SUPPORT TO NOWCASTING AND
VERY SHORT RANGE FORECASTING

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, Issue 1, Rev.0

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Applicable to iSHAI and MTG-S/IRS WPs in CDOP-3

Prepared by Agencia Estatal de Meteorología (AEMET).

REPORT SIGNATURE TABLE

Function	Name	Signature	Date
Prepared by	Miguel A. Martínez (AEMET)		*31 January 2022*
Reviewed by	Pilar Ripodas, Xavier Calbet and Llorenc Lliso, AEMET		*31 January 2022*
Authorised by	Pilar Ripodas, AEMET (NWC SAF Project Manager)		*31 January 2022*

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Table of Contents

List of Tables and Figures

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 at CDOP-3 phase related to the preparation for MTG-I/FCI and MTG-S/IRS and some other side activities not included in the documentation of the regular iSHAI version deliveries.

iSHAI (imager Satellite Humidity and Instability), former PGE13 SPhR(SEVIRI Physical Retrieval), is the clear air product on NWCSAF/GEO framework.

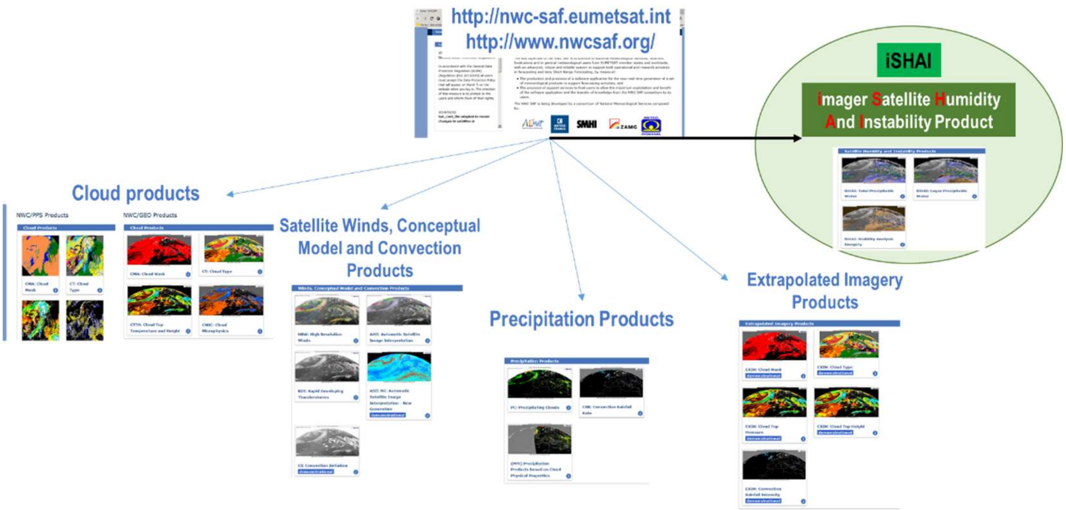

Figure 1: iSHAI on NWCSAF/GEO framework.

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 adjusts in the activities has been done. In [AD.1] the WPs related to iSHAI and MTG-I/FCI considered as responsibility of AEMET NWC SAF clear air team can be seen.

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 considered in next CDOP-4 phase.

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

Due to the lack of good scientifically correct MTG test data the main focus in this document are the activities made to generate scientifically correct MTG test data. 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 MTG-I/FCI and MTG-S/IRS test data.

iSHAI (**i**mager **S**atellite **H**umidity **A**nd **I**nstability) is since version 2016 the name of the clear air product of the NWC/GEO software package from GEO imager instrument. GEO-iSHAI product is a heritage of former PGE13 SPhR (SEVIRI Physical Retrieval) product. The name of the product was changed to avoid the word SEVIRI because since release 2018 of the NWC/GEO software package it can be used with other GEO imager instruments different from MSG (AHI on board Himawari satellites and ABI on board GOES-R class satellites).

The name iSHAI was chosen to be coherent with names of NWC SAF products from MTG-FCI ("iSHAI") and MTG-IRS ("sSHAI) in CDOP-3 and future CDOP-4. Thus prefix "**i**" indicates generated with input data from one GEO **i**mager instrument and "**s**" prefix will indicate generated with input data from MTG-IRS **s**ounder instrument.

In the case of the MTG-I/FCI software package it will be for MTG-I/FCI Day-1 a continuation of the current MSG NWCSAF GEO package; with almost the same products (cloud mask, iSHAI, etc.).

In the case of the MTG-S/IRS hyperspectral instrument it will be developed one new, optional and independent software package for MTG-S/IRS Day-2. It will provide three main services/products:

> ***Quick-IRS L1:*** users will make the automatic generation of IRS L1 imagery related products or will use them for locally generation of NWC SAF or users products.
>
> ***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 will be used directly by users in combination with the ones from MTG-I/FCI fields for same regions. As example, for the comparison of MTG-I/FCI, MTG-S/IRS and NWP instability indices. Also the IRS L2 fields on NWCSAF region could also be used in a future as input to locally generated products. As example, IRS SKT or IRS emissivities fields could be used as other inputs of MTG-I/FCI products in future versions.
>
> ***sSHAI:*** development of product executed locally by the users.

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

a) Use of McIDAS-V tool as main visualization tool and proxy of future user needs and tools.

b) The use of the AEMET tools PGE00* to made ECMWF 4D interpolation from ECMWF GRIB files to get vertical, spatial and temporally collocated NWP profiles and satellite data. These profiles are written as 3D or 4D data cubes in netCDF files that can be used on McIDAS-V tool.

c) The PGE00 tools can use the above NWP profiles to get synthetic MSG, GOES-R, MTG-I/FCI, MTG-S/IRS and IASI BTs on clear or cloudy pixels. Thus, it could be used to get synthetic images. They can be used also for validation/training purposes. These synthetic images are written also on files that can be used also on McIDAS-V tool.

Some of the results and Figures described in this Scientific Report haves been shown in several Workshops and Conferences. It will be indicated in each chapter.

In addition to the activities for the preparation of MTG-I / FCI described in this scientific report, it has have been carried out activities for the preparation of MTG-S/IRS on parallel. In the case of the generation of synthetic data of MTG-S/IRS L1, the same NWP profiles used for the generation of synthetic FCI datasets have been used as input to the PGE00* tools for hyperspectral instrument to generate synthetic IRS datasets. Thus, scientifically correct collocated FCI and IRS datasets have been generated for the first time. To avoid to write a huge report the activities have been divided into three scientific reports. The activities related to generation and management of synthetic MTG-S/IRS L1 datasets has been written in Scientific Report [RD.1]. The activities related to management of MTG-S/IRS L2 datasets has been written in Scientific Report [RD.2].

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_{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.

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-S/IRS L1 in CDOP-3	NWC/CDOP3/GEO/AEMET/SCI/RP/qIRS_NWC-157	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

Table 2: List of Referenced Documents.

2 INTRODUCTION AND AIM OF THE STUDIES

In CDOP-3 proposal, working packages for preparation of MTG-I/FCI iSHAI were foreseen as activities to do in CDOP-3 phase (March 2017- February 2022). In [AD.1] the description of the activities proposed in these WPs are shown. It was foreseen to develop one version for MTG-I/FCI Day-1 iSHAI and even to start preparation a second version Day-2 of iSHAI to be delivered in 2023 just at beginning of CDOP-4 phase. 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 of MTG mission have been delayed several years and MTG-I and MTG-S will be launched finally in CDOP-4. Only a prototype for MTG-I/FCI Day-1 version of iSHAI has been developed. Since EUMETSAT has only distributed data valid for engineering purposes (are based on SEVIRI data with some channels replicated) it has only been tested from an engineering point of view.

At the time to write this Scientific Report scientifically correct MTG test data are not available. In this Scientific Report it is described the way that in AEMET clear air team has been developed the tools for the generation of the first MTG-I/FCI synthetic dataset. In [RD.1] it is described how the AEMET clear air team has developed the tools for the generation of the first MTG-S/IRS synthetic dataset. 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 satellites.

In this Scientific Report some early studies of this FCI dataset to explore new products of MTG-I/FCI from the new FCI channels has been also summarized. This early studies should be understood as exploratory prototypes.

All the activities have been made based in the evolution of the PGE00* tools used originally for validation and training of iSHAI algorithm and for the bias BT correction in NWC SAF GEO software packages. For this reason, in this chapter the iSHAI algorithm and product is introduced first, then PGE00* tools are introduced. In the Chapter 3 the activities for generation of the first MTG-I/FCI synthetic datasets are described.

2.1 iSHAI INTRODUCTION

iSHAI algorithm is a combination of statistical and physical retrieval algorithms. As can be seen in Figure 2, iSHAI algorithm has two main steps:

- ✓ **First step:** uses a set of nonlinear regressions to build a First-Guess (FG) profile from collocated background NWP temperature, humidity and ozone profiles and bias corrected satellite BTs.
- ✓ **Second step:** physical retrieval (optimal estimation) with with use of EOFs (or Principal Components) to reduce the dimension of matrix to invert and reduce the computation time.
    - In MSG: 2 EOFs for T, 3 EOFs for q and 1 EOF for T_{skin}

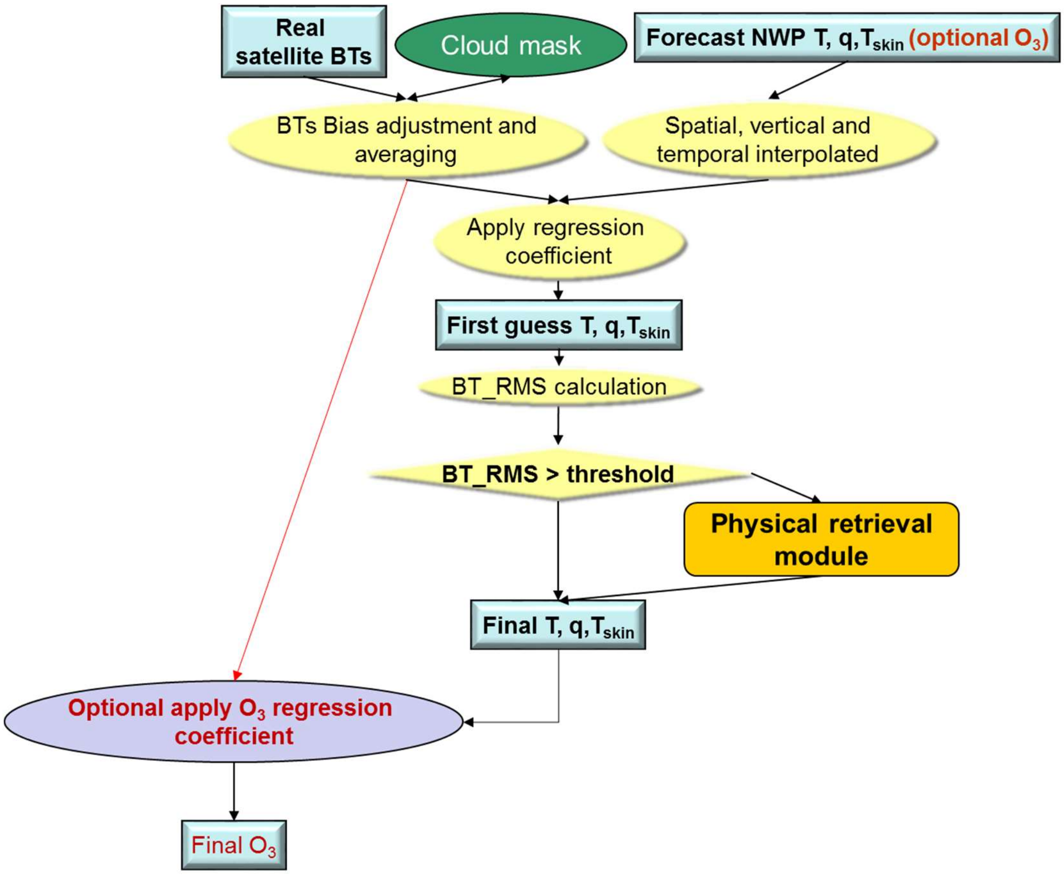

Figure 2: iSHAI flowchart.

iSHAI modifies the background (T, q, ozone) profiles 4D interpolated to time and position of the pixels from a forecasted numerical model (NWP) based on the differences between real bias corrected $\boldsymbol{BT_{satellite}}$ and synthetic $\boldsymbol{BT_{RTTOV}}$ weighted by the jacobians (partial derivatives of BT and the profiles of T and q) on clear air pixels. Only on clear air pixels (or configurable NxN boxes) it is calculated.

In Figure2, ***BT_RMS*** is the distance in absorption channels (for MSG: WV6.2, WV7.3 y IR13.4) between $\boldsymbol{BT_{SATELLITE}}$ (bias corrected) and synthetic $\boldsymbol{BT_{RTTOV}}$ calculated with the radiative transfer model RTTOV.

The iSHAI algorithm is fully described in the Algorithm Theoretical Basis Document ATBD [RD.3] that it is available on the website of the NWCSAF. The algorithm is similar to that used by NOAA for the GOES-R. The base of the algorithm was provided by Dr. Jun Li of CIMSS-Wisconsin in 2007 *http://www.ssec.wisc.edu/~junl/*

2.1.1 iSHAI evolution in CDOP-3

Together with the continuation of the support of iSHAI from MSGs satellites it was approved for CDOP-3 the adaptation of iSHAI software to other GEO imager instruments as preparation of iSHAI from MTG-I/FCI in Day-1.

In the Table 3 a comparative of the supported GEO imager instruments is shown. Due to the different number of IR channels between SEVIRI and FCI instruments versus AHI and ABI instruments it was considered as adequate for the developments to consider iSHAI as four independent PGEs for each one of the instruments. The sources are maintained in four directories with the same name of the functions. Thus, the basis of the code is always the same and it is easy using the standard UNIX diff commands (diff, gvimdiff, kompare, ..) to get a list of the "mutations" in the sources of every one of the iSHAI PGEs. For the user this fact is transparent because as in other NWCSAF PGEs these four PGEs are managed with a ksh that executes the correct iSHAI PGE for the satellite configured in the *$SAFNWC/config/sat_conf_file*.

Instrument	Number of channels	Number of IR channels (λ>4)	Resolution in IR (km x km)	Temporal resolution minutes
SEVIRI	12	7 **IR channels** (**2** *WV channels*) (**2** *in split window*)	3x3	15
AHI	16	9 **IR channels** *(3 WV channels) (3 in split window)*	2x2	10
ABI	16	9 **IR channels** *(3 WV channels) (3 in split window)*	2x2	10
FCI	16	7 **IR channels** *(2 WV channels) (2 in split window)*	2x2	10

Table 3: Comparative of IR channels that can be used as input to iSHAI in supported NWCSAF/GEO instruments.

In CDOP-3, iSHAI version 2018 was the first on started the support of Himawari/AHI instrument while continuation with the support of MSG/SEVIRI.

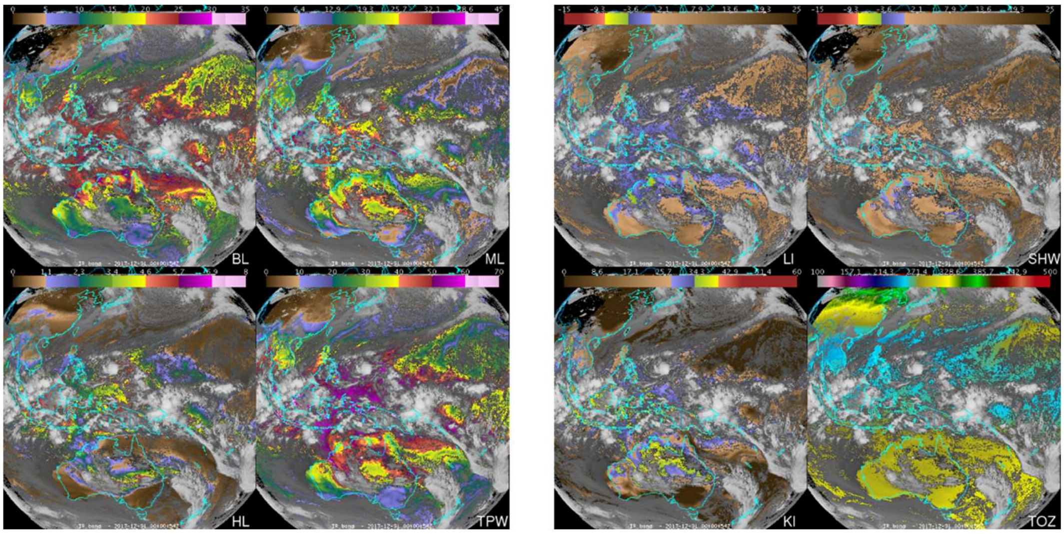

Figure 3: iSHAI GEO-iSHAI AHI early example on 2017-12-31 00Z

In version 2018.1 was added the support of GOES-R class satellites with the support of GOES-16 in GOES-East position. Examples of iSHAI outputs from GOES-16 with version 2018.1 can been seen in Figure 4; a loop of the images can be seen in Martinez 2020 (a).

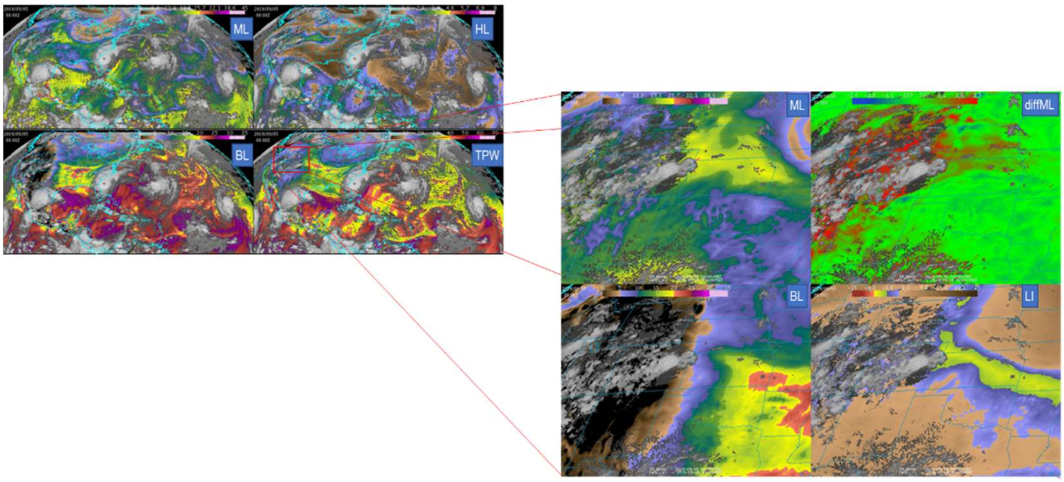

Figure 4: Example of iSHAI from GOES-16: 5th September 2019 00Z. Hurricane Dorian off the East Coast and TS Gabrielle on the Atlantic Ocean for case study and zoom over Rocky Mountains. It was used as background NWP ECMWF GRIBs on hybrid levels from run 00Z every 1 hour spatial resolution 0.125˚x0.125˚.

In version v2021, iSHAI v4.0.1 will allow the processing also of GOES-17 in GOES-W position. Thus, iSHAI will be available on the whole GEO ring. See loop on GEO ring in Martinez 2021 (f).

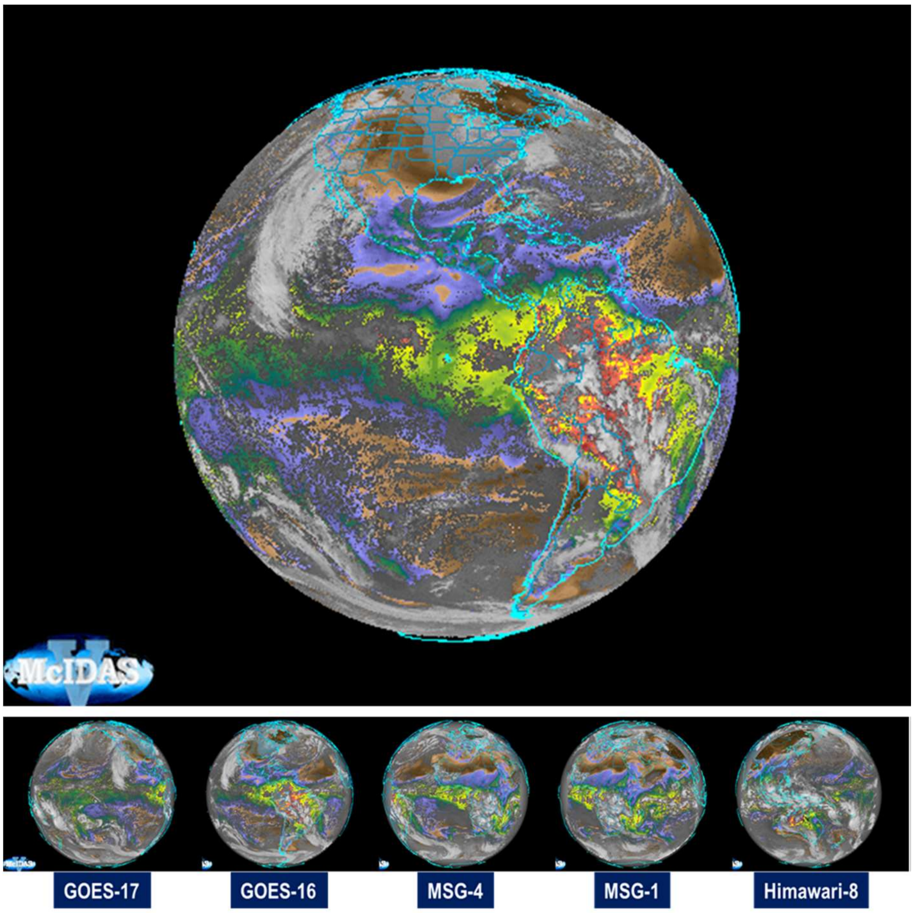

Figure 5: example of iSHAI covering the whole GEO ring.

2.1.2 Preparation of iSHAI for MTG era.

The iSHAI developments in CDOP-3 phase have three main objectives:

1. maintenance and evolution of the MSGs iSHAI version
2. adaptation of iSHAI to other third party GEO imager instruments
3. preparation of iSHAI version for the use from next MTG-I/FCI

When the CDOP-3 proposal was written it was foreseen to have an early GEO/NWCSAF software for testing just before the ***MTG-I launch on end CDOP-3 phase***. Activities started end of the CDOP-2 phase, after delivering of iSHAI version 2016. The roadmap was the adaption of iSHAI algorithm from SEVIRI/MSG => AHI/HIMAWARI => ABI/GOES-R => FCI/MTG-I.

In the case of the objectives 1 and 2, iSHAI use as radiative transfer model RTTOV-11.2 (since it is the version accorded by the NWC SAF Project Team).

For preparation for MTG era it was started in 2018 the use of RTTOV-12.1 (see chapter 2.2.2). With the gained experience with PGE00, it was recommended to NWCSAF Project Team to use for MTG developments one more actual version of RTTOV. Thus, for the MTG STRR revision the NWCSAF library was developed using **RTTOV-12.3** version (state of the art available version at that moment). For the MTG STRR revision iSHAI it was developed an iSHAI beta version from MTG-I/FCI data and using to NWCSAF vMTG_STRR library and **RTTOV-12.3** version as radiative transfer model.

As commented above, iSHAI has one program for every GEO instrument. Thus, FCI iSHAI code on vMTG STRR version is a “mutation” of the MSG iSHAI code adapted to FCI. The list of differences between ABI and AHI iSHAI versions as guide of the differences to implement has been used. The main differences between SEVIRI iSHAI and FCI iSHAIs programs are in the use of different iSHAI coefficients files; while the differences between SEVIRI and FCI iSHAIs codes are mainly linked to RTTOV coefficients, execution messages, etc.

In November 2020 it was released RTTOV-13.0. Then, it was started the migration of iSHAI and PGE00 programs to it. During spring 2021, it was started the presentation in several workshops of the first results of the version MTG updated to RTTOV-13.0. And as can be seen in this report it has been tested using as input the synthetic data described later in this report. Then, the third objective of CDOP-3 phase, to get iSHAI version ready for MTG-I/FCI, has been achieved and there is the possibility to test it with synthetic MTG-I/FCI data.

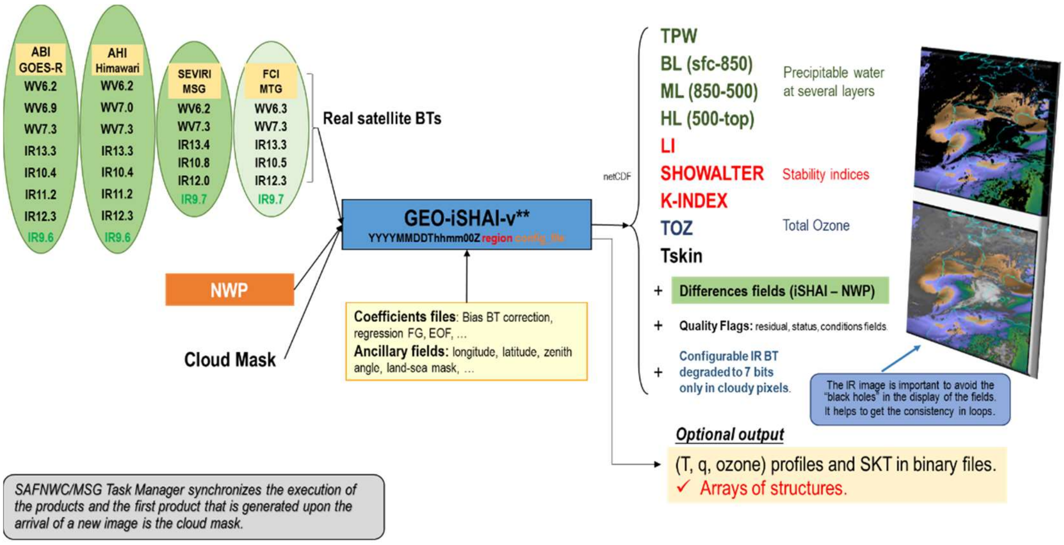

Figure 6: iSHAI inputs and outputs scheme on version MTG.

2.1.3 iSHAI Model Configuration File

iSHAI is highly modular and configurable. In the iSHAI execution the third parameter is an ASCII file with all the processing options. The main iSHAI configurable options and parameters are:

- The window size for processing in boxes of M x N pixels or FOR (Field Of Regard). The *default window size is 3 x 3. The optimal should be 1x1 but for large region the execution could need a lot of time. The iSHAI images on the presentations in References and in this report has been processed in 1x1 pixels. To increase the window size to M x N reduces in a factor 1/(M*N) the number of pixels and the execution time; it could be used to get a compromise between the processing region and the execution time on the users machines.*
- *BT_RMS_THRESHOLD* and *MAX_RESIDUAL* keywords. They control the level of the desired error between the bias BT corrected SEVIRI BTs and the RTTOV BTs. *If BT_RMS_THRESHOLD is increased the number of pixel that pass to physical retrieval step decrease; since the physical retrieval step is very CPU time consume this speed up the iSHAI execution.*
- Number of iterations. Maximum number of iterations is 3 iterations.
- TOZ calculation: if GRIB files have ozone profile could be activated
- The name of all coefficients files are keywords in the configuration files.
- **The change from iSHAI mode P to iSHAI mode Hybrid is made changing in the iSHAI 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 on binary files.

Note: full details in the Product User Manual Document available on the NWCSAF Help-Desk Web page

All these options are activated or modified through editing the ASCII iSHAI Model Configuration File (extension .cfm) by the user.

As it will be shown in this report the use of the keywords in the iSHAI configuration files described here has been used in the design of several of the studies for MTG era.

2.1.4 Description of iSHAI outputs

As can be seen in Figures 2 and 6, from the retrieved temperature and specific humidity profiles, iSHAI calculates several outputs fields. The main outputs of GEO-iSHAI product on clear air pixels (or FORs) are:

1. **iSHAI_tpw:** Total Precipitable Water (TPW) calculated in layer (P_{sfc}- 0.1 hPa)
2. Layer Precipitable Water (LPW). Corresponding to the precipitable water in three layers:
   a. **iSHAI_bl:** precipitable water in low layer [P_{sfc} - 850 hPa]
   b. **iSHAI_ml**: precipitable water in middle layer [850 - 500 hPa]
   c. **iSHAI_hl**: precipitable water in high layer [500 – 0 hPa]
3. Stability indices: they are calculated from the retrieved profiles of temperature and humidity. The calculated indices are:
   a. **iSHAI_li:** Lifted Index (LI)
   b. **iSHAI_shw:** Showalter Index (SHW)
   c. **iSHAI_ki:** K-index (KI)
4. **iSHAI_skt:** Skin Temperature (SKT)

The Total Ozone (**iSHAI_toz**) parameter is optional, it must be activated by the users the generation of it and the background NWP GRIB files must contains ozone fields.

Also the differences with the ones calculated from the background NWP are obtained. Besides the main outputs, the differences between the above parameters calculated from the retrieved profiles of temperature and humidity (and ozone profile if activated) with the parameters calculated from the spatial, temporal and vertical interpolated profiles from background NWP are written as other outputs (following 2007 Madrid Workshop recommendation). Thus the parameters diffTPW, diffBL, diffML, diffHL, diffLI, diffSHW, diffKI, diffSKT and diffTOZ are also written in the netCDF output file.

The **iSHAI_residual** field provides the root mean square of differences between the bias BT corrected real satellite brightness temperatures and calculated RTTOV brightness temperatures on several absorption channels.

Together with the above fields it is added an IR field only on cloudy pixels. This field is a configurable IR channel BT degraded to 7 bits only in cloudy pixels. This IR field is included with the objective that iSHAI files be self-contained and it can be used to generate IR image overlays on gray scales on cloudy pixels; this help to provide spatial patterns to the forecasters and to avoid the black holes effects on images and loops. The use of this overlay IR images is highly recommended and it is also a common practice with similar products (as the ones from CIMSS/Wisconsin web). When used in loops, they helps to better monitoring of convection ingredients.

The format of the output file is netCDF and it is described in [RD.6]. In release 2018, the outputs are not image like fields and are data fields. It is the responsibility of the user to use adequate tools to generate images from them.

2.1.5 iSHAI binary files and the conversion to NetCDF format compatibles with McIDAS-V

As an **optional output**, the intermediate and retrieved profiles and the profiles from the background NWP model interpolated at 54 RTTOV levels may be written as another output on binary format files.

The users can activate the generation of this optional output editing the ASCII iSHAI configuration file. Then, the binary files will be written in the *$SAFNWC/tmp* directory. This allows users to debug their local implementation, to get access to the retrieved temperature and humidity profiles and to compare them with the background NWP profiles.

Together with the profiles, for every processed pixel, some ancillary data fields (longitude, latitude, topo, emissivity, etc) that made iSHAI binary files self-contained are written. Thus, they could be used to build 3D (or 4D) datacubes. In the previous versions it was needed to read them from some NWCSAF files on the *$SAFNWC/tmp* directory.

Since 2010 it has been developed some IDL procedures to convert to NetCDF files the optional iSHAI binary files; see [RD.3] or Martinez presentations on References chapter. It would be easy the migration to C, FORTRAN or even to Python. Theses IDL programs are available as best effort basis and could be provided on request to mmartinezr@aemet.es

These NetCDF files can be used on some interactive meteorological tools; as example, IDV and McIDAS-V. As on these netCDF files the fields have similar structure than usual NWP models (the structure of the netCDF and attributes fields were in 2010 a heritage of WRF model output file) they can be used on the same way. Thus, they can be used to interactive display of sounding display, 2D displays, vertical cross-sections and 3D or 4D representations.

One example of advanced representations are the 3D normalized vertical cross sections that has been shown in several of the Martinez presentations in the iSHAI References web page. The normalized 3D arrays are generated after calculation of the mean and standard deviation at every layer from an analysis GRIB file of the case study and then are created the normalized 3D data cube subtracting the mean and dividing by the standard deviation at every layer for the rest of iSHAI or NWP slots. As example in figure 7 normalized T, q and θ_e calculated from the retrieved iSHAI profiles and from the background ECMWF NWP model are show. This normalized representation with adequate colour palettes are very convenient to detect anomalies in the 3D structures. In the example of the Figure 7, in the normalized T red colour indicates hotter than the mean value and blue indicated colder than the mean at its layer, this allows to look for the layers with cold air in high levels. In the case of the normalized q the green colour indicates more humid than the mean value and it allows to localize the presence of humid air in low layers below the cold air in high levels. The normalized θ_e the vertical gradient from blue (high levels) to yellow/orange (low levels) could indicate the presence of instability.

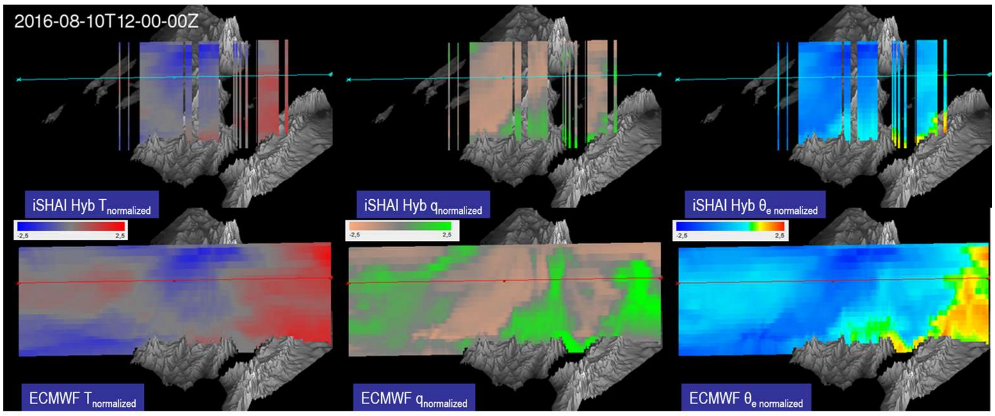

Figure 7: example of normalized 3D fields from iSHAI and ECMWF. Case study 10th August 2016 at 12Z.

2.2 INTRODUCTION TO PGE00

In Figure 2 it can be seen that one of the steps 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) it was created since many year ago one ad hoc tool, called PGE00, which made this process 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 (CMa) as input in order to make the 4D interpolation in all 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 this moment) to calculate also synthetic RTTOV BTs. Then, instead to use the optional binary iSHAI files it was started to use for bias BT adjustment because it allows to make the calculation of synthetic BTs for all IR MSG/SEVIRI channels; while in the optional binary iSHAI files are written only the synthetic BTs for the 5 IR MSG/SEVIRI channels used in iSHAI algorithm.

Thus, the original PGE00 is a simplified version of the NWP interpolation and RTTOV management of iSHAI. It can be used as:

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

It can be used as input ECMWF GRIB files in hybrid levels or use the GRIB files in pressure levels used in NWC SAF normal processing.

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

- ➢ **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) could 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 as for example the 1000 hPa temperature.*
- **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 8.

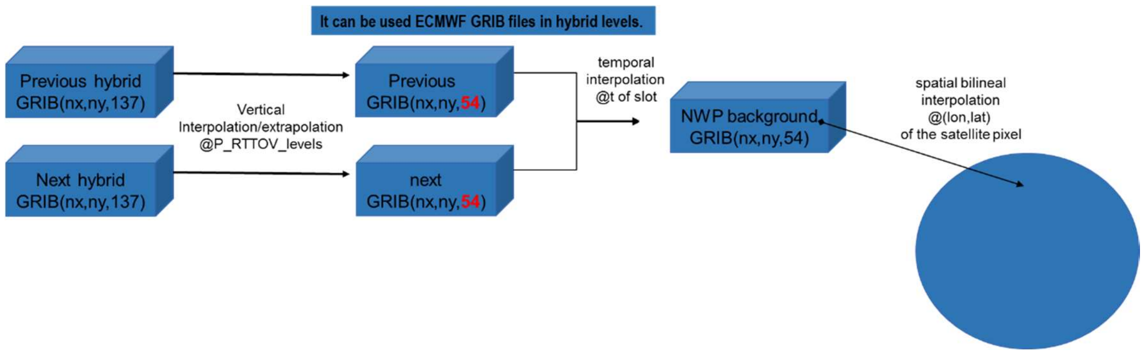

Figure 8: scheme of the 4D interpolation in the case of ECMWF GRIB files on hybrid levels.

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*). *The optimal should be 1x1 but for large region or channels number the execution could need a lot of time.*
- ✓ Optional writing for all the pixels or just at clear pixels or just on a set of pixels.
- ✓ To write the profiles at the different steps in function of the user choice:
  - ✓ a) at hybrid levels just after read them from the ECMWF hybrid GRIB file
  - ✓ b) interpolated/extrapolated at RTTOV pressure levels (or user's set of fixed pressure levels in case PGE00 with simple modifications),
  - ✓ c) after temporal interpolation step
  - ✓ d) using a cloud mask (or a set of predefined pixels) to choose the writing for all pixels or only on clear air pixels (or a set of predefined pixels)
- ✓ Activation of BTs calculation also for the configured satellite. In case of VIS channels or hyperspectral instruments *is very CPU time consume.*
- ✓ 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.

As in the case of iSHAI, it is used a PGE00 Model Configuration File. All these options are activated through editing the PGE00 Model Configuration File (extension .cfm). As in iSHAI, in the PGE00* execution the third parameter is an ASCII file with all the processing options.

All the PGE00 programs are written in C and Fortran-90 (the core of the process is Fortran-F90).

This initial PGE00 program is also used for the generation of training and validation datasets. In the iSHAI Validation Reports [RD.5] for MSG/Himawari and GOES-R class satellites and in the Early adaptation of iSHAI v2016 to future MTG-I FCI using 2013 dataset Report [RD.4] for the case of the MTG-FCI instrument, the process to build the validation and training datasets is described.

2.2.1 PGE00_1d version for training and validation activities.

The above initial PGE00 program is adequate for 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 has been used 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 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 $N_{channels}$ x N_{pixels} floats in a binary file.

In CDOP-3 it has been developed two versions of this PGE00_1d.

The first PGE00_1d uses RTTOV-11.2 and it is the one used for training and validation activities on versions 2018 and 2021. Till 2017 (version 2016) it was used as training and validation dataset the 2013 dataset. But, at the beginning of CDOP-3, it was generated the 2017 training and validation dataset that is the one used for versions 2018x, 2021 and for early version MTG-STRR developments. As can be seen in Figure 9, in versions 2018x it has been used as radiative transfer model RTTOV-11.2. In the process, together the Validation Reports are generated the FG non-linear regression, the EOFs and Physical retrieval iSHAI coefficients. Although in Figure 9, 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 much too big to be on memory it is chopped first in several sub-datasets using the module 3 of the positions. The pixels with module 3 equal 0 are used for validation and for writing of the Validation reports; with position 1 for calculation of iSHAI coefficients, etc. The Validation Reports of version 2018x for SEVIRI on MSG, AHI on Himawari and ABI on GOES-R has been written using this process.

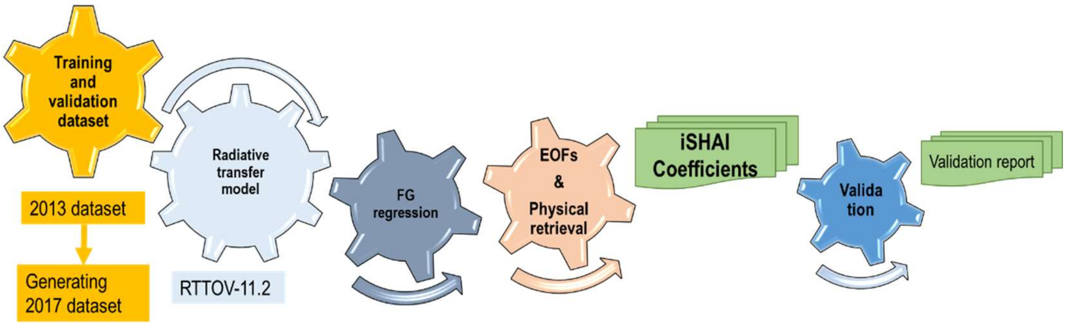

Figure 9: scheme of the PGE00_1d use for training and validation activities.

A second version of PGE00_1d using RTTOV-13.0 has been developed in 2021 for the generation of iSHAI coefficients for MTG STRR version. It would be the one used initially in CDOP-4 phase.

2.2.2 GEO-PGE00-VISIR

The initial PGE00 programs only was 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). The evolution of this early program was used to calculate synthetic MSG before the launch of the first MSG. Since this experience, there is the idea, in some moment, to repeat the same but with a modern RTTOV that will allow to calculate synthetic MTG data on VIS and IR channels and in clear and cloudy conditions. With the gained experience in the management of T, q and ozone profile it could be repeated the 4D interpolation with the cloud related profiles parameters from the ECMWF GRIB files on hybrid levels and to use to them to call RTTOV in cloudy conditions. The first version of the set of GEO-PGE00-VISIR* was developed in first half of 2017 programs; it was used RTTOV-12.1. It was used to make high quality simulation of clouds for both Visible and IR channels from imager instruments.

GEO-PGE00-VISIR allows to generate high quality simulation of MTG-I/FCI (or other imager instruments) clear and cloudy BTs or reflectance using:

- Implementation of read emissivities and BRDF atlases. Emissivities and BRDF from RTTOV atlases
- call to RTTOV direct using the clouds and solar options
- In version RTTOV-12.1, the scattering coefficients for clouds and aerosol are available for both Visible and IR channels of most imager instruments

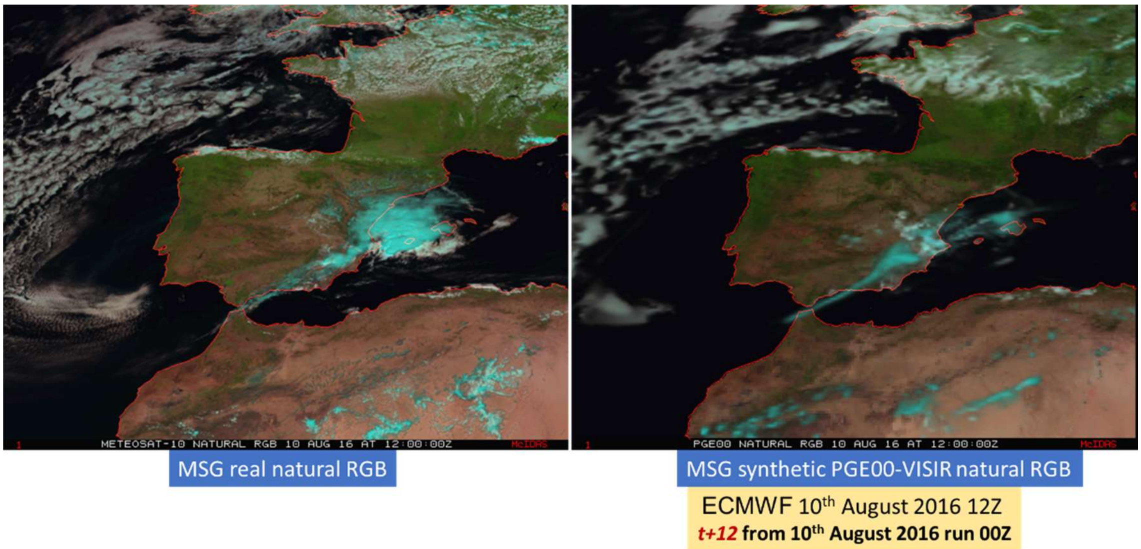

Figure 10: Comparison of MSG synthetic and real RGB images. a) left: MSG real natural RGB. b) right: MSG synthetic (generated with PGE00-VISIR) natural RGB using ECMWF t+12 from 10th August 2016 run 00Z. 10th August 2016 12Z.

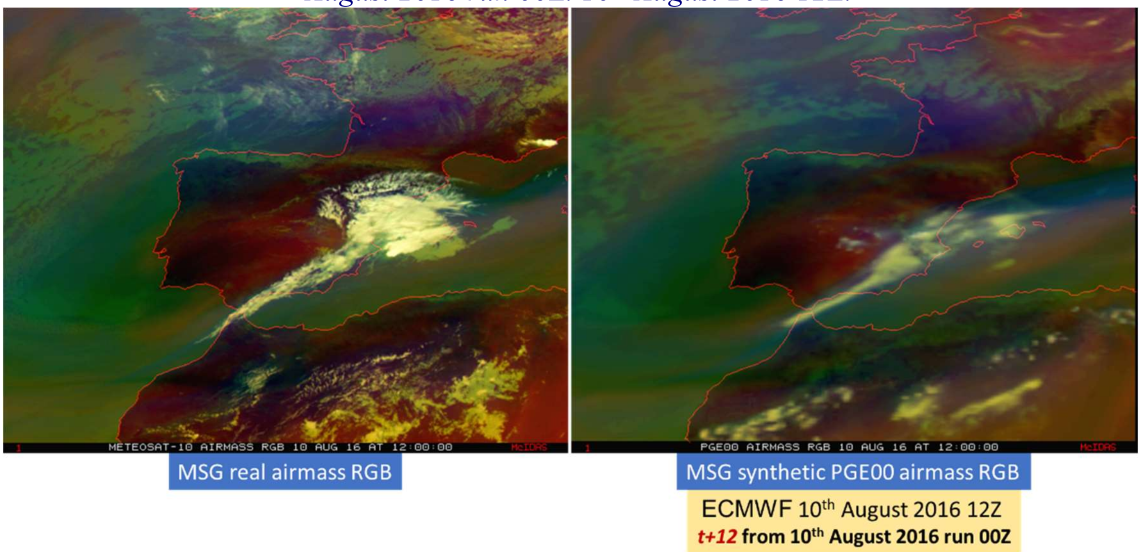

Figure 11: Comparison of MSG synthetic and real RGB images. a) left: MSG real airmass RGB. b) right: MSG synthetic (generated with PGE00-VISIR) airmass RGB. ECMWF 10th August 2016 12Z t+12 from 10th August 2016 run 00Z. 10th August 2016 12Z.

GEO-PGE00-VISIR was used to generate 24 hours synthetic dataset for several case studies; at night the solar zenith angle is fixed to 75º to avoid generate black images on visible channels. 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.

This first version using RTTOV-12.1 was used to show the advantages and possibilities. As it will be described later this first version was migrated to RTTOV-12.3 and finally to RTTOV-13.0.

2.2.3 GEO-PGE00-hyper

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 atlas.

GEO-PGE00-hyper was used first to generate high quality synthetic clear and cloudy BTs of IASI (or other hyper spectral instruments with RTTOV coefficients). The main steps are:

- get emissivities for the hyper spectral instrument from RTTOV functions and atlases
- call to RTTOV direct using the cloudy options. On RTTOV-12.1 the scattering coefficients for clouds and aerosol are available for all channels for some hyper spectral IR instrument as IASI.

It was used IASI as proxy of future MTG-S/IRS because there were not RTTOV coefficients for IRS instrument.

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 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*) are used. 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.

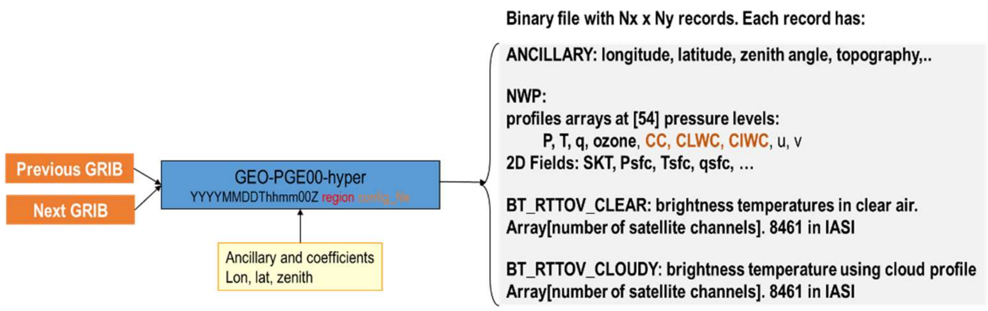

Figure 12: PGE00-hyper inputs and outputs scheme in the case of ECMWF GRIB files on hybrid levels.

In Figure 12 it can be seen the scheme of the inputs and outputs of GEO-PGE00-hyper. For every pixel is written in a binary file one record (one C structure) with the fields shown in Figure 12. 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 the width and height of the box (M x N size of the FOR) determines the number of pixels (or FORs) processed; as example, the first attempt of IASI simulation had to be done using a FOR of 5x5 size to speed up the very slow calculation due to the huge number of IASI channels in the slow computer available at this date.

The inputs and outputs in the case of GEO-PGE00-VISIR is similar to the scheme for GEO-PGE00-hyper shown in Figure 12. 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.

In the examples shown above in Figures 10 and 11, it was used ECMWF GRIB files on hybrid levels with the profiles between *t+0* to *t+24* hours range forecast (every 1 hour) with 0.1º x 0.1º spatial resolution. See loops for this case study and others on Martinez presentation in 2020 Nowcasting SAF workshop

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 for a full IASI spectra (since this can be made only for 8 channels).

2.2.4 UPDATED PGE00s to NWCSAF vMTG_STRR library and RTTOV-12.3

The early outputs of the above 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.

After the delivery of the NWCSAF MTG_STRR library, the set of GEO-PGE00-* programs was migrated in 2020 to RTTOV-12.3 to use the NWCSAF vMTG_STRR library. Thus, GEO-PGE00-VISIR was used in 2020 to make high quality synthetic images of MTG-I/FCI clear and clouds BTs on the future MTG-I/FCI grid for first time.

2.2.5 Updated of PGE00* programs to RTTOV-13.0

And finally in November 2020 it was released RTTOV-13.0. Then, NWCSAF GEO clear air team made the migration of NWCSAF vMTG_STRR library and later the migration of the GEO-PGE00-* programs to RTTOV13.0 at the end of 2020 and early 2021.

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.

Thus, PGE00s 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.

As in GEO-PGE00-VISIR with RTTOV-12.3, the output files are binary files with N_x x N_y records for each position on the FOR (boxes W_x x W_y of configurable width) on satellite grid projection determined by the *$SAFNWC/config/sat_conf_file*. As the satellite to calculate the synthetic data it is a keyword in the PGE00 configuration file it is possible calculate synthetic data with any combination of satellite projection and resolution for any satellite. As example, it could be generated synthetic MSG/SEVIRI, MTG-I/FCI, GOES/ABI and MTG-S/IRS on FCI grid projection for the same NWCSAF region and with any resolution (1x1, 2x2, ..) of the IR FCI resolution (2x2 km at nadir). As shown in Figure 12, each record contains:

- $radiance_{clear}$: In the case of IR channels the BTs temperature is obtained. In the case of visible channel the BDRF is obtained. The number of channels depends of the satellite to simulate and 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.
- $radiance_{cloudy}$: 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*

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 demand for it. Due to 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.

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

The PGE00* tools introduced in Section 2.2 has been used for the tasks to build the first synthetic MTG scientifically correct datasets. The main purpose was to get synthetic data for MTG-I/FCI and MTG-S/IRS on the future MTG-I/FCI projection grid.

In the first attempts with PGE00* tools using RTTOV-12.1 and RTTOV-12.3 there were not correct MTG-S/IRS RTTOV coefficients, but with RTTOV-13.0 PGE00* version it has been possible to do it. In this chapter it is shown 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 the Figure 13, 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 0.1º x 0.1º downloaded from MARS. In first place, it was generated MTG-I/FCI and SEVIRI/MSG synthetic datasets that will be shown and described in Chapter 3.2. In second place it was generated MTG-S/IRS synthetic data using the operational ECMWF NWP model; see [RD.1]. As it is shown below in Chapter 3.3, 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.

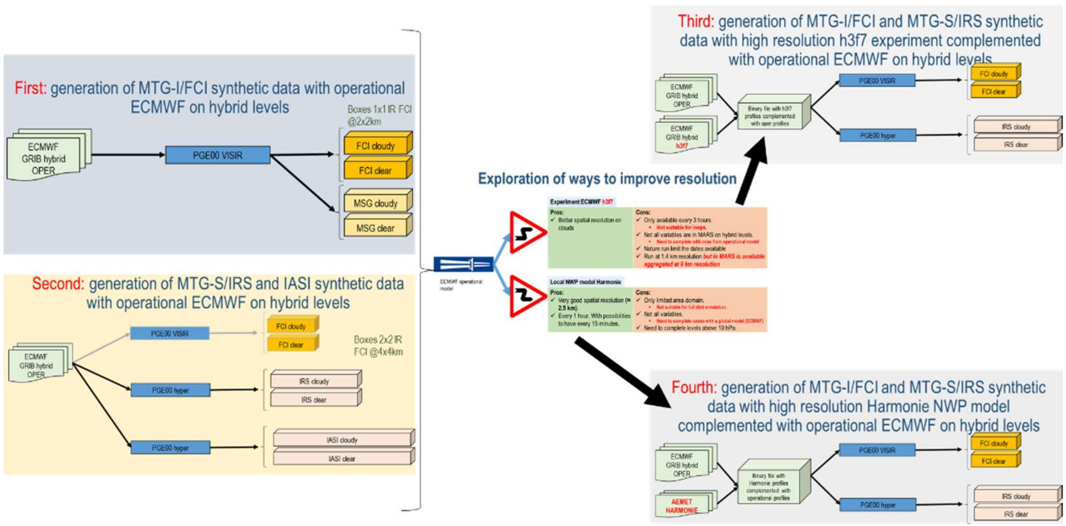

Figure 13: scheme of the generated synthetic MTG datasets.

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 3.4.1) 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 3.5.

3.2 First: generation of MTG-I/FCI synthetic data with operational ECMWF on hybrid levels

As can be seen in Figures 13 and 14, 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 0.1º x 0.1º spatial resolution.

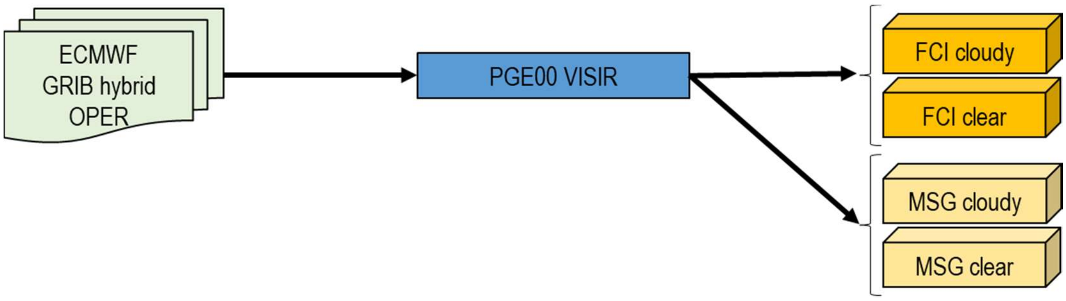

Figure 14: scheme GEO-PGE00-VISIR simulations using as input operational ECMWF NWP model.

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. They could be used in experiments to compare the performance of products from FCI and MSG or to make comparison of the FCI channels versus MSG channels.

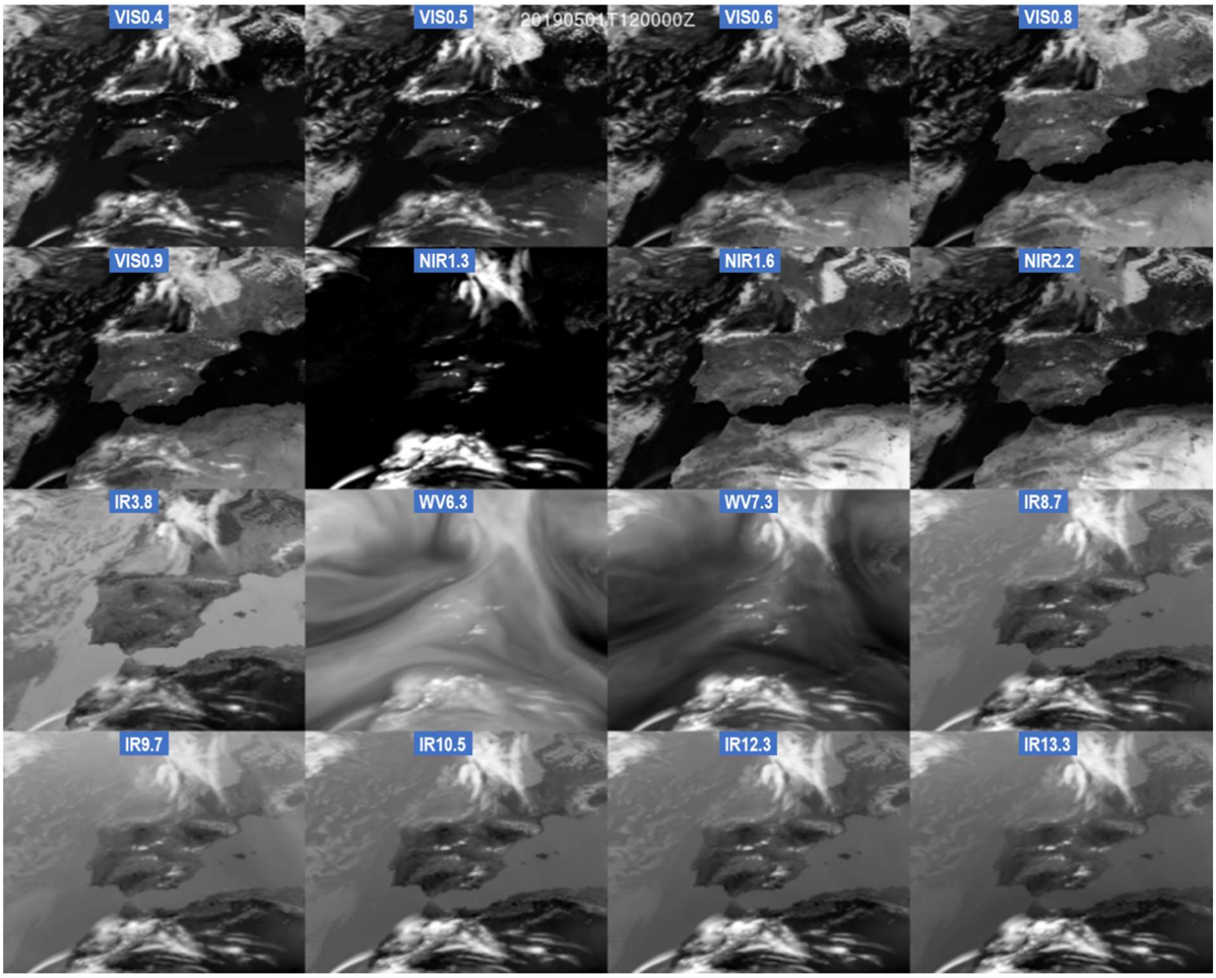

Figure 15: MTG-I/FCI simulation on cloudy conditions using as input operational ECMWF NWP model from 2019-05-01 00Z run t+12 forecast.

As can be seen in Figure 15, 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 needed to compare with real MSG data and products.

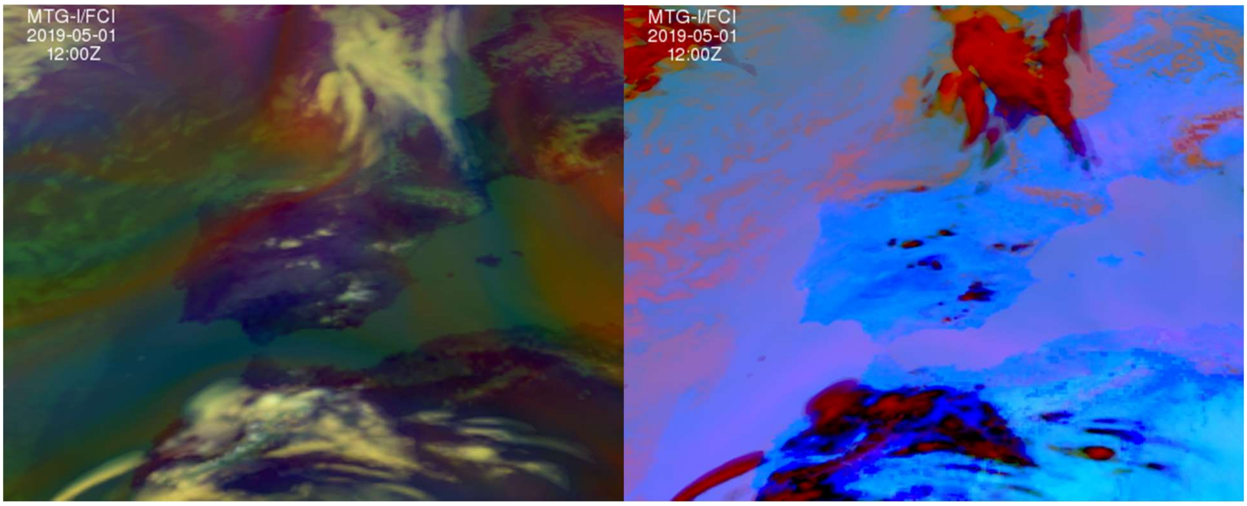

Figure 16: (left) synthetic MTG-I/FCI air mass RGB image and (right) synthetic MTG-I/FCI dust RGB. RGB images generated using as input operational ECMWF NWP model from 2019-05-01 00Z run t+12 forecast.

As early example of the use of FCI synthetic data it has been generated first the current operational RGBs images recipes; one example can be seen in Figure 16. But the synthetic FCI data could be also used to generate and test new RGB images not available in MSG or in GOES-R or in Himawari class satellites.

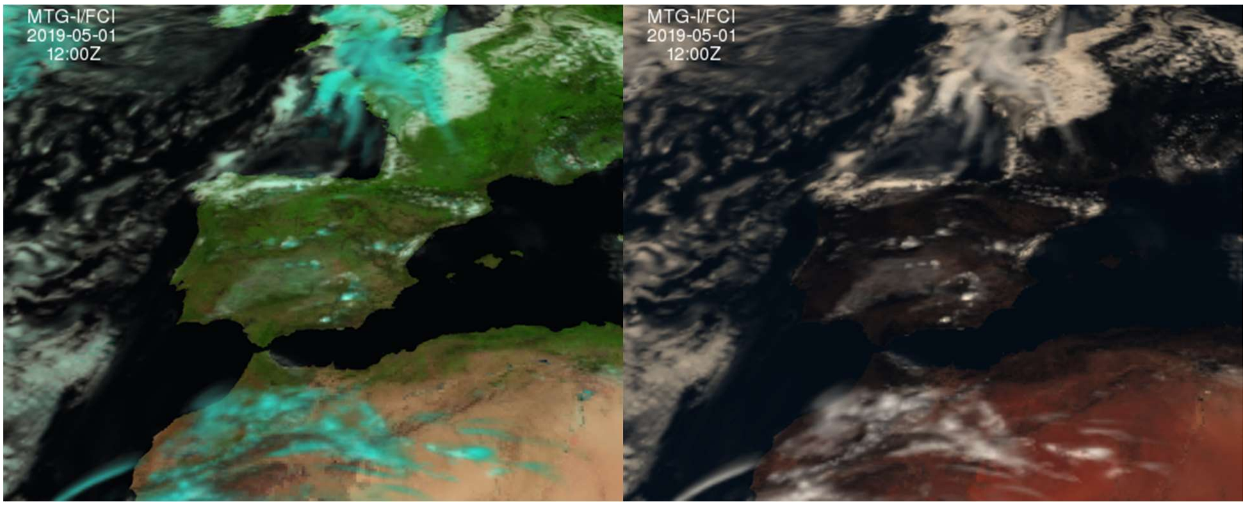

Figure 17: (left) synthetic MTG-I/FCI natural RGB image and (right) synthetic MTG-I/FCI true color RGB. RGB images generated using as input operational ECMWF NWP model from 2019-05-01 00Z run t+12 forecast.

As example in Figure 17, there is a comparison of the natural and true colour RGBs images. The Red, Green and Blue components on these RGB images has been scaled between minimum and maximum of every FCI channel. As commented above, in order to have data on 24 hours it is used a fixed 75º solar zenith angle during night.

The loops of images every 10 minutes are available in the links to 2021 Martinez presentations in Chapter 7 or in the iSHAI References web page.

The synthetic data of FCI and the comparison with synthetic data for Himawari/AHI could be used as a basis to develop and generate software to apply the reflectance atmospheric (Rayleigh) correction to get high quality true colour RGB images. As the NWC SAF GEO software package is installed in the user side of the EUMETCast, it is an ideal place where the Rayleigh correction (and any additional correction) could be applied to the satellite data distributed by EUMETCast to the user. A coordination of the activities with EUMETSAT, SAFs or third party agencies (as Australian Bureau of Meteorology, CIMSS or CIRA or Japan Agency) should be promoted.

3.3 SYNTHETIC MTG-I/FCI USED AS INPUT OF NWC SAF PGES

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-PGEO-VISIR as input to some of NWCSAF PGEs.

On mid-2020, the test data provided by EUMETSAT CAF for STRR revision at this time could only be used for technical testing; because they were just MSG data interpolated to FCI projection and some channels were just replications of same MSG channel.

The synthetic RTTOV-12.3 PGE00 synthetic dataset FCI data generated in that moment could be used better than the bad EUMETSAT MTG STRR test data. The first idea was the conversion from the binary files to EUMETSAT delivery netCDF format to be used as input to NWCSAF GEO software package. But after some informal and exploratory contacts with EUMETSAT CAF people about this possibility it was not possible to convert this RTTOV-12.3 PGE00 synthetic dataset to EUMETSAT delivery netCDF format because EUMETSAT CAF considered as not possible because it will imply a huge job.

Then, as a proof of concept, I started the design of one internal procedure in order to use this RTTOV-12.3 PGE00 synthetic dataset at least in NWCSAF GEO vMTG STTR GEO package. This was made using the "back door trick". The first version of this procedure was made with that RTTOV-12.3 PGE00 synthetic dataset; then, it has been improved early 2021 with RTTOV-13.0 PGE00 synthetic dataset.

The "back door trick" is based in the following mechanisms. When a new satellite image slot arrive and the first NWCSAF GEO PGE is executed the needed satellite input data matrices are stored as binary raw files on *$SAFNWC/tmp/Sat_data* directory with dimensions N_x x N_y of floats; this storage is known as the DATABUF. This speeds up the execution on the NWCSAF GEO packages because if other PGEs need the same channel they check before if the raw binary file is available in the DATABUF (avoiding the need to open the real satellite data and made the conversion from raw count to radiance and BRDF or BTs). The "back door trick" is the overwriting of the raw binary file on the *$SAFNWC/tmp/Sat_data* directory with other data or the generation of new ones raw files. In this case is just needed the writing on the *$SAFNWC/tmp/Sat_data* directory with N_x x N_y of floats with the synthetic FCI data with correct names in raw binary files.

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 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 to 2021 Martinez presentations in Chapter 7 or in the iSHAI References web page.

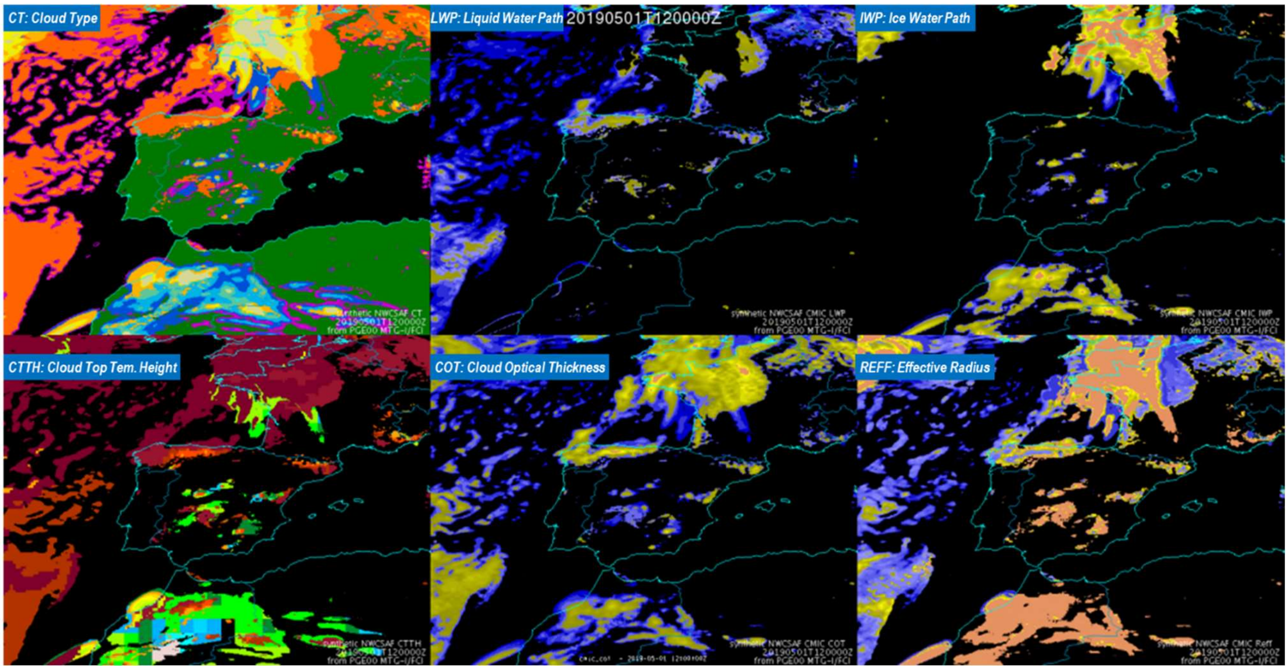

Figure 18: NWC SAF CT, CTTH and CMIC fields generated using as inputs synthetic MTG-I/ FCI data from 1st May 2019 12Z with cloudy PGE00 RTTOV-13.0 simulations.

As continuation of the proof of concept the images in Figure 18 has been generated with McIDAS-V from the NWCSAF netCDF files of every PGEs. As it will be shown later in Chapter 5, the main advantage to have synthetic data is that it could be used as "truth" the profiles (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. Tools as McIDAS-V allow to do it interactively and on 3D or 4D; as example to compare the cloud profile with the CTTH outputs or to compare the 3D influence on iSHAI retrieved profiles with the 3D clouds profiles on undetected cloudy pixels by the Cloud Mask PGE (see Chapter 5).

In Figure 18, the images for every field has been later combined and created animated gif with Image-Magick program. This is one example of the main recommendation to used combinations of fields better than just one field.

3.4 Exploration of ways to improve spatial and temporal resolution

The spatial and temporal resolution of ECMWF operational model is not enough for some PGEs as High Resolution Winds (HRW).

Then, I started to look for the possibilities to use NWP models with better spatial and temporal resolution than the operational ECMWF model. In Figure 19, 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. The second attempt was the use of Harmonie model. In both case it is needed to complement the deficiencies of these NWP models for use in simulations with the ECMWF operational model. Below there is a summary of the IDL programs developed to get the synthetic data from these high resolution NWP models and some examples.

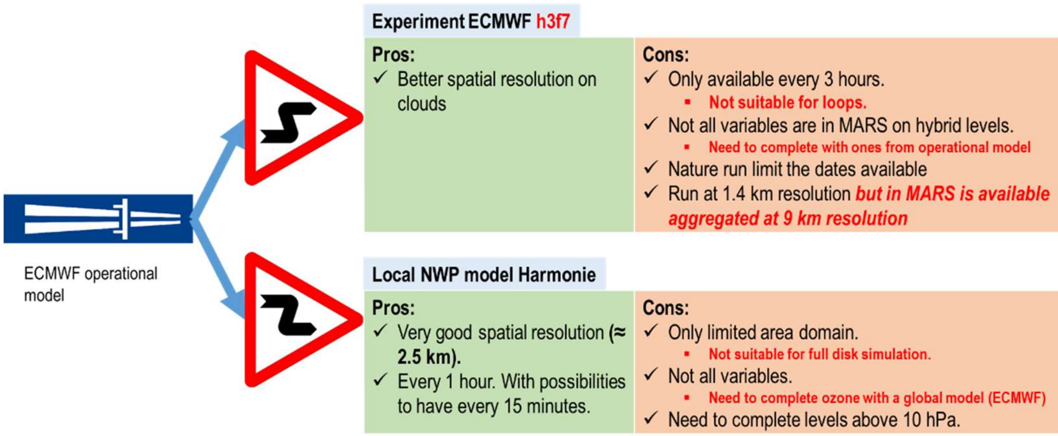

Figure 19: scheme of the attempts to use of NWP models with better spatial and temporal resolution than operational ECMWF as input to PGE00 programs.*

3.4.1 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 till 1x1 km; instead of the equivalent to ≈ 10x10 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** is a seasonal (4-months) nature run at 1.4 x 1.4 km resolution NWP model experiment. 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 for the use of 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 ECWMF model.
2. The **h3f7** GRIBs files are accessible in MARS but, due some problems in actual MARS capability, the GRIBs files are only available:
   a. Aggregated at effective 9x9 km spatial resolution.
   b. Only available every 3 hours.
   c. Not all variables 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.

All of these limitations make the need to complement the parameters in h3f7 with other from operational ECMWF model and due to the nature run this is only be possible to do for the initial date of the nature run (this fact limit the dates available). To solve this issue, 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 T 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*). After making similar requests to MARS for h3f7 model and for operational ECMWF model two GRIBs files are obtained. Then, h3f7 and operational ECMWF GRIB files are both split in different directories in order to get separated files of every grid on each 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 (just >> 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 profiles available on hybrid levels complemented with the resto of needed profiles from the ECMWF operational model (ozone and T profiles).

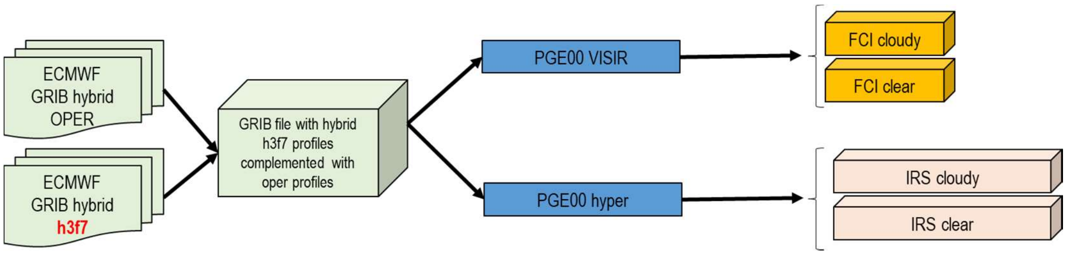

Figure 20: scheme of ECMWF h3f7 experiment simulation with PGE00.*

As can be seen in Figure 20, the combination of the fields from the h3f7 and ECMWF operational GRIBs files in 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. This tests is a precursor of future high resolution simulations if MARS restrictions and other high resolution ECMWF NWP are available someday. More details and images on the simulations with the experiment h3f7 are available in [RD.1] and in Martinez 2021d and 2021f presentations.

3.5 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 5º on a region centred in the Iberian Peninsula (see Figure 22). 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 º x 0.025º. 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 Diez (NWP Area of AEMET).

But Harmonie model has some limitations:

- ✓ Harmonie is only a limited area domain (not suitable for full disk simulation).
- ✓ Not all profiles variables needed by PGE00-VISIR 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 as IR9.7 in SEVIRI/MSG and MTG-I/FCI. Thus, it is needed to get ozone profile from a NWP global model as ECMWF operational model.

- ✓ Need to complement levels above 10 hPa.

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 and writing on binary file of the variables in ECMWF and Harmonie.
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 º x 0.025º are read. From ECMWF operational binary files it is read the 3D arrays of ozone profiles on the regular 0.1º x 0.1º 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, a spatial and vertically interpolated ECMWF ozone profile collocated with the Harmonie profiles is obtained.
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 been seen in Figure 21, 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.

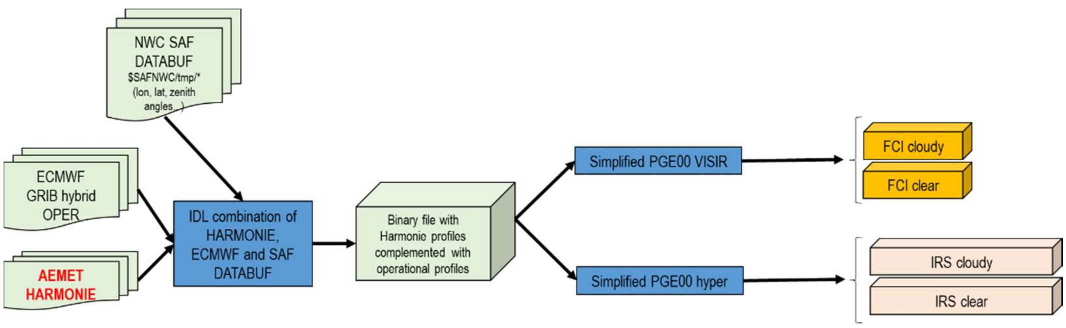

Figure 21: scheme of Harmonie and ECMWF simulation with PGE00.*

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 Figure 22 and 23 some examples of synthetic FCI RGB images are shown. The first loops of FCI synthetic images (air mass and natural RGB synthetic images) with Harmonie 2021-04-25 00 to 23Z every 1 hour are available in Martinez 2021f presentation.

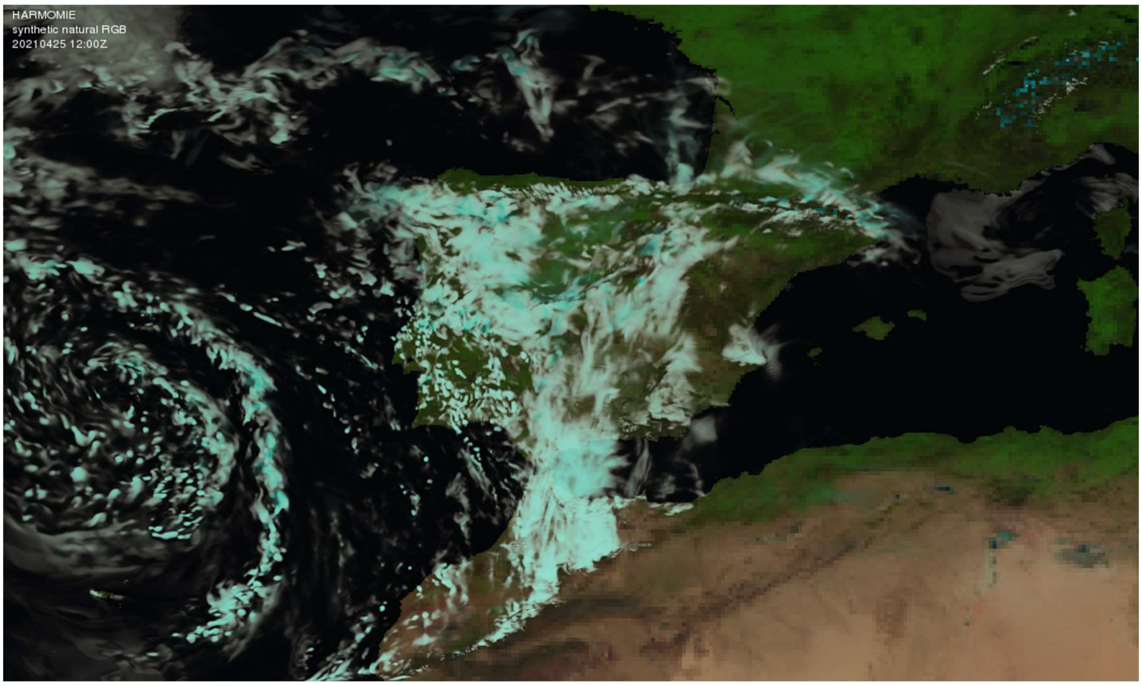

Figure 22: synthetic natural RGB image from HARMONIE AEMET complemented with ECMWF operational model. Case study 25th April 2021 at 12Z from t+12 forecast of 00Z run.

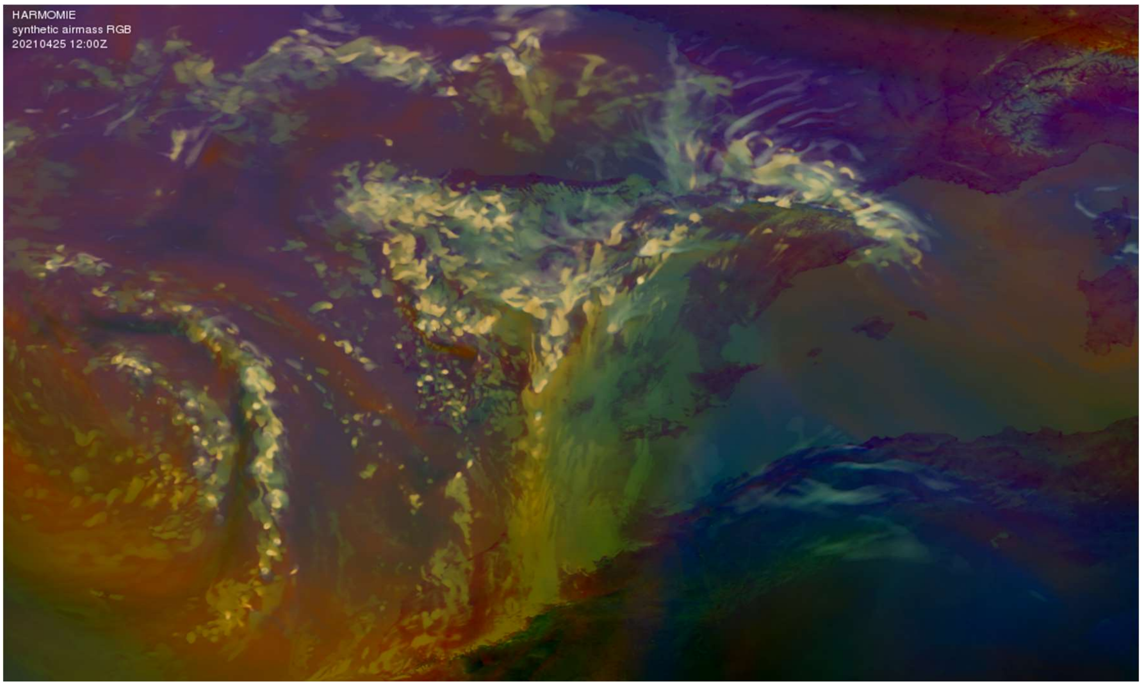

Figure 23: synthetic air mass RGB image from HARMONIE AEMET complemented with ECMWF operational model. Case study 25th April 2021 at 12Z from t+12 forecast of 00Z run.

It is important to note the reddish colours in some pixels in Figure 23; this fact is due to an intrusion of cold air from the stratosphere. In Figure 23 this fact is correctly represented in the synthetic MTG-I/FCI air mass RGB image because 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.

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.

As can be seen in Figure 21, 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 one intermediate and combined binary file 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.

In summary, the use of programs like PGE00* allows to generate synthetic test datasets from NWP models. It could be improved the simulations in future if ECMWF improves the access to high spatial resolution experiment or using local NWP model complemented with some global (ECMWF) NWP fields. These synthetic test datasets could be used to explore ideas, as new products from new FCI channels and from IRS. These test data could be used also to explore ideas as Optical flows; using the (u,v) 4D-interpolated datacube used as input as a "truth".

4 SEARCH OF NEW RGBS FROM IMAGERS USING SYNTHETIC BTS

The availability of synthetic datasets (and in other cases of collocated synthetic and real satellite datasets) allows the search of new RGBs from imager instruments using the input profiles as a "truth" to evaluate the performances. One of the first attempt was the design of a new RGBs using blended real+synthetic images to create a blended NWP+real airmass RGB.

4.1 IMPROVED AIRMASS RGB

The first attempt of a new RGBs using blended real+synthetic data was the blended NWP+real airmass RGB. It was shown in CWG Workshop 2018 as can be seen in Martinez 2018a.

In summer times on very hot surfaces the MSG air mass RGB present regions of very dark colors where it is very difficult to distinguish the reddish tones in pixels with stratospheric ozone intrusions that reveals the presence of cold air in high levels. The presence of cold air in upper levels is one of the ingredients in convection. In Iberian Peninsula is common the presence of small regions of cold air in upper levels and it is one the main convection triggering mechanism. These regions of cold air on upper levels are clearly revealed by the air mass RGB in sea pixels but difficult to monitor when moves to ground, especially in summer times on day time.

The channel on SEVIRI/MSG and MTG-I/FCI most affected by ozone concentrations is the IR9.7 channel. As can be seen in Figure 24, IR9.7 channel presents one relative maximum contribution in upper levels contribution linked to temperature and ozone profiles but there is also a non-zero contribution from surface and low levels. In the original air mass RGB, in the green component it is used the difference (BT_{IR97}-$BT_{IR10.8}$) in one attempt to attenuate the contribution of the surface and low levels in the BT_{IR97}. But as can be seen in the mean weighting functions for SEVIRI IR channels the weighting functions for IR97 and IR10.8 are different. In case of not very hot pixels the difference (BT_{IR97}-$BT_{IR10.8}$) work reasonably well but in case of ground very hot pixels this is not the case.

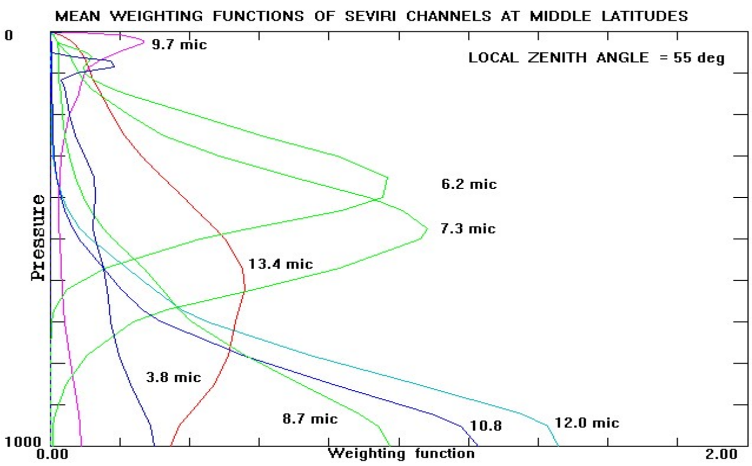

Figure 24: weighting functions of IR SEVIRI/MSG channels.

To mitigate this problem in air mass RGB image it was started the investigation on the IR9.7 and IR10.8 channels behaviors to improve the detection.

The first test was made using only synthetic BTs. BTs of two simulations of the IR9.7 channel were used:

a) ClearIR97$_{RTTOV}$: synthetic RTTOV IR9.7 BTs using the original ECMWF profiles with the profile of T, q and ozone in each pixel.

b) meanO3_clearIR97$_{RTTOV}$: synthetic RTTOV IR9.7 BTs in clear air mode using the original ECMWF profiles of T and q in each pixel but **using as ozone profile for all the pixels the average value of the ozone in each level**. This is made using a functionality added to PGE00* programs that can be activated through the ASCII PGE00 configuration file. When the keyword for this functionality is activated after reading of 3D arrays from the GRIB file are executed some FORTRAN lines to calculate for every hybrid level the mean on the level and assigning this mean level to all pixels at this level.

The influence of the content and ozone profile on the IR9.7 channel is clearly shown in the difference (clearIR97$_{RTTOV}$ - meanO3_clearIR97$_{RTTOV}$). If this difference is used in the green layer of the new air mass RGB, the presence of the ozone intrusion is highlighted in pixels with dark colors and the surface cannot be seen; this indicates that a good cancellation of surface and low levels influence has been made. In the case to use "BT$_{\mathbf{meanO3_IR97}}$" and BT$_{\mathbf{IR97}}$ the weighting function in low levels and surface is very similar since the values of ozone profile at these levels is usually very low. Then, the difference BT$_{\mathbf{IR97}}$-BT$_{\mathbf{meanO3_IR97}}$ is determined mainly by the ozone profile in high levels.

If this difference is used as the green component of air mass RGB (see Figure 25) the result is a near perfect detection of cold air regions on upper levels using ozone as proxy of the stratospheric intrusion, as can be seen in Figure 26.

Original airmass RGB

RED	WV6.2-WV7.3	[-25,0]
GREEN	IR9.7-IR10.8	[-40,5]
BLUE	WV6.2	[243,208]

Improved airmass RGB

RED	WV6.2-WV7.3	[-25,0]
GREEN	**clearIR97$_{RTTOV}$ – meanO3_clearIR97$_{RTTOV}$**	[-4,4]
BLUE	WV6.2	[243,208]

Figure 25: comparison of original air mass RGB recipe and blended recipe in case of synthetic data.

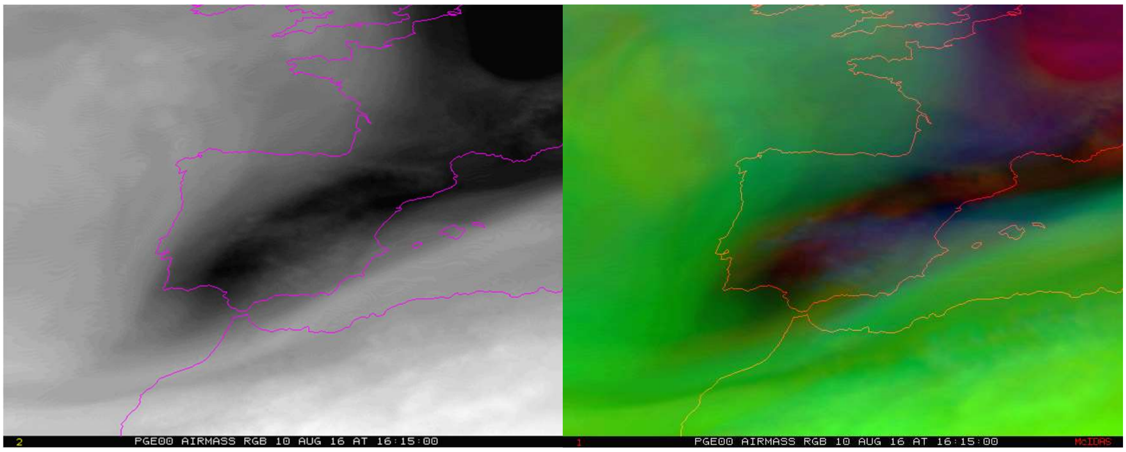

Figure 26: left) GREEN component: (clearIR97$_{RTTOV}$ - meanO3_clearIR97$_{RTTOV}$.
Right) blended synthetic air mass RGB using this difference. Case study 10th of August 2016 16:15Z.

4.1.1 Blended NWP-real air mass RGB with real images

When BTs of real images are used, it is also necessary to correct the difference between the BTs of RTTOV and real BTs in the IR9.7 channel. This has been implemented using a regression of the difference between the real BTs and RTTOV between the IR10.8 channel and IR9.7.

The **GREEN component** proposed for real images includes also **a regression** from the difference real and RTTOV in **IR10.8** and IR9.7. It can be seen in Figure 27.

$$\underbrace{(BT_{IR9.7} - meanO3\_clearIR97_{RTTOV})}_{\text{Differences due to ozone contribution}} - \underbrace{(0.54*(BT_{IR10.8} - meanO3\_clearIR108_{RTTOV}) + 0.18)}_{\text{Correction of the differences between real and NWP skin temperatures and emissivities}}$$

blended (real&synthetic) air mass RGB

RED	WV6.2-WV7.3	[-25,0]
GREEN	(BTIR97- meanO3_clearIR97$_{RTTOV}$) -(0.54*(BTIR108 - meanO3_clearIR108$_{RTTOV}$) +0.18)	[-4,4]
BLUE	WV6.2	[243,208]

Figure 27: the proposed Green component has two parts: differences due to ozone contribution and a correction of the differences between real and NWP skin temperatures and emissivities.

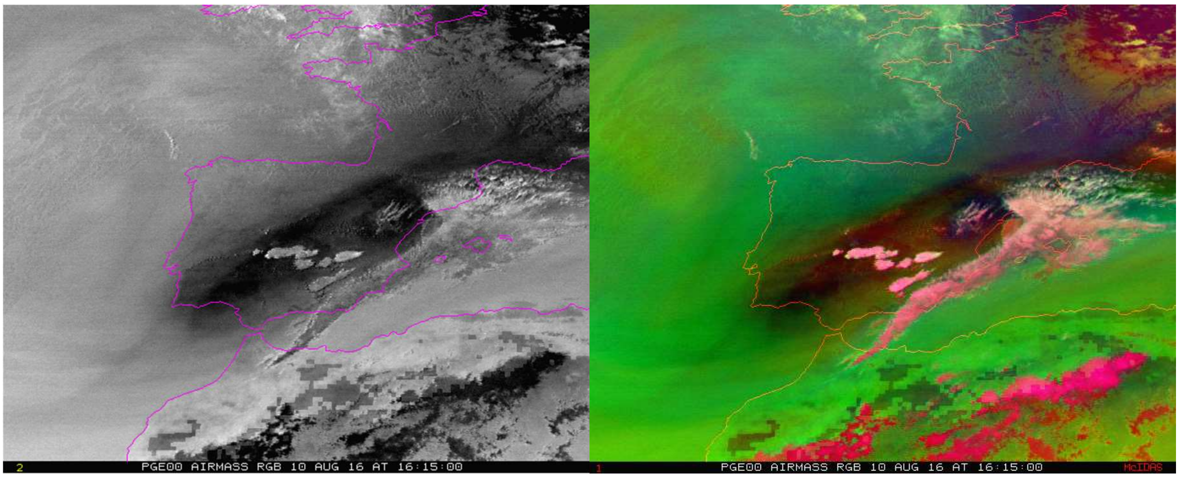

Figure 28: left) GREEN component in blended (real&synthetic) satellite images case: (clearIR97$_{RTTOV}$ - meanO3_clearIR97$_{RTTOV}$) Right) blended (real&synthetic) air mass RGB using it. Case study 10th of August 2016 16:15Z.

It can be seen in Figure 29 like in the original air mass RGB (Left top) it is very difficult to localize the pixels with reddish tones at the Iberian Peninsula. The comparison of the original air mass RGB images from real and from synthetic data with clear sky simulations (Left top and bottom respectively) indicates that the problems is intrinsic to the original air mass RGB recipe. In the case of the proposed blended air mass RGB the contrast in colour and tones between greenish and dark and reddish pixels in ground pixels at Iberian Peninsula allows to localize perfectly the region of ozone stratospheric intrusion proxy of cold air in upper levels (centre top). The agreement between the region with dark pixels in the blended air mass RGB and the region with high Total Ozone values (right bottom) is very high. It is inside of this dark region on the blended air mass RGB where the convection is started to trigger (right top).

In Martinez presentation 2018a in the 2018 Convection Working Group it can be seen the 24 hours loop of the montage of these RGB images and it is shown like the convention is triggered south of the Toledo Mountains by the arrival of the trough of cold air on upper levels above the region with high humidity in low levels.

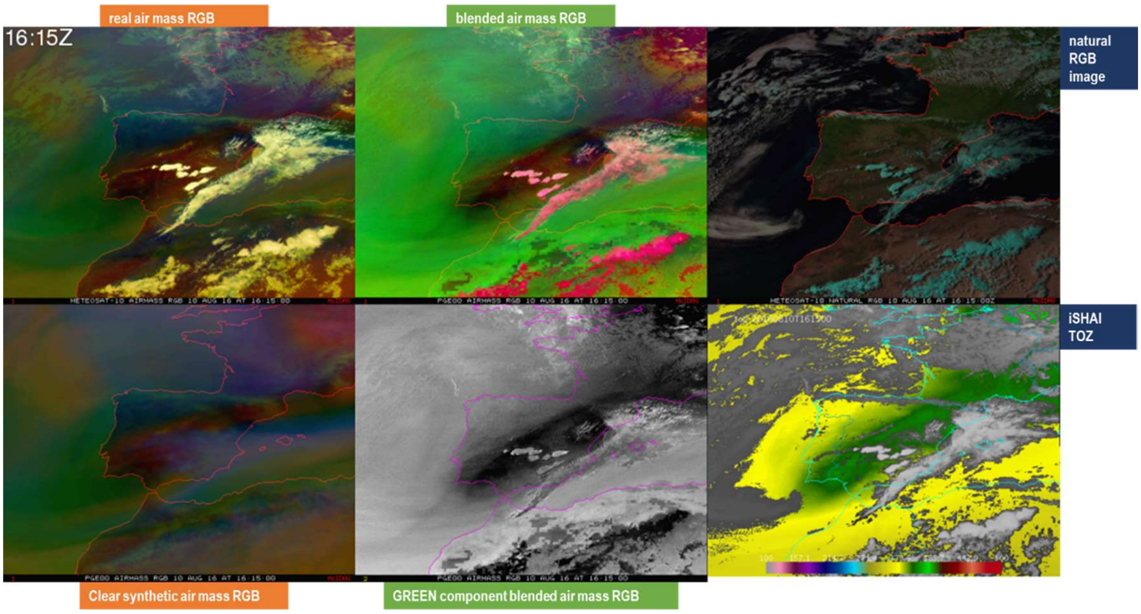

Figure 29: Left top) original real air mass RGB. Left bottom) clear synthetic original air mass RGB. Center top) proposed blended real air mass RGB. Center bottom) GREEN component of the blended real air mass RGB. Right top) synthetic natural RGB image. Right bottom) Total ozone field from iSHAI. Case study 10th of August 2016 16:15Z.

4.2 TPW WITH BLENDED TECHNIQUE FROM MTG-I/FCI VIS0.9

In MTG-I/FCI will go on board, by first time on a geostationary imager instrument, a VIS0.9 channel. VIS0.9 channel has the peculiarity to be a visible channel with absorption by water vapour. For this reason, it is of interest in convection since it provides another independent estimation of precipitable water in the column from the visible range complementary to the one calculated in iSHAI using IR channels and with higher spatial resolution 1x1 km than 2x2 km spatial resolution of IR channels.

The design of an algorithm using VIS0.9 in for a quantitative estimation of precipitable water at Day-1 is very difficult. But, the developing of new RGBs to get one subjective estimation of precipitable water using this channel could be possible. Thus, a RGB images using VIS0.9 could help in validation of iSHAI product.

Using the first version of GEO-PGE00-VISIR with RTTOV-12.1 in early 2018 it was generated the first set of synthetic MTG-I/FCI data with the 16 channels in clear and cloudy conditions. This allowed to generate the first VIS0.9 synthetic data; but as can be seen in Figure 30 (left bottom) the spatial pattern is very different to ECMWF TPW field (see Figure 30 right top).

In 2007 Workshop in Madrid, it was presented one algorithm developed by Rene Preusker (Institut für Weltraumwissenschaften Freie Universität Berlin Germany), using the difference of the logarithms between the VIS0.9 and other near channel (out of oxygen band) with data from ENVISAT/MERIS.

Following this idea, it was tested first the use of difference of logarithm of FCI VIS0.9 and FCI VIS0.8 but the result was not good enough.

As one opportunity development, since PGE00* programs with RTTOV-12.1 were modified to add the optional functionality of the calculation of radiances using the mean ozone profile at every level it was easy to add also in PGE00* the functionality to add a configurable keyword to activate the change of the q profile by the mean at every level with the $q_{mean\_at\_level}$ value.

As in Section 4.1 for ozone case, it was executed PGE00-VISIR two times to generate synthetic FCI data for all channels but with q profiles. The first time with the ECMWF q profiles in each pixel and the second time using mean q profile in all the pixels. Then, it was tested the symmetric difference of the logarithm of VIS0.9 and VIS0.8 channels calculated with the NWP profiles and with the q profile changed by the mean profile of q in the NWP:

Estimation_wv = (Log(VIS0.9) -Log(VIS0.9mean_q)) - (Log(VIS0.8) -Log(VIS0.8mean_q))

As can be seen in Figure 30 (*right bottom*) the "**Estimation_wv**" field resembles the spatial pattern of the ECMWF TPW field in Figure 30 (*right top*). This early results were first shown at Convection Working Group 2018. The loop with the images for the 24 hours is available in the Martinez 2018a presentation.

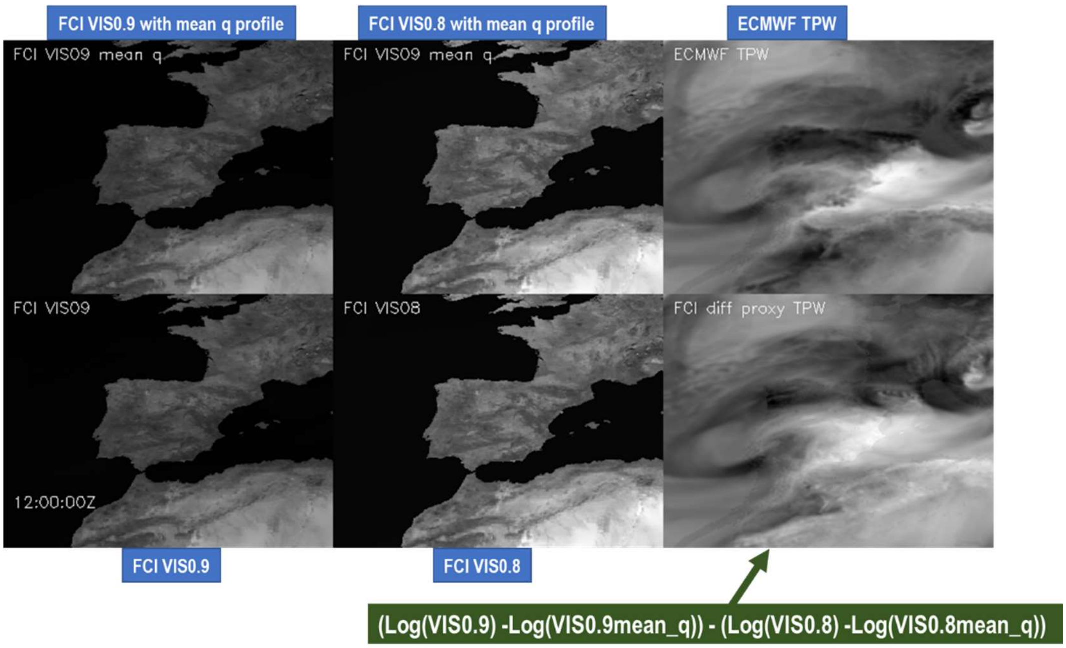

Figure 30: Left top) VIS0.9 FCI reflectivity calculated with mean q profile. Left bottom) VIS0.9 FCI reflectivity calculated with ECMWF q profile. Center top) VIS0.8 FCI reflectivity calculated with mean q profile. Center bottom) VIS0.8 FCI reflectivity calculated with ECMWF q profile. Right top) ECMWF TPW field. Right bottom) estimation of precipitable water using the formula in the figure. Case study 10th of August 2016 12Z using GEO-PGE00-VISIR with RTTOV-12.1.

In order to discard that the results were only correct for the case study 10th of August 2016, the experiment was repeated with the case study of 22th July 2019 and similar results was obtained. The images for this case study se can be seen in Figure 31. These results were first presented in NWCSAF

Workshop 2020; the loops with the images for the 24 hours are also available in the presentation Martinez 2020a.

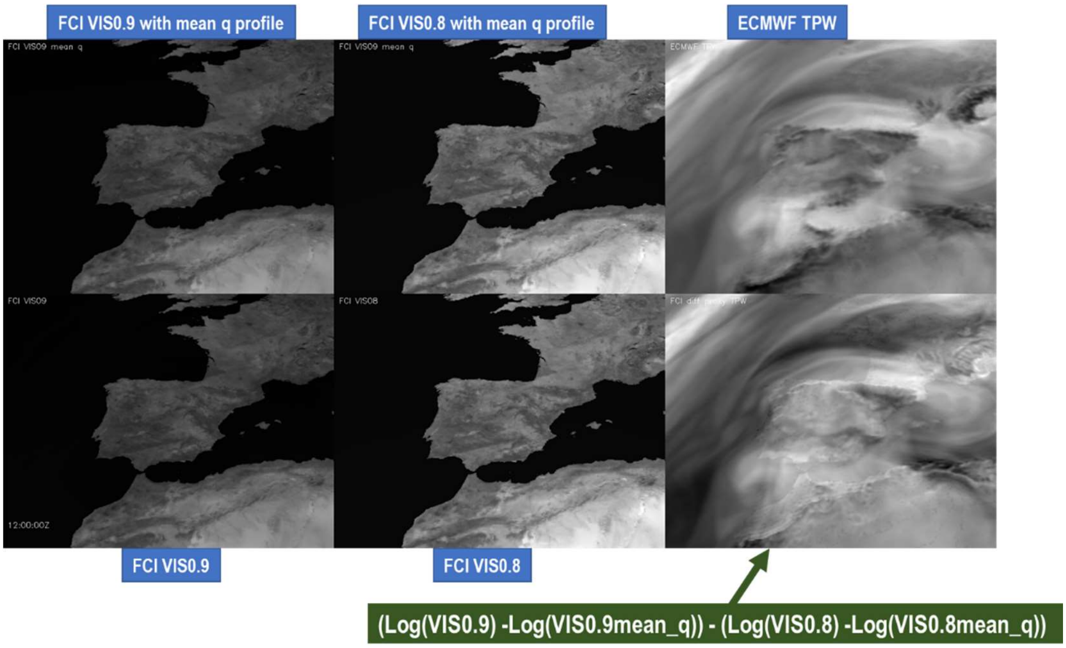

Figure 31: same fields as in Figure 30 but for case study 22th July 2019 12Z using FCI synthetic data calculated with RTTOV-12.1 GEO-PGE00-VISIR version.

To discard the results were due to the use of PGE00* using previous version RTTOV-12.1, this test was repeated using GEO-PGE00-VISIR with RTTOV-13.0 developments for the case study of 1st May 2019. The results has been shown in Martinez presentations 2021 (b), (c) and (f). The results are similar to case studies presented on CWG 2018 on Ljubljana and in NWCSAF Workshop 2020.

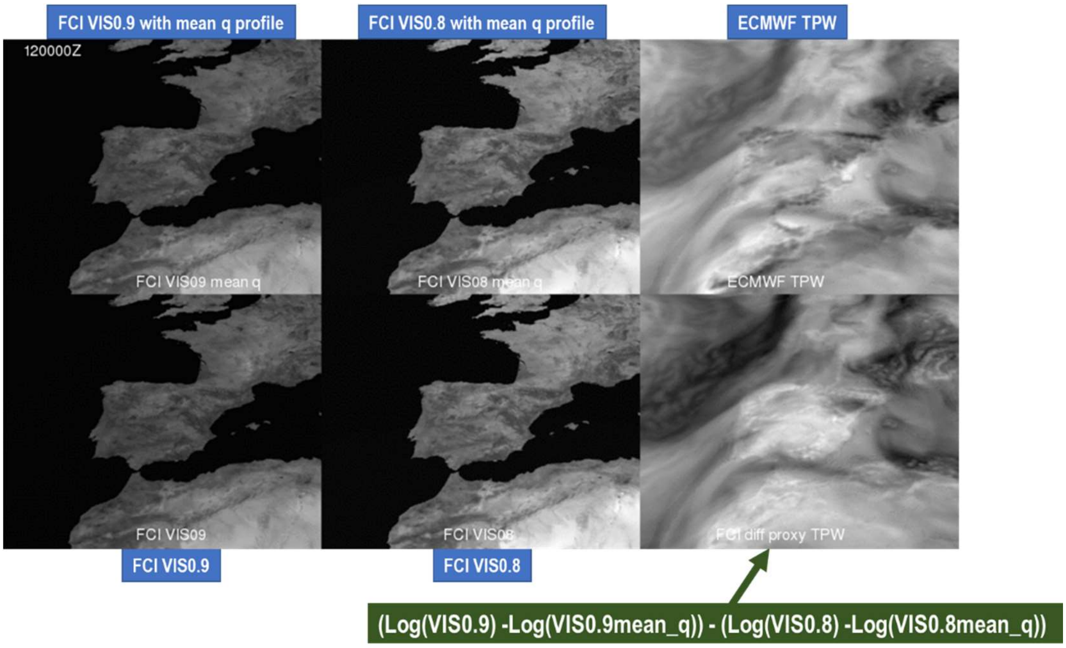

Figure 32: same fields as in Figures 30 and 31 but for case study 1st of May 2019 12Z using FCI synthetic data calculated with RTTOV-13.0 GEO-PGE00-VISIR version.

The previous tests (case studies 10th August 2016 and 22nd July 2019) were made using the PGE00-VISIR version on SEVIRI/MSG grid every 15 minutes; the test 1st May 2019 has been with PGE00-VISIR version RTTOV-13.0 in MTG-I/FCI grid every 10 minutes.

The use of synthetic dataset should be use also to know the contribution of the moisture in each layer. Thus, it could be studied if the estimated water vapor VIS09 parameter content is similar to the TPW product or if the contribution of each layer in VIS0.9 channel imply that the parameter is different to TPW and with more proportion and non-linear behavior in low levels.

Also, these preliminary tests should be repeated with real images in commissioning phase of MTG-I; the objective is to investigate how to correct the differences between synthetic and real data and to design corrections as the implemented in Section 4.1.1 for real IR97 images and the ozone. As commented above if it is possible a quantitative product with estimation of precipitable water in column could be developed; in case not possible it will be studied the implementation on subjective products as example on RGB images.

Another issue that should be studied is the impact of Earth Stray Light correction on VIS0.9 data.

In case to be obtained some quantitative or qualitative products with this channel they will help to validate and compare with the iSHAI precipitable water fields. It is not foreseen to make more developments in CDOP-3 and they will do more tests in next CDOP-4 phase.

In CDOP-4 phase there will also be an opportunity to compare with equivalent products from Sentinel-3. As can be seen in [RD.2], in 2020 there were made some early experiments on the reprojection of Sentinel-3 <==> NWCSAF regions. But due to an issue in the calculation on precipitable water in Sentinel-3 the quality of the precipitable water field was not good and the results are not shown here.

4.2.1 proxy of HL field with blended technique from MTG-I/FCI NIR1.3 channel

In MTG-I/FCI the new NIR1.3 channel is located in NIR range on a band with strong WV absorption. Thus, it can be of interest in convection to help on monitoring of the water vapour in high levels.

As commented in previous section, in the synthetic FCI dataset all the channels are available and NIR1.3 channel synthetic data are also available in the execution with the ECMWF profiles and the other execution using mean q profiles.

Thus, as another opportunity development experiment it is possible to test the use of:

$$(\log(NIR1.3) - \log(NIR1.3mean\_q))$$

and the relation with the iSHAI precipitable water in high layer HL field. In the Figure 33 it is shown the result to calculate this estimation of precipitable water in the high layer using the synthetic data from PGE00 with RTTOV-12.1 on case study 22nd July 2019.

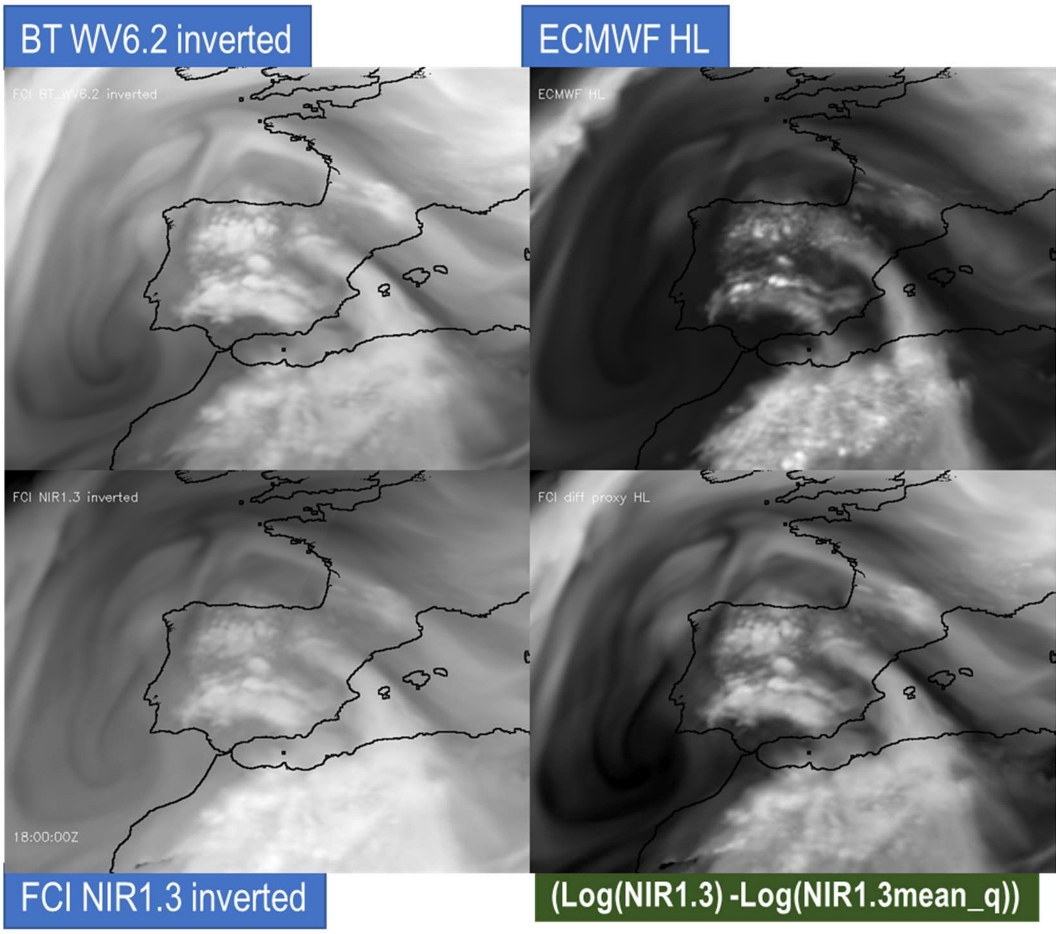

Figure 33: Left top) synthetic FCI WV62 BT inverted. Left bottom) synthetic FCI NIR1.3 reflectivity inverted calculated with ECMWF q profile. Right top) ECMWF HL (precipitable water in layer 500 to 10 hPa). Right bottom) estimation of precipitable water in high levels using the formula in the figure. Case study 22nd July 2019 12Z using GEO-PGE00-VISIR with RTTOV-12.1.

Developing of new RGBs or products with this channel would help to validate the iSHAI HL field. Although characterization of different levels contribution to the absorption and the relation with HL field must be checked before introduce them in testing and operation by forecasters.

There is the opportunity to test in CDOP-4 this approach with GOES-R class satellites. It could be used NWCSAF/GEO v2021 using data from GOES-R class satellites and PGE00 on cases studies with real data and simulations. In any case all must be tested in MTG-I commissioning phase due to NIR1.3 channel is the most affected by the impact of Earth Stray Light correction on data.

5 ISHAI TESTS WITH SYNTHETIC DATASET: COMPARISON OF ISHAI OUTPUTS FROM SYNTHETIC CLEAR AIR AND CLOUDY BTS

It has been made a first set of tests with the comparison of iSHAI outputs from synthetic clear air and cloudy BTs. These tests has been made using as inputs to iSHAI the synthetic MTG-I/FCI datasets from 1st May 2019 from 12:00Z generated with PGE00-VISIR the MTG version with RTTOV-13.0 described in Section 3.2.

In the first place it was made an execution of iSHAI using as input the synthetic MTG-I/FCI BTs generated on ***clear air*** conditions. In this test, it has been used as Cloud Mask (CMA) input a null CMA with all pixels fixed to clear value. This null CMA file has been obtained with the process:

1. Read the cloud mask data matrix from the original CMA netCDF file
2. Fix as clear air value all pixels in the CMA data matrix on memory
3. Overwrite the CMA field in the netCDF file with the modified cloud matrix with all pixels with clear air value.

Some of the iSHAI fields for this test with synthetic MTG-I/FCI on clear-air conditions can be seen in Figure 34.

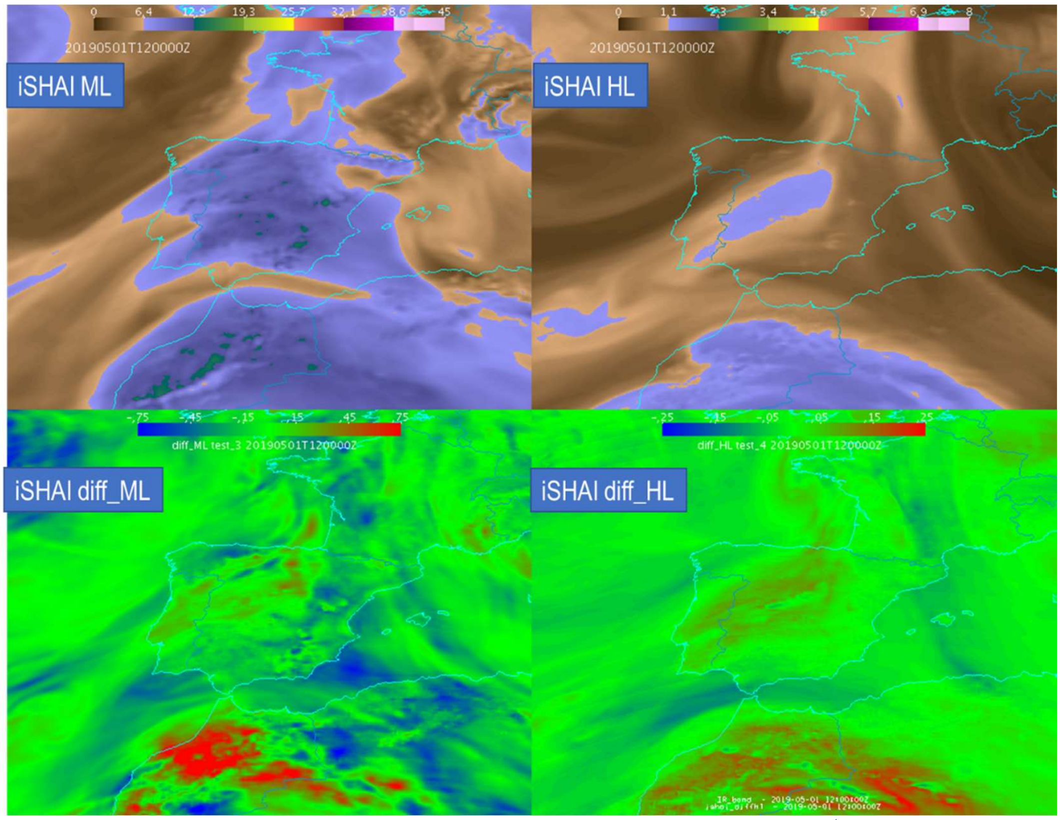

*Figure 34: iSHAI outputs from test using **clear air** synthetic dataset from 1st of May 2019 at 12Z. Left top) ML Precipitable water in layer (850-500). Right top) HL Precipitable water in layer (500-top). Left bottom) difference ML field. Right top) difference HL field.*

In second place, it was made the execution of iSHAI using as input the synthetic MTG-I/FCI BTs generated on ***cloudy*** conditions and the original cloud mask (CMA) netCDF file (see section 3.3). The same fields that appear in Figure 34, but for this second test with synthetic MTG-I/FCI on cloudy conditions, can be seen in Figure 35. The most interesting is the comparison of differences (between retrieved and from NWP background NPW) of ML and HL fields between the two tests. The spatial structure and pattern on the differences fields in both tests are similar but around the cloudy pixels in centre of Iberian Peninsula can be seen some pixels with red colours in the test made using FCI BTs on cloudy conditions that are not present in the test using FCI BTs on clear air conditions. In this case this effect is very light and the range (minimum and maximum) in the difference fields (diff HL and diff ML) has been reduced to enhance the differences. All the images in this section has been generated using the NWCSAF netCDF files and the McIDAS-V tool that allows to choose the colour palette and range (minimum and maximum) interactively (instead to use the default ranges (minimum and maximum) in the diff HL and diff ML parameters). Theoretically this red pixels are contaminated by clouds and they should have been filtered by the Cloud Mask product. In this synthetic case the alteration on the values due to unscreened cloudy pixels is very light; but in real satellite images this effect of presence of red pixels or pixels with larger and sharper deviations from the background NWP fields than the shown here are also present in iSHAI fields. Thus, the main outcome of these synthetic tests are the confirmation of the present of this effect due to not fully screening of cloud contaminated pixels.

Note: The images has been later combined and saved on PNG graphic format using Image-Magick.

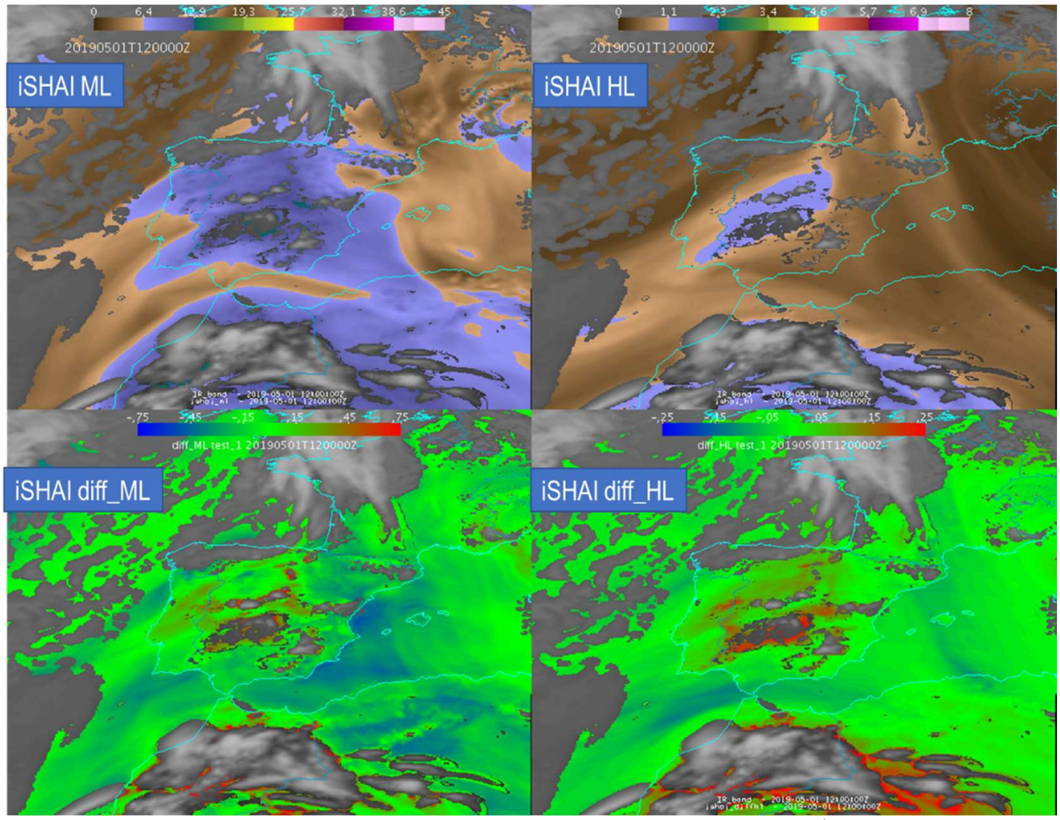

*Figure 35: iSHAI outputs from test using **cloudy** synthetic dataset from 1st of May 2019 at 12Z. Left top) ML Precipitable water in layer (850-500). Right top) HL Precipitable water in layer (500-top). Left bottom) difference ML field. Right top) difference HL field.*

Since these tests has been made using synthetic data as input to PGE00-VISIR, it can be configured to save also on binary the 3D arrays with the profiles used as input to it. So, iSHAI was configured to also write on binary files the input profiles together with the retrieved profiles after applying the iSHAI algorithm (used to calculate the iSHAI parameters shown in the Figures above). Thus, the iSHAI and PGE00 binary files can be read to get the 3D data cubes with the inputs and the outputs; and as it has been shown several times they could be written on netCDF files compatibles with McIDAS-V. Then, McIDAS-V 3D display capacities could be used interactively to investigate the influence of cloud contamination on iSHAI profiles retrieved profiles; as example of this capability it has been prepared the Figures 36 and 37.

In the Figure 36 it can be seen the difference in the q and T profiles due to the influence of the cloud contamination on the synthetic cloudy BTs. As it was shown in Figure 7 one way to get a good vertical representation is use of normalized 3D arrays. Normalized 3D arrays are calculated after calculation of the mean and standard deviation on the analysis in the case study at every layer and then are created the normalized 3D data cube subtracting the mean and dividing by the standard deviation at every layer for each image. In the Figure 36 it has been subtracted the normalized 3D data cube of both tests for the cases of normalized q and normalized T parameters. This allows to detect and to search the layers were the humidity increase (green colours) and/or temperature decrease (blue colours) due to contamination of clouds.

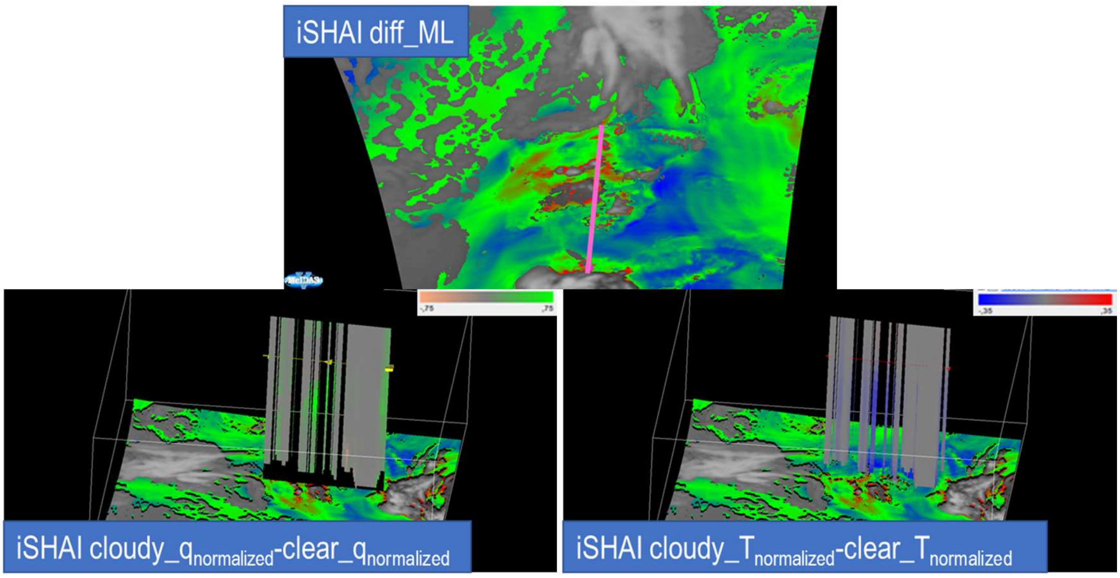

*Figure 36: Center top) difference ML field and over imposed in pink the line with the position on vertical cross section on bottom images. Left bottom) vertical cross section with the difference between normalized q vertical profile results of the tests on clear-air and cloudy conditions. Right bottom) vertical cross section with the difference between normalized T vertical profile results of the tests on clear-air and cloudy conditions. iSHAI outputs from tests **clear-air** and **cloudy** synthetic dataset from 1st of May 2019 at 12Z.*

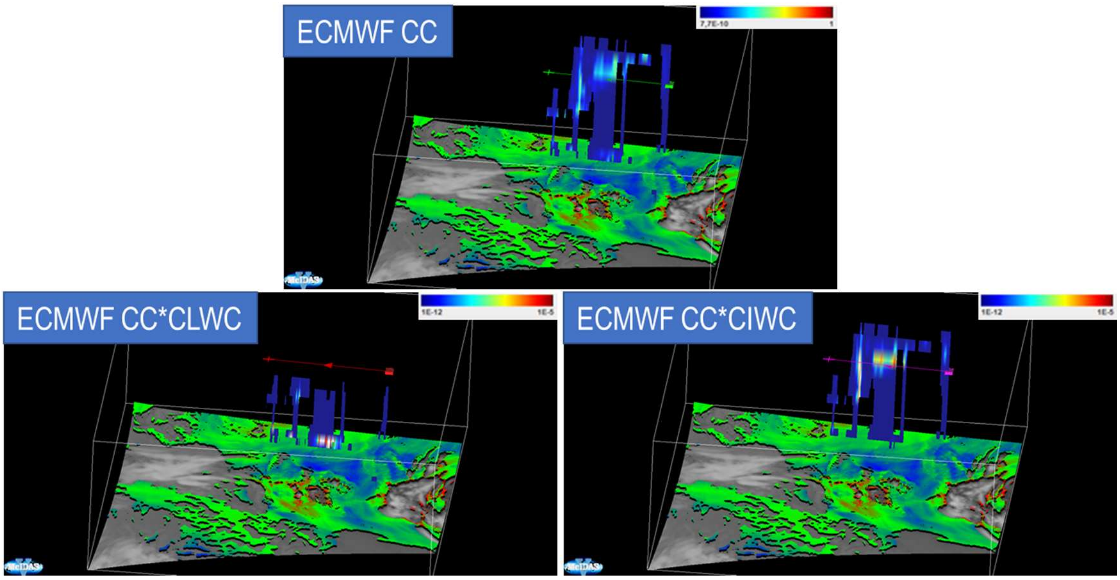

Figure 37: Vertical cross section on same line that in Figure 36. Center top) Cloud profile (CC) from ECMWF used as input to PGE00-VISIR in the generation of ***cloudy*** *synthetic dataset. Left bottom) vertical cross section of the product of cloud profile (CC) by CLWC from ECMWF. Right bottom) vertical cross section of the product of cloud profile (CC) by CLWC from ECMWF. 4D interpolated field outputs from tests* ***clear-air*** *and* ***cloudy*** *synthetic dataset from 1st of May 2019 at 12Z.*

As demonstration of the high capabilities of the synthetic datasets and tools like McIDAS-V on the analysis of undetected cloud contamination influence in q and T profiles in Figure 37 the vertical cross sections of the ECMWF 3D data cube of cloud (CC) and the multiplication of CC by the ECMWF 3D data cubes of Cloud Liquid Water Content (CLWC) and Cloud Ice Water Content (CWIC) used as input to PGE00-VISIR are shown. Figures 36 and 37 have been generated interactively with McIDAS-V on the vertical cross section line of Figure 36.

6 EARLY DEVELOPMENTS TO EXPLORE NEW ALGORITMS

In this Chapter early developments and results for some of the possible evolution of the iSHAI algorithm are shown.

The present iSHAI algorithm is based in the combination of FG regression step and physical retrieval step.

But using the same training and validation datasets that the used for iSHAI it could be tested the use of Machine Learning algorithms and to compare the performance of both. In the first NWCSAF phases the precursors (PGE07 and PGE08) of iSHAI algorithm were based in neural network using as input on satellite and ancillary data; but in 2007 it was decided by recommendation of EUMETSAT to migrate to the actual iSHAI algorithm based in the algorithm of Jun Li (CIMSS/U. Wisconsin). In the calculation of FG regression coefficients of iSHAI, it is used one radiative transfer model to calculate the synthetic BTs from one analysis and the profiles of one near forecast from the same NWP model. The synthetic BTs from the analysis and the profiles from the forecast are used to build the state vector (independent term of the regression); the profiles used in the radiative transfer model are the used in the FG regression calculation as dependent term. This training dataset will be used and tested in CDOP-4 in machine learning tools to assess and to compare the performances of some machine learning algorithms with the ones from the iSHAI algorithm. When the training of PGE07 and PGE08 algorithm in 2002 was made the machine CPU and speed was very limited and the capacity to train neural network with the configuration and training dataset as the commented now was impossible. Now in the second machine learning spring with improved machine power and new machine learning tools it would be the time to test these kind of algorithms.

The second way to improve the iSHAI algorithm is the look for new inputs to iSHAI algorithm. It could be tested several possibilities:

- **Use of more BTs channels from other satellites.** In this case there are two possibilities:
    - The use IR BTs from other GEO imager instrument. As commented below it could be explored dual (or IR stereo) FG GEO imager instruments configurations on regression calculations. These studies could be made in CDOP-4 before MTG-I/FCI launch; especially in the case of delay of MTG-I/FCI launch.
    - The use IR BTs from other GEO sounder instrument. In the case of MTG-I/FCI iSHAI algorithm, it will tested the use of some channels from the MTG-S/IRS to complement MTG-I/FCI channels. This FCI and IRS blend will be tested in order to assess it. These studies could be made in CDOP-4 on MTG-S/IRS commissioning phase for a Day-2 MTG version.
- **Use of L2 outputs from other satellites.** It will tested the combination of forecast NWP, MTG-I/FCI BTs and MTG-S/IRS L2 products (as emissivity atlases, SKT and/or IRS L2 profiles) as input to one blended version of iSHAI algorithm. This studies could be made in CDOP-4, after MTG-S/IRS commissioning phase, for a Day-2 version to explore a future full synergetic MTG version.

In all the cases this approach includes the modification of software for the state vector construction. For this reason and for preparation of future developments, it was started first the exploration of the modification of the software to modify the state vector to test dual (or IR stereo) FG configurations on regression calculations.

6.1 EARLY TEST TO EXPLORE THE DUAL (OR IR STEREO) FG-REGRESSION POSSIBILITIES

In First-Guess step of iSHAI algorithm are used First-Guess regression coefficients; there is one set First-Guess regression coefficients for every zenith angle degree in the range [0º, 75º]. In the process to calculate the First-Guess regression coefficients the synthetic BTs with zenith angle for every degree in the range [0º, 75º] for every pixel in the training dataset used are generated. The training dataset has been extracted from the 2017 training and validation dataset. As this process could be made for every supported GEO satellite it can be generated datasets with synthetic BTs for every zenith angle degree for other instruments than MSG/SEVIRI. Thus, this fact offer the opportunity development to explore the simultaneous use of two GEO satellites located on different subsatellite positions and compare the theoretical performance with the one to use the data from only one GEO satellite to calculate the FG regression.

As proof of this concept of GEO dual (or stereo IR) regression a very preliminary test to build the creation of the GEO dual training dataset and to start the comparison with the equivalent from mono satellite generation of coefficients has been made. The first main objective was to develop the programs to build the creation of the GEO dual training dataset.

As can be seen in Figure 38, there are the opportunity to test at this moment two GEO dual configuration using satellites of same class. This first test was made during the testing of next version 2021 that it will support of both GOES-R class satellites (GOES-16 at GOES-East position and GOES-17 at GOES-West). The other configuration with same class satellites is the MSGs satellites at 0º degree and at IODC position (actually MSG-1 at 41.5º E). These two satellite GEO dual configurations will be modified in 2022; the first with the launch of the future GOES-18 to replace GOES-17 (due to the problems with pipe cooling) and the second with the end of life of MSG-1 that will be replaced by MSG-2 (but at 45.5º E).

The use of GEO dual configurations of GOES-16 and MSG-4 it is more difficult due to the different scanning time; but it could be studied when MTG-I/FCI be operational with same scanning time of 10 minutes.

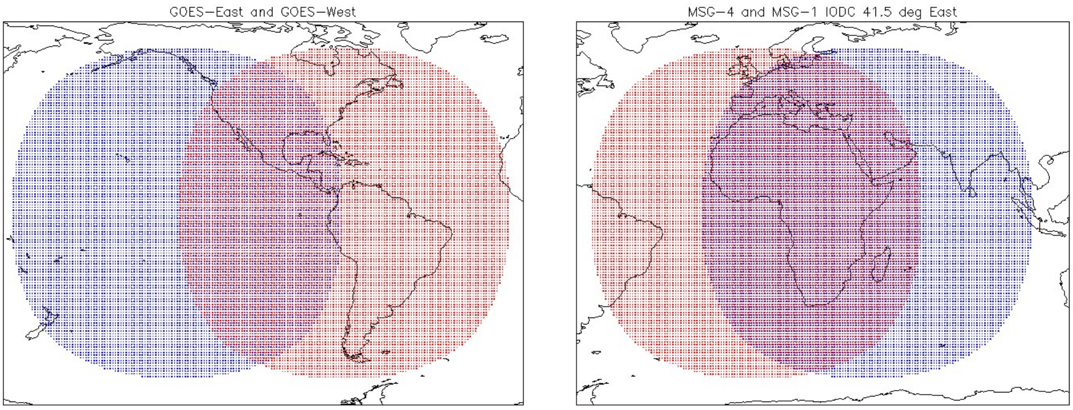

Figure 38: GEO dual configurations with same satellite class. left) GOES-16 at GOES-East position and GOES-17 at GOES-West. Right) MSG-4 satellite at 0º and MSG-1 at IODC position 41.5º E. Regions where satellite field of view has zenith angle less than 70º.

The first step was the developing of the programs to build the GEO dual training dataset and calculate later the FG regression coefficients from a state vector with BTs from satellite 1 and satellite 2. As can be seen in Figure 39, it was modified the IDL program that calculates the FG regression in the mono-satellite case to include the BTs and the square of the BTs of the two satellites. In the case of the mono-satellite configuration the set of FG regression coefficients are calculated for every parameter in the

FG T, q, ozone profiles (at the 54 RTTOV pressure levels) and SKT for every degree in the range [0º, 75º]. In the case of the GEO dual configurations it would require the calculations of FG regression coefficients for every combinations of zenith angles in matrix [0º, 75º] x [0º, 75º] if made for every degree configurations. As 76x75 configurations are too much then at this early test it was made for every 5º reducing the number of configurations to 26x25.

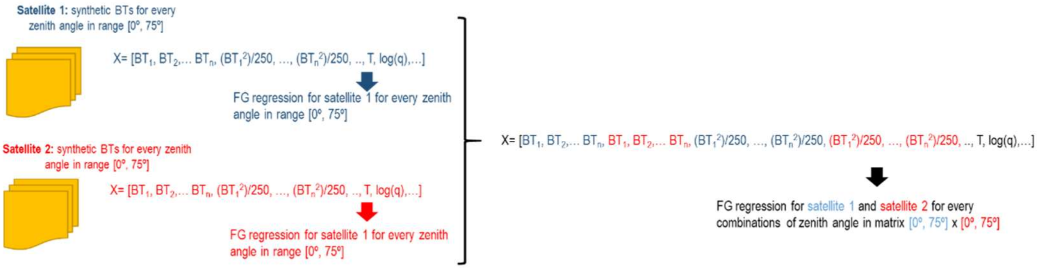

Figure 39: Modification of the IDL program for calculation of FG regression coefficient to test one GEO dual configuration of GEO satellites.

The first test to explore GEO the dual (or IR stereo) possibilities was made with GOES-16 and GOES-17 for every 5º x 5º combination to reduce computation.

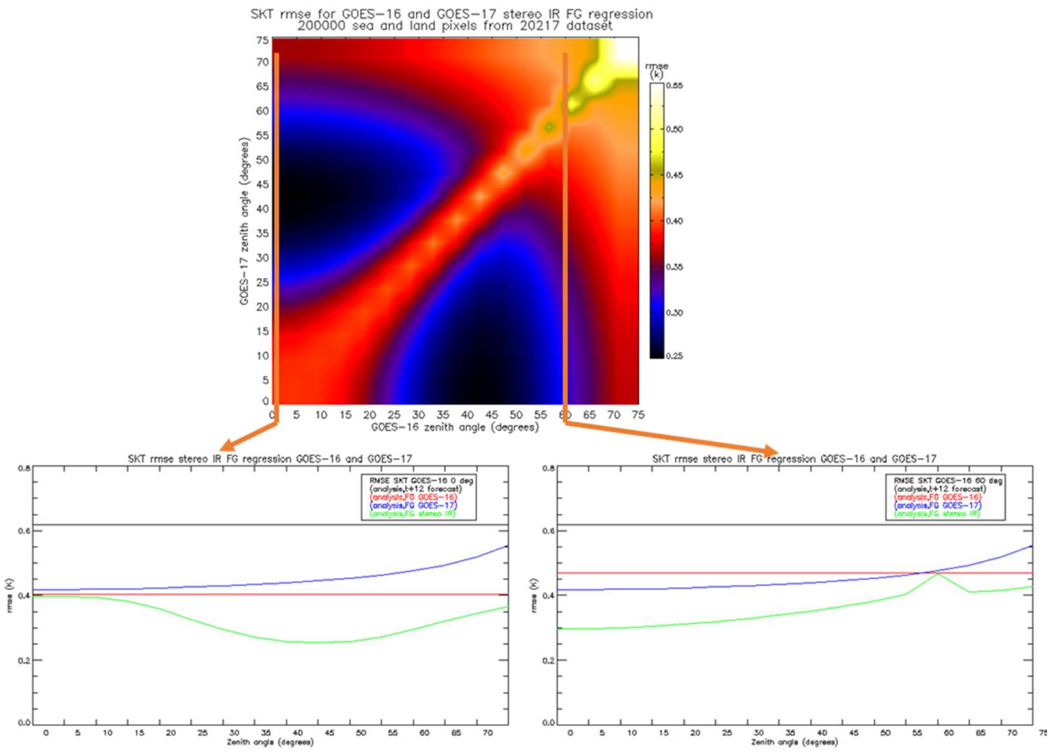

Figure 40: Variation on SKT rmse on the initial test made with GEO dual configuration using GOES-16 and GOES-17 for every 5º x 5º combination.

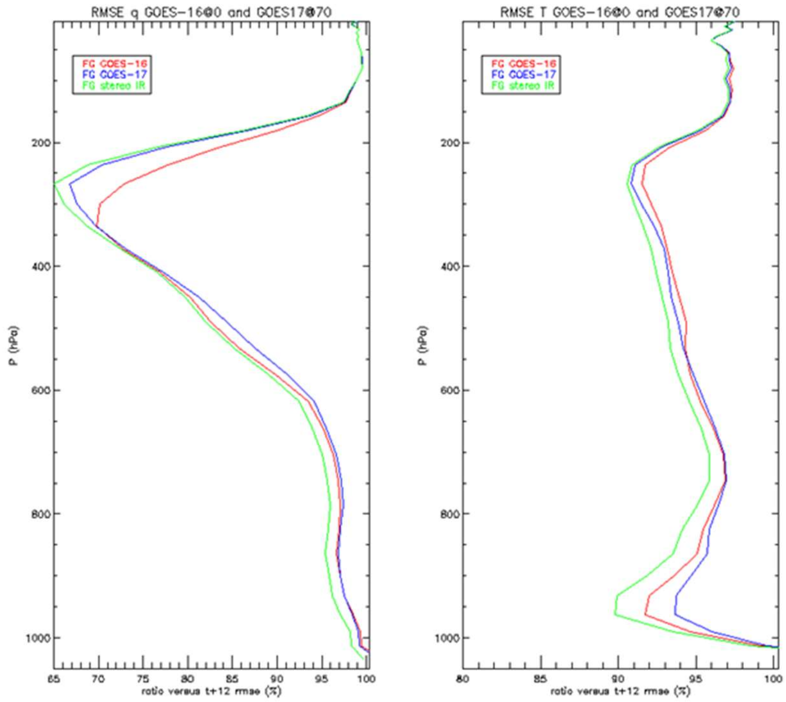

Figure 41: comparison of rmse T and q profiles performances in the case of a theoretical dual configuration using GOES-16 with zenith angle of 0º and GOES-17 with zenith angle of 70º.

This test is very preliminary since it has not been taking into account several important issues as:

- No different slant path in the profiles from the two GEO imager satellites.
- It was assumed same pixel size for the two GEO imager satellites
- It was used a reduced dataset without additional checks
- No tested with real satellite data

The early results can be seen in Figures 40 and 41. It can be seen one slight improvement in the case of a theoretical GEO dual IR configuration. They were shown in the 2021 Convection Working Group Workshop (see Martinez 2021c presentation).

The current NWCSAF GEO software package it is not prepared to use data from more than one GEO IR satellite. But the functions and routines in the software for the PGE00* using Harmonie NWP model, for synthetic iSHAI execution and for IRS remapping (see Report [RD.2]) could be adapted and combined to test with synthetic data first and with real data later the configurations on Figure 38.

6.2 Synergy with IRS L1

Also it is very important to note that the availability of collocated synthetic MTG-I/FCI and MTG-S/IRS data described as described in Chapter 3 will allow to test and prototype the ideas proposed for CDOP-4 to combine the use FCI L1 with IRS L1 and/or IRS L2 in the developments of iSHAI Day-2 algorithms.

In Chapter 3 of [RD.7] document are shown the results of a test made to repeat the process of calculation of FG regression coefficients but using as input to the FG regression 314 IR channels of

IASI as a proxy of the future MTG-S/IRS instrument performance. In this test, instead of using the complete iSHAI training and validation 2013 dataset it was used a reduced dataset with 200,000 pixels and equal weighted iSHAI training/validation dataset extracted from the complete 2013 dataset. A first summary was presented at the 2018 Workshop of the Convection Working Group in Ljubljana (see Martinez 2018a presentation). The list of 314 IASI channels chosen was the one assimilated by some NWP models at 2016 time. The main outcome of this test was that the performance in the 314 IASI channel test was much better than the performance of MTG-I/FCI only test; this outcome is due to have use a significant greater number of IR channels in the IASI test. The importance of this test is not the early results but to establish a basis of the process and to use the programs for future wider and more significant tests. It will be possible to use the software in GEO dual test as basis to build training datasets combining collocated synthetic FCI and IRS (some channels). Then, it would be used to make some early tests combining the use FCI L1 with IRS L1 as input of an iSHAI blended FCI and IRS algorithm for Day-2.

7 CONCLUSIONS, SUMMARY AND FUTURE ACTIVITIES

In CDOP-3 proposal some working packages for preparation of MTG-I/FCI iSHAI were foreseen as activities to do in CDOP-3 phase (March 2017- February 2022). In this Report, a summary of the pioneering activities in CDOP-3 of NWC SAF clear air team for preparation of the use of MTG-I/FCI in NWCSAF has been made. Also, it has been summarized some other side activities not included in the documentation of the delivered regular iSHAI versions.

After delivering of iSHAI software version 2021 and 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 considered in next CDOP-4 phase.

Due to EUMETSAT has not provided good and scientifically correct MTG test data, the main activity in this Report has been the description of the activities made to develop and update the PGE00* tools to generate scientifically correct MTG test data.

All the activities has been made based in the evolution of the PGE00* tools used originally for validation and training of iSHAI algorithm and for the bias BT correction in NWC SAF GEO software packages. It has been described the path followed from the early attempts to the latest version.

GEO-PGE00-VISIR allows to generate high quality simulations of MTG-I/FCI (or other imager instruments) clear and cloudy BTs or reflectance. To get it 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. These profiles used as input to RTTOV are also available as output on the optional PGE00 binary files if it is activated in the PGE00 configuration file the option to write also the input profiles. After release of RTTOV-13.0 and using the previous developments it has been possible to generate the first scientifically correct and collocated MTG-I/FCI and MTG-S/IRS test data on the MTG-I/FCI grid.

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 the early attempts, it was used the operational ECMWF GRIB files on hybrid levels forecasts every 1 hour with 0.1º x 0.1º downloaded from MARS. Also, it was started the exploration of the ways to improve the spatial and temporal resolution of the NWP models used as input to PGE00* programs. It was tested first the use of experimental high resolution executions of the ECMWF (h3f7 experiment); the problems found and the solutions have been described. Then it was created a synthetic dataset using Harmonie model complemented with the operational ECMWF as example of the use of high resolution local model to get high quality simulation.

These synthetic test datasets could be used to explore ideas, as new products from new FCI channels and from IRS. It has been shown first an attempt of a new airmass RGBs using blended real+synthetic data that improves the performance on hot land pixels on summer days. Using similar approach, it has been presented early ideas to estimate the total water vapour in the column using the new FCI VIS0.9 channel; the synthetic dataset will be used also to assess if this parameter is similar to the TPW from iSHAI and to know the contribution of the moisture in each layer. Exploratory developments for the use of the new NIR1.3 channel to help monitoring the water vapour in high levels have also been presented. But the VIS0.9 and NIR1.3 developments have to wait till MTG-I/FCI commissioning phase due to uncertainty of effect of Earth Stray Light issue on real data.

Then, as a proof of concept, these synthetic datasets have been used as input to NWCSAF PGEs. This has been made using the “back door trick” avoiding the need to have official EUMETSAT format files. The products have been used for experiments of theoretical NWCSAF PGEs execution and calculate performances using as “truth” the input data to PGE00 programs.

It has been made an experiment with the comparison of iSHAI outputs using as iSHAI input first synthetic clear air BTs and later synthetic cloudy BTs. The experiment has allowed to determine the influence of unscreened cloudy pixels by the cloud mask on iSHAI. It has been used McIDAS-V to make early comparison of the 3D structure of the cloud profiles on the 3D difference data cube. As demonstration of the high capabilities of the synthetic datasets and tools like McIDAS-V on the analysis of undetected cloud contamination influence in q and T profiles. These outcomes will be used to advice and to recognize the present of cloud contaminated values on iSHAI fields especially near clouds edges.

It has been presented some ideas to improve the iSHAI algorithm for Day-2 version. One of the ideas is to use in CDOP-4 the synthetic datasets to test the design of algorithm based in machine learning.

Other idea is to look for new inputs to iSHAI algorithm. It has been made early test to develop an iSHAI version with a GEO dual (or IR stereo) configuration. These developments would be used to explore the complementation of iSHAI BTs with BTs from some channels of the IRS sounder instrument in a Day-2 blended iSHAI version. Other possibility to test in CDOP-4 it is to test the use of L2 outputs from IRS (emissivity atlases, skin temperature, etc..) as another input to iSHAI.

All these activities have been made as preparation for a future full and synergistic exploitation of MTG-I/FCI and MTG-S/IRS data and products from the METEOSAT Third Generation (MTG) on the NWCSAF/GEO software package. The NWC SAF is developing computer packages that will allow to manage the data from all the three MTG instruments. 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 and users can generate locally their own data cube of products. As a proof of concept it has been used McIDAS-V as a proxy of the layer of user's tools to get an advanced exploitation of the products from the NWCSAF.

Many of the results and Figures described in this Scientific Report have been showing in several Workshops and Conferences on CDOP-3 period. This Report allows to provide also a global view and a map of the developments and achievements.

8 REFERENCES

Martinez M. A.; 2021 (f). Preparation of MTG era: developing of nowcasting tools for GEO imagers and sounders. *EUMETSAT Meteorological Satellite Conference 2021 Virtual Edition 20-24 September 2021. Link to PowerPoint pptx file in NWCSAF web page.*

Martinez M. A.; 2021 (e). Preparation of MTG era: developing of nowcasting tools for GEO imagers and sounders. *ITSC-23 online Virtual meeting 24 to 30 June 2021 online. Link to PDF in NWCSAF web page.*

Martinez M. A.; 2021 (d). Preparation of MTG era: status of simulation of MTG-S/IRS data. *IRS MAG Jun 2021. Link to pptx in NWCSAF web page.*

Martinez M. A.; 2021 (c). Preparation of MTG era: first scientifically realistic synthetic MTG-I/FCI and MTG-S/IRS data generated with RTTOV-13.0. *Convection Working Group Workshop online 2021-04-06 to 2021-04-08. Link to pptx in NWCSAF web page.*

Martinez M. A.; 2021 (b). Preparation of MTG era: first scientifically realistic synthetic MTG-I/FCI and MTG-S/IRS data generated with RTTOV-13.0. *MTG 3T Workshop online 2021-03-08 to 2021-03-11. Link to pptx in NWCSAF web page.*

Martinez M. A.; 2021 (a). Preparation of MTG era: status of MTG-I/FCI and MTG-S/IRS data generation. Updated with RTTOV-13.0.*AEMET internal meeting 2021-02-02. Link to pptx in NWCSAF web page.*

Martinez M. A.; 2020 (b). Preparation of MTG era: status of proxy IRS data generation. *IRS MAG Jun 2020. Link to pptx in NWCSAF web page.*

Martinez M. A.; 2020 (a). Preparation of MTG era: developing of imager and sounder nowcasting products and services for pre-convection phase. *NWCSAF Users' Workshop 2020. Link to pptx in NWCSAF web page.*

Martinez M. A.; Calbet X, 2019. iSHAI and PGE00: key tools for preconvective monitoring and for the preparation of the MTG era. *EUMETRAIN Convection Event Week 2019. Link to pptx in NWCSAF web page.*

Martinez M A.; 2018 (b). Action.M5.A14 - NWC-SAF services and products for MTG-IRS. *IRS Mission Advisory group (IRS-MAG) November 2018 in Brussels, Belgium. Link to PDF in EUMETSAT web page with HAnis loops in NWC SAF web page.*

Martinez M. A.; Calbet X, 2018 (a). iSHAI and PGE00 as key tools in pre-convection. 2018 *Convection Working Group Workshop in Ljubljana, Slovenia. Link to pptx in CWG web page. Link to PDF in CWG web page with HAnis loops in NWC SAF web page.*

Martinez M.A.,; Calbet X, 2016 (c). NWCSAF/GEO clear air product version 2016. Evolution to the MTG era. *Proc. The 2016 EUMETSAT Meteorological Satellite Data User's Conference, Darmstadt, Germany. (S2_Martinez_Miguel.pdf) in zip with oral proceedings in Nowcasting Session. Zip*

Martinez M.A.,; Calbet X, 2016 (b). Instability indices and water content in clear air NWCSAF product. *2016 Convection Working Group Workshop in Florence, Italy.*

Martinez M.A.; 2016 (a). Studies for comparison of NWCSAF/MSG PGE13 SPhR and IASI L2 products. *NWC/CDOP2/GEO/AEMET/SCI/RP03, Issue 1, Rev.0 28-January-2016. Available in NWCSAF Help Desk private document archive.*

Martinez 2015. Presentation in the 2015 NWC SAF Workshop of the former PGE13 SPhR. See the loops and several examples of the use of vertical cross sections for nowcasting for case studies 12th August 2011 and 20th June 2013. Also the ideas for generalization to other GEO satellites and the extension to MTG-IRS applications in nowcasting are shown.

Martinez M.A., Calbet X., 2013. *Innovative ideas for using the hyperespectral level 1 data of the next geostationary MTG-IRS in nowcasting.* Proc. of the 2013 EUMETSAT Conference, Vienna, Austria.

Martínez M.A., X. Calbet, Prieto J., Tjemkes S. 2010 (c). *Use of synthetic RGB images in training.* Proceedings of the 2010 EUMETSAT Meteorological Satellite Conference, Cordoba, Spain.

Martinez M.A.; 2010 (b). Presentation in the 2010 NWC SAF Workshop of the former PGE13 SPhR. See the loops for nowcasting for case study 24th May 2009, 4th October 2009 and 23rd June 2008. It was the first time that interactive 3D examples with IDV were shown.

Martinez M.A.; Li, J.; Romero, R., 2010 (a). NWCSAF/MSG PGE13 Physical Retrieval product version 2010. *Proc. The 2010 EUMETSAT Meteorological Satellite Data User's Conference, Córdoba,Spain.*

Martinez M.A.; Li, J.; et al. (2009). First operational results of the NWCSAF/MSG PGE13 SEVIRI Physical Retrieval algorithm. *Proceedings of the 2009 EUMETSAT Meteorological Satellite Data User's Conference, Bath, United Kingdom.*

Martínez M.A.; Li, J.; et al. (2008). Physical retrieval algorithm development for operational SEVIRI clear sky nowcasting products. *Proceedings of the 2008 EUMETSAT Meteorological Satellite Data User's Conference, Darmstadt, Germany.*