South Pole Neutron Monitor Lives Again

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Abstract: The neutron monitor at Amundsen-Scott station at South Pole was reactivated in February 2010 after a four-year, three month gap, and has since been equipped with an enhanced array of "bare" neutron detectors. We discuss capabilities of the new installation and present results of our efforts to normalize the new data to the old. In light of these new results, the long-term decline in the South Pole neutron rate is more puzzling than ever.

Keywords: Solar Energetic Particles; Modulation

1 Introduction

The neutron monitor at Amundsen-Scott station at South Pole was reactivated in February 2010 after a four-year, three month gap, and has since been equipped with an enhanced array of "bare" neutron detectors.. The new configuration will greatly enhance the ability of IceTop, the surface component of the IceCube neutrino observatory at the South Pole, to determine spectra and element composition of solar energetic particles in the energy range 1-10 GeV. This was accomplished by recycling many components of the former South Pole neutron monitor to construct an enhanced suite of neutron detectors whose response functions (primarily due to hadrons) have a different dependence on energy and element composition from those of IceTop (primarily due to photons and leptons).

2 Hardware Configuration

CosRay at Pole had its origins in 1964 as a neutron monitor installed by Martin Pomerantz and is still often referred to simply as "the neutron monitor" but CosRay has been reinvented and reinvigorated several times over the years. In contrast to investigations that seek to extend the range of IceCube to higher energy, CosRay works with IceTop to extend the energy range to lower energy (1-10 GeV) primarily to study the acceleration and transport of solar energetic particles. Most of the processes invoked in acceleration models for high energy astrophysical particles also occur on the sun but at different scales.

Even though the sun is much closer, and many independent acceleration episodes have been observed, there is still much that is not understood about both acceleration and transport of the energetic particles. Although it now works closely with IceTop CosRay is funded separately by NSF as event A-118-S.

Figure 1: CosRay 3NM64 in present location at Amundson-Scott South Pole Station

A neutron monitor is actually an air shower experiment like IceTop but with one key difference – the "air showers" are originated by low energy (typically 1-10 GeV) particles that produce only one secondary at the detector.

Spacecraft instruments are elegant examples of design that return fantastically detailed information on particle intensity and spectrum. Unfortunately they are almost invariably small and even in principle cannot detect enough particles significantly above 1 GeV to be useful to study transient events (e.g. solar flares). Although surface detectors are crude by comparison they can be made large and thus offer excellent event timing. Some spectral information can also be extracted from the data.

There are two types of neutron monitor now operating at Pole. Both use ^{3}He filled proportional counters that detect neutrons via the fission reaction $n + {}^3He \rightarrow p + {}^3H$. Three standard monitors (NM-64) are installed on a platform located between the station and the clean air facility (Figure 1). NM-64 have the proportional counters embedded in layers of lead and polyethylene. Their peak response is to 100 MeV hadrons (mostly neutrons but also protons) that interact with ^{208}Pb to produce multiple low energy "evaporation" neutrons which "thermalize" in the polyethylene and are ultimately detected by the proportional counters. On the mezzanine in B2-Science is an array of twelve unleaded (or bare, hence "Polar Bare") detectors (Figure 2). Ten of these detectors are completely unmoderated while two are installed in paraffin moderators. Tests at the South Pole show that there is little difference in the counting rate of moderated and unmoderated detectors and calculations indicate that there should be little difference in the energy response. However the moderated detectors shown in the figure have precisely determined (sea level) response functions due to their inclusion in a latitude survey conducted aboard the icebreaker Oden during 2009 and 2010. Results of that calibration are being prepared for
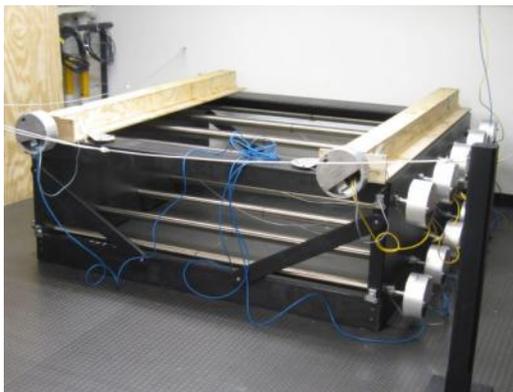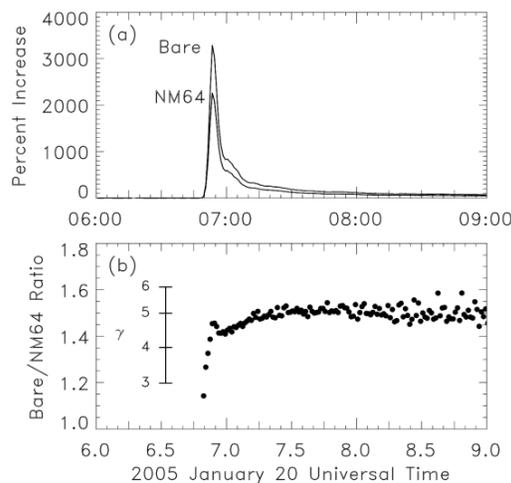

Figure 3: Determining solar particle energy spectrum with neutron monitors.

spectral index under the assumption that the spectrum is a power law in momentum.

In contrast, the "Cherenkov tank" detectors of IceTop produce analog signals that carry more information on the incident particles. One tank in effect has a whole series of response functions, each corresponding to a particular signal threshold, and all of the responses can be measured simultaneously. This allows extraction of a more precisely determined spectrum than can be obtained from the monitors.

Figure 2: "Polar Bare" installation

publication.

3 Solar Particle Composition

Because the Polar Bares and NM64 have different response functions the ratio of their counting rates reflects the incident particle spectrum. The top panel of Figure 3 shows the increase in counting rate of both types in response to a large solar flare. The lower panel shows the ratio of the increases along with a scale that gives the
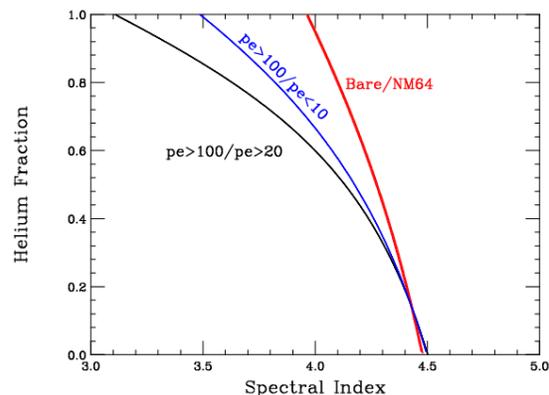

Figure 4. Determining solar particle element composition.

Although the monitor response functions are similar to the lowest energy IceTop response function, they have a crucial difference in shape that enables determination of the composition of solar energetic particles which has heretofore never been measured at GeV energies. Solar particle composition is extremely variable at lower energies, with different particle species often having significantly different spectral shapes; simple extrapolation is essentially meaningless.

Unknown composition has traditionally been an important source of error when measuring the spectral index using neutron monitors alone. Figure 4 shows a simulation based on the spectral index and intensity of the large solar flare of 20 January 2005, under the assumption that the particles have the same composition as "galactic" cosmic rays. Considering the neutron monitors alone, any point on the Bare/NM64 curve is equally allowed – in other words the deduced spectral index can range from 4.0 to 4.5 depending on the actual composition. Statistical errors (+/- one sigma) are represented by the line thickness.

The situation with IceTop is somewhat better because several (in fact multiple) ratios can be formed using the set of response functions. The other lines in Figure 4 correspond to ratios of count rates formed from the indicated thresholds which are expressed in terms of signal amplitude measured in detected photoelectrons. Over some of the parameter space, requiring agreement of the spectral index and composition measured by all of the separate thresholds concurrently could resolve the ambiguity. However the various curves all tend to converge in what is the most likely region of parameter space – a helium abundance of 10% or less.

Critically, when the two types of detector are operated together the ambiguity is resolved. The IceTop and CosRay lines have a well defined intersection at the correct (i.e. simulation input) values of spectral index and helium fraction.

4 Long Term Decline

Recently Bieber *et al.* [1] published a discussion of an enigmatic decline in the counting rate of the former neutron monitor at South Pole. This paper was featured in the "Editors Choice" column in Space Weather Quarterly [2]. Our specific conclusions were (a) that there is no explanation internal to the instrumentation for the long term decline in the monitor counting rate and (b) the energy response of this monitor was sufficiently unique that it could have observed a decline in galactic cosmic rays over an energy range where no other detector could either confirm or refute the observation. (See also [3])

As illustrated in Figure 5, most neutron monitors return to approximately the same count rate from one solar minimum (cosmic ray maximum) to the next. However the South Pole monitor displays a remarkably different behavior consistent with a steady long-term downtrend. Even the monitor at Mt. Washington (not shown), which is perhaps most comparable to South Pole in terms of cutoff and altitude, displays no such marked downtrend [4].

In the past we presumed this anomalous downtrend at South Pole was artificial and resulted from some unknown instrumental instability perhaps related to the harsh Antarctic environment. In our paper [1] we reevaluated this presumption based upon recent reports of long-term secular changes in the primary cosmic ray flux.

In summary, we were not able to identify definitively any instrumental or environmental effect that could cause the long-term decrease in the South Pole neutron rate.
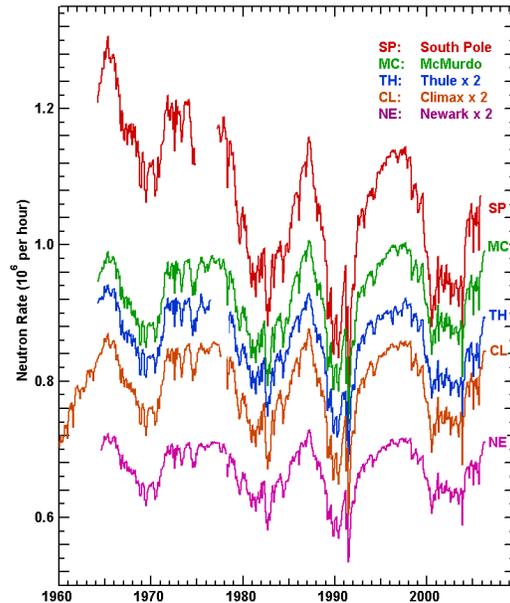

Figure 5. Time history of several neutron monitors counting rates.

There was however one possibility that we were not able to quantify to any significant degree. The neutron monitor was formerly located approximately 30 meters from the iconic "dome" structure that formerly housed the Amundsen-Scott Station and ten meters from the "Skylab" building (Figure 6). Both structures remained in place over the lifetime of the NM64 monitor, but snow gradually built up around them. The monitor platform was raised several times to keep the monitors themselves above the snow. Thus there were two changes in the

Figure 6. Former location of the 3NM64.

environment of the monitor, namely it rose with respect to the structures, and large voids developed in the snow close to the monitor. We had no specific evidence that this process affected the count rate of the monitor, and in fact no reason to believe that there would be such an effect based on some simple numerical simulations. We also noticed no change in the count rate of the detector located on the side facing the dome relative to that on the outer side.

Restarting the monitor in a new location, approximately half way between the station and the Clean Air facility, allowed us to investigate this environment issue directly. This test was complicated because all of the cabling from the old platform had been removed. It was therefore impossible to (economically) restart the monitor in the old location before moving it. Instead we constructed insulated housings for the neutron detector electronics and a battery powered data acquisition system housed in an insulated container. When these detectors were installed in the NM-64 shell the configuration was non-standard, but could be exactly reproduced at the old and new locations. The test at the old location took place in 25 November 2009 and at the new location 25 January 2010.

	25 November 09	25 January 10
Measured Rate	350.57/s	323.83/s
Barometer	511.99 mm	520.52 mm
Detector Temp.	-29.5 C	-17.4C
McMurdo Monitor Count Rate	10450	10350
Correct barometer to 510.0 mm	1.01984	1.10941
Correct temperature to -10 C	1.01716	1.00651
Correct modulation to 25 January	0.9856	1.0000
Corrected Rate	358.424	361.599

The table above summarizes the data for both locations, followed by the correction factors for differences in barometer, temperature, and modulation level. The barometer and temperature corrections are done using our standard procedures. The modulation correction was derived from a linear regression of the South Pole and McMurdo

monitors for a two month period after the Pole monitor had been restarted in its standard configuration.

The primary conclusion is that the difference in counting rate is approximately 1% and therefore the long term decline reported by Bieber et al. [1] cannot be explained by the presence of the Dome. Indeed the difference of only one percent speaks to the general issue of neutron monitor stability. Unless some unforseen effect is identified in the future, it would appear that the origin of the decrease must be a change in the Sun or solar wind, with an attendant change in the strength of solar modulation of cosmic rays [5,6,7,8] or possibly a change in the local interstellar density of Galactic cosmic rays [9].

Acknowledgements

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