Spring 2019

Normalization of Leadville Neutron Monitor to Climax Neutron Monitor

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Friday, May 24, 2019

1. Introduction

UNH began using neutron monitors to study cosmic ray activity soon after their introduction in the early 1950s. One of the earliest detectors was installed at the Climax molybdenum mine in Leadville, Colorado in 1953. The monitor continued to record data until 2007, when it was decommissioned and later replaced by a new monitor in the town of Leadville proper in 2009. The Climax monitor provided one of the longest running continuous sets of cosmic ray data available, covering a period of over 50 years. The relative geographic proximity of the new monitor at Leadville presents an intriguing opportunity. By comparing known steady periods of cosmic ray flux, a calibration could be created between the currently active monitor and the old Climax station, allowing for the data from both monitors to be connected into a single continuous record of cosmic ray activity reaching from the early 1950s into perpetuity.

Cosmic rays are energetic particles that permeate space, originating at both the sun and far more distant stars and supernovae. Galactic cosmic rays, those originating from outside our solar system, constantly impact the earth's atmosphere, but are moderated and diverted by two magnetic fields, the earth's and the sun's. The earth's magnetic field results in a latitudinal variation in cosmic ray flux, with locations closer to the poles experiencing higher fluxes, and the opposite for locations closer to the equator. The sun's magnetic field creates a time dependence for cosmic ray flux. The solar magnetic field follows the 11 year sunspot cycle, become more intense with more sunspots, and less intense with less sunspots. The more intense the sun's magnetic field, the more cosmic rays are diverted from impact the earth. This results in cosmic ray flux tracking inversely with sunspot number and overall solar activity over time.[1]

Cascades occur when a cosmic ray does finally impact the earth's atmosphere. The cosmic ray impacts a molecule in the atmosphere, shattering it into various energetic particles, which have their own collisions and so on. These cascades or air showers continue towards the ground, where energetic nucleons begin to impact the lead producers of neutron monitors, beginning the detection process.[2]

The detector used by the Climax and Leadville Neutron Monitors is an NM64 Boron Trifluoride detector. The detector consists of 3 components: a lead producer, a moderator, and counter tube. The lead producer is a layer of lead wrapped around the counter tubes, used to increase the number of neutrons that could be connected. The large cross section of lead atoms gives the best odds of producing collisions with incoming cosmic ray secondaries. These collisions result in ~15 evaporation neutrons each, greatly increasing odds of detection. Wrapped around each counter tube, shielding it from the lead producer, is the moderator. Consisting of water and polyethylene in the NM64 monitor, the moderator uses nucleon collisions to reduce the energy of incoming evaporation neutrons to thermal energies. Collisions between particles of similar mass will result in the most effective energy reduction, hence polyethylene is used to provide hydrogen atoms for the evaporation neutrons to collide with. At the center of the monitor is the counter tube. This tube contains Boron Trifluoride, which is ionized by the incoming thermal neutrons.

$$^{10}\text{B}_5 + n \rightarrow ^7\text{Li}_3 + ^4\text{He}_2$$

[1] Neutron Monitor Database http://www01.nmdb.eu/public_outreach/en/02/

[2] Neutron Monitor Database http://www01.nmdb.eu/public_outreach/en/03/

This ionization is then measured and registered as a count by the detector. The count rate is then averaged over a ten second period and recorded. This count rate, though passed through several steps, is directly correlated to the cosmic ray flux at the top of the atmosphere above the detector.[3]

2. Method

The geographic proximity of the detectors is key in making such a calibration possible. Neutron monitor count rates can be affected by both longitude and latitude, as a result of earth's magnetic field, and altitude, as a result of the cascade effect. While latitudinal changes are consistent and can be accounted for, longitudinal changes are effectively random due to slight changes in the earth's magnetic field, and can result in otherwise nonsensical variations in geographically separated monitors.

First proper points for comparison between the two monitors had to be found. The two monitors we care comparing were never active at the same time, so points of comparison had to be found with as little interference as possible. The primary source of interference for galactic cosmic rays is the sun's magnetic field, the strength of which tracks with the sunspot cycle. Therefore the weaker the sun's magnetic field, or the less sunspots there are, the less affected the cosmic ray flux. We should find at each minimum of the solar cycle a peak in neutron monitor count rates, and these peaks would provide a basis for comparison.

Using sunspot numbers from SpaceWeatherLive[4], I determined solar minima to

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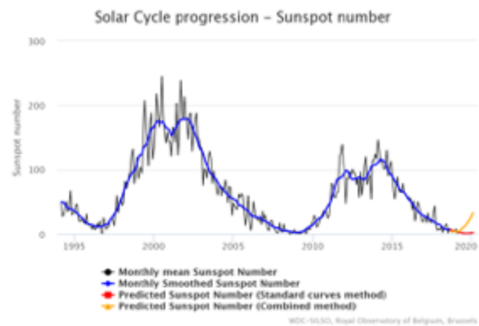
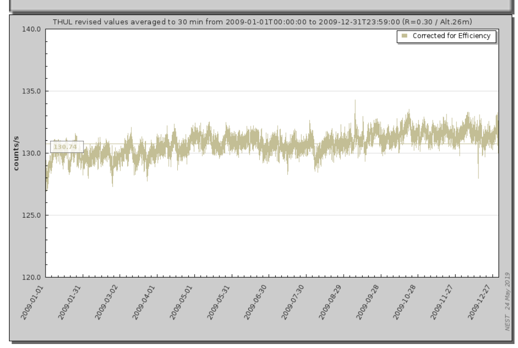
[3] Neutron Monitor Database http://www01.nmdb.eu/public_outreach/en/04_nm/

[4] Space Weather Live https://www.spaceweatherlive.com/en/solar-activity/solar-cycle

occur in 2008 and 1997, which would be our comparison periods for the Leadville and Climax monitors respectively. The Leadville monitor was turned on in 2009, meaning it caught the tail end of the minimum.

To check that count rates should be stable, I checked neutron monitor data from 2009 through the Neutron Monitor Database, particularly the JUNG and THUL monitors.[5] These two monitors confirmed that count rates were stable throughout the year and there was no significant solar interference, despite being the tail end of the solar minimum.





Before a comparison could be made, the raw count rates from Leadville had to be corrected for atmospheric pressure. This is because the atmospheric pressure changes the effect altitude has on count rates through the air shower process, so all monitors are corrected to sea level to account for these differences using the following equation:

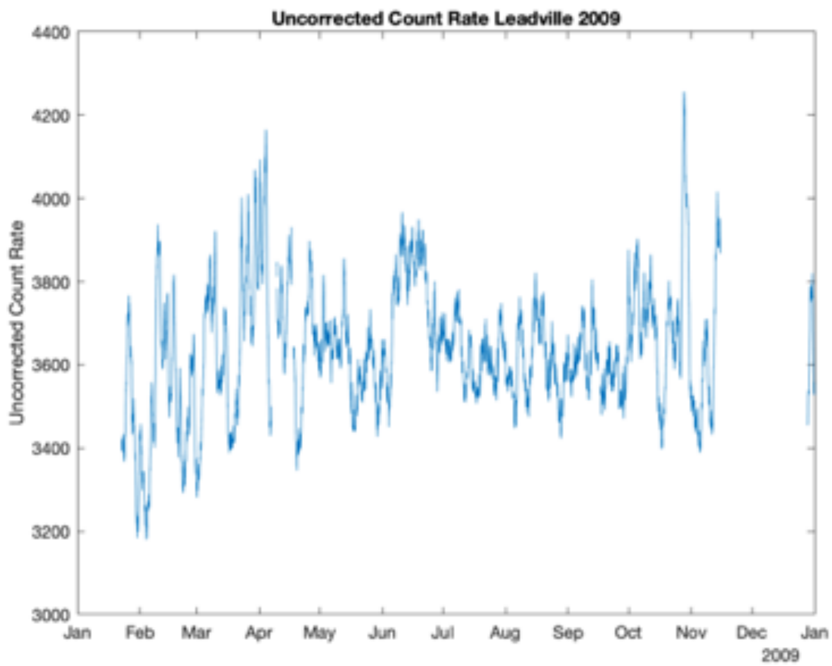
$$C = C_0 \frac{P - P_0}{138.2}$$

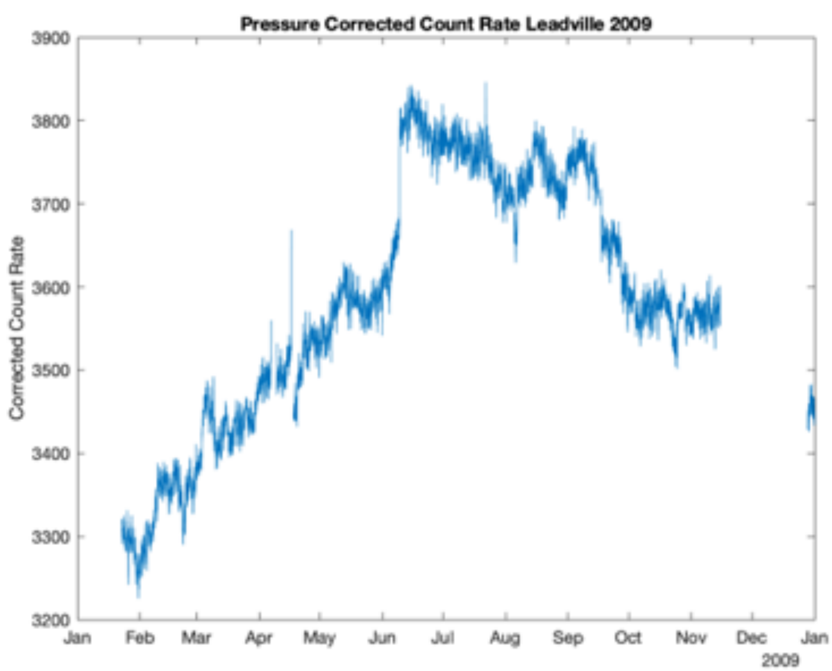
where C_0 is the raw count rate, P is the atmospheric pressure in millibars, and P_0 is

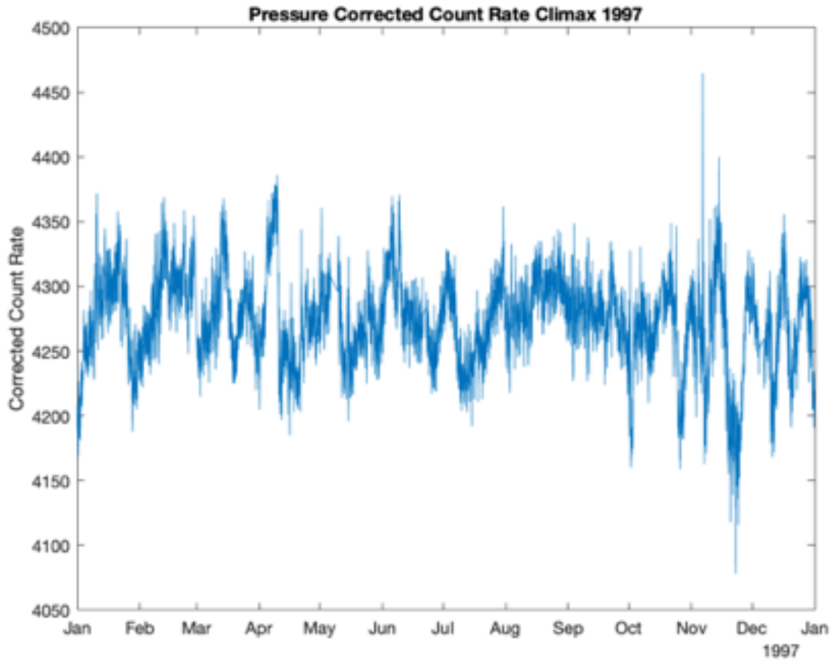
[5] NMDB Event Search Tool http://www.nmdb.eu/nest/search.php

the standard air pressure at the monitor's altitude. According to the *US Standard Atmosphere* this pressure for Leadville is 698.85 mbar. This same correction is not necessary for the 1997 Climax data, as it was provided pre-corrected. The uncorrected and corrected Leadville data can be seen below.

3. Data







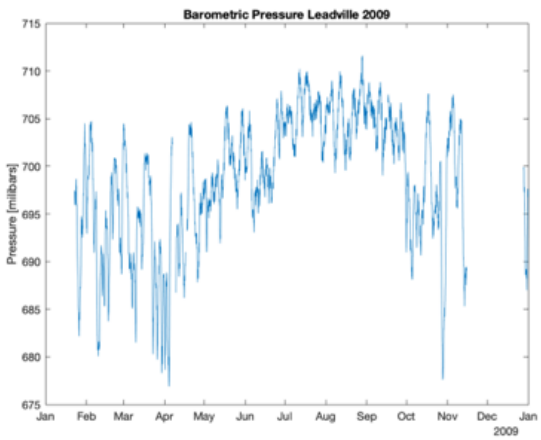
4. Discussion

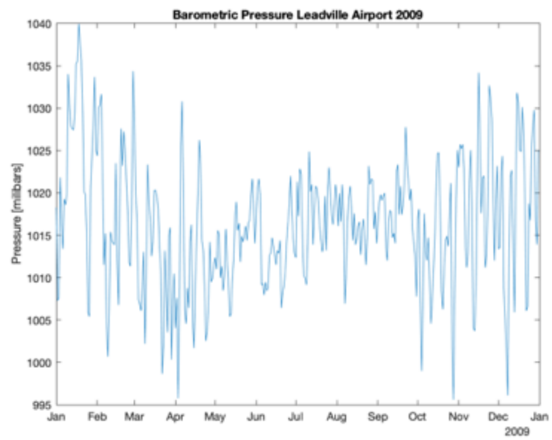
A fairly obvious flaw presents itself in the corrected Leadville data. While the point to point noise is tightly contained, a pronounced bulge in the count right exists right in the middle of the year. This cannot be reflective of actual count rates or cosmic ray flux, going by the records of the two other stations shown above. Additionally the climax data presents no such bulge in 1997, though this comparison is not one to one.

It is entirely possible the deviation could be cause by an inaccurate barometer. I compared the pressure measured on the barometer at the Leadville station to the recorded barometric pressure from the Leadville airport, shown below.[6] While similarities exist between the two in short term patters, the larger trend of the

[6] WeatherUnderground https://www.wunderground.com/history/daily/us/co/aspen/KASE/date/2009-1-1

pressure peaking in the middle of the year does not seem to occur by the airport's records. This difference would explain the bulge in the corrected count rate. It is also possible that seasonal temperature variations, so far not corrected for, could be the source of the inconsistent pattern.





5. Conclusion

The most immediate next step is going ahead with creating a normalization between the corrected Leadville and Climax data, despite current discrepancies in the Leadville correction. I would then compare the normalized Leadville 2009 count rate to other solar minima measured by climax to ascertain the validity of the normalization.

Beyond this it would be beneficial to investigate other sources of error in the Leadville data, such as temperature, alluded to above. At the very least eliminating other potential causes would aid in resolving the barometer issue.

Once all necessary corrections have been applied to resolve the bulging problem, a true normalization can be created and applied to all current Leadville data, as well as all future data. By connecting the Leadville monitor to the Climax monitor, we can assemble a record of cosmic ray and solar activity stretching back nearly 70 years, and hopefully many more decades to come. Such data will be instrumental in our understanding of the sun and the health and safety of countless aerospace crews.