Improvements in Version 2013 of the NWCSAF/MSG PGE13 SevIRi Physical Retrieval (SPhR) Product

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Abstract

The main improvement in the 2013 version is that it allows the use of ECMWF GRIB files on hybrid levels as the background NWP input. The 2012 version of PGE13 SPhR only allowed the use of GRIB files on fixed pressure levels as the background NWP input.

This improvement appears as one small milestone in the generation of better clear air MSG L2 products, but now the spatial and temporal resolution could be used together with the vertical resolution provided by the hybrid levels GRIB files to get 3D uses. The reason is that the use of hybrid GRIB files as input to the algorithm avoids the stepwise aspect on the vertical cross sections created by the linear interpolation between too separated levels in the previous PGE13 versions (using fixed pressure levels). This fact combined with the local execution of PGE13, that allows the generation of optional files with temperature and humidity 3D arrays, can be used by the users to interactively display the 3D structure of the atmosphere. As example, forecasters could detect unstable vertical gradients on medium levels.

All these changes allow the PGE13 SPhR users a better monitoring of key ingredients in regions where convective storms can be developed and also advice of the regions where NWP disagrees with the PGE13 SPhR outputs. The use of PGE13 SPhR using ECMWF hybrid files in one case study is presented.

Introduction

The main objective of the NWC SAF is to produce software packages for MSG and Polar satellites. In the case of the NCWSAF/MSG package, the purpose is to obtain products related to nowcasting on a region selected by user for every MSG image.

After Jun Li’s Visiting Scientist Activities, the product PGE13 MSG Physical Retrieval (SPhR) was developed in 2010. Since version 2013 the PGE13 SPhR includes software to manage ECMWF hybrid GRIB files as a new mode of the PEG13 called PGE13Hyb. All documentation is available in the NWC SAF web page http://www.nwcsaf.org.

The paper is divided in two parts. In the first part, the NWCSAF/MSG physical retrieval algorithm and the improvements of version 2013 are briefly summarized. The use of PGE13Hyb mode in a case study is presented in the second part.

Description of PGE13 SPhR Product

PGE13 SPhR is based on the algorithm of Jun Li (Li 1999 and 2000) from CIMSS/Wisconsin for GOES sounder and then it is similar to the future GOES-R clear air product. The original algorithm was adapted to use NWP SAF RTTOV as radiative transfer model and all the coefficients have been calculated using the PGE13 training and validation dataset (Martinez 2009 and 2011).

PGE13 SPhR has been optimized for the purpose of an operational implementation. The algorithm targets the monitoring of the regions where the atmosphere is unstable and convective storms could be developed.
PGE13 SPhR is based in an optimal estimation algorithm with some differences over the classical physical retrieval approach. These ones are:

- **Use of non-linear regressions to build the First Guess (hereafter FG).** Instead to use directly the NWP profiles as FG, the FG profiles are the result of non linear regressions using as inputs one NWP profile (hereafter background NWP) and bias corrected brightness temperatures (BT) from five MSG IR channels.

- **Use of Empirical Orthogonal Functions (EOFs)** to represent the temperature and moisture profiles in order to reduce the dimension of matrices to invert. In version 2013 of PGE13, three EOFs are used for humidity, two EOFs are used for temperature and one for skin temperature.

The algorithm is only applied on clear air pixels or Field of Regards (FOR) of configurable width; the default FOR width is 3x3. RTTOV-9.3 is used for synthetic BT calculations (forward model) and Jacobian calculations. After the FG regression calculation step, an estimation of the distance (BT\_RMS) between MSG BTs and synthetic BTs using as input to RTTOV the FG profile is made. BT\_RMS is the distance on the non-window channels (WV6.2, WV7.3 and IR13.4) between MSG BTs and RTTOV BTs. If the distance is greater than a configurable threshold (BT\_RMS\_THRESHOLD) the iterative physical retrieval process is applied. For whole mathematical description and details, see the PGE13 SPhR Algorithm Theoretical Basis Document (ATBD) at the NWC SAF web page.

All the coefficients of version 2013 have been updated. They have been calculated with the profiles of the 2012 year from the PGE13 validation and training dataset. Also the emissivity atlases have been updated using the 2012 IREMIS datasets from CIMSS/Wisconsin.

Since the physical retrieval can be applied only over the clear pixels, the PGE01 Cloud Mask program must be executed before the PGE13 program. In operational mode, NWCSAF/MSG “Task Manager” tool synchronises the execution of the products so the first product that is generated upon the arrival of a new image is the PGE01 Cloud Mask. Once the Cloud Mask is available, the “Task Manager” tool executes PGE13 using as inputs MSG images on HRIT format, background NWP and Cloud Mask (see Figure 1).

Due to the few number of MSG channels, temperature and humidity profiles from a background NWP model are needed as other input to the algorithm to provide a good start profile. Then, NWP GRIB files from t+00 to t+24 hours forecast are needed. Background NWP profiles must be spatial, temporal and vertically interpolated at the MSG pixel in order to get NWP data at the 43 RTTOV pressure levels collocated with MSG data. But, NWC SAF library only allows the use of NWP GRIB files on fixed pressure levels for the NWP management. By this reason in previous versions only NWP GRIB files at fixed pressure levels could be used as input to PGE13 limiting the vertical resolution in the background NWP profile. In the case of ECMWF the number of fixed pressure levels is just only 15 fixed pressure levels.

In version 2013 of PGE13 SPhR there are two optional modes of execution that depend on the kind of the background NWP GRIB files used as input to PGE13:

- **PGE13P mode:** it uses NWP GRIB files only at fixed pressure levels
- **PGE13Hyb mode:** it allows now only ECMWF GRIB files at hybrid pressure levels

In order to maintain the continuity, PGE13P mode is the default mode in the distributed version 2013 of the NWCSAF/MSG software package. PGE13P mode is an update of the 2010 version with all the coefficients updated and trained with 2012 year of the PGE13 training dataset. PGE13P mode uses the NWC SAF library for the NWP background management and PGE13P mode only allows the use NWP GRIB files on fixed pressure levels as input. The order of NWP interpolations in PG13P is spatial, temporal and vertical interpolation to the 43 RTTOV pressure levels. Spatial and temporal interpolations are made outside of the PGE13 by the “Task Manager” tool at the pre-processing step.

**NEW PGE13Hyb MODE IN VERSION 2013**

The new PGE13Hyb mode is the result of a major update in the code of PGE13 SPhR to allow the use of ECMWF GRIB files on hybrid levels as the background NWP input. The code has been rewritten
in Fortran-90 and C and using structures. It will allow a better maintenance and future improvements. The whole management of the NWP GRIB files is made now inside of the PGE13Hyb code and no pre-processing of the ECMWF GRIB files by the “Task Manager” tool is needed.

The change from PGE13P mode to PGE13Hyb mode is made changing the keyword “NWP_EXEC_MODE” from “P” to “HYB” in the PGE13 configuration file using one text editor. See details in the PGE13 SPhR Program User Manual (PUM).

In PGE13Hyb mode, the order of NWP interpolations is first vertical, second temporal and third spatial. The vertical interpolation to the 43 RTTOV pressure levels is made from the hybrid levels. In the case of ECMWF the number of hybrid pressure levels is now 137 (before June 2013 the number was 91). The spatial interpolation is only made at the clear air FORs minimizing the memory needed.

All the coefficients of the new PGE13Hyb mode have been calculated using only profiles from hybrid levels ECMWF GRIBs of the 2012 year from the PGE13 validation and training dataset. The training dataset has been built using only temperature and specific humidity profiles from hybrid levels (91 levels of the 2012) interpolated to the 43 RTTOV pressure levels. Since the profile is now complete and independent in all the levels, the FG regressions are made with all the 43 levels. This avoids the extrapolation above pressure level of the top that is made in the PGE13P mode. The skin temperature from ECMWF has been also added as other dependent variable in the FG regressions.

In PGE13Hyb, the humidity profile is directly read as specific humidity from the ECMWF GRIB files avoiding the conversion from relative humidity that is made in PGE13P mode.

By these reasons, the PGE13Hyb mode has a background NWP profile with high quality and the PGE13 SPhR outputs are obtained with higher quality than in PGE13P mode. This allows other kinds of applications for the PGE13Hyb outputs.

PGE13 is highly modular and configurable. In the execution of PGE13, the third parameter is the name of one ASCII file with all the processing options. The users can edit this PGE13 Model Configuration File (extension .cfm) to tune PGE13. The main configurable options are:

- The window size for processing in boxes (FOR) of M x M pixels (default 3 x 3).
- Method to calculate the BTs of the MxM window: a) the mean of all clear pixels that is the default, b) the MSG BTs of the warmest clear pixel at the IR10.8
- The keywords: BT_RMS_THRESHOLD and MAX_RESIDUAL. They control the level of the desired error between the bias corrected MSG BTs and the RTTOV BTs.
- Number of iterations. Maximum number of iterations. The default is 3 iterations.
- The name of all coefficients files are keywords in the configuration files.
- MSG BT bias corrections coefficients

Figure 1: PGE13 SPhR inputs and outputs scheme on PGE13Hyb version.

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Optional writing of temperature profile, specific humidity profile and skin temperature at clear processed FOR (M x M pixels) or for all FOR at several steps of the algorithm. These options have been used to create the PGE13 training and validation datasets. See PGE13 PUM for more details.

MSG BT BIAS CORRECTION

In order to calculate the MSG BT bias correction, the evolution of the BT bias correction between MSG BTs and synthetic RTTOV BTs must be analyzed first. This has been made using the PGE13 MSG BT bias correction dataset to choose an adequate period. This dataset is built after reprocessing for a wide period the 00 UTC and 12 UTC MSG images with ECMWF analysis (00 UTC and 12 UTC respectively) using as options: a) window size of 25x25, b) MSG BTs of the warmest clear pixel at the IR10.8 and c) save profiles on binary files at clear FOR. Only sea pixels are used for BT bias correction or monitoring to avoid emissivity issues.

As example, after the inspection of the evolution of the BT biases for MSG-2 (see Figure 2) the period after the decontamination maneuver on March 2013 has been chosen for the calculation of MSG-2 BT bias correction coefficients of version 2013. Similar process has been repeated for MSG-1 and MSG-3 (the days of July 2013 after MSG-3 decontamination maneuver has been used).

Once the period is chosen, the calculation of BT bias correction is made using robust regression between the collocated MSG BTs and synthetic MSG RTTOV BTs calculated from ECMWF analysis. Thus, all the BT bias corrections delivered with 2013 have been updated to their actual states at the end of July 2013. There are BT bias correction coefficients for PGE13P and PGE13Hyb due to slight differences.

It is recommended to update the software. In other case, the users should just copy the BT_GLOBAL_OFFSET_ and BT_GLOBAL_OFFSET_ lines from the default 2013 version PGE13 configuration file corresponding to the satellite and PGE13 mode that the user is processing.

Following a similar process, a full validation of the PGE13Hyb has been made. See the Scientific Report: “Improvements in “PGE13 MSG Physical Retrieval Product (SPhR)” using as input ECMWF GRIB files on hybrid levels” that is available in the NWC SAF web server.

PGE13 SPhR HDF-5 MAIN OUTPUTS

The main output of PGE13 SPhR is one HDF-5 file that contains several fields. The main fields are key ingredients in convection triggering. There are four fields related with the content of the precipitable water calculated from the specific humidity retrieved profiles: Total Precipitable Water (SPhR_TPW) and the Layer Precipitable Water (LPW) in three layers of the atmosphere (SPhR_BL [PressureSurface, 850 hPa], SPhR_ML [850, 500 hPa] and SPhR_HL [500, 0.1 hPa]). There are also three instability indexes calculated from the specific humidity and temperature retrieved profiles: Lifted Index (SPhR_LI), Showalter Index (SPhR_SHOWALTER) and K-Index (SPhR_KI).
Together with the parameters calculated directly from the retrieved profile, the differences between the parameters calculated from the retrieved profiles and the ones calculated from background NWP are also available as other outputs.

**CASE STUDY: CONVECTION ON THE IBERIAN PENINSULA THE 12th AUGUST 2011**

As can be seen in the Figure 3, strong convection took place the 12th August 2011 in the northern Iberian plateau and in the Iberica Mountains.

![Figure 3: 12th August 2011 normalized natural RGB images every three hours from 06 to 21 UTC. They are made after normalization of VIS channel radiances to the same sun zenith position and date in order to enhance the contrast at twilights and improve comparison. Normalization is made using an internal AEMET McIDAS command.](image)

As can be seen in Figure 4, one cold air core is approaching to the northern Iberian plateau from Lisbon. Cold air in high and medium levels is one of the ingredients for convection.

![Figure 4: 12th August 2011 strong convection over Iberian Peninsula: sequence of eight images every three hours 00 to 21 UTC of airmass RGB.](image)

At least in Spain, for Nowcasting purposes the monitoring of the precipitable water on the medium layer is very important to determine the region where convection could be triggered. Also, this is the layer with highest value add from satellite due to the MSG WV channels.

It could be seen in loops of PGE13Hyb images every 15 minutes a strong moist air flow in medium levels from the South (likely connected with the subtropical jet). In the Figure 5, the PGE13Hyb ML images every three hours are shown as example. They have been calculated after reprocessing at pixel by pixel resolution with ECMWF hybrid levels (91 levels). It has been used ECMWF GRIB files from $t+00$ to $t+24$ every hour with high spatial resolution ($0.125\degree \times 0.125\degree$) from the 12th August 2011 00UTC run. In this case study, the humid air flow from the South is the other main ingredient for the convection. The convection started at 9 UTC at the Sistema Central Mountains where orographic factors combined with the above ingredients meet.

It is a good idea to have the possibility to show the background NWP in the same projection, colour palette and time that the PGE13 SPhR outputs. This provides the spatial structure that can be hidden by the clouds. It is possible with one slight modification of PGE13Hyb code (hereafter PGE00Hyb tool) to get the parameters calculated directly from ECMWF GRIB files interpolated temporally, vertically and spatially to one MSG image for the whole region. The PGE00Hyb ML parameter every three hours are shown in Figure 6. The forecasted moist air flow by the ECMWF is clearly shown.
In the Figure 7, it is shown the difference at 9 UTC between the ML parameter calculated from the retrieved q profiles and ML calculated from the ECMWF q profiles. In the diffML image, a red pixel indicates that the background NWP underestimates the precipitable water in the layer 850-500 hPa. The red spot in the Sistema Central region indicates that a moist air flow and wetter than forecasted by the \( t+9 \) ECMWF from 00UTC is over Sistema Central Mountains region. diffML is one of the parameters with more value add of PGE13 SPhR due to the contribution of the WV channels. diffML (and the other diff parameters) can help forecasters to detect disagreements between the forecasted NWP fields and the PGE13 SPhR outputs that are based in actual observations from MSG images.

If the availability time of the parameters is compared, it can be also seen the importance of the PGE13 SPhR product. In the Figure 8, the ML parameter calculated from the ECMWF \( t+12 \) forecast from the 00 UTC run and the ML parameter from ECMWF analysis from the 12 UTC run are shown. The region inside the red circle is clearly wetter in the 12 UTC ECMWF analysis than in \( t+12 \) from 00 UTC run. This confirms the conclusion from the Figure 7. Thus, it is shown that PGE13 SPhR can advice to...
forecaster that the Sistema Central region is wetter than expected some minutes after the reception of the MSG images and several hours before that 12 UTC analysis of the ECMWF can confirm this.

**Figure 8:** Availability time of Precipitable Water in Middle Layer ML(850-500 hPa) images for 12th August 2011 at 12:00.

### OPTIONAL PGE13 SPhR BINARY FILES OUTPUTs. CONVERSION TO netCDF FORMAT.

Taking into account that PGE13 SPhR is executed locally and no dissemination by EUMETCast is needed, the temperature and humidity profiles interpolated at the 43 RTTOV pressure levels at the main steps of the PGE13Hyb algorithm (after NWP interpolation, FG regressions and physical retrieval) may be written as optional outputs on binary files. The users can activate the generation easily by editing a keyword in the ASCII 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.

Since the binary files are not easy to manage, one IDL prototype to convert the PGE13 binary files to netCDF format has been written. The files on netCDF format can be managed by several tools like McIDAS-V and IDV (they are freely available on their respective web pages) to produce 3D displays interactively.

In the Figure 9, the vertical cross sections of the normalized 3D arrays of T and q for 9 UTC are shown as example. The images are one example of 3D interactive use by users of PGE13Hyb and PGE00Hyb netCDF files. In loops of the vertical cross sections (not shown here) can be seen the entrainment of the cold air in high levels over the low and medium levels moist air flow.

**Figure 9:** Vertical cross sections using McIDAS-V of normalized 3D arrays of T and q for 9 UTC on 12th August 2011 from PGE13Hyb and ECMWF (PGE00Hyb). To normalize them it has been subtracted the mean on every level for the $t+12$ ECMWF forecast in the region of the Figure 5 and divided by the standard deviation on the level for this slot.

In the Figure 9, it can be seen on the vertical of Sistema Central area that high and middle levels are colder than average (blue), that low levels are warmer than average (red colours) and that there is wet air on low and medium levels (green colours). Following R. Petersen (U. Wisconsin) idea, the $\theta_e$ 3D arrays has also been written in the netCDF files to monitor unstable regions and levels. The $\theta_e$ images for 9 UTC are shown in Figure 10. The $\theta_e$ vertical cross sections of PGE13Hyb (right) show deeper
orange and red colours than the PGE00hyb ones (left) on low levels in Sistema Central region; the upper levels show deeper green colours. These facts show that PGE13Hyb is able to detect the presence of unstable vertical profiles and that they are more unstable than forecasted by the t+9 ECMWF forecast.

![Image: PGE13Hyb and ECMWF (PGE00Hyb) vertical cross sections of θ, for 9 UTC on 12th August 2011.]

**Figure 10:** PGE13Hyb and ECMWF (PGE00Hyb) vertical cross sections of θ, for 9 UTC on 12th August 2011.

**CONCLUSIONS**

PGE13Hyb is available from version 2013. It allows the use as background NWP input of ECMWF GRIB files on hybrid levels. This is the first step in the use of better NWP GRIB files in the NWC SAF.

PGE13 SPhR provides useful spatial information; especially to detect disagreement between the background NWP model and the PGE13 SPhR outputs based on MSG observations. The best results are obtained for humidity in medium layers due to the contribution of the two MSG water vapor channels. Although, MSG has limited information to improve the vertical information of the background NWP a certain degree of vertical value add can be obtained. This can be exploited with 3D display tools.

It must be created a set of web pages in the NWC SAF web server for PGE13 SPhR product where cases studies and frequent updates and monitoring of the BT bias correction should be available.

**FUTURE WORKS**

In CDOP-2 phase, it is foreseen the extension of the clear air product to other geostationary satellites and to prepare for MTG-FCI era. The IASI RTTOV coefficients and the conversion of IASI radiances to MTG-IRS BTs will be used to explore the development of MTG-IRS algorithms (Martinez, 2013). The PGE13 validation and training dataset will be used for these developments.

**REFERENCES**


