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AWDP Test Plan and Test Report

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KNMI, De Bilt, the Netherlands

AWDP Test Report

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1.0.14	Oct 2008	Anton Verhoef	First version
2.0	Sep 2010	Anton Verhoef	Version for AWDP version 2.0. Added section 2.11 and corrected some typo’s.
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2.2	Jul 2013	Anton Verhoef	Version for AWDP version 2.2.

Contents

Preface

This document is the test plan and test report for the ASCAT Wind Data Processor (AWDP) 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 AWDP 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 (Chapter 3 of the AWDP User Manual and Reference Guide [*Verhoef et. al.*, 2013]) are related to the tests in this document.

Most of the module tests described in this document have been developed and performed for older versions of AWDP and SDP (the SeaWinds Data Processor, a large part of the code in genscat is shared between AWDP and SDP). For this new AWDP version, all module tests have been repeated.

Anton Verhoef, July 2013

Chapter 1

Introduction

1.1 Aims and scope

The ASCAT Wind Data Processor (AWDP) is a software package written in Fortran 90 for handling data from the Advanced Scatterometer (ASCAT) and European Remote Sensing satellite (ERS) scatterometer instruments. Details of these instruments can be found on several web sites and in several other documents, see e.g. [*Portabella*, 2002; *Stoffelen*, 1998] and information on the ESA and EUMETSAT web sites.

AWDP generates surface winds based on ASCAT and ERS 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 AWDP consists of wind vectors which represent surface winds within the ground swath of the scatterometer. Input of AWDP is Normalized Radar Cross Section (NRCS, σ^0) data. These data may be real-time. The input files of AWDP are in BUFR or Product Format Specification (PFS, native Metop) format. BUFR input may be provided using the BUFR templates for ERS or ASCAT; output is always written using the ASCAT BUFR template. Moreover, AWDP 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 AWDP

AWDP is developed within the Numerical Weather Prediction Satellite Application Facility (NWP SAF) and Ocean and Sea Ice Satellite Application Facility (OSI SAF) programs as code which can be run in an operational setting. The coding is in Fortran 90 and has followed the procedures specified for the NWP SAF. Special attention has been paid on robustness and readability. AWDP may be run on every modern Unix or Linux machine. In principle, AWDP can also run on a Windows machine if a Unix emulator like Cygwin is installed. Details on the AWDP package can be found in [*Verhoef et. al.*, 2013].

The AWDP code is based on code developed for the ERS, NSCAT and SeaWinds scatterometers, and the simulations of the ESA Rotating Fan beam Scatterometer (RFSCAT). The common code of these projects is consolidated in the generic scatterometer (genscat) layer. In each development step, following from the heritage, the output of the code developments has been compared to the output of the original code. Moreover, KNMI runs an experimental suite in the framework of the

OSI SAF, where AWDP, in different modes, is routinely compared to the operational OSI SAF suite at http://www.knmi.nl/scatterometer/. This comparison is both field-wise and statistical.

Several developers work with and on AWDP at KNMI, and even more with the genscat layer for SeaWinds, ERS, OSCAT or ASCAT projects. Improvements to the code follow the test procedures as described in this document. The effort of maintaining a unique reference code greatly improves robustness and reliability of the code, i.e., sharing results and enjoying the benefits.

1.3 Testing AWDP, traceability matrix

This section describes the Test Plan of the AWDP deliverable. Tests have been carried out in all stages of the development of AWDP. The inversion module is not tested for the AWDP package, because such a test has already been made for the QuikSCAT Data Processor (QDP) development. AWDP 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 SUN machine.

Chapter 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. Chapter 3 describes the AWDP integration test. A test folder containing some sample data is provided with AWDP and some of the resulting wind fields from these data are shown. Chapter 4 discusses the validation tests. AWDP has been compared with the Prescat wind processing software using ERS data, and the results of both processors have been compared for identical output. AWDP ASCAT winds have also been compared with ECMWF model winds in the scope of this report; buoy validations are performed in the scope of the OSI SAF. Chapter 4 also contains a technical check of the ice screening algorithm. Chapter 5 describes the portability tests. It contains an overview of platform/operating systems and Fortran compilers for which AWDP is supported. Finally, Chapter 6 is devoted to testing the user documentation.

The table below is the traceability matrix. It shows the requirements in the User Manual and Reference Guide [Verhoef et. al., 2013], Chapter 3, how they are tested and where in this report these tests are described.

Requirement	**Section of UM & RG**	**Testing method**	**Test plan reference (section)**	**Comment**
AWDP generates surface winds	3.1, 3.5.6, 3.5.8	Process L1B file in awdp/test folder and inspect output	3.1	
AWDP generates BUFR output	3.1, 3.5.1	Process L1B file in awdp/test folder and	3.1	

Requirement	Section of UM & RG	Testing method	Test plan reference (section)	Comment
		inspect output		
AWDP generates 25 or 12.5 km Wind Vector Cells	3.2, 3.5.2	Process L1B files in awdp/test folder and inspect output	3.1	
AWDP output contains latitude, longitude and other parameters	3.2	Process L1B file in awdp/test folder and inspect output	3.1	
AWDP can use either L1B ASCAT data or L2 ERS BUFR data as input	3.3	Process ASCAT and ERS data in awdp/test folder	3.1, 3.2	PFS ASCAT data are not tested in the scope of this document
AWDP reads GRIB data containing LSM, SST and forecast winds	3.3	Process L1B file in awdp/test folder and check that a consistent wind field is obtained	3.1	
AWDP will compile and run on different Linux and Unix platforms	3.4	Compile and run AWDP on different platforms	5	
AWDP can ingest full resolution ASCAT data and build a coastal wind product	3.5.3	Process 12.5 km L1B file in combination with full resolution data		Not tested in the scope of this document
WVCs with high MLEs must be rejected by Quality Control	3.5.5	Process L1B file in awdp/test folder and check if QC flag is set for high MLE values	3.1	
Bayesian ice screening is implemented	3.5.7	Process a few days of L1B data and inspect ice maps	4.3	
A product monitoring flag is implemented	3.5.9	Not tested since there are no data with anomalous instrument performance available	-	
AWDP can process data within reasonable CPU time.	3.6	Process L1B file in awdp/test folder and check processing time.	3.1	

Table 1.1 Traceability matrix.

1.4 Test folders

The Test folder of the AWDP software package is located in subdirectory `awdp/tests`. This subdirectory contains several input files for AWDP that are discussed in more detail in Chapter 3. The scripts for executing these tests are located in directory `awdp/execs`. It is recommended to use these scripts (or a modified version) also for normal AWDP operation, as the environment variables needed by AWDP are set in these scripts.

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

1.5 Conventions

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

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

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

References are in square brackets with the name of the author italic (e.g. [*Stoffelen*, 1998]).

Chapter 2

Module tests

In this chapter the various tests to individual modules within AWDP 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 AWDP 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.

Module name	Location	Test program
awdp_data	`awdp/src`	*awdp_data_test*
BFGSMod	`genscat/support/BFGS`	*Test_BFGS*
BufrMod	`genscat/support/bufr`	*test_modules*
convert	`genscat/support/convert`	*test_convert*
CostFunction	`genscat/ambrem/twodvar`	*Test_SOS*
StrucFunc	`genscat/ambrem/twodvar`	*Test_SOS*
DateTimeMod	`genscat/support/datetime`	*TestDateTimeMod*
ErrorHandler	`genscat/support/ErrorHandler`	*TestErrorHandler*
gribio_module	`genscat/support/grib`	*test_read_GRIB1, test_read_GRIB2, test_read_GRIB3*
LunManager	`genscat/support/file`	*TestLunManager*
numerics	`genscat/support/num`	*test_numerics*
pfs_ascat	`genscat/support/pfs`	*test_pfs_ascat*
SingletonFFT	`genscat/support/singletonfft`	*TestSingleton*
SortMod	`genscat/support/sort`	*SortModTest*

Table 2.1 Overview of module tests.

2.1 Module *awdp_data*

Module *awdp_data.F90* in directory `awdp/src` contains the data structure definitions for the AWDP software. It is tested by program *awdp_data_test*, the output of which is listed in table 2.2.

```
 === CELL INFO: Level 1b data ===
Originating centre:    2147483647
Origin sub-centre:     2147483647
Software id:           2147483647
Satellite id:          2147483647
Satellite instr:       2147483647
Dir of motion:         1.7000000E+38
Year:****** month:**** day:****
Hour:******   min:**** sec:****
Latitude:              1.7000000E+38
Longitude:             1.7000000E+38
Pixel size on hor:     1.7000000E+38
Orbit number:          2147483647
Node number:           2147483647
Height of atmosph:     1.7000000E+38
Loss per unit len:     1.7000000E+38
Beam collocation:   missing
Beam colloc value:     2147483647

 BEAM nr. 1
Identifier:            2147483647
Incidence angle:       1.7000000E+38
Azimuth angle:         1.7000000E+38
Sigma0:                1.7000000E+38
Noise value:           1.7000000E+38
Kp estimate qual:   missing
Kp est qual value:     2147483647
Sigma0 usability:      2147483647
Synt data quantity:    1.7000000E+38
Synt data quality:     1.7000000E+38
Orbit quality:         1.7000000E+38
Solar refl contam:     1.7000000E+38
Telemetry pres/qua:    1.7000000E+38
Extrapol ref pres:     1.7000000E+38
Land fraction          1.7000000E+38

 BEAM nr. 2
Identifier:            2147483647
Incidence angle:       1.7000000E+38
Azimuth angle:         1.7000000E+38
Sigma0:                1.7000000E+38
Noise value:           1.7000000E+38
Kp estimate qual:   missing
Kp est qual value:     2147483647
Sigma0 usability:      2147483647
Synt data quantity:    1.7000000E+38
Synt data quality:     1.7000000E+38
Orbit quality:         1.7000000E+38
Solar refl contam:     1.7000000E+38
Telemetry pres/qua:    1.7000000E+38
Extrapol ref pres:     1.7000000E+38
Land fraction          1.7000000E+38

 BEAM nr. 3
Identifier:            2147483647
Incidence angle:       1.7000000E+38
Azimuth angle:         1.7000000E+38
Sigma0:                1.7000000E+38
Noise value:           1.7000000E+38
Kp estimate qual:   missing
Kp est qual value:     2147483647
Sigma0 usability:      2147483647
Synt data quantity:    1.7000000E+38
Synt data quality:     1.7000000E+38
Orbit quality:         1.7000000E+38
Solar refl contam:     1.7000000E+38
Telemetry pres/qua:    1.7000000E+38
Extrapol ref pres:     1.7000000E+38
Land fraction          1.7000000E+38

 === CELL INFO: Level 2 soil moisture data ===
Software id:           2147483647
Database id:           2147483647
Surf soil moisture:    1.7000000E+38
```

```
Error in surface sm:   1.7000000E+38
Sigma0 at 40 deg:      1.7000000E+38
Error in sigma0_40:    1.7000000E+38
Slope at 40 deg:       1.7000000E+38
Error in slope_40:     1.7000000E+38
Sm sensitivity:        1.7000000E+38
Dry backscatter:       1.7000000E+38
Wet backscatter:       1.7000000E+38
Mean surface sm:       1.7000000E+38
Rain fall detection:   1.7000000E+38
Sm correction flag:    2147483647
Sm processing flag:    2147483647
Sm quality:            1.7000000E+38
Snow cover fraction:   1.7000000E+38
Frozen land frac:      1.7000000E+38
Inundat/wetland fr:    1.7000000E+38
Topogr complexity:     1.7000000E+38

 === CELL INFO: Level 2 wind data ===
Software id:           2147483647
Generating appl:       2147483647
 MODEL WIND
Wind speed:            1.7000000E+38
Wind direction:        1.7000000E+38
Ice probability:       1.7000000E+38
Ice age A-param:       1.7000000E+38
 WVC QUALITY
WVC quality: missing
WVC quality value:     2147483647
Num of ambiguities:             0
Index of sel wind:     2147483647
Skill for AR:          1.7000000E+38

 === CELL INFO: Process information ===
Process flag: POOR satellite id
Process flag: POOR satellite instrument
Process flag: POOR satellite dir of motion
Process flag: POOR time
Process flag: POOR lat/lon
Process flag: POOR pixel size on horizontal
Process flag: POOR node number
Process flag: POOR beam           1
Process flag: POOR beam           2
Process flag: POOR beam           3
Process flag: POOR model wind
Process flag: POOR ambiguity
Process flag: POOR selection
Level 1/2 of input:    2147483647
Analysis speed    :    1.7000000E+38
Analysis direction:    1.7000000E+38
Observation cost  :    1.7000000E+38

 === CELL INFO: Level 1b data ===
Originating centre:            99
Origin sub-centre:              5
Software id:                    1
Satellite id:                   3
Satellite instr:              100
Dir of motion:          180.0000
Year:  2005 month:  10 day:   6
Hour:    10   min:   3 sec:  33
Latitude:               50.00000
Longitude:              12.00000
Pixel size on hor:      25000.00
Orbit number:               12345
Node number:                    4
Height of atmosph:      5000.000
Loss per unit len:     9.9999997E-06
Beam collocation:     T
Beam colloc value:              1

 BEAM nr. 1
Identifier:                     1
Incidence angle:        40.00000
```

```
Azimuth angle:          45.00000
Sigma0:                -10.00000
Noise value:            5.000000
Kp est. qual. flag:   F
Kp est qual value:             0
Sigma0 usability:              0
Synt data quantity:    0.1000000
Synt data quality:     0.2000000
Orbit quality:         0.3000000
Solar refl contam:     0.4000000
Telemetry pres/qua:    0.5000000
Extrapol ref pres:     0.6000000
Land fraction          0.7000000

 BEAM nr. 2
Identifier:                    2
Incidence angle:        30.00000
Azimuth angle:          90.00000
Sigma0:                -7.000000
Noise value:            2.000000
Kp est. qual. flag:   T
Kp est qual value:             1
Sigma0 usability:              1
Synt data quantity:    0.2000000
Synt data quality:     0.3000000
Orbit quality:         0.4000000
Solar refl contam:     0.5000000
Telemetry pres/qua:    0.6000000
Extrapol ref pres:     0.7000000
Land fraction          0.8000000

 BEAM nr. 3
Identifier:                    2
Incidence angle:        40.00000
Azimuth angle:          135.0000
Sigma0:                -10.00000
Noise value:            5.000000
Kp est. qual. flag:   F
Kp est qual value:             0
Sigma0 usability:              0
Synt data quantity:    0.3000000
Synt data quality:     0.4000000
Orbit quality:         0.5000000
Solar refl contam:     0.6000000
Telemetry pres/qua:    0.7000000
Extrapol ref pres:     0.8000000
Land fraction          0.9000000

 === CELL INFO: Level 2 soil moisture data ===
Software id:                   2
Database id:                  15
Surf soil moisture:     12.30000
Error in surface sm:    4.500000
Sigma0 at 40 deg:      -12.34000
Error in sigma0_40:     4.560000
Slope at 40 deg:      -0.2300000
Error in slope_40:    -0.1200000
Sm sensitivity:         6.780000
Dry backscatter:        7.890000
Wet backscatter:        8.900000
Mean surface sm:        45.60000
Rain fall detection:    78.90000
Sm correction flag:            1
Sm processing flag:            5
Sm quality:             34.50000
Snow cover fraction:    1.230000
Frozen land frac:       2.340000
Inundat/wetland fr:     3.450000
Topogr complexity:      5.670000

 === CELL INFO: Level 2 wind data ===
Software id:                   3
Generating appl:              99
 MODEL WIND
```

```
Wind speed:              5.000000
Wind direction:          234.0000
Ice probability:        0.1000000
Ice age A-param:         10.00000
 WVC QUALITY
WVC quality: KNMI Quality Control fails
WVC quality: some portion of WVC over land
WVC quality value:         163840
Num of ambiguities:             2
Index of sel wind:              1
Skill for AR:          1.7000000E+38

 AMBIGUITY nr.   1
Wind speed:              6.000000
Wind direction:          222.0000
Probability:            0.9000000
Cone distance:          0.1000000

 AMBIGUITY nr.   2
Wind speed:              5.000000
Wind direction:          15.00000
Probability:            0.1000000
Cone distance:          0.2000000

 === CELL INFO: Process information ===
Process flag: OK satellite id
Process flag: OK satellite instrument
Process flag: OK satellite dir of motion
Process flag: OK time
Process flag: OK lat/lon
Process flag: OK pixel size on horizontal
Process flag: OK node number
Process flag: OK beam            1
Process flag: OK beam            2
Process flag: OK beam            3
Process flag: OK model wind
Process flag: OK ambiguity
Process flag: OK selection
Level 1/2 of input:             2
Analysis speed    :    1.7000000E+38
Analysis direction:    1.7000000E+38
Observation cost  :    1.7000000E+38
```

Table 2.2 Output of program *awdp_data_test*.

2.2 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 [*Liu and Nocedal* 1989].

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 2.3.

```
Program Test_BFGS testing routine LBFGS

 Behavour 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 2.3 Output of program Test_BFGS.

2.3 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 2.4 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 -  7.2
            1 APRIL  2007.



 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 2.4 Output of program *test_modules*.

2.4 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 2.5. 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,rot(z)) to three-dimensional position (x,y,z).

Only the results for p = 0° and 90° are (partly) shown in table 2.5; those for p = 10°, 45°, and 70° 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
```

```
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 2.5 Output of program *test_convert*

2.5 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 2.6 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 ε 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 $J_t^{fin} = J_o^{fin} + J_b^{fin} = ½\, J_t^{init}$ with $J_b^{fin} = J_o^{fin}$. This allows construction of the final solution and its gradient, see *Vogelzang* [2007] 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 Helmholz 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 *Vogelzang* [2007] 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 2.6 it is 0.00345 for the stream function ψ and 0.0 for the velocity potential χ, since the latter quantity is identically zero in this example. The precision of the covariances depends on the correlation lengths R_ψ and R_χ.

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 2.7 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 :    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:  Tropics:
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:  Southern hemisphere:
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

CheckCovMat - checking precision of Covariances
  Relative precision in covariances of psi:    0.000000
  Relative precision in covariances of chi:   3.1197767E-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  0.77160E-01 -0.30864E+00  0.00000E+00

The gradient velocity fields duo and dvo (nonzero components only):
 i  j         duo          dvo
------------------------------
 1  1 -0.30864E+00  0.00000E+00

The cost function of the solution:
  Observation part :   7.7160493E-02
  Background part  :   7.7160530E-02        precision   3.7252903E-08

The background velocity field:
  u(1,1)         :   0.5000000
  Expected value :   0.5000000                precision   2.9802322E-08
  v(1,1)         :   3.1561567E-20
```

```
  Expected value :    0.000000                 precision   3.1561567E-20

Check background cost function
  Direct calculation from psi and chi   :   7.7160530E-02
  Calculation by Jb from control vector :   7.7160537E-02        precision
  7.4505806E-09

Check observation cost function
  Expected value                        :   7.7160493E-02
  Calculation by Jo from control vector :   7.7160463E-02        precision
  2.9802322E-08
  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 2.6 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 2.7 Input file for *Test_SOS*.

2.6 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 2.8.

```
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
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: 21-01-2013
time: 09:44:43.25
```

Table 2.8 Output of program *TestDateTimeMod*.

2.7 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 2.9.

```
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 2.9 Output of program *TestErrorHandler*.

2.8 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 2.10 to 2.12. 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
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 2.10 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 2.11 Output of program *test_read_GRIB2*.

```
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 2.12 Output of program *test_read_GRIB3*.

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_mumerics*.

2.11 Module *pfs_ascat*

Module *pfs_ascat* in directory `genscat/support/pfs` contains routines for reading and decoding files in the Product Format Specification (PFS, native Metop) format. The associated test program is *test_pfs_ascat* which reads a small sample file present in this directory. Its output is shown in table 2.16.

```
file: ./ascat_1b.szo
nrecords          161
nnodes           21
swath            2 node           1
date/time of first record 2002 08 08 20 05 02
mean s0 fore beam   -4.831188444324852      dB
mean s0 mid beam    -5.020170888184862      dB
mean s0 aft beam    -4.390880841944516      dB
```

Table 2.15 Output of program *test_pfs_ascat*

2.12 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 2.16.

```
=========================================================================
 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 2.16 Output of program *TestSingleton*

2.13 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 2.17.

```
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 2.17 Output of program *SortModTest*

Chapter 3

AWDP integration test

Directory `awdp/tests` contains two ASCAT BUFR files to test the AWDP executable. File `ascat_20070426_test_250.l1_bufr` contains ASCAT level 1b data from 26 April 2007, 9:51 to 10:29 UTC with 25 km cell spacing. The same data, but on 12.5 km cell spacing, is available in file `ascat_20070426_test_125.l1_bufr`. 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 AWDP using the files in the `awdp/tests` directory. To do this, first create a small file containing a list of NWP files:

```
ls -1 ECMWF_200704260000_0* > nwpflist
```

Then run AWDP on 25 km and 12.5 km cell spacing:

```
../execs/awdp_run -f ascat_20070426_test_250.l1_bufr -nwpfl nwpflist -mon -calval
```

```
../execs/awdp_run -f ascat_20070426_test_125.l1_bufr -nwpfl nwpflist -mon -calval
```

The result should be two ASCAT level 2 files in BUFR format, called `ascat_20070426_095102_metopa_02681_srv_o_250_ovw.l2_bufr` and `ascat_20070426_095100_metopa_02681_srv_o_125_ovw.l2_bufr`, respectively.

Directory `awdp/tests` also contains an ERS file in ESA BUFR format, called `scatt_20070426_test_250.l1_bufr`. The data are from the same date as the ASCAT data in this directory and they can be processed using the same ECMWF files.

```
../execs/awdp_run -f scatt_20070426_test_250.l1_bufr -nwpfl nwpflist -mon
```

The result should be an output file in ASCAT BUFR format, called `scatt_20070426_063627_ers2___00000_srv_o_250_ovw.l2_bufr`

Note that by default, the winds will be calculated using the CMOD5.n GMF will be used which results in equivalent neutral 10m winds.

3.1 ASCAT test data

Figure 3.1 shows the global coverage of the ASCAT test run on 25 km. The colours show the magnitude of the wind speed as indicated by the legend. The result on 12.5 km should be very similar to this. The figures 3.2 and 3.3 show detailed wind vector plots over the Atlantic near the UK, with 25 km and 12.5 km cell spacing, respectively. In the detail plots, a magenta marker on top of the wind arrow denotes land presence. Yellow wind arrows indicate that the Variational Quality Control flag is set, i.e. the Wind Vector Cell is spatially inconsistent. A yellow dot means that the KNMI Quality Control Flag is set.

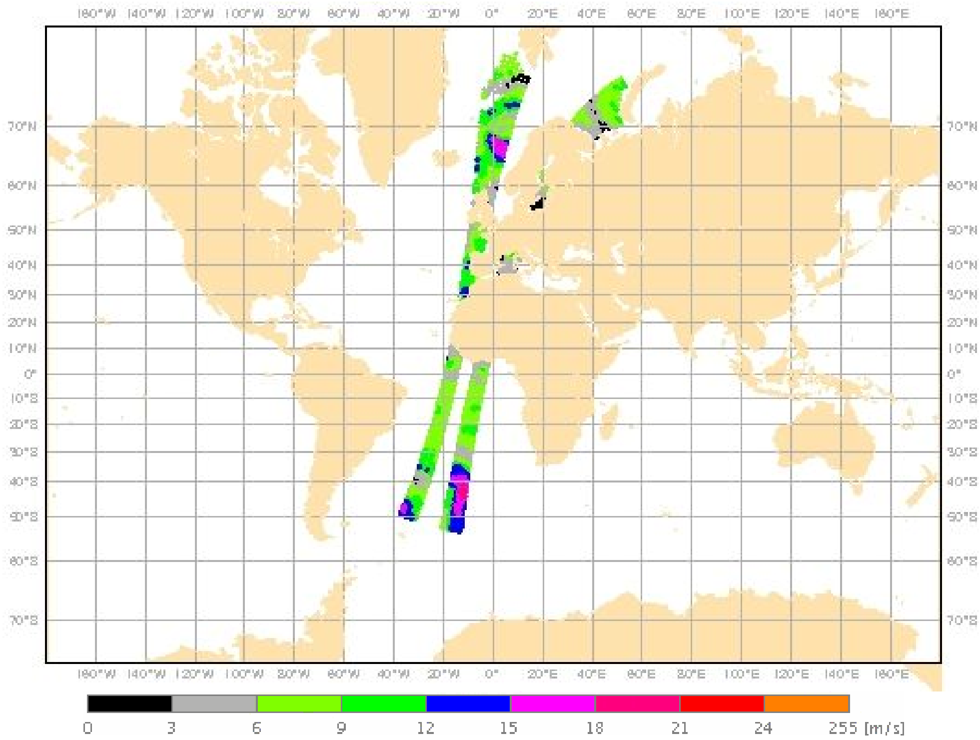

Figure 3.1 Global coverage of the ASCAT test run. Wind speed results for the 25 km product are shown.

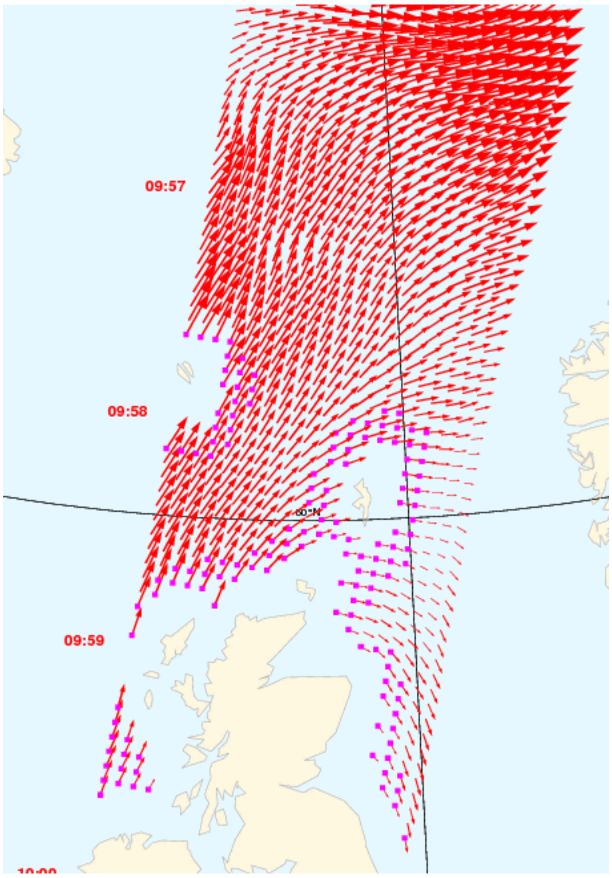

Figure 3.2 Detail plot of the ASCAT test run. Wind vectors for the 25 km product are shown.

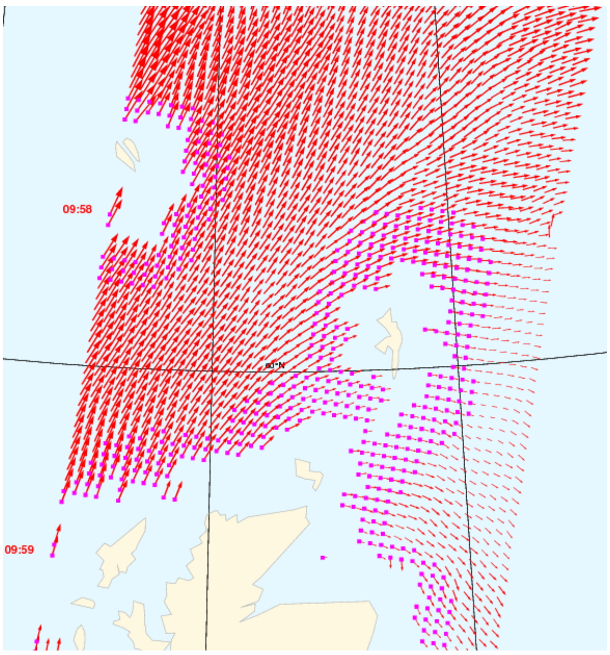

Figure 3.3 Detail plot of the ASCAT test run. Wind vectors for the 12.5 km product are shown.

```
 1 IDENTIFICATION OF ORIGINA          99.0000 CODE TABLE 1033
 2 IDENTIFICATION OF ORIGINA           0.0000 CODE TABLE 1034
 3 SOFTWARE IDENTIFICATION (           0.0000 NUMERIC
 4 SATELLITE IDENTIFIER                4.0000 CODE TABLE 1007
 5 SATELLITE INSTRUMENTS             190.0000 CODE TABLE 2019
 6 DIRECTION OF MOTION OF MO         229.0000 DEGREE TRUE
 7 YEAR                             2007.0000 YEAR
 8 MONTH                               4.0000 MONTH
 9 DAY                                26.0000 DAY
10 HOUR                                9.0000 HOUR
11 MINUTE                             51.0000 MINUTE
12 SECOND                             58.0000 SECOND
13 LATITUDE (HIGH ACCURACY)           75.7223 DEGREE
14 LONGITUDE (HIGH ACCURACY)          52.1184 DEGREE
15 PIXEL SIZE ON HORIZONTAL        25000.0000 M
16 ORBIT NUMBER                     2681.0000 NUMERIC
17 CROSS-TRACK CELL NUMBER            21.0000 NUMERIC
18 HEIGHT OF ATMOSPHERE USED       12500.0000 M
19 LOSS PER UNIT LENGTH OF A           0.0000 dB/M
20 BEAM COLLOCATION                    1.0000 CODE TABLE 21150
21 BEAM IDENTIFIER                     1.0000 CODE TABLE 8085
22 RADAR INCIDENCE ANGLE              36.8700 DEGREE
23 ANTENNA BEAM AZIMUTH               13.0900 DEGREE
24 BACKSCATTER                       -14.1700 dB
25 RADIOMETRIC RESOLUTION (N           1.5000 %
26 ASCAT KP ESTIMATE QUALITY           0.0000 CODE TABLE 21158
27 ASCAT SIGMA-0 USABILITY             2.0000 CODE TABLE 21159
28 ASCAT USE OF SYNTHETIC DA           0.0000 NUMERIC
29 ASCAT SYNTHETIC DATA QUAL           0.0000 NUMERIC
30 ASCAT SATELLITE ORBIT AND           1.0000 NUMERIC
31 ASCAT SOLAR ARRAY REFLECT           0.0000 NUMERIC
32 ASCAT TELEMETRY PRESENCE            1.0000 NUMERIC
33 ASCAT EXTRAPOLATED REFERE           0.0000 NUMERIC
34 ASCAT LAND FRACTION                 0.0000 NUMERIC
35 BEAM IDENTIFIER                     2.0000 CODE TABLE 8085
36 RADAR INCIDENCE ANGLE              27.6300 DEGREE
37 ANTENNA BEAM AZIMUTH              328.4400 DEGREE
38 BACKSCATTER                        -8.0800 dB
39 RADIOMETRIC RESOLUTION (N           2.0000 %
40 ASCAT KP ESTIMATE QUALITY           0.0000 CODE TABLE 21158
41 ASCAT SIGMA-0 USABILITY             2.0000 CODE TABLE 21159
42 ASCAT USE OF SYNTHETIC DA           0.0000 NUMERIC
43 ASCAT SYNTHETIC DATA QUAL           0.0000 NUMERIC
44 ASCAT SATELLITE ORBIT AND           1.0000 NUMERIC
45 ASCAT SOLAR ARRAY REFLECT           0.0000 NUMERIC
46 ASCAT TELEMETRY PRESENCE            1.0000 NUMERIC
47 ASCAT EXTRAPOLATED REFERE           0.0000 NUMERIC
48 ASCAT LAND FRACTION                 0.0000 NUMERIC
49 BEAM IDENTIFIER                     3.0000 CODE TABLE 8085
50 RADAR INCIDENCE ANGLE              36.8600 DEGREE
51 ANTENNA BEAM AZIMUTH              283.4600 DEGREE
52 BACKSCATTER                       -15.4100 dB
53 RADIOMETRIC RESOLUTION (N           2.0000 %
54 ASCAT KP ESTIMATE QUALITY           0.0000 CODE TABLE 21158
55 ASCAT SIGMA-0 USABILITY             2.0000 CODE TABLE 21159
56 ASCAT USE OF SYNTHETIC DA           0.0000 NUMERIC
57 ASCAT SYNTHETIC DATA QUAL           0.0000 NUMERIC
58 ASCAT SATELLITE ORBIT AND           1.0000 NUMERIC
59 ASCAT SOLAR ARRAY REFLECT           0.0000 NUMERIC
60 ASCAT TELEMETRY PRESENCE            1.0000 NUMERIC
61 ASCAT EXTRAPOLATED REFERE           0.0000 NUMERIC
62 ASCAT LAND FRACTION                 0.0000 NUMERIC
63 SOFTWARE IDENTIFICATION (          MISSING NUMERIC
64 DATABASE IDENTIFICATION            MISSING NUMERIC
65 SURFACE SOIL MOISTURE (MS          MISSING %
66 ESTIMATED ERROR IN SURFAC          MISSING %
67 BACKSCATTER                        MISSING dB
68 ESTIMATED ERROR IN SIGMA0          MISSING dB
69 SLOPE AT 40DEG INCIDENCE           MISSING dB/DEG
70 ESTIMATED ERROR IN SLOPE           MISSING dB/DEG
71 SOIL MOISTURE SENSITIVITY          MISSING dB
72 BACKSCATTER                        MISSING dB
73 WET BACKSCATTER                    MISSING dB
```

```
 74 MEAN SURFACE SOIL MOISTUR           MISSING NUMERIC
 75 RAIN FALL DETECTION                 MISSING NUMERIC
 76 SOIL MOISTURE CORRECTION            MISSING FLAG TABLE 40005
 77 SOIL MOISTURE PROCESSING            MISSING FLAG TABLE 40006
 78 SOIL MOISTURE QUALITY               MISSING %
 79 SNOW COVER (SEE NOTE 4)             MISSING %
 80 FROZEN LAND SURFACE FRACT           MISSING %
 81 INUNDATION AND WETLAND FR           MISSING %
 82 TOPOGRAPHIC COMPLEXITY              MISSING %
 83 SOFTWARE IDENTIFICATION (         2201.0000 NUMERIC
 84 GENERATING APPLICATION              91.0000 CODE TABLE 1032
 85 MODEL WIND SPEED AT 10M              7.8500 M/S
 86 MODEL WIND DIRECTION AT 1          341.7600 DEGREE TRUE
 87 ICE PROBABILITY                     MISSING NUMERIC
 88 ICE AGE ("A" PARAMETER)             MISSING dB
 89 WIND VECTOR CELL QUALITY             0.0000 FLAG TABLE 21155
 90 NUMBER OF VECTOR AMBIGUIT            2.0000 NUMERIC
 91 INDEX OF SELECTED WIND VE            1.0000 NUMERIC
 92 DELAYED DESCRIPTOR REPLIC            4.0000 NUMERIC
 93 WIND SPEED AT 10 M                   9.2500 M/S
 94 WIND DIRECTION AT 10 M             338.8000 DEGREE TRUE
 95 BACKSCATTER DISTANCE                 0.7000 NUMERIC
 96 LIKELIHOOD COMPUTED FOR S           -0.2560 NUMERIC
 97 WIND SPEED AT 10 M                   8.9100 M/S
 98 WIND DIRECTION AT 10 M             156.5000 DEGREE TRUE
 99 BACKSCATTER DISTANCE                -1.0000 NUMERIC
100 LIKELIHOOD COMPUTED FOR S           -0.3520 NUMERIC
101 WIND SPEED AT 10 M                  MISSING M/S
102 WIND DIRECTION AT 10 M              MISSING DEGREE TRUE
103 BACKSCATTER DISTANCE                MISSING NUMERIC
104 LIKELIHOOD COMPUTED FOR S           MISSING NUMERIC
105 WIND SPEED AT 10 M                  MISSING M/S
106 WIND DIRECTION AT 10 M              MISSING DEGREE TRUE
107 BACKSCATTER DISTANCE                MISSING NUMERIC
108 LIKELIHOOD COMPUTED FOR S           MISSING NUMERIC
```

Table 3.1 Wind Vector Cell in BUFR format

Table 3.1 shows one decoded Wind Vector Cell of the resulting output file in BUFR format.

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

- Output is provided in BUFR format.
- The Wind Vector Cell spacing is 25 km in this case, see field 15 in the BUFR outputs and figure 3.2. With 12.5 km input, the output is also on 12.5 km WVC spacing, see figure 3.3.
- The output contains latitude, longitude, time, orbit and node numbers, NWP background wind vector, WVC quality flag, and information on the radar backscatter including σ^0 and K_p data.
- AWDP can process ASCAT input data.
- A consistent wind field is obtained which proves that both BUFR and GRIB data are read successfully.

Table 3.3 shows what happens when the MLE value exceeds a threshold for Quality Control. The MLE of the first wind solution (the one closest to the model wind) is contained in field 95 and has a value of 25.3. This is above the threshold value of 19.8 for node number 23. The Wind Vector Cell Quality (field 89) has an integer value of 139328, i.e., Fortran bits 6, 13 and 17 are set, corresponding to the flags for ‘Distance to GMF too large’, ‘Wind inversion not successful’ and ‘KNMI Quality Control’.

```
 83 SOFTWARE IDENTIFICATION (         2201.0000 NUMERIC
 84 GENERATING APPLICATION              91.0000 CODE TABLE 1032
```

```
 85 MODEL WIND SPEED AT 10M              8.9000 M/S
 86 MODEL WIND DIRECTION AT 1           14.9900 DEGREE TRUE
 87 ICE PROBABILITY                     MISSING NUMERIC
 88 ICE AGE ("A" PARAMETER)             MISSING dB
 89 WIND VECTOR CELL QUALITY        139328.0000 FLAG TABLE 21155
 90 NUMBER OF VECTOR AMBIGUIT            4.0000 NUMERIC
 91 INDEX OF SELECTED WIND VE            1.0000 NUMERIC
 92 DELAYED DESCRIPTOR REPLIC            4.0000 NUMERIC
 93 WIND SPEED AT 10 M                   9.5200 M/S
 94 WIND DIRECTION AT 10 M              25.6000 DEGREE TRUE
 95 BACKSCATTER DISTANCE                25.3000 NUMERIC
 96 LIKELIHOOD COMPUTED FOR S           -0.0650 NUMERIC
 97 WIND SPEED AT 10 M                   7.3000 M/S
 98 WIND DIRECTION AT 10 M             274.3000 DEGREE TRUE
 99 BACKSCATTER DISTANCE                28.5000 NUMERIC
100 LIKELIHOOD COMPUTED FOR S           -0.9350 NUMERIC
101 WIND SPEED AT 10 M                   9.5800 M/S
102 WIND DIRECTION AT 10 M             187.5000 DEGREE TRUE
103 BACKSCATTER DISTANCE                30.8000 NUMERIC
104 LIKELIHOOD COMPUTED FOR S           -1.6320 NUMERIC
105 WIND SPEED AT 10 M                   7.7300 M/S
106 WIND DIRECTION AT 10 M              84.2000 DEGREE TRUE
107 BACKSCATTER DISTANCE                41.7000 NUMERIC
108 LIKELIHOOD COMPUTED FOR S           -4.8390 NUMERIC
```

Table 3.3 Part of Wind Vector Cell, rejected by Quality Control

The processing of the 25 km test file (approximately half an orbit) takes ~6 seconds on a Linux workstation and the processing of the corresponding 12.5 km test file takes ~18 seconds. Hence the ASCAT wind processing can be done easily in near-real time on an affordable computer system.

3.2 ERS test data

Figure 3.4 shows the coverage of the ERS test run (winds computed with AWDP) on 25 km. The colours show the magnitude of the wind speed as indicated by the legend. Since the ERS data were only available when the satellite was in sight of a ground station, only a limited spatial coverage is obtained. Figure 3.5 shows detailed wind vector plots over the Pacific near the US west coast. In the detail plots, a magenta marker on top of the wind arrow denotes land presence. Yellow wind arrows indicate that the Variational Quality Control flag is set, i.e. the Wind Vector Cell is spatially inconsistent. A yellow dot means that the KNMI Quality Control Flag is set.

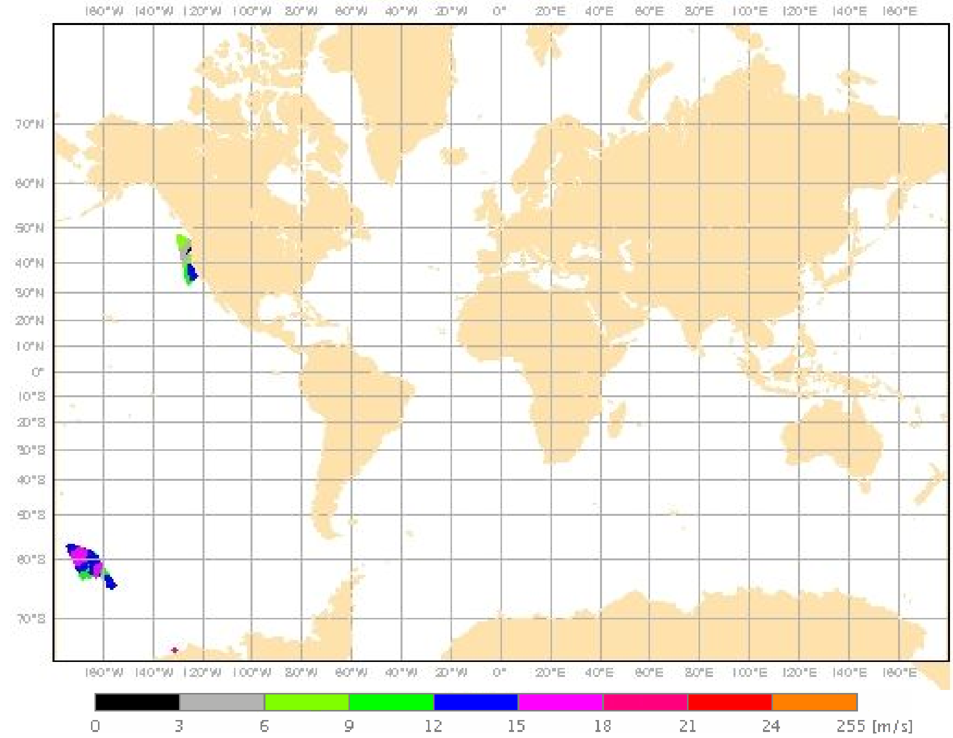

Figure 3.4 Global coverage of the ERS test run with AWDP.

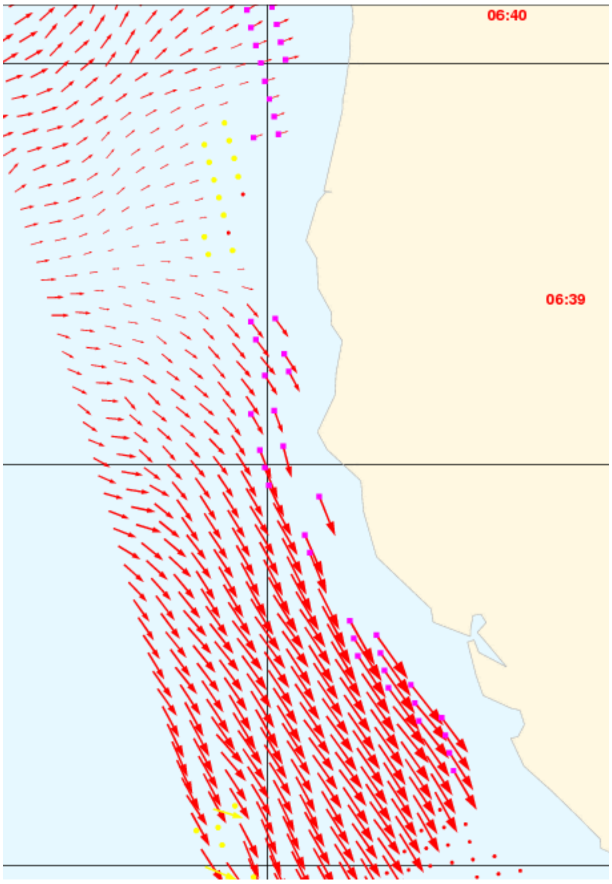

Figure 3.5 Detail plot of the ERS test run.

Chapter 4

Validation tests

There is no other wind processing software available for ASCAT data so it is not possible to compare ASCAT winds from AWDP with ASCAT winds from other sources. On the other hand, there is ERS wind processing software available: the Prescat package [*Stoffelen*, 1998] has been used to routinely process ERS winds at KNMI for many years. In the next section we compare ERS winds computed with Prescat with those computed by AWDP.

ASCAT winds from AWDP are routinely compared with NWP and buoy data 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 AWDP winds versus model wind forecasts from the ECMWF model, see section 4.2.

4.1 AWDP versus Prescat

Figure 4.1 shows the collocations of the ERS winds computed by Prescat and those computed by AWDP. Contoured histograms are shown for wind speed, wind direction and *u* and *v* wind components. In the wind direction plots, only those wind vectors where the Prescat 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 5° for wind direction.

The ERS data are those from 26 April 2007 which are also used in the previous section. It is clear from the plots that the results are almost spot on and no biases are discernable. Although a limited data set is used in this experiment, it is obvious that the AWDP winds are equivalent to the Prescat winds.

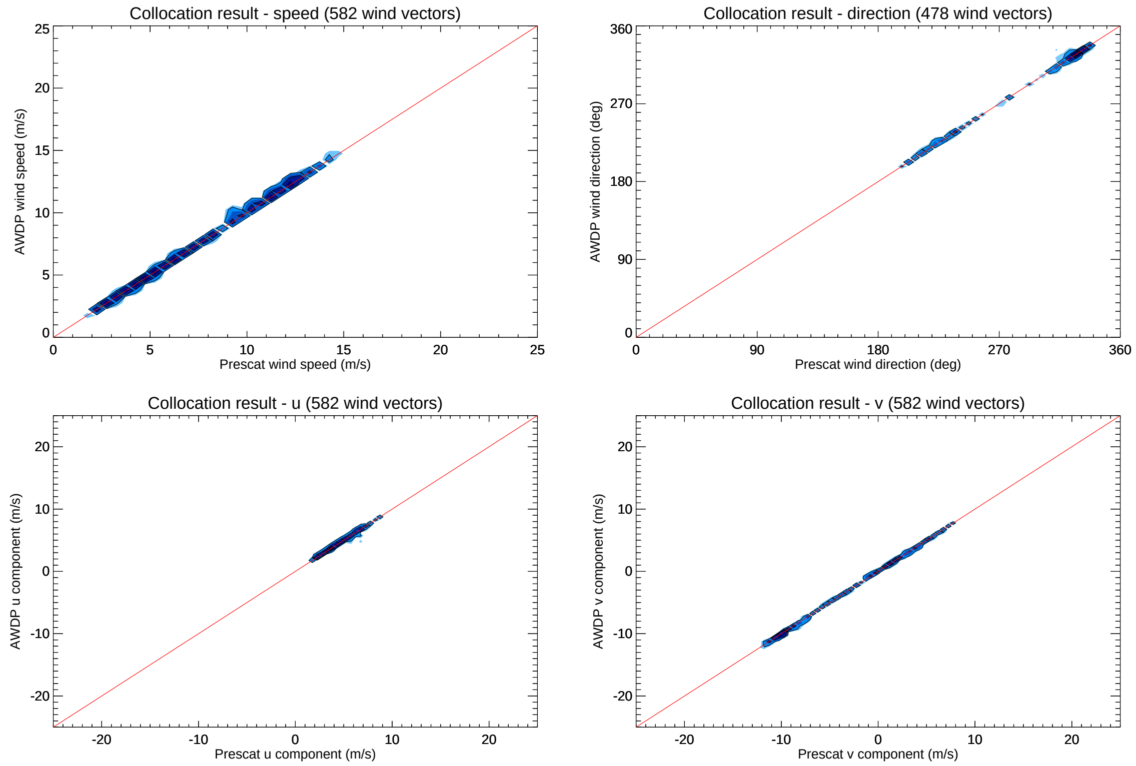

Figure 4.1 Collocation results of ERS winds from Prescat and AWDP.

4.2 AWDP winds versus ECMWF winds

We compared the ASCAT winds from AWDP with ECMWF forecast winds from the operational model (+3 to +21 hours forecasts from the 00 UTC and 12 UTC runs). The ASCAT data are 25 km Metop-A and Metop-B level 1b data from 1 and 2 November 2012 (28 orbits from both satellites).

Figure 4.2 shows the collocations of the ASCAT 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 1.44 in *u* and 1.49 in *v* directions, both for Metop-A and Metop-B.

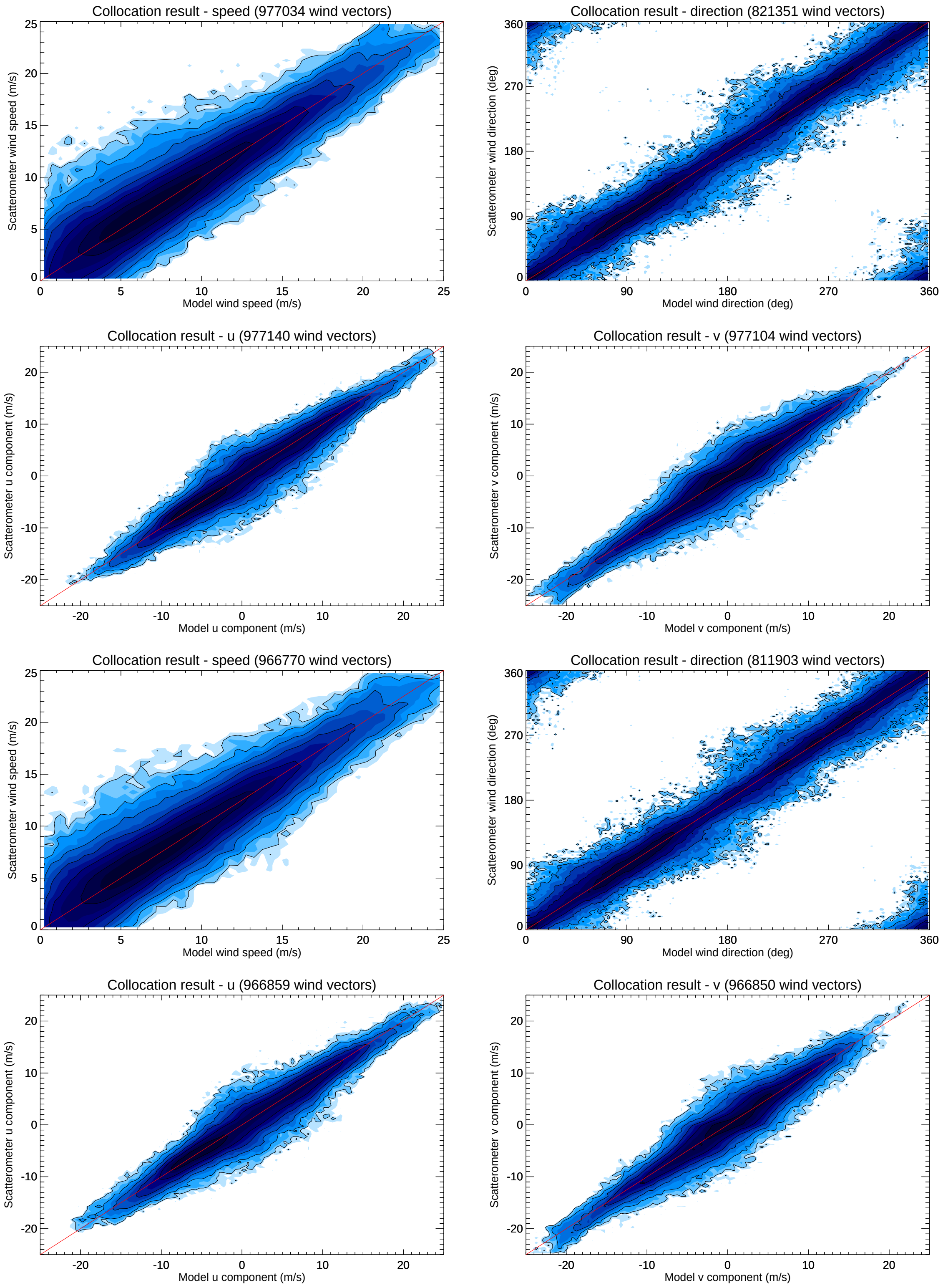

Figure 4.2 Collocation results of ASCAT winds from Metop-A (top) and Metop-B (bottom) versus ECMWF forecast winds.

4.3 Ice screening test

Figure 4.3 shows the ice maps for North and South poles after processing three days of data. The test data are from 1 to 3 November 2012 (25 km Metop-A data only). 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 three 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 [*Belmonte et al.*, 2011].

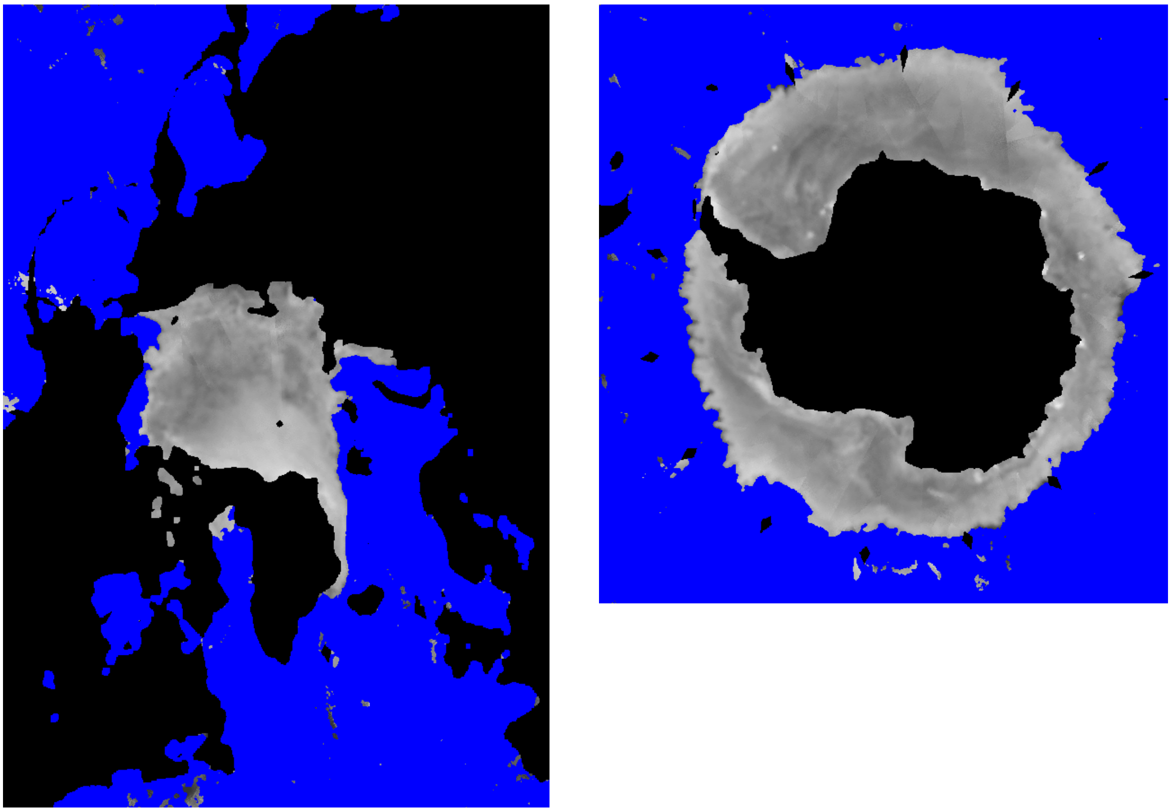

Figure 4.3 AWDP ice maps for North Pole (left) and South Pole (right).

Chapter 5

Portability tests

The AWDP software package inherits its portability by using strict Fortran 90 code (with a few low level routines for reading and writing binary in C). AWDP 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 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 AWDP. Table 5.1 provides an overview of the platforms and compilers on which AWDP was tested successfully. Note that AWDP can be run under Windows when the Linux emulator Cygwin is installed.

Platform	Operating system	Fortran compiler
Intel-based workstation	Fedora Linux	GNU g95, Portland f90, gfortran, Intel Fortran
SUN	SUN OS UNIX	Sun Fortran
PC	Windows XP with Cygwin	GNU g95

Table 5.1 Supported platforms and compilers for AWDP.

Chapter 6

User documentation tests

The user documentation (readme files within the software package and the AWDP User Manual and Reference Guide, [*Verhoef et. al.,* 2013]) has been and will be provided to beta testers for review. The beta tester's comments are implemented in newer versions of the user documentation.

References

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  Two dimensional variational ambiguity removal (2DVAR). Report NWPSAF-KN-TR-004, UKMO, UK. (Available on http://www.knmi.nl/scatterometer/publications/).

Appendix A

Acronyms

Name	Description
AMI	Active Microwave Instrument, scatterometer on ERS-1 and ERS-2 satellites
AR	Ambiguity Removal
ASCAT	Advanced SCATterometer on Metop
BUFR	Binary Universal Form for the Representation of data
C-band	Radar wavelength at about 5 cm
ERS	European Remote Sensing satellites
ECMWF	European Centre for Medium-range Weather Forecasts
EUMETSAT	European Organization for the Exploitation of Meteorological Satellites
genscat	generic scatterometer software routines
GMF	Geophysical model function
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
LUT	Look up table
Metop	Meteorological Operational Satellite
MLE	Maximum Likelihood Estimator
MSS	Multiple Solution Scheme
NRCS	Normalized Radar Cross-Section (σ^0)
NWP	Numerical Weather Prediction
OSI	Ocean and Sea Ice
OSCAT	Scatterometer onboard of the Indian Oceansat-2 satellite
PFS	Product Format Specification (native Metop file format)
QC	Quality Control
RFSCAT	Rotating Fan beam Scatterometer
RMS	Root Mean Square
SAF	Satellite Application Facility
SSM	Surface Soil Moisture
SST	Sea Surface Temperature
WVC	Wind Vector Cell, also called node or cell

Table A.1 List of acronyms.