Cloud Monitoring for Large Cosmic Ray Sites

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Abstract

The next generation of air fluorescence experiments requires improved monitoring of the cloud distribution in the night sky within the experimental fiducial volume. We have developed infra-red detectors which are capable of responding to cloud in daytime or night-time. We describe here the operation of wide angle detectors at the HiRes site and the development of higher angular resolution scanning detectors for imaging the cloud cover prior to triangulation between detectors to define the cloud distribution.

1 Introduction:

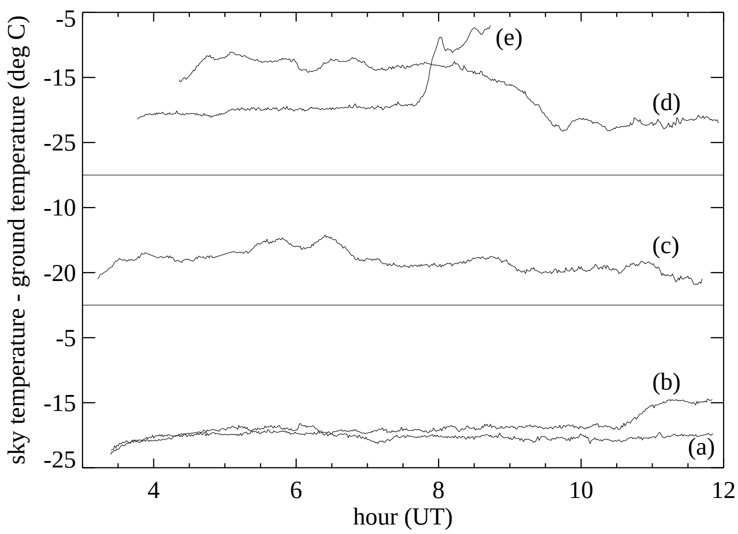

Figure 1: Examples of wide angle cloud monitor signals from Dugway in March/April 1999. Each line represents the difference between the measured sky temperature and the ground temperature. Large negative values represent clear skies. Details in Section 3.

Air fluorescence experiments with large sensitive volumes, such as those now being proposed or becoming operational, require significantly better atmospheric monitoring information than in the past. The monitoring of background cloud is an aspect of the experimental requirements which requires upgrading from past practice in which a regular, simple, operator observation of the dark night sky was considered sufficient. Current requirements for shower profile fitting require that the presence of patchy cloud be known and its spatial distribution determined.

We have been developing cloud detection systems based on far infrared sensors which respond to the relatively warm temperatures of cloud compared to the clear sky. Such detectors work equally well in daytime or at night. We have begun trial operations of two wide angle detectors in conjunction with the HiRes air fluorescence detector. These are operated to view in the directions of two of the mirror units and have enabled us to make a comparison with operator cloud information. We have also developed a narrow-angle detector with infra-red optics which is the basis of a scanning system capable of imaging the whole sky for clouds.

The actual temperature of the clouds (the parameter which is the basis of the cloud signal) depends mainly on the altitude of the cloud, the ground (or screen) temperature and the optical thickness (or emissivity) of the cloud, with some dependence on the general atmospheric humidity. There is thus reason to believe that the cloud signal also contains altitude information.

The operation of infra-red cloud detectors in high energy astrophysics has been described by Clay et al. (1998) and by Buckley et al. (1998).

2 Thermopile Infra-red Sensors:

We use thermopile infra-red sensors (EG&G Heimann TPS 534) with a sensitive area of $1.44\,\mathrm{mm}^2$ described in Clay et al. 1998. The detection system responds to the temperature difference between a sensitive thermopile element, which is in thermal equilibrium with a pre-determined field of view, and the detector canister whose temperature is measured with an internal thermistor. The passband of the detector extends through 10 microns, corresponding to the peak of the black-body curve at terrestrial temperatures. Details of the detector response depend on the fraction of that curve which is within the passband for a particular temperature and on the transmission properties of any elements between the source and the detector. We protect the detector with infra-red transmitting plastic sheets or use an infra-red fresnel lens when a narrow field of view is required.

3 Cloud Detection at the HiRes site:

The Five Mile Hill site of the High Resolution Fly's Eye consists of 22 mirror units, each viewing a region of sky roughly $15^\circ \times 15^\circ$. We have added wide angle ($30^\circ \times 30^\circ$) cloud detectors pointing in the same general direction as two of these mirror units, viewing the lowest 30° of elevation at azimuths of 188° and 220° (anticlockwise from East). These have been operating routinely since November 1998. Figure 1 shows examples of detector outputs covering extended periods of time (usually the full observing night). The plots show lines representing the difference between the sky temperature and the temperature of the detector canister, the latter being close to the ground temperature.

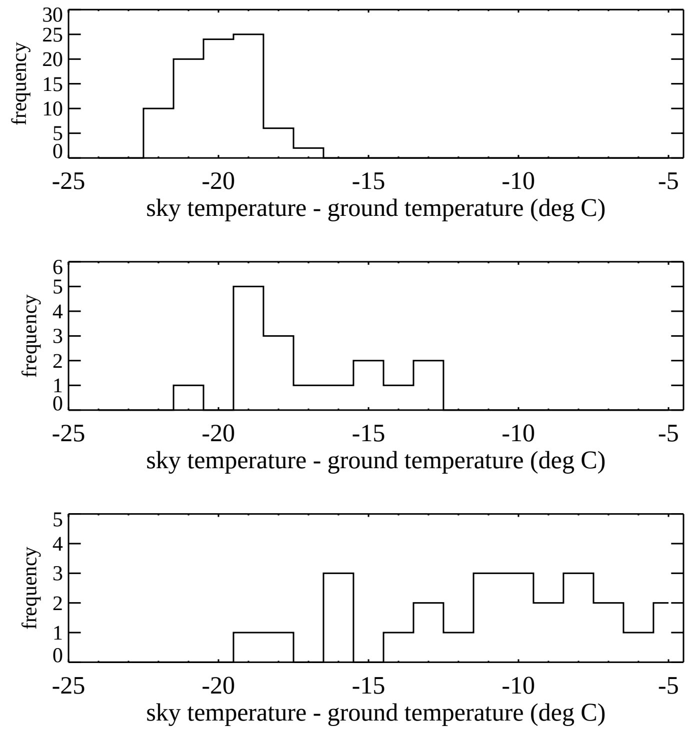

Figure 2: Difference between the sky and ground temperatures for March/April 1999 runs at Dugway. Operators classified the conditions as clear (top plot), thin cloud (middle plot) and cloudy (bottom plot).

Some aspects of these data are noteworthy: 1. Clear skies result in large differences between the sky temperature and the ground-level air temperature (the screen temperature). 2. Even apparently clear skies produce non-noise signals which are presently not understood but may be due to thin cloud, temperature variations in the atmosphere due to wind variations at altitude, or humidity variations. 3. The cloud detector data generally agree with operator observations but add significant detail.

Figure 1a is characteristic of a clear sky. The difference between the detector local thermistor temperature and the sky temperature is large and roughly constant. Figure 1b was for a clear but windy night with a little haze which increased over the period of the run. Figure 1c relates to a night with variable cloud and haze which improved over the night. The night of figure 1d was noted as partly cloudy, high clouds and a little haze. For figure 1e, the night was noted as clear with cloud in the last 20 minutes of the run. In these cases, the operator comments were always broadly in agreement with the detector information. However, the detector data contain a wealth of detail not previously available. The increase in cloud at the end of 1b was not noted, details of the time variation of the cloud in 1c was unknown, the clear sky late in the run for 1d was not noted, nor was the correct time of the cloud onset in 1e. These deficiencies simply result from the limitations of human eyes and from the inability of operators to continually monitor the atmosphere.

The operator comments do allow us to judge criteria for interpreting the cloud detector data. The detector outputs were compared to the most up to date operator comments for the March and April 1999 data every hour. Figure 2 shows an interpretation of those data. The temperature difference between the detector-measured sky temperature and the thermistor (ground) temperature is shown for three types of operator comments. That is, clear, thin cloud and cloudy. As noted above, the operator comments are not always up to date (and this was a significant cause of overlap in the data) but there is a clear separation between cloudy and clear fields of view such that discrimination criteria can readily be determined for the data set. This is particularly reassuring since the level of any cloud signal depends on the uncontrolled variables of the fraction of the field of view filled by the cloud, the emissivity of the atmosphere (which depends on the humidity) and the cloud emissivity.

4 Cloud Pictures:

Wide angle (mechanically collimated) detectors are convenient and powerful for identifying the presence of cloud but have clear limitations for determining its spatial distribution. We have developed a detector utilising an infra-red fresnel lens giving a 3° field of view. We have then used this detector at the University of Adelaide campus with a gimbal (Sagebrush Technologies) which enables us to scan the sky, sampling at three degree intervals. The time taken for such a scan is currently over 30 minutes with a possibility of reducing this to below 10 minutes. Figure 3 shows examples of such scans as images over a full hemisphere. Figure 3a corresponds to a sky free of cloud. The horizon shows city buildings, including a large tower close to the detector in the NNW direction. A further aspect of the sky temperature is evident in this plot. The clear sky is coldest near the zenith and ranges to almost ground temperature close to the horizon. This is largely an optical

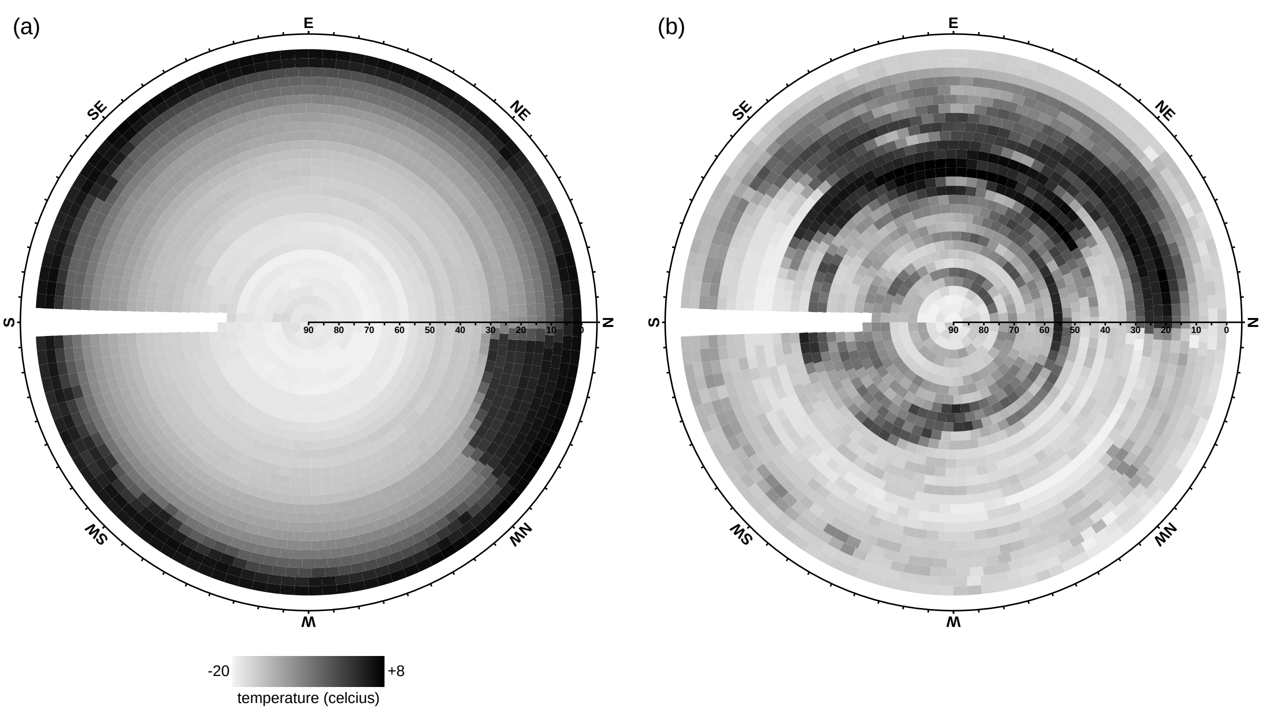

Figure 3: Sky images from scanning cloud monitor. (a) Clear sky with shading indicating sky temperature from -20 degrees C (white) to +8 degrees C (black). (b) Partly cloudy sky with clear sky zenith variation subtracted.

depth effect. On the other hand, a totally overcast sky (not shown) has a sky temperature almost independent of elevation angle (see Figure 4 below).

Figure 3b shows a scan of a partly cloudy sky. To enhance the appearance of this cloud, this plot was created by subtracting a clear sky scan from the actual scan of the partly cloudy night, thus removing the zenith angle dependence of the clear sky signal. (The actual scan and the clear sky scan were taken at times of similar ground temperature). Here cloud is seen as dark regions of the plot.

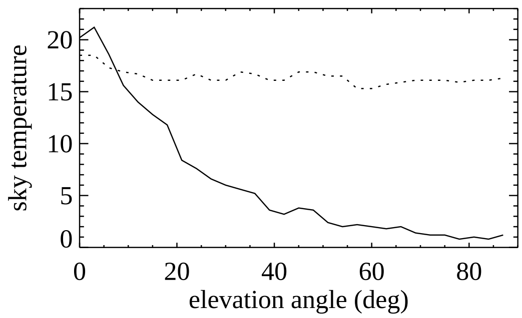

Figure 4: Sky temperature as a function of elevation angle for a clear sky (solid line) and a cloudy sky (dotted line).

Figure 4 shows the elevation angle dependence of sky temperature for a clear sky and a cloudy sky, referred to above. It shows the origin of the cloud discrimination of the cloud detector. Cloud is at a temperature rather lower than ground temperature but the clear part of the sky shows an effective temperature which falls rapidly above the horizon so that the clouds are then appreciably warmer than the background sky. The recorded cloud temperature is independent of zenith angle.

We expect that a number of sites (two or three) with scanning detectors (with possibly a number of wide angle detectors) will enable the horizontal spatial distribution of the cloud to be determined.

5 Cloud Altitude Determination:

The temperature of the atmosphere decreases with increasing altitude at a lapse rate which is (for an ideal dry atmosphere) close to 10K per kilometre. This means that a determination of the temperature of a cloud, and the assumption that it is at the temperature corresponding to the surrounding air, allows one to estimate the altitude of the cloud and to add a third dimension to the cloud spatial information discussed above.

For this technique to be reliable, one must estimate the cloud emissivity (close to 1.0 for thick cloud, but very different to 1.0 for thin cloud) and one must know the actual lapse rate on the night in question, which will be affected by the water content of the atmosphere.

Work is in progress to see how feasible it will be to estimate cloud heights from our cloud monitor data. We are investigating correlations between cloud heights based on our cloud temperatures and cloud heights estimated from radiosonde soundings taken at Adelaide every 12 hours. We are also planning comparisons with an infra-red lidar measurements of cloud height. It is likely that we will have some success with relating the temperature of optically thick cloud to its height, but it will be more difficult with thinner cloud.

6 Conclusions and Acknowledgements:

We have developed infra-red cloud detectors capable of automatically recording cloud conditions at cosmic ray air fluorescence sites with better precision than previous techniques. Those detectors have been developed to produce all-sky cloud images capable of determining the spatial distribution of clouds when using a number of detectors. The technique may also be capable of producing useful cloud altitude estimates.

Our colleagues in the High Resolution Fly's Eye Collaboration are thanked for their support for this work including operational support at the Dugway site. The gimbal used for scanning the sky was on loan from the University of New Mexico.

References

Clay, R.W. et al. 1998, Publ. Ast. Soc. Aust. **15**, 332

Buckley, D.J. et al. 1998. Preprint, astro-ph/9810496, submitted to Experimental Astronomy.