Studies of the Mysterious Late-Night Rate Increase and the Estimation of Backgrounds in Milagro

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Significant rises in the Milagro shower-layer PMT low-threshold scaler rate lasting ~10 hours have been observed during the winter months. Accompanying the rise in the scaler rate is a rise in the trigger rate. The only correlation that could be uncovered for this increase was with temperature - the increase appeared to occur when temperatures (outside and inside the counting house) got cold. Further study eliminated temperature effects in the counting house, ground-loop problems, the UPS system, and many other possibilities. The remaining cause must be the outside temperature.

In mid-February, the idea was floated (pardon the pun) that the culprit is a thin layer of ice forming on the top of the water on cold, clear nights. In this model, the ice eliminates the optical contact between the cover and the water, dramatically increasing the total internal reflection of upward-going light. If this theory is correct, the rate increase should have the following properties:

1) The increase should occur on clear, cold nights (after the pond water temperature has cooled to near freezing).
2) The increase should only occur when there is no water on the cover (so that the cover and the water just beneath it are in thermal contact with the night sky).
3) The low-threshold shower-layer scalers should show the largest increase; the high-threshold scalers and the muon layer should have much smaller increases.
4) The events responsible for the increased trigger rate should come primarily from large zenith angles (>50°), which produce upward-going light. Note that this property is smeared out somewhat due to multiple scattering of the shower electrons producing the Cherenkov light.
5) There should be an increased late-light tail for events during the rate increase, especially at large zenith angles. This tail should only be apparent in PMTs with low pulse heights as PMTs with high pulse heights have predominantly registered prompt light from nearby shower particles.

In his logbook entry of Feb. 21, 2000, David Williams reports evidence supporting the ice theory, namely correlations between rises in scaler rates and the absence of water on top of parts of the cover: this addresses properties (1) and (2) above. More recently, Don and Linda have written a memo describing some physical tests that also seem to confirm this theory.

This memo presents evidence related to points (4) and (5) above. A disquieting conclusion is that one of the basic assumptions of all of our techniques of background estimation may not always be correct.

Comparison of "No-Ice" and "Ice" Data

We have analyzed data from January 24, 2000, which had a large event-rate rise at night. The "no-ice" data had an event rate of 1175 Hz, while the "ice" data, after the rate increase, had a trigger rate of 1456 Hz. Figure 1a shows the zenith-angle distributions for these data normalized to the same live time. It can be seen that there is a small (~10%) increase in the number of events below 45° for "ice" data but a much larger (~35%) increase above 50°. Figure 1b shows the same data normalized to the same total number of events. From this plot it is apparent that the angular distributions have the same shape below ~45° but the high-rate data is significantly flatter for larger angles. This agrees with our expectation (4) above.

Figure 2 compares the tchi distributions for PMTs with low pulse heights (<1.5 PEs) for "no-ice" and "ice" events with small zenith angles and events with large zenith angles; the distributions are similar for the small-angle data but the "ice" data has a much larger late-light tail (tchi <0) at large zenith angles. Figure 3 shows the tchi distributions for PMTs with large pulse heights (>10 PEs); the "no-ice" and "ice" distributions are quite similar. This agrees with our expectation (5) above.

These results further confirm the "ice" theory of increased event rate on cold nights. In this theory, the increased event rate is caused by a large increase in the probability of reflection by the cover of upward-going light produced by large zenith-angle showers.

Background Estimation in Milagro

Several methods of background estimation have been used in Milagrito and Milagro analyses. Two of these, time-sloshing and direct integration, have been recently described in a memo dated 7/7/99 by Andy Smith "Search for Point Sources and Emission from the Galactic Plane in Milagrito." The fundamental assumption in these methods was discussed in Alexandreas *et al.*, NIM **A328**, 570 (1993). The number of background events expected to fall within a given (RA, δ) bin is:

$$N_b = \int\int\int \varepsilon\, R(\theta, \phi, t)\, d\cos(\theta)\, d\phi\, dt,$$

where $R(\theta, \phi, t)$ is the background event rate per solid angle as a function of local zenith angle, θ, local azimuthal angle, ϕ, and time, t. $\varepsilon = 1$ when θ, ϕ, and t are such that they fall within the given (RA, δ) bin and $\varepsilon = 0$ otherwise. The fundamental assumption made is that the local-angle dependence and the time dependence of R are independent for the period of time over which the background is estimated:

$$R(\theta, \phi, t) = E(\theta, \phi)\, \mathcal{R}(t).$$

The local-angle dependence is obtained from the actual distribution of events (either by time sloshing or by constructing an event map) and the time dependence is obtained from the event arrival times. One typically obtains $E(\theta, \phi)$ for ~2-hour periods, to obtain good statistical accuracy in the efficiency map. Figure 1 illustrates a situation in which $E(\theta, \phi)$ is certainly not constant over 2-hour periods. Thus this leads to a systematic error in the background estimates for these periods. The size of the error depends on the source location during these periods and where the time of the change occurs relative to the 2-

hour period. It would be worthwhile to estimate this with a Monte Carlo simulation. This would tell us how important it may be to devise methods to avoid this problem next winter.

Another situation that might lead to a rapid change in $E(\theta, \phi)$ is when the HV for a patch trips off because of a bad PMT. We have examined several instances in which a patch went off and see no change in either the zenith-angle or azimuthal-angle distributions - of course, the event rate changes, but this is taken care of in the background estimation procedure.

Conclusion

A study of the zenith-angle and Tchi distributions before and after the late-night event-rate rise lends further support to the theory that the rise is due to a layer of ice forming on the water surface. The change in the zenith-angle distribution implies that the background is not correctly estimated during these periods. An examination of data before and after the HV for a patch goes out reveals no appreciable change in $E(\theta, \phi)$.

This brings to mind several recent cautions by Todd of possible systematic errors in our background estimation.

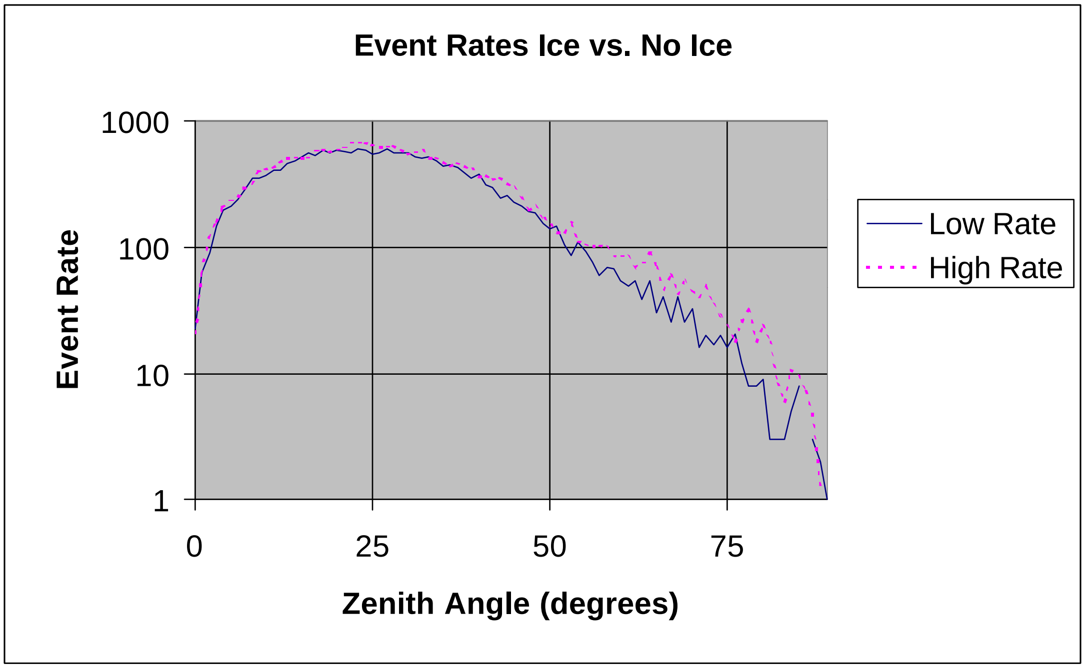

Figure 1a: The Event Rates at low and high trigger rates vs. zenith angle. The data are normalized to the same live time.

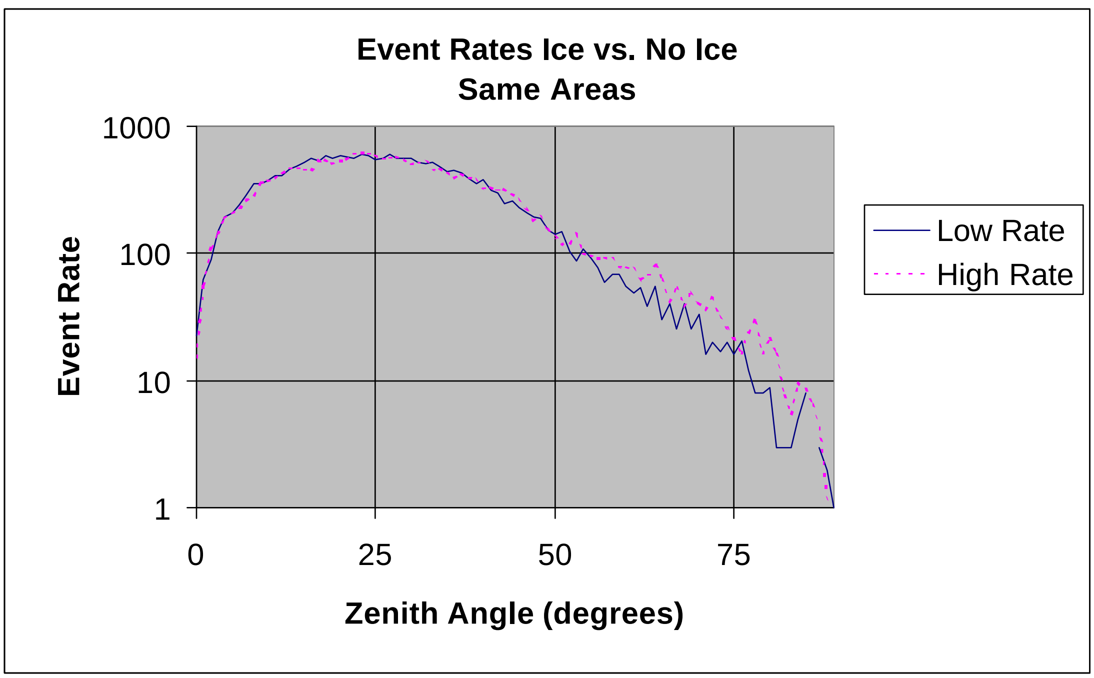

Figure 1b: The Event Rates at low and high trigger rates vs. zenith angle. The data are normalized to the same area.

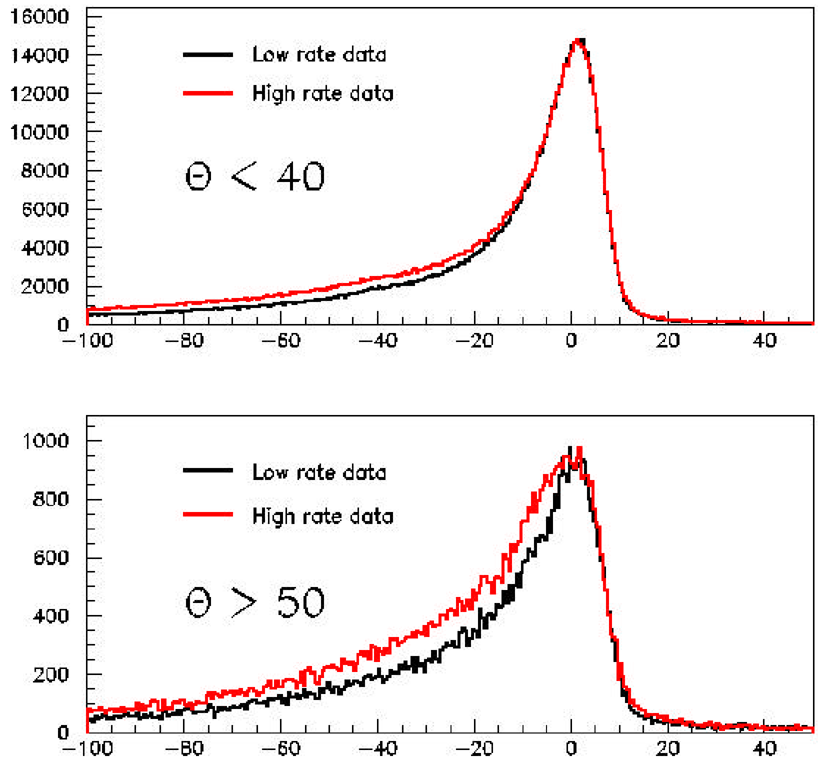

Figure 2. The Tchi distributions for events with low pulse heights (< 1.5 pe) for events at low rate ("no ice") and high rate ("ice"). The abscissa is time in ns, with early times to the right. The ice and no-ice data have been normalized to have the same peak heights.

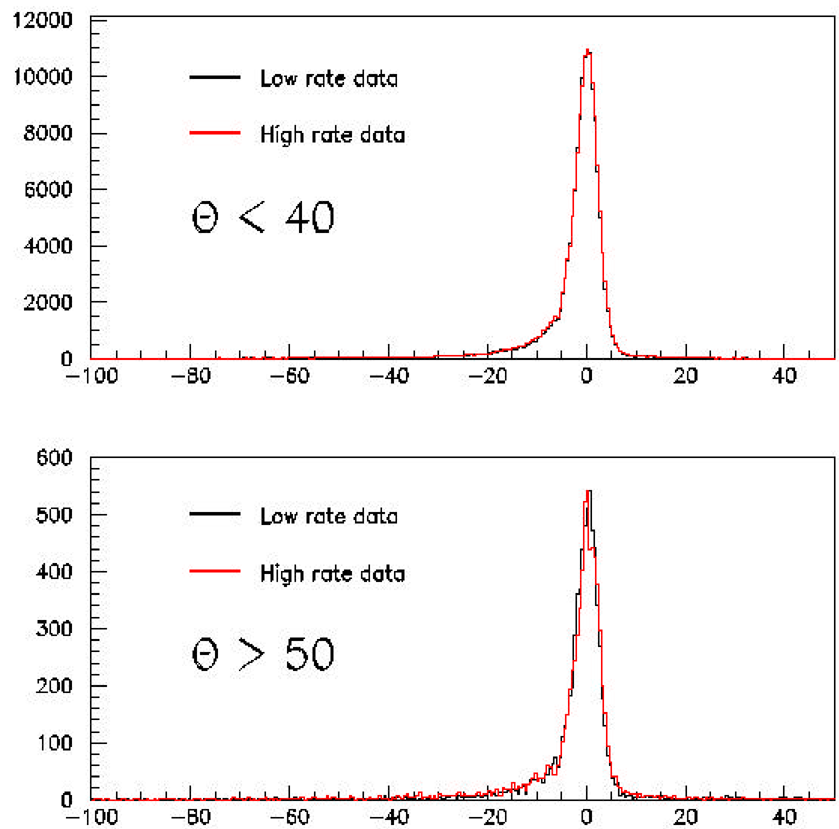

Figure 3. The Tchi distributions for events with high pulse heights (> 10 pe) for events at low rate ("no ice") and high rate ("ice").