**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/CDOP3/MTG/ZAMG/SCI/UM/EXIM, Issue 1.2.1

*30 June 2025*

*Applicable to*

*GEO-EXIM-v3.1 (NWC-045)*

**Prepared by GeoSphere Austria**

## REPORT SIGNATURE TABLE

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# DOCUMENT CHANGE RECORD

| Version | Date | Pages | CHANGE(S) |
|---------|------|-------|-----------|
| 1.0 | *13 November 2020* | 27 | First version. |
| 1.1.0 | *3 February 2023* | 28 | Update for ORR: New organization name and logo; inclusion of new validation report [RD.5] |
| 1.2.0 | *31 March 2025* | 30 | Minor editorial changes (version number, output file names, addition of cmic_cot) for the first MTG-I1 release |
| 1.2.1 | *30 June 2025* | 28 | Editorial changes in sections 1.3, 1.4, 2.1, 3.x and 4.x to account for the release 2025, "GOES19 patch", which allows extrapolation of imagery in HR resolution. |

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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.4].

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.8]-[AD.10] 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 v2025 NWC/GEO software package delivery, first patch ("GOES-19 patch").

## 1.4 IMPROVEMENT FROM PREVIOUS VERSION

Implementation of extrapolation of high-resolution channels; implementation of user option to define the lead times of the extrapolations.

## 1.5 DEFINITIONS, ACRONYMS AND ABBREVIATIONS

| AeMet | Agencia Estatal de Meteorología |
|---|---|
| AMV | Atmospheric Motion Vector |
| CDOP | Continuous Development and Operations Phase |
| CMa | Cloud Mask |
| CMIC | Cloud Microphysics |
| CTTH | Cloud Top Temperature and Height |
| CT | Cloud Type |
| EUMETSAT | European Organisation for the Exploitation of Meteorological Satellites |
| EXIM | Extrapolated Imagery |
| FCI | Flexible Combined Imager |
| GSA | GeoSphere Austria |
| HRIT | High Rate Information Transmission |
| HRVIS | High-resolution VISible |

| **HrW** | High-resolution Winds |
|---|---|
| **IR** | Infrared |
| **MFG** | Meteosat First Generation |
| **MSG** | Meteosat Second Generation |
| **NWCSAF** | SAF to support NoWCasting and Very-Short-Range Forecasting |
| **NWP** | Numerical Weather Prediction |
| **PGE** | Product Generation Element |
| **SAF** | Satellite Application Facility |
| **SEVIRI** | Spinning Enhanced Visible & Infrared Imager |
| **VIS** | Visible (channel) |
| **WV** | Water vapour (channel) |

## 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: http://nwc-saf.eumetsat.int.

| Ref | Title | Code | Vers | Date |
|---|---|---|---|---|
| [AD.1] | Proposal for the Fourth Continuous Development and Operations Phase (CDOP 4) March 2022 – February 2027 | /NWC/SAF/AEMET/MGT/CDOP4Proposal | 1.0 | 12/03/21 |
| [AD.2] | Project Plan for the NWCSAF CDOP4 phase | NWC/CDOP4/SAF/AEMET/MGT/PP | 3.0.0 | 21/10/24 |
| [AD.3] | Configuration Management Plan for the NWCSAF | NWC/CDOP4/SAF/AEMET/MGT/CMP | 1.2.0 | 29/03/24 |
| [AD.4] | NWCSAF Product Requirement Document | NWC/CDOP4/SAF/AEMET/MGT/PRD | 3.0.0 | 21/10/24 |
| [AD.5] | NWCSAF CDOP 4 Service Specifications | NWC/CDOP4/SAF/AEMET/MGT/SSD | 1.0.0 | 31/10/22 |
| [AD.6] | System and Components Requirements Document for the NWC/GEO MTG-I day-1 | NWC/CDOP2/MTG/AEMET/SW/SCRD | 1.3.1 | 31/03/25 |
| [AD.7] | Architecture Design Document for the NWC/GEO MTG-I day-1 | NWC/CDOP2/MTG/AEMET/SW/ACDD | 1.3.0 | 31/03/25 |
| [AD.8] | Interface Control Document for Internal and External Interfaces of the NWC/GEO MTG-I day-1 | NWC/CDOP2/MTG/AEMET/SW/ICD/1 | 1.4.0 | 31/03/25 |
| [AD.9] | Interface Control Document for the NWCLIB of the NWC/GEO MTG-I day-1 | NWC/CDOP2/MTG/AEMET/SW/ICD/2 | 1.4.0 | 31/03/25 |
| [AD.10] | Data Output Format for the NWC/GEO MTG-I day-1 | NWC/CDOP2/MTG/AEMET/SW/DOF | 1.4.0 | 31/03/25 |
| [AD.11] | User Manual for the NWC/GEO: Software Part | NWC/CDOP3/MTG/AEMET/SW/UM | 1.3.0 | 31/03/25 |

*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: http://nwc-saf.eumetsat.int

| Ref | Title | Code | Vers | Date |
|---|---|---|---|---|
| [RD.1] | The Nowcasting SAF Glossary | NWC/CDOP3/SAF/AEMET/MGT/GLO | 1.0 | 31/10/23 |
| [RD.2] | Scientific and Validation Report for the Extrapolated Imagery Processor of the NWC/GEO | NWC/CDOP2/GEO/ZAMG/SCI/VR/EXIM | 1.0 | 22/05/17 |
| [RD.3] | Scientific and Validation Report for the Extrapolated Imagery Processor of the NWC/GEO | NWC/CDOP3/GEO/ZAMG/SCI/VR/EXIM | 1.0 | 21/01/19 |
| [RD.4] | Algorithm Theoretical Basis Document for the Extrapolated Imagery Processor of the NWC/GEO | NWC/CDOP2/MTG/ZAMG/SCI/ATBD/EXIM | 1.1.2 | 30/06/25 |
| [RD.5] | Scientific and Validation Report for the Extrapolated Imagery Processor of the NWC/GEO | NWC/CDOP3/GEO/ZAMG/SCI/VR/EXIM | 2.0 | 10/01/22 |
| [RD.6] | Scientific and Validation Report for the Extrapolated Imagery Processor of the NWC/GEO | NWC/CDOP4/GEO/GSA/SCI/VR/EXIM | 1.0 | 31/03/25 |

*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 applies kinematic extrapolation using atmospheric motion vectors (AMVs) for displacing FCI/SEVIRI/GOES-R/Himawari pixels and/or selected NWCSAF products. Thereby, one gets forecast imagery / NWCSAF products up to a lead time of 1 hour[1] (this is a restriction that emerged in the CDOP-2 Evaluation Board review; it was argued that beyond this lead time, NWP models are the preferable choice also for forecasting satellite imagery).

The catalogue of input undergoing extrapolation, from which the user can select, consists of

1) all SEVIRI channels, analogously for GOES-R and Himawari;

2) all FCI channels with corresponding MSG channels

3) the NWCSAF products "cloud mask", "cloud type", "cloud top temperature and height", "cloud microphysics", "precipitating cloud", and "convective rainfall rate".

## 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 FCI/SEVIRI/GOES-R/Himawari 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.

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[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)

- 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, 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. As an example, the forecasts of CMa starting with the analysis of 1 April 2012, 12.15 UTC, are found in a file named S_NWC_EXIM-CMA_MSG2_Region-VISIR_20120401T121500Z.nc; it contains the analysis and the forecast fields bundled in a 3D matrix (the NWC/GEO netCDF model provides the time axis of the data cube (in minutes) in the data container "fct").

(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. For example, forecasts of IR10.8 brightness temperature and radiance based on the observations of 1 April 2015, 12.15 UTC, could be found in a file named S_NWC_EXIM-IR108_MSG3_Europe-VISIR_20150401T121500Z.nc, again the starting point and the forecasts being assembled together in a 3D matrix.

(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 (and inserted in the file name before the '.nc' extension) 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 data container "exim_status_flag" in the netCDF file holding this flag is a 3D matrix corresponding to the forecasts. As already mentioned, the NWC/GEO netCDF model provides the time axis of the data cube (in minutes) in the data container "fct".

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_hfeet, 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, cmic_cot |

*Table 3: NWCSAF fields handled by EXIM. The designations in the right column are those of the netCDF output files, according to [AD.10].*

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** | Nearest-neighbour (if CTTH | 255 |

| | | |
|---|---|---|
| **ct**<br><br>**pc**<br><br>**cmic_phase** | filtering is turned on, cf. sections 2.2 and 4.2: None) | |
| **ctth_alti, ctth_pres, ctth_effectiv, ctth_hfeet**<br><br>**crr_intensity**<br><br>**pcph**<br><br>**crrph_intensity**<br><br>**cmic_cot** | Averaging (if CTTH filtering is turned on, cf. sections 2.2 and 4.2: None) | 65535 |
| **cma_status_flag**<br><br>**ct_status_flag**<br><br>**ctth_status_flag**<br><br>**pcph_status_flag**<br><br>**cmic_status_flag** | None | 32768 |
| **crr_status_flag**<br><br>**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.10].*

# 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.8]). 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 the cloud products is YES, NO for the other parameters; this was decided at some point on grounds of comparatively large computation times to keep the initial stress on platforms with fresh NWCSAF/GEO installations low, and is not to be construed as a statement of relative quality). 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. Alternatively, users can specify the lead times via entry LEADTIMES (which – if set - overwrites the MAX_LEADTIME specification). This allows, for example, to obtain comparable forecasts for parallel MSG and MTG generation chains by specifying in the model configuration of the MSG chain

   LEADTIMES 10 20 30 40 50 60

   while keeping the default

   MAX_LEADTIME 60

   in the MTG chain.
   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 MTG, 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/HrW"
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 MTG/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).

<u>Submitting GEO-EXIM-v30 in stand-alone mode, not using the task manager:</u>

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-v30 can be called as follows (from the directory where it is situated, which normally should be $SAFNWC/bin):

GEO-EXIM-v30 *<YYYYMMDDThhmmssZ> <region_conf_file> <model_conf_file>*

Example:

GEO-EXIM-v30 20200229T120000Z 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 YYYYMMDDThhmmssZ <region_conf_file> <model_conf_file>" | Error when launching | Check instruction for launching the EXIM PGEs |
| 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: <br> – for missing configuration files, copy them from delivered SW; <br> – 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. |

| Code (E/W) | Message | Comment | Recovery action |
|---|---|---|---|
| E | All messages containing the strings:<br>"OUTPUT_PRODUCT…ERROR"<br>"Error initiating/writing/finalizing…"<br>"Error in module Write…"<br>"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<br>• NWCLIB initialization functions: NwcRegionSet, NwcCFRead, NwcSatInit<br>• NWCLIB Reading function NwcSatReadBand<br>• 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 |
| 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) | |
| W | "Difference image for **-minute interval requested. This interval is, however, not in the set of leadtimes - no difference image is generated" | The set of lead times derived from keywords MAX_LEADTIME / LEADTIMES does not contain the value specified under keyword D_IMG_LEADTIME | Depending on whether the user actually wants to have a difference image, either:<br>- Adjust LEADTIMES / MAX_LEADTIME / D_IMG_LEADTIME such that the value of D_IMG_LEADTIME is among the forecast intervals, or<br>- Set the D* entries in the model configuration file triggering difference image computations to NO |
| 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, v3.0.*

# 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):

- FCI data or SEVIRI data or GOES-R data or Himawari 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 "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 MTG, MSG, Himawari, and GOES-R):

| Keyword(s) | Description | Type | Possible Value(s) |
|---|---|---|---|
| CMA<br>CT<br>CTTH<br>CMIC<br>PC<br>PCPh<br>CRR<br>CRRPh | Decide whether the extrapolation for the product with this acronym (cf. Table 3) is to be carried out. Products not generated for GOES-R/Himawari are not listed in the GOES/Himawari model configuration file. | chain of characters | YES or NO<br>(the software interprets any expression with a "Y" or "y" in it as a "Yes".) |
| VIS06<br>VIS08<br>IR16<br>IR38<br>WV62<br>WV73<br>IR87<br>IR97<br>IR108<br>IR120<br>IR134<br>HRVIS | Decide whether the extrapolation for the SEVIRI channel 0.6, 0.8, 1.6 etc. is to be carried out (MTG/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-R/Himawari, the keyword is not present in the GOES/Himawari configuration file) | chain of characters | YES or NO<br>(the software interprets any expression with a "Y" or "y" in it as a "Yes".) |

| 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<br>DVIS08<br>DIR16<br>DIR38<br>DWV62<br>DWV73<br>DIR87<br>DIR97<br>DIR108<br>DIR120<br>DIR134<br>DHRVIS | 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 MTG/GOES-R/Himawari channels, the same remarks as for the VIS06, VIS08… entries apply) | chain of characters | YES or NO<br>(the software interprets any expression with a "Y" or "y" in it as a "Yes".) |
| SAT_CLOUDS_ONLY | Specifies whether the forecast IR and VIS 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<br>(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<br>(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). Ignored if values are specified under item LEADTIMES. | integer | all |
| LEADTIMES | User-specified lead times | (array of) integer(s) | all |
| VIS_LAYER_1_1<br>VIS_LAYER_1_2<br>VIS_LAYER_2_1<br>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<br>IR_LAYER_1_2<br>IR_LAYER_2_1<br>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 one of the latest validation exercise (see [RD.3]). 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.4]. 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.4]. 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 5.1.x are derived from the validation reported in [RD.2]. 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 1.6µm, the evaluation results suggested that the EXIM approach should generally not be exercised upon the field.

A subsequent evaluation [RD.3] 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.2], 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).

Coming back to CMIC, the re-evaluation of its sub-parameter "cloud optical thickness" in [RD.6] led to the conclusion that it its inclusion into the EXIM portfolio is justifiable. Another recent evaluation ([RD.5]) confirmed the applicability of the EXIM approach to the CTTH sub-field ctth_effectiv (→ 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 ∈ [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<br>-<br>Radiances = 8 | Summer, Autumn: LT +60 min,<br>Spring: LT ≥ +45 min<br>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  CRRPh: Convective Rainfall Rate from Cloud Physical properties

| Product | Use of EXIM | Exceptions |
|---|---|---|
| CRRPh | CRRPh ≤ 11 (2.2 mm/h) | - |
| | Summer: CRRPh ≤ 71 (14.2 mm/h) | - |
| | Autumn: CRRPh ≤ 71 (14.2 mm/h) | 61, 71: LT +60 min |
| | Winter: CRRPh ≤ 41 (8.2 mm/h) | LT +60 min |
| | Winter: CRRPh ≤ 71 (14.2 mm/h) | LT ≥ 45 min |
| | Spring: CRRPh ≤ 41 (8.2 mm/h) | LT +60 min |
| | Spring: CRRPh ≤ 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 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 is 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[3]'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°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.
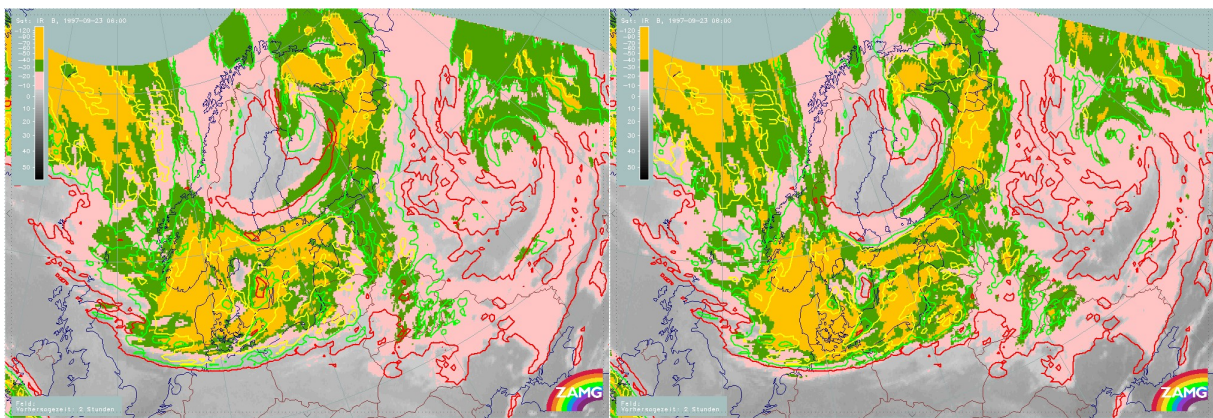


*Figure 1: Kinematic extrapolation applied to cloud top temperatures. Left: Meteosat First Generation IR10.8 μm image from 23 September 1997, 06:00 UTC with the superimposed isoline forecast for 08:00 UTC (see text). Right: Validation - MFG IR10.8 μm image at 08:00 UTC, with the isoline forecast for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



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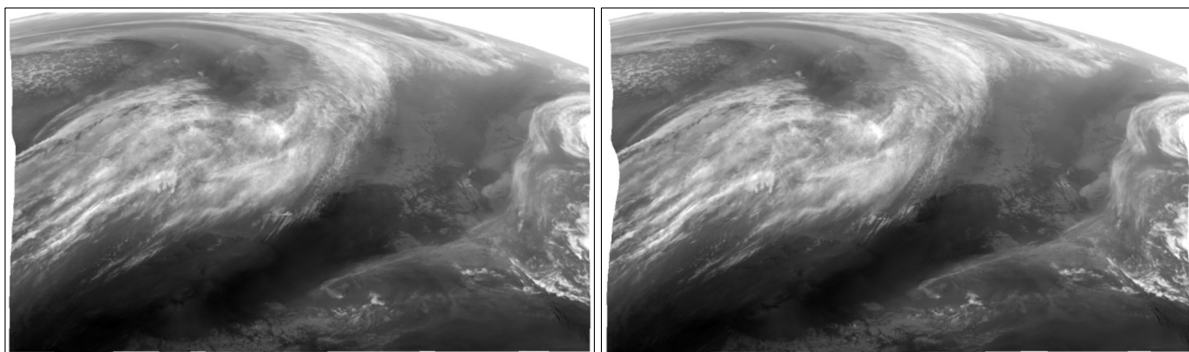
[3] Predecessor organization of today's GeoSphere Austria
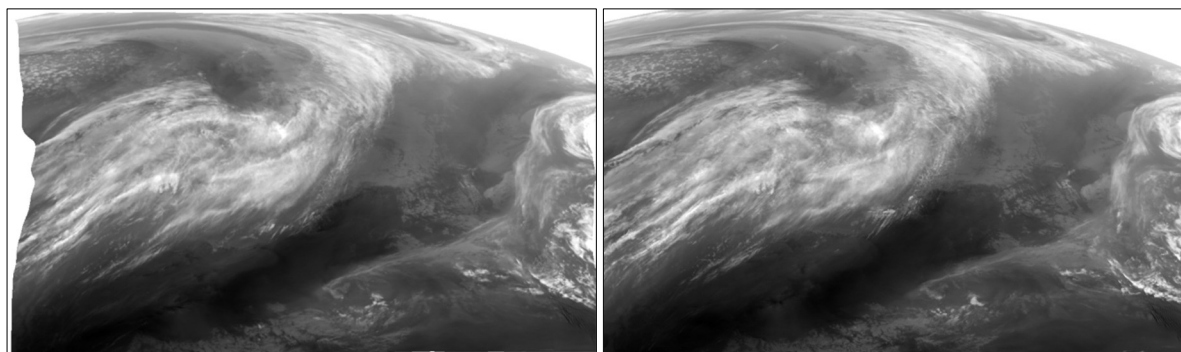
*Figure 2: EXIM output for the MSG WV7.3 channel, for 24 March 2016, 15:15 UTC. Upper row, left: 15-minute forecast (i.e. based on the 15-UTC image); right: 30-minute forecast, based on the 14:45-UTC image. Bottom row, left: 1-hour forecast, based on the 14:15-UTC image; right: the observed WV7.3 channel 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.
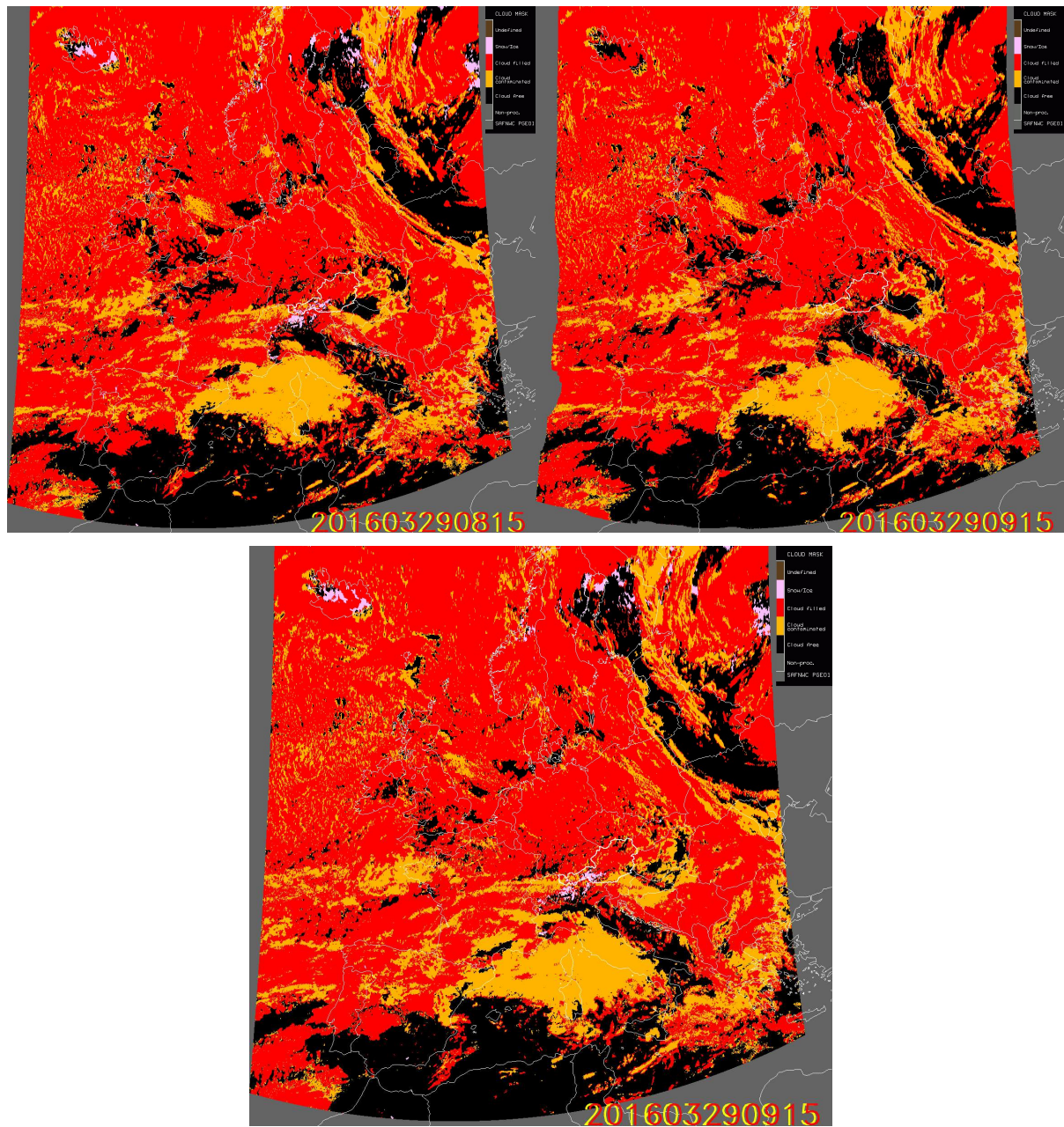
*Figure 3: EXIM applied to the cloud mask product. Upper left: NWCSAF cloud mask for 29 March 2015, 08:15 UTC; upper right: EXIM 1-hour forecast based on the left image. Bottom: the analysed NWCSAF cloud mask for 29 March 2015, 09:15 UTC.*
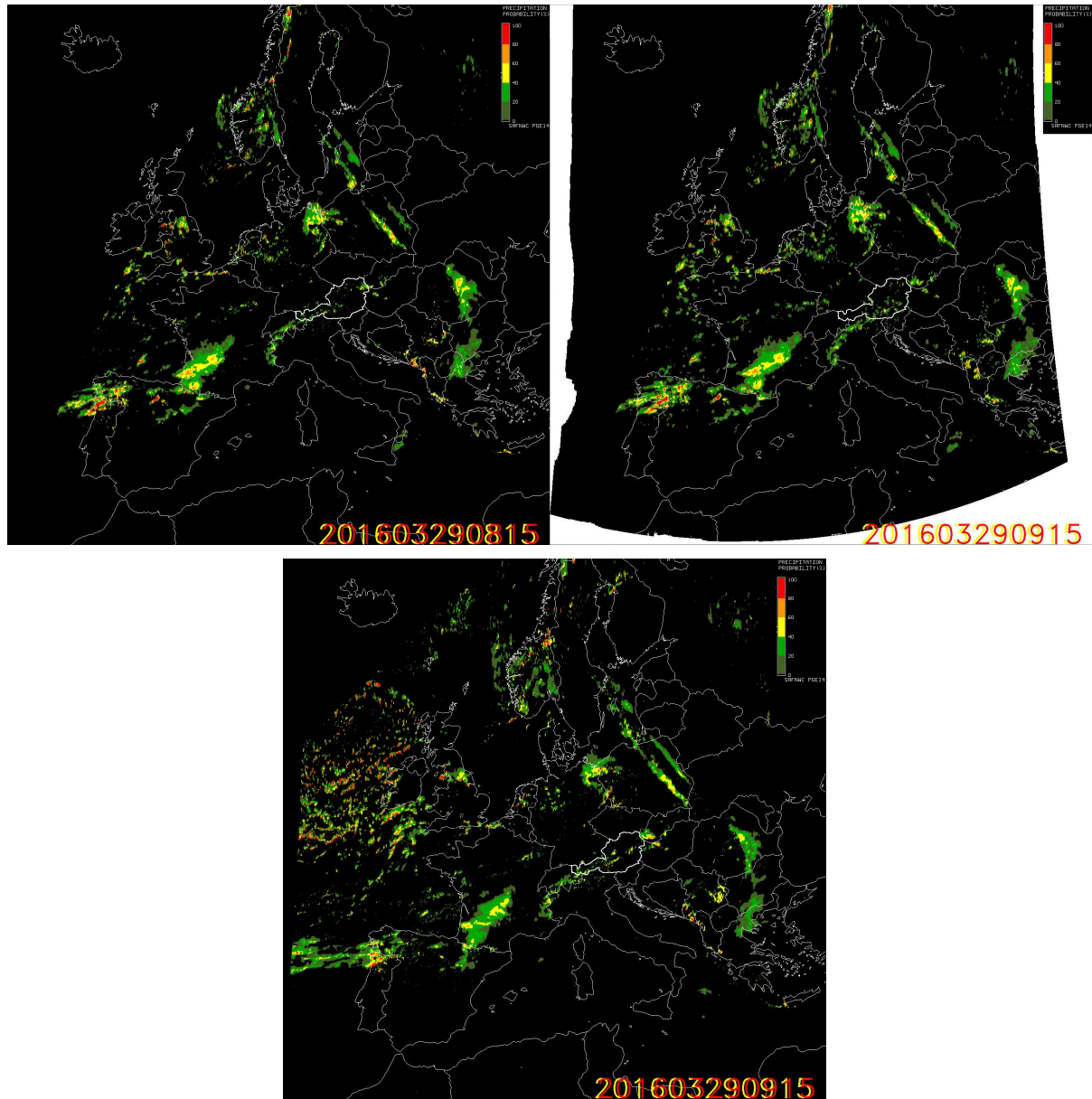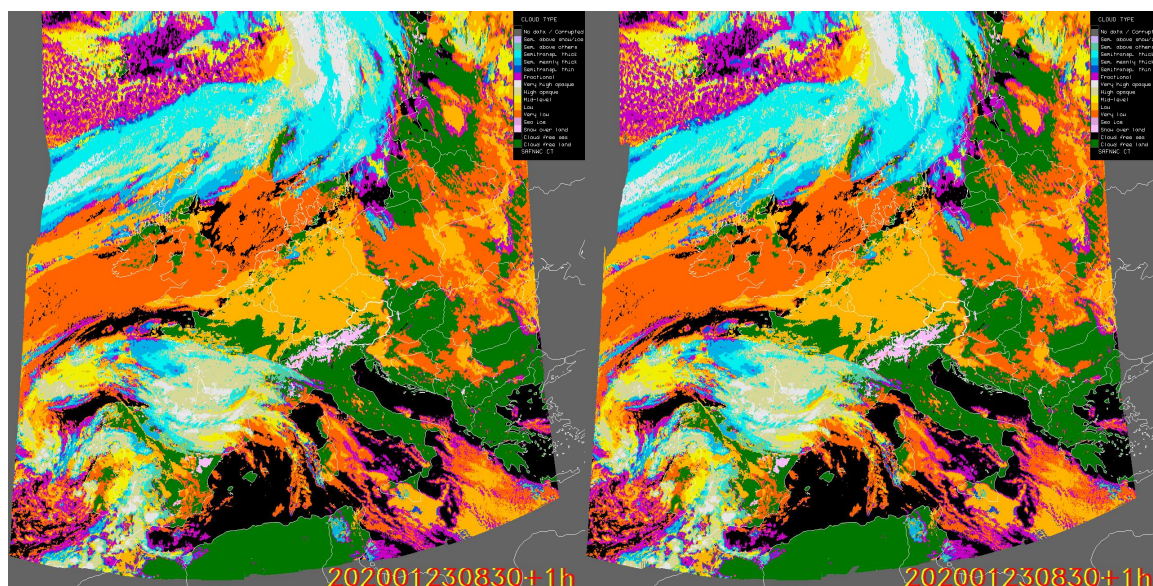
*Figure 4: Similar to Figure 3 but with EXIM applied to the "Precipitating Clouds – Physical Retrieval" (PcPh) product. Upper left: NWCSAF PcPh analysis for 29 March 2015, 08:15 UTC; upper right: EXIM 1-hour forecast based on the left image. Bottom: The analysed NWCSAF PcPh field for 29 March 2015, 09:15 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.*
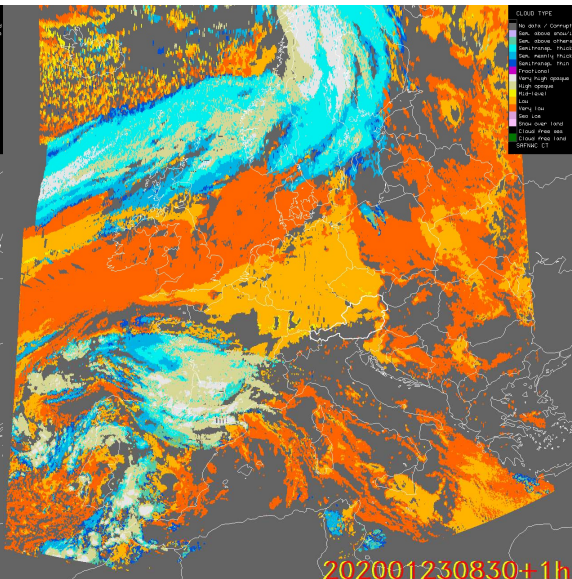
*Figure 6: 60-minute forecasts of the MSG cloud type product for target date 23 January 2020, 09:30 UTC. Upper left: forecast carried out with one trajectory field comprising all available HrW; upper right: forecast carried out with two trajectory fields, 0-500 hPa and 501-1000 hPa; lower left: the same, but displacing the pixels with the vectors of "their" layer (judged by the CTTH 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 file[4]. 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 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 sensibilize 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

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

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.