Generating imagery from FengYun-3 satellites

Satellite Applications Technical Memo 3

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Satellite Data Processing Systems

05 December 2013

History:

Version	Date	Comment
1.0	18 Oct 2013	Initial release
1.1	05 Dec 2013	Correct MERSI channel numbering

Contents

Abstract

This report describes the imagers on the Chinese FengYun-3 polar-orbiter satellites and the generation of imagery products from those instruments. A processing package provided by the China Meteorological Administration (CMA) converts the raw direct broadcast data to level 1B. The contents and handling of the 1B datasets are described. The report is primarily aimed at documenting procedures used within the Met Office, but some sections have wider applicability.

1. Satellites and instruments

The FY-3A and FY-3B satellites have northbound local equator crossing times of 22:00 and 13:45 respectively. Each has two imagers. FY-3C will have the same instruments.

1.1. VIRR - Visible and Infra-Red Radiometer

See http://www.wmo-sat.info/oscar/instruments/view/607
Broadcast on L-band
Resolution = 1.1km at nadir, 2048 spots across the swath
Channels are shown in Table 1.

Table 1: VIRR channels. Reflective bands in blue, emissive in red.

Channel number	Band and number in band (R=reflective, E=emissive)	Nominal wavelength µm	Range µm
1	R1	0.630 (red)	0.58 - 0.68
2	R2	0.865	0.84 - 0.89
3	E1	3.740	3.55 - 3.93
4	E2	10.80	10.3 - 11.3
5	E3	12.00	11.5 - 12.5
6	R3	1.600	1.55 - 1.64
7	R4	0.455 (blue)	0.43 - 0.48
8	R5	0.505	0.48 - 0.53
9	R6	0.555 (green)	0.53 - 0.58
10	R7	1.360	1.325 - 1.395

The VIRR is essentially the same instrument as the MVISR on FY-1C and FY-1D. The channel numbering reflects the fact that channels 1-5 are similar to channels 1, 2, 3B, 4 and 5 of AVHRR.

1.2. MERSI - Medium Resolution Spectral Imager

See http://www.wmo-sat.info/oscar/instruments/view/278
Broadcast on X-band

Resolution 1.0km (15 channels) or 0.25km (5 channels) at nadir, 2048 spots across swath
20 channels: 19 narrow-bandwidth in VIR/NIR/SWIR and one broadband in the thermal IR

For FY-3D onwards, the VIRR and MERSI will be merged into a new instrument, MERSI-2.

Table 2: MERSI channels. Reflective 250m bands in green, emissive 250m in red, reflective 1km bands in blue

Channel number	Band and number in band (H=hi res reflective, E=emissive L=low res reflective)	Nominal wavelength µm	Bandwidth µm
1	H1	0.470 (blue)	0.050
2	H2	0.550 (green)	0.050
3	H3	0.650 (red)	0.050
4	H4	0.865	0.050
5	E1	11.5	2.50
6	L1	1.640	0.050
7	L2	2.130	0.050
8	L3	0.412	0.020
9	L4	0.443	0.020
10	L5	0.490	0.020
11	L6	0.520	0.020
12	L7	0.565	0.020
13	L8	0.650	0.020
14	L9	0.685	0.020
15	L10	0.765	0.020
16	L11	0.865	0.020
17	L12	0.905	0.020
18	L13	0.940	0.020
19	L14	0.980	0.020
20	L15	1.030	0.020

2. Reception

The MEOS polar reception systems at the Met Office generate “clear” files containing raw data (VCDUs), e.g.

clear_FY3A_23556_12-DEC-2012_09:33:23.000
clear_FY3B_10894_11-DEC-2012_13:24:59.000

3. Processing to level 1 using CMA package

CMA have made available a level 1 processing package for the imagers (VIRR, MERSI) and sounders (MWTS, MWHS, IRAS) on FY-3A and FY-3B. It comes in 2 parts:

- fy3l0pp – for processing raw data to level 0
- fy3l1pp – for processing level 0 to level 1

Ony the executables are supplied, no source code. Currently fy3l0pp is 32-bit only: you have to dynamically load 32-bit versions of libstdc++.so.6 and libgcc_s.so.1, but that is not a problem as they are available on the Met Office radsat machines (e.g. exprsatappdev01). The fy3l1pp package is available as either 32-bit or 64-bit, and on radsat it's easiest to run the 64-bit version.

High level scripts to link together the various proecssing steps can be found at:

exprsatappdev01:/data/radsat/frpd/FY3/process_L0.ksh
exprsatappdev01:/data/radsat/frpd/FY3/process_L1.ksh

4. Unpacking VIRR level 1 files

The VIRR level 1 files are in HDF5 format. The fy3l1pp package creates them in directory ${fy3_home}/fy3l1db/data/virr_l1, where we have defined fy3_home as /data/radsat/frpd/FY3. It may be convenient to move them elsewhere prior to imagery generation.

The essential information is contained in the datasets and attributes listed in Table 3.

Table 3: Key VIRR HDF5 datsets and attributes. In the "Dimension" column, the most rapidly varying subscript is given first.

Name	Dataset or attribute	Type	Dimension (n = number of scans)	Comment
Latitude	D	F32	2048 × n	Degrees
Longitude	D	F32	2048 × n	Degrees
SolarZenith	D	I16	2048 × n	scale by 0.01
EV_RefSB	D	U16	2048 × n × 7	"R" Channels
EV_Emissive	D	U16	2048 × n × 3	"E" Channels
Emissive_Radiance_Offsets	D	F32	3 × n	Units: $mW/m^2/str/cm^{-1}$
Emissive_Radiance_Scales	D	F32	3 × n	
RefSB_Cal_Coefficients	A	F32	2 × 7	scale, offset Units: percent
RefSB_Effective_Wavelength	A	F32	7	microns
Emmisive_Centroid_Wave_Number[1]	A	F32	3	cm^{-1}

The values can be extracted via h5dump, as follows:

```
h5dump -d Latitude -b LE -o Latitude.dat $datadir/$file
h5dump -d Longitude -b LE -o Longitude.dat $datadir/$file
h5dump -d SolarZenith -b LE -o SolarZenith.dat $datadir/$file
h5dump -d EV_Emissive -b LE -o EV_Emissive.dat $datadir/$file
h5dump -d EV_RefSB -b LE -o EV_RefSB.dat $datadir/$file
h5dump -d Emissive_Radiance_Offsets -b LE -o Emissive_Radiance_Offsets.dat $datadir/$file
h5dump -d Emissive_Radiance_Scales -b LE -o Emissive_Radiance_Scales.dat $datadir/$file
h5dump -a RefSB_Cal_Coefficients -y $datadir/$file | tail -n -5 | head -n +2 \
   >RefSB_Cal_Coefficients.txt
```

[1] Note the unusual spelling in Emmisive_Centroid_Wave_Number for VIRR

```
h5dump -a RefSB_Effective_Wavelength -y $datadir/$file | tail -n -4 | head -n +1 \
   >RefSB_Effective_Wavelength.txt
h5dump -a Emmisive_Centroid_Wave_Number -y $datadir/$file | tail -n -4 | head -n +1
   \ >Emmisive_Centroid_Wave_Number.txt
```

(With attributes, binary output doesn't seem to work using hdf5 version 1.8.5 – hence the use of ASCII output above. It does work correctly with 1.8.7.).

5. Unpacking MERSI level 1 files

The MERSI level 1 files are in HDF5 format. The fy3l1pp packages creates them in directory ${fy3_home}/fy3l1db/data/mersi_l1, where fy3_home=/data/radsat/frpd/FY3. The 250m channels are provided at native resolution and also aggregated to 1km.

The essential information is contained in the datasets and attributes listed in Table 4, for the 1km file, and Table 5, for the 250m file.

Table 4: Key MERSI HDF5 datsets and attributes, 1km file. In the "Dimension" column, the most rapidly varying subscript is given first.

Name	Dataset or attribute	Type	Dimension (n = number of lines)	Comment
Latitude	D	F32	2048 × n	Degrees
Longitude	D	F32	2048 × n	Degrees
SolarZenith	D	I16	2048 × n	Scale by 0.01. Only in the 1km file.
EV_1KM_RefSB	D	U16	2048 × n × 15	Low res "R" Channels Scale by 0.01 to get percent reflectivity
EV_250_Aggr.1KM_RefSB	D	U16	2048 × n × 4	Aggregated Hi res "R" Channels. Apply cal coefs to get percent reflectivity
EV_250_Aggr.1KM_Emissive	D	U16	2048 × n	Aggregated emissive channel (band 5) Apply cal coefs to get $mW/m^2/str/cm^{-1}$
VIR_Cal_Coeff	A	F64	57	Intercept, slope, 2nd order for 19 visible channels
IR_Cal_Coeff	A	F64	4×n/10	Intercept, slope, 2nd order, 3rd order for each scan (10 lines)
SV_DN_average	D	F32	n × 20	Space counts for each channel

Table 5: Key MERSI HDF5 datsets and attributes, 250m file.

Name	Dataset or attribute	Type	Dimension (n = number of high-res lines)	Comment
Latitude	D	F32	2048 × n	Degrees
Longitude	D	F32	2048 × n	Degrees
EV_250M_RefSB_b1	D	U16	8192 × n	Hi res band 1. Scale by 0.01 to get percent reflectivity
EV_250M_RefSB_b2	D	U16	8192 × n	Hi res band 2
EV_250M_RefSB_b3	D	U16	8192 × n	Hi res band 3
EV_250M_RefSB_b4	D	U16	8192 × n	Hi res band 4
EV_250_Emissive	D	U16	8192 × n	Hi res emissive channel (band 5) Apply cal coefs to get mW/m^2/str/cm^{-1}
VIR_Cal_Coeff	A	F64	57	Intercept, slope, 2nd order for 19 visible channels, but only the first 4 channels have data
IR_Cal_Coeff	A	F64	4×n/40	Intercept, slope, 2nd order, 3rd order for each scan (40 lines)
SV_DN_average	D	F32	n × 20	Space counts for each hi-res channel

The values can be extracted via h5dump in the usual way. Note that when generating images from high resolution data the user needs to interpolate the lat/lon/zenith to 250m resolution. Solar zenith angles are only available from the 1km file. Latitude and longitude are the same in the 1km and 250m files.

6. VIRR reflective (visible) channels

To generate visible imagery we need to convert from counts, *c* (0 to 1023), to reflectance, *R*, in the usual way:

$R = (A + B\,c)/\cos(z')$

where *A* is the offset from RefSB_Cal_Coefficients, *B* is the scale from RefSB_Cal_Coefficients and *z'* is lower of the solar zenith angle and some predefined limit (e.g. 85°).

To generate true-colour imagery, we can use
Channel R1 (0.63µm) = red
Channel R6 (0.55µm) = green

Channel R4 (0.46µm) = blue

The standard Wisconsin non-linear mapping reflectivity to counts can be used. Note that a correction for Rayleigh scattering is not yet available.

In the CMA software, the reflectance scaling attributes are set as “refCalCoef” in files FY3A_VIRR_CAL.XCONF and FY3B_VIRR_CAL.XCONF in the fy3l1db/SysData/ directory. It was found that the values had not been updated since 2009 for FY3A and 2010 for FY3B. More recent values were substituted, based on VIRR data downloaded from the CMA web portal http://satellite.cma.gov.cn/portalsite/default.aspx (Sept 2013). The values are given in Appendix A.

An example true-colour image is shown in Figure 1.

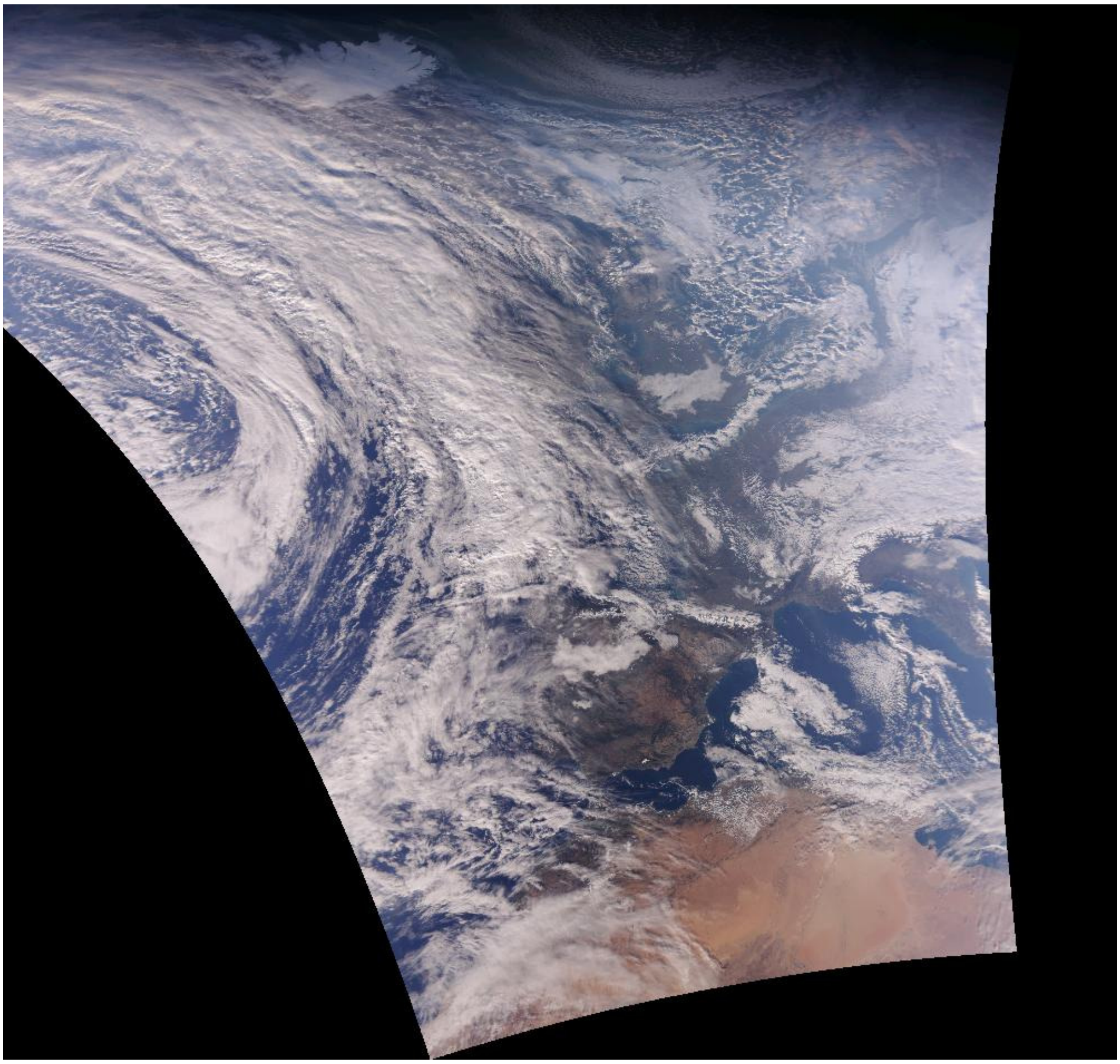

Figure 1: True-colour image for clear_FY3B_10894_11-DEC-2012_13:24:59. Platte Carrée projection.

7. VIRR emissive (IR) channels

To generate I/R imagery we need to convert from counts, c (0 to 1023), to radiance, r, in the usual way:

$$r = (A + B\,c)$$

where A is the appropriate element from "Emissive_Radiance_Offsets" and B is from "Emissive_Radiance_Scales".

We then convert to Brightness Temperature using the Planck function, using the supplied wavenumbers. An example product is shown in Figure 2.

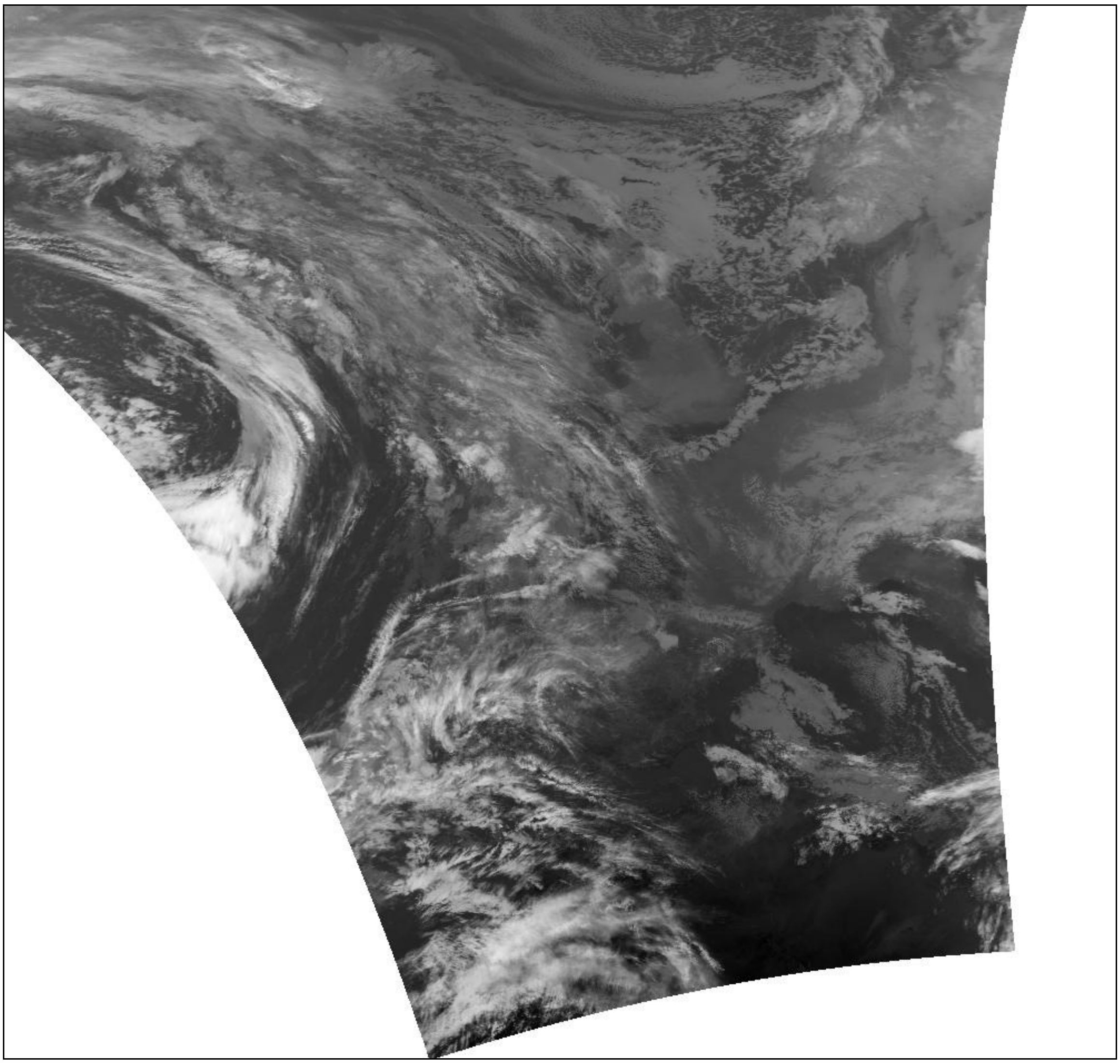

Figure 2: 10.8µm image for clear_FY3B_10894_11-DEC-2012_13:24:59. Grey-scale range 208K to 301K.

8. MERSI reflective (visible) channels

The original CMA intention was that the counts for visible channels should be converted to reflectances using the information in the "VIR_Cal_Coeff" attribute:

$R = (k0 + k1\ c + k2\ c^2)/\cos(z')$

where $k0$, $k1$ and $k2$ are the calibration constants from "VIR_Cal_Coeff", c is the count value (0 to 4095) and z' is the solar zenith angle, as for VIRR. In practice, $k2 = 0$.

However, it has been reported (see Sun et al., 2012[2]) that substantial degradations have occurred since launch. Therefore it is better to use the following procedure that tracks the calibration drift:

$\text{Slope} = \alpha + \beta\ \text{DSL} + \gamma\ \text{DSL}^2$
$R = (\text{Slope} \times (c - c_{sp}))\ /\cos(z')$

where DSL is the number of days since launch and c_{sp} are the space view counts.

For FY-3B direct readout, and for files downloaded from the CMA web portal, the space counts can be obtained from dataset "SV_DN_average" in the 1000M and 250M output files. Unfortunately this dataset is not present in the FY-3A output from direct broadcast. But the information can be obtained from datasets "DN_avg_SV_1km" and "DN_avg_SV_250m" in the OBCXX output file. It is awkward that different data sources require different processing. Note that "SV_DN_average" contains all 20 channels; we don't need to use the space counts for IR channel 5.

We also need the values of the trend coefficients α, β and γ. For FY-3B, they can be found in datasets downloaded from the CMA web portal: they are given in a new attribute "RSB_Cal_Cor_Coeff" which is not found in the direct readout datasets. See Appendix B. (The equation for R above has been simplified slightly from the official version, which has an additional factor d^2 on the right hand side, where d is the earth-sun distance in AU). The dataset RSB_Cal_Cor_Coeff does not exist for FY-3A, but values of the coefficients are given in Table III of Sun et al. – also reproduced in Appendix B.

I also tried a regression of CMA web-portal reflectances for FY-3B against direct readout reflectances, in order to derive update $k0$ and $k1$ values. The results were in good agreement with the drift equation. The updated $k0$ and $k1$ values can be inserted into the configuration (cfg) file fy3l1db/SysData/DPPS_MERSI_Calibration_Parameters_F3B.cfg, which is used to set the VIR_Cal_Coeff attribute. If we update the cfg file then we can continue to use the standard calibration method, and do not require the space counts – but regular updates to the cfg file may be needed. It was also noted that there is a 20-line (2-scan) striping in some channels (notably channel 7 of FY-3B); this is similar to an artefact observed in VIIRS day-night-band imagery in which the two sides of a reflector have slightly different reflectivities. This striping is less prominent in the file from the web portal.

In the web portal datasets, the attribute "Software Revision Date" is given as 2013-01-23 for FY-3B, but 2009-05-11 for FY-3A. This may be why the FY-3A dataset does not include the calibration drift model.

[2] Ling Sun et al., 2012, "Multisite Calibration Tracking for FY-3A MERSI Solar Bands", IEEE Trans. Geosci., Rem. Sens., **50**, 12, December 2012, pp 4929-4942.

9. MERSI emissive channel

Channel 5 is the only emissive channel. It is a high resolution channel. The counts are converted to radiance using the conversion coefficients in IR_Cal_Coeff. This has one value per channel per scan. A scan is 10 lines of 1km imagery, or 40 lines of 250m imagery.

Note that the channel 5 of FY3B MERSI is not giving sensible results for direct broadcast processing, but appears to be OK in data from the CMA web portal. The reason for this is not known.

10. Reflectance correction for MERSI

University of Wisconsin have developed reflectance correction software (crefl) for MERSI, to correct for Rayleigh scattering. Willem Marais has given us a copy of the software. It allows production of true-colour images similar to those that we generate for MODIS and VIIRS, and the output files are in the same hdf4 format. Running the software is very similar to the procedure for MODIS and VIIRS, so will not be discussed in detail in this note.

Example true-colour images are shown in Figure 3 and Figure 4. These use the updated fy3l1db cfg files as described in section 8. The colours in the FY-3B image appear slightly better than FY-3A, perhaps reflecting the fact that in the latter case the calibration drift equation has not been updated since the end of 2011.

For 250m resolution imagery it is necessary to interpolate the lat/lon which are supplied at 1km resolution. The crefl package interpolates the solar zenith angles, and these are not needed by the display software.

The first and last 5 spots contain some missing data – which is different for the three bands. Hence the coloured edges to the image.

The software produces corrected reflectance files at 1km and 250m resolution. At 250m, the datasets are “CorrRefl_nn”, where nn = 01 to 04 for MERSI channels 1 to 4 , and nn = 06, 07 for channels 6 and 7 (see Table 2). At 1000m, the dataset names are the same but MERSI channels 9, 12, 13, 16, 6 and 7 are used.

It is easier to work with corrected reflectance files than the original MERSI files, because (i) a constant scaling factor of 0.0001 is used, and (ii) no solar zenith angle correction is needed.

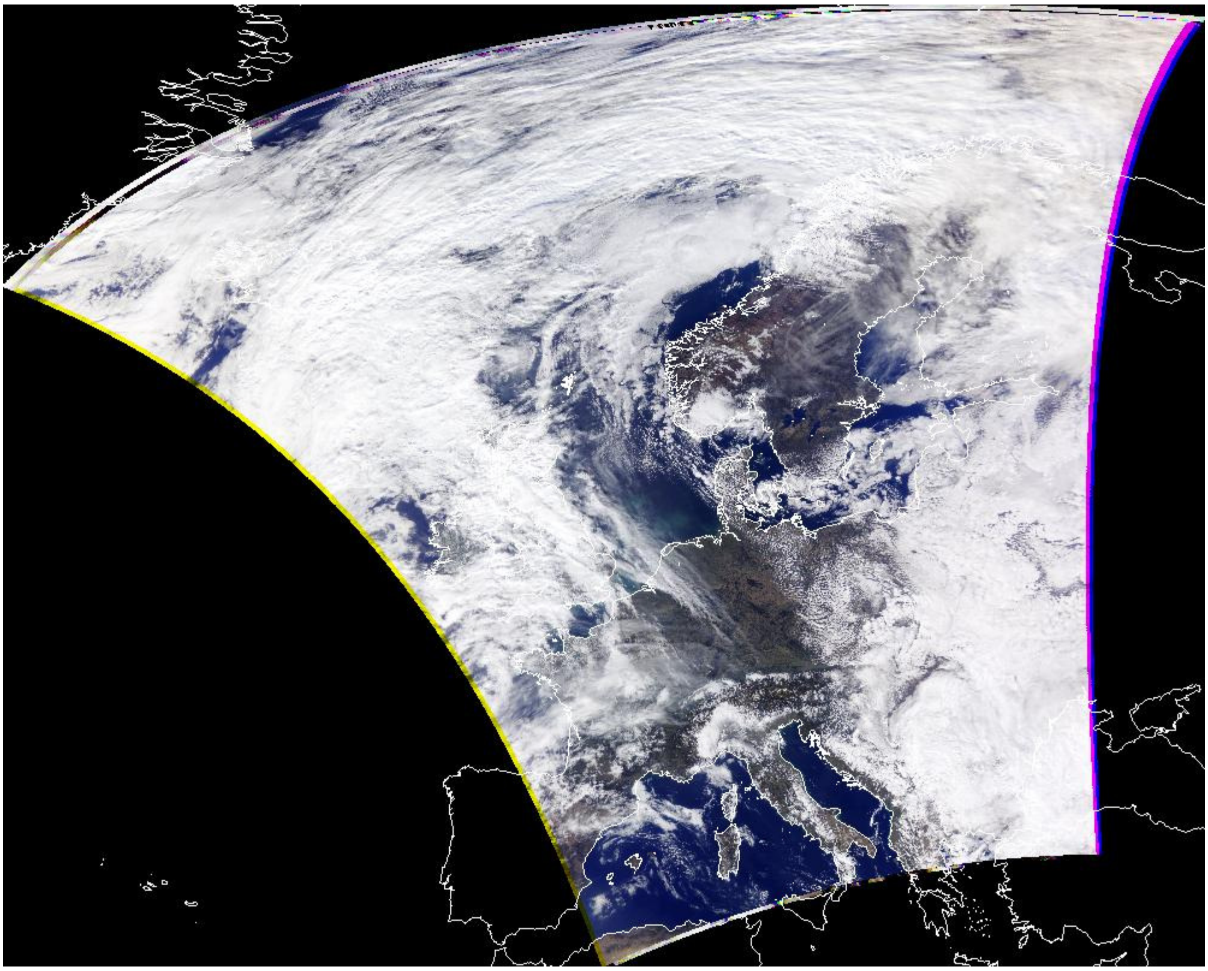

Figure 3 True-colour image for FY-3B MERSI, produced using corrected reflectances. The MERSI calibration coefficients were first updated to allow for calibration drift (see text). Raw data were acquired by Dartcom (Yelverton, Devon)

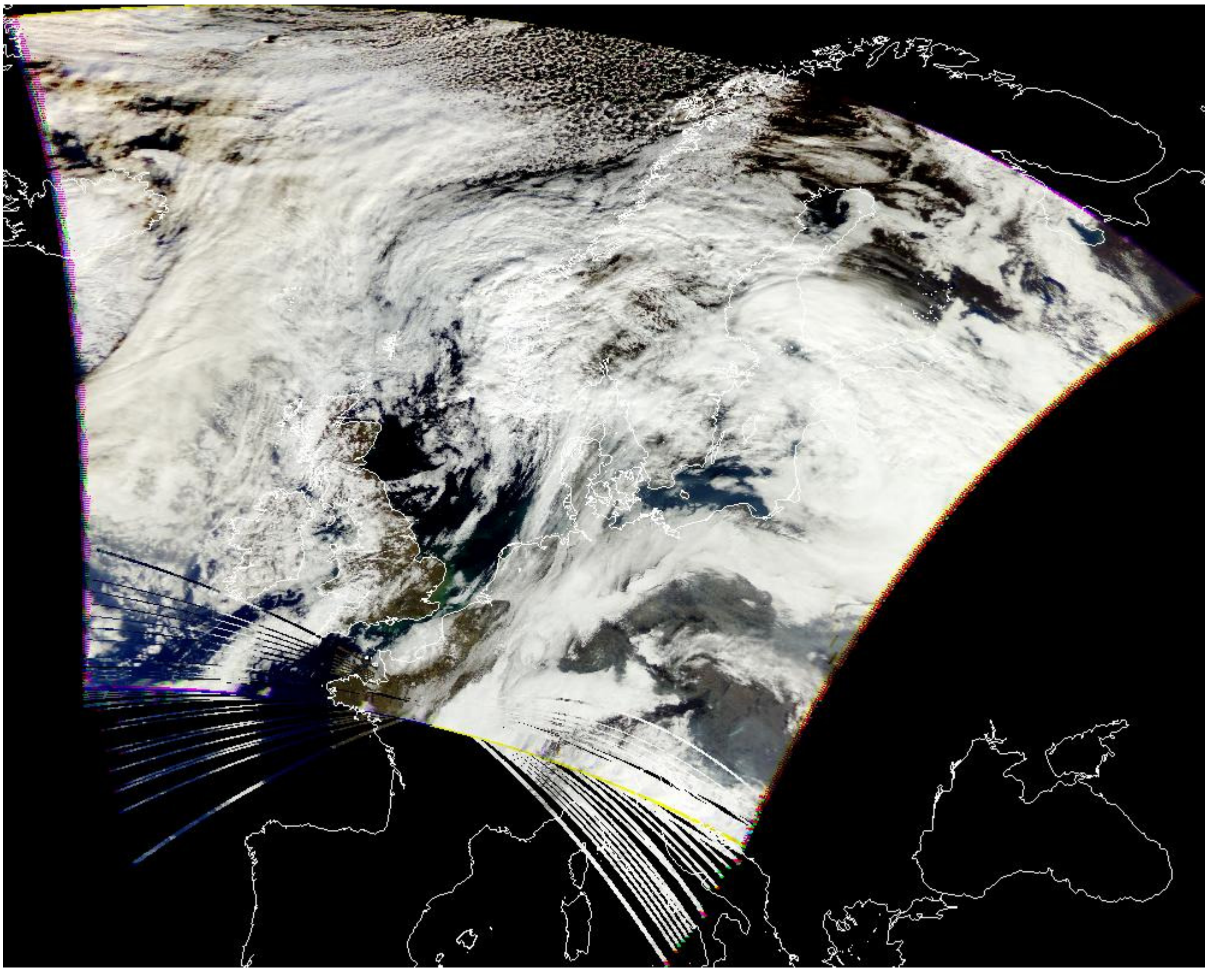

Figure 4: True-colour image for FY-3A MERSI. Raw data were acquired by Météo-France (Lannion). Note the corrupt navigation in the south of the image, probably a problem with the fy3l1db sofware.

Appendix A: VIRR visible channels calibration (valid September 2013)

FY3A_VIRR_CAL.XCONF

```
refCalCoef =
[0.1457,      -1.7484,                         #channel1#
0.1435,       -1.7348,                         #channel2#
0.0995,       -2.3061,                         #channel6#
0.0894,       -1.1622,                         #channel7#
0.0742,       -0.8916,                         #channel8#
0.0687,       -0.8236,                         #channel9#
0.0443,       -0.5663];                        #channel10#
```

FY3B_VIRR_CAL.XCONF

```
refCalCoef =
[0.12640,     -1.43200,                        #channel1#
0.13530,      -1.62360,                        #channel2#
0.09193,      -2.48207,                        #channel6#
0.07480,      -0.90980,                        #channel7#
0.07590,      -0.91080,                        #channel8#
0.07460,      -0.89520,                        #channel9#
0.06300,      -0.76280];                       #channel10#
```

Appendix B: MERSI visible channels degradation constants

FY3B launch date: 4th November 2010

```
HDF5 "FY3B_MERSI_GBAL_L1_20131002_1220_1000M_MS.HDF" {
DATASET "RSB_Cal_Cor_Coeff" {
   DATATYPE  H5T_IEEE_F32BE
   DATASPACE  SIMPLE { ( 19, 3 ) / ( 19, 3 ) }
   DATA {
   (0,0): 0.0289, 5.08e-06, 0,
   (1,0): 0.0288, 2.84e-06, 0,
   (2,0): 0.0279, -5.19e-07, 0,
   (3,0): 0.029, -4.78e-07, 0,
   (4,0): 0.0235, -3.28e-06, 0,
   (5,0): 0.0166, 7.63e-07, 0,
   (6,0): 0.0256, 5.99e-06, 0,
   (7,0): 0.0234, 5.15e-06, 0,
   (8,0): 0.0217, 3.48e-06, 0,
   (9,0): 0.0216, 2.83e-06, 0,
   (10,0): 0.0218, 1.63e-06, 0,
   (11,0): 0.0219, -3.29e-07, 0,
   (12,0): 0.0194, -4.2e-07, 0,
   (13,0): 0.0207, -5.66e-07, 0,
   (14,0): 0.0223, -2.8e-07, 0,
   (15,0): 0.0225, 1.62e-06, 0,
   (16,0): 0.0191, 4.69e-06, 0,
   (17,0): 0.0233, 2.75e-06, 0,
   (18,0): 0.0261, 4.94e-06, 0
   }
```

FY3A launch date: 27th May 2008

Table 6: FY3A MERSI visible channel degradation parameters, from Sun et al., 2012. No data are given for channels 6, 7, 17, 18 or 19.

Band	β	α
1	0.0306	4.72e-06
2	0.0293	2.29e-06
3	0.0251	-2.05e-07
4	0.0286	3.25e-08
8	0.0216	8.98e-06
9	0.0235	5.08e-06
10	0.0245	3.22e-06
11	0.0199	1.98e-06
12	0.0232	1.21e-06
13	0.0229	-8.89e-08
14	0.0224	-7.38e-08
15	0.0299	5.82e-07
16	0.0212	2.24e-07
20	0.0255	3.21e-06

IDL procedure to return the slope

```
function mersi_slope,sat,yyyy,mm,dd

;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
;Calibration model:
;  slope = b + a*(days_since_launch)
;  use the space counts to give the intercept
;
;FY-3B values from CMA web portal, dataset RSB_Cal_Cor_Coeff, Oct 2013.
;FY-3A values from Sun et al., 2012.
;FY-3A channels 6,7,17,18,19 copied from slope of attribute VIR_Cal_Coeff.
;
;16/10/2013 NCA
;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;

nowjd = JULDAY(mm, dd, yyyy)

if sat eq 'FY3B' then begin

  launchjd = JULDAY(11, 4, 2010)   ;month, day, year

  coefs = [[0.0289, 5.08e-06], $
           [0.0288, 2.84e-06], $
           [0.0279, -5.19e-07], $
           [0.029, -4.78e-07], $
           [0.0235, -3.28e-06], $
           [0.0166, 7.63e-07], $
           [0.0256, 5.99e-06], $
           [0.0234, 5.15e-06], $
           [0.0217, 3.48e-06], $
           [0.0216, 2.83e-06], $
           [0.0218, 1.63e-06], $
           [0.0219, -3.29e-07], $
           [0.0194, -4.2e-07], $
           [0.0207, -5.66e-07], $
           [0.0223, -2.8e-07], $
           [0.0225, 1.62e-06], $
           [0.0191, 4.69e-06], $
           [0.0233, 2.75e-06], $
           [0.0261, 4.94e-06]]
```

```
endif else if sat eq 'FY3A' then begin

  launchjd = JULDAY(5, 27, 2008)   ;month, day, year

  coefs = [[0.0306, 4.72e-06], $
           [0.0293, 2.29e-06], $
           [0.0251, -2.05e-07], $
           [0.0286, 3.25e-08], $
           [0.0229, 0.0], $
           [0.0241, 0.0], $
           [0.0216, 8.98e-06], $
           [0.0235, 5.08e-06], $
           [0.0245, 3.22e-06], $
           [0.0199, 1.98e-06], $
           [0.0232, 1.21e-06], $
           [0.0229, -8.89e-08], $
           [0.0224, -7.38e-08], $
           [0.0299, 5.82e-07], $
           [0.0212, 2.24e-07], $
           [0.0267, 0.0], $
           [0.0247, 0.0], $
           [0.0249, 0.0], $
           [0.0255, 3.21e-06]]

endif else begin
  print,'Unsupported satellite ',sat
  return,0
endelse

slope = coefs(0,*) + coefs(1,*)*(nowjd-launchjd)
return,slope

    end
```

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