Project idea for the „Green Deal“ Call 2020/2021

Implications of cosmic rays on environmental ecosystems

F. Krasniqi et al., 03.12.2020

Air showers generated by the primary cosmic rays ionize the atmosphere and irradiate the Earth surface with secondary cosmic radiation (SCR), primarily muons [1]. An increased atmospheric ionization can significantly affect the biosphere by depleting the ozone layer. Here, cosmic rays trigger electron-induced reactions that lead to formation of free radicals in the atmosphere (NO_x, HO_x and chlorofluorcarbon-radicals) which, subsequently, act as catalysts that initiate the breakdown of ozone molecules [2,3]. As ozone shields the Earth from harmful ultraviolet (UV) rays from the Sun, its depletion would lead to an increase of the UV radiation flux. Both cosmic rays and UV radiation have a significant impact on Earth's ecosystems. Overexposure to UV light reduces the size, productivity, and quality in many of the crop plant species and impairs the productivity of phytoplankton in aquatic ecosystems [4]. In addition, laboratory and epidemiological studies demonstrate that UV radiation causes non-melanoma skin cancer and plays a major role in malignant melanoma development [5]. These will add to the biological damage caused by the cosmic rays which typically lead to genetic and epigenetic alterations [6].

The goal of the proposed idea is to develop a metrological framework that allows simultaneous ground-based measurements of SCR flux and UV spectrum for the very first time. This would help understanding (*i*) the dependence of the ozone layer thickness on the intensity of the cosmic radiation and its local variations and (*ii*) their contemporary impact on both flora and fauna (for example, radiation-induced mutation rate in bacterial systems and modulation of life processes triggered by the germ cell damage) [6,7]. Since muons are generated at about the same altitude as ozone layer, they could be a good indicator of the primary cosmic ray flux that initiates ozone depletion. In addition, simultaneous measurement of SCR (muons and neutrons) and UV radiation could also be carried out at sites with different nitrous oxide (NO_2) concentrations to supplement the study with the influence of anthropogenic emissions on ozone dynamics, since NO_2 is likely to remain one of the largest ozone-destroying compounds in the foreseeable future [8].

The preliminary objectives of the project are:

1. To determine correlations between the SCR and solar UV radiation. This should include simultaneous measurement of (a) ground-level muon and neutron fluxes, (b) solar UV-irradiance, and (c) total ozone column. These measurements should be complemented with atmospheric concentrations of greenhouse gases such as N_2O, CO_2 and CH_4. This objective should also include the development of a portable muon detector.
2. To develop new instrumentation and methods to quantify the relationship between the SCR and primary cosmic radiation fluxes. This should include the development or use of a LIDAR system to establish dependence of SCR flux on the ground to atmospheric parameters (pressure, temperature, aerosol density, etc.).
3. To determine the effects of secondary cosmic electrons and UV-C radiation on the ozone depletion and recovery. This should include table-top experiments to measure the cross section of electron collisions with atmospheric free radicals.
4. To determine the effects of SCR on cells (for example, mutation rates). This should include measurements above ground and in a radiation-free environment (PTB underground laboratory UDO II).

References

[1] J. E. Martin, *Physics for Raadiation Protection*, Wiley-VCH (2013).
[2] Q. -B. Lu, Phys. Rev. Lett. **102**, 118501 (2009) and references therein.
[3] B. J. Kellet, *The production of atmospheric nitric oxide by cosmic rays & solar energetic particles*, Workshop on Ion-Aerosol-Cloud Interactions, pp.139-149, DOI: 10.5170/CERN-2001-007.139
[4] J. Bornman *et al*., Photochem. Photobiol. Sci., 2019, **18**, 681.
[5] D. L. Narayanan *et al*., International Journal of Dermatology, 2010, **49**, 978.
[6] D. A. Juckett, International Journal of Astrobiology, 6:307-319 (2007).
[7] N. Lampe *et al*. (2016), PLoS ONE **11** (11): e0166364.
https://doi.org/10.1371/journal.pone.0166364
[8] R. W. Portmann *et al.*, Phil. Trans. R. Soc. B (2012) **367**, 1256.

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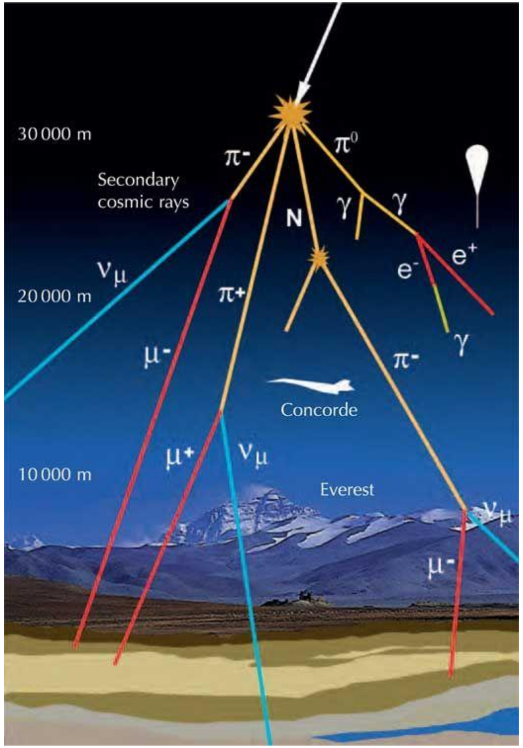
Primary cosmic radiation and ozone

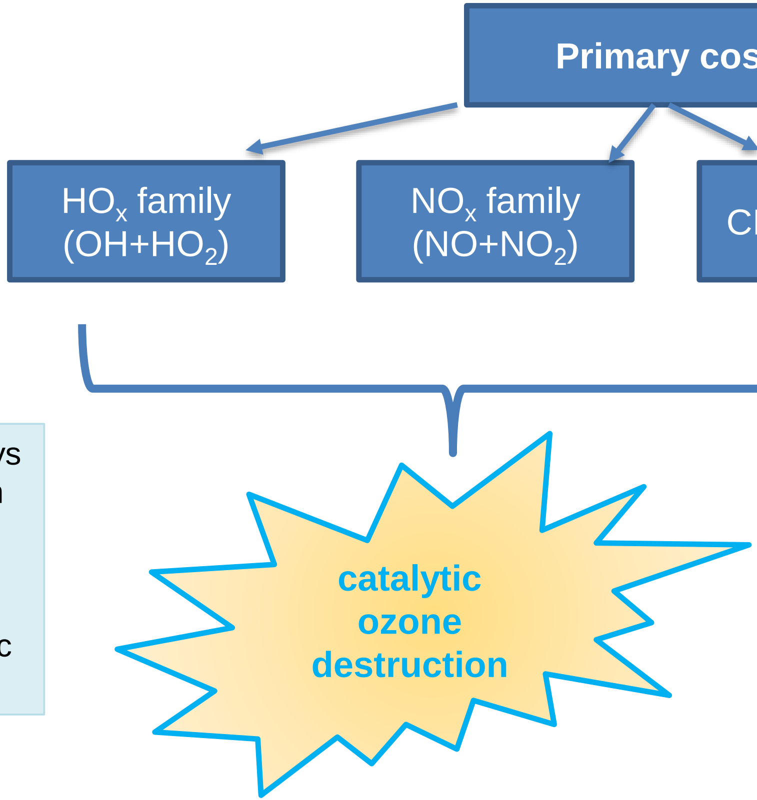


After J. Hewitt, "Cosmic rays could power subsurface life in the universe", ExtremeTech 2015.

Air showers generated by the **primary cosmic** rays ionize the atmosphere and irradiate the Earth surface with secondary radiation, primarily muons.

An increased atmospheric ionization can significantly affect the biosphere by **depleting the ozone layer**.

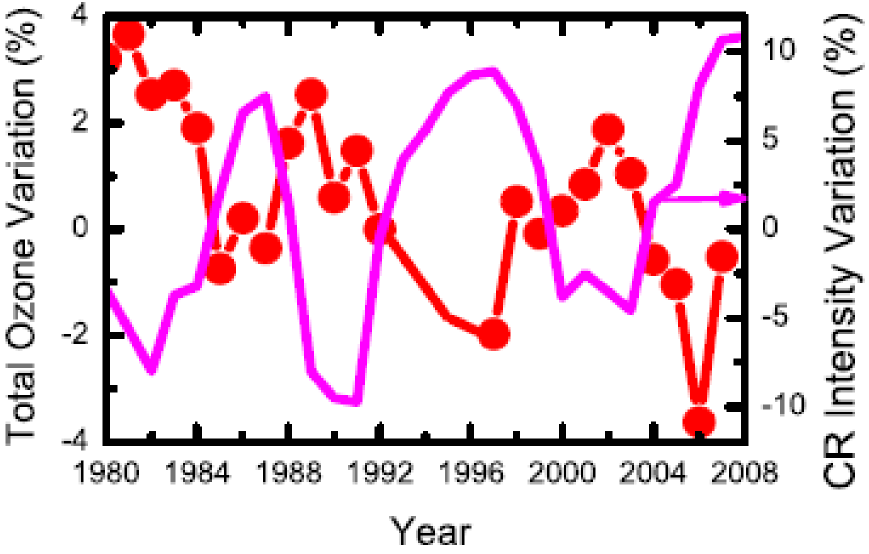
Cosmic rays on the environment



Primary cosmic rays produce, in addition to CFC-, also NOx- and HOx-radicals. These substances lead also to catalytic ozone destruction.

SCR contribution TOTAL~40 nSv/h	muons	20 nSv/h
	electrons and positrons	10 nSv/h
	neutrons	8 nSv/h
	photons	<2 nSv/h

Ozone layer is "burned" by cosmic rays

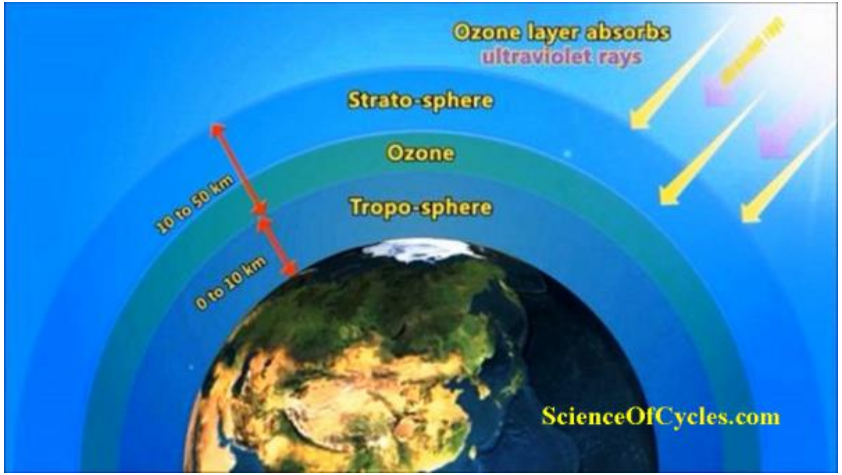


Correlation between cosmic rays and ozone depletion [After Q. –B. Lu, Phys. Rev. Lett. 102, 118501 (2009)]

Cosmic rays break down CFC (chluorofluorocarbon) molecules buried inside polar stratospheric clouds.

Active chlorine released from the CFC **tears apart ozone molecules**.

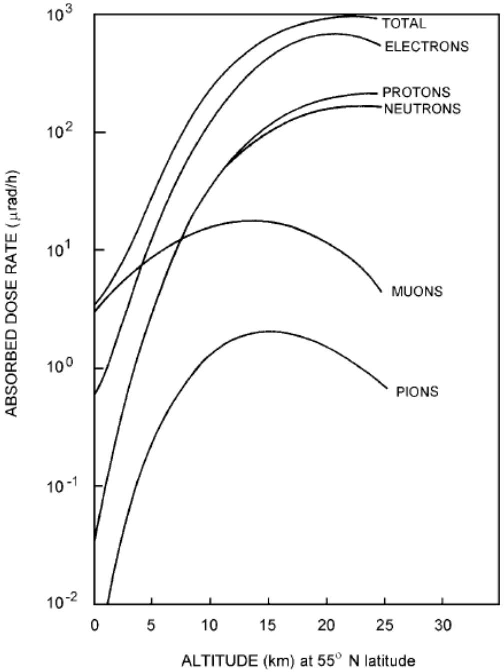
Cosmic rays and N- and H-Radicals



https://www.scienceofcycles.com/tag/ozone-layer/

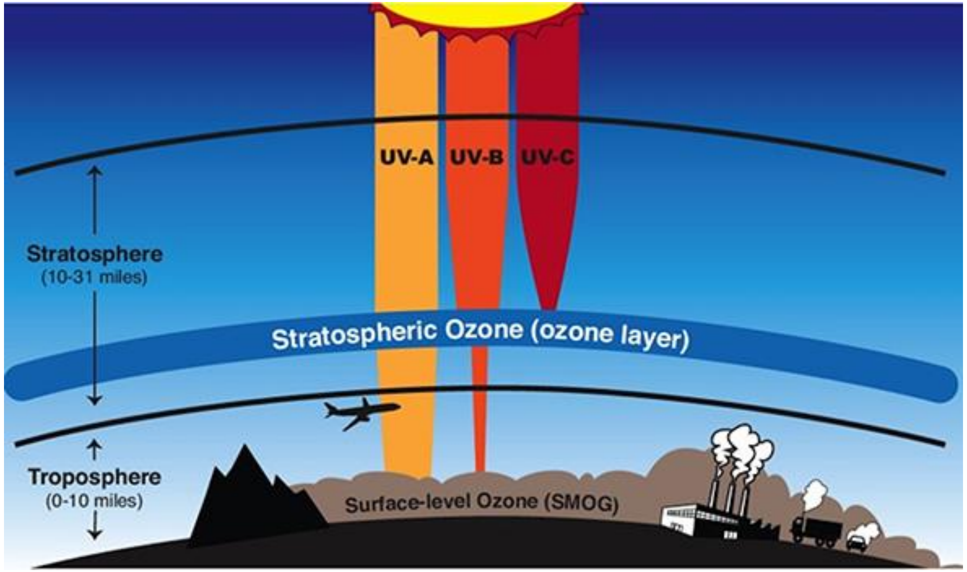
The density of NOx, HOx and CFC breakups and muons depends on the intensity of the cosmic radiation (constant) and the density of air.

The denser the air, the more we have NOx, HOx, CFC breakups and muons.



Absorbed dose rates from various components of cosmic radiation at solar minimum at 5 cm depth in a 30 cm slab of tissue. (To convert to µSv/h, multiply by 0.01). After: Martin, Physics for Radiation Protection, 3rd Ed. (2013), Fig. 6-3.

Ozone

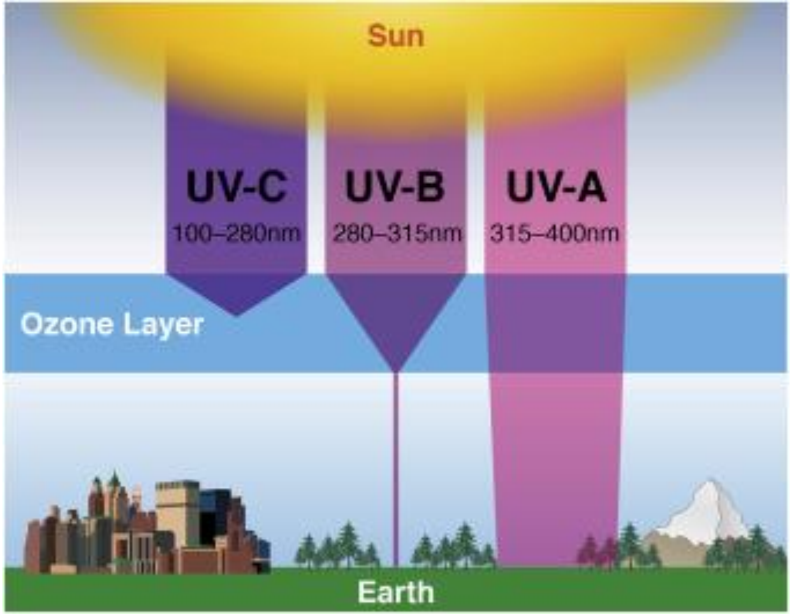


https://scied.ucar.edu/ozone-layer

Ozone shields the Earth from harmful ultraviolet (UV) rays from the Sun.

Depletionof the ozone layer leads to an increase of the UV-B radiation flux.

UV Radiation

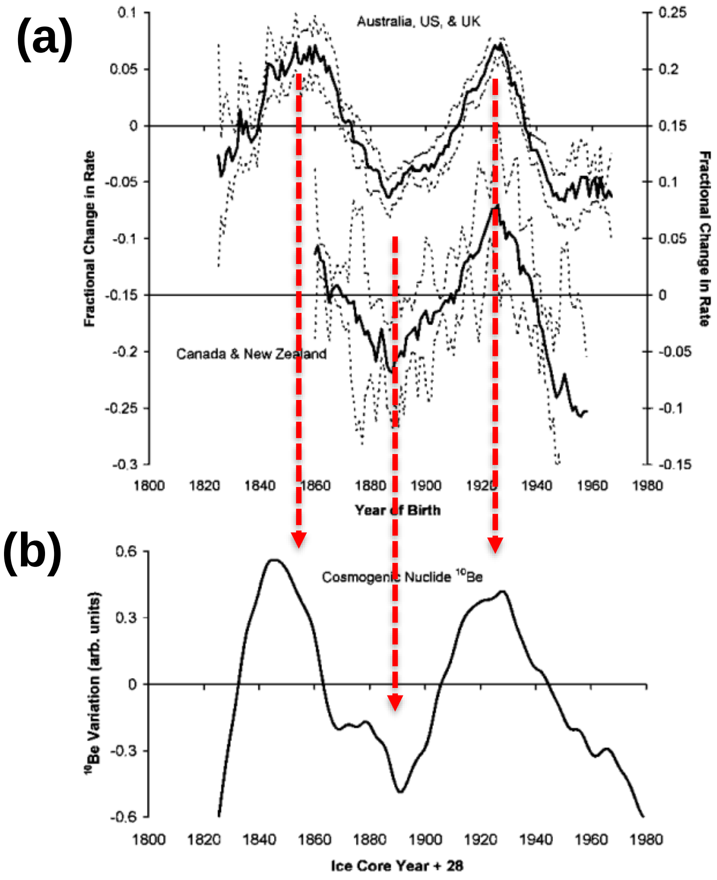


D. W. Wilmouth et. al., Green Chemsitry, Ch. 3.3 (2018), https://doi.org/10.1016/B978-0-12-809270-5.00008-X

Overexposure to UV-B reduces the size, productivity, and quality in many of the crop plant species and impairs the productivity of phytoplankton in aquatic ecosystems.

UV-B causes non-melanoma skin cancer and plays a major role in malignant melanoma development. These will add to the biological damage caused by the cosmic rays whose world population-weighted annual effective dose was estimated to be around 0.32 mSv.

Cosmic ray modulation of life processes



Cosmic radiation **induces damages** in the **germ cells**: the genetic and epigenetic alternations are manifested in individuals of the **following generation**.

(a) *Fractional changes for total cancer mortality rate in US (male and female), UK (female) and AU (male and female).*
(b) *The variations in the cosmic ray surrogate, Be-10 from Greenland ice-core sections.*

After D. A. Juckett, *Correlation of a 140-year global time signature in cancer mortality birth cohorts with galactic cosmic ray variation*. International Journal of Astrobiology, **6**:307-319 (2007).

Objectives

1. To determine correlations between the secondary cosmic radiation (SCR) and solar ultraviolet (UV) radiation. This includes simultaneous measurement of (a) ground-level muon and neutron fluxes, (b) solar UV-irradiance, and (c) total ozone column.
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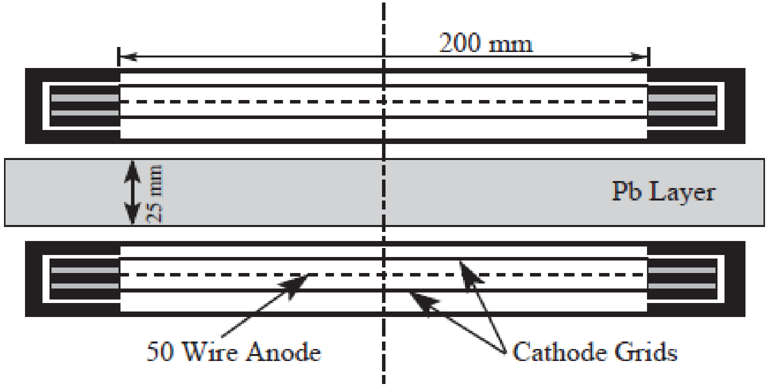
Muon Detection

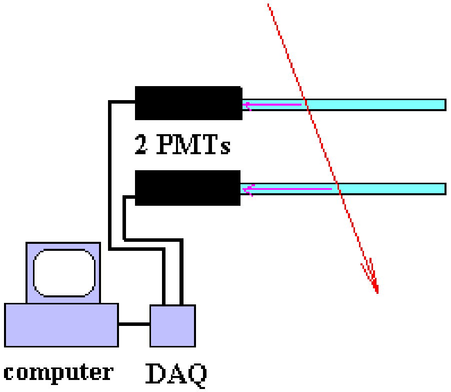


MUDOS

MUDOS (developed at thePTB)
It consists of two cylindrical multi-wire proportional chambers which are operated in coincidence mode.

Only muons with energies >54 MeV are able to penetrate the lead layer and thus generate a coincidence signal.

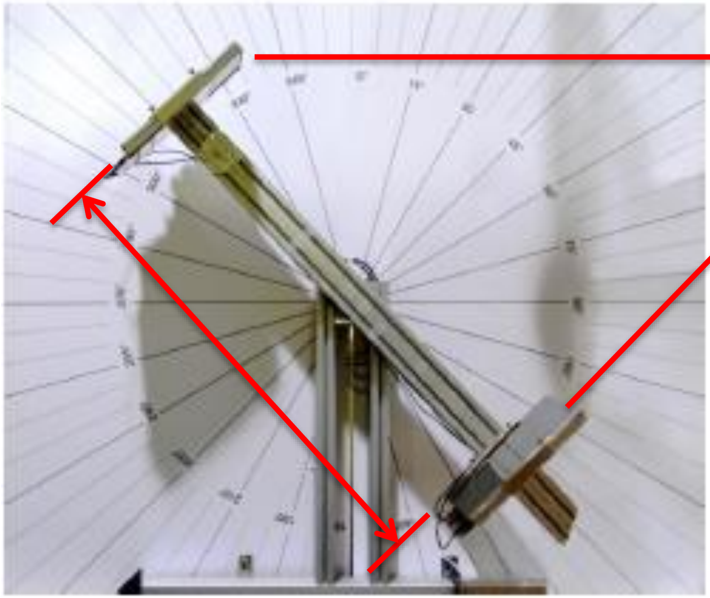
F. Wissmann, Radiat. Prot. Dosimetry **118**, 3 (2006).
F. Wissmann et al., Radiation Measurements **39**, 95 (2005).



DECOS

DECOS (developed at the PTB)
It consists of two large area scintillation detectors working in coincidence mode.

Directional observation of muons



Two counters in coincidence mode.

Solid angle subtended by the **detector is adjustable.**

Example: The CosMO mill (Cosmic Muon Observer), permanently installed at DESY Zeuthen.

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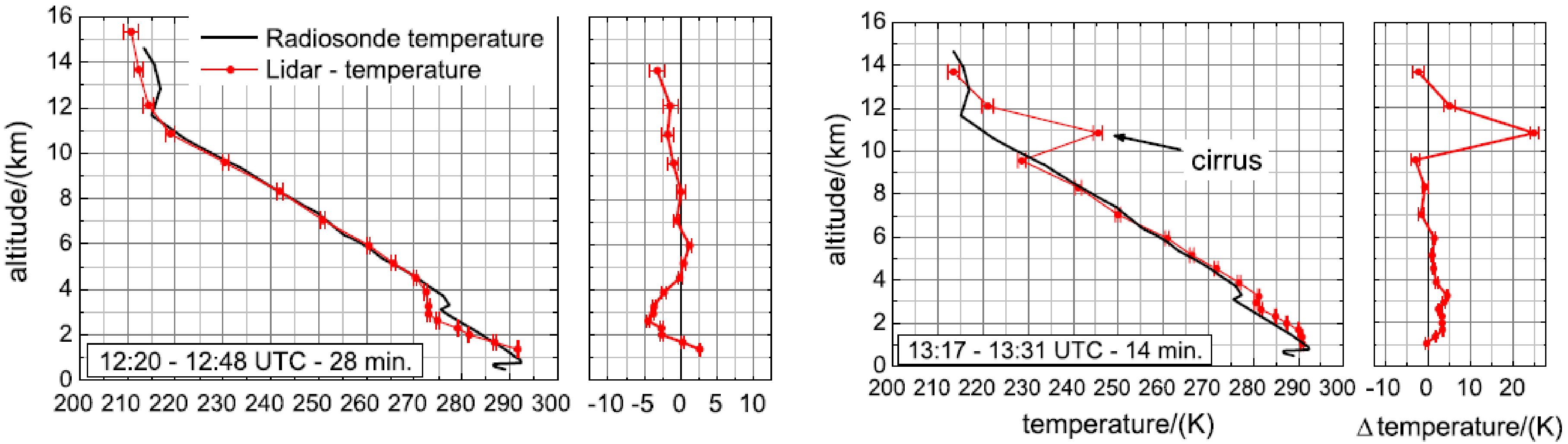
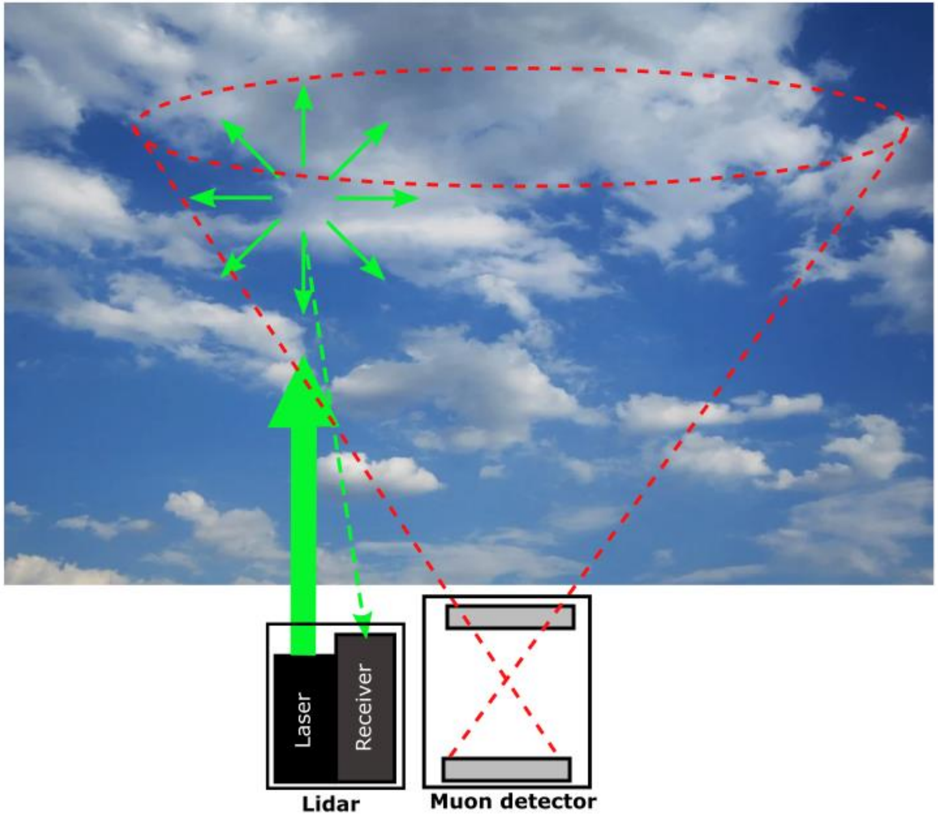
SCR rate $\propto f(T,P,\Phi)$
T $\rightarrow$ Temperature
P $\rightarrow$ Pressure
Φ $\rightarrow$ primary cosmic ray flux

Atmospheric temperature and pressure profiles



Witschas et al., Daytime measurements of atmospheric temperature profiles (2–15 km) by lidar utilizing Rayleigh–Brillouin scattering, Optics Letters 39, 1972 (2014).

Muon rate correction. LIDAR



Correlate several atmospheric parameters to the muon count rate on the ground.

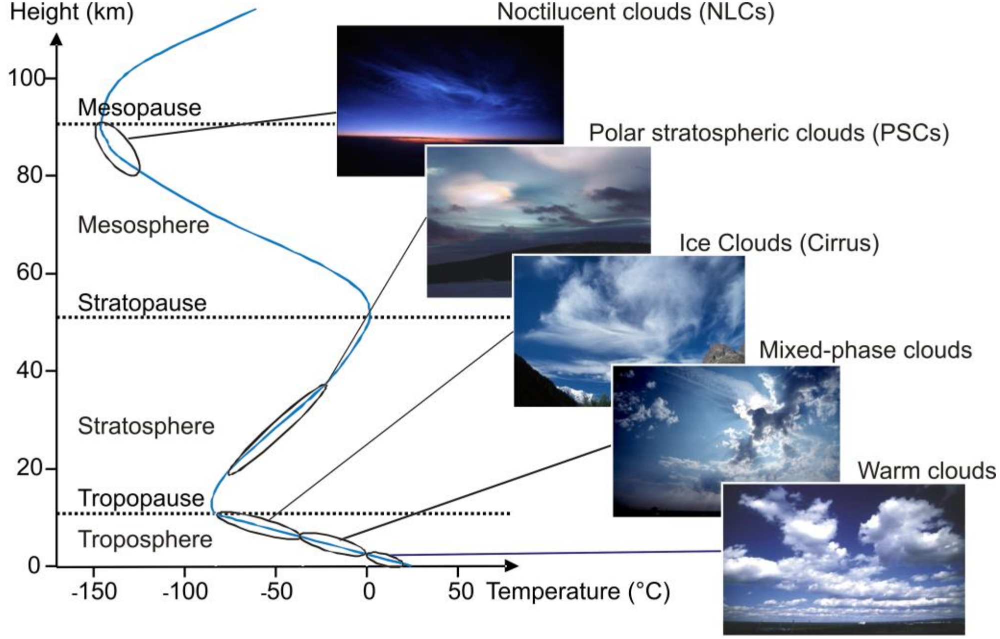
Helps to create/validate models on cosmic shower creation and propagation.

Atmospheric LIDARs

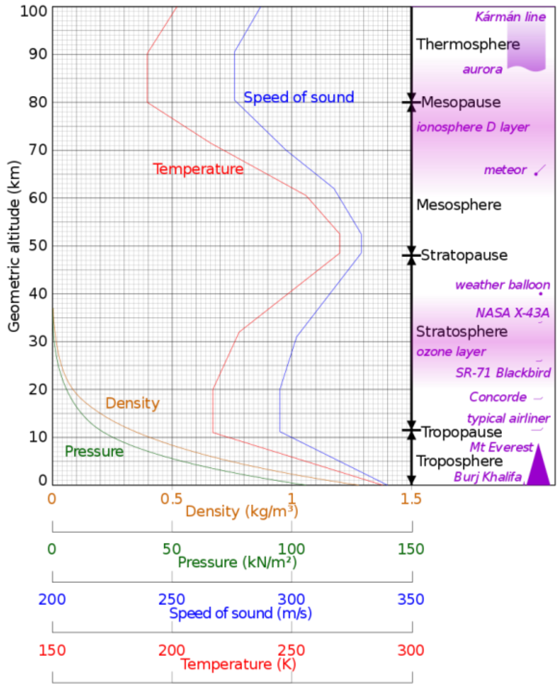
Raman Depolarization LIDAR for Meteorological Applications

https://www.raymetrics.com/product/vertical-lidar

Cloud Types



After http://www.imk-aaf.kit.edu/415.php



The 1962 US Standard Atmosphere graph of geometric altitude against air density, pressure, the speed of sound and temperature.

Thank you!

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