NASA Cross-track Infrared Sounder (CrIS) IMG / IMG_COL Product Users' Guide

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2	2.0	0.1.13	17 Aug 2020	Initial revision
2, Rev A	2.1 (JPSS-1) 2.2 (SNPP)	0.1.15	01 Feb 2021	Added JPSS-1
2, Rev B	2.4 (SNPP) 2.5 (JPSS-1)	0.1.15	23 Apr 2024	Described latest versions

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1. Introduction

1.1 Overview

This document provides information for using the Cross-track Infrared Sounder (CrIS) "IMG" and "IMG_COL" data products.

The IMG product supplements the CrIS Level 1B (L1B) hyperspectral radiance product by providing collocated high-spatial resolution data from the Visible Infrared Imaging Radiometer Suite (VIIRS) imager located on the same platform. VIIRS radiance and cloud mask values are grouped and aggregated for every CrIS field of view (FOV) and made available in a format intended for use alongside the CrIS L1B data. Figure 1 shows an example of an IMG product variable displayed using the Panoply data viewer.

The IMG_COL product additionally makes available CrIS and VIIRS data array index values that result from the collocation process that is performed as part of producing IMG. These index values can be leveraged by end users to further augment CrIS data by extracting collocated observations from any additional VIIRS data products that aren't already present in IMG. Figure 2 gives an example of a set of VIIRS pixels identified in IMG_COL as being located within a CrIS FOV.

The software to create IMG and IMG_COL is maintained by the CrIS Level 1 Software Team. The datasets are generated via the VIIRS Atmosphere SIPS (Science Investigator-led Processing System) at the University of Wisconsin - Madison. Products are archived and made available to the public by NASA's GES DISC (Goddard Earth Sciences Data and Information Services Center) with support from the NASA Sounder SIPS.

Figure 1: Display of an IMG product variable using the Panoply data viewer. Mean VIIRS M5 (0.673µm) band reflectance values are shown, restricted to only the cloudy VIIRS pixels in each CrIS FOV.

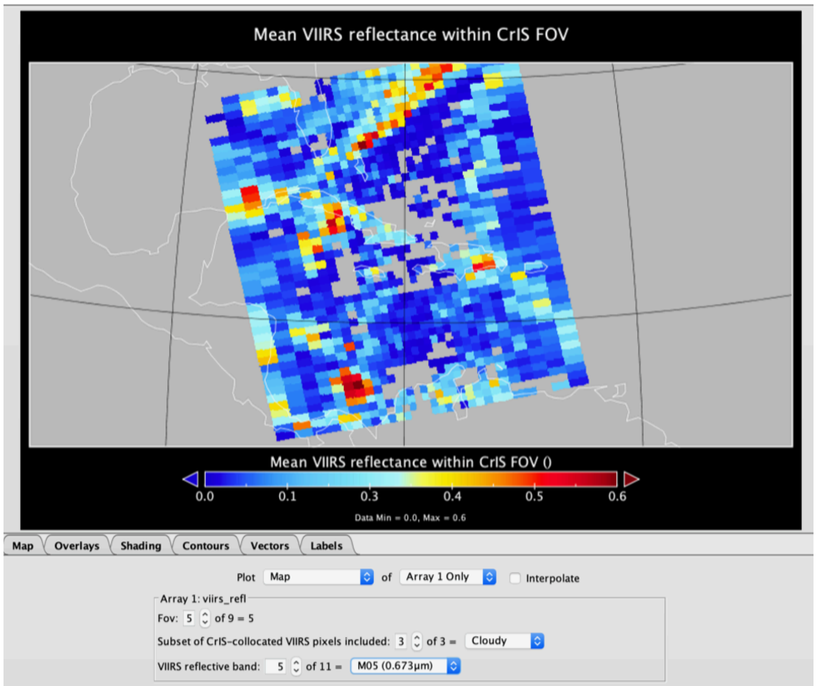
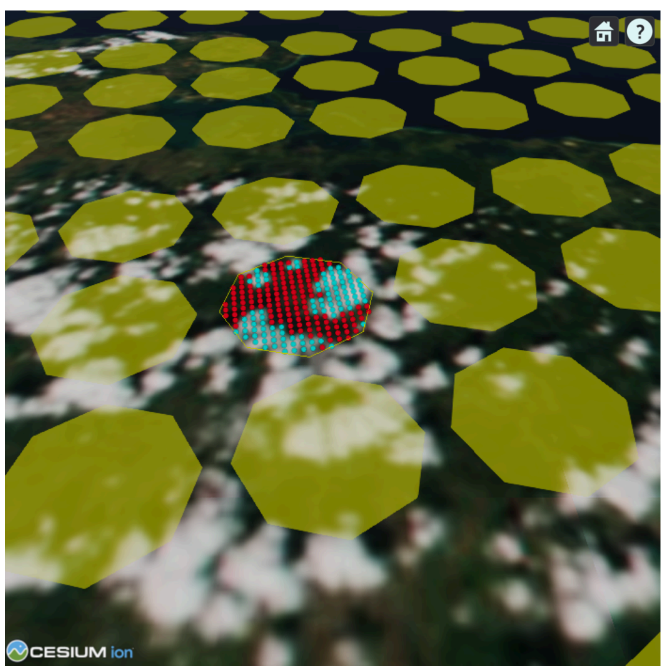


Figure 2: Collocated VIIRS pixels shown within a single CrIS FOV (cloudy pixels shaded cyan, clear shaded red). The IMG_COL product provides data arrays that describe which VIIRS pixels fall within which CrIS FOVs.



1.2 Data Disclaimer

The Version 2 CrIS IMG and IMG_COL data products are released to the public as is.

1.3 Obtaining the Product

The IMG and IMG_COL products can be downloaded from the DAAC (Distributed Active Archive Center) web interface provided by the GES DISC: https://disc.gsfc.nasa.gov/. The following table identifies the GES DISC datasets described in this users' guide.

GES DISC Short Name	GES DISC Long Name
SNDRSNCrISL1BIMG	S-NPP CrIS IMG: Collocated VIIRS level 1 / cloud mask statistical summary
SNDRSNCrISL1BIMGC	S-NPP CrIS IMG_COL: Array indices for collocated VIIRS observations
SNDRJ1CrISL1BIMG	JPSS-1 CrIS IMG: Collocated VIIRS level 1 / cloud mask statistical summary
SNDRJ1CrISL1BIMGC	JPSS-1 CrIS IMG_COL: Array indices for collocated VIIRS observations

1.4 Contact Information

Inquiries regarding the data product can be directed to sounder.sips@jpl.nasa.gov.

Inquiries regarding the software and underlying algorithms can be directed to cris.l1b.support@ssec.wisc.edu.

1.5 What's New

The version 2.1 product added the JPSS-1 mission dataset to the existing SNPP product. A version 2.2 SNPP product began production in July 2021, changing the upstream CrIS L1B version from 2.0.15 to 3.0.4. Version 2.2 additionally fixed a problem with missing collocated VIIRS pixels near the edge of the CrIS swath, and fixed an error in the `comment` attribute of the

IMG_COL `viirs_gran` variable. Version 2.3 (September 2021) for JPSS-1 similarly changed the upstream CrIS L1B version from 2.1.3 to 3.0.4. Version 2.4 for SNPP (May 2023) further updated CrIS L1B to 3.0.8. Version 2.5 for JPSS-1 (October 2023) updated the version of the VIIRS cloud mask input (CLDMSK_L2_VIIRS_NOAA20) from 1.0.1 to 1.0.5.

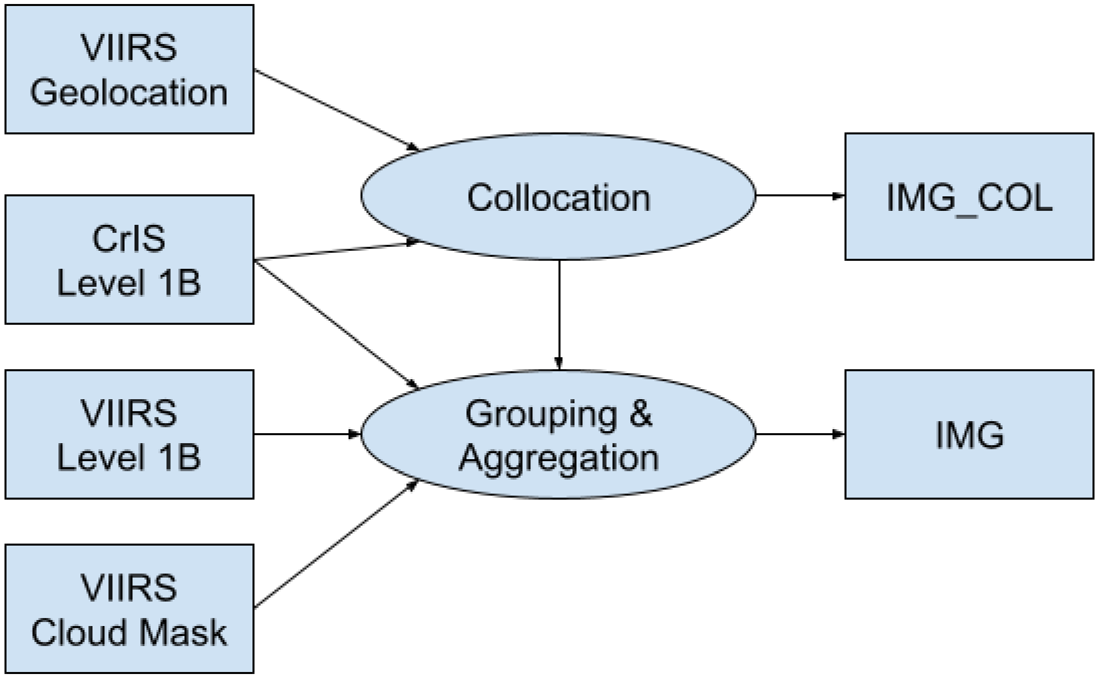
2. Input datasets and algorithm overview

The IMG and IMG_COL products are intended to be supplementary to the CrIS Level 1B radiance product. For background on the CrIS instrument and CrIS Level 1B product contents and usage see the CrIS Level 1B Product Users' Guide [1].

IMG and IMG_COL incorporate data from the VIIRS imaging sensor. As the CrIS and VIIRS instruments are carried aboard the same spacecraft, with VIIRS observing the earth over a wider spatial swath than CrIS, collocated VIIRS measurements are consistently available within every CrIS field of view. The VIIRS datasets used for IMG and IMG_COL include the Level 1B radiometric and geolocation data and the Level 2 cloud mask product. For VIIRS instrument background and product details consult the L1B and cloud mask products users' guides [2, 3].

Figure 3 gives an overview of the process used for product creation. The collocation step identifies which VIIRS pixels are located within the spatial extent of each CrIS FOV. The process characterizes the CrIS FOV at nadir as a 13km diameter circle and accounts for FOV elongation and scaling for off-nadir observations. The collocation step uses the "Collopak" collection of general-purpose collocation tools available at https://www.ssec.wisc.edu/~gregq/collopak/. Details on the techniques involved in performing the collocation efficiently are described in [4]. The grouping and aggregation steps are executed by a Python program developed and maintained by the CrIS L1B software team.

Figure 3: Dataflow for IMG and IMG_COL product creation



3. File format

The IMG and IMG_COL products are stored in 6-minute data granules that exactly correspond to the 6-minute granules of the CrIS L1B product. Each granule has one IMG product file and one IMG_COL product file, both in NetCDF version 4 format. Separate files were chosen to store the collocation index values apart from the aggregated VIIRS observations in order to keep the data volume down for users who do not need access to the detailed collocation information. The table below shows the data volume for both products, with CrIS L1B included for reference.

Product	**Granule size**	**Daily volume**	**Annual volume**
IMG	3.6 MB	871 MB	310 GB
IMG_COL	7.1 MB	1686 MB	601 GB
L1B	167 MB	39 GB	14 TB

IMG and IMG_COL file names follow the same convention as CrIS L1B. For example the IMG, IMG_COL, and L1B file names for a single 6-minute granule might be:

```
SNDR.SNPP.CRIS.20200101T0000.m06.g001.IMG.std.v2_0.W.200618171125.nc
SNDR.SNPP.CRIS.20200101T0000.m06.g001.IMG_COL.std.v2_0.W.200618171125.nc
SNDR.SNPP.CRIS.20200101T0000.m06.g001.L1B.std.v02_22.G.200101082810.nc
```

The CrIS L1B Product Users' Guide [1] describes each component of the file name format in detail. In the above example, notice that the IMG and IMG_COL file names differ from the corresponding L1B file name in the following ways:

- The product type field indicates IMG or IMG_COL rather than L1B.
- The product version is different since the IMG software is versioned separately from L1B and additionally the IMG processing workflow depends on VIIRS products that are also independently versioned.
- The producer field for IMG and IMG_COL is "W" to signify production at the NASA VIIRS Atmosphere SIPS at the University of Wisconsin - Madison.
- The production timestamp does not match L1B.

4. Product walkthrough

This section describes the primary contents of an IMG file, then concludes by describing how to interpret the collocation index arrays provided in IMG_COL. See Appendix A for a complete reference to IMG and IMG_COL product contents.

Code snippets and plots shown in this section were generated using the MATLAB programming environment. Note that the order in which data variable dimensions are presented in MATLAB is reversed from the order presented by NetCDF tools like `ncgen`, and that MATLAB index values start from 1, not 0. Most example plots in this section use S-NPP granule 115 (11:24 UTC) from 2015-Apr-22.

4.1 Variables `viirs_count` and `viirs_cloud_frac`

The `viirs_count` variable indicates the number of VIIRS pixels located within the spatial extent of each CrIS FOV. This data array is 4-dimensional, with the following dimension names and sizes:

- `atrack`: 45 CrIS scans per 6-minute granule
- `xtrack`: 30 CrIS fields of regard (FORs) per scan
- `fov`: 9 CrIS fields of view (FOVs) per FOR
- `viirs_subset`: 3 different groupings of VIIRS pixels that are considered (all pixels, clear pixels only, cloudy pixels only)

The clear and cloudy designations come from the VIIRS cloud mask. The cloud mask labels each VIIRS pixel with one of: "confident clear", "probably clear", "probably cloudy", or "confident cloudy". In the IMG product, confident and probably clear labels result in a clear designation, while confident and probably cloudy labels are designated cloudy.

Note that the VIIRS cloud mask uses a separate labelling scheme for identification of thin cirrus clouds. Thus a pixel labeled clear by the main cloud mask algorithm may also be identified as containing thin cirrus. This thin cirrus detection is not reflected in `viirs_count`, but rather in the `viirs_thin_cirrus_*` variables described later.

The MATLAB expression `viirs_count(3,:,:,:) / viirs_count(1,:,:,:)` divides the per-FOV cloudy pixel counts by the total pixel counts (recall in MATLAB the first index position references the `viirs_subset` dimension). The result should match the `viirs_cloud_frac` variable, also available in the IMG product.

Figure 4: The `viirs_count` *variable for S-NPP on 2015-Apr-22 granule 115*

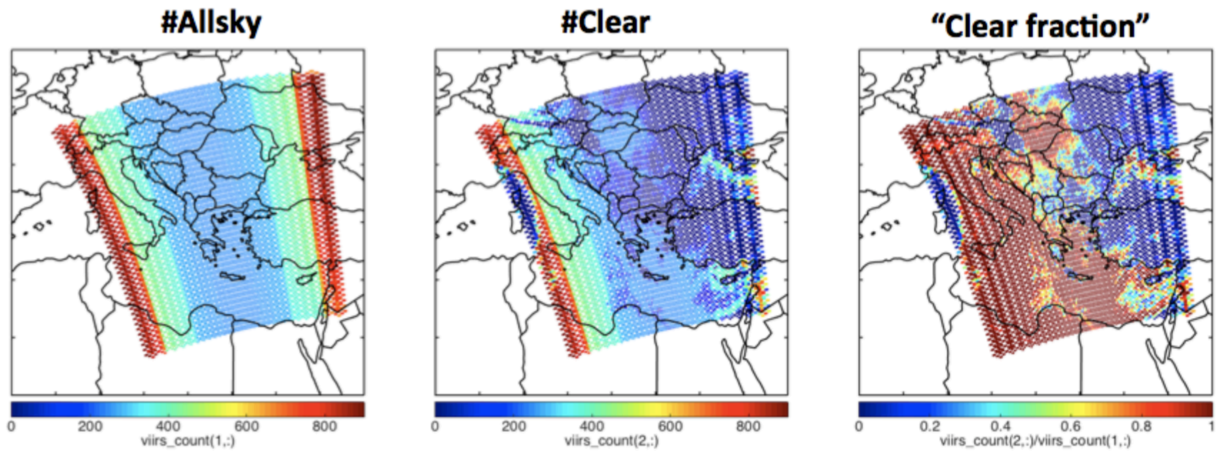
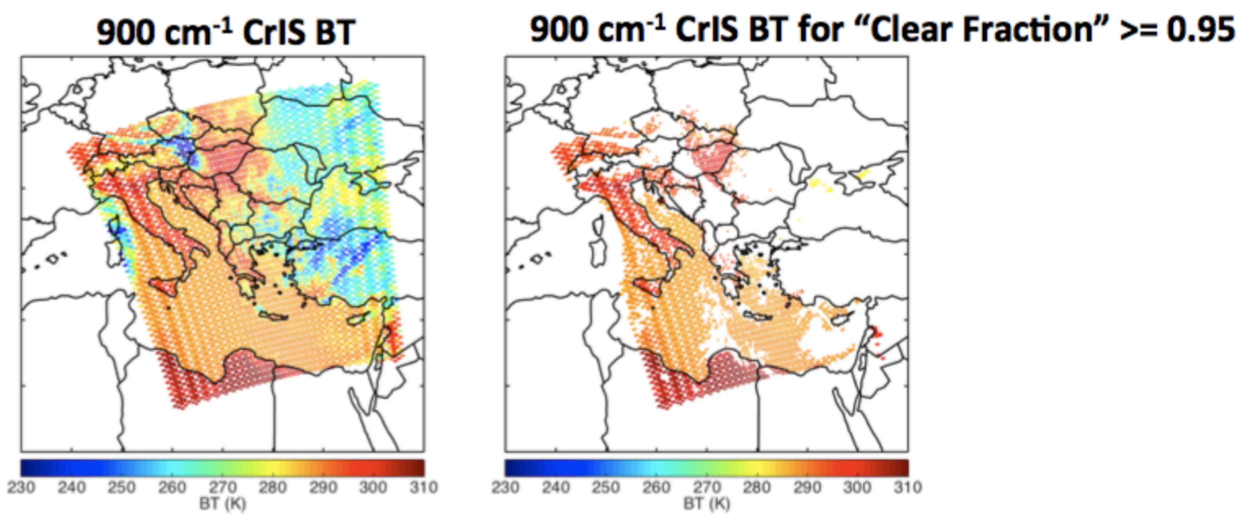


Figure 5: Using `viirs_count` *to selectively plot CrIS brightness temperature (BT) data*



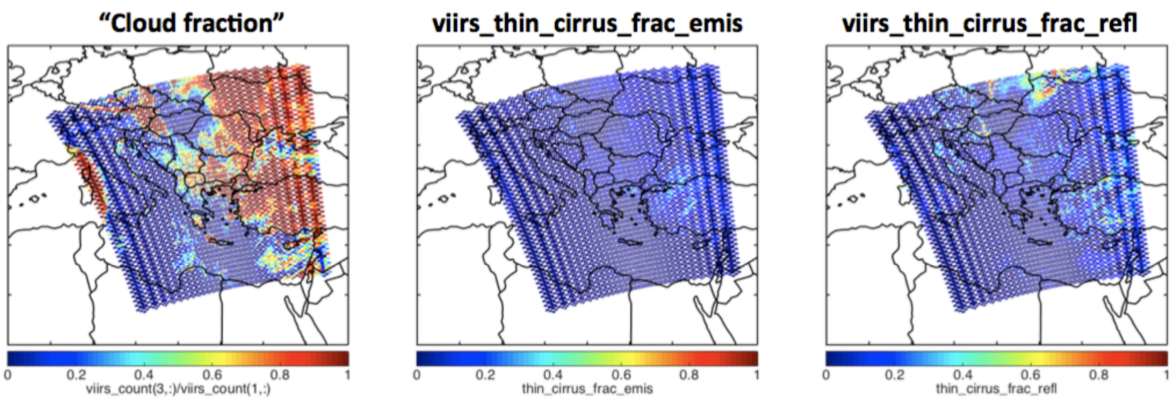
4.2 VIIRS thin cirrus variables

The VIIRS cloud mask product used as input to IMG performs two radiometric tests to detect the presence of thin cirrus clouds within each VIIRS observation: daylight-only reflective (band M9, 1.38μm) and day-night emissive (band M16, 12.0μm). The result of these tests for thin cirrus are independent from the overall cloudy/clear classification made by the cloud mask algorithm.

The IMG product provides the `viirs_thin_cirrus_frac_refl` and `viirs_thin_cirrus_frac_emis` variables to characterize the results of both thin cirrus tests within each CrIS FOV. These variables quantify the number of pixels determined to contain thin cirrus divided by the number of pixels on which the thin cirrus test was performed. Note that the thin cirrus tests are not always performed for every VIIRS pixel residing in each CrIS FOV.

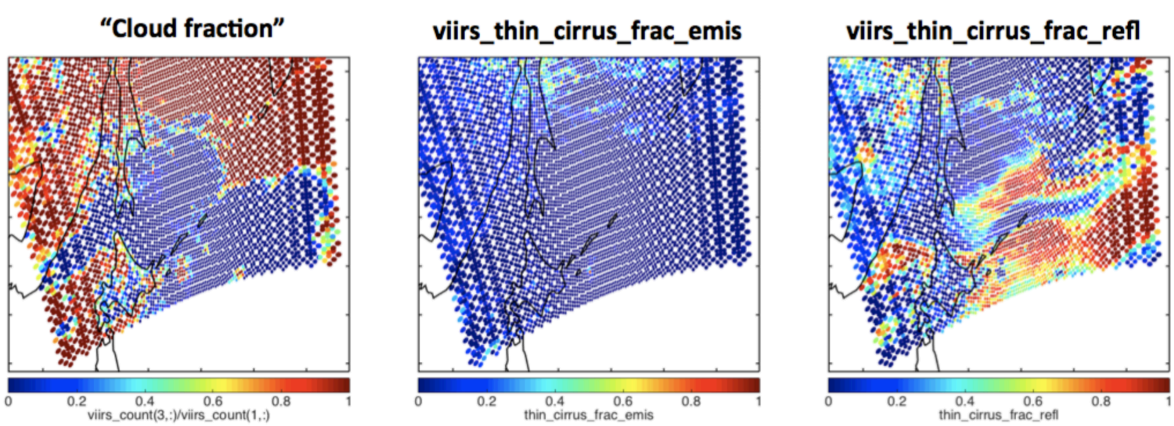
The `viirs_thin_cirrus_test_count_refl` and `viirs_thin_cirrus_test_count_emis` variables describe the number of tests actually performed.

Figure 6: `viirs_thin_cirrus_frac_emis` *and* `viirs_thin_cirrus_frac_refl`



In the VIIRS cloud mask, pixels can be categorized as clear but additionally test positive for thin cirrus; depending on the application it may be important to consider both methods of cloud detection.

Figure 7: A granule showing VIIRS pixels classified as clear but flagged with thin cirrus by the reflective test



4.3 VIIRS and CrIS radiometric data

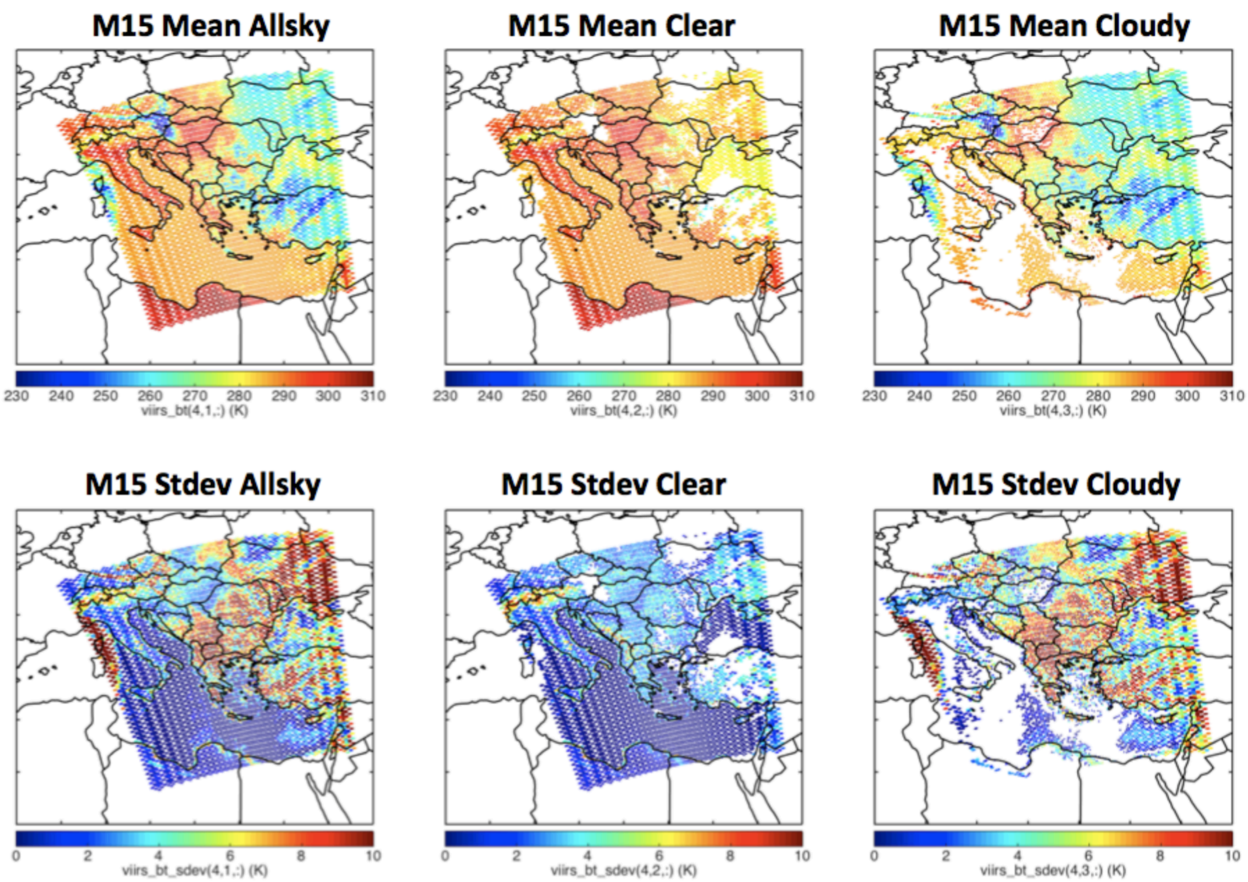
The `viirs_bt` and `viirs_bt_sdev` variables store brightness temperature statistics (mean and standard deviation) from the VIIRS emissive bands. These variables use the same dimensions as `viirs_count` described above, with one additional dimension to deal with the multiple bands. This extra `viirs_emis_band` dimension of size 5 represents bands M12 (3.70μm), M13 (4.05μm), M14 (8.55μm), M15 (10.8μm), and M16 (12.0μm).

Looking at `viirs_bt` and `viirs_bt_sdev` from a MATLAB programming perspective, the first dimension (size 5) classifies VIIRS band, the next (size 3: all-pixels, clear, cloudy) handles VIIRS pixel subset, and the remaining (sizes 9, 30, 45) identify the CrIS FOV. Consider the following MATLAB expressions:

`viirs_bt(4,3,:,:,:)`	Mean M15 (10.8μm) brightness temperature from cloudy pixels only within each CrIS FOV
`viirs_bt_stdev(2,1,:,:,:)`	Standard deviation in M13 (4.05μm) brightness temperature among all VIIRS pixels within each CrIS FOV

The `viirs_emis_rad` and `viirs_emis_rad_sdev` variables are also available to provide emissive band radiometric data in radiance units rather than brightness temperature. Other than the units difference they are used in the same way as `viirs_bt` and `viirs_bt_stdev`.

Figure 8: `viirs_bt` and `viirs_bt_sdev` data plotted in MATLAB

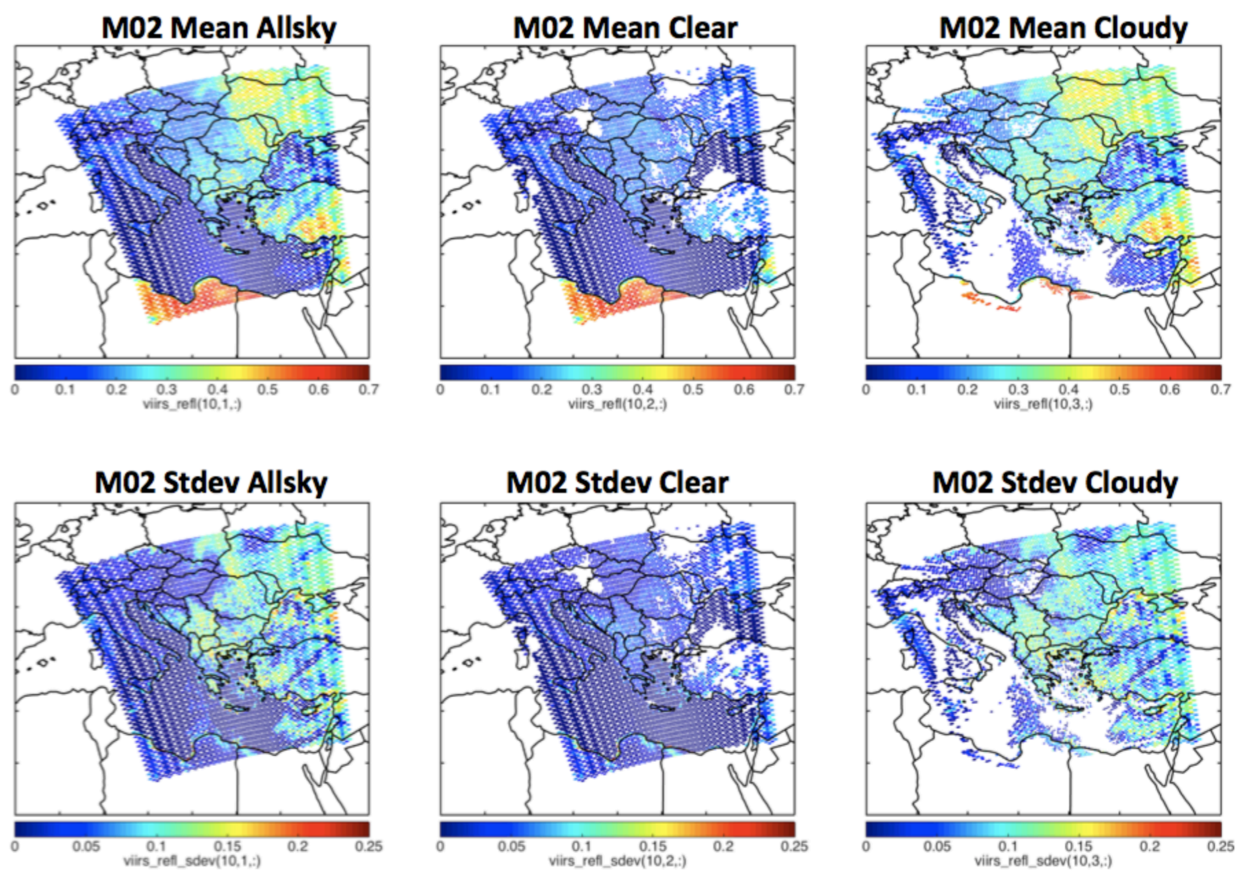


For reflective band VIIRS data, the `viirs_refl` and `viirs_refl_sdev` variables are available and structured similarly to the emissive band variables. The `viirs_refl_band` dimension used by these variables allots for 11 VIIRS reflective bands: M01 (0.415μm), M02 (0.445μm), M03 (0.490μm), M04 (0.555μm), M05 (0.673μm), M06 (0.746μm), M07 (0.865μm), M08 (1.24μm), M09 (1.38μm), M10 (1.61μm), and M11 (2.25μm). An example MATLAB expression using the reflective band data follows the same logic as above:

`viirs_refl_stdev(10,1,:,:,:)`	Standard deviation in M10 (1.61μm) reflectance among all VIIRS pixels within each CrIS FOV

As above for the emissive bands, the `viirs_refl_rad` and `viirs_refl_rad_sdev` variables are also available to provide reflective band radiometric data in radiance units.

Figure 9: `viirs_refl` and `viirs_refl_sdev` data plotted in MATLAB

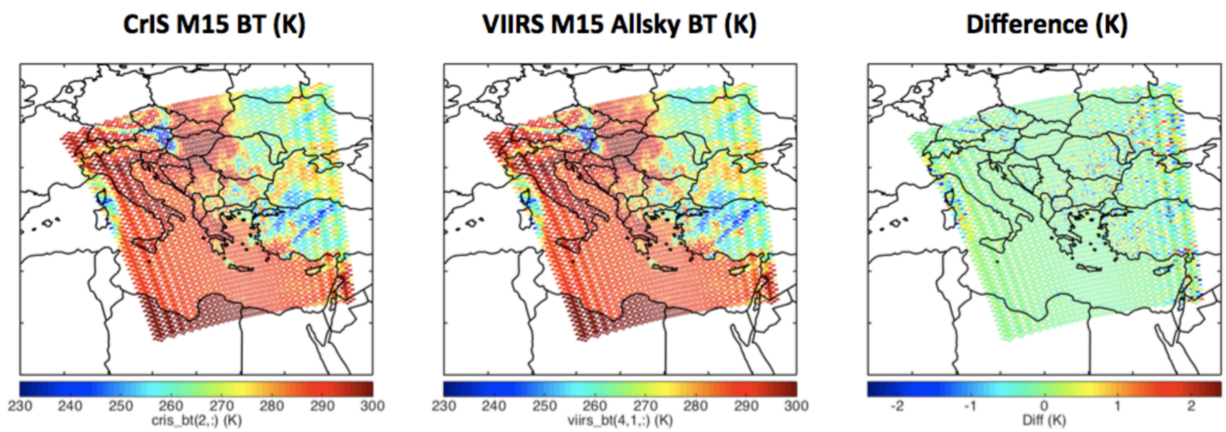


For 3 of the VIIRS emissive bands, the CrIS instrument observes hyperspectral radiance data that fully overlaps the VIIRS bands' spectral response functions (SRFs). For these 3 bands the IMG product contains the CrIS observations aggregated via weighted average according to the

SRFs. The cris_bt and cris_rad variables contain this CrIS data using both brightness temperature and radiance units. These variables use the viirs_cris_band dimension to represent the 3 bands with full CrIS/VIIRS overlap: M13 (4.05mm), M15 (10.8mm), and M16 (12.0mm).

cris_bt enables cross-validating the CrIS and VIIRS observations. For example the MATLAB expression viirs_bt(4,1,:,:,:)-cris_bt(2,:,:,:) computes the difference between VIIRS and CrIS observed BTs for band M15. Note that the band index is 4 for the VIIRS data but 2 for the CrIS data, due to the misalignment created because not all of the VIIRS emissive bands are available in cris_bt. Furthermore, the CrIS array has one less dimension because viirs_subset (all-pixels, clear-only, cloudy-only) does not apply.

Figure 10: cris_bt versus viirs_bt data plotted in MATLAB



4.4 Collocation indexes

The examples above illustrate the way in which the IMG product presents VIIRS L1 and cloud mask data aggregated for use alongside CrIS L1B. The IMG_COL product additionally enables fetching and aggregating VIIRS data from other sources by making available index values that identify collocated observations.

The table below lists all variables contained in the IMG_COL product. The arrays are all single-dimensional, and contain one item for every VIIRS pixel found to be located within a CrIS FOV.

cris_atrack	Along-track index of collocated CrIS observation
cris_xtrack	Across-track index of collocated CrIS observation
cris_fov	Field of view index of collocated CrIS observation

`viirs_gran`	Granule of collocated VIIRS pixel
`viirs_atrack`	Along-track index of collocated VIIRS pixel
`viirs_xtrack`	Across-track index of collocated VIIRS pixel

All but one of these variables correspond directly to dimensions used in either the CrIS or VIIRS L1B datasets. These variables contain 0-based array indexes, and thus contain values ranging from zero to one less than the size of the corresponding CrIS or VIIRS L1B dimension.

The `viirs_gran` variable does not correspond to an L1B dimension, but instead allows for collocated VIIRS pixels from multiple granules. In order to properly handle granule boundaries, each CrIS granule is collocated with three different VIIRS files: the 6-minute VIIRS granule with the same timestamp as the CrIS granule, and additionally the two temporally adjacent VIIRS granules. The `viirs_gran` variable identifies each collocated VIIRS pixel's source granule using values `0` through `2` to indicate if the VIIRS pixel is from the granule before (`0`), equal to (`1`), or after (`2`) the granule time of the IMG_COL file itself.

IMPORTANT NOTE: The version 2.0 SNPP IMG_COL product contained an error in the `comment` attribute attached to the `viirs_gran` variable. The attribute should read: "`1 means pixel is from VIIRS granule with same start time as CrIS granule; 0 means previous VIIRS granule; 2 means next VIIRS granule`".

5. Known issues

- The version 2.0 SNPP IMG_COL product contained an error in the `comment` attribute attached to the `viirs_gran` variable. The attribute should read: `"1 means pixel is from VIIRS granule with same start time as CrIS granule; 0 means previous VIIRS granule; 2 means next VIIRS granule".`

6. References

1. NASA Cross-track Infrared Sounder (CrIS) Level 1B Product Users' Guide, Version 2

2. NASA Visible Infrared Imaging Radiometer Suite Level-1B Product User Guide, Version 2.0

3. The Continuity MODIS-VIIRS Cloud Mask (MVCM) User's Guide, Version 1.0

4. Nagle, Frederick W; Holz, Robert E; "Computationally Efficient Methods of Collocating Satellite, Aircraft, and Ground Observations", J. Atmos. Oceanic Technol. (2009) 26 (8): 1585–1595

Appendix A: Product reference

This appendix contains output from the `ncdump -h` command executed on example IMG and IMG_COL data files. This provides a full listing of all dataset dimensions, variables, and attributes.

Section 4 provided a guided introduction to the primary IMG contents and to all variables in IMG_COL. Most of the remaining IMG file variables shown below are simply copied from the corresponding CrIS L1B file for convenience; this includes `lat`, `lon`, `obs_time_tai93`, `sat_zen`, `sat_azi`, `sol_zen`, and `sol_azi`.

A.1 IMG file contents

The contents of an example SNPP IMG file are shown.

```
netcdf SNDR.SNPP.CRIS.20200609T1700.m06.g171.IMG.std.v2_0.W.200610013059 {

dimensions:
  atrack = 45 ;
  xtrack = 30 ;
  fov = 9 ;
  viirs_subset = 3 ;
  viirs_refl_band = 11 ;
  viirs_emis_band = 5 ;
  viirs_cris_band = 3 ;

variables:

  string viirs_subset(viirs_subset) ;
    viirs_subset:long_name = "Subset of CrIS-collocated VIIRS pixels included" ;
    viirs_subset:comment = "All pixels, Clear, Cloudy" ;

  string viirs_refl_band(viirs_refl_band) ;
    viirs_refl_band:long_name = "VIIRS reflective band" ;
    viirs_refl_band:comment =
      "M01, M02, M03, M04, M05, M06, M07, M08, M09, M10, M11" ;

  string viirs_emis_band(viirs_emis_band) ;
    viirs_emis_band:long_name = "VIIRS emissive band" ;
    viirs_emis_band:comment = "M12, M13, M14, M15, M16" ;

  string viirs_cris_band(viirs_cris_band) ;
    viirs_cris_band:long_name = "VIIRS band with CrIS spectral overlap" ;
    viirs_cris_band:comment = "M13, M15, M16" ;
```

```
double obs_time_tai93(atrack, xtrack) ;
    obs_time_tai93:long_name = "CrIS observation time" ;
    obs_time_tai93:comment =
      "TAI93 format; epoch is 1993-01-01 0Z UTC; count includes leap seconds" ;
    obs_time_tai93:units = "seconds since 1993-01-01 00:00:27" ;
    obs_time_tai93:_FillValue = -999. ;

  float lat(atrack, xtrack, fov) ;
    lat:long_name = "CrIS FOV center latitude" ;
    lat:units = "degrees_north" ;
    lat:valid_range = -90.f, 90.f ;
    lat:standard_name = "latitude" ;
    lat:_FillValue = -999.f ;

  float lon(atrack, xtrack, fov) ;
    lon:long_name = "CrIS FOV center longitude" ;
    lon:units = "degrees_east" ;
    lon:valid_range = -180.f, 180.f ;
    lon:standard_name = "longitude" ;
    lon:_FillValue = -999.f ;

  float sat_zen(atrack, xtrack, fov) ;
    sat_zen:long_name = "Zenith angle to satellite from CrIS FOV center" ;
    sat_zen:units = "degrees" ;
    sat_zen:valid_range = 0.f, 90.f ;
    sat_zen:standard_name = "sensor_zenith_angle" ;
    sat_zen:coordinates = "lat lon" ;
    sat_zen:_FillValue = -999.f ;

  float sat_azi(atrack, xtrack, fov) ;
    sat_azi:long_name = "Azimuth angle to satellite from CrIS FOV center" ;
    sat_azi:units = "degrees" ;
    sat_azi:valid_range = 0.f, 360.f ;
    sat_azi:comment = "North is 0, east is 90" ;
    sat_azi:standard_name = "sensor_azimuth_angle" ;
    sat_azi:coordinates = "lat lon" ;
    sat_azi:_FillValue = -999.f ;

  float sol_zen(atrack, xtrack, fov) ;
    sol_zen:long_name = "Zenith angle to sun from CrIS FOV center" ;
    sol_zen:units = "degrees" ;
    sol_zen:valid_range = 0.f, 180.f ;
    sol_zen:standard_name = "solar_zenith_angle" ;
    sol_zen:coordinates = "lat lon" ;
    sol_zen:_FillValue = -999.f ;
```

```
float sol_azi(atrack, xtrack, fov) ;
    sol_azi:long_name = "Azimuth angle to sun from CrIS FOV center" ;
    sol_azi:units = "degrees" ;
    sol_azi:valid_range = 0.f, 360.f ;
    sol_azi:comment = "North is 0, east is 90" ;
    sol_azi:standard_name = "solar_azimuth_angle" ;
    sol_azi:coordinates = "lat lon" ;
    sol_azi:_FillValue = -999.f ;

  short viirs_count(atrack, xtrack, fov, viirs_subset) ;
    viirs_count:long_name = "Number of VIIRS pixels within CrIS FOV" ;
    viirs_count:coordinates = "lat lon" ;
    viirs_count:_FillValue = -999s ;

  float viirs_cloud_frac(atrack, xtrack, fov) ;
    viirs_cloud_frac:long_name =
      "Fraction of VIIRS pixels within CrIS FOV flagged as cloudy" ;
    viirs_cloud_frac:valid_range = 0.f, 1.f ;
    viirs_cloud_frac:coordinates = "lat lon" ;
    viirs_cloud_frac:_FillValue = -999.f ;

  float viirs_thin_cirrus_frac_refl(atrack, xtrack, fov) ;
    viirs_thin_cirrus_frac_refl:long_name =
      "Fraction of tested VIIRS pixels within CrIS FOV flagged with thin ",
      "cirrus via 1.38µm test" ;
    viirs_thin_cirrus_frac_refl:valid_range = 0.f, 1.f ;
    viirs_thin_cirrus_frac_refl:coordinates = "lat lon" ;
    viirs_thin_cirrus_frac_refl:_FillValue = -999.f ;

  float viirs_thin_cirrus_frac_emis(atrack, xtrack, fov) ;
    viirs_thin_cirrus_frac_emis:long_name =
      "Fraction of tested VIIRS pixels within CrIS FOV flagged with thin ",
      "cirrus via 11µm/12µm test" ;
    viirs_thin_cirrus_frac_emis:valid_range = 0.f, 1.f ;
    viirs_thin_cirrus_frac_emis:coordinates = "lat lon" ;
    viirs_thin_cirrus_frac_emis:_FillValue = -999.f ;

  short viirs_thin_cirrus_test_count_refl(atrack, xtrack, fov) ;
    viirs_thin_cirrus_test_count_refl:long_name =
      "Number of VIIRS pixels within CrIS FOV tested for thin cirrus ",
      "via 1.38µm test" ;
    viirs_thin_cirrus_test_count_refl:coordinates = "lat lon" ;
    viirs_thin_cirrus_test_count_refl:_FillValue = -999s ;

  short viirs_thin_cirrus_test_count_emis(atrack, xtrack, fov) ;
    viirs_thin_cirrus_test_count_emis:long_name =
      "Number of VIIRS pixels within CrIS FOV tested for thin cirrus ",
      "via 11µm/12µm test" ;
    viirs_thin_cirrus_test_count_emis:coordinates = "lat lon" ;
    viirs_thin_cirrus_test_count_emis:_FillValue = -999s ;
```

```
float viirs_daytime_frac(atrack, xtrack, fov, viirs_subset) ;
  viirs_daytime_frac:long_name =
    "Fraction of VIIRS pixels within CrIS FOV that are in daylight" ;
  viirs_daytime_frac:comment =
    "Daytime defined as in VIIRS cloud mask, solar zenith angle ",
    "less than 85 degrees" ;
  viirs_daytime_frac:valid_range = 0.f, 1.f ;
  viirs_daytime_frac:coordinates = "lat lon" ;
  viirs_daytime_frac:_FillValue = -999.f ;

float viirs_refl(atrack, xtrack, fov, viirs_subset, viirs_refl_band) ;
  viirs_refl:long_name = "Mean VIIRS reflectance within CrIS FOV" ;
  viirs_refl:units = "1" ;
  viirs_refl:coordinates = "lat lon" ;
  viirs_refl:_FillValue = -999.f ;

float viirs_refl_sdev(atrack, xtrack, fov, viirs_subset, viirs_refl_band) ;
  viirs_refl_sdev:long_name =
    "VIIRS reflectance standard deviation within CrIS FOV" ;
  viirs_refl_sdev:units = "1" ;
  viirs_refl_sdev:coordinates = "lat lon" ;
  viirs_refl_sdev:_FillValue = -999.f ;

float viirs_refl_rad(atrack, xtrack, fov, viirs_subset, viirs_refl_band) ;
  viirs_refl_rad:long_name = "Mean VIIRS reflective band radiance within CrIS FOV" ;
  viirs_refl_rad:units = "W/(m2 sr µm)" ;
  viirs_refl_rad:standard_name = "toa_outgoing_radiance_per_unit_wavelength" ;
  viirs_refl_rad:coordinates = "lat lon" ;
  viirs_refl_rad:_FillValue = -999.f ;

float viirs_refl_rad_sdev(atrack, xtrack, fov, viirs_subset, viirs_refl_band) ;
  viirs_refl_rad_sdev:long_name =
    "VIIRS reflective band radiance standard deviation within CrIS FOV" ;
  viirs_refl_rad_sdev:units = "W/(m2 sr µm)" ;
  viirs_refl_rad_sdev:coordinates = "lat lon" ;
  viirs_refl_rad_sdev:_FillValue = -999.f ;

float viirs_bt(atrack, xtrack, fov, viirs_subset, viirs_emis_band) ;
  viirs_bt:long_name = "VIIRS brightness temperature within CrIS FOV" ;
  viirs_bt:units = "K" ;
  viirs_bt:standard_name = "toa_brightness_temperature" ;
  viirs_bt:comment = "Calculated from viirs_emis_rad and VIIRS spectral response" ;
  viirs_bt:coordinates = "lat lon" ;
  viirs_bt:_FillValue = -999.f ;
```

```
float viirs_bt_sdev(atrack, xtrack, fov, viirs_subset, viirs_emis_band) ;
    viirs_bt_sdev:long_name =
      "VIIRS brightness temperature deviation within CrIS FOV" ;
    viirs_bt_sdev:units = "K" ;
    viirs_bt_sdev:comment =
      "Brightness temperature increase resulting from adding one ",
      "viirs_emis_rad_sdev to viirs_emis_rad" ;
    viirs_bt_sdev:coordinates = "lat lon" ;
    viirs_bt_sdev:_FillValue = -999.f ;

  float viirs_emis_rad(atrack, xtrack, fov, viirs_subset, viirs_emis_band) ;
    viirs_emis_rad:long_name = "Mean VIIRS emissive band radiance within CrIS FOV" ;
    viirs_emis_rad:units = "W/(m2 sr µm)" ;
    viirs_emis_rad:standard_name = "toa_outgoing_radiance_per_unit_wavelength" ;
    viirs_emis_rad:coordinates = "lat lon" ;
    viirs_emis_rad:_FillValue = -999.f ;

  float viirs_emis_rad_sdev(atrack, xtrack, fov, viirs_subset, viirs_emis_band) ;
    viirs_emis_rad_sdev:long_name =
      "VIIRS emissive band radiance standard deviation within CrIS FOV" ;
    viirs_emis_rad_sdev:units = "W/(m2 sr µm)" ;
    viirs_emis_rad_sdev:coordinates = "lat lon" ;
    viirs_emis_rad_sdev:_FillValue = -999.f ;

  float cris_rad(atrack, xtrack, fov, viirs_cris_band) ;
    cris_rad:long_name = "CrIS radiance over VIIRS band spectral response" ;
    cris_rad:units = "W/(m2 sr µm)" ;
    cris_rad:standard_name = "toa_outgoing_radiance_per_unit_wavelength" ;
    cris_rad:coordinates = "lat lon" ;
    cris_rad:_FillValue = -999.f ;

  float cris_bt(atrack, xtrack, fov, viirs_cris_band) ;
    cris_bt:long_name =
      "CrIS brightness temperature over VIIRS band spectral response" ;
    cris_bt:units = "K" ;
    cris_bt:comment = "Calculated from cris_rad and VIIRS spectral response" ;
    cris_bt:standard_name = "toa_brightness_temperature" ;
    cris_bt:coordinates = "lat lon" ;
    cris_bt:_FillValue = -999.f ;

// global attributes:
    :title = "S-NPP CrIS IMG: ",
      "Collocated VIIRS level 1 / cloud mask statistical summary" ;
    :project = "NASA CrIS L1B Science and Software Team" ;
    :institution = "Space Science & Engineering Center, ",
      "University of Wisconsin - Madison" ;
    :processing_level = "2" ;
    :Conventions = "CF-1.7, ACDD-1.3" ;
    :platform = "SUOMI-NPP > Suomi National Polar-orbiting Partnership" ;
    :platform_vocabulary = "GCMD:GCMD Keywords" ;
```

```
    :time_coverage_start = "2020-06-09T17:00:00Z" ;
    :time_coverage_end = "2020-06-09T17:06:00Z" ;
    :geospatial_lat_min = 2.487948f ;
    :geospatial_lat_max = 26.85393f ;
    :geospatial_lon_min = -69.95734f ;
    :geospatial_lon_max = -44.67385f ;
    :geospatial_bounds = "POLYGON ((",
      "2.61 -63.90, 5.89 -44.97, 26.73 -48.90, 23.18 -69.62, 2.61 -63.90))" ;
    :orbitDirection = "Ascending" ;
    :inputs =
      "CLDMSK_L2_VIIRS_SNPP.A2020161.1654.001.2020162011835.nc, ",
      "CLDMSK_L2_VIIRS_SNPP.A2020161.1700.001.2020162011830.nc, ",
      "CLDMSK_L2_VIIRS_SNPP.A2020161.1706.001.2020162011827.nc, ",
      "SNDR.SNPP.CRIS.20200609T1700.m06.g171.L1B.std.v2_0_16.W.200609230512.nc, ",
      "VNP02MOD.A2020161.1654.001.2020161222210.uwssec.nc, ",
      "VNP02MOD.A2020161.1700.001.2020161222156.uwssec.nc, ",
      "VNP02MOD.A2020161.1706.001.2020161222239.uwssec.nc, ",
      "VNP03MOD.A2020161.1654.001.2020161222242.uwssec.nc, ",
      "VNP03MOD.A2020161.1700.001.2020161222232.uwssec.nc, ",
      "VNP03MOD.A2020161.1706.001.2020161222227.uwssec.nc" ;
    :creator_name = "NASA Suomi-NPP Atmosphere SIPS" ;
    :creator_url = "https://sips.ssec.wisc.edu/" ;
    :creator_email = "sips.admin@ssec.wisc.edu" ;
    :publisher_name = "Goddard Earth Science Data and Information Services Center" ;
    :publisher_url = "http://disc.sci.gsfc.nasa.gov/" ;
    :publisher_email = "gsfc-help-disc@lists.nasa.gov" ;
    :license = "Freely Distributed" ;
    :product_version = "2.0" ;
    :date_created = "2020-06-10T01:30:59Z" ;
    :source = "cris_l1 2.0.15; viirs_l1 2.0.2; CLDMSK_L2_VIIRS 1.0" ;
    :algorithm_version = "crisimg 0.1.13; collopak 0.1.78" ;
    :short_name = "SNDRSNCrISL1BIMG" ;
    :id = "10.5067/NC505NHFIHCY" ;
    :naming_authority = "http://dx.doi.org/" ;
}
```

A.2 IMG_COL file contents

The contents of an example SNPP IMG_COL file are shown.

```
netcdf SNDR.SNPP.CRIS.20200609T1700.m06.g171.IMG_COL.std.v2_0.W.200610013059 {

dimensions:
  colloc_num = UNLIMITED ; // (4265760 currently)

variables:

  byte cris_atrack(colloc_num) ;
    cris_atrack:long_name = "Along-track index of collocated CrIS observation" ;
    cris_atrack:valid_range = 0b, 44b ;
    cris_atrack:_FillValue = -1b ;

  byte cris_xtrack(colloc_num) ;
    cris_xtrack:long_name = "Across-track index of collocated CrIS observation" ;
    cris_xtrack:valid_range = 0b, 29b ;
    cris_xtrack:_FillValue = -1b ;

  byte cris_fov(colloc_num) ;
    cris_fov:long_name = "Field of view index of collocated CrIS observation" ;
    cris_fov:valid_range = 0b, 8b ;
    cris_fov:_FillValue = -1b ;

  byte viirs_gran(colloc_num) ;
    viirs_gran:long_name = "Granule of collocated VIIRS pixel" ;
    viirs_gran:comment =
      "1 means pixel is from VIIRS granule with same start time as CrIS granule; ",
      "0 means previous VIIRS granule; 2 means next VIIRS granule" ;
    viirs_gran:valid_range = 0b, 2b ;
    viirs_gran:_FillValue = -1b ;

  short viirs_atrack(colloc_num) ;
    viirs_atrack:long_name = "Along-track index of collocated VIIRS pixel" ;
    viirs_atrack:valid_range = 0s, 3247s ;
    viirs_atrack:_FillValue = -1s ;

  short viirs_xtrack(colloc_num) ;
    viirs_xtrack:long_name = "Across-track index of collocated VIIRS pixel" ;
    viirs_xtrack:valid_range = 0s, 3199s ;
    viirs_xtrack:_FillValue = -1s ;

// global attributes:
    :title = "S-NPP CrIS IMG_COL: Array indices for collocated VIIRS observations" ;
    :project = "NASA CrIS L1B Science and Software Team" ;
    :institution = "Space Science & Engineering Center, ",
      "University of Wisconsin - Madison" ;
```

```
    :processing_level = "2" ;
    :Conventions = "CF-1.7, ACDD-1.3" ;
    :platform = "SUOMI-NPP > Suomi National Polar-orbiting Partnership" ;
    :platform_vocabulary = "GCMD:GCMD Keywords" ;
    :time_coverage_start = "2020-06-09T17:00:00Z" ;
    :time_coverage_end = "2020-06-09T17:06:00Z" ;
    :geospatial_lat_min = 2.487948f ;
    :geospatial_lat_max = 26.85393f ;
    :geospatial_lon_min = -69.95734f ;
    :geospatial_lon_max = -44.67385f ;
    :geospatial_bounds = "POLYGON ((",
      2.61 -63.90, 5.89 -44.97, 26.73 -48.90, 23.18 -69.62, 2.61 -63.90))" ;
    :orbitDirection = "Ascending" ;
    :inputs =
      "SNDR.SNPP.CRIS.20200609T1700.m06.g171.L1B.std.v2_0_16.W.200609230512.nc, ",
      "VNP03MOD.A2020161.1654.001.2020161222242.uwssec.nc, ",
      "VNP03MOD.A2020161.1700.001.2020161222232.uwssec.nc, ",
      "VNP03MOD.A2020161.1706.001.2020161222227.uwssec.nc" ;
    :creator_name = "NASA Suomi-NPP Atmosphere SIPS" ;
    :creator_url = "https://sips.ssec.wisc.edu/" ;
    :creator_email = "sips.admin@ssec.wisc.edu" ;
    :publisher_name = "Goddard Earth Science Data and Information Services Center" ;
    :publisher_url = "http://disc.sci.gsfc.nasa.gov/" ;
    :publisher_email = "gsfc-help-disc@lists.nasa.gov" ;
    :license = "Freely Distributed" ;
    :product_version = "2.0" ;
    :date_created = "2020-06-10T01:30:59Z" ;
    :source = "cris_l1 2.0.15; viirs_l1 2.0.2; CLDMSK_L2_VIIRS 1.0" ;
    :algorithm_version = "crisimg 0.1.13; collopak 0.1.78" ;
    :short_name = "SNDRSNCrISL1BIMGC" ;
    :id = "10.5067/8ABZCV1TKE8D" ;
    :naming_authority = "http://dx.doi.org/" ;
}
```