# IMPROVEMENT OF ALGORITHM IN CLOUD THERMAL INFRARED SPECTROSCOPY

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M. Collet (1), T. Besnard (1), F. Zanghi (2), P.W. Chan (3), L. Berger (4), C.N Long (5),D. Gillotay (6)

(1) ATMOS Sarl, 9 rue Lucien Chaserant, 72650 Saint Saturnin, France.
(2) Météo France, DSO/DOS, Rue Teisserenc de Bort, Trappes, France.
(3) Hong Kong Observatory, Hong Kong, China
(4) Université du Maine, Avenue O. Messiaen, Le Mans, France
(5) PNNL, Richland, WA, USA.
(6) IASB/BIRA, 3 Avenue Circulaire, B-1180 Brussels

***Abstract:*** *Observation of cloud cover has became, since several decades ago, a key topic of interest for study for several purposes such as greenhouse effect study, freezing and de-freezing of roads and highways, airport observation and atmospheric UV radiation transfer. Several instruments measuring thermal infrared radiation and providing cloud base brightness temperature have been developed, like the CIR (Cloud Infrared Radiometer) technique. We will show in this paper that several ways of research have been initialised to improve the algorithm performance of the cloud brightness temperature measurement and optimize the accuracy of cloud data provided by CIR instruments.*

## 1. INTRODUCTION

Since several decades ago, cloud cover monitoring has became a topic of interest throughout the world for many research groups and also for weather monitoring networks of national weather offices. Several techniques are used for the measurement of cloud cover, including thermal infrared spectroscopy. In our previous papers, Gillotay et al. (2001), Berger et al. (2003), Besnard et al. (2004), we presented the concept of our instruments and their use in the field. The feedback of the different measurement campaigns that we performed under various locations and climates showed us some bias in the measurements that are linked to geometric and atmospheric considerations, such as the effects of water vapour and aerosols. We shall discuss here, for CIR instruments, such effects on the cloud brightness temperature measurements and the improvement methods.

## 2. UNDER ESTIMATION OF BRIGHTNESS TEMPERATURE RETRIEVAL

### 2-1- Introduction

Pyrometric devices field of view, used in the CIR4 (which consists of four pyrometric transducers), is 4° and zenith angle set up is 30° (from zenith). The total “observation surface” monitored by the instrument at 3000 m high is around 0.18 km².

*Corresponding author address : Collet Matthieu, ATMOS Sarl 72650 St Saturnin, FRANCE*
*e-mail : matthieu-atmos@orange.fr*

This value has to be compared to 33 m² sensed by a laser ceilometer beam at the same height (Field of view 0.06° / zenith angle 15°). These data are represented on Figure #1.

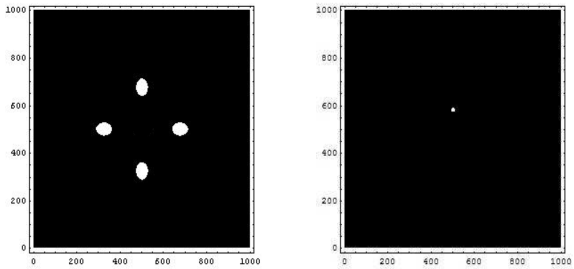

**Figure #1: Comparison of CIR4 (left) and ceilometer (right) field of view**

CIR4 pyrometers receive infrared energy from the “observation surface” of each pyrometer. Under broken cloud situation, transducers with finite field of view receive integration of radiation from cloud bottom layer and/or clouds located above the first layer and/or the sky. In the observation of the brightness temperature of the clouds of the lowest base height, there would be effect from the clouds higher up as well as the sky, which are of lower temperatures, and hence underestimation of the brightness temperature. We call this effect the “background” effect. In order to simplify our discussion, we consider that the background is only “clear sky”. In that case, the background brightness temperature is the average tropopause temperature which varies with the season, geographic location and time of the day, between -25°C and -55°C.

This situation implies that the smaller the cloud fraction, the lower would be the observed brightness temperature. This bias due to the CIR4's finite field of view is proportional to cloud fraction and altitude.

Cloud fraction is a continuous variable. As a first approximation, we adopt a discrete approach to the cloud fraction. Moreover, instead of developing a theoretical equation about the effect of cloud fraction on the brightness temperature measurement for the clouds of the lowest base height, we take on an empirical approach as a first step based on the data in a a measurement campaign. The classification of cloud fraction in this discrete and empirical approach is described in Chart #1 and Figure #2 below.

| Sky state | Cloud fraction |
|---|---|
| Clear Sky | 0-1 Octa (0-12,5%) |
| Broken Clouds | 1-7 Octa (12,5-87,5%) |
| Overcast | 7-8 Octa (87,5-100 %) |

**Chart #1: Discrete state of the model**

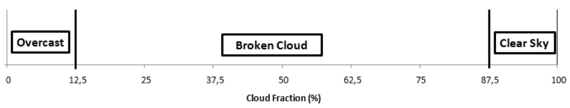


**Figure #2: Sky state diagram versus cloud fraction.**

## 2-2- Processing method

The aim of this empirical model is based on the three discrete "sky states" described above, to determine for each of them an offset coefficient to apply on the measured brightness temperature. By analogy with Long et al. (2003), we decided to use the variance of the measured brightness temperature. Long et al. (2003) used a running variance with a 5Hz sampling rate which is not available with our experimental devices. That's the reason why we decided to apply a variance over a period of 10 minutes. Long et al. (2003) looked for variations due to cloud shape. In the scope of this study we looked for statistical data corresponding to changes of the sky condition due to clouds.

Figure #3 is the diagram showing, for the three discrete "sky states", the relation between brightness temperature variance versus temperature difference between sky and ground. It is based on experimental data in a measurement campaign of Meteo France in Trappes (France) in the first quarter of 2008.

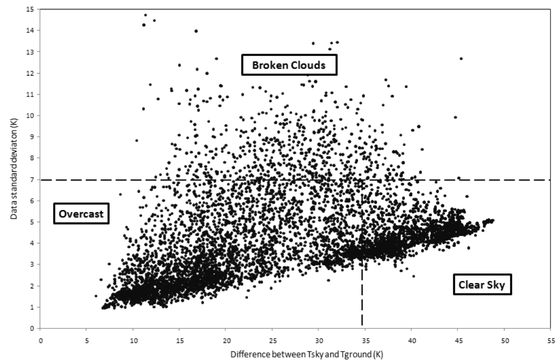


**Figure #3: Partial experimental results of the field measurement campaign.**

The classification of the three different sky states (cf. Chart#1) should be performed by an external method. We chose data produced by Vaïsala CT25K ceilometer that we processed for each 10 minute period according to the ASOS algorithm of U.S.A. The Figures #4, #5 and #6 show graphical representation of experimental data sets respectively for clear sky, broken clouds and overcast situations based on the sky states determined from the ASOS algorithm.

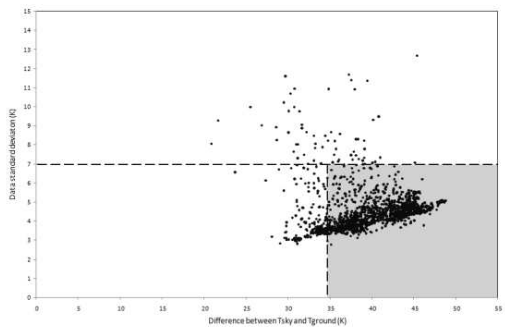


**Figure #4: Cloud brightness temperature variance versus difference between $T_{sky}$ and $T_{ground}$, for clear sky conditions**

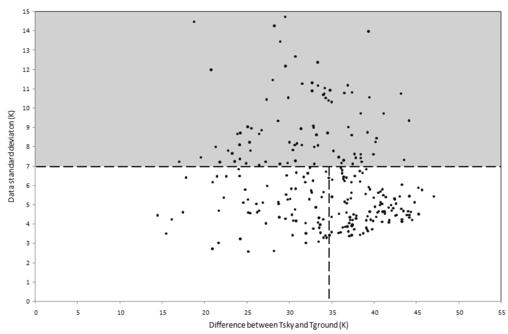


**Figure #5: Cloud brightness temperature variance versus difference between $T_{sky}$ and $T_{ground}$, for broken clouds conditions**

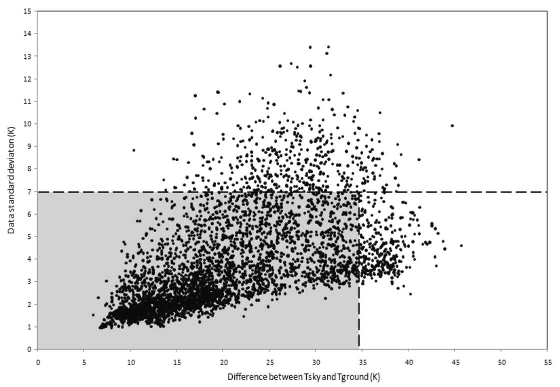


**Figure #6: Cloud brightness temperature variance versus difference between $T_{sky}$ and $T_{ground}$, for overcast conditions**

Through a statistical analysis of the entire set of data obtained during the measurement campaign, using CIR4 deployed in Trappes, we have reached at the following limits:

$$\sigma T_{brightness} = 7\ K$$

$$T_{ground} - T_{brightness} = 35\ K$$

Values presented above should be linked to statistical data presented in the chart #2. Coherence is the percentage of experimental data placed in the correct area of the diagram.

| Results | Clear sky | Broken cloud | Overcast |
|---|---|---|---|
| Situation ratio | 27% | 20% | 53% |
| Coherence | 68% | 22% | 88% |

**Chart #2: Statistical data based on the thresholds of brightness temperature**

Several aspects could be discussed concerning the validity of this algorithm. Most of the situations implemented in the diagram construction are overcast. That's the reason why data are still collected and will be analyzed in a near future in order to modify the threshold values mentioned above with a larger dataset. Results show readily a lack of coherence for broken cloud situation. It seems useful to keep in mind that these situations are extremely complex to describe due to phenomena like different cloud layers, overlapping of clouds, and cloud dynamics

The second step is the determination of the offset for the cloud base height to apply per each sky state. The offset has been calculated considering the adiabaticity of the troposphere with an average linear slope of 0.55℃/100m, which allow converting brightness temperature to altitude. Results are gathered in Chart #3 here after.

| Correction value | Clear sky | Broken cloud | Overcast |
|---|---|---|---|
| $T_{offset}$ (K) | +14 K | +11 K | +4 K |
| $H_{offset}$ (m) | -2545 m | -2000 m | -727 m |

**Chart #3: Ceiling offsets values for the three sky states studied**

In Figures #7 and #8, we present respectively distributions of ceiling differences between CIR4 and a ceilometer, before and after application of the corrective algorithm presented above.

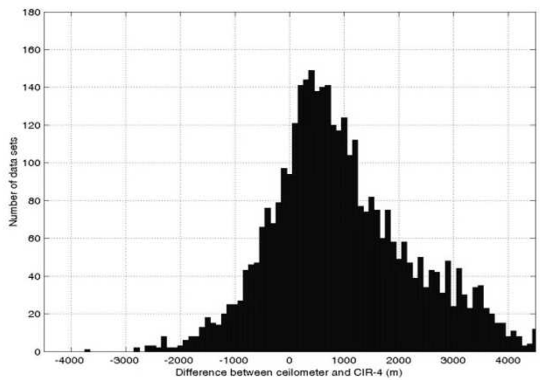


**Figure #7: Distribution of ceiling differences between CIR4 and ceilometer before application of corrective algorithm.**

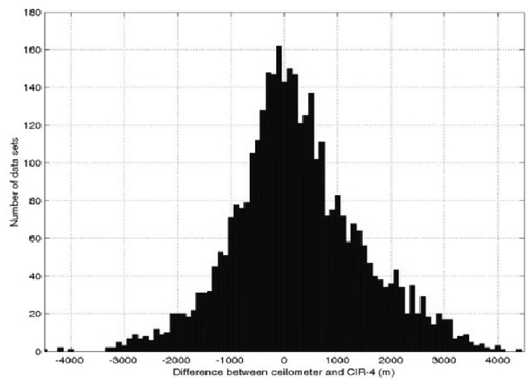


**Figure #8: Distribution of ceiling differences between CIR4 and ceilometer after application of corrective algorithm.**

| Results | Before | After |
|---|---|---|
| Mean error (m) | 949 m | 245 m |

**Chart #4: Results of mean difference between CIR4 and ceilometer**

This example shows improvement of results of the ceiling height. However it would be better to confirm these offset values based on data collected at other geographic locations. If the values determined for Trappes site have a wider spatial validity, this algorithm will have a significant interest for "self sufficient" instruments like CIR4. Otherwise, it would be necessary to include a look up table in the software system of CIR4.

## 3. OVER ESTIMATION OF BRIGHTNESS TEMPERATURE RETRIEVAL

### 3-1 Introduction

Throughout several of our former communications, Besnard (2003), Genkova et al. (2004), we mentioned that water vapour and potentially aerosols along the optical path between the clouds and the pyrometric devices of CIRs could affect significantly retrieval of accurate cloud brightness temperatures. The aerosols and water vapour would contribute to the brightness temperature. Since they appear below the cloud base, they are of higher temperature than the cloud, thus leading to over-estimation of the brightness temperature. In the field of atmospheric UV radiation, this factor is called air mass which varies with the inverse of the cosine of zenith angle.

### 3-2 Analytical approach

In the range of 9 to 14 µm, the energy received by the instrument (CIR-4 or CIR-13) is in fact the energy emitted by the cloud ceiling, added from the energy emitted by water droplets and potentially other aerosols along the optical path. This drives us to the following formula:

$$E(ZA) = E_c(ZA) + \frac{E_g}{\cos(ZA)} \quad (1)$$

where $E$ is the measured energy, $ZA$ is zenith angle of the transducer, $E_c(ZA)$ is the energy released by the observed cloud and $E_g$ is the energy released along the optical path by water droplets and aerosols. For this study, we consider that $E_c(ZA)$ is a constant (overcast or clear sky situation). For $ZA = 0$, the formula become :

$$E_0 = E_c + E_g \quad (2)$$

With equations (1) and (2), we obtain:

$$[E(ZA) - E_0] = E_g * \left[\frac{1}{\cos(ZA)} - 1\right] \quad (3)$$

With this method, we can evaluate in real time the air mass value. The only restriction is to obtain simultaneous infrared measurement with different ZA values.

### 3-3 Instrumental device

#### a) CIR-13 instrument

As preliminary research, we chose to use the CIR-13 experimental data (Cloud Infrared Radiometer with 13 pyrometers), released from a measurement campaign performed on the experimental facility of Hong Kong Observatory in the last quarter of 2007.

The first goal of the post treatment program is to select only situations of homogeneous sky (overcast or clear sky), to be able to use equation (3). In Figure #9, we present the distribution of Pearson correlation coefficient value, between CIR-13 retrieved energy data set and $\left[\frac{1}{\cos(\mathrm{ZA})} - 1\right]$ function.

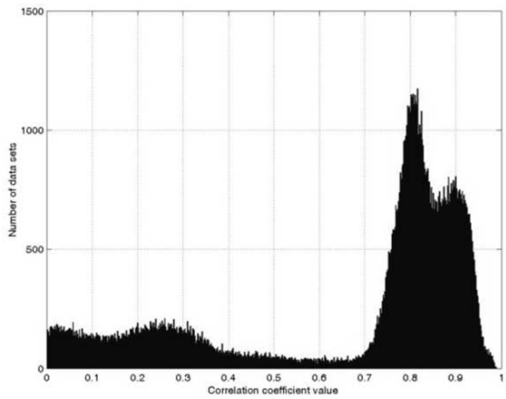


**Figure #9: Distribution of correlative coefficient between HKO CIR-13 data and analytical function**

Due to signal stability, data sets stemmed from clear sky and overcast situations allow adjustment through equation (3) with high values of the correlation coefficient ($\mathrm{R_{set}}$). We decided in an arbitrary way a threshold:

$$\boldsymbol{R_{threshold} = 0,7}$$

With this threshold value, we select only data sets where $\mathrm{R_{set}} > \mathrm{R_{threshold}}$.

For each data set, $\mathrm{E_g}$ value was calculated using a linear adjustment of equation (3). We applied least square method between experimental data and theoretical function.

The distribution of these values is presented on Figure #10.

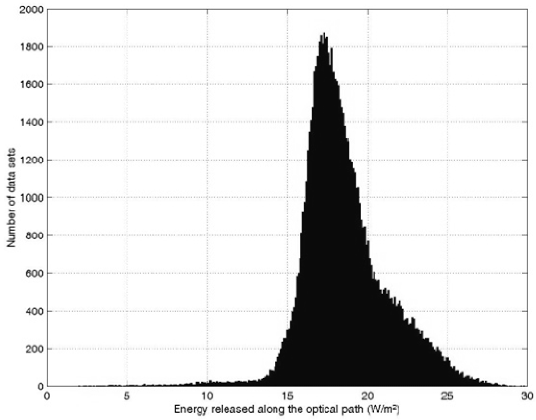


**Figure #10: Distribution of energy released along the optical path value, measured by HKO CIR-13 instrument**

This preliminary step of the study show an average value of $E_g$ equal to 18,5 W/m². This data is obtained with only few months of data. The value in itself and the width of distribution should be confirmed over a longer time period.

However, it seems useful to keep in mind that the response curve of each pyrometric transducer of CIR-13 is very close but not identical. That is the reason why we decided, only for research purpose, to develop CIR-M instrument which consists of a single pyrometric transducer only.

#### b) CIR-M instrument

To measure more accurately the effect of water droplets and aerosols on cloud brightness temperature, it is considered useful to measure brightness temperatures with one single transducer, in order to avoid measurements dispersion due to variation (even very slight) of the response curves between different detectors. This major consideration led us to the concept of CIR-M. This instrument owns a single infrared pyrometer, rotating with a stepper motor from -60° up to +60° ZA . This device is shown on the Figure #11.

Figures #12 and #13 present results from a measurement campaign, performed on ATMOS instrumental garden at Saint Saturnin, France, between October and November 2008.

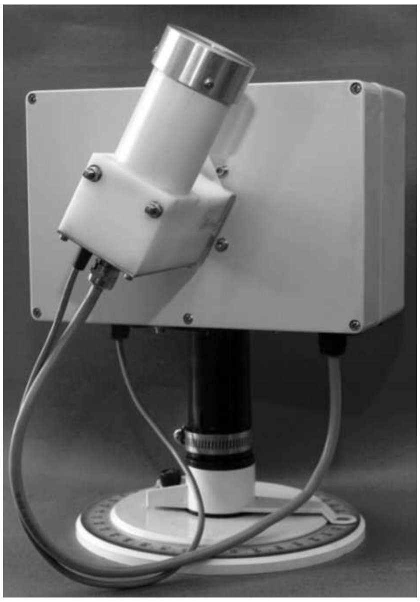

**Figure #11: CIR M instrument**

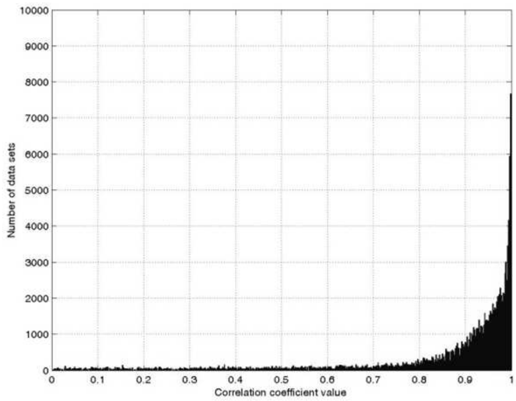


**Figure #12: Distribution of correlative coefficient between ATMOS CIR-M data and analytical function**

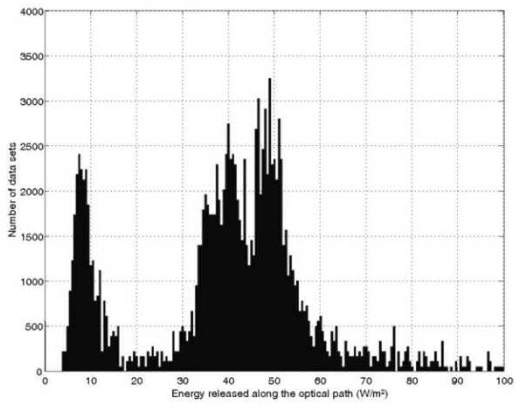


**Figure #13: Distribution of energy released along the optical path value, measured by ATMOS CIR-M instrument**

With this second step, under different climatic conditions from the CIR-13 measurements in section 3-3 a), the average of $E_g$ obtained reaches 40.1 W/m². It will be also necessary to confirm this data over a longer measurement period, covering seasonal variations of the climatic conditions.

## 4. CONCLUSIONS AND FUTURE WORK

With measurements accumulated over longer periods, an upgrade of processing could be implemented for CIR13. Two possibilities of improvement could be foreseen. On one hand, using a CIR-M as reference, values of background energy (emitted by water droplets and aerosols along the optical path) can be obtained in real time and used to modify infrared temperature measurements of CIR-13 and hence remove the positive bias mentioned in Section 3 above.

A measurement campaign is under planning in Hong Kong to run both CIR-13 and CIR-M at the same time at the same site. On the other hand, we could just use a mean value, which varies with season or nebulosity for example, to adjust CIR-13 results.

With CIR-4 instrument, the situation will be more complicated due to identical ZA position of transducers. It will be perhaps of interest to design a CIR-5 instrument, with a zenithal sensor.

In conclusion, all research ways that we developed on this abstract aim at improving the cloud cover measurement by thermal infrared spectroscopy. Algorithms of CIR instruments (CIR-4, CIR-13 and CIR-M) will probably be upgraded during the following year.

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