IMPROVEMENT OF ALGORITHM IN CLOUD THERMAL INFRARED SPECTROSCOPY

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INTRODUCTION

- Since several decades ago, cloud cover monitoring has became a topic of interest throughout the world for many research groups. Several techniques are used for the measurement of cloud cover, including thermal infrared spectroscopy.

- The feedback of the different measurement campaigns that we performed showed us some bias in the measurements that are linked to geometric and atmospheric considerations.

- We shall discuss here such effects on the cloud brightness temperature measurements and the improvement methods.

PART I : UNDER ESTIMATION OF BRIGHTNESS TEMPERATURE RETRIEVAL

- CIR4 pyrometers receive infrared energy from the “observation surface” of each pyrometer (Figure #1).

- Under “broken clouds” situation, transducers 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 would added a correlative coefficient to brightness temperature according to the sky situation (Clear Sky, Broken Clouds or Overcast / Chart #1)

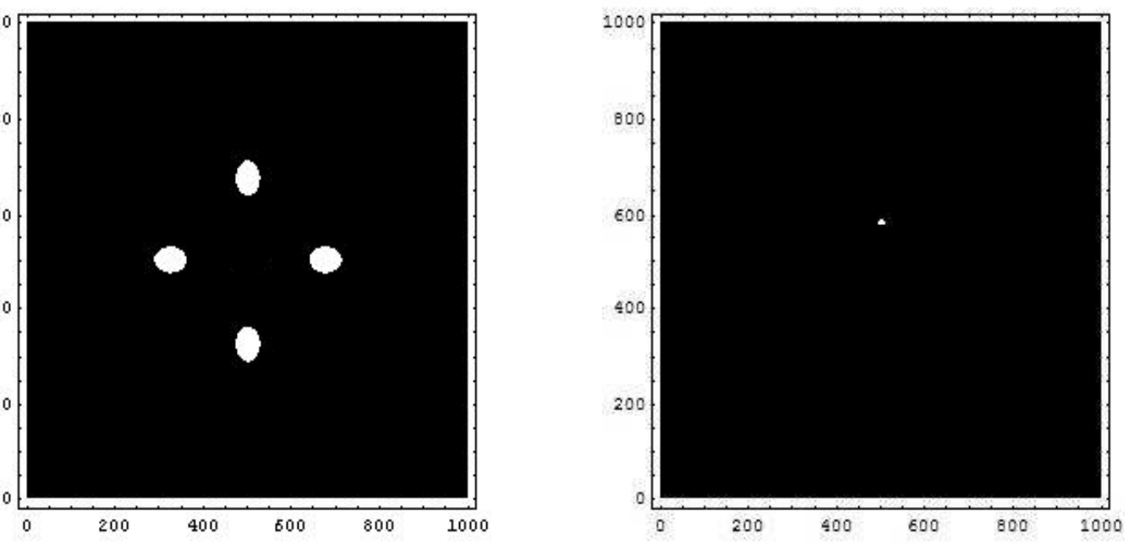

Figure #1 : Comparison of CIR4 (left) and ceilometer (right) field of view

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 : Relation between sky state and cloud fraction

I.A : Processing method

- Standard deviation of brightness temperature signal and mean difference between T_{sky} and T_{ground} could be used to determined the sky situation (figure #2). We use measurement periods of 10 minutes to generate a new data.

- Thresholds between areas are :

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

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

- We use a ceilometer with ASOS algorithm to determine the effective sky state for each measure.

- Figures #3, #4 and #5 present data for each sky situation (determine by ceilometer).

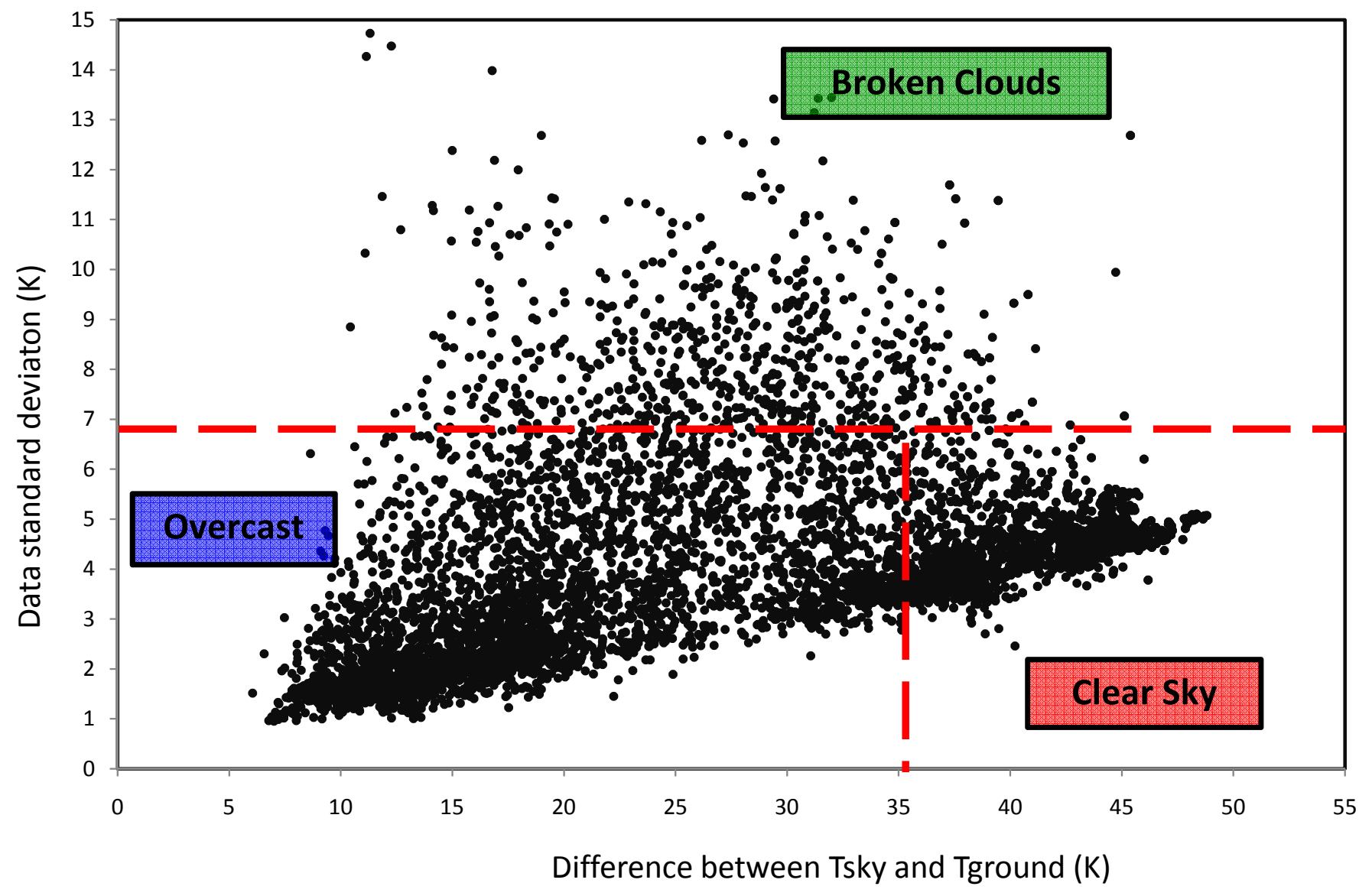

Figure #2 : Diagram of signal standard deviation versus difference between T_{sky} and T_{ground}

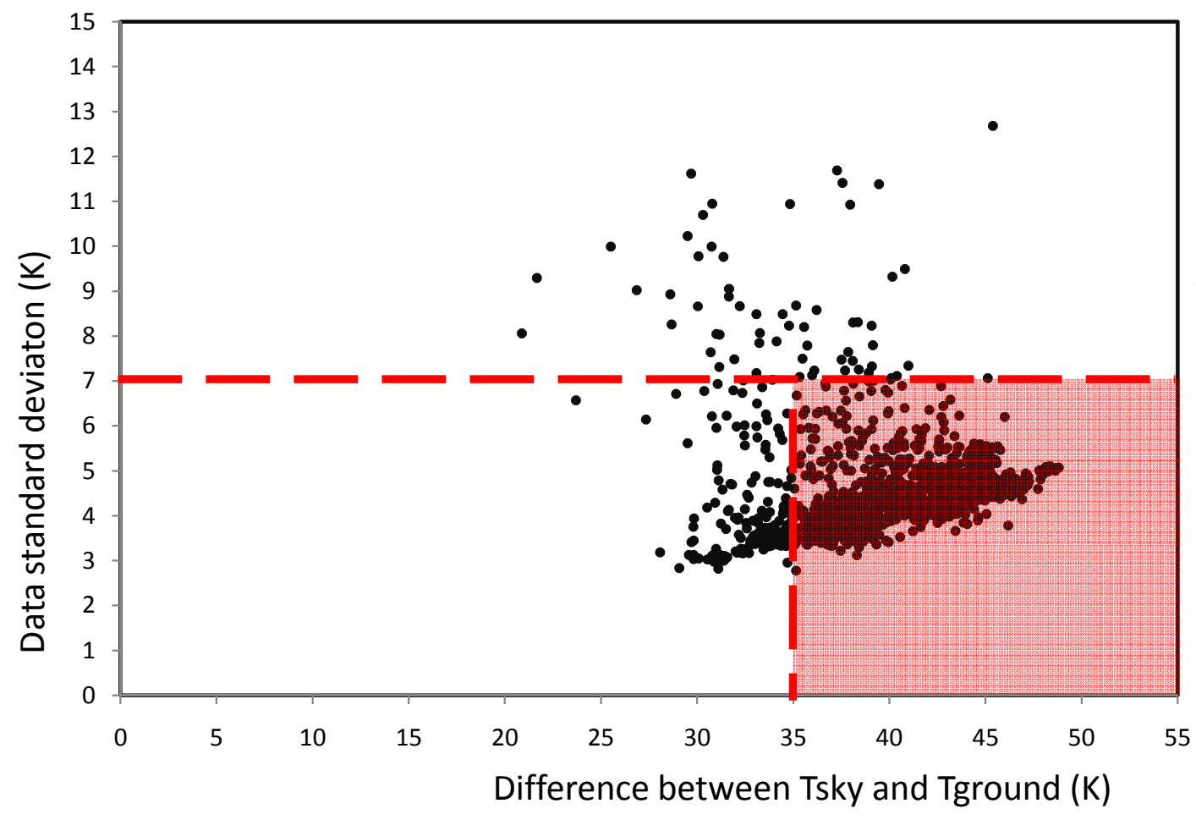

Figure #3 : Signal standard deviation versus difference between T_{sky} and T_{ground}, for clear sky conditions

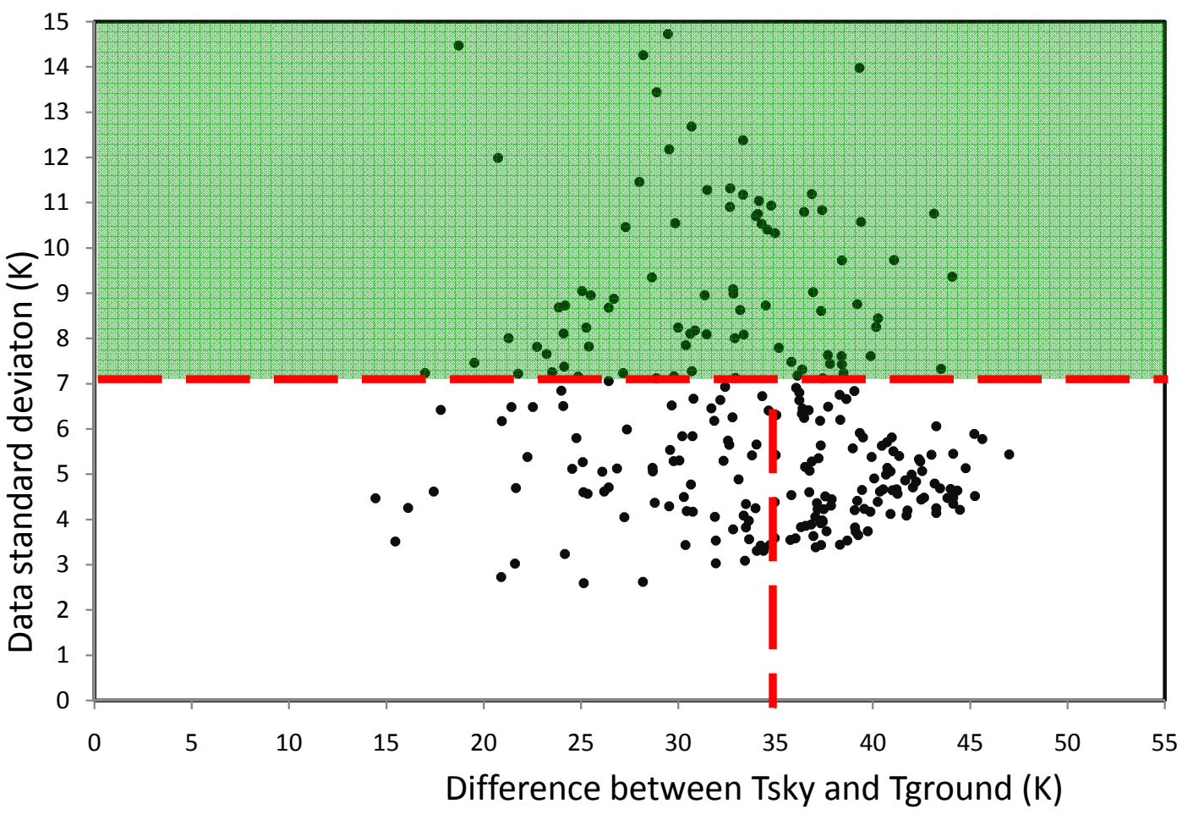

Figure #4: Signal standard deviation versus difference between T_{sky} and T_{ground}, for broken clouds conditions

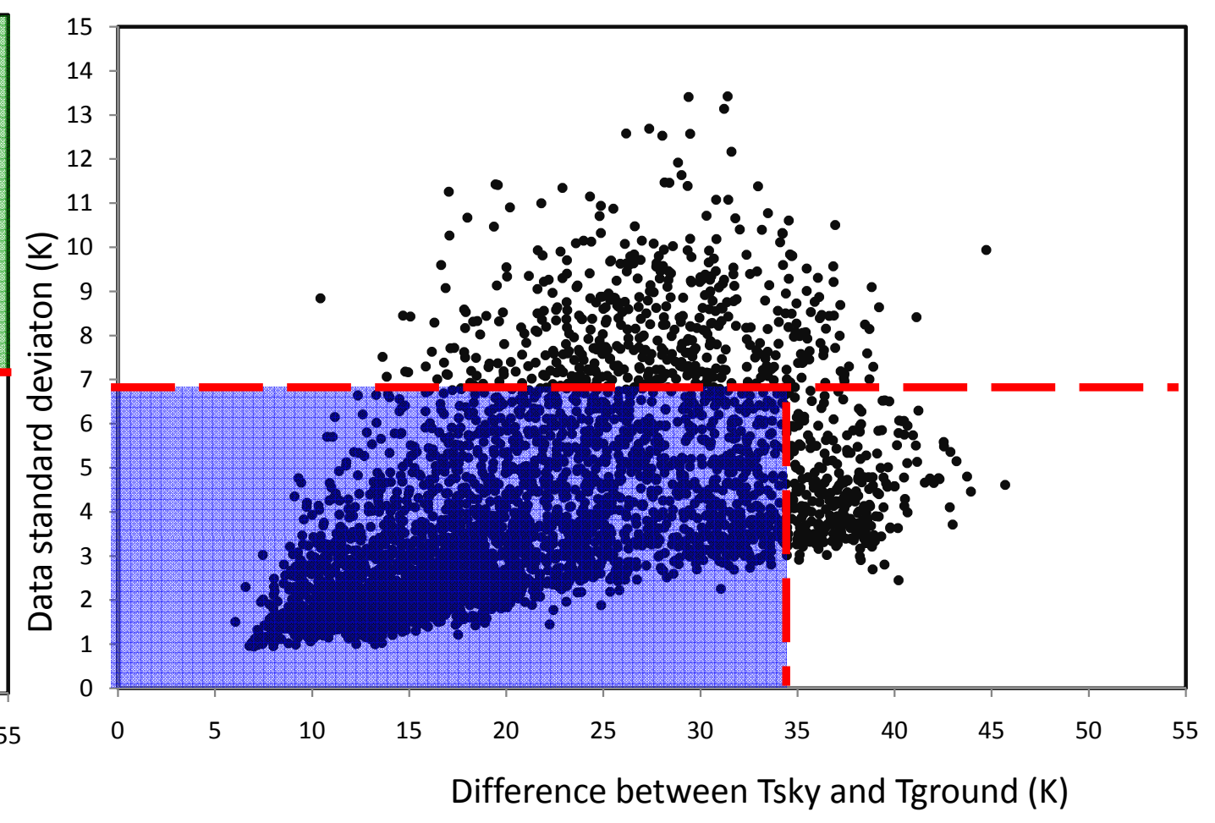

Figure #5 : Signal standard deviation versus difference between T_{sky} and T_{ground}, for overcast conditions

I.B : Intermediate results

- For each sky condition, we determine the coherence of our method (percentage of experimental data placed in the correct area of the diagram).

- The second step is the determination of the offset for the cloud base height to apply per each sky state.

- The corrective coefficients in meter have been calculated considering the adiabaticity of the troposphere with an average linear slope of 0.55℃/100m, which allow converting brightness temperature to altitude (Chart #2)

Results	Clear sky	Broken clouds	Overcast
Situation ratio	27%	20%	53%
Coherence	68%	22%	88%
Corrective coefficient (°C)	+14 K	+11 K	+4 K
Corrective coefficient (m)	-2545 m	-2000 m	-727 m

Chart #2 : Statistic results and corrective coefficients

I.C : Corrective algorithm

- We apply the corrective coefficients to CIR-4 height cloud ceiling measurement, according to the sky condition.

- Figures #6 and #7 present respectively distributions of ceiling differences between CIR4 and a ceilometer, before and after application of the corrective algorithm presented above.

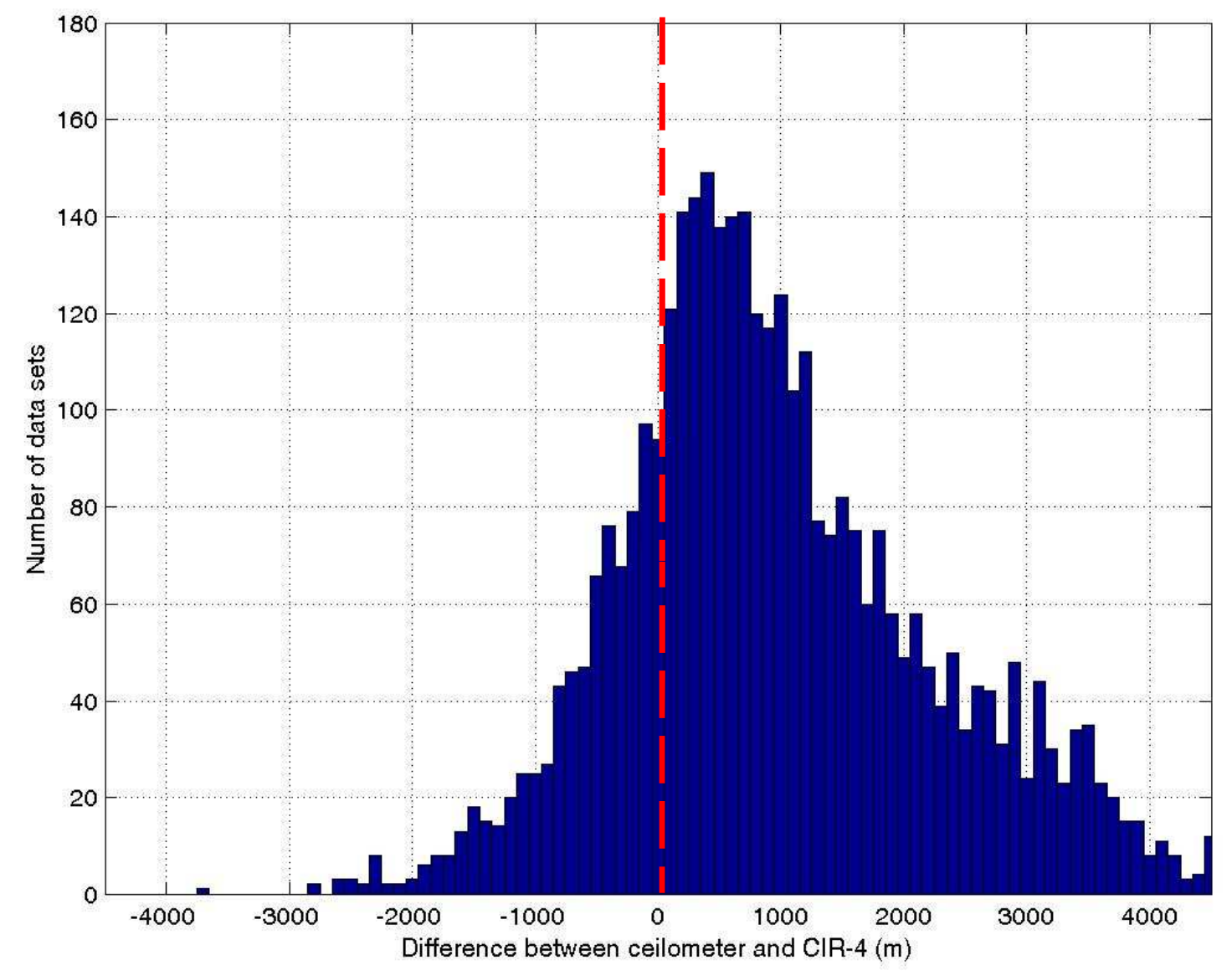

Figure #6 : Distribution of ceiling differences between CIR4 and ceilometer before application of corrective algorithm.

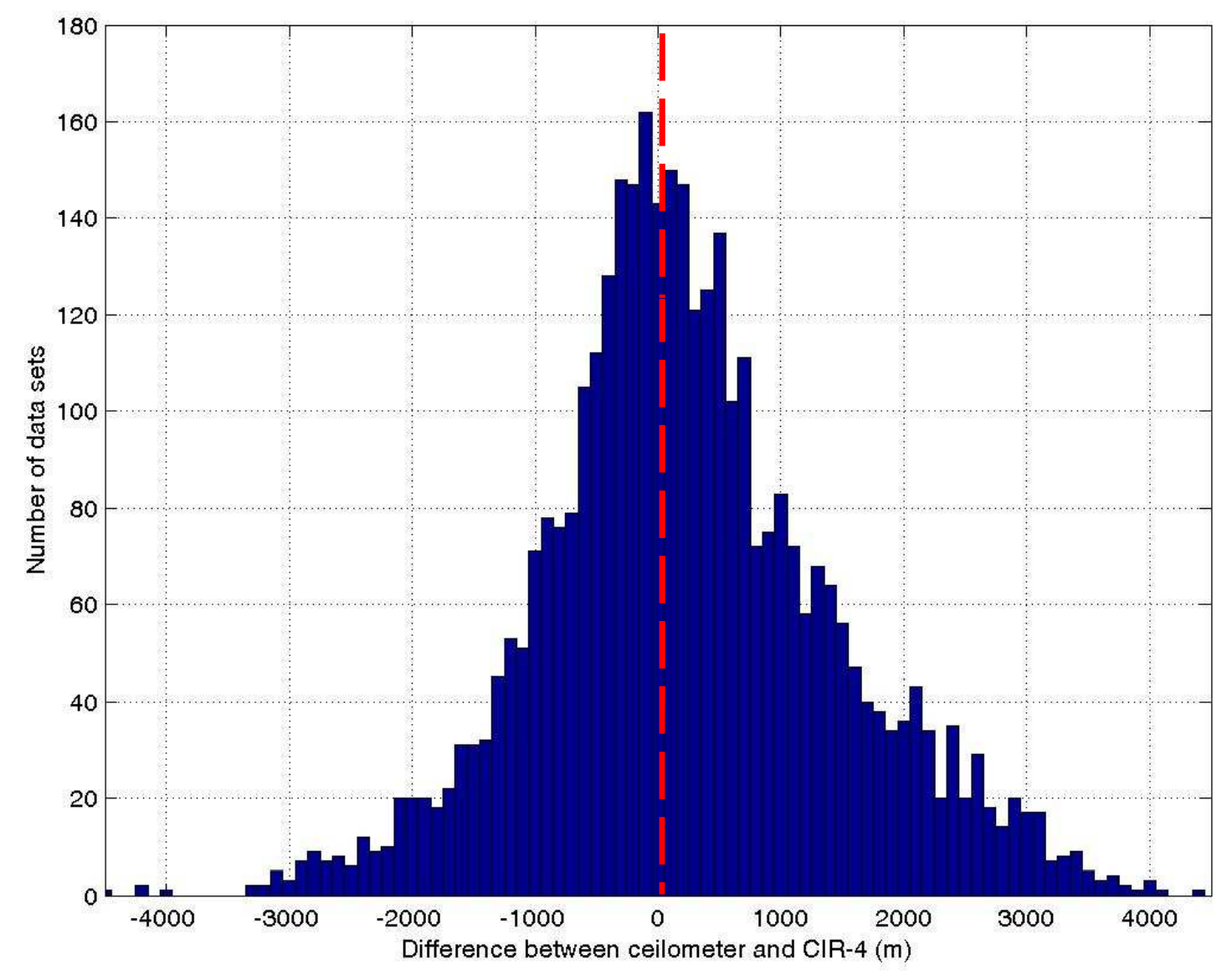

Figure #7 : Distribution of ceiling differences between CIR4 and ceilometer after application of corrective algorithm.

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

Chart #3 : Results of corrective algorithm

I.D : Results and conclusions

- 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 this example 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.

PART II : OVER ESTIMATION OF BRIGHTNESS TEMPERATURE RETRIEVAL

- Energy retrieved by CIR instruments is the energy emitted by the cloud ceiling, added from the energy emitted by water vapour along the optical path.
- We consider that this supplementary energy is emitted in a homogeneous way between the cloud ceiling and the ground.
- The more the zenith angle is important, the more this background energy is high and the more the cloud brightness temperature is over estimate

II.A : Analytical approach

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

- $E(ZA)$: measured energy versus zenith angle
- $E_c(ZA)$: energy released by the observed cloud
- We consider that $E_c(ZA)$ is a constant (Overcast or Clear Sky situation)
- E_g : energy released along the optical path (constant to determined)
- E_0 : measured energy for $ZA = 0$

$$E_0 = E_c + E_g$$

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

Equation #1

II.B : Instruments device

- We must obtain simultaneous infrared measurement with different ZA values. We use CIR-13 et CIR-M instruments (Figures #8 and #11)

- The first goal of the post treatment program is to select only situations of homogeneous sky (Overcast or Clear Sky). We calculate the Pearson correlation coefficient value between retrieved energy data set and equation #1 (Figures #9 and #12)

- For each data set with high Pearson correlation coefficient, we calculated E_g value using a linear adjustment of equation #1, applying least square method between experimental data and theoretical function.

- Distribution of these values is presented on Figures #10 and #13.

Figure #8 : CIR-13 Instrument

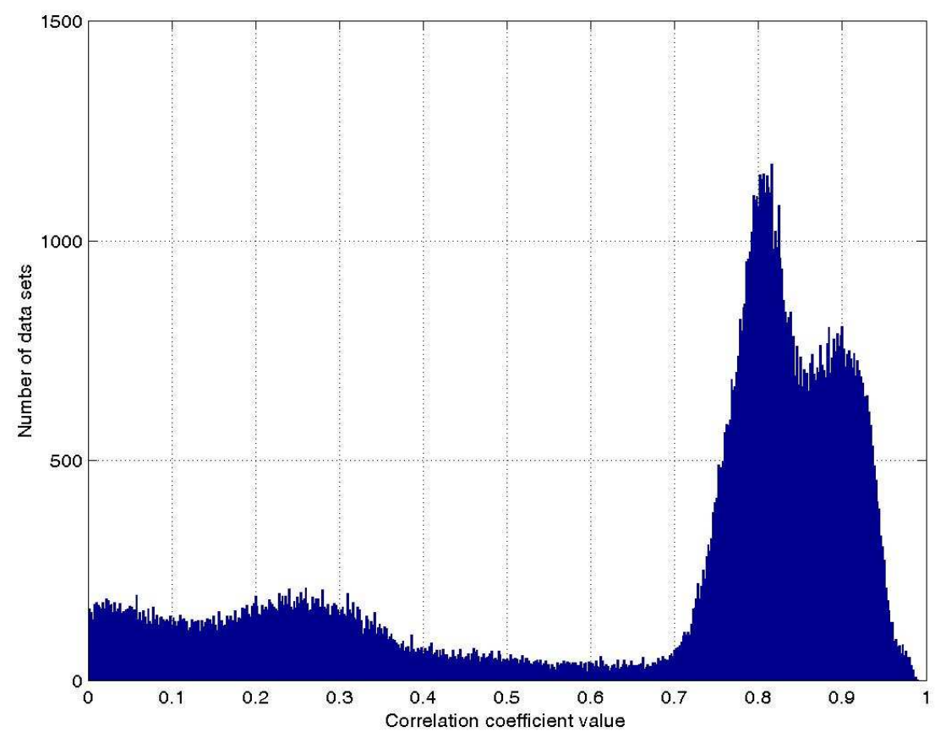

Figure #9: Distribution of correlative coefficient between HKO CIR-13 data and analytical function

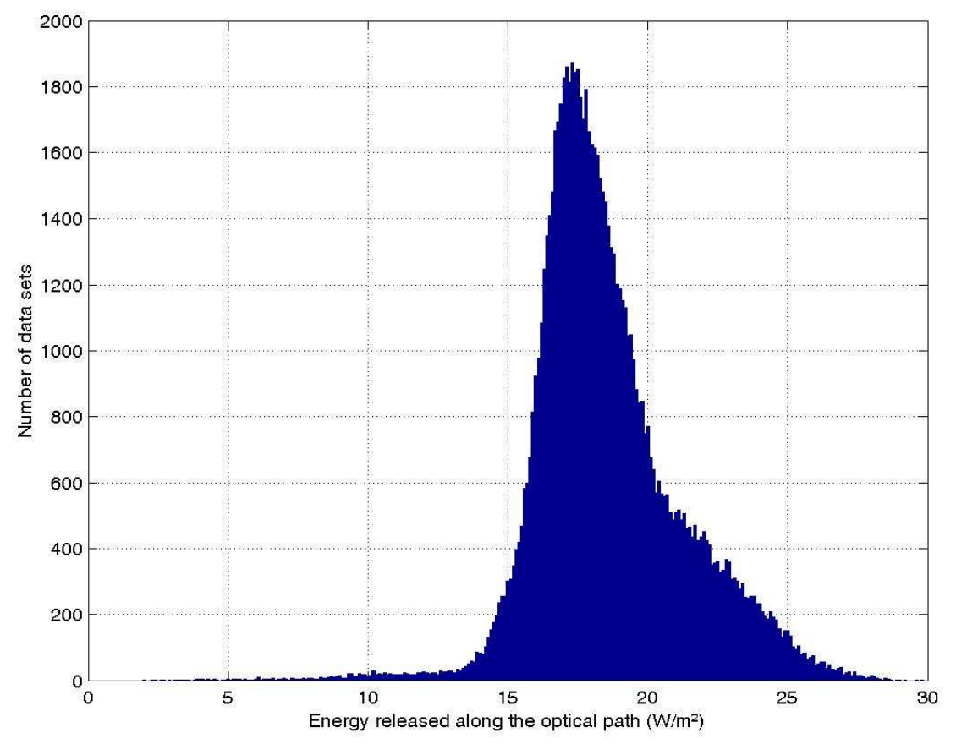

Figure #10 : Distribution of energy released along the optical path value, measured by HKO CIR-13 instrument

Figure #11 : CIR-M Instrument

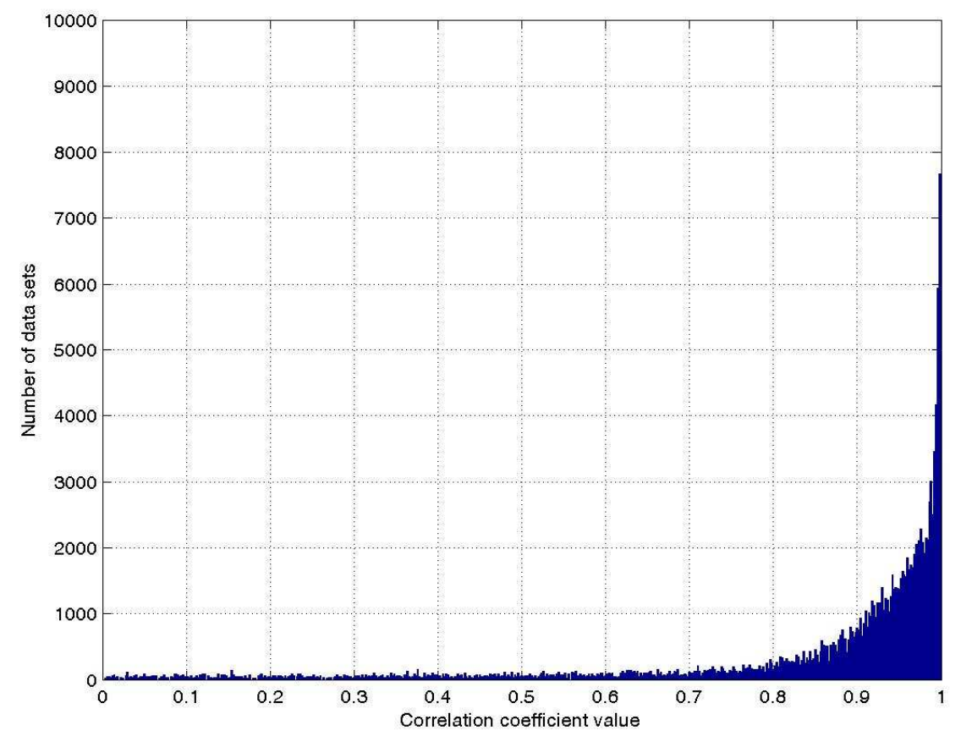

Figure #12 : Distribution of correlative coefficient between ATMOS CIR-M data and analytical function

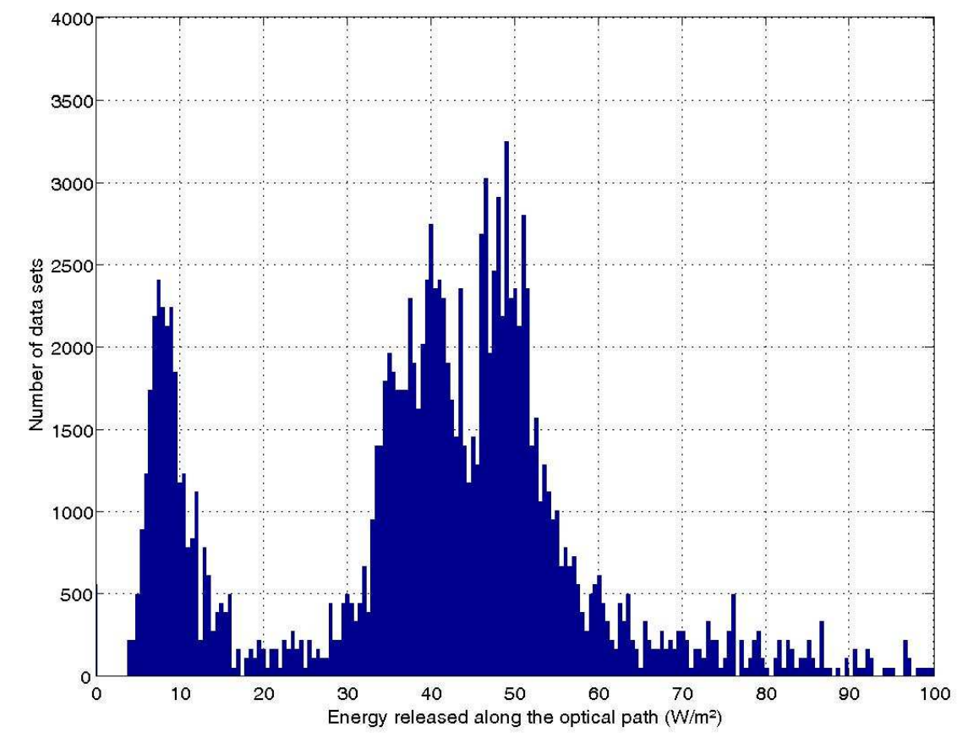

Figure #13 : Distribution of energy released along the optical path value, measured by ATMOS CIR-13 instrument

Conclusions and perspectives

- 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 can be obtained in real time and used to modify infrared temperature measurements of CIR-13. 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.