NWP SAF AAPP
VIIRS-CrIS Mapping

Change record

Version	Date	Author / changed by	Remarks
1.0	20.11.14	P. Brunel	Initial Document version
2.0	31.10.18	P. Roquet	Add cluster analysis

CONTENTS

Reference documents

Ref 1: Cross Track Infrared Sounder (CrIS) Sensor Data Records (SDR) Algorithm theoretical Basis Document (ATBD) Code 474-00032 July 31, 2011
Ref 2: VIIRS Geolocation Algorithm Theoretical Basis Document (ATBD) code 474-00053 July 31, 2011
Ref 3: Document for Common Adjacency Software, Operational Algorithm Description (OAD) code 474-00097 June 3rd, 2013
Ref 4: Dossier de définition des algorithmes IASI: CNES IA-DF-0000-2006-CNE Fiche 41 Version 3.0 Analyse des radiances dans les FOVs sondeur

1 Introduction

This document presents the VIIRS-CrIS mapping software. The Cross-track Infrared Sounder (CrIS) on board Suomi-NPP has a ground footprint of 14km at nadir. A good knowledge of the surface conditions will benefit any use of CrIS radiances. The Visible Infrared Imaging Radiometer Suite (VIIRS) can provide exclusive information about clouds or surface in the CrIS field of view. The CrIS AAPP level 1c and 1d formats has some reserved variables for VIIRS data. The AAPP command viirs_to_cris will feed those variables with relevant VIIRS data.
This document explains the method, the command and gives some results. The software description document is separate and has been automatically generated by Doxygen tool.

This command override any use of navigation routines that needs instrument geometry, but use all geo-location data provided with the SDR files. So one will use an off-line reference data base of CrIS footprints for all fields of regard, all field of view, one scan line, one satellite altitude. The most important thing to take care is the particular VIIRS scanning characteristics which implies that different pixels may have the same geographical position and that the next pixel may not be the true next neighbour. One will use the “adjacency” method (see ref 1) which is able to provide the true nearest VIIRS neighbours for a given VIIRS pixel.

The software allows a cluster analysis based on the method called “Nuées Dynamiques” extracted from the OPS-LRS Software. The VIIRS clusters analysis is perform an envelope of the 9 CrIS FOVs. For each CrIS FOVs, the number of clusters are computed, and for each VIIRS channel, the mean and the standard devitation of the radiance of the VIIRS pixels are computed.

2 CrIS footprint

The AAPP navigation routines are been used to calculate viewing vectors for the CrIS optical axis and centre field of views. Some routines already exist in AAPP for the IASI scanning, they were modified according the CrIS scanning mode which is a bit different. The field of regard contains 9 field of views and rotates by 45 degrees along the scan (see Figure 1 and Figure 2).

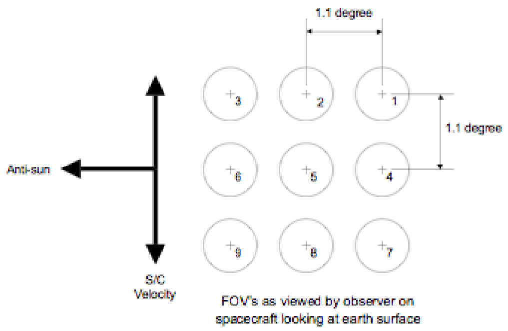


Figure 1: CrIS field of regard definition (from Ref1)

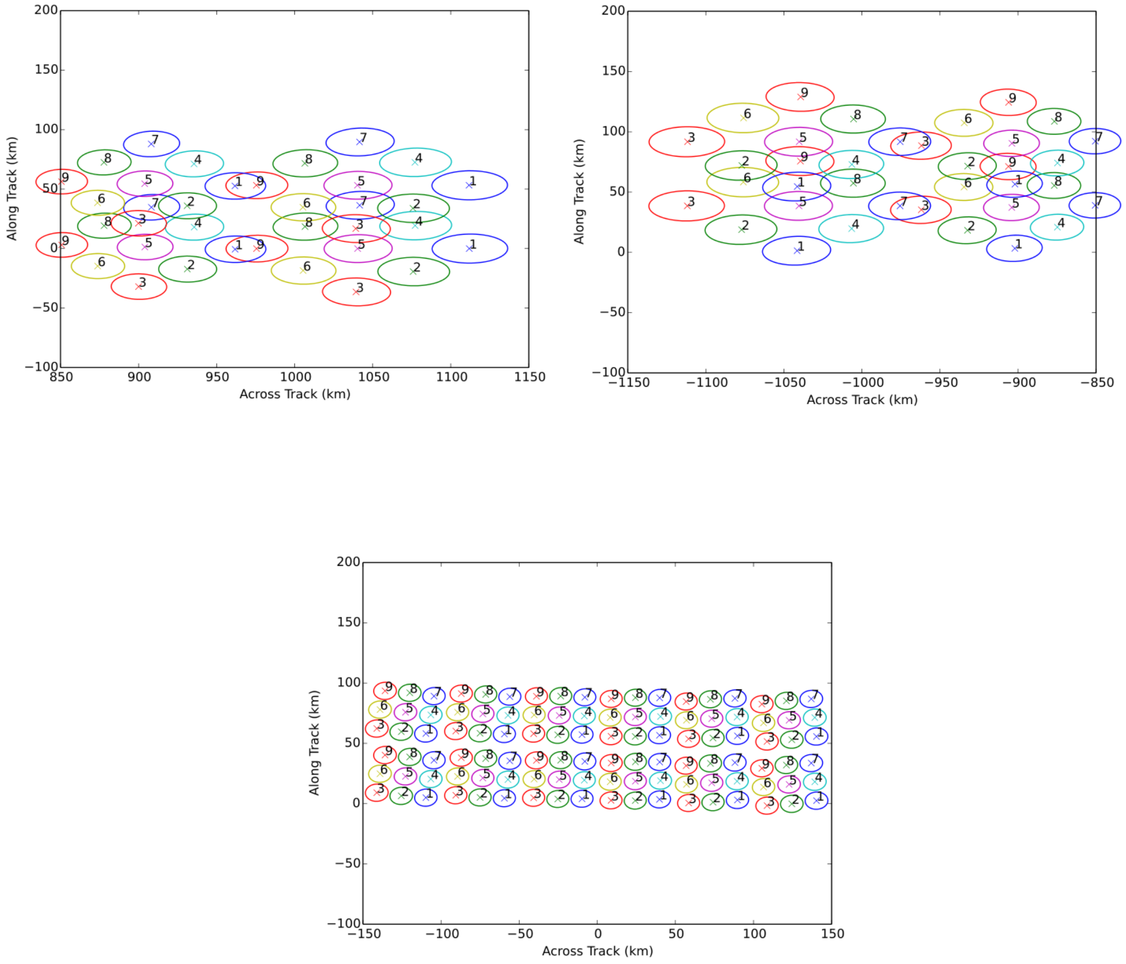


Figure 2: CrIS footprint on a perfect plane for two scans. The FOR rotates by 45 degrees along the scan. Top left, FOR 1 and 2, Top right FOR 29 and 30, Bottom center FORs.

The CrIS footprint is considered as a cone(16.8mrad) centred on the centre field of views. The intersection with Earth is converted in across and along track distances. The size of the footprint varies from 14x14km at nadir to up to 48x24km on the edges. The geolocation of each FOV is validated against the CrIS SDR data, results give a very good agreement. The accuracy of the exact geolocation is not a goal, we need to ensure that the scanning equations and routines are properly coded. The important result is the size of the field of view, and this does not need a very good accuracy of the geolocation. This is the only place where navigation software has been used in the study.

For each field of view the four semi-axes are calculated for several full orbit passes. For a given FOV the footprint size is a function of scanning angles and satellite altitude. Given a reference altitude, it can be considered that the axis size is linear with the satellite altitude difference.

Complete calculations are done for a set of orbits and regression coefficients are derived. The two regression coefficients are are stored in the fixed data file mapping_viirs_cris.fdf.

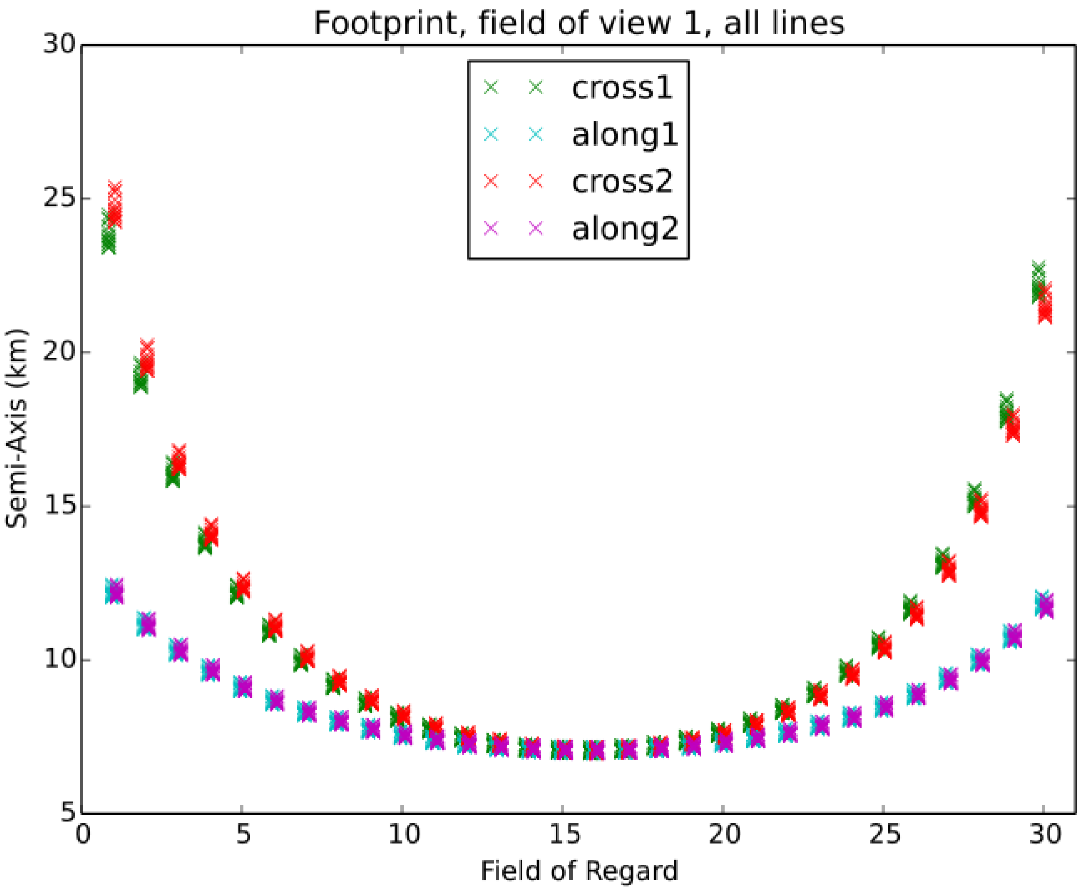


Figure 3: Footprint axis size for field of view number 1, all scan lines of a typical orbit.

3 Mapping to VIIRS

3.1 Bow-Tie effect

The bow-tie effect (Ref 2) of the VIIRS instrument complicates the mapping of the CrIS field of view (see Figure 4 and Figure 5). We use a Fortran90 generalisation of the Common Adjacency algorithm (Ref 3) to find the exact VIIRS pixels that fall into the CrIS FOV. The original software only considers three VIIRS scans which limits the search radius to 16 pixesl/lines. Our version of source code has been extended without software limits, so we can use it for the CrIS mapping, or anything else.

Any user who wants to average some VIIRS data inside a perimeter should take care of the bow-tie effect. Inside a VIIRS scan there is no issue, all neighbours are real neighbours, but if one try to cross scans the neighbourhood is not straightforward and the true next pixel can be part of the next scan (Figure 5). This is managed by the “adjacency” algorithm. It calculates the distance between adjacent rows and columns. One try to find the true pixel next to the considered one, the algorithm selects the pixel which is at a distance of one nominal pixel. This algorithm should be used in any case when a user needs to check local variability or needs to do some statistics.

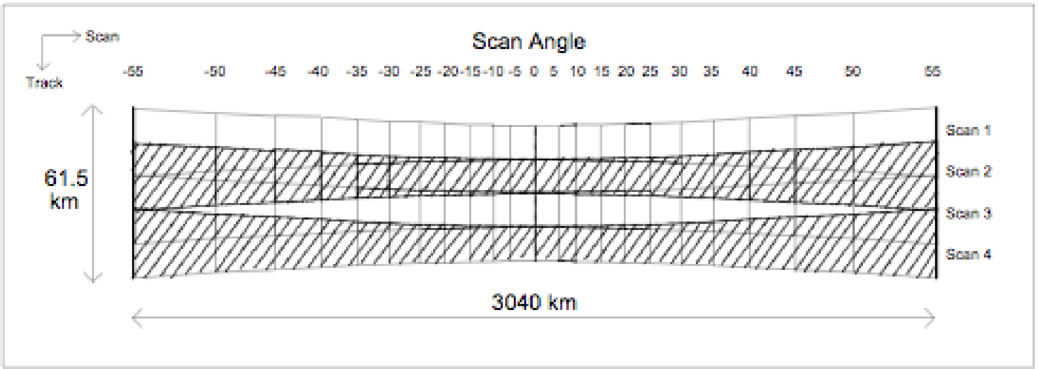


Figure 4: Panoramic bow tie effect (from Ref2)

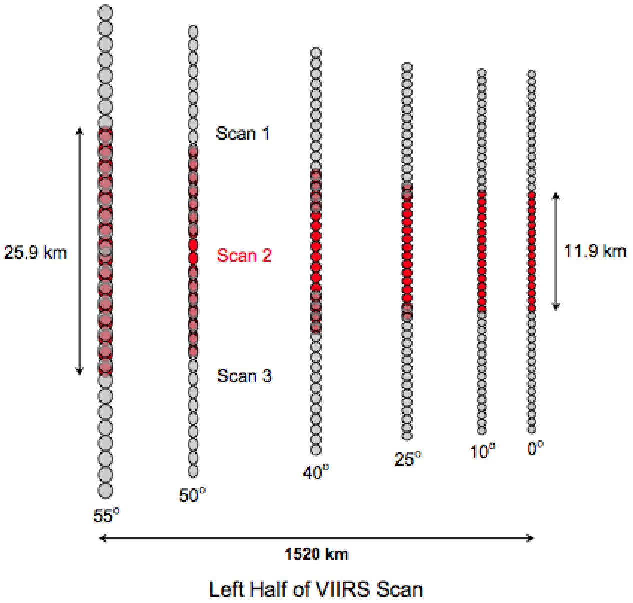


Figure 5: Pixel growth and overlap within a scan (from Ref2). We can see that the 3 scans overlap at the end of the scan; some ground geolocation can be seen 3 times.

3.2 VIIRS along scan spatial resolution

The VIIRS scanning is continuous and regular. The scan is divided in 5 zones where pixels are aggregated with a factor of [3,1,1,2,3] (Figure 6). The aggregation provide a more uniform ground sample size and moderates the pixel growth so the spatial size for band M is in the range [750, 1600] metres.

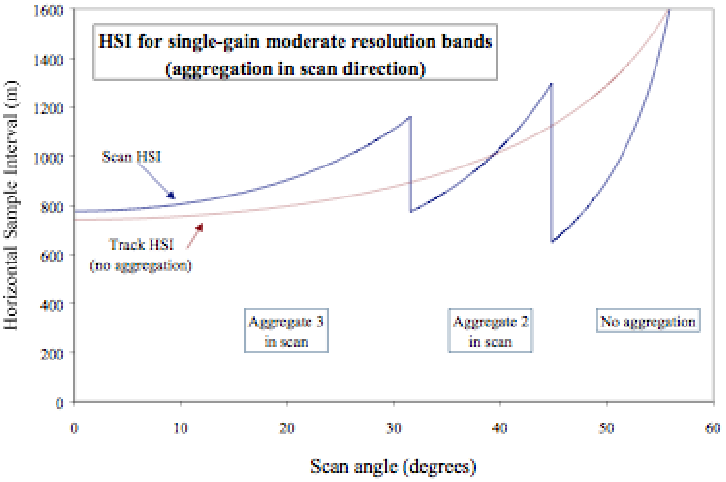


Figure 6: Growth of spatial element ground field of view

When a CrIS field of view is overlapping an area where the aggregation factor is changing, the projected CrIS FOV on the VIIRS image needs a specific treatment.

3.3 Adjacency and neighbourhood

The size of a CrIS FOV is so large that it my cover 3 VIIRS scans. The adjacency algorithm has been coded in fortran 90 and extended to cover any number of scans. The figures Figure 7 and Figure 8 present the impact of the VIIRS scanning on neighbourhood. If we plot the latitude values for an array of VIIRS pixels we can clearly see discontinuities. Moreover when we plot great circle distance of pixels with the centre of the box array, it is evident that closer pixels are not always the closest in distance. The adjacency algorithm solves this issue.
Note that the adjacency algorithm is only able to manage non terrain corrected geolocation.

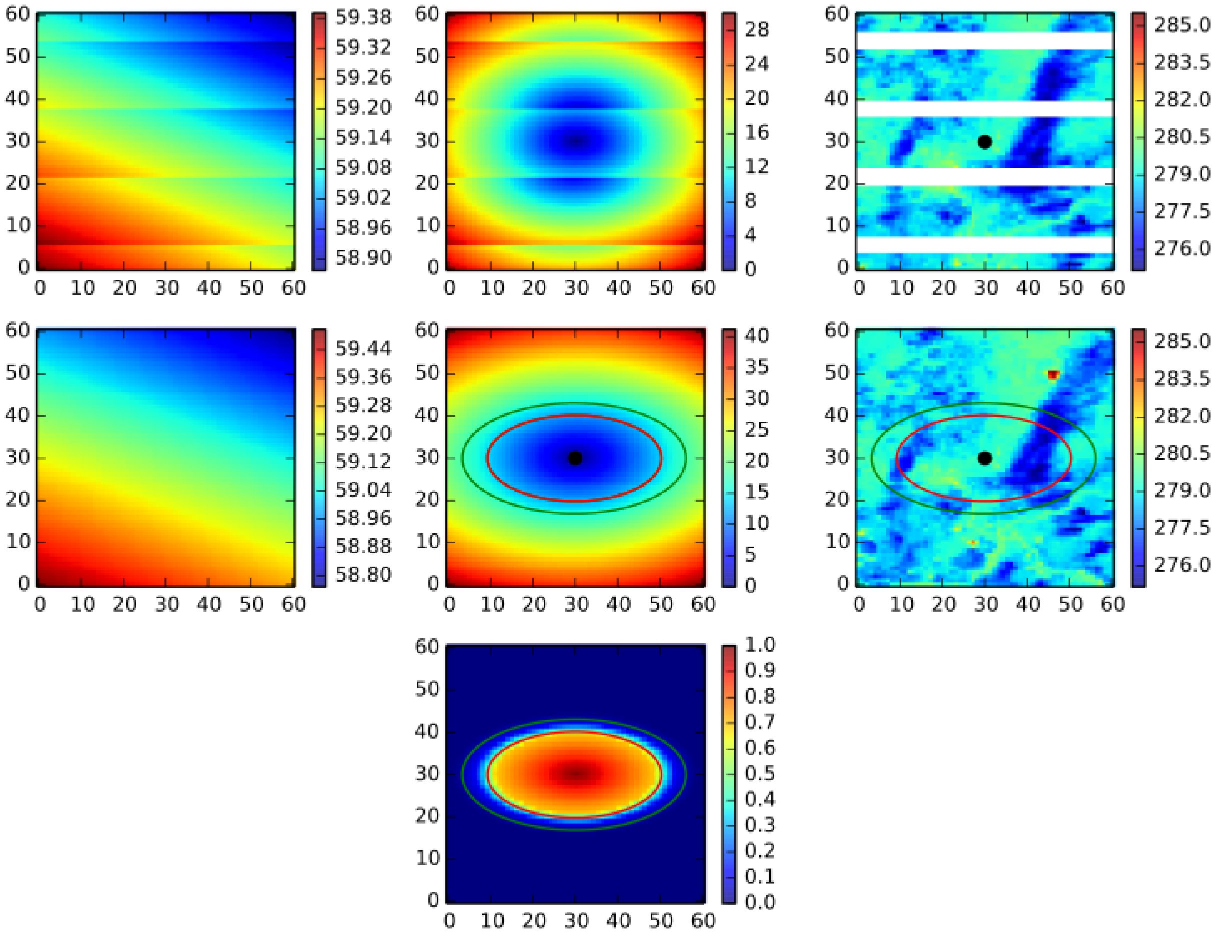


Figure 7: The figure illustrates the VIIRS scanning and a simulated CrIS field of view mapped to VIIRS image. The box is centred on the VIIRS pixel 2600 (see black circle) with a fictitious ellipse of 12x14 km. The top row shows the raw data as read from the VIIRS files. The centre row shows the same data after the adjacency algorithm software has been applied. Left column, plot of the latitudes of the VIIRS pixels. Centre column, plot of the distance in kilometres from centre box. Right column, plot of the VIIRS brightness temperature, see missing values for the overlapping pixels. Bottom image shows a simulated CrIS FOV shape projected on the VIIRS image after reconstruction.

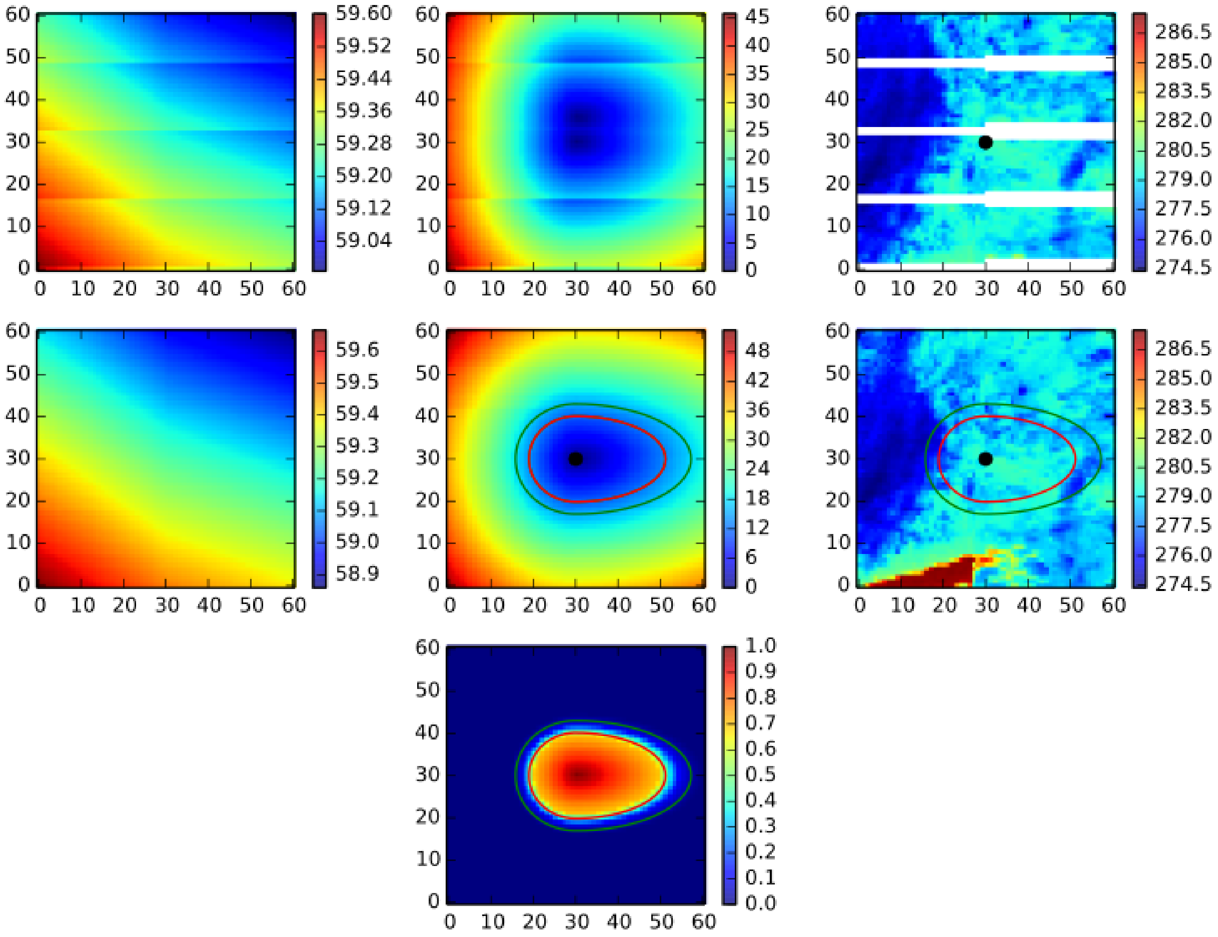
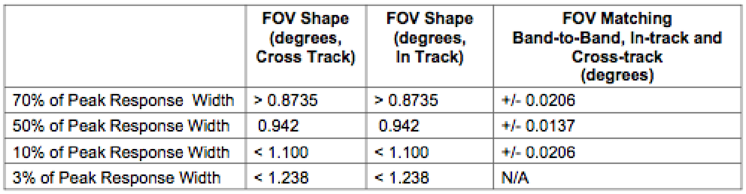


Figure 8: Same as Figure 7, for an extreme case. The centre FOV lies on a bow-tie border pixel and at a VIIRS resolution changing step, i.e. pixel 2560, line 413.

We can clearly see with Figure 8 that the algorithm does a good job in taking the right pixels and setting a good FOV shape. The CrIS ellipse is shown in red and green colours for two different FOV enlarging coefficients (1 and 1.2). The projected CrIS ellipse is highly transformed, this justifies the use of two different semi-axis for mapping. The bottom row presents the weights that can be applied to the VIIRS convolution following the nominal FOV shape characteristics.



	FOV Shape (degrees, Cross Track)	FOV Shape (degrees, In Track)	FOV Matching Band-to-Band, In-track and Cross-track (degrees)
70% of Peak Response Width	> 0.8735	> 0.8735	+/- 0.0206
50% of Peak Response Width	0.942	0.942	+/- 0.0137
10% of Peak Response Width	< 1.100	< 1.100	+/- 0.0206
3% of Peak Response Width	< 1.238	< 1.238	N/A

Figure 9: CrIS FOV shape characteristics

4 Implementation of CrIS-VIIRS mapping in AAPP

The Adjacency algorithm has been coded in Fortran90 and is stored in a module named map_viirs_adjacency. It calculates the nearest VIIRS pixels of a given one, taking care of the bow-tie pixel trim, and Earth rotation between scans This step takes some time to run, as for all VIIRS pixels there are some trigonometric calculations. One have optimised a routine that is used lot of time for distance calculation between successive pixels. The optimisation makes two assumptions, the Earth is flat and the conversion of longitude difference to kilometres is done with a tabulated cosine of latitude rounded to 1/100°.

Another Fortran90 module is created for the mapping, named map_viirs_cris_mod. It is in charge of setting the FOV size, searching for the nearest VIIRS pixel to the CrIS FOV centre (2 to 4 iterations), build the "true" neighbours and calculate the FOV nominal ellipse and weights relative to FOV shape. A F90 "mapping" structure is returned to user level containing all necessary information to be able to map user data. Two convolution subroutines are provided, one for VIIRS SDRs, and one for MAIA4 cloud mask. Those routines are subject to be modified by the user, so one could retrieve any kind of product.
Note that VIIRS radiances are converted from W/m^2.sr.µm to mW/m^2.sr.cm^{-1} for compatibility with CrIS in 1d file, the reference wavelength used for the conversion are stored in the fixed data file.

A main program and an associated script viirs_to_cris are provided. The program only takes VIIRS I or M channels at once, because the adjacency table is relative to the band. All available channels in the SDR are considered for the convolution. The user can run the program several time with the same CrIS 1d file, new results will not overwrite previous ones, so one can first run band I and then the band M.
CrIS input file can be AAPP level 1c or level 1d and may contain any number of CrIS granules. Level 1d files basically store only one field of view (see atovpp command), if user wants the mapping to consider all FOVs one should update the spatial thinning in fixed data file data/preproc/CRIS.fdf and put 0 for full resolution.

A fortran 77 file cris1c1d.F is in charge if the interface between fortran 90 code and the input/output AAPP routines which are coded in fortran 77.

VIIRS SDR files (and optionally MAIA4) should be aggregated before calling the mapping in order to cover the CrIS data. One recommend the use of the nagg software (http://www.hdfgroup.org/projects/jpss/).

VIIRS geolocation file can be provided separately but the default is to use the geolocation data stored in the SDR file. Geolocation and SDR should be entirely compatible. When VIIRS geolocation is terrain corrected (GITCO or GMTCO) the mapping un-corrects any position above 50m high to an altitude lower than 10m by an iterative approximate method.
The FOV shape (Figure 9) can be considered during the convolution step by the convolution routines. The convolution of the VIIRS data take care of the FOV shape for VIIRS radiances, but this is not considered for the mapping of cloud mask data.

CrIS 1c files are only updated if MAIA4 data is available, as the 1c format only provide space for VIIRS cloud products. CrIS 1d files are updated for VIIRS radiances and reflectances and cloud mask; see annex for details.

The Clusters analysis is only done with the CrIS 1c file. VIIRS channels used as input are the channels present in VIIRS file. The VIIRS pixels used for the clusters analysis are, for each FOR, the VIIRS envelope of the nine CrIS FOVs. Clusters are sorted by default by the channel with the most large wavelength. Statistics (number of pixels by cluster, mean and standard deviation for each channel) are then computed for each CrIS FOVs. Results are stored in a separate hdf5 file (See Annex Clusters analysis output description).
The clusters analysis method (SD_Nuees_Dynamiques) is extracted from the OPS-LRS V7 software from the source code file src/SD/ALG/src/SD_ALG_AVHRR.c. The name of 2 defined constants are changed (SD_BAS_NPI_AVHRR in SD_BAS_NPI_IMAGER and SD_BAS_NLI_MAX_UTIL_IMAGER inSD_BAS_NLI_MAX_UTIL_IMAGER).

Some imput parameters of the NueesDynamiques method have been fixed for AAPP and defined in NueesParam.h. They are:

- Maximum number of clusters: CCSNbClusMax = 6 (pixels with are not classified are put in the cluster number 7)
- Convergence threshold: CCSIterConvCutoff = 0.010000
- Split threshold: CCSSplitCutoff = 30.000000
- Coalescence threshold: CCSGlueCutoff = 35.000000
- Eigen value cut off: EigValCutoff = 0.010000
- Initial value of the aglomeration distance: CCSDistAgloInit = 10000000000.000000
- Minimum number of iteration for the calculation of the unclassified threshold: CCSMinIterNCCutoff= 10
- Maximum interclass distance: CCSDistMax = 10.000000
- Maximum number of unclassified: CCSNbNonClassifMax = 80
- Maximum number of iterations: CCSNbIterMax = 9

The other input parameters for NueesDynamiques are defined in the mapping_viirs_cris.fdf file. They are :

- the channel noise for each viirs channels (in W/(m2.sr.m-1))
- the channel weight for each viirs channels (0 to 1)

The algorithm of the NueesDynamiques method is described in the Reference document 4.
Here is a brief description:
The first step is the initialization: radiances are normalised and weighted, the first centroid is computed and correponds to the mean radiances in each channels. The second centroid is computed: it is the most distant pixel from the first centroid. Finaly a third centroid is computed. It corresponds to the most distant pixel from the second and first centroid. Each pixels are then associated to its nearest centroid and new means are calculated.

Then nine iterations are performed:
At each iteration: if the number of clusters is greater to a first threshold, two clusters are merged. If the number of clusters is lower to a second threshold, the most scattered cluster is splitted. Each pixels are then associated to its closed centroid and new means are computed.

Finaly the clusters are sorted (descending) according to the chosen channel.

The user level command is:

```
viirs_to_cris [-d|-D] [-t threshold] [-b band] [-m Maia4file] [-C
cluster_output_file ]  [-g Geofile] [-s sorting_channel] CrISfile
VIIRSfile

where  band      is a VIIRS band name I or M
       Maia4file is a VIIRS MAIA 4 HDF5 file
       Geofile   is a VIIRS geolocation HDF5 file
       Crisfile  is a CrIS AAPP level 1c/1d file
       VIIRSfile is a VIIRS SDR  HDF5 file
       cluster_output_file is a output file name for the hdf5 file
which contains the results of the clusters analysis
       sorting channel : (1 to 16) VIIRS channel number for clusters
sorting (by default the channel with the most larger wavelength)
       -d debug level 1
       -D debug level 2
       threshold is the minimum percentage of valid VIIRS pixels for
mapping
```

If debug is set, log and debug files are created in the working directory.

The software modules are commented with doxygen marks. So the full software documentation can been generated by doxygen.

List of files

Source code files update to VIIRS-CrIS mapping are

```
src/maia4/
      bin
           viirs_to_cris.F90
           viirs_to_cris.ksh
      libmapviirscris
           map_viirs_adjacency_def.F90
           map_viirs_adjacency_mod.F90
           map_viirs_cris_def.F90
           map_viirs_cris_mod.F90
           mapping_viirs_cris.fdf
src/preproc
      libatovpp
           cris1c1d.F
src/preproc
     libclusters
           NueesDynamiques.c
           clusters.c
src/preproc
     liblapack-lite
daxpy.F   dgebal.F  dgehrd.F  dgemv.F   dlabad.F  dlahrd.F
dlanv2.F  dlarft.F  dlaset.F  dlasq5.F  dlasv2.F  dorgl2.F
dorml2.F  dscal.F   idamax.F  xerbla.F  dbdsqr.F  dgebd2.F
dgelq2.F  dgeqr2.F  dlabrd.F  dlaln2.F  dlapy2.F  dlarfx.F
dlasq1.F  dlasq6.F  dnrm2.F   dorglq.F  dormlq.F  dswap.F
```

```
ieeeck.F  dcopy.F   dgebrd.F  dgelqf.F  dgeqrf.F  dlacpy.F
dlamch.F  dlarfb.F  dlartg.F  dlasq2.F  dlasr.F   dorg2r.F
dorgqr.F  dormqr.F  dtrevc.F  ilaenv.F  ddot.F    dgeev.F
dgelss.F  dger.F    dladiv.F  dlange.F  dlarf.F   dlas2.F
dlasq3.F  dlasrt.F  dorgbr.F  dorm2r.F  drot.F    dtrmm.F   lapack-
lite.c-F  dgebak.F  dgehd2.F  dgemm.F   dhseqr.F  dlahqr.F dlanhs.F
dlarfg.F  dlascl.F  dlasq4.F  dlassq.F  dorghr.F  dormbr.F drscl.F
dtrmv.F   lsame.F

include
cluster.interface NueesParam.h Nuees.h clusters.h lapack-lite.h
fortran-lock.h misc-complex.h
```

5 Results and Validation

The mapping was tested over several Lannion local passes and a global pass which allows to test on some specific cases such as polar data. Run time is less than 30 second for a 15 minutes of M data (without the clusters analysis), more time is spent in aggregation.

The clusters analysis took consumes more CPU. Run time is 2:50 minutes for a 15 minutes of M data.

Validation is performed by comparing the VIIRS radiances spatially convolved in CrIS FOV and the CrIS 1c spectrum convolved with the VIIRS instrument spectral response functions.

Validation of the extracted Nuees Dynamiques methods was done in comparing the cluster image generated by the stand alone NueesDynamiques method for a IASI/AVHRR case with the cluster image computed by OPS-LRS. We checked that the same imput produced the same output with the stand alone method.

Validation of the VIIRS/CrIS clusters analysis was then performed as follow: for each CrIS FOVs we seek the most populated cluster and if more 80% of pixels belongs to the cluster, we compare the mean VIIRS radiance of the cluster and the CrIS 1c spectrum convolved with the VIIRS instrument spectral response functions.
Results of the validation can be seen in the viirs_to_cris software test report.

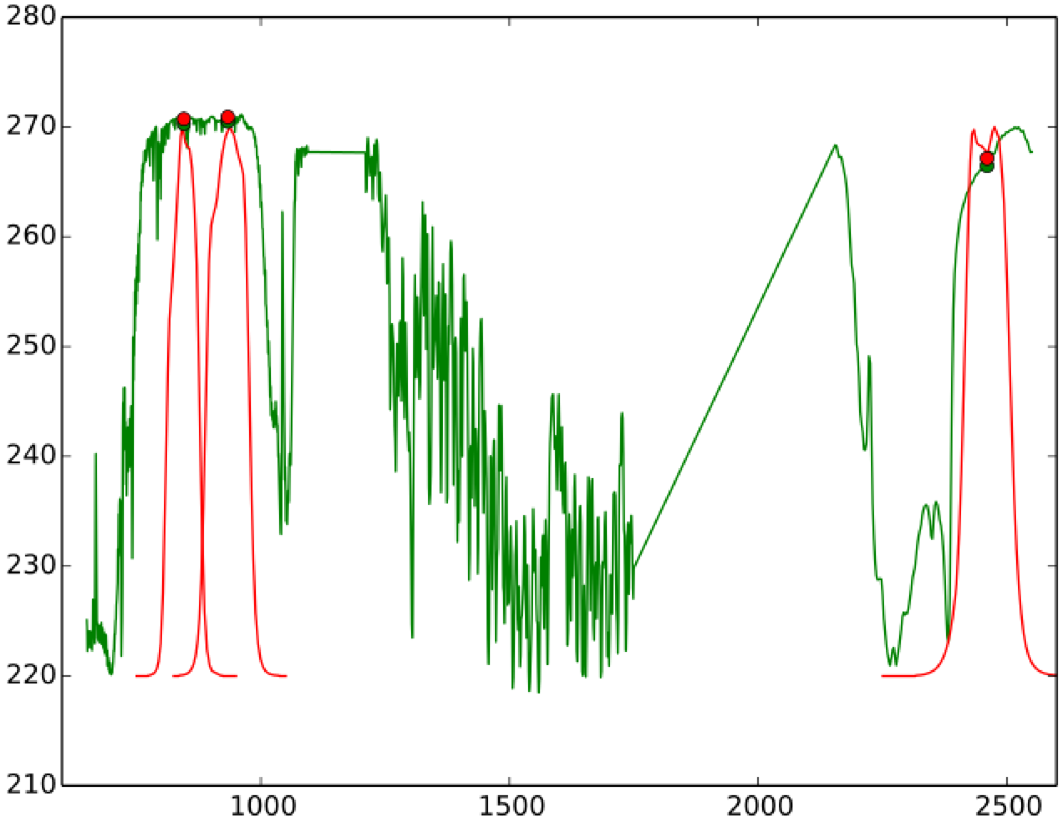


Figure 10: VIIRS SRFs (M13, M15 and M16) are shown above overlaid with a CrIS spectrum. Green circle: CrIS radiances convolved with VIIRS SRF. Red circle: VIIRS radiances mapped to CrIS FOV.

The VIIRS channels that lay in the CrIS spectrum are I5, M13, M15 and M16. All those channels are considered in the validation process, so band I and M are tested. Results show rms errors always below 0.8K. Any test trying to spatially shift the VIIRS data gives worse results. The small observed bias can be explained by the unit conversion of the VIIRS radiances, due to uncertainty of central frequencies used in ADL/CSPP for calibration and conversion algorithms.

It is shown that the VIIRS and CrIS geolocation are in good agreement and that the adjacency method is of great interest for mapping those two instruments.

The Figure 11shows an example of scatter plots that we get for a CrIS granule when comparing the VIIRS results of the mapping algorithm and the CrIS 1c spectrum convolved with the VIIRS SRFs. The 4 infrared VIIRS channels show the same behaviour. For plotting one only retain CrIS FOVs that are entirely covered by VIIRS granules. The spread is due to cloudy scenes where the radiances inhomogeneity in the FOV and the FOV shape uncertainties do occur.

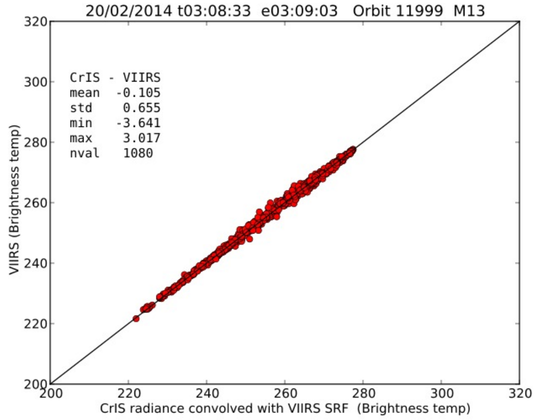


Figure 11: Scatter plot of VIIRS mapped brightness temperatures and CrIS spectrum convolved with VIIRS spectral response function. Channel M13

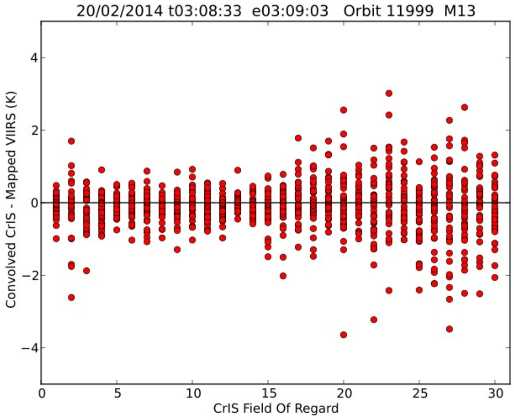


Figure 12: Same data as Figure 11 Plot of differences with respect of the field of regard number.

5.2 Test on full orbit

The orbit pass 15537 of the October 27th 2014 (11h33-13h25) has been used for testing (all VIIRS geolocation is terrain corrected). The first thing was to confirm the mapping is able to run over the poles and this is confirmed.

The main thing is that the results are almost same quality over the pass. But we can observe a general worse quality for field of regards that are in second part of the swath (field of regard 15 to 30). This needs more investigation, a comparison with locally received and processed data has been done. This test show the same behaviour. Most of the high difference values are observed for low brightness temperatures, but this is not the major effect. More study will be done, in particular focusing on central field of view.

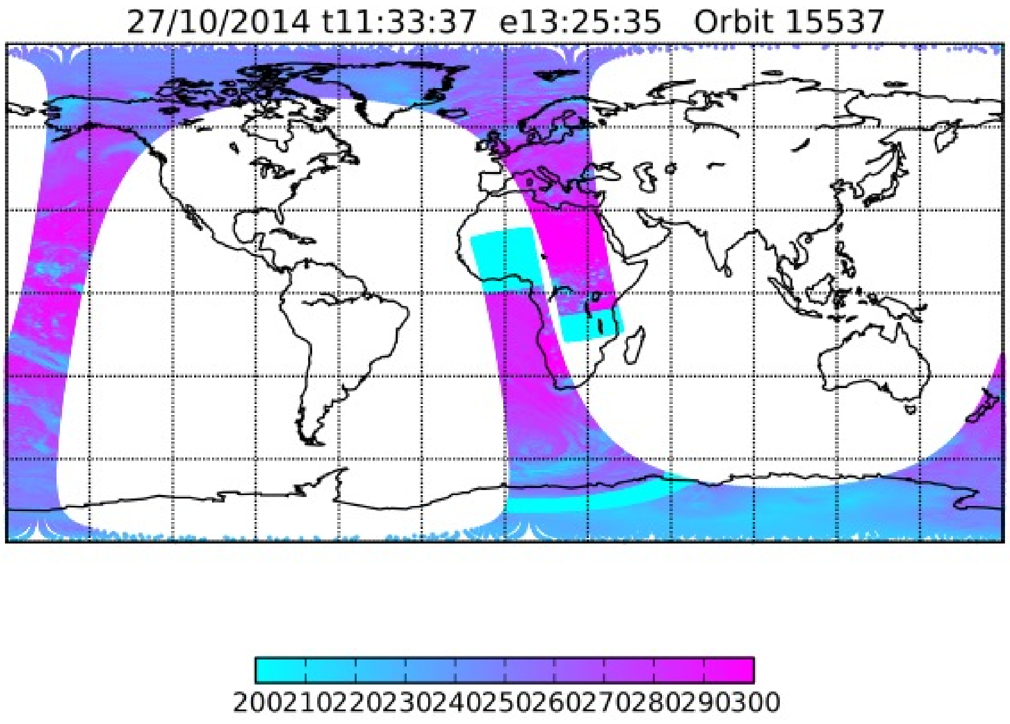


Figure 13: Full orbit pass 15537, VIIRS M16 brightness temperature mapped to CrIS. At beginning and end of orbit some areas without VIIRS data. Some missing VIIRS in ascending part, near South pole.

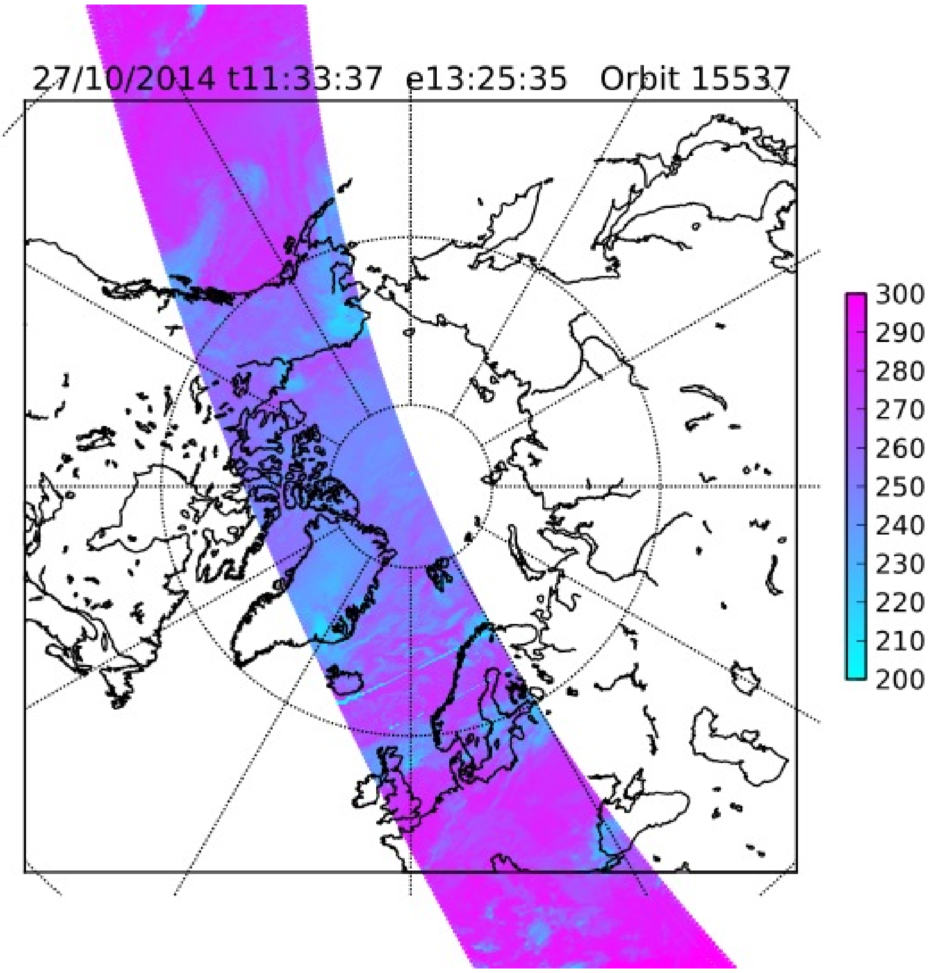


Figure 14: Zoom on North pole. Full orbit pass 15537, VIIRS M16 brightness temperature mapped to CrIS.

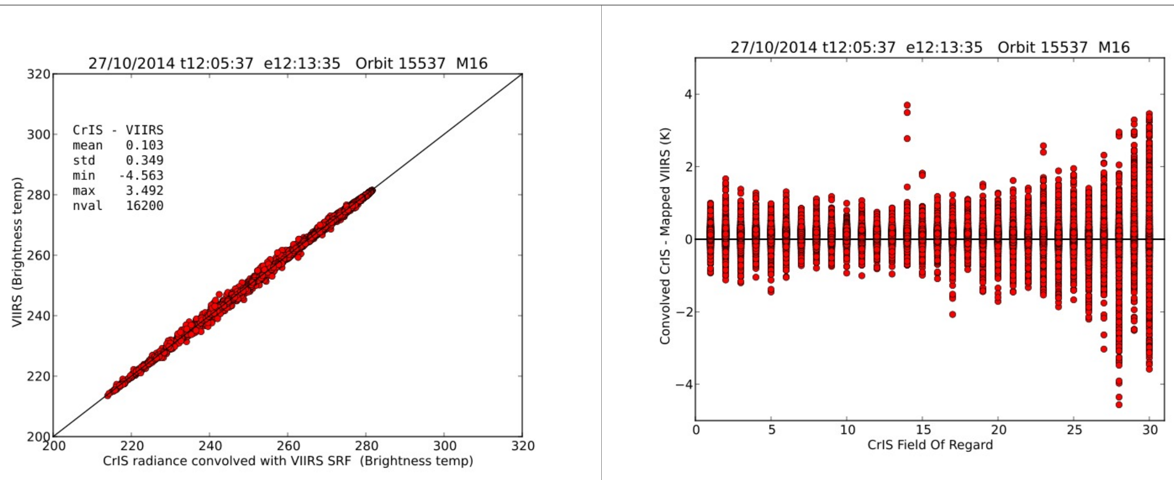


Figure 15: Same plot as Figure 11 for CrIS granule from 12h05 to 12h13

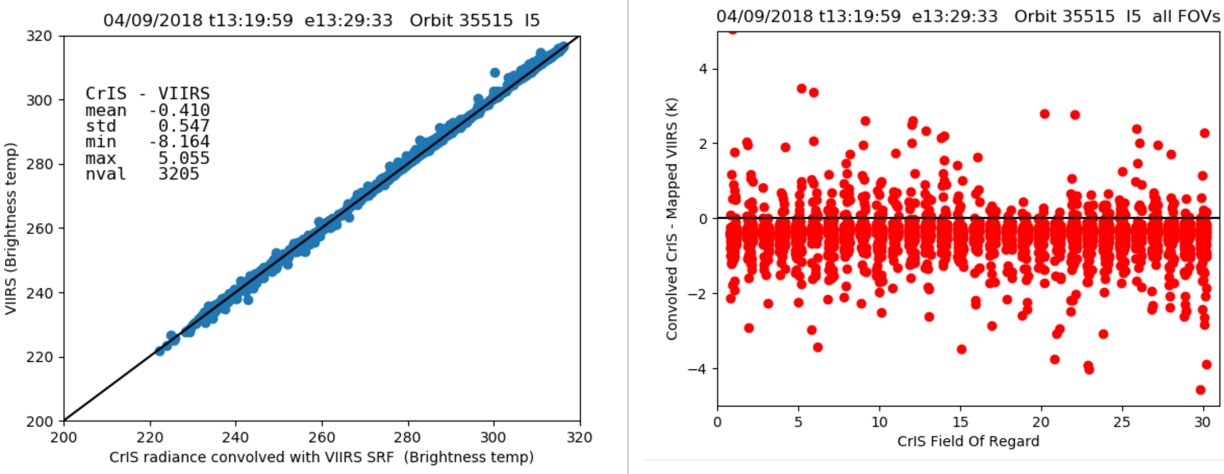


Figure 16: Same plot as Figure 11 Cris granules on data from 04/09/2018

5.3 MAIA4 results

The MAIA4 cloud mask product file can be input to the program. Some of the information like cloud cover percentage, cloud top temperature and cloud top pressure can be stored in the level 1d CrIS file; see annex for full list of variables. The Figure 17 shows an example of MAIA4 cloud percentage mapped to the CrIS field of view.

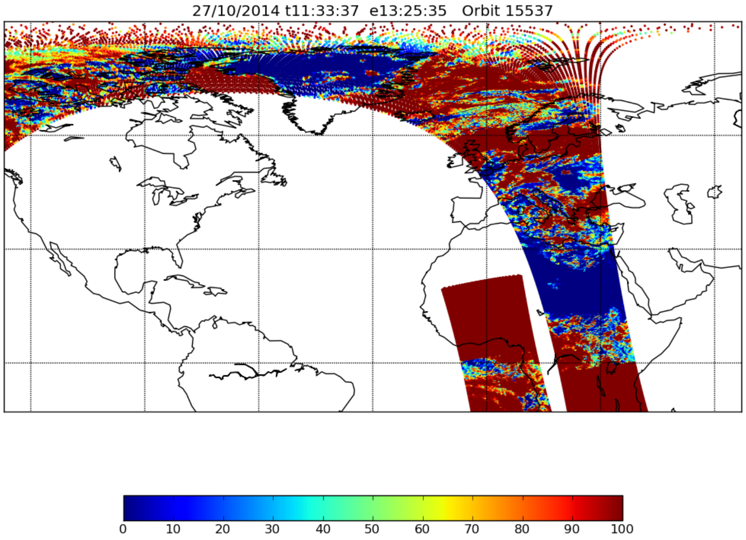


Figure 17: Maia4 cloud cover percentage for a part of the full orbit test case.

6 Conclusion and future work

We have shown that the VIIRS-CrIS mapping version 2.0 is able to provide results for all field of view and for any part of the world with quite good quality. The fortran source code has been highly tested over numerous CMS Lannion local passes and for a full orbit. Any improvement to the algorithm should not change the interfaces.

The worse quality for the field of regard 15 to 30 which appeared on the version 1 of the software has been corrected (bug fix).

The current release is good enough for users who wants to merge a VIIRS cloud mask such as MAAI4 with the CrIS radiances.

Regarding the cluster analysis, the output is written in an hdf5 file, in order to be processed by NWP center, it is necessary to define a new BUFR format for the CrIS 1c files.

Annex AAPP l1c l1d variables updated by mapping

CrIS level 1C format
cris1c.h
integer*4 cris1c_landfrac(cris_1cnfov,cris_1cnfor) ! land fraction (0-100)
integer*4 cris1c_landsea(cris_1cnfov,cris_1cnfor) ! land/sea qualifier (0=land, 1=sea,2=coast)
integer*4 cris1c_cloudcover(cris_1cnfov,cris_1cnfor) ! cloud cover (percent)
*integer*4 cris1c_cloudtopht(cris_1cnfov,cris_1cnfor) ! height of top of cloud (m) Not available in MAIA4 output*

CrIS level 1d format
cris1d.h

header record
! Channel order: 1-16 M band, 17-21 I band, 22 DNB
integer*4 cris1d_h_nviirschan !number of VIIRS channels in format
integer*4 cris1d_h_nviirschanused !number of channels used
integer*4 cris1d_h_viirschans(cris_1dnchanviirs) !Channel numbers
integer*4 cris1d_h_viirsbands(cris_1dnchanviirs) !Band numbers 5=M, 6=I, 7-DN

data record
integer*4 cris1d_cloudflag(10,cris_1dnfor)

- 1 % clear
- 2 % cloudy
- 3 % clear over snow
- 4 % clear over ice
- 5 % aerosol_dust_ash_fire
- 6 mean CLOUD Top Pressure (hPa * 10) Missing value : -9999
- 7 mean CLOUD Top Temperature (Celsius * 100) Missing value : -9999
- 8 mean surface temperature over sea (Celsius * 100) Missing value : -9999
- 9 mean surface temperature over land (Celsius * 100) Missing value : -9999
- 10 Pixel quality flags: % of good quality flags (fov_qual==0)

integer*4 cris1d_viirsradiance(cris_1dnchanviirs,cris_1dnfor)
integer*4 cris1d_viirsreflectance(cris_1dnchanviirs,cris_1dnfor)
units are mW/m^2.sr.cm^{-1} for radiances

Annex Clusters analysis output description

The hdf5 output clusters file contains each FOR a group named cluster-band-line_number-for_number
with band= M or I
line number : number if the CrIS line
for number : number of the FOV (1 to 30)
the group contains:

dataset name	dimension	comment
RadAnaMean	9 x 7 x nb_channels	For each Field of View/cluster/channel: Mean Radiance (units: W/(m2.sr.m-1)
RadAnaNbPix	9x7	For each Field of View/cluster: Number of pixels in the cluster
RadAnaStd	9 x 7 x nb_channels	For each Field of View/cluster/channel: Standard deviation (units: W/(m2.sr.m-1)
cluster_image	nlines x npixels	cluster image after the clusters analysis (output of the Nuees Dynamiques function)
cluster_image_on_viirs_grid	mlines x mpixels	same cluster image mapped on the VIIRS grid
flv	1	first line in VIIRS grid of the cluster image of the cluster_image_on_viirs_grid
for	1	for number
fpv	1	first pixel in VIIRS grid
line	1	CrIS line number
llv	1	last line in VIIRS grid
lpv	1	last pixel in VIIRS grid
nb_clusters	1	number of clusters

nb_channels = 16 for M band, 5 for I band