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AWDP Top Level Design

Anton Verhoef, Jur Vogelzang, Jeroen Verspeek and Ad Stoffelen

KNMI, De Bilt, the Netherlands

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Contents

1 Introduction

The ASCAT Wind Data Processor (AWDP) is a software package mainly written in Fortran 90 with some parts in C for handling data from the Advanced Scatterometer (ASCAT) and European Remote Sensing satellite (ERS) scatterometer instruments. This document is the Top Level Design (TLD) of the AWDP software package and it also contains the Module Design. Section 2 provides information on the general design of the AWDP software. Section 3 and further provide information on the individual modules that are part of AWDP.

More information about AWDP can be found in several other documents. The User Manual and Reference Guide (UM) [1] contains more details about the installation and use of the AWDP package. The Product Specification (PS) [2] provides information on the purpose, outputs, inputs, system requirements and functionality of the AWDP software. Reading the UM and the PS should provide sufficient information to the user who wants to apply the AWDP program as a black box. This TLD document is of interest to developers and users who need more specific information on how the processing is done.

Please note that any questions or problems regarding the installation or use of AWDP can be addressed at the NWP SAF helpdesk at http://nwpsaf.eu/.

1.1 Design drivers

A user requirements assessment is performed to verify the user requirement for the improvements available in the new version. AWDP users from NOAA, MetNo, IPMA, the OSI SAF and many others require optimised spatial resolution for depicting mesoscale flow characteristics in dynamical conditions, such as near moist convection, polar lows, tropical hurricanes, or low-level coastal jets. Moreover, through the OSI SAF and CMEMS products, these improvements allow ocean forcing (studies) on the ocean eddy scale. The improved ASCAT spatial resolution product (true spatial resolution 19 km), posted at an irregular grid of 5.6 km has been brought forward from CDOP-3 planned work on spatial resolution improvements. The improvement in spatial representation of the AWDP furthermore includes better 2D Variational Ambiguity Removal (2DVAR) by exploiting Numerical Structure Functions in 2DVAR. This follows results of an Associate Scientist mission by Wenming Lin, ICM, which shows NSF to be more valuable than originally anticipated.

AWDP users from ECMWF (also C3S), NOAA, NASA and others stressed the relevance and appreciation of the improvements to AWDP for their requirements on the intercalibration with other scatterometers, notably the ESA ERS scatterometers, which AWDP now supports. This allows the production of consistent long-term Climate Data Records (CDR) since 1991 of ocean vector winds and wind stresses, an Essential Climate Variable (ECV), which is a high user priority. A consistent ocean wind vector climatology is essential in depicting any changes in air-sea interaction over 71% of the earth's surface.

Another high user priority is an improved coastal processing, but this depends on the provision of the EUMETSAT L1B land contributions flag, and has not been made available yet. This development is being incorporated into spatial resolution improvements planned for CDOP-3.

1.2 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/).

Numbers between square brackets refer to references (e.g. [3]).

2 Program Design

In this chapter, the design of the AWDP software package is described in detail. Readers to whom only a summary will suffice are referred to the Top Level Design (TLD) in section 4.1. Readers who really want to know the very detail should not only read the complete chapter, but also the documentation within the code. Some more detailed information is also given in the NWPSAF Technical Reports listed in the references.

2.1 Top Level Design

2.1.1 Main program

The main program, AWDP, (file `awdp` in the `awdp/src` directory) is a Unix (Linux) executable which processes ASCAT BUFR, ASCAT PFS, or ERS BUFR input files. The main output consists of BUFR files. The output BUFR messages are always in the ASCAT BUFR format, for a list of descriptors see appendix A in the Product Specification [2]. The user may provide arguments and parameters according to Unix command line standards. The purpose of the different options is described in the User Manual [1].

When executed, AWDP logs information on the standard output. The detail of this information may be set with the verbosity flag. The baseline of processing is shown in Figure 2.1, but note that not all of these steps are always invoked. Some of them may be skipped, depending on the command line options supplied to AWDP. A more detailed representation of the AWDP structure is given in Appendices A and B.

The first step is to process the arguments given at the command line using the genscat *Compiler_Features* module. Next, AWDP reads the input file specified in the arguments. The BUFR messages or PFS records are read and mapped onto the AWDP data structure, see subsection 2.1.3. As part of the pre-processing a similar AWDP data structure is created for the output. Subsequently, the input data are sorted with respect to data acquisition time, duplicate rows are merged and the output data structure is filled with level 1b (σ^0 related) data. Then, the NWP GRIB data (wind forecasts, land-sea mask and sea surface temperature) are read and the data are collocated with the Wind Vector Cells. The next steps are the inversion and the ambiguity removal. These steps are performed on the output data. The program ends with the post-processing step (which includes some conversions and the monitoring) and the mapping of the output data structure onto BUFR messages of the BUFR output file. The different stages in the processing correspond directly to specific modules of the code. These modules form the process layer, see section 2.3.

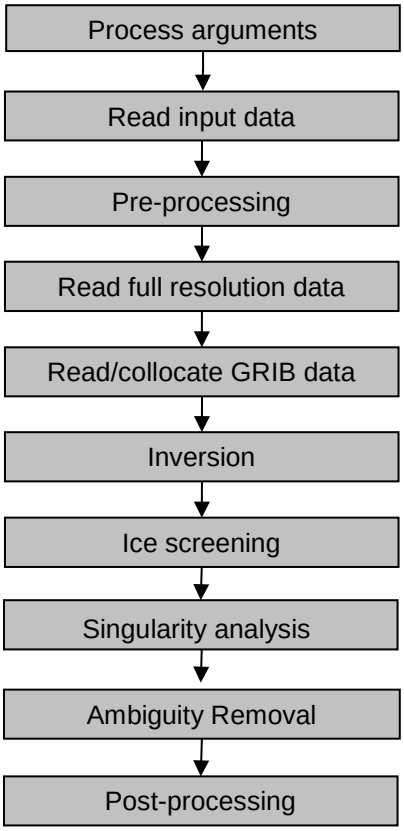

Figure 2.1 Baseline of the ASCAT Wind Data Processor

2.1.2 Layered model structure

AWDP is a Fortran 90 software package consisting of several Fortran 90 modules which are linked after their individual compilation. The AWDP software is set up from two layers of software modules. The purpose of the layer structure is to divide the code into generic scatterometer processing software and ASCAT specific software. Details on the individual modules can be found in sections 2.2 and 2.3.

The first layer (the process layer) consists of modules which serve the main steps of the process. Each module contains code for performing one or more of the specific tasks. These tasks are briefly described in table 2.1. A more elaborate description is given in section 2.3. The first module listed, *awdp_data* is a general support module. This module is used by the other modules of the process layer for the inclusion of definitions of the data structures and the support routines.

The second module layer is the genscat layer. The genscat module classes (i.e., groups of modules) used in the AWDP software package are listed in table 2.2. The genscat package is a set of generic modules which can be used to assemble processors as well as pre, and post-processing tools for different scatterometer instruments available to the user community. A short description of the main (interface) modules is given in section 2.2. The most important classes of modules are related to the inversion processing step (chapter 3), the Ambiguity Removal step (chapter 4), the BUFR file handling (chapter 6), and the GRIB file handling (chapter 7). The genscat modules are located in subdirectory `genscat`.

Module name	Tasks	Comments
awdp_data	Definition of data structures	
awdp_bufr	BUFR file handling	Interface to `genscat/support/bufr`
awdp_pfs	PFS file handling	Interface to `genscat/support/pfs`
awdp_szf	Grid generation and PFS file handling for ASCAT-5.6	Interface to `genscat/support/pfs`
awdp_prepost	Sorting of input	Duplicate rows are merged
	Quality control	Usability of input data is determined
	Post processing	Setting of flags
	Monitoring	
	Clean up	Deallocation of used memory
	Flow-dependent errors	Assignment of flow-dependent errors
awdp_calibrate	Backscatter calibration	
awdp_grib	GRIB file handling	Interface to `genscat/support/grib`
	Collocation of GRIB data	NWP data are interpolated w.r.t. time and location
awdp_inversion	Inversion	Interface to `genscat/inversion`
awdp_ambrem	Ambiguity Removal	Interface to `genscat/ambrem`
awdp_icemodel	Ice screening	Interface to `genscat/icemodel`

Table 2.1 AWDP process modules.

In addition, genscat contains a large support class to convert and transform meteorological, geographical, and time data, to handle file access and error messages, sorting, and to perform more complex numerical calculations on minimization and Fourier transformation. Many routines are co-developed for ERS, ASCAT and SeaWinds data processing.

Module class	Tasks	Description
Ambrem	Ambiguity Removal	2DVAR and other schemes, see 4
Inversion	Wind retrieval	Inversion in one cell, see 3
IceModel	Ice screening	Uses ice line and wind cone for ice discrimination
Support	BUFR support	*BufrMod*, based on ECMWF library
	PFS support	Reading of PFS files; grid generation and σ^0 aggregation for ASCAT-5.6; reading of full resolution data
	GRIB support	*gribio_module*, based on ECMWF library
	FFT, minimization	Support for 2DVAR
	Singularity analysis	Flow dependent errors in 2DVAR
	Error handling	Print error messages
	File handling	Finding, opening and closing free file units
	Conversion	Conversion of meteorological quantities
	Sorting	Sorting of ambiguities to their probability
	Date and time	General purpose

Table 2.2 genscat module classes.

2.1.3 **Data Structure**

Along track, the ASCAT swath is divided into rows. Within a row (across track), the ASCAT orbit is divided into cells, also called Wind Vector Cells (WVCs) or nodes. This division in rows and cells forms the basis of the main data structures within the AWDP package. In fact, both the input and the output structure are one dimensional arrays of the row data structure, *row_type*. These arrays represent just a part of the swath. Reading and writing (decoding and encoding) ASCAT BUFR files corresponds to the mapping of a BUFR message to an instance of the *row_type* and

vice versa.

The main constituent of the *row_type* is the cell data structure, *cell_type*, see figure 2.2. Since most of the processing is done on a cell-by-cell basis the *cell_type* is the pivot data structure of the processor.

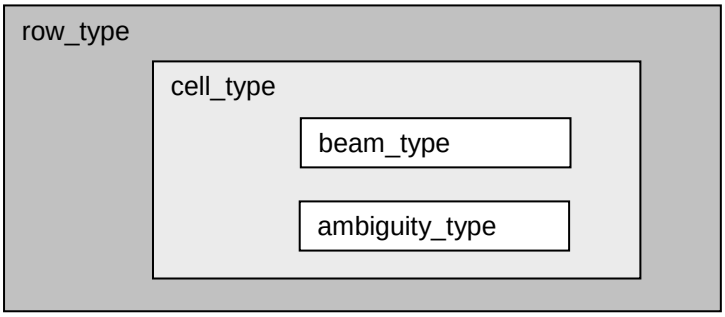

Figure 2.2 Schematic representation of the nested data definitions in the *row_type* data structure.

The σ^0 related level 1b data of a cell are stored in a data structure called *beam_type*. Every cell contains three instances of the *beam_type*, corresponding to the fore, middle and aft beams.

A cell may also contain an array of instances of the *ambiguity_type* data structure. This array stores the results of a successful wind retrieval step, the wind ambiguities (level 2 data). Details of all the data structures and methods working on them are described in the next sections.

2.1.4 Quality flagging and error handling

Important aspects of the data processing are to check the validity of the data and to check the data quality. In AWDP two flags are set for every WVC, see table 2.3. The flags themselves do not address a single aspect of the data, but the flags are composed of several bits each addressing a specific aspect of the data. A bit is set to 0 (1) in case the data is valid (not valid) with respect to the corresponding aspect. In order to enhance the readability of the code, each flag is translated to a data type consisting of only booleans (false = valid, true = invalid). On input and output these data types are converted to integer values by *set* and *get* routines.

Flag	Tasks	Description
wvc_quality	Quality checking	In BUFR output
process_flag	Range checking	Not in BUFR output

Table 2.3 Flags for every WVC (attributes of *cell_type*).

Apart from the flags on WVC level, also the beams contain quality indicators. Most of them are implemented as real values ranging from 0 to 1, where 0 stands for good quality and 1 for degraded quality. See section 2.3.1 for more information on this.

2.1.5 Verbosity

Every routine in a module may produce some data and statements for the log of the processor. To control the size the log, several modules contain parameters for the level of verbosity. The verbosity of AWDP may be controlled by the verbosity command line option `-verbosity`. In

general, there are three levels of verbosity specified:

≤ -1: be as quiet as possible;

0: only report top level processing information;

≥ 1: report additional information.

Of course, errors are logged in any case. Table 2.4 gives a (incomplete) list of verbosity parameters. They are not all set by the command line option as some of them serve testing and debugging purposes.

Module	Verbosity parameter
Ambrem2Dvar	*TDVverbosity*
AmbremBGclosest	*BGverbosity*
BatchMod	*BatchVerbosity*
Ambrem	*AmbremVerbosity*
awdp_bufr	*BufrVerbosity*
awdp_grib	*GribVerbosity*
awdp_icemodel	*dbgLevel*

Table 2.4 Verbosity parameters.

2.2 Module design for genscat layer

2.2.1 Module inversion

The module *inversion* contains the *genscat* inversion code. Module *post-inversion* contains some routines specific for ERS and ASCAT inversion and quality control. The modules are located in subdirectory `genscat/inversion`. Details of this module are described in 3. In AWDP, the inversion module is only used in the *awdp_inversion* module, see section 2.3.8.

2.2.2 Module *ambrem*

The module *ambrem* is the main module of the genscat Ambiguity Removal code. It is located in subdirectory `genscat/ambrem`. Details of this module are described in 4. In AWDP, the *ambrem* module is only used in the *awdp_ambrem* module, see section 2.3.9.

2.2.3 Module icemodel

The module *icemodel* contains the *genscat* ice screening code. It is located in subdirectory `genscat/icemodel`. In AWDP, the *icemodel* module is only used in the *awdp_icemodel* module, see section 2.3.10.

2.2.4 Module *Bufrmod*

Genscat contains several support modules. In particular, the *BufrMod* module is the Fortran 90 wrapper around the BUFR library used for BUFR input and output. It is located in subdirectory `genscat/support/bufr`. Details of this module are described in 6. In AWDP, the *BufrMod* module is only used in the *awdp_bufr* module, see subsection 2.3.2.

2.2.5 Module gribio_module

The *gribio_module* module is the Fortran 90 wrapper around the GRIB library used for GRIB input and collocation of the NWP data with the scatterometer data. It is located in subdirectory `genscat/support/grib`. Details of this module are described in 7. In AWDP, the *gribio_module* module is used in the *awdp_grib* and *awdp_pfs* modules, see subsection 2.3.7.

2.2.6 Support modules

Subdirectory `genscat/support` contains more support modules besides *Bufrmod* and *gribio_module*. The KNMI 2DVAR Ambiguity Removal method requires minimization of a cost function and numerical Fourier transformation. These routines are located in subdirectories `BFGS` and `singletonfft`, respectively, and are discussed in more detail in section 4.4. 2DVAR also features flow-dependent errors, set according to the value of the MLE and the singularity exponent. The latter is calculated by the routines in subdirectory `singularity_analysis`.

Subdirectory `Compiler_Features` contains module *Compiler_Features* for handling some compiler specific issues, mainly with respect to command line argument handling. The `Makefile` in this directory compiles on of the available source files, depending on the Fortran compiler used.

Subdirectory `constants` contains a small module *constants* with some mathematical and physical constants.

Subdirectory `convert` contains module *convert* for the conversion of meteorological and geographical quantities, e.g. the conversion of wind speed and direction into *u* and *v* components and vice versa.

Subdirectory `datetime` contains module *DateTimeMod* for date and time conversions. AWDP only uses routines *GetElapsedSystemTime* (for calculating the running time of the various processing steps), and *julian2ymd* and *ymd2julian* (for conversion between Julian day number and day, month and year). Module *DateTimeMod* needs modules *ErrorHandler* and *numerics*.

Subdirectory `ErrorHandler` contains module *ErrorHandler* for error management. This module is needed by module *DateTimeMod*.

Subdirectory `file` contains module *LunManager* for finding, opening and closing free logical units in Fortran. AWDP uses only routines *get_lun* and *free_lun* for opening and closing of a logical unit, respectively.

Subdirectory `num` contains module *numerics* for defining data types and handling missing values, for instance in the BUFR library. This module is needed by many other modules.

Subdirectory `pfs` contains modules *pfs_ascat* and *szf_ascat* for opening, reading and closing of files in PFS format. Further, *szf_ascat* contains routines for generating a grid of wind vector cells synchronised to the ASCAT mid beam pulse pattern and calculating the average radar cross sections (aggregation) for the ASCAT-5.6 product [3].

Subdirectory `sort`, contains module *SortMod* for sorting the rows according to their acquisition date and time, or the wind vector solutions according to their probability.

Subdirectory `stringtools`, finally, contains module *StringTools* for handling character strings.

2.3 Module design for process layer

The process layer consists of the modules *awdp_data*, *awdp_bufr*, *awdp_pfs*, *awdp_szf*, *awdp_prepost*, *awdp_calibrate*, *awdp_grib*, *awdp_inversion*, *awdp_icemodel* and *awdp_ambrem*. The routines present in these modules are described in the next sections.

2.3.1 Module awdp_data

The module *awdp_data* contains all the important data types relevant for the processing. Elementary data types are introduced for the most basic data structures of the processing. These are e.g. *wind_type* and *time_type*. Using these data types (and of course the standard types as integer, real etc.), more complex (composed) data types are derived. Examples are *beam_type*, *ambiguity_type*, *cell_type*, and *row_type*. A complete description of all types is given below. The attributes of all these types have intentionally self-documenting names.

Ambiguity data: The *ambiguity_type* data type contains information on an individual ambiguity (wind vector solution). The attributes are listed in table 2.5. The routine *init_ambiguity()* sets all ambiguity data to missing. The routine *print_ambiguity()* may be used to print all ambiguity data.

Attribute	Type	Description
wind	*wind_type*	Wind vector solution
prob	real	Probability of wind vector solution
conedistance	real	Distance of solution to the GMF

Table 2.5 Ambiguity data structure.

Beam data: Every WVC contains three beams. The information of every beam is stored in the data type *beam_type*. The attributes are listed in table 2.6. Most of the attributes are explained in detail in [4]. The routine *init_beam()* sets all beam data to missing and the routine *test_beam* checks if the data in the beam are within valid ranges. The routine *print_beam()* may be used to print all beam data.

Attribute	Type	Description
identifier	integer	Beam number: 1 = fore, 2 = mid, 3 = aft
incidence	real	Incidence angle (degrees, 0 is vertical, 90 is horizontal)
azimuth	real	Radar look angle (degrees, counted clockwise from the south)
sigma0	real	Radar backscatter (σ^0) in dB
noise_val	real	Noise value in %
kp_estim_qual	*kp_estim_qual_type*	Flag related to the quality of the Kp estimate
s0_usability	integer	Usability of σ^0: 0 = good, 1 = usable, 2 = bad
synt_data_quantity	real	Amount of synthetic data in σ^0 (0..1)
synt_data_quality	real	Quality of used synthetic data in σ^0 (0..1)
orbit_quality	real	Satellite orbit and attitude quality (0..1)
solar_reflec	real	Solar array reflection contamination in σ^0 (0..1)
telemetry	real	Telemetry quality (0..1)
land_frac	real	Land fraction in σ^0 (0..1)
sigma0_corr	real	Correction applied to σ^0 from NOC or other corrections

Table 2.6 Beam data structure.

Cell Data: The *cell_type* data type is a key data type in AWDP, because many processing steps are done on a cell by cell basis. The attributes are listed in table 2.7. The routine *init_cell()* sets the cell data to missing values. Also the flags are set to missing. The routine *test_cell()* tests the validity of data. This routine sets the cell process flag. The routine *print_cell()* may be used to print the cell data.

Attribute	Type	Description
centre_id	integer	Identification of originating/generating centre
sub_centre_id	integer	Identification of originating/generating sub-centre
software_id_l1b	integer	Software identification of level 1 processor
satellite_id	integer	Satellite identifier
sat_instruments	integer	Satellite instrument identifier
sat_motion	real	Direction of motion of satellite
time	*time_type*	Date and time of data acquisition
lat	real	Latitude of WVC
lon	real	Longitude of WVC
pixel_size_hor	real	Distance between WVCs (meters)
orbit_nr	integer	Orbit number
node_nr	integer	Across track cell number
height_atmosphere	real	Height of atmosphere used
loss_unit_lenght	real	Loss per unit length of atmosphere
beam_collocation	*beam_collocation_type*	Beam collocation flag
beam (3)	*beam_type*	Beam data
full_res	*full_res_type*	Averaged full resolution data
software_id_sm	integer	Soil moisture information
database_id	integer	Soil moisture information
surface_sm	real	Soil moisture information
surface_sm_err	real	Soil moisture information
sigma0_40	real	Soil moisture information
sigma0_40_err	real	Soil moisture information
slope_40	real	Soil moisture information
slope_40_err	real	Soil moisture information
sm_sensitivity	real	Soil moisture information
dry_backscatter	real	Soil moisture information
wet_backscatter	real	Soil moisture information
mean_surface_sm	real	Soil moisture information
rain_fall_detect	real	Soil moisture information
sm_corr_flag	integer	Soil moisture information
sm_proc_flag	integer	Soil moisture information
sm_quality	real	Soil moisture information
snow_cov_frac	real	Soil moisture information
froz_land_frac	real	Soil moisture information
inund_wet_frac	real	Soil moisture information
topo_complexity	real	Soil moisture information
software_id_wind	integer	Software identification of level 2 wind processor
generating_app	integer	Generating application of model information
model_wind	*wind_type*	Model wind used for Ambiguity Removal
ice_prob	real	Probability of ice
ice_age	real	Ice age A-parameter
wvc_quality	*wvc_quality_type*	WVC quality flag
num_ambigs	integer	Number of ambiguities present in WVC
selection	integer	Index of selected wind vector
se, se_filt	real	Unfiltered and filtered singularity exponent
err_bgu, err_bgv	real	Errors in background wind components
err_obu,err_obv	real	Errors in scatterometer wind components

Attribute	Type	Description
skill	real	Parameter used for PreScat Ambiguity Removal
ambig (0..144)	*ambiguity_type*	Array of wind ambiguities
ice	*icemodel_type*	Ice information
stress_param	*nwp_stress_param_type*	Wind stress information
process_flag	*process_flag_type*	Processing flag
level_of_input	integer	Level of input data (1 or 2)

Table 2.7 Cell data structure.

All soil moisture information is read from the input BUFR file into the cell data structure and not used within the program. It is written to the output BUFR file at the end of the processing.

Full resolution data: The *full_res_type* contains average full resolution data, read from a PFS file, which are used to replace the 25-km or 12.5-km beam data. The attributes are listed in table 2.8. The routine *init_full_res()* sets the full resolution averaged data to zero. The routine *print_full_res()* may be used to print the full resolution data.

Attribute	Type	Description
count_tot	integer	Number of full res measurements used
lat	real	Mean value of full res lats
lon	real	Mean value of full res lons
count_fore	integer	Number of full res fore beams used
incidence_fore	real	Mean value of full res values
azimuth_fore	real	Mean value of full res values
sigma0_fore	real	Mean value of full res values
sigma0_sq_fore	real	Sum of squares
land_frac_fore	real	Mean value of full res values
count_mid	integer	Number of full res mid beams used
incidence_mid	real	Mean value of full res values
azimuth_mid	real	Mean value of full res values
sigma0_mid	real	Mean value of full res values
sigma0_sq_mid	real	Sum of squares
land_frac_mid	real	Mean value of full res values
count_aft	integer	Number of full res aft beams used
incidence_aft	real	Mean value of full res values
azimuth_aft	real	Mean value of full res values
sigma0_aft	real	Mean value of full res values
sigma0_sq_aft	real	Sum of squares
land_frac_aft	real	Mean value of full res values

Table 2.8 Full res data structure.

Ice model data: The *icemodel_type* contains information related to the ice screening. The attributes are listed in table 2.9. The routine *init_icemodel()* sets the ice model data to missing values. The routine *print_icemodel()* may be used to print the ice data.

Attribute	Type	Description
class	integer	Code for WVC being ice or wind
ii	integer	Coordinate on the ice map
jj	integer	Coordinate on the ice map

Attribute	Type	Description
a	real	Ice coordinate
b	real	Ice coordinate
c	real	Ice coordinate
dIce	real	Distance to the ice line
wind_sol	integer	Wind solution to be used

Table 2.9 Ice model data structure.

NWP stress parameter data: The *nwp_stress_param_type* data type contains information relevant for the ice screening and wind stress calculations (stress calculation is not yet implemented in AWDP). The attributes are listed in table 2.10. The routine *init_nwp_stress_param()* sets the NWP stress parameter data to missing values. The routine *print_nwp_stress_param ()* may be used to print the stress data.

Attribute	Type	Description
u	real	Eastward (zonal) wind component
v	real	Northward (meridional) wind component
t	real	Air temperature
q	real	Specific humidity
sst	real	Sea surface temperature
chnk	real	Charnok parameter
sp	real	Surface pressure

Table 2.10 NWP stress parameter data structure.

Row data: The data of a complete row of the swath is stored in the data type *row_type*, see table 2.11. A complete row corresponds to a single BUFR message in the AWDP output. The level 1 BUFR data may contain more than one row per BUFR message.

Attribute	Type	Description
time_stamp	integer	Time stamp of row data in seconds, used for sorting
num_cells	integer	Actual number of WVC's
Cell(82)	*cell_type*	Array of Wind Vector Cells

Table 2.11 Row data structure.

Time data: The *time_type* data type contains a set of 6 integers representing both the date and the time, see table 2.12. The routine *init_time()* sets the time entries to missing values. The routine *test_time()* tests the validity of the date and time specification (see also the cell process flag). The routine *print_time()* can be used to print the time information.

Attribute	Type	Description
year	integer	19XX or 20XX
month	integer	1 – 12
day	integer	1 – 31
hour	integer	0 – 23
minute	integer	0 – 59
second	integer	0 – 59

Table 2.12 Time data structure.

Wind Data: The *wind_type* data type contains the wind speed and wind direction, see table 2.13. The routine *init_wind()* sets the wind vector to missing. The routine *print_wind()* may be used to print the wind vector. The routine *test_wind()* tests the validity of the wind specification, see also the cell process flag.

Attribute	Type	Description
speed	real	Wind speed
dir	real	Wind direction

Table 2.13 Wind data structure.

Some special data types are introduced for the data (quality) flags. These are discussed below.

Beam collocation flag: The *beam_collocation_type* data type is used to indicate whether data of the three beams is originating from a single ground station or from multiple ground stations (collocated data). This is relevant for so-called direct readout data from different ground stations which maybe merged into one single product. In a WVC, e.g. the fore beam information from one ground station may be combined with the mid and aft beam information from another ground station, in order to make a complete WVC. The attributes are listed in table 2.14. The routine *get_beam_collocation()* converts an integer value to the logical beam collocation structure. The routine *set_beam_collocation ()* converts a logical beam collocation structure to an integer value.

Attribute	Bit	2^{Bit}	Description
missing			Flag not set (all bits on)
collocation	0	1	Beam information originates from different ground stations

Table 2.14 Beam collocation flag bits.

***K_p* estimate quality flag**: The *kp_estim_qual_type* data type contains the flag indicating the quality of the K_p estimate. Each one of the three beams in a WVC contain an instance of this flag. The attributes are listed in table 2.15. The function *get_kp_estim_qual()* interprets an integer flag (BUFR input) to an instance of *kp_estim_qual_type*. The function s*et_kp_estim_qual()* transforms an instance of *kp_estim_qual_type* to an integer flag.

Attribute	Bit	2^{Bit}	Description
missing			Flag not set (all bits on)
estim_qual	0	1	Inferior quality of K_p estimate

Table 2.15 K_p estimate quality flag bits (Fortran).

Wind Vector Cell quality flag: Every WVC contains a flag for its quality. Therefore the *cell_type* contains an instance of the *wvc_quality_type*. Table 2.16 gives an overview of its attributes. The function *get_wvc_quality()* interprets an integer flag (BUFR input) to an instance of *wvc_quality_type*. The function *get_wvc_quality()* transforms an instance of *wvc_quality_type* to an integer flag. The routine *print_wvc_quality()* may be used to print the bit values of the flag.

Attribute	Bit	2^{Bit}	Description
missing			Flag not set (all bits on)
qual_sigma0	22	4194304	Not enough good σ^0 available for wind retrieval
azimuth	21	2097152	Poor azimuth diversity among σ^0
kp	20	1048576	Any beam noise content above threshold
monflag	19	524288	Product monitoring not used
monvalue	18	262144	Product monitoring flag
knmi_qc	17	131072	KNMI quality control fails
var_qc	16	65536	Variational quality control fails
land	15	32768	Some portion of wind vector cell is over land
ice	14	16384	Some portion of wind vector cell is over ice
inversion	13	8192	Wind inversion not successful
large	12	4096	Reported wind speed is greater than 30 m/s
small	11	2048	Reported wind speed is less than or equal to 3 m/s
rain_fail	10	1024	Rain flag not calculated
rain_detect	9	512	Rain detected
no_background	8	256	No meteorological background used
redundant	7	128	Data are redundant
gmf_distance	6	64	Distance to GMF too large

Table 2.16 Wind Vector Cell quality flag bits (Fortran).

Cell process flag: Besides a cell quality flag, every WVC contains a process flag. The process flag checks on aspects that are important for a proper processing, but are not available as a check in the cell quality flag. The cell process flag is set by the routine *test_cell*, which calls routines *test_time*, *test_beam* and *test_wind*.

Table 2.17 lists the attributes of the *process_flag_type*. The process flag is only available internally in AWDP. The routine *print_process_flag()* may be used to print the bit values of the flag.

Table 2.18 provides an overview of all routines and their calls in module *awdp_data*.

Attribute	Description
satellite_id	Invalid satellite id
sat_instruments	Invalid satellite instrument id
sat_motion	Invalid satellite direction of motion
time	Invalid date or time specification
latlon	Invalid latitude or longitude
pixel_size_hor	Invalid cell spacing
node_nr	Invalid across track cell number
beam (3)	Invalid data in one of the beams
model_wind	Invalid background wind
ambiguity	Invalid ambiguities
selection	Invalid wind selection

Table 2.17 Cell process flag bits (Fortran).

Routine	Call	Description
copy_cell		Copy all information from one cell into another
get_beam_collocation	*init_cell*	Convert integer beam collocation to logical structure
get_kp_estim_qual	*init_beam*	Convert integer K_p estimate quality to logical structure
get_wvc_quality	*init_cell*	Convert integer WVC quality to logical structure
init_ambiguity		Initialise ambiguity structure
init_beam	*init_cell*	Initialise beam structure
init_cell		Initialise cell structure
init_full_res	*init_cell*	Initialise full resolution structure
init_icemodel	*init_cell*	Initialise ice model structure
init_nwp_stress_param	*init_cell*	Initialise NWP stress parameters structure
init_process_flag	*init_cell*	Initialise process flag structure
init_time	*init_cell*	Initialise time structure
init_wind	*init_cell*	Initialise wind structure
print_ambiguity		Print ambiguity structure
print_beam		Print beam structure
print_cell		Print cell structure
print_full_res		Print full resolution structure
print_icemodel		Print ice model structure
print_nwp_stress_param		Print NWP stress parameters structure
print_process_flag		Print process flag structure
print_time		Print time structure
print_wind		Print wind structure
print_wvc_quality		Print quality flag structure
set_beam_collocation		Convert logical beam collocation to integer
set_knmi_flag		Sets/unsets KNMI QC flag depending on other flag settings
set_kp_estim_qual		Convert logical K_p estimate quality to integer
set_wvc_quality		Convert logical WVC quality to integer
test_beam	*test_cell*	Test validity of beam data
test_cell		Test validity of cell data
test_time	*test_cell*	Test validity of time data
test_wind	*test_cell*	Test validity of wind data

Table 2.18 Routines in module *awdp_data*

2.3.2 **Module awdp_bufr**

The module *awdp_bufr* maps the AWDP data structure on BUFR messages and vice versa. A list of the BUFR data descriptors can be found in appendix C. Satellite and instrument identifiers are

listed in tables 2.19 and 2.20. Note that the first Metop mission is Metop 2, which is also known as Metop A. The *awdp_bufr* module uses the genscat module *BufrMod*, see subsection 2.2.3 for the interface with the BUFR routine library.

Satellite	Value
ERS-1	1
ERS-2	2
Metop 1 = Metop B	3
Metop 2 = Metop A	4
Metop 3 = Metop C	5

Table 2.19 BUFR satellite identifiers.

Instrument	Parameter	Value
AMI/scatt	*sat_instr_ers*	142
ASCAT	*sat_instr_ascat*	190

Table 2.20 BUFR instrument identifiers.

Table 2.21 provides an overview of the different routines and their calls in this module. The genscat support routines *ymd2julian()* and *julian2ymd()* are used to provide each row in AWDP with a date/time stamp that can be used for sorting easily.

Routine	Call	Description
ascat_bufr_to_row_data	*read_bufr_file*	ASCAT BUFR message into one or more *row_types*
ers_bufr_to_row_data	*read_bufr_file*	ERS BUFR message into 19 *row_types*
init_bufr_processing	*read_bufr_file*, *write_bufr_file*	Initialise module
read_bufr_file	AWDP	Read a complete BUFR file into *row_types*
row_to_bufr_data	*write_bufr_file*	AWDP *row_type* into ASCAT BUFR message
write_bufr_file	AWDP	Write all *row_types* into a complete BUFR file

Table 2.21 Routines in module *awdp_bufr*

Note that the acquisition date and time of ERS data are modified when they are read in routine *ers_bufr_to_row_data*. An ERS BUFR message contains 19 rows of data which all have the same date and time of acquisition. This would cause problems in AWDP when the rows are sorted with respect to the acquisition date and time. Therefore, the date and time of each ERS row are recalculated assuming that the 10^{th} (middle) row of the ERS BUFR message contains the 'true' acquisition time and that subsequent rows are 3.766 seconds apart. The time corrections are rounded to an integer number of seconds. Hence, in the first row, 34 seconds are subtracted from the acquisition time, in the second row 30 seconds, et cetera, until in the last (19^{th}) row, 34 seconds are added to the acquisition time.

2.3.3 **Module awdp_pfs**

The module *awdp_pfs* maps the records in a PFS file on the AWDP data structure. It also contains a routine to read in a full resolution PFS file and use the data to calculate averaged beam data

which are used to replace 25/12.5/6.25-km row data.

Table 2.22 provides an overview of the different routines and their calls in this module. Several routines from the *pfs_ascat* module in genscat are called from this module to handle the PFS data. Appendix B5 shows the calling trees of the routines in module *pfs_ascat* that are used in AWDP.

Routine	Call	Description
ascat_pfs_to_row_data	*read_pfs_file*	ASCAT PFS record into one *row_type*
read_full_res_data	AWDP	Read full resolution PFS data and replace beam data
read_pfs_file	AWDP	Read a complete PFS level 1b file into *row_types*

Table 2.22 Routines in module *awdp_pfs*

2.3.4 Module awdp_szf

The module *awdp_szf* is needed for processing on a 5.65 km grid (ASCAT-5.6 product). It reads the records in a PFS file into an instance of the SZF_Type struct which is defined in the genscat module *szf_ascat.* It also reads from file an aggregation table containing the information which full resolution measurements contribute to a certain WVC. The module calculates the average radar cross sections very efficiently and stores them in the AWDP data structure.

Table 2.23 provides an overview of the different routines and their calls in this module. Several routines from the *szf_ascat* module in genscat are called from this module to handle the PFS data. Appendix B6 shows the calling trees of the routines in module *szf_ascat* that are used in AWDP.

Routine	Call	Description
read_and_aggregate_szf_data	AWDP	Read PFS data and aggregation table; generate grid and calculate average σ^o.
find_szf_files	*read_and_aggregate_szf_data*	Find full resolution files needed
set_GRIB_land_sea_mask	*read_and_aggregate_szf_data*	Set land/sea mask as long as this is not included in the PFS data.
init_cell_data	*read_and_aggregate_szf_data*	Set some other data in AWDP data structure
get_offsets	*read_and_aggregate_szf_data*	Calculate libration correction
aggregate	*read_and_aggregate_szf_data*	Perform σ^o aggregation
update_szf_correlation_sum	*aggregate*	Update K_p calculation

Table 2.23 Routines in module *awdp_szf*

2.3.5 Module awdp_prepost

Module *awdp_prepost* contains the routines to do all the pre and post processing. Pre processing consists of the procedures between the reading of the BUFR input and the wind retrieval for the output product. This includes sorting and merging, and assessments of the quality of the input data. Post processing consists of the procedure between the ambiguity removal step and the BUFR encoding of the output. The post processing includes the monitoring of the wind data and the setting of some of the flags in the output product.

Routine	Call	Description
merge_rows	*preprocess*	Merge the data of two input rows
monitoring	*postprocess*	Monitoring
postprocess	AWDP	Main routine of the post processing
pre_inversion_qc	*preprocess*	Perform quality checks on input data
preprocess	AWDP	Main routine of the pre processing
process_cleanup	AWDP	Memory management
write_binary_output	*postprocess*	Write WVC data to a binary output file
write_properties	*postprocess*	Write some properties of the data into a text file
do_singularity_analysis	AWDP	Assign flow-dependent errors

Table 2.24 Routines of module *awdp_prepost*.

Table 2.24 lists the tasks of the individual routines. AWDP calls *preprocess()* to sort the rows with respect to the acquisition data and time. It also checks on the appearance of double rows, that is, rows which are less than half the nominal cell distance (pixel size on horizontal in the input data) apart. If *preprocess()* finds a double row it merges the two rows into one row. In that case the number of input rows will be reduced. Once the input rows are sorted and merged, an output row structure is allocated ant the input data are copied into the output rows.

The routine *pre_inversion_qc()* which is called by *preprocess()* performs land flagging and checks the setting of flags in the level 1b beam information. If the input data is of inferior quality, the *qual_sigma0* flag in the *wvc_quality* is set, which prevents further processing of this WVC. Also the land fractions present in the beam information in the level 1b product are considered: if any land fraction in the fore, mid or aft beam exceeds 0.02, the *qual_sigma0* flag in *wvc_quality* is set, as well. The *land* flag in *wvc_quality* is set whenever any level 1b land fraction is above zero.

Parameter	Description
observation	Number of Wind Vector Cells in output = *N1*
land	Fraction of WVCs with land flag set
ice	Fraction of WVCs with ice flag set
background	Fraction of WVCs containing model winds
backscatter_info	Fraction of WVCs containing sufficient valid σ^0's for inversion =*N2*
knmi_flag	Ratio number of WVCs with KNMI QC flag set / *N2*
wind_retrieval	Fraction of *N2* that actually contains wind solutions = *N3*
wind_selection	Fraction of *N3* that actually contains a wind selection = *N4*
big_mle	Number of WVCs containing a wind solution but no MLE value
avg_mle	Averaged (over *N4*) MLE value of 1st wind selection
var_qc	Fraction of *N4* that has the Variational QC flag set
rank_1_skill	Fraction of *N4* where the first wind solution is the chosen one
avg_wspd_diff	Averaged (over *N4*) difference between observed and model wind speeds
rms_diff_wspd	RMS (over *N4*) difference between observed and model wind speeds
wspd_ge_4	Fraction of *N4* where the selected wind speed is $\geq$ 4 m/s = *N5*
rms_diff_dir	RMS (over *N5*) difference between observed and model wind directions
rms_diff_u	RMS (over *N5*) difference between observed and model wind *u* components
rms_diff_v	RMS (over *N5*) difference between observed and model wind *v* components
rms_diff_vec_len	RMS (over *N5*) vector length between observed and model winds
ambiguity	Fraction of *N5* where the chosen solution is *not* the one closest to the model wind

Table 2.25 Parameters in monitoring output.

The monitoring, which is performed as part of the post processing, calculates some statistics from the wind product and writes them to an ASCII file called *monitoring_report.txt*. The monitoring parameters are listed in table 2.25. They are calculated separately for three different regions of each swath (left and right). Note that the monitoring is invoked only if the `–mon` command line option is set.

Before doing the ambiguity removal, AWDP calls routine *do_singularity_analysis* to assign flow-dependent errors to the scatterometer and background model wind components if requested. The flow-dependent errors are set according to the value of the MLE of the closest-to-background wind and an alternative for the singularity exponent. See also section 4.4.7.

2.3.6 Module awdp_calibrate

The module *awdp_calibrate* performs the calibration of the σ^0's in routine *calibrate_s0*. Calibration coefficients for each level 1 processing version and instrument (ASCAT on Metop A or Metop B) have been obtained using the so-called NWP Ocean Calibration (NOC). Note that the calibration is done again in the reverse order after the post processing in order to write the σ^0's to output as plain copies of the input σ^0's. More information about the calibration can be found in [5].

Routine	Call	Description
calibrate_s0	AWDP	Perform forward or backward backscatter calibration
correct_noc	*calibrate_s0*	Apply ocean calibration, depending on satellite and GMF
correct_l1b	*calibrate_s0*	Bring the calibration of historic σ^0's back to the reference version
interpolate_corr_42_82	*correct_noc* *correct_l1b*	Interpolate a σ^0 correction table for 42 WVCs into one for 82 WVCs
interpolate_corr_82_162	*correct_noc* *correct_l1b*	Interpolate a σ^0 correction table for 82 WVCs into one for 162 WVCs

Table 2.26 Routines in module *awdp_calibrate*

2.3.7 Module awdp_grib

The module *awdp_grib* reads in ECMWF GRIB files and collocates the model data with the scatterometer measurements. The *awdp_grib* module uses the genscat module *gribio_module*, see subsection 2.2.5 for the interface with the GRIB routine library.

Table 2.27 provides an overview of the routines and their calls in this module. The genscat support routines *uv_to_speed()* and *uv_to_dir()* are used to convert NWP wind components into wind speed and direction.

Routine	Call	Description
get_grib_data	AWDP	Get land mask, ice mask and background winds using GRIB data
init_grib_processing	*get_grib_data*	Initialise module

Table 2.27 Routines in module *awdp_grib*

NWP model sea surface temperature and land-sea mask data are used to provide information about possible ice or land presence in the WVCs. WVCs with a sea surface temperature below 272.16 K

(-1.0 °C) are assumed to be covered with ice and the *ice* and *qual_sigma0* flags in *wvc_quality* are set. Note that this step is omitted if the Bayesian ice screening is used; see section 2.3.10. In this case, sea surface temperature information from GRIB will still be used if it is present to support the ice screening. When the sea surface temperature is above 278.15 K (+5.0 C), the WVC will be assumed to contain no ice.

Land presence within each WVC is determined using the land-sea mask available from the model data. The weighted mean value of the land fractions of all model grid points within 80 km of the WVC centre is calculated and if this mean value exceeds a threshold of 0.02, the *qual_sigma0* flag in *wvc_quality* is set. The *land* flag in *wvc_quality* is set if the calculated land fraction is above zero.

NWP forecast wind data are necessary in the ambiguity removal step of the processing. Wind forecasts with forecast time steps of +3h, +6h, …, +36h can be read in. The model wind data are linearly interpolated with respect to time and location and put into the *model_wind* part of each WVC.

2.3.8 **Module awdp_inversion**

Module *awdp_inversion* serves the inversion step in the wind retrieval. The inversion step is done cell by cell. The actual inversion algorithm is implemented in the genscat modules *inversion* and *post_inversion*, see subsection 2.2.1. Table 2.28 provides an overview of the routines and their calls in this module.

Routine	Call	Description
init_inversion	*invert_wvcs*	Initialisation
invert_node	*invert_wvcs*	Call to the genscat inversion routines
invert_wvcs	AWDP	Loop over all WVCs and perform inversion

Table 2.28 Routines of module *awdp_inversion*.

2.3.9 **Module awdp_ambrem**

Module *awdp_ambrem* controls the ambiguity removal step of AWDP. The actual ambiguity removal schemes are implemented in the genscat module *ambrem*, see section 2.2.2. The default method is the KNMI 2DVAR scheme. Table 2.29 lists the tasks of the individual routines.

Routine	Call	Description
fill_batch	*remove_ambiguities*	Fill a batch with observations
remove_ambiguities	AWDP	Main routine of ambiguity removal
select_wind	*remove_ambiguities*	Final wind selection

Table 2.29 Routines of module *awdp_ambrem.*

The ambiguity removal scheme works on a so-called batch. The batch is defined in the *fill_batch()* routine. For AWDP a batch is just a set of rows. The size of the batch is determined by the resolution of the structure functions and the number of FFT. The genscat routine *remove_ambiguities()* performs the actual ambiguity removal. Finally *select_wind()* passes the selection to the output WVCs.

2.3.10 **Module awdp_icemodel**

Module *awdp_icemodel* performs the ice screening of the wind product. The ice screening works on the principle that WVCs over water yield wind solutions which are close to the GMF ('cone'). If a WVC is over ice, the σ^0 triplets from fore, mid and aft beam will be close to the so-called ice line. Hence, there is a possibility to discriminate between water (wind) and ice WVCs. The implementation of this principle is described in more detail in [6]. The ice screening is done directly after the ambiguity removal step. Table 2.30 provides an overview of the routines and their calls in this module.

Routine	Call	Description
bayesianIcemodel	*ice_mode*	Implementation of the Bayesian ice model
calc_aAve	*bayesianIcemodel*	Calculate space-time averaged *A*-parameter
calc_aSd	*bayesianIcemodel*	Calculate standard deviation of *A*-parameter
calcIceCoord	*bayesianIcemodel*	Calculate ice coordinates and distance to ice line
calcIcelineParms	*nonbayesianIceModel* *calcIceCoord*	Calculate distance to ice line from given σ^0's
calc_pIceGivenX	*bayesianIcemodel*	Calculate a posteriori ice probability
calcSubClass	*bayesianIcemodel*	Determine the sub class of the ice pixel
getPx	*updateIcePixel*	Calculate a priori ice probability
iceGMF	not used	Calculate the σ^0 values from the ice coordinates
iceLine	*iceGMF* (not used)	Calculate the ice line origin and slope
iceMap2scat	*bayesianIcemodel*	Update cell data structure with information in ice map
ice_model	AWDP	Main routine of ice screening
nonbayesianIceModel	*ice_mode*	Implementation of the basic ice model without history
scat2iceMap	*bayesianIcemodel*	Update the ice map with the information in cell data
setCmix	*bayesianIcemodel*	Compute geophysical ice model tolerance parameter
smooth	*bayesianIcemodel*	Spatial smoothing of the a posteriori probability
updateIcePixel	*scat2iceMap*	Update one ice pixel

Table 2.30 Routines of module *awdp_icemodel*.

2.3.11 **Module *awdp***

Module *awdp* is the main program of AWDP. It processes the command line options and controls the flow of the wind processing by calling the subroutines performing the subsequent processing steps. If any process step returns with an error code, the processing will be terminated.

3 Inversion module

3.1 Background

In the inversion step of the wind retrieval, the radar backscatter observations in terms of the normalized radar cross-sections (σ^0's) are converted into a set of ambiguous wind vector solutions. In fact, a Geophysical Model Function (GMF) is used to map a wind vector (specified in terms of wind speed and wind direction) to the σ^0 values. The GMF further depends not only on wind speed and wind direction, but also on the measurement geometry (relative azimuth and incidence angle), and beam parameters (frequency, polarisation). A maximum likelihood estimator (MLE) is used to select a set of wind vector solutions that optimally match the observed σ^0's. The wind vector solutions correspond to local minima of the MLE function

$$\mathrm{MLE} = \frac{1}{N}\sum_{i=1}^{N}\frac{\left(\sigma^0_{obs}(i) - \sigma^0_{GMF}(i)\right)^2}{K_p(i)} \tag{3.1}$$

With N the number of independent σ^0 measurements available within the wind vector cell, and K_p the covariance of the measurement error. Following a Bayesian approach, K_p is a constant representing the noise in all three ERS or ASCAT beams together [7]. This selection depends on the number of independent σ^0 values available within the wind vector cell. The MLE can be regarded upon as the distance between an actual scatterometer measurement and the GMF in N-dimensional measurement space. The MLE is related to the probability P that the GMF at a certain wind speed and direction represents the measurement by

$$P \propto e^{-\mathrm{MLE}} \quad . \tag{3.2}$$

Therefore, wind vectors with low MLE have a high probability of being the correct solution. On the other hand, wind vectors with high MLE are not likely represented by any point on the GMF.

Details on the inversion problem can be found in [7] and [8]. AWDP includes the Multiple Solution Scheme (MSS), see [9].

3.2 Routines

The inversion module class contains two modules named *inversion* and *post_inversion*. They are located in subdirectory `genscat/inversion`. Tables 3.1 and 3.2 list all routines in the modules. Appendix B.1 shows the calling tree for the inversion routines.

To establish the MLE function (1), the radar cross section according to the GMF, σ^0_{GMF}, must be calculated. This is done in routine *calc_sigma0*. The GMF used is read as a Look Up Table (LUT) from a binary file. The value for σ^0_{GMF} is obtained from interpolation of this table. The interpolation is done via symbolic routine *INTERPOLATE* which is set to *interpolate1d*,

interpolate2d, *interpolate2dv*, or *interpolate3d*, depending on the type of interpolation needed.

Routine	Call	Routine	Call
invert_one_wvc	AWDP	*INTERPOLATE*	generic
fill_wind_quality_code	*invert_one_wvc*	*interpolate1d*	*calc_sigma0*
save_inv_input	not used	*interpolated2d*	*calc_sigma0*
read_inv_input	not used	*interpolate2dv*	*calc_sigma0*
save_inv_output	not used	*interpolate3d*	*calc_sigma0*
do_parabolic_winddir_search	*invert_one_wvc*	*read_LUT*	*calc_sigma0*
calc_normalisation	*invert_one_wvc*	*create_LUT_C_VV*	*calc_sigma0*
calc_sign_MLE	*invert_one_wvc*	*test_for_identical_LUTs*	*calc_sigma0*
print_message	see B.1	*my_mod*	not used
init_inv_input	AWDP	*my_min*	see B.1
init_inv_output	*invert_one_wvc*	*my_max*	see B.1
init_inv_settings_to_default	AWDP	*my_average*	see B.1
write_inv_settings_to_file	not used	*get_indices_lowest_local_minimum*	*invert_one_wvc*
get_inv_settings	AWDP	*my_index_max*	see B.1
set_inv_settings	AWDP	*my_exit*	see B.1
check_input_data	*invert_one_wvc*	*print_wind_quality_code*	see B.1
find_minimum_cone_dist	*invert_one_wvc*	*print_input_data_of_inversion*	*check_input_data*
get_parabolic_minimum	*do_parabolic_winddir_search*	*print_output_data_of_inversion*	see B.1
calc_cone_distance	*find_minimum_cone_dist*	*print_in_out_data_of_inversion*	not used
calc_dist_to_cone_center	not used	*calc_sigma0_cmod4*	*create_LUT_C_VV*
convert_sigma_to_zspace	*invert_one_wvc*	*f1*	*calc_sigma0_cmod4*
get_ers_noise_estimate	*calc_var_s0*	*Get_Br_from_Look_Up_Table*	*calc_sigma0_cmod4*
calc_var_s0	*calc_normalisation*	*calc_sigma0_cmod5*	*create_LUT_C_VV*
get_dynamic_range	not used	*calc_sigma0_cmod5_5*	*create_LUT_C_VV*
get_GMF_version_used	not used	*calc_sigma0_cmod5_n*	*create_LUT_C_VV*
calc_sigma0	see B.1	*calc_sigma0_cmod6*	*create_LUT_C_VV*

Table 3.1 Routines in module *inversion*.

Routine	Call
normalise_conedist_ers_ascat	AWDP
calc_kp_ers_ascat	*normalise_conedist_ers_ascat*
calc_geoph_noise_ers_ascat	*calc_kp_ers_ascat*
check_ers_ascat_inversion_data	see B.1
check_wind_solutions_ers_ascat	AWDP
remove_one_solution	*check_wind_solutions_ers_ascat*
calc_probabilities	AWDP

Table 3.2 Routines of module *post_inversion*.

For C-band at VV polarization the GMF (CMODx, see [10]) is given in analytical form (routines *calc_sigma0_cmodxxx*) for versions from 4 up to and including 6. If a C-band LUT is not present it will be created by routine *create_LUT_C_VV*. This routine calls one of the routines *calc_sigma0_cmodxxx* that contain the analytical expressions of the CMOD4, CMOD5, CMOD5N or CMOD6 functions. There is a parameter in the inversion settings type that is used to determine which CMOD function is to be used. Routines *get_lun* and *free_lun* from module *LunManager* in subdirectory `genscat/support/file` are needed when reading and creating the LUTs. Note that for CMOD7, an analytical form is not available and the GMF table (`gmf_cmod7_vv.dat`)

needs to be read from `awdp/data/little_endian` or `awdp/data/big_endian`.

Note that module *post_inversion* uses some tables for the normalisation of MLEs and noise values. These tables are read from ASCII files which are present in direction `genscat/inversion`. The environment variable `$INVERSION_LUTSDIR` should contain the proper directory name.

3.3 Antenna direction

The output wind direction of inversion routines are generally given in the meteorological convention, see table 3.3. The inversion routine uses a wind direction that is relative to the antenna direction. The convention is that if the wind blows towards the antenna then this relative wind direction equals to 0. Therefore, it is important to be certain about the convention of your antenna (azimuth) angle.

For ERS and ASCAT, the radar look angle (antenna angle or simply azimuth) equals 0 if the antenna is orientated towards the south. The radar look angle increases clockwise. Therefore, the antenna angle needs a correction of 180 degrees.

Meteorological	Oceanographic	Mathematical	*u*	*v*	Description
0	180	270	0	-1	Wind blowing from the north
90	270	180	-1	0	Wind blowing from the east
180	0	90	0	1	Wind blowing from the south
270	90	0	1	0	Wind blowing from the west

Table 3.3 Conventions for the wind direction.

4 Ambiguity Removal module

4.1 Ambiguity Removal

Ambiguity Removal (AR) schemes select a surface wind vector among the different surface wind vector solutions per cell for the set of wind vector cells in consideration. The goal is to set a unique, meteorological consistent surface wind field. The surface wind vector solutions per cell, simply called ambiguities, result from the wind retrieval process step.

Whenever the ambiguities are ranked, a naive scheme would be to select the ambiguity with the first rank (e.g., the highest probability, the lowest distance to the wind cone). In general, such a persistent first rank selection will not suffice to create a realistic surface wind vector field: scatterometer measurements tend to generate ambiguous wind solutions with approximately equal likelihood (mainly due to the ~180° invariance of stand alone scatterometer measurements). Therefore one needs additional spatial constraints and/or additional (external) information in order to make sensible selections.

A common way to add external information to a WVC is to provide a background surface wind vector. The background wind acts as a first approximation for the expected mean wind over the cell. In general, a NWP model wind is interpolated for this purpose. Whenever a background wind is set for the WVC, a second naive Ambiguity Removal scheme is at hand: the Background Closest (BC) scheme. The selected wind vector is just the minimizer of the distance (e.g., in the least squares sense) to the background wind vector. This scheme may produce far more realistic wind vector fields than the first rank selection, since the background surface wind field is meteorologically consistent.

However, background surface winds have their own uncertainty. Therefore, sophisticated schemes for Ambiguity Removal take both the likelihood of the ambiguities and the uncertainty of the background surface wind into account. Examples are the KNMI Two-Dimensional Variational (2DVAR) scheme and the PreScat scheme.

The implementation of these schemes is described in sections 4.4 and 4.5.

4.2 Module *ambrem*

Module *Ambrem* is the interface module between the various ambiguity removal methods and the different scatterometer data processors. Table 4.1 provides an overview of the different routines and their calls. A dummy method and the first rank selection method are implemented as part of *ambrem.* More elaborate Ambiguity Removal methods have an interface module, see table 4.2. Figure 4.1 shows schematically the interdependence of the various modules for Ambiguity Removal.

Routine	Call	Description
InitAmbremModule	AWDP	Initialization of module *Ambrem*
InitAmbremMethod	AWDP	Initialization of specified AR scheme
DoAmbrem	AWDP	Execution of specified AR scheme
Ambrem1stRank	*DoAmbrem*	First rank selection method
DoDummyMeth	*DoAmbrem*	Dummy AR scheme for testing
SetDummyMeth	*DoAmbrem*	Batch definition of dummy method
InitDummyMeth	*DoAmbrem*	Initialization of dummy method
InitDummyBatch	not used	
ExitAmbremMethod	AWDP	Deallocation of memory

Table 4.1 Routines of module *Ambrem*.

Routine	Description	Documentation
Ambrem2DVAR	Interface to KNMI 2DVAR method	Section 4.4
AmbremBGClosest	Interface to Background Closest method	Section 4.1
AmbremPrescat	Interface to Prescat method	Section 4.5

Table 4.2 Interface modules for different Ambiguity Removal schemes.

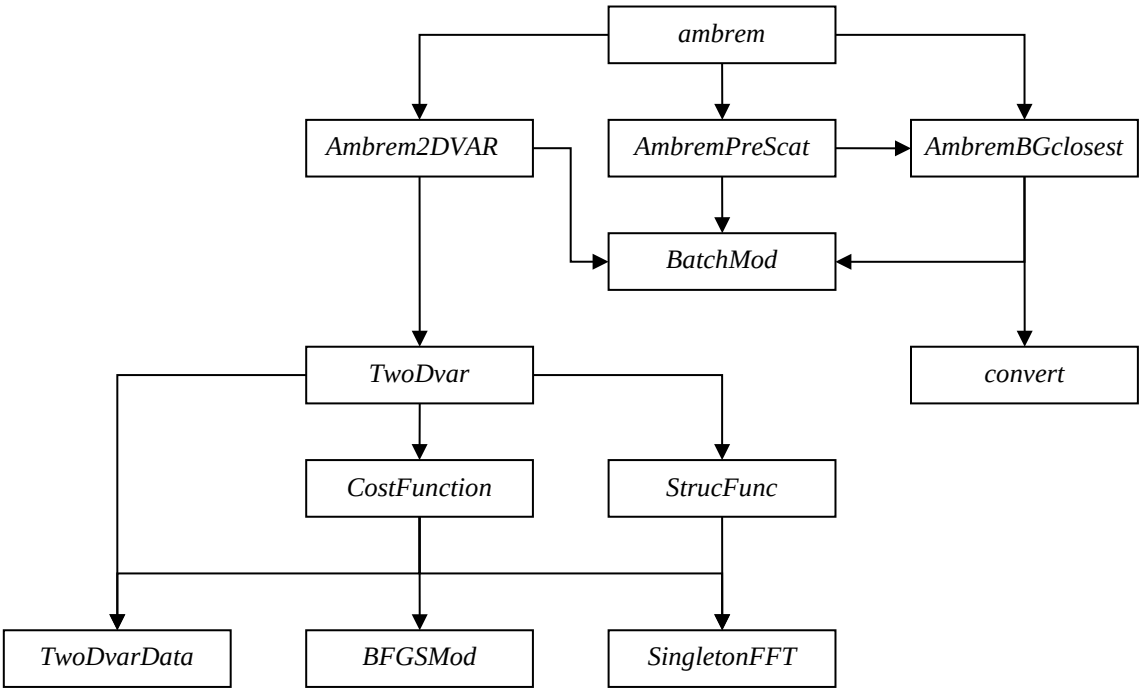

Figure 4.1 Interdependence of the modules for Ambiguity Removal. The connections from module *ambrem* to module *BatchMod* and from module *Ambrem2DVAR* to *convert* are not drawn.

4.3 Module *BatchMod*

After the wind retrieval step, the Ambiguity Removal step is performed on selections of the available data. In general, these selections are just a compact part of the swath or a compact part of the world ocean. The batch module *BatchMod* facilitates these selections of data. In fact, a batch data structure is introduced to create an interface between the swath related data and the data

structures of the different AR methods. Consequently, the attributes of the batch data structures are a mixture of swath items and AR scheme items. Figure 4.2 gives a schematic overview of the batch data structure. Descriptions of the attributes of the individual batch data components are given in table 4.3.

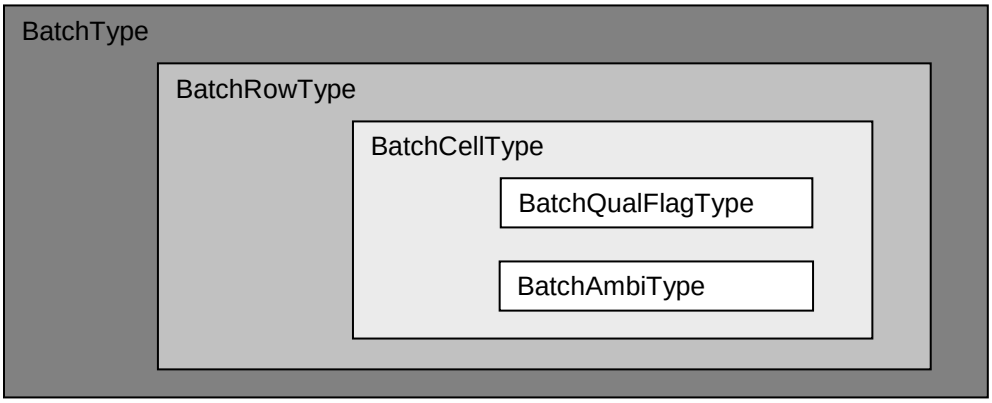

Figure 4.2 Schematic representation of the batch data structure.

BatchType

Attribute	**Type**	**Description**
NrRows	Integer	Number of rows in batch
Row	*BatchRowType*	Array of rows

BatchRowType

Attribute	**Type**	**Description**
RowNr	Integer	Row number within orbit
NrCells	Integer	Number of cells in batch (max 76)
Cell	*BatchCellType*	Array of cells within row

BatchCellType

Attribute	**Type**	**Description**
NodeNr	Integer	Node number within orbit row
lat	Real	Latitude
lon	Real	Longitude
ubg	Real	*u*-component of background wind
vbg	Real	*v*-component of background wind
SkipForAnalysis	Logical	Skip this cell in cost function calculation
NrAmbiguities	Integer	Number of ambiguities
ambi	*BatchAmbiType*	Array of ambiguities
selection	Integer	Index of selected ambiguity
uana/vana	Real	u/v-component of analysis wind
Attribute	**Type**	**Description**
f	Real	Contribution of this cell to cost function
gu/gv	Real	Derivatives of *f* to *u/v*
err_bgu/errbgv	Real	Background error in *u/v*
err_obu/err_obv	Real	Observation error in *u/v*
qualflag	*BatchQualFlagType*	Quality control flag

BatchAmbiType		
Attribute	**Type**	**Description**
u/v	Real	Analysis increments
prob	Real	A-priori probability

Table 4.3 Batch data structures.

To check the quality of the batch a quality flag is introduced for instances of the *BatchCellType*. The flag is set by routine *TestBatchCell()*. The attributes of this flag of type *BatchQualFlagType* are listed in table 4.4.

Attribute	**Description**
Missing	Quality flag not set
Node	Incorrect node number specification
Lat	Incorrect latitude specification
Lon	Incorrect longitude specification
Ambiguities	Invalid ambiguities
Selection	Invalid selection indicator
Background	Incorrect background wind specification
Analysis	Incorrect analysis
Threshold	Threshold overflow
Cost	Invalid cost function value
Gradient	Invalid gradient value

Table 4.4 Batch quality flag attributes.

Routine	**Call**	**Description**
AllocRowsAndCellsAndInitBatch	Processor	Allocation of batch
AllocAndInitBatchRow	*AllocRowsAndCellsAndInitBatch*	Allocation of batch rows
AllocAndInitBatchCell	*AllocAndInitBatchRow*	Allocation of batch cells
AllocRowsOnlyAndInitBatch	not used	
InitBatchModule	*Ambrem*	Initialization module
InitBatch	*AllocRowsAndCellsAndInitBatch*	Initialization of batch
InitBatchRow	*InitBatch*	Initialization of batch rows
InitBatchCell	*InitBatchRow*	Initialization of batch cells
InitbatchAmbi	*InitBatchCell*	Initialization of batch ambiguities
DeallocBatch	Processor	Deallocation of batch
DeallocBatchRows	*DeallocBatch*	Deallocation of batch rows
DeallocBatchCells	*DeallocBatchRows*	Deallocation of batch cells
DeallocBatchAmbis	*DeallocBatchCells*	Deallocation of batch ambiguities
TestBatch	Processor	Test complete batch
TestBatchRow	*TestBatch*	Test complete batch row
TestBatchCell	*TestBatchRow*	Test batch cell
TestBatchQualFlag	Processor	Print the quality flag
getBatchQualFlag	not used	
setBatchQualFlag	not used	
PrnBatchQualFlag	not used	

Table 4.5 Routines of module *BatchMod*.

Module *BatchMod* contains a number of routines to control the batch structure. The calls and tasks of the various routines are listed in table 4.5. The batch structure is allocatable because it is only active between the wind retrieval and the ambiguity removal step.

4.4 The KNMI 2DVAR scheme

4.4.1 Introduction

The purpose of the KNMI 2DVAR scheme is to make an optimal selection provided the (modelled) likelihood of the ambiguities and the (modelled) uncertainty of the background surface wind field. First, an optimal estimated surface wind vector field (analysis) is determined based on variational principles. This is a very common method originating from the broad discipline of Data Assimilation. The optimal surface wind vector field is called the analysis. Second, the selected wind vector field (the result of the 2DVAR scheme) consists of the wind vector solutions that are closest to the analysis wind vector. For details on the KNMI 2DVAR scheme formulation the reader is referred to [11]. Information on 2DVAR can also be found in [12], [13] and [14].

From AWDP version 3.0 onwards, the 2DVAR scheme has been extended with empirical background error correlations, invoked by the `-nbec` command line option. More information on this feature can be found in [15] and references therein.

The calculation of the cost function and its gradient is a rather complex matter. The reader who is only interested in how the 2DVAR scheme is assembled into the genscat module class *ambrem* is referred to subsection 4.4.2. Readers interested in the details of the cost function calculations and the minimization should also read the subsequent subsections. Subsection 4.4.3 forms an introduction to the cost function. It is recommended to first read this section, because it provides necessary background information to understand the code. Subsections 4.4.8 on the actual minimization and 4.4.9 on Fast Fourier Transforms are in fact independent of the cost function itself. The reader might skip these subsections.

4.4.2 Data structure, interface and initialisation

The main module of the 2DVAR scheme is *TwoDvar*. Within the genscat ambiguity removal module class, the interface with the 2DVAR scheme is set by module *Ambrem2DVAR*. Table 4.6 lists its routines that serve the interface with *TwoDvar*.

These routines are sufficient to couple the 2DVAR scheme to the processor. The actual 2DVAR processing is done by the routines of module *TwoDvar* itself. These routines are listed in table 4.7. Figures B2.1-B2.6 show the complete calling tree of the AR routines.

Routine	Call	Description
Do2DVARonBatch	*DoAmbrem*	Apply 2DVAR scheme on batch
BatchInput2DVAR	*Do2DVARonBatch*	Fills the 2DVAR data structure with input
BatchOutput2DVAR	*Do2DVARonBatch*	Fills the batch data structure with output
Set_WVC_Orientations	*BatchInput2DVAR*	Sets the observation orientation
GetBatchSize2DVAR		Determine maximum size of batch

Table 4.6 Routines of module *Ambrem2DVAR*.

Routine	Call	Description
InitTwodvarModule		Initialization of module *TwoDvar*
Do2DVAR	*Do2DVAROnBatch*	Cost function minimization
PrintObs2DVAR	*BatchInput2DVAR*	Print a single 2DVAR observation
ExitTwodvarModule	*ExitAmbremMethod*	Deallocation of module *TwoDvar*

Table 4.7 Routines of module *TwoDvar*.

The *Obs2dvarType* data type is the main data structure for the observed winds. Its attributes are listed in table 4.8. The *TDV_Type* data type contains all parameters that have to do with the 2DVAR batch grid: dimensions, sizes, and coordinates. These data structures are defined in module *TwoDvarData* and the routines in this module are listed in table 4.10.

Attribute	Type	Description
alpha	Real	Rotation angle
cell/row	Integer	Batch cell/row numbers
igrid/jgrid	Integer	Row/Node indices
lat/lon	Real	Observation coordinates
Wll/Wlr	Real	Weights lower left/right
Wul/Wur	Real	Weights upper left/right
ubg/vbg	Real	Background EW/NS wind components
NrAmbiguities	Integer	Number of ambiguities
incr()	*AmbiIncrType*	Ambiguity increments
uAnaIncr	Real	Analysis increment
vAnaIncr	Real	Analysis increment
selection	Integer	Selection flag
QualFlag	*TwoDvarQualFlagType*	Quality control flag
f	Real	Cost function at observation
gu/gv	Real	Cost function gradient to *u*/*v*

Table 4.8 The *Obs2dvarType* data structure.

Attribute	Type	Description
delta	Real	2DVAR grid size in position domain
delta_p/delta_q	Real	2DVAR grid sizes in frequency domain
N1/N2	Integer	Dimension 1/2 of 2DVAR grid
H1/H2	Integer	Half of *N1/N2*
K1/K2	Integer	*H1*+1/*H2*+1;number of nonnegative frequencies
GridExtent	Integer	Number of free cells around 2DVAR grid
lat/lon	Real	Latitude/longitude
Ncontrol	Integer	Size of control vector
VarQC_Type	Integer	Type of Variational Quality Control
GEP	Real	Gross Error Probabilities
Action	Character	Action to be taken by TDV_Init
Verbosity	Integer	Verbosity parameter

Table 4.9 The *TDV_Type* data structure.

Routine	Call	Description
TDV_Init	*InitTwodvarModule*	Initialization of 2DVAR grid and preparations
Set_HelmholzCoefficients	*TDV_Init*	Set Helmholz transformation coefficients
Set_CFW	*TDV_Init*	Set cost function weights
TDV_Exit	*ExitTwodvarmodule*	Deallocate memory
InitObs2dvar	*BatchInput2DVAR, BatchOutput2DVAR*	Allocation of observations array
DeallocObs2dvar	*BatchOutput2DVAR*	Deallocation of observations array
InitOneObs2dvar	*InitObs2dvar*	Initialization of single observation
TestObs2dvar	*Do2DVAR*	Test single observation
Prn2DVARQualFlag	*Do2DVAR*	Print observation quality flag
set2DVARQualFlag	*TestObs2DVAR*	Convert observation quality flag to integer
get2DVARQualFlag	not used	Convert integer to observation quality flag

Table 4.10 Routines in module *TwoDvarData*.

The quality status of an instance of *Obs2dvarType* is indicated by the attribute *QualFlag* which is an instance of *TwoDvarQualFlagType*. The attributes of this flag are listed in table 4.11.

Attribute	Description
missing	Flag values not set
wrong	Invalid 2DVAR process
Lat	Invalid latitude
Background	Invalid background wind increment
Ambiguities	Invalid ambiguity increments
Selection	Invalid selection
Analyse	Invalid analysis wind increment
Cost	Invalid cost function specification
gradient	Invalid gradient specification
weights	Invalid interpolation weights
grid	Invalid grid indices

Table 4.11 Attributes of 2DVAR observation quality flag.

4.4.3 **Reformulation and transformation**

The minimization problem to find the analysis surface wind field (the 2D Variational Data Assimilation problem) may be formulated as

$$\min_{v} J(v) \quad , \quad J(v) = J_{obs}(v) + J_{bg}(v), \tag{4.1}$$

where v is the surface wind field in consideration and J the total cost function consisting of the observational term J_{obs} and the background term J_{bg}. The solution, the analysis surface wind field, may be denoted as v_a. Being just a weighted least squares term, the background term may be further specified as

$$J_{bg}(v) = [v - v_{bg}]^T B^{-1} [v - v_{bg}], \tag{4.2}$$

where B is the background error covariance matrix. The J_{obs} term of the 2DVAR scheme is not simply a weighted least squares term.

The background error covariance is split into standard deviations and a correlation. By default, AWDP takes a Gaussian form for the background error correlations. This can be overridden by the `-nbec` command line argument, which invokes a tabulated empirical background error correlation.

The formulation above does not closely match the code of the 2DVAR scheme. In fact, for technical reasons several transformations are applied to reformulate the minimization problem. Understanding of these transformations is essential to understand the different procedures within the code. The interested reader is referred to [11].

4.4.4 Module CostFunction

Module *CostFunction* contains the main procedure for the calculation of the cost function and its gradient. It also contains the minimization procedure. Table 4.12 provides an overview of the routines.

Routine	Call	Description
Jt	*Minimise*	Total cost function and gradient
Jb	*Jt*	Background term of cost function
Jo	*Jt*	Observational term of cost function
JoScat	*Jo*	Single observation contribution to the cost function
Unpack_ControlVector	*Jo*	Unpack of control vector
Pack_ControlVector	*Jo*	Pack of control vector (or its gradient)
Uncondition	*Jo*	Several transformations of control vector
Uncondition_adj	*Jo*	Adjoint of *Uncondition.*
Minimise	*Do2DVAR* (*TwoDvar*)	Minimization
DumpAnalysisField	*Do2DVAR*	Write analysis field to file

Table 4.12 Routines of module *CostFunction.*

4.4.5 Adjoint method

The minimization of cost function is done with a quasi-Newton method. Such a method requires an accurate approximation of the gradient of the cost function. The adjoint method is just a very economical manner to calculate this gradient. For introductory texts on the adjoint method and adjoint coding, see, e.g., [15] and [17]. For detailed information on the adjoint model in 2DVAR see [11].

4.4.6 Structure Functions

Module *StrucFunc* contains the routines to calculate the covariance matrices for the stream function, ψ, and the velocity potential, χ. Its routines are listed in table 4.13.

Routine	Call	Description
SetCovMat	*Do2DVAR*	Calculate the covariance matrices
InitStrucFunc	*SetCovMat*	Initialize the structure functions
StrucFuncPsi	*SetCovMat*	Calculate ψ
StrucFuncChi	*SetCovMat*	Calculate χ

Table 4.13 Routines of module *StrucFunc.*

By default, 2DVAR uses Gaussian structure functions with a cut-off of 600 km in the Tropics and 300 km outside. If the `-fde` command line option is given, the structure functions are interpolated from a table of numerical values stored in file `/genscat/ambrem/nbec_ascat-a-coa_cos-auto-4000_tccal_obserrcorr.dat` and addressed by the environment variable `NBEC_FILE`. See [18] and references therein for more details.

4.4.7 Flow-dependent errors

2DVAR constructs an analysis from the ambiguous scatterometer observations and the model background. The analysis is controlled by the structure functions (background error correlations) described in the previous section, and by the error standard deviatiobns of the scatterometer and the background. By default, these have constant values (1.8 m/s for the scatterometer and 2.0 m/s for the model), but if the `-fde` command line argument is given, the observation and background errors are set according to the value of the MLE and the singularity exponent. The singularity exponent used here is not the original (patented) one, but a parameterisation. See [18] and references therein for more details.

4.4.8 Minimization

The minimization routine used is *LBFGS*. This is a quasi-Newton method with a variable rank for the approximation of the Hessian written by J. Nocedal. A detailed description of this method is given by [18]. Routine LBFGS is freeware and can be obtained from web page http://www.netlib.org/opt/index.html, file `lbfgs_um.shar`. The original Fortran 77 code has been adjusted to compile under Fortran 90 compilers. Routine LBFGS and its dependencies are located in module `BFGSMod.F90` in directory `genscat/support/BFGS`. Table 4.14 provides an overview of the routines in this module.

Routine LBFGS uses reverse communication. This means that the routine returns to the calling routine not only if the minimization process has converged or when an error has occurred, but also when a new evaluation of the function and the gradient is needed. This has the advantage that no restrictions are imposed on the form of routine *Jt* calculating the cost function and its gradient.

The formal parameters of *LBFGS* have been extended to include all work space arrays needed by the routine. The work space is allocated in the calling routine *minimise*. The rank of *LBFGS* affects the size of the work space. It has been fixed to 3 in routine *minimise*, because this value gave the best results (lowest values for the cost function at the final solution).

Routine	Call	Description
LBFGS	*minimise*	Main routine
LB1	*LBFGS*	Printing of output (switched off)
daxpy	*LBFGS*	Sum of a vector times a constant plus another vector with loop unrolling.
ddot	*LBFGS*	Dot product of two vectors using loop unrolling.
MCSRCH	*LBFGS*	Line search routine.
MCSTEP	*MCSRCH*	Calculation of step size in line search.

Table 4.14 Routines in module *BFGSMod*.

Some of the error returns of the line search routine *MCSRCH* have been relaxed and are treated as a normal return. Further details can be found in the comment in the code itself.

Routines *daxpy* and *ddot* were rewritten in Fortran 90. These routines, originally written by J. Dongarra for the Linpack library, perform simple operations but are highly optimized using loop unrolling. Routine *ddot*, for instance, is faster than the equivalent Fortran 90 intrinsic function *dot_product.*

4.4.9 SingletonFFT_Module

Module *SingletonFFT_Module* in directory `genscat/support/singletonfft` contains the multi-variate complex Fourier routines needed in the 2DVAR scheme. A mixed-radix Fast Fourier Transform algorithm based on the work of R.C. Singleton is implemented.

Routine	Call	Description
SingletonFFT2d	*SetCovMat, Uncondition, Uncondition_adj*	2D Fourier transform
fft	*SingletonFFT2d*	Main FFT routine
SFT_Permute	*fft*	Permute the results
SFT_PermuteSinglevariate	*SFT_Permute*	Support routine
SFT_PermuteMultivariate	*SFT_Permute*	Support routine
SFT_PrimeFactors	*fft*	Get the factors making up *N*
SFT_Base2	*fft*	Base 2 FFT
SFT_Base3	*fft*	Base 3 FFT
SFT_Base4	*fft*	Base 4 FFT
SFT_Base5	*fft*	Base 5 FFT
SFT_BaseOdd	*fft*	General odd-base FFT
SFT_Rotate	*fft*	Apply rotation factor

Table 4.15 Fourier transform routines.

Table 4.15 gives an overview of the available routines. The figures in Appendix B2 shows the calling tree of the FT routines relevant for 2DVAR.

Remark: the 2DVAR implementation can be made more efficient by using a real-to-real FFT routine rather than a complex-to-complex one as implemented now. Since AWDP satisfies the requirements in terms of computational speed, this has low priority.

4.5 The PreScat scheme

The PreScat ambiguity removal scheme can be invoked within AWDP by the use of command line option `–armeth prescat`. More information on this scheme can be found in [12]. Currently, the PreScat scheme can be used only in combination with ERS data.

5 Module *iceModelMod*

Module *iceModelMod* is part of the genscat support modules. It contains all the routines for initialising, reading, writing and printing of the SSM/I grids for the North Pole and South Pole region.

5.1 Background

The `-icemodel` option in AWDP basically fills the fields Ice Probability (BUFR item 87) and Ice Age (BUFR item 88). Also it can output graphical maps of ice model related parameters on an SSM/I grid for the North Pole and for the South Pole region.

Each time the Metop satellite passes over the pole region the corresponding ice map is updated with the new ASCAT data. A spatial and temporal averaging is performed in order to digest the new information. After the overpass, at the end of processing an entire BUFR file, the updated information on the ice map is put back into the BUFR structure. Optionally graphical maps are plotted, which can be controlled by optional input parameters for routine printIceMap. The graphical filenames have encoded the North Pole/South Pole, the date/time as well as the parameter name. The most important ones are:

print_a: file `[N|S][yyyymmddhhmmss].ppm` contains the ice subclass and the a-ice parameter on a grey-scale for points classified as ice.

print_t: file `[N|S][yyyymmddhhmmss]t.ppm` contains the ice class.

print_sst: file `[N|S][yyyymmddhhmmss]sst.ppm` contains the sea surface temparature

print_postprob: file `[N|S][yyyymmddhhmmss]postprob.ppm` contains the a-posteriori ice probability.

Typically at least two days of ASCAT data are needed to entirely fill the ice map with data and give meaningful ice model output. Because AWDP handles only one BUFR file at a time, a script is needed that calls AWDP several times. After each AWDP-run a binary restart file is written to disk containing the information of an icemap (`latestIceMapN.rst` for the North Pole and `latestIceMapS.rst` for the South Pole). With the next call of awdp, these restart files are read in again. Environment variable `$RESTARTDIR` contains the directory for the ice model restart files.

Optionally sea surface temperature (SST) data from GRIB files can be used to further improve the quality of the ice algorithm (the use_sst logical must be turned on).

Processing l1b input with the use of NWP data and SST data can be done with the following command line options:

```
awdp –f <bufr file> -nwpfl <gribfilelist> -icemodel 2 –mon -handleall
```

Reprocessing of level 2 input with only running the ice model on top of it can be done with the following command line options:

```
awdp –f <bufr file> -icemodel 2 –noinv –noamb –mon -handleall
```

The SSM/I grids are widely used for representation of ice related parameters. A good description as well as some software routines can be found on the website of the National Snow and Ice Data Centre (NSIDC): http://www.nsidc.org/data/docs/daac/ae_si25_25km_tb_and_sea_ice.gd.html.

A more detailed description of the Bayesian statistics method and ice model is given in [6].

5.2 Routines

Table 5.1 provides an overview of the routines in module *iceModelMod*.

Routine	Call	Description
calcPoly3	AWDP	Calculate a 3rd order polynomial
ExpandDateTime	AWDP	Converts a date/time to a real
ij2latlon	not used	Calculate lat lon values from SSM/I grid coordinates
initIceMap	AWDP	Initialise ice map
inv_logit	not used	Calculate the inverse of the logit of p: 1/(1+exp(-p))
latlon2ij	AWDP	Calculate SSM/I grid coordinates from lat lon values
logit	not used	Calculate the logit of p: ln(p/(1-p))
MAPLL	*latlon2ij*	Convert from lat/lon to polar stereographic coordinates
MAPXY	*ij2latlon* (not used)	Convert from polar stereographic to lat/lon coordinates
printClass	not used	Print the ice class (sea or ice)
print_ice_age_ascat	not used	Print ice age map to graphical .ppm file
printIceAscat	*printIceMap*	Print ASCAT ice map to graphical .ppm file
printIceMap	*bayesianIcemodel*	Print one or more ice map variables to graphical .ppm files
printIcePixel	AWDP	Print contents of an ice pixel
printIceQscat	*printIceMap*	Print QuikSCAT ice map to graphical .ppm file
printppm_qc	not used	Print WVC quality flag contents to graphical .ppm file
printppmvar	*printIceMap*	Print variable to .ppm file, mapped on gray scale
printppmvars	not used	Print three variables to .ppm file, mapped to an RGB scale
printSubclass	*printIceMap*	Print the ice subclass to a .ppm file
RW_IceMap	AWDP	Read or write an ice map from/to a binary restart file
wT	AWDP	Calculate the moving time average function

Table 5.1 Routines of module *iceModelMod*.

5.3 Data structures

There are two important data structures defined in this module. The first contains all relevant data of one pixel on the ice map (IcePixel). The second one contains basically a two-dimensional array of ice pixels and represents an entire ice map (IceMapType). This could be either an ice map of the North Pole region or the South Pole region.

Attribute	Type	Description
aIce	real	*A* ice parameter
aIceAves	real	Average of the *A* ice parameter
aSd	real	*A* ice parameter standard deviation
class	integer	Ice class
subClass	integer	Ice subclass
sst	real	Sea surface temperature (K)
pXgivenIce	real	
pXgivenOce	real	
pYgivenIce	real	
pYgivenOce	real	
Pice	real	A-priori ice probability
pIceGivenX	real	A-posteriori ice probability
pIceGivenXave	real	Average of a-posteriori ice probability
sumWeightST	real	Sum of weight factors
landmask	logical	land/sea indicator
timePixelNow	DateTime	Date/time of measurement
timePixelPrev	DateTime	Date/time of previous measurement

Table 5.2 Attributes for the *IcePixel* data type.

Attribute	Type	Description
nPixels	integer	Number of pixels for the ice map
nLines	integer	Number of lines for the ice map
pole	integer	Indicator for Northpole or Southpole
use_sst	integer	Use SST value in ice screening
timeMapNow	DateTime	Date/time of latest ice map update
timeMapPrev	DateTime	Date/time of previous ice map update
xy	IcePixel(nPixels, nLines)	Pointer to the ice map contents

Table 5.3 Attributes for the *IceMapType* data type.

6 Module *BufrMod*

Module *BufrMod* is part of the genscat support modules. The current version is a Fortran 90 wrapper around the ECMWF BUFR library (see http://www.ecmwf.int/). The goal of this support module is to provide a comprehensive interface to BUFR data for every Fortran 90 program using it. In particular, *BufrMod* provides all the BUFR functionality required for the scatterometer processor based on genscat. Special attention has been paid to testing and error handling.

6.1 Background

The acronym BUFR stands for Binary Universal Form for the Representation of data. BUFR is maintained by the World Meteorological Organization WMO and other meteorological centres. In brief, the WMO FM-94 BUFR definition is a binary code designed to represent, employing a continuous binary stream, any meteorological data. It is a self defining, table driven and very flexible data representation system. It is beyond the scope of this document to describe BUFR in detail. Complete descriptions are distributed via the websites of WMO (http://www.wmo.int/) and of the European Centre for Medium-range Weather Forecasts ECMWF (http://www.ecmwf.int/).

Module *BufrMod* is in fact an interface. On the one hand it contains (temporary) definitions to set the arguments of the ECMWF library functions. On the other hand, it provides self explaining routines to be incorporated in the wider Fortran 90 program. Section 6.2 describes the routines in module *BufrMod*. The public available data structures are described in section 6.3. *BufrMod* uses two libraries: the BUFR software library of ECMWF and *bufrio*, a small library in C for file handling at the lowest level. These libraries are discussed in some more detail in section 6.4.

6.2 Routines

Table 6.1 provides an overview of the routines in module *BufrMod*. The most important ones are described below.

Routine	Call	Description
InitAndSetNrOfSubsets	AWDP	Initialization routine
set_BUFR_fileattributes	AWDP	Initialization routine
open_BUFR_file	AWDP	Opens a BUFR file
get_BUFR_nr_of_messages	AWDP	Inquiry of BUFR file
get_BUFR_message	AWDP	Reads instance of *BufrDataType* from file
get_expected_BUFR_msg_size	*get_BUFR_message*	Inquiry of BUFR file
ExpandBufrMessage	*get_BUFR_message*	Convert from *BufrMessageType* to *BufrSectionsType*
PrintBufrErrorCode	*ExpandBufrMessage*, *EncodeBufrData*	
CheckBufrTables	*ExpandBufrMessage*	Data check
get_file_size	*CheckBufrTables*	Determine size of BUFR file
get_bufrfile_size_c	*get_file_size*	Support routine in C
encode_table_b	*CheckBufrTables*	

Routine	Call	Description
encode_table_d	*CheckBufrTables*	
FillBufrSecData	*ExpandBufrMessage*	Convert from *BufrSectionsType* to *BufrDataType*
close_BUFR_file	AWDP	Closes a BUFR file
BufrReal2Int	AWDP	Type conversion
BufrInt2Real	AWDP	Type conversion
save_BUFR_message	AWDP	Saves instance of *BufrDataType* to file
EncodeBufrData	*save_BUFR_message*	Convert from *BufrSectionsType* to *BufrMessageType*
CheckBufrData	*EncodeBufrData*	Data check
FillBufrData	*EncodeBufrData*	Convert from *BufrDataType* to *BufrSectionsType*
bufr_msg_is_valid	not used	
set_bufr_msg_to_invalid	not used	
PrintBufrData	not used	
GetPosBufrData	not used	
GetRealBufrData	not used	
GetIntBufrData	not used	
GetRealBufrDataArr	not used	
GetIntBufrDataArr	not used	
GetRealAllBufrDataArr	not used	
CloseBufrHelpers	not used	
missing_real	not used	
missing_int	not used	
int2real	not used	
do_range_check_int	not used	
do_range_check_real	not used	
AddRealDataToBufrMsg	not used	
AddIntDataToBufrMsg	not used	
PrintBufrModErrorCode	not used	
GetFreeUnit	*encode_table_b,* *encode_table_d*	Get free file unit

Table 6.1 Routines of module *BufrMod*.

Reading (decoding): Routine *get_BUFR_message()* reads a single BUFR message from the BUFR file and creates an instance of *BufrDataType*.

Writing (encoding): Routine *save_BUFR_message()* saves a single BUFR message to the BUFR file. The data should be provided as an instance of *BufrDataType*.

Checking and Printing: The integer parameter *BufrVerbosity* controls the extent of the log statements while processing the BUFR file. The routines *PrintBufrData()* and *CheckBufrData()* can be used to respectively print and check instances of *BufrDataType*.

Open and Close BUFR files: The routine *open_BUFR_file()* opens the BUFR file for either reading (*writemode*=.false.) or writing (*writemode*=.true.). Routine *set_BUFR_fileattributes()* determines several aspects of the BUFR file and saves these data in an instance of *bufr_file_attr_data*, see table 6.5. Routine *get_BUFR_nr_of_messages()* is used to determine the number of BUFR messages in the file. Finally, routine *close_BUFR_file()* closes the BUFR file.

As said before, the underlying encoding and decoding routines originate from the ECMWF BUFR library. Appendix B3 shows the calling trees of the routines in module *BufrMod* that are used in AWDP.

6.3 Data structures

The data type closest to the actual BUFR messages in the BUFR files is the *BufrMessageType*, see table 6.2. These are still encoded data. Every BUFR message consists of 5 sections and one supplementary section. After decoding (expanding) the BUFR messages, the data are transferred into an instance of *BufrSectionsType*, see table 6.3, which contains the data and meta data in integer values subdivided in these sections.

Attribute	Type	Description
buff	integer array	BUFR message, all sections
size	integer	Size in bytes of BUFR message
nr_of_words	integer	Idem, now size in words

Table 6.2 Attributes for the *BufrMessageType* data type.

Attribute	Type	Description
ksup(9)	integer	Supplementary info and items selected from the other sections
ksec(3)	integer	Expanded section 0 (indicator)
ksec1(40)	integer	Expanded section 1 (identification)
ksec2(4096)	integer	Expanded section 2 (optional)
ksec3(4)	integer	Expanded section 3 (data description)
ksec4(2)	integer	Expanded section 4 (data)

Table 6.3 Attributes for the *BufrSectionsType* data type.

Attribute	Type	Description
Nsec0	integer	ksup (9) dimension section 0
nsec0size	integer	ksec0(1) size section 0
nBufrLength	integer	ksec0(2) length BUFR
nBufrEditionNumber	integer	ksec0(3)
Nsec1	integer	ksup (1) dimension section 1
nsec1size	integer	ksec1(1) size section 1
kEditionNumber	integer	ksec1(2)
Kcenter	integer	ksec1(3)
kUpdateNumber	integer	ksec1(4)
kOptional	integer	ksec1(5)
ktype	integer	ksec1(6)
ksubtype	integer	ksec1(7) local use
kLocalVersion	integer	ksec1(8)
kyear	integer	ksec1(9) century year
kmonth	integer	ksec1(10)
kday	integer	ksec1(11)
khour	integer	ksec1(12)
kminute	integer	ksec1(13)
kMasterTableNumber	integer	ksec1(14)
kMasterTableVersion	integer	ksec1(15)
ksubcenter	integer	ksec1(16)
klocalinfo()	integer	ksec1(17:40)
Nsec2	integer	ksup (2) dimension section 2
nsec2size	integer	ksec2(1) size section 2

Attribute	Type	Description
key(46)	integer	ksec2(2:) key
Nsec3	integer	ksup (3) dimension section 3
nsec3size	integer	ksec3(1) size section 3
Kreserved3	integer	ksec3(2) reserved
ksubsets	integer	ksec3(3) number of reserved subsets
kDataFlag	integer	ksec3(4) compressed (0,1) observed (0,1)
Nsec4	integer	ksup (4) dimension section 4
nsec4size	integer	ksec4(1) size section 4
kReserved4	integer	ksec4(2) reserved
nelements	integer	ksup (5) actual number of elements
nsubsets	integer	ksup (6) actual number of subsets
nvals	integer	ksup (7) actual number of values
nbufrsize	integer	ksup (8) actual size of BUFR message
ktdlen	integer	Actual number of data descriptors
ktdexl	integer	Actual number of expanded data descriptors
ktdlst()	integer array	List of data descriptors
ktdexp()	integer array	List of expanded data descriptors
values()	real array	List of values
cvals()	character array	List of CCITT IA no. 5 elements
cnames()	character array	List of expanded element names
cunits()	character array	List of expanded element units

Table 6.4 Attributes of the BUFR message data type *BufrDataType*.

The next step is to bring the section data to actual dimensions, descriptions and values of data which can be interpreted as physical parameters. Therefore, instances of *BufrSectionsType* are transferred to instances of *BufrDataType*, see table 6.4. The actual data for input or output in a BUFR message should be an instance of the *BufrDataType* data type. Some meta information on the BUFR file is contained in the self explaining *bufr_file_attr_data* data type, see table 6.5.

Attribute	Type	Description
nr_of_BUFR_mesasges	integer	Number of BUFR messages
bufr_filename	character	BUFR file
bufr_fileunit	integer	Fortran unit of BUFR file
file_size	integer	Size of BUFR file
file_open	logical	Open status of BUFR file
writemode	logical	Reading or writing mode of BUFR file
is_cray_blocked	integer	Cray system blocked?
list_of_BUFR_startpointers()	integer	Pointers to BUFR messages
message_is_valid()	logical	Validity of BUFR messages

Table 6.5 Attributes of the *bufr_file_attr_data* data type for BUFR files.

6.4 Libraries

Module *BufrMod* uses two libraries: the BUFR software library of ECMWF and *bufrio*, a small library in C for file handling at the lowest level.

The BUFR software library of ECMWF is used as a basis to encode and decode BUFR data. This software library is explained in [20].

Library *bufrio* contains routines for BUFR file handling at the lowest level. Since this is quite hard

to achieve in Fortran, these routines are coded in C. The routines of *bufrio* are listed in table 6.6. The source file (`bufrio.c`) is located in subdirectory `genscat/support/bufr`.

Routine	Call	Description
bufr_open	*open_BUFR_file*	Open file
bufr_split	*open_BUFR_file*	Find position of start of messages in file
bufr_read_allsections	*get_BUFR_message*	Read *BufrMessageType* from BUFR file
bufr_get_section_sizes	*get_BUFR_message*	
bufr_swap_allsections	*get_BUFR_message, save_BUFR_message*	Optional byte swapping
bufr_write_allsections	*save_BUFR_message*	Write *BufrMessageType* to BUFR file
bufr_close	*close_BUFR_file*	
bufr_error	see appendix B.3	Error handling

Table 6.6 Routines in library *bufrio*.

6.5 BUFR table routines

BUFR tables are used to define the data descriptors. The presence of the proper BUFR tables is checked before calling the reading and writing routines. If absent, it is tried to create the needed BUFR tables from the text version, available in genscat.

6.6 Centre specific modules

BUFR data descriptors are integers. These integers consist of class numbers and numbers for the described parameter itself. These numbers are arbitrary. To establish self documenting names for the BUFR data descriptors for a Fortran 90 code several centre specific modules are created. These modules are listed in table 6.7. Note that these modules are just cosmetic and not essential for the encoding or decoding of the BUFR data. They are not used in AWDP.

Module	Description
WmoBufrMod	WMO standard BUFR data description
KnmiBufrMod	KNMI BUFR data description
EcmwfBufrMod	ECMWF BUFR data description

Table 6.7 Fortran 90 BUFR modules.

7 Module *gribio_module*

Module *gribio_module* is part of the genscat support modules. The current version is a Fortran 90 wrapper around the ECMWF GRIB API library (see http://www.ecmwf.int/). The goal of this support module is to provide a comprehensive interface to GRIB data for every Fortran 90 program using it. In particular, *gribio_module* provides all the GRIB functionality required for the scatterometer processor based on genscat. Special attention has been paid to testing and error handling.

7.1 Background

The acronym GRIB stands for GRIdded Binary. GRIB is maintained by the World Meteorological Organization WMO and other meteorological centres. In brief, the WMO FM-92 GRIB definition is a binary format for efficiently transmitting gridded meteorological data. It is beyond the scope of this document to describe GRIB in detail. Complete descriptions are distributed via the websites of WMO (http://www.wmo.int/) and of the European Centre for Medium-range Weather Forecasts ECMWF (http://www.ecmwf.int/).

Module *gribio_module* is in fact an interface. On the one hand it contains (temporary) definitions to set the arguments of the ECMWF library functions. On the other hand, it provides self explaining routines to be incorporated in the wider Fortran 90 program. Section 7.2 describes the routines in module *gribio_module*. The available data structures are described in section 7.3. The *gribio_module* uses two libraries: from the GRIB software library of ECMWF. This is discussed in some more detail in section 7.4.

7.2 Routines

Table 7.1 provides an overview of the routines in module *gribio_module*. The most important ones are described below.

Routine	Call	Description
init_GRIB_module	AWDP	Initialization routine
dealloc_all_GRIB_messages	AWDP	Clear all GRIB info from memory and close GRIB files
set_GRIB_filelist	AWDP	Open all necessary GRIB files
get_from_GRIB_filelist	AWDP, *get_colloc_from_GRIB_filelist*	Retrieve GRIB data for a given lat and lon
inquire_GRIB_filelist	AWDP, *get_analyse_dates_and_times*, *get_colloc_from_GRIB_filelist*	Inquiry of GRIB file list
get_colloc_from_GRIB_filelist	AWDP	Retrieve time interpolated GRIB data for a given lat and lon
get_GRIB_msgnr	*get_field_from_GRIB_file*, *get_from_GRIB_file*,	Inquiry of GRIB file list

Routine	Call	Description
	get_from_GRIB_filelist, *inquire_GRIB_filelist*	
display_req_GRIB_msg_properties	*get_GRIB_msgnr*, *get_from_GRIB_filelist*	Prints GRIB message info
display_GRIB_message_properties	*get_GRIB_msgnr*, *get_from_GRIB_filelist*	Prints GRIB message info
open_GRIB_file	*get_field_from_GRIB_file*, *get_from_GRIB_file*, *set_GRIB_filelist*, *add_to_GRIB_filelist*	Open GRIB file and get some header information from all messages in this file
read_GRIB_header_info	*open_GRIB_file*	Read header part of a GRIB message
extract_data_from_GRIB_message	*get_from_GRIB_file*, *get_from_GRIB_filelist*	Interpolate data from four surrounding points for a given lat and lon
get_GRIB_data_values	*get_field_from_GRIB_file*, *get_from_GRIB_file*, *get_from_GRIB_filelist*	Read all data from GRIB message
dealloc_GRIB_message	*open_GRIB_file*, *dealloc_all_GRIB_messages*, *get_field_from_GRIB_file*	Clear GRIB message from memory
get_analyse_dates_and_times	*get_colloc_from_GRIB_filelist*	Helper routine
check_proximity_to_analyse	*get_colloc_from_GRIB_filelist*	Helper routine
get_field_from_GRIB_file	not used	
get_from_GRIB_file	not used	
add_to_GRIB_filelist	not used	

Table 7.1 Routines of module *gribio_module*.

Reading: Routine set_GRIB_filelist reads GRIB messages from a list of files, decodes them and makes the data accessible in a list of GRIB messages in memory.

Retrieving: Routine *get_from_GRIB_filelist()* returns an interpolated value (four surrounding grid points) from the GRIB data in the list of files/messages for a given GRIB parameter, latitude and longitude. It is also possible to get a weighted value of all grid points lying within a circle around the latitude and longitude of interest. This is used in the land fraction calculation in AWDP. The land fraction is calculated by scanning all grid points of the land-sea mask lying within 80 km from the centre of the WVC. Every grid point found yields a land fraction (between 0 and 1). The land fraction of the WVC is calculated as the average of the grid land fractions, where each grid land fraction has a weight of $1/r^2$, r being the distance between the WVC centre and the model grid point.

Routine *get_colloc_from_GRIB_filelist()* returns an interpolated value (four surrounding grid points) from the GRIB data in the list of files/messages for a given GRIB parameter, latitude, longitude, and time. The list of messages must contain a sequence of forecasts with constant time intervals (e.g. +3 hrs, +6 hrs, +9 hrs, et cetera or +4 hrs, +5 hrs, +6 hrs, +7 hrs, et cetera). At least three forecasts need to be provided; ideally two lying before the sensing time and one after.

```
----|-----|-----|----
    1     2  ^  3
```

In this diagram, the `1`, `2`, and `3` mean the three forecast steps with intervals of three hours between them. The `^` is the sensing time. The software will perform a cubic time interpolation. Note that

the 1, 2 and 3 in the diagram may correspond to +3, +6 and +9 forecasts, but also e.g. to +9, +12 and +15. If more forecasts are provided, e.g. like this:

```
----|-----|-----|-----|-----|----
    1     2     3  ^  4     5
```

the software will use forecast steps 2, 3, and 4, i.e., it will pick the optimal values by itself. If one forecast before, and two after are provided:

```
----|-----|-----|----
    1  ^  2     3
```

the software will still work, and use all three forecasts.

Checking and Printing: The integer parameter *GribVerbosity* controls the extent of the log statements while processing the GRIB data.

As said before, the underlying encoding and decoding routines originate from the ECMWF GRIB library. Appendix B4 shows the calling trees of the routines in module *gribio_module* that are used in AWDP.

7.3 Data structures

Some meta information on the GRIB file is contained in the self explaining grib*_file_attr_data* data type, see table 7.2.

The decoded GRIB messages in the GRIB files, with their meta information, are contained in the *grib_message_data*, see table 7.3.

Attribute	Type	Description
nr_of_GRIB_messages	integer	Number of messages in this file
grib_filename	character array	Name of GRIB file
grib_fileunit	integer	Unit number in file table
file_size	integer	Size of GRIB file in bytes
file_open	logical	Status flag
list_of_GRIB_message_ids	integer array	Message ids assigned by GRIB API
list_of_GRIB_level	integer array	Key to information in messages
list_of_GRIB_level_type	integer array	Key to information in messages
list_of_GRIB_date	integer array	Key to information in messages
list_of_GRIB_hour	integer array	Key to information in messages
list_of_GRIB_analyse	integer array	Key to information in messages
list_of_GRIB_derived_date	integer array	Key to information in messages
list_of_GRIB_derived_hour	integer array	Key to information in messages
list_of_GRIB_par_id	integer array	Key to information in messages
list_of_GRIB_vals_sizes	integer array	Size of data values arrays

Table 7.2 Attributes for the *grib_file_attr_data* data type.

Attribute	Type	Description
message_pos_in_file	integer	Position of message in GRIB file
message_id	integer	Message id assigned by GRIB API

Attribute	Type	Description
date	real	Date when data are valid
time	real	Time when data are valid
derived_date	real	date + time/24
derived_time	real	mod(time/24)
total_message_size	integer	Size of message
vals_size	integer	Size of data values array
is_decoded	logical	Status flag
nr_lon_points	integer	Information about grid
nr_lat_points	integer	Information about grid
nr_grid_points	integer	Information about grid
lat_of_first_gridpoint	real	Information about grid
lat_of_last_gridpoint	real	Information about grid
lon_of_first_gridpoint	real	Information about grid
lon_of_last_gridpoint	real	Information about grid
lat_step	real	Information about grid
lon_step	real	Information about grid
real_values	real array, pointer	Decoded real data values

Table 7.3 Attributes for the *grib_message_data* data type.

Attribute	Type	Description
grib_file_attributes	grib_file_attr_data	GRIB file attributes
list_of_GRIB_msgs	grib_message_data array	List of messages in file

Table 7.4 Attributes of the *list_of_grib_files_type* data type for GRIB files.

7.4 Libraries

Module *gribio_module* uses two libraries: from the GRIB API software library of ECMWF: `libgrib_api.a` and `libgrib_api_f90.a`. The GRIB API software library of ECMWF is used as a basis to decode GRIB data. This software library is explained on http://www.ecmwf.int/.

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Appendix A: Calling tree for AWDP

The figures in this appendix show the calling tree for the AWDP software package. Routines in normal print are part of the AWDP process layer. Routines in italic print are part of genscat. An arrow (→) before a routine name indicates that this part of the calling tree is a continuation of a branch in a previous figure. The same arrow after a routine name indicates that this branch will be continued in a following figure.

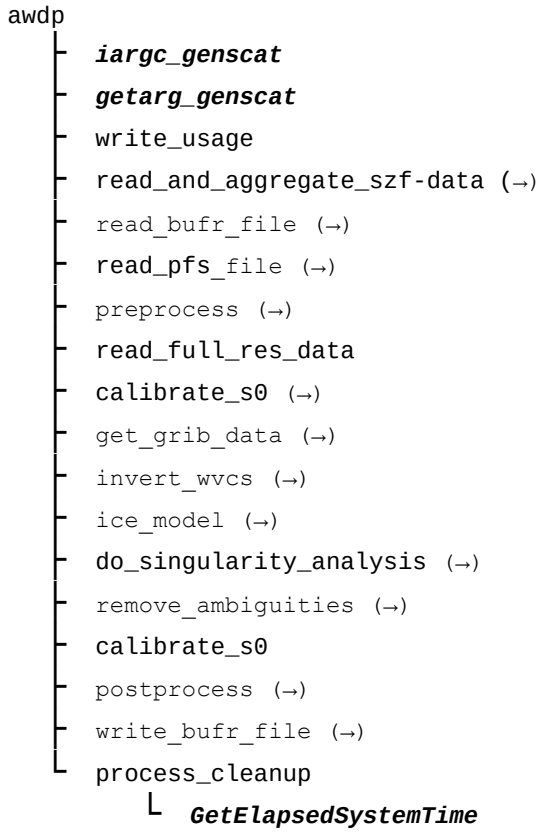


Figure A.1 Calling tree for program *awdp* (top level). White boxes are cut here and will be continued in one of the first level or second level calling trees in the next figures. Lines with italic text indicate genscat routines.

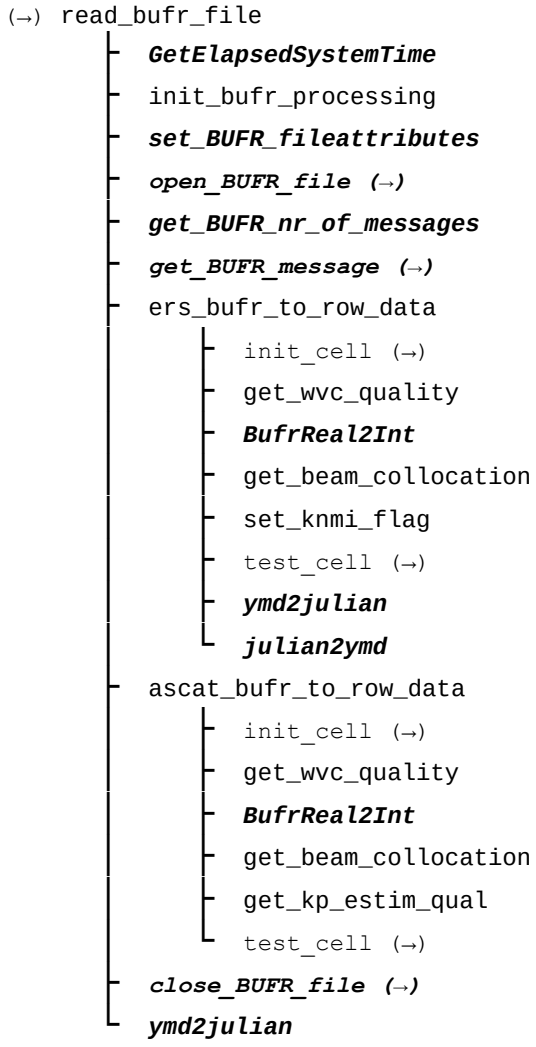


Figure A.2 Calling tree for routine *read_bufr_file* (first level).

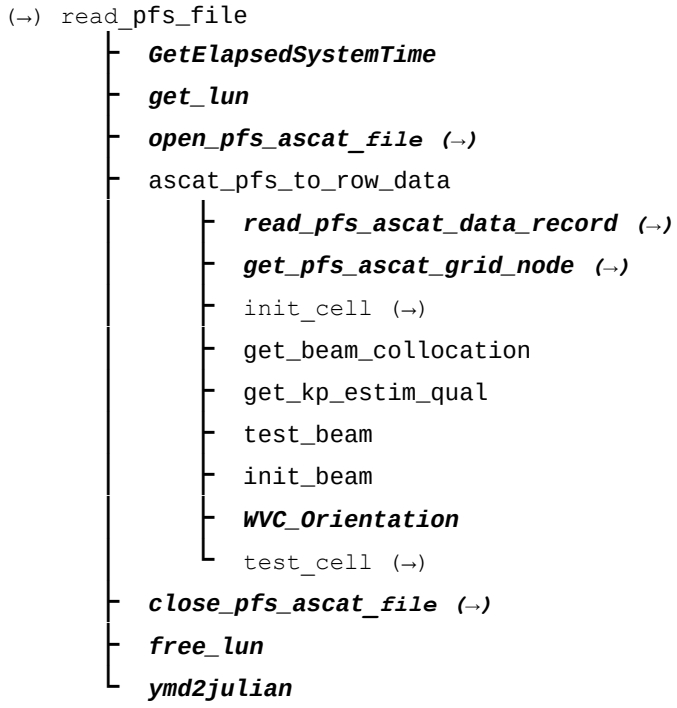


Figure A.3 Calling tree for routine *read_pfs_file* (first level).

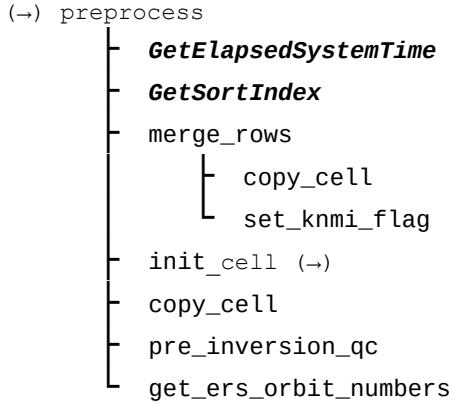


Figure A.4 Calling tree for routine *preprocess* (first level).

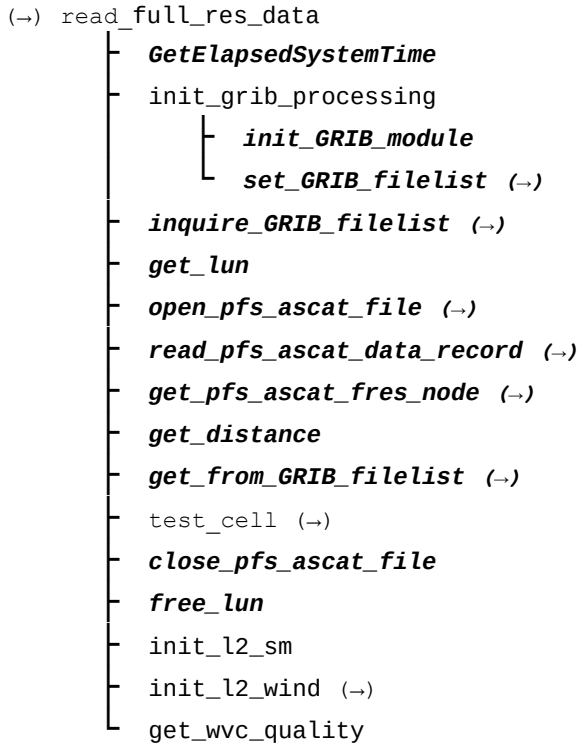


Figure A.5 Calling tree for routine *read_full_res_data* (first level).

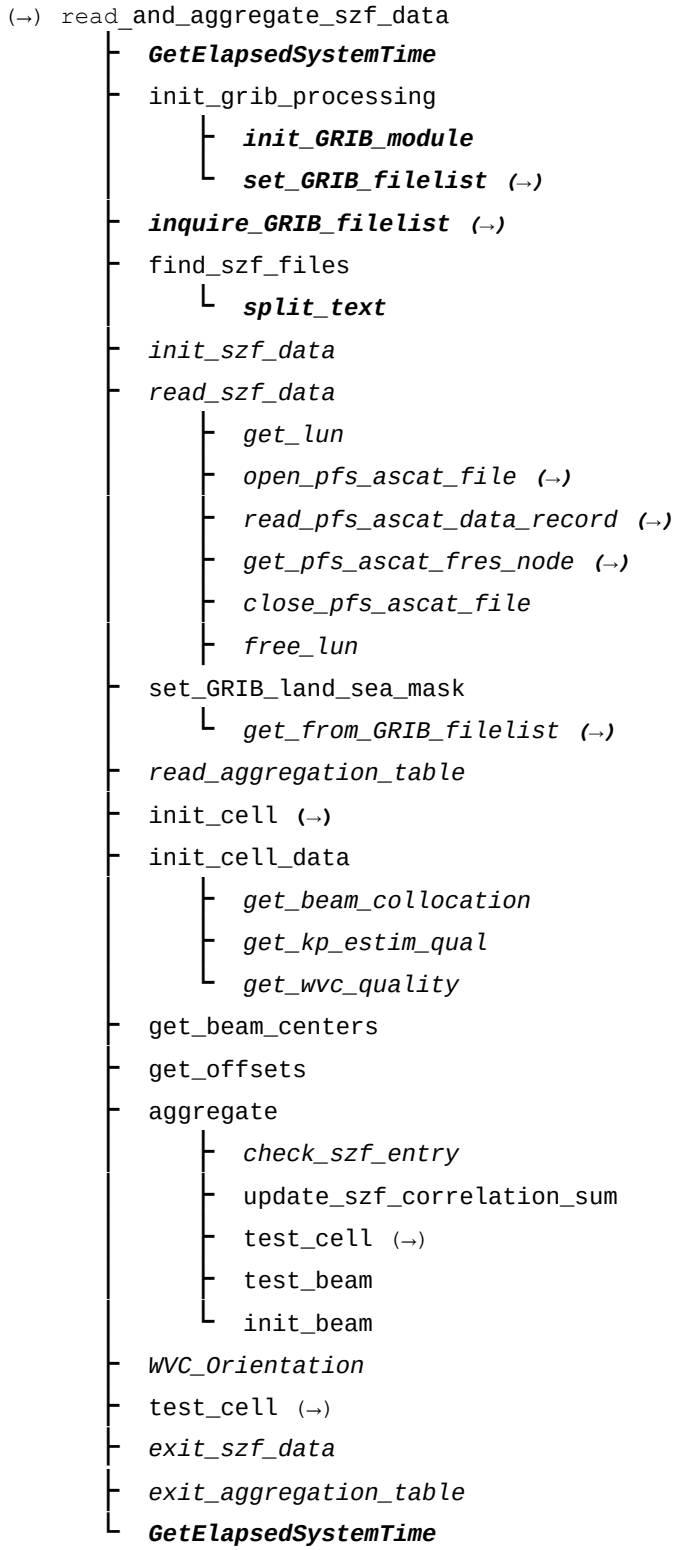


Figure A.6 Calling tree for routine *read_and_aggregate_szf_data* .(first level)

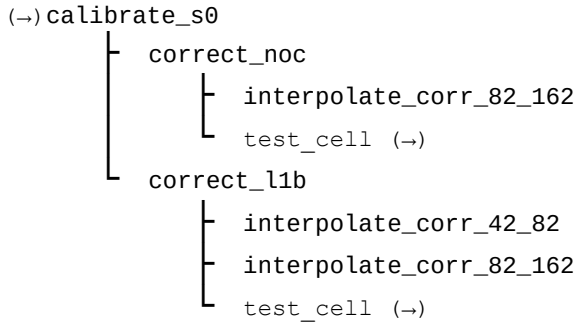


Figure A.7 Calling tree for routine *calibrate_s0* (first level).

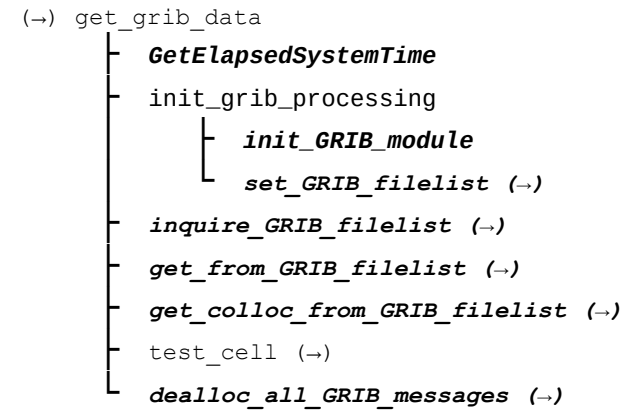


Figure A.8 Calling tree for routine *get_grib_data* (first level).

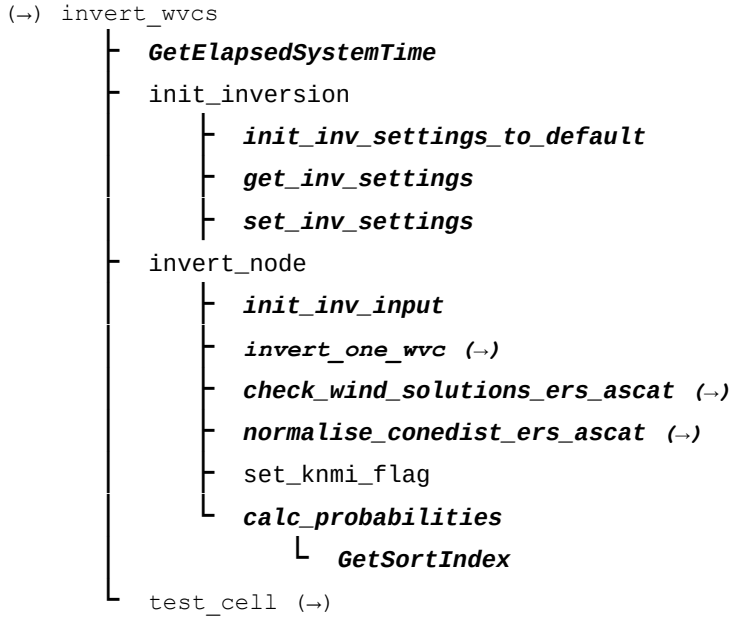


Figure A.9 Calling tree for routine *invert_wvcs* (first level).

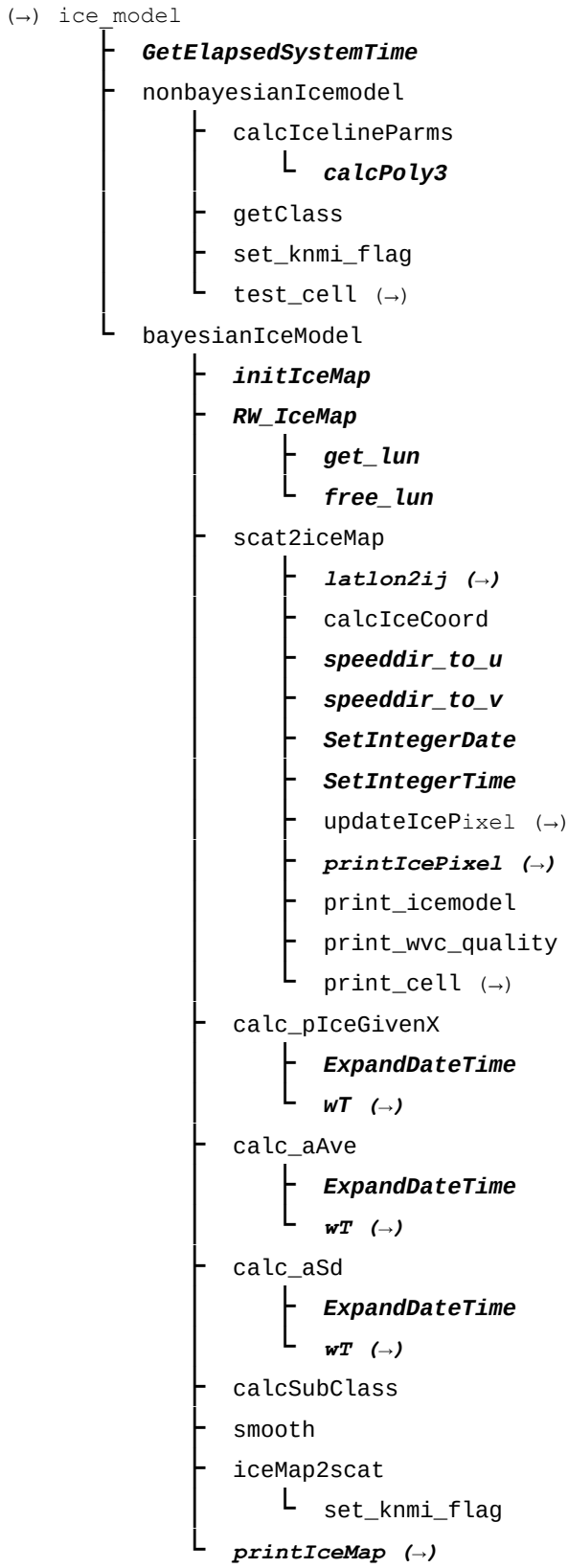


Figure A.10 Calling tree for routine *ice_model* (first level).

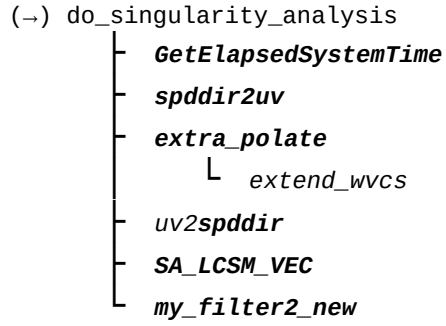


Figure A.11 Calling tree for routine *do_singularity_analysis.*

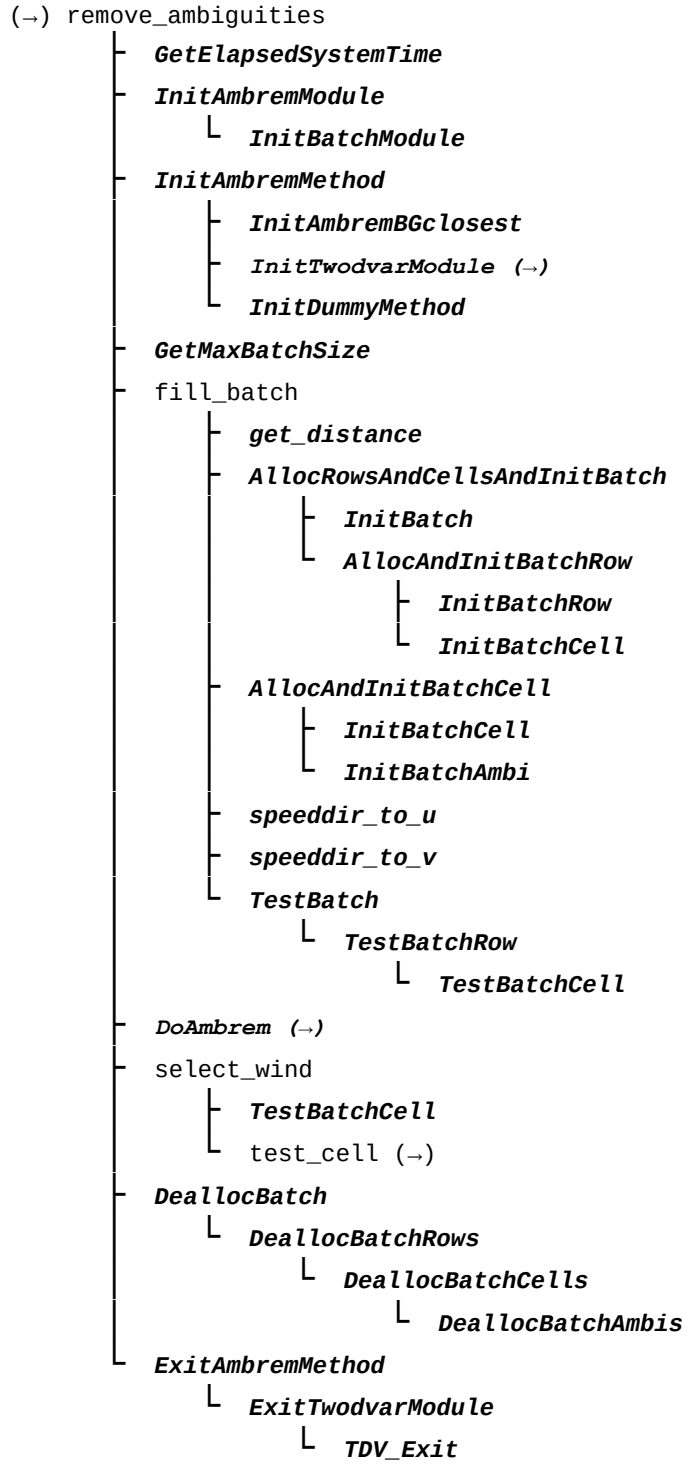


Figure A.12 Calling tree for routine *remove_ambiguities* (first level).

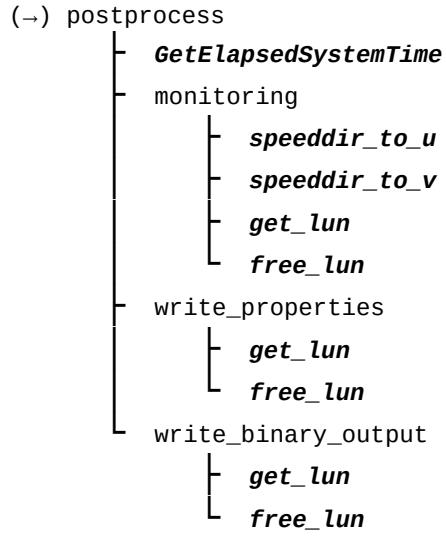


Figure A.13 Calling tree for routine *postprocess* (first level).

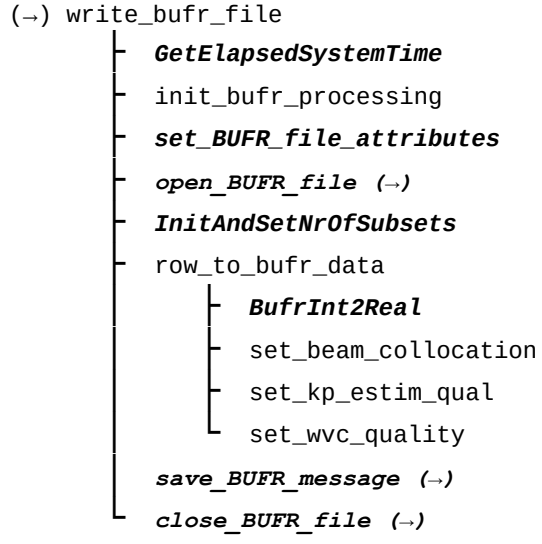


Figure A.14 Calling tree for routine write_bufr_file (first level).

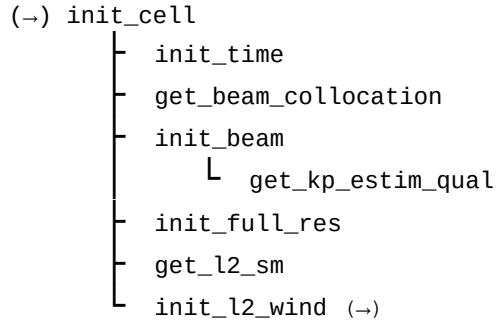


Figure A.15 Calling tree for routine *init_cell* (second level).

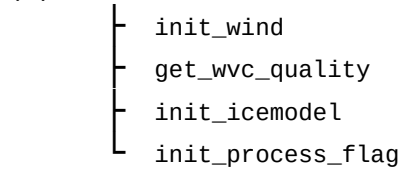


Figure A.16 Calling tree for routine *init_l2_wind* (second level).

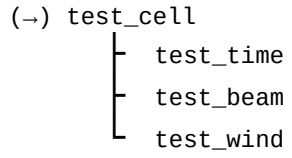


Figure A.17 Calling tree for routine *test_cell* (second level).

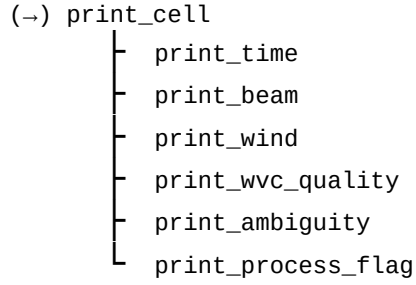


Figure A.18 Calling tree for routine *PrintCell* (second level).

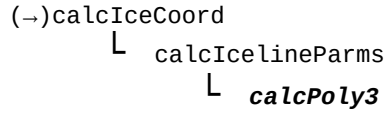


Figure A.19 Calling tree for routine *calcIceCoord* (second level).

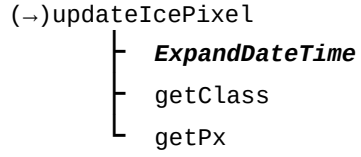


Figure A.20 Calling tree for routine *updateIcePixel* (second level).

Appendix B1: Calling tree for inversion routines

The figures in this appendix show the calling tree for the inversion routines in genscat. All routines are part of genscat, as indicated by the italic printing. An arrow (→) before a routine name indicates that this part of the calling tree is a continuation of a branch in a previous figure. The same arrow after a routine name indicates that this branch will be continued in a following figure.

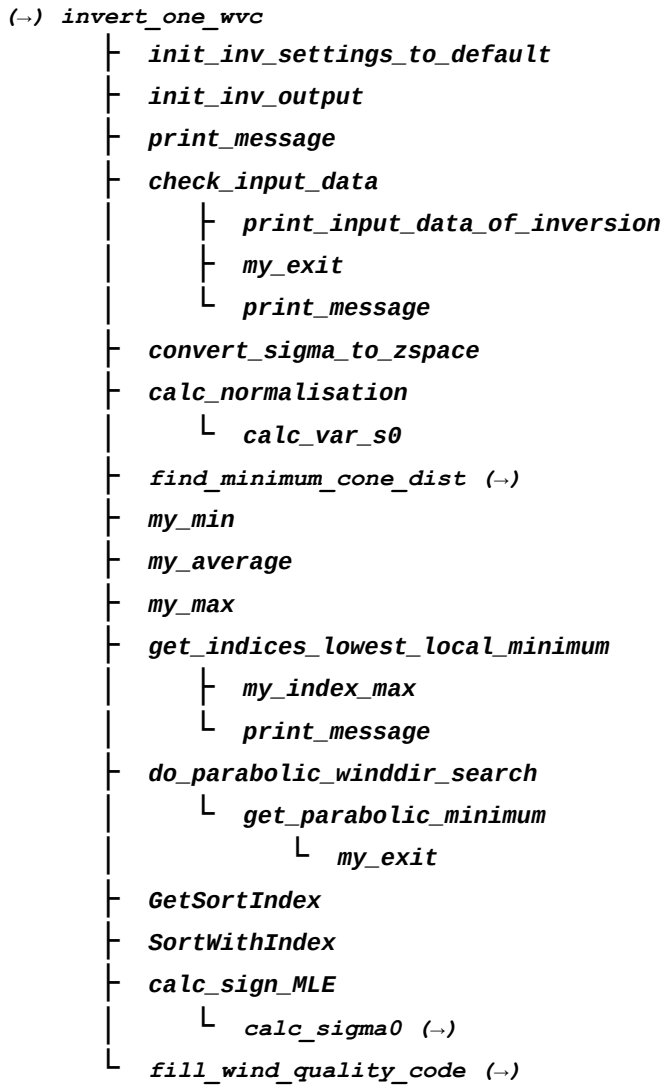


Figure B1.1 Calling tree for inversion routine *invert_one_wvc*.

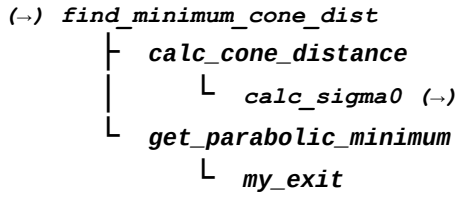


Figure B1.2 Calling tree for inversion routine *find_minimum_cone_dist*

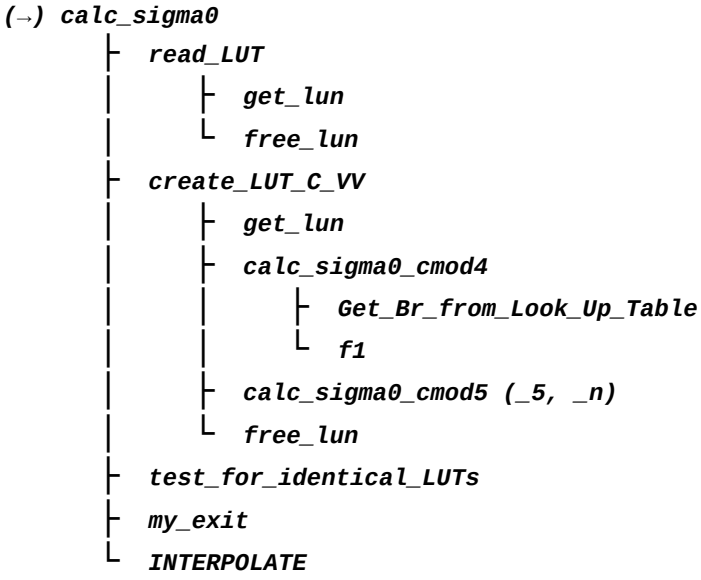


Figure B1.3 Calling tree for inversion routine *calc_sigma0*. Routine *INTERPOLATE* is an interface that can have the values *interpolate1d, interpolate2d*, *interpolate2dv* or *interpolate3d*. There are several equivalent routines to calculate the CMOD backscatter, like *calc_sigma0_cmod5*, *calc_sigma0_cmod5_5*, *calc_sigma0_cmod5_n*, *calc_sigma0_cmod6*.

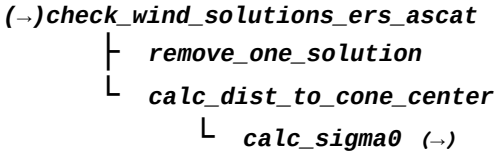


Figure B1.4 Calling tree for inversion routine *check_wind_solutions_ers_ascat*.

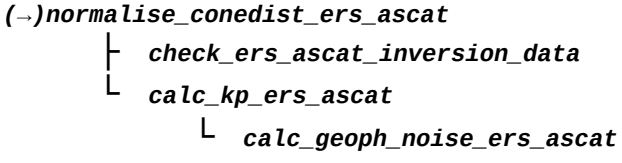


Figure B1.5 Calling tree for inversion routine *normalize_conedist_ers_ascat*.

Appendix B2: Calling tree for AR routines

The figures in this appendix show the calling tree for the Ambiguity Removal routines in genscat. All routines are part of genscat, as indicated by the italic printing. An arrow (→) before a routine name indicates that this part of the calling tree is a continuation of a branch in a previous figure. The same arrow after a routine name indicates that this branch will be continued in a following figure.

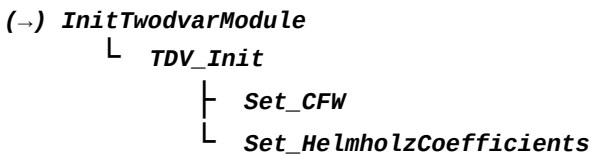


Figure B2.1 Calling tree for AR routine *InitTwodvarModule*.

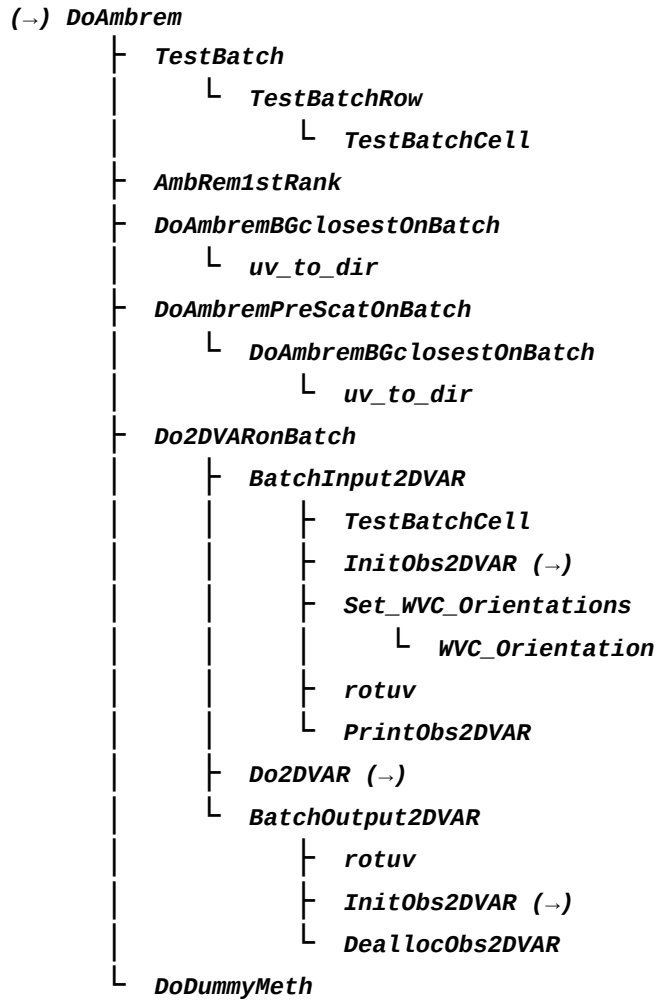


Figure B2.2 Calling tree for AR routine *DoAmbrem*.

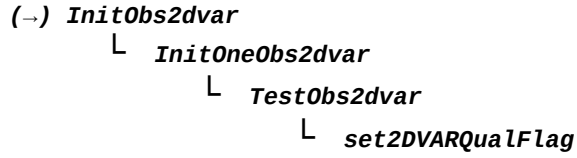


Figure B2.3 Calling tree for AR routine *InitObs2dvar*.

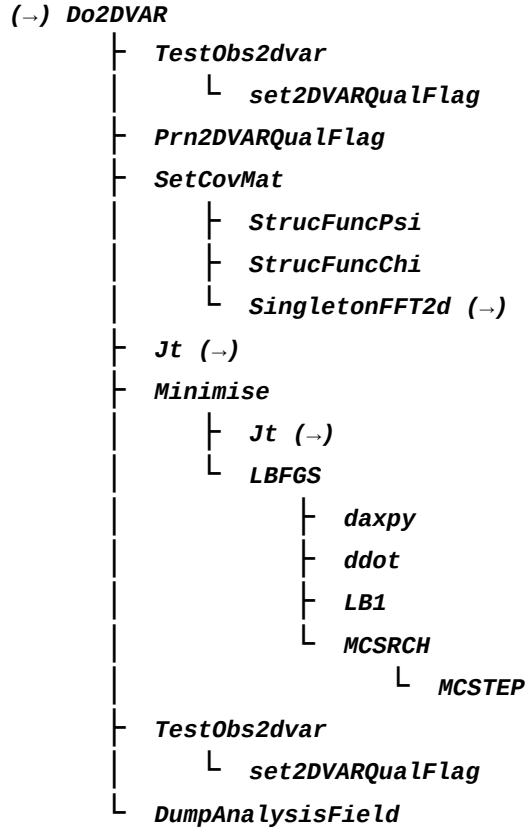


Figure B2.4 Calling tree for AR routine *Do2DVAR*.

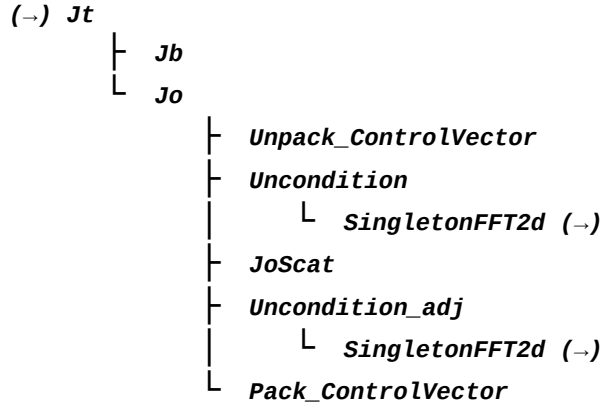


Figure B2.5 Calling tree for AR routine *Jt* (calculation of cost function).

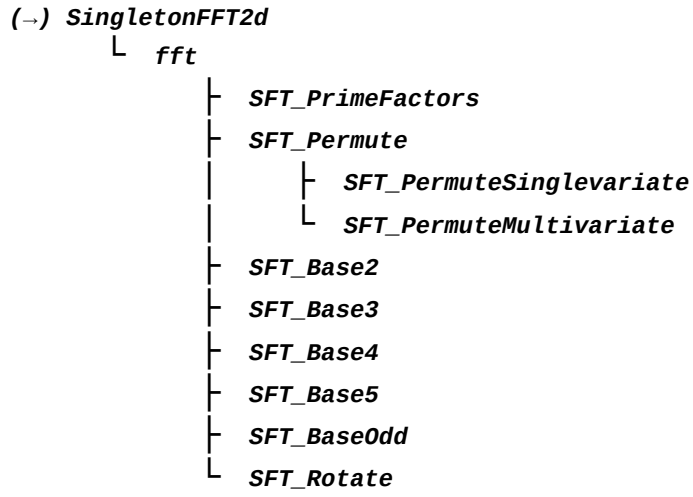


Figure B2.6 Calling tree for AR routine *SingletonFFT2D*.

Appendix B3: Calling tree for BUFR routines

The figures in this appendix show the calling tree for the BUFR file handling routines in genscat. Routines in italic are part of genscat. Underlined routines followed by (E) belong to the ECMWF BUFR library. Other underlined routines belong to the *bufrio* library (in C). An arrow (→) before a routine name indicates that this part of the calling tree is a continuation of a branch in a previous figure. The same arrow after a routine name indicates that this branch will be continued in a following figure.

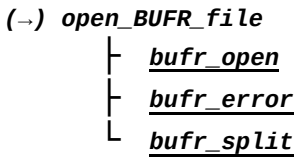


Figure B3.1 Calling tree for BUFR file handling routine *open_BUFR_file*.

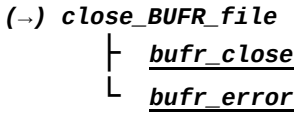


Figure B3.2 Calling tree for BUFR handling routine *close_BUFR_file*.

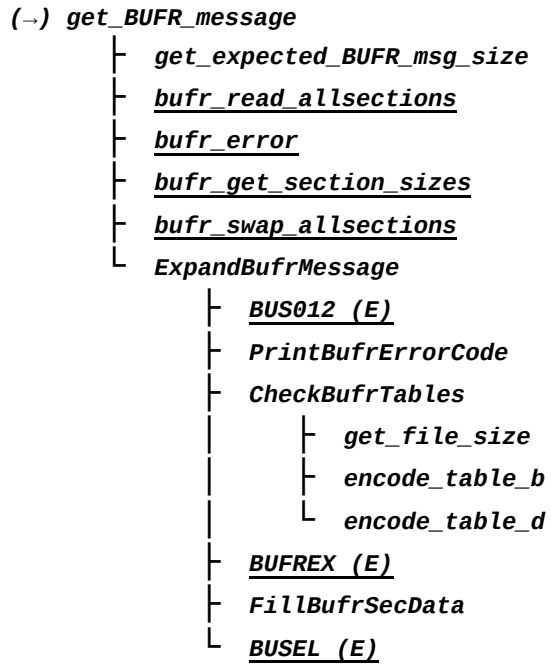


Figure B3.3 Calling tree for BUFR handling routine *get_BUFR_message*.

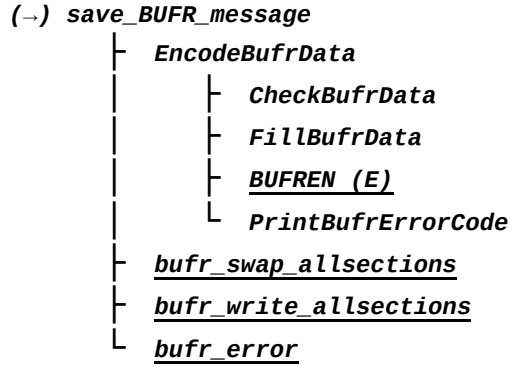


Figure B3.4 Calling tree for BUFR file handling routine *save_BUFR_file*.

Appendix B4: Calling tree for GRIB routines

The figures in this appendix show the calling tree for the GRIB file handling routines in genscat. Routines in italic are part of genscat. Underlined routines followed by (E) belong to the ECMWF GRIB API library. An arrow (→) before a routine name indicates that this part of the calling tree is a continuation of a branch in a previous figure. The same arrow after a routine name indicates that this branch will be continued in a following figure.

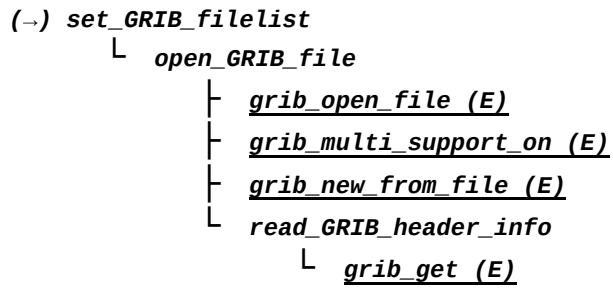


Figure B4.1 Calling tree for GRIB file handling routine *set_GRIB_filelist*.

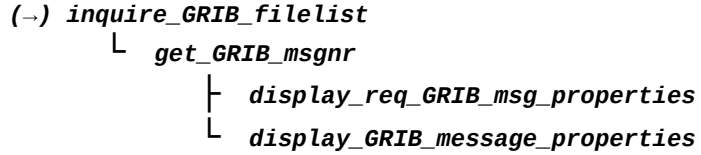


Figure B4.2 Calling tree for GRIB file handling routine *inquire_GRIB_filelist*.

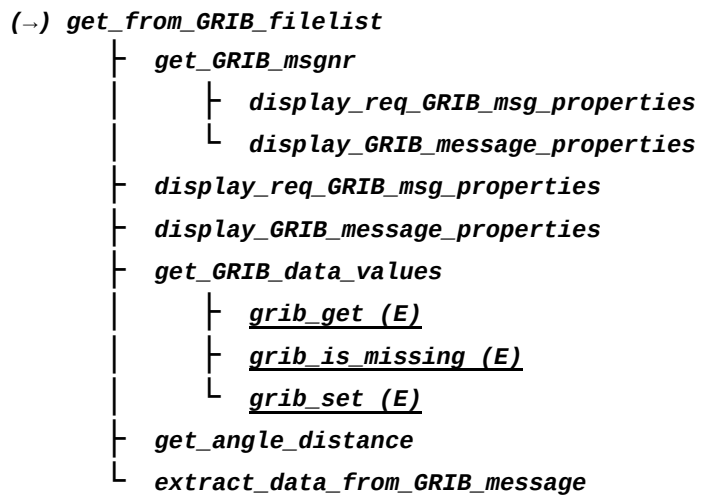


Figure B4.3 Calling tree for GRIB file handling routine *get_from_GRIB_filelist*.

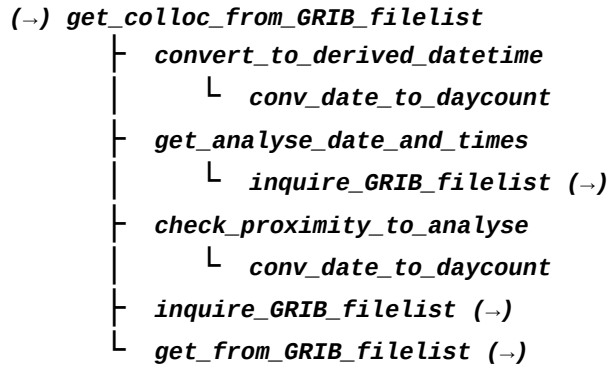


Figure B4.4 Calling tree for GRIB file handling routine *get_colloc_from_GRIB_filelist*.

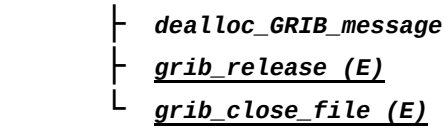


Figure B4.5 Calling tree for GRIB file handling routine *dealloc_all_GRIB_messages*.

Appendix B5: Calling tree for PFS routines

The figures in this appendix show the calling tree for the PFS (native Metop format) file handling routines in genscat. All routines are part of genscat, as indicated by the italic printing. An arrow (→) before a routine name indicates that this part of the calling tree is a continuation of a branch in a previous figure. The same arrow after a routine name indicates that this branch will be continued in a following figure.

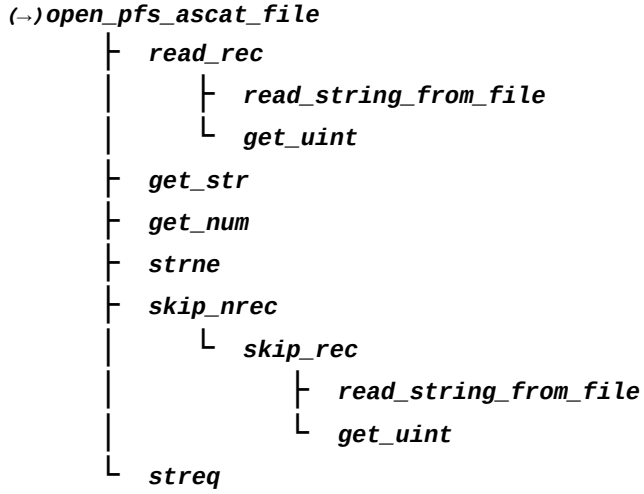


Figure B5.1 Calling tree for PFS file handling routine *open_pfs_ascat_file*.

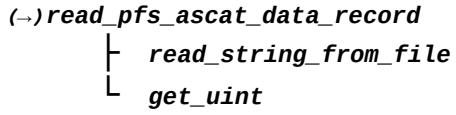


Figure B5.2 Calling tree for PFS file handling routine *read_pfs_ascat_data_record*.

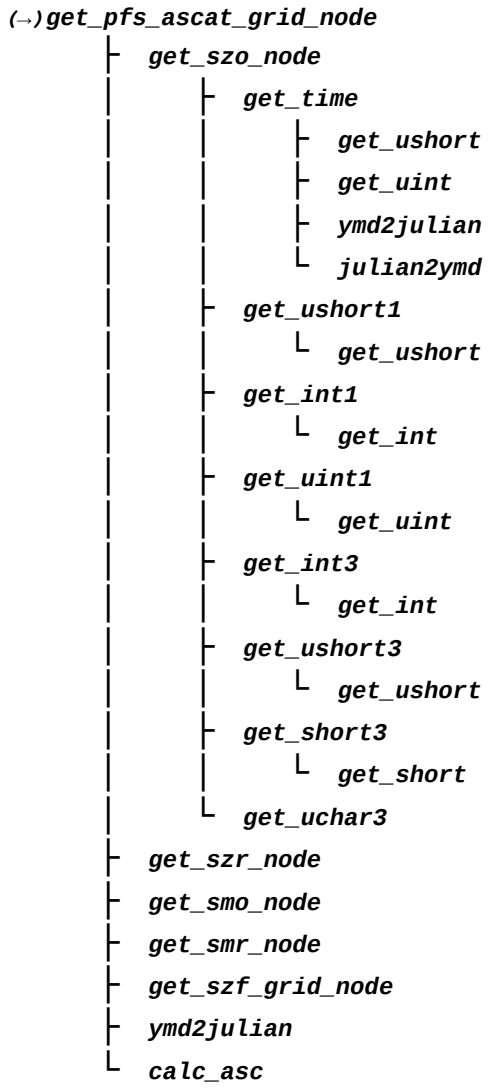


Figure B5.3 Calling tree for PFS file handling routine *get_pfs_ascat_grid_node*. The calling tree for *get_szr_node*, *get_smo_node*, *get_smr_node* and *get_szf_grid_node* is identical to to the one of *get_szo_node*.

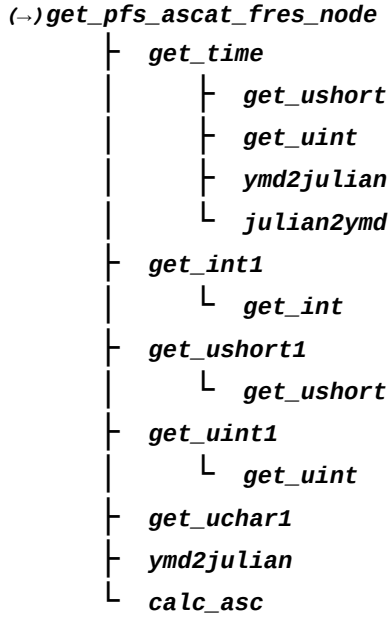
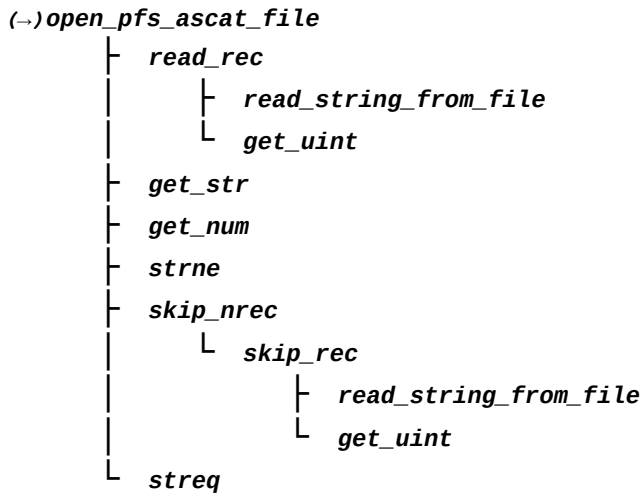


Figure B5.4 Calling tree for PFS file handling routine *get_pfs_ascat_fres_node*.

Appendix B6: Calling tree for ASCAT-5.6 routines

The figures in this appendix show the calling tree for the routines needed to generate the ASCAT-5.6 product. This product is based on a different approach to generate the gridded σ^0 values PFS (native Metop format) file handling routines in genscat. All routines are part of genscat, as indicated by the italic printing. An arrow (→) before a routine name indicates that this part of the calling tree is a continuation of a branch in a previous figure. The same arrow after a routine name indicates that this branch will be continued in a following figure.



Appendix B7: Calling tree for ice model routines

The figures in this appendix show the calling tree for the ice model routines in genscat. All routines are part of genscat, as indicated by the italic printing. An arrow (→) before a routine name indicates that this part of the calling tree is a continuation of a branch in a previous figure. The same arrow after a routine name indicates that this branch will be continued in a following figure.

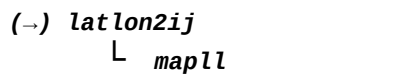


Figure B7.1 Calling tree for routine *latlon2ij*.

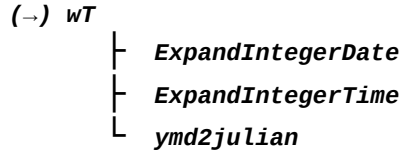


Figure B7.2 Calling tree for routine *wT* (second level).

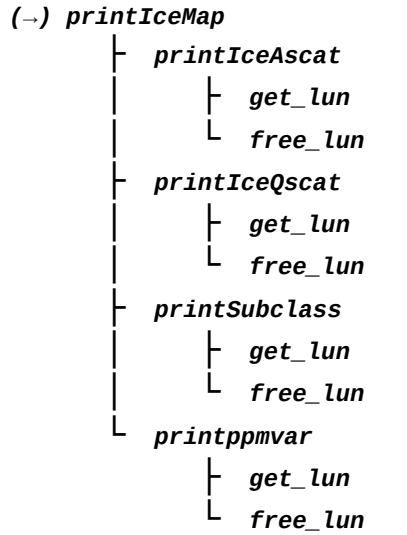


Figure B6.3 Calling tree for routine *printIceMap* (second level).

Appendix C: 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
HIRLAM	High resolution Local Area Model
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
NCEP	United States National Centers for Environmental Prediction
NRCS	Normalized Radar Cross-Section (σ^0)
NWP	Numerical Weather Prediction
OSI	Ocean and Sea Ice
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 C.1 List of acronyms.