EUMETSAT

NWC SAF

SUPPORT TO NOWCASTING AND VERY SHORT RANGE FORECASTING

User Manual for the Extrapolated Imagery Processor of the NWC/GEO: Science Part

NWC/CDOP2/GEO/ZAMG/SCI/UM/EXIM, Issue 1.0

22 May 2017

Applicable to

GEO-EXIM-v1.0 (NWC-043)

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REPORT SIGNATURE TABLE

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DOCUMENT CHANGE RECORD

Version	Date	Pages	CHANGE(S)
1.0	*22 May 2017*	22	Initial version for the NWC/GEO release 2016 (Temporary change bars highlight changes after STRR 2016; the latest, Post-DRR, changes added in spring 2017 concern: - changes in the used displacement field (sections 4.2 and 5.2), - cloud masking (section 4.2) - change in the output format of extrapolated satellite imagery from DATABUF to netCDF (section 2.3))

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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.4]-[AD.6] 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 2016 NWC/GEO software package delivery.

1.4 IMPROVEMENT FROM PREVIOUS VERSION

Not applicable (first release).

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.

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

Ref	Title	Code	Vers	Date
[AD.1]	Proposal for the Second Continuous Development and Operations Phase (CDOP) March 2012 – February 2017	NWC/CDOP2/MGT/AEMET/PRO	1.0d	15/03/11
[AD.2]	NWCSAF Project Plan	NWC/CDOP2/SAF/AEMET/MGT/PP	1.9	15/10/16
[AD.3]	System and Components Requirements Document for the NWC/GEO	NWC/CDOP2/GEO/AEMET/SW/SCRD	1.2	15/10/16
[AD.4]	Interface Control Document for Internal and External Interfaces of the NWC/GEO	NWC/CDOP2/GEO/AEMET/SW/ICD/1	1.2	
[AD.5]	Interface Control Document for the NWCLIB of the NWC/GEO	NWC/CDOP2/GEO/AEMET/SW/ICD/2	1.2	30/10/15
[AD.6]	Data Output Format for the NWC/GEO	NWC/CDOP2/GEO/AEMET/SW/DOF	1.2	
[AD.7]	Architectural Design Document for the NWC/GEO	NWC/CDOP2/GEO/AEMET/SW/ACDD	1.2	

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/CDOP2/SAF/AEMET/MGT/GLO		
[RD.2]	Algorithm Theoretical Basis Document for the Extrapolated Imagery Processor of the NWC/GEO	NWC/CDOP2/GEO/ZAMG/SCI/ATBD/EXIM	1.1	05/05/17
[RD.3]	Scientific and Validation Report for the Extrapolated Imagery Processor of the NWC/GEO	NWC/CDOP2/GEO/ZAMG/SCI/VR/EXIM	1.0	05/05/17

Table 2: List of Referenced Documents

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) imagery or NWCSAF products up to a lead time of 1 hour[1]. It does so by applying kinematic extrapolation using atmospheric motion vectors 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 channels
- the NWCSAF products "cloud mask", "cloud type", "cloud top temperature" and "height", "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 meaningless).

- 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)

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).

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_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_IR108_MSG3_Europe-VISIR_20150401T121500Z_030.nc.

The files also contain the EXIM-specific quality flag applicable to all products (data container “exim_status_flag” in the netCDF file). The quality flag file has one byte per pixel and the flag can assume values 0, 1, 2, with the following meanings:

Code	Meaning
0	No EXIM forecasts available for this pixel
1	Forecast through trajectory displacement available
2	Forecast made available at this pixel through post-processing using adjacent pixels with quality=1

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_status_flag
Precipitating clouds (PC)	pc
Convective Rainfall Rate (CRR)	crr_intensity, crr_status_flag
Precipitating clouds – Physical Retrieval (PC-Ph)	pcph, pcph_status_flag
Convective Rainfall Rate – Physical Retrieval (CRR-Ph)	crrph_intensity, crrph_iqf, crrph_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.6].

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**	Nearest-neighbour	255
ctth_alti, ctth_pres **crr_intensity** **pcph** **crrph_intensity, crrph_iqf**	Averaging	65535
cma_status_flag **ct_status_flag** **ctth_status_flag** **pcph_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.6].

3. IMPLEMENTATION OF EXTRAPOLATED IMAGERY (EXIM)

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.4]). Files are situated in $SAFNWC/config. In particular, set the entries in the “product ordering” section of $SAFNWC/config/safnwc_EXIM.cfm to NO if a certain NWCSAF product or satellite channel extrapolation is desired (in the delivery, the default for all products is: YES). The entry MAX_LEADTIME, which is the maximum lead time in minutes, is preset to 60 but can be modified. Technically it is possible to specify a value greater than 60, however, NWCSAF can not guarantee the quality of results in this case since EXIM has only been tested for a maximum lead time of 60 minutes.
2. Algorithm configuration files are situated in the directory “$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}”
5. Likewise, if satellite images are selected for extrapolation, the SEVIRI image files in HRIT format (or: the GOES-N files in netCDF 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-v10 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-v10 can be called as follows (from the directory where it is situated, which normally should be $SAFNWC/bin):

GEO-EXIM-v10 YYYY-MM-DDThh:mm:ssZ <region_conf_file> <model_conf_file>

Example:

GEO-EXIM-v10 2015-06-26T12:00:00Z test_exim.cfg safnwc_EXIM.cfm

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, channels according to user orders
- NWC/GEO product "Cloud mask"
- NWC/GEO product "Cloud type"
- NWC/GEO product "Cloud top temperature and height"
- 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 and GOES-N), which are separated into four blocks:

Keyword(s)	Description	Type	Possible Value(s)
CMA CT CTTH PC PC-Ph CRR CRR-Ph	Decide whether the extrapolation for the product with this acronym (cf. Table 3) is to be carried out. Products not generated for GOES-N are not listed in the GOES 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 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, the keyword is not present in the GOES configuration file)	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".)
MAX_LEADTIME	The maximum lead time of EXIM products (in minutes).	integer	all

Note that IR imagery and NWCSAF products are extrapolated with high-level IR/VIS vectors, VIS imagery with low-level IR/VIS AMVs. 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 are given showing for which products EXIM can be used to provide skilful forecasts. The 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 1.6µm, the evaluation results suggested that the EXIM approach should generally not be exercised upon the field.

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 ∈ [250, 280] K Autumn, Spring: BT ∈ [250, 270] K Winter: BT ∈ [250, 270] K	- - 270 K, LT +60 min
IR8.7	Summer: BT ∈ [230, 280] K Autumn, Spring: BT ∈ [230, 270] K Winter: BT ∈ [230, 270] K	- - 270 K, LT +60 min
IR9.7	Summer: BT ∈ [230, 250] K Autumn, Spring: BT ∈ [230, 250] K Winter: BT ∈ [230, 240] K	- - -
IR10.8	Summer, Autumn: BT ∈ [230, 280] K Spring: BT ∈ [230, 280] K Winter: BT ∈ [230, 270] K	- - 280 K, LT ≥ +45 min
IR12.0	Summer, Autumn: BT ∈ [230, 280] K Spring: BT ∈ [230, 280] K Winter: BT ∈ [230, 270] K	- - 280 K, LT ≥ +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

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	

It should be noted that, since data for the SEVIRI visible channels were not available for winter, a recommendation for the usage of EXIM in winter could not be made.

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 ≤ 11 (2.2 mm/h)	-
	Summer: CRPh ≤ 71 (14.2 mm/h)	-
	Autumn: CRPh ≤ 71 (14.2 mm/h)	61, 71: LT +60 min
	Winter: CRPh ≤ 41 (8.2 mm/h)	LT +60 min
	Winter: CRPh ≤ 71 (14.2 mm/h)	LT ≥ 45 min
	Spring: CRPh ≤ 41 (8.2 mm/h)	LT +60 min
	Spring: CRPh ≤ 61 (12.2 mm/h)	LT ≥ 45 min

5.1.8 PC: Precipitating Clouds

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

5.1.9 PCPh: Precipitating Clouds from Cloud Physical Properties

Product	Use of EXIM	Exceptions
PCPh	Recommended for PCPh ≤ 31%	Winter, LT +60 min for PCPh ≥ 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 version NWC/GEO v2016 as 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

5.2 NOTE: SPHR WAS THE DESIGNATION IN V2013 (FOR WHICH THE VALIDATION WAS CARRIED OUT). THE PRODUCT HAS BEEN RENAMED IN VERSION NWC/GEO V2016 AS ISHAI (IMAGING SATELLITE HUMIDITY AND INSTABILITY).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. Compromises were made after some expert discussions in the interest of keeping this tool at a lower complexity in order to match the requirements of nowcasting: IR imagery is extrapolated with high-level IR/VIS vectors (high-level means: < 400 hPa; the vectors are derived from VIS 0.6 and 0.8, HRVIS, IR 10.8 and 12.0; for GOES-N, just VIS 0.7 and IR 10.7 are available), VIS imagery with low-level IR/VIS AMVs (> 700 hPa). Obviously, this opens up two potential weaknesses: In VIS imagery, the quality of extrapolation of high-level clouds may sometimes suffer due to the made selection of displacement vectors. For IR imagery, the same may be observed for low-level clouds.

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

For many years, forecast satellite imagery have 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 -30°C to -40°C in yellow, -40°C to -50°C depicted in red, -50°C to -60°C in green. Superimposed are the isolines -30°C, -40°C, -50°C of the forecast image, showing how far the "yellow", "red", and "green" areas are expected to move in the next hour. The right panel shows the observed image of the forecast date for verification purposes.

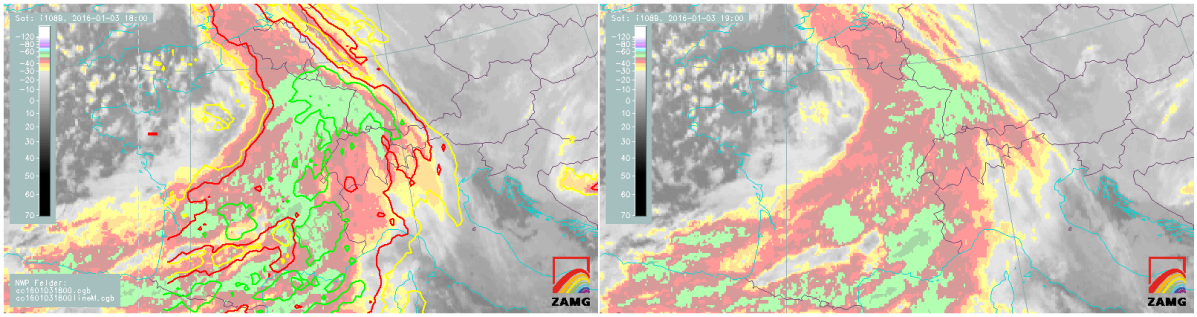


Figure 1: Kinematic extrapolation applied to cloud top temperatures. Left: MSG IR10.8μm image from 3 January 2016, 18:00 with the superimposed isoline forecast for 19 UTC (see text). Right: MSG IR10.8μm image at 19:00 UTC.

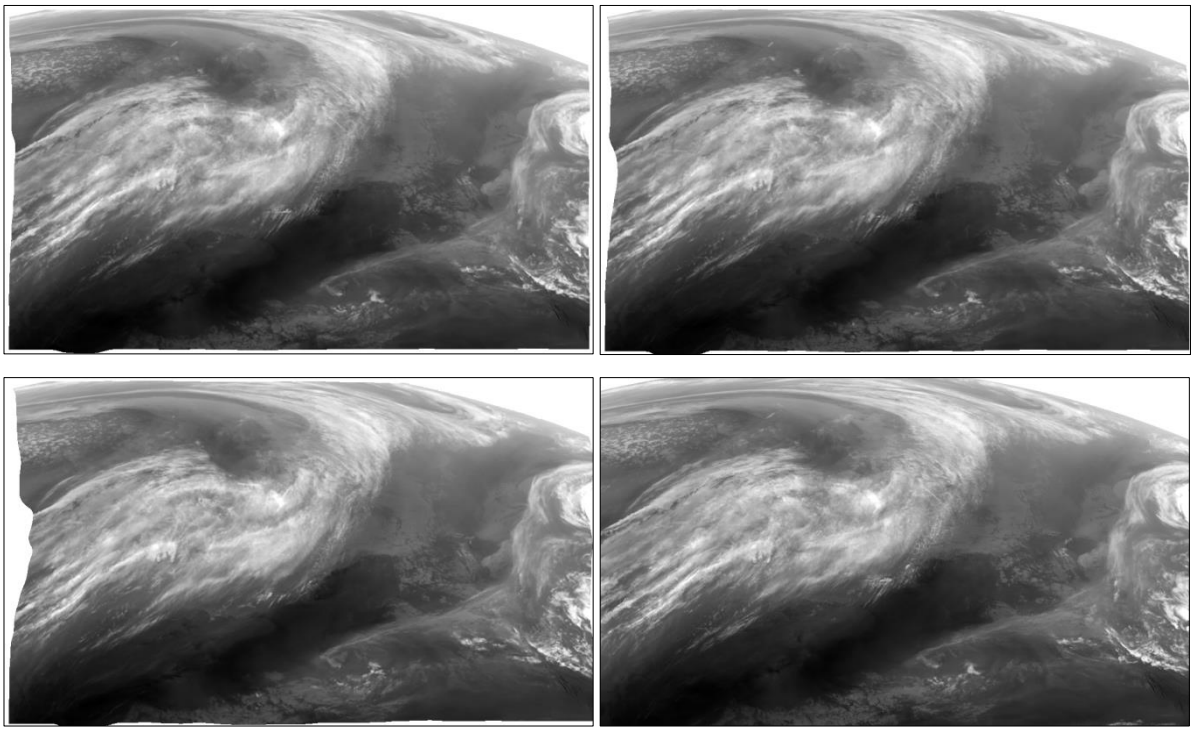
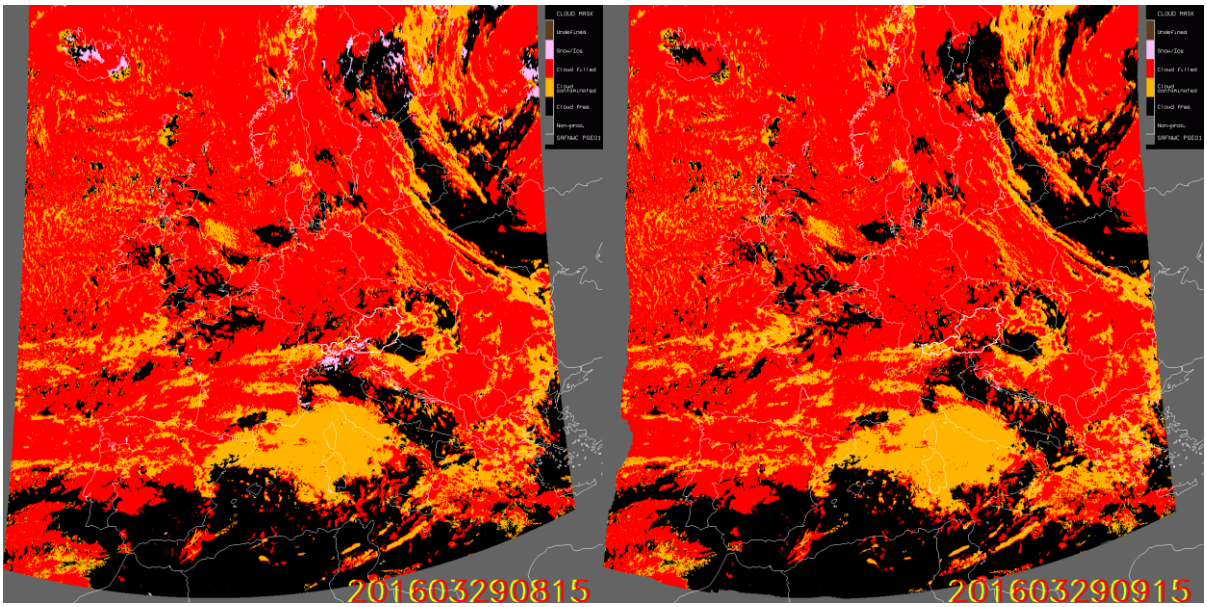


Figure 2: EXIM output for the MSG WV7.3 channel, for 24 March 2016, 15:15 UTC. Upper row, left: 15-minute forecast (i.e. based on the 15-UTC image); right: 30-minute forecast, based on the 14:45-UTC image. Bottom row, left: 1-hour forecast, based on the 14:15-UTC image; right: the observed WV7.3 channel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



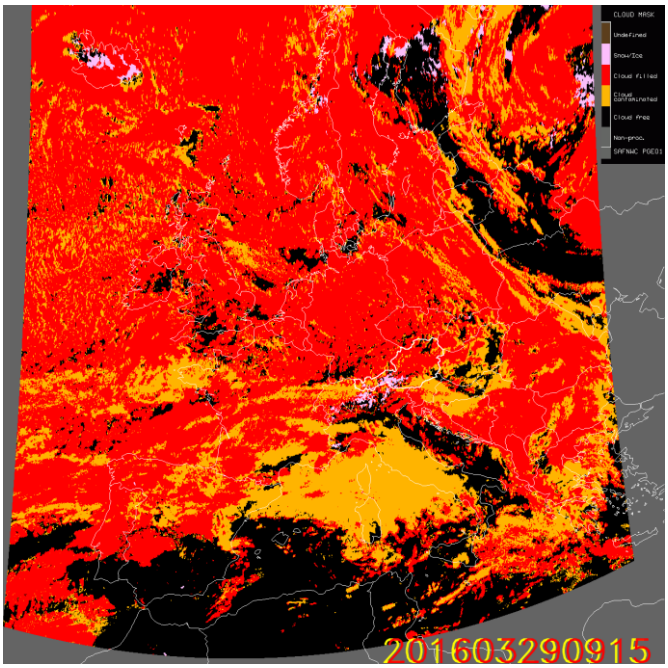
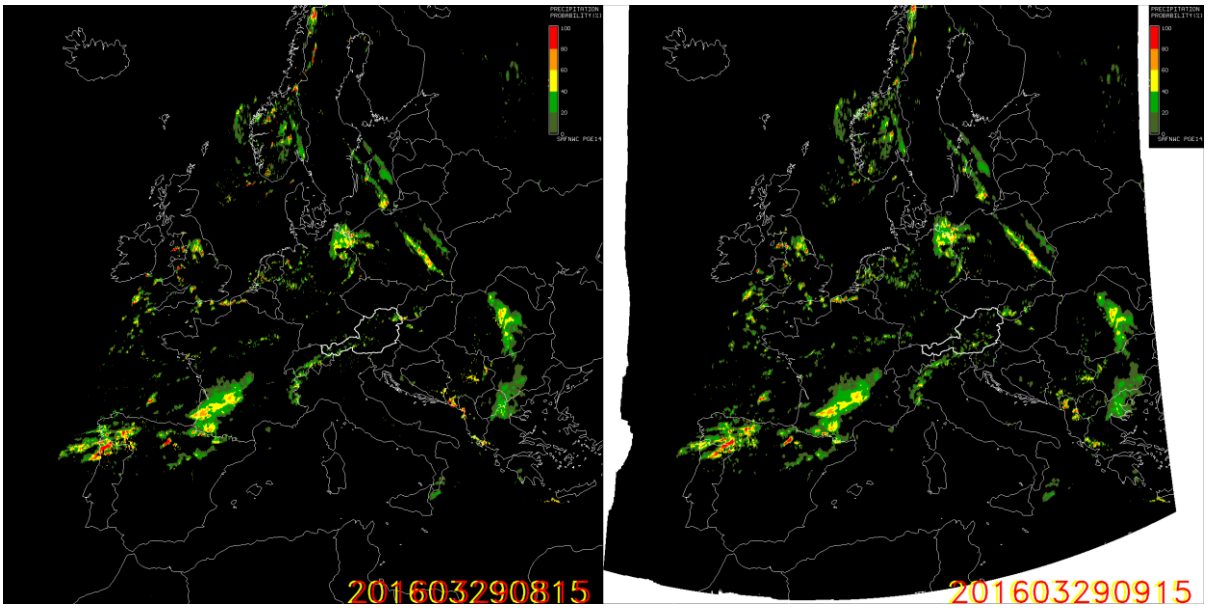


Figure 3: EXIM applied to the cloud mask product. Upper left: NWCSAF cloud mask for 29 March 2015, 08:15 UTC; upper right: EXIM 1-hour forecast based on the left image. Bottom: the analysed NWCSAF cloud mask for 29 March 2015, 09:15 UTC.



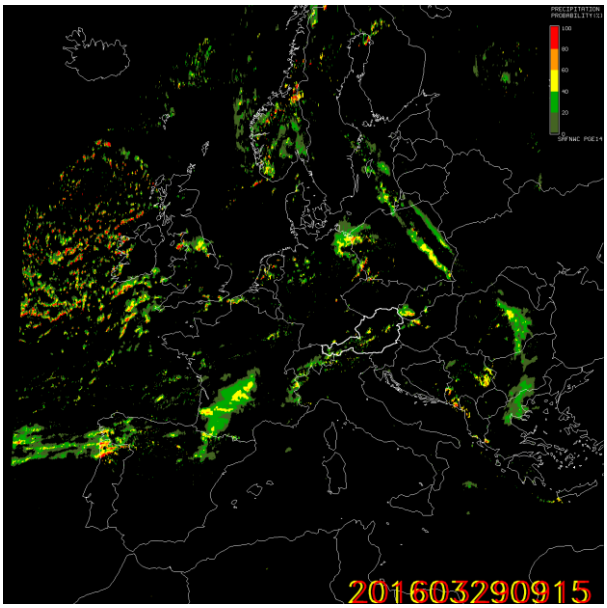


Figure 4: Similar to Figure 3 but with EXIM applied to the "Precipitating Clouds – Physical Retrieval" (PcPh) product. Upper left: NWCSAF PcPh analysis for 29 March 2015, 08:15 UTC; upper right: EXIM 1-hour forecast based on the left image. Bottom: The analysed NWCSAF PcPh field for 29 March 2015, 09:15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

7. REFERENCES