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Cloud Monitoring at HiRes Detector using Infra-Red Sensors

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Abstract: Monitoring of the atmospheric conditions is very important for fluorescence observations. Particularly, the presence of clouds can drastically distort the signal from the extensive air shower. Infra-red (IR) sensors, measuring sky temperature, can help to distinguish clouds, which are usually significantly warmer than clear skies. Array of such sensors, covering the detector's field of view, was installed, and have been collecting data every minute of detector operation. Using this information, a cloud database was created. This database is used to select cloud free CR events. In this paper we present the description of the array and the method used to analyze IR data.

Introduction

The fluorescence detector is a very sensitive instrument designed to detect UV light from extensive air showers (EAS) associated with cosmic rays. Such sensitivity requires the operation of the detector on moonless nights with clear sky conditions. Small changes in the weather affect the measured parameters of EAS and, consequently, high energy particle characteristics. The presence of clouds could lead to particle energy overestimation due to the enhancement of the signal at cloud level as well as to the energy underestimation due to overcorrection for Cherenkov light which in reality could be cut off by clouds above the field of view. The transition to the remote operation of HiRes1 with HiRes2 located 12 km apart increased the demand for cloud cover information got even higher. An infra-red cloud monitoring system was designed to accommodate this need[1] .

Cloud monitor design

An array of 11 infra-red sensors(Heinmann TPS 534) has been installed and tested at HiRes in August 1999 [2]. Each IR sensor measures the temperature of the sky in patches of $30^\circ \times 30^\circ$, pointed slightly above the horizon. This configuration covers the HiRes1 detector's field of view (FOV) completely. The measurements are made and data are collected every minute during HiRes1 data taking, and are stored as a part of the detector status information. In absence of moving parts, the system does not require any specific maintenance. With cloud temperature being warmer than clear sky temperature, one can easily see clouds coming into the detector's FOV and use this information to determine periods of good weather. However, the unambiguous definition of the clear sky temperature represents a significant challenge. The clear sky temperature depends on many atmospheric parameters (such as water vapor content, presence of dust and CO_2, atmospheric temperature profile etc.) Due to variations in these parameters, the fluctuations in clear sky temperature from night to night can easily reach 10°C. The uncertainty in zenith coverage for each sensor also makes their cross-calibration very difficult.

Method description

Data selection

Because it takes some time for IR sensor readings to stabilize after opening the doors, the first 30 minutes of data from each night are not taken into account in determining the "cloudless" level.

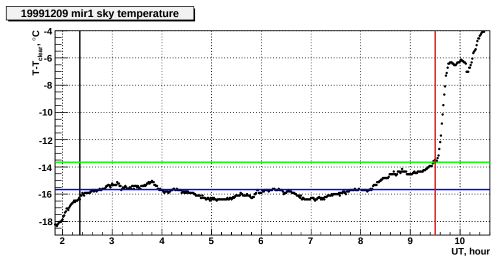

Figure 1: An example of IR readings from one of the sensors. Blue line indicates the "cloudless" level. All readings above green line considered as cloudy.

With that restriction, nights with less than 50 minutes of sensor data are thus considered useless for analysis. Additionally, if we have less than 40 minutes of data from an individual sensor for a given night, that sensor is also considered as "not working", and its readings are disregarded.

If less than half of the sensors (less than 6 out of 11) are in the working order, then that entire night is also thrown away. (Note that the absence of data from a particular sensor usually means that the associated mirror was also down. Therefore the requirement for about half of the sensors to be working also ensures that most of the HiRes1 mirrors are operational).

"Cloudless" level

The "cloudless" level for operating sensors is found by noting the minimal temperature measured by a sensor during the night and taking the average of the readings within $2.5°$C of that minimum. To avoid drops in the measured temperature due to some glitches, the minimum temperature for a given sensor is found from Gaussian-weighted average readings (sigma of 4 minutes). This approach works well when we have clear sky for at least half hour in the sensor's FOV. If "cloudless" level for an individual sensor determined using this algorithm is higher than -8°C then all readings from the sensor are considered as overcast data. With "cloudless" levels calculated in this way, all readings which do not exceed this level by 2°C are marked as clear sky (see Figures 1 and 3).

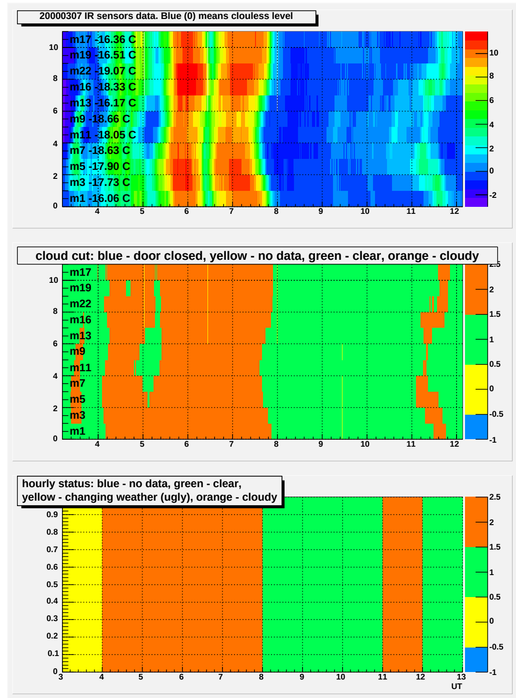

Figure 2: Partly cloudy night: IR readings from all sensors (at the top); cloud cut (in the middle); hourly cloud status (at the bottom).

Data quality

The "cloudless" levels from the various sensors are sorted each night from coldest to warmest. A general data quality value is assigned according to the "cloudless" level of the third coldest sensor. An a priori assignment of a specific reference is impractical because any sensor on any night could be off. Also, the evolution of the "cloudless" levels through seven years of observation from climatic changes, and deterioration of the sensors, makes this task impossible. The use of the third coldest sensor appears to be a safe choice; if its "cloudless" level is low enough (there was a clear sky), the next coldest sensors would confirm it. It also minimizes effects of electronics malfunctioning.

If the third coldest sensor has a cloudless level, $\mathrm{T}_{clear} < -11°$C then all data for that night are considered as overcast data (Data quality $= -1$). A value of $\mathrm{T}_{clear} < -15°$C means that we have at least 30 minutes of clear sky through the night, so that we can be confident of ”cloudless” levels obtained (Data quality $= 1$). If we have T_{clear} values between $-15°\mathrm{C}$ and $-11°\mathrm{C}$, then the weather condition are deemed uncertain (Data quality $= 0$). A data quality of -2 is assigned to short nights (total time less than 50 minutes) and those nights with less than half of the IR array working.

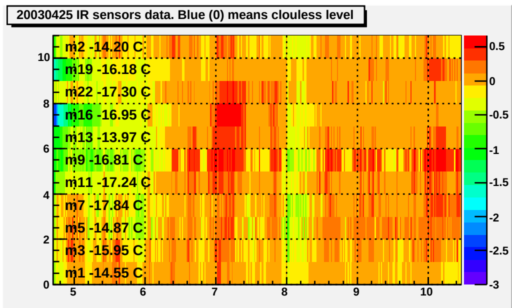

Figure 3: IR data for clear stable night.

Hourly cloud status

For each hour the clear sky readings are counted for all working sensors (along with the total number of readings).

The expression

$$\mathrm{cover} = 1 - \frac{\sum clear(\mathrm{min})}{\sum total(\mathrm{min})} \qquad (1)$$

then characterizes the cloud cover for given hour. Those hours with cover$<$0.1 are considered as clear sky hours. The value 0.1 gives some flexibility when we are dealing with ”cloudy” readings from pathological behavior of one out of 11 sensors, which happens occasionally and which is difficult to formalize and take into account. On the other hand, a 0.1 cloud cover equates to 6 minutes of clouds per sensor, which is likely to be negligible. The range 0.1$<$cover$<$0.2 is classified as ugly weather (introduced just in case somebody wants softer cuts). A value of cover$>$0.2 denotes noticeably cloudy weather.

Figure 2 shows three stages of data processing: raw IR data shifted by ”cloudless” level, selection of the readings corresponding to clear skies and assignment of the cloud cover status for each hour of observations.

Conclusion

The system used at HiRes for monitoring weather conditions proved to be inexpensive, very robust and stable in seven years of operation. A cloud cover database based on the collected IR data was created. Being superior to the visual estimates made by HiRes operators, the database provides strong grounds in selecting events for analysis.

Acknowledgments

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