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A SYSTEMATIC APPROACH OF THE CLOUD COVER BY THERMIC INFRARED MEASUREMENTS

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1. INTRODUCTION

The description of the meteorological conditions from the ground is part of the synoptic observation message defined by the WMO code (WMO, 1996). This message concerns mainly the cloud observations that are useful for general and local forecasting, aeronautical operations, climatology, and radiation transfer physics (see e.g. Gillotay et al., 1997) Up to recently, the cloud cover, and the cloud's properties (type, altitude…) were, in most of the cases, parameters estimated by human observers, with as consequences measurements performed mainly during daytime and highly uncertain in terms of accuracy and repeatability. More recently some methods using digital photography and/or ceilometer's techniques begin to appear, but remain experimental and/or of marginal use.

In this paper, a new approach based on the use of IR pyrometers is described. The determination of the cloud cover in all conditions (day and night) is discussed and compared with measurements performed by other techniques. Altitude of the first cloud layer estimations and, in broken clouds conditions, of the second one will also be discussed. Some recent results show that the cloud typology could also be reached by this method; this aspect will be outlined but require further steps of development planned for the future.

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2. METHODOLOGY

As mentioned above, the method used to determine the cloud cover is based on temperature data provided by modified commercial IR (8-14 μm) pyrometers observing elementary solid angles of the sky and scanning the all sky dome during predefined automatic sequences.

2.1 Principe of the measurement

The downward thermal emission from the clouds and from the air column between clouds and the instrument is measured by infrared pyrometers.

Temperature of the clouds is derived from a combination of the Planck and the Stephan-Boltzmann 's laws, resulting in an equation of the general form:

$$F = \varepsilon f(T) \qquad (1)$$

Where F is the downward IR flux integrated for the band pass of the detector (Wm^{-2}), ε is the hemispheric emissivity and f(T) is a 4-order relationship between temperature and infrared emittance in the spectral range of the detector.

The estimation of the hemispheric emissivity value is of great importance and can affect significantly the quality of the temperature measurement. For practical reasons and in agreement with the values published in the literature (Davies, 2001), a mean value of ε = 0.90 has been selected for the whole-sky dome in presence or absence of cloud cover. Consequences of this choose is that the emissivity variations are not taken into account inducing some errors on the temperature determination. Temperature is in fact not the true temperature but an equivalent or apparent temperature. However, temperature differences between cloudy and clear sky conditions are in most of the cases large enough for discrimination.

An empiric analyses of the temperature limit between clear sky and cloudy elements gives an apparent temperature value of T = 240K.
This limit has been adopted for the discrimination cloudy-clear sky for each solid angle element observed by the IR pyrometers. This result is in agreement with previous studies; e.g., Gaumet and Leroux (1998**).**

2.2 Systematic errors on the temperature

As mentioned just above, the variability of the hemispherical emissivity is not taken into account ; the mean value (ε = 0.90) seems to be reasonable to describe practically all type of clouds. However, cirrus clouds with very variable emissivity factors (0.7-1.0) will be probably poorly identified by this method.

A second source of error could be induced by the composition of the lower layer of the troposphere (0-2 km). An atmosphere rich in green-house effect constituents like ozone, carbon dioxide, water vapor, … can affect significantly the downward IR flux and consequently, the measured temperature. This contribution will depend of course of the zenith angle (minimum at the zenith and maximum for the observations close to the horizon).

Finally, in clear sky or broken clouds conditions, the presence of the direct sun radiation will disturb temperature determination, but just in one solid angle element. This disturbance can be useful to determine the presence or absence of direct sun radiations.

3. INSTRUMENTATION

3.1 Infrared pyrometer

The infrared pyrometers are based on OMEGA OS 65–V-R2-4-BB models sensitive in the 8-14 µm wavelength range. The original sensors were modified in order to reduce the total weight from 0.3 to 0.1 kg per sensor, and to prevent the accumulation of liquid water in front of the entrance optics.

The main technical characteristics of the sensor are given in Table 1.

TABLE 1: Technical characteristics of the pyrometer

OMEGA OS65-BB Specifications	
Spectral range	**8-14 µm**
Temperature range	**-57 °C - +125 °C** **216K –398 K**
Temperature accuracy	**± 1K**
Repeatability	**± 1K**
Response time	**300 ms**
Field of view (Half angle)	**5.95°**
Emissivity	**0.1 to 0.99**

3.2 Scanning device

Seven pyrometers are mounted on a semi-circular portico as illustrated in figure 1

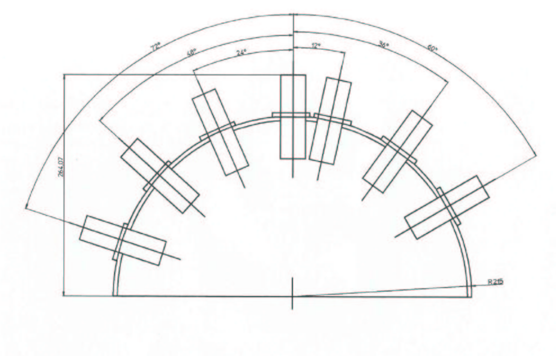

Figure 1. Schematic view of the instrument design

Each sensor is covering a 12° (nominal), 10° effective solid angle consequently, the design, presented in figure 1, prevent any overlap of the observations.

A mosaic of 181 points centered on the zenith is obtained by the rotation of the semi-circular portico around the vertical axis, scanning successively 30 positions, every 12° from 0° (North) to 348 °.

The full sequence of observations takes around 30 seconds and can be described as thirty time: 0.3 sec for stabilization
0.4 sec for measurement
0.3 sec for one rotation.
Half a minute is used for data treatment and repositioning the portico in the reference direction.
The 30-measurements set obtained by the "zenith" sensor is used to determine the stability of each observation sequence.

4. PRELIMINARY RESULTS

4.1 Estimation of nebulosity

The nebulosity is assumed as the ratio between the observed cloudy solid angle elements and clear sky elements taking 240K as temperature limit. An error in the discrimination (cloudy-clear sky) in 5 among the 181 observed elements induce an error lower than 3 % (around ¼ octa) in the total nebulosity.

Comparisons between nebulosity, determined by human observers (Station # 6447 Uccle – Belgium) and by the instrument (nephelometer) on the same site (Lat: 50.8°N, Long: 4.35°E) have been conducted during the fourth first months of 2001.

An example of one broken clouds day is illustrated in figure 2.

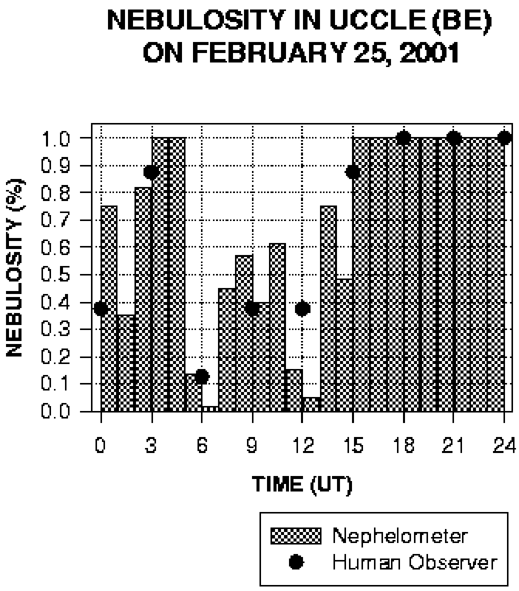

Figure 2 . Comparison of nebulosity determined by human observer an Nephelometer

The results from this comparison are summarized in figure 3. The histogram shows that more 85% of the cases are estimated within an error of ± 1 octa. The asymmetry of the graph reveals a small nebulosity underestimation by human observer but do not show any significant differences between daytime and nighttime.

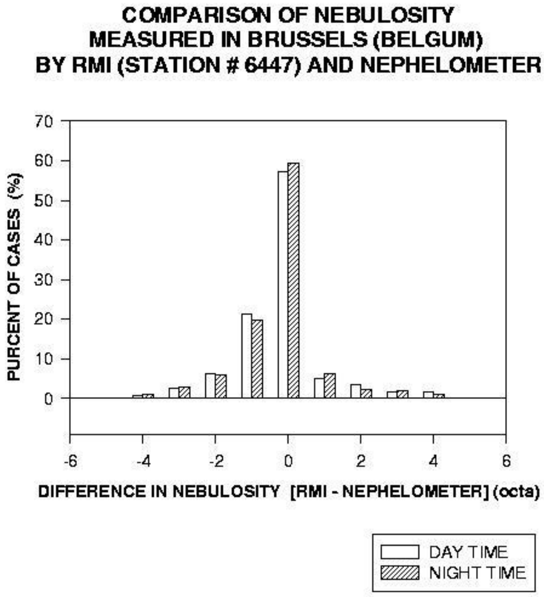

Figure 3. Summary of the nebulosity comparison

4.2 Estimation of altitude class of clouds

Clouds are usually classified in three different classes depending on their basis altitude (class1 from 0 to 2000 m, class 2 from 2000 to 6000 m and class 3 for altitude higher than 6000 m) (WMO, 1996)

Assuming that the temperature profile is known with enough accuracy for each specific geographic localisation and for any period of the year, it is possible to use the nephelometer measurements to estimate the altitude class of the observed clouds.

Different temperature profiles, [MSISE-90 (Hedin A.E., 1991 ; Labitzke K,1985), Jacchia, (1970), experimental sounding], have been compared for the specific sites of Uccle–Belgium (50.8°N, 4.35°E) and Trappes-France (48.8°N, 2.0°E).

The main differences are observed between 0 and 1000 m where the air temperature is largely influenced by the albedo of the ground surface.

Some preliminary comparison between ceilometer and nephelometer determination have been performed in January 2001 in Trappes-France.

Results are illustrated in figure 4 and summarized in Table 2.

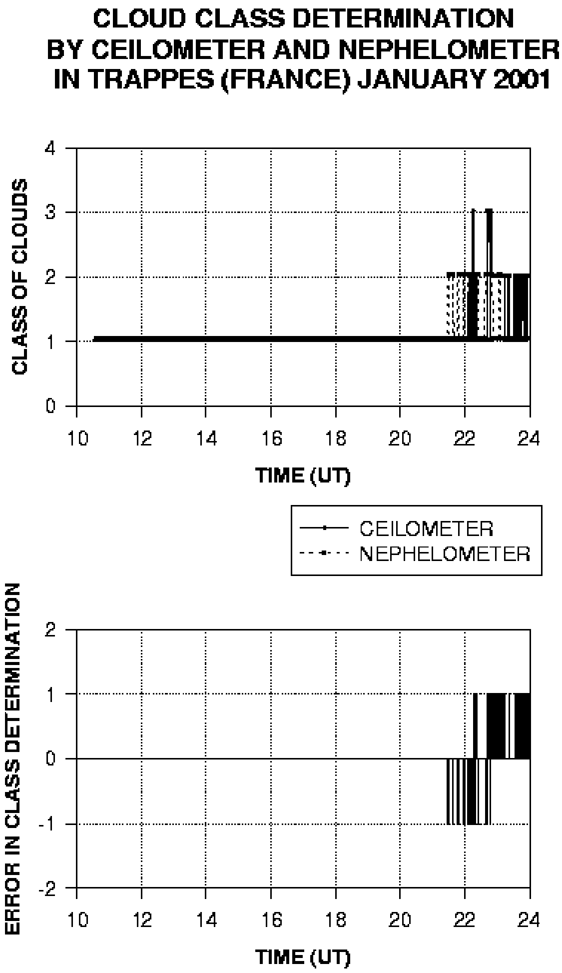

Figure 4. Cloud altitude class measurements in Trappes-France

TABLE 2: Summary of comparison Ceilometer Nephelometer.for different type of cloud cover

TYPE OF CLOUDS	Difference of class		
	0	+1	-1
Homogeneous	92%	6%	2%
Broken	65%	20%	15%

From table 2, it is clearly shown that the nephelometer measurements are in very close agreement with the ceilometer determinations in homogeneous cloud conditions (more than 90% of the cases agrees). In broken cloud conditions, the agreement decreases from 92% to 65%. This fact could be partially explained by the difference in the pointing of the sky dome by the two instruments.

5. DISCUSSION AND CONCLUSION

The nephelometer instrument yields very encouraging preliminary results with automatic sky observations in very good agreement with human observations and visible wide field of view digital pictures (like Total Sky Imager from Yankee Environmental System, Inc).

The method to convert temperature in more accurate altitude should be improved to be able to define more precisely the basis of cloud altitude. This last parameter is of crusial importance for aeronautical activities.

The study of consecutive sequence of observation (181 solid angle elements) by nephelometer should provide an interesting way to study kinetics of cloud circulation, cloud formation and offer an useful tools for the cloud typology determination.

Future development will focussed on the miniaturization of the captors to increase their number, the introduction of sensors centred around 5-7 µm to obtain information on the density of the different clouds.

6. REFERENCE

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