	User Manual for the Extrapolated Imagery Processor of the NWC/GEO: Science Part	Code: NWC/CDOP3/GEO/ZAMG/SCI/UM/EXIM Issue: 2.0 Date: 10 January 2022 File: NWC-CDOP3-GEO-ZAMG-SCI-UM-EXIM_v2.0.docx Page: 1/26
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User Manual for the Extrapolated Imagery Processor of the NWC/GEO: Science Part

NWC/CDOP3/GEO/ZAMG/SCI/UM/EXIM, Issue 2.0

10 January 2022



Applicable to

GEO-EXIM-v2.1 (NWC-087)

Prepared by ZAMG

REPORT SIGNATURE TABLE

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 	<p>User Manual for the Extrapolated Imagery Processor of the NWC/GEO: Science Part</p>	<p>Code:NWC/CDOP3/GEO/ZAMG/SCI/UM/EXIM Issue: 2.0 Date: 10 January 2022 File:NWC-CDOP3-GEO-ZAMG-SCI-UM-EXIM_v2.0.docx Page: 3/26</p>
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DOCUMENT CHANGE RECORD



Version	Date	Pages	CHANGE(S)
1.0	<i>22 May 2017</i>	22	Initial version for the NWC/GEO release 2016
1.0 (of CDOP-3)	<i>21 January 2019</i>	24	Version for the NWC/GEO release 2018; changes concern <ul style="list-style-type: none"> - Options on selection of layers for the displacement field (sections 4.2, 5.1. 5.2) - Option to order difference images EXIM – observation (sections 3., 4.2) - Inclusion of Himawari and CMIC input
1.0, rev.1	<i>1 October 2019</i>	26	Version for SAFNWC/GEO v2018.1 (GOES-R patch; minor additions).
2.0	<i>10 January 2022</i>	26	Version for SAFNWC/GEO v2021. Inclusion of optional CTTH filtering; transfer of information on output files and error codes from SUM/2 to this document.

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1. INTRODUCTION

The EUMETSAT's "Satellite Application Facilities" (SAFs) are dedicated centres of excellence for processing satellite data, and form an integral part of the distributed EUMETSAT Application Ground Segment (<http://www.eumetsat.int>). This documentation is provided by the SAF on Support to Nowcasting and Very Short Range Forecasting, NWC SAF. The main objective of NWC SAF is to provide, further develop and maintain software packages to be used for Nowcasting applications of operational meteorological satellite data by National Meteorological Services. More information can be found at the NWC SAF webpage, <http://nwc-saf.eumetsat.int>.

1.1 SCOPE OF THE DOCUMENT

This document is the Product User Manual for NWC/GEO Extrapolated Imagery Products (PGE16).

This document contains practical information on the characteristics of the above mentioned products, on their applicability and limitations.

1.2 SCOPE OF OTHER DOCUMENTS

The algorithms used to extract the NWC/GEO Extrapolated Imagery Products (PGE16) are detailed in an Algorithm Theoretical Basis Document [RD. 6].

Instructions to install, configure and execute the NWC/GEO software in order to extract the Extrapolated Imagery Products (PGE16) are detailed in a Software User Manual.

The documents [AD.5]-[AD.7] detail the input and output data format for the NWC/GEO software.

1.3 SOFTWARE VERSION IDENTIFICATION

This document describes the products obtained from the PGE16 version included in the 2021 NWC/GEO software package delivery.

1.4 IMPROVEMENT FROM PREVIOUS VERSION

Optional exploitation of the CTTH product to match pixel height with layer of used displacement vectors. Parameter `crrph_iqf` removed (not present anymore in the new CRRPh product) and replaced by `ctth_effectiv`.

1.5 DEFINITIONS, ACRONYMS AND ABBREVIATIONS



See [RD.1] for a complete list of acronyms for the SAF project.

1.6 REFERENCES

1.6.1 Applicable Documents

The following documents, of the exact issue shown, form part of this document to the extent specified herein. Applicable documents are those referenced in the Contract or approved by the Approval Authority. They are referenced in this document in the form [AD.X].

For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. For undated references, the current edition of the document referred applies.

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Current documentation can be found at the NWC SAF Helpdesk web: <http://nwc-saf.eumetsat.int>.

Ref	Title	Code	Vers	Date
[AD.1]	Project Plan for the NWCSAF CDOP3 phase	NWC/CDOP3/SAF/AEMET/MGT/PP	1.6	01/12/21
[AD.2]	NWCSAF CDOP3 Project Plan Master Schedule	NWC/CDOP3/SAF/AEMET/MGT/PP/Ma sterSchedule	1.6	01/12/21
[AD.3]	Configuration Management Plan for the NWC SAF	NWC/CDOP3/SAF/AEMET/MGT/CMP	1.1	15/04/20
[AD.4]	System and Components Requirements Document for the NWC/GEO	NWC/CDOP3/GEO/AEMET/SW/SCRD	1.0	01/09/21
[AD.5]	Interface Control Document for Internal and External Interfaces of the NWC/GEO	NWC/CDOP3/GEO/AEMET/SW/ICD/1	2.0	01/09/21
[AD.6]	Interface Control Document for the NWCLIB of the NWC/GEO	NWC/CDOP3/GEO/AEMET/SW/ICD/2	2.0	01/09/21
[AD.7]	Data Output Format for the NWC/GEO	NWC/CDOP3/GEO/AEMET/SW/DOF	2.0	10/01/22
[AD.8]	Component Design Document for the NWCLIB of the NWC/GEO	NWC/CDOP2/GEO/AEMET/SW/ACDD/ NWCLIB	2.0.1	31/07/18
[AD.9]	NWC SAF Product Requirements Document	NWC/CDOP3/GEO/AEMET/MGT/PRD	1.5	01/12/21
[AD.10]	User Manual for the Tools of the NWC/GEO	NWC/CDOP3/GEO/AEMET/SCI/UM/To ols	2.0	10/01/22

Table 1: List of Applicable Documents

1.6.2 Reference Documents



The reference documents contain useful information related to the subject of the project. These reference documents complement the applicable ones, and can be looked up to enhance the information included in this document if it is desired. They are referenced in this document in the form [RD.X].

For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. For undated references, the current edition of the document referred applies.

Current documentation can be found at the NWC SAF Helpdesk web: <http://nwc-saf.eumetsat.int>

Ref	Title	Code	Vers	Date
[RD.1]	The Nowcasting SAF Glossary	NWC/CDOP3/SAF/AEMET/MGT/GLO	1.0	20/10/20
[RD.2]	Algorithm Theoretical Basis Document for the Extrapolated Imagery Processor of the NWC/GEO	NWC/CDOP3/GEO/ZAMG/SCI/ATBD/E XIM	1.0	01/09/21
[RD.3]	Scientific and Validation Report for the Extrapolated Imagery Processor of the NWC/GEO	NWC/CDOP2/GEO/ZAMG/SCI/VR/EXI M	1.0	22/05/17
[RD.4]	Scientific and Validation Report for the Extrapolated Imagery Processor of the NWC/GEO	NWC/CDOP3/GEO/ZAMG/SCI/VR/EXI M	1.0	21/01/19
[RD.5]	Scientific and Validation Report for the Extrapolated Imagery Processor of the NWC/GEO	NWC/CDOP3/GEO/ZAMG/SCI/VR/EXI M	2.0	10/01/22

Table 2: List of Referenced Documents

 	User Manual for the Extrapolated Imagery Processor of the NWC/GEO: Science Part	Code: NWC/CDOP3/GEO/ZAMG/SCI/UM/EXIM Issue: 2.0 Date: 10 January 2022 File: NWC-CDOP3-GEO-ZAMG-SCI-UM-EXIM_v2.0.docx Page: 8/26
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2. DESCRIPTION OF THE EXTRAPOLATED IMAGERY (EXIM) PRODUCTS

2.1 GOAL OF THE EXTRAPOLATED IMAGERY (EXIM) PRODUCTS

PGE16 of the NWC/GEO provides forecast SEVIRI (or GOES-N or GOES-R or Himawari) imagery or NWCSAF products up to a lead time of 1 hour¹. It does so by applying kinematic extrapolation using atmospheric motion vectors (AMV) for displacing either SEVIRI pixels or selected NWCSAF analyses. The results are plausible short-term forecast fields of

- all SEVIRI channels except HRVIS
- GOES-N or GOES-R or Himawari channels
- the NWCSAF products “cloud mask”, “cloud type”, “cloud top temperature and height”, “cloud microphysics”, “precipitating cloud” and “convective rainfall rate”

under the assumption that dynamic changes in the fields may be neglected.

2.2 OUTLINE OF THE EXTRAPOLATED IMAGERY (EXIM) ALGORITHM



The AMVs generated by the NWC/GEO High Resolution Wind Package PGE09-HrW are interpolated onto the SEVIRI pixel grid using an inverse distance weighted interpolation scheme. The AMV field corresponding to a time interval T between current and precursor image is applied n times to the current image at time t , thus producing extrapolative forecasts up to $n \times T$ minutes, with the maximum lead time in minutes being chosen by the user.

For each pixel, the next position $P=(x,y)$ at time $t+T$ is determined by assuming that the movement of the pixel persists. In a possible second extrapolation step (for $t+2 \times T$), the position of the pixel is extrapolated with the AMV that had been observed at position $P(t)$. The repetitive application of the procedure yields trajectories under the assumption of a temporally invariable displacement field.

The trajectory field is smoothed and then applied to the analysis fields in order to make the kinematic forecasts. A distinction is made between fields consisting of continuous variables (i.e. quantities where operations such as averaging can be applied) and categorical variables (where any combination of two distinct values is meaningful).

- For the continuous variables, the parameter value of the displaced pixel is apportioned to the (normally) 4 pixels with which the "forecast pixel" overlaps. After evaluation of all trajectories, the pixel value at any position of the forecast image is determined from the individually collected contributions through a weighted average. For pixels that are not touched by a trajectory, the post-processing step searches for adjacent pixels that have been assigned a value. The search is in 8 directions regularly arranged around a circle (at angles of 22.5° , 67.5° ,... against the horizontal direction) until an already classified pixel in the respective direction is encountered. To obtain the parameter value for the pixel in question, a weighted average is computed from the values at the up to 8 neighbours. The weights are $1/r_i^2$, with r_i being the distance between the void pixel and its i -th neighbour.
- For categorical variables, the parameter value at the trajectory's origin is copied to the forecast image at the position given by the rounded “new” x - and y -coordinates. If by chance another trajectory would target that pixel later, then the previously assigned parameter value will be overwritten. Also here, a post-processing step may be appended,

¹ The software does not actually block the user from specifying larger lead times. The application is then, however, outside NWCSAF responsibility (with respect to e.g. validation or timeliness requirements)

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searching in the 8 directions at angles of 22.5°, 67.5°,... against the horizontal direction until an already classified pixel in the respective direction is hit. From the up to 8 neighbours, the class to which the majority of neighbours belongs to is determined. If there is a tie between two categories, a decision is made on the criterion which class has the lower sum-of-distances between the currently considered void pixel and the affected neighbours. If also this criterion leads to no decision, the selection is arbitrary, depending on the order in which the adjacent pixels were assembled. Note that for certain categorical parameters, even this sort of nearest-neighbours processing is not permissible and EXIM rather leaves (usually small) gaps in the images (compare Table 4).

The software offers options to follow a two-layer approach (trajectories computed separately for an upper and lower layer, respectively) and to perform CTTH checking (if a pixel falls outside the defined layer(s), it does not undergo extrapolation); cf. keyword CTTH_FILTER and everything with “LAYER” in 4.2 and the graphical illustrations of effects of changing these parameters, section 6.2.

2.3 DESCRIPTION OF EXTRAPOLATED IMAGERY (EXIM) OUTPUTS

- (1) For the NWCSAF products forecast in EXIM, it was decided to encode them in netCDF, mimicking the format of the NWCSAF product file forming the input/starting point for the EXIM extrapolation. The contents are described e.g. in the NWCSAF Data Output Format Document [RD.1] and in product-specific documentation. The forecast files are altogether assembled in the EXIM output directory \$SAFNWC/export/EXIM. The names of the EXIM output files adhere to the NWC/GEO convention on netCDF file naming, and have an insertion of the leadtime before the extension .nc. As an example, a 30-minute forecast of CMA valid for 1 April 2012, 12.45 UTC, may have been found in a file named S_NWC_EXIM-CMA_MSG2_Region-VISIR_20120401T121500Z_030.nc.
- (2) The forecast satellite imagery are also encoded in netCDF. The contents are described in the NWCSAF Data Output Format Document [RD.1]. The names of the output files (located in \$SAFNWC/export/EXIM) adhere to the NWC/GEO convention on netCDF file naming, and have an insertion of the leadtime before the extension indicating the physical quantity in the file. For example, 30-minute forecasts of IR10.8 brightness temperature and radiance valid for 1 April 2015, 12.45 UTC, could be found in a file named S_NWC_EXIM-IR108_MSG3_Europe-VISIR_20150401T121500Z_030.nc.
- (3) The optional difference images between forecast satellite imagery and the actual observation at the target date are also encoded in netCDF. They have the same characteristics as the forecast imagery, yet the channel designation is preceded by a “D” (for difference) in netCDF data containers and the output file names. For example, the difference between a 30-minute forecast of IR10.8 valid for 1 April 2015, 12.45 UTC, and the image measured at that point in time would be found in a file named S_NWC_EXIM-DIR108_MSG3_Europe-VISIR_20150401T121500Z_030.nc (the leadtime of the forecasts inspected in this way is user-configurable, cf. 4.2).

Note that the files of items (1) and (2) also contain the EXIM-specific quality flag applicable to all products. The quality flag file has one byte per pixel and the flag can assume values 0-255, with the following meanings:

Code	Meaning
0	No EXIM forecasts available for this pixel
1-254	Forecast through trajectory displacement available; the numerical value indicates the distance of the nearest vector in terms of satellite pixels+1; everything >254 set to 254
255	Not hit by a trajectory but forecast made available at this pixel through post-processing using adjacent pixels

The “product completeness” field in the netCDF file derives from the number of processed pixels divided by the total number of pixels (a baseline effect is to be expected if the processing region has space pixels in it; the ratio goes further down (possibly considerably) in case the default setting to disregard cloudfree pixels is active). The “product quality” field expresses the percentage of processed pixels derived through actual extrapolation (rather than gap filling through interpolation using adjacent extrapolated information). (Note: for the forecast SAF products of EXIM, no viable general strategy has been devised so far for the two summary statistics; as the NWCSAF netCDF model requires the two figures, some meaningless dummy values are written to the output for the time being.)

NWCSAF product (and acronym)	Sub-fields forecast by EXIM
Cloud Mask (CMA)	cma, cma_status_flag
Cloud Type (CT)	ct, ct_status_flag
Cloud Top Temperature and Height (CTTH)	ctth_pres, ctth_alti, ctth_effectiv, ctth_status_flag
Precipitating clouds (PC)	pc
Convective Rainfall Rate (CRR)	crr_intensity, crr_status_flag
Precipitating clouds – Physical Retrieval (PCPh)	pcph, pcph_status_flag
Convective Rainfall Rate – Physical Retrieval (CRRPh)	crrph_intensity, crrph_status_flag
Cloud Microphysics (CMIC)	cmic_phase, cmic_status_flag

Table 3: NWCSAF fields handled by EXIM. The designations in the right column are those of the netCDF output files, according to [AD.7].



For different reasons, sometimes only subsets of the matrices found in the NWCSAF analysis files undergo extrapolation. Table 3 shows the product sub-fields that are actually extrapolated provided the user orders the product.

Parameters differ in their character and in their encoding. It is important to know which values in the EXIM fields indicate an outage (e.g. at the edge of the domain where EXIM does not fill in values) and how the fields are post-processed (e.g. if not at all, an outage code may appear anywhere in the interior of the domain when a pixel was not touched by any trajectory). Table 4 lists this information for all NWC/GEO parameters considered in EXIM. Note that the indicator for “missing” can be found in NWC/GEO netCDF files as attribute `_FillValue`.

NWCSAF parameter(s)	Post-processing	Code for “Missing”
cma ct pc cmic_phase	Nearest-neighbour (if CTTH filtering is turned on, cf. sections 2.2 and 4.2: None)	255

ctth_alti, ctth_effectiv crr_intensity pcph crrph_intensity	ctth_pres, Averaging (if CTTH filtering is turned on, cf. sections 2.2 and 4.2: None)	65535
cma_status_flag ct_status_flag ctth_status_flag pcph_status_flag cmic_status_flag	None	32768
crr_status_flag crrph_status_flag	None	0

Table 4: List of the type of post-processing (the methods were detailed in section 2.2) and the numerical value indicating that the parameter is not available at a certain location, for the forecast NWCSAF products of EXIM. The parameter designations are those used in the netCDF output files, following [AD.7].

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3. IMPLEMENTATION OF EXTRAPOLATED IMAGERY (EXIM)

3.1 NWC/GEO SOFTWARE PACKAGE INSTALLATION AND PREPARATION

EXIM is extracted by PGE16 of the NWC/GEO software package. Detailed information on how to run this software package is available in the "Software User Manual for the NWC/GEO application".

The implementation of the EXIM software follows the general implementation of components of the NWC/GEO software (see the software part of the Software Users Manual of the NWC/GEO software for more details).

The following steps are needed to run the EXIM software:

1. Create or update configuration files (system, region, model and run configuration files) according to their format (see the Interface Control Document ICD/1 [AD.5]). Files are situated in \$SAFNWC/config. In particular, set the entries in the "product ordering" section of \$SAFNWC/config/safnwc_EXIM.cfm to YES or NO depending on whether a certain NWCSAF product or satellite channel extrapolation is desired (in the delivery, the default for all products and for all SEVIRI channels except IR16 is YES). The entry MAX_LEADTIME, which is the maximum lead time in minutes, is preset to 60 but can be modified. Technically it is possible to specify a value greater than 60; however, NWCSAF can not guarantee the quality of results in this case since EXIM has only been tested for a maximum lead time of 60 minutes. The entry D_IMG_LEADTIME specifies the forecast leadtime (in minutes) in case a difference image EXIM forecast minus measurement is ordered, and may be changed if something else than the default value of 15 (for Himawari and GOES-R: 20) seems more desirable. There are switches for each channel to enable/disable the production of the difference image (the default for these entries is NO).
2. Algorithm configuration files are situated in the directory "\$SAFNWC/import/Aux_data/EXIM". These PGE16 input files are provided with the software package, installed together with it, and are not foreseen for modification by users.
3. The NWCSAF HRW product matching slot and region has to be made available (in "predecessor wind format") in the directory "\$SAFNWC/tmp"
4. The NWCSAF products selected for extrapolation (which are the outputs of other PGEs of the NWC/GEO) matching slot and region have to be made available in their respective output directories "\$SAFNWC/export/{CMA,CT,CTTH,PC,CRR,CMIC}"
5. Likewise, if satellite images are selected for extrapolation, the SEVIRI image files in HRIT format (or: the GOES-N/GOES-R files in netCDF format; the Himawari files in either netCDF or native HSD format) have to be available in the directory \$SAFNWC/import/Sat_data/.



Then, the processing of EXIM is automatically monitored by the task manager (see the Software Users Manual for the Task Manager of the NWC/GEO software).

Submitting GEO-EXIM-v21 in stand-alone mode, not using the task manager:

Ensure that all required input data are available in their respective directories, and that pre-requirements listed under items 1-5 above are fulfilled.

The EXIM executable GEO-EXIM-v21 can be called as follows (from the directory where it is situated, which normally should be \$SAFNWC/bin):

GEO-EXIM-v21 YYYY-MM-DDThh:mm:ssZ <region_conf_file> <model_conf_file>

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Example:

GEO-EXIM-v21 2015-06-26T12:00:00Z test_exim.cfg safnwc_EXIM.cfm

3.2 NWC/GEO-EXIM DIAGNOSTIC ERRORS

The following table shows the whole list of errors and warnings that can appear during the execution of the NWC/GEO-EXIM PGE, the reasons causing these errors and warnings, and the way the NWC SAF user can try to solve them. In any case, if the errors or warnings persist, the NWC SAF Helpdesk should be contacted.

Code (E/W)	Message	Comment	Recovery action
E	“Usage: %s YYYY-MM-DDThh:mm:ssZ <region_conf_file> <model_conf_file>”	Error when launching	Check instruction for launching the EXIM PGE
E	All messages related to NWCLIB time handling functions: NwcTimeSetStr, NwcTimeSetT	Time input when launching PGE may be wrong.	Check the slot time input when launching PGE.
E	All messages including the following strings: “memory allocation” “allocation error” “Unable to allocate” “Error allocating” “not allocated” “cannot be allocated”	Problem of memory allocation	Check memory
E	All messages containing the following string: “ERROR when opening”	Problem to open an existing file or to create a new file.	Check permission and disk space on the directory. Check presence of the requested file. The recovery actions depends on the type of file: <ul style="list-style-type: none"> – for missing configuration files, copy them from delivered SW; – for missing file to be input by user: check why they are missing; for new file, check permission/disk space on the directory.
E	All messages containing the strings: “mod(el)_conf(iguration)_file” “PRODIO_CONF_FILE” “CONF_FILE_ERROR” “couldn’t find all parameters for...”	Problem when looking for configuration file or reading a key from it.	Check corresponding configuration file for presence and content. If needed, copy them from delivered SW.
E	All messages containing the strings: “OUTPUT_PRODUCT...ERROR” “Error initiating/writing/finalizing...” “Error in module Write...” “coding failed”	Problem to send output to file.	Check permission and disk space on the output directories.
E	All messages (and knock-on messages) related to <ul style="list-style-type: none"> • NWCLIB initialization functions: NwcRegionSet, NwcCFRead, NwcSatInit • NWCLIB Reading function NwcSatReadBand • NWCLIB numerical function NwcNavGetLatLon 		Consult NWCLIB-specific documentation
E	“Error in reading the supplementary input”	Refers to land-sea mask	Check correct installation of NWCSAF land-sea auxiliary data

Code (E/W)	Message	Comment	Recovery action
E	“Not enough vectors, hence no forecast images”	Threshold is set to 5 vectors from the HRW product (all channels together), hence this error indicates a fairly total outage	Check your HRW installation / configuration
E	“some issues arose when copying PRODIO_CONF_FILE”	EXIM has a problem to access one of the product configuration files	Check your EXIM installation.
E/W	Messages containing the term “LAYER”; “Problem with mod_conf_file parameter MAX_LEADTIME”; “Problem reading SAT_CLOUDS_ONLY from model configuration file”	Problem with EXIM model configuration file	Check your EXIM configuration.
W	“couldn’t read from the forecast file – no difference image is generated”	(self-explanatory)	
E	Messages stating in which part / which subroutine the problem occurred	Introduced mainly to facilitate debugging activities by the developers	Such messages should have been preceded by another error message (in most cases on memory allocation) → see the recovery actions under these categories

Table 5: List of possible errors reported by GEO-EXIM, v2.1.

4. INPUTS AND CONFIGURABLE PARAMETERS FOR EXTRAPOLATED IMAGERY (EXIM)

4.1 LIST OF INPUTS

- NWC/GEO product “High-Resolution Winds”, which is the output of HRW/PGE09 of the NWC/GEO (to be precise, the intermediate result in a simpler format, called “predecessor winds”, is used)

and conditionally (depending on whether the user ordered the extrapolation or not, cf. next section):

- SEVIRI data and/or GOES-N data and/or GOES-R data and/or Himawari data, channels according to user orders²
- NWC/GEO product “Cloud mask”
- NWC/GEO product “Cloud type”
- NWC/GEO product “Cloud top temperature and height”
- NWC/GEO product “Cloud microphysics”
- NWC/GEO product “Precipitating clouds”
- NWC/GEO product “Convective Rainfall Rate”
- NWC/GEO product “Precipitating clouds – Physical Retrieval”
- NWC/GEO product “Convective Rainfall Rate – Physical Retrieval”

4.2 CONFIGURABLE PARAMETERS FOR EXTRAPOLATED IMAGERY (EXIM)

The configurable parameters can be found in the model configuration files for the PGE16 (somewhat different between MSG, Himawari, GOES-R and GOES-N):

Keyword(s)	Description	Type	Possible Value(s)
CMA CT CTTH CMIC PC PCPh CRR CRRPh	Decide whether the extrapolation for the product with this acronym (cf. Table 3) is to be carried out. Products not generated for GOES-N/Himawari are not listed in the GOES-N/Himawari model configuration file.	chain of characters	YES or NO (the software interprets any expression with a “Y” or “y” in it as a “Yes”.)
VIS06 VIS08 IR16 IR38 WV62 WV73 IR87 IR97 IR108 IR120 IR134	Decide whether the extrapolation for the SEVIRI channel 0.6, 0.8, 1.6 etc. is to be carried out (GOES-N/GOES-R/Himawari channels may have slightly different wavelengths but there is an internal remapping to the most analogous SEVIRI channels so that there are no additional entries needed in the configuration file; when a channel does not exist on GOES-N/GOES-R/Himawari, the keyword is not present in the GOES/Himawari configuration file)	chain of characters	YES or NO (the software interprets any expression with a “Y” or “y” in it as a “Yes”.)

² The HRVIS channel of SEVIRI and the VIS channels of Himawari/GOES-R have different spatial resolution than the other channels of the respective instrument. Their extrapolation thus would require computation of their own dedicated trajectory field. Addition of this extra complexity shall be envisaged only after sufficiently favourable user reception of the EXIM products justifies this.

Keyword(s)	Description	Type	Possible Value(s)
D_IMG_LEADTIME	Specifies the lead time of the forecast compared with the actual measurements in the generation of the difference image	integer	All (note: the SW does not check whether the value makes sense)
DVIS06 DVIS08 DIR16 DIR38 DWV62 DWV73 DIR87 DIR97 DIR108 DIR120 DIR134	Decide whether the extrapolation for the SEVIRI channel 0.6, 0.8, 1.6 etc. is to be compared with the actually observed image at the target date (concerning GOES-N/GOES-R/Himawari channels, the same remarks as for the VIS06, VIS08... entries apply)	chain of characters	YES or NO (the software interprets any expression with a “Y” or “y” in it as a “Yes”.)
SAT_CLOUDS_ONLY	Specifies whether the forecast satellite imagery shall contain only the cloudy areas (default setting YES) or if the cloudfree areas shall be filled with the best possible estimate (setting NO)	Chain of characters	YES or NO (the software interprets any expression with a “Y” or “y” in it as a “Yes”.)
CTTH_FILTER	Specifies whether a check should be applied that suppresses extrapolation of those pixels that fall outside the layers defined with the keywords below	chain of characters	YES or NO (the software interprets any expression with a “Y” or “y” in it as a “Yes”.)
MAX_LEADTIME	The maximum lead time of EXIM products (in minutes).	integer	all
VIS_LAYER_1_1 VIS_LAYER_1_2 VIS_LAYER_2_1 VIS_LAYER_2_2	The numerically lower pressure threshold of layer 1 (or the only layer) of the VIS extrapolation, then the higher pressure threshold. Then follow the numerically lower and higher pressure thresholds of layer no.2.	integer	All (interpreted in units of hPa). If the two layers overlap, the second one is disregarded. If the second layer shall be avoided on purpose, it is clearer to set both thresholds to 0, for example.
IR_LAYER_1_1 IR_LAYER_1_2 IR_LAYER_2_1 IR_LAYER_2_2	The numerically lower pressure threshold of layer 1 (or the only layer) of the IR extrapolation, then the higher pressure threshold. Then follow the numerically lower and higher pressure thresholds of layer no.2.	integer	All (interpreted in units of hPa). If the two layers overlap, the second one is disregarded. If the second layer shall be avoided on purpose, it is clearer to set both thresholds to 0, for example.

Note that IR imagery and the NWCSAF products CMa, CT and CMIC are extrapolated with a certain selection of high-level IR/VIS vectors, VIS imagery and the NWCSAF products CTTH, PC, PCPh, CRR and CRRPh possibly with another selection (there was the idea that for this, one rather chooses low-level IR/VIS AMVs); the grouping was suggested by the outcome of the latest validation exercise (see [RD.4]). The water vapour absorption bands have different characteristics which eventually allows to avoid any thresholding, i.e. WV6.2 is extrapolated with all WV6.2 that are generated by the HrW module (and analogously for WV7.3) [RD.2]. This means that one can accomplish considerable time savings e.g. by turning off WV extrapolation as two of the four trajectory computations are omitted (provided, of course, there is no need for extrapolated WV imagery).

Usage of cloud mask information is generally considered positive for the extrapolation of the satellite imagery [RD.2]. It is therefore advised to leave the CMA configuration entry at “YES” even if there is no interest in the extrapolation of this parameter as such.

5. EXTRAPOLATED IMAGERY (EXIM) VALIDATION

5.1 RECOMMENDATIONS FOR THE USE OF EXIM

The following sections are derived from the validation reported in [RD.3]. Based on analyses of Peirce Skill Scores comparing persistence with the extrapolation forecast, recommendations were given for which products EXIM can be used to provide skilful forecasts. The following tables state the reliably forecasted isolines (column “Use of EXIM”) and those situations where more caution is advised (column “Exceptions”). For the product “SEVIRI physical retrieval” and the SEVIRI channel 1.6 μ m, the evaluation results suggested that the EXIM approach should generally not be exercised upon the field.

A subsequent evaluation ([RD.4]) added the “cloud phase” field of the Cloud Microphysics (CMIC) product to the list of parameters where EXIM extrapolation gives very satisfactory results. This evaluation also made it clear that generally the best results are obtained when all vectors from the HrW input are taken to derive the displacement field. This was indeed the approach followed in [RD.3], and it must be stressed that the results reproduced hereafter from that study hold only for the “All HrW” option (which in terms of the user configuration file (see 4.2) are accomplished through a setting of e.g. IR/VIS_LAYER_1_1=0, IR/VIS_LAYER_1_2=1100, IR/VIS_LAYER_2_1=IR/VIS_LAYER_2_2=0).

The most recent evaluation ([RD.5]) confirmed the applicability of the EXIM approach to the CTTH sub-field ctth_effectiv (\rightarrow taken on board for the first time in NWC/GEO v2021) and the new PCPh and CRRPh products (“new” insofar as they underwent substantial changes in the underlying algorithms at NWC/GEO v2021).

Abbreviations used in the following: BT: brightness temperature; LT: leadtime.

5.1.1 Thermal Channels: Infrared

Product	Use of EXIM	Exceptions
IR3.9	Summer: BT \in [250, 280] K Autumn, Spring: BT \in [250, 270] K Winter: BT \in [250, 270] K	- - 270 K, LT +60 min
IR8.7	Summer: BT \in [230, 280] K Autumn, Spring: BT \in [230, 270] K Winter: BT \in [230, 270] K	- - 270 K, LT +60 min
IR9.7	Summer: BT \in [230, 250] K Autumn, Spring: BT \in [230, 250] K Winter: BT \in [230, 240] K	- - -
IR10.8	Summer, Autumn: BT \in [230, 280] K Spring: BT \in [230, 280] K Winter: BT \in [230, 270] K	- - 280 K, LT \geq +45 min
IR12.0	Summer, Autumn: BT \in [230, 280] K Spring: BT \in [230, 280] K Winter: BT \in [230, 270] K	- - 280 K, LT \geq +45 min

IR13.4	Summer, Autumn: BT ∈ [230, 260] K Spring: BT ∈ [230, 260] K Winter: BT ∈ [230, 250] K	- - 260 K, LT +60 min
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5.1.2 Thermal Channels: Water Vapour

Product	Use of EXIM	Exceptions
WV6.2	BT ∈ [220, 240] K	-
WV7.3	BT ∈ [220, 260] K	-

5.1.3 Visible Channels

Product	Use of EXIM	Exceptions
VIS0.6	Radiances ∈ [4, 8]	Spring, Autumn: LT +60 min
VIS0.8	Radiances = 6 - Radiances = 8	Summer, Autumn: LT +60 min, Spring: LT ≥ +45 min Spring: LT +60 min
NIR1.6	Not recommended	

(Note that not enough sufficiently illuminated winter scenes were available for the validation report from which these figures are copied; therefore, no recommendation for the usage of EXIM in winter could be made there.)

5.1.4 CT: Cloud Type

Product	Use of EXIM	Exceptions
CT	Recommended for all seasons and lead times	Winter: LT +60 min

5.1.5 CTTH: Cloud Top Temperature and Height

Product	Use of EXIM
CTTH	Recommended for CTTH ≤ 8000 m

5.1.6 CRR: Convective Rainfall rate

Product	Use of EXIM
CRR	Recommended for CRR ≤ 5 mm/h

5.1.7 CRPh: Convective Rainfall Rate from Cloud Physical properties

Product	Use of EXIM	Exceptions
CRPh	CRPh \leq 11 (2.2 mm/h) Summer: CRPh \leq 71 (14.2 mm/h) Autumn: CRPh \leq 71 (14.2 mm/h) Winter: CRPh \leq 41 (8.2 mm/h) Winter: CRPh \leq 71 (14.2 mm/h) Spring: CRPh \leq 41 (8.2 mm/h) Spring: CRPh \leq 61 (12.2 mm/h)	- - 61, 71: LT +60 min LT +60 min LT \geq 45 min LT +60 min LT \geq 45 min

5.1.8 PC: Precipitating Clouds

Product	Use of EXIM	Exceptions
PC	Summer: \leq 60 % Autumn \leq 30 % Winter = 20% Spring \leq 30 %	+15 min at 40 % and 60 % - - 10%

5.1.9 PCPh: Precipitating Clouds from Cloud Physical Properties

Product	Use of EXIM	Exceptions
PCPh	Recommended for PCPh \leq 31%	Winter, LT +60 min for PCPh \geq 21 %

5.1.10 SPhR: SEVIRI Physical Retrieval Products – Layer Precipitable Water

Product	Use of EXIM
SPhR_BL	Not recommended
SPhR_ML	Not recommended
SPhR_HL	Not recommended
SPhR_TPW	Not recommended

Note: SPhR was the designation in v2013 (for which the validation was carried out). The product has been renamed in later versions to iSHAI (Imaging Satellite Humidity and Instability).

5.1.11 SPhR: SEVIRI Physical Retrieval Products – Stability Analysis

Product	Use of EXIM
SPhR_KI	Not recommended

SPhR_LI	Not recommended
SPhR_SHW	Not recommended

Note: SPhR was the designation in v2013 (for which the validation was carried out). The product has been renamed in later versions to iSHAI (Imaging Satellite Humidity and Instability).

5.2 KNOWN PROBLEMS

It is clear that all limitations mentioned for the NWCSAF input products in the respective sections of their ATBDs apply to the EXIM forecasts as well. In addition, dynamic changes in the meteorological parameters cannot be captured by the extrapolation approach. The implicit assumption behind the maintenance and development of EXIM is that NWP is not (yet?) able to provide adequate nowcasts of certain parameters.

The 2-D algorithm cannot be expected to capture the 3-D movements in the real atmosphere in every situation. Clearly, compromises are made in the interest of keeping this tool at a lower complexity in order to match the requirements of nowcasting, and even with two layers (with arbitrarily chosen and fixed boundaries), the approximation to the real atmosphere is a very coarse one.

Note that the validation results listed in Section 5.1 motivated a removal of the “SEVIRI Physical Retrieval” product from the EXIM portfolio. For the near-infrared channel 1.6 μm with a likewise negative judgement, however, we could not rule out an unanticipated application where its displacement might still be desired. The option to extrapolate IR16 was therefore not entirely removed, but the respective entry in the model configuration file was set to “NO” as default.

6. EXAMPLES OF EXTRAPOLATED IMAGERY (EXIM) VISUALISATION

6.1 SOME GENERAL EXAMPLES

For many years, forecast satellite imagery has been used at ZAMG's operational forecasting service to monitor/predict the advancing of frontal cloud bands. *Figure 1* shows the chosen visualization using a false colour representation with the range -7.5°C to -25°C in light red, -25°C to -40°C depicted in green, brightness temperatures $<-40^{\circ}\text{C}$ in yellow. Superimposed are the isolines -7.5°C , -25°C , -40°C of the forecast image, showing how far the “yellow”, “green” and “red” areas are expected to move in the next 2 hours. The right panel shows the observed image of the forecast date for verification purposes.

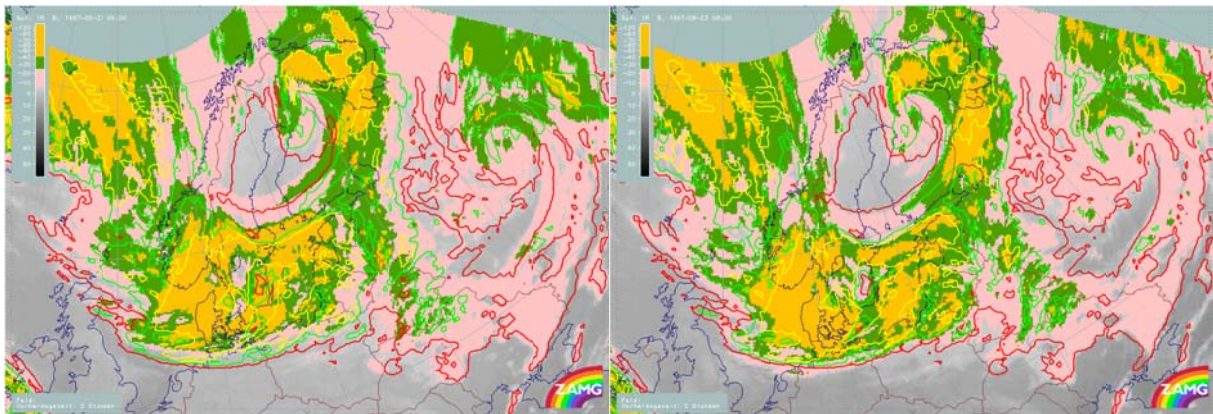


Figure 1: Kinematic extrapolation applied to cloud top temperatures. Left: Meteosat First Generation IR10.8 μm image from 23 September 1997, 06:00 UTC with the superimposed isoline forecast for 08:00 UTC (see text). Right: Validation - MFG IR10.8 μm image at 08:00 UTC, with the isoline forecast for 08:00 UTC again being superimposed.

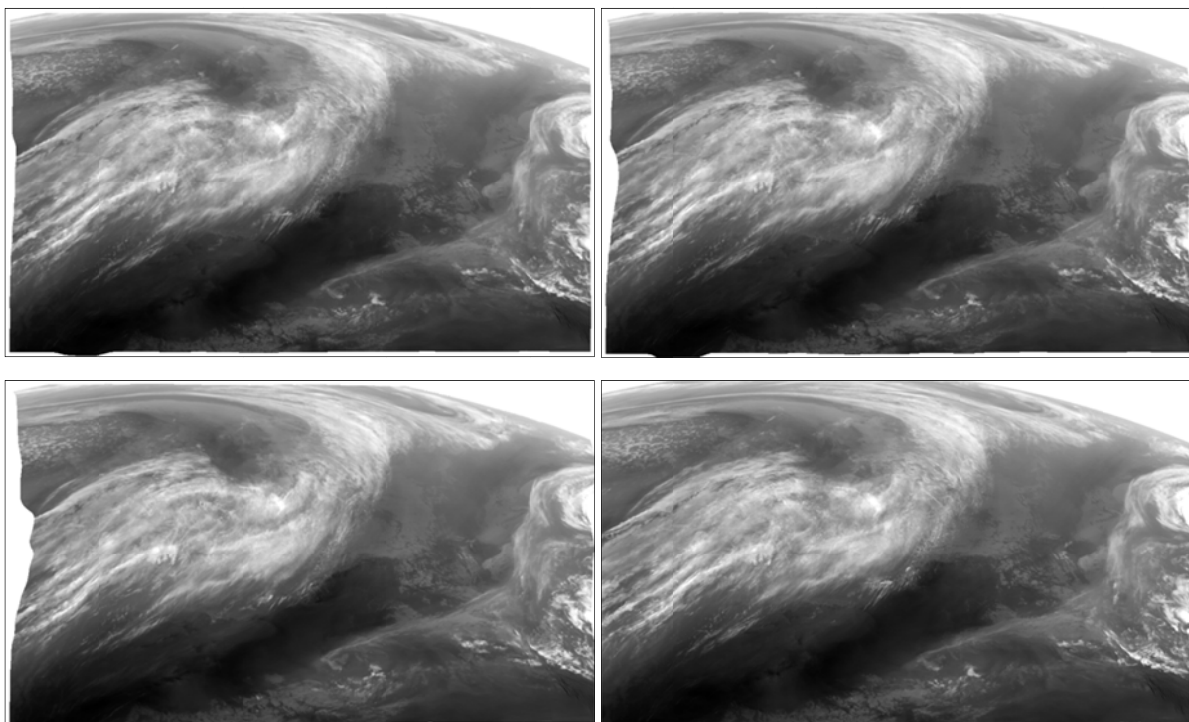
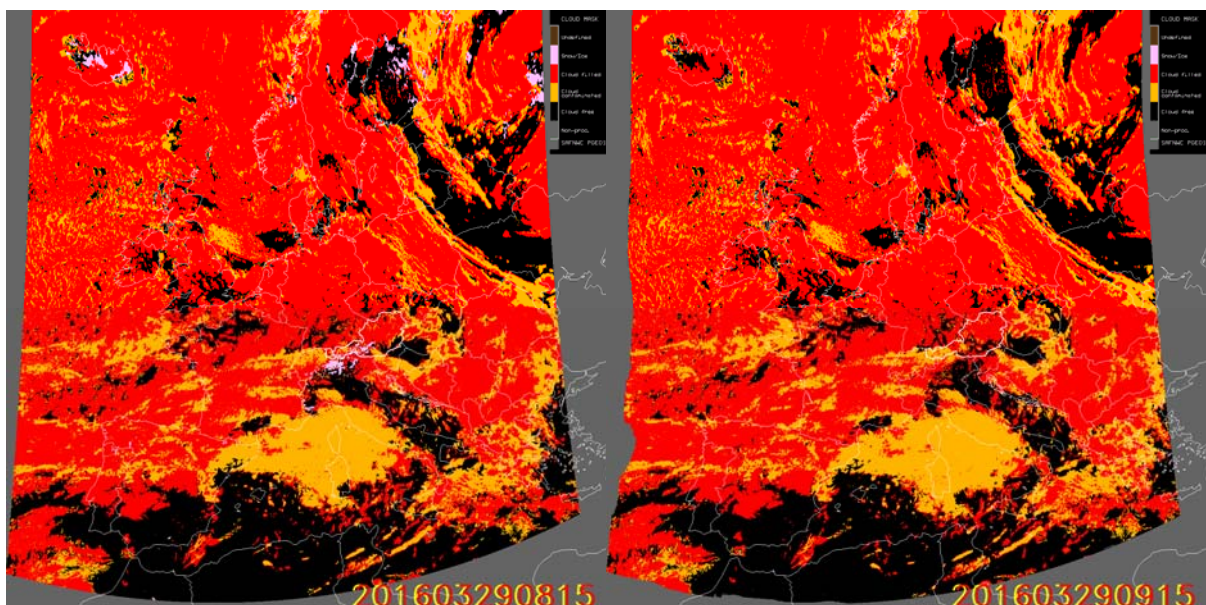


Figure 2: EXIM output for the MSG WV7.3 channel, for 24 March 2016, 15:15 UTC. Upper row, left: 15-minute forecast (i.e. based on the 15-UTC image); right: 30-minute forecast, based on the 14:45-UTC image. Bottom row, left: 1-hour forecast, based on the 14:15-UTC image; right: the observed WV7.3 channel at 15:15 UTC.

Figure 2 depicts the +15 min, +30 min and +60 min forecast images along with the observation made at the target date and time. The most conspicuous feature of the forecast images is at the western edge, where for displacement vectors which point inward, a void zone increasing in breadth with time appears. This occurs due to the restricted domain and the lack of observations from regions further to the west to fill the image. This void feature will become larger as the maximum leadtime is set to large values (e.g. several hours) and is something that users need to be aware of.

The EXIM software allows the extrapolation of NWCSAF cloud products, which means that, rather than extrapolating the isoline representation of clouds as shown in Figure 1, the clouds themselves can be extrapolated. This can be achieved by using the “cloud mask” product, or alternatively the “cloud type” or “cloud top height” products. Figure 3 shows forecast vs. actual observation for a cloud mask (NWC/GEO version 2013) example – the first panel shows the analysis at 08:15 UTC, the second is the +60 min forecast for 09:15 UTC, and the third panel shows the observations at 09:15 UTC. A visual evaluation of the performance of EXIM is difficult to make in this case, but it gives an indication how the forecast looks like. A better visual evaluation of EXIM for cloud products can be performed by focussing on precipitation-bearing clouds; Figure 4 gives an illustration, using the physical retrieval variant of the “Precipitating clouds” product (of NWC/GEO v2013). The +60 min forecast from EXIM compares very well to the observations (third panel) over Eastern Poland and Romania. However, the patch of precipitation over Southern France did not move as fast as predicted.



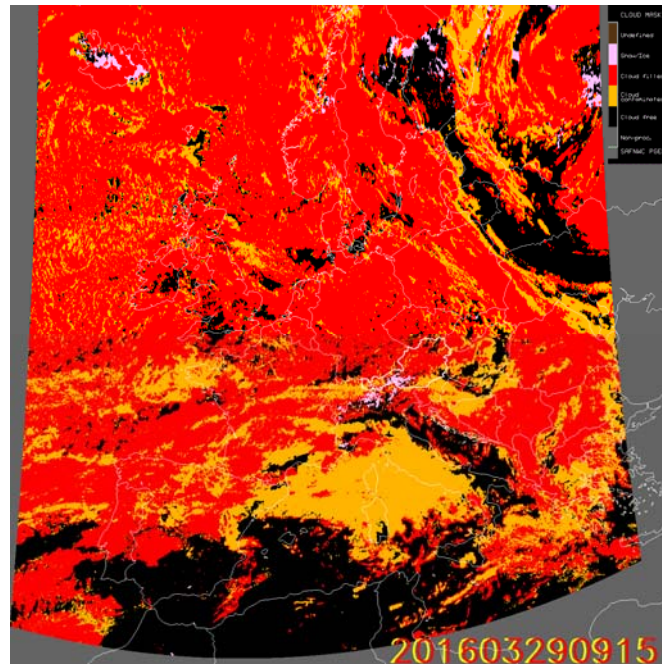
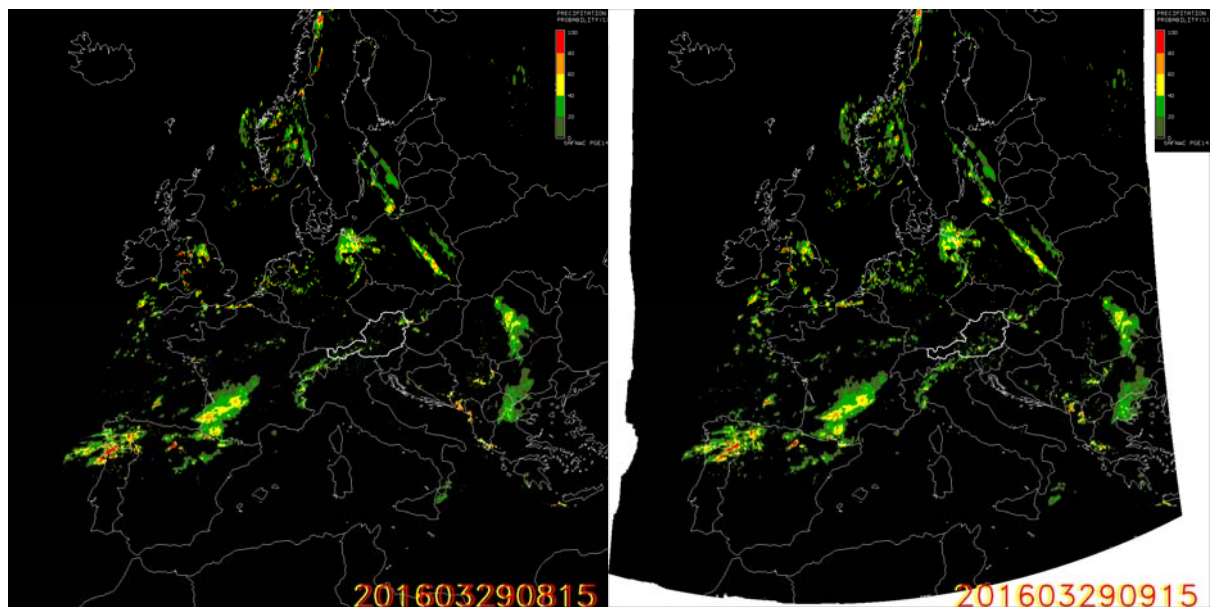


Figure 3: EXIM applied to the cloud mask product. Upper left: NWCSAF cloud mask for 29 March 2015, 08:15 UTC; upper right: EXIM 1-hour forecast based on the left image. Bottom: the analysed NWCSAF cloud mask for 29 March 2015, 09:15 UTC.



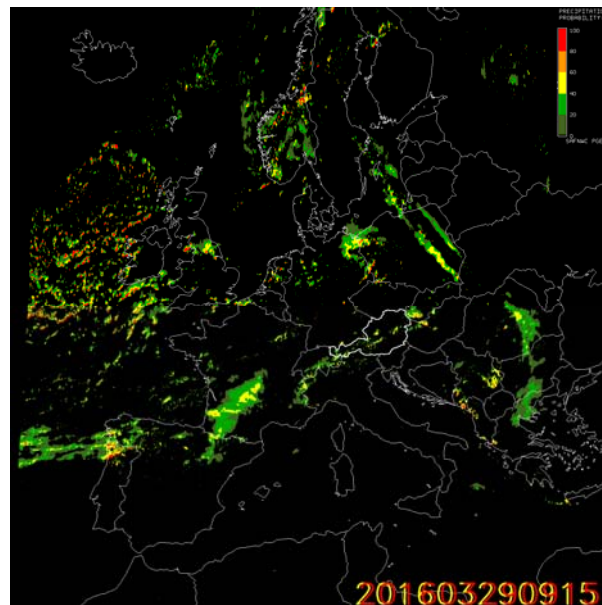


Figure 4: Similar to Figure 3 but with EXIM applied to the “Precipitating Clouds – Physical Retrieval” (PcPh) product. Upper left: NWCSAF PcPh analysis for 29 March 2015, 08:15 UTC; upper right: EXIM 1-hour forecast based on the left image. Bottom: The analysed NWCSAF PcPh field for 29 March 2015, 09:15 UTC.

6.2 ILLUSTRATIONS OF THE EFFECTS OF USER-CONFIGURABLE SETTINGS

This section contrasts the outcomes of runs with different settings of user-configurable parameters (which were introduced in 4.2). First, *Figure 5* illustrates the effect of keyword `SAT_CLOUDS_ONLY`, simply omitting cloudfree areas from the EXIM output when set to YES. Especially for initially cloudy pixels becoming cloudfree in the course of the extrapolation, the creation of a proper surface radiance is a challenge, and users without need for a gap filling or sceptical about its prospects of success may like to skip this part. The sudden exposure of the earth surface is a problem constrained to IR and VIS channels, hence the keyword has no effect for the water vapour channels and the forecast WV images always cover the full domain.

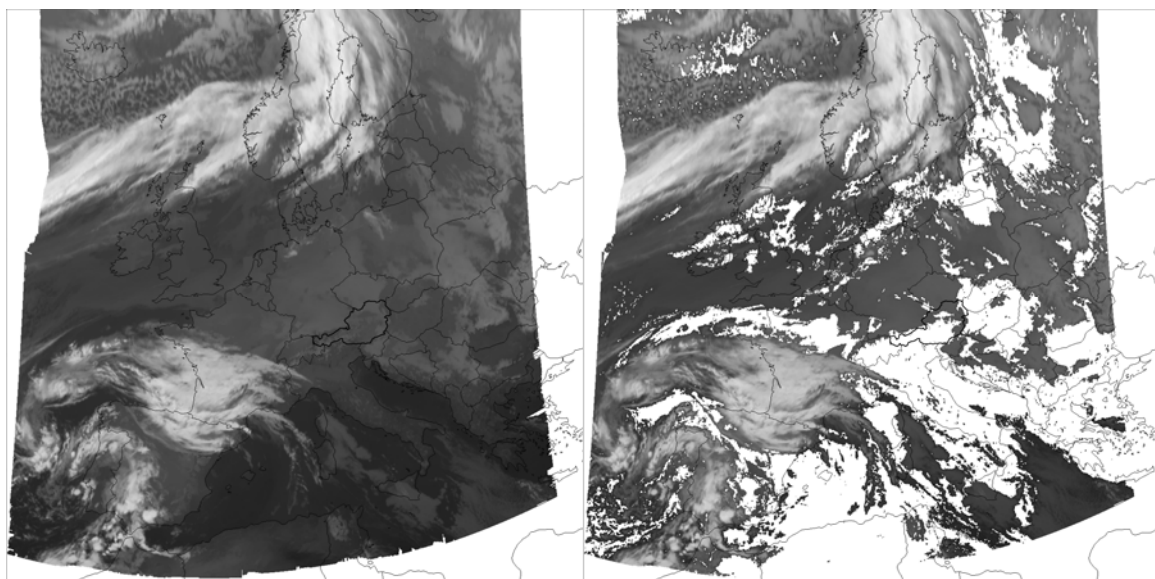


Figure 5: 60-minute forecasts of MSG 10.8 imagery for target date 23 January 2020, 09:30 UTC. Left: full image, with pixels in cloudfree areas filled with values from the initial 08:30 UTC image; right: cloud-only mode, i.e. areas to which no cloudy pixel is advected are masked.

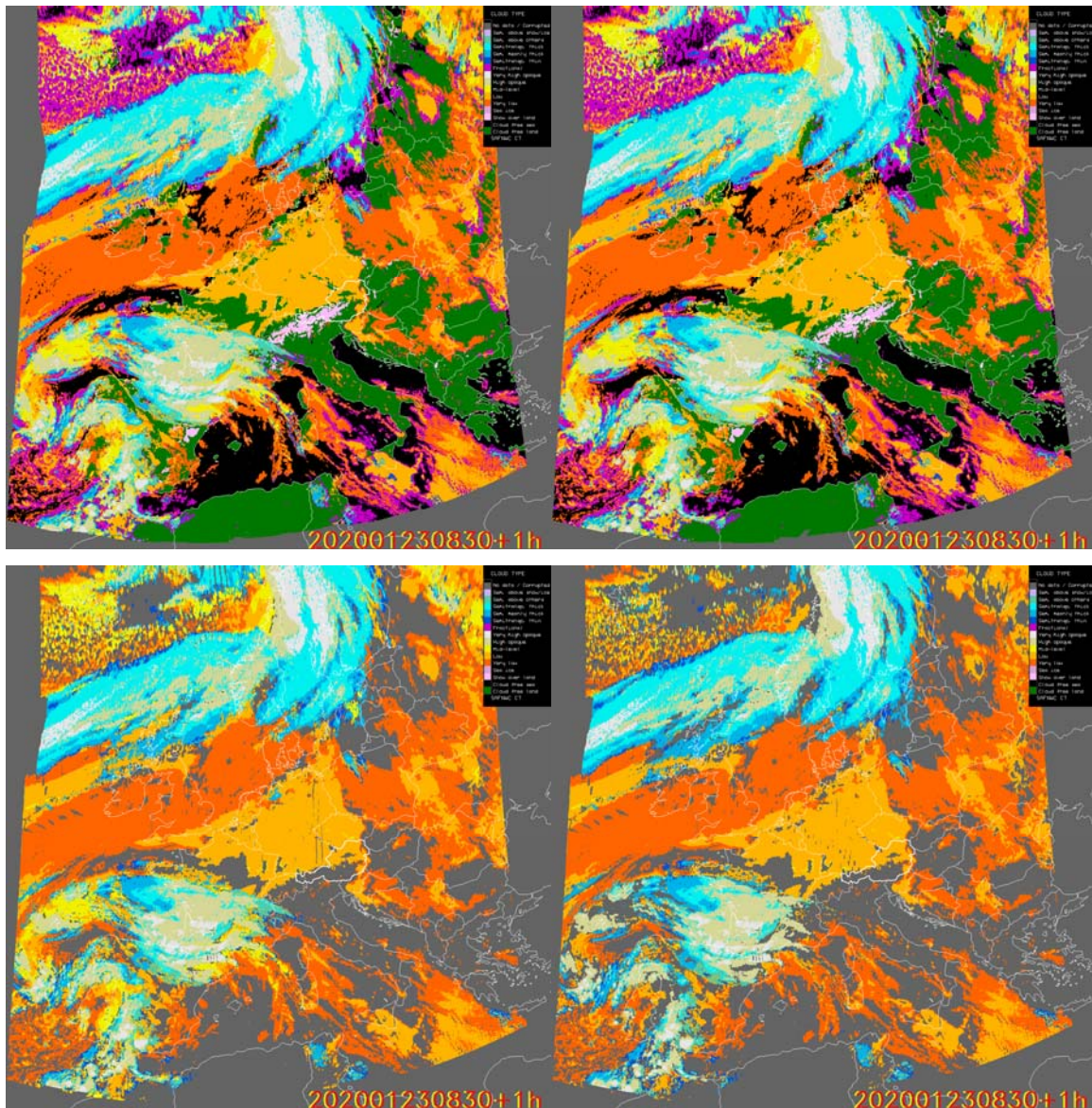


Figure 6: 60-minute forecasts of the MSG cloud type product for target date 23 January 2020, 09:30 UTC. Upper left: forecast carried out with one trajectory field comprising all available HrW; upper right: forecast carried out with two trajectory fields, 0-500 hPa and 501-1000 hPa; lower left: the same, but displacing the pixels with the vectors of “their” layer (judged by the CTHH product); lower right: the same, but for vector layers 0-400 hPa and 700-1000 hPa.

Figure 6 documents experiments with the IR_LAYER keywords in the configuration file³. The first two panels show results of “mechanical” extrapolations. In the first case, all available vectors were taken to form a single trajectory field; where the displacements left gaps, they were filled using the information of adjacent pixels and the codes for land, sea, and cloudfree snow were inserted where appropriate. Bearing in mind the fact that streams in the upper and lower troposphere normally should differ, the atmosphere was divided into layers of 0-500 hPa and 501-1000 hPa for the second panel; for displacing a pixel, the layer with the horizontally closest

³ The evaluation report [RD.5] addresses the effects of different settings of these keywords from a statistical perspective.

vectors were taken. As is often the case, the differences between the two schemes are hard to see on the scale used here (but at least the shape of the western edge proves that different trajectory fields were indeed employed). Moving to the third panel, the changes are more noticeable: using the same layers as before, pixels with a cloud top pressure 0-500 hPa were extrapolated with the upper-layer trajectories, those where the CTTH product indicated a height between 501 and 1000 hPa followed the lower-layer trajectories. Also, horizontal extrapolations to fill gaps were avoided. One conspicuous change is that the dark violet pixels (=fractional clouds) have disappeared, since the “physical” EXIM scheme had to ignore them as the CTTH product assigned no height to them. Moreover, with cloudy pixels withdrawn from the extrapolation process, it is no longer viable to assign the attribute “cloudfree” to a pixel, and therefore the postprocessing filling in the land/sea/snow categories could also not be carried out. The fourth panel just shows that, if the 500hPa thickness of layers is still considered too excessive, EXIM allows to work with something like 0-400 hPa and 700-1000 hPa, as an example, but naturally the price to pay is that even more pixels disappear.

The purpose of this section is to sensitize for the (perhaps unapparent) side-effects that changing the settings may have on some products, and the CT product was chosen for this demonstration as it gives the clearest illustrations. Still, the adequacy of choices made in the user configuration file has to be judged on a case-by-case basis, as it certainly depends on the desired application and the EXIM product required for it.