EUMETSAT OSI SAF
OCEAN AND SEA ICE

CWDP Top Level Design

CFOSAT Wind Data Processor

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1. Introduction

The CFOSAT Wind Data Processor (CWDP) is a software package written mainly in Fortran 90. It has some parts written in C for handling HDF5, NetCDF and BUFR data formats. CWDP is intended to be a generic wind processor for Ku band rotating fan beam scatterometer data. It can be adapted to handle data from future instruments such as WindRAD. This document is the Top Level Design (TLD) of the CWDP software package including module design. Section 2 describes the general design of the CWDP software. Section 3 describes the individual modules that are part of CWDP.

More information about CWDP as well as L2A processor can be found in [1], [2]. The User Manual (UM) [1] and Product Specification (PS) [2] provide sufficient information for a user who wants to apply the CWDP as a black box. This TLD document gives more specific information on how the processing is done and is of interest to more experienced users.

The model is designed as layered model structure. The purpose of this structure is to separate the generic scatterometer processing from the specific Ku-band rotating fan beam processing. The first layer is defined as the rotating fan beam processing layer and the second layer is defined as the generic scatterometer processing layer (in genscat).

1.1 User requirements

According to the NWP SAF Development Procedures for Software Deliverables [4], user requirements must be subject to review before the start of development, to ensure planned developments are relevant and respond to user requirements. The development of CWDP was motivated by the OSI SAF requirement to have a processor capable of processing CFOSAT level 1 data into wind products. The CFOSAT wind products need to fulfill the requirements specified in the OSI SAF Product Requirements Document in terms of product quality and timeliness. These requirements are the basis for CWDP development and they are detailed in the traceability matrix in the CWDP Test Plan and Test Report [5].

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. `cwdp/src`), files (e.g. `cwdp.F90`), and commands (e.g. `cwdp -f input`) are printed in Courier. Software systems in general are addressed using the normal font (e.g. CWDP, genscat).

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

2. L2A processor design

2.1 Top level design

The L2A processor `cfosat_l1b_l2a` and `cfosat_hdf2bufr` are Unix (Linux) executables which process the L1B data. The final output data is in BUFR format and NetCDF format. The user may provide arguments and parameters according to Unix command line standards and those options are described in [2]. When executed, the L2A processor logs information on the terminal screen. The baseline of processing is shown in Figure 1. The arguments given at the command line are processed by the genscat module *Compiler_Features*. The first part of the processor (`cfosat_l1b_l2a`) is to assign the slices onto proper WVCs with their attached information and write into HDF5 output. The second part of the processor (`cfosat_hdf2bufr`) is to aggregate the information of the slices in the WVC into views. The reason of writing into HDF5 file first and then converting into BUFR file is to keep the process consistent with other types of scatterometers. After HDF5 is converted to BUFR, the BUFR output can be converted into NetCDF format.

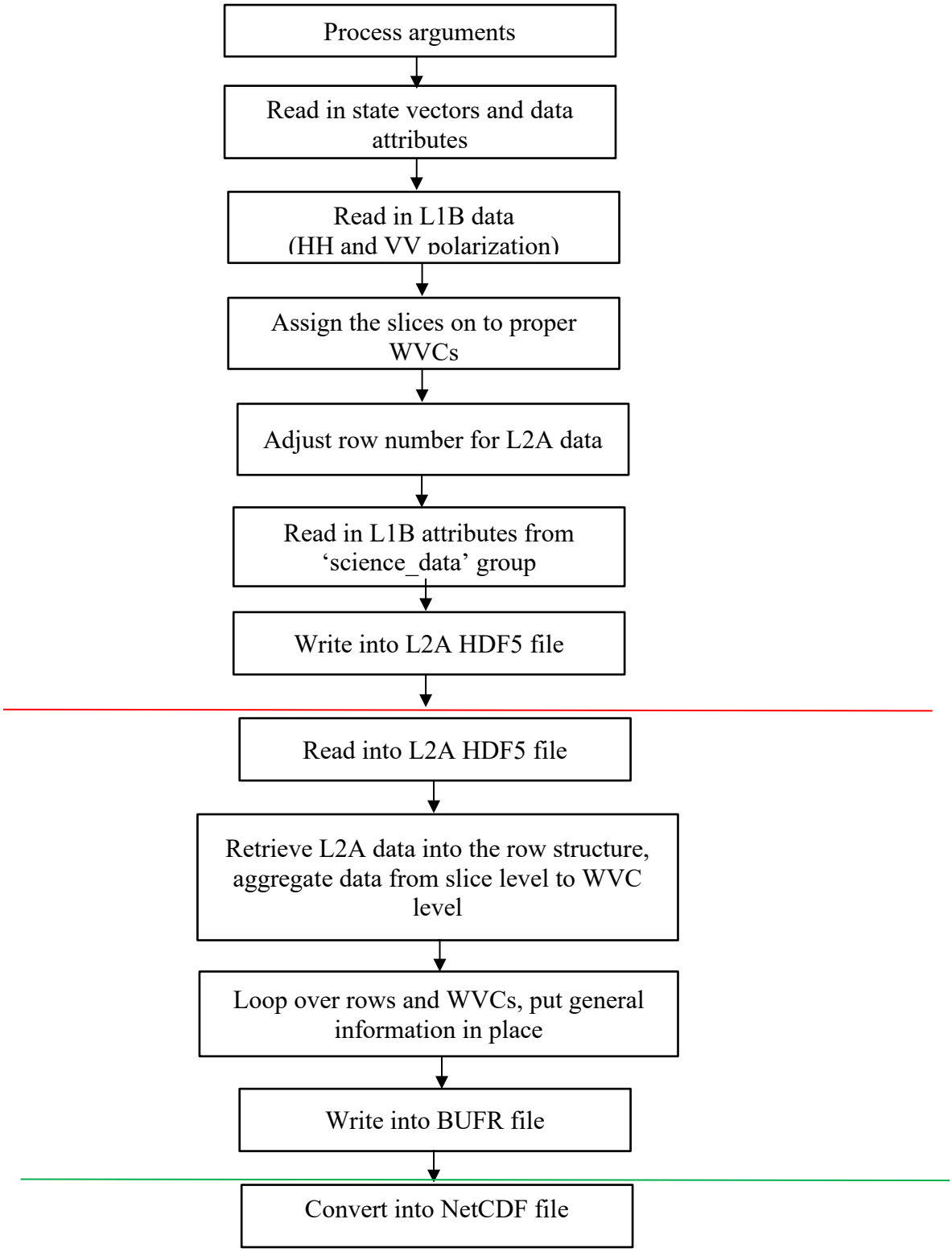


Figure 1 Baseline of the L2A processor (above the red line is the 1st part `cfosat_l1b_l2a`, below the red line and above the green line is the 2nd part `cfosat_hdf2bufr`).

2.2 Layered model structure

The L2A processor is a Fortran90 software package with a number of Fortran90 modules and routines. It is set up from two layers. The first one is the process layer and the second one is the generic scatterometer processing layer (genscat).

Table 1 shows the process layer of the processor `cfosat_l1b_l2a` and Table 2 shows the modules in genscat used by `cfosat_l1b_l2a`. Table 3 shows the process layer of the processor `cfosat_hdf2bufr` and Table 4 contains the modules in genscat used by `cfosat_hdf2bufr`. Table 5 shows the modules in genscat used for converting BUFR to NetCDF. The calling trees for `cfosat_l1b_l2a` and `cfosat_hdf2bufr` are shown in Figure 2 and Figure 3.

Table 1 L2A processor modules and routines (`cfosat_l1b_l2a`).

Module/routine name	Tasks	Comments
cwdp_data	Definition of data structure	
constant	Define types and constants	L1B type and L2A type
asc2sec	Convert time in character string to Julian seconds	
group_sigma0	Assign the L1B slices onto proper WVCs and aggregate them to views	
compute_orbit_elements	Get frame time and frame ephemeris data, calculate and return the following instantaneous orbit elements: Nodal Period, Longitude of Ascending Node, Orbit Inclination, Orbital Major Axis, and Orbit Eccentricity. These elements combined with the sigma0 cell longitude and latitude are used by	Used in *group_sigma0*

Module/routine name	Tasks	Comments
	sws_ijbin	
sws_ijbin	Utilizes the orbit elements calculated by *compute_orbiteElements* and maps every measurement into sub-track coordinates	Called in *group_sigma0*
sec2asc	Convert Julian seconds to a character string containing year, day, hour, minute, second	
reverse_cell_index	Reverse cell index to be consistent with ISRO	
reverse_num_sig_in_cell	Reverse the number of sigma0 in cell	
write_l2a	Write L2A output into HDF5 format	

Table 2 genscat process modules used in `cfosat_l1b_l2a`.

Module	Tasks	Comments
DateTimeMod	Convert year, month, day to Julian day	JulianDay is used.
Compiler_Features	Handling command line arguments	
HDF5Mod	Create HDF5 files	
NetcdfReaderWriter	Read NetCDF files	

Table 3 L2A processor modules and routines (`cfosat_hdf2bufr`).

Module/routine name	Tasks	Comments
cwdp_data	Definition of data structures	
cwdp_bufr	BUFR file handling	Interface to `genscat/support/bufr`
cwdp_prepost	Quality control Atmospheric attenuation Post processing Monitoring Clean up	Only `write_properties` is used here to obtain and write some properties of the last row in the file
get_l2a_data	Retrieve L2A data into the row structure and aggregate slice level data to WVC level	
add_slice_to_wvc	Add slice data to WVC view for aggregate	Called by *get_l2a_data*

Table 4 genscat process modules used in `cfosat_hdf2bufr`.

Module	Tasks	Comments
Compiler_Features	Handling command line arguments	
HDF5Mod	Create HDF5 files	
numerics	Convert dB to linear scale and linear scale to dB	
DateTimeMod	Convert day to Julian date	

Table 5 genscat process modules used for convert BUFR to NetCDF.

Module	Tasks	Comments
bufr2nc_cfosat_L2A	Convert BUFR format to	

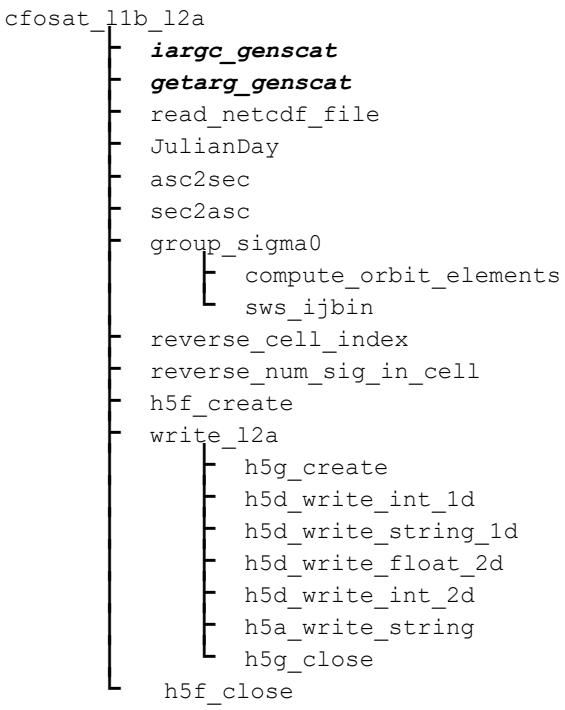
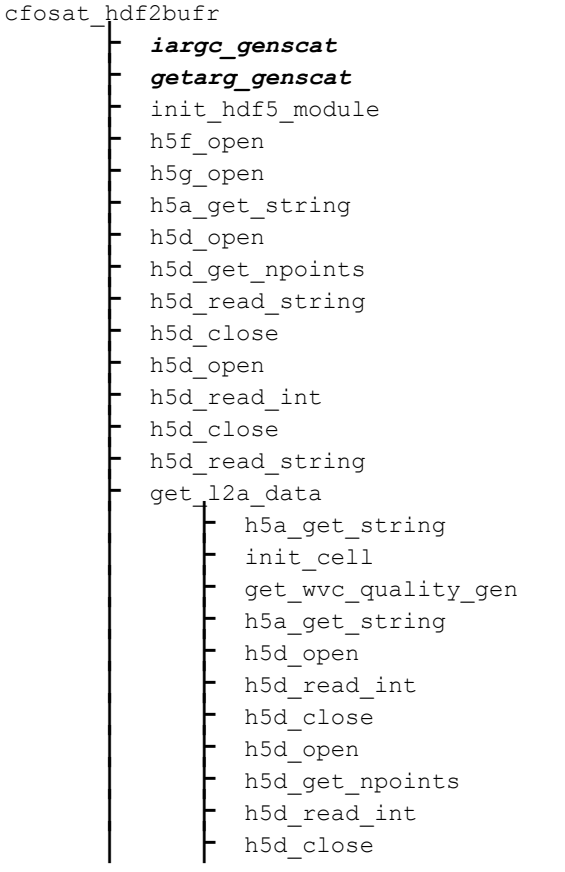


Figure 2 Calling tree for `cfosat_l1b_l2a`.



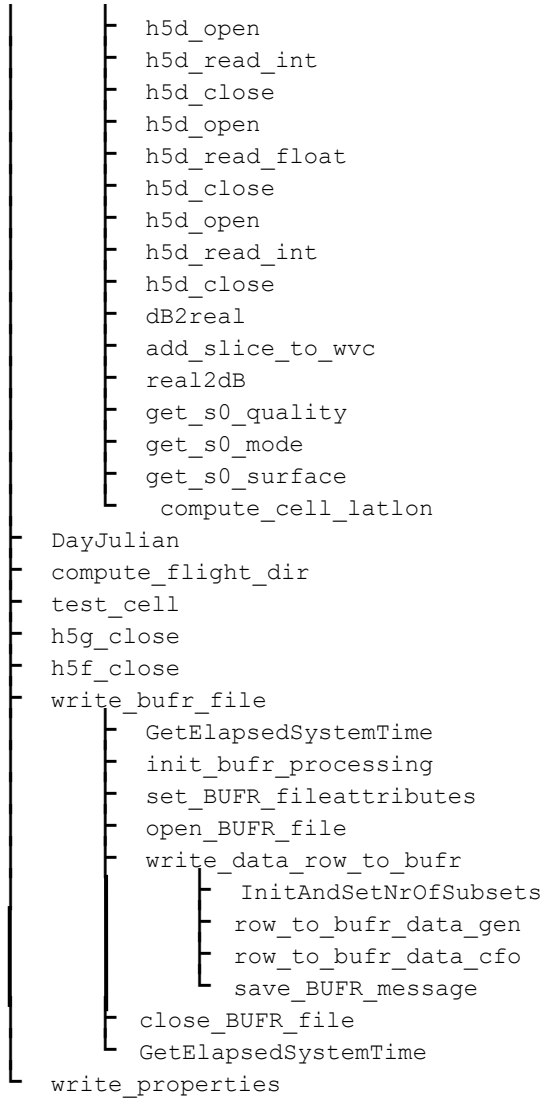


Figure 3 Calling tree of `cfosat_hdf2bufr`.

2.3 Data structure

The data structure of L2A output is organized in WVCs for each row. For one WVC, the geometry data, sigma0, etc. of each view are stored. The L2A data structure is illustrated in Figure 4.

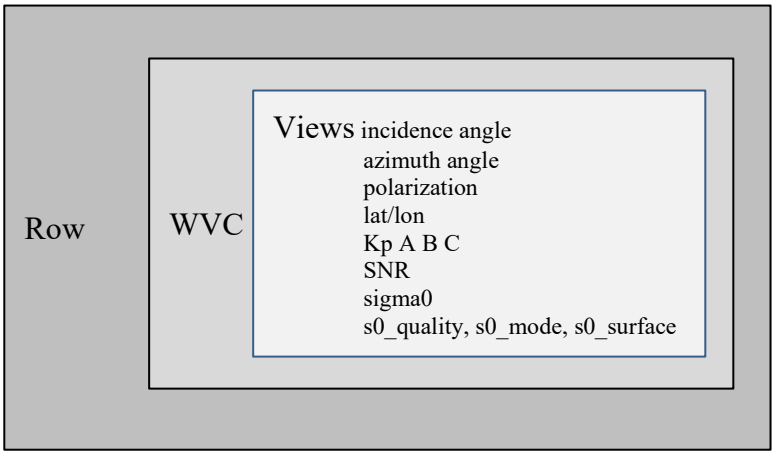


Figure 4 Data structure illustration of L2A.

3. CWDP design

In this chapter, the design of the CWDP software package is described in detail. Section 3.1 is a summary of this software and the readers who are interested in every detail of the software are recommended to read the complete chapter as well as the documentation within the code.

3.1 Top level design

3.1.1 Main program

The main program CWDP (file `cwdp` in the `cwdp/src` directory) is a Unix (Linux) executable which processes CFOSAT RFSCAT (Rotating Fan-beam SCATterometer) Ku-band L2A BUFR files. The output is in BUFR format and can be converted to NetCDF format. The specifications of the output are in [1]. The user may provide arguments and parameters according to Unix command line standards and the available options are described in [1]. When executed, the CWDP logs information on the terminal screen, and the log information detail level can be set with the verbosity flag.

The baseline of processing is shown in Figure 5 and some of the steps might be skipped according to the command line arguments chosen by the user . The arguments given at the command line are first processed with the genscat *Compiler_Features* module. Then CWDP reads in the L2A BUFR input and maps it to the CWDP data structure (see section 3.1.3). A pre-processing and checking of the input data are done, followed by reading in atmospheric attenuations. The atmospheric attenuations are read from a table of climatologic values. Ocean calibration is also a look up table that can be read in by the software. The ECMWF GRIB data (wind forecasts, land-sea mask and sea surface temperature) are read in and they are collocated with the WVCs. The inversion and the ambiguity removal on WVC are the following steps. Post-processing does some conversions and monitoring. Finally, the output data are written into BUFR format and the BUFR format can be converted into NetCDF format for standardized distribution.

The different steps in the baseline are corresponding directly to different modules and those modules are largely adopted from PenWP [1] (see section 3.3).

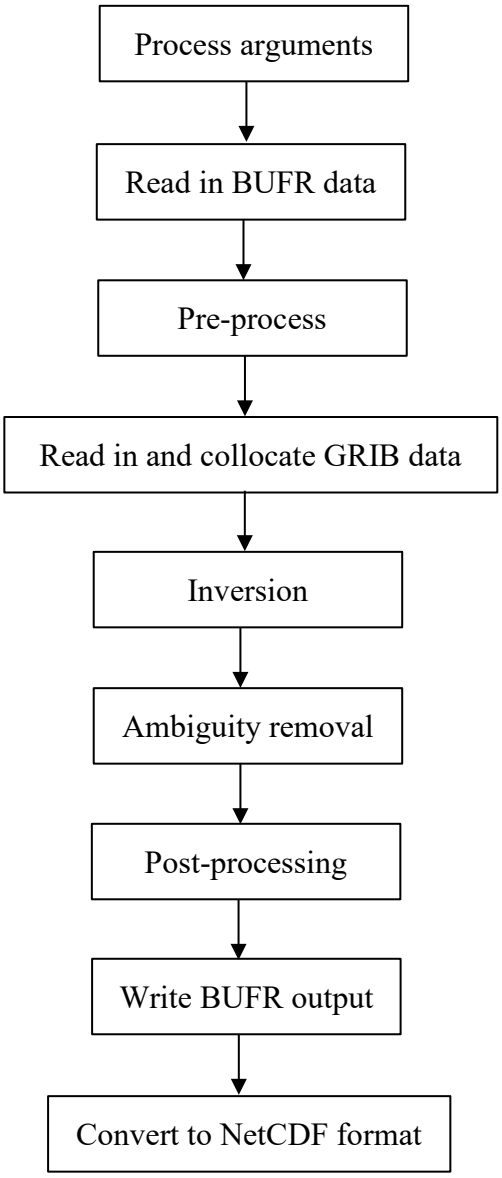


Figure 5 Baseline of CWDP.

3.1.2 Layered model structure

CWDP is a Fortran 90 software package consisting of several Fortran 90 modules and they are linked after their individual compilation. With the same layer concept as the L2A processor, CWDP contains two layers to separate the generic scatterometer processing software and Ku-band RFSCAT software. The first layer is the process layer containing the modules which are used in the main processing. This layer is adapted from PenWP. The second layer is the generic scatterometer processing layer. Details of these two layers can be found in 3.3 and 3.2. The modules serving the main steps in the first layer are listed in Table 6. Each module contains one or more tasks and those tasks are elaborated in section 3.3.

Table 6 CWDP process modules (adapted from PenWP [3]).

Module name	**Tasks**	**Comments**
cwdp_data	Definition of data structures	
cwdp_bufr	BUFR file handling	Interface to `genscat/support/bufr`
cwdp_prepost	Quality control Atmospheric attenuation Post processing Monitoring Clean up	Usability of input data is determined Setting of flags De-allocate memory
cwdp_grib	GRIB file handling Collocation of GRIB data	Interface to `genscat/support/grib` GRIB data are interpolated w.r.t. time and location
cwdp_calibrate	Perform ocean calibration	
cwdp_inverion	Inversion	Interface to `genscat/inversion`
cwdp_ambrem	Ambiguity removal	Interface to `genscat/ambrem`

The second layer is the genscat layer. The genscat module classes (i.e., group of modules) used in the CWDP package are listed in Table 7. The genscat package is a set of generic modules which are used in different scatterometer processors and it also can be used for other processing purposes such as the L2A processor. A brief description of the main modules used in CWDP is given in section 3.2. The genscat layer has a few modifications to adapt to CWDP configurations and those modifications are described in section 3.2. The major part is consistent with PenWP. The most important module classes are elaborated: the inversion step ([3] section 3), the ambiguity removal step ([3] section 4), the BUFR file handling ([3] section 6), the GRIB file handling ([3] section 7).

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.

Table 7 genscat module classes.

Module class	**Tasks**	**Description**
Ambrem	Ambiguity Removal	2DVAR and other schemes
Inversion	Wind retrieval	Inversion in one cell
IceModel	Ice screening	Uses ice line and wind cone for ice discrimination
Support	BUFR support HDF5 support NetCDF support GRIB support FFT, minimization Error handling File handling Conversion Sorting Date and time	*BufrMod*, based on ECMWF library Reading of HDF5 files Writing NetCDF files *gribio_module*, based on ECMWF library Support for 2DVAR Print error messages Finding, opening and closing free file units Conversion of meteorological quantities Sorting of ambiguities to their probability General purpose
tools	BUFR to NetCDF conversion	Convert BUFR format of L2A and L2B data to NetCDF format

3.1.3 Data structure, quality flagging and error handling, verbosity

The data structure is kept the same as the output of PenWP ([3] section 2.1.3). The differences are: firstly, the CWDP output of each WVC contains a flexible number of views while PenWP output of each WVC contains a fixed number of four views; secondly, because of the flexible number of views, the BUFR table is adapted for CWDP and new entries are added

which can hold a maximum number of 18 beams instead of four. Quality flagging and error handling is described in [3] section 2.1.4. and verbosity handling is described in [3] section 2.1.5.

3.2 Module design for genscat layer

The process layer consists of the modules cwdp_data, cwdp_bufr, cwdp_prepost, cwdp_calibrate, cwdp_grib, cwdp_inversion, cwdp_icemodelF and cwdp_ambrem. The routines present in these modules are consistent with the modules in PenWP [3] section 2.3 except for a few modules which are described in 3.2.1 and 3.2.2.

3.2.1 Module *bufr2nc*

The module bufr2nc is used in two locations:
genscat/tools/bufr2nc_cfosat_L2A and
genscat/tools/bufr2nc_cfosat_L2B. The retrieved information from L2A BUFR and L2B BUFR are different, so the module bufr2nc located at different locations are adapted to L2A output and L2B output separately to convert BUFR to NetCDF. They are only used after all the processing is completed.

3.2.2 Module *bufr_data_extraction_module*

The module *bufr_data_extraction_module* provides an easier way to extract the parameters from BUFR data. The module locates at `genscat/tools/bufr_l2_reader`. It is used in module *bufr2nc* in both L2A and L2B conversion.

3.3 Module design for process layer

The processing layer contains a number of modules *cwdp_data, cwdp_bufr, cwdp_grib, cwdp_prepost, cwdp_inversion*, *cwdp_icemodel (not implemented)* and *cwdp_ambrem*. They are all adopted from PenWP, so only changes are presented in the report (Table 8) and the other details are in [3] section 2.3.

Table 8 The adaptions from PenWP to CWDP.

Module name	**Adaption**	
	CWDP	**PenWP**
cwdp_data	**max**_beams = 18 **max**_grib_files=55 **sat**_id_cfosat=802 **sat**_instr_cfosat=943 **software**_version=1003 **Add** variable nr_of_beams	max_beams = 4 max_grib_files=25 software_version=2001
cwdp_bufr	**BUFR** table D uses data descriptor 3 12 034 **num**_descriptors=328	BUFR table D uses data descriptor 3 12 028 num_descriptors=118
cwdp_grib	none	none
cwdp_prepost	**Add** is_cfosat and sat_id_cfosat **Add** option filter for selecting WVCs to the output (e.g. exclude outer swath) **The** way to set wvc_quality%qual_sigma0 modified due to the changing number of views in each WVC **Number** of WVC per row is 42	 Number of WVC per row is 76

References

[1] Z. Li, A. Verhoef, A. Stoffelen, “CWDP User Manual and Reference Guide,” SAF/OSI/CDOP3/KNMI/TEC/MA/320, 2021

[2] Z. Li, A. Verhoef, A. Stoffelen, “CWDP L2A processor Specification and User Manual,” SAF/OSI/CDOP3/KNMI/TEC/MA/319, 2021

[3] A. Verhoef, J. Vogelzang, J. Verspeek, and A. Stoffelen, “PenWP Top Level Design”, 2017.

[4] "NWP SAF Development Procedures for Software Deliverables", NWPSAF-MO-SW-002, EUMETSAT NWP SAF 2016

[5] Z. Li, A. Verhoef, and A. Stoffelen, CWDP Test Plan and Test Report", SAF/OSI/CDOP3/KNMI/TEC/PL/322, 2021

Appendix A: Acronyms

BUFR	Binary Universal Form for the Representation of data
CFOSAT	China-France Oceanography SATellite
CWDP	CFOSAT Wind Data Processor
ECEF	Earth Centered Earth Fixed
ECI	Earth Centered Inertial
ECMWF	European Centre for Medium-Range Weather Forecasts
GRIB	GRIdded Binary or General Regularly-distributed Information in Binary form
HDF5	Hierarchical Data Format version 5
ISRO	Indian Space Research Organization
L2A	Level 2-A
L2B	Level 2-B
lat	latitude
lon	longtitude
NetCDF	Network Common Data Form
PenWP	Pencil-beam Wind Processor
PS	Product Specification
SGP4	Simplified General Perturbations 4
TLD	Top Level Design
UCAR	University Corporation for Atmospheric Research
UM	User Manual
UNIDATA	a member of the UCAR Community Program
WVC	Wind Vector Cell