EUMETSAT Satellite Application Facility on Climate Monitoring

Algorithm Theoretical Baseline Document

Joint Cloud property Histogram products

AVHRR / SEVIRI

CM-SAF Products CM-11, CM-12

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1. The EUMETSAT SAF on Climate Monitoring

The importance of climate monitoring with satellites was recognized in 1999 by EUMETSAT Member States when they amended the EUMETSAT Convention to affirm that the EUMETSAT mandate is also to contribute to the operational monitoring of climate and the detection of global climatic changes". Following this, EUMETSAT established within its Satellite Application Facility (SAF) network a dedicated centre, the SAF on Climate Monitoring (CM SAF, http://www.cmsaf.eu). Since the start of the CM SAF in 1999 the project went through three phases, i.e., the Development Phase lasting from 1999 to 2004, the Initial Operations Phase (IOP) and the Continued Development and Operations Phase (CDOP). The consortium of CM SAF currently comprises the DeutscherWetterdienst (DWD) as host institute, and the partners from the Royal Meteorological Institute of Belgium (RMIB), the Finnish Meteorological Institute (FMI), the Royal Meteorological Institute of the Netherlands (KNMI), the Swedish Meteorological and Hydrological Institute (SMHI) and the Meteorological Service of Switzerland (MeteoSwiss).

After focusing on the development of retrieval schemes to derive a subset of Essential Climate Variables (ECVs) in the development phase, CM SAF delivered to its users products based on Meteosat and polar orbiter data for Europe and Northern Africa supporting NMHSs in their provision of climate services in the IOP from 2004 to 2007. During CDOP, lasting from 2007 to 2012, the product validation continued, the time series were expanded and algorithms were further improved, while the study domain was extended from the baseline area to the MSG disk for the geostationary products and to include global and Arctic coverage for the polar orbiter products. In addition, long term climate datasets from polar orbiting and geostationary satellites are being generated for climate monitoring (i.e. HOAPS, METEOSAT and AVHRR-GAC based products).

A catalogue of available CM SAF products is available via the CM SAF webpage, http://www.cmsaf.eu/. Here, detailed information about product ordering, add-on tools, sample programs and documentation are provided.

2. Introduction

This CM-SAF Algorithm Theoretical Baseline document provides detailed information on a new cloud type product derived from VIS-NIR-SWIR-IR satellite imagers.

The motivation for proposing a new or revised cloud type product is mainly because of problems of using the current products in quantitative applications. In addition, since cloud typing depends mainly on information on the vertical distribution of clouds but also on cloud microphysical information, it was found that the current product could take further advantage of existing improved cloud top and cloud physical products for a better delineation of cloud types.

The revised cloud type algorithm is described in detail in Section 3 and in the associated sub-sections. Notice that what is now proposed is a product defined as a 3-D histogram of frequencies of occurrences within geographical grid squares of specified combinations of parameter values (orvalue intervals). The combined parametersare cloud optical thickness, cloud top temperature and cloud phase. Because of this we propose to rename the product to **Joint Cloud property Histograms (JCH).**

Since the new methodology depends on the availability of a valid cloud top pressure estimate, a particular problem is the fact that the current cloud top pressure product (for both AVHRR and SEVIRI) produces a significant fraction of pixels without a valid estimate. An attempt to improve this situation by introducing a cloud top pressure restoral method is presented in Section 4.

Section 5 discusses further optional extensions of the methodology and puts the development into context with regard to planned developments in the CDOP-2 phase for the CM SAF project.

2.1. Applicable documents

Reference	Title	Code
AD-1	Product User Manual CLOUDS	SAF/CM/DWD/PUM/CLOUDS/1.4
AD-2	Algorithm Theoretical Basis Document for SAFNWC/PPS “Cloud Type” (CT-PGE02 v1.5).	SAF/NWC/CDOP/SMHI-PPS/SCI/ATBD/2 V2.3.2 17/08/10
AD-3	Algorithm Theoretical Basis Document for SAFNWC/PPS “Cloud Top Temperature and Height” (CTTH-PGE03 v3.0).	SAF/NWC/CDOP/SMHI-PPS/SCI/ATBD/3 v2.3.1 15/04/10
AD-4	Algorithm Theoretical Basis Document for SAFNWC/PPS “Cloud Mask” (CM-PGE01 v3.0).	SAF/NWC/CDOP/SMHI-PPS/SCI/ATBD/1 v2.3.3 17/08/10
AD-5	Algorithm Theoretical Basis Document for “Cloud Products” (CMa-PGE01 v2.0, CT-PGE02 v1.5 & CTTH-PGE03 v2.0)	SAF/NWC/CDOP/MFL/SCI/ATBD/01 v3.1 24/03/11
AD-7	CDOP Service Specifications	SAF/CM/DWD/SeSp/1.7
AD-8	CDOP Product Requirements Document	SAF/CM/DWD/PRD/1.6

Reference	Title	Code
AD-9	Product Definition Change Document Cloud Type	SAF/CM/SMHI/PDC/CTY/1.0

3. Joint Cloud property Histogram Algorithm description

3.1. Theoretical basis for a revised Cloud Type algorithm

The proposed algorithm makes use of the Cloud Top Temperature and Height [CTTH]product and the Cloud Physical Product [CPP – more specifically components Cloud Phase [CPH] and Cloud Optical Thickness [COT]] in order to characterize cloud level – low, mid, high – and cloud types. The algorithm is largely based on the well-documented relationship between Cloud Top Pressure [CTP] and Cloud Optical Thickness [COT] (e.g. Rossow and Schiffer 1991, 1999; Hahn et al. 2001), however, with CPH information added as a third dimension. Figure 3-1 is a CTP-COT cloud-type classification taken from Rossow and Schiffer (1999). Cloud types are segregated by level (CTP) and visible opacity (COT), and the 2-D histogram based on the statistical distribution of global cloud cover. The CTP-COT thresholds shown in Figure 3-1 are an example of potential cloud-type thresholds and are not entirely robust (see Hahn et al. 2001). For example, numerous, low-level cumulus clouds within one satellite pixel compared to a pixel with a single low-level cumulus filling the entire pixel will have distinctly different COTs but represent in reality the same cloud type. Variable swath and satellite zenith angle will also effectively impact the actual COT relative to the satellite pixel size. Nevertheless, we argue that in terms of cloud climatologies, the actual cloud type is not nearly as relevant as a climate variable compared to cloud level [low, mid, high], cloud thermodynamic structure [temperature and phase] or cloud radiative impact [COT, effective emissivity].

Following previous reasoning, CTTH and CPP products must now be calculated and used as input for the new proposed JCH algorithm, in contrast to the order of processing for the old cloud type product. A consequence of this is that the old CTY algorithm still has to be run to provide a separation between semitransparent or fractional clouds and opaque clouds (needed as input to the CTTH algorithm).

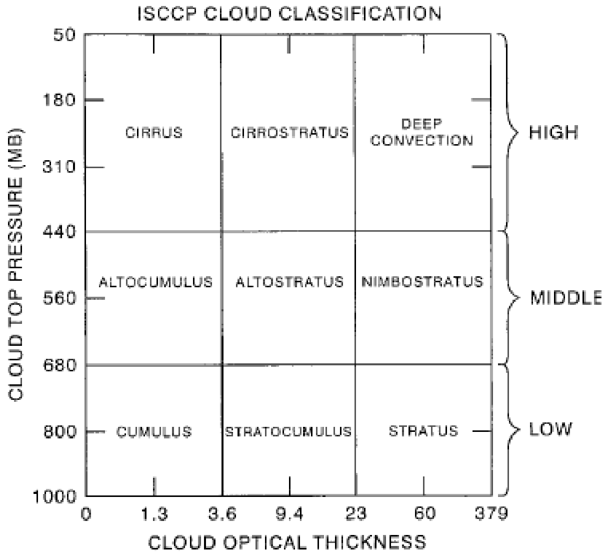


Figure 3-1*Cloud type and level classifications based on CTP [mb] and COT developed for the ISCCP cloud type, taken from Rossow and Schiffer (1999).*

3.2. Method

3.2.1. Revised Cloud Type algorithm

The description of the new JCH product based on the CTP, CPH and COT parameters is similar to the 2-D histogram bins as shown in Figure 3-1 but with CPH as a third dimension. The vertical temperature and moisture profiles, used as references when deriving the CTP product, come from analyses or short-forecasts from Numerical Weather Prediction (NWP) systems. For the current EDR (Environmental Data Record) chain the CMSAF uses analyses from the GME model. However, for the AVHRR GAC TCDR (Thematic Climate Data Record) cloud dataset CMSAF uses the ERA-Interin reanalysis products with a vertical resolution of 25 hPa. We have used products from the latter in the prototyping of the new JCH product. Thus, the pressure-level limits of low- and high-level clouds are changed accordingly from 680 and 440 hPa to 675 and 450 hPa.

3.3. Input data

The proposed JCH product requires input from four PPS data products, namely the CFC, the (current) CTY, CTTH and CPP products. The algorithm is run as a post-processing of these data products at the satellite pixel level. In particular, the proposed JCH algorithm follows the following logic:

- CFC product is used to identify all cloudy pixels
- Results from current CTY product is analyzed – separates cloudy pixels into categories Opaque and Semitransparent/Fractional pixels.
- CTTH product – the estimated CTP determines the cloud level [low, mid, high] based on pressure-level thresholds of 675 and 450 hPa. The CTP pressure levels are binned at a vertical resolution of 25 hPa.

- CPP product – these products are available only for solar zenith angles less than 72°, therefore the proposed CTY productis produced only during sunlit times. The COT is used to distinguish the shortwave opacity of the clouds, and the bin size can be adjusted. We have separated COT bins according to those described in Rossow and Schiffer (1999), which results in 9 cloud types depending on where the pixel is observed on the CTP-COT histogram (see Figure 3-1). Output data

The proposed JCH algorithm produces

a CTP-COT-CPH joint histogram for each orbit (Level 2) and for each day (Level 2b) and month (Level 3) of the full GAC data set. The joint histogram approach can be used as a measure of the distribution of cloud level, cloud opacity and cloud type (in terms of cloud phase). An example of these joint histograms for the full GAC for July 2007 descending overpasses of the NOAA17 satellite are shown in Figure 3-2. We use the native COT bin resolution proposed by Rossow and Schiffer (1999). The relative frequency distribution [RFD] indicates a dominance of low- to mid-level clouds with COT ranging from 3.6 to 23. The distribution of CPH indicates a general decreasing trend in liquid clouds as cloud-top height increases, although there are relatively large fractions of liquid clouds at both mid-levels and for optically thin high clouds. The July 2007 mean CTP and COT is shown as the magenta star in the middle panel. Although the mean COT generally agrees with the joint histogram distribution, the CTP is generally too low. Clearly these types of joint histograms are superior to simplistic mean values which fail to capture the observed distributions and introduce incorrect biases relative to the observed data. A possible enhancement of the methodology could be to increase the bin size for a finer resolution of the information (TBC).

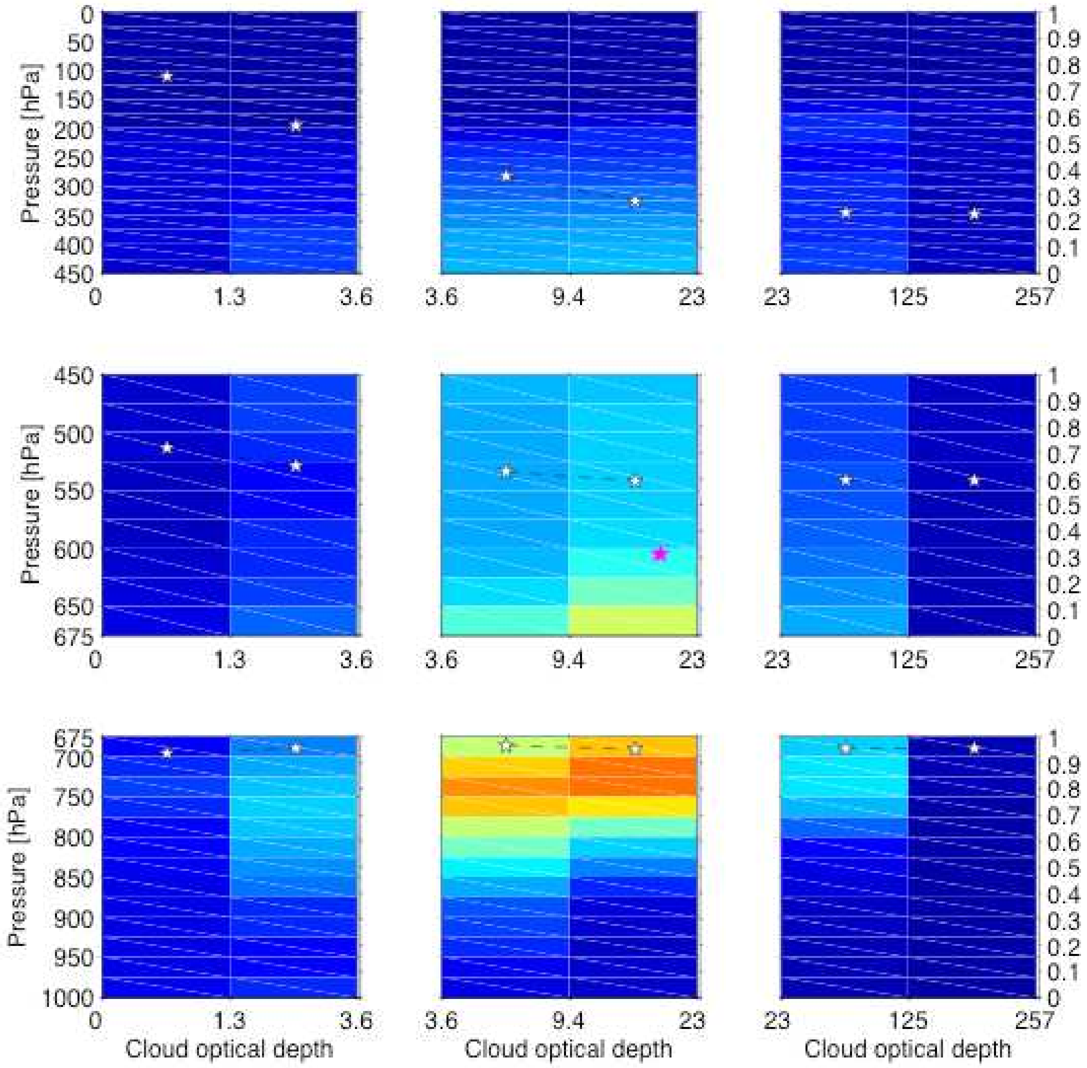


Figure 3-2 *Relative frequency distribution [colors, warmer colors represent increasing frequency] of CTP [hPa] as a function of cloud optical depth for the full GAC data set from July 2007 for the descending passes of NOAA17. Each panel represents the corresponding cloud-type box defined in Rossow and Schiffer (1999) (see Figure 3-1). White stars joined by a dashed black line represent the relative frequency (right-hand axes, labeled in the right-most panels) of liquid-phase clouds per COT bin and cloud level [low, mid, high] as determined by the CPP product CPH. The magenta star in the middle panel represents the location of the mean CTP and COT values for these data.*

4. Semi-transparent/Fractional CTTH restoration

As described briefly in [AD-9], the method to solve for CTTH for semitransparent/fractional pixels (from now referred to as SFP) does not always converge to a solution (see AD-3 for more on the solution methodology). As an example, pixel-level cloud characterstics for 25 July 2007 for the full GAC are given in [AD-9]. Of the nearly 57% of cloudy GAC pixels, approximately 19% are SFP, which correponds to slighly more than one-third of all cloudy pixels (33.4%). Of these SFP, only approximately 9% have a CTTH solution representing a relative SFP data loss of approximately 73.4%. However, if applying a simple SFP restoration method, we may reach nearly 20% of the total cloudy pixels with a CTTH solution, which effectively reduces our SFP data loss to 41.3%. Thus, we would gain a significant amount of cloudy pixel information using the restoration technique. The method of SFP restoration is described below.

4.1. Methodology

Semitransparent/fractional pixel restoration is a post-processing technique using the solutions from the current CTY and CTTH algorithms. The method of pixel restoration is based on the assumption that high-level clouds retain a general coherency over a relatively large spatial extent. Then, we can examine the neighboring pixels of a determined SFP without a CTTH solution and “restore” the missing CTTH value. Figure 4-1 is a cartoon schematic illustrating the principles of such a restoration. The grid boxes represent the GAC satellite 4km x 4km pixels, from which the radiances and Tbs are used by the CM, CTY and CTTH algorithms. The restoration method employs a symmetric moving-grid technique, centered on the SFP that is missing a CTTH value, illustrated as the red pixel with the white ‘X’. The moving-grid is set by examining the nearest 8 pixels on all four sides of the missing CTTH pixel. Thus the moving grid has a 17x17 pixel resolution, representing approximatly 68x68 km. This analysis is performed on each orbit individually. Thus, the resotration grid is not always symmetric when the SFP in question is near the pixel or line edges. Note the schematic grid resolution in Figure 4-1 is not drawn on the same scale, nevertheless the same methods pertain.

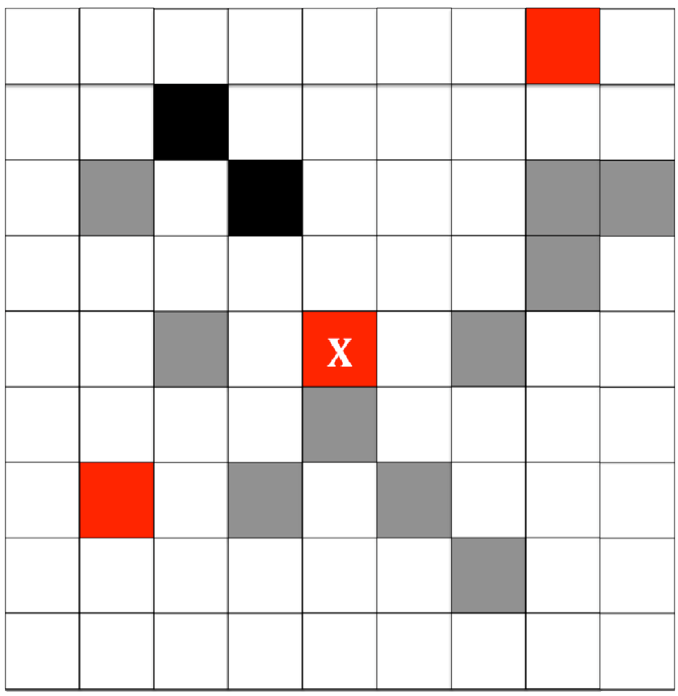
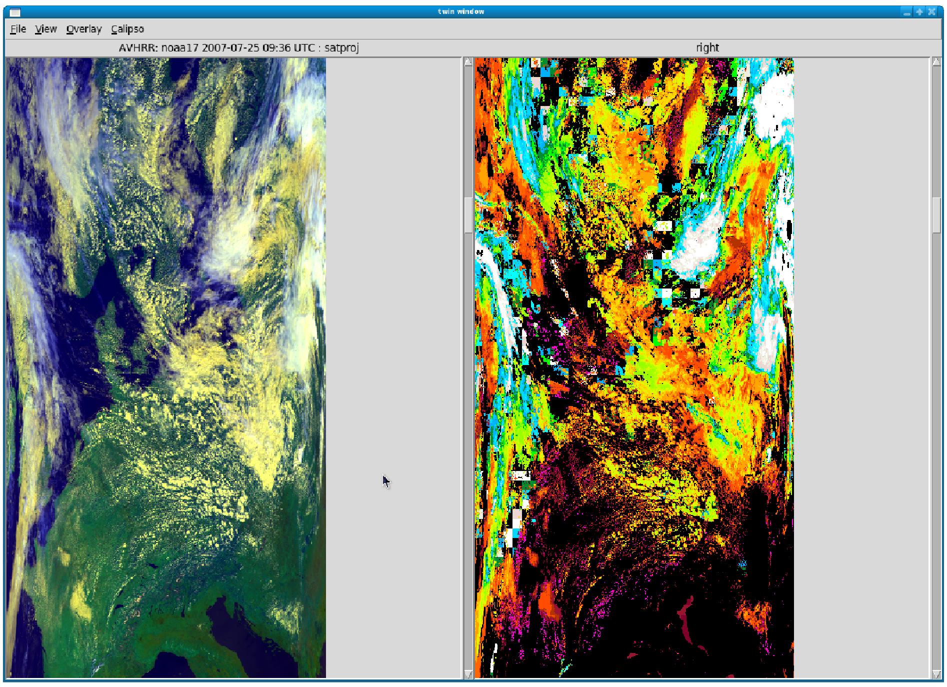


Figure 4-1*Cartoon schematic of restoration process. The grid is downsized from the 17x17 pixel grid size implemented. Red pixels represent semitransparent/fractional cloud*

pixels without a CTTH solution; gray pixels represent semitransparent/fractional clouds with a CTTH solution; black pixels represent opaque pixels with CTTH values. The white X is the identified pixel centered on the moving grid where a restoration solution is attempted.

The gray pixels in Figure 4-1 represent SFP that do have a CTTH solution, while the red pixels are those that do not; the black pixels represent low- and mid-level opaque cloudy pixels. The CTTH restoration identifies pixels within the moving grid that are cloudy and for which a CTTH solution exists. The algorithm ignores pixels within the grid box that are low- and mid-level opaque pixels (black pixels) and those that are SFP with a CTTH value but are labeled as subpixel or fractional clouds. The purpose of these criteria is to avoid including opaque cloud characteristics but also to avoid surface contamination on the observed radiances and Tbs. The pixels that are retained are those identified as semitransparent/fractional cirrus and cirrus above low- or mid-level clouds that have a CTTH (gray pixels in Figure 4-1). Additionally, we also retain the high and very-high opaque cirrus pixels under the assumption that the SFP we are attempting to restore have characterisitics similar to any opaque high cirrus within the spatial extent of the moving grid. If any pixels within the grid satisfy these requirements, medians of CTTH values of those pixels are computed and assigned, or “restored”, to the original pixel in examination. We flag these restored pixels and disregard them in future attempts to restore surrounding SFP that are missing CTTH solutions. This assures that we do not incorporate a “runaway” restoration.

Figure 4-2 shows an example of the cloud scene and corresponding cloud-top temperature estimated from CTTH observed on 25 July 2007 by 0936 UTC orbit on NOAA17. Cloud-top temperatures in the top panel (right-most image) are for the original CTTH processing. The square pixelization of temperatures is an artifact of the SFP solution fitting system, using the texture of surrounding pixels to converge to a solution (see AD-3). There is a rather significant portion of the scene for which the CTTH algoritihm is unable to converge to a solution, thus these pixels, although cloudy, remain black signifying no CTTH information.



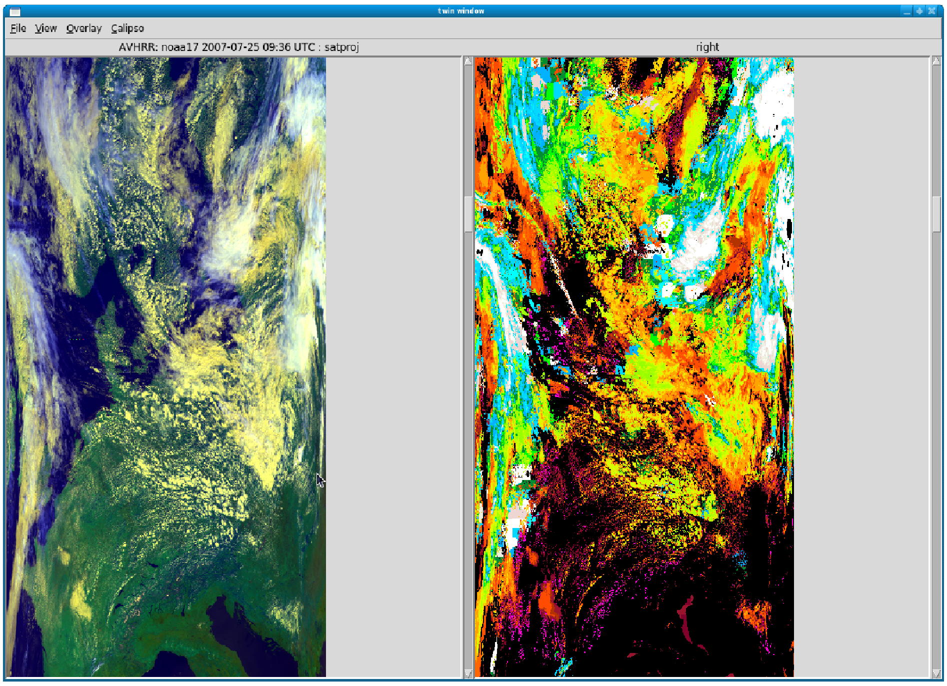


Figure 4-2*Left-panels: RGB color composite using channels 1, 2 and 4 from a cloud scene taken from the 0936 UTC orbit onboard NOAA17 scene on 25 July 2007; Right panels: The cloud-top temperature product from the CTTH algorithm. The top panels are for the original NWCSAF CTTH solutions, while the lower panels include the semitransparent/fractional cloud restoration method proposed in this study.*

The lower panel in Figure 4-2 is for the same scene, however here the SFP restoration method is applied. A portion of the cloud-top temperatures that were originally missing now take on characterisitcs from the surrounding semitransparent and opaque cirrus pixels. The result is a large amount of data recovery and an increasingly coherent picture of the cloud-top temperature (cloud-top pressure and height are also restored but not shown). It is important to note that not all SFP can be restored, only those that satisfy the methodology within the grid described above can obtain a restored CTTH solution.

4.2. Example of CTTH Restoration

An example of the joint histogram results for the full GAC from NOAA17 during July 2007 using the CTTH restoration technique is shown in Figure 4-3. Additionally, the COT bin size has been refined in order to better quantify the physical properties of the observed clouds. In general, the inclusion of restored pixels becomes translated into the 10 km regridded global data sets. The RFDs reflect this inclusionthrough an increase in the frequency of high-level, and to some exent mid-level clouds, at the expense of the frequency of low-level clouds. This is consistent with the intent of the semitransparent/fractional pixel restoration methodology.

The enhanced COT bin resolution provides a more physical representation of the cloud observed properities which, in general, become lost with the larger bin sizes (see Figure 3-2). For example, the peak distribution of observed clouds tends to range in pressure levels from approximately 750-700 hPa and optical thicknesses between 5 and 15. Clearly the mean of CTP and COT does not represent these primary observed distributions (Figure 4-3, magenta star). Additionally, the frequency of high-level liquid clouds has increased slightly, suggesting the semitransparent/fractional pixels often contain liquid signatures. These results illustrate the large amount of cloud-top information contained within the joint histograms.

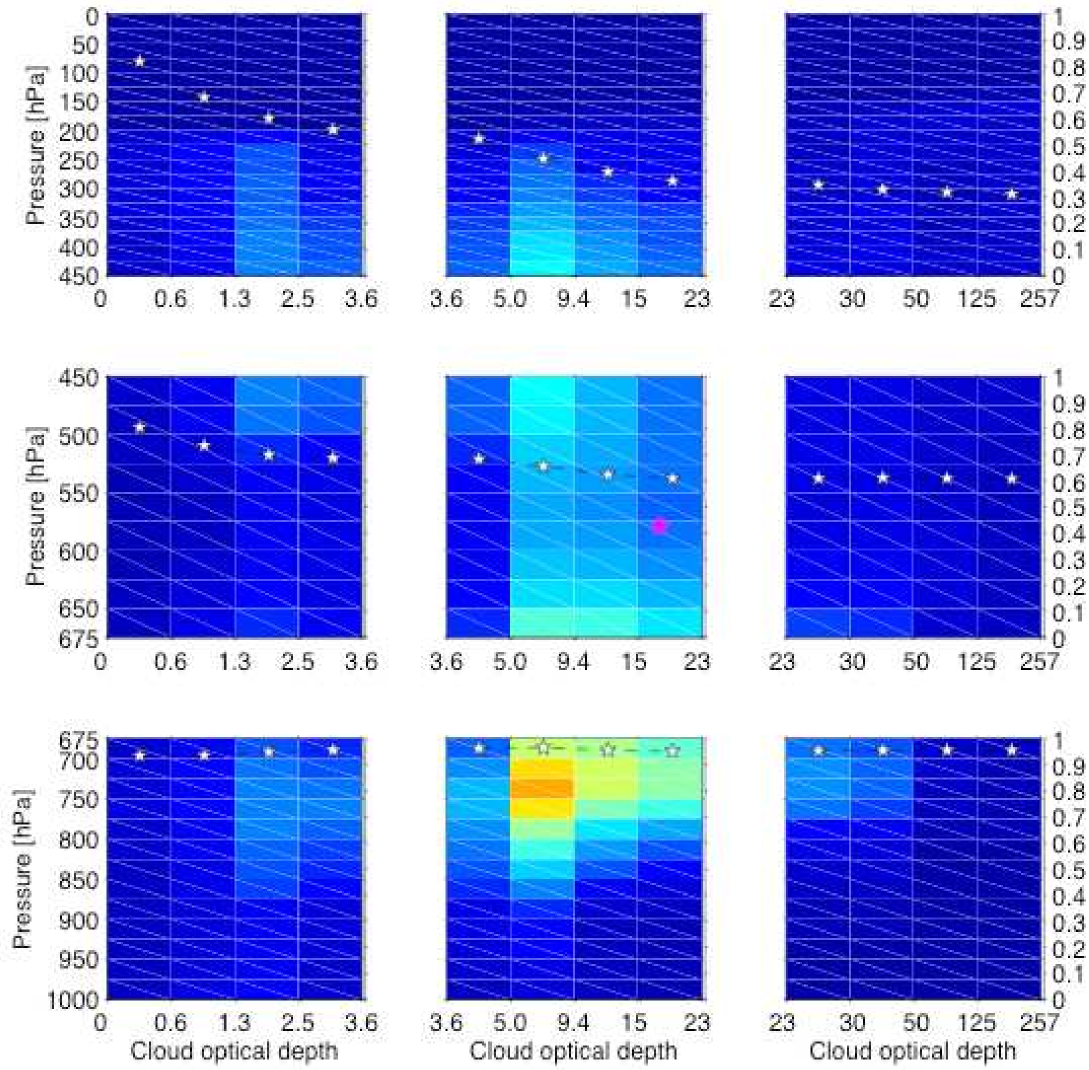


Figure 4-3 *Same as Figure 3-2, expect the RFD includes restored semitransparent/fractional pixels according to the methodology described in Section 4.1. Additionally, the COT bin size has been reduced relative to Figure 3-2.*

5. Concluding remarks

We have described how to compile information from original CMSAF products CFC, CTP, CPH and COT into a condensed joint-histogram structure providing information about product distributions (which could be interpreted as cloud-type frequencies) for individual grid points. The methodology is applicable to both AVHRR and SEVIRI products. We believe that cloud products presented in this form would be a valuable asset in further quantitative applications of CMSAF data (e.g., for evaluation of cloud simulations in climate models).

However, one particular problem with this approach is that information on cloud-top pressure cannot be given with confidence for all pixels labelled as being cloudy. Thus, the histogram information to be compiled has also to be complemented with information about the fraction of undefined pixels in order to be fully consistent with other products (e.g. CFC). One interesting approach for reducing the fraction of undefined pixels has been outlined but further studies are needed here to evaluate and optimise this methodology. Also, further development here has to be coordinated with method developments already planned by the NWCSAF consortium regarding the cloud processing software. This means that the use of CTP restoral methods will be introduced in later editions of the AVHRR GAC TCDR and the SEVIRI ICDR during the CDOP-2 phase.

6. References

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