




Summary of activities of NWC SAF clear air team for preparation of MTG-S/IRS L1 in CDOP-3

NWC/CDOP3/GEO/AEMET/SCI/RP/qIRS_NWC-157, Issue 1, Rev.0

31 January 2022


*Prototyping studies qIRS NWC- 157
Applicable to WP2610 in CDOP-3*

Prepared by Agencia Estatal de Meteorología (AEMET)

	Summary of activities of NWC SAF clear air team for preparation of MTG-S/IRS L1 in CDOP-3	Code: NWC/CDOP3/GEO/AEMET/SCI/RP/qIRS_NWC-157 Issue: 1.0 Date: 31 January 2022 File: NWC-CDOP3-GEO-AEMET-SCI-RP-studies_qIRS Page: 2/57
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REPORT SIGNATURE TABLE

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DOCUMENT CHANGE RECORD

Version	Date	Pages	Changes
1.0	31 January 2022	57	First version of the summary of activities of NWC SAF clear air team for preparation of MTG-S/IRS L1 in CDOP-3

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1 INTRODUCTION

The Eumetsat “Satellite Application Facilities” (SAF) 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, hereafter 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>. This document is applicable to the NWC SAF processing package for geostationary meteorological satellites, NWC/GEO.

1.1 PURPOSE AND SCOPE OF THE DOCUMENT

The purpose of this document is to present a summary of the pioneering activities made by NWC SAF clear air team in CDOP-3 phase related to the preparation for a full and synergetic support of MTG-S/IRS and MTG-I/FCI.

The Working Packages for CDOP-3 was planned in the CDOP-2 and due to the delays in dates of the launches of MTG satellites and the findings and facts in CDOP-3 some adjustments in the activities has been done. In Figure 1 and taken from [AD.1] the original wording of WP2610 related to MTG-S/IRS L1 activities can be seen. This Working Package can be considered as responsibility of AEMET NWC SAF clear air team.


After the delivering of iSHAI software version 2021 and few months before end CDOP-3, it has been considered the best time to write this report because also it could be used as introduction to some activities included in next CDOP-4 phase.

Due to the lack of MTG-S/IRS L1 test data the main focus in this document are the activities made to generate scientifically correct MTG-S/IRS L1 synthetic data by the NWCSAF clear air team. It is described the path followed from the early attempts to the latest version. Now after release of RTTOV-13.0 and using the previous developments it has been possible to generate the first scientifically correct synthetic MTG-S/IRS and MTG-I/FCI test data. Something that is important to note is that the synthetic IRS and FCI have been generated on the same region in FCI IR grid for 24 hours periods; FCI on spatial resolution of 1x1 FCI IR grid (2x2 km resolution on nadir) every 10 minutes and IRS on spatial resolution of 2x2 FCI IR grid (4x4 km resolution on nadir) every 30 minutes.

All this activities has been made as preparation for a future full and synergistic use of MTG-S/IRS and MTG-I/FCI data and products from the METEOSAT Third Generation (MTG) on the NWCSAF/GEO software packages.

In the case of the MTG-I/FCI, NWCSAF GEO software package for MTG-I/FCI Day-1 will be a continuation of the current NWCSAF GEO package with almost the same products (cloud mask, iSHAI, etc.) but with improved performances due to the use of the new FCI channels and improved characteristic of FCI. The AEMET clear air team develop iSHAI product that is the clear air product of the NWC/GEO software package from GEO imager instruments.

In the case of the MTG-S/IRS hyperspectral instrument it will be developed one optional and independent IRS NWCSAF GEO software package for MTG-S/IRS Day-2. The idea is that the IRS NWCSAF/GEO software package be operated in coordination with FCI NWCSAF/GEO software package; in order to share as much as possible the infrastructure and allowing one synergetic exploitation of FCI and IRS data and products by the users. The IRS NWCSAF/GEO software package will provide three main services or products to users:

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Quick-IRS L1: support of the MTG-S/IRS L1 activities for local generation of simple products of image type and for the use IRS L1 as input for local generation of NWC SAF or user's products. As example they could be generated:

- MTG-S/IRS RGB images
- Normalized IRS-L1 channels in spectral region as CO₂ or WV branches representing the state of the atmosphere at several layers.
- Simple operations with MTG-S/IRS L1 fields as differences or regressions between several IRS channels.
- Blending products generated with the combination of FCI and IRS data.

Thus, users could made the automatic generation of IRS L1 imagery related products or to use them for locally generation of NWC SAF or users products. The activities related to the preparation of Quick-IRS L1 are the main objective of this Scientific Report.

sSHAI ES: support of the MTG-S/IRS L2 files disseminated by EUMETSAT Secretariat (ES). The idea is that ES MTG-S/IRS L2 fields could be used directly by users in combination with the ones L1 and L2 fields from FCI or IRS for the same regions. An example is the comparison of instability indices or precipitable water fields from MTG-I/FCI, MTG-S/IRS and NWP.

sSHAI: development of product executed locally by the users. Local generation of NWCSAF MTG-S/IRS L2 product using algorithms with light CPU demand.

As can be seen in the name of the products prefix “i” indicates generated with input data from one GEO imager instrument and “s” prefix will indicate generated with input data from MTG-S/IRS sounder instrument.

In all the services/products it will be made also the concatenation and reprojection from the “dwell” files disseminated by EUMETSAT to users regions of interest on FCI IR grid on resolution of 2x2 boxes ($\approx 4 \times 4$ km spatial resolution on nadir) or 1x1 boxes depending on user's choices.

There are also some remarkable points in the activities described in this report:

- a) All the synthetic data in this report has been generated using the AEMET PGE00* tools. The PGE00* tools use the 4D interpolated NWP profiles to get synthetic data for imager (MSG, GOES-R, MTG-I/FCI) or sounder (MTG-S/IRS and IASI) instruments on clear and cloudy conditions. These synthetic datasets could be used to get synthetic images or for validation/training purposes.
- b) The use of the AEMET PGE00* involves as first step the 4D interpolation from GRIB files of some NWP models to get vertical, spatial and temporally collocated NWP and satellite. This 4D interpolated profiles and data used as input to PGE00* tools can be also written on binary files. Thus, together with the synthetic data also the 4D datacube used for the generation of the synthetic data is available and it can be used as a “truth” for training, performance assessments and validation in the developments.
- c) Also this binary files can be converted to netCDF files to be used on meteorological tools. The use of McIDAS-V tool as main visualization tool of this report allows to manage interactively and at the same time the synthetic IRS and FCI data cubes together with the 4D NWP data cube. McIDAS-V can be considered as proxy of future user needs and tools for IRS use in nowcasting.

Some of the results and Figures described in this Scientific Report has been shown in several workshop or communicate to EUMETSAT on private discussions. It will be indicated in each chapter.

1.2 DEFINITIONS, ACRONYMS AND ABBREVIATIONS

Please refer to the “Nowcasting SAF Glossary” document in the NWC SAF web for a wider glossary and a complete list of acronyms for the NWC SAF project.

ABI	Advanced Baseline Imager
AEMET	Agencia Estatal de Meteorología Meteorology State Agency (Spain)
AHI	Advanced Himawari Imager
ASCII	American Standard Code for Information and Interchange
ATBD	Algorithm Theoretical Basis Document
BL	Precipitable water in low layer ($P_{\text{sfc}} - 850$ hPa)
BT	Brightness Temperature
CDOP (CDOP-1)	Continuous Development and Operations Phase (1)
CDOP-2	Continuous Development and Operations Phase 2
CDOP-3	Continuous Development and Operations Phase 3
CF	NetCDF Climate and Forecast (CF) Metadata Conventions
CIMSS	Cooperative Institute for Meteorological Satellite Studies (USA)
CMa	Cloud Mask
COTS	Commercial-Off-The-Shelf
CPU	Central Processor Unit
DEM	Digital Elevation Model
ECMWF	European Centre for Medium-range Weather Forecasts
EOF	Empirical Orthogonal Function
EUMETSAT	European Organisation for the Exploitation of Meteorological Satellites
FCI	Flexible Combined Imager (MTG)
FG	First Guess
FOV	Field Of View
FOR	Field Of Regard
GEO	Geostationary Satellites
GEO-CMa	GEO Cloud Mask and Cloud Amount
GEO-iSHAI	GEO imaging Satellite Humidity And Instability

GRIB	Gridded Information in Binary Form
HDF5	Hierarchical Data format version 5
HL	Precipitable water in High Layer (500 – 0 hPa)
hPa	Hecto Pascal
HRIT	High Rate Image Transmission
IDL	Interactive Data Language
IR	InfraRed
IREMIS	InfraRed Emissivity
IRS	Infrared Sounder (MTG)
iSHAI	imaging Satellite Humidity And Instability
K	Kelvin
KI	K-Index
km	kilometre
LI	Lifted Index
LPW	Layer Precipitable Water
LST	Land Surface Temperature
MARS	ECMWF Meteorological Archive and Retrieval Facility
McIDAS	Man Computer Interactive Data Access System
ML	Precipitable water in Medium Layer (850 – 500 hPa)
MSG	Meteosat Second Generation
MTG	Meteosat Third Generation
MTG-FCI	Meteosat Third Generation Flexible Combined Imager
MTG-IRS	Meteosat Third Generation Infra Red Sounder
netCDF	Network Common Data Form
NRT	Near Real Time
NWC	Nowcasting
NWC/GEO	Geostationary part of the Nowcasting SAF
NWCLIB	Nowcasting Library
NWCSAF	Nowcasting SAF
NWP	Numerical Weather Prediction


NWP SAF	SAF for Numerical Weather Prediction
LPW	Layer Precipitable Water
PGE	Product Generation Element PGE01 Cloud Mask (GEO-CMa) Product Generator PGE13 SEVIRI Physical Retrieval (SPhR) Product Generator
PW	Precipitable Water
RTM	Radiative Transfer Model
RTTOV	Radiative Transfer for TOVs
SAF	Satellite Application Facility
SEVIRI	Spinning Enhanced Visible InfraRed Imager
SG	Steering Group
SHAI	Satellite Humidity And Instability
SHW	Showalter Index
SKT	Skin Temperature
SST	Sea Surface Temperature
SW	Software
TOZ	Total ozone
TPW	Total Precipitable Water
TM	Task Manager
UM	User Manual
VR	Validation Report
VSA	Visiting Scientist Activities
WV	Water Vapour Channel

1.3 REFERENCES

1.3.1 NWC SAF 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 versioned references, subsequent amendments to, or revisions of, any of these publications do not apply. For unversioned references, the current edition of the document referred applies.

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

Ref.	Title	Code	Vers
[AD.1]	Proposal for the Third Continuous Development and Operations Phase (CDOP-3) March 2017-February 2022	NWC SAF: CDOP-3 proposal	1.0
[AD.2]	Project Plan for the NWCSAF CDOP3 phase	NWC/CDOP3/SAF/AEMET/MGT/PP	1.6

Table 1: List of Applicable Documents


1.3.2 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.

Ref.	Title	Code	Vers	Date
[RD.1]	Summary of activities of NWC SAF clear air team for preparation of MTG-I/FCI in CDOP-3	NWC/CDOP3/GEO/AEMET/SCI/RP/synthetic_FCI	1.0	31/01/22
[RD.2]	Summary of activities of NWC SAF clear air team for preparation of MTG-S/IRS L2 from EUMETSAT in CDOP-3	NWC/CDOP3/GEO/AEMET/SCI/RP/sSHAI_ES_NWC-158	1.0	21/02/22
[RD.3]	Algorithm Theoretical Basis Document for iSHAI Product Processors of the NWC/GEO	NWC/CDOP2/MTG/AEMET/SCI/ATBD/iSHAI	1.1	13/11/20
[RD.4]	Early adaptation of iSHAI v2016 to future MTG-I FCI using 2013 dataset	NWC/CDOP3/GEO/AEMET/SCI/RP01	1.0	31/01/20
[RD.5]	Validation Report for "Clear Air Products"	NWC/CDOP3/GEO/AEMET/SCI/VR/ClearAir	1.1	31/01/20
[RD.6]	Product User Manual for "Clear Air Products"	NWC/CDOP3/GEO/AEMET/SCI/UM/ClearAir	1.1	31/01/20
[RD.7]	Optimal use of MTG-IRS spectra on NWC SAF package for Nowcasting purposes	NWC/CDOP3/GEO/AEMET/SCI/RP/IRS_on_CDOP2	1.0	31/03/20
[RD.8]	Studies for comparison of NWCSAF/MSG PGE13 SPhR and IASI L2 products	NWC/CDOP2/GEO/AEMET/SCI/RP03	1.0	28/01/16
[RD.9]	Studies for the use of MTG-IRS L1 in nowcasting based in validation and training activities of the NWCSAF clear air products	NWC/CDOP2/GEO/AEMET/SCI/RP/02	1.0	30/11/14

Table 2: List of Referenced Documents

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2 INTRODUCTION AND AIM OF THE STUDIES

In CDOP-3 proposal the working package WP 2610 “AEMET GEO-S v202X Quick IRS” was foreseen as activities to do at CDOP-3 phase (March 2017- February 2022). As can be seen in Figure 1 (taken from [AD.1]), it was planned to do the preparation of the products and services for MTG-S/IRS for a Day-2 IRS NWCSAF/GEO software package. A secondary objective was to do all the activities in coordination and in synergetic way with the activities for preparation for MTG-I/FCI support.

NWC SAF: CDOP-3 proposal


Version 1.0, 11 April 2016

WP ID 2610	Title of WP:	GEO-S v202X Quick IRS	
Start:	Mar-2017	Effort (mm):	9
End:	Feb-2022	Responsible partner:	AEMET
WP Objective/s	Development of an operational service for MTG-IRS L2 images and other intermediate outputs on user defined regions (as default same NWCSAF MTG-FCI regions).		
WP Tasks	<p><u>Create a quick MTG-IRS L2 prototype:</u></p> <ul style="list-style-type: none"> *) Built a prototype to generate quick and simple MTG-IRS L2 products from MTG-IRS L1 proxy data or IASI *) Generation of one reduced number of profiles dataset by sampling in the sSHA1 validation and training dataset for a quick IRS-L2 suitable water vapour and instability training dataset. *) Generation of dataset of collocated IASI L1 and L2, NWP and imagery products (Cloud Mask). *) Calculation of simulated MTG-IRS BTs spectra dataset for clear air and cloudy (clouds at several levels and layers) conditions from the previous dataset. *) Calculations of the principal components (PC) for MTG-IRS. Test on calculations of principal components with physical meaning using selected spectral ranges and lines. *) Generation of preliminary reports on the use of MTG-IRS spectra on nowcasting by using the NWC SAF package. *) Generation of different auxiliary configuration matrices to generate different MTG-IRS L2 output products which can be useful for Nowcasters (see ideas summarized in Martinez and Calbet 2013). <p><u>Development of the operational tool for MTG-IRS L1 images on user defined regions</u></p> <ul style="list-style-type: none"> *) Developments for optimal reprojection and dwells concatenation of BTs from MTG-IRS L1 files to NWCSAF MTG-FCI projection. 		
WP Input	RTTOV software. EUMETSAT software to convert IASI spectra to MTG-IRS spectra EUMETSAT software for IASI management McIDAS-V software (HYDRA) for IASI and AIRS management McIDAS-X software to test the reprojection software		
WP Output	MTG-IRS-WPR scientific documentation (Scientific Report)		
WP Interfaces			
Interactions with other SAFS and/or Federated Activities	Coordination with EUMETSAT Secretariat on the format of MTG-IRS L1 and other issues as navigation, Principal Component decompression, etc.		

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Figure 1: WP 2610 “AEMET GEO-S v202X Quick IRS” in CDOP-3 proposal [AD.1].

The purpose of WP 2610 was to make preparatory developments of an operational service for generation of MTG-S/IRS L1 images, other easy products type image (as IRS RGB images) or other

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intermediate and immediate outputs (as linear combinations or regressions from IRS channels) on user defined regions. As commented above other guideline was that these images type products must be obtained by default on same user's regions that the defined by the user on their NWCSAF MTG-I/FCI GEO instance; this will allow to get a synergetic exploitation of the full MTG mission. From these developments a prototype would be obtained.


It must be taken into account that due to the SAFs five year scheduling basis, at the moment when the proposal for CDOP-3 was written in 2016 the schedule of the launches of MTG-I/FCI and MTG-S/IRS was different. The launches on MTG mission have been delayed several years and MTG-I and MTG-S will be launched finally in CDOP-4. When the CDOP-3 proposal was written the purpose of this WP was to create first a collocated dataset with: IASI L1 spectra, IASI L2 retrieved profiles, SEVIRI or FCI NWCSAF products and ECMWF profiles from several forecast steps and nearest analysis. This task was proposed thinking on a continuation of the EUMETSAT NRT IRS experiment; but due to the cancellation of the second phase of the EUMETSAT NRT IRS experiment, this task was reduced to create datasets from IASI L1 and IASI L2 netCDF files from EUMETSAT for just several case studies. The expertise on the use of real IASI L1 and IASI L2 netCDF files from EUMETSAT at the beginning of CDOP-3 has been shown on Martinez presentations (2018b, 2018a, 2020a) and a broad summaries are available also in [RD.7], [RD.8] and [RD.9]. In the use of real IASI L1 and L2 files, the use of programs to convert to McIDAS-V compatible netCDF fields and the tools developed on the participation in the NRT IRS Project are the basis. Due to the lack of more EUMETSAT testing datasets, I improved my tools for the generation of synthetic datasets. Now at the end of CDOP-3, I have created synthetic datasets for IASI, IRS, FCI and SEVIRI instruments on collocated pixels of a region in FCI grid are much useful and it far exceeds expectations with the proposed IASI dataset as proxy of IRS. In Chapter 3 are described these synthetic IASI, IRS, FCI and SEVIRI datasets.

It was also foreseen in WP 2610 the calculation of simulated MTG-IRS BTs spectra datasets for clear air and cloudy (clouds at several levels and layers) conditions. This task has been improved with the development and update of the state of the art PGE00* tools shown in Chapter 2 and used for the generation of the synthetic datasets of IRS and IASI.

In relation with the generation of one dataset with reduced number of profiles (by sampling in the sSHAI validation and training dataset) for a quick IRS-L2 suitable water vapour and instability training dataset, this task has been far exceeded because the whole 2017 iSHAI training and validation dataset can now be used with PGE00* tools to create a good, wide and common synthetic reference dataset for IASI, IRS, FCI and SEVIRI. This common synthetic reference dataset for IASI, IRS, FCI and SEVIRI will be used for further tests and developments. These reference synthetic datasets together with an evolution of *PGE00_Id* tool will allow also to create improved synthetic reference datasets after the addition of systematic and controlled perturbation on the inputs profiles datasets; they will be used to the generation of different auxiliary configuration matrices to generate different MTG-S/IRS L2 simple output products which can be useful for Nowcasters (see ideas summarized in Martinez 2013 and in [RD.9]).

With the recent incorporation of new machines (with more memory available) and the new IDL version it will be increased the number of elements in the tests and studies. Also it will be tested new possibilities as the use of Machine Learning tools through Python interfaces. Some engineering tests (repeating tests made between 2010 and 2013) with the 2017 dataset has been done; but they are not shown here because are not enough mature and they have been delayed to CDOP-4 to do it on a systematic way.

Related of the calculations of the principal components (PC) MTG-IRS with physical meaning (see Martinez 2013), although it has been tested the calculation of Principal Components in new IDL it has been delayed the realization of more tests to CDOP-4.

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Due to the lack of EUMETSAT data test the task to build a prototype to generate quick and simple MTG-S/IRS L2 products from MTG-IRS L1 proxy data has been slowed down. But now with the availability of the synthetic IASI, IRS, FCI and MSG or IASI on regions for some case studies it has been indirectly resumed. One of these activities, the search of IRS RGB has been resumed and it shown in Chapter 4. This activity has involved the update of the old 2010 IDL programs and they will be used as basis for more developments in CDOP-4 phase to be ready for MTG-S launch.

Also it is important to note that the use of synthetic FCI data as input to NWCSAF/GEO software and the generation of the synthetic NWCSAF products has allowed to create software that could be used using the “back door” trick to made parallel tests to explore also the developments of software and products using blended FCI and IRS data.

In relation with the generation of preliminary reports and presentations on the use of MTG-S/IRS spectra on nowcasting by using the NWC SAF packages this activity has been made in the CDOP-3 through:

- The participation on several workshops and Conferences. The presentations are listed in the Chapter 6 References and in the [iSHAI References](#) web page. The links to the presentations in pptx format are provided in both References lists.
- The participation on the IRS MAG (Mission Advisory Group). The links to some of the presentations made by Miguel Angel Martinez are available in the [EUMETSAT Science Meeting web page](#). On IRS MAG June 2021 [link](#), IRS Mag June 2020 [link](#), IRS Mag November 2018 [link](#).
- This Report is other opportunity to do it and to provide a summary of the activities.


In relation with the development of the operational tool for MTG-S/IRS L1 images on user defined regions this activity has been slowed down into CDOP-3 due to the lack of EUMETSAT engineering test data on EUMETSAT delivery format. Due to the lack of IRS L1 test data on full disk or only in LAC4 region, the development of the operational tools for MTG-S/IRS for optimal reprojection and concatenation of dwells files to NWCSAF MTG-FCI projection has not been possible to make. The reprojection procedure and the related activities are shown in [RD.2]; the proposed reprojection algorithm was shown in Martinez 2018b and it has been used several times. EUMETSAT has provided till now only a test data and a PC test data on a dwell file. In both cases, it has been made the update of the software of the reader prototype available for the reading and for the reconstruction of the BTs spectra from the PCs; see Section 4.5.3. It is expected that once MTG-I1 be launched and advanced the commissioning phase more effort and activities will be dedicated to prepare MTG-S1 launch by EUMETSAT. On this horizon, more and better test data will be deliver by EUMETSAT and one or more set of dwell files will be available; then, it will be resumed the preparation of reprojection and concatenation prototype.

As it will be shown through this Report, the activities for preparation for MTG-S/IRS are based and made in parallel with the ones for iSHAI (imager Satellite Humidity And Instability).

2.1 MTG-S/IRS ON NWC-SAF

The main objective of the NWC SAF is to provide software packages to ensure the optimal use of meteorological satellite data in Nowcasting and Very Short Range Forecasting. For this reason, the NWC SAF is one special SAF because it develops and provides software. Since NWCSAF products are generated locally by users this implies that there are no bandwidth constraints on local generated products. As can be seen in Figure 2, it works in the user’s side of the EUMETCast. For this reasons, NWC SAF is the SAF nearest to users.

The plan for MTG-S IRS is to offer a user friendly and optional software package to manage MTG-S/IRS L1 data and to generate MTG-S/IRS L2 products to get added value nowcasting products. The

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second guideline of the MTG-S/IRS NWC SAF/GEO package is that it must be designed and operated in a way that allows to explore the synergies and differences of MTG-S/IRS products, MTG-I/FCI products and the NWP models. Thus, NWC SAF users with the instances of NWCSAF GEO software packages configured for MTG-I and MTG-S/IRS will be able to manage MTG-I L1 (FCI and LI) data, MTG-S/IRS L1 data and to generate MTG-I (FCI and LI) L2, MTG-S/IRS L2 products and to get their own collocated local datacubes on their region of interest. The MTG-S/IRS NWC SAF/GEO package will be prepared during CDOP-4 and they will be available at Day-2.

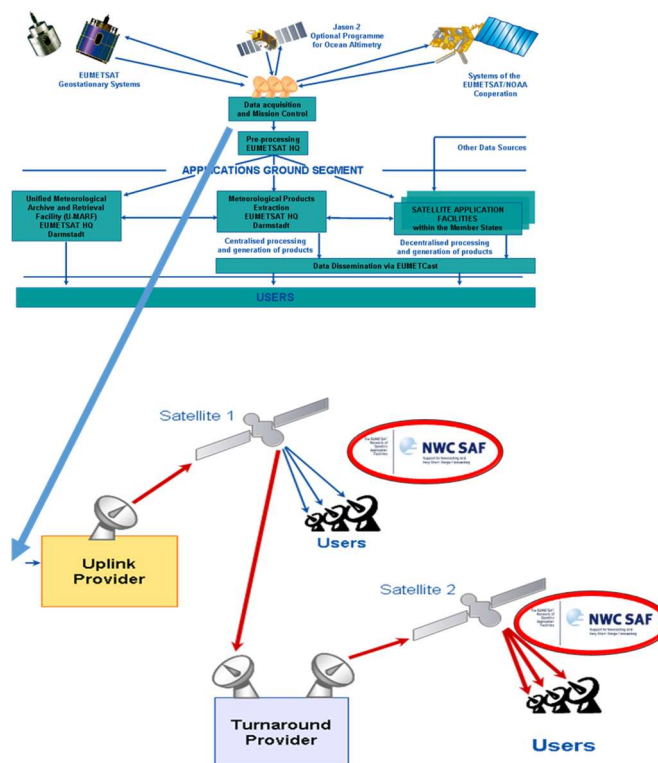


Figure 2: NWCSAF software is installed and executed on the user side of the EUMETCast.


2.2 PROPOSED NWCSAF IRS PRODUCTS AND SERVICES

As can be seen in Figure 3, for MTG-S/IRS are foreseen three products and services:

Quick-IRS L1: support of the MTG-S/IRS L1 activities related to the local generation of simple image type products and to the generation of inputs for local generation of NWC SAF or users products.

Since EUMETSAT will disseminate by EUMETCast satellite just 300 Principal Components in 160x160 pixels dwell files, this service/product will make the following steps:

- A) IRS BTs spectra reconstruction from the 300 Principal Components for every pixel on every needed dwell file to cover the user region of interest.

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- B) For every MTG-S/IRS L1 channel in one user configurable predefined list, it will made the combination and reprojection from the needed dwells files to user NWC SAF regions on a geostationary grid (by default the IR FCI grid on 2x2 boxes). This is needed because the disseminated EUMETSAT dwell files are not reprojected to a fixed grid and just latitude and longitude matrices are included in the dwell files.
- C) Finally some easy IRS image type products will be generated. As a few examples quick-IRS L1 could generate:
 - MTG-S/IRS RGB images
 - Normalized IRS-L1 channels in some spectral regions (as CO₂ or WV branches) representing the state of the atmosphere at several layers.
 - Simple operations with MTG-IRS L1 as difference or regressions between several IRS L1 channels. It could be also tested the outputs of simple Machine Learning algorithms.

Thus, users could make the automatic generation of IRS L1 imagery related products or to use them for locally generation of NWC SAF or users products. See also Chapter 6 References for some examples.

sSHAI ES: support of the MTG-S/IRS L2 files disseminated by EUMETSAT Secretariat (ES). Thus, 2D and 3D fields read from the IRS L2 dwells files will be combined and reprojected to users NWC SAF regions. Since EUMETSAT will disseminate by EUMETCast also in 160x160 pixels dwell files, this service/product will have the following steps:

- The combination and reprojection from several dwell files to user NWC SAF regions on a geostationary grid will be made with the disseminated EUMETSAT Secretariat (ES) MTG-S/IRS L2 products.
- Vertical interpolation from hybrid levels to a configurable set of fixed pressure levels.
- Calculation of several nowcasting parameters (TPW, LPW and instability indices) will be made also if needed.

The idea is that ES MTG-S/IRS L2 fields could be used directly by users in combination with the ones from MTG-I/FCI fields for the same regions. As an example, the comparison of instability indices from MTG-I/FCI, MTG-S/IRS and NWP.

Also, the IRS L2 fields on NWCSAF region could also be used in the future as input to locally generated products. As an example, IRS SKT field or IRS emissivities could be used as input for MTG-I/FCI product in future versions. See more details on [RD.2].

sSHAI: development of product executed locally by the users. Local generation of NWCSAF MTG-S/IRS L2 product using light demand CPU algorithms.

- The first product of this type is the local retrieval of T, q profiles using as additional input local NWP models (executed using light CPU algorithms) for a set of selected dwells. At this moment, the NWC SAF is developing an algorithm that use kernel ridge regression trained with IASI L1 and NWP analysis of the previous day using a rolling training approach.
- Calculation of nowcasting parameters (TPW, LPW and Instability indices) at dwells.
- Then, combination and reprojection from dwells to user NWC SAF defined regions.

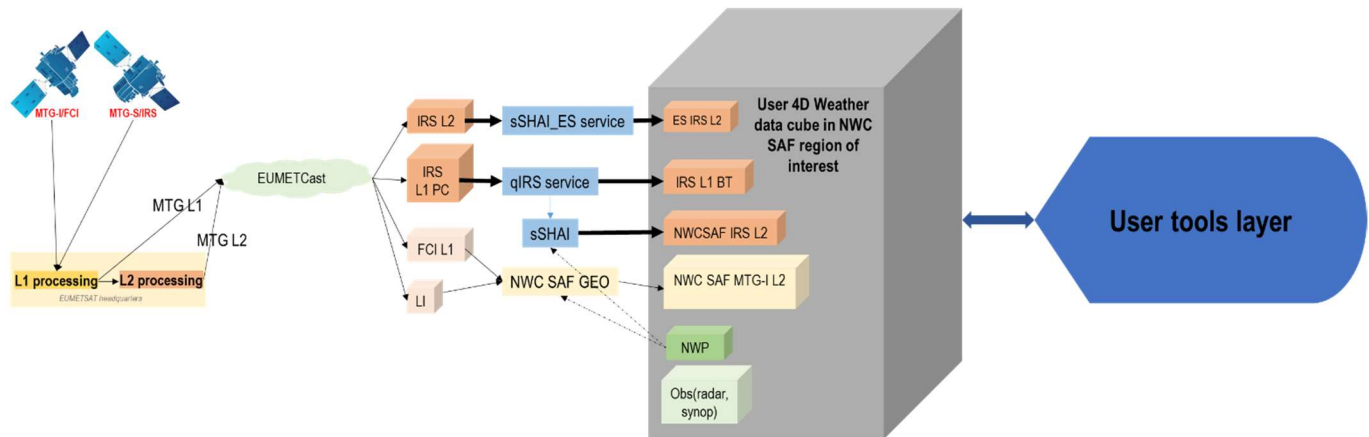


Figure 3: Scheme of the proposed NWCSAF/GEO services and products for MTG-S/IRS. The users will have the possibility to create their own 4D weather data cube in their region of interest. As proxy of users tools layer able to manage all the types of the L1 and L2 files it has been used McIDAS-V in this Report.

As commented previously, at the time to write this Scientific Report, scientifically correct MTG test data were not available in EUMETSAT. In the following Sections it is described the way that I have developed the PGE00* tools for the generation of the first scientifically correct MTG-I/FCI and MTG-S/IRS synthetic datasets. In Chapter 3 are described the synthetic MTG-S/IRS dataset generated. In [RD.1] it is described how the first MTG-I/FCI synthetic dataset has been generated. Other added value of these synthetic FCI and IRS datasets is that they have been generated on collocated time and regions allowing to explore a full synergetic exploitation of FCI and IRS data.


In Chapter 4 some early studies with this synthetic MTG-S/IRS dataset to explore new products of MTG-S/IRS are shown. Also collocated IRS and FCI images are shown. This early studies should be understood as exploratory prototypes.

2.3 INTRODUCTION TO PGE00

A complete introduction to iSHAI and PGE00 tools is available in Chapter 2 of [RD.1]. As it shown in [RD.1], all the activities have been based in the evolution of the PGE00* tools; they were used originally for validation and training of iSHAI algorithm and for the bias BT correction in NWC SAF GEO software packages. In this chapter the PGE00* tools are only briefly introduced with the objective to add some notes related to IRS simulations not commented in [RD.1]. In Chapter 3, the activities for generation of the first MTG-I/IRS synthetic datasets are described.

For preparation for MTG era it was started in 2018 the use of RTTOV-12.1 (see Sections 2.3.2 and 2.3.3) in PGE00* programs. In November 2020 it was released RTTOV-13.0 by the NWP SAF. Then, it was started the migration of PGE00* programs to RTTOV-13.0; this is an important milestone because are the IRS coefficients on RTTOV-13.0 are first that allows the generation of synthetic MTG-S/IRS data in the new spectral grid of IRS. During spring 2021, it was started the presentation in several workshops of the first results generated using the PGE00* programs with RTTOV-13.0.

In Figure 2 of [RD.1] it can be seen that one of the steps in iSHAI algorithm is the 4D interpolation from a background NWP to get collocated in time and space profiles with the satellite data. As in iSHAI, this step is only made in the clear pixels (or FORs) then PGE00 was created many years ago as an ad hoc tool which made this particular processing in all pixels. In the origin, PGE00 sources were a copy of the iSHAI (named PGE13 at this moment) sources retaining only the 4D interpolation step and suppressing the use of the Cloud Mask (C_{Ma}) as input in order to make the 4D interpolation in all

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the pixels. As there are not need to use satellite data and CMa as inputs it could be executed before the arrival of satellite data and by this reason it was named PGE00.

Later it was added to PGE00 the functions available on iSHAI (named PGE13 at that moment) to calculate also synthetic RTTOV BTs. Thus, PGE00* programs can be used as:

- NWP 4D (pressure, time, longitude, latitude) interpolator of NWP GRIB files to satellite positions
- RTTOV BTs simulator for bias BT correction, iSHAI validation and testing, etc

One of the key parts in PGE00* programs is the **4D interpolation of the NWP models (ECMWF as example) to satellite**

- **The 4D interpolation (p, time, lon, lat)** get vertical, time and spatially collocated NWP forecast temperature, moisture, ozone profiles at the time and position of the satellite pixels (*here at the 54 RTTOV pressure levels*).
- ECMWF GRIB files on hybrid levels on regular representation (equidistant lon-lat) can be also used as inputs.
- The 4D-Interpolation is made in several consecutive steps:
 - Vertical interpolation: from NWP levels to RTTOV pressure levels are interpolated or extrapolated to the 54 (or 101) RTTOV levels. But could be adapted to a configurable set of pressure levels. It can made also from hybrid ECMWF levels.
 - Temporal interpolation: from previous and next GRIB file to date and time of the slot
 - Spatial interpolation: bilinear interpolation to satellite coordinates
- Since the lowest RTTOV pressure levels could have values greater than the lowest hybrid level at Psfc (especially on mountains pixels) **it has been implemented in PGE00 programs one extrapolation process based in the one made by ECMWF**. First, it is made the extrapolation of the T profile (starting at the RTTOV level just above of Psfc using formulas described in the ECMWF) and then it is extrapolated the q profile maintaining the relative humidity at the surface pressure level. *This allows to get fields from as low as the 1000 hPa level for temperature and humidity in all pixels.*
- **In the case of HYB mode all the NWP process is made inside the iSHAI or PGE00 codes.** PGE00 programs open directly the **previous** and **next** (relative to the time of the satellite image) ECMWF GRIB files on hybrid levels, makes the vertical interpolation on ECMWF position to the 54 RTTOV pressure levels, **makes the temporal interpolation to the date+time of the image** and finally makes the bilinear spatial interpolation just over the processed pixel (or FOR). See Figure 4.

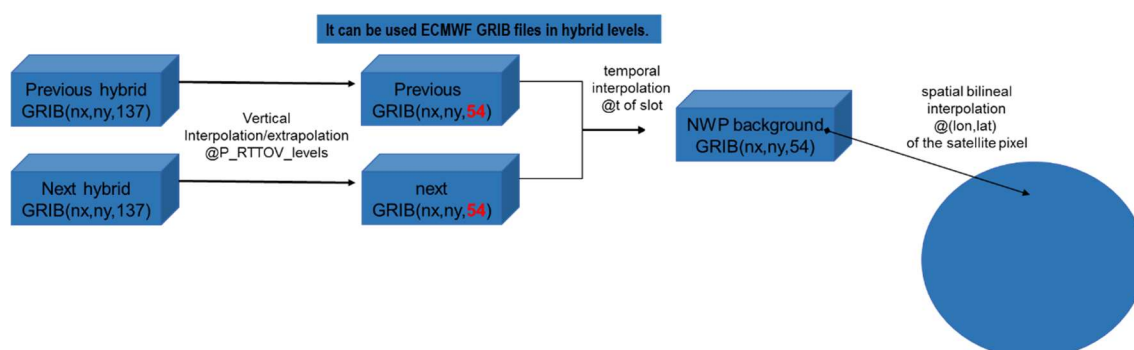



Figure 4: scheme of the 4D interpolation in the case of ECMWF GRIB files on hybrid levels.

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PGE00* programs are also highly modular and configurable. The main PGE00 configurable options and parameters are:

- ✓ The window size for processing in boxes of **M x N** pixels (*default 3 x 3*).
- ✓ Optional writing for all the pixels or just at clear pixels or just on a set of pixels.
- ✓ Activation of BTs calculation also for the configured satellite.
- ✓ TOZ calculation: if GRIB files have ozone profile could be activated to make the 4D interpolation of ozone profile and to use in the RTTOV calculation.
- ✓ **The change from mode P to mode Hybrid is made changing in the iSHAI or PGE00 configuration file the keyword *NWP_EXEC_MODE* from P to HYB.**
- ✓ Activation of optional writing of temperature, specific humidity and ozone profile and skin temperature at clear processed Fields of Regards (**M x N** pixels) or for all pixels.

It is used a PGE00 Model Configuration File. All these options are activated through editing the PGE00 Model Configuration File (extension .cfm). In the PGE00* execution the third parameter is an ASCII file with all the processing options. See in more details [RD.1].

All the PGE00 programs are written in C and Fortran-90 (but the core of the process is Fortran90 as in the RTTOV sources).

2.3.1 PGE00_1d version for training and validation activities.

The first PGE00 program was adequate for GEO imager bias BT correction and generation later of training and validation datasets. But for calculation of new iSHAI coefficients and for validation statistics (writing of the iSHAI Validation Reports) it was started to use always a reduced PGE00 version called internally *PGE00_1d* during all NWC SAF phases.

Basically this *PGE00_1d* version is one only FORTRAN program that reads a binary file with a set of records for every pixel and generate as output the RTTOV synthetic BTs in clear air conditions. The used RTTOV functions are the same used in PGE00 and iSHAI of the same versions. The binary input file is easily written using IDL or C o FORTRAN. The output are just $N_{channels} \times N_{pixels}$ floats in a binary file.

In CDOP-3 it has been developed two versions of this *PGE00_1d*. The first *PGE00* in CDOP-3 *_1d* used RTTOV-11.2. A second version of *PGE00_1d* using RTTOV-13.0 has been developed in 2021; this will be the one used initially in CDOP-4 phase.

Together with the *PGE00_1d* program it is needed to use a reference dataset. Till 2017 (version 2016) it was used as training and validation dataset the iSHAI 2013 dataset. But, at the beginning of CDOP-3, it was generated the 2017 training and validation dataset.

As can be seen in Figure 5, *PGE00_1d* program and the reference dataset can be used to generate synthetic datasets for two branches: one for GEO imager instruments and other for hyperspectral or sounder instruments. In the case of GEO imager instruments it has been used for the generation of iSHAI coefficients and Validation Reports for version 2018*, 2021 and preliminary vMGT (for STRR reviews).

It can be seen in Figure 5 that this 2017 training and validation dataset could be used also to generate synthetic datasets for sounder instruments. It is only needed to call RTTOV using the corresponding sounder RTTOV coefficients to generate reference synthetic dataset for MTG-S/IRS or IASI or any other sounder instrument.

Once the synthetic datasets are generated they could be used in further tests. In Section 4.1 it can be seen how the synthetic MSG, IRS and IASI datasets has been used to repeat the 2010 test to search the IRS or IASI channels nearest statistically to IR MSG channels in order to generate IRS (or IASI) RGB images heritage of the MSG RGB composites. More ideas to use in the future the reference synthetic IRS (or IASI) dataset can be seen in Figure 5 and they are briefly introduced in Chapter 4.

Finally, in Figure 5 it is shown that the synthetic imager and sounder datasets could be used together to explore the possibility to make one assessment of the performance of future blended FCI and IRS products; they are briefly introduced also in Chapter 4.

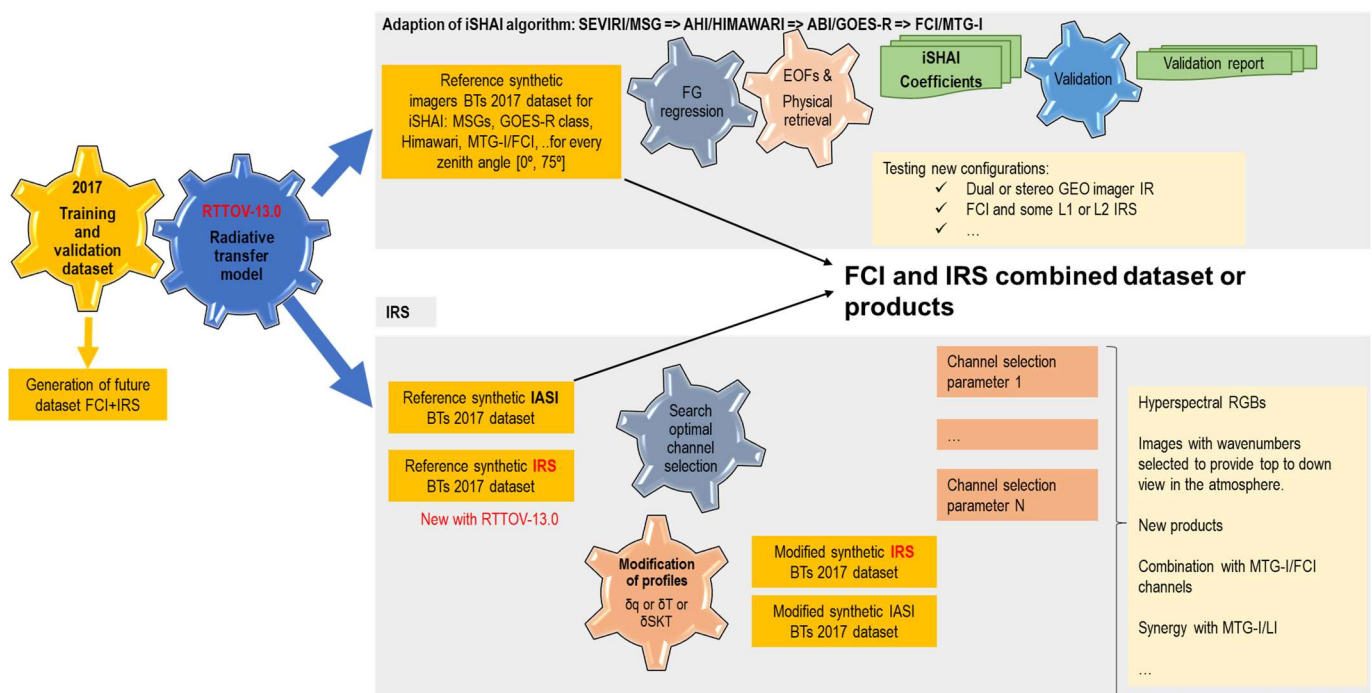



Figure 5: scheme of the PGE00_1d use for training and validation activities.

Although in Figure 5, it appears all the pixels are used for both training and validation activities actually the validation and training is made using different sub-datasets extracted from the full 2027 dataset. Since the whole 2017 dataset is too big to be on memory it is chopped first in several sub-datasets (using the module 3 of the positions for example).

In CDOP-4 it could be generated more training and validation datasets, the important thing now is that the tools to build them have been created. In CDOP-4 commissioning phase of MTG-S/IRS it could be incorporated real IRS and FCI data; then, the training and validation datasets combining real and synthetic data could be used for bias BT detection, tuning of coefficients, writing of validation reports, etc.

2.3.2 GEO-PGE00-VISIR

The initial PGE00 programs was only able to calculate synthetic RTTOV BTs on clear air conditions. Starting on 1997 with RTTOV5 version I created the first version of a program to create synthetic IR image from IR and WV channels of METEOSAT First Generation (EUMETSAT operational satellite at this time); clouds simulations were simple through fixing one cloud level and fraction of the clouds.

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Starting with PGE00* version using RTTOV-12.1 it was started to make the simulation of clouds using the clouds parameters profiles in the simulations. As it is described in [RD.1] this first version was migrated to RTTOV-12.3 and finally to RTTOV-13.0. These GEO-PGE00-VISIR are important because they are able to generate the synthetic data on the future MTG-I/FCI grid.

GEO-PGE00-VISIR was used to generate 24 hours synthetic dataset for several case studies; at night the solar zenith angle is fixed to 75° to avoid generate black images on visible channels. It can be seen in [RD.1] the simulations with RTTOV-12.1 and later with RTTOV-13.0 of synthetic FCI images. Several examples are available in iSHAI References web page. GEO-PGE00-VISIR is used now for NRT generation on AEMET intranet of synthetic natural and airmass RGB images.

Here it is commented because for the same regions and case studies shown in Chapter 3 for IRS and IASI cases it was created synthetic datasets also synthetic FCI and on same resolution 2x2 for comparison with FCI in 1x1 (see [RD.1]) and for comparison with synthetic IRS data. Also has been made the same to obtain synthetic MSG/SEVIRI data.

2.3.3 GEO-PGE00-hyper

The first synthetic IRS dataset was made in 2010 using RTTOV-5 and a simple clouds scheme (see Martinez 2010 and Martinez 2013). It was make the generation of a synthetic IASI dataset from an ECMWF GRIB file; then it was used the *IASI2IRS* tool (Xavier Calbet, private communication) to create the first synthetic IRS dataset in 2010.

GEO-PGE00-VISIR allows to simulate GEO imager instruments on NWCSAF regions using 4D interpolation from NWP GRIB files. But for the simulation of hyperspectral sounder instruments some of the steps made on GEO-PGE00-VISIR are not needed. Following the strategy to use the sources of a program as basis and made “mutations” to generate a new one, it was created *GEO-PGE00-hyper* to simulate sounder instruments on NWCSAF regions using 4D interpolation from NWP GRIB files suppressing in the code the management of the reflectivity atlases.

The first version of *GEO-PGE00-hyper* used RTTOV-12.1 and it was used for the generation of first high quality synthetic clear and cloudy BTs of IASI. The early outputs of the PGE00* programs were shown to NWCSAF Project Team as one example of the need to update for MTG era the NWCSAF library to one more recent RTTOV version than RTTOV-11.2. Finally, it was adopted at the end of 2019 the decision to upgrade to RTTOV-12.3 the NWC SAF library used for MTG developments for MTG STRR revision. Together with the update to RTTOV-12.3, the main advance in NWCSAF MTG_STRR version is that it is the first beta version for MTG-I/FCI support (STRR revision). This fact allowed for first time to create NWCSAF regions using the future MTG-I/FCI grid resolution. Then, after the delivery of the NWCSAF MTG_STRR library, the *GEO-PGE00-hyper* programs was migrated in 2020 to RTTOV-12.3 to use the NWCSAF vMTG_STRR library. Thus, *GEO-PGE00-hyper* was used in 2020 to make high quality synthetic images of IASI clear and clouds BTs on the future MTG-I/FCI grid for first time; see Martinez 2020b.

Until RTTOV version RTTOV-13.0 no appropriated **MTG-S/IRS RTTOV coefficients were available**. The MTG-S/IRS coefficient file (March 2020) in RTTOV-12.3 does not have the proposed IRS spectral grid step of 0.6 cm⁻¹ and it used the old one 0.6125 cm⁻¹.

Since IASI2IRS was used first in 2010 (see Martinez 2010 and Martinez 2013), it was also tested the use of *IASI2IRS* software to convert pixel by pixel IASI spectra to IRS spectra. After update to the new figures of IRS instrument it was tested the conversion of one slot of IASI spectra to IRS spectra but

the time consumed was very high to be used for the conversion of the whole 24 hours IASI dataset. For this reason the use of IASI2IRS was discarded.

And finally, in November 2020 RTTOV-13.0 was released. In version RTTOV-13.0 (as in RTTOV-12.3) the scattering coefficients for clouds and aerosol are available for both visible and IR channels for most of imager instruments; including MTG-I/FCI instrument. But the most important fact is that RTTOV-13.0 is the first RTTOV version with RTTOV coefficients with the state of the art spectral grid of MTG-S/IRS with the proposed step of 0.6 cm^{-1} .

Then, I made the migration of NWCSAF vMTG_STRR library and later the migration of the *GEO-PGE00-hyper* program to RTTOV13.0 at the end of 2020 and early 2021. **Thus, PGE00* programs with RTTOV-13.0 is the first version of PGE00* programs that allows simultaneous generation of synthetic MTG-I/FCI, MTG-S/IRS and IASI radiances on MTG-I/FCI grid.** They have been used to generate the first scientifically realistic synthetic MTG-I/FCI and MTG-S/IRS datasets as it is shown in Chapter 3.

After these early works RTTOV-13.0 has been adopted for MTG era by the NWC SAF Project Team for the NWCSAF vMTG_STRR library. *PGE00*, *GEO-PGE00-VISIR* and *GEO-PGE00-hyper* remains currently as an AEMET internal tool.

The main steps on *GEO-PGE00-hyper* are:

- get emissivities for the hyper spectral instrument from RTTOV functions and atlases
- call to RTTOV direct using the cloudy options. On RTTOV the scattering coefficients for clouds and aerosol are available for all channels for some hyper spectral IR instruments

In *GEO-PGE00-VISIR* and *GEO-PGE00-hyper* it was added in the 4D interpolation (p, time, lon, lat) the CC, CLWC, CIWC, u, v profiles at the time and position of the satellite pixels. Thus, in the high quality simulations are used profiles of temperature, moisture, ozone, CC, CLWC, CIWC, u and v parameters that are vertical, time and spatially interpolated from NWP forecast to the time and position of the satellite pixels (*here at the 54 RTTOV pressure levels*). These profiles used as input to RTTOV are also available as output on the PGE00 binary files (if it is activated in the PGE00 configuration file the option to write also the input profiles).

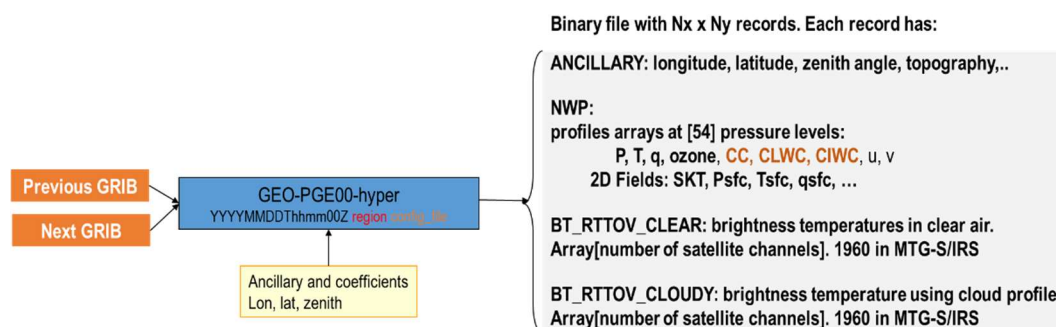



Figure 6: *PGE00-hyper* inputs and outputs scheme in the case of MTG-S/IRS simulation from ECMWF GRIB files on hybrid levels.

In Figure 6 it can be seen the scheme of the inputs and outputs of *GEO-PGE00-hyper* program execution for a MTG-S/IRS simulation. For every pixel is written in a binary file one record (one C structure) with the fields shown in Figure 6. PGE00 options allows to activate or not the writing of NWP or synthetic BTs as part of the structure. Also the keywords on the PGE00 configuration file as

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the width and height of the box ($M \times N$ size of the FOR) determines the number of pixels (or FORs) processed; as an example, in 2018 the first attempt of IASI simulation had to be done using a FOR of 5×5 size to speed up the very slow calculation due to the huge number of IASI channels in the slow computer available at this date.

In *GEO-PGE00-VISIR* and *GEO-PGE00-hyper* the output files are binary files with $N_x \times N_y$ records for every FOR (boxes $W_x \times W_y$ of configurable width) on satellite grid projection determined by the *\$SAFNWC/config/sat_conf_file*. Since the satellite to calculate the synthetic data is a keyword in the PGE00 configuration file, it is possible to calculate synthetic data with any combination of satellite projection and resolution for any satellite. As an example, it could be generated synthetic MTG-S/IRS or IASI (or other sounder instrument) on FCI grid projection for the same NWCSAF region and with any resolution (1×1 , 2×2 , ..) of the IR FCI resolution (2×2 km at nadir). As shown in Figure 6, each record contains:

- BT_{clear} : RTTOV brightness temperature in clear air mode is obtained in the case of IR channels. The number of channels depends on the satellite to simulate and it is determined by the channels in the RTTOV coefficients files. In the RTTOV coefficients files is possible to get the coefficients (central wavenumber) needed to apply the inverse of Planck function to convert from BTs to radiances.
- BT_{cloudy} : same as above but calculated by RTTOV on cloudy condition using the cloud profile
- Profiles 4D interpolated from NWP at the 54 RTTOV levels: T/q/ozone/cc/clwc/cwic/u/v
- Surface fields from NWP: P_{sfc} , Skin Temperature (SKT), T_{2m} , q_{2m}
- Ancillary fields: longitude, latitude, topography, sun angles and GEO satellite angles for the satellite configured in *\$SAFNWC/config/sat_conf_file*

The inputs and outputs in the case of *GEO-PGE00-VISIR* are similar to the scheme for *GEO-PGE00-hyper* shown in Figure 6. The differences are the number of synthetic channels (the number of channels depends on the number of channels in the imager instrument) and that the array of floats with synthetic data instead to be all BTs are reflectances in the case of visible channels.

Due to the mix of VIS and IR channels and the low number channels in the case of *GEO-PGE00 VISIR* it has not been used parallelization. Since UNIX machines allow to launch several programs at same time it has been used the execution at the same time on an adequate machine number of *GEO-PGE00 VISIR* at the same time. In the *GEO-PGE00_hyper* case it has been made an early attempt of parallelization (OpenMP RTTOV interface) since the high number of only IR channels encourages to make it. Due the low number of threads available (4 to 10) the reduction of time is moderate. It will be studied the migration and execution of *GEO-PGE00_hyper* to more powerful computer with more threads available.

In the case of *GEO-PGE00-hyper*, the solar options in RTTOV for simulations of solar radiance contribution in SW band has not been included because it is not possible to do the simulation for a full IASI spectra (since this can be made only for 8 channels).

3 SYNTHETIC MTG SIMULATIONS. FIRST SYNTHETIC MTG-I/FCI AND MTG-S/IRS SCIENTIFICALLY CORRECT DATASET

The PGE00* tools introduced in Chapter 2 have been used for the tasks to build the first synthetic MTG scientifically correct datasets. The main purpose was to get collocated synthetic data for MTG-I/FCI and MTG-S/IRS on the future MTG-I/FCI projection grid.

In the first attempts were used PGE00* tools with RTTOV-12.1 and RTTOV-12.3 versions; on these first attempts the MTG-S/IRS RTTOV coefficients were not exact. But with the RTTOV-13.0 PGE00* version it has been possible to do it. In this chapter it is described how it has been generated the first scientifically realistic synthetic MTG-I/FCI and MTG-S/IRS datasets generated with PGE00* version using RTTOV-13.0.

3.1 SUMMARY OF GENERATED SYNTHETIC DATASETS

Together with the availability of the RTTOV and PGE00* tools other important aspect to take care in a simulation are the characteristics of the NWP GRIB files used as input. In Figure 7, it can be seen the summary of the NWP models and synthetic MTG datasets generated in this early MTG simulations activities.

In the early attempts, it was used the operational ECMWF GRIB files on hybrid levels forecasts every 1 hour with $0.1^\circ \times 0.1^\circ$ spatial resolution downloaded from MARS. In the first place, it was generated MTG-I/FCI and SEVIRI/MSG synthetic datasets that are shown in Chapter 3 of [RD.1]. In second place it was generated MTG-S/IRS synthetic data using the operational ECMWF NWP model; see Section 3.3. As it is commented below in case FCI on Section 3.2 (more details on [RD.1]), these synthetic datasets could be used as input to NWCSAF PGEs and to be used for experiments of theoretical NWCSAF PGEs execution and calculate performances using as truth the input data to PGE00 programs. But for some PGEs, as in the case of High Resolution Winds (HRW) product, the synthetic images with the spatial resolution of the operational ECMWF NWP model it is not enough.

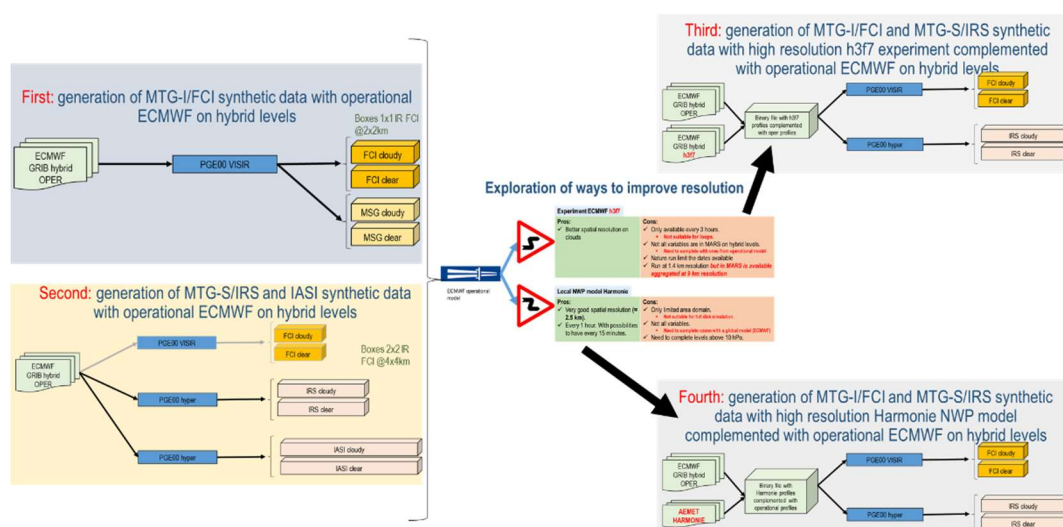


Figure 7: scheme of the generated synthetic MTG datasets.

For this reason, it was started the exploration of the ways to improve the spatial and temporal resolution of the NWP model used as input to PGE00* programs. In third place, it was created synthetic dataset

using experimental high resolution executions of the ECMWF; but, as commented below (Section 3.5) this way has been discarded by the moment due to some problems found. In fourth place, it was created a synthetic dataset using a combination of the NWP models Harmonie and ECMWF; this way is described below in Section 3.6.

3.2 FIRST: GENERATION OF MTG-I/FCI SYNTHETIC DATA WITH OPERATIONAL ECMWF ON HYBRID LEVELS

As can be seen in Figure 8 and in more detail in [RD.1], in first place it was used as input to GEO-PGE00-VISIR program the operational ECMWF NWP model GRIB files on hybrid levels. It was used the ones from case study 2019-05-01 from 00Z run between $t+00$ to $t+24$ hours forecast (every 1 hour) downloaded from MARS with $0.1^\circ \times 0.1^\circ$ spatial resolution.

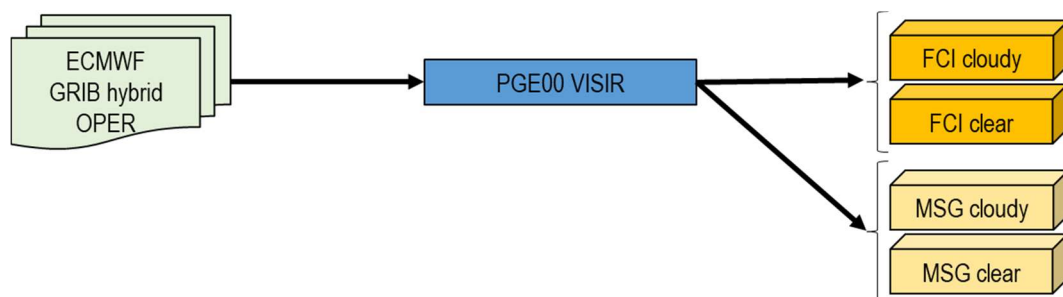


Figure 8: scheme synthetic GEO imager simulations (FCI and MSG) using GEO-PGE00-VISIR and using as input the operational ECMWF NWP model.

As commented above, for the same NWCSAF region and projection it could be generated synthetic RTTOV data for different GEO imager instruments. In this case, it has been generated in future MTG-I/FCI projection the synthetic data for MTG-I/FCI and SEVIRI/MSG.

As can be seen in [RD.1], for case study 2019-05-01 the synthetic MTG-I/FCI outputs are:

- The 16 MTG-I/FCI channels. The synthetic data for both VIS and IR are available in simulations on clear and cloudy conditions.
- 144 slots from 00:00Z to 23:50Z every 10 minutes.
- In a region of 1000 x 800 pixels on FCI projection grid at IR FCI resolution (2x2 km nadir).
As an example of a typical region of a mean user of the NWCSAF.

Also, there are available synthetic SEVIRI/MSG data on MSG projection grid every 15 minutes from previous experiments; it could be generated also with RTTOV-13.0 version if it is needed to compare with real MSG data and products.

Also, as one complementary dataset for IRS developments both FCI and MSG have been also simulated in boxes 2x2 on FCI grid every 10 minutes. Thus, as they have been generated on the FCI grid for the same region they could be used in experiments to compare the FCI channels (or MSG channels) with IRS channels. Also it could be used FCI simulations on boxes 1x1 and on boxes 2x2 to explore the difference when the spatial resolution is doubled.

One of the application of the synthetic data from imager instruments is the use as inputs to some of the NWCSAF PGEs. As a demonstration it has been used the synthetic FCI data generated with GEO-PGE00-VISIR as input to some of NWCSAF PGEs.

Then, as a proof of concept, I started the design of one internal procedure in order to use this imager RTTOV PGE00 synthetic dataset as input at least in NWCSAF GEO vMTG STTR GEO package. This was made using the “back door” trick that it is described in detail in [RD.1]. The “back door trick” is based in the overwritten (or direct generation) of the intermediate raw binary files on the `$SAFNWC/tmp/Sat_data` directory of the brightness temperature (or reflectances in case of visible channels) with float arrays of dimensions $N_x \times N_y$; this storage is known as the DATABUF. Using this trick it is just needed the writing on the `$SAFNWC/tmp/Sat_data` directory with $N_x \times N_y$ of floats with the synthetic FCI data with correct names in raw binary files. Thus, it was developed and used an IDL program to read the PGE00 synthetic binary files and to the replace the data on the binary raw files on `$SAFNWC/tmp/Sat_data` from the processing a “real” slot. Once tested it, on this IDL program was later added the functions generate the set of binary files in the DATABUF to execute some of the NWCSAF GEO PGEs with the synthetic MTG-I/FCI dataset.

In the Figure 18 of [RD.1] it can be seen the first outcomes of several PGEs (CMA/CT/CTTH/CMIC). The loop of PGEs outputs images for the 24 hours (from 00:00Z to 23:50Z every 10 minutes) are available in the links of 2021 Martinez presentations in Chapter 6 or in the iSHAI References web page. For IRS development these outcome are very important because they are available and collocated with synthetic IRS dataset (in the same projection, region for the same time) and they can be used as a complement for IRS developments. For example the NWCSAF Cloud Mask using high resolution and visible channels could be used to make screening of IRS cloudy pixels.

The main advantage to have synthetic data is that it could be used in combination with the “truth” 4D datacube (with the profiles of the T, q, CC (clouds profiles), LWP (Liquid Water Profile), IWP (Ice Water Profile), etc.) used as input to RTTOV to compare and validate the outputs of the NWCSAF products. As continuation of the proof of concept, it has been used the McIDAS-V to make an interactive comparison on 3D or 4D; some examples are available in Chapter 5 of [RD.1].

3.3 SECOND: GENERATION OF MTG-S/IRS AND IASI SYNTHETIC DATA WITH OPERATIONAL ECMWF ON HYBRID LEVELS

As can be seen in Figure 9, it was used as input to *GEO-PGE00-hyper* program the operational ECMWF NWP model GRIB files on hybrid levels. It was used the ones from case study 2019-05-01 from 00Z run between $t+00$ to $t+24$ hours forecast (every 1 hour) downloaded from MARS with $0.1^\circ \times 0.1^\circ$ spatial resolution. In all the cases it has been used ECMWF GRIB files on hybrid levels.

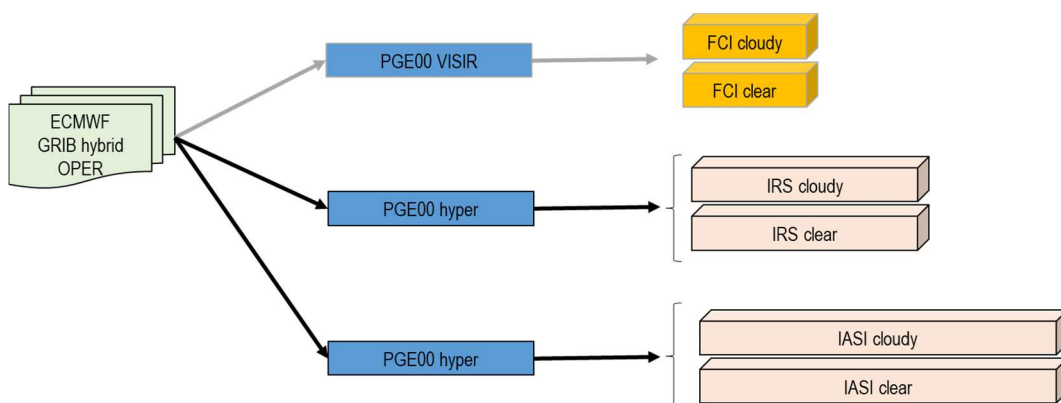


Figure 9: scheme GEO-PGE00-hyper simulations using as input operational ECMWF NWP model.

The outputs are:

a) **The synthetic MTG-S/IRS dataset** on MTG-I/FCI projection for case study 2019-05-01. The main characteristic of MTG-S/IRS dataset are:


- Case study 2019-05-01 from ECMWF 00Z run.
- The 1960 MTG-S/IRS channels on RTTOV-13.0 coefficients on the new spectral grid adopted for EUMETSAT every $\approx 0.6 \text{ cm}^{-1}$ on the two IRS bands.
- All the channels are available on clear and cloudy conditions.
- Every 30 minutes.
- 48 slots from 00:00Z to 23:30Z
- At boxes 2x2 pixels IR FCI resolution => similar to theoretical IRS spatial resolution (4x4 km nadir)
- Size: 500 x 400 pixels

b) **The synthetic IASI dataset** on MTG-I/FCI projection for case study 2019-05-01. The main characteristic of IASI dataset are:

- Case study 2019-05-01 from ECMWF 00Z run.
- The 8461 IASI channels.
- All the channels are available on clear and cloudy conditions.
- Every 30 minutes.
- 48 slots from 00:00Z to 23:30Z
- At boxes 2x2 pixels IR FCI resolution => similar to theoretical IRS spatial resolution (4x4 km nadir)
- Size: 500 x 400 pixels

In the Figures below it has been selected 4 wavenumbers in CO₂ branch to show that IRS will allow to provide a top to down view in the atmosphere. In the case of IASI the selected channels are 695, 706, 734 and 919.5 cm⁻¹. These wavenumbers were selected several years ago interactively using McIDAS-V in CO₂ branch in order to provide top to down view in the atmosphere. These IASI channels are only one selection example but in CDOP-4 could be selected other set; also the qIRS will be configurable in order the users could select any set of channels. In the case of MTG-S/IRS channels it was used the channels with the nearest wavenumbers to the IASI ones.

As it shown in the Figures below and in the loops available in Martinez 2021 presentations the spatial and temporal resolution of IRS are enough to be used in operations by forecasters. The use of montages like the shown in the Figures are one example. In order to generate operationally in near real time, these kind of images montages some software as the proposed on qIRS is needed. In first place for the conversion from PCs to BTs, then to combine the dwells and reprojection to NWCSAF region (as presented on the Figures) for a selection of channels made by the users. The outputs of qIRS will be brightness temperature fields on netCDF (or binary) files on NWCSAF region. Then, the graphical tools of the user could be used to read and generate the image from every channel, add the map and labels to generate individual images for every channel. Finally some presentations tools could be used for the combination of the individual images. Just as one example in the generation of the Figures it has been used: a) IDL for the read of the binary files with the BTs of IRS (it has been generated in the FCI grid directly for the region) and for the generation of the individual images with the addition of the map. b) It has been used Image-Magick *montage* command for the combination of the four image, c) it was used Image-Magick for the generation of the animated GIF with the loop. This is only one example; users will use their own graphic and presentations tools. It must be understood that NWC SAF will provide a layer to cover the gap between the set of puzzle and packed pieces delivered by EUMETSAT on the EUMETCast and the graphic and presentations layers on the user side.

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In the Figures 10 to 13 all the images are for 1st of May 2019 at 12Z; they have been generated using the $t+12$ forecast from the 00Z ECMWF run. The loops of images every 30 minutes for the 24 hours are available on Martinez 2021 presentations (see Chapter 6). In the case of the (top left) images at $\approx 695 \text{ cm}^{-1}$ they are from a stratospheric channel and the images are similar in clear and cloudy conditions. In the case of the (top right) images at $\approx 706 \text{ cm}^{-1}$ they are from a high level channel and only high level clouds are visible in cloudy image simulations. In the case (bottom left) images at $\approx 734 \text{ cm}^{-1}$ the high and medium level clouds are visible in cloudy image simulations. In the case (bottom right) at $\approx 919.5 \text{ cm}^{-1}$ all the clouds are visible in cloudy image simulations in cloudy pixels and the ground. Similar montages could be made from WV bands. In operations in case convection it could be seen like the clouds get height with the time.

As PGE00* tools allows to write as optional outputs the profile used as input it is possible to use this to create the "truth" 4D datacube used as input to RTTOV with the profiles of T, q, CC (cloudiness), LWP, IWP etc. As commented above, the McIDAS-V allows to use this "truth" 4D datacube interactively to compare with the IRS data or the outputs of future qIRS fields.

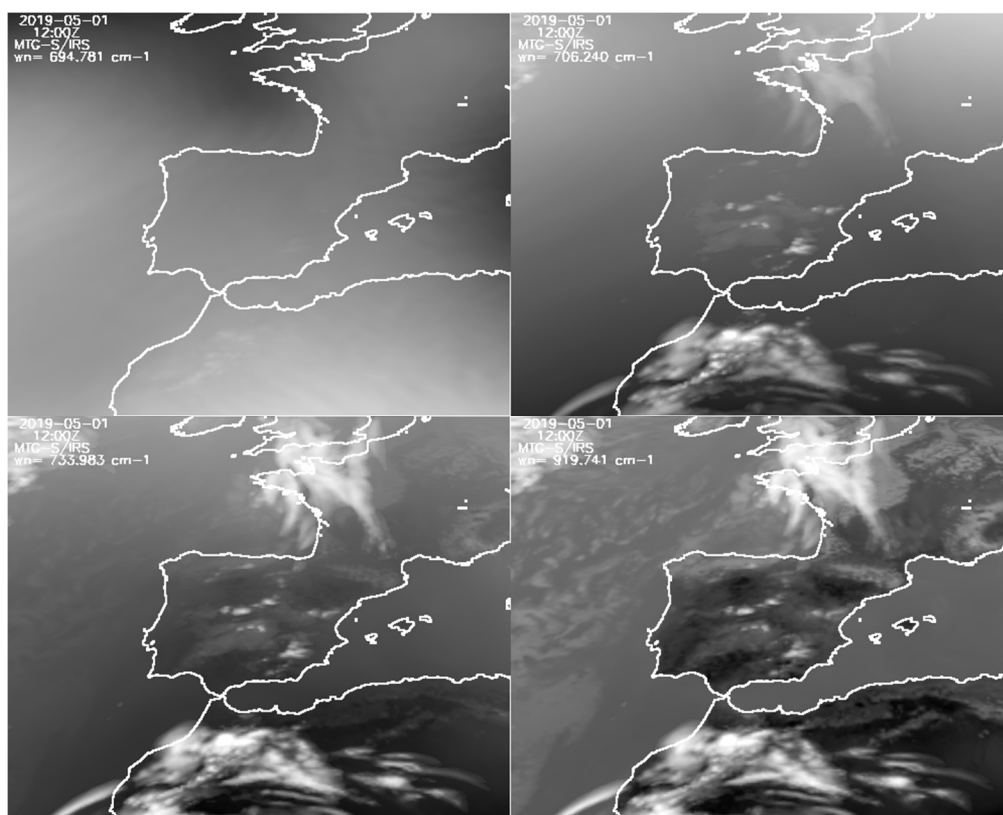


Figure 10: synthetic MTG-S/IRS data nearest to IASI channels at 695, 706, 734 and 919.5 cm^{-1} .

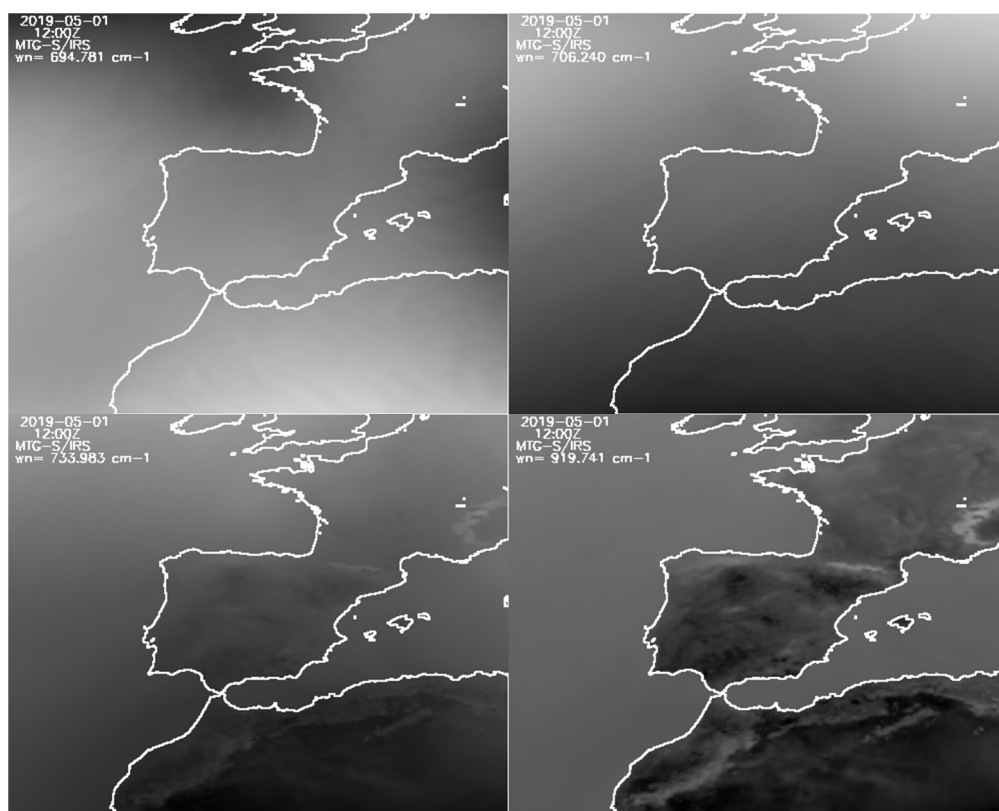


Figure 11: synthetic MTG-S/IRS data nearest to IASI channels at 695, 706, 734 and 919.5 cm^{-1} on clear air mode.

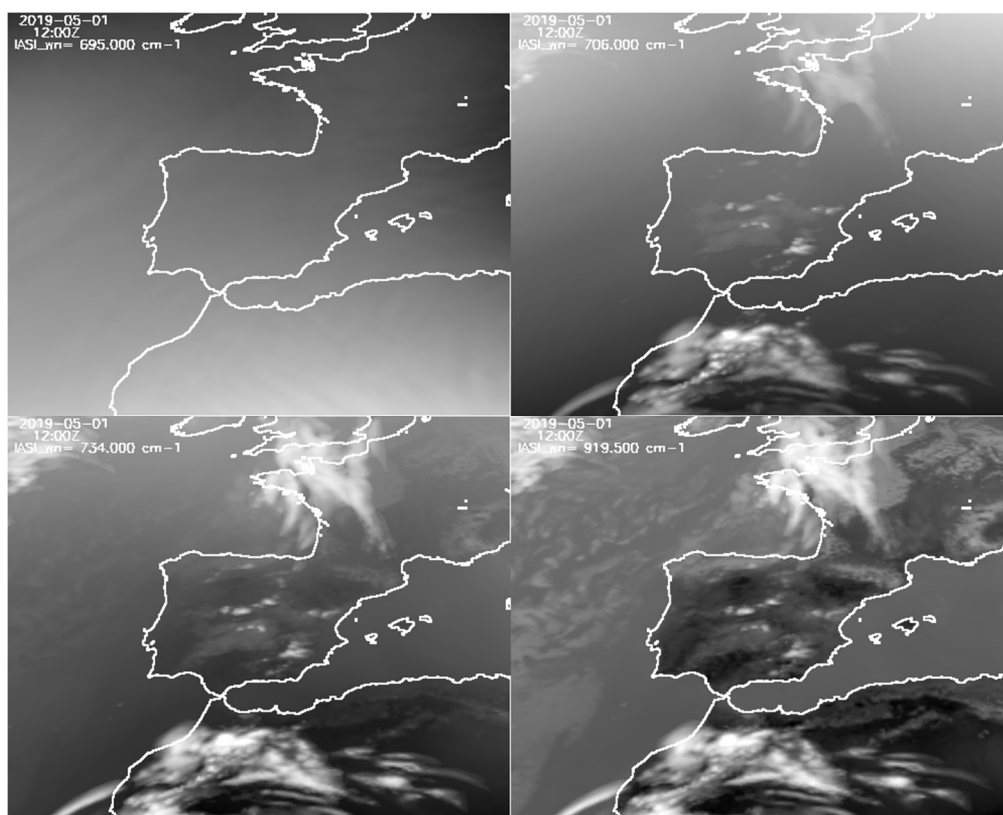


Figure 12: synthetic IASI channels at 695, 706, 734 and 919.5 cm^{-1} .

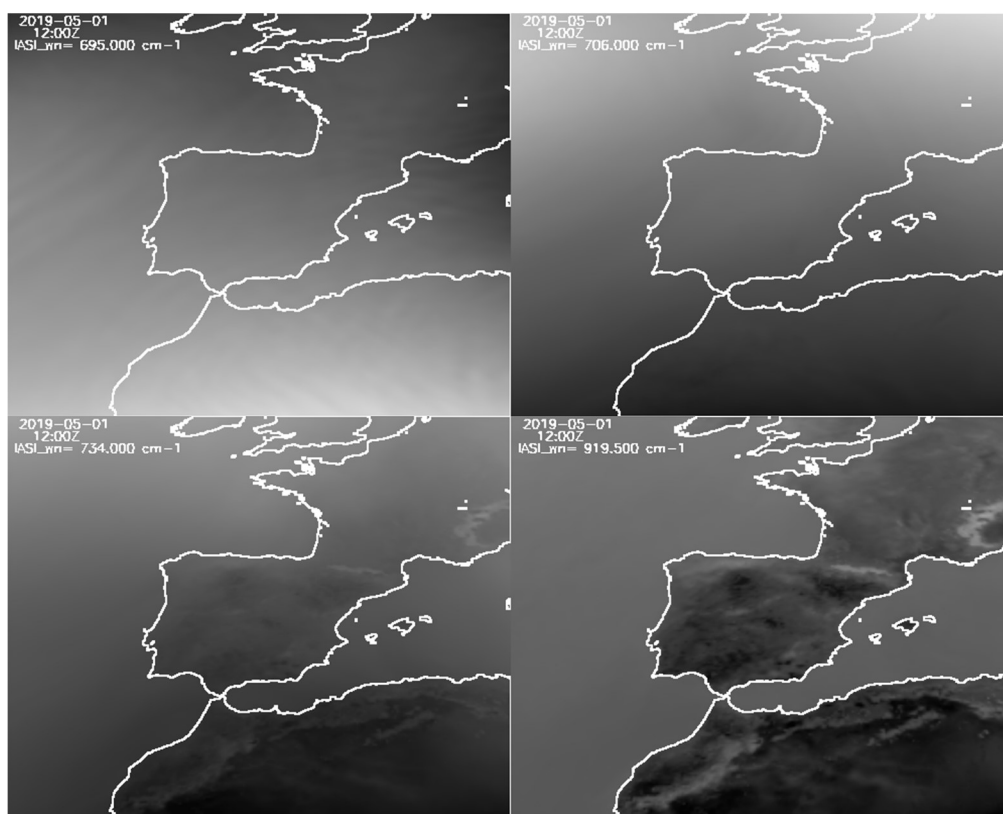


Figure 13: synthetic IASI channels at 695, 706, 734 and 919.5 cm^{-1} on clear air mode.

3.4 EXPLORATION OF WAYS TO IMPROVE SPATIAL AND TEMPORAL RESOLUTION

The spatial and temporal resolution of ECMWF operational model was not enough to get good synthetic outputs for some PGEs using as input on NWCSAF/GEO software package the synthetic FCI data generated from the ECMWF operational model. This is the case of the synthetic High Resolution Winds (HRW) product where few winds are generated due to the low generation of good tracers (the synthetic images are too smooth for HRW PGE).

For this reason, I started to look for the possibilities to use NWP models with better spatial and temporal resolution than the operational ECMWF model. In Figure 14, it can be seen one scheme of the high resolution NWP models tested, the problems found and the ways to solve them. The first attempt was the use of an ECMWF experimental high resolution version that it is described in Section 3.5. The second attempt was the use of Harmonie model that it is described in Section 3.6.

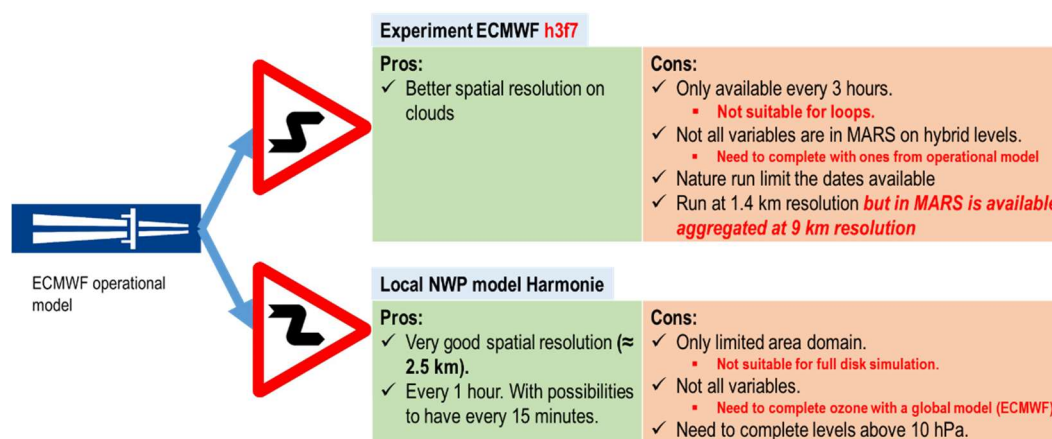


Figure 14: scheme of the attempts to use of NWP models with better spatial and temporal resolution than operational ECMWF as input to PGE00* programs.

In both case it has been needed to complement the deficiencies of these NWP models for use in the simulations with the ECMWF operational model. In Sections 3.5 and 3.6 there is a summary of the processes developed to get the synthetic data from these high resolution NWP models complemented with the ECMWF operational model and some examples.

3.5 GENERATION OF MTG-I/FCI AND MTG-S/IRS SYNTHETIC DATA WITH ECMWF HIGH RESOLUTION EXPERIMENT h3f7 MODEL COMPLEMENTED WITH OPERATIONAL ECMWF ON HYBRID LEVELS.

Some ECMWF colleagues had previously commented in some presentations the existence of experimental ECMWF versions with high spatial resolution up to 1x1 km; instead of the equivalent to $\approx 10 \times 10$ km spatial resolution of the operational ECMWF model.

After a consultation to ECMWF User's Service (Xavier Abellan) I was informed about the high spatial resolution experiment ECMWF h3f7 model. h3f7 experiment is a seasonal (4-months) nature run experimental NWP model at 1.4 x 1.4 km resolution. It is a baseline for future Global Weather and Climate Simulations at 1 km Resolution; see description in [link](#). h3f7 has some advantages over the

operational ECMWF model as the high spatial resolution of 1.4 x 1.4 km resolution but for the time being there are some handicaps to use it in simulations:

1. **h3f7** is executed as nature run. That means, that once started the experiment at the initial date (2018-11-01) there is not assimilation of data and the atmosphere evolves differently than at the operational ECMWF model.
2. The **h3f7** GRIBs files are accessible in MARS but, due some problems in actual MARS capability, the GRIBs files are only available (see Table 3):
 - a. Aggregated at effective 9x9 km spatial resolution.
 - b. Only available every 3 hours.
 - c. As can be seen in Table 3 not all variables needed in the simulations are available in MARS on hybrid levels. For this reason it is needed the combination of profiles of some variables from GRIBs files from h3f7 experiment with profiles of other variables from GRIBs files from operational ECMWF model.

MARS Catalogue

Time (1 values)	anoffset (1 values)	Step (961 values)	Level (137 values)	Parameter (6 values)
00:00:00	9	2853	1	Fraction of cloud cover
		2856	2	Specific cloud ice water content
		2859	3	Specific cloud liquid water content
		2862	4	Specific humidity
		2865	5	Specific rain water content
		2868	6	Specific snow water content
		2871	7	
		2874	8	
		2877	9	
		2880	10	

Table 3: List of available parameters from experimental h3f7 model on ECMWF MARS catalogue.

All of this limitations create the need to complement the parameters in h3f7 experiment with other parameters (temperature and ozone profile) from operational ECMWF model. And due to the nature run this is more convenient to do for the initial date of the nature run (this fact limit the dates available).

To solve these issues, it has been used one old trick to create a combined GRIB files combining some variables (as cloud CC/CLWC/CIWC and q profiles) from h3f7 experiment and other variables (as temperature and ozone profiles) from the operational ECMWF.

As a GRIB file is indeed the concatenation of individual GRIB grids coded in GRIB code format and there is not a common header for every grid, a GRIB file can be split in different files for every one of the grids contained using standard GRIB tools (ECFS commands as [grib_copy](#)).

Thus, making similar requests to MARS for h3f7 model and for operational ECMWF model two GRIBs files are retrieved. Then, h3f7 experiment GRIB file and operational ECMWF GRIB file are both split in different directories in order to get separated files of every grid from each original GRIB file.

Finally, after choosing the individual grid files from both directories one simple Unix *cat* command using the redirecting and concatenation of the output (use of `>>` in the Unix script) creates a combined GRIB file that can be used as input to PGE00* programs. This final GRIB file contains the h3f7 cloud parameters and humidity profiles available on hybrid levels complemented with the rest of needed profiles from the ECMWF operational model (ozone and T profiles).

h3f7	Oper
q	T
CC	ozone
CLWC	
CIWC	

Table 4: List of input parameters from h3f7 experiment and operational ECMWF.

As can be seen in Table 4, the combination of selected fields from the h3f7 GRIBs files and ECMWF operational GRIBs files in only one GRIB file allowed to be used as input to PGE00-VISIR and PGE00-hyper and to generate the simulation for MTG-I/FCI and MTG-S/IRS. The scheme of the simulations made with this combined GRIB file can be seen in Figure 15.

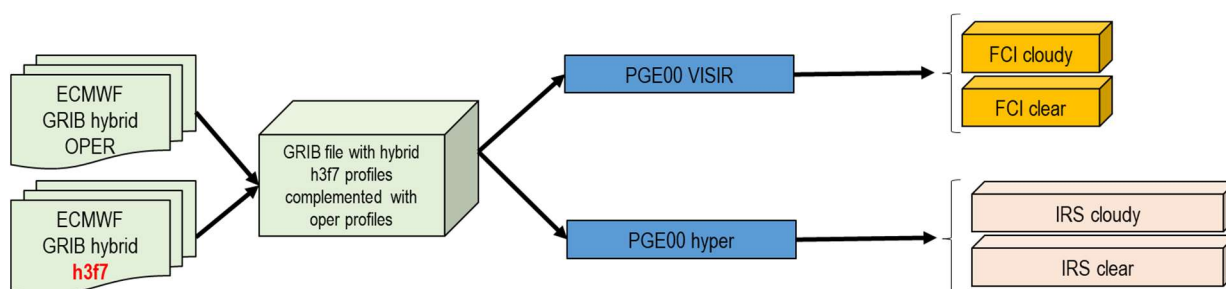


Figure 15: scheme of ECMWF h3f7 experiment simulation with PGE00*.

In the Figures 16 and 17 images with the montage of the synthetic MTG-S/IRS channels nearest to 695, 706, 734 and 919.5 cm^{-1} wavenumbers using the ECMWF operational model (Figure 16) and the ECMWF h3f7 experimental model and complemented with ECMWF operational model (Figure 17) are shown. The images have generated for the case study of the 1st November 2018 at 18Z using the $t+18$ forecast from 00Z run (it is the first day of the nature run experiment). It can be seen that clouds are different in both images; due to higher spatial resolution and nature run on h3f7 experiment. The high spatial resolution on h3f7 (Figure 17) creates clouds with higher details level than in the ECMWF operational model (Figure 16). The images on the simulations with the experiment h3f7 are available in Martinez 2021d and 2021f presentations where the transition from one slide to other allows better to appreciate the changes in cloud representation.

This tests is a precursor of future high resolution simulations if MARS restrictions are removed and other high resolution ECMWF NWP experiments are available someday.

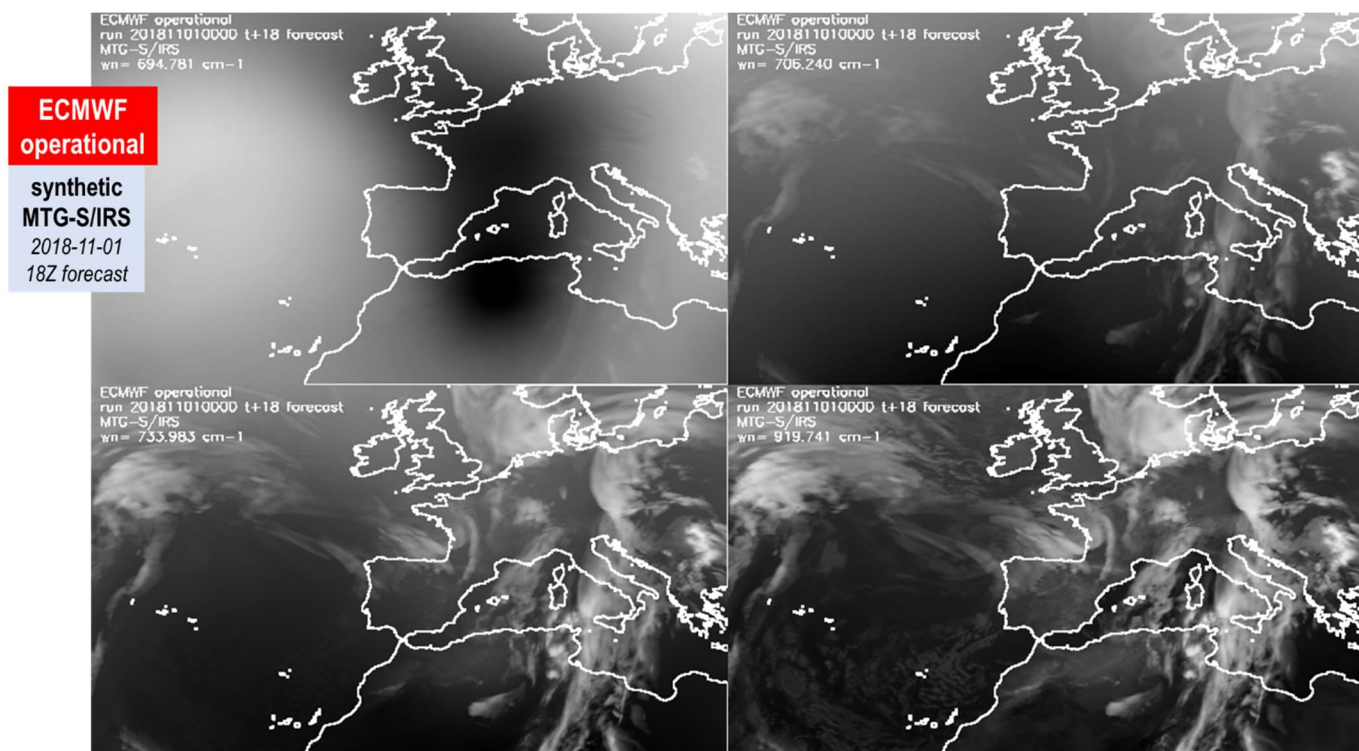


Figure 16: synthetic MTG-S/IRS channels nearest to 695, 706, 734 and 919.5 cm^{-1} wavenumbers using ECMWF operational model. Case study: 1st November 2018 18Z (t+18 forecast 00Z run).

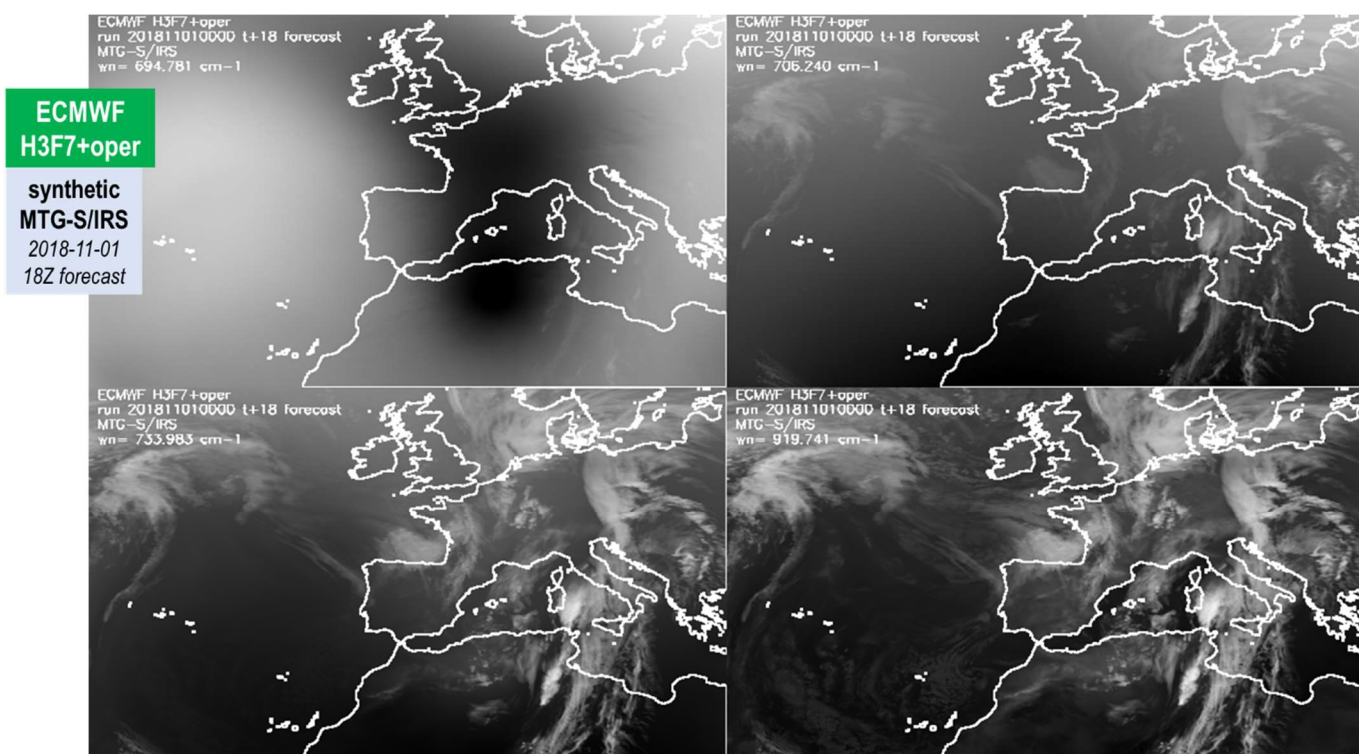


Figure 17: synthetic MTG-S/IRS channels nearest to 695, 706, 734 and 919.5 cm^{-1} wavenumbers using ECMWF h3f7 experimental model and complemented with ECMWF operational model. Case study: 1st November 2018 18Z (t+18 forecast from 00Z run). Clouds are different due to higher spatial resolution and nature run on h3f7 experiment.

3.6 FOURTH: GENERATION OF MTG-I/FCI AND MTG-S/IRS SYNTHETIC DATA WITH HIGH RESOLUTION HARMONIE NWP MODEL COMPLEMENTED WITH OPERATIONAL ECMWF ON HYBRID LEVELS

Due to above limitations, it was started a second attempt using a high spatial resolution local NWP model as input to PGE00* programs. In this second attempt to get better spatial and temporal resolutions synthetic data it has been used the AEMET instance of Harmonie model as one demonstrator of the possibilities of the use of local NWP models for synthetic data generation.

The AEMET instance of the Harmonie NWP model uses a Lambert projection grid of 2.5 x 2.5 km resolution on a grid rotated 5° on a region centred in the Iberian Peninsula (see Figure 19). AEMET Harmonie has 65 hybrid levels from P_{sfc} to 10 hPa and the outputs are available every 1 hour (with possibilities to have every 15 minutes). In this report, it has been used re-projected AEMET Harmonie GRIBs files on a regular grid 0.025° x 0.025°. The GRIB files have dimensions of 1170 x 700 enough for high quality simulations of a usual NWCSAF user's region. The Harmonie GRIBs files has been provided by Javier Calvo and María Díez (NWP Area of AEMET).

But Harmonie model alone has some limitations for the use in simulations:

- ✓ Harmonie is only a limited area domain (not suitable for full disk simulation).
- ✓ Not all profiles variables needed by *PGE00-VISIR* and *PGE00-hyper* are available in AEMET Harmonie model. Harmonie has T, q, CC, CLWC and CIWC profiles. But, AEMET instance of the Harmonie model does not have ozone profile needed for simulation of channels in region 9.7 microns. Thus, it is needed to get ozone profile from a NWP global model as the ECMWF operational model.
- ✓ Need to complement levels above 10 hPa.

Harmonie AEMET	ECMWF Oper
T	ozone
q	
CC	
CLWC	
CIWC	

Table 5: List of input parameters to PGE00-hyper program from Harmonie and ECMWF.

Since Harmonie model does not have ozone profile then it was started a new way to make the simulations. It was created an IDL program that:

1. It was executed simple PGE00* programs and PGE00 configuration files (it was used one ad hoc version) to make just the read from GRIB files and the writing of the profiles on each GRIB file on binary files of the variables in ECMWF and Harmonie GRIB files.
2. Then, the IDL procedure read the combination of needed binary files with data from Harmonie, operational ECMWF model and NWCSAF ancillary fields. From Harmonie PGE00 binary files the 3D arrays of T, q, CC, CLWC and CIWC profiles on AEMET Harmonie regular grid of 0.025° x 0.025° are read. From ECMWF operational binary files it is read the 3D arrays of ozone profiles on the regular 0.1° x 0.1° grid (chosen in the MARS request) on a region covering the AEMET Harmonie region. From the NWCSAF DATABUF (*\$SAFNWC/tmp/**) are read the satellite and solar zenith angles; these angles are generated using an ad hoc reduced PGE00 programs that just contains the lines that trigger the generation of the satellite and solar zenith angles.

3. For every pixel in the AEMET Harmonie region on Harmonie grid is spatially interpolated one ozone profile in the 137 ECWMF hybrid levels from the ECMWF ozone 3D array to the position of Harmonie pixel. The spatially interpolated ECMWF ozone profile in the 137 ECWMF hybrid levels is vertically interpolated to the Harmonie 65 hybrid pressure levels. Thus, it is get a spatial and vertically interpolated ECMWF ozone profile collocated with the Harmonie profiles.
4. Finally, the IDL procedure creates for every pixel in the Harmonie grid one structure with the Harmonie profiles, the ozone profile 4D interpolated to the Harmonie time, position and vertical levels and as ancillary variables (topography, zenith angles, etc) the ones interpolated to time and date from NWCSAF DATABUF.

Then, as can be seen in Figure 18, it was created, modified and simplified *PGE00-VISIR* and *PGE00-hyper* versions for use as input the combined Harmonie, ECMWF operational and NWCSAF binary files. These ad hoc *PGE00** versions adapted to use as input the above dataset are the ones used to call RTTOV and to calculate the MTG-I/FCI or MTG-S/IRS synthetic data in Harmonie+ECMWF case.

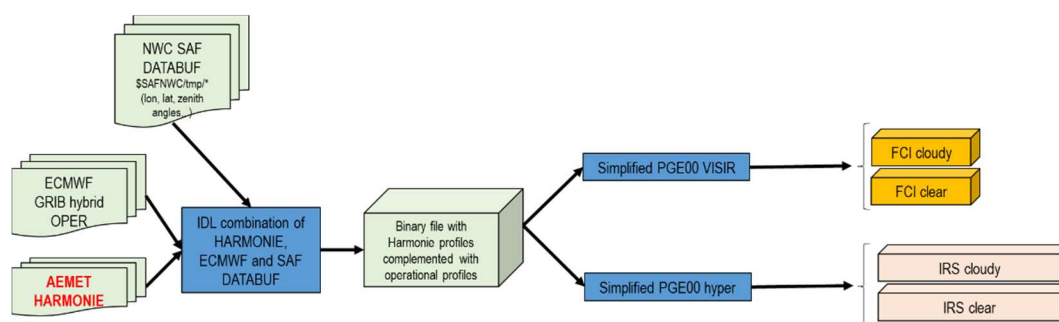


Figure 18: scheme of Harmonie complemented with ECMWF simulation in the simulations with *PGE00** programs.

In future improvements, it will be added and tested the extrapolation of Harmonie above 10 hPa using collocated operational ECMWF hybrid levels profiles.

It has been used as case study the 24 hours of AEMET Harmonie GRIB files from 25th April 2021. In the Figure 19 the montage of the synthetic MTG-S/IRS channels nearest to 695, 706, 734 and 919.5 cm⁻¹ wavenumbers using the Harmonie model complemented with ECMWF operational model at 12Z is shown. The first loop of IRS synthetic images with Harmonie 2021-04-25 00 to 23Z every 1 hour is available in Martinez 2021f presentation. In Figures 22 and 23 of [RD.1] some examples of the complementary synthetic FCI RGB images are shown.

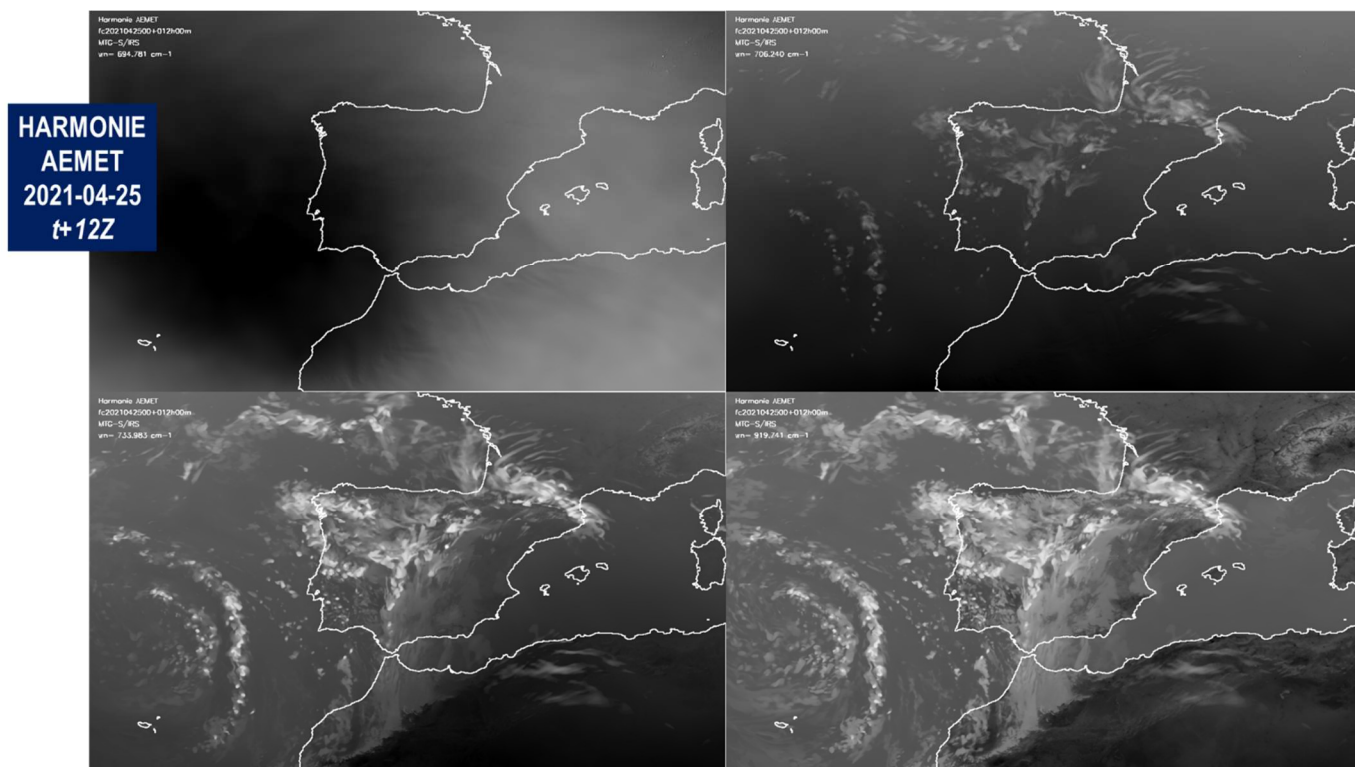


Figure 19: synthetic MTG-S/IRS channels nearest to 695, 706, 734 and 919.5 cm⁻¹ wavenumbers from HARMONIE AEMET complemented with ECMWF operational model. Case study 25th April 2021 at 12Z from t+12 forecast of 00Z run.

It is important to note the ozone profile from the ECMWF operational model complement the Harmonie profiles in the call to RTTOV-13.0; this likely could not be made using other tools as *radsim* tool from NWP SAF.

As can be seen in Figure 18, the most important for future MTG-I/FCI and MTG-S/IRS simulations was the idea to develop an IDL procedure to combine the fields from several GRIBs files and NWCSAF DATABUF files and to write them in one intermediate and combined binary file. This combined binary file is used as input to an only FORTRAN versions of *PGE00-VISIR* and *PGE00-hyper*. This PGE00* programs differs to GEO-PGE00* ones in that they don't have the C shell that use API of NWCSAF to read input NWC SAF files and the interface to GRIB files. This idea could be important because once the input binary file is written this FORTRAN only programs does not need the NWCSAF environment; thus, there is the possibility to be used in main computers and with better parallelization capabilities.

Even with the handicaps commented above, the modified *GEO-PGE00-VISIR* and *GEO-PGE00-hyper* version for use high resolution NWP models complemented with ECMWF operational can be considered as precursors of future high resolution simulations if higher resolution NWP are available someday.

4 EARLY USES OF SYNTHETIC IRS DATASETS

It has been used the new synthetic datasets and PGE00* programs first to repeat some of the activities made in the last 12 years for the search of the uses of IRS L1 images in nowcasting. This activity has been made first to consolidate the developments made and to check that they are consistent with new synthetic datasets. Second objective is to use the updated programs as basis on new developments.

The first activity was to repeat with the new synthetic dataset based on iSHAI 2017 training and validation dataset the search of IRS and IASI channels nearest to SEVIRI/MSG IR channels. This activity is the basis for the proposed IRS RGB images with MSG heritage. It is shown in Section 4.1.

The second activity was to repeat with the new synthetic dataset based on iSHAI 2017 training and validation dataset the search of peak and valleys channels on IRS and IASI spectra. This activity is the basis for the selection of channels on CO₂ branch that could be used for to provide in operational and near real time a top to down view of the atmosphere. It is shown in Section 4.2.

It is shown in Section 4.3 how the new synthetic dataset based on iSHAI 2017 training and validation dataset could be used in CDOP-4 for search of new developments.

4.1 STARTING POINT OF IRS RGBS: HYPERSPECTRAL RGBS WITH MSG RGB HERITAGE

The idea of RGB images form hyperspectral data was introduced in 2010 as one counterexample to the question “*Is it possible the use of IRS L1 in Nowcasting?*”

One of the most immediate applications of satellite data, especially for Nowcasting, is the use in RGB images composites. The RGB images provides good monitoring of spatial structures. In regular algorithm, the algorithm are only applied normally on clear or cloudy pixels; this creates images with a part of the image not processed and the human eye loss the spatial structure over not processed regions. In the case of RGB all pixels have one RGB colour assigned; when sequence of images are displayed the human eye is able to follow adequately the spatial structures. Also they are fast to calculate and can later be analysed visually.

The first problem that obviously arises is to choose the channels to use among all the possible endless combinations of the IRS channels. RGB image is only one image generation technique but the main important question is to get a physical interpretation and foundation of one specific RGB generation recipe. To answer this question one good start point is the generation of RGB similar to MGS RGB in order to start to use them.

Thus, a possibly good start is to choose the IRS channels which are more similar statistically to MSG channels and start with the generation of IRS RGBS similar SEVIRI/MSG composites. These IRS RGB images could then be directly compared to the MSG or FCI ones. Later it could be used as basis to search of new RGB images.

In Martinez 2010c it was shown the first MTG-S/IRS RGB image. In 2010, with the goal of familiarizing the public of the countless applications that the future METEOSAT Third Generation infrared sounder (MTG-IRS) will bring, it was calculated synthetic BTs using RTTOV-9.3 with IASI and MSG coefficients to obtain synthetic IASI and MSG BTs for one GRIB file of the 2009 ECMWF model. In 2010, the IASI BTs were converted to MTG-S/IRS spectral resolution with a radiation converter tool (iasi2irs) built at EUMETSAT (Tjemkes, 2008), which transforms the 8461 RTTOV IASI channels into the MTG-S/IRS radiances (1738 channels; the defined spectral grid at this epoch). After one selection of the nearest statistically MTG-S/IRS brightness temperatures (BTs) fields to

MSG BTs fields, the first MTG-S/IRS synthetic RGBs was created. The first IRS RGB was a synthetic airmass IRS RGB image that it is shown in Figure 20 copied from Martinez 2010c paper; it was shown in 2010 EUMETSAT Conference in Cordoba.

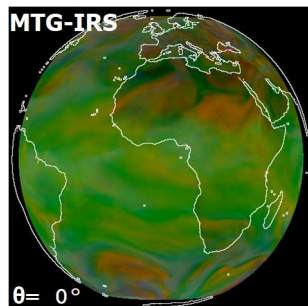


Figure 20: copy of the **first** synthetic MTG-S/IRS airmass RGB generated in 2010 with clear RTTOV-9.3 BTs calculated with zenith angle fixed to 0° using the MTG-S/IRS channels closest to MSG channels for case study 25th May 2019 at 12Z.

Also in 2010 it was repeated the search of IASI channels statistically nearest to the synthetic IR MSG channels using the synthetic IASI and MSG data. In Martinez 2013 there are shown IASI RGB images using real IASI data using the same IASI channels than the used for the IASI RGB recipe in Martinez 2010c.

Since 2010, it has not been revisited and updated the selection of the hyperspectral channels nearest statistically to the MSG ones. The first activity has been now to repeat with the new reference synthetic dataset based on iSHAI 2017 training and validation dataset the search of IRS and IASI channels nearest statistically to SEVIRI/MSG IR channels that was made 2010. On this first activity with the new synthetic dataset it was revisited and updated the 2010 programs to search IRS and IASI RGB images equivalents to MSG RGB images. The 2010 activity was the basis for the proposed IRS RGB images on CDOP proposals; the programs and findings on this revisit activity will be the basis for future developments on IRS RGB images.

Now instead to use as basis one ECMWF GRIB file it has been used the 2017 training and validation dataset. It has been used the *PGE00_1d* program shown in Section 2.4.1 to calculate the synthetic BTs for IRS, IASI, FCI and SEVIRI dataset for IR channels on clear air mode from the profiles the 2017 training and validation dataset. It has been used the 2017 training and validation dataset in order to provide a better generalization of the results; the atmospheric variability on GRIB files is very low compared with the great atmospheric variability in the 2017 training dataset.

Then, it was started the process to find the regression from MTG-S/IRS (or IASI) channels nearest statistically to the SEVIRI/MSG channels. This will be used to generate the hyperspectral RGB images equivalent to MSG RGBs; in this report it will show the IRS and IASI air mass RGBs. The whole process can be seen in Figure 21 and it is similar the one made in 2010.

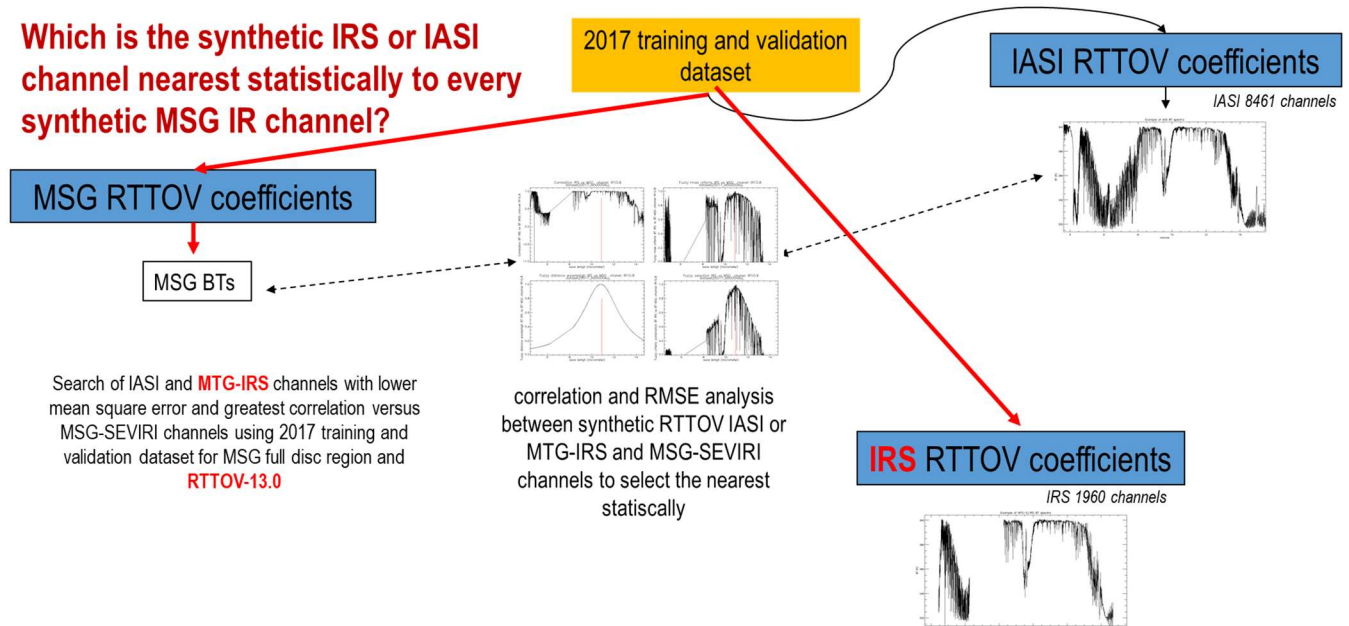


Figure 21: scheme of the process to select the nearest statistically IRS (or IASI) channels to every MSG IR channel.

To achieve this, it is needed first to find for every IR MSG channel the regression from every MTG-S/IRS channel nearest statistically. To make the selection it has been made the following process:

- It has been read the synthetic BTs arrays for MSG and IRS (or IASI) from 2017 datasets.
- It has been calculated the correlation and RMS between each one of MSG IR channels and the regressions from the MTG-S/IRS (or IASI ones) for all the pixels in the 2017 synthetic dataset to each one of the MSG IR channels.
- For every MSG IR channel it has been selected the MTG-S/IRS channel (or IASI channel) with highest correlations and lowest RMSE in the neighbourhood of the wavenumber of the MSG IR channel. This have been using one approach based on fuzzy logic:
 - It is calculated the normalized inverted RMSE (1 for lowest RMSE and 0 for RMSE greater the mean RMSE value) factor for every IRS channel. See Figure 22 (top right).
 - It is calculated the normalized factor with the difference of wavenumbers of the IRS and MSG channels. See Figure 22 (bottom left).
 - The arrays with the correlation, the normalized RMSE and wavenumber distance are multiplied.
 - It is searched the IRS channels with greater value in the multiplication. This is the selected IRS channel nearest statistically to the MSG IR channel. In Figure 22 this nearest IRS channel is the IRS channel whose wavenumber is indicated by the red line.

Repeating the process for all IR MSG channels it is determined a set of IRS channels and other for IASI channels. These sets of sounder channels can now be tested generating MTG-S/IRS and IASI RGB composites using the synthetic datasets described in Chapter 3. The list of channels used to build the MTG-S/IRS RGB images is shown in Table 6. This channel correspondence should be contemplated as an initial first guess, because there has been no noise introduced in the simulations. It just illustrates the technique.

In the Figures 23 to 28 are shown hyperspectral air mass RGB; but any other hyperspectral RGB equivalent to MSG RGBs using only IR channels could be obtained.

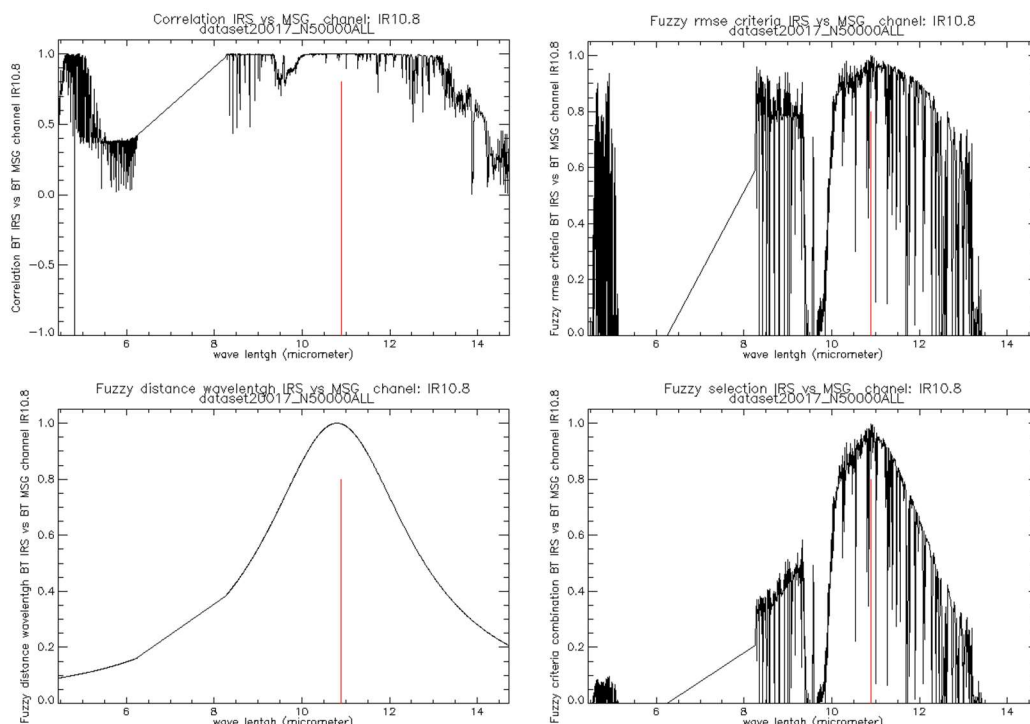


Figure 22: factors for selection of IRS channel nearest statistically to SEVIRI/MSG IR10.8 channel calculated from synthetic 2017 training and validation dataset. Top left) correlation between regressions of IRS channels and MSG IR10.8 channel, top right) fuzzy normalization of RMSE between a regression of IRS channel and MSG IR10.8 channel, bottom left) fuzzy style factor calculated from distance of IRS and MSG IR10.8 wavenumbers. Bottom right) multiplication of the three factors. In all the figures the red line mark the position of the selected IRS channel as nearest statistically to MSG IR10.8 channel.

SEVIRI channel	Nearest IRS channel number (0-based)	λ (μm) nearest IRS channel	Regression coefficients	
			a	b
IR3.9	1807	4.63224	1.00460	-1.53276
WV6.2	886	6.23913	0.968182	6.38449
WV7.3	820	8.51606	0.982582	-2.43596
IR8.7	766	8.75899	0.988151	2.52985
IR9.7	577	9.73049	0.955317	10.3667
IR10.8	395	10.8941	0.990678	2.57308
IR12.0	259	11.9630	0.999451	-0.293075
IR13.4	118	13.3179	0.858466	28.3422

Table 6: List of MTG-S/IRS channels nearest statistically to IR MSG channels. It have been used in MTG-S/IRS airmass RGB generation in the Figures 25 to 30.

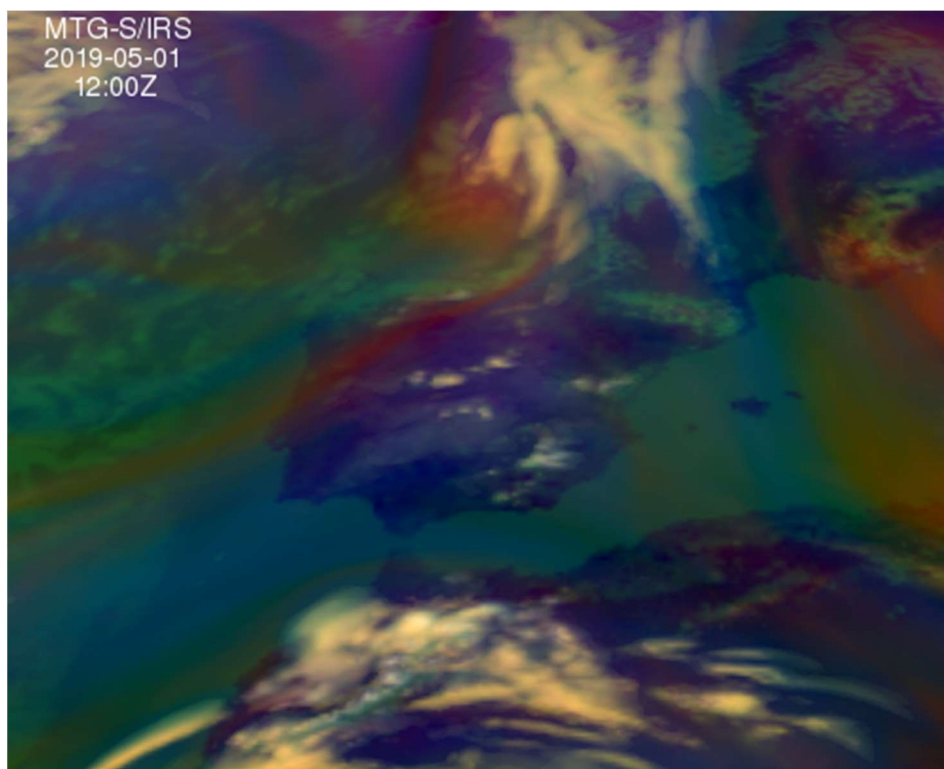


Figure 23: synthetic IRS air mass RGB. 1st of May 2019 at 12Z (using $t+12$ ECMWF forecast).

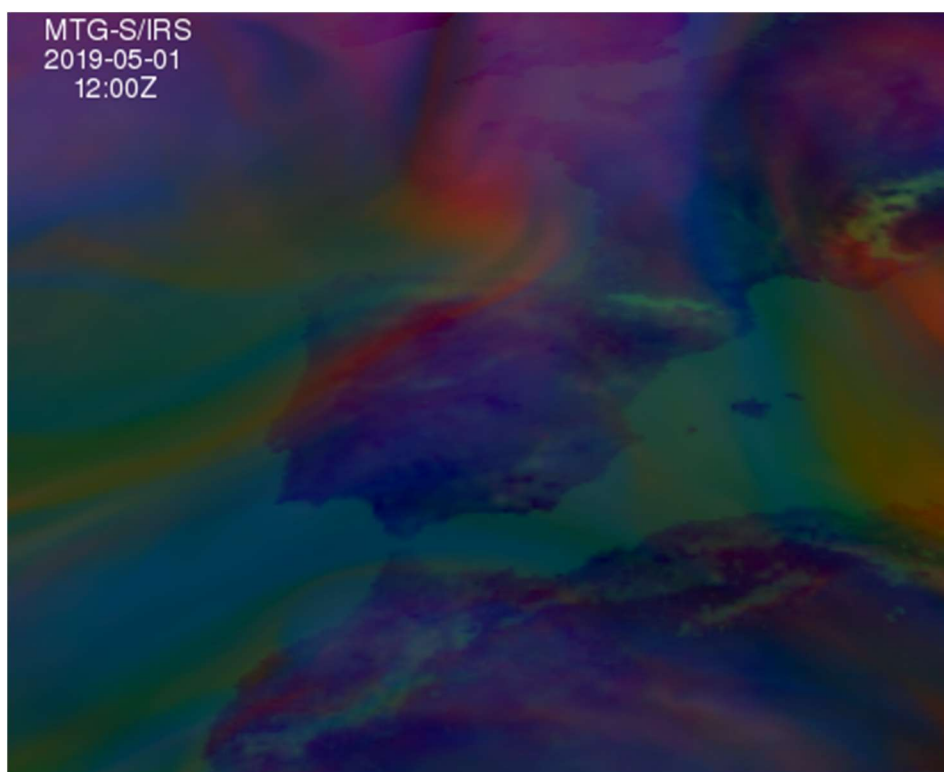


Figure 24: synthetic IRS air mass RGB. 1st of May 2019 at 12Z (using $t+12$ ECMWF forecast) calculated on clear air mode.

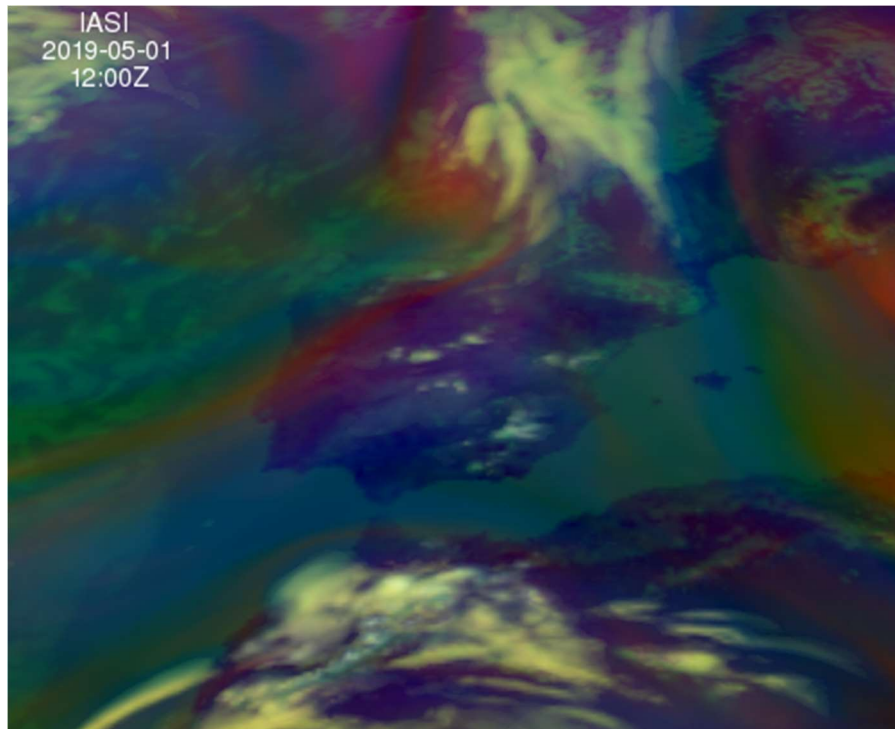


Figure 25: synthetic IASI air mass RGB. 1st of May 2019 at 12Z (using $t+12$ ECMWF forecast).

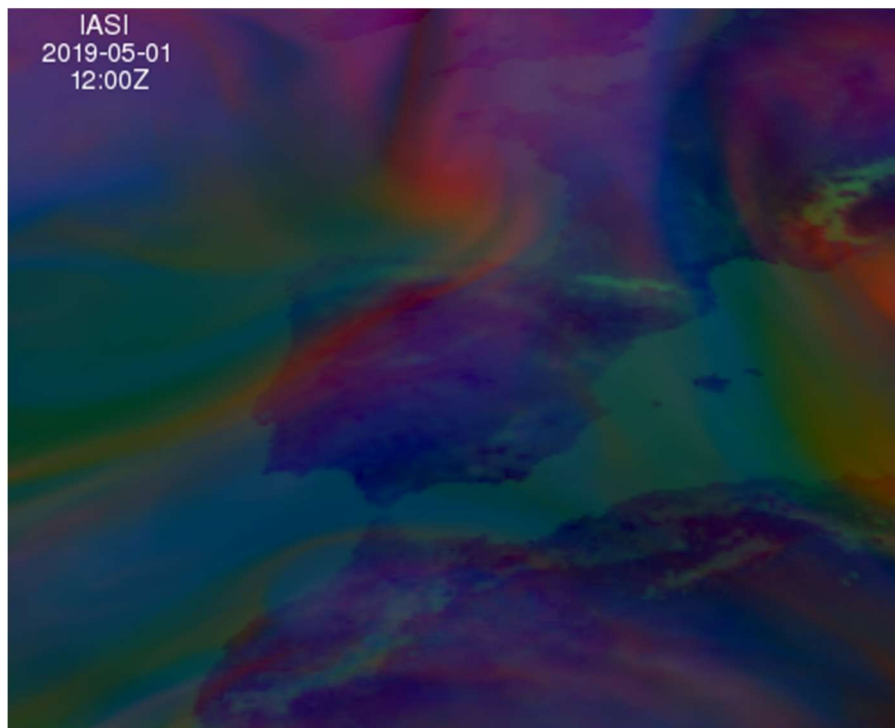


Figure 26: synthetic IASI air mass RGB. 1st of May 2019 at 12Z (using $t+12$ ECMWF forecast) calculated on clear air mode.

Since there are also synthetic FCI data obtained for same region and times than the synthetic IRS and IASI the synthetic IRS and IASI air mass RGB images can be compared with the FCI air mass RGB image. These comparisons of air mass RGB images are shown in Figures 27 and 28. It can be clearly seen that sounder air mass RGB images reproduce similar structures and patterns that the FCI air mass RGB image. The differences between the IASI, IRS and FCI RGBs could be analysed using the 4D input datacube and the 4D spectra datacubes. Likely there are due to the differences in the weighting functions between the sounder and imager channels; special PGE00_1d to generate also de jacobian for selected pixels could be developed in the future.

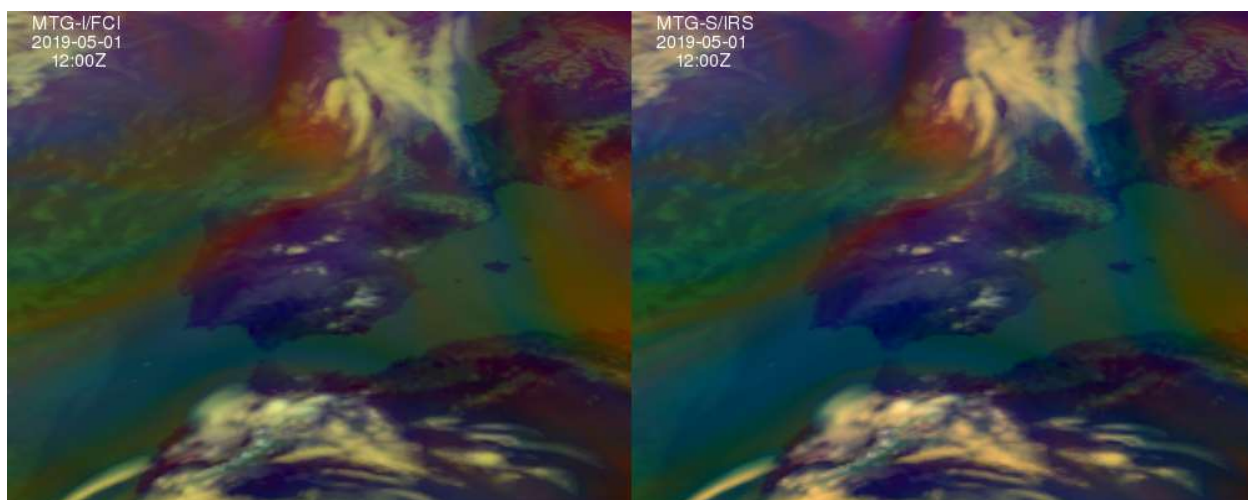


Figure 27: comparison of synthetic FCI (left) and IRS (right) air mass RGBs. 1st of May 2019 at 12Z (using t+12 ECMWF forecast).

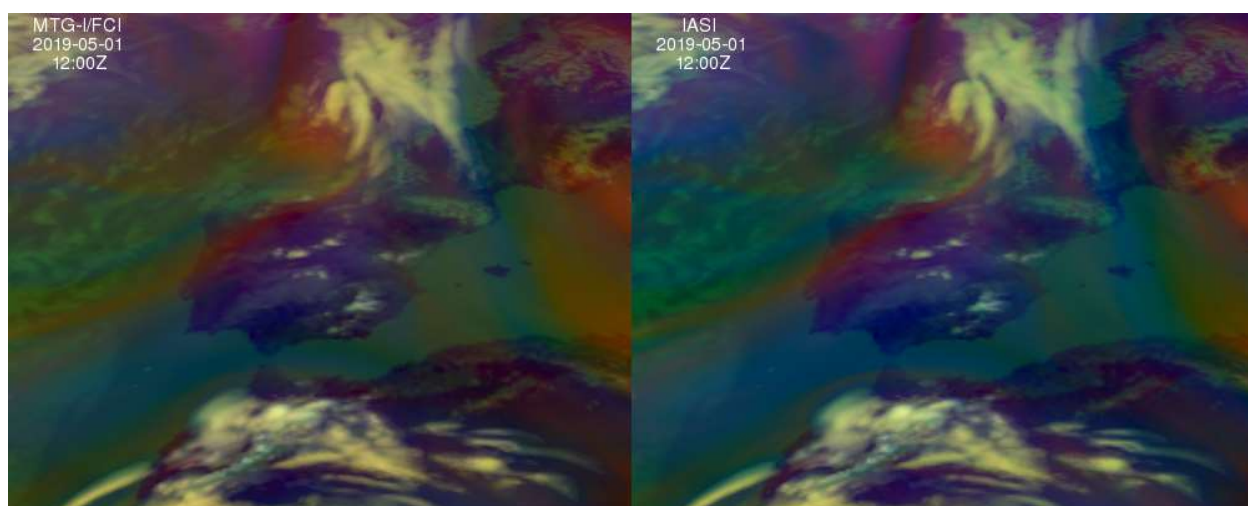


Figure 28: comparison of synthetic FCI (left) and IASI (right) air mass RGBs. 1st of May 2019 at 12Z (using t+12 ECMWF forecast).

In Martinez 2021 presentations are shown loops of IRS air mass RGBs every 30 minutes. These synthetic datasets have been generated without noise added. Pending of final noise in real IRS data (or other fails) when MTG-S/IRS be launched, these synthetic IRS air mass RGB images show that the spatial and temporal resolution of IRS L1 is enough to be considered as useful for weather forecasting and to answer yes to the question “Is it possible the use of IRS L1 fields in Nowcasting?”

4.2 PEAKS AND VALLEYS REPRESENTATIONS

One of the key aspects for an adequate exploitation of hyperspectral L1 data is the need of hyperspectral L1 files be compatible with management and display tools. As proxy of future management and display tools to exploit IRS L1 data it has been used here the McIDAS-V tool.

On UMARF it is possible to download IASI L1 files in native or netCDF-4 formats. But in both cases the UMARF IASI L1 files cannot be used directly as input to any standard meteorological tool. The problem of UMARF IASI L1 netCDF-4 is that it has been designed just as transcript from EUMETSAT IASI natural format to netCDF format without taking into account any rule or convention in order to be compatible with any standard visualization tool. This implies that just ad hoc programs or using user developing programs environments must be used to read and use them.

Likely due to Marianne Koenig interest and collaboration with McIDAS-V developers, several years ago the McIDAS-V tool had special code to read and use UMARF IASI L1 files on HDF-5 format. But after several changes and versions updates in the UMARF, now the direct use of the UMARF IASI L1 netCDF files in McIDAS-V is impossible.

Thereby, it is needed a converter program; see Martinez 2013 and 2015. At early CDOP-3 phase (end 2017) the converter IDL/GDL program was updated to the updated UMARF IASI L1 version using as basis previous prototype as the used in Martinez 2013 and 2015. It was incorporated an important improvement. When the first IASI L1 compatible McIDAS-V netCDF files were used in McIDAS-V the aspect of the images was not smooth and the movement of the mouse was not fully continuous. The reasons were attributed to the noise and low resolution of the IASI images and the huge memory demand to read in memory an IASI L1 array. But after the experience described in [RD.7] Section 5.1.2.2 it was clear the need to reorder IASI L1 pixels depending on the IASI detectors order. As it is described in [RD.7] Section 5.1.2.2 the IASI files are written thinking on the way are observed and to be used in NWP. Thus, they are written not thinking in to be exploited as image arrays. If the use is for NWP or for just plot the data order is not important, but if the use is for display as image field it is crucial to reorder the data to be aligned as continuous arrays. This fact it is one example of the need of NWC SAF software in the users' side of EUMETCAST to cover the gap between EUMETSAT disseminated files and users' needs.

Since 2012, it has been downloaded from UMARF IASI L1 files for several cases studies to investigate the use of IASI L1 images in nowcasting after conversion of EUMETSAT IASI L1 files to McIDAS-V compatible netCDF format using the above converter. See in References examples in Martinez 2013, 2015, 2016a, 2016c, 2018a and 2018b.

One example of the use with real IASI L1 images can be seen in the Figure 29. In the Figure 29 it is shown an example of McIDAS-V interactive display of real IASI L1 after conversion to McIDAS-V compatible netCDF files. Users can move interactively the green lines on spectra images to change the wavenumber of the IASI channel displayed; this allows display IASI channels from different spectral region and due to the difference in the weighting functions travel vertically in the atmosphere.

Also users can move the pink, green and blue probes positions; thus, they can compare interactively the spectra at different pixels of interest (it is also possible to add additional probes). In the Figure 29 it has been selected in pink probe a clear sea IASI pixel, in blue probe low cloud IASI pixel and in green probe a high cloud IASI pixel. The IASI spectra for the three probes can be seen in Figure 29 (upper right) image. In the (upper right) image of the Figure 29 it can be shown the difficulties in the comparison of the full IASI spectra at the three probes. The comparison of the spectra between several pixels is nearly impossible due to the mixing of the lines due to the high oscillation present in the spectra.

In 2013 took place in EUMETSAT a MTG-S/IRS Nowcasting Workshop chaired by Paul Menzel and Hervet Roquet in which I made a presentation with some early ideas for the use of IRS L1 images in

nowcasting; unfortunately, the presentations on this workshop were never published. In Martinez 2013 there is a summary of this early ideas.

To avoid the mixing of the lines from several spectra, I presented in the above workshop as an early brainstorm idea to use separately only the wavenumbers of the relative maxima (“peaks”) and minima (“valleys”) in IASI spectra. It was used as reference the mean IASI spectra on the IASI pixels labelled as “clear sea” from dataset with real IASI L1 pixels created round 2011. To obtain the sets of “peak” and “valley” wavenumbers, a set of collected real IASI spectra labelled as “clear sea pixel” were used to calculate an average BT spectra; then, the wave numbers of the relative maxima (“peaks”) and minima (“valleys”) were found using an iterative process repeated twice.

This representation is adequate for the comparison of the spectra slopes and shapes of several of hyperspectral pixels. The separate “peaks” and “valleys” lines can be considered as the envelope lines of the spectra. The simultaneous representation of the “peaks” and “valleys” provides useful information about the temperature profiles and the amount of absorbers present in the pixel that originated the spectra. Thus, the area between the “peaks” line and the “valleys” line could provide an idea of the amount of absorbent present. Since the “valleys” line has a higher oscillation than the “peaks” line it was proposed also the use of a moving average on the “valleys” line. Taking into account the geostationary orbit of MTG-S/IRS, the change of these lines with the time (every 30 minutes) on a fixed location (for example at one airport) could provide the forecasters an indirect and subjective monitoring about the processes that are taking place.

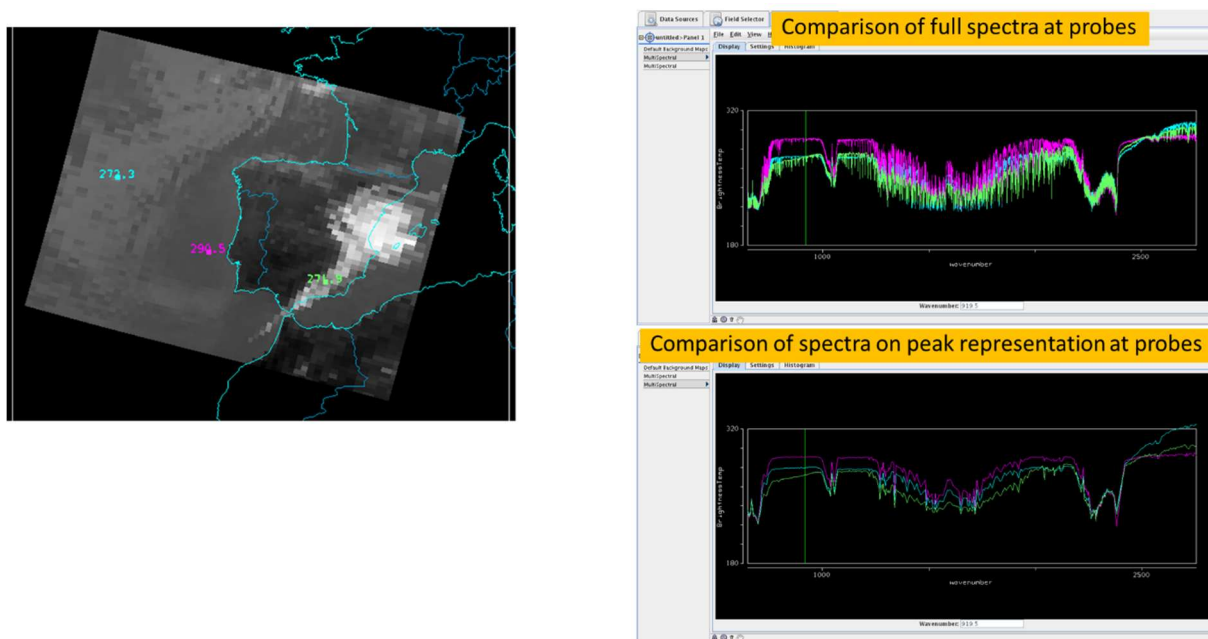


Figure 29: Example of McIDAS-V interactive displays of IASI METOP-B 2016-08-10T10:32:26Z. (left) IASI brightness temperature at wavenumber in green line of right images. (right upper) comparison of full IASI spectra at pink, blue and green probes on left image. (right bottom) comparison of simplified spectra representation with relative “peaks” representation.

To get a simplified “peak” spectra representation, just IASI channel of a set of selected wavenumbers that are relative maxima or peaks in the spectra are written in the McIDAS-V compatible netCDF IASI L1 file. Also it can be made the same with the relative IASI minima wavenumbers (valley spectra

representation). Using in McIDAS-V the proposed simplified peak spectra netCDF file the comparison of the spectra can be easily done (see as example Martinez2013, Martinez2015 and Martinez 2018b).

In Figure 29 (bottom right), an example of “peaks” comparison for several kinds of pixels can be seen. The “peaks” representation allows to clearly distinguish the shape of the spectra and could be used later to develop algorithms based on these features. This technique would avoid the use of differences between only two channels that could be misleading and could produce errors.

Other brain storm idea (see Martinez2013 and Martinez2015) is to add in future users’ tool some interactive graphical support to represent at the same time the peak and valley representations. This kind of applications can be easily configured in the proposed quick-IRS L1 service.

It has been updated and improved the old 2012 IDL procedure for the search of “peaks” and “valleys” in the old 2011 real IASI dataset. It has been now repeated the search “peaks” and “valleys” using the synthetic 2017 training and validation dataset for IRS and IASI. In CDOP-4 it will start the search of applications and the result will be published.

4.3 TOP2DOWN

Images from selected hyperspectral channels from some spectral regions (as CO₂, O₃ or WV absorption bands) can be used to provide top to down views of the atmosphere. The montages in the Figures of Chapter 3 from synthetic MTG-S/IRS and IASI channels nearest to 695, 706, 734 and 919.5 cm⁻¹ wavenumbers are one example of this application of IRS L1 on nowcasting.

But some considerations must be taken into account to do it comfortably with interactive tools. When IASI L1 netCDF files are used in McIDAS-V interactively and it is changed the displayed image from one wavenumber to another (it is made interactively moving the green line on the spectra that can be seen in Figure 29) it appears a sharp change in the contrast and grey levels between images (roller coaster effect) due to the change in absorption properties from one wavenumber to others.

To avoid this roller coaster effect when images of all IASI channels are displayed in one loop a solution is to make loops with just the images of the main “peaks” or “valleys” on selected spectral regions as the CO₂, O₃ or WV absorption bands. This allows creating gently varying image loops which probe deeper and deeper in the atmosphere from very high levels to the surface. One example of the usefulness could be the search of low levels jets on satellite images.

Usually the display tools use the minimum and maximum in the data (BT or radiance) to create a fast conversion from data to a byte representation assigning 0 (or black) to minimum and 255 (or white) to maximum; in the case of IR satellite images is usual to assign 0 (or black) to maximum and 255 (or white) minimum. Due to this fact, a secondary oscillations in the pattern and in the grey levels of the images is create due to change in the structures (clouds) that gradually are appearing when travelling with the images from high level peaking channels to low level peaking channel or IR window channels. To remove this secondary oscillations, one alternative is instead to display the BTs on every channel is to use one ad hoc brit calibration; for example, using normalized images after removing the mean and dividing by the standard deviation (see Martinez 2013 and Martinez 20215). The process could be made interactively if the adequate software is developed or quick-IRS can be configured to prepare adequate files to users. It can also be made with the BT relative minima (i.e. “valleys”). Also for WV channels it should be needed some colour or grey levels palettes management

On summary, these ideas could be implemented in quick-IRS software helping users an adequate use of IRS L1 images in nowcasting.

4.4 READERS OF EUMETSAT SAMPLE IRS L1 FILES

As it was commented previously, at the time to write this Scientific Report, EUMETSAT has not provided enough sample MTG-S/IRS L1 netCDF files to develop an engineering prototype. For the development of the operational tools for generation of MTG-S/IRS L1 images on user defined regions are also needed EUMETSAT engineering IRS L1 test data written on the EUMETSAT delivery format test data on full disk (or at least on LAC4 region). This fact has slowed down the development of a quick-IRS prototype into CDOP-3.

In CDOP-3 only it can be made some advances in the development of reader prototypes for the two dwell example IRS L1 files distributed by EUMETSAT.

On 22-23 February 2016, EUMETSAT organized a Topical Meeting on MTG-IRS Level 1 Processing with experts, the science working group (SWG) and the MTG-IRS Mission Advisory Group. As one of the preparatory activities for this meeting, EUMETSAT distributed a sample netCDF IRS L1 file for a dwell in order to familiarize with the IRS L1 format and to provide feedback on them. This sample file contained a dwell simulation with synthetic IRS spectra on clear air (without cloud simulations) from NWP profiles on an area covering the Alps and the Gulf of Genoa. The area covered can be seen in Figure 30. Due to this 2016 EUMETSAT sample netCDF IRS L1 file could not be used by any standard application, the first activity was to develop an IDL program to read the content of the EUMETSAT distributed sample IRS L1 netCDF file and to convert it to a netCDF file with one internal design that could be used as input to the Hydra component of the McIDAS-V tool. The converter IDL program read the radiances, longitude, latitude and wavenumber variables and write in a netCDF format compatible with McIDAS-V. Using this converted and compatible with McIDAS-V netCDF files, it was possible to display and use interactively the data in the McIDAS-V tool as proxy nowcasting application of one future user; see Figure 30.

In [RD.7] the outcomes during this activity and the content of the “*Technical Note: comments on the structure of sample 2016 IRS L1 netCDF files*” from November 2017 can be seen.

In January 2020 EUMETSAT distributed another dwell IRS L1 netCDF file sample using now the representation on 300 IRS Principal Component (PC) L1; this format is very close to the one that will be used for the dissemination of IRS on EUMETCast satellite. Based on the EUMETSAT instructions and the 2016 IDL procedure it was updated the reader prototype to read the new EUMETSAT MTG-IRS PC L1 file, reconstruct the radiances and BTs spectra from the 300 PC. Unfortunately all deficiencies and problems described in the above Technical Note and in [RD.7] persists. For this reason it was needed to add the conversion one more time to a McIDAS-V compatible netCDF file. Examples of the interactive use of this converted file from the 300 PC IRS dwell file can be seen in the Figure 31. Thus, this fact is another example of the need for quick-IRS type of software.

Due to the lack of at least IRS L1 engineering test data for on full disk (or at least on LAC4 region), more developments of the operational tools for MTG-S/IRS for optimal reprojection and concatenation of dwells files to NWCSAF MTG-FCI projection cannot be carried out in CDOP-3. In the meantime, in [RD.7] are summarized the activities made using UMARF IASI L1 as proxy of management of several files in order to obtain future MTG-S/IRS L1 netCDF files for a region that could be compatible with standard meteorological tools. In [RD.7], it was also analysed the EUMETSAT IRS L1 netCDF file design and contents. Since the issues raised and the proposed solutions in [RD.7] to contribute to the final objective to get a design of IRS netCDF L1 adequate for EUMETSAT and users for nowcasting purposes were not taken in account, it will be needed to compensate these deficiencies in the design of the quick-IRS netCDF output files.

The early reprojection procedure and the related activities are shown in [RD.2].

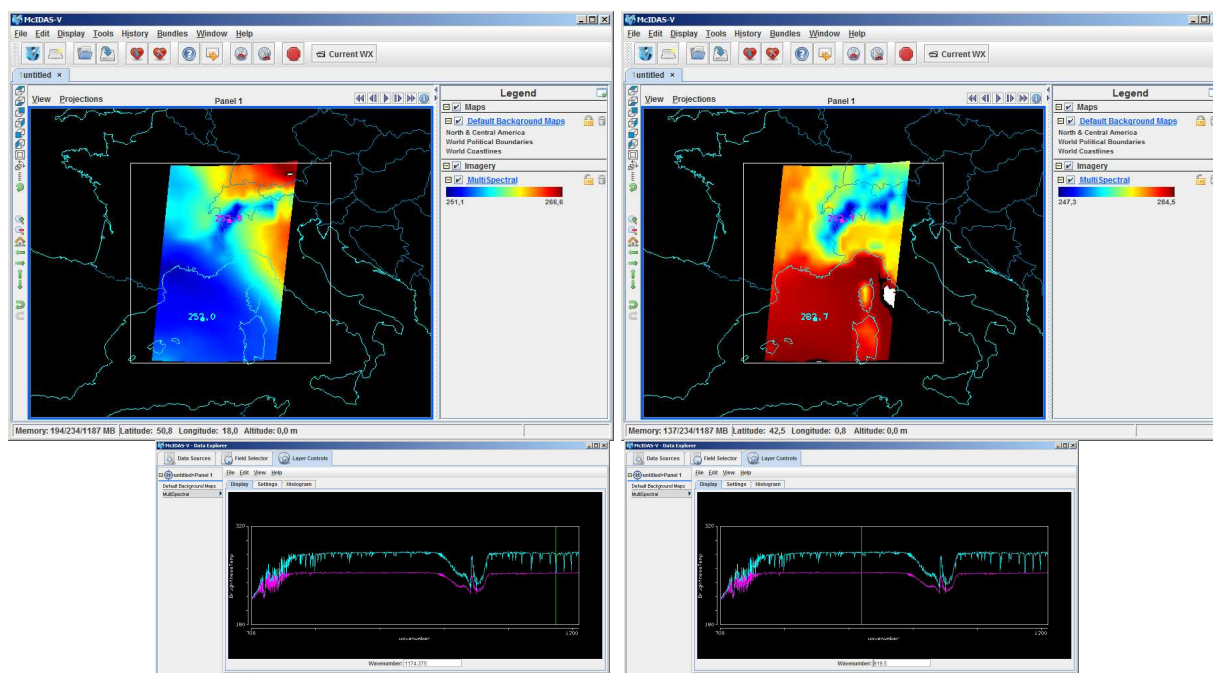


Figure 30: Example of McIDAS-V interactive displays from sample 2016 IRS L1 dwell after conversion of EUMETSAT sample 2016 IRS L1 netCDF files to McIDAS-V compatible netCDF files. (top) brightness temperature at two wavenumbers. (bottom) show the spectra on the pink and blue pixels in the top images on LWIR MTG-IRS band. Users can move interactively the green lines on bottom images to change the wavenumbers of images in the top; moving the pink and blue cross compare the spectra at different pixels.

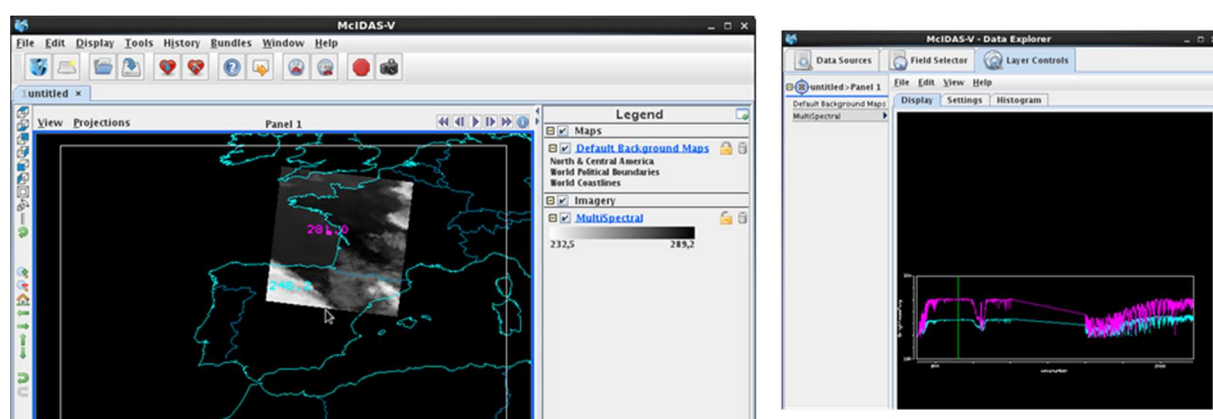


Figure 31: Example of McIDAS-V interactive displays from sample 2020 IRS Principal Component L1 dwell after conversion to McIDAS-V compatible netCDF files. (left) brightness temperature at wavenumber in green line of right image. (right) the spectra on the pink and blue pixels in the left image on LWIR MTG-IRS band. Users can move interactively the green lines on bottom images to change the wavenumber of image; moving the pink and blue cross they can compare interactively the spectra at different pixels.

4.5 FURTHER USE FOR NEW DEVELOPMENTS

The traditional use of hyperspectral data is mainly related to NWP and physical retrieval algorithms. This has been motivated by the polar orbit and the spatial resolution of the current hyperspectral

instruments. But as it has been shown with the synthetic IRS images, MTG-S/IRS on geostationary orbit with a spatial resolution of 4 km in the subsatellite point and 30 minutes temporal resolution will open new possibilities on the use of hyperspectral Level 1 data. In order to foster the use of MTG-S/IRS L1 in nowcasting applications and especially on cloudy pixels (where the NWP and physical retrieval algorithms may not be applied), some innovative ideas to use the MTG-S/IRS L1B data as an imagery instrument have been shown here and since 2010 in the presentations and References documents.

In this section it is just first briefly introduced like the synthetic dataset and the procedures shown in this document will be used to revisit the rest of ideas and findings described on Martinez 2013 and Martinez 2015. Also it is just briefly advanced how the synthetic dataset and the procedures shown in this document could be used to take the next steps in the search of new uses of IRS L1 fields in nowcasting. Although the list of branches to explore is not exhaustive, it provides a broad overview of the possibilities that can be carried out in CDOP-4.

4.5.1 Search of new MTG-S/IRS L1 FIELDS AND RGBs

RGB images from geostationary satellites have been converted on a great aid for weather forecasters on nowcasting. An added advantage is that RGB images are quickly generated directly from satellite data. To take full advantage of the added value of the MTG-S/IRS spectral resolution with respect to MSG SEVIRI, it is obviously better to follow another strategy than just emulating the MSG RGB behaviour. With this goal in mind it was tried in the past to find other, potentially more interesting, MTG-S/IRS RGBs and search of new IRS L1 derived fields. In [RD.9] it was made a summary of the early experiments for the use of IRS L1 in nowcasting; in this document the activities shown in Martinez 2010b, the presentation made in the 2013 “MTG-S/IRS Nowcasting Workshop”, Martinez 2013 and Martinez 2015 are described. By these reasons, the search of new RGBs from MTG-S/IRS should be considered a high priority task.

In [RD.9] it is described an early experiment to get estimations of vertical distribution of water vapour monitoring and ozone (as proxy of cold air intrusions from the stratosphere) from synthetic IRS L1 fields. It was calculated on one hand directly from the profiles from an ECMWF GRIB files some nowcasting parameters (TPW, HL, BL, ML and TOZ values) and on the other hand, the synthetic MTG-S/IRS BT for every channel; then it was proceeded to calculate the correlation and RMSE matrices. These matrices was obtained by performing a regression between two synthetic MTG-S/IRS BTs and each one of the parameters. Due to the huge size of the matrices and the large variability between near positions on the matrices, one automatic process must be used. Then, using a “fuzzy-logic” like scheme (similar to the used in Section 4.1) it was made the search for the regressions with lowest RMSE and highest correlation for every nowcasting parameter. This algorithm worked well with that reduced synthetic MTG-S/IRS BTs. Now, the first step will be to update the software and repeat the search of simple functions of IRS L1 to estimate nowcasting interest parameters using the synthetic IRS L1 dataset from the 2017 training and validation dataset. Then, the obtained functions (regressions, neural networks, etc) could be tested with synthetic IRS L1 dataset similar to the one shown in Chapter 3. As in the previous studies in a later step noise must be introduced in the simulations before applying it to real data.

The nowcasting interest fields could be combined later in a RGB to detect the humid regions or upper cold regions. Channel differences could be used instead of the regressions in the final design of the MTG-S/IRS RGBs, (which would simplify the MTG-S/IRS RGBs calculations).

4.5.2 Use of spectral features. Example, low levels inversions RGB using “Fingers-up” feature after Paul Menzel’s communication

In 2013, I received an email from S. Tjemkes (EUMETSAT) about a personal communication from Paul Menzel (CIMSS-Wisconsin) with the existence of features in the IASI spectra to detect inversions on low levels; see the paper (Sieglaff, 2009). In this email Tjemkes proposed one event which had strong low levels inversion on the 17th January 2013 in Finland; using this event an early test to develop one RGB image for low levels inversions was made. In this test, after downloading the IASI L1 from UMARF on HDF-5 files the McIDAS-V software was used to analyse the IASI images.

Following the Paul Menzel personal communication, it was searched on the IR window wavenumbers IASI pixels that present the “finger up” signal in the spectra in areas with low level inversions. The “finger up” signal is caused when on low level inversion pixels some absorption lines change from local minima to local maxima in the spectra in some absorption lines.

In the 2013 “MTG-S/IRS Nowcasting Workshop”, it was used McIDAS-V to show how can be used the movement of the probes interactively to compare two near IASI pixel that present this “finger-up” (or Roman emperor finger) differences in their spectra. On one hand the spectra from a pixel inside of the low level inversion region showed a “finger up” lines configuration in this part of the spectra and on the other hand a pixel outside of the low level inversion area which showed a “finger down” lines configuration in the spectra; see Figure 32 taken from Martinez2013.

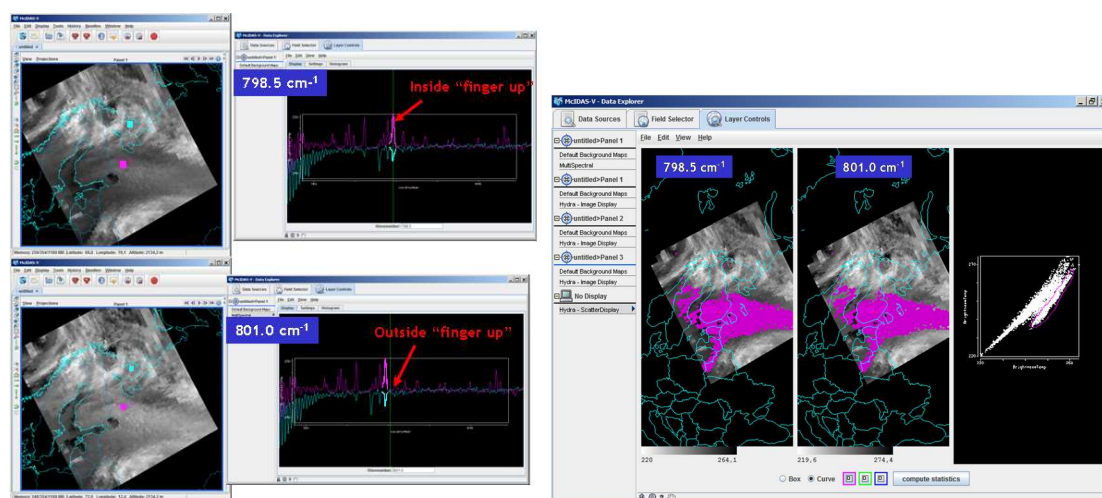


Figure 32: (top left) Image on 798.5 cm^{-1} inside of the line with “finger-up” feature. (bottom right) Image on 801.0 cm^{-1} outside of the line with “finger-up” feature. Comparison of the IASI spectra of pink probe (inside of low-level inversion area) and light blue probe (outside low-level inversion area). Finland case low-level inversion 17th January 2013 at 18:01:47 Z

Afterwards, the difference between two IASI channels, one inside the “finger up” wavelengths and another one outside of the “finger up” was used to build a test for the presence of low level inversions. Then, two of the “fingers up” features were combined to build one RGB image; see Figure 33.

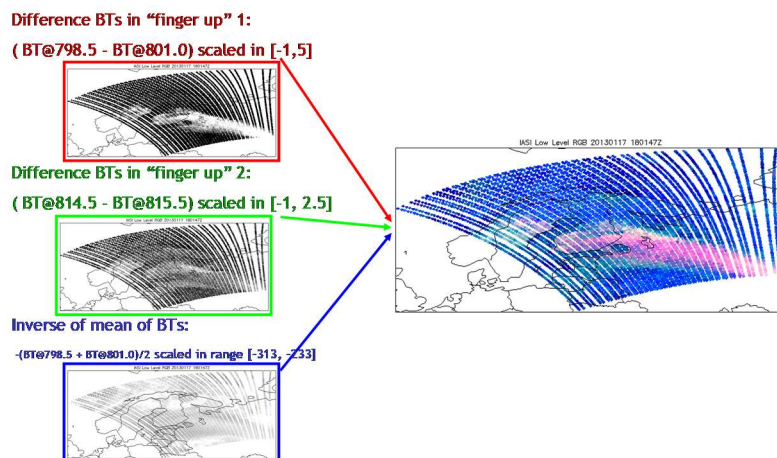


Figure 33: The differences between two IASI channels, one inside and other outside of the “finger-up” line feature, are used to create the mask of the pixels inside the low-level inversion region. The red component and green component uses two different “finger-up” lines. The third is an IR image with inverse brightness to complete the RGB. 17th January 2013 at 18:01:47 Z

Now the proposal is to use the synthetic data to repeat experiments in order to investigate if this “finger-up” feature can be reproduced in synthetic data or only appears in real images. This will help in to the search of algorithms (including IRS RGBs images) to detect low level inversions in the atmosphere.

4.5.3 Search of Principal Components (PC) with physical meaning

In Martinez2013 it is shown a test to investigate generation of Principal Component (PC) images with direct physical interpretation in some spectral regions of the IRS spectra. The idea was to calculate the PC using only some spectral regions (instead to use the full IASI (or IRS) spectra); then to look for a physical meaning of these PC or the use on regressions to estimate nowcasting parameters. One of the applications could be a direct use of these PCs or to obtain RGB images.

Now the proposal is to use the new synthetic data to repeat this kind of experiments.

4.5.4 Subpixels tests and Use of IRS L1 to test blended IRS and FCI products

In Chapter 3 it has been commented the generation of synthetic FCI in boxes 2x2 in order to get synthetic FCI data collocated with the synthetic IRS data. Taking into account that in [RD.1] it shown the generation of synthetic FCI data in boxes 1x1, it is available a set of synthetic datasets that could be used to make subpixels tests and the use of IRS L1 to test blended IRS and FCI products.

The synthetic IRS and FCI data from the 2017 validation and validation dataset could be used to make tests complementing FCI channels (in 1x1 boxes) with a set of IRS channels (in 2x2 boxes); as an example it could be tested the calculation of FG linear regression using blended IRS and FCI channels. Then, the “back door” trick shown in [RD.1] could be used to make an assessment of the performance using the synthetic FCI and IRS datasets from NWP.

In Martinez2018 (2018 Workshop of the Convection Working Group in Ljubljana) it was shown one advance when some results using a FG regression 314 IR channels of IASI as a proxy of the future MTG-S IRS instrument performance.

5 CONCLUSIONS, SUMMARY AND FUTURE ACTIVITIES

Validation and training dataset generation is a continuous and important task.

Some of the IDL prototypes developed in this activities will be needed in CDOP-4. Later it will migrated to other languages as C or Fortran-90 or Python for operational use. The decision of the migration from IDL to Python or Fortran/C as proxy or future NWCSAF developments will be taken later during CDOP-4 phase.

The works, studies and ideas described in this report will help to implement NWC SAF use and generation of NWC SAF products and services for MTG-S/IRS L1 and L2. These studies are also valuable to anticipate the new ways that MTG-S/IRS L1 data and L2 products could be used in MTG-S/IRS era for nowcasting by users. Also this must be done in coordination and synergy with FCI and NWP.

The AEMET NWCSAF team has written some working packages on the proposal for CDOP-4 with the inclusion of the services in order nowcasting users' community could get a full synergy and provision of imagery and products from MTG/FCI and from MTG/IRS.

NWC SAF will deliver an optional and complementary software package in order nowcasting users could make use of MTG/IRS L1 data disseminated in PC, together with EUMETSAT Secretariat IRS L2 products and locally generated NWCSAF MTG-S/IRS L2.

The NWC SAF is developing computer packages that will allow to manage the data from all the three MTG instruments and to generate locally products by the users. Since the NWC SAF provides software that it is installed on the users' computers there are not bandwidth constraints and the whole set could be used in combination with local NWP and data. Thus, all the synergies can be exploited.

To say that a file is written in netCDF only means that it is a needed the netCDF of HDF-5 libraries to open and read it. It is also needed to take care in the design of the internal structure of the netCDF file. The details in the design of the internal structure of a netCDF files are very important; just a small bug in a declaration, dimension or attribute of a variable is the different that a netCDF file be usable by several meteorological applications or not. The design of the internal structure of a netCDF files for sSHAI products should be as closer and as flexible to the user tools as possible. The optimal format be one that will allow the users just "click and play" files and some coordination should be promote in the meteorological and satellite community.

The use of programs like PGE00* allows to generate synthetic test datasets from NWP models. It could be improved the simulations in future if better NWP models are available; as an example, if ECMWF improves the access to high spatial resolution experiments. In the meantime, local NWP model complemented with operational ECMWF NWP fields is the best option.


The development of hyperspectral RGB images will be investigated following the heritage of MSG/SEVIRI RGB images.

These synthetic test data could be used to explore ideas, as new products from new FCI channels and from IRS. These test data could be used to explore ideas as optical flows; using the (u,v) 4D-interpolated datacube used as input as a "truth".

Some of the ideas as:

- ✓ New RGB images from IRS L1 data.
- ✓ PCs from chopped spectral domain to generate PCs with direct physical interpretation

will be investigated in CDOP-4 in order to be developed and used operationally in Day-2.


	Summary of activities of NWC SAF clear air team for preparation of MTG-S/IRS L1 in CDOP-3	Code: NWC/CDOP3/GEO/AEMET/SCI/RP/qIRS_NWC-157 Issue: 1.0 Date: 31 January 2022 File: NWC-CDOP3-GEO-AEMET-SCI-RP-studies_qIRS Page: 55/57
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These early tests should be understood as an example against the preconceived idea that MTG-S/IRS L1 is only for NWP or generation of L2 products.

Due to the synthetic MTG-S/IRS and IASI spectra used in this paper have created without noise added, although noise could be added using some IRS model further studies should be made for each one of these early ideas with real IRS spectra during commissioning phase.

A lot of slight different products will be generated: it should be needed to develop some kind of integration tools for integration of L1 and L2 products.

The [iSHAI References](#) and [iSHAI MTG web page](#) are being used as references web page where these activities are collected.

	Summary of activities of NWC SAF clear air team for preparation of MTG-S/IRS L1 in CDOP-3	Code: NWC/CDOP3/GEO/AEMET/SCI/RP/qIRS_NWC-157 Issue: 1.0 Date: 31 January 2022 File: NWC-CDOP3-GEO-AEMET-SCI-RP-studies_qIRS Page: 56/57
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