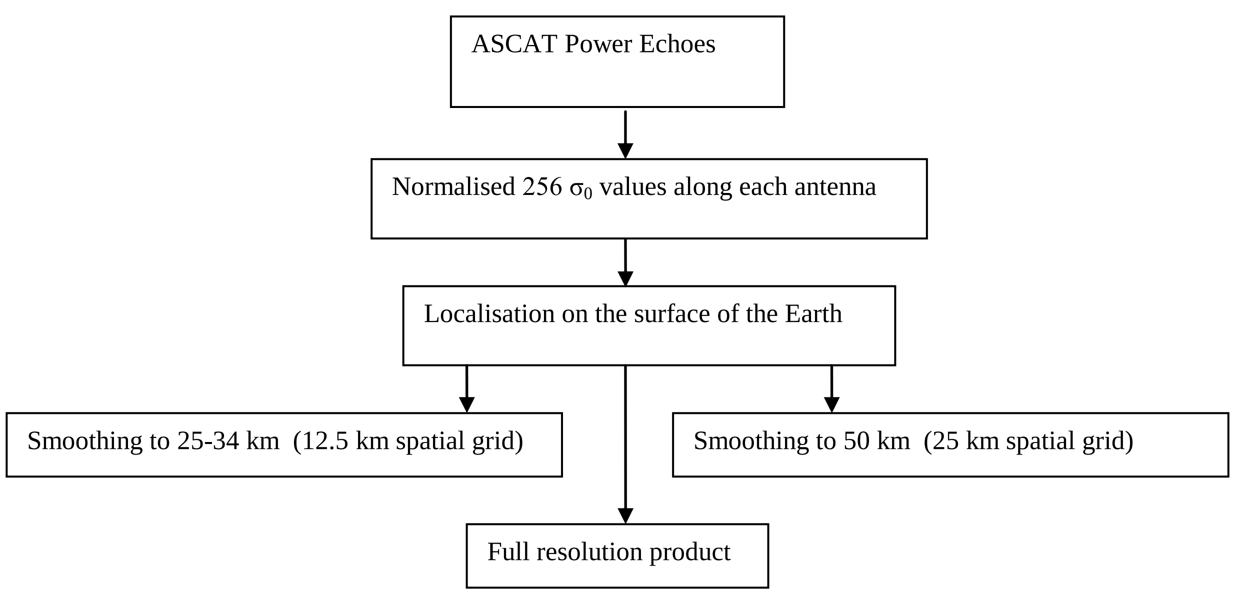

Figure 4: Level 1b main processing chain.

Figure 5 shows the ground geometry of the spatial smoothing. The data from adjacent nodes are correlated due to the characteristics of the spatial averaging. The size of the spatial resolution window is about 100km, and thus the σ_0 value corresponding to a node contains information from individual σ_0 values corresponding to several adjacent nodes along- and across-track.

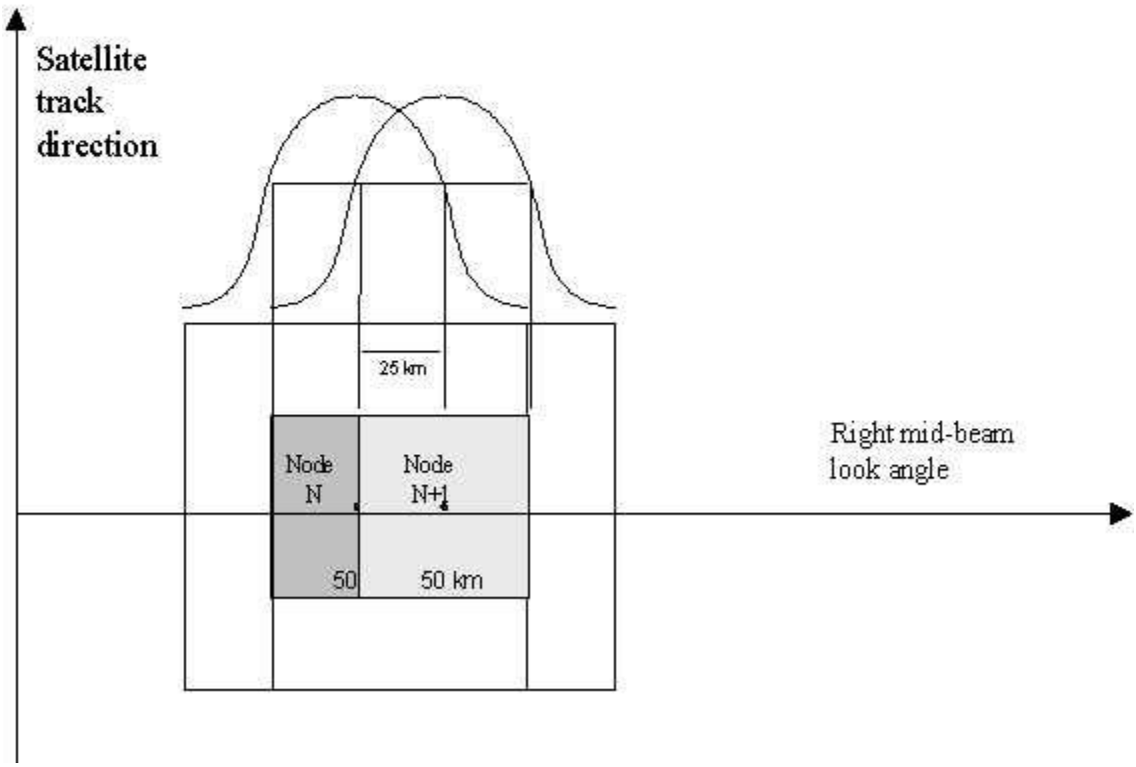

Figure 5: Ground geometry of the across-track component of the spatial smoothing for σ_0 values corresponding to two across-track adjacent nodes

<u>RapidScat data</u>

This section is based on the RapidScat wind Product User Manual v 1.2 (2016) and the JPL RapidScat mission website http://winds.jpl.nasa.gov/missions/RapidScat/

The RapidScat level 2a input data are kindly provided by the National Aeronautics and Space Administration (NASA) Jet Propulsion Laboratory (JPL). The data are organized in eggs, each σ_0 is based on the sum of the echo energies measured among the eight centre high resolution slices in a single scatterometer pulse. The product contains geo-located backscatter measurements on a satellite swath WVC grid of 25km size.

JPL generates two orbit-based 25km level 2a scatterometer products with different timeliness: approximately 2 hours and approximately 3 hours after the sensing time of the middle of an orbit file which contains close to 80% and 98% of the theoretical data amount, respectfully. KNMI effectively realizes its own wind inversion. The 25km level 2a files from the 2 hours and 3 hours data streams are processed into 25 km and 50 km level 2 wind products. This processing results in four different products: 25 km in resolution with a timeliness of 2 hours, 25 km in resolution with a timeliness of 3 hours, 50 km in resolution with a timeliness of 2 hours and 50 km in resolution with a timeliness of 3 hours. We chose to assimilate the 50km–3 hours timeliness wind product since it contains approximately 98% of the theoretical data amount and better suites the needs of the data assimilation systems.

NWP Collocation

KNMI receives model data from ECMWF twice daily. The model wind data are cubically interpolated with respect to time and linearly interpolated with respect to location and put into the level 2 information part of each WVC. Sea surface temperature and land-sea mask data are used to provide information about possible land or ice presence in the WVCs. Surface water with a temperature below 272.16K is assumed to be covered by ice and wind vectors are not calculated. Also, a prescribed threshold is applied to the land fraction within each WVC. If this threshold is exceeded, the land contamination flag is set and no wind retrieval is performed.

Wind retrieval

ASCAT data

Eumetsat makes available in near real-time level 1b scatterometer products from the MetOp satellite through the EUMETCast system (global data) and through a private network (regional data). These products are used for further processing and distributed by the Ocean and Sea Ice Satellite Application Facility (OSI SAF) at KNMI. The processing software developed at KNMI is called the ASCAT Wind Data Processor (AWDP). KNMI performs its own wind inversion by using the CMOD5.n geophysical model function for calculating equivalent neutral winds. On average, conversion of real winds to equivalent neutral winds results in the addition of a value of approximately 0.2 m/s regardless of stability conditions (Hersbach, 2008).

For the OSI SAF and EARS ASCAT wind products, the geophysical model function (GMF) CMOD5.n is used to produce 10m equivalent neutral winds. The Geophysical Model Function (GMF) is an empirical function (or lookup table) which relates the wind vector to the backscatter measurement. The GMF corresponds to a cone in the three-dimensional backscatter space (triplets), defining the wind speed which would produce the observed backscatter triplets. This model is based on collocation studies with observed and/or modeled wind data at 10m height.

The CMOD5.n GMF provides estimates of equivalent neutral winds corresponding to observed backscatter triplets. Its design is based on the CMOD5 GMF which provides improved estimates of real (stability-dependent) winds (Hersbach et al. 2007). For CMOD5.n, ECMWF performed a refit of the 28 tunable coefficients of the GMF in order to reproduce the 0.2 m/s global difference between equivalent neutral and real winds. Subsequently, KNMI produced a CMOD5.n lookup table and tested the re-tuned coefficients against a more straightforward way of obtaining equivalent neutral winds by using CMOD5 + 0.7 m/s (referred to CMOD5.7) retrieval outputs. The 0.7 m/s value corresponds to a the well-known 0.5 m/s bias of CMOD5 and a 0.2 m/s global difference between equivalent neutral and real winds. The CMOD5.n retrieved winds were found to compare well to those obtained through CMOD5.7. At MSC, we use the winds produced by the geophysical model CMOD5.n since its implementation in November 2008. Following the recommendations by KNMI, we subtract 0.2 m/s to wind speed values to account for the global difference between equivalent neutral and real 10m winds before their assimilation into our systems.

An inversion procedure is carried out to find the most probable triplet on the cone surface corresponding to the measured triplets. The inversion is based on the minimization of the maximum-likelihood estimator (MLE) for determining wind vector solutions. The MLE is defined by (ASCAT Wind Product User Manual from KNMI):

$$MLE = \frac{1}{SD^2} \sum_{i=1}^{N} (z_{o,i} - z_{m,i})^2$$

where

z_{oi} are the backscatter measurements.

$z_{m,i}$ are the model backscatter values corresponding to the measurements.

SD is the standard deviation of the measurement set noise related to both instrument and geophysical noise

$z = (\sigma_0)^{625}$ are the backscatter data after transformation into z-space that limits the wind direction sensitivity of the GMF to two harmonics.

The index i indicates beam position: 1=fore, 2=mid, 3=aft.
The transformation to z-space results in a circular distribution that is ideal for inversion.

The minimization is done for each triplet of measured σ_0 values at each node. The MLE minimization results in two local minima which correspond to the two most likely solutions that differ by approximately 180 degrees in direction. The three independent measurements (fore, mid and aft beam) well sample the azimuth variation of the GMF in order to resolve the wind direction, albeit ambiguously.

KNMI provides up to four wind solutions. Their product also includes a chosen wind solution, its corresponding ambiguous wind solutions and quality information such as the distance to cone and quality flag.

RapidScat data

This section is based on the RapidScat wind Product User Manual v 1.2 (2016). Details can also be found in the Algorithm Theoretical Basis Document for the OSI SAF wind products v1.2 (2015).

The input data used by KNMI are acquired from the National Aeronautics and Space Administration (NASA) Jet Propulsion Laboratory (JPL) in near-real time. The processing software developed at KNMI is named Pencil Beam Wind Processor (PenWP).

A variety of GMF exists for Pencil-beam scatterometers. KNMI is using the NSCAT-4 geophysical model function for the RapidScat retrievals. The NSCAT-2 GMF was used in the past for calculating EN winds but overestimated wind speeds above 15m/s, both when compared to buoy winds and NWP model winds. NSCAT-2 was changed for wind speeds above 15m/s and named NSCAT-4. Below 15m/s nothing was changed and above 15 m/s a linear scaling of the wind speed was applied.

KNMI uses a criterion on Rn which is defined as the Normalized Maximum Likelihood Estimate (MLE).

Rn = MLE/<MLE> (SeaWinds Data Processor User's Manual and Reference Guide v1.4, 2007, p55)

where MLE= $\frac{1}{N}\sum_{i=1}^{N}\left(\frac{\sigma_0^{obs,i}-\sigma_0^{simul,i}}{K_p(\sigma_0^{simul,i})}\right)^2$

$\sigma_0^{obs,i}$ is the i[th] radar backscattering cross-section measurement

$\sigma_0^{simul,i}$ is the i[th] GMF-simulated radar backscattering cross-section

K_p is an estimate for the observation error

N is the total number of measurements in the cell
An average <MLE> has been pre-computed for each cross-track position over an ensemble of revolutions.

The MLE represents the probability of a trial vector solution being the "true" wind. In the standard wind retrieval procedure, the MLE cost function gives up to four ambiguous wind solutions corresponding to the cost function minima. However, this results in inaccurate winds in the poor-azimuthal-diversity nadir region for pencil-beam scatterometers. Their inherent broad and skew minima may be well represented in the wind vector solution space by a multiple solution inversion output in combination with a variational analysis (2D-Var) ambiguity removal called the Multiple Solution Scheme (MSS). In the MSS approach, the full circle of possible wind directions is divided in 144 equal sectors of 2.5° and for each wind direction an optimal wind speed with its corresponding probability is calculated in the wind retrieval step. Subsequently, the 144 solutions of each WVC are used in the ambiguity removal for all wind directions simultaneously, thus representing the full wind vector probability density function in order to select the optimal solution. In this way, the full probability density function of the wind solutions is used (Portabella and Stoffelen, 2004).

After the wind inversion step, up to four solutions corresponding to the inversion residual (MLE) relative minima are stored. However, subsequently the wind speed and wind direction of the after 2DVAR-selected Multiple Solution Scheme (MSS) wind solution is put at the index of the selected wind solution. This index is set to the initial wind vector solution which is closest to the MSS wind vector selection obtained after 2DVAR. Thus, the former wind vector is not provided in the product, but rather the MSS selected wind vector. The 'Formal Uncertainty in Wind Direction' does not contain the uncertainty, but the normalised inversion residual (referred to as Rn).

2D-Var Ambiguity Removal (AR)

To select the most probable wind vector from the multiple solutions given by the inversion and to provide meteorologically balanced wind fields every solutions (up to 4 wind vectors) from each WVC are subjected to an ambiguity removal (AR) procedure. These ambiguities are removed by applying constraints on the spatial characteristics of the output wind field, such as rotation and divergence. At KNMI this AR step takes the form of a 2D-Var analysis of the wind field on a regular grid, in a very similar fashion to a 3D-Var. It uses a 10 m model wind field from ECMWF as a background term which is available twice a day (00 and 12 UTC) at +3h, +6h, …, +36h time steps. The best possible ECMWF wind forecasts, closest in space and time to the time the observation is processed, are used during the AR procedure. A QC-Var procedure is also applied during the minimization which is done in 2D Fourier space. A background error covariance matrix for wind components is defined using the hypothesis of spatially homogeneous and isotropic error correlations. Specified error correlation lengths for stream function and velocity potential, as well as a meridionally varying tuning parameter (ν) for the ratio of divergent to rotational wind are postulated for the NH, the Tropics and the SH (NWPSAF_KN_TR_001, 2004, ch. 3).

For the pencil-beam scatterometer (RapidScat) processing, the variable inversion minima is represented by the Multiple Solution Scheme (MSS). The 2D-Var AR explicitly uses the probability of the multiple solutions. This allows the possibility of transferring from the inversion, all retrieved quality information of the 144 ambiguous solution candidates representing the full circle of possible wind directions. Subsequently, the optimal solution is selected from the 144 solutions. The 2D-Var ensures spatial consistency and meteorological balance of the retrieved winds. Moreover, the MSS method has been shown to improve wind field consistency in the nadir part of the swath where azimuthal angle diversity is lacking.

Quality Control and Monitoring

In the last stage of production KNMI monitors the quality of its product on a global basis. Statistics of swath data are computed and compared against expected values in order to raise a flag in case of suspicious behavior of the instrument. Statistical checks are made of the number of WVC Quality Control rejections, the wind speed bias with respect to the ECMWF NWP background and the wind vector RMS difference with respect to the NWP background. In each WVC, the backscatter data are checked for quality, completeness and the inversion residual which accounts for cases of extreme variability (at fronts or centers of lows) or other geophysical variables affecting the radar backscatter. If the expected values are above certain thresholds values the product is consider suspicious and the monitoring flag is raised.

Scatterometer wind vector filtering and selection at MSC

The operational data processing of scatterometers at MSC is illustrated in figure 6. The processing steps will be described in the following sections.

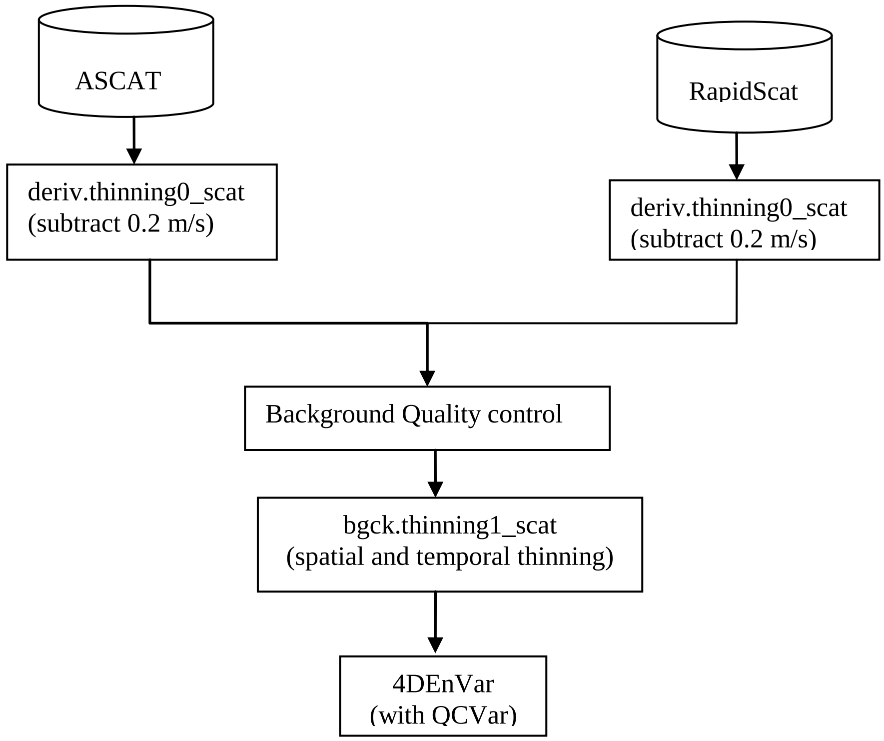

Figure 6: Flowchart of Scatterometer data processing

The scatterometer decoder at MSC reads BUFR files from KNMI and creates dbase files in BURP format. The scatterometer dbase files keep the observations in so-called grouped records (lat-lon boxes). The BURP codtyp for scatterometer data is 254. The program **deriv.thinning0_scat.f90** was written to process both the 25km grid-spacing ASCAT dbase and the RapidScat 50km dbase files to generate Var-ready BURP files (derivate).

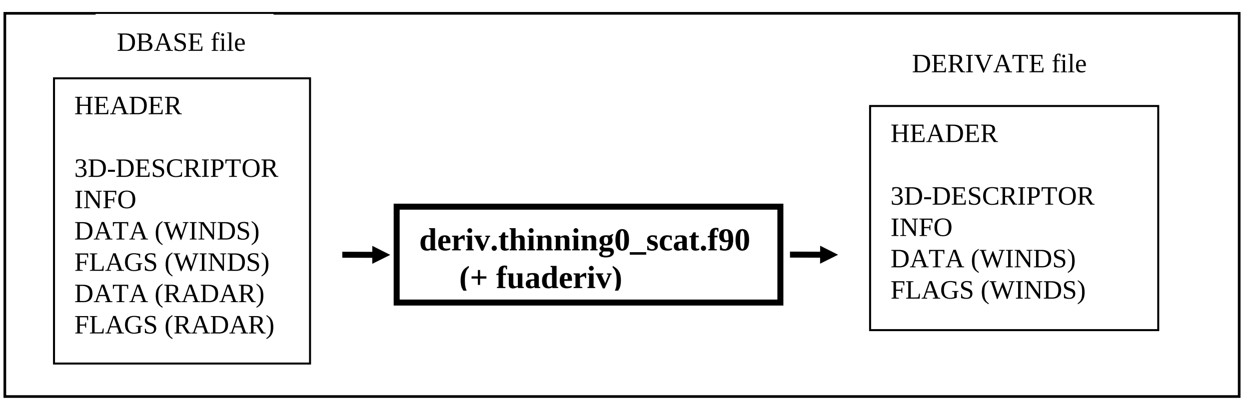

Figure 7: Transformation of Scatterometer dbase file into derivate file by program deriv.thinning0_scat.f90

Figure 7 illustrates this transformation. **deriv.thinning0_scat.f90** is written in Fortran 90 and uses the Fortran BURP_MODULE interface (found in cmda/libs domain 15.2) to access and create BURP files.

The program command line for ASCAT has the form:
deriv.thinning0_scat -s ${dbase} -d ${date}_sc –date ${date} -biais 2 –quiksc F <-deriv> <-qcknmi> -nodup F <-dt T> <-debug>

and for RapidScat, it has the form:
deriv.thinning0_scat -s ${dbase} -d ${date}_sc –date ${date} -biais 2 –quiksc T <-deriv> <-qcknmi> -nodup T <-dt T> <-debug>

where
-date specifies the date of the dbase file
-deriv informs that program BUADERIV will process its output file
-nodup filters duplicate records for RapidScat
-biais indicates the value of the bias correction (used for ASCAT data)
-quiksc indicates which type of scatterometer data is treated (ASCAT: quiksc = F; Rapidscat : quiksc = T)
-qcknmi eliminates observations based on KNMI QC flag
-dt T is a time cutoff (in minutes) applied in order to keep data within T minutes of the central time. Default is 180 minutes, i.e. all data are used from -3H to +3H
-debug controls output of extra information on standard output

Element 21102 from the INFO block stores the selected ambiguities. This number should be comprised within [1,4]. It is a pointer to the most likely wind vector chosen by the KNMI 2D-Var ambiguity removal procedure from the multiple vector solutions returned as a result of the inversion step. This one vector is written in the output file and will be assimilated. A lot of reports are discarded because this element is not defined (rank error).

A threshold on the minimum wind speed is applied. Winds slower than 4 m/s are not used (Draper, 2003, p14). The radar return from the sea-surface is unlikely to be sensitive enough in such calm wind conditions.

ASCAT data

Here is a brief overview of the program algorithm when treating ASCAT data. In the case of ASCAT data, the WVC ranges from 1 to 42. Figure 8 shows an overview of the algorithm.

deriv.thinning0_scat program

a) Read each report from dbase grouped file;
b) Check for the following flags: KNMI's quality control, variational quality control, land contamination and ice contamination;
c) Select wind data reports over 4 m/s;
d) Select ambiguity solution as suggested by KNMI;
e) Subtract 0.2 m/s from wind speed;
f) Write new observation record to grouped output file keeping only the necessary information (i.e. 3D-DESCRIPTORS, INFO, DATA (WIND RETRIEVALS) and FLAG blocks).
a) Output statistics.

Figure 8: Program **deriv.thinning0_scat.f90** algorithm.

Finally, the following information is retained after deriv.thinning0 is executed.

3D-DESCRIPTOR block	INFO block	DATA block
yyyymmdd (4208)	Originating/generating centre (1033)	speed (11012)
hhmm (4198)	Originating/generating sub-centre (1034)	direction (11011)
latitude (5002)	Software identification (25060)	backscatter distance (21156)
longitude (6002)	Satellite identifier (1007)	likelihood solution (21104)
report flag (55200)	Satellite instruments (2019)	
	Direction of motion of moving observing platform (1012)	
	seconds (4006)	
	Pixel Size on horizontal-1 (5033)	
	orbit number (5040)	
	Cross track cell number (6034)	
	Height of atmosphere used (10095)	
	Loss per unit length of atmosphere used (21157)	
	Beam collocation (21150)	
	Generating application (1032)	
	Model wind speed at 10m (11082)	
	Model wind direction at 10m (11081)	
	Ice probability (20095)	
	Ice age (20096)	
	Wind vector cell quality (21155)	
	Number of vector ambiguities (21101)	
	Index of selected wind vector (21102)	
	Delayed descriptor replication factor (31001)	

Table 1: Information kept in burp file after **deriv.thinning0_scat** program.

Figure 9 gives an example of the statistics output by the **deriv.thinning0_scat** program for ASCAT dbase file 2016050300_ that contains both METOP-1(B) and METOP-2(A) observations. On a total of 483840 observations, 179427 are written to derivate file 2016050300_sc and will pass to the background check, leaving behind a large number of observation reports (224340) which are unusable for diverse reasons.
224340 are not usable because they are missing retrieval information (-1).
8341 wind retrievals are rejected based on a minimum wind speed threshold (set to 4m/s).
71732 observations have been rejected by KNMI quality control flag (i.e. element 21155 different from 0).

```
STATISTICS:


N_rpt=  483840                    Total number of obs. in dbase file
N_winds (3Dvar ready)=   179427          Total number of wind obs. written to derivate file

N_flagged=   71732                       Number of obs. flagged by KNMI QC- 21155 (REJECTED)
       N_monitor_flag=     0
       N_monitor_val =     0
       N_qc_rej       =     2339
       N_varqc      =    472
       N_land       =    12337
       N_ice        =    0

N_toolow=   8341                         Number of obs. with wind speed below threshold (REJECTED)
N_rankerr=  224340                       Number of  obs. Report without a selected ambiguity (REJECTED)
N_wvc_error=     0
N_missing=     0
N_timeoff=     0

max_cell= 42
 ******************************************************************************************
 *        deriv.thinning0_scat                           v1.5                            *
 *        Tue May 9 09:03:08 2016                                                        *
 *        END EXECUTION                                                                  *
 *        CP SECS =      1.199                                                           *
 ******************************************************************************************
```

Figure 9: Example output statistics from program **deriv.thinning0_scat.f90**

The KNMI QC flag has 24 bits and each one has a different meaning (see appendix A for more details). Program **deriv.thinning0_scat.f90** checks only a few of them (presence of land, ice, KNMI's QC, QC-Var rejection, absence of monitoring or monitoring value) solely for diagnostic purposes since only the observations having element 21155 set to 0 should be used.

RapidScat data

As for Quikscat, RapidScat scans the ocean with 2 beams in a rotating fashion the same field of view on the ocean surface is seen 4 times (T1, T2, T3 and T4 in figure 4) in a few minutes while the satellite is moving forward in space. One consequence of this operating mode is that the swath read by our decoder contains multiple records (duplicate) pertaining to the same WVC in the swath. Multiple wind retrievals are produced by the KNMI software which are based on a varying number of radar sigma0's. Element 4210, time to edge of pass (in seconds), is used to identify which of the multiple records should be kept. The record with the highest value in element 4210 is deemed of the highest quality. All other records referring to the same WVC are discarded.

This treatment also requires the program to read the input dbase file twice.

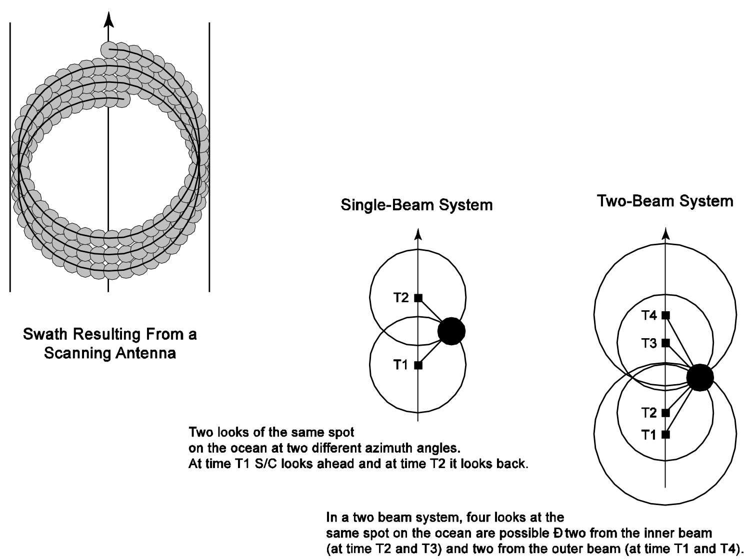

Figure 4. Schematic representation of the SeaWinds scan pattern.

Figure 10: Quikscat conical scan pattern taken from Quikscat ATBD (fig.4).

In order to ease the filtering process, during the first pass on the input file, all the information is gathered and stored internally in a data structure which relates to the orbit.

Here we give a brief overview of the program algorithm. As mentioned earlier it executes two reading passes on the input dbase file. In the first pass (**jpass**=1) each report is read to gather information in two 3D arrays.

qsorbit_wvc_keep(cell, row, maxrev) of derived type (structure) **WVC_STATE**

which is a 3D array of structures used to store selected parameters associated to a specific wind vector cell (WVC) and satellite orbit number read from the 3D DESCRIPTOR AND INFO blocks.
and
qsorbit_wvc_count(cell, row, maxrev) of type INTEGER
which is used to keep accounting of the number of observation reports having identical values of cell, row and orbit number.
For RapidScat **cell** is in [1:42] (i.e. pixel position across-track)
row is in [1:1624]
maxrev is set arbitrarily to a limit of 10

allowing for a maximum of 10 different orbit numbers in the 6 hours of data stored in the input dbase file. Typically, in a 6 hour period RapidScat will make 4 or 5 revolutions around the globe.

The f90 derived type **WVC_STATE** will keep the following information on each WVC

From 3D-DESCRIPTOR block	From INFO block	From DATA block
yyyymmdd (4208)	seconds (4006)	speed (11012)
hhmm (4198)	time to edge of pass (4210)	direction (11011)
latitude (5002)	number of sigma0's (21103)	likelihood solution (21104)
longitude (6002)	orbit number (5040)	
report flag (55200)	row (5034)	
	cell (6034)	
	Wind vector cell quality (21109)	
	Software identification (25060)	
	Satellite identifier (1007)	
	Direction of motion of moving observing platform (1012)	
	Model wind speed at 10m (11082)	
	Model wind direction at 10m (11081)	
	Number of vector ambiguities (21101)	
	Index of selected wind vector (21102)	

Table 2: Information kept in structure **this_wvc**.

The BURP input grouped report **key number** as well as the **ordinal number** of the actual observation inside the grouped report are also stored in the structure **this_wvc** and later copied to **qsorbit_wvc_keep** if the observation is to be kept. Figure 11 gives an overview of the algorithm.

PASS 1: Information gathering, QC and selection based on Time to Edge

1) Gather WVC information from 3D-DESCRIPTOR and INFO blocks of the report

2) Check if WVC (5034, 6034) is within normal limits
3) Check if a wind ambiguity (21102) has been selected by the Pencil Beam wind Processor
4) Check if KNMI QC flag (21109) is set (different from 0)
5) Read wind speed (11012) and direction (11011) from DATA block
6) Check if windspeed (11012) > 4 m/s
   If either step in 2-6 fails jump to next observation in grouped report
7) Else fill temporary variable **this_wvc** (derived type WVC_STATE) with report information
8) Check for duplicate/incomplete reports in array **qsorbit_wvc_keep**.

When the current observation, with parameters stored in variable **this_wvc,** is found having a twin observation read previously in the array **qsorbit_wvc_keep** with same WVC (i.e. identical cell and row numbers) and orbit numbers, array **qsorbit_wvc_count (cell, row, rev)** is incremented. At this stage we have to look further and determine if this observation is a duplicate or an incomplete observation. Two possibilities arise even for two observations with identical WVC/orbit number:

a) identical space and time parameters, i.e. identical values for the following 4 parameters: lat, lon, hhmm, ss. -→ Discrimination based on value of element **Time to Edge**. We use the best wind estimate by keeping the observation with the greater value of **Time to Edge** which is the time elapsed from the beginning of the pass. This observation will contain the most complete information in terms of sigma0 measurements.
b) space and/or time parameters are different -→ Reject (like a thinning)

PASS 2: Create derivate file

a) Reload each report from dbase file.
b) Select good reports using information previously stored in arrays **qsorbit_wvc_keep** and **qsorbit_wvc_count** during pass 1.
c) Write new observation record on output file (derivate) keeping only the necessary information for 3Dvar (i.e. 3D-DESCRIPTORS, INFO, DATA (WIND RETRIEVALS) and FLAG blocks).
c) Output statistics.

Figure 11: Program **deriv.thinning0_scat.f90** algorithm.

Figure 12 gives an example of the statistics output by the program for RapidScat dbase file 2016050300_. On a total of 44058 observations, only 28846 will be written in derivate file 2016050300_sc and ready to be assimilated by 4DEnVar (after being submitted to a background check), leaving behind a large number of observation reports (15212) for diverse reasons:
15212 are not usable, they are missing retrieval information (-1)
2327 wind retrievals are rejected based on a minimum wind speed threshold (set to 4m/s).
and 12885 observations have been rejected by KNMI quality control flag (i.e. element 21109 different from 0).

```
FILTERING AND SELECTION COMPLETED (jpass= 2)

STATISTICS:

N_rpt=  44058                              Total number of obs. in dbase file
N_winds (3Dvar ready)=   28846             Total number of wind obs. written to derivate file

N_flagged=   12885                         Number of obs. flagged by KNMI QC- 21109 (REJECTED)
      N_monitor_flag=     0
      N_monitor_val =     0
      N_rain       =     1470
      N_varqc      =   9
      N_land       =   1398
      N_ice        =   0

N_toolow=   2327                           Number of obs. with windspeed below threshold (REJECTED)
N_rankerr=  15212                          Number of  obs. Report without a selected ambiguity (REJECTED)
N_wvc_error=     0
N_missing=     0
N_timeoff=     0

revcount=  4                               Number of Quikscat revolutions found in the file and their
                                           orbit numbers
revs_in_file= 9136 9137 9138 9139    0     0    0    0    0    0

max_row=82
max_cell= 19
 *********************************************************************************************
 *        deriv.thinnin0_scat                          v1.5                                 *
 *        Tue May 3 09:03:08 2016 May 11 2016                                               *
 *        END EXECUTION                                                                     *
 *        CP SECS =      0.410                                                              *
 *********************************************************************************************
```
Figure 12: Example output statistics from program **deriv.thinning0_scat.f90**

KNMI QC flag has 17 bits and each one has a different meaning (see appendix A for more details). Program **deriv.thinning0_scat.f90** checks only a few of them (presence of rain, land, ice, QC-Var rejection, absence of monitoring or monitoring value) solely for diagnostic purposes since only the observation having element 21109 set to 0 should be used.

Scatterometer spatial thinning at MSC

Before their assimilation into the 4DEnVar analysis system, scatterometer data undergo a spatial thinning in order to achieve a target resolution of 100 km. The resolution of our variational analysis is approximately 50km (0.45 degree). Consequently, the 25 km grid-spacing ASCAT data and the 50 km RapidScat data are sufficient for our assimilation needs. Moreover, there is an overlapping of adjacent nodes, or horizontal correlations, that exists in the 25 km grid-spacing ASCAT data. So, this additional step to the processing of scatterometer (both ASCAT and RapidScat) data is needed to filter the high resolution ASCAT data and make a selection between RapidScat and ASCAT where both sources of data are available. The spatial thinning is carried out right after the background check.

The program **bgck.thinning1_scat.f90** was written in Fortran 90 to process both the 50km RapidScat and the 25 km grid-spacing ASCAT data files issued by the background check.

The program command line has the form:
bgck.thinning1_scat -inburp file1 -outburp file2 –step 0.25 -deltmax 90 –deltax1 75 –deltax2 100
where
-step specifies the stepobs in hours (0.25 for 4DEnVar). The time window used in 4DEnVar analysis is 6 hours and is divided into 25 bins of 15 minutes.
-deltmax is the time window per bin (90)
-deltax1 is not used
-deltax2 indicates the target resolution in km.

Figure 13 shows an overview of the algorithm of the **bgck.thinning1_scat** program.

bgck.thinning1_scat program
a) Read each report from file which passed the background check; b) Create a grid of dimension 400 X 200 (0.9 degree); c) Among all the existing reports in the predefined grid box, 1) Choose observation report closest to center of time window bin; 2) Choose ASCAT over RapidScat report; 3) Choose observation report closest to center of grid box. d) Write new observation reports on output file; e) Output statistics.

Figure 13: Program **bgck.thinning1_scat.f90** algorithm.

Figure 14 gives an example of the statistics output by the program **bgck.thinning1_scat** for scatterometer file 2016050300_. On a total of 208273 observations only 23213 reports remain to be assimilated by 4DenVar. A large number of observation reports, mostly ASCAT data, are discarded because of its high resolution, which is not required for the 4DEnVAR analysis.

```
STATISTICS:

STEP= 0.25 hours                          Stepobs
DELTMAX= 90                               Time window per bin
Deltax1= 75 km
Delatx2=100 km
Nblat = 200                               Number of points in latitude
Nblon = 400                               Number of points in longitude
Nbbin = 0.25   25                         Stepobs and number of bins

Number of obs in input file               Number of obs.
METOP-1 = 87198                           Number of ASCAT observations from METOP-1 in the input file
METOP-2 = 92229                           Number of ASCAT observations from METOP-2 in the input file
Rapid = 28846                             Number of RapidScat observations in the input file

Number of obs not selected due to topo = 144 Number of obs rejected because of topography

Number of obs in output file
METOP-1 = 7239                            Number of ASCAT observations from METOP-1 in the output file
METOP-2 = 7487                            Number of ASCAT observations from METOP-2 in the output file
Rapid = 8487                              Number of RapidScat observations in the output file

 *************************************************************************************
 *       TH1_SC                        v3.0                                          *
 *       Tue May 3 09:09:41 2016                                                     *
 *       END EXECUTION                                                               *
 *       CP SECS =      9.984                                                        *
 *************************************************************************************
```

Figure 14: Example output statistics from program **bgck.thinning1_scat.f90**

Scaterometer data assimilation in MSC's 4DEnVar system

At MSC, we assimilate the solution selected by the KNMI ambiguity removal 2D-Var procedure. This means that a single wind vector is assimilated in 4D-Var as if it was a buoy observation. ASCAT winds are simply assimilated with the existing surface operator (horizontal interpolation of background field in the surface layer at 10m above sea-level) already used for other surface wind observations like buoys and ships.

Observation error

Observation error standard deviations for wind components $\sigma_{\varepsilon,u}^{obs}$ and $\sigma_{\varepsilon,v}^{obs}$ have been set to a constant global value over the oceans,

$\sigma_{\varepsilon,u}^{obs} = \sigma_{\varepsilon,v}^{obs}$ =1,7 m/s

This value could be revised and even be made spatially varying.

Background Check

During the background quality control, the model counterparts for scatterometer observations are calculated through the observation operator. The square of the background departure is considered as being suspect when it exceeds its expected variance by a predefined value or what is called the normalized innovation squared (*NIS*):

$$NIS = \frac{(Hx - y)^2}{\sigma_{obs}^2 + \sigma_{bg}^2}$$

which is the ratio between the variance of the background departure and the sum of the variance of the background error and the variance of the observational error. The *NIS* is used to apply the different background check QC levels prior to analysis. These BG check rejection levels are defined as follows in the background check code:

NIS in [8, 14) → BG flag 1
NIS in [14, 20) → BG flag (reject level 2)
NIS => 20 → BG flag (reject level 3)

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Appendix A: ASCAT BURP report structure (KNMI 50 km - 25 km grid spacing)

An ASCAT BURP file (**dbase**) is composed of multiple BURP grouped reports each containing a report header followed by 6 blocks as follows:

REPORT HEADER

hhmm = 600 flgs = 1024 codtyp = 254 stnids = ^METOP-1
blat = 14500 blon = 21500 dx = 50 dy = 50 stnhgt = 54
yymmdd = 20160505 oars = 0 runn = 0 nblk = 6 dlay = 0

3D-DESCRIPTOR BLOCK

BLOCK HEADER
blkno = 1 nele = 6 nval = 1 nt = 514 bfam = 0
bdesc = 0 btyp = 5120 nbit = 25 bit0 = 0 datyp = 2

List of elements:

4208	4197	55200	5002	6002	4195

4208: Date from report header in format 'yyyymmdd'
4197: Observation time in format 'hhmm'
55200: Report header flag
5002: Mean latitude of WindVectorCell (WVC).
6002: Mean longitude of WindVectorCell (WVC).
4195: Reception Delay (minutes).

INFO BLOCK

BLOCK HEADER
blkno = 2 nele = 23 nval = 1 nt = 514 bfam = 0
bdesc = 0 btyp = 3072 nbit = 23 bit0 = 1207 datyp = 2

List of elements:

1033	1034	25060	1007	2019	1012	4006	5033	5040	6034
10095	21157	21150	1032	11082	11081	20095	20096	21155	21101
21102	31001								

1033: Identification of originating/generating centre
1034: Identification of originating/generating sub-centre
25060: Software identification
1007: Inversion Satellite Identifier
2019: Satellite instruments
1012: Direction of motion of moving observing platform
4006: seconds
5033: Pixel Size on horizontal-1

5040: orbit number
6034: Cross track cell number
10095: Height of atmosphere used
21157: Loss per unit length of atmosphere used
21150: Beam collocation
1032: Generating application
11082: Model wind speed at 10m
11081: Model wind direction at 10m
20095: Ice probability
20096: Ice age
21155: Wind vector cell quality
21101: Number of vector amibiguities
21102: Index of selected wind vector
31001: Delayed descriptor replication factor

DATA (WIND RETRIEVALS) BLOCK

BLOCK HEADER
blkno = 3 nele = 4 nval = 2 nt = 514 bfam = 0
bdesc = 0 btyp = 9217 nbit = 15 bit0 = 5462 datyp = 2

List of elements :

11012	11011	21156	21104

Block 3 is the first DATA block used to store winds retrieved by the KNMI ASCAT Data Processor. It is referred to as the WIND RETRIEVALS data block. This data block has only 4 elements with NVAL=4 to keep a maximum of 4 wind vector ambiguities that may result from the ASCAT inversion process. Each element of the WIND RETRIEVAL block is defined below.

11012: Retrieved Wind speed at 10 m
11011: Retrieved Wind Direction at 10 m
21156: Backscatter distance
21104: Value of Maximum Likelihood Estimate (MLE) computed for the solution

FLAG (WIND RETRIEVALS) BLOCK

BLOCK HEADER
blkno = 4 nele = 4 nval = 2 nt = 514 bfam = 0
bdesc = 0 btyp = 15361 nbit = 1 bit0 = 7391 datyp = 2

List of elements :

211012	211011	221156	221104

DATA (RADAR) BLOCK

BLOCK HEADER
blkno = 5 nele = 14 nval = 3 nt = 514 bfam = 0
bdesc = 0 btyp = 9218 nbit = 15 bit0 = 7521 datyp = 2

List of elements:

8085	2111	2134	21062	21063	21158	21159	21160	21161	21162
21163	21164	21165	21166						

Block 5 is a DATA block referred to as the RADAR data block. Most of the elements in that block have 3 values associated to each ASCAT beam (AFT, MID, FORE). It contains values of backscatter information for each one of the beam flavors.

8085: Beam Identifier
2111: Radar incidence angle.
2134: Antenna beam azimuth
21062: Backscatter
21063: Radiometric Resolution (Noise Value)
21158: ASCAT Kp Estimate quality
21159: ASCAT sigma-0 usability
21160: ASCAT Use of synthetic data
21161: ASCAT synthetic data quality
21162: ASCAT satellite orbit and attitude quality
21163: ASCAT solar array reflection contamination
21164: ASCAT telemetry presence and quality
21165: ASCAT extrapolated reference function
21166: ASCAT land fraction

FLAG (RADAR) BLOCK

BLOCK HEADER
blkno = 6 nele = 14 nval = 3 nt = 331 bfam = 0
bdesc = 0 btyp = 15362 nbit = 1 bit0 = 6161 datyp = 2

List of elements:

208085	202111	202134	2021062	2021063	2021158	2021159	2021160	2021161
2021162	2021163	2021164	2021165	2021166				

An ASCAT BURP file (**derivate**) is composed of multiple grouped BURP reports each containing a report header followed by 4 blocks as follows:

REPORT HEADER

hhmm = 600 flgs = 3072 codtyp = 254 stnids = ^METOP-1
blat = 14500 blon = 21500 dx = 50 dy = 50 stnhgt = 429
yymmdd = 20160505 oars = 0 runn = 18 nblk = 4 dlay = 0

3D-DESCRIPTOR BLOCK

BLOCK HEADER
blkno = 1 nele = 6 nval = 1 nt = 514 bfam = 0
bdesc = 0 btyp = 5120 nbit = 25 bit0 = 0 datyp = 2

List of elements:

4208	4197	55200	5002	6002	4195

INFO BLOCK

BLOCK HEADER
blkno = 2 nele = 23 nval = 1 nt = 429 bfam = 0
bdesc = 0 btyp = 3072 nbit = 23 bit0 = 1008 datyp = 2

List of elements:

1033	1034	25060	1007	2019	1012	4006	5033	5040	6034
10095	21157	21150	1032	11082	11081	20095	20096	21155	21101
21102	31001								

DATA (WIND RETRIEVALS) BLOCK

BLOCK HEADER
blkno = 3 nele = 4 nval = 1 nt = 429 bfam = 0
bdesc = 0 btyp = 1057 nbit = 15 bit0 = 4560 datyp = 2

List of elements :

11012	11011	21156	21104

FLAG (WIND RETRIEVALS) BLOCK

BLOCK HEADER
blkno = 4 nele = 4 nval = 1 nt = 429 bfam = 0
bdesc = 0 btyp = 7201 nbit = 1 bit0 = 4964 datyp = 2

List of elements :

211012	211011	221156	221104

Appendix B: ASCAT Wind Vector Cell (WVC) quality flag

The ASCAT Wind Vector Cell quality flag is stored in BUFR element 21155 with a width of 24 bits. Here we give the geophysical condition, data processing software results or measurement deficiencies associated with activation bit 2 to 18 of the flag.

21155=**2**	(2**1): Not enough good sigma-0 available for wind retrieval
21155=**4**	(2**2): Poor azimuth diversity among sigma-0 for wind retrieval
21155=**8**	(2**3): Any beam noise content above threshold
21155=**16**	(2**4): Product monitoring not used
21155=**32**	(2**5): Product monitoring flag
21155=**64**	(2**6): KNMI quality control fails
21155=**128**	(2**7): Variational quality control fails
21155=**256**	(2**8): Some portion of WVC is over land
21155=**512**	(2**9): Some portion of WVC is over ice
21155=**1024**	(2**10): Wind inversion not successful for WVC
21155=**2048**	(2**11): Reported wind speed > 30 m/s
21155=**4096**	(2**12): Reported wind speed < 3 m/s
21155=**8192**	(2**13): not used
21155=**16384**	(2**14): not used
21155=**32768**	(2**15): No meteorological background used
21155=**65536**	(2**16): Data are redundant
21155=**131072**	(2**17): Distance to GMF too large

All definitions are taken from KNMI’s ASCAT wind product user manual.

Appendix C: RapidScat BURP report structure (KNMI 50 km)

A RapidScat BURP file (**dbase**) is composed of multiple BURP grouped reports having each a report header followed by 6 blocks like this:

REPORT HEADER

hhmm = 600 flgs = 0 codtyp = 254 stnids = ^ISS
blat = 5000 blon = 31500 dx = 50 dy = 50 stnhgt = 54
yymmdd = 20160505 oars = 0 runn = 0 nblk = 6 dlay = 0

3D-DESCRIPTOR BLOCK

BLOCK HEADER
blkno = **1** nele = 6 nval = 1 nt = 54 bfam = 0
bdesc = 0 btyp = 5120 nbit = 25 bit0 = 0 datyp = 2

List of elements:

4208	4197	55200	5002	6002	4195

4208: Date from report header in format 'yyyymmdd'
4197: Observation time in format 'hhmm'
55200: Report header flag
5002: Mean latitude of WindVectorCell (WVC).
6002: Mean longitude of WindVectorCell (WVC).
4195: Reception Delay (minutes).

INFO BLOCK

BLOCK HEADER
blkno = **2** nele = 22 nval = 1 nt = 54 bfam = 0
bdesc = 0 btyp = 3072 nbit = 15 bit0 = 128 datyp = 2

List of elements:

1007	1012	2048	21119	25060	2026	2027	5040	4006	8025
5034	6034	21109	11081	11082	21101	21102	21103	21120	21121
13055	21122								

1007: Satellite Identifier
1012: Direction of motion of moving observing platform with respect to north, positive clockwise (degrees)
2048: Satellite Sensor Identifier (Numeric Code)
21119: Wind Scatterometer Geophysical Model Function Fonction (GMF) (Numeric Code)
25060: Inversion Software Identification (Numeric Code)
2026: Across-Track resolution
2027: Along Track Resolution

5040: Orbit number
4006: Time (seconds)
8025: Time Difference Qualifier applied to element 4006 (Numeric Code)
4210: Time to edge of pass (seconds)
5034: Along Track Row Number
6034: Across-Track Cell Number (WVC)
21109: RapidScat WVC Quality Flag
11081: Model Wind Direction at 10m
11082: Model Wind Speed at 10m
21101: Number of Vector Ambiguities (possible wind solutions)
21102: Index of Selected Wind Vector (in this case KNMI QCvar)
21103: Total numer of sigma0's (σ^0) measurements
21120: Probability of Rain (MUDH Algorithm)
21121: NOF Rain Index (linked to probability of precipitation)
13055: Intensity of Precipitation from Tb (TO COME)
21122: Atmospheric Attenuation Correction on σ^0 based on Tb (TO COME)

DATA (WIND RETRIEVALS) BLOCK

BLOCK HEADER
blkno = 3 nele = 5 nval = 4 nt = 54 bfam = 0
bdesc = 0 btyp = 9217 nbit = 15 bit0 = 425 datyp = 2

List of elements :

11012	11052	11011	11053	21104

Block 3 is the first DATA block used to store retrieved winds by KNMI Pencil-beam Data Processor. It is referred to as the WIND RETRIEVALS data block. This data block has only 5 elements with NVAL=4 to keep a maximum of 4 wind vector ambiguities that may result from the RapidScat inversion process. Each element of the WIND RETRIEVAL block is defined below.

11012: Retrieved Wind speed at 10 m
11052: Uncertainty on wind speed at 10 m
11011: Retrieved Wind Direction at 10 m
11053: Uncertainty on wind speed at 10 m
21104: Value of Maximum Likelihood Estimate (MLE) computed for the solution

FLAG (WIND RETRIEVALS) BLOCK

BLOCK HEADER
blkno = 4 nele = 5 nval = 4 nt = 54 bfam = 0
bdesc = 0 btyp = 15361 nbit = 1 bit0 = 680 datyp = 2

List of elements :

211012	211052	211011	211053	221104

DATA (RADAR) BLOCK

BLOCK HEADER
blkno = 5 nele = 15 nval = 4 nt = 154 bfam = 0
bdesc = 0 btyp = 9218 nbit = 17 bit0 = 698 datyp = 2

List of elements:

8085	5002	6002	21118	2112	2111	2104	21123	21106	21107
21114	21115	21116	8018	21117					

Block 5 is a DATA block referred to as the RADAR data block. Most of the elements in that block have 4 values associated with each one of the 4 Rapidcat beam flavors (INNER-FOR polHH, OUTER-FOR polVV, INNER-AFT polHH, OUTER-AFT polVV).

8085: Beam Identifier
5002: Beam Latitude
6002: Beam Longitude
21118: Monthly-climatological sigma0 rain-free two-way atmospheric attenuation correction at Nadir derived from SSMI (Wentz).
2112: Weighted mean azimuthal radar look angle for WVC
2111: Weighted mean incidence angle for WVC
2104: Beam Polarization
21123: Normalized backscattering cross-section σ^0 (dB) return at top of atmosphere
21106: Coefficient α used for σ^0 measurement error variance estimate (K_p) computation
21107: Coefficient β used for σ^0 measurement error variance estimate (K_p) computation

21114: Coefficient γ used for σ^0 measurement error variance estimate (K_p) computation
21115: Quality Flag for sigma0 measurement (Numeric code)
21116: Modal Flag for sigma0 measurement (Numeric code)
8018: SeaWinds Land/Ice Surface Flag
21117: Quality Flag for sigma0 variance (Numeric code).

FLAG (RADAR) BLOCK

BLOCK HEADER
blkno = 6 nele = 22 nval = 4 nt = 16 bfam = 0
bdesc = 0 btyp = 15362 nbit = 1 bit0 = 571 datyp = 2

List of elements:

202104	208022	212063	212065	221110	221111	221112	221113	205002	206002
221118	202112	202111	202104	221123	221106	221107	221114	221115	221116
208018	221117								

A Quikscat BURP file (**derivate**) is composed of multiple <u>ungrouped</u> BURP reports having each a report header followed by 3 blocks like this:

REPORT HEADER

hhmm = 600 flgs = 0 codtyp = 254 stnids = QUIKSCAT
blat = 15000 blon = 35000 dx = 0 dy = 0 stnhgt = 400
yymmdd = 20060605 oars = 0 runn = 0 nblk = 3 dlay = 0

INFO BLOCK

BLOCK HEADER
blkno = 1 nele = 22 nval = 1 nt = 1 bfam = 0
bdesc = 0 btyp = 3104 nbit = 16 bit0 = 39 datyp = 2

List of elements:

1012	2048	21119	25060	2026	2027	5040	4006	8025	4210
5034	6034	21109	11081	11082	21101	21102	21103	21120	21121
13055	21122								

DATA (WIND RETRIEVALS) BLOCK

BLOCK HEADER
blkno = 2 nele = 5 nval = 4 nt = 1 bfam = 0
bdesc = 0 btyp = 1057 nbit = 15 bit0 = 132 datyp = 2

List of elements :

11012	11052	11011	11053	21104

FLAG (WIND RETRIEVALS) BLOCK

BLOCK HEADER
blkno = 3 nele = 5 nval = 4 nt = 1 bfam = 0
bdesc = 0 btyp = 7201 nbit = 1 bit0 = 208 datyp = 2

List of elements :

211012	211052	211011	211053	221104

Appendix D: RapidScat Wind Vector Cell (WVC) quality flag

RapidScat Wind Vector Cell quality flag is stored in BUFR element 21109 with a width of 17 bits. Here we give the geophysical condition, data processing software results or measurement deficiencies leading to the activation bit 2 to 16 of the flag.

21109=**2** (2**1): Not enough good sigma-0 available for wind retrieval
21109=**4** (2**2): Not used
21109=**8** (2**3): VV polarized data in more than two beams
21109=**16** (2**4): Product monitoring not used
21109=**32** (2**5): Product monitoring flag
21109=**64** (2**6): KNMI quality control (including rain) data rejection
21109=**128** (2**7): Variational quality control rejection
21109=**256** (2**8): Some portion of WVC is over land
21109=**512** (2**9): Some portion of WVC is over ice
21109=**1024** (2**10): Not used
21109=**2048** (2**11): Reported wind speed > 30 m/s
21109=**4096** (2**12): Reported wind speed < 3 m/s
21109=**8192** (2**13): not used
21109=**16384** (2**14): Rain flag algorithm detects rain
21109=**32768** (2**15): Data from at least one of the four possible beam/view combinations are not available

All definitions are taken from KNMI's RapidScat wind product user manual.