Cosmic Ray Air Shower Lateral Coincidence

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We have investigated the structure of cosmic ray showers with altitude. In order to do this we have measured the omnidirectional cosmic ray count, the vertical coincidence cosmic ray flux, and the horizontal coincidence flux during a balloon flight. All the measurements reach a maximum at nearly the same altitude, the Regener - Pfotzer (RP) maximum. The RP maximum has generally been interpreted as the altitude at which the maximum number of ionizing particles are detected. More flights will be carried out to confirm these results or detect differences among the maxima and examine the effects of atmospheric conditions on the cosmic ray shower structure. The goal is to develop a mathematical description of the cosmic ray shower structure and RP maximum as a function of altitude and other atmospheric conditions. We are also working on a more efficient design to carry out the measurements.

I. Nomenclature

e±	= electrons and positrons
γ	= gamma rays
GM	= Geiger Mueller counter
$\mu\pm$	= muons
n	= neutrons
$\pi\pm$	= pions
p	= protons
RP	= Regener- Pfotzer maximum

II. Introduction

At the University of Minnesota, Morris, we have been developing balloon and surface based measurements to incorporate the study the structure of the cosmic rays flux versus altitude. This research work has been incorporated into Modern Physics (a second semester sophomore level course) and into undergraduate research projects. Cosmic rays provide an interesting intersection between balloon flights and the physics curriculum, and they provide one of the few opportunities for undergraduate students to measure relativistic, subatomic particles.

High energy cosmic rays are continuously impinging on the Earth's atmosphere from all directions. These cosmic rays, the majority of which are protons, interact with an air atom or molecule. The interaction commonly generates neutral and charged pions, πs. The π^os decay to photons in ~ 10^{-16} s. These photons pair produce e^-s and e^+s. The $\pi^\pm$s engage in further collisions or decay into charged muons, μs, and neutrinos, νs. If the $\pi^\pm$'s energy is high enough the relativistic time dilation permits further interactions before the decay of the particle. In the rest frame of the $\pi^\pm$s the lifetime is ~ 26 ns.

The cascade of particles generated by the primary cosmic ray is known as an extensive air shower or an air shower. As the air shower progresses into the atmosphere it spreads out laterally. Fig. 1 is a cartoon indicating the changes in size and composition of the air shower as the shower proceeds more deeply into the atmosphere. The number and type of particles in the shower change with depth in the atmosphere because of the creation, the decay, and the energy loss of particles.

Fig. 1 demonstrates that the constituents and structure of the secondary cosmic ray shower changes with altitude. The challenge is to try to examine these changes in the cosmic ray flux with altitude and other atmospheric conditions and develop a mathematical description of the flux.

Zabori et al. [1] used a rocket launch to 88 km to measure the non-isotropic behavior of the cosmic ray flux in the troposphere and stratosphere. They found a directional dependence in their GM counter results. The RP maximum [2] for a vertically oriented coincidence counter was measured to be 21.5 km ± 0.3 km. The RP maximum for a

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horizontal coincidence counter was measured at 22.4 km ± 0.3 km. They stated that below the RP maximum the vertical component of cosmic rays was dominant and that above ~50 km the cosmic ray flux was isotropic. They did not present a theory to describe their observations.

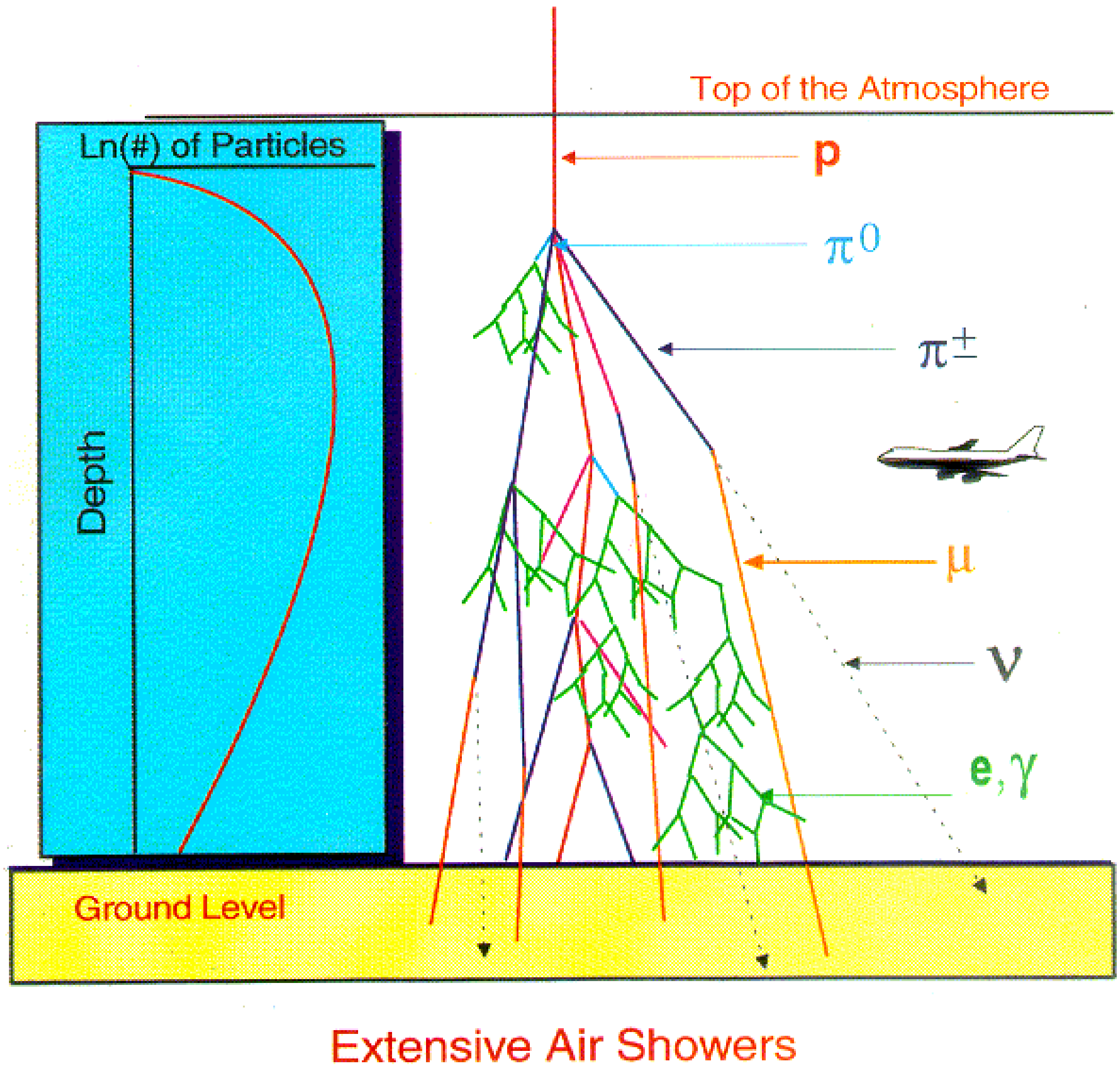

Fig. 1. The changes in the constituents and lateral extension of an air shower as it propagates through the Earth's atmosphere. From The University of Adaleide, "Ultra High Energy Cosmic Rays (UHECR)" http://www.physics.adelaide.edu.au/astrophysics/hires/uhecr.html [retrieved 18 October 2017]

III. Equipment

Fig. 3. is a photograph of the pod used by the UMM group to measure the omnidirectional, vertical, and horizontal coincidence cosmic ray flux versus altitude. The omnidirectional flux is measured by an Aware RM-60 GM counter. This GM counter has a cylindrical tube. It is thought that the cylindrical tube, though having a smaller cross sectional area, has a more uniform sensitivity to omnidirectional cosmic rays. The vertical and horizontal coincidence fluxes are measured using Aware RM-80 GM counters. These are “pancake” counters and have much larger horizontal than vertical cross sectional areas. Two RM-80s are stacked to make the vertical flux measurement. This arrangement limits the solid angle to which the counters are sensitive to 1.65 sr in the vertically upward direction. An assumption is made that the cosmic rays are incident from above. This assumption is supported by the general downward direction of incident cosmic ray primaries. Three RM-80s are used to make the horizontal coincidence flux measurement. Two are stacked to limit the solid angle to match the vertical measurement and one RM-80 is placed 40 cm away.

Future work involves the development of software based coincidence measurements based on the Arduino platform.

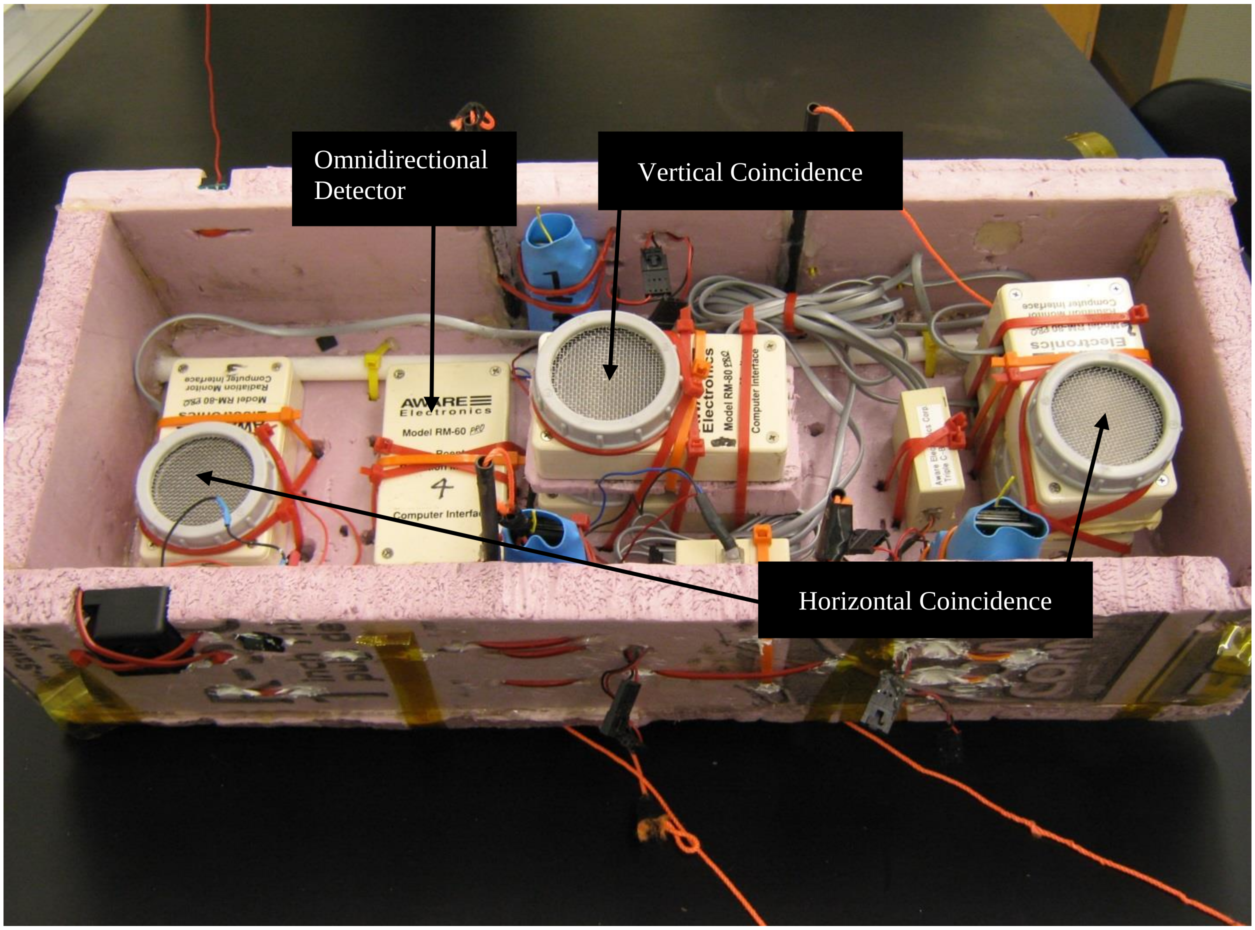

Fig. 3. The UMM module used to measure the omnidirectional cosmic ray counts and the vertical and horizontal coincidence fluxes. StratoStar modules are used to communicate the count rates to the ground.

IV. Results

The results presented in this section were acquired during a balloon flight on 19 April 2016.

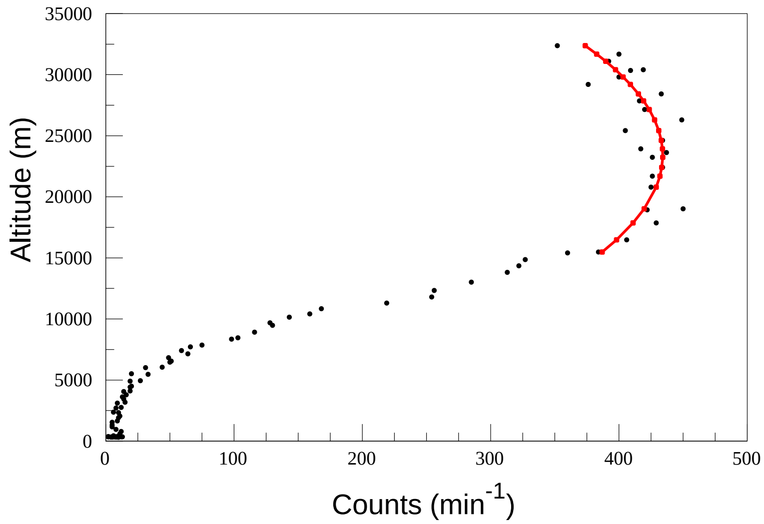

Fig. 4. Omnidirectional counts per minute versus altitude including a fit to the count rate above 15,000 m.

The parabolic fit to the omnidirectional count rate shows a maximum at 23,200 m. This maximum is generally referred to as the RP maximum. The temperature at this altitude was 261.0 K. The pressure was 2.74×10^{3} Pa. The count rate is much lower near the surface than high in the atmosphere

The counts do not decrease exponentially over any large change in altitude.as might be generated by radioactive decays. So the decrease in counts with altitude is probably due to a mixture of energy loss through collisions, the existence of various ionizing particles with different decay times, and a mixture of particle energies.

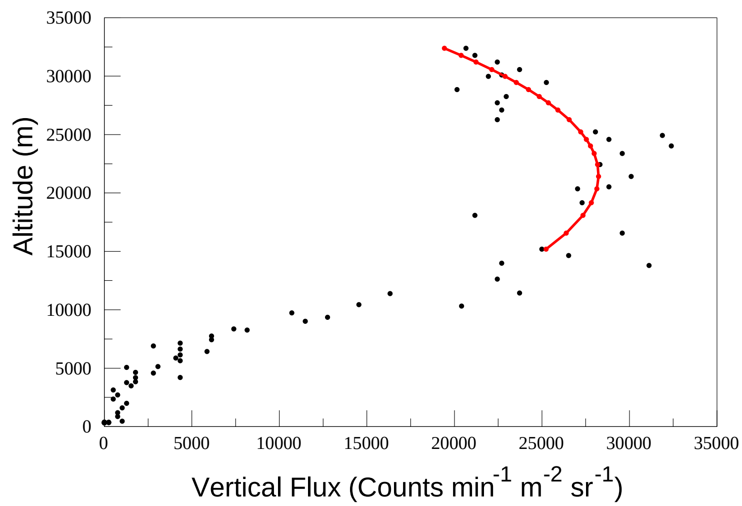

Fig. 5. Vertical coincidence flux versus altitude including a fit to the count rate above 15,000 m.

The parabolic fit to the vertical flux shows a maximum at 21,400 m. The temperature at this altitude was 260.5 K. The pressure was 3.87×10^3 Pa. Again the vertical flux at the surface is far smaller than the flux near the RP maximum. The general shape of the vertical flux versus altitude is similar the curve of omnidirectional counts versus altitude.

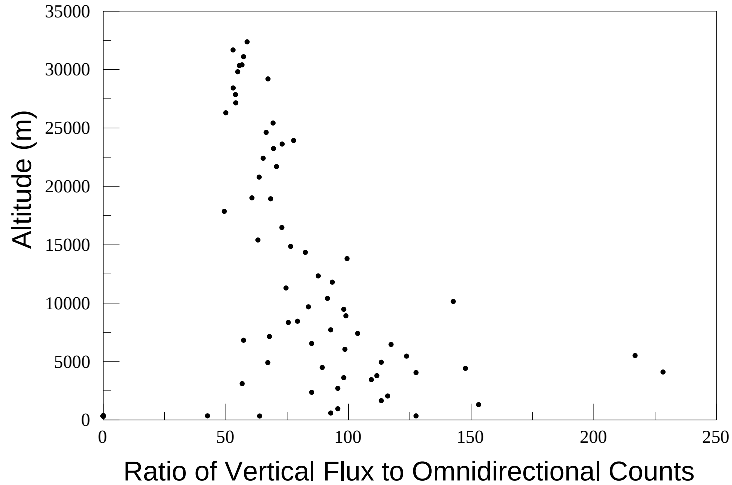

Fig. 6. The ratio of the vertical flux to omnidirectional counts versus altitude.

Near the RP maximum the ratio of vertical flux to omnidirectional counts is relatively constant. This relative constancy may be due to the isotropic nature of the ionizing radiation high in the atmosphere. Near the surface the ratio increases indicating a higher proportion of vertical flux lower in the atmosphere.

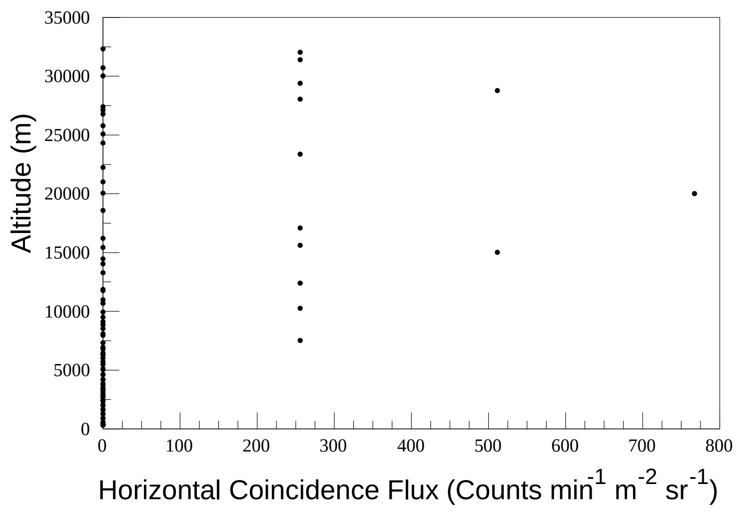

Fig. 7. Horizontal coincidence flux versus altitude

Using the limited horizontal data, the maximum horizontal coincidence flux occurs at 20,000 m. The temperature at this altitude was 255.6 K. The pressure was 5.01×10^3 Pa. No horizontal coincidences were detected below 7,000 m. In the lab we measured the horizontal coincidence flux for a 40 cm separation to be approximately 1.32 Counts min^{-1} m^{-2} sr^{-1}, far lower than the horizontal coincidence flux near the RP maximum.

V. Future Work

We will collect cosmic ray flux, pressure, and temperature data from a number of balloon flights. These data will allow us to describe the cosmic ray shower structure and the RP maximum in terms of the altitude and the atmospheric conditions. The omnidirectional, vertical coincidence, and horizontal coincidence cosmic ray data will be included in this analysis.

We are developing the equipment necessary to carry out the coincidence measurements in software rather than in hardware. This equipment will use the Arduino platform with appropriate shields and coding to make coincidence measurements. This measurement technique will require fewer Geiger counters thus producing a lighter apparatus.

We will also investigate the effects of the 2017 total solar eclipse on the cosmic ray shower structure. Bhattyacharyya et al. [3] suggested that during an eclipse, "a significant amount of cooling takes place of the mass of air of the atmosphere along the umbral path. Because of this, the production region of 90 g cm^{-2} of the atmosphere is pushed down to lower altitude…" and "The cooling of the atmosphere in the path of the umbra induces a reduction of the height of the main production layer of the nuclear component of cosmic rays." These statements were based on surface measurements of γ-rays during an eclipse. Other publications have supported the conclusion that the cosmic ray flux is affected by solar [4, 5, 6]. Bhattyacharyya's suggestions are interpreted to mean that during a total solar eclipse the decrease in the temperature of the atmosphere will reduce the pressure and the RP maximum will decrease in altitude.

VI. Acknowledgments

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VII. References

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