

SAFNWC/MSG SEVIRI CLOUD PRODUCTS

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ABSTRACT

Within the SAF in support to Nowcasting and Very Short Range Forecasting (SAF NWC), Météo-France has developed a software to extract cloud parameters (cloud mask and types, cloud top temperature and height) from MSG SEVIRI imagery. These modules are part of the SAFNWC/MSG software package, whose version v1.0 (scientifically checked with real SEVIRI images) will be available in 2004.

This paper outlines the cloud mask and type algorithms (prototyped using GOES-East, AVHRR and MODIS imagery), summarizes the results of the extensive validation performed using GOES and ground-based observations (SYNOP), and finally presents the first results obtained from SEVIRI images.

1. INTRODUCTION

Within the SAF in support to Nowcasting and Very Short Range Forecasting (SAF NWC), Météo-France has developed a software to extract cloud parameters (cloud mask and types, cloud top temperature and height) from MSG SEVIRI imagery. These modules are part of the SAFNWC/MSG software package whose version v1.0 (scientifically checked with real SEVIRI images) will be distributed in 2004.

During the development phase 1 (1997-1999), prototypes to extract these cloud parameters from locally-received AVHRR imagery (to simulate European conditions), GOES-East imagery (to simulate geostationary conditions) and HIRS sounder (to simulate sounding channels) have been developed and validated. The experience gained during this prototyping phase has allowed to design the final software. Since Autumn 2000, this software has been routinely applied to GOES-East imagery (acting as SEVIRI images with missing channels); retrieved cloud type and top pressure may be still displayed from www.meteorologie.eu.org/safnwc. Taking benefits of the MSG launch delay, the software has been intensively checked during the period 2001-2003 with MODIS imagery (some examples are available on www.meteorologie.eu.org/safnwc) leading to algorithm's improvements implemented in the version v0.1 of the SAFNWC/MSG software package. Finally, SEVIRI images are presently being used to scientifically check and tune the algorithms that will be available in SAFNWC/MSG software package version v1.0.

This paper focuses on the algorithms to extract the cloud mask and type. We outline the latest version of the algorithms, detail the product's content and recall the validation results obtained during the prototyping phase using ground-based observations (SYNOP). We present examples from SEVIRI images (more examples can be found on www.meteorologie.eu.org/safnwc). A detailed description of the algorithms can be obtained from www.meteorologie.eu.org/safnwc or from the SAFNWC helpdesk (nwcsaf.inm.es).

2. CLOUD MASK (CMA) ALGORITHM

The cloud mask (CMA) algorithm is based on a multispectral threshold technique applied to each pixel of the image. A first series of tests allows the identification of pixels contaminated by clouds or snow/ice; this process is stopped if one test is really successful (i.e., if the threshold is not too close to the measured value). The characteristics of this set of tests are summed up below:

- The tests, applied to land or sea pixels, depend on the solar illumination and on the viewing angles (daytime, night-time, twilight, sunglint) and are listed in tables 1 and 2.
- Most thresholds are determined from satellite-dependent look-up tables (available in coefficients' files) using as input the viewing geometry (sun and satellite viewing angles), NWP forecast fields (surface temperature and total atmospheric water vapour content) and ancillary data (elevation and climatological data). These look-up tables have been prepared off-line using radiative transfer models (RTTOV-6 (Eyre, 1991) for infrared channels except for 3.8 μ m channel (MODTRAN 3.5 is used for this channel, because RTTOV-6 gave bad simulations for this band), 6S (Tanre et al., 1990) for the solar channels). An example of such dynamic threshold is given in figure 1. Some thresholds are empirical, constant or satellite-dependent values (available in coefficients' files).
- The quality of the cloud detection process is assessed by analysing how close the measurements and the thresholds are from each other.
- A spatial filtering is applied. It may reclassify pixels having a class type different from their neighbours.
- A simple test is applied to cloud contaminated pixels to check whether the cloud cover is opaque and completely fills the FOV.

This first series of tests determines the cloud cover category of each pixel (cloud-free, cloud contaminated, cloud filled, snow/ice contaminated or undefined/non processed) and computes a quality flag on the processing itself. Moreover, the tests that have caused the cloud detection (more than one test are possible, if some tests were not really successful) are stored.

A second process aimed to the identification of dust clouds at daytime is applied to all pixels (even already classified as cloud-free or contaminated by clouds): visible reflectances, 10.8 μ m brightness temperatures and their textures, and 10.8 μ m-12.0 μ m brightness differences are thresholded, the 3.8 μ m brightness temperatures being used only over continental areas. The result is stored in a separate dust cloud flag.

A third process aimed to the identification of volcanic ash clouds is applied to all pixels: it relies on the low 10.8 μ m-12.0 μ m brightness differences of most volcanic ash clouds, the 3.8 μ m-10.8 μ m brightness differences and the 0.6 μ m/1.6 μ m reflectances (over land only) being used to minimize the false alerts. The result is stored in a separate volcanic ash cloud flag.

Daytime	Twilight	Nighttime
Snow detection	T10.8 μ m	T10.8 μ m
T10.8 μ m	R0.6 μ m	T10.8 μ m-T12.0 μ m
R0.6 μ m	T10.8 μ m-T12.0 μ m	T8.7 μ m-T10.8 μ m
T10.8 μ m-T12.0 μ m	T8.7 μ m-T10.8 μ m	T10.8 μ m-T3.8 μ m
T8.7 μ m-T10.8 μ m	T10.8 μ m-T3.8 μ m	T3.8 μ m-T10.8 μ m
T10.8 μ m-T3.8 μ m	T3.8 μ m-T10.8 μ m	Local Spatial Texture
T3.8 μ m-T10.8 μ m	Local Spatial Texture	
Local Spatial Texture		

Table 1. Cloud mask test sequence over land

Daytime	Sunlight	Twilight	Nighttime
Ice detection	Ice detection	SST	SST
SST	SST	R0.8 μ m (R0.6 μ m)	T10.8 μ m-T12.0 μ m
R0.8 μ m (R0.6 μ m)	T10.8 μ m-T12.0 μ m	R1.6 μ m	T8.7 μ m-T10.8 μ m
R1.6 μ m	T8.7 μ m-T10.8 μ m	T10.8 μ m-T12.0 μ m	T10.8 μ m-T3.8 μ m
T10.8 μ m-T12.0 μ m	Local Spatial texture	T8.7 μ m-T10.8 μ m	T3.8 μ m-T10.8 μ m
T8.7 μ m-T10.8 μ m	R0.8 μ m (R0.6 μ m)	T10.8 μ m-T3.8 μ m	Local Spatial Texture
T10.8 μ m-T3.8 μ m	T10.8 μ m-T3.8 μ m	T3.8 μ m-T10.8 μ m	
T3.8 μ m-T10.8 μ m	Low Clouds in Sunlight	Local Spatial Texture	
Local Spatial Texture			

Table 2. Cloud mask test sequence over sea

[T3.8 μ m, T8.7 μ m, T10.8 μ m and T12.0 μ m stand for brightness temperatures at 3.8, 8.7, 10.8 and 12.0 micrometer ; R0.6 μ m, R0.8 μ m and R1.6 μ m stand for VIS/NIR bi-directional top of atmosphere reflectances at 0.6, 0.8 and 1.6 micrometer normalised for solar illumination ; SST is the split-window (used for SST calculation) computed from T10.8 μ m and T12.0 μ m measurements. Low Clouds in Sunlight is a specific module for low clouds identification in sunlight areas.]

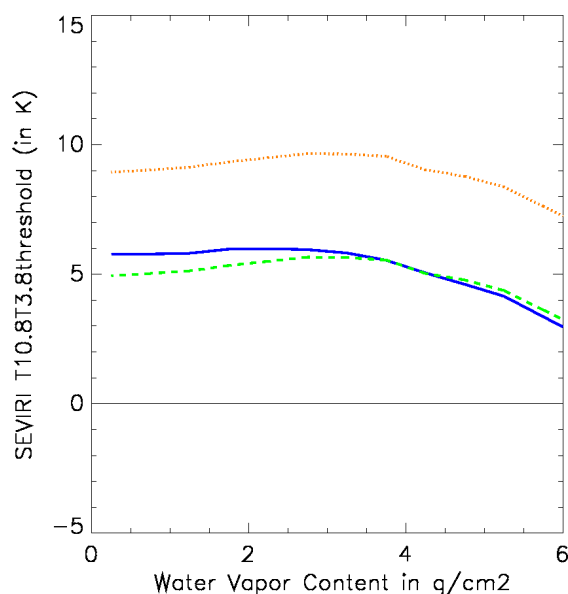


Figure 1. Illustration of SEVIRI T10.8 μ m-T3.8 μ m threshold for a satellite zenith angle of 48 degrees. Over ocean (solid blue line), vegetated areas (dashed green line) and desert (brown dotted line).

This algorithm has been prototyped using GOES-East and AVHRR imagery (for the use of the 1.6 μ m), and further checked and improved with MODIS imagery. A comprehensive validation has been performed by comparing the cloud mask retrieved from GOES-East imagery over continental areas to visual cloud observations done in meteorological synoptic stations (available in SYNOP messages). Validation results for mid-latitude regions for the period July 1997-July 1999 are summed up in figure 2.

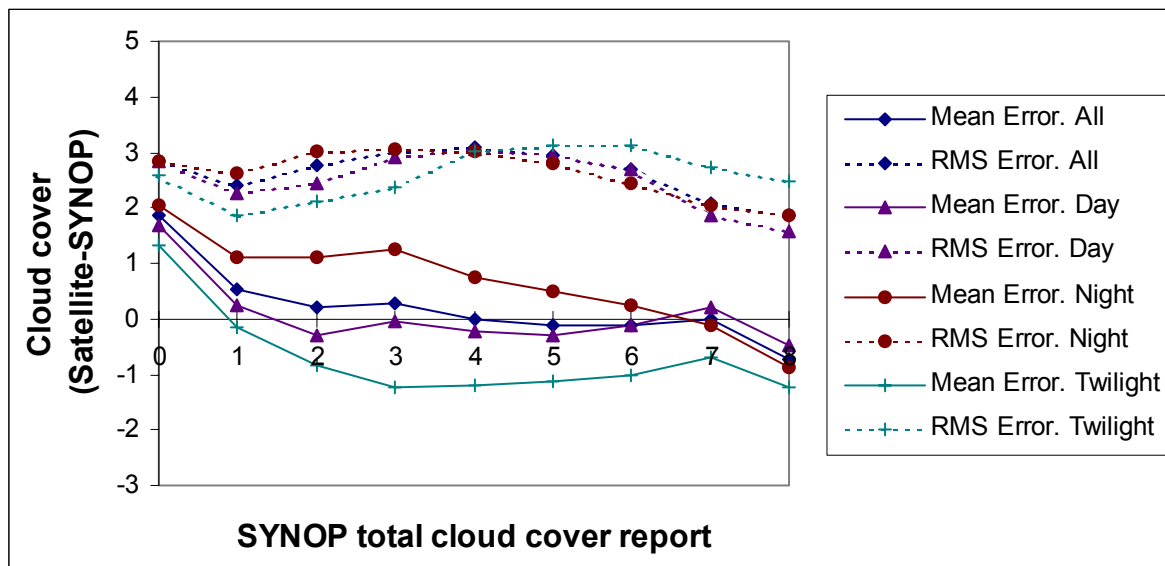


Figure 2. Comparison of cloud cover (in octa) automatically derived from satellite measurement (GOES-East imagery) and visually observed in meteorological station (SYNOP measurements) for continental mid-latitude regions.

3. CLOUD TYPE (CT) ALGORITHM

The cloud type (CT) output consists in twenty-one classes (listed in table 3), a separate cloud phase flag (indicating whether the cloud top is made up with ice or water) and a quality flag.

Non processed	Very low clouds	(cumuliform & stratiform)
Land	Low clouds	(cumuliform & stratiform)
Sea	Medium clouds	(cumuliform & stratiform)
Snow	High clouds	(cumuliform & stratiform)
Sea Ice	Very high clouds	(cumuliform & stratiform)
Unclassified	Semi-transparent ice clouds (3 classes according to thickness + cirrus above clouds)	
Fractional clouds		

Table 3. Cloud type classes

The cloud type (CT) algorithm is a threshold algorithm applied at the pixel scale, based on the use of the Cloud Mask (CMa) and spectral & textural features computed from the multispectral satellite images and compared with a set of thresholds.

The CT classification algorithm is based on the following approach:

- Main cloud types are separable within two sets: the fractional and high semitransparent clouds, from the low/medium/high opaque clouds. These two systems are distinguished using spectral features : $T_{10.8\mu m} - T_{12.0\mu m}$, $T_{3.8\mu m} - T_{10.8\mu m}$ (in night-time conditions only), $R_{0.6\mu m}$ (in day-time conditions only), and textural features (variance $T_{10.8\mu m}$ coupled to variance $R_{0.6\mu m}$ in daytime conditions).
- Within the first set, the fractional and high semitransparent are separated mainly using their $T_{8.7\mu m} - T_{10.8\mu m}$ brightness temperature differences.
- The remaining categories are distinguished through the comparison of their $T_{10.8\mu m}$ to NWP forecast temperatures at several pressure levels (850, 700 and 500hPa, and at tropopause level)
- No separation between cumuliform and stratiform clouds is performed in the current version of CT.
- No cloud phase flag is available in the current version of CT.

The test sequence to be applied depends on the illumination conditions (an example is given on figure 4), whereas the values of the thresholds themselves may depend on the illumination, the viewing geometry, the

geographical location and NWP data describing the water vapour content and a coarse vertical structure of the atmosphere.

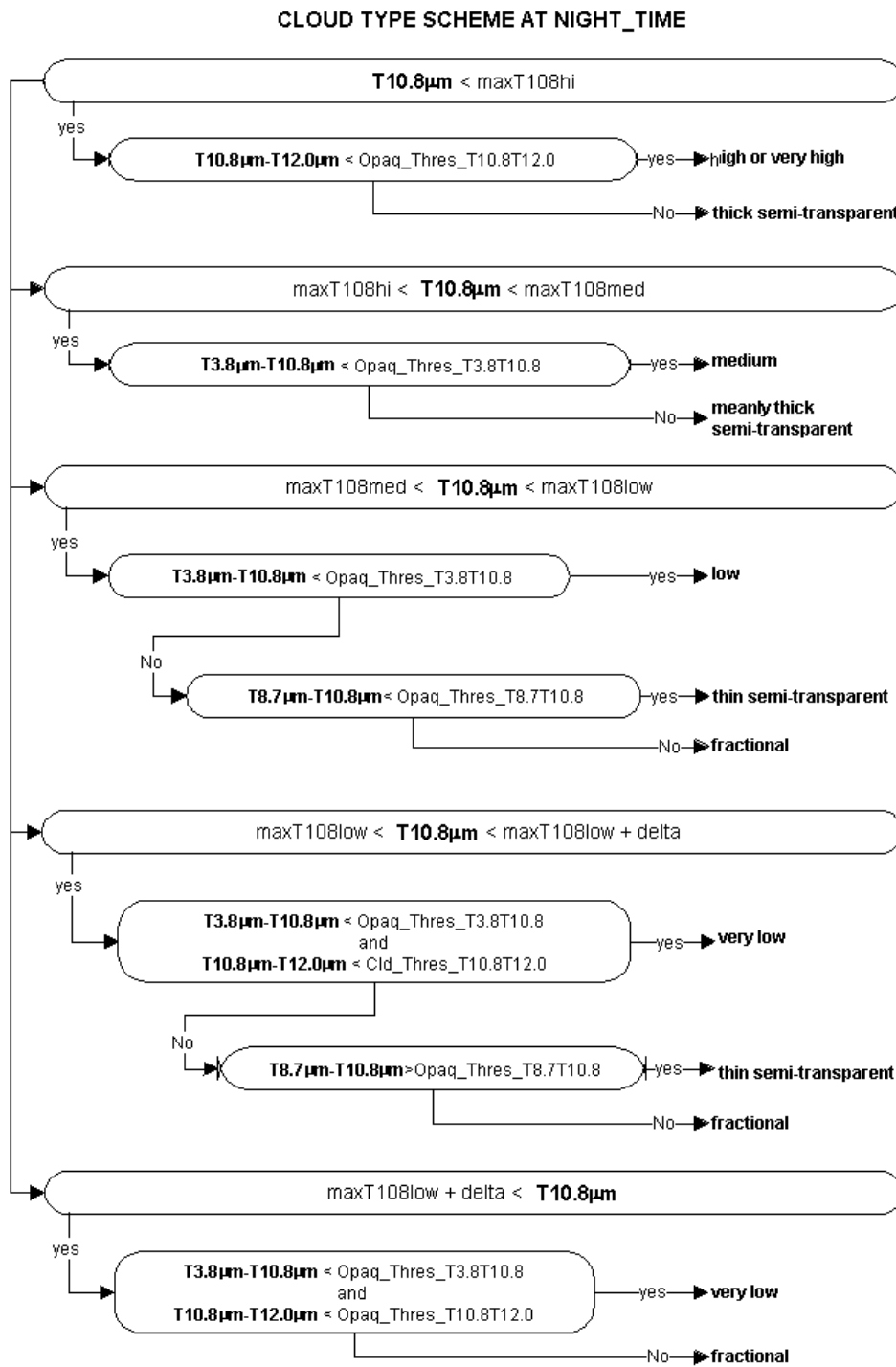


Figure 3. Test sequence used in the CT algorithm in night-time conditions.

A comprehensive validation has been performed by comparing the cloud type automatically retrieved from GOES-East imagery to cloud classification manually labelled from the satellite imagery using an interactive visualization tool (more than 20000 such interactive comparisons have been done, including 10000 in mid-latitude regions). Validation results for mid-latitude regions have been illustrated in figure 4 by plotting the CT user accuracy, defined as the probability of a pixel classified into a category to really belong to that category, for various illuminations.

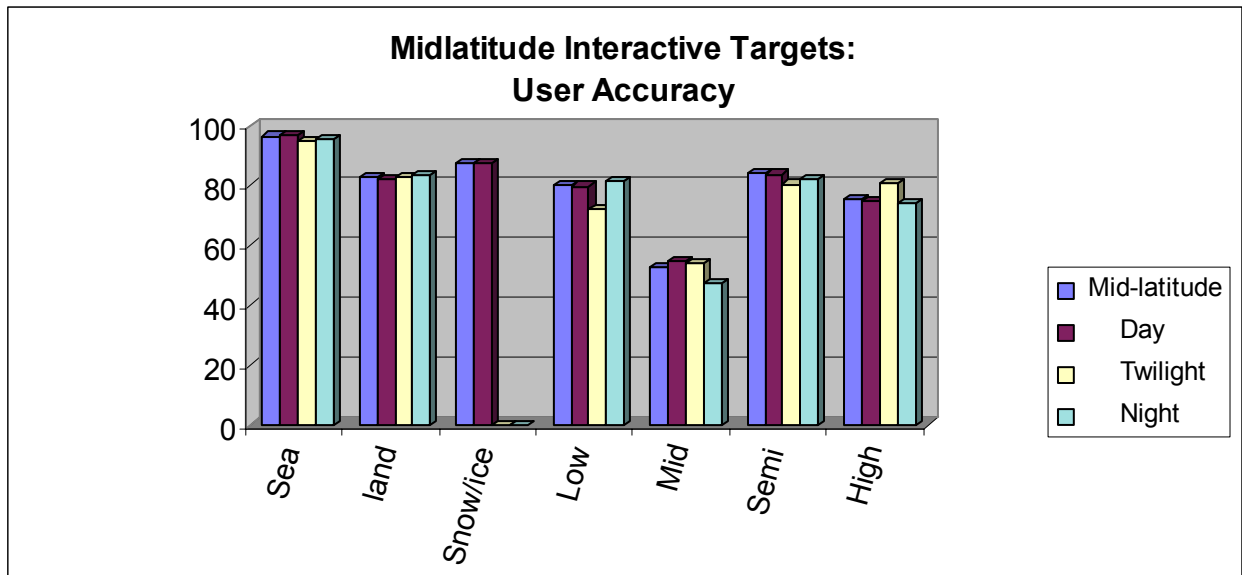


Figure 4. Variation of the Cloud Type's user accuracy with illumination for mid-latitude regions.

4. FIRST RESULTS WITH SEVIRI IMAGERY

The first SEVIRI images that were processed at CMS with the SAFNWC cloud modules were a daytime image (12 February 2003 at 13h30UTC) made available on CD-Rom by Eumetsat and a nighttime image locally received through the EUMETCast system (29 April 2003 at 22h45). Since June 2003, SEVIRI images are regularly received at CMS and processed using SAFNWC cloud modules.

A regular analysis of the Cloud Types obtained with the SAFNWC cloud modules has led to identify some needed improvements that will be included in v1.0. Most of them concern the cloud detection step: better snow detection in case low solar elevation, better tuning of the visible tests in case low solar elevation, better use of the $3.8\mu\text{m}$ channel in the low cloud detection (both daytime and nighttime), better tuning of infrared thresholds over desert. The night-time cloud classification of thin cirrus clouds has also been improved.

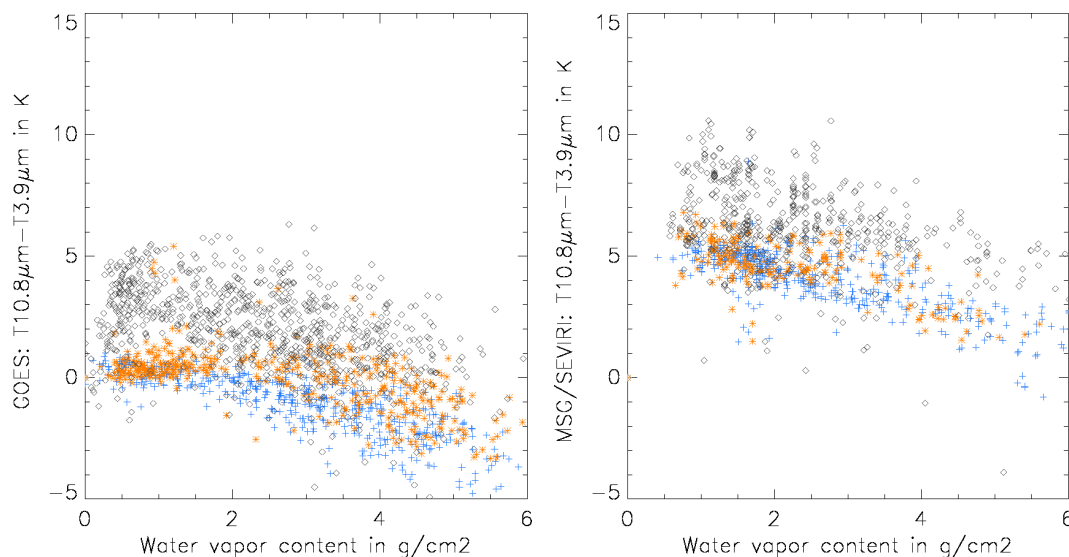


Figure 5. Variation of night-time $T_{10.8\mu\text{m}} - T_{3.8\mu\text{m}}$ brightness temperature difference with integrated atmospheric water vapour content for GOES-8 (left) and MSG1/SEVIRI (right). For cloud free continental surface (brown stars *), cloud free ocean (plus symbol +) and low clouds (diamonds).

A database is being interactively gathered (similarly to what was done for GOES-8, see paragraph 3) to ease the improvement of the algorithms. For example, the $T_{10.8\mu\text{m}}-T_{3.8\mu\text{m}}$ brightness temperature in nighttime conditions is illustrated on figure 5 with such interactive database. This spectral feature is essential for the nighttime low cloud detection. It can be seen on figure 5 that the observed $T_{10.8\mu\text{m}}-T_{3.8\mu\text{m}}$ values are quite different for GOES-8 and MSG1/SEVIRI, which can be explained by their different spectral filter. The use of an infrared radiative transfer model to compute the cloud detection thresholds (as explained in paragraph 2) allows the algorithm to easily adapt to each instrument's spectral characteristics.

Some cloud types examples obtained with the last available software version (a draft version of V1.0) are presented in figure 6 and 7. You can also find cloud types from the day before on the web page: www.meteorologie.eu.org/safnwc

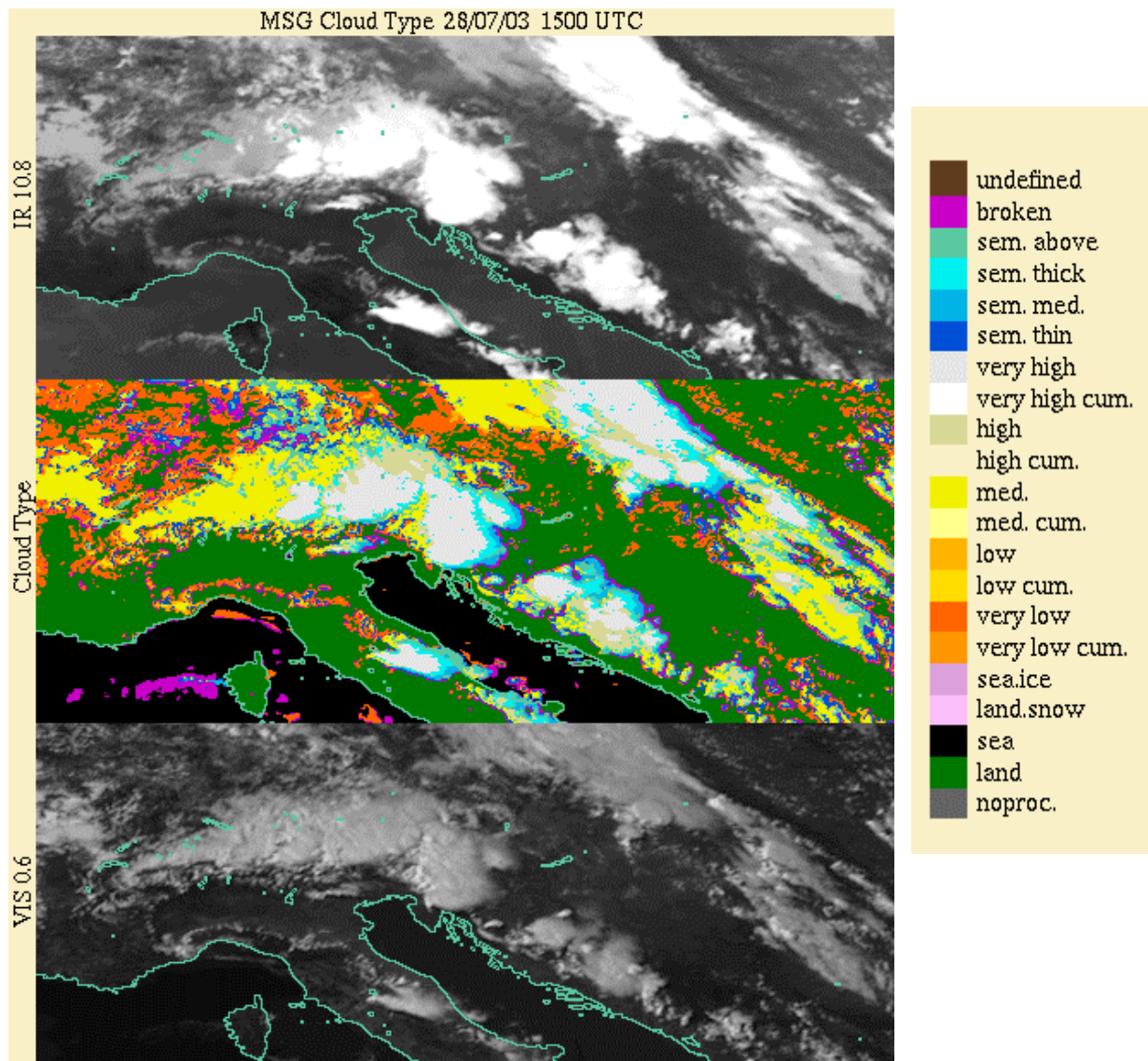


Figure 6. SEVIRI Cloud type, $0.6\mu\text{m}$ visible and $10.8\mu\text{m}$ infrared channels.

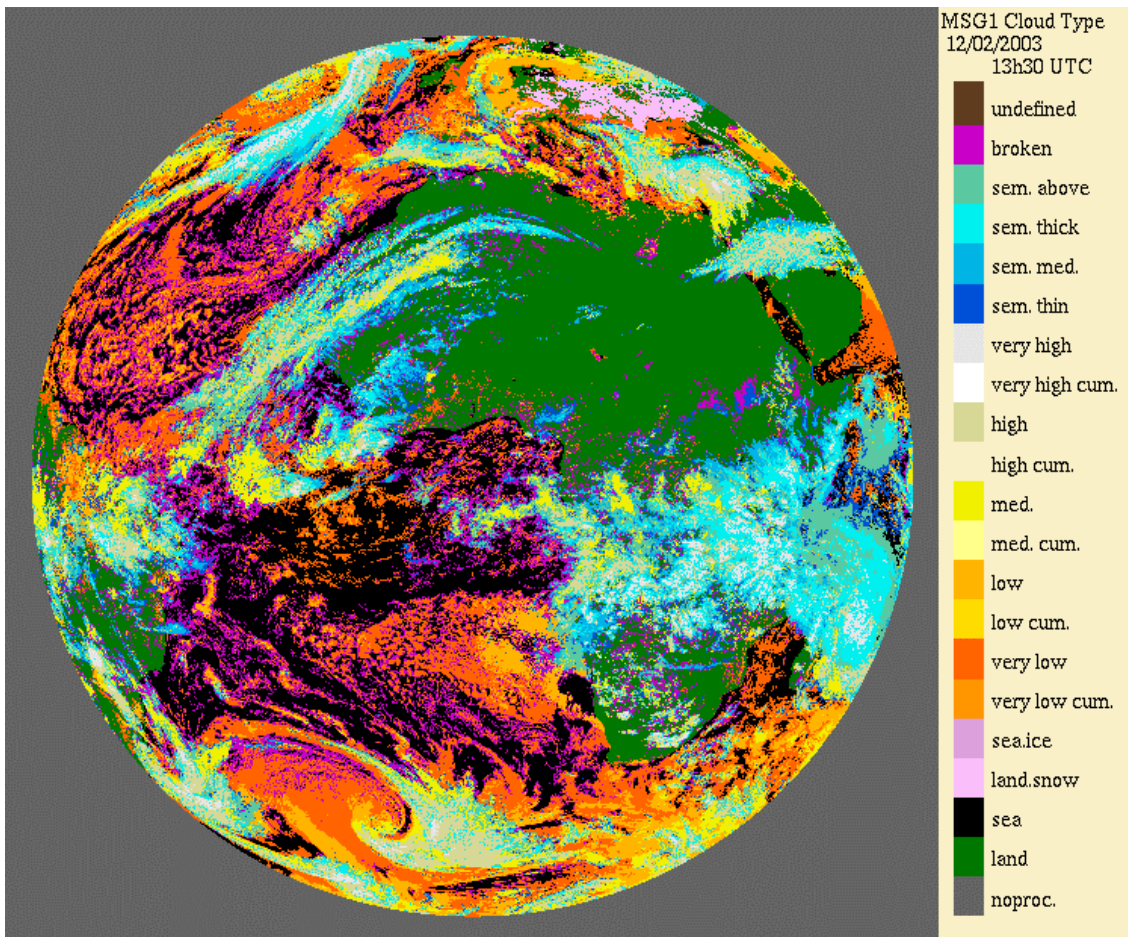


Figure 7. Cloud type extracted from the first MSG-1/SEVIRI image made available by Eumetsat: 12 February 2003 at 13h30 UTC.

5. ON-GOING AND PLANNED DEVELOPMENTS

The SEVIRI cloud software (partly presented in this paper) will be tuned using additional SEVIRI images before being delivered to INM (SAFNWC host institute) at the end of 2003 for integration in the SAFNWC package version 1.0. This software will be routinely applied at Météo-France to SEVIRI imagery over the whole MSG disk; retrieved cloud types and top pressures are available for visualisation on www.meteorologie.eu.org/safnwc.

The algorithms will then be intensively validated in 2004 against ground based visual observations following the same procedure applied during the validation of the prototypes with GOES imagery.

6. REFERENCES

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

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.