Measuring atmospheric attenuation of cosmic-ray muons in the lower troposphere with the Cosmic Watch

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Introduction

- Continuous flux of cosmic radiation in form of high-energy protons and nuclei
- Interaction with Earth’s atmosphere provides natural source of collisions
- Enables tests of fundamental physics and the Standard Model

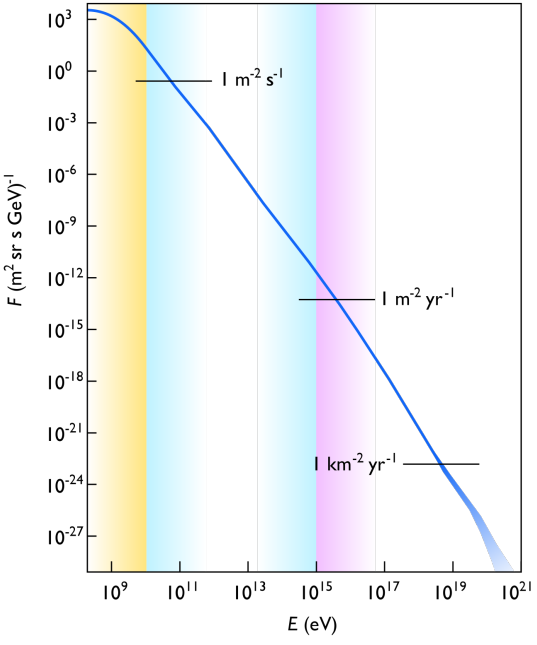
Motivation

- Measure atmospheric attenuation of cosmic-ray muons at 800 m above sea level
- Investigate relationship of other atmospheric parameters to altitude

Cosmic rays

- Refers to flux of relativistic massive particles, excludes electromagnetic radiation
- Composed of approximately 74% ionized hydrogen, 18% helium, and 8% heavier elements and electrons by mass
- Flux drops off sharply above 10^{19} eV due to interaction of protons with CMB

Cosmic rays (cont.)

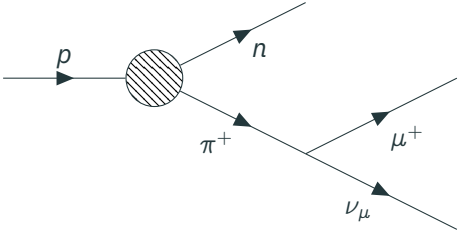


- Yellow, blue, purple represent solar, galactic, and extragalactic sources
- A 10^9 eV proton is moving at $0.35c$
- A 10^{10} eV proton is moving at $0.996c$

Figure taken from Wikimedia Commons

Cosmic rays (cont.)

- Collisions between primary cosmic ray particles and Earth's atmosphere result in secondary cascades of particles extending several kilometers
- Collision of energetic proton with air molecule produces pion or other hadrons
- Pion preferentially decays into muon and neutrino



Overview of Earth's atmosphere

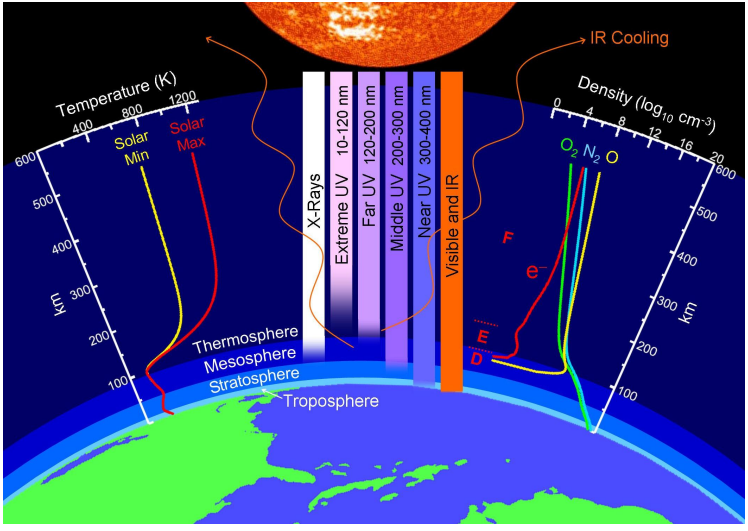


Figure taken from NASA

Atmospheric attenuation

- Muons are unstable particles with mean lifetime of 2.2 μs in rest frame
- Energetic cosmic ray muons produced in upper atmosphere can be detected at sea level due to relativistic effects
- Drops off with altitude angle of detector due to greater distance traveled near horizon

Cosmic Watch detectors

- Consist of plastic scintillators, silicon photomultiplier, and analog to digital converter, secured inside aluminum case
- Pair of detectors can be used to record coincidences and differential cross section
- Alpha, beta, gamma background radiation are filtered by taking advantage of absorption and scattering patterns

Cosmic Watch detectors (cont.)

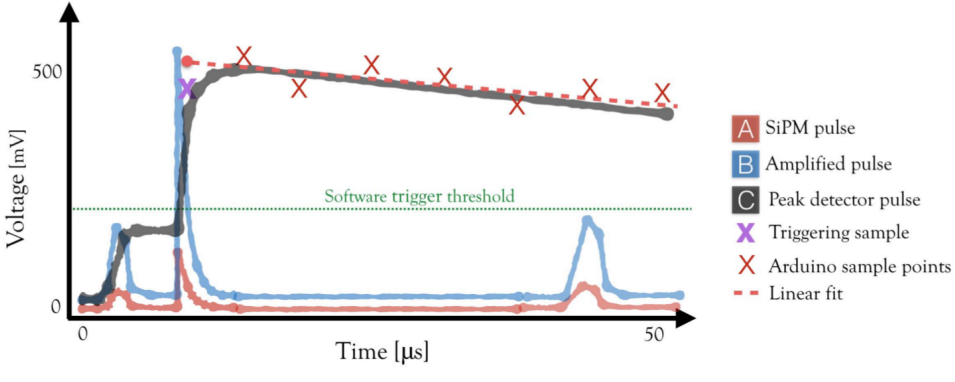
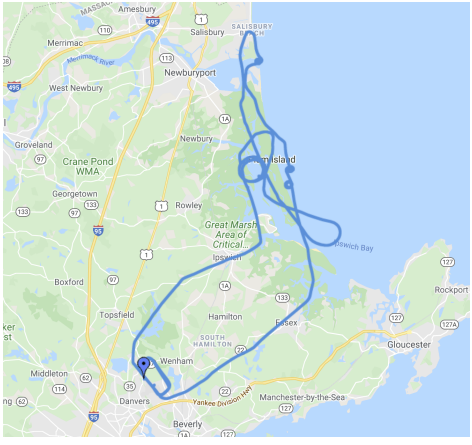


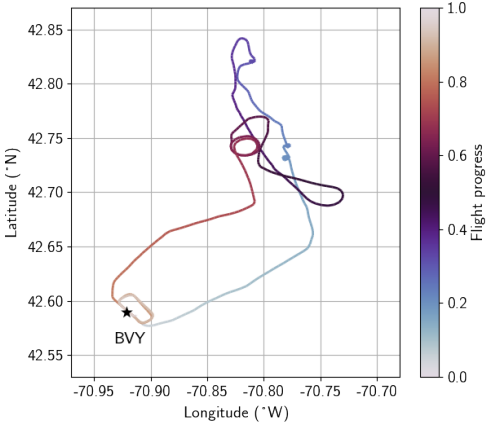
Figure taken from Cosmic Watch project website

Experiment conditions

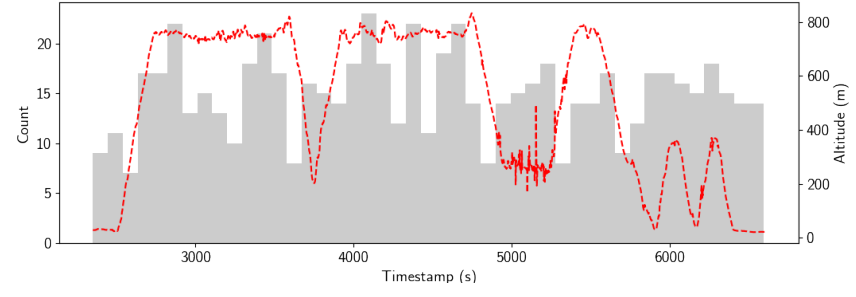
- Data collected between 4:30-6:00 PM EDT on 2021-11-06
- High pressure, clear conditions minimize interference from weather patterns
- Pair of Cosmic Watch detectors stacked vertically and secured on airplane
- Plane altitude typically between 400-800 m

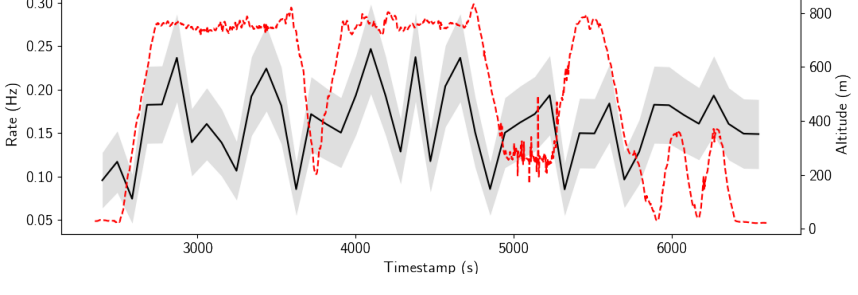
Flight data


Amesbury
Salisbury
Merrimac
Newburyport
West Newbury
Newbury
Crane Pond WMA
Georgetown
Rowley
Great Marsh Area of Critical...
Ipswich
Boxford
Topsfield
Hamilton
Essex
Rockport
Gloucester
Wenham
Middleton
Danvers
Manchester-by-the-Sea
Beverly


42.85
42.80
42.75
42.70
42.65
42.60
42.55
Latitude (˚N)
-70.95
-70.90
-70.85
-70.80
-70.75
-70.70
Longitude (˚W)
BVY
1.0
0.8
0.6
0.4
0.2
0.0
Flight progress

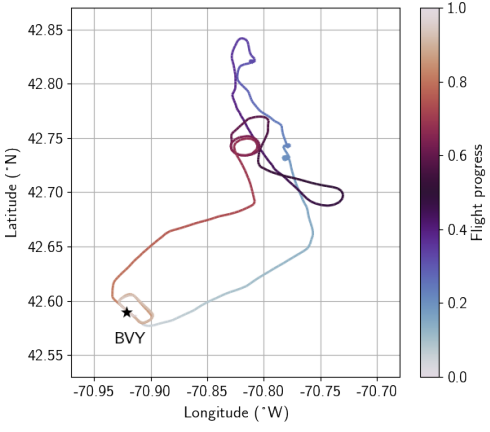
Event count and rate with altitude



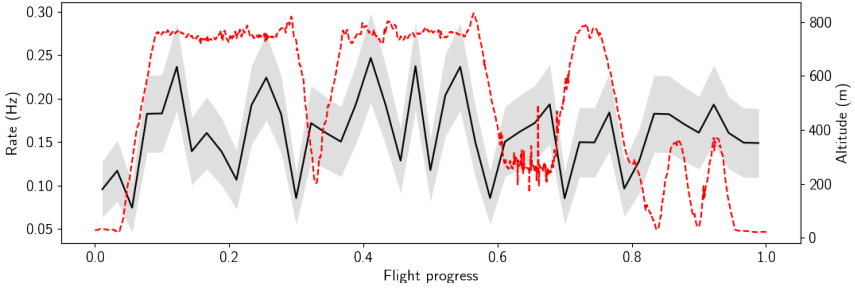


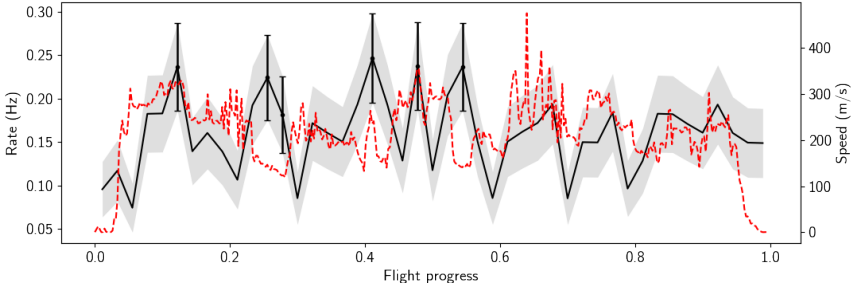
Accounting for tilt

- Plane is tilted during turns, altitude changes, and other maneuvers
- No orientation data for flight was available, but maneuvers can be inferred from geographic data

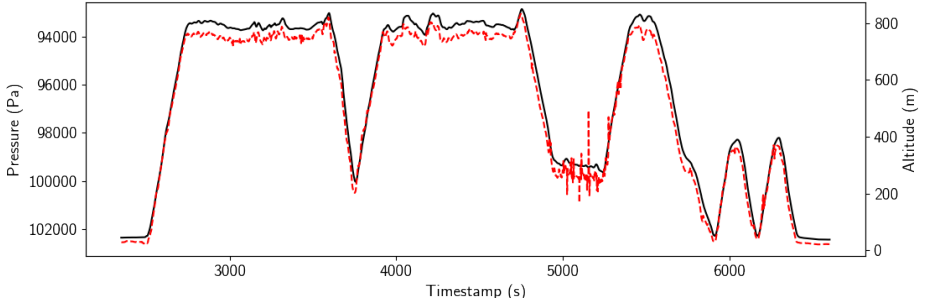


Rescaled plots

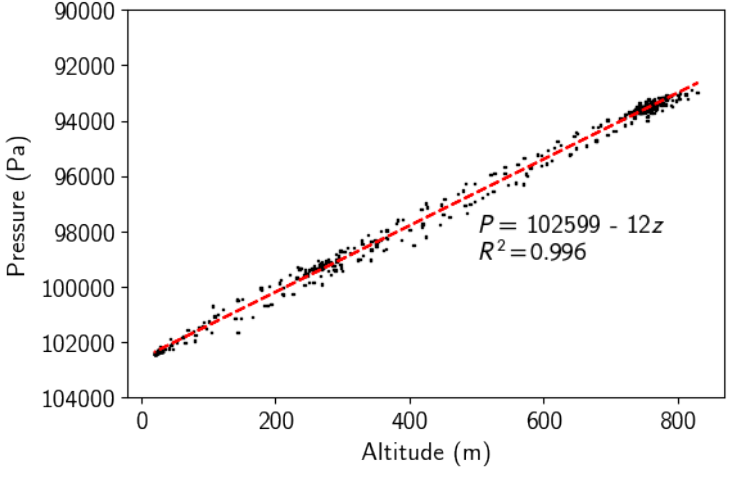




Pressure measurements

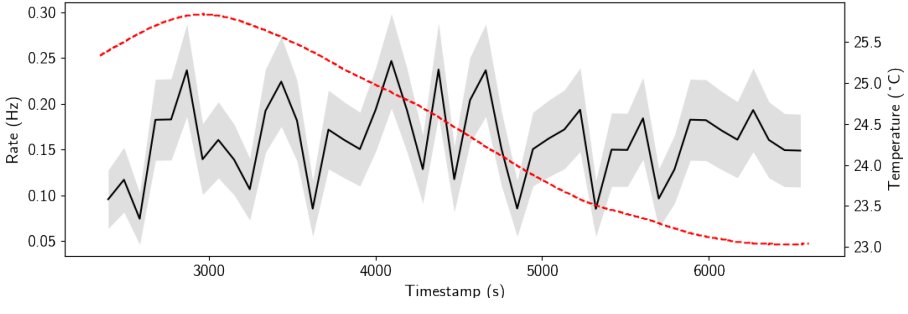


Pressure measurements (cont.)



Recorded pressure at BVY between 102530-102700 Pa

Temperature measurements



- No obvious relationship between temperature and altitude or cosmic muon events
- Variation in temperature most likely due to heat dissipation of electronics

Results and analysis

- Cosmic muon rate at 800 m measured as 0.23 ± 0.02 (stat) Hz, taking into account dead time of electronic components and plane maneuvers
- Pressure at sea level measured to be 102599 Pa, within quoted range

Conclusions

- Small aviation aircraft enables measurement of cosmic muon rate altitude dependence in lower atmosphere
- Significant attenuation due to altitude angle observed when oriented towards horizon
- Cosmic Watch detectors capable of accurately measuring pressure, which can be used as proxy variable for altitude

Acknowledgements

- Richard Luhtaru
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