RESEARCH DEPARTMENT
MEMORANDUM

ECMWF

To:	RD, FD, DR, DF, DG, Copernicus Section Heads	
Copy:		
From:	Cristina Lupu and Tomas Wilhelmsson	
Date:	March 8, 2016	File: RD16-064
Subject:	**A guide to simulated satellite images in the IFS**	

Abstract

The system to simulate satellite images from the ECMWF forecast fields (out to ten days) has been significantly upgraded with the implementation of the new high resolution model (cy41r2). In addition to important technical improvements including moving the system to the IFS post-processing suite for dissemination - the new images are no longer tied to geostationary satellite geometry and produced globally on every model grid point. This extension offers particular advantages to member state users in high latitude locations.

1 Background

Model-simulated satellite images produced at ECMWF provide unique information about the NWP model output and are proven to be a very popular forecast tool. Forecasters have been using it in their day to day procedures to visualize model forecast cloud and moisture features, whereas model developers have been using it in research activities, particularly to validate model developments which affect the temperature and moisture fields.

Since 2005, model-simulated satellite images were routinelly generated using the operational ECMWF high-resolution forecast model output from the 00 UTC and 12 UTC cycles and the same fast radiative transfer model as in the operational data assimilation (e.g., RTTOV-11, Hocking *et al.*, 2013; Lupu and Geer, 2015). Output from the high-resolution forecast models is used as input to the RTTOV, which calculates the cloudy brightness temperatures expected from satellites using the relevant atmospheric model profiles (i.e., temperature, specific humidity, ozone mass mixing ratio, cloud cover, specific cloud liquid water content, specific cloud ice water content, specific rain water content, specific snow water content) and the relevant surface parameters (i.e., skin temperature, 10m u and v wind components, 2m temperature and 2m dewpoint temperature, volumetric soil water layer 1, convective available potential energy). The result is a 120-hours sequence of forecast-generated satellite images showing the evolution of the model-derived cloud or humidity features at 3-hours or 6-hours intervals.

Errors in simulated satellite images can derive from errors in the NWP parameters on which the simulation is based, the resolution of the model and the RTTOV model performance. Continuous maintainance and upgrades were required to reflect changes in the operational configuration of geostationary network used in the assimilation and to generate the forecast simulated images for new or replacement satellites, or to reflect model cycle upgrades (e.g., horizontal or vertical resolution upgrades of the ECMWF deterministic model) or RTTOV

model upgrades (e.g., updates in cloudy infrared simulations, updates in the radiative transfer coefficient files).

Up to and including the IFS cycle 41r1, the satellite images in both the window and water vapour channels were simulated for all ECMWF operational geostationary satellites operates by EUMETSAT, NOAA and JMA (Lupu and McNally, 2011; Lupu and McNally, 2012; Lupu and McNally, 2014; Letertre-Danczak, 2016a; 2016b). The simulated satellite images (SIM) were generated in geostationary satellite view projection to mimics real satellite imagery and to allows a like-to-like comparison with the observed satellite imagery (IG). The geostationary satellite simulated images in both water vapour and window channels have been encoded using GRIB edition 1, archived in MARS and presented on the ECMWF website as image files. Figure 1 shows an example of 48-hour simulated Meteosat-10 satellite imagery from the operational ECMWF model cycle 41r1 run at T_L1279 horizontal resolution with 137 vertical levels on 1st March 2016 at 00 UTC. Annex A guidelines for further details on the simulated satellite images prior to IFS cycle 41r2. Due to the nature of geostationary orbit, this product had very limited utility for high latitude users. Furthermore, the production of these images for different forecast steps runs outside the critical path as a serial task, is slow, resource-hungry and disconected code.

The overall high computational cost to generate the simulated satellite images will increase in the context of planned increase in the horizontal resolution of the high resolution forecasting system from T_L1279 (16 km horizontal grid resolution) to $T_{CO}1279$ (9 km horizontal grid resolution, cubic octohedral). Though the stand alone code could be improved for efficiency, the computational cost remains and renders the generation of current simulated satellites images difficult using present computational resources. A study has been undertaken to profile the various aspects of the satellite image simulation in the IFS, with the aim of addressing the inefficienties in the current system. This memo summarize the approach of generating simulated satellite images in post-processing within the IFS cycle 41r2, show a number of examples, and provide information for both forecasters users and RD scientists on where to obtain the forecast satellite imagery.

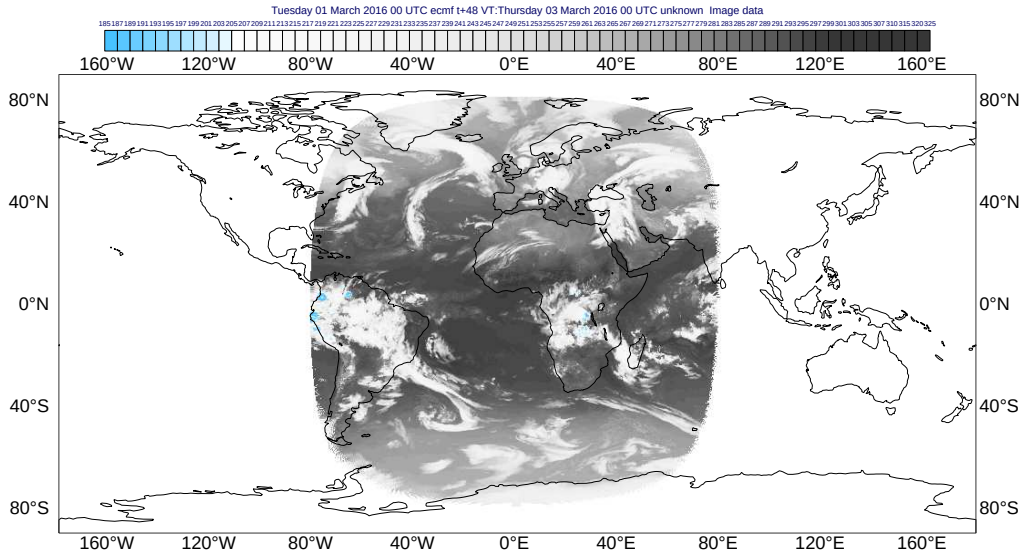

Figure 1: 48-h simulated Meteosat-10 satellite imagery at 10.8 µm from the operational ECMWF model cycle 41r1 at T_L1279 horizontal resolution with 137 vertical levels run on 1st March 2016 at 00 UTC.

2 Simulated satellite images (SSD) in the IFS cycle 41r2

The new simulated satellite images have been enhanced in various aspects in the IFS cycle 41r2, as summarized below:

- *A new configuration has been fully implemented in the IFS cycle 41r2 (both RD and o-suite) to include the simulated satellite images in post-processing within the IFS with no mapping on satellite grid.*

  The simulated satellite images (SSD) can be now generated in RD experiments and are part of the research tests for operational release. This is an enhancement with respect to the previous product (SIM) generated only in an early delivery configuration of the ECMWF operational suite (Haseler, 2004).

  To produce the simulated satellite images in RD experiments, one has to run an 'analysis' or 'forecast' suite with **LSATIM_NEW** turn 'On' on the prepIFS group Satellite Image Simulation. Simulated satellite images will be generated at every required post-processing steps, as controlled by **SATIMSTART***hh* and **SATIMEND***hh*, with *hh*=1-hourly, 3-hourly, 6-hourly or 12-hourly post-processing steps. Defaults settings in the o-suite are: 3-hourly in the beginning from 0-h to 48-h, then 6-hourly from 48-h to 120-h, then 12-hourly from 120-h to 240-h.

  The main program for the simulated satellite images is **satsim.F90**. The RTTOV initialisations and the mapping between the WMO satellite identifier and the RTTOV series and satellite number are done in **susatsim.F90** and use the **yomsatsim.F90** module. Annex B guidelines for further details on the IFS 41r2 source code changes. To produce and archive the new fields the **model** and **archive_satim_new** scripts, have been updated.

- *Global simulated satellite imagery from ECMWF forecasts are used to evaluate forecast of cloud or moisture.*

  The simulated satellite image includes latitudes greater than 60 degrees north and south, extending the simulated geostationary-type imagery over high-latitudes and polar regions. The product is global and shows the high-resolution ECMWF forecasts as a weather satellite (e.g. Meteosat-10) would see it. It captures detailed cloud or humidity features. This is an enhancement with respect to the old simulated satellite images (SIM) tied to the geostationary disk domain. As an example, 48-hour simulated satellite image from the ECMWF model cycle 41r2 at $T_{CO}1279$ horizontal resolution with 137 vertical levels on 1st March 2016 at 00 UTC is shown in Figure 2.

- *The new image product assume a nadir view for every model grid point, independent from satellite geometry.*

  The new simulated satellite images assume a nadir view for every model grid point so the effect of looking slantwise through the atmosphere is neglected. Consequently, the atmosphere appears less opaque than with the old simulated images (SIM).

  The IFS code developed in RD was designed to generate the new simulated satellite images as viewed by any of the RTTOV supported geostationary satellites in both, the water vapour and atmospheric window bands (Table 1 lists the ECMWF operational network of geostationary satellites in March 2016). Using multiple water vapour channels from Meteosat-10 or similar Himawari-8 allow to view different atmospheric levels since the weighting functions peak at different levels. As an example, SEVIRI 6.3 μm and 7.36 μm channels are sensitive to the water vapor content in the upper (e.g. 300 hPa) and mid-troposphere (500 hPa), respectively, and the 10.79μm atmospheric window channel is sensitive to the surface or cloud tops.

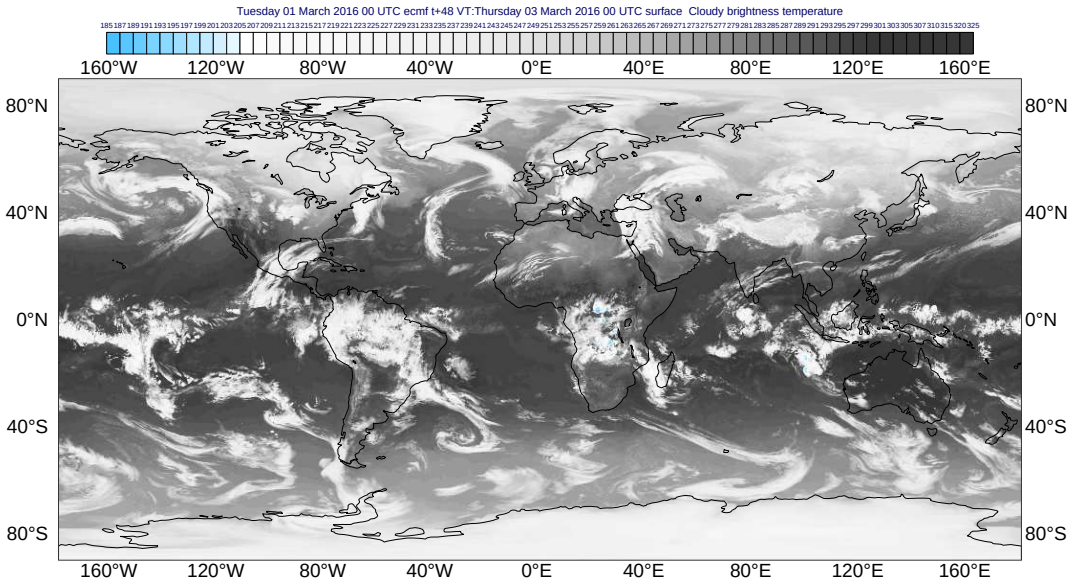

Figure 2: 48-hour global simulated Meteosat-10 SEVIRI image at 10.8 μm from the ECMWF model cycle 41r2 (experiment identifier ='0069') at $T_{CO}1279$ horizontal resolution with 137 vertical levels run on 1st March 2016 at 00 UTC.

Table 1: Overview of the ECMWF operational network of geostationary satellites in March 2016.

Satellite (name)	Instrument (name)	SatId (ident)	Series	Inst (instrument)	Sensor	Channel (channel)	Nominal central wavelength (μm)
GOES-15	Imager	259	241	615	22	3	6.55
						4	10.68
GOES-13	Imager	257	241	615	22	3	6.54
						4	10.67
Meteosat-10	SEVIRI	57	333	207	21	5	6.30
						6	7.36
						9	10.79
Meteosat-7	MVIRI	54	332	205	20	2*	6.34
						3*	11.52
Himawari-8	AHI	173	273	297	56	8	6.21
						9	6.93
						10	7.35
						13	10.40

* *The difference in the channel numbering for Meteosat-7 between the new (i.e., Table 1) and the old configuration (i.e., Table 4) is due to an offset in the RTTOV initialisations. This was addressed in the new system configuration by directly mapping the WMO instrument channels and the RTTOV channels.*

- *Availability of the new simulated satellite images in MARS.*

  From 8 March 2016 onwards, Meteosat-10-like simulated satellite data will be made available from the operational ECMWF high-resolution cycle 41r2.

  The simulated satellite images from the ECMWF high-resolution forecasts (CLASS=OD, EXPVER=0001 and STREAM=OPER) are archived in MARS under TYPE=SSD (Simulated Satellite Data). The SSD data fields are encoded in GRIB edition 2 and are available at every post-processing step, out to 240-hours: 3 hourly from T+0 to T+48, then 6 hourly from T+48 to T+120, then 12 hourly from T+120 to T+240. This is an enhancement with respect to the old satellite image product available in GRIB edition 1, out to T+120 forecast.

  Below is an example of MARS request to retrieve a sequence of global simulated satellites images, as viewed by Meteosat-10 at 10.8μm:

  RETRIEVE,
  CLASS = OD,
  TYPE = SSD,
  STREAM = OPER,
  EXPVER = 0001,
  PARAM = 260510,
  DATE = YYYYMMDD,
  TIME = 0000,
  STEP = 0/3/6/9/12/15/18/21/24/27/30/33/36/39/42/45/48/54/60/120/132/216/228/240,
  DOMAIN = G,
  CHANNEL = 9,
  IDENT = 57,
  INSTRUMENT = 207,
  TARGET = ”new_simulated_met10_ch9.grib2”

  In the mars request, ’PARAM’ is set to ’260510’ (Table 2), while IDENT, INSTRUMENT and CHANNEL correspond to Meteosat-10 (Table 1) and are compliant with the WMO Manual on codes. Please refer to MARS and GRIB_API documentation for a thorough description of language and functionalities. Any MARS post-processing keywords, such as AREA or GRID can be applied to the request to interpolate the fields to lower resolutions or geographical sub-areas. The fields are stored on the model O1280 octahedral reduced Gaussian grid. GRIB_API version 1.14.5, or later needs to be used in order to decode the simulated satellite data products.

Table 2: Simulated satellite images GRIB encoding

ParamId	shortName	longName	units	GRIB edition
260510	clbt	cloudy brightness temperature	K	2

- *Availability of the simulated satellite images in dissemination.*

  In the new configuration, the timeliness of delivery is optimal for dissemination. The new simulated images, as viewed by Meteosat-10 water vapour and atmospheric window channels will be added to the list of products that can be requested in dissemination.

3 Conclusions

Visualization of clouds or moisture features in the form of simulated satellite imagery provide information about the NWP model output and have proved to be a high value part of our users forecasting process. The generation of simulated satellite images has been reviewed in the IFS cycle 41r2. A new configuration has been fully implemented across the RD and FD suites to enhance the usefulness of this product not only for forecasters but also for modellers and researchers.

References

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Letertre-Danczak, J., 2016b: Monitoring and operational assimilation of Himawari-8 clear-sky geostationary radiances, RD Memo RD16-052, 13 pp.

Acknowledgements

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Appendix A. Simulated satellite images prior to the implementation of IFS cycle 41r2

Source code and experiments set-up in the IFS cy41r1

Prior to the implementation of IFS cycle 41r2, the main program to generate the satellite image simulation is **gensatim.F90**, that call **satproj2geo.F90**. The scripts associated with this product were generally updated to reflect changes in the opearational geostationary satellite network: **an.def**, **fc.def**, **archive_satim**, **satimsim**.

The old-way to generate the simulated satellite images requires the following prepIFS settings:

- In 'Data assimilation mode', set IFSMODE to 'early delivery'.
- In 'Satellite Image Simulation', set **LSATIMSIM** to 'On' and enter the start, end and step in hours for the forecast images (i.e., **SATIMSTART**, **SATIMEND** and **SATIMSTEP**).

Overview of the operational geostationary satellites in the IFS cy41r1

The constellation of operational geostationary satellites in the IFS cycle 41r1 include satellites at 0°and 57.5°E longitudes (Meteosat-10 and Meteosat-7 operated by EUMETSAT), a satellite at 145°E longitude (MTSAT-2 operated by JMA), and satellites at 135°W and 75°W longitudes (GOES-15 and GOES-13 operated by NOAA). The date when the old simulated satellite image (SIM) generation did begin is indicated in Table 3.

Table 3: Overview of operational geostationary satellites in the IFS cycle 41r1.

Sector	Longitude	Name	SIM since	SIM Dimensions(pixels)	Satellite subpoint (pixels)
East Pacific	135°W	GOES-15	2012-04-25	1250 x 1250	625 x 625
West Atlantic	75°W	GOES-13	2010-04-29	1250 x 1250	625 x 625
East Atlantic	0°	Meteosat-10	2013-01-24	1856 x 1856	928 x 928
Indian Ocean	54.5°E	Meteosat-7	2009-03-10	2500 x 2500	1250 x 1250
West Pacific	145°E	MTSAT-2	2011-01-25	1250 x 1250	625 x 625

Request the old simulated satellite images from MARS catalogue

Prior to the implementation of IFS cycle 41r2, the simulated satellite images were stored in MARS with TYPE=SIM and REPRES=SV (Space View). SIM products are encoded in GRIB edition 1.

Below is an example of MARS request for retrieving pre-IFS cy41r2 (i.e., 'YYYYMMDD' before 20160308) simulated Meteosat-10 satellite images at 10.8μm for all post-processing time steps out to 5-days forecasts:

```
RETRIEVE,
CLASS = OD,
TYPE = SIM,
```

STREAM = OPER,
EXPVER = 0001,
REPRES = SV,
DATE = YYYYMMDD,
TIME = 0000,
STEP = 0/3/6/9/12/15/18/21/24/27/30/33/36/39/42/45/48/54/60/66/72/78/84/90/96/102/108/114/120,
DOMAIN = G,
CHANNEL = 9,
IDENT = 57,
INSTRUMENT = 207,
TARGET = ”old_simulated_met10_ch9.grib”

To get the list of old simulated satellites images (SIM) available in MARS for different geostationary satellites (Table 4) for a given date use:

LIST,
CLASS = OD,
TYPE = SIM,
DATE = YYYYMMDD,
REPRES = SV

Table 4: SIM images at ECMWF. SIM are specified using the satellite identifier, instrument, channel number and nominal central wavelength (μm).

Sector (name)	Satellite (name)	Instrument (ident)	SatId	Inst (instrument)	Sensor	Channel (channel)	Nominal central wavelength (μm)
East Pacific	GOES-15	Imager	259	615	22	3	6.55
						4	10.68
	GOES-11	Imager	255	615	22	3	6.74
						4	10.72
	GOES-10	Imager	254	615	22	3	6.72
						5	10.68
West Atlantic	GOES-13	Imager	257	615	22	3	6.54
						4	10.67
	GOES-12	Imager	256	615	22	3	6.48
						4	10.71
	GOES-8	Imager	252	615	22	3	6.74
						4	10.69
East Atlantic	Meteosat-10	SEVIRI	57	207	21	5	6.30
						6	7.36
						9	10.79
	Meteosat-9	SEVIRI	56	207	21	5	6.30
						6	7.36
						9	10.79
	Meteosat-8	SEVIRI	55	207	21	5	6.30
						6	7.36
						9	10.79
Indian Ocean	Meteosat-7	MVIRI	54	205	20	1	6.34
						2	11.52
West Pacific	MTSAT-1R	JAMI	171	294	24	2	10.8
						4	6.75
	MTSAT-2	Imager	172	295	24	2	10.8
						4	6.77
	Himawari-8	AHI	173	297	56	8	6.21
						9	6.93
						10	7.35
						13	10.40

Appendix B. Global simulated satellite images at cycle 41r2 developed by Tomas Wilhelmsson

1) Branch **nat_CY41R2_satsim** has been merged in **dag_CY41R2_esuite_highres** to allow the generation of new simulation of satellite images (SSD) for any number of geostationary satellites/channels (e.g., currently 5 satellites and a total of 13 water vapour and window channels, as listed in Table 1).

2) Testing: cy41r2, T_{CO}159/137 levels, CTRL: gg94; EXP: gg95

3) Are the results bit-reproducible with CY42R1? Yes, the branch is bit-reproducible over two days of cycling.

4) Categorise the contribution: 'Technical'

5) Does the branch contain source or scripts or both? Both, source and scripts modifications.

6) 'q2 check_norms11' no norm violations for the modified files

7) Are there any new parameters which should be archived in the operational suite? Yes, see Table 2.

8) Are there any ecFlow (or prepIFS) changes needed? Yes, prepIFS has been updates to reflect the new changes in Satellite Image Simulation group.

9) Are there dependencies on particular versions of ifs-support, grib_api etc.? Yes, GRIB_API 1.14.5 is required for the new simulated satellite images.

Files created(IFS):
dia/satsim.F90
module/yomsatsim.F90
setup/susatsim.F90

Files created (SCRIPTS):
scripts/gen/archive_satim_new

Files modified(IFS):
adiab/cpedia.F90 postphy.F90
control/gp_model.F90
fullpos/cpclimi.F90 hpos.F90 scan2m_hpos.F90 scan2m_mpos.F90 sufp_ctl.F90 sufpc.F90 sufpphy.F90
io_serv/io_serv_suiosctmpl.F90 io_serv_writefld_ec.F90
module/fdb_utils_mod.F90 grib_utils_mod.F90 iogride_mod.F90 iostream_mix.F90 parfpos.F90 surface_fields_mix.F90
yom_grib_codes.F90 yomafn.F90 yomfpc.F90 yomio_serv.F90 yomphyder.F90 yomppc.F90
namelist/namfpc.nam.h
phys_ec/ec_phys_drv.F90 postphy_layer.F90
setup/su0yomb.F90 su_surf_flds.F90 suafn1.F90 suafn2.F90 suafn3.F90 supp.F90
var/rtsetup.F90

Files modified(SATRAD):
interface/rttvi.h
programs/calc_radiance_fields.F90 gensatim.F90
rttov/ifs/phrtsetup.F90 ifs/rttvi.F90

Files modified(SCRIPTS):
gen/mklinks model