The EUMETSAT Network of Satellite Application Facilities

NWC SAF

Support to Nowcasting and Very Short Range Forecasting

Algorithm Theoretical Basis Document for the Extrapolated Imagery Processor of the NWC/GEO

NWC/CDOP2/GEO/ZAMG/SCI/ATBD/EXIM, Issue 2.1.1

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Applicable to

GEO-EXIM-v2.0 (NWC-044)

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REPORT SIGNATURE TABLE

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1.1	15 October 2016	23	Updated version, for the actual NWC/GEO release 2016.
2.0	27 February 2017	19	Updated version, for the PCR of NWC/GEO release 2018.
2.1	21 January 2019	21	Updated version, for release 2018; changes concern - Options on selection of layers for the displacement field (section 3.1) - Option to order difference images EXIM – observation (sections 3.2.3) - Inclusion of CMIC input
2.1, rev.1	1 October *2019*	21	Version for SAFNWC/GEO v2018.1 (GOES-R patch; minor additions).

Table of contents

1. INTRODUCTION 6

1.1 SCOPE OF THE DOCUMENT 6
1.2 SOFTWARE VERSION IDENTIFICATION 6
1.3 IMPROVEMENTS SINCE THE PREVIOUS RELEASE 6
1.4 DEFINITIONS, ACRONYMS AND ABBREVIATIONS 6
1.5 REFERENCES 7
1.5.1 Applicable Documents 7
1.5.2 Reference Documents 7

2. EXTRAPOLATED IMAGERY (EXIM) OVERVIEW 9

3. EXTRAPOLATED IMAGERY (EXIM) ALGORITHM DESCRIPTION 10

3.1 THEORETICAL DESCRIPTION 10
3.1.1 Physics of the problem 10
3.1.2 Mathematical description of the algorithm 10
3.1.2.1 Atmospheric motion vectors (AMV) 10
3.1.2.2 The extrapolation step 11
3.1.2.3 Handling of cloudfree pixels 13
3.2 PRACTICAL CONSIDERATIONS 14
3.2.1 Validation 14
3.2.2 Quality control and diagnostics 14
3.2.3 Description of Extrapolated Imagery (EXIM) output 14

4. ASSUMPTIONS AND LIMITATIONS 16

5. EXAMPLES OF EXTRAPOLATED IMAGERY (EXIM) VISUALISATION 17

ANNEX 1: ANCILLARY DATA 21

List of Tables and Figures

Table 1: List of Applicable Documents 7

Table 2: List of Referenced Documents 8

Figure 1: Kinematic extrapolation applied to cloud top temperatures. Left: Meteosat First Generation IR10.8µm image from 23 September 1997, 06:00 UTC with the superimposed isoline forecast for 08:00 UTC (see text). Right: Validation - MFG IR10.8µm image at 08:00 UTC, with the isoline forecast for 08:00 UTC again being superimposed. 17

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. 17

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. 19

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. 20

1. INTRODUCTION

1.1 SCOPE OF THE DOCUMENT

This document is the Algorithm Theoretical Basis Document for the "extrapolated imagery" product PGE16 (EXIM) of the NWC/GEO software package.

This document contains a description of the algorithms, including scientific aspects and practical considerations.

1.2 SOFTWARE VERSION IDENTIFICATION

This document describes the algorithms implemented in the EXIM/PGE16 version included in the 2018.1 NWC/GEO software package delivery (GEO-EXIM v2.0).

1.3 IMPROVEMENTS SINCE THE PREVIOUS RELEASE

Improvements concern extended sets of satellite (Himawari, GOES-R) and NWC/GEO input data (CMIC). This does, however, not affect the algorithm so the impact of v2018 on the ATBD is generally only on the formalistic side. An option to derive difference images between EXIM forecast and the actual satellite image observed at the target date was introduced, as well as OpenMP commands included for optional parallelization. Those are changes that do not impact the ATBD, however.

1.4 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
CTy	Cloud Type
EUMETSAT	European Organisation for the Exploitation of Meteorological Satellites
EXIM	Extrapolated Imagery
HDF	Hierarchical data Format
HRIT	High Rate Information Transmission
HRVIS	High-resolution VISible
HrW	High-resolution Winds
IR	Infrared
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)

1.5 REFERENCES

1.5.1 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]	Project Plan for the NWCSAF CDOP3 phase	NWC/CDOP3/SAF/AEMET/MGT/PP	1.3	12/07/19
[AD.2]	NWCSAF CDOP3 Project Plan Master Schedule	NWC/CDOP3/SAF/AEMET/MGT/PP/MasterSchedule	1.1	28/02/18
[AD.3]	Configuration Management Plan for the NWC SAF	NWC/CDOP3/SAF/AEMET/MGT/CMP	1.0	21/02/18
[AD.4]	System and Components Requirements Document for the NWC/GEO	NWC/CDOP2/GEO/AEMET/SW/SCRD	2.2	01/04/19
[AD.5]	Interface Control Document for Internal and External Interfaces of the NWC/GEO	NWC/CDOP3/GEO/AEMET/SW/ICD/1	1.1	01/10/19
[AD.6]	Interface Control Document for the NWCLIB of the NWC/GEO	NWC/CDOP3/GEO/AEMET/SW/ICD/2	1.1	01/10/19
[AD.7]	The Nowcasting SAF Glossary	NWC/CDOP2/SAF/AEMET/MGT/GLO	2.1	03/02/17
[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	1.1	21/12/18
[AD.10]	User Manual for the Tools of the NWC/GEO	NWC/CDOP3/GEO/AEMET/SCI/UM/Tools	1.0	21/01/19

Table 1: List of Applicable Documents

1.5.2 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.

Reference	Title	Code	Vers	Date
[RD.1]	Data Output Format for the NWC/GEO	NWC/CDOP3/GEO/AEMET/SW/DOF	1.1	01/10/19
[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]	User Manual for the Extrapolated Imagery Processor of the NWC/GEO: Science Part	NWC/CDOP3/GEO/ZAMG/SCI/UM/EXIM	1.0.1	01/10/19
[RD.4]	Algorithm Theoretical Basis Document for the Wind product processor of the NWC/GEO	NWC/CDOP2/GEO/AEMET/SCI/ATBD/Wind	2.2	18/12/19
[RD.5]	Scientific and Validation Report for the Wind product processor of the NWC/GEO	NWC/CDOP3/GEO/AEMET/SCI/VR/Wind	1.1	18/12/19
[RD.6]	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

Table 2: List of Referenced Documents

2. EXTRAPOLATED IMAGERY (EXIM) OVERVIEW

PGE16 of the NWC/GEO applies kinematic extrapolation using atmospheric motion vectors (AMVs) for displacing SEVIRI/GOES-N/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 except HRVIS (whose incorporation shall be decided upon at a later stage), analogously for GOES-N, GOES-R and Himawari;
2) the NWCSAF products "cloud mask", "cloud type", "cloud top temperature and height", "cloud microphysics", "precipitating cloud", and "convective rainfall rate".

[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)

3. EXTRAPOLATED IMAGERY (EXIM) ALGORITHM DESCRIPTION

3.1 THEORETICAL DESCRIPTION

3.1.1 Physics of the problem

Meteorological flows have a continuous character – the movement seen in the preceding interval between two consecutive satellite images hence is most likely the best guess for the movement in the forthcoming interval. Consequently, a simple way of short-term forecasting is to exploit vector fields derived from several channels (such as the NWC/GEO HrW product) and extrapolate the position of pixels along trajectories of this displacement field.

Undoubtedly, this simple 2-D approach has its limitations in capturing the 3-D dynamics of the real atmosphere, and in adverse situations high cloud patches may move over lower clouds in completely different directions, with little prospect to assign each pixel exactly to the right layer, to assign the right vector to each pixel/layer and last but not least, to merge the pixels running in two different directions into an interpretable satellite image. As a compromise, it was agreed for v2016 after some expert discussions to concentrate on extrapolation of the features most prominently reflected in the individual channels, and in turn to discard displacement vectors stemming from other layers. Hence, 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). The extrapolated NWCSAF products were thought to be generally driven to a higher degree by the higher clouds, so the trajectories were the same as for IR imagery. The subsequent evaluation [RD.6] led to different conclusions, however: in order to still enable the v2016 scheme for those users who want to continue with it, the EXIM software now offers options to define one selection of layer(s) to extrapolate VIS, CMa, CT, CMIC, and another selection to extrapolate IR, CTTH, PC, PCPh, CRR, CRRPh. Actually, however, the EXIM developers feel they must recommend, on the basis of the obtained statistical evaluation results, not to differentiate and to use for both groups the same set comprising all vectors of the AMV input. As a compromise between the two extremes, an optional "two-layer scheme" has been introduced, whereby it is possible to exploit all the AMV information, while still having a separation between high-level and low-level flow. Though users have any freedom in defining the layer(s), the mathematical principle (ch. 3.1.2) behind the product generation is always the same and also has not been altered from v2016 to the new release.

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).

3.1.2 Mathematical description of the algorithm

3.1.2.1 Atmospheric motion vectors (AMV)

The AMVs are made available from the NWC/GEO High Resolution Wind Package PGE09-HrW (consult [RD.4][RD.5] for details). The EXIM software assumes that the end points of the input AMVs form a regular grid. As this is not the case in the HrW output (and the spatial resolution is much coarser than that of the SEVIRI/GOES-N/GOES-R/Himawari image), spatial interpolation of the field is performed before it is submitted to the EXIM computations. The first step in this process is to identify for each pixel (x_p, y_p) the AMVs lying closest. The coordinate system for computing the geometrical distance is the pixel grid of the satellite imagery; this distance is, however, modified by division through the confidence q_a assigned to each vector in the HrW input. The distance thus is given by (x_a and y_a designate the coordinates of a vector's endpoint):

$$r(x_a, y_a) = \frac{\sqrt{(x_a - x_p)^2 + (y_a - y_p)^2}}{q_a}$$

Thus, a vector with a good quality indicator q_a (i.e. close to 1) will for our purposes be virtually "closer" than another vector in similar geometric distance, but with a confidence close to 0. Only a limited number of neighbours are used to derive the interpolated vector components at a certain pixel, in the current implementation: the 5 closest, in the described sense. The u- and v-components of these vectors (actually, the directly related increments of geographical longitude and latitude $\Delta\lambda$ and $\Delta\varphi$) undergo an inverse distance weighted interpolation scheme. The employed weights are inspired by those used in the so-called Shepard gridding:

$$w = \left(\frac{r(x_a, y_a) - r_{max}}{r(x_a, y_a) r_{max}}\right)^2,$$

where r_{max} stands for the maximum distance found for any of the accepted neighbours. Finally the components of the displacement vector at any pixel are computed as:

$$\Delta\varphi(x_p, y_p) = \frac{\sum_{i=1}^{5} w_i\,(\Delta\varphi)_i}{\sum_{i=1}^{5} w_i}$$

(analogously for $\Delta\boldsymbol{\lambda}$).

In case the software (upon user request) follows a two-layer approach, two lists are considered at any pixel holding the five closest neighbour AMVs in the upper and the lower layer, respectively. The layer with the smaller sum of the five distances is assigned to the pixel and the associated list enters the formulas just given.

3.1.2.2 The extrapolation step

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.

The NWC/GEO EXIM software performs the following major steps for the computation of forecast images:

- For each pixel, the next position (at t+T) is determined by assuming that the movement of the pixel persists. In a possible second extrapolation step (for t+2×T), the position of the pixel is extrapolated with the AMV that had been observed at the new position at starting time *t*. The repetitive application of the procedure yields trajectories under the assumption of a temporally invariable displacement field.
- For every time step, two arrays are obtained which hold the *x*- and *y*-coordinates, respectively, of the trajectories originating at the individual pixels. These arrays of trajectories' coordinates need to be smoothed. An $m\times m$-average filter is applied (to *x*- and *y*-coordinates separately) where the filter size *m* is currently fixed at twenty-one[2].

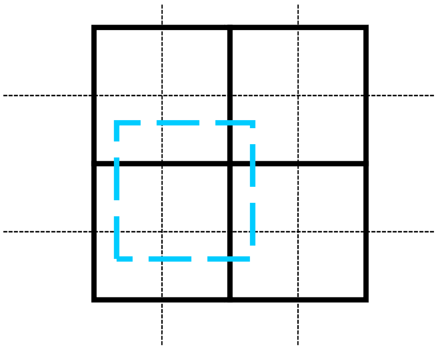
[2] The relatively strong smoothing has its origin in applications with IR-only AMVs produced by commercial software packages that were used at the developer's premises. It has turned out to be particularly necessary there at the borders between cloudy and cloudless areas in IR imagery. There, IR AMVs tend to show abrupt changes

When applying the trajectory field to the analysis fields in order to make the kinematic forecasts, a distinction is made between 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). Typical examples covered by the EXIM software are:

- For the group "continuous": SEVIRI/GOES-N/GOES-R/Himawari radiances and reflectances/brightness temperatures.
- For the group "categorical": CMa and CTy analyses.

For the continuous variables, the proceeding is:

- For each "new" position of a pixel given in the trajectories for the currently considered time step, the contribution of the pixel to the pixel(s) of the forecast image around this new position is assessed. In the general case, the new *x*- and *y*-coordinates are not integer values, so we use weighted contributions to the 4 pixels with which the "forecast pixel" overlaps. Example: Position of pixel forecast at x=286.2/y=117.3:



  Pixel 286|117 overlaps with 0.8*0.7=56% of the area of the forecast pixel depicted by the dashed blue line. Hence, the value p_i of the pixel at the starting point of the trajectory is stored with a relevance factor (=weight w_i) of 0.56 at that position. The other three affected pixels are treated analogously. After evaluation of all trajectories, the pixel value at any position of the forecast image is determined from the individually collected contributions through the weighted average $\frac{\sum_i w_i p_i}{\sum_i w_i}$.

- For pixels being not at all 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 it hits an already classified pixel in the respective direction. 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 procedure necessarily has a lower degree of sophistication:

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from noticeable movement to near-zero vectors. This leads to unrealistic (random) convergence and divergence (not matching the real atmospheric flow) and – resulting therefrom – incoherent trajectories and deformation of cloud patterns).

- Knowing the "new" position of a pixel, 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. In the above example of a pixel forecast at position *x*=286.2/*y*=117.3, the parameter value at pixel 286/117 is set (pixels at positions 286/118, 287/117 and 287/118 are not impacted in this step). If accidentally another trajectory would target that pixel later, the parameter value is a guess just as good as the one assigned before. Of the possible arbitrary decision rules, overwriting is chosen in EXIM, i.e. the last candidate wins.

- For pixels being not at all 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 it hits an already classified pixel in the respective direction. From the up to 8 neighbours, the class to which the majority of neighbours belongs is determined. If there is a draw 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 parameters exist where even this sort of nearest-neighbours processing does not seem permissible and EXIM rather leaves (the usually small) gaps in the images. This option is chosen when associated quality flags are transported together with the NWCSAF parameter in order to preserve the information about the quality at the starting point. Gaps are fortunately of little concern there as those parameters should hardly be viewed in image form.

Product-specific post-processing steps may be necessary. A parameter where this is clearly advisable is the cloud type product, which has classes “land”, “sea” and “snow” that should not be shifted with AMVs. Hence, for the areas that belong to a cloudfree category in the forecast image, a land/sea mask and the CTy class in the analysis are considered, and the forecast CTy value is reset if it is disproven by the supplementary information.

3.1.2.3 Handling of cloudfree pixels

Evidently, it is problematic to displace pixels of satellite images which are free of clouds and thus show features from the Earth’s surface. Coastlines and snow patches then start to wander. The NWCSAF package offers a cloud mask, which can be exploited as a remedy. The default mode is to mask the cloudfree pixels, i.e. the EXIM output comprises only the displaced cloud pixels. For users wishing to have a full satellite image as output, there is an option to fill the cloudfree pixels in a way keeping the ground features essentially stationary. It

(1) copies pixels that were cloudfree at the beginning to the pixel in the forecast image if the forecast CMa product indicates it is still cloudfree.
(2) seeks the nearest cloudfree pixels in the original image for pixels that were cloudy at the start but became clear as the clouds were extrapolated away. An average of the radiance there is used to compute the best possible estimate how the satellite image would have looked like there if cloudfree. A land/sea mask is used in order to ensure that land pixels receive contributions only from land, and sea from sea. The snow information in the CMa product is exploited as well since cloudfree snowy pixels normally represent no proper candidates to spread their brightness to the vicinity.

The cloud masking is not applied for the forecasts of the two WV channels 6.2 and 7.3, which by their different characteristics are immune against surface features.

3.2 PRACTICAL CONSIDERATIONS

3.2.1 Validation

Validation of EXIM products is straightforward by comparing the extrapolative forecast with the analysis made at the forecast time (which is considered the truth) and computing established skill scores. Concrete figures are provided in separate validation reports [RD.2] and [RD.6].

3.2.2 Quality control and diagnostics

The input NWCSAF products generally have associated quality flags which are extrapolated by the EXIM module together with the meteorological quantity. Thus, at pixels of the forecast products that result from displacement with trajectories, the information about the quality of the analysed pixel at the trajectory's origin is provided. An additional EXIM-specific quality flag is provided which for any pixel gives the information whether it is the result of a trajectory extrapolation or a post-processing operation (or not covered at all by EXIM, a typical category at the border of the analysis domain).

3.2.3 Description of Extrapolated Imagery (EXIM) output

(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) During the NWCSAF product processing chain, satellite data are internally transformed from HRIT to the so-called DATABUF format which essentially is just a binary dump of the matrices of radiances, reflectivities and brightness temperatures, located in the $SAFNWC/tmp directory. It was, however, decided to put highest priority on coherence among the EXIM outputs, and consequently also the forecast satellite imagery are 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. 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

(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 (the lead time is user-configurable) 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_DIR108_MSG3_Europe-VISIR_20150401T121500Z_030.nc.

4. ASSUMPTIONS AND LIMITATIONS

All limitations mentioned for the NWCSAF input products in the respective sections of their ATBDs apply to the EXIM forecasts as well, of course. In addition, dynamic changes in the meteorological parameters cannot be captured by the extrapolation approach. The implicit assumption behind the maintenance of EXIM thus obviously is that NWP is not (yet?) able to provide the parameters for the next hour in an adequate manner to all the users that are interested in them.

It was discussed in section 3.1.1 that 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.

5. EXAMPLES OF EXTRAPOLATED IMAGERY (EXIM) VISUALISATION

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°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.

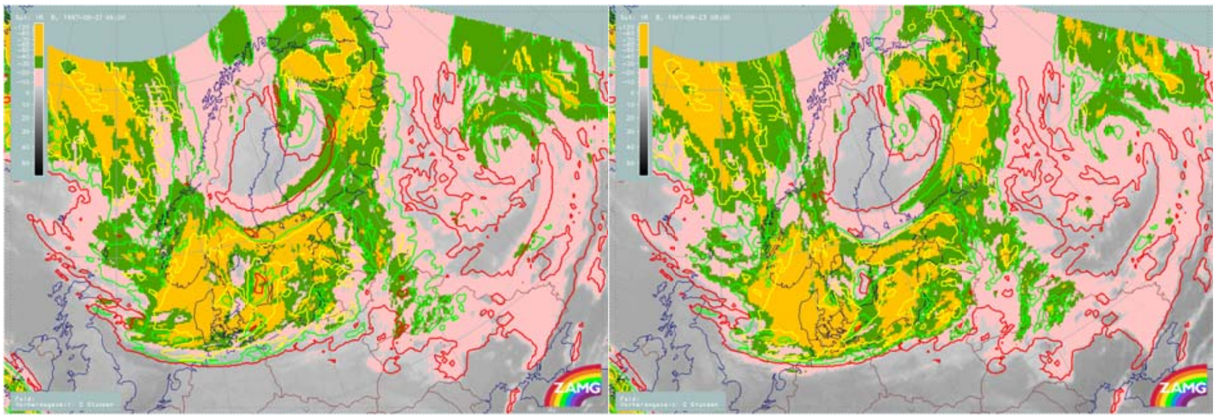


Figure 1: Kinematic extrapolation applied to cloud top temperatures. Left: Meteosat First Generation IR10.8µm image from 23 September 1997, 06:00 UTC with the superimposed isoline forecast for 08:00 UTC (see text). Right: Validation - MFG IR10.8µm image at 08:00 UTC, with the isoline forecast for 08:00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

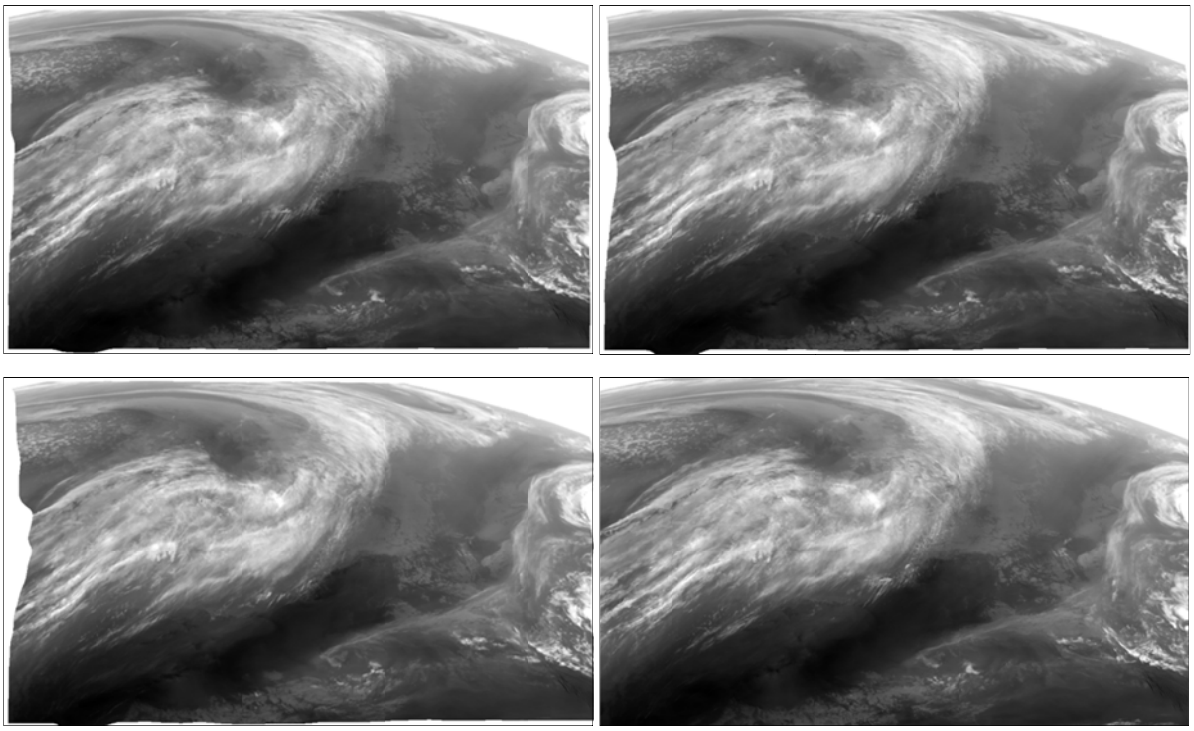
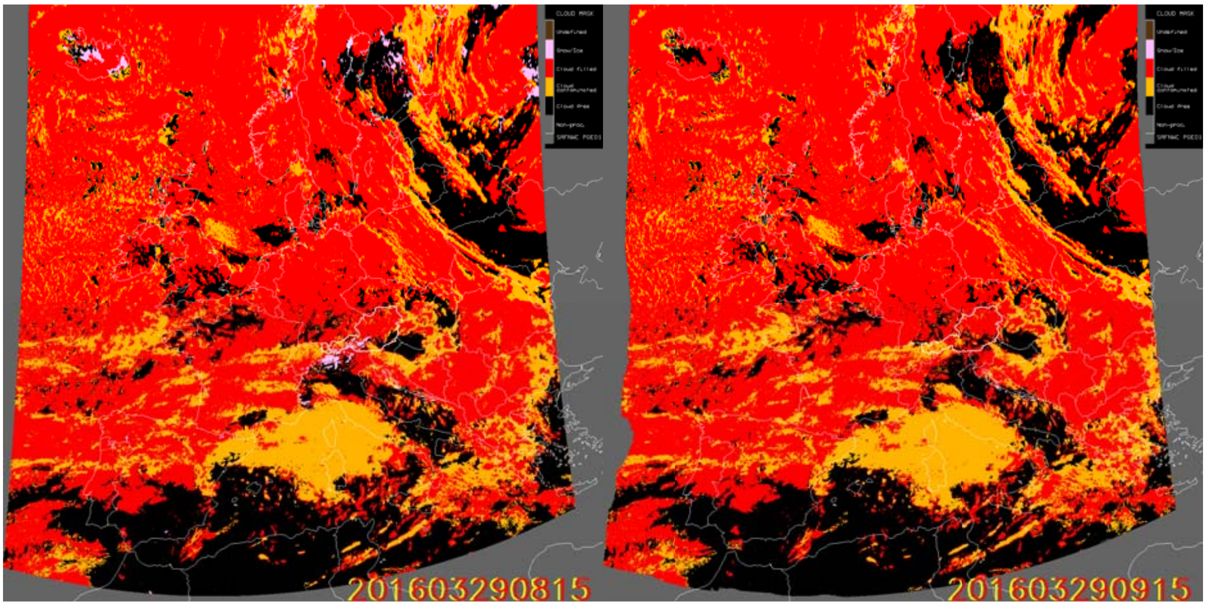


Figure 2: EXIM output for the MSG WV7.3 channel, for 24 March 2016, 15:15 UTC. Upper row, left: 15-minute forecast (i.e. based on the 15-UTC image); right: 30-minute forecast, based on the

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 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. 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.



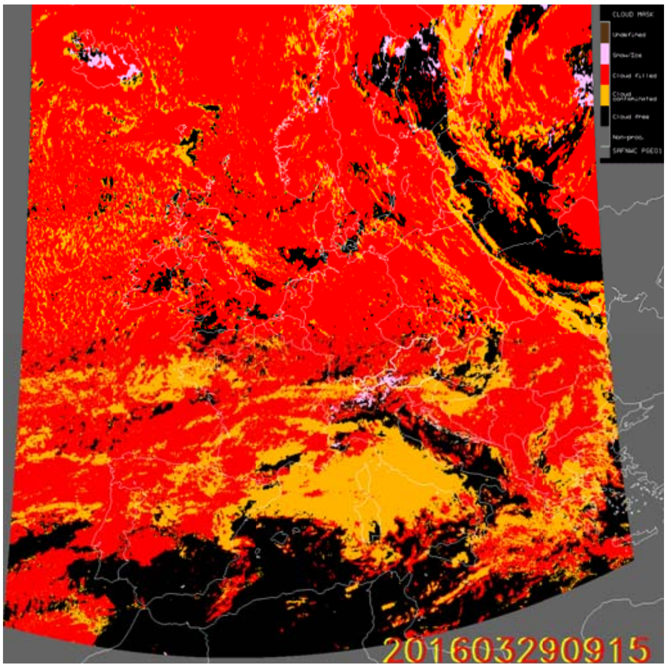
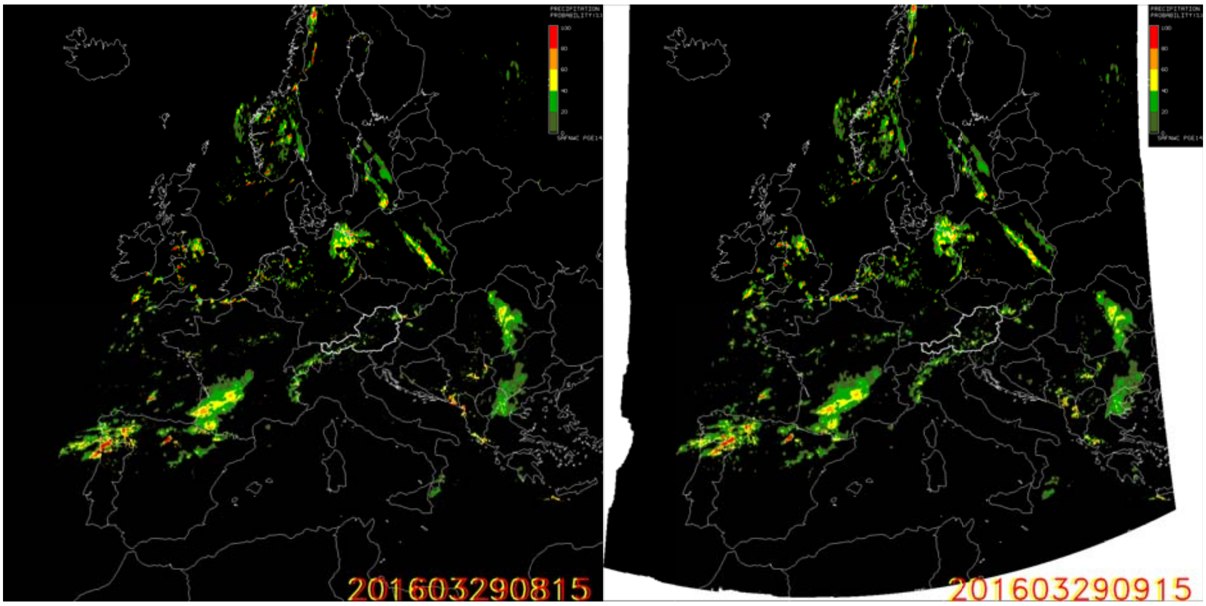


Figure 3: EXIM applied to the cloud mask product. Upper left: NWCSAF cloud mask for 29 March 2015, 08:15 UTC; upper right: EXIM 1-hour forecast based on the left image. Bottom: the analysed NWCSAF cloud mask for 29 March 2015, 09:15 UTC.



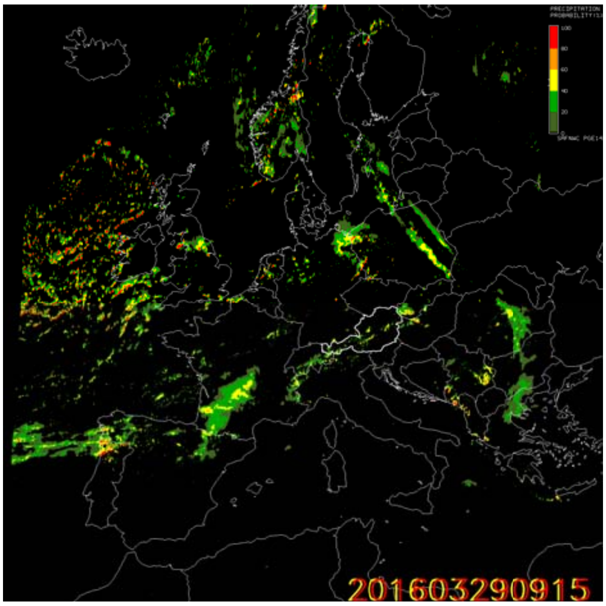


Figure 4: Similar to Figure 3 but with EXIM applied to the "Precipitating Clouds – Physical Retrieval" (PcPh) product. Upper left: NWCSAF PcPh analysis for 29 March 2015, 08:15 UTC; upper right: EXIM 1-hour forecast based on the left image. Bottom: The analysed NWCSAF PcPh field for 29 March 2015, 09:15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

ANNEX 1: ANCILLARY DATA

A land/sea/coast atlas covering the whole MSG disk in the default satellite projection at full SEVIRI IR horizontal resolution is available within the NWC/GEO software package and is used in the elaboration of EXIM. More detailed information on this dataset can be found in documentation on the NWC/GEO as a whole.