Seasonal Variations in Muon Rate or Climatology With IceCube?

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Past Studies

- Seasonal variations in muon rate have been documented since 1952, first published in a paper by Barrett et al.
- In 1999, Adam Bouchta published a paper on seasonal variations using AMANDA data.
- AMANDA data documented the effect for part of the year, but not all.
- Also, data was averaged into one-week bins for the AMANDA studies, decreasing quality of the fit.
Past Studies

Henrike Wissing used AMANDA data to document the effect for data from 2000-2003. She found a strange peak in the trigger rate towards the end of 2002.
Past Studies

- Henrike found that in mid-late September of 2002, the ozone hole over the south pole split due to chlorine and bromine compounds in the atmosphere.
- Tracking seasonal variations is also a good measure of how well our detector responds to known phenomena.
Why does the Muon Rate Vary?

- **Summer:**
  - Air density is low, atmosphere is tall.
  - Pions, Kaons have a greater likelihood of decaying into Muons.

- **Winter:**
  - Air density is high, atmosphere is shallow.
  - Pions, Kaons will be more likely to lose energy through interaction before they decay.

- The relative Muon rate has been found to vary linearly as a function of relative effective temperature:

\[
\frac{\Delta R_\mu}{\langle R_\mu \rangle} = \alpha \frac{\Delta T_{\text{eff}}}{\langle T_{\text{eff}} \rangle}
\]
Effective Temperature

- The atmosphere is not isothermal.
- Effective temperature [°C] is a single value which summarizes atmospheric conditions throughout the entire atmosphere.
- The effective temperature integral takes into account temperature as a function of slant depth [X] as well the attenuation length of pions and nucleons.
- Slant depth is a column density of the atmosphere, in units of g/cm².

\[
T_{\text{eff}} = \frac{\int_0^\infty \frac{dX}{X} T(X) e^{-X/\Lambda_\pi} - e^{-X/\Lambda_\nu}}{\int_0^\infty \frac{dX}{X} e^{-X/\Lambda_\pi} - e^{-X/\Lambda_\nu}}
\]

\[
X = \int_{h_0}^\infty \rho(h) dh
\]
Effective Temperature

- Weather data is taken by daily balloon flights at the south pole.
- As the weather balloon ascends into the atmosphere, it takes readings on pressure and temperature every two seconds.
- This detailed information on temperature and pressure makes numerical integration for effective temperature easy.
Effective Temperature Throughout The Year

- Not all balloon flights give good results, some balloons explode early or stop sending data.
- Bad balloon flights can be selected and removed by assessing the last pressure value read.
- If the last pressure reading is lower, the balloon achieved a greater altitude.
- The bottom plot shows all balloon flights that reached 55mbar of pressure or lower, implying higher flights.
Uncut

Cut: Flights reaching 55mbar
The DST data I am using starts as many subruns per day, each with their own mean event rate.

A daily mean event rate is obtained by a Gaussian fit over the event rates for each subrun.

The plot shown contains one data point for each subrun.
Plotting relative rate and effective temperature variation vs. day, we can see that there is a strong correlation between the two.

There are many places where a jump in temperature matches a jump in rate.

There are some jump discontinuities in the rate data, we believe these come from changes in calibration.

The weather data becomes unstable in the spring. Due to the rapid warming of the spring, the rate data remains more stable than the weather data.
Relative Rate vs. Relative Temp

- Recall that:
  \[
  \frac{\Delta R_\mu}{\langle R_\mu \rangle} = \alpha \frac{\Delta T_{\text{eff}}}{\langle T_{\text{eff}} \rangle}
  \]

- The slope of the plot at right will be equal to \( \alpha \), our temperature coefficient.

- The plot at right shows two fit lines with:
  \[
  \alpha_1 = 0.75469 \pm 1.34354 \\
  \alpha_2 = 0.79689 \pm 0.02816
  \]

- These slopes are similar, but with different offsets.

- The change in line offset is caused by a change in trigger threshold level.

- Further, the slope of the more robust \( \alpha_2 \) line is within the error on \( \alpha_1 \).
Residual Values

- The uppermost plot at right is a zoomed view of the DST trigger rate vs. Days since 01/01/07.
- The lower plot shows the residual:

\[ \delta = \frac{\Delta R_\mu}{\langle R_\mu \rangle} - \alpha \frac{\Delta T_{\text{eff}}}{\langle T_{\text{eff}} \rangle} \]

- From these plots, one can clearly see that the change occurs around day 250, exactly the time of the threshold adjustment.
Future

• The temperature coefficient, $\alpha$, has been found to vary with energy threshold and zenith angle:

$$\langle \alpha_r \rangle = \frac{1}{\left(1 + \frac{\gamma}{\gamma+1} + \frac{\epsilon_\pi}{1.1E_{th}\cos \theta} \right)}$$

• Our future goal is to investigate energy and zenith dependencies of temperature effect with IC-40 data.

• DST data will allow us to do this because, though reduced, it still contains zenith and nChannel information.
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