Cosmic Rays and Climate

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IceCube Journal Club
9 February 2009
Outline

• Cosmic Rays, Clouds and Climate
• Sudden stratospheric warmings seen with MINOS in deep underground muon data
• Similar studies with AMANDA/IceCube
In 1997 a variation in cloud cover throughout the solar cycle was reported.

The solar cycle is realized in modulation of solar irradiance as well as cosmic ray intensity. The solar cycle was discovered when Astronomer Royal William Herschel noticed that there was an anti-correlation between wheat prices and the number of visible sunspots. The solar cycle leads to global average temperature of about 0.1K
Cosmic Rays: Known Effects

- Create light isotopes such as carbon-14 and beryllium-10.
- Cosmic Rays provide a source of ions which to contribute to the atmosphere being a very dilute conducting plasma, allowing an electric current to flow from the top of the atmosphere to the earth's surface.
- The energy input of cosmic rays is miniscule, one-billionth that of the solar irradiance.
Cloud Formation

- Water requires a non-gaseous surface to condensate to make the transition from vapor to liquid.
- Water droplets form around aerosol particles in the air called Cloud Condensation Nuclei, about 100nm in size.
- Polluted air leads to a higher concentration of CCN.
- Over oceans, the number of CCN depends on their creation through cluster nucleation.
- Side note: In absence of CCN, water vapor can be cooled below 0°C, this is the basis for cloud chamber experiments.
Ion-aerosol clear-air mechanism

- “The presence of ions serves to lower the nucleation barrier and stabilize embryonic particles.”
- Charged particles can grow from 1-5nm more quickly.
- This period is critical because the coagulation loss rate of 1nm particles is 20 times that of 5nm particles.
Ion-aerosol near-cloud mechanism
Ion-aerosol near-cloud mechanism

- Conductivity is lower in clouds than in clear atmosphere, leading to a buildup of charge and increased electric field at the top of clouds.
- The paper suggests that this charge buildup could influence microphysical properties, such as ice-particle formation.
Overall Effects

• Larger densities of CCN in clouds lead to higher density of (smaller) water droplets, leading to higher reflectivity.

• Over cities, this effect arises from pollution, so the cosmic ray effect would become more effective in clear-air regions like above oceans.

• If ice-nucleation was effected, a decrease in cosmic ray activity could lead to a decrease in rainfall.
Moving forward...

- To deep underground detectors!
- Sound familiar?
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 interact before they decay.

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

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

- Rossby waves are generated by shear in rotating fluids or gasses.
- In the atmosphere, Rossby waves are caused by variations in the coriolis force with latitude.
- Rossby waves can be seen in the atmosphere by observing meanders in the jet stream.
Sudden Stratospheric Warmings

- Sudden stratospheric warmings are caused when the winds around the polar vortex suddenly change due to large amplitude Rossby waves.
- The SSW which this paper investigates occurred in February 2005.
MINOS Observations

- MINOS data shows that the muon rate jumped significantly as the cold air was displaced by warmer air.
Similar results...

- Henrike Wissing noticed a 2003 split of the Antarctic ozone hole.
• I have been studying seasonal variations in IceCube muon rate since last summer.

• In September 2007, the ozone hole shifted from the center of the continent.

• This shift correlates with a jump in IceCube trigger rate.
\[ T_{\text{eff}} = \frac{\int_{0}^{\infty} \frac{dX}{X} T(X) e^{-X/\Lambda_{\tau}} - e^{-X/\Lambda_{\nu}}}{\int_{0}^{\infty} \frac{dX}{X} e^{-X/\Lambda_{\tau}} - e^{-X/\Lambda_{\nu}}} \]

\[ X_{\nu} = \int_{h_0}^{\infty} \rho(h) \, dh \]