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# PenWP Test Plan and Test Report

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## PenWP Test Plan and Test Report

KNMI, De Bilt, the Netherlands

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# 1 Introduction

This document is the test plan and test report for the Pencil beam Wind Processor (PenWP) software package. It is set up according to the guidelines of the NWP SAF; see the NWP SAF Development Procedures for Software Deliverables. Parts of the PenWP developments are in fact genscat developments. The tests for genscat modules are also included in this document. Part of the test plan is a traceability matrix to show how requirements as described in the Product Specification [2] are related to the tests in this document.

Most of the module tests described in this document have been developed and performed for OWDP (the OSCAT Wind Data Processor), AWDP (the ASCAT Wind Data Processor) and SDP (the SeaWinds Data Processor) a large part of the code in genscat is shared between PenWP and other NWP SAF wind processors. For this new PenWP version, all module tests have been repeated.

## 1.1 Aims and scope

The Pencil Beam Wind Processor (PenWP) is a software package written mainly in Fortran 90 with some parts in C for handling data from the SeaWinds (on QuikSCAT or ADEOS-II), OSCAT (on Oceansat-2), HSCAT (on HY-2A) and RapidScat (on the International Space Station) scatterometer instruments. Details of these instruments can be found in [4] and [5], respectively, and on several web sites, see e.g. information on the NASA and ISRO web sites. PenWP is intended to be a generic wind processor for Ku band pencil beam scatterometer data. It will be adapted to handle data from future instruments like the OSCAT successor ScatSAT (from ISRO) once they become available.

PenWP generates surface winds based on pencil beam radar backscatter data. It allows performing the ambiguity removal with the Two-dimensional Variational Ambiguity Removal (2DVAR) method and it supports the Multiple Solution Scheme (MSS). The output of PenWP consists of wind vectors which represent surface winds within the ground swath of the scatterometer. Input of PenWP is Normalized Radar Cross Section (NRCS,  $\sigma^0$ ) data. These data may be near real-time. The input files of PenWP are in BUFR. Conversion programs are included in the package to convert Hierarchical Data Format (HDF5) data from various instruments to BUFR. Output is written using the SeaWinds BUFR template or the KNMI BUFR template with generic wind section.

Depending on the grid spacing of the BUFR product, PenWP will process the data on 25 km, 50 km or 100 km grid spacing. The SeaWinds/RapidScat HDF5 to BUFR converter can create BUFR data on 25, 50 or 100 km grid spacing by averaging the backscatter data in the level 2a input file to the requested gridding. The OSCAT HDF5 to BUFR converter will create BUFR data with the same grid spacing as the level 2a input file. This can be 50 km when using the level 2a input data from the Indian Space Research Organisation (ISRO), or 25 km when using level 1b

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input data from ISRO in combination with a separate OSCAT level 1b to level 2a converter which is also included in the software package and which is based on software provided by NOAA. HY-2A input data are currently available on 25 km grid spacing but can also be averaged to a 50 km product.

Apart from the scatterometer input data, PenWP needs Numerical Weather Prediction (NWP) model winds as a first guess for the Ambiguity Removal step. These data need to be provided in GRIB edition 1 or 2.

## 1.2 Development of PenWP

PenWP is developed within the Numerical Weather Prediction Satellite Application Facility (NWP SAF) and Ocean and Sea Ice Satellite Application Facility (OSI SAF) projects as code which can be run in an operational setting. The coding is mainly in Fortran 90 with some parts in C and has followed the procedures specified for the NWP SAF. Special attention has been paid on robustness and readability. PenWP may be run on every modern Unix or Linux machine. In principle, PenWP can also be run on a Windows machine if a Linux environment like the Windows Installer for Ubuntu (Wubi) is installed. Details on the PenWP package can be found in [1], [2] and [3].

## 1.3 Testing PenWP, traceability matrix

This section describes the Test Plan of the PenWP deliverable. Tests have been carried out in all stages of the development of PenWP. The inversion module is not tested for the PenWP package, because such a test has already been made for the QuikSCAT Data Processor (QDP) development. PenWP contains several methods for Ambiguity Removal within module *ambrem* and its sub modules. Only modules needed for the KNMI 2DVAR scheme for Ambiguity Removal are tested within this project.

Compilation is done on several platforms (operating systems) and with different Fortran 90 compilers. The integration and validation tests were done on both a Linux work station and a Linux server environment.

Section 2 contains the tests for a number of individual modules. In general, modules are tested with the associated test programs that are located in the folder containing the module under consideration. The output of the test programs is always the standard output (screen) which may be redirected to any test log file or to some output files which are stored in the associated folders. Section 3 describes the PenWP integration test. A test folder containing some sample data is provided with PenWP and some of the resulting wind fields from these data are shown. Section 4 discusses the validation tests. PenWP has been compared with ECMWF model winds in the scope of this report, buoy validations are or will be performed in the scope of the OSI SAF. Section 4 also contains a technical check of the ice screening algorithm. Section 5 describes the portability tests. It contains an overview of platform/operating systems and Fortran and C compilers for which PenWP is supported. Finally, section 6 is devoted to testing the user documentation.

The table below is the traceability matrix. It shows the requirements in the Product Specification [2], how they are tested and where in this report these tests are described.

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<b>Requirement</b>	<b>Section of PS</b>	<b>Testing method</b>	<b>Test plan reference (section)</b>	<b>Comment</b>
PenWP generates surface winds	2.1, 3.5, 3.7	Process L2A file in penwp/test folder and inspect output	3.1	
PenWP generates BUFR output in NOAA format and in KNMI format	2.1, 3.1	Process L2A file in penwp/test folder and inspect output	3.1	
PenWP generates output in the same WVC spacing as the input data	2.2, 3.2	Process L2A file in penwp/test folder and inspect output	3.1	
PenWP output contains latitude, longitude and other parameters	2.2	Process L2A file in penwp/test folder and inspect output	3.1	
PenWP can use either L2A HDF5 data or BUFR data as input (HDF5 after conversion to BUFR)	2.3	Process L2A HDF5 data in penwp/test folder and subsequently reprocess BUFR output	3.1	
PenWP reads GRIB data containing LSM, SST and forecast winds	2.3	Process L2A file in penwp/test folder and check that a consistent wind field is obtained	3.1	
PenWP will compile and run on different Linux and Unix platforms	2.4	Compile and run PenWP on different platforms	5	
L2A backscatter slices are averaged correctly, unusable backscatter data are rejected.	3.2	Process a few orbits of L2A data and compare output winds to ECMWF background.	4.1	When averaging is not done well, a noisy or inconsistent wind field is obtained. This is reflected in the statistics of scatterometer winds vs. ECMWF.
Atmospheric attenuations are computed and stored in output	3.3	Process L2A file in penwp/test folder and inspect output	3.1	Atmospheric attenuations should be in the order of 0.2 to 0.3 dB
WVCs with high MLEs must be rejected by Quality Control	3.4	Process L2A file in penwp/test folder and check if QC flag is set for high MLE values	3.1	
Bayesian ice screening is implemented	3.6	Process a few orbits of L2A data and inspect ice maps	4.2	
A product monitoring flag is implemented	3.8	Not tested since there are no data with anomalous instrument performance available	-	
PenWP can process data within reasonable CPU time.	3.9	Process L2A file in penwp/test folder and check processing time.	3.1	

**Table 1.1** Traceability matrix.

## 1.4 Test folders

The Test folder of the PenWP software package is located in subdirectory `penwp/test.s`. This

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subdirectory contains several input files for PenWP that are discussed in more detail in section 3. The scripts for executing these tests are located in directory `penwp/execs`. It is recommended to use these scripts (or a modified version) also for normal PenWP operation, as the environment variables needed by PenWP are set in these scripts.

As stated before, most test programs are located in the same directory as the module to be tested. See section 2 for detailed information.

## 1.5 Conventions

Names of physical quantities (e.g., wind speed components  $u$  and  $v$ ), modules (e.g. *BufMod*), subroutines and identifiers are printed italic.

Names of directories and subdirectories (e.g. `penwp/src`), files (e.g. `penwp.F90`), and commands (e.g. `penwp -f input`) are printed in Courier. Software systems in general are addressed using the normal font (e.g. PenWP, genscat).

Hyperlinks are printed in blue and underlined (e.g. <http://www.knmi.nl/scatterometer/>).

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## 2 Module tests

In this section the various tests to individual modules within PenWP are presented. The tests are listed alphabetically in the module name. Table 2.1 gives an overview of the modules tested, their location and the name of the associated test programs.

Module tests have been included in PenWP if the following conditions were satisfied:

1. The test does not require additional software.
2. The output of the test program is self-explanatory enough to judge the outcome of the test.

<b>Module name</b>	<b>Location</b>	<b>Test program</b>
<i>BFGSMod</i>	genscat/support/BFGS	<i>Test_BFGS</i>
<i>BufrMod</i>	genscat/support/bufr	<i>test_modules</i>
<i>convert</i>	genscat/support/convert	<i>test_convert</i>
<i>CostFunction</i>	genscat/ambrem/twodvar	<i>Test_SOS</i>
<i>StrucFunc</i>	genscat/ambrem/twodvar	<i>Test_SOS</i>
<i>DateTimeMod</i>	genscat/support/datetime	<i>TestDateTimeMod</i>
<i>ErrorHandler</i>	genscat/support/ErrorHandler	<i>TestErrorHandler</i>
<i>gribio_module</i>	genscat/support/grib	<i>test_read_GRIB1, test_read_GRIB2, test_read_GRIB3</i>
<i>HDF5Mod</i>	genscat/support/hdf5	<i>TestHDF5</i>
<i>LunManager</i>	genscat/support/file	<i>TestLunManager</i>
<i>numerics</i>	genscat/support/num	<i>test_numerics</i>
<i>SingletonFFT</i>	genscat/support/singletonfft	<i>TestSingleton</i>
<i>SortMod</i>	genscat/support/sort	<i>SortModTest</i>

**Table 2.1** Overview of module tests.

### 2.1 Module *BFGSMod*

Directory genscat/support/BFGS contains program Test\_BFGS. This program tests the minimization routine LBFGS and its associated routines in module *BFGSMod*. The routines in *BFGSMod* are slightly modified versions of the freeware routine LBFGS and its subroutines. LBFGS was written by J. Nocedal, see [6].

Program Test\_BFGS finds the minimum of the function

$$f(x) = \sum_{i=1}^{100000} (x-i)^4$$

The minimum is the point (1, 2, ..., 100000). The search starts at the origin. The typical output is shown in table 2.2.



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```

Program Test_BFGS testing routine LBFGS

Behaviour of cost function:
Iter      Cost
-----
   0  0.20001E+25
   1  0.19527E+25
   2  0.17724E+25
...
  84  0.29492E-15
  85  0.95608E-16
  86  0.30995E-16

Routine LBFGS completed succesfully
Number of iterations      :      87
Dimension of problem      :    100000
Number of corrections in BFGS update :      5
Cost function at start    :    0.20001D+25
Cost function at end      :    0.30995D-16
Precision required        :    0.10D-19
Norm of final X           :    0.18258D+08
Norm of final G           :    0.97625D-13
Minimum and Maximum error in solution : 0.000003  0.000005
Time needed               :    0.460  seconds
Program Test_BFGS completed succesfully.

```

---

**Table 2.2** Output of program Test\_BFGS.

## 2.2 Module *BufrMod*

Directory `genscat/support/bufr` contains program `test_modules`. This program is compiled and called automatically by the `genscat` make system, since it is needed to translate the ASCII BUFR tables to binary form. It will also read in a small BUFR test file, decode it, encode the data again and write them to an output BUFR file. Hence, the program can be used to check the BUFR library. Table 2.3 shows the output generated by `test_modules`. The program can be invoked by calling the shell script `run_test_modules`, which sets the environment variable `$BUFR_TABLES` and calls `test_modules`.

---

```

nr of BUFR messages in this file is:      1
      ECMWF

      BUFR DECODING SOFTWARE VERSION - 403

Your path for bufr tables is :
./bufr_tables/
BUFR TABLES TO BE LOADED  B0000000000210000001.TXT,D0000000000210000001.TXT
tbd#nelements =          44
pos_lat =                25
pos_lon =                26
latitude range:         -3.630000          1.260000
longitude range:        2.850000          7.690000
      ECMWF

      BUFR ENCODING SOFTWARE VERSION - 7.2
      1 April 2007.

Your path for bufr tables is :
./bufr_tables/
BUFR TABLES TO BE LOADED  B0000000000210000001.TXT,D0000000000210000001.TXT

```

---

**Table 2.3** Output of program `test_modules`.

### 2.3 Module *convert*

Directory `genscat/support/convert` contains module *convert.F90*, a number of routines for the conversion of meteorological and geographical quantities. Its associated test program is *test\_convert*, and part of its output is listed in table 2.4. Program *test\_convert* produces quite a lot of output.

It starts with checking some conversions between different wind vector representations and transformations between different geographical coordinate systems, followed by a check of the transformation from orbit angles ( $p, a, \text{rot}(z)$ ) to three-dimensional position ( $x, y, z$ ).

Only the results for  $p = 0^\circ$  and  $90^\circ$  are (partly) shown in table 2.4; those for  $p = 10^\circ, 45^\circ$ , and  $70^\circ$  are omitted. Program *test\_convert* ends with some trigonometric calculations on a sphere.

```

=====
u =      5.000000      v =     -7.000000
uv_to_speed, uv_to_dir =====> sp =      8.602325      dir =      324.4623
=====
sp =      8.602325      dir =      324.4623
speeddir_to_u, speeddir_to_v =====> u =      5.000002      v =     -6.999999
=====
met2uv: sp =      10.00000      dir =      135.0000
met2uv: =====> u =     -7.071068      v =      7.071068
uv2met: u =     -7.071068      v =      7.071068
uv2met: =====> sp =      10.00000      dir =      135.0000
=====
lat,lon =      55.00000      5.000000
latlon2xyz: =====> x,y,z =      0.5713938      4.9990479E-02      0.8191521
x,y,z =      0.5713938      4.9990479E-02      0.8191521
xyz2latlon: =====>lat,lon =      55.00000      5.000000
=====
      p      a      rot_z      x      y      z      a1      rot_z1      a2      rot_z2
0.00000 -90.00000  0.00000  0.00000  0.00000 -1.00000 -90.00000 106.16298 270.00000  0.00000
0.00000 -90.00000 15.00000  0.00000  0.00000 -1.00000 -90.00000 105.59795 270.00000  9.72975
0.00000 -90.00000 30.00000  0.00000  0.00000 -1.00000 -90.00000 103.95005 270.00000 27.91061
0.00000 -90.00000 45.00000  0.00000  0.00000 -1.00000 -90.00000 101.35209 270.00000 43.81981
0.00000 -90.00000 60.00000  0.00000  0.00000 -1.00000 -90.00000 98.00070 270.00000 59.32336
0.00000 -10.00000  0.00000  0.98481  0.00000 -0.17365 -10.00000  0.00000 190.00000 180.00000
0.00000 -10.00000 15.00000  0.95125  0.25489 -0.17365 -10.00000 15.00000 190.00000 -164.99998
0.00000 -10.00000 30.00000  0.85287  0.49240 -0.17365 -10.00000 30.00000 190.00000 -149.99998
...
90.00000 45.00000 30.00000  0.25882  0.96593  0.00000  74.99999  0.00000 105.00000  0.00000
90.00000 45.00000 45.00000  0.00000  1.00000  0.00000  90.00000  0.00000  90.00000  0.00000
90.00000 45.00000 60.00000 -0.25882  0.96593  0.00000  74.99999  0.00000 105.00000  0.00000
90.00000 90.00000  0.00000  0.00000  1.00000  0.00000  90.00000  0.00000  90.00000  0.00000
90.00000 90.00000 15.00000 -0.25882  0.96593  0.00000  74.99999  0.00000 105.00000  0.00000
90.00000 90.00000 30.00000 -0.50000  0.86603  0.00000  59.99999  0.00000 120.00000  0.00000
90.00000 90.00000 45.00000 -0.70711  0.70711  0.00000  45.00000  0.00000 135.00000  0.00000
90.00000 90.00000 60.00000 -0.86603  0.50000  0.00000  30.00000  0.00000 149.99998  0.00000
=====
latlon1 =      5.000000      5.000000      latlon2 =      6.000000
5.000000
angle distance =      1.000000
km distance =      111.3188
latlon1 =      55.00000      5.000000      latlon2 =      56.00000
5.000000
angle distance =      1.000000
km distance =      111.3188
latlon1 =      85.00000      5.000000      latlon2 =      86.00000
5.000000
angle distance =      1.000000
km distance =      111.3188
=====
latlon1 =      5.000000      5.000000      latlon2 =      5.000000
6.000000
angle distance =      0.9961947
km distance =      110.8952
=====

```

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```

latlon1 = 55.00000 5.000000 latlon2 = 55.00000
6.000000
angle distance = 0.5735765
km distance = 63.84987
latlon1 = 85.00000 5.000000 latlon2 = 85.00000
6.000000
angle distance = 8.7155804E-02
km distance = 9.702084
=====

Test WVC_Orientation
WVC1 coordinates (Lam1,Phi1) = -115.2000 -18.61000
WVC2 coordinates (Lam2,Phi2) = -123.6500 -17.52000
WVC1 orientation Alfa1 = 173.5995 (Should equal 173.5994720)
WVC2 orientation Alfa2 = 170.9747 (Should equal 170.9747467)
=====

```

---

**Table 2.4** Output of program *test\_convert*

## 2.4 Modules *CostFunction* and *StrucFunc*

Module *CostFunc.F90* in directory *genscat/ambrem/twodvar* contains the cost function definition of the 2DVAR method. Module *StrucFunc* in the same directory contains the error covariance model of the background field. Large parts of these modules are tested in the single observation solution test implemented in program *Test\_SOS*. Table 2.5 lists its output.

The main idea behind this test is that the 2DVAR analysis increment can be calculated analytically in case of one single observation with unit probability. Starting with zero background increment and an observation increment  $(t_o, l_o)$  on the 2DVAR grid at the position with indices (1,1), the initial total cost function equals

$$J_t^{init} = \frac{t_o^2 + l_o^2}{\varepsilon^2}$$

where  $\varepsilon$  stands for the standard deviation of the observation error, which is set to 1.8 in *Test\_SOS*. The 2DVAR problem now reduces to a simple optimal interpolation problem. If the standard deviation of the background error is set to the same value as that of the observation error, the final solution has  $J_t^{fin} = J_o^{fin} + J_b^{fin} = 1/2 J_t^{init}$  with  $J_b^{fin} = J_o^{fin}$ . This allows construction of the final solution and its gradient, see [7] for more detailed information and a complete description of the 2DVAR method.

Program *Test\_SOS* reads the observation increment and the structure function parameters from an input file with default name *Test\_SOS.inp*, see below. The Helmholtz transformation coefficients are set according to option JV, which is the default option standing for sampled continuum (the other option is for periodic boundary conditions but these do not reproduce the correct scaling, see [7] for more details. The program copies the structure function parameters into the *SF*-struct, and the observation increments in the *TwoDvarObs*-struct. The structure function parameters are printed by routine *PrnStrucFuncPars*.

The error covariances are calculated numerically in module *StrucFunc*. For Gaussian structure functions, they can also be calculated analytically. The two methods are compared and the relative precision is printed. In table 2.5 it is 0.00345 for the stream function  $\psi$  and 0.0 for the velocity potential  $\chi$ , since the latter quantity is identically zero in this example. The precision of the covariances depends on the correlation lengths  $R_\psi$  and  $R_\chi$ .

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The total cost function and its gradient is evaluated by routine *JoScat* in module *CostFunction*. From this the cost function components and gradients at the final solution are calculated and checked against their analytical value. The (absolute) precision is printed. Finally, *Test\_SOS* checks the packing and unpacking routines of the control vector in both directions.

As stated before, program *Test\_SOS* reads its input from an input file. The name (and path) of that file must be given as command line argument of *Test\_SOS*. When omitted, the program assumes *Test\_SOS.inp* as input file. Table 2.6 gives the structure and contents of the input file. It is in free format.

```
=====
PROGRAM Test_SOS - Single Observation Soluton Check
=====
```

```
Input read from file      : Test_SOS.inp
Helmholz coefficients type : JV
2DVAR:
2DVAR: Parameters inside the StructFunc module:
2DVAR: Grid size in position domain      : 100000.0      m
2DVAR: Grid dimensions                   :              32 by          32
2DVAR: Free edge size                    :              5 points
2DVAR: Structure function type           : Gaus
2DVAR: Northern hemisphere:
2DVAR: Error standard deviation in psi   : 1.800000      m/s
2DVAR: Error standard deviation in chi   : 1.800000      m/s
2DVAR: Rotation/divergence ratio        : 1.000000
2DVAR: Range parameter for psi          : 300000.0
2DVAR: Range parameter for chi          : 300000.0
2DVAR: Tropics:
2DVAR: Error standard deviation in psi   : 2.000000      m/s
2DVAR: Error standard deviation in chi   : 2.000000      m/s
2DVAR: Rotation/divergence ratio        : 0.1000000
2DVAR: Range parameter for psi          : 300000.0
2DVAR: Range parameter for chi          : 300000.0
2DVAR: Southern hemisphere:
2DVAR: Error standard deviation in psi   : -1.000000     m/s
2DVAR: Error standard deviation in chi   : 76.00000      m/s
2DVAR: Rotation/divergence ratio        : 0.000000
2DVAR: Range parameter for psi          : 1.800000
2DVAR: Range parameter for chi          : 1.800000
```

```
CheckCovMat - checking precision of Covariances
Relative precision in covariances of psi: 3.3184644E-04
Relative precision in covariances of chi: 2.7596165E-04
```

```
Number of observations      : 1
Number of control variables : 2046
```

```
Obs2dvar after initialization:
i j Namb u v Jo gu gv
-----
1 1 1 1.0 0.0 0.00000E+00 0.00000E+00 0.00000E+00
```

```
The gradient velocity fields duo and dvo (nonzero components only):
i j duo dvo
-----
```

```
The cost function of the solution:
Observation part : 0.000000
Background part : 0.000000 precision 0.000000
```

```
The background velocity field:
u(1,1) : 0.000000
Expected value : 0.5000000 precision 0.5000000
v(1,1) : 0.000000
Expected value : 0.000000 precision 0.000000
```

```
Check background cost function
Direct calculation from psi and chi : 0.000000
```

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---

```

Calculation by Jb from control vector :    0.000000          precision    0.000000

Check observation cost function
Expected value                          :    0.000000
Calculation by Jo from control vector :    0.000000          precision    0.000000
Precision in gradients better than      1.9753901E-10

Check packing/unpacking:
Precision in packing/unpacking of xi     0.000000
Precision in packing/unpacking of psi    0.000000
Precision in packing/unpacking of chi    0.000000

Program Test_SOS completed.
=====

```

---

**Table 2.5** Output of the single observation solution test.

Record	Item nr.	Name	Meaning
1	1	u0_ini	Initial observation increment in transversal direction (m/s)
1	2	v0_ini	Initial observation increment in longitudinal direction (m/s)
2	1	lparameter	Logical parameter indicating if 2DVAR parameters should be read from file
3	1	TDVParameterFile	Name of 2DVAR parameter file

**Table 2.6** Input file for *Test\_SOS*.

## 2.5 Module *DateTimeMod*

Module *DateTimeMod.F90* in directory `genscat/support/datetime` contains general purpose date and time help functions. These are tested by program *TestDateTimeMod*, the output of which is listed in table 2.7.

---

```

time-tests
time: 14:22:03.70
time_real      = 51723.70
time_real + 77.2 = 51800.90
time: 14:23:20.90
time2 is valid
time1 =
time: 14:22:03.70
time2 =
time: 14:23:20.90
time 1 .ne. time2
date-tests
date: 15-12-1999
date_int =      19991215
date_int + 1 =      19991216
date: 16-12-1999
date2 is valid
date1 =
date: 15-12-1999
date2 =
date: 16-12-1999
date 1 .ne. date2
date-stepping-tests
ERROR: The date      21000101 is outside the range
19000101...20991231, this is not implemented at this time
ERROR: Julian routines differ from my own routines
date: 31-12-2099
next_date_int =      2147483647
date: 01-01-2100
next_julian_date_int =      21000101
all OK
before:
time: 23:59:57.70
date: 31-12-1999

```

---

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---

```

after incrementing by: 5.22 seconds
time: 00:00:02.92
date: 01-01-2000
  valid time
  test of function date2string: 19991231
  test of function date2string_sep: 1999-12-31
  test of function time2string: 235957
  test of function time2string_sep: 23:59:57
  before convert_to_derived_datetime:
date: 28-02-2005
time: 52:00:00.00
  after convert_to_derived_datetime:
date: 02-03-2005
time: 04:00:00.00
  Current date and time:
date: 16-04-2015
time: 09:20:37.13

```

---

**Table 2.7** Output of program *TestDateTimeMod*.

## 2.6 Module *ErrorHandler*

Module *ErrorHandler.F90* in directory `genscat/support/ErrorHandler` contains routines for handling errors during program execution. The module is tested by program *TestErrorHandler*, the output of which is listed in table 2.8.

---

```

The Error Handler program_abort routine is set to
return after each error,
in order to try and resume the program...
testing: report_error
an error was reported from within subroutine: dummy_module_name1
error while allocating memory
testing: program_abort (with abort_on_error = .false.)
an error was reported from within subroutine: dummy_module_name2
error while allocating memory
==> trying to resume the program ...
The Error Handler program_abort routine is set to
abort on first error...
testing: program_abort (with abort_on_error = .true.)
an error was reported from within subroutine: dummy_module_name2
error while allocating memory

```

---

**Table 2.8** Output of program *TestErrorHandler*.

## 2.7 Module *gribio\_module*

Module *gribio\_module.F90* in directory `genscat/support/grib` contains routines for reading and decoding GRIB files. The module is tested by programs *test\_read\_GRIB1*, *test\_read\_GRIB2* and *test\_read\_GRIB3*, the output of which is listed in tables 2.9 to 2.11. The test programs read in two small GRIB files (`testfile.grib` in GRIB edition 1 format and `testfile.grib2` in GRIB edition 2 format) present in this directory and print some of their contents to the standard output. The environment variable `$GRIB_DEFINITION_PATH` needs to be set and has to point to the directory containing GRIB definition tables. These are available in `(...)/genscat/support/grib/definitions`.

---

```

open GRIB edition 1 file
file name = ./testfile.grib
date of grib field =          20031111
time of grib field =           24
derived date of grib field =   20031112

```

---

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---

```

derived time of grib field =          0

   lat   lon   10u   10v   speed
54.00  4.00  -4.576  8.006  9.221
54.00  4.50  -5.143  7.764  9.313
54.00  5.00  -5.034  7.520  9.050
54.00  5.50  -4.925  7.276  8.786
54.50  4.00  -4.849  8.455  9.747
54.50  4.50  -5.139  8.315  9.775
54.50  5.00  -5.200  8.426  9.902
54.50  5.50  -5.261  8.537  10.028
55.00  4.00  -5.267  8.577  10.065
55.00  4.50  -5.398  8.454  10.031
55.00  5.00  -5.416  8.620  10.180
55.00  5.50  -5.434  8.786  10.330
55.50  4.00  -5.686  8.699  10.392
55.50  4.50  -5.657  8.594  10.289
55.50  5.00  -5.632  8.814  10.459
55.50  5.50  -5.606  9.034  10.632

```

```

open GRIB edition 2 file
file name = ./testfile.grib2
date of grib field =          20031111
time of grib field =          24

```

---

End of tests

---

**Table 2.9** Output of program *test\_read\_GRIB1*.

---

```

retrieve grib field par_id_t
lat of first gridpoint = 89.142
lat step                = -1.121
number of lat points   = 160
lon of first gridpoint = 0.000
lon step                = 1.125
number of lon points   = 320

   i   j  field(i,j)
80 160  302.663
80 161  302.445
80 162  302.148
80 163  301.560
81 160  301.999
81 161  302.298
81 162  301.808
81 163  301.708
82 160  302.056
82 161  302.117
82 162  301.490
82 163  301.888
83 160  302.214
83 161  302.001
83 162  301.796
83 163  302.361

```

---

**Table 2.10** Output of program *test\_read\_GRIB2*.

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---

```

retrieve grib field par_id_10u
date of grib field = 20031111
time of grib field = 24
WARNING: latitude dimension of field is too small to contain
WARNING: the read data; truncating the array !!!!!
original: nr_lat_points = 160
truncated: nr_lat_points = 50
WARNING: longitude dimension of field is too small to contain
WARNING: the read data; truncating the array !!!!!
original: nr_lon_points = 320
truncated: nr_lon_points = 50

  i   j  field(i,j)
 48  48   -0.414
 48  49    0.477
 48  50   -0.111
 49  48    3.330
 49  49    2.899
 49  50    3.252
 50  48    3.503
 50  49    2.408
 50  50    3.212

```

---

**Table 2.11** Output of program *test\_read\_GRIB3*.

## 2.8 Module HDF5Mod

Module *HDF5Mod.F90* in directory *genscat/support/hdf5* contains routines for reading and writing HDF5 files. It is tested by program *TestHDF5*, the output of which is listed in table 2.12. The test program reads in a small HDF5 file called *deflate.h5* and displays some of its contents. After that, it creates a file called *testfile.h5* and writes some data into it. Its contents can be checked e.g. with the command line utility *h5dump*.

---

```

Successfully opened file deflate.h5 with f_id 67108864
Successfully opened dataset //Dataset1 with d_id 335544320
Successfully closed dataset with d_id 335544320
Successfully opened group / with g_id 134217728
Successfully opened dataset Dataset1 with d_id 335544321
Number of datapoints of dataset 335544321 is 20000
First data values are:
  0   1   2   3   4   0   1   2   3   4
  0   1   2   3   4   0   1   2   3   4
Successfully closed dataset with d_id 335544321
Successfully closed group with g_id 134217728
Successfully closed file with f_id 67108864

End of file reading tests in TestHDF5

Successfully opened file testfile.h5 with f_id 67108865
Successfully created group Group1 with g_id 134217729
Successfully wrote Attribute Attribute1 in group 134217729
Successfully wrote Dataset Dataset1_int_1d in group 134217729
Successfully wrote Dataset Dataset2_int_2d in group 134217729
Successfully wrote Dataset Dataset3_float_1d in group 134217729
Successfully wrote Dataset Dataset4_float_2d in group 134217729
Successfully wrote Dataset Dataset5_string_1d in group 134217729
Successfully closed group with g_id 134217729
Successfully closed file with f_id 67108865

End of file writing tests in TestHDF5

A HDF5 file called testfile.h5 was created
You can check its contents e.g. using the h5dump utility

End of TestHDF5

```

---



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**Table 2.12** Output of program *TestHDF5*.

## 2.9 Module *LunManager*

Module *LunManager.F90* in directory `genscat/support/file` contains routines for file unit management. It is tested by program *TestLunManager*, the output of which is listed in table 2.13.

---

```

Starting fileunit test program
===== lun_manager =====
fileunit:          31  was not in use !!!
free_lun returns without freeing any fileunit
fileunit:          88  was not in the range that is handled
by this module ! (          30  -          39  )
free_lun returns without freeing any fileunit
fileunit:          88  was not in the range that is handled
by this module ! (          30  -          39  )
enable_lun returns without enabling any fileunit
fileunit:          88  was not in the range that is handled
by this module ! (          30  -          39  )
disable_lun returns without disabling any fileunit
fileunit:          21  was not in the range that is handled
by this module ! (          30  -          39  )
disable_lun returns without disabling any fileunit
unit:              31  is used?:  F
unit:              31  is used?:  T
start of inspect_luns
  lun              0  is open
  lun              0  has a name: stderr
  lun              5  is open
  lun              5  has a name: stdin
  lun              6  is open
  lun              6  has a name: stdout
  lun             31  is open
  lun             31  has a name: TestLunManager.F90
end of inspect_luns
fileunit:          31  is still in use !
disabling it is only possible if it is not used !
disable_lun returns without disabling any fileunit
fileunit:          30  is in use
fileunit:          31  is in use
fileunit:          32  is still available
fileunit:          33  is still available
fileunit:          34  is still available
fileunit:          35  is still available
fileunit:          36  is still available
fileunit:          37  is still available
fileunit:          38  is still available
fileunit:          39  is still available
fileunit:          21  was not in the range that is handled
by this module ! (          30  -          39  )
enable_lun returns without enabling any fileunit
fileunit:          22  was not in the range that is handled
by this module ! (          30  -          39  )
enable_lun returns without enabling any fileunit

```

---

**Table 2.13** Output of program *TestLunManager*.

## 2.10 Module *Numerics*

Module *numerics.F90* in directory `genscat/support/num` contains routines for checking and handling numerical issues like variable sizes and ranges. These are tested by program *test\_numerics*, the output of which is listed in Table 2.14.

```

Starting numerics test program
===== representation tests =====
REALACC(6)
r4: digits           24
r4: epsilon         1.1920929E-07
r4: huge            3.4028235E+38
r4: minexponent     -125
r4: maxexponent     128
r4: precision       6
r4: radix           2
r4: range           37
r4: tiny            1.1754944E-38
ENDREALACC
REALACC(12)
r8: digits           53
r8: epsilon         2.2204460492503131E-016
r8: huge            1.7976931348623167E+308
r8: minexponent     -1021
r8: maxexponent     1024
r8: precision       15
r8: radix           2
r8: range           307
r8: tiny            2.2250738585072010E-308
ENDREALACC
===== numerics tests =====
int1 = 127
int2 = 32767
int4 = 2147483647
int8 = 9223372036854775807
huge(int1) = 127
huge(int2) = 32767
huge(int4) = 2147483647
huge(int8) = 9223372036854775807
REALACC(6) r4 = 1.7000000E+38 ENDREALACC
REALACC(12) r8 = 1.7000000000000000E+038 ENDREALACC
===== check variable sizes =====
Variable sizes are as expected
===== detect and print variable sizes =====
var_type nr_of_words range precision
i         4         9
i1_       1         2
i2_       2         4
i4_       4         9
i8_       8        18
dr        4        37         6
s_        4        37         6
l_        4        37         6
r_        4        37         6
r4_       4        37         6
r8_       8        307        15
===== dB conversion test =====
REALACC(6)
input test number: 1.2300001E-04
converted to dB: -39.10095
converted back to a real: 1.2299998E-04
ENDREALACC
===== done =====

```

**Table 2.14** Output of program *test\_numerics*.

## 2.11 Module *SingletonFFT*

Module *SingletonFFT* in directory `genscat/support/singletonfft` contains routines for Fast Fourier Transforms. The associated test program is *TestSingleton*. Part of its output is shown in table 2.15.

```

=====
PROGRAM TestSingleton
Test of SingletonFFT routines by comparing with analytical FT
=====

```

Spreading times grid size in dimension 1: 0.1000000 (should be ~ 0.1)  
 Spreading times grid size in dimension 2: 0.1000000 (should be ~ 0.1)

```

=====
1D          F O R W A R D          B A C K W A R D
   P r e c i s i o n           P r e c i s i o n
N1      Real      Imag      Real      Imag
-----
32 0.83631E-06  0.10286E-04  0.11921E-06  0.69247E-07
34 0.61329E-06  0.78932E-05  0.11921E-06  0.11285E-07
36 0.94782E-06  0.12215E-04  0.11921E-06  0.11036E-06
38 0.27877E-06  0.20358E-05  0.17881E-06  0.22604E-07
40 0.83631E-06  0.12143E-04  0.11921E-06  0.54017E-07
42 0.44603E-06  0.56252E-05  0.77824E-07  0.92940E-07
44 0.12900E-06  0.27819E-06  0.17881E-06  0.14948E-06
46 0.94782E-06  0.13554E-04  0.35763E-06  0.34905E-07
48 0.94782E-06  0.14143E-04  0.23842E-06  0.12666E-06
50 0.50178E-06  0.66967E-05  0.17881E-06  0.10431E-06
=====

```

```

=====
2D          F O R W A R D   F F T          B A C K W A R D   F F T
   P r e c i s i o n           P r e c i s i o n
N1 N2      Real      Imag      Time      Real      Imag      Time
-----
32 32 0.11995E-05  0.20572E-04  0.0000  0.17881E-06  0.10663E-06  0.0000
32 34 0.10952E-05  0.18179E-04  0.0001  0.11921E-06  0.63061E-07  0.0000
32 36 0.12516E-05  0.22501E-04  0.0000  0.11921E-06  0.11339E-06  0.0000
32 38 0.88658E-06  0.82503E-05  0.0001  0.17881E-06  0.66826E-07  0.0001
32 40 0.12516E-05  0.22430E-04  0.0000  0.17881E-06  0.95745E-07  0.0000
32 42 0.99089E-06  0.15911E-04  0.0000  0.11921E-06  0.12151E-06  0.0000
32 44 0.88658E-06  0.10286E-04  0.0001  0.29802E-06  0.17938E-06  0.0001
32 46 0.11473E-05  0.23840E-04  0.0001  0.35763E-06  0.63112E-07  0.0001
32 48 0.12516E-05  0.24430E-04  0.0000  0.27816E-06  0.12973E-06  0.0000
32 50 0.10430E-05  0.16983E-04  0.0000  0.17881E-06  0.11206E-06  0.0000
34 32 0.11473E-05  0.18179E-04  0.0001  0.11921E-06  0.78046E-07  0.0001
...
48 50 0.10952E-05  0.20840E-04  0.0001  0.30120E-06  0.12803E-06  0.0001
50 32 0.99089E-06  0.16983E-04  0.0000  0.17881E-06  0.11192E-06  0.0000
50 34 0.83443E-06  0.14590E-04  0.0001  0.17881E-06  0.10692E-06  0.0001
50 36 0.10430E-05  0.18912E-04  0.0001  0.23842E-06  0.11300E-06  0.0001
50 38 0.46937E-06  0.47101E-05  0.0001  0.17881E-06  0.10619E-06  0.0001
50 40 0.93873E-06  0.18840E-04  0.0001  0.35763E-06  0.11030E-06  0.0001
50 42 0.62582E-06  0.12322E-04  0.0001  0.29802E-06  0.11184E-06  0.0001
50 44 0.46937E-06  0.66967E-05  0.0001  0.29802E-06  0.14250E-06  0.0001
50 46 0.99089E-06  0.20251E-04  0.0001  0.23842E-06  0.10202E-06  0.0001
50 48 0.10430E-05  0.20840E-04  0.0001  0.29802E-06  0.15117E-06  0.0001
50 50 0.57367E-06  0.13393E-04  0.0001  0.35763E-06  0.11255E-06  0.0001
=====

```

Program TestSingleton: Resume  
 Worst case accuracies

```

          F O R W A R D          B A C K W A R D
         Real      Imag      Real      Imag
-----
1D 0.94782E-06  0.14143E-04  0.35763E-06  0.14948E-06
2D 0.13559E-05  0.28287E-04  0.77486E-06  0.28650E-06

```

Program TestSingleton: Normal termination.

**Table 2.15** Output of program *TestSingleton*

## 2.12 Module *SortMod*

Module *SortMod* in directory `genscat/support/sort` contains two routines for sorting the wind vector solutions found in the inversion step to their probability. The associated test program is *SortModTest*. Its output is shown in table 2.16.

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---

```

Test program for the SortMod module
Unsorted array
10.0  9.0  8.0  7.0  6.0  5.0  4.0  3.0  2.0  1.0
After GetSortIndex
 1.0  2.0  3.0  4.0  5.0  6.0  7.0  8.0  9.0 10.0
Sorted array, after SortWithIndex
 1.0  2.0  3.0  4.0  5.0  6.0  7.0  8.0  9.0 10.0

```

---

**Table 2.16** Output of program *SortModTest*

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### 3 PenWP integration test

Directory `penwp/tests` contains one HDF5 file for testing the PenWP executable. File `S1L2A2012006_12113_12114_2.h5.gz` contains (gzipped) OSCAT level 2a data from 6 January 2012, 13:51 to 14:03 UTC with 50 km cell spacing, as obtained from ISRO. The files `ECMWF*.grib` contain the necessary NWP data (SST, land-sea mask and wind forecasts) to perform the NWP collocation step.

The user can test the proper functioning of PenWP using the files in the `penwp/tests` directory. To do this, first create a small file containing a list of NWP files:

```
ls -l ECMWF_* > nwpflist
```

Then, gunzip the HDF5 file:

```
gunzip -c S1L2A2012006_12113_12114_2.h5.gz >
S1L2A2012006_12113_12114_2.h5
```

Set the `$BUFR_TABLES` environment variable:

```
export BUFR_TABLES=../../genscat/support/bufr/bufr_tables/
```

for Korn shell or Bourne shell or

```
setenv BUFR_TABLES ../../genscat/support/bufr/bufr_tables/
```

for C shell. Convert the level 2a input file to BUFR:

```
../execs/oscat_hdf2bufr -allswath -f S1L2A2012006_12113_12114_2.h5
-o oscat.bufr
```

Then run PenWP:

```
../execs/penwp_run -f oscat.bufr -nwpfl nwpflist -mss -mon -noc
-genericws 4
```

The result should be two OSCAT level 2 files in BUFR format, called

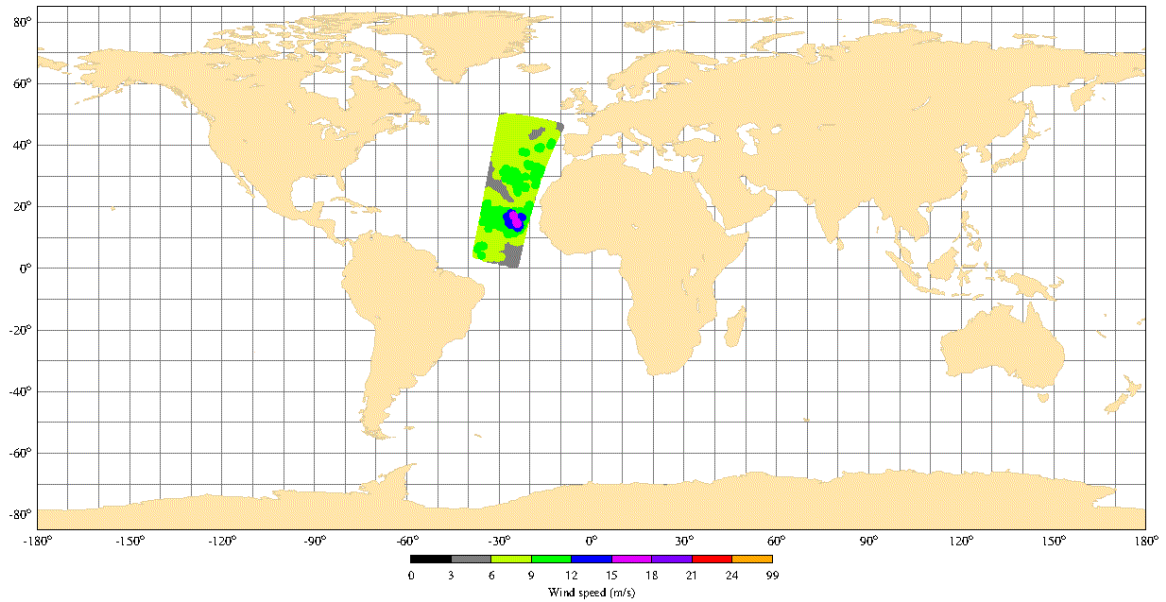
```
oscat_20120106_135109_ocsat2_12113_o_500_ovw_12.bufr and
oscat_20120106_135109_ocsat2_12113_o_500_ovw_12.bufr.genws.
```

The first file is in NOAA BUFR format and the second file is in KNMI format with generic wind section.

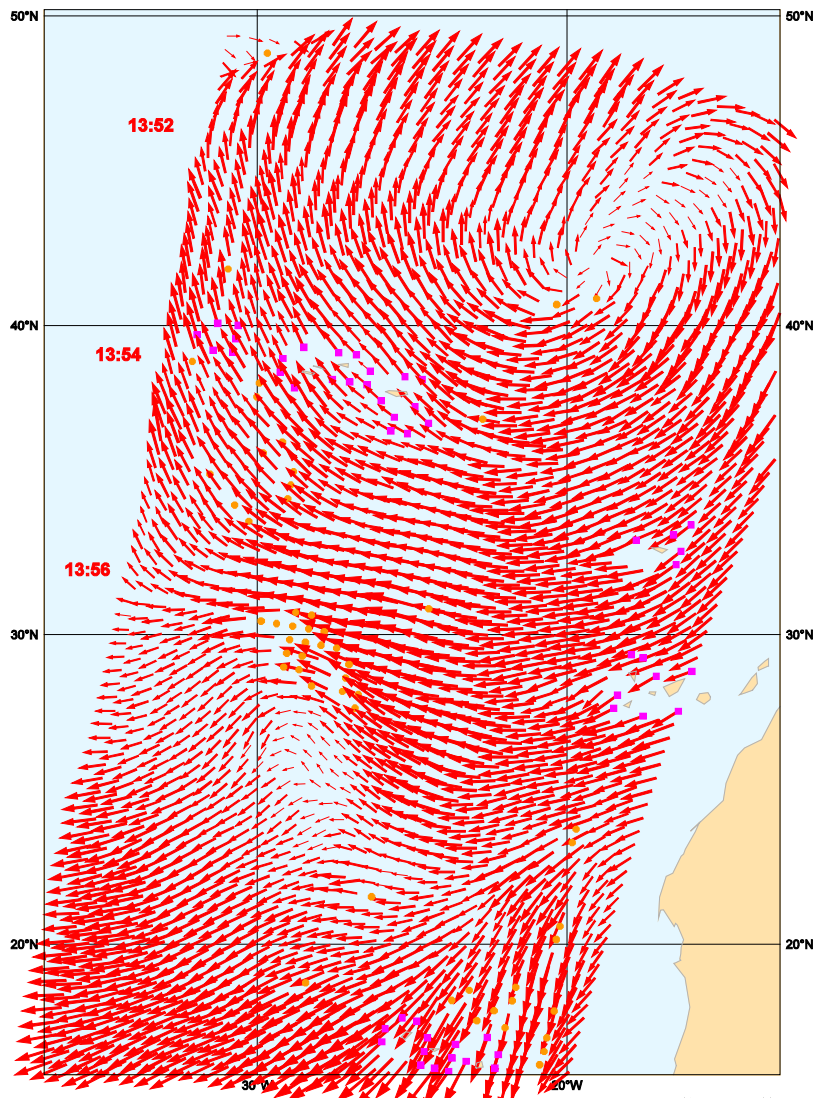
#### 3.1 OSCAT test data

Figure 3.1 shows the global coverage of the OSCAT test run on 50 km. The colours show the magnitude of the wind speed as indicated by the legend. Figure 3.2 shows detailed wind vector plots over the Atlantic west of Africa, with 50 km cell spacing. In the detail plot, a magenta marker on top of the wind arrow denotes land presence. Orange wind arrows indicate that the Variational

Quality Control flag is set, i.e. the Wind Vector Cell is spatially inconsistent. An orange dot means that the KNMI Quality Control Flag is set.



**Figure 3.1** Global coverage of the OSCAT test run. Wind speed results for the 50 km product are shown.



**Figure 3.2** Detail plot of the OSCAT test run. Wind vectors for the 50 km product are shown.

Table 3.1 shows one decoded Wind Vector Cell of the resulting output file in NOAA BUFR format and table 3.2 the same WVC in KNMI BUFR format with generic wind section.

1	SATELLITE IDENTIFIER	421.0000	CODE TABLE 1007
2	DIRECTION OF MOTION OF MO	195.0000	DEGREE TRUE
3	SATELLITE SENSOR INDICATO	MISSING	CODE TABLE 2048
4	WIND SCATTEROMETER GEOPHY	9.0000	CODE TABLE 21119
5	SOFTWARE IDENTIFICATION (	1903.0000	NUMERIC
6	CROSS TRACK RESOLUTION	50000.0000	M
7	ALONG TRACK RESOLUTION	50000.0000	M
8	ORBIT NUMBER	12113.0000	NUMERIC
9	YEAR	2012.0000	YEAR
10	MONTH	1.0000	MONTH
11	DAY	6.0000	DAY
12	HOUR	13.0000	HOUR
13	MINUTE	51.0000	MINUTE
14	SECOND	9.0000	SECOND
15	LATITUDE (COARSE ACCURACY	46.1700	DEGREE
16	LONGITUDE (COARSE ACCURAC	-11.4400	DEGREE
17	TIME DIFFERENCE QUALIFIER	5.0000	CODE TABLE 8025
18	SECOND	0.0000	SECOND

19	ALONG TRACK ROW NUMBER	MISSING	NUMERIC
20	CROSS-TRACK CELL NUMBER	6.0000	NUMERIC
21	SEAWINDS WIND VECTOR CELL	0.0000	FLAG TABLE 21109
22	MODEL WIND DIRECTION AT 1	314.0900	DEGREE TRUE
23	MODEL WIND SPEED AT 10M	4.4500	M/S
24	NUMBER OF VECTOR AMBIGUIT	2.0000	NUMERIC
25	INDEX OF SELECTED WIND VE	1.0000	NUMERIC
26	TOTAL NUMBER OF SIGMA-0 M	4.0000	NUMERIC
27	PROBABILITY OF RAIN	MISSING	NUMERIC
28	SEAWINDS NOF* RAIN INDEX	13.0000	NUMERIC
29	INTENSITY OF PRECIPITATIO	MISSING	KG/(M**2)S
30	ATTENUATION CORRECTION OF	MISSING	dB
31	WIND SPEED AT 10 M	4.5900	M/S
32	FORMAL UNCERTAINTY IN WIN	MISSING	M/S
33	WIND DIRECTION AT 10 M	327.5000	DEGREE TRUE
34	FORMAL UNCERTAINTY IN WIN	2.0200	DEGREE TRUE
35	LIKELIHOOD COMPUTED FOR S	0.6080	NUMERIC
36	WIND SPEED AT 10 M	4.1000	M/S
37	FORMAL UNCERTAINTY IN WIN	MISSING	M/S
38	WIND DIRECTION AT 10 M	170.0000	DEGREE TRUE
39	FORMAL UNCERTAINTY IN WIN	2.6300	DEGREE TRUE
40	LIKELIHOOD COMPUTED FOR S	0.3920	NUMERIC
41	WIND SPEED AT 10 M	MISSING	M/S
42	FORMAL UNCERTAINTY IN WIN	MISSING	M/S
43	WIND DIRECTION AT 10 M	MISSING	DEGREE TRUE
44	FORMAL UNCERTAINTY IN WIN	MISSING	DEGREE TRUE
45	LIKELIHOOD COMPUTED FOR S	MISSING	NUMERIC
46	WIND SPEED AT 10 M	MISSING	M/S
47	FORMAL UNCERTAINTY IN WIN	MISSING	M/S
48	WIND DIRECTION AT 10 M	MISSING	DEGREE TRUE
49	FORMAL UNCERTAINTY IN WIN	MISSING	DEGREE TRUE
50	LIKELIHOOD COMPUTED FOR S	MISSING	NUMERIC
51	ANTENNA POLARISATION	0.0000	CODE TABLE 2104
52	TOTAL NUMBER (WITH RESPEC	58.0000	NUMERIC
53	BRIGHTNESS TEMPERATURE	124.9000	K
54	STANDARD DEVIATION BRIGHT	9.1000	K
55	ANTENNA POLARISATION	1.0000	CODE TABLE 2104
56	TOTAL NUMBER (WITH RESPEC	42.0000	NUMERIC
57	BRIGHTNESS TEMPERATURE	198.0000	K
58	STANDARD DEVIATION BRIGHT	12.8000	K
59	NUMBER OF INNER-BEAM SIGM	1.0000	NUMERIC
60	LATITUDE (COARSE ACCURACY	46.1700	DEGREE
61	LONGITUDE (COARSE ACCURAC	-11.4200	DEGREE
62	ATTENUATION CORRECTION ON	0.1700	dB
63	RADAR LOOK ANGLE	133.0400	DEGREE
64	RADAR INCIDENCE ANGLE	48.9600	DEGREE
65	ANTENNA POLARISATION	0.0000	CODE TABLE 2104
66	SEAWINDS NORMALIZED RADAR	-31.7800	dB
67	KP VARIANCE COEFFICIENT (	1.0040	NUMERIC
68	KP VARIANCE COEFFICIENT (	0.0000	NUMERIC
69	KP VARIANCE COEFFICIENT (G	-86.2750	dB
70	SEAWINDS SIGMA-0 QUALITY	0.0000	FLAG TABLE 21115
71	SEAWINDS SIGMA-0 MODE	0.0000	FLAG TABLE 21116
72	SEAWINDS LAND/ICE SURFACE	0.0000	FLAG TABLE 8018
73	SIGMA-0 VARIANCE QUALITY	MISSING	NUMERIC
74	NUMBER OF OUTER-BEAM SIGM	1.0000	NUMERIC
75	LATITUDE (COARSE ACCURACY	46.1900	DEGREE
76	LONGITUDE (COARSE ACCURAC	-11.4400	DEGREE
77	ATTENUATION CORRECTION ON	0.1700	dB
78	RADAR LOOK ANGLE	154.6300	DEGREE
79	RADAR INCIDENCE ANGLE	57.9000	DEGREE
80	ANTENNA POLARISATION	1.0000	CODE TABLE 2104
81	SEAWINDS NORMALIZED RADAR	-26.2300	dB
82	KP VARIANCE COEFFICIENT (	1.0040	NUMERIC
83	KP VARIANCE COEFFICIENT (	0.0000	NUMERIC
84	KP VARIANCE COEFFICIENT (G	-77.6000	dB
85	SEAWINDS SIGMA-0 QUALITY	0.0000	FLAG TABLE 21115
86	SEAWINDS SIGMA-0 MODE	8192.0000	FLAG TABLE 21116
87	SEAWINDS LAND/ICE SURFACE	0.0000	FLAG TABLE 8018
88	SIGMA-0 VARIANCE QUALITY	MISSING	NUMERIC
89	NUMBER OF INNER-BEAM SIGM	1.0000	NUMERIC
90	LATITUDE (COARSE ACCURACY	46.1700	DEGREE
91	LONGITUDE (COARSE ACCURAC	-11.4400	DEGREE
92	ATTENUATION CORRECTION ON	0.1700	dB



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93	RADAR LOOK ANGLE	76.6300	DEGREE
94	RADAR INCIDENCE ANGLE	48.9600	DEGREE
95	ANTENNA POLARISATION	0.0000	CODE TABLE 2104
96	SEAWINDS NORMALIZED RADAR	-33.8500	dB
97	KP VARIANCE COEFFICIENT (	1.0040	NUMERIC
98	KP VARIANCE COEFFICIENT (	0.0000	NUMERIC
99	KP VARIANCE COEFFICIENT (G	-86.2560	dB
100	SEAWINDS SIGMA-0 QUALITY	0.0000	FLAG TABLE 21115
101	SEAWINDS SIGMA-0 MODE	4096.0000	FLAG TABLE 21116
102	SEAWINDS LAND/ICE SURFACE	0.0000	FLAG TABLE 8018
103	SIGMA-0 VARIANCE QUALITY		MISSING NUMERIC
104	NUMBER OF OUTER-BEAM SIGM	1.0000	NUMERIC
105	LATITUDE (COARSE ACCURACY	46.1700	DEGREE
106	LONGITUDE (COARSE ACCURAC	-11.4500	DEGREE
107	ATTENUATION CORRECTION ON	0.1700	dB
108	RADAR LOOK ANGLE	55.5400	DEGREE
109	RADAR INCIDENCE ANGLE	57.9000	DEGREE
110	ANTENNA POLARISATION	1.0000	CODE TABLE 2104
111	SEAWINDS NORMALIZED RADAR	-32.0100	dB
112	KP VARIANCE COEFFICIENT (	1.0040	NUMERIC
113	KP VARIANCE COEFFICIENT (	0.0000	NUMERIC
114	KP VARIANCE COEFFICIENT (G	-78.2850	dB
115	SEAWINDS SIGMA-0 QUALITY	0.0000	FLAG TABLE 21115
116	SEAWINDS SIGMA-0 MODE	12288.0000	FLAG TABLE 21116
117	SEAWINDS LAND/ICE SURFACE	0.0000	FLAG TABLE 8018
118	SIGMA-0 VARIANCE QUALITY		MISSING NUMERIC

**Table 3.1** Wind Vector Cell in NOAA BUFR format

1	SATELLITE IDENTIFIER	421.0000	CODE TABLE 1007
2	DIRECTION OF MOTION OF MO	195.0000	DEGREE TRUE
3	SATELLITE SENSOR INDICATO		MISSING CODE TABLE 2048
4	WIND SCATTEROMETER GEOPHY	9.0000	CODE TABLE 21119
5	SOFTWARE IDENTIFICATION (	13.0000	NUMERIC
6	CROSS TRACK RESOLUTION	50000.0000	M
7	ALONG TRACK RESOLUTION	50000.0000	M
8	ORBIT NUMBER	12113.0000	NUMERIC
9	YEAR	2012.0000	YEAR
10	MONTH	1.0000	MONTH
11	DAY	6.0000	DAY
12	HOUR	13.0000	HOUR
13	MINUTE	51.0000	MINUTE
14	SECOND	9.0000	SECOND
15	LATITUDE (COARSE ACCURACY	46.1700	DEGREE
16	LONGITUDE (COARSE ACCURAC	-11.4400	DEGREE
17	TIME DIFFERENCE QUALIFIER	5.0000	CODE TABLE 8025
18	SECOND	0.0000	SECOND
19	ALONG TRACK ROW NUMBER		MISSING NUMERIC
20	CROSS-TRACK CELL NUMBER	6.0000	NUMERIC
21	TOTAL NUMBER OF SIGMA-0 M	4.0000	NUMERIC
22	PROBABILITY OF RAIN		MISSING NUMERIC
23	SEAWINDS NOF* RAIN INDEX	13.0000	NUMERIC
24	INTENSITY OF PRECIPITATIO		MISSING KG/(M**2)S
25	ATTENUATION CORRECTION OF		MISSING dB
26	ANTENNA POLARISATION	0.0000	CODE TABLE 2104
27	TOTAL NUMBER (WITH RESPEC	58.0000	NUMERIC
28	BRIGHTNESS TEMPERATURE	124.9000	K
29	STANDARD DEVIATION BRIGHT	9.1000	K
30	ANTENNA POLARISATION	1.0000	CODE TABLE 2104
31	TOTAL NUMBER (WITH RESPEC	42.0000	NUMERIC
32	BRIGHTNESS TEMPERATURE	198.0000	K
33	STANDARD DEVIATION BRIGHT	12.8000	K
34	NUMBER OF INNER-BEAM SIGM	1.0000	NUMERIC
35	LATITUDE (COARSE ACCURACY	46.1700	DEGREE
36	LONGITUDE (COARSE ACCURAC	-11.4200	DEGREE
37	ATTENUATION CORRECTION ON	0.1700	dB
38	RADAR LOOK ANGLE	133.0400	DEGREE
39	RADAR INCIDENCE ANGLE	48.9600	DEGREE
40	ANTENNA POLARISATION	0.0000	CODE TABLE 2104
41	SEAWINDS NORMALIZED RADAR	-31.7800	dB
42	KP VARIANCE COEFFICIENT (	1.0040	NUMERIC
43	KP VARIANCE COEFFICIENT (	0.0000	NUMERIC

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44	KP VARIANCE COEFFICIENT (G	-86.2750	dB
45	SEAWINDS SIGMA-0 QUALITY	0.0000	FLAG TABLE 21115
46	SEAWINDS SIGMA-0 MODE	0.0000	FLAG TABLE 21116
47	SEAWINDS LAND/ICE SURFACE	0.0000	FLAG TABLE 8018
48	SIGMA-0 VARIANCE QUALITY	MISSING	NUMERIC
49	NUMBER OF OUTER-BEAM SIGM	1.0000	NUMERIC
50	LATITUDE (COARSE ACCURACY	46.1900	DEGREE
51	LONGITUDE (COARSE ACCURAC	-11.4400	DEGREE
52	ATTENUATION CORRECTION ON	0.1700	dB
53	RADAR LOOK ANGLE	154.6300	DEGREE
54	RADAR INCIDENCE ANGLE	57.9000	DEGREE
55	ANTENNA POLARISATION	1.0000	CODE TABLE 2104
56	SEAWINDS NORMALIZED RADAR	-26.2300	dB
57	KP VARIANCE COEFFICIENT (	1.0040	NUMERIC
58	KP VARIANCE COEFFICIENT (	0.0000	NUMERIC
59	KP VARIANCE COEFFICIENT (G	-77.6000	dB
60	SEAWINDS SIGMA-0 QUALITY	0.0000	FLAG TABLE 21115
61	SEAWINDS SIGMA-0 MODE	8192.0000	FLAG TABLE 21116
62	SEAWINDS LAND/ICE SURFACE	0.0000	FLAG TABLE 8018
63	SIGMA-0 VARIANCE QUALITY	MISSING	NUMERIC
64	NUMBER OF INNER-BEAM SIGM	1.0000	NUMERIC
65	LATITUDE (COARSE ACCURACY	46.1700	DEGREE
66	LONGITUDE (COARSE ACCURAC	-11.4400	DEGREE
67	ATTENUATION CORRECTION ON	0.1700	dB
68	RADAR LOOK ANGLE	76.6300	DEGREE
69	RADAR INCIDENCE ANGLE	48.9600	DEGREE
70	ANTENNA POLARISATION	0.0000	CODE TABLE 2104
71	SEAWINDS NORMALIZED RADAR	-33.8500	dB
72	KP VARIANCE COEFFICIENT (	1.0040	NUMERIC
73	KP VARIANCE COEFFICIENT (	0.0000	NUMERIC
74	KP VARIANCE COEFFICIENT (G	-86.2560	dB
75	SEAWINDS SIGMA-0 QUALITY	0.0000	FLAG TABLE 21115
76	SEAWINDS SIGMA-0 MODE	4096.0000	FLAG TABLE 21116
77	SEAWINDS LAND/ICE SURFACE	0.0000	FLAG TABLE 8018
78	SIGMA-0 VARIANCE QUALITY	MISSING	NUMERIC
79	NUMBER OF OUTER-BEAM SIGM	1.0000	NUMERIC
80	LATITUDE (COARSE ACCURACY	46.1700	DEGREE
81	LONGITUDE (COARSE ACCURAC	-11.4500	DEGREE
82	ATTENUATION CORRECTION ON	0.1700	dB
83	RADAR LOOK ANGLE	55.5400	DEGREE
84	RADAR INCIDENCE ANGLE	57.9000	DEGREE
85	ANTENNA POLARISATION	1.0000	CODE TABLE 2104
86	SEAWINDS NORMALIZED RADAR	-32.0100	dB
87	KP VARIANCE COEFFICIENT (	1.0040	NUMERIC
88	KP VARIANCE COEFFICIENT (	0.0000	NUMERIC
89	KP VARIANCE COEFFICIENT (G	-78.2850	dB
90	SEAWINDS SIGMA-0 QUALITY	0.0000	FLAG TABLE 21115
91	SEAWINDS SIGMA-0 MODE	12288.0000	FLAG TABLE 21116
92	SEAWINDS LAND/ICE SURFACE	0.0000	FLAG TABLE 8018
93	SIGMA-0 VARIANCE QUALITY	MISSING	NUMERIC
94	SOFTWARE IDENTIFICATION (	1903.0000	NUMERIC
95	GENERATING APPLICATION	91.0000	CODE TABLE 1032
96	MODEL WIND SPEED AT 10M	4.4500	M/S
97	MODEL WIND DIRECTION AT 1	314.0900	DEGREE TRUE
98	ICE PROBABILITY	MISSING	NUMERIC
99	ICE AGE ("A" PARAMETER)	MISSING	dB
100	WIND VECTOR CELL QUALITY	0.0000	FLAG TABLE 21155
101	NUMBER OF VECTOR AMBIGUIT	2.0000	NUMERIC
102	INDEX OF SELECTED WIND VE	1.0000	NUMERIC
103	DELAYED DESCRIPTOR REPLIC	4.0000	NUMERIC
104	WIND SPEED AT 10 M	4.5900	M/S
105	WIND DIRECTION AT 10 M	327.5000	DEGREE TRUE
106	BACKSCATTER DISTANCE	-2.0000	NUMERIC
107	LIKELIHOOD COMPUTED FOR S	-0.2160	NUMERIC
108	WIND SPEED AT 10 M	4.1000	M/S
109	WIND DIRECTION AT 10 M	170.0000	DEGREE TRUE
110	BACKSCATTER DISTANCE	-2.6000	NUMERIC
111	LIKELIHOOD COMPUTED FOR S	-0.4070	NUMERIC
112	WIND SPEED AT 10 M	MISSING	M/S
113	WIND DIRECTION AT 10 M	MISSING	DEGREE TRUE
114	BACKSCATTER DISTANCE	MISSING	NUMERIC
115	LIKELIHOOD COMPUTED FOR S	MISSING	NUMERIC
116	WIND SPEED AT 10 M	MISSING	M/S
117	WIND DIRECTION AT 10 M	MISSING	DEGREE TRUE

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118 BACKSCATTER DISTANCE	MISSING NUMERIC
119 LIKELIHOOD COMPUTED FOR S	MISSING NUMERIC

**Table 3.2** Wind Vector Cell in KNMI BUFR format with generic wind section

From the plots and tables in this section it is clear that:

- Output can be provided in two BUFR formats.
- The Wind Vector Cell spacing is 50 km, see fields 6 and 7 in the BUFR outputs and figure 3.2.
- The output contains latitude, longitude, time, orbit and node numbers, NWP background wind vector, WVC quality flag, and information on the radar backscatter including  $\sigma^0$  and  $K_p$  data.
- A consistent wind field is obtained which proves that both HDF5 and GRIB data are read successfully.
- The atmospheric attenuations are present in the BUFR output (fields 62, 77, 92 and 107 in the NOAA BUFR format).

The test was re-run with the BUFR output file as input and this results in a new output file with the same wind information. Hence, it is clear that PenWP accepts BUFR data as input as well as HDF5.

Table 3.3 shows what happens when the MLE value exceeds the threshold for Quality Control. The MLE of the fourth wind solution (the selected one by ambiguity removal) is contained in field 49 and has a value of 94.38. This is above the threshold value of 14.4 corresponding to wind speeds close to 9 m/s. The Wind Vector Cell Quality (field 21) has an integer value of 1028, i.e., Fortran bits 10 and 2 are set, corresponding to the flags for KNMI Quality Control and Rain.

21 SEAWINDS WIND VECTOR CELL	1028.0000	FLAG TABLE 21109
22 MODEL WIND DIRECTION AT 1	148.4800	DEGREE TRUE
23 MODEL WIND SPEED AT 10M	6.2700	M/S
24 NUMBER OF VECTOR AMBIGUIT	4.0000	NUMERIC
25 INDEX OF SELECTED WIND VE	4.0000	NUMERIC
26 TOTAL NUMBER OF SIGMA-0 M	4.0000	NUMERIC
27 PROBABILITY OF RAIN	MISSING	NUMERIC
28 SEAWINDS NOF* RAIN INDEX	13.0000	NUMERIC
29 INTENSITY OF PRECIPITATIO	MISSING	KG/(M**2)S
30 ATTENUATION CORRECTION OF	MISSING	dB
31 WIND SPEED AT 10 M	7.7900	M/S
32 FORMAL UNCERTAINTY IN WIN	MISSING	M/S
33 WIND DIRECTION AT 10 M	290.0000	DEGREE TRUE
34 FORMAL UNCERTAINTY IN WIN	14.9900	DEGREE TRUE
35 LIKELIHOOD COMPUTED FOR S	1.0000	NUMERIC
36 WIND SPEED AT 10 M	8.9600	M/S
37 FORMAL UNCERTAINTY IN WIN	MISSING	M/S
38 WIND DIRECTION AT 10 M	112.5000	DEGREE TRUE
39 FORMAL UNCERTAINTY IN WIN	48.4600	DEGREE TRUE
40 LIKELIHOOD COMPUTED FOR S	0.0000	NUMERIC
41 WIND SPEED AT 10 M	7.9600	M/S
42 FORMAL UNCERTAINTY IN WIN	MISSING	M/S
43 WIND DIRECTION AT 10 M	2.5000	DEGREE TRUE
44 FORMAL UNCERTAINTY IN WIN	89.1800	DEGREE TRUE
45 LIKELIHOOD COMPUTED FOR S	0.0000	NUMERIC
46 WIND SPEED AT 10 M	8.5300	M/S
47 FORMAL UNCERTAINTY IN WIN	MISSING	M/S
48 WIND DIRECTION AT 10 M	147.5000	DEGREE TRUE
49 FORMAL UNCERTAINTY IN WIN	94.3800	DEGREE TRUE
50 LIKELIHOOD COMPUTED FOR S	0.0000	NUMERIC

**Table 3.3** Part of Wind Vector Cell in NOAA BUFR format, rejected by Quality Control

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The processing of the test file (1/8<sup>th</sup> of a full orbit) takes ~3 seconds on a Linux workstation with an Intel Xeon quad core CPU at 3.20GHz and 8 GB of memory. Hence the OSCAT wind processing can be done easily in near-real time on an affordable computer system.

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## 4 Validation tests

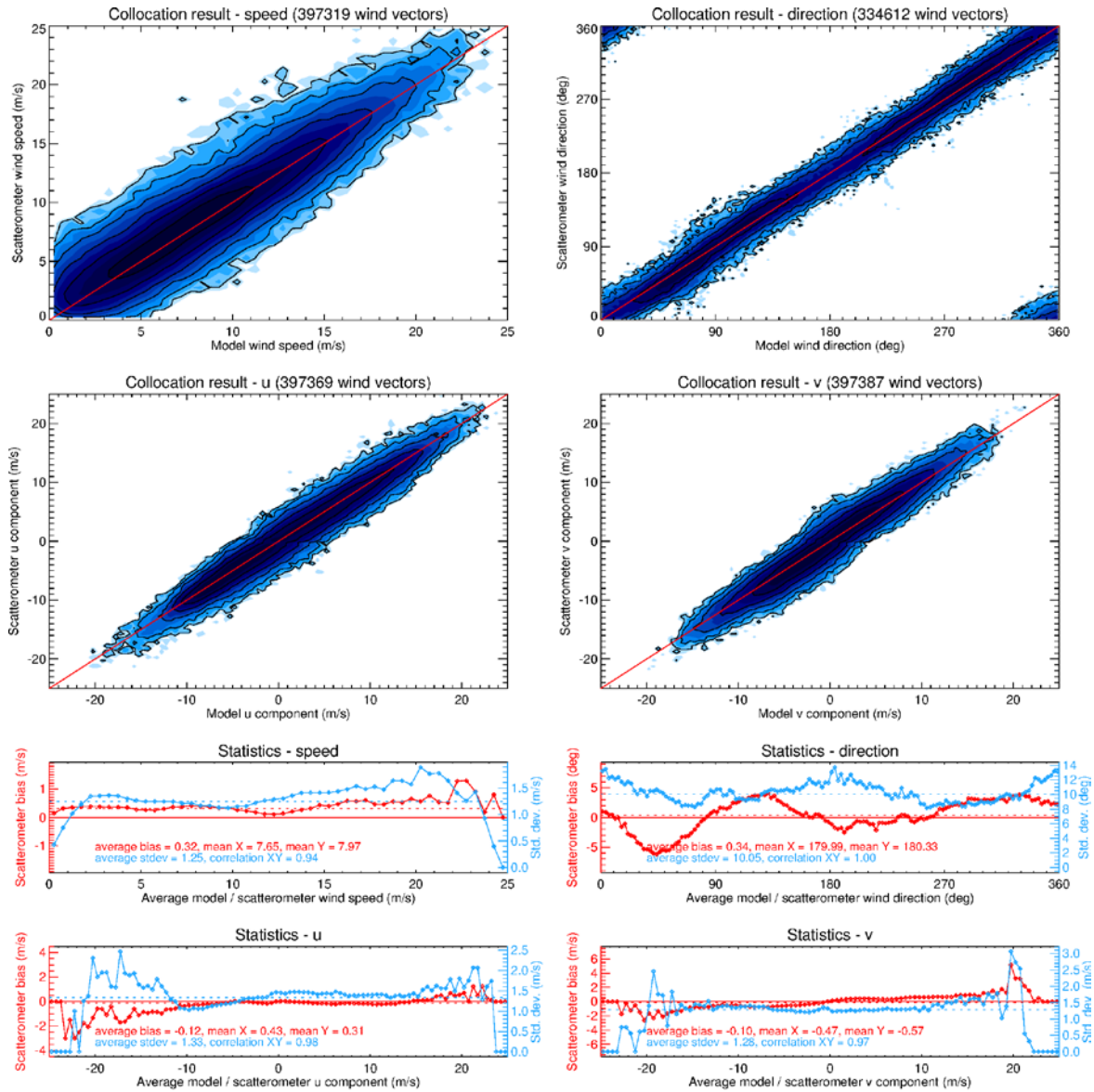
There are several methods to validate scatterometer winds. Scatterometer winds are routinely compared with NWP data and in situ buoy winds in the OSI SAF project. See <http://www.knmi.nl/scatterometer/osisaf/> for more information. In the scope of this Test Report, we show the results of a validation study of PenWP winds versus model wind forecasts from the ECMWF model. The correct implementation of the ice screening algorithm is demonstrated in section 4.2.

### 4.1 PenWP winds versus ECMWF winds

We compared the OSCAT winds from PenWP with ECMWF forecast winds from the operational model (+3 to +21 hours forecasts from the 00 UTC and 12 UTC runs). The OSCAT data are level 2a data version 1.3 from ISRO from 9 and 10 February 2012 (28 orbits), reprocessed with PenWP.

Figure 4.1 shows the collocations of the OSCAT and ECMWF winds. Contoured histograms are shown for wind speed, wind direction and  $u$  and  $v$  wind components and after rejection of Quality Controlled (KNMI QC flagged) wind vectors. Note that the ECMWF winds are real 10m winds, whereas the scatterometer winds are equivalent neutral 10m winds, which are on average 0.2 m/s higher. In the wind direction plots, only those wind vectors where the model wind speed is at least 4 m/s are taken into account. The bin sizes for the histograms are 0.5 m/s for wind speed,  $u$  and  $v$ , and 2.5° for wind direction.

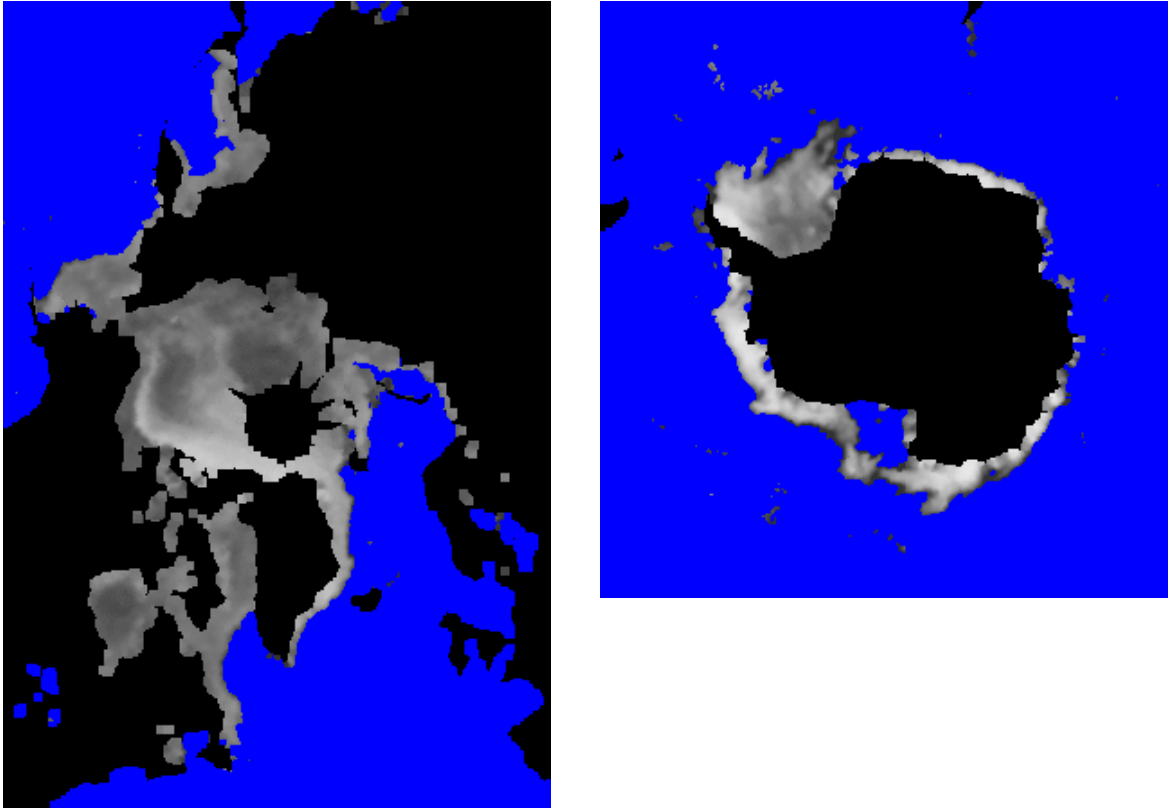
From the contour plots it is clear that biases are generally low. We obtain wind component standard deviations of 1.33 in  $u$  and 1.28 in  $v$  directions. This is comparable to the values we found for SeaWinds in the past: approximately 1.33 for  $u$  and  $v$  for the 25-km product and approximately 1.5 for both components for the 100-km product in the same period of the year. We expect that the OSCAT results can be improved by applying better calibration on the backscatter data. This is subject to further study in the NWP SAF and OSI SAF projects.



**Figure 4.1** Collocation results of Oceansat-2 winds from PenWP and ECMWF forecast winds. Biases and standard deviations in bottom plots are in m/s for wind speed and components, in degrees for wind direction.

## 4.2 Ice screening test

Figure 4.2 shows the ice maps for North and South poles after processing two days of data. The test data are the same as in the previous section, i.e., 9 and 10 February 2012. Ice maps of the North Pole and South Pole are provided. The blue parts in the maps indicate open water; the black parts correspond to land areas or areas not visited within these two days. The gray scale is a measure of the ice A-parameter (albedo). Multi year ice has in general a higher albedo than first year ice, so lighter areas correspond to older ice. In the scope of this report we did not verify the ice extent in detail with other measurements. More information about the ice screening algorithm can be found in [8].



**Figure 4.3** PenWP ice maps for North Pole (left) and South Pole (right).

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## 5 Portability tests

The PenWP software package inherits its portability by using strict Fortran 90 code (with a few low level routines for reading and writing binary in C). PenWP is delivered with a complete make system. The Makeoptions include file of genscat takes care of the different settings needed under various platforms. This Makeoptions file is also used for the SeaWinds scatterometer wind processor SDP, The ASCAT wind processor AWDP and the OSCAT scatterometer wind processor OWDP.

The default platform for development is a Linux work station. Different Fortran 90 compilers were used to compile both genscat and PenWP. Table 5.1 provides an overview of the platforms and compilers on which PenWP was tested successfully.

<b>Platform</b>	<b>Operating system</b>	<b>Fortran compiler</b>
Intel-based workstation	Fedora Linux v.19	GNU g95 v0.94
	3.14.27-100.fc19.x86_64	Portland f90 v11.10-0
		gfortran v4.8.3-7
Linux cluster	Redhat Linux v5.11 2.6.18-404.el5	Intel Fortran v12.1.4
		Portland f90 v11.8-0

**Table 5.1** Supported platforms and compilers for PenWP.



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## 6 User documentation tests

The user documentation (readme files within the software package and the PenWP user documents, [1], [2], [3]) have been provided to beta testers for review. The beta tester's comments have been implemented in the user documentation. User feedback on the documentation will also be implemented in future versions of the documentation.

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- [2] Verhoef, A., Vogelzang, J., Verspeek, J. and Stoffelen, A., 2015, *PenWP Product Specification*, Report NWPSAF-KN-DS-002, EUMETSAT.
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## Appendix A: Acronyms

Name	Description
ASCAT	Advanced SCATterometer on Metop
AWDP	ASCAT Wind Data Processor
BUFR	Binary Universal Form for the Representation of data
C-band	Radar wavelength at about 5 cm
ECMWF	European Centre for Medium-range Weather Forecasts
EUMETSAT	European Organization for the Exploitation of Meteorological Satellites
genscat	generic scatterometer software routines
KNMI	Koninklijk Nederlands Meteorologisch Instituut (Royal Netherlands Meteorological Institute)
Ku-band	Radar wavelength at about 2 cm
L1b	Level 1b product
LSM	Land Sea Mask
Metop	Meteorological Operational Satellite
MLE	Maximum Likelihood Estimator
MSS	Multiple Solution Scheme
NRCS	Normalized Radar Cross-Section ( $\sigma^0$ )
NWP	Numerical Weather Prediction
OSI	Ocean and Sea Ice
OSCAT	Scatterometer onboard of the Indian Oceansat-2 satellite
OWDP	OSCAT Wind Data Processor
PenWP	Pencil beam Wind Processor
QC	Quality Control
SAF	Satellite Application Facility
SDP	SeaWinds Data Processor
SST	Sea Surface Temperature
WVC	Wind Vector Cell, also called node or cell

**Table A.1** List of acronyms.