SHORTCASTING OF ONE HOUR MICRO SCALE CLOUD FRACTION TREND THROUGH CLOUD INFRARED RADIOMETER DATA

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ABSTRACT

Since quite two decades, numerous instruments have been designed for automatic cloud cover monitoring. Through them, we can mention the Hemispherical Sky Imager HSI (Long and De Luisi) and the Cloud Infrared Radiometers range CIR (Besnard et al.). The aim of this communication will be particularly dedicated to the CIR-4V. This instrument is devoted to microscale observation (few square kilometers. Even if the profitability and the repeatability of these instruments versus human observers have been clearly demonstrated, the deployment of such instruments in Automatic Weather Observing Systems (AWOS) stays low. In parallel of pure weather activities, another filed moved up quickly during the same period. That's the field of renewable energies like photovoltaic energy. Few square meters of solar cells on the roof of private houses are not concerned by this talk. We speak about farms with several hundreds of Photovoltaic cells square meters and even several thousand for some recent projects. The goal of these investments is to highlight this type of renewable energy. Such a position in the electrical supply network implies a question which is the production trend during the coming hour. Along this period other electrical production means could be activated in order to match consumer's needs. The clear sky irradiance could be nowadays calculated very accurately but most of the time, we face to broken cloud conditions and the impact of clouds is significant. In this communication, we will show that the cloud fraction is linked to correlation and anti-correlations between cloud fraction and cloud height and in a second time, the application of the algorithm that we designed for a period of several months. Through this campaign, statistical results will be presented, discussed and ways of improvement proposed.

1. INTRODUCTION

As a preamble of the scientific talk, it seems useful to locate the aim of this research program. In our daily life, electricity is a key element. At the same time, climate changes with catastrophe induced worries more and more people on the planet. To match electricity needs of humans, up to now there were just to « switch on « a nuclear reactor or the oven of a thermal electricity plant. This ease cannot continue and progressively actual means of production should be replaced by renewable and natural ways of electricity production. The difficulty for wind and solar energy is that the switch on concept is not usable. In this field to match needs it is necessary to know within one hour the trend of production. For photovoltaic production, the incoming energy reaching potentially cells is known versus Latitude, Longitude and time of the day. The factor disturbing this ideal situation is called clouds. In a basic approach, the photovoltaic electricity production will be inversely proportional to cloud fraction. Such information could be retrieved from satellite data but it is necessary to keep in mind that first of all satellite will retrieve mesoscale data (average few tenth of square kilometers) and that even the biggest photovoltaic concerned needs reliable information over only few square kilometers. This means that the only way to provide the right data is through microscale ground based measurements. This impact has been quantified by Gillotay et al. (2002).

The principle of cloud base height measurement through measurement of brightness temperature has been showed by Gaumet et al. In 1998. Since that time several instrumental have been done. Through them, we can mention the IRT from Long and the Cloud Infrared Radiometer CIR. Such type of instrument is passive which means that it does ot emits any electromagnetic signal. It retrieves natural atmospheric radiations.

2. CLOUD INFRARED RADIOMETR

This concept of instrument has been declined into two types:

- Scanning instrument CIR-13 (13 detectors)
- Time series instrument CIR-4 (4 detectors)

Several versions of the CIR-4 have been presented into three versions:

- CIR-4 with a basic naturally ventilated shield surrounding each pyrometer.
- CIR-4V with a ventilated shield surrounding each detector.
- CIR-4VH with a ventilated and heated shield surrounding each detector.

The figure 1 shows a CIR-4V deployed.

Figure 1: CIR-4V instrument deployed.

These instruments and their uses have been widely described in various communications,

Berger et al., Genkova et al, Gillotay et al., Besnard et al. The different versions have been deployed in various locations of the world like Belgium, Japan, Brazil...During the two past years, feedbacks transmitted by users have been analyzed and improvements implemented.

3. CIR-4V IMPROVMENTS

3-1 Ground base air temperature measurement

In this cloud cover measurement principle, the knowledge of the ground base temperature has a significant importance. The temperature transducer is set inside each pyrometer. The system can be compared to problematic of air temperature under a shield. It is well known that data retrieved by the temperature retrieved from the probe is submitted to two incertitude:

- The incertitude linked to the probe in itself which is fixed in the range of measurement.
- The incertitude linked to the shield which is with natural ventilation proportional to wind speed , solar irradiance, nature of the pavement below the instrument and potential obstacles (walls, trees) surrounding.

During 2013 and 2014, a measurement campaign has been performed in Urbe airport near Roma in association with ENAV (M. Taddini, private communication. Raw air temperature value supplied by CIR-4V has been recorded simultaneously with air temperature data supplied by the local AWOS system. To determine a transfer function has been calculated assuming a linear relation between both values.

The figure 2 below show experimental data and results of the linear regression.

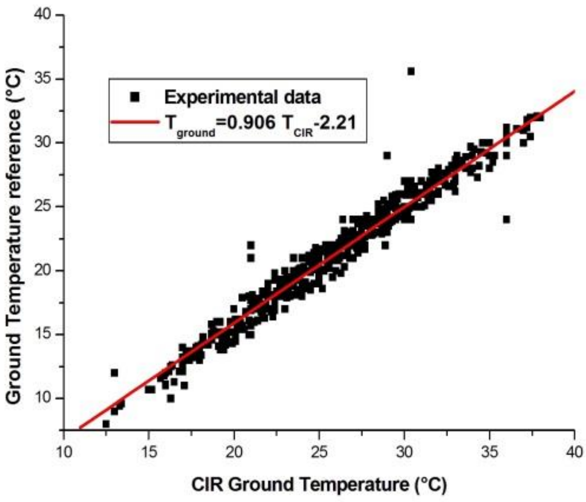

Figure 2: AWOS air temperature values versus raw CIR air temperature values in Urbe Airport

Even if the body of the motor aspirated of each pyrometer is white (high reflectivity to incoming solar radiations), it owns a thermal inertia versus energy represented by the slope slightly below one. The offset represents the regular radiative error of any shield.

Results show that the shield of CIR ventilated pyrometer is a poor shield but its aim is the retrieval of cloud base brightness temperature and not to be an air temperature measurement device.

Values of slope and offset are factory set according to this campaign but it can be user modified in the config file of the instrument.

3.2 Cloud base temperature versus altitude

In the previous versions, this evolution was assumed as being linear. This relation is currently used in the literature with the common values of (-0.5 °C/100 m). This is an approximate which does not describe the sigmoidal shape of a true temperature profile.

The figure 3 below shows the interest of a true sigmoidal approach.

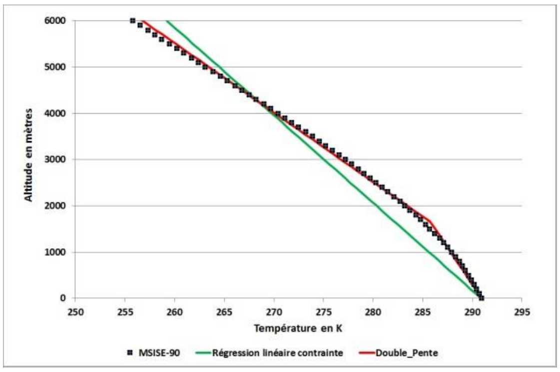

Figure 3: Sigmoidal approach of the temperature decrease versus altitude

3.3 Cloud altitude range review

It is necessary to keep in mind that this technic is based in the range of 9 to 14 µm on the Stefan Botzmann Law:

$$\mathbf{M = \varepsilon.\sigma.T^4}$$

Where:

M is energy into W/m²

ε is the emissivity of concerned cloud

σ: the Stefan Botzmann constant.

T is the thermodynamic temperature Kelvin degrees.

The dry air has an emissivity quite equal to zero. This situation is the basis of the contrast between clear sky and clouds. The situation is unfortunately not so obvious. The atmosphere above our head is a mixture between dry air, wet air, aerosols and clouds. The potential emission of infrared radiation in the wavelength of 9 to 14 µm has not been checked but cannot be neglected even if we can assume that the strength is weak.

Physics of clouds is right now relatively well known and more particularly emissivity. Below 6000 m (in terms of cloud base height), cloud types met have an emississivity close of 1 (0,96 for cumulus clouds), which means that they could be assumed without inducing a hazardous bias like black bodies.

Above the limit of 6000 m high emissivity is very low (around 0,2). This means that the contrast between cloud and background is quite difficult to manage.

The other element to look at is the CIR transducer. This element has been designed in the aim of monitoring instruments. In the range of very low energy signal is difficult to discriminate from the electronic noise.

All these elements drove us to decide to limit the height range of CIR instruments between 0 and 6000 m high.

4. KINETIC OF CLOUD DOVER CHANGES

In such project before writing any equation, it is necessary to know the state of events that we will have to describe in the cloud cover data retrieved by the instrument.

It is well known that in cloud fraction data, 4 phenomena are present:

- Overcast cloud fraction stability.

- Clear Sky cloud fraction stability.
- Growth of cloud fraction trend.
- Decrease of cloud cover trend.
- Evolution of cloud fraction through convective clouds.

Some intermediate state between overcast and clear sky exists but in the frame of a trend study, we decided to assimilate them to overcast.

This analysis has been performed on cloud data retrieved from CIR-4V deployed in the seven stations of the UV monitoring network from IASB/BIRA in Belgium. For each station an average period of seven years is available.

The other issue to match forecasting goal is the kinetic of transition between the different states described above.
The presence of convective clouds is a fast phenomenon with duration far below one hour. That's the reason why we decided to not investigate this aspect and to focus on pure atmospheric phenomena.

Figure 4, 5 and 6 below show histogram of states transition for the station of Uccle in Belgium. Data between 2010 and three quarters of 2015 have been processed. Cloud fraction signal presents a relative noise. In the scope of this paper, it is not possible to do reliable assumptions about it. To obtain these histogram and to remove noise, we calculated for each time value the speed of evolution of the cloud cover thanks to a linear regression integrating the point in itself but also three points before and three after. Slope values below 3%/min have been considered as steady situations.

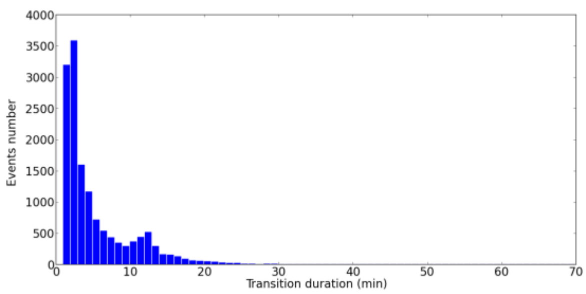

Figure 4: Histogram of Cloud fraction decrease durations for Uccle data (2010/2015).

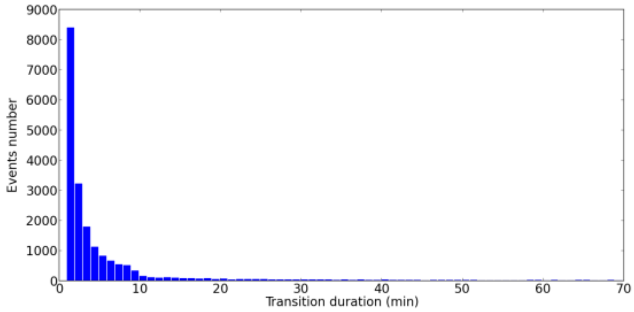

Figure 5: Histogram of Cloud fraction stability durations for Uccle data (2010/2015).

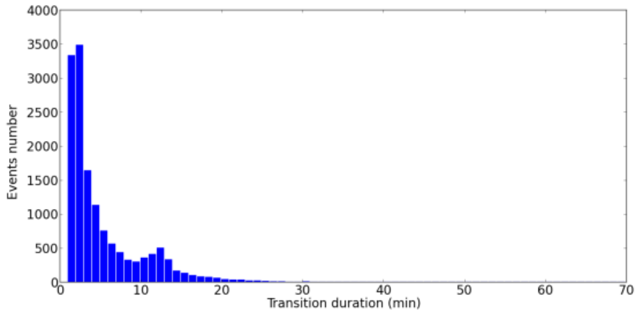

Figure 6: Histogram of Cloud fraction growth durations for Uccle data (2010/2015).

We know through numerous communications about automatic retrieval of cloud cover that the frequency of 3 hours (human observers) is not at all adequate to describe properly variations of cloud fraction in sky dome. Figures above show those stability periods (mostly overcast and clear sky) have a significant duration over few hours. Increase and decrease it has a much faster kinetic within less than one hour. This phenomenon does not ease cloud fraction trend modelling. The persistence technic which is the most obvious

5. MODELLING

5.1 Introduction

For reasons of industrial properties, the short casting algorithm cannot be revealed. In this paragraph we will detail results obtained. As short casting algorithm should be integrated to an embedded CPU, the way of processing should be as simple as possible. The use of an internet link is not realistic for a monitoring instrument deployed in industrial farms. For any model, the rate of success should be defined. For each value in data files retrieved a data filed is added (-1: Cloud fraction decrease, 0 : Steadiness of cloud fraction, 1 : growth of cloud fraction). As records are retrieved one per minutes 60 samples later the Cloud Fraction value is compared to the value at t time and the true trend is processed like this. Some other ways of success rate calculation could be imagined but we did not perform further investigations in this way.

5.2 Results

The chart below shows the rate of success for the different stations of the Belgian UV monitoring network. As previously mentioned, model has been designed using Uccle station data. The “state of the art” of modelling normally forbids the application of model on data used to design it. However, we decided to present them in order to show the convergence with other deployment sites.

Station location	Period of data record	Rate of success (%)
Uccle	2010-2015	71,7
Virton	2008-2015	74,8
Redu	2007-2015	72,9
Mol	2010-2015	72,7
Ostende	2009-2015	73,1
Mont Riggi	2012-2015	71,9

Chart 1: Modelling results over the full set of data retrieved from the UV monitoring network (6 stations)

6. DISCUSSION

Results shown in the previous chart show an effectiveness of the micro scale model that we designed. Another interesting aspect to highlight is that success samples are randomly set along the period of records. This means in another way that there is no significative period during which the model does not show erroenenous values. A remark about our research activity could be that the data processed are retrieved through station deployed in avery narrow territory. The size of the territory is effectively small, but it is necessary to keep in mind that the climatology of the Belgian kingdom show a significative diversity. Ostende station is at the coast line and Mont Riggi in in the Ardennes region.

7. CONCLUSION AND PERSPECTIVES

Even if this model is a first approach; it shows that the micro scale forecast of cloud fraction trend could be reached. We think that success rates could be optimized and we are planning to deploy stations in other locations on the French territory. A deployment in Japan is also under discussion with one of our local partners.

8. ACKNOWLEDGMENT

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