Current development of community satellite processing package (CSPP) to support direct broadcast remote sensing satellite data processing

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Abstract. The Community Satellite Processing Package (CSPP) is developed by the Cooperative Institute for Meteorological Satellite Studies (CIMSS) at the Space Science and Engineering Center (SSEC) at the University of Wisconsin to support Direct Broadcast (DB) communities in processing various remote sensing satellite data. Currently, there are eleven satellites and 25 instruments supported by fifteen CSPP packages. Some packages have dependency with another package when an output of a package become an input to another package. However, there is no document that describes relationships among input and output data of the packages. Each package is only accompanied by its installation instruction and user manual. Thus, a main document describing interdependency of the packages is required. This paper can act as the main document because it describes the current development of the CSPP packages and their interdependency among one another. Information was gathered through installation, user manual and literature (proceedings and journal articles) reviews. The results are illustrated in term of intuitive diagrams that are not available in the current instructions or manuals. Thus, the main document that is described in this paper can be utilized to identify gaps that should be taken into considerations when developing the existing system in the future.

1. Introduction
The Community Satellite Processing Package (CSPP) (http://cimss.ssec.wisc.edu/cspp) is developed by the Cooperative Institute for Meteorological Satellite Studies (CIMSS) at the Space Science and Engineering Center (SSEC) at the University of Wisconsin to support Direct Broadcast (DB) communities in processing various remote sensing satellite data. CIMSS itself has a long history in supporting these communities since the release of the International MODIS/AIRS Processing Package (IMAPP) to process NASA Terra and Aqua satellite data. CSPP continues IMAPP’s support and extend it to include more Low Earth Orbit (LEO) satellite data, such as the first Joint Polar Satellite System (JPSS-1) / NOAA-20, Suomi National Polar-orbiting Partnership (Suomi-NPP), Terra, Aqua, NOAA-19, NOAA-18, Metop, FY-3B, FY-3C, and GCOM-W1 [1]. Supported by the NOAA and NASA program scientist and funding, CSPP is also being developed to support geostationary meteorological and environmental satellite data processing for the global weather and environmental user communities. In the future, it is hoped that CSPP can be utilised to support all satellite data that are down-linked by L-band and/or X-band receiving system owned by international meteorological and environmental satellite agencies. CSPP is pre-compiled and runs only on computers with 64-bit Linux operating system such as CentOS or other compatible packages. It is packaged and distributed as a collection of freely available open source software systems. To become a useful science software for the DB communities, CSPP is developed so that it is easy to be installed and operated on modest hardware. The host computers are typically a server with specifications: (1) Multi-core CPUs @ 2.5 GHz, (2) 64 GB RAM, (3) 8 TB hard drives, and (4) 1 Mbit/sec internet connection to download ancillary data. CSPP also includes test data to verify its installation and up-to-date algorithms are implemented in the current version of the software.
However, there is still no main documentation available that can describe all CSPP packages as a whole. Documentations are available but they are separated and only explain each package in term of installation and operation manual. There is no further information about relationships among one package and others in one document. Even though, this information is needed by developers of remote sensing data processing systems so that they can develop systems more effective and efficient based on their requirements.

2. Method
A comprehensive literature review was taken to obtain as many information about the CSPP software packages. There are three main sources that are used to obtain the information. First of all is the official website of CIMSS as the main developer of the CSPP software packages. In the Download section of the website (http://cimss.ssec.wisc.edu/cspp/download/), all of relevant documentations of each CSPP package are available in pdf format. Second of all is poster presentations and meeting notes that are obtained from the CSPP/IMAPP User’s Group Meeting documentations (https://www.ssec.wisc.edu/meetings/cspp/). Additional information about relevant issues to usage and applications of CSPP software packages can be obtained from the meeting documentations. Third of all is scientific papers or articles obtained from several online digital libraries, viz. The University of Melbourne Library (https://library.unimelb.edu.au/), Science Direct (https://www.sciencedirect.com/), and Google Cendekia (https://scholar.google.co.id/).

After downloaded all relevant materials, the materials then were categorized according to each CSPP software package. Information finding was focused on required inputs for each package and all outputs that can be generated from each package. Additional information about relevant software outside CSPP packages that are required to produce required inputs was also taken into consideration. Finally, a comprehensive block diagram was drawn to explain the CSPP software packages as a whole processing chain system.

3. Results
Currently, there are eleven satellites and 25 instruments supported by fifteen CSPP packages [1, 2]. No less than 1,200 users have registered to the CSPP website (http://cimss.ssec.wisc.edu/cspp) with more than 5,000 users have downloaded the package [3].

CSPP consists of a suite of science algorithms implemented in a software system infrastructure (scripts, executables, ancillary, and auxiliary files) that can be used to generate products from satellite data with low latency. CSPP comprises three main components: Algorithm Development Library (ADL), Python, and bash scripting.

ADL is a test satellite data processing system that mimics the operational NOAA’s Interface Data Processing Segment (IDPS) [4]. It enables researchers and scientists to develop algorithms and integrate these algorithms into the operational baseline. Sometimes, satellite data calibration or validation activities yield requirements to change existing operational algorithms for improving or replacing existing products. ADL allows researchers and scientist to implement these changes into the operational baseline. In addition, effects of a new or modified product to other products can be evaluated using the ADL [5].

ADL is built upon two things: a series of configuration XML files and a binary executable. It allows the operational processing algorithms to be run in a Linux environment without any modification. CSPP uses ADL as basis for its science algorithms.

A series of python scripts are used in CSPP to manage algorithm execution, retrieve ancillary data and ingest them into ADL, and provide settings for algorithm development. In addition, the scripts are also used to parse log files that are required to trace errors and to handle them.
Bash scripts are used to execute python scripts inside a CSPP package through command line interface available in a terminal of Linux environment. Bash scripts are also used to develop automation algorithm so that a CSPP package can be run automatically in supporting near real-time applications.

CSPP supports the production of calibrated observational data and their derived geophysical products as well as georeferenced images from visible, infrared, and microwave instruments. In general, currently there are five main categories of CSPP software, viz. CSPP Sensor Data Record (SDR) Software, CSPP Imager Environmental Data Record (EDR) Retrieval Software, CSPP Infrared Sounder Retrieval Software, CSPP IR/Microwave Retrieval Software, and CSPP Utility Software [2]. A big picture of all current available CSPP packages and their input-output relationships is depicted in Figure 1. The high resolution of the picture can be downloaded at http://bit.ly/CSPPMainDiagram. Each of the package is discussed briefly in the following paragraphs.

![Figure 1. A main block diagram of all current available CSPP packages.](http://bit.ly/CSPPMainDiagram)

3.1. CSPP SDR Software
CSPP SDR software is used to transform direct broadcast Suomi-NPP and JPSS-1 / NOAA-20 Visible Infrared Imager Radiometer Suite (VIIRS), Advanced Technology Microwave Sounder (ATMS) and Cross-track Infrared Sounder (CrIS) data files from Raw Data Record (RDR) products into Sensor Data Record (SDR) products [6]. The products created by the software have identical naming convention, format and structure with NOAA/NESDIS CLASS archive that is described in Common Data Format Control Book (CDFCB) External Vol. III [7]. The current version of the software was released on 26 September 2018 but the software can only be used to process historical Suomi-NPP RDR products from 8 August 2017 onward and JPSS-1 / NOAA-20 RDR products from 1 February 2018 onward.

3.2. CSPP Imager EDR Retrieval Software
3.2.1. VIIRS Flood Detection Software
VIIRS flood detection software is used for transforming Suomi-NPP and JPSS-1 / NOAA-20 VIIRS data files from SDR products into 375 m spatial resolution flood detection products [8]. It is designed to cover global region with latitudes from 80S to 80N. However, the software can only process the
products that are acquired during daytime. In general, there are three modules included in the software, the VIIRS Swath Projection module (to project input files into equidistant cylindrical projection before they are processed by the main module), the VIIRS Flood Detection module (the main module), and Image Display module (to display output files into GeoTIFF format). The main module requires several mandatory input files, viz. geolocated and calibrated I-Band files (SVI01*.h5, SVI02*.h5, SVI03*.h5 and SVI05*.h5) and I-Band terrain corrected geolocation file (GITCO*.h5). Additionally, the module also uses Environmental Data Record (EDR) cloud mask files (IICMO*.h5) and M-Band terrain corrected geolocation files (GMTCO*.h5) if they are available. All static files required for the processing steps (such as global land cover and global Digital Elevation Model – DEM) are included in the software. Output products are in HDF4 format with naming convention as follows: 

Water_VIIRS_Praj_SVI_<sat>_<date_begin-time_end-time_orbit-number>._cspp_dev_<rows>_<columns>_01.hdf

Where <sat> can be npp for Suomi-NPP satellite data and j01 for JPSS-1 / NOAA-20 satellite data. The latest version of the software was released on 14 November 2018.

3.2.2. VIIRS Active Fire Software

VIIRS active fires software is used to transform Suomi-NPP and JPSS-1 / NOAA-20 VIIRS data files from SDR products into active fires products [9]. The algorithm that is used in the software is based on the VIIRS Active Fire Detection and Characterization Algorithm Theoretical Basis Document (ATBD) 1.0 [10]. The software produces two types of data format for its output products, viz. a NetCDF4 file with naming convention that conforms with JPSS Common Data Format Control Book – External Volume I – Overview [11] and an ASCII text file. Some primary information included in the output files are locations of the active fires in latitude (degrees) and longitude (degrees), pixel resolution and fire detection confidence. The current version of the software was released on 14 March 2019.

3.2.3. VIIRS ASCI EDR Software

VIIRS ASCI EDR software is used to transform Suomi-NPP and JPSS-1 / NOAA-20 VIIRS data files from SDR products into Aerosols, Snow, Clouds, and Ice (ASCI) EDR products [12]. It also creates volcanic ash products as part of its outputs. Identical naming, format (NetCDF), and structure are produced that corresponds to JPSS CDFCB-X Volume IV Parts 2 and 3 [13, 14]. The software requires all VIIRS band and geolocation files. Dynamic ancillary data such as numerical weather prediction forecast from National Center for Environmental Prediction (NCEP) Global Forecast System (GFS) and Optimum Interpolation Sea Surface Temperature (OISST) from NOAA will be downloaded during runtime automatically. Therefore, the software has to run with an Internet connection. The latest version of the software was released on 18 June 2019.

3.2.4. VIIRS EDR Software

VIIRS EDR software is used for transforming Suomi-NPP VIIRS data from SDR products to EDR products. The EDR products include Cloud Mask, Active Fires, Suspended Matter, Aerosol Optical Thickness (AOT), Normalized Difference Vegetation Index (NDVI), Enhanced Vegetation Index (EVI), Sea Surface Temperature (SST), Surface Type, Surface Reflectance, and Land Surface Temperature (LST) [15]. The software produces output files with identical structure, format (HDF5), and naming convention according to JPSS Common Data Format Control Book (CDFCB) [16]. However, the software only works with VIIRS SDR files that are produced by CSPP SDR software version 2.0 or higher. All VIIRS bands and geolocation files are required as inputs to the software. The latest version of the software was released on 4 August 2014.

3.2.5. VIIRS Imagery EDR Software

VIIRS imagery EDR software is used to transform intermediate files that are produced by CSPP SDR software when the software process Suomi-NPP VIIRS data from RDR products to SDR products [17]. The output of VIIRS Imagery EDR software are Imagery products in Ground Track Mercator (GTM) projection [18] with identical structure, format (HDF5), and naming convention based on JPSS CDFCB
The software requires minimum three contiguous granules of input SDR data for producing one Imagery EDR product. The latest version of the software was released on 4 August 2014, in the same time with VIIRS EDR software was released.

### 3.2.6. CLAVRx Cloud Retrieval Software

CLAVRx cloud retrieval software is used for transforming level 1B or SDR products from NOAA-18, NOAA-19, Metop-A and Metop-B AVHRR, Terra and Aqua MODIS, and Suomi-NPP VIIRS data into single Field-of-View (FOV) quantitative cloud products [19]. The software can also be used to produce quicklook images of the output products in PNG format. It requires input files with certain naming conventions. There are some direct broadcast processing software that can be used to support in generating required input files, such as ATOVS and AVHRR Processing Package (AAPP), modisI1bdb, and IMAPP. CLAVRx software has become operational since 2002 and has been updated significantly to support more satellite instruments since 2006. The latest version of it was released on 7 April 2016.

### 3.2.7. ACSPO SST Software

ACSPO software is used to transform geolocated and calibrated radiance data (level 1B or SDR) from AVHRR, MODIS, and VIIRS instruments into SST products [20]. The software requires Global Forecast System (GFS) forecast data and Canadian Meteorological Center (CMS) 0.1 or 0.2 deg global sea surface temperature analyses that are fetched automatically by itself. It produces output in netCDF4 format. The latest version of the software was released on 9 February 2017.

### 3.3. CSPP Infrared Sounder Retrieval Software

#### 3.3.1. CSPP NUCAPS S-NPP/NOAA-20 CrIS/ATMS Retrieval Package

CSPP NUCAPS S-NPP/NOAA-20 CrIS/ATMS retrieval package, as the name implies, is used for transforming Suomi-NPP and JPSS-1 / NOAA-20 CrIS and ATMS data files from SDR products into Field-of Regard (FOR) of atmospheric profiles products, such as temperature, moisture, trace gases and cloud-cleared radiances [21]. The required SDR products as inputs to the software are antenna temperature and its geolocation (TATMS*.h5 and GATMO*.h5) and radiance and its geolocation (SCRIS*.h5, SCRIF*.h5 and GCRSO*.h5). Notes that these products have to be produced by CSPP SDR software version 2 or later. The software uses algorithm that is based on the NOAA NUCAPS Algorithm Theoretical Basis Document [22]. The current version of the software was released on 1 April 2019.

#### 3.3.2. CSPP NUCAPS Metop IASI Retrieval Package

CSPP NUCAPS Metop IASI retrieval package is used to transform MetOp-A and MetOp-B Infrared Atmospheric Sounding Interferometer (IASI), Advanced Microwave Sounding Unit-A (AMSUA), and Microwave Humidity Sounder (MHS) data files from Level-1C (IASI) and Level-1B (AMSUA and MHS) into atmospheric profiles products similar to outputs of CSPP NUCAPS S-NPP/NOAA-20 CrIS/ATMS retrieval package which was discussed previously [23]. The software requires IASI/AMSUA/MHS calibrated and geo-located data (viz. IASI_xxx_1C_{M01,M02}_.*, amusal1b_{M01,M02}_.11b or *.AMAX_{M1,M2}_. and mhsI1b_{M01,M02}_. or *.MHSX_{M1,M2}_.) that are produced by AAPP software version 7.15 or later. There are two output files created for each set of inputs: IASI_L02_<sat>\_V??????\_?????????????Z_?????????????Z.nc and IASI_CCR_<sat>_V??????\_?????????????Z_?????????????Z.nc where <sat> is M01 for MetOp-B data or M02 for MetOp-A data. The latest version of the software was released on 3 August 2018.

#### 3.3.3. CSPP UW Hyperspectral Retrieval Package

CSPP UW HyperSpectral ReTrieVal (HSRTV) Package is used for transforming Suomi-NPP and JPSS-1 / NOAA-20 CrIS, MetOp-A and MetOp-B IASI, and Aqua Atmospheric InfraRed Sounder (AIRS) data into geophysical retrieval of atmospheric, cloud, and surface parameters [24]. It requires CrIS data in SDR level and IASI or AIRS data in level 1B. The software produces outputs in HDF5 format. The outputs contain information about geolocation (latitude and longitude in degrees), pressure levels in hPa,
surface emissivity wavenumber in cm⁻¹, channel index, quality flags, and Global Data Assimilation System (GDAS) / Global Forecast System (GFS) values (i.e. surface pressure, temperature, and humidity profiles) that are interpolated to sounder grid. The latest version of the software was released on 22 June 2018.

3.4. CSPP IR/Microwave Retrieval Software

3.4.1. CSPP MIRS Microwave Retrieval Software

CSPP MIRS Microwave Retrieval software is used for transforming Suomi-NPP and JPSS-1 / NOAA-20 ATMS data files from SDR products into single Field-of-View (FOV) atmospheric profiles and surface properties. The software can also be used to transform NOAA-19, NOAA-18, MetOp-B, and MetOp-A AMSU-A and MHS data files from level 1B products into surface properties and atmospheric profiles [25]. The ATMS SDR products required as inputs by the software are radiance, antenna temperature, and geolocation (SATMS*.h5, TATMS*.h5, and GATMO*.h5) that are produced by CSPP SDR software version 3 or later. The AMSU-A and MHS level 1B products required as inputs by the software are amsual1b*.l1b and mhsl1b*.l1b that are produced by AAPP software version 7. There are sixteen types of official validated products that are produced as the outputs of the software, viz. (1) temperature profile, (2) humidity profile, (3) Total Precipitable Water (TPW), (4) Land Surface Temperature (LST), (5) Surface Emissivity, (6) surface type classification, (7) Snow Water Equivalent (SWE), (8) Sea Ice Concentration (SIC), (9) Snow Cover Extent (SCE) based on SWE, (10) Cloud Liquid Water (CLW), (11) Ice Water Path (IWP), (12) Rain Water Path (RWP), (13) Rainfall Rate (RR), (14) effective grain size of snow, (15) Snow Fall Rate (SFR), and (16) Probability of falling snow for Suomi-NPP and JPSS-1 / NOAA-20. There are also two additional experimental products that have not been validated because no reliable ground truth measurements are available. They are Cloud Liquid Water Profile (CLWP) and surface temperature in the snow-covered land surface type and open ocean water. The latest version of the software was released on 9 May 2019.

3.4.2. CSPP IAPP Software

CSPP IAPP software is used for transforming NOAA-15, NOAA-16, NOAA-18, NOAA-19, Metop-A, and Metop-B ATOVS radiance measurements into single Field-of-Regard (FOR) retrieval that consists of total ozone, temperature and moisture profiles in the atmosphere, as well as other parameters in both clear and cloudy atmospheres [26]. It takes level 1d calibrated/geolocated data as its inputs. The software requires radiances/brightness temperatures from all three instruments, viz. HIRS, AMSU-A, and MHS so that it can execute properly. The latest version of the software was released on 16 February 2017.

3.5. CSPP Utility Software

3.5.1. CSPP Sounder QuickLook (QL) Software for NUCAPS, HSRTV, MIRS and IAPP Retrievals

CSPP Sounder QuickLook (QL) software is used to generate plots of navigated sounder datasets (level 2 atmospheric retrievals) produced from one of several packages, viz. CSPP IAPP, CSPP MIRS, CSPP HSRTV, and CSPP NUCAPS [27]. The plots can be in term of temperature, dewpoint, water vapor mixing ratio, and relative humidity 2D plots for a given pressure level in PNG format or in Skew-T thermodynamic diagrams. The latest version of the software was released on 14 July 2015.

3.5.2. Polar2Grid Reprojection Software for VIIRS, MODIS, AVHRR, ACSPO, MIRS

Polar2Grid software is used to remap earth-observing satellite instrument data into gridded data in various file format so that they can be viewed, manipulated, and stored as required by users [28]. The instruments include Suomi-NPP VIIRS, Terra and Aqua MODIS, NOAA-18, NOAA-19, Metop-A and Metop-B AVHRR, and GCOM-W1 AMSR2. The inputs to the software are data in Sensor Data Record (SDR) or 1B level. The software can also be used for remapping CLAVR-x Cloud Retrievals and ACSPO SST products. The outputs of the software are data in Advanced Weather Interactive Processing System (AWIPS) Sectorized Cloud and Moisture Imagery (SCMI), binary, GeoTIFF, HDF5, and/or NinJoTIFF format. The latest version of the software was released on 27 April 2018.
3.5.3. CSPP S-NPP HYDRA2 Visualization and Analysis Toolkit

HYDRA2 software is used to explore and visualize relationships between different wavelengths measured by a same or different satellite instruments on a pixel by pixel basis [29]. There are some visualization tools that are included in the software, such as cross section, spectral diagram, and scatter plot. It also support multi-band combinations and color enhancements. Many satellites are supported by the software, viz. Suomi-NPP, Terra, Aqua, Metop, and Chinese Feng Yun-3. The latest version of the software was released on 22 February 2016.

4. Discussions

The main benefit of the block diagram is to make users easier in understanding the whole process chain for obtaining certain information using CSPP packages. Suppose a user wants to obtain information about fire detection. From the block diagram, it can be seen in Figure 2 that the active fire products is generated by CSPP VIIRS Active Fire package. The package requires terrain-corrected M-band (GMTCO) products as well as geolocated and calibrated M-file (SVMxx) products that are produced by CSPP SDR VIIRS package with RDR VIIRS products as its input. The RDR VIIRS products are created from JPSS-1 satellite data in rawdata level using non-CSPP software, named Real-Time Software Telemetry Processing System (RT-STPS). In summary, to obtain fire detection information, a user will need JPSS-1 VIIRS data in rawdata level, RT-STPS software, and two of CSPP packages, viz. CSPP SDR VIIRS and CSPP VIIRS Active Fires.

Another example is shown in Figure 3. In this case, a user wants to produce a quick look for contour images consisting of humidity and temperature on certain atmospheric pressure level. The block diagram shows that to obtain the image, the user will require the CSPP Sounder Quicklook. Humidity and temperature information themselves can be generated by using CSPP NUCAPS SNPP CrIS/ATMS Retrieval package with ATMS and CrIS data in SDR level as its inputs. Further, the data in this level are produced by CSPP SDR software.

5. Conclusions

A detailed block diagram that elaborates relationships among inputs and outputs of CSPP software packages (and their relationships with other software) has been made through a comprehensive literature review. The diagram can be used by software developers or integrators as a reference in designing remote sensing data processing system, especially for direct broadcast remote sensing data applications, in more effective and efficient way. An example has been provided to show how to design a remote sensing data processing system and what software should be used based on the diagram. However, the CSPP packages described in this paper only work with environmental and weather satellites data. Therefore, the diagram should be updated as soon as more new satellites or instruments are being supported by latest CSPP packages in the future.
Figure 2. A part of the block diagram that focuses on active fire information retrieval.
Figure 3. A part of the block diagram that focuses on how to retrieve humidity and temperature information as well as to produce the information in a quicklook contour image.

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