CLOUD CLASSIFICATION EXTRACTED FROM AVHRR AND GOES IMAGERY

M.Derrien, H.Le Gléau

Météo-France / SCEM / Centre de Météorologie Spatiale
BP 147 22302 Lannion. France

ABSTRACT

We developed an automated pixel-scale thresholding algorithm to classify clouds from locally-received AVHRR and GOES-8 satellite imageries. The thresholds are computed from atlas and NWP model outputs , and are tuned to AVHRR/GOES spectral characteristics by an off-line use of radiative transfer models (6S, RTTOVS). The accuracy of the method is estimated using a large test and validation database (interactively fed during two years). GOES Cloud Type products will be routinely available (in GIF format) on Météo-France ftp public server during a few months, as a participation to the SAF NWC demonstration experiment.

1. INTRODUCTION

Within the SAF in support to Nowcasting and Very Short Range Forecasting (SAF NWC), Météo-France is developing a software to extract cloud parameters (cloud masks (abbreviated CMa) and types (CT), cloud top temperature and height (CTTH)) from MSG SEVIRI imagery over European areas. During the first development phase (1997-1999), prototypes to extract these cloud parameters from locally-received AVHRR imagery (to simulate European conditions) and GOES-8 imagery (to simulate geostationary conditions) have been developed and routinely validated. The final algorithm tuned to MSG SEVIRI spectral characteristics will be elaborated during a second development phase in 2000, taking advantage of experience gained during the prototyping phase.

This paper focuses on the thresholding techniques developed at Météo-France to detect and classify clouds from AVHRR and GOES satellite imageries within the SAF NWC project. After having outlined the aim of the AVHRR and GOES prototyping, we detail the multi-spectral threshold technique itself, in particular the use of atlas maps and NWP model outputs [that allows to apply the method on various regions] and the tuning to AVHRR/GOES spectral characteristics which is performed by an off-line use of radiative transfer models. The accuracy and limits of the method are illustrated using a large database (interactively fed during more two years). Examples of cloud types extracted from AVHRR (Europe) and GOES (North America) are finally given.

2. AIMS OF AVHRR AND GOES PROTOTYPES

The software, that will be developed within the SAF NWC frame to extract cloud parameters from MSG SEVIRI imagery, should be ready very soon after MSG launch. Therefore, prototypes using AVHRR and GOES-8 imagery locally received at CMS/Lannion have been developed, both to validate algorithms and to check the technical feasibility of real-time processing. In fact, most of the channels available on MSG SEVIRI and useful for cloud classification are also available both on AVHRR and GOES-8 imagery.

- AVHRR (locally received at Lannion) allows to test algorithms in European conditions. We improved and adapted an existing AVHRR processing scheme (Ref.[2]) to produce cloud categories as close as possible to those defined in the SAF NWC.
- GOES-8 images, which are available every 30 minutes over a large area covering North America and north-west Atlantic Ocean (see figure 3), simulate geostationary conditions. A completely new scheme has been developed, following specifications defined in the SAF NWC.

The use of radiative transfer model to tune algorithms to the exact channels' spectral characteristics should allow a fast and easy tuning to MSG SEVIRI.

The Cloud Type product to be prototyped with GOES data contains 21 categories listed below :

Cloud Type categories	
Non processed	Very low clouds (2 possible classes : cumuliform & stratiform)
Land [non contaminated by clouds, aerosol or snow]	Low clouds (2 possible classes : cumuliform & stratiform)
Sea [non contaminated by clouds, aerosol or ice]	Medium clouds (2 possible classes : cumuliform & stratiform)
Land contaminated by snow	High opaque clouds (2 possible classes : cumuliform & stratiform)
Sea contaminated by ice/snow	Semi-transparent ice clouds (3 classes according to thickness) + cirrus above clouds
Aerosol (2 possible classes : sand/ash)	
Unclassified	Fractional clouds

Table 1. Cloud Type categories tested during GOES prototyping

The highest priority was the identification of the major cloud classes, i.e. low, medium, high, semi-transparent, the distinction between convective and stratiform clouds and the aerosol detection being optional. A water cloud flag (optional) and a quality flag are also parts of the cloud type product. The definition of the final SEVIRI Cloud Type product will depend on the result of the prototyping.

3. CLOUD MASK AND TYPES THRESHOLDING ALGORITHM

3.1 OVERVIEW

Clouds are first distinguished from cloud free surfaces during the cloud mask process by a comparison to simulated radiative surface properties. Cloudy pixels are then classified in cloud types according to their radiative characteristics. Both steps are performed by thresholding techniques. The distinction between stratiform and cumuliform clouds has not yet been studied.

To meet real-time constraints, the threshold computations that do not require satellite imagery, are performed off-line, in a preparation step prior to the availability of the satellite image. These thresholds are computed on segments (for AVHRR, the segment is a 34*39 AVHRR pixels box centred on HIRS spot; for GOES : the segment size is up to the user (we used 4*4)). The tests are then applied on-line to full resolution satellite imagery using the thresholds that have been computed off-line at the segment resolution and features computed when having the satellite data.

The justification for pre-computing thresholds on segment is of course time constraints, but also registration errors (mainly for AVHRR) and difficulty to compute thresholds at full resolution imagery (climatological maps, NWP model outputs used to compute thresholds are not available at such a fine mesh).

3.2 DETAILS ON THE CLOUD MASK (CMa)

3.2.1 Cloud detection tests :

During the cloud detection process, every pixel of a segment go through the same tests sequence governed by illumination (day, night, dawn or sunglint for the sunlit portion of the image) and its geographical location (sea, land, coast) [A distinction between sea and land pixels within a coastal segment is done for GOES]. Each test consists in detecting cloudy pixels by thresholding single channels ($T11_{\mu m}$ brightness temperature, $R0.6_{\mu m}$ or $R0.9_{\mu m}$ visible reflectance), simple combinations of channels (Sea Surface Temperature (derived from satellite imagery), $T11_{\mu m}$-$T12_{\mu m}$, $T11_{\mu m}$-$T3.9_{\mu m}$ and $T3.9_{\mu m}$-$T12_{\mu m}$ (nighttime only), $T3.9_{\mu m}$-$T11_{\mu m}$ (daytime only) brightness temperatures differences), combined spatial local variances (of $T11_{\mu m}$ brightness temperatures, of $R0.6_{\mu m}$ visible reflectances and even of $T11_{\mu m}$-$T3.9_{\mu m}$ brightness temperatures differences) previously computed on a 3 by 3 window for each pixel of the entire region to process. A snow detection test, based on the analysis of the $R1.6_{\mu m}$ reflectance (AVHRR only) or the contribution of the solar reflected part in the 3.9 μm measurement, is also applied at daytime to sunlit enough pixels.

For AVHRR prototype, the process stops when one test triggers. For GOES prototype, a pixel is considered as cloudy if one test is satisfied, but the process stops only when one test is really successful (i.e., the thresholded value is “far” from the threshold). This leads to assign a quality flag: a cloudy pixel is said poorly classified if no test is really successful.

3.2.2 Thresholds’ computation :

To be efficient, most of the thresholds are based on simulations of the cloud free surface radiative characteristics:

- The use of atlas maps (Land/Sea/Coast atlas, elevation atlas) and climatological atlas (monthly minimum sea surface temperature, monthly mean visible reflectances corrected from atmospheric effects) allows to compute refined thresholds in various surface types. All these maps available at about 10km resolution except the land/sea atlas (full imagery resolution) are remapped to the geostationary projection.
- NWP outputs (total integrated water vapour content and land ground temperatures) allow for the adaptation to different atmospheric conditions.
- Finally, radiative transfer algorithms are used to account for satellite geometry and spectral characteristics :
    - for solar channel processing, the radiative transfer model 6S (Ref.[7]) has been applied to pre-compute tables (with angles, water vapour content as input) that are used together with the bi-directional models developed by Roujean (Ref.[6]) for land and Cox&Munck (Ref.[1]) for sea ;

- for IR channels thresholding, the radiative transfer model RTTOVS (Ref.[3]) has been applied to the TIGR radiosondes dataset (using Masuda tables (Ref.[5]) for sea emissivities) to pre-compute tables (with angles, water vapour content as input).

For example, the strong bi-directional effects that affect AVHRR visible channel (figure 1, top) can be correctly simulated using 6S and Roujean's bi-directional model, especially in the back-scatter direction (figure 1, bottom).

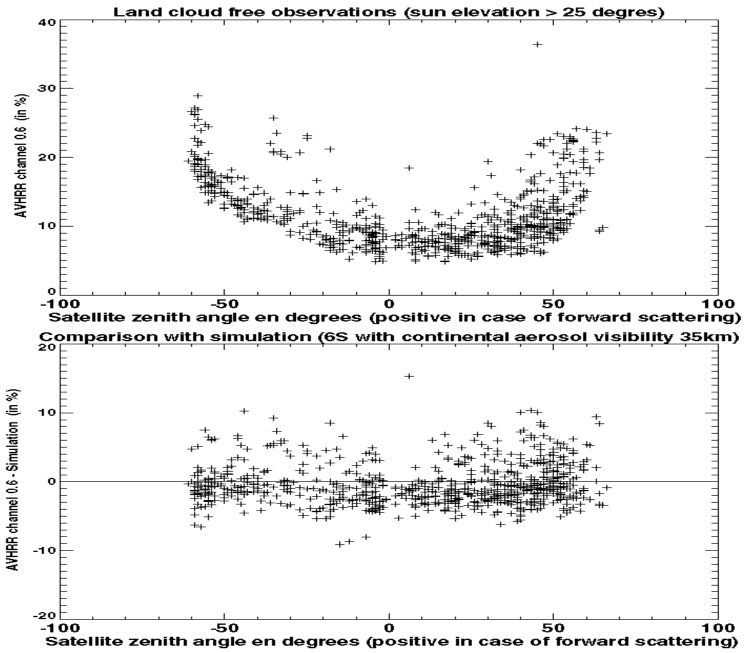

Figure 1. Comparison between AVHRR visible observations and simulations. [using the continental cloud-free targets of the AVHRR « interactive test file » (defined in 3.2.3)]

3.2.3 Cloud Mask (CMa) accuracy :

The quality of the Cloud Mask (CMa) product has been estimated using the GOES « interactive test file". [These files, elaborated from GOES and AVHRR imagery, contain the radiative characteristics of small targets (5x5 IR pixels for GOES) manually labelled when selected from numerous images, collocated with their NWP forecast surface and atmospheric parameters, and their atlas and climatological informations. These targets have been labelled by three skilled forecasters and ourselves (for GOES : only 1.5% of the targets labelled by ourselves) as cloud free or contaminated by all sorts of clouds as shown on table 2. 20400 targets have been extracted from GOES-8 imagery (only 15549 have been used in this study, because the collocated NWP information had not been archived for the others) and 4300 from AVHRR].

	sea	land	snow & ice	St/Sc	Ac/As	Cu	Cb	Ci over clouds	Ci	Cs over Ac,As	aerosol
AVHRR	17.6 %	15.7 %	9.3 %	22 %	3.6 %	3.8 %	2.3 %	4.5 %	6.1 %	4.0 %	10.5 %
GOES	11.2 %	9.5 %	5.9 %	17.1 %	5.5 %	8.2 %	12.8 %	8.1 %	15.8 %	4.8 %	1.1 %

Table 2. Statistics on cloud and earth types available in the interactive test files.

Statistics on CMa product are displayed in table 3 [Global score is the overall accuracy of CMa. Cloud failure score reflects the failure among cloudy labelled targets (CMa underestimation of clouds), Clear failure reflects the failures among clear labelled targets (CMa overestimation of clouds). The producer's accuracy represents the probability of a cloud-free surface to be correctly classified by CMa, whereas the user's accuracy corresponds the probability of a pixel classified as cloud free by CMa to be really cloud free]. In the table 3, a target (5*5 IR pixels) is classified as cloudy if more than 50% of its pixels are masked by CMa, and classified as cloud-free is less than 20% of the pixels are considered as cloud free by CMa. The results are globally better over ocean than over land, with a trend to more often overestimate clouds over land. Surprisingly results are better in night than in day conditions, the tendency to cloud overestimation being slightly stronger at daytime over land while for oceanic areas more frequent cloud omissions are noted at daytime.

	Contingency table		Global Score	Cloud Failure Score	Clear Failure Score	Producer accuracy	User accuracy
Night	423	11					
over Sea	11	2416	99.2%	0.5%	2.5%	97.5%	97.5%
Day	1267	28					
over Sea	109	4202	97.6%	2.5%	2.2%	97.8%	92.0%
Twilight	93	2					
over Sea	1	609	99.6%	0.2%	2.1%	97.9%	98.9%
Sunglint	136	6					
over Sea	9	313	96.8%	2.8%	4.2%	95.8%	93.8%
Night	401	11					
over Land	32	1063	97.1%	2.9%	2.7%	97.3%	92.6%
Day	1002	91					
over Land	104	2553	94.8%	3.9%	8.3%	91.7%	90.6%
Twilight	87	20					
over Land	1	209	93.4%	0.5%	18.7%	81.3%	98.8%

Table 3. Statistical characteristics of CMa based on GOES interactive test file.
Coastal areas are excluded from these statistics.

3.3 DETAILS ON THE CLOUD TYPES (CT)

3.3.1 Cloud classification tests :

A sequence of thresholding tests (depending on the illumination conditions) is applied to every cloudy pixel for their classification, according to the Cloud Type categories listed in table 1. At present time, neither the distinction between stratiform and cumuliform clouds nor the detection of aerosols have been performed yet.

First, main cloud types are separable within two sets ; the semitransparent and fractional clouds, from the low/medium/high clouds. These two systems are distinguished using spectral features : $T11_{\mu m}$-$T12_{\mu m}$, $T39_{\mu m}$-$T11_{\mu m}$, and $T11_{\mu m}$ in night-time conditions, and $R0.6_{\mu m}$, $T11_{\mu m}$-$T12_{\mu m}$ in day-time conditions. Then within these two sets fractional and semitransparent are separated using textural features (local variance $T11_{\mu m}$ coupled to local variance $R0.6_{\mu m}$ only in day-time conditions) and spectral features ($T11_{\mu m}$-$T12_{\mu m}$, $T39_{\mu m}$-$T11_{\mu m}$ only in night-time condition). The remaining clouds are distinguished through the comparison of their $T11_{\mu m}$ to NWP forecast temperatures at several pressure levels.

3.3.2 Thresholds' computation :

The set of thresholds to be applied depends mainly on the illumination conditions, whereas the values of the thresholds themselves may also depend on the viewing geometry, the geographical location and NWP data describing the water vapour content and a coarse vertical structure of the atmosphere. Most of the thresholds are empirical and have been deduced from the statistical study of a training data set. For example, combinations of forecast air temperatures at various levels (850, 700, 500 hPa and tropopause) are used to separate low, medium and high level clouds, and to define three cirrus classes according to their thickness. The test applied to the $R0.6_{\mu m}$ reflectance to separate semitransparent from opaque clouds accounts for bi-directional effects over clouds (especially strong on AVHRR and simulated with Manalo-Smith's model (Ref.[5])) as well as for the surface reflectance beneath the cloud. The $T11_{\mu m}$ -$T12_{\mu m}$ and $T3.9_{\mu m}$ -$T11_{\mu m}$ thresholds used to distinguish semi-transparent clouds relies on look-up tables governed by satellite angle and water vapour content.

3.3.3 Cloud Types (CT) accuracy :

The quality of the Cloud Type (CT) product has been estimated from the GOES « interactive Test File », by computing error matrixes using all CT classes (see table 5), and also after having gathered the CT classes in major cloud classes (see table 4). [In those error matrixes (also called contingency table), the rows represent the cloud or surface categories manually labelled (considered as reference), while the columns corresponds to the CT categories. The producer's accuracy represents the probability of a cloud or surface category to be correctly classified by the CT algorithm, whereas the user's accuracy corresponds the probability of a pixel classified into a CT category to really belong to that category]. In tables 4 and 5, a target (5*5 IR pixels) is classified with the most frequent category given by CT algorithm. This rule is different from what was used for the estimation of the CMa's accuracy (see paragraph 3.2.3).

CT Label	Sea	Land	Snow/Ice	Low	Mid	Semi	High	Fract	Total	Producer accuracy
Sea	**1756**	8	7	41	0	9	0	8	1829	96.0%
Land	13	**1346**	1	20	2	3	0	19	1404	95.9%
Snow/Ice	0	55	**280**	105	8	8	4	0	460	60.9%
Low	48	169	11	**2555**	252	82	4	305	3426	74.6%
Mid	1	13	0	236	**851**	114	118	23	1356	62.8%
Semi	7	53	13	57	215	**2466**	572	75	3458	71.3%
High	0	0	0	4	75	234	**2788**	0	3101	89.9%
Total	1825	1644	312	3018	1403	2916	3486	430	**15034**	
User accuracy	96.2%	81.9%	89.7%	84.7%	60.7%	84.6%	80.0%			

Table4. Statistical characteristics of CT based on GOES interactive test for all climatic and viewing conditions, using the major cloud classes [Computed when low clouds, when semitransparent clouds and when high clouds have been collapsed, and when sand, ash and unknown cases are removed from the interactive data set]. Coastal areas are excluded from these statistics.

While the quality of the cloud detection step was assessed with statistics presented in table 3, results presented in tables 4 & 5 allow to analyse the confusion between different clouds categories, identify which clouds are difficult to detect, and also have a synthetic view of the illumination effect on the CT product. Main comments about the results are :

- The overall CT accuracy is about 80% for major cloud categories (table 4), the best being observed at nighttime. The comparison with the overall accuracy of CMa shows that introducing snow and ice classes and detailing the cloudy targets into major classes leads to decrease the overall accuracy from about 97% to about 80%.

- When detailing the major cloud classes into all the CT categories (see table 5), the overall accuracy decreases to about 60%: it carries the difficulty to separate several classes of low clouds and of semitransparent clouds, belonging to same families. A misclassification inside a given family having the same weight as an error between two classes really different. This difficulty which is also present in the observer's classification contributes to make the reference dependent on the observer's skill.

- Table 4 illustrates clearly a difficulty to identify snow or ice (difficult at daytime and impossible at night-time) and mid level clouds. From the user point of view, the less reliable class among the major cloud classes is the mid level clouds, with a user accuracy of 60%. It can be understood by the weak spectral separability of the medium clouds.

- When fractional cloud is identified, it is probably a very low (45.3%), low (17.8%) or thin semitransparent cloud (15%).
- For a given CT category, the users' accuracies are rather similar in daytime, night-time and twilight conditions (except for snow and fractional clouds), thus indicating a certain independency of the CT classifier to the illumination conditions.

CT Label	Sea	Land	Ice	Snow	Very Low	Low	Mid	Semi Above	Semi Thin	Semi Thick	High Nocu	High Cum	Sand	Ash	Fract	No Proc	Total
Sea	**1756**	8	6	1	39	2	0	2	5	2	0	0	0	0	8	0	1829
Land	13	**1346**	0	1	13	7	2	1	1	1	0	0	0	0	19	0	1404
Ice	0	2	**124**	23	31	18	1	1	1	2	3	0	0	0	0	0	206
Snow	0	53	0	**133**	32	24	7	0	1	3	1	0	0	0	0	0	254
Very Low	24	114	1	7	**629**	351	50	9	37	6	0	0	0	0	228	0	1456
Low	27	64	2	1	490	**1054**	205	6	12	15	4	0	0	0	90	0	1970
Mid	1	13	0	0	116	120	**851**	28	14	72	117	1	0	0	23	0	1356
Semi Above	0	3	0	0	6	15	151	**182**	15	376	74	1	0	0	4	0	827
Semi Thin	7	54	7	10	30	15	81	202	**242**	839	28	0	0	0	74	0	1589
Semi Thick	0	0	0	0	0	0	10	11	1	**537**	416	67	0	0	0	0	1042
High Nocu	0	0	0	0	0	1	54	10	0	196	**703**	331	0	0	0	0	1295
High Cu	0	0	0	0	3	0	22	0	0	45	331	**1405**	0	0	0	0	1806
Sand	0	0	0	0	1	7	2	0	0	0	0	0	**0**	0	0	0	10
Ash	9	21	0	0	111	1	0	0	0	0	0	0	0	**0**	52	0	194
Unknon.	0	0	0	0	1	1	3	0	0	0	7	1	0	0	**3**	0	16
No Proc	1	4	0	0	0	1	0	0	1	0	0	0	0	0	0	0	7
Total	1838	1682	140	176	1502	1617	1439	452	330	2094	1684	1806	0	0	501	0	**15261**

Table 5. Statistical characteristics of CT based on GOES interactive test file for all climatic and viewing conditions, using CT categories, but mean and thick cirrus gathered.[Coastal areas are excluded from these statistics]

4. EXAMPLES OF AVHRR CLOUD TYPES MAPS

AVHRR Cloud Types maps (upgraded in the SAF NWC context) are routinely computed over the entire AVHRR passes (from north Africa up to Scandinavian countries) that are received at CMS. An area covering France (see figure 2) is then extracted, remapped onto a polar stereographic grid (at 3km spatial resolution) and sent to all the french forecasters to be displayed either on Meteotel or SYNERGIE workstation.

Cloud Type products are routinely extracted from locally-received GOES-8 imagery at full IR spatial resolution for every slot (i.e., 30 minutes) over the extended Northern Hemisphere (see figure 3). They are made available to selected french forecasters on SYNERGIE workstation. During a few months, they will also be available in GIF format (spatially sampled every 3*3 IR pixels) on the Météo-France ftp public server (ftp://www.meteo.fr) on a dedicated directory /pub/SAFNWC/DEMO/CT (the corresponding 11µm IR images and cloud top pressure available respectively on /pub/SAFNWC/DEMO/CTP & /pub/SAFNWC/DEMO/IR).

5. NEXT DEVELOPMENTS

The CMa and CT products that have been outlined in this paper, will be also evaluated using a two-years data set of coincident satellite data and surface observations of cloud cover reported by meteorologists from weather ground stations, and on-board ships. Additional developments are planned before the end of this year : aerosol detection (using the “interactive test file”); cloud phase determination (during a visiting scientist stay). Unhappily, due to time constraints the separation between stratiform and cumuliform clouds will not be studied during the prototyping phase.

Examples of CT products prototyped from GOES-8 imagery will be routinely available on Météo-France ftp public server (ftp://www.meteo.fr), during a few months (contribution of Météo-France to the SAF NWC demonstration phase) ; a detailed scientific documentation of the prototyped algorithm will be available for the next SAF NWC review (planned in March 2000).

The final algorithm tuned to MSG SEVIRI spectral characteristics will be designed and coded during development phase 2 in 2000, taking advantage of experience gained during the prototyping phase. Its validation will begin when SEVIRI data will be available.

6. REFERENCES

[1] Cox.C and Munck W, 1954, Measurements of the roughness of the sea surface from the sun’s glitter. *J.Opt.Soc.Am*, 44, 838-850.

[2] Derrien M, Farki B., Harang L., Le Gléau H., Noyalet A., Pochic D., A.Sairouni, 1993, Automatic cloud detection applied to NOAA-11 / AVHRR imagery, *Remote Sensing of Environment*, 46, pp 246-267.

[3] Eyre J., 1991, A fast radiative transfer model for satellite soundings systems. ECMWF Res.Dep.Tech.Mem 176. ECMWF, Reading, United Kingdom.

[4] Manalo-Smith N., Smith G.L., 1996, Analytic forms of bi-directional reflectance functions for earth radiation budget studies. International Geoscience and Remote Sensing Symposium, Lincoln (USA) 27-31 may 1996.

[5] Masuda K., Takashima T., Takayama Y., 1988, Emissivity of Pure and Sea Waters for the model sea surface in the infrared window regions. *Remote Sensing of Environment* 24 : 313-329.

[6] Roujean J.L., LeRoy M.J., Deschamps P.Y., 1992, A bi-directional reflectance model of the Earth’s surface for the correction of remote sensing data. *J.Geophys.res.*, 97, 20455-20468.

[7] Tanre D, Deroo C., Duhaut P., Herman M., Morcrette J.J., Perbos J., Deschamps P.Y., 1990, Description of a computer code to simulate the satellite signal in the solar spectrum. *International Journal of Remote Sensing*, 11, pp 659-668.

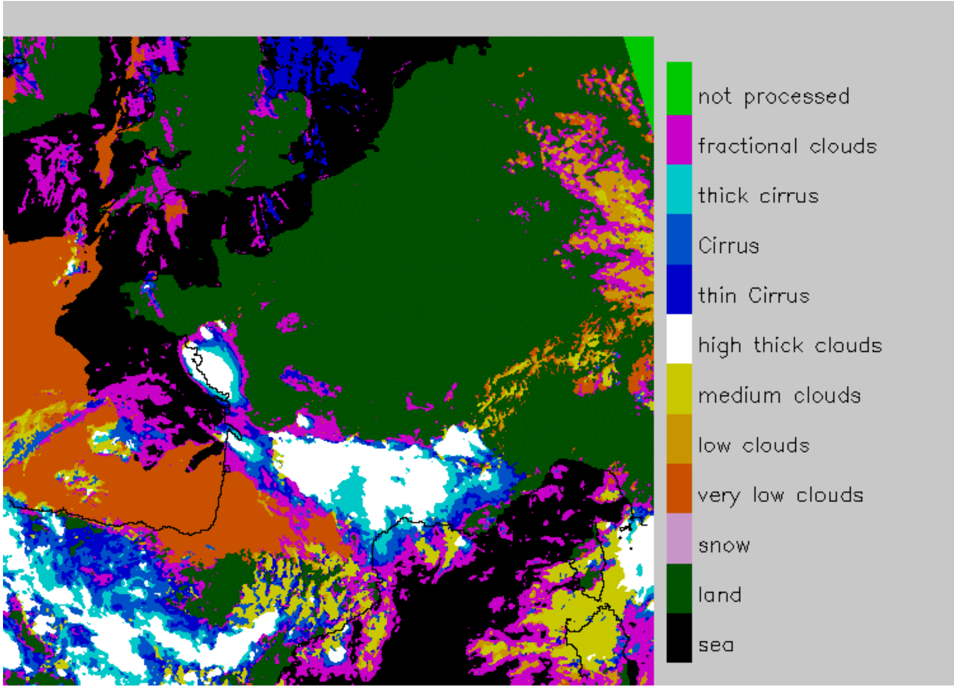

Figure 2. AVHRR Cloud Type map. NOAA-12 15th May 1998. 17h23 UTC

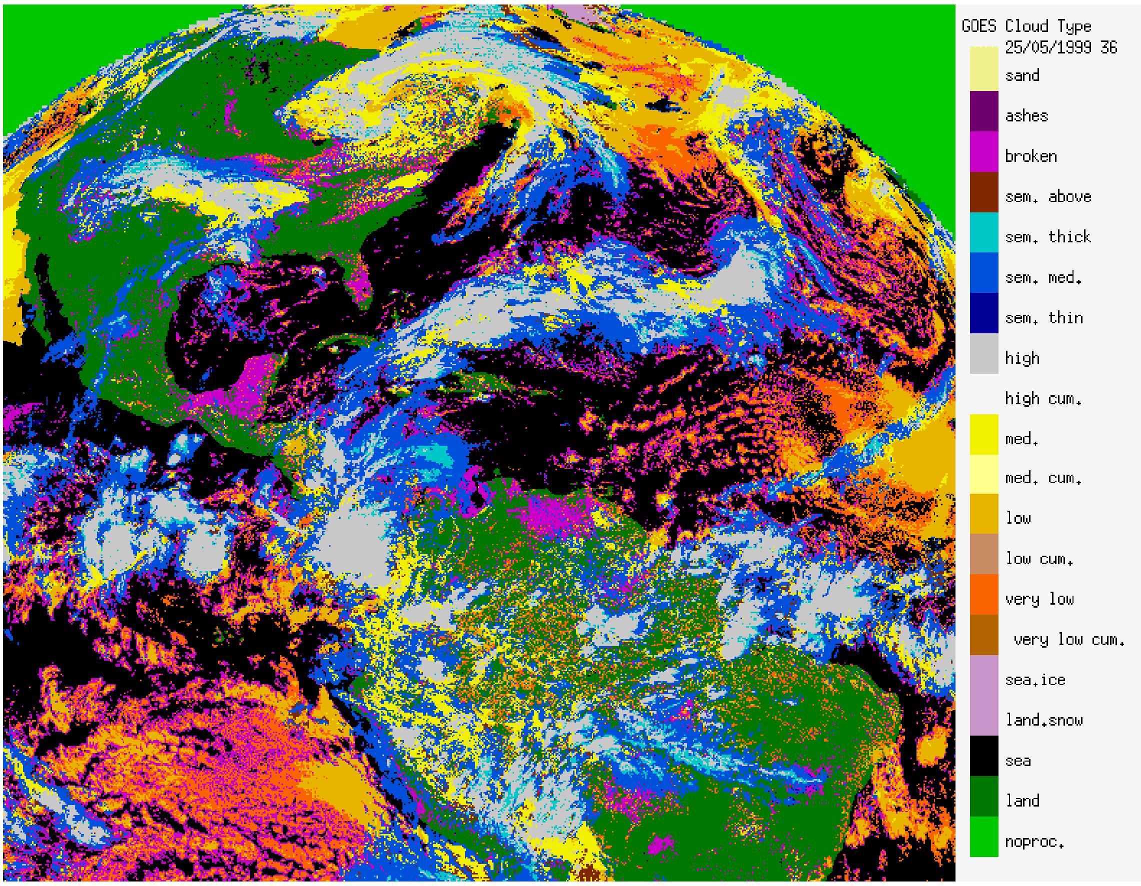

Figure 3. Example of Cloud Type product prototyped with GOES-8
25 May 1999. Slot 36 (18UTC)