16.3 CLEAR SKY GAC RADIATION BUDGET PRODUCT SYSTEM AT NESDIS

David R. Donahue, Science and Technology Corporation, Suitland, MD*
John Sapper, National Oceanic and Atmospheric Administration, Suitland, MD
Vaishali Kapoor, Science and Technology Corporation, Suitland, MD

1. INTRODUCTION

The effect of clouds on the radiative fluxes at the top of the atmosphere (TOA) has become increasingly important for studying climate. One useful way for quantifying this effect is by determining what is generally referred to as "cloud radiative forcing," which is often defined as the difference in the TOA flux between the cloudy or “all-sky” atmosphere and the cloud-free or “clear-sky” atmosphere. This paper provides an overview of the current NOAA-16 experimental clear-sky radiation budget products generation system (RBPGS) used under Computer Sciences Corporation’s (CSC) Central Satellite Data Processing contract to the National Oceanic and Atmospheric Administration’s (NOAA’s) National Environmental Satellite, Data, and Information Service (NESDIS). The RBPGS uses a Clouds from AVHRR (CLAVR) cloud mask to identify clear Global Area Coverage (GAC) fields-of-view. For completeness, this paper includes a brief discussion of the enhanced CLAVR system (CLAVR-x), as this system will eventually become the primary input to the RBPGS.

2. BACKGROUND

The radiation budget products generation system produces top-of-the-atmosphere radiation parameters such as outgoing longwave radiation (OLR) from the Advanced Very High Resolution (AVHRR) and High-Resolution Infrared Sounder (HIRS), Shortwave Absorbed Radiation (SWAR) from AVHRR, and histograms of OLR and SWAR. The current all-sky products are produced from GAC AVHRR and HIRS 1B* data from operational polar-orbiting satellites NOAA-15, 16, and 17. 1B* files are internal files used within the Information Processing Division (IPD) of NESDIS and are, essentially, unpacked 1B files. The OLR products are divided into daytime and nighttime (ascending and descending) products.

Orbital processing for the radiation budget system collocates arrays of AVHRR GAC with HIRS data. Because of the collocation with HIRS data, the base unit of processing is an 11 x 11 array (target) of AVHRR GAC fields-of-view. This target matches up well with the along-track spacing of the HIRS fields-of-view (42 km). Processing proceeds on a target-by-target basis resulting in a retrieval for each target. The retrieval is one observation unit that contains several parameters including time, date, GAC and HIRS OLR sums (sum of the OLR fluxes for each of 121 fields-of-view in the target), OLR total populations, OLR sums of squares, OLR histogram populations, GAC SWAR sums, sums of squares, total population, solar and satellite zenith angle, a scene index for daytime data, and the six by six cross populations histogram. The retrievals are the major input to the subsequent mapping processes that produce the end products as described by Sapper (1998).

3. CLAVRKLM PROCESSING SYSTEM

In 2001, the Office of Research and Applications (ORA) provided IPD with the CLAVRKLM processing software. Because of limited resources, the CLAVRKLM system was set up only for NOAA-16. The primary purpose of the CLAVRKLM module is to implement the CLAVR-1 classification algorithms (Stowe et al, 1999) on each 2 x 2 pixel array and arrive at a cloud code for each pixel array. These cloud codes roughly identify the type of cloud within the 2 x 2 array. The codes also identify the path through the CLAVR algorithm’s decision tree.

The classification routines use a number of thresholds on the individual radiances, ratios of radiances, or differences between radiances in arriving at a classification. The classifications are further refined using a sequence of tests for confirming or revising an earlier clear/cloudy decision. Thus, a number of pixels get restored on the basis of such follow-on tests.

While the CLAVR-1 classifications lead to three final categories consisting of "clear," "cloudy," and "mixed" pixels, over 40 separate cloud codes are set up in the system covering daytime, nighttime, and all land-surface types. The clear/cloudy/mixed tests consist of gross channel reflectance tests and reflectance uniformity tests performed on each pixel. These tests are described in detail by Stowe et al, 1999. Each pixel is tested for the presence of clouds. Based on the results of these first tests, a binary clear/cloud flag is assigned (0=failed [clear], 1=passed[cloudy]). Used by the clear-sky orbital processing module, this flag identifies clear GAC fields-of-view. Spatial uniformity tests are then applied to determine whether the array should be classified as partly cloudy or “mixed.” If all four pixels are ‘0,’ they are assigned a clear-cloud code. If all are ‘1,’ they are assigned a cloudy code. If there are ‘0’s and ‘1’s, then the array gets assigned a mixed code. Figure 1 provides a schematic of the decision tree used to determine the three final categories.

The CLAVRKLM module reads and processes NOAA-KLM-era level 1B AVHRR GAC data. This data set contains pixel-level data, structured by time-sequential scan lines. The output from CLAVRKLM is a GAC “1C“ data set, which essentially retains the structure of the original data except that it includes calibrated normalized albedos, brightness temperatures equivalent blackbody temperatures, and the cloud codes determined by CLAVRKLM for each GAC pixel. Additional output from the module is a modified 1B data set with cloud codes derived from the 1C data set.

* *Corresponding author address:*
David R. Donahue, STC, FB#4, Rm. 0343; 4401 Suitland Road, Suitland, MD 20746-4303
e-mail: David.R.Donahue@noaa.gov.

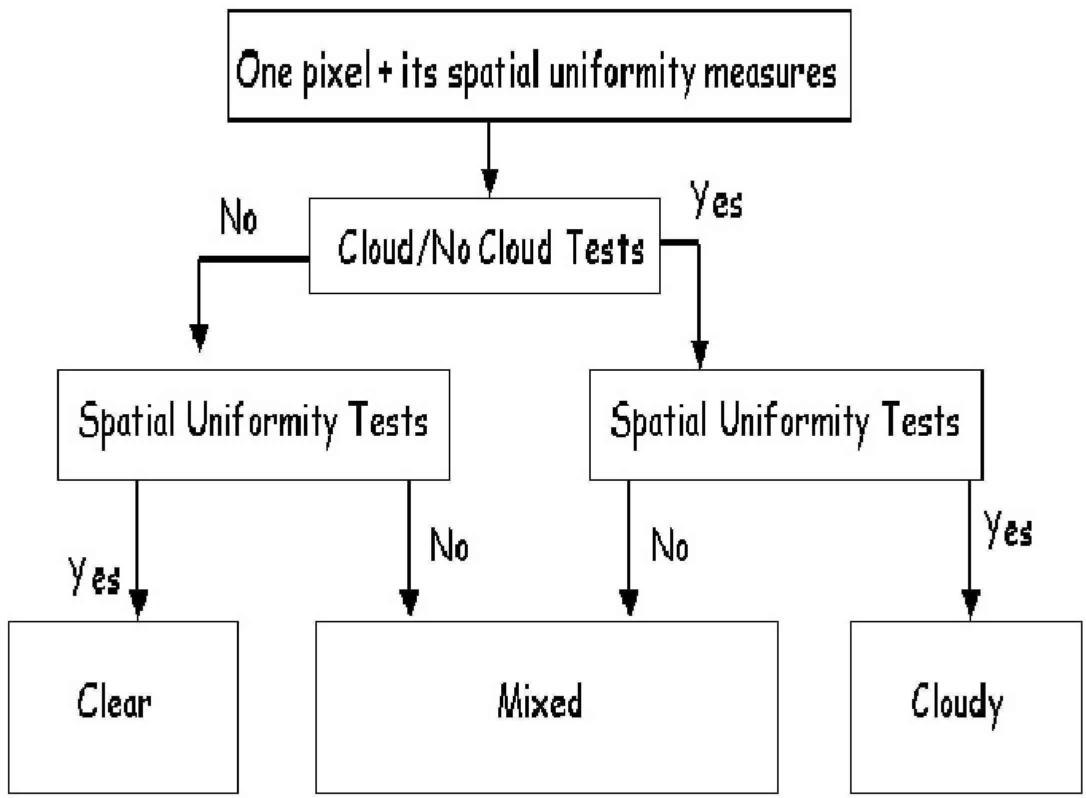

Figure 1. Schematic of CLAVRKLM Decision Tree Used to Determine the Three Final Cloud Categories

4. CLEAR-SKY ORBITAL PROCESSING

In 2002, the operational KLM all-sky radiation budget orbital processing module, RBKLM, was modified to read the CLAVRKLM 1C file, in addition to the GAC and HIRS 1B* orbital files. The new module, RBKLM1C, uses the 1C cloud code and the CLAVR clear/overcast flag in place of the RUFF scene ID (Ruff, 1988) for each pixel in the 11 x 11 target to determine the Earth Radiation Budget Experiment (ERBE) scene index (see Table 1) for the whole target area. If there is valid cloud information in the target area, the percentage of cloud cover for the area is computed based on the 1C clear/overcast flag for each pixel. An index based on the percentage is used to determine the ERBE scene index and associated angular model used in the retrieval process.

In polar latitudes, use of the CLAVR-1 clear snow and ice cloud codes was found to result in unrealistic scene indices and clearly erroneous radiation budget retrievals. To correct this problem, a terrain field was incorporated into the system that has AMSU-derived snow and ice tags, which are updated daily. Any clear pixel with one of these snow or ice tags is now automatically assigned an ERBE scene index of 3 (clear snow).

Table 1. ERBE Scene Indices

Index	Scene
1	Clear ocean
2	Clear land
3	Clear snow
4	Clear desert
5	Clear ocean/land mix
6	Partly cloudy (5 to 50%) over ocean
7	Partly cloudy (5 to 50%) over land
8	Partly cloudy (5 to 50%) over coast
9	Mostly cloudy (50 to 95%) over ocean
10	Mostly cloudy (50 to 95%) over land
11	Mostly cloudy (50 to 95%) over coast
12	Overcast cloud

RBKLM1C was originally designed to read daytime cloud codes only. For clear-sky, the ability to read nighttime cloud data was added, and the retrieval subroutine was modified to make retrievals for clear-sky only. The code was modified so that the target flux retrievals for clear-sky scenes are computed from clear pixels only and processed (binned and averaged) in exactly the same manner as for all-sky retrievals. This is now done by simply selecting targets identified as one of the five clear-sky scene types, averaging those pixels in the 11 x 11 GAC array identified by the CLAVR software as clear-sky fields-of-view, and retrieving the target flux using the mean clear-sky radiance. The number of clear pixels within the target was also added to each retrieval record in the clear-sky orbital output file. In post orbital gridded analysis processing, the clear targets are binned into an equal-area grid and further averaged with other clear-sky fluxes in the same bin. Figure 2 displays a comprehensive flow diagram of the entire clear-sky system, including 1C processing.

5. CLEAR-SKY OLR PRODUCTS

Subtracting the clear-sky from the all-sky product produces a measure of the cloud radiative forcing. Figures 3a and 3b display all-sky and clear-sky orbital-level retrievals of GAC OLR, respectively.

For Figure, 3c, the clear-sky OLRs were subtracted from the all-sky OLRs, producing an image of near real-time cloud radiative forcing in Watts/m^2 . Figure 3d is the associated ERBE scene index. In general, clouds have a longwave cooling effect. At the orbital level, this effect can only be displayed in “mixed” targets, because there are no clear retrievals to subtract in completely overcast targets. This is unfortunate, as that is where the greatest cloud forcing occurs. Luckily, the primary use of cloud forcing is for long-term studies. Over longer periods, such as one month, clear retrievals will be made over most of the earth, allowing measurements of the mean forcing at a global level. Figure 4 was produced from a post processed, equal-area, monthly, mean-gridded analysis of all sky and clear-sky daytime GAC OLRs from NOAA-16 for September 2003. The image displays the daytime effect of clouds on global outgoing longwave flux in Watts/m^2. The accuracy of such products for long-term climate studies is still being evaluated but is expected to improve with future upgrades to CLAVR.

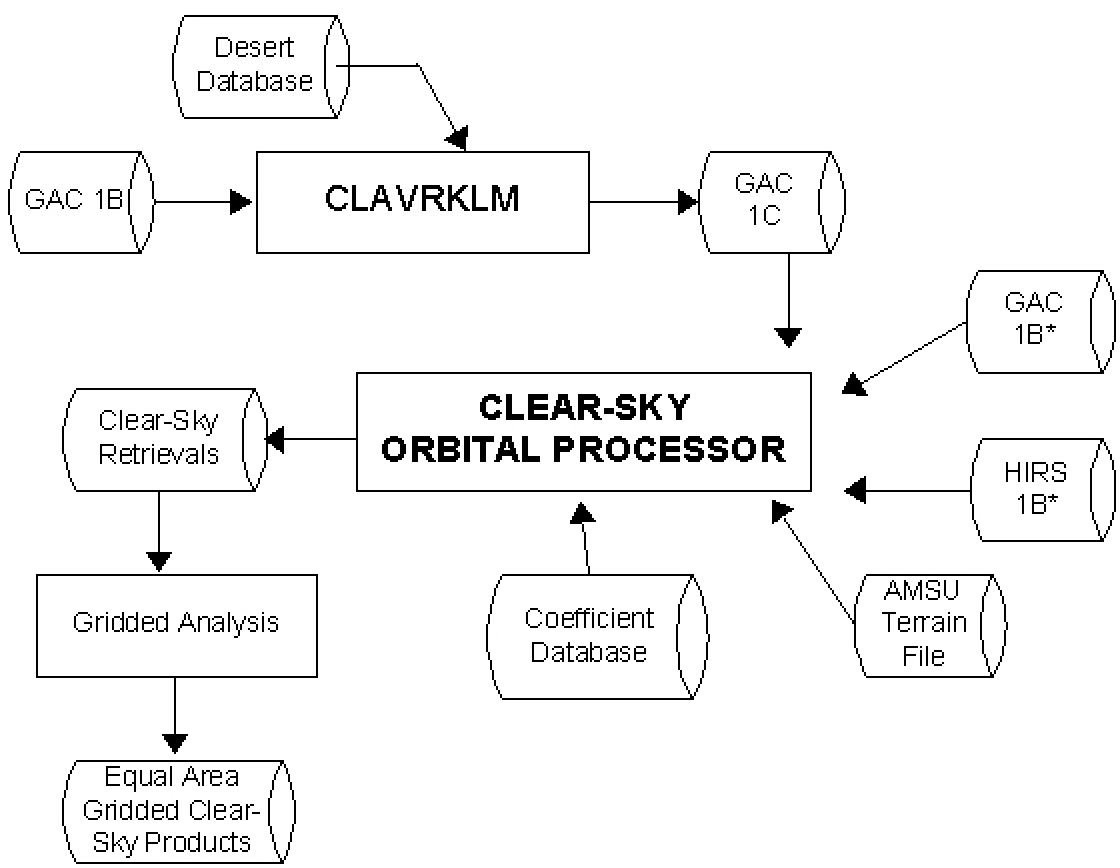

Figure 2. Clear-Sky Processing System

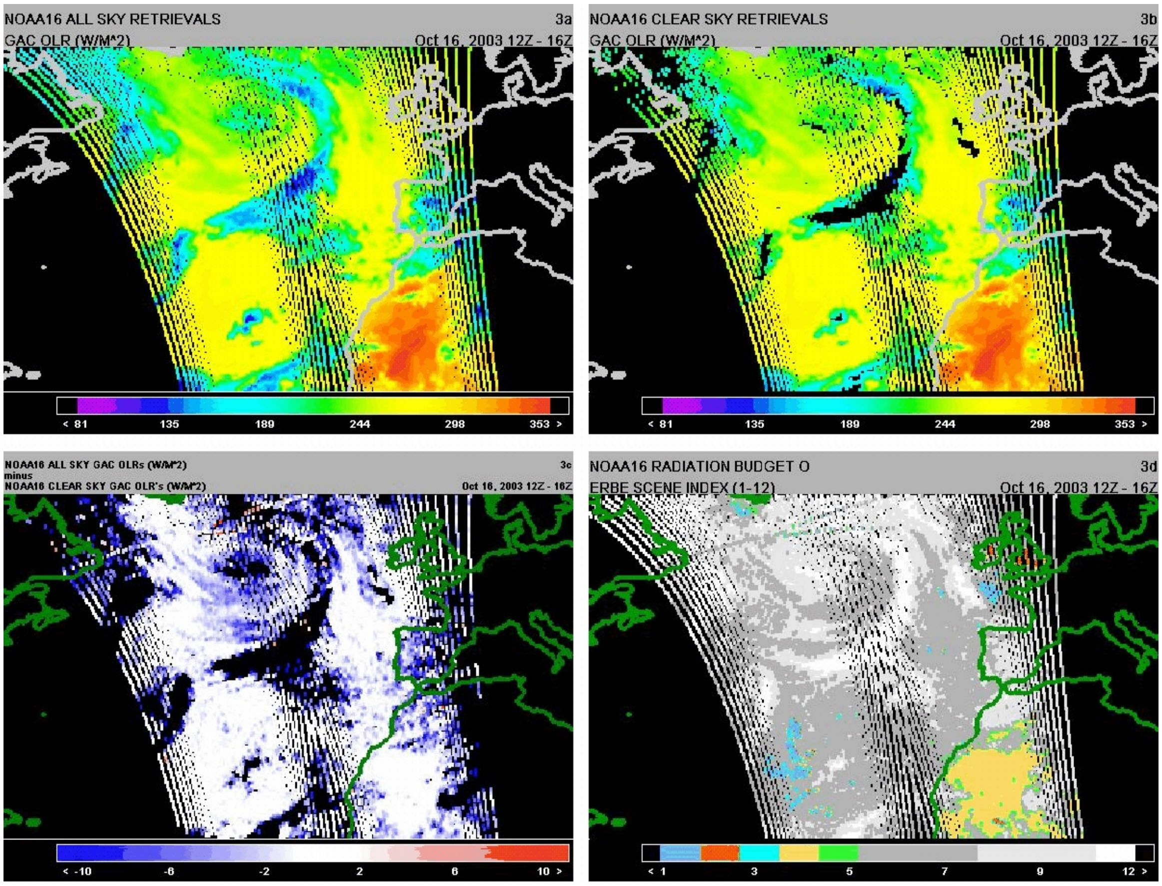

Figure 3. Orbital-Level Products

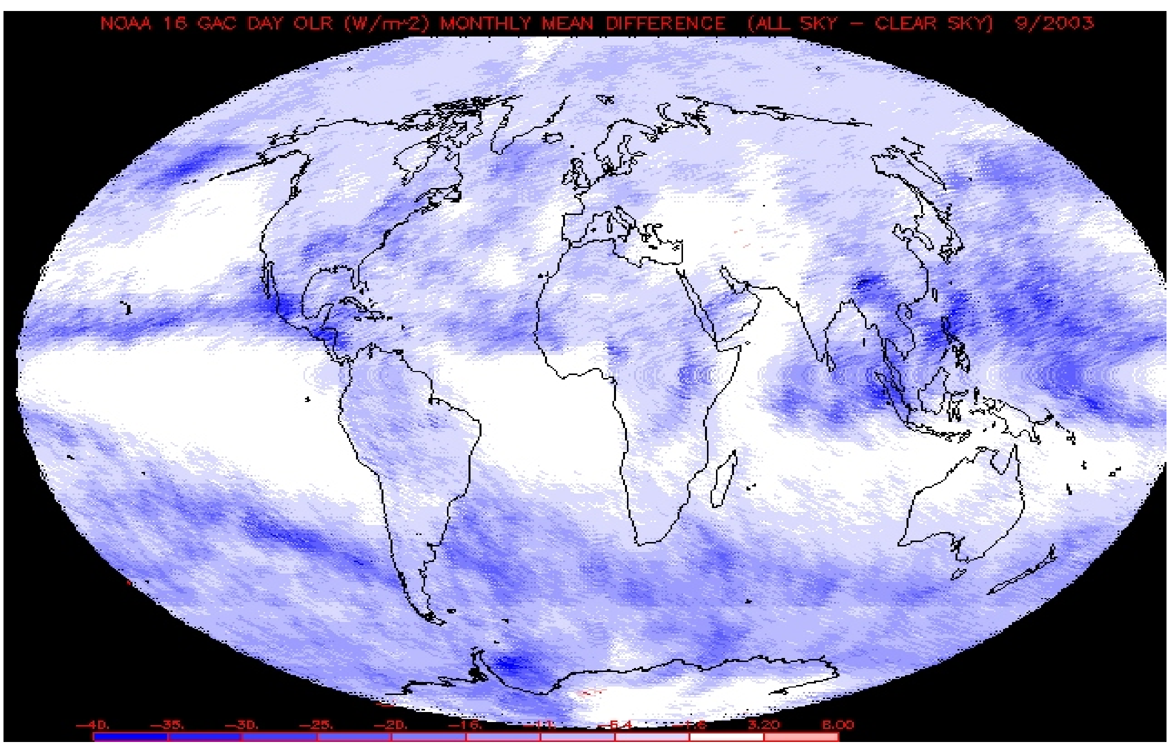

Figure 4. Difference between All-Sky and Clear-Sky Mean Monthly Daytime GAC OLR (Watts/m^2) from NOAA-16 for September 2003

6. CLAVR-X

Work is currently underway to replace the CLAVR-1 system with CLAVR-x. The CLAVR-x system writes cloud mask information back to the AVHRR 1B level file, eliminating the need for the non-operational 1C file. And, since CLAVR-x is not limited to afternoon satellites, it makes the CLAVR cloud mask available and production of clear-sky retrievals possible for all satellites with AVHRR. In addition, the CLAVR-x development system, currently running at NESDIS, incorporates a number of upgrades over CLAVR-1. It separates partly cloudy from cloudy pixels in the derivation of cloudy radiances. This is a four-level mask, as opposed to the CLAVR-1three-level mask. Pixels previously assigned a classification of "mixed" are now classified as "partly clear" or "partly cloudy". CLAVR-x detects more cloud than CLAVR-1. Performance over day ocean is comparable, while performance over night ocean is superior. All evidence so far indicates global performance equaling or surpassing CLAVR-1.

9. CONCLUSION

For the first time, a CLAVR cloud mask is being used as input to a NESDIS operational product system, the NOAA-16 Radiation Budget Product Generation System. This cloud mask has also allowed the production of experimental clear-sky radiation budget retrievals for NOAA-16. The NOAA-16 clear-sky radiation budget products are displayed via the Web along with their all-sky counterparts at:
http://www.osdpd.noaa.gov/PSB/EPS/RB/RB.html. These products are currently being evaluated by NESDIS scientists. The implementation of the CLAVR-x operational system will allow the operational production of improved clear-sky products for all NESDIS polar satellites and provide a mechanism for studying long-term cloud radiative forcing.

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