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Processing of GeoRad Clear Sky Radiance at the Canadian Meteorological Centre

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Revision history			
Version	Date	Author/modifications	Remarks
1.0	2012/06/06	A. Beaulne, R. Sarrazin	For Strato2b-R (GDPS 2.2.0) implementation in date of 2011/11/16
1.1	April 2013	A. Beaulne	For GEM4 (GDPS 3.0.0) implementation in date of 2013/02/13
1.2	Nov 2013	A. Beaulne	Addition of MeteoSat10
1.3	Apr 2016	A. Beaulne	Addition of Himawari-8 Update for the GDPS5.0.0 implementation of December 15, 2015

Table of Contents

1. Introduction.

This document is a summary description of the operational processing of GeoRad Clear Sky Radiances (CSR) at the Canadian Meteorological Centre (CMC). An overview of quality control, bias correction, data thinning and operational monitoring is presented. In operations, the GeoRad family replaced the GOES family of radiances on November 16, 2011. This new naming is a more general term which describes the global coverage of geostationary satellites now being assimilated instead of only the American geostationary satellites assimilated until the aforementioned date. Another important aspect of this transition has to do with the technical aspects of the processing of the radiances.

The assimilated data are the radiances from the water vapor channel of the geostationary satellites. This channel is mainly sensitive to moisture and temperature in the layer 250-550 hPa. The radiative transfer model RTTOV is now used as observation operator, as is done for all the other radiance families operationally assimilated. This replaces the local production of the "_go" family of data which used in-house operators on the GOES satellites (Garand, 1993) by the products coming from NOAA/NESDIS, EUMETSAT and JMA, thus creating the new "_csr" family of data.

This document is organized in the following way. The table below shows the assimilation history of the different geostationary satellites. Then, a flowchart in section 2 gives a summary of the different steps in the processing of the GeoRad imager radiances. In sections 3 through 7, each process is described individually. In the final section, a description of the operational GeoRad imager monitoring is presented.

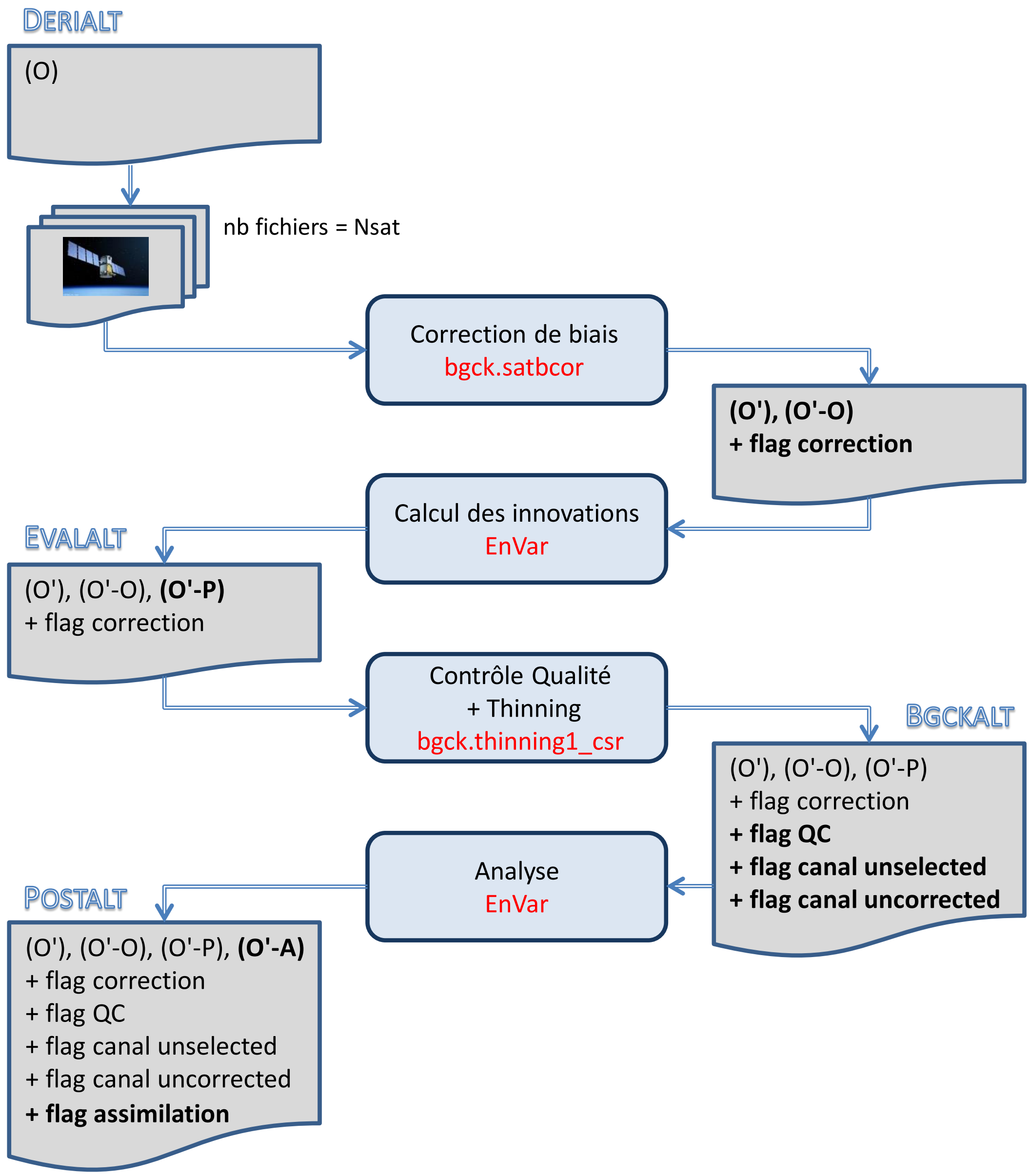
Date of change	GOES-W	GOES-E	Meteosat-W	Meteosat-E	Himawari
16 nov. 2011	11		9	7	MTSAT-1R
6 déc. 2011			9	7	MTSAT-1R
26 déc. 2011			9	7	
18 oct. 2012			9	7	MTSAT-1R
26 déc. 2012			9	7	
21 jan. 2013				7	
13 fév. 2013	15	13		7	MTSAT-2
7 nov. 2013	15	13	10	7	MTSAT-2
10 nov. 2014	15	13	10	7	MTSAT-1R
28 nov. 2014	15	13	10	7	MTSAT-2
16 mars 2016	15	13	10	7	Himawari-8

This table shows the modifications that were made in the geostationary satellite assimilation since the implementation of the GeoRad family. A gray box indicates no assimilation. MTSAT-1R is also known as Himawari-6 while MTSAT-2 is also known as Himawari-7.

2. Flowchart of GeoRad radiance processing.

The different steps leading to the assimilation of GeoRad radiances are illustrated in the following flowchart, which has been modified since the use of the Maestro sequencer in November 2014. A gray wavy bottom edge rectangle represents a BURP file while a blue rounded corners rectangle is a process. Variables shown are the observed radiance (O), the bias corrected radiance (O'), the trial simulated radiance (P) and the analysis simulated radiance (A). The processes are:

1) Start with a DERIALT file,
2) From file in (1), compute the radiance bias correction (O'-O), using the bias correction coefficient file, and apply to raw observed radiance (O) to obtain the corrected radiance (O'),
3) From file in (2), compute the innovation (O'-P) using the EnVar, creating the EVALALT file,
4) From file in (3), apply a quality control and then a thinning at 150km, creating the BGCKALT file,
5) [not shown] Also from file in (3), compute the innovation (O'-A) using only the conventional type of data in a 3Dvar analysis (Gauthier et al., 1999) and, from the resulting file, apply a quality control and then a thinning at 200km,
6) [not shown] From file in (5), create the bias correction table file and, using the historic from the last seven days, compute the coefficients and create the bias correction coefficient file to be used next date in step (2),
7) From file in (4), assimilation in the EnVar (Buehner et al., 2015).



Processing of GeoRad radiances. Gray wavy bottom edge rectangles represent BURP files while blue rounded corners rectangles represent processes (with the program names in red).

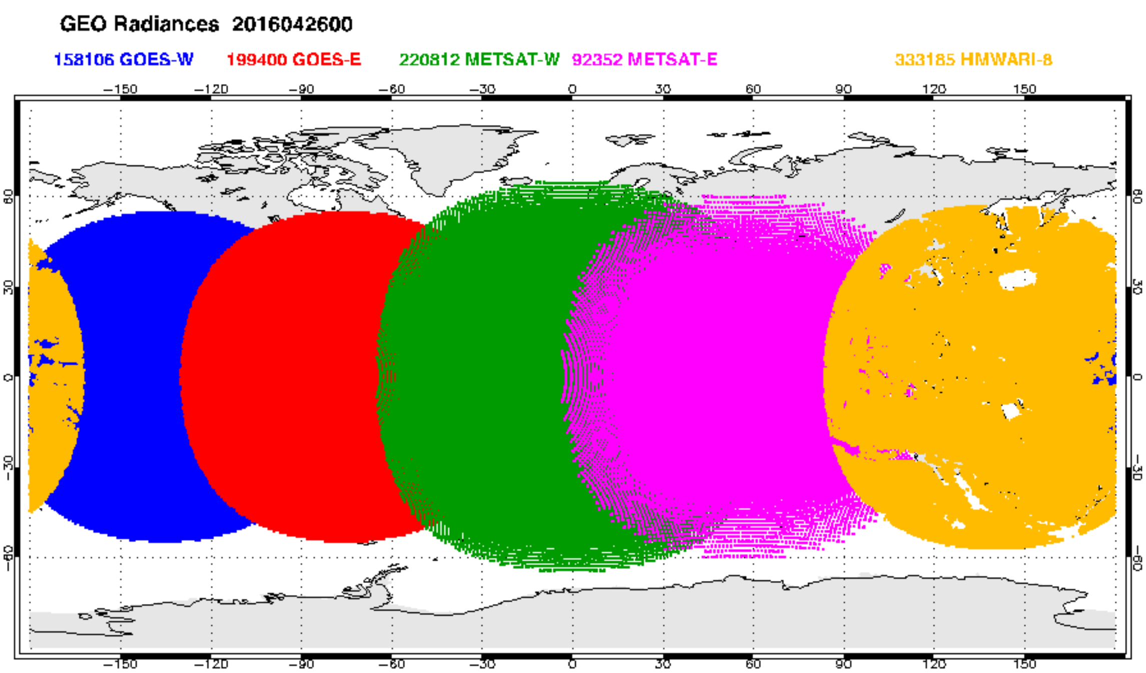
3. Observed radiance.

Data for the GOES satellites (NOAA/NESDIS) are gathered by ftp on the NESDIS server while data for Himawari (JMA) and Meteosat (EUMETSAT) are gathered on the GTS.

All these data are coded in BUFR format. The bulletins from the different producers are more or less similar. All data assimilated include a complete disk every hour. The following show the central wavelength of the channels decoded, with the channel actually assimilated in italics.

GOES-W, GOES-E:				
Instrument IMAGER:	ch2: 3.90µm,	*ch3: 6.55µm*,	ch4: 10.70µm,	ch5: 13.35µm
Meteosat-W:				
Instrument SEVIRI:	ch4: 3.92µm,	*ch5: 6.25µm*,	ch6: 7.35µm	ch7: 8.70µm,
	ch8: 9.66µm,	ch9: 10.80µm,	ch11: 12.00µm,	ch12: 13.40µm
Meteosat-E:				
Instrument MVIRI:	*ch1: 6.40µm*,	ch2: 11.5µm		
Himawari-8:				
Instrument AHI:	ch1: 3.85µm,	*ch2: 6.25µm*,	ch3: 6.95µm,	ch4: 7.35µm,
	ch5: 8.60µm,	ch6: 9.63µm,	ch7: 10.45µm,	ch8: 11.20µm,
	ch9: 12.35µm,	ch10: 13.30µm		

Here an example of decoded data:



The assimilated brightness temperature is the spatial average of the pixels from the segment which is considered as being in clear air. For instance, JMA uses segments of 16*16 pixels (32*32 km^2) (Takahito and Daisaku, 2016) and determines which pixels from the segments are in cloudy or clear zones. EUMETSAT uses segments of 16*16 pixels (about 80*80 km^2) while NESDIS uses segments of 11*17 pixels (about 45*45 km^2). For Himawari-8 and Meteosat-10, a cloudy pixel can be regarded as a clear one when the contribution of cloud top emission to total radiance is negligible. The bulletins also include information relevant to the data: localization, hour, zenith angle, cloudy and clear fraction in the segment, quality flags, etc.

The greatest amount of data comes from the Meteosat-10 and Himawari-8 satellites. To reduce the amount of data assimilated from these satellites in addition to avoid cloud contamination due to their different perception of a clear pixel, a lower threshold is set on the percentage of clear pixels in a segment in order for it to be considered for further quality control. This lower limit is strictly set to 86% for Meteosat-10 but up to 100% for Himawari-8, while it is of only 11% for the GOES and Meteosat-7 satellites.

During periods of eclipses the data are not available at certain hours. Also, Meteosat satellites from first generation (like Meteosat-7) show anomalies near local midnight all year long, even outside periods of eclipses. C. Köpken (2001) identified this effect as « Solar Stray Light Effects ». These data should be removed from the ones to be assimilated. Finally, GOES data have a calibration problem near local midnight, hence ECMWF blacklist these data.

Research work is being carried to make use of the other infrared channels (the so-called window channels) which are greatly sensible to the surface temperature.

4. Derivate sequence

The derivate sequence only applies minor changes to the BURP file coming from the DBASE. The bgck.thinning0_csr program eliminates a part of the data and reduces the size of the BURP file. The criteria used are:

- A record should contain a Tb to assimilate for a clear-air zone.
- Maximum angle which correspond to a latitude of around 62 deg.
- A cloud fraction should be inferior to the limit (note : this limit vary as a function of the satellite, 95% for GOES and Himawari while 30% for Meteosat, since the different producers do not give the same kind of fraction for the WV channel to assimilate).
- Eliminate some data near the local midnight for Meteosat-7 (Solar Stray Light Effect).
- Eliminate some data near the local midnight for GOES.

5. Bias correction.

Radiance observations, as well as radiative transfer models, contain important errors. It is essential to remove the radiance biases in order to optimally extract the information content for data assimilation. Radiance biases are evaluated using an “unbiased” 3DVar analysis (A) without any satellite radiances assimilated.

Radiance < *O-A* > biases (< > indicates time average) manifest in two different ways, one of which depends on a global bias and the second of which is air-mass dependent. This led to a two-step approach at CMC, the first of which is to remove the global bias, followed by a second step that removes the remaining bias, using a linear regression between the bias and the following model predictors:

- geopotential thickness of the layer 1000hPa-300hPa (T1);
- geopotential thickness of the layer 200hPa-50hPa (T2);
- geopotential thickness of the layer 50hPa -5hPa (T3);

A different set of regression coefficients are computed for each satellite, instrument and channel. The regression coefficients are recomputed every 6 hours, based on the O-A/predictor statistics of the previous 7 days.

The implementation of this radiance correction at the level of the BURP observation file proceeds in the following way:

1) a data quality flag indicates that a radiance has been corrected (bit 6 is set);
2) the bias correction itself appears as a separate element in the BURP file.

Therefore, it is always possible to re-construct the original observed radiance by using the corrected radiance and its correction. Appendix A has a summary of the main BURP descriptors associated with GeoRad data.

6. Simulated radiance.

In order to assimilate GeoRad radiances, we need to calculate the so-called (O-P) innovation

$y-H(x)$, where:

> *y*: observed (corrected) radiance (O),
> *x*: model state (temperature TT,
> *natural log* specific humidity LQ,
> surface pressure PS,
> surface temperature TS,
> surface winds UU and VV),
> *H*: non-linear observation operator.
> *H(x)*: simulated radiance (P)

Surface winds (UU,VV) are needed by the radiative transfer model to estimate surface emissivity over open water for the surface contribution.

The operator *H* includes the following:

- horizontal interpolation of the background model state (*x*) to GeoRad observation points;
- vertical interpolation of TT and LQ from the background hybrid levels to the RTTOV radiation model's pressure levels;
- computation of simulated GeoRad radiances using the RTTOV fast radiative transfer model.

The EnVar program used to assimilate data computes the innovations. Currently, we use the RTTOV-10 radiative transfer model, maintained and distributed by the EUMETSAT Satellite Application Facility on Numerical Weather Prediction (NWP SAF). The RTTOV web site can be found at: http://www.metoffice.com/research/interproj/nwpsaf/rtm/index.html.

It replaces the MSCFAST radiative transfer model, developed by Louis Garand (Garand et al., 1999), which was previously used with assimilation of GOES data.

7. Quality control and horizontal thinning

After the data reduction and some quality control checks of the derivate sequence, bias correction and computation of the O-P innovations, GeoRad radiances pass another series of quality control checks listed below:

- Satellite zenith angle: remove data where value > 62 degrees.
- Stray Light effects for Meteosat-7: remove data at 21Z. Also, from January 20th until May 14th and from August 1st until October 31st, remote data at 20Z and 22Z.
- GOES local midnight: for GOES-W, remove data at 08Z and 09Z while for GOES-E, remove data at 04Z and 05Z.
- Remove data rejected for topography.
- Remove data for which the innovation is too large (from 5 K to 6 K depending on the satellite).
- Remove data for which the percentage of clear pixels in the segment is too low, as discussed in section 3.

Then, in order not to overwhelm the assimilation system and to provide an appropriate volume of data for the analysis grid, the density of data from all satellites are reduced to a separation of about 150 km. This separation seems to be optimal with the current system, due to the fact that it assumes no horizontal correlation of the observational error for radiances and given the rather broad horizontal correlation functions of the background error.

The thinning process for ATMS proceeds the following way. Data are separated into time slots, corresponding to each time step of the model background (trial) field. Currently, the time slot delta (dstepobs) is 15 minutes giving a total of 25 time slots in the 6-hour assimilation window. For each time slot, data are grouped into 150 x 150 km square thinning boxes and filtered as described here:

- Data for which distance from the center of the box exceeds 45km are rejected.
- When a data from the same instrument has already been chosen, compare their value of percentage of cloud in the segment and keep the profile which has the lowest.
- When a data from another instrument has already been chosen, compare their value of satellite zenith angle and keep the profile which has the lowest.

A thinning done at 200km resolution is also performed for the data which will be saved in the bias correction table files.

8. Monitoring.

The operational monitoring of GeoRad radiances is part of the CMC on-line monitoring system, developed for all observations used in the EnVar assimilation. The address of this web site is the following:

Internal:

http://iweb.cmc.ec.gc.ca/~afsdwww/monitoring/index.html

External:

http://collaboration.cmc.ec.gc.ca/cmc/data_monitoring/

The external site requires a username and password for access that are easily available, by sending a request via e-mail to simon.pellerin@ec.gc.ca

The GeoRad monitoring is divided in four parts:

- data reception;
- data quality monitoring;
- data included in the analysis;
- monthly means.

Information is available on the number of GeoRad data and their geographical distribution, both on reception and following data thinning. Time series of innovations are also available and their use is mainly to detect any drift in the satellite measurements and/or in the bias correction of the radiances. Maps of 6-hour innovations are available for each satellite, channel and synoptic hour, while monthly means of these are useful in detecting systematic errors in the system, if any should exist.

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10. Glossary.

3DVar	3-Dimensional Variational [analysis]
AHI	Advanced **Himawari** Imager
BUFR	Binary Universal Form for the Representation [of Meteorological Data]
BURP	Binary Universal Report Protocol
CMC	Canadian Meteorological Center
CSR	Clear Sky Radiance
ECMWF	European Center for Medium-Range Forecasts
EnVar	[Hybrid] Ensemble-Variational [analysis]
EUMETSAT	European Organization for the Exploitation of Meteorological Satellites
GeoRad	Geostationnary Radiance
GOES	Geostationnary Operational Environmental Satellite
GTS	Global Telecommunication System
Himawari	[Japanese word for "sunflower"]
JMA	Japanese Meteorological Agency
Meteosat	Meteorological Satellite
MTSAT	Multi-Function Transport Satellite
MVIRI	**Meteosat** Visible Infra-Red Imager
NESDIS	National Environmental Satellite, Data and Information Service
NOAA	National Oceanic and Atmospheric Administration
RTTOV	Radiative Transfer for **TOVS**
SEVIRI	Spinning Enhanced Visible Infra-Red Imager
TIROS	Television and Infrared Observation Satellite
TOVS	**TIROS** Operational Vertical Sounder

Appendix A. BURP descriptors for GeoRad files (based on BUFR).

<u>NOTE</u>: BURP file code type for GeoRad is 185.

Descriptor number	Descriptor
005042	GeoRad instrument channel number
012163	Brightness temperature
012233	Brightness temperature correction
001007	Satellite identifier
002019	Satellite instrument
055043	Surface emissivity
007024	Satellite zenith angle
007025	Solar zenith angle
008012	Land/sea qualifier
020081	Cloud amount in segment (%)