Atmospheric ionisation in Snowdonia

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Abstract Atmospheric ionisation from natural radioactivity and cosmic rays has been measured at several sites in Snowdonia from 2005-present. The motivation for this project was a combination of public engagement with science, and research into the effects of ionisation on climate. A four-component atmospheric radiometer instrument is co-located with the ionisation detectors and the data is remotely logged and displayed on the Web. Atmospheric ionisation from natural radioactivity varies with local geology, and the cosmic ray ionisation component is modulated by solar activity and altitude. Variations due to all these effects have been identified and are described.

1. Introduction
Motivated by a possible relationship between atmospheric ionisation and climate [1], we have been measuring atmospheric ion production [2], and the long and short wave radiation at mountain locations in Snowdonia since 2005. We have also been displaying the data, updated daily, on the Web, to increase public understanding of atmospheric and particle physics in the North Wales area and beyond1.

The experiment has been located at two mountain sites, Snowdon Summit (1085m) (2004-2006, with ionisation measurements from 2005), Marchlyn Mawr Reservoir (660m) (2009-present) and briefly at a low-level local site, Llanberis (120m) (2005 and 2009), all within 8 km of each other in Snowdonia. Additionally, the equipment underwent an extended outdoor test at a second low-level site in Gloucestershire (2008-2009). The basic instrumentation comprises a Kipp and Zonen CNR1 four-component radiometer to measure atmospheric radiation, and ZP1442 Geiger counters, which are used to measure ionisation from both local radioactivity and cosmic rays. Ionisation rate is measured, as it is an effective proxy for ion concentration in clean air [3]. (Instruments that measure atmospheric ions directly need more maintenance than is possible at a remote mountain site.) The Geiger counters were located with the data logger inside an IP68 sealed box, which was in turn placed inside a secure, sealed box containing the battery. Drainage holes drilled in the bottom of the boxes prevent catastrophic flooding of the equipment.

1 http://snowdon.physics.ox.ac.uk/Snowdon/Cosmic_Ray_Station.html

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This range of sites has enabled the equipment to be optimised for the harsh mountain conditions and has also permitted measurements at different altitudes and climates. Solar activity has also changed over the duration of the experiment. The sun’s magnetic field deflects cosmic rays away from Earth, and also varies on an 11-year cycle, with a deep minimum, and associated cosmic ray maximum, in 2009, and a more active Sun (fewer cosmic rays) when the measurements began in 2005.

Table 1 Summary of Welsh mountain measurements, including an extended low-level test. Local radioactivity was measured using Geiger counters, cosmic rays using a Geiger telescope, broadband atmospheric radiation with a Kipp and Zonen CNR1 net radiometer and narrowband radiation with a filter radiometer.

| Location (lat/long N/W, altitude) | Dates | Measurements | Power and data logging |
|----------------------------------|-------|--------------|------------------------|
| Llanberis (53.1167, 4.11959, 120m) | July 2005, July 2009 | Local radioactivity and cosmic rays | Battery, Campbell 21X (2005) and Campbell CR3000 (2009) |
| Marchlyn Mawr (53.1367, 4.0691, 660m) | July 2009 – present | Local radioactivity, cosmic rays, down and up-welling short- and long-wave radiation | Mains power to charge 90Ah lead acid battery Campbell CR3000 logger, data retrieved by mobile phone |
| Snowdon Summit (53.0689, 4.0756, 1085m) | May 2004 – September 2006 | Local radioactivity, downwelling short- and long-wave radiation, cosmic rays (29th July 2005 - 25th March 2006) | 60W solar panel to charge 90Ah dryfit battery Campbell 21X logger, data retrieved manually over RS-232 interface |
| Cheltenham (51.8929, 2.1300, 30m) | July 2008 - May 2009 | Local radioactivity, cosmic rays, downwelling short- and longwave radiation, narrowband longwave radiation [1] | 80W solar panel to charge 90Ah lead acid battery Campbell CR3000 logger, data retrieved by mobile phone or manually over RS-232 interface |

2. Atmospheric ionisation measurements
Near the Earth’s surface, cluster-ions are formed by both natural radioactivity and cosmic rays. Natural radioactivity is principally alpha and gamma radiation emitted from radon isotopes and the soil [4], and cosmic rays are energetic ionising radiation from outer space. In the lower troposphere most cosmic ray ionisation is from muons with mean energy 4GeV, half of which is lost to ionisation [5]. The instrumentation used for ionisation rate measurements are two Geiger counters, both independently responsive to beta and gamma radiation, stacked vertically. Coincident triggering of both counters is usually due solely to high-energy particles, and this enables the cosmic ray ionisation to be measured. This coincidence configuration is known as a cosmic ray telescope [2]. At the surface, the typical ionisation rate \( q \) is usually quoted as 10 cm\(^{-3}\)s\(^{-1}\) (although this can be highly variable) with 20% from cosmic radiation, 40% alpha radiation from radon and 40% beta and gamma radiation from radon decay [4]. In clean air, \( q \) is related to the ion concentration \( n \) by the ion balance equation with \( q = \alpha n^2 \) where \( \alpha \) is a self-recombination coefficient [3].

2.1 Ion production from natural radioactivity
The ZP1442 Geiger counters used are sensitive to beta and gamma radiation. The individual count rates of each counter are therefore expected to represent about 40% of \( q \). The Geiger tube is calibrated in terms of a known dose of gamma radiation from a \(^{137}\)Cs source of 10 µGy/hr, corresponding to 1.14mR/hr in air where 1Roentgen=208230 ions m\(^{-3}\) [6] and giving the number of ions produced in air for one Geiger count as 66 cm\(^3\). Natural radioactivity measurements are shown in table 2 below. For
the low altitude test site, the mean count rate is 11.4 cpm corresponding to (12.4±1.4) ions cm\(^{-2}\)s\(^{-1}\), within the range reported in the literature [4]. It is also possible to estimate the radon concentration if the background gamma dose rate is assumed to be linearly proportional to the \(^{222}\)Rn concentration in the air [7]. From the Geiger tube calibration, which relates dose to count rate, the mean count rate at Cheltenham corresponds to a radon concentration of 1.3±0.4 atoms cm\(^{-2}\)s\(^{-1}\). (This is likely to be an over-estimate, since beta radiation will also contribute to the measured count rate.) The European radon inventory, based on interpolated gamma dose rate measurements, gives the radon concentration for the Cheltenham grid square to be 0.70 atoms cm\(^{-2}\)s\(^{-1}\), consistent with our measurements. In North Wales the underlying geology is different, leading to higher radon concentrations [7] and increased ion production rates compared to Cheltenham.

Table 2 Summary of Geiger counter measurements. Energetic particles are recorded in counts per hour (cph), and local radioactivity in counts per minute (cpm) with standard errors (se) indicated.

| Location (height asl) | Date | Mean Energetic Particle Rate (cph±se) | Top Geiger Count Rate (cpm±se) | Bottom Geiger Count Rate (cpm±se) |
|----------------------|------|-------------------------------------|-------------------------------|----------------------------------|
| **Low altitude test site** | | | | |
| Cheltenham           | 19/8/08-12/11/08 | 12.46±0.11 | 11.51±0.01 | 11.38±0.01 |
|                      | 12590 5 minute averages, summed energetic particles | | | |
| **High altitude sites** | | | | |
| Marchlyn Mawr (660m) | 28/07/09-25/11/09 | 14.50±0.07 | 16.93±0.01 | 16.97±0.01 |
|                      | 32,621 5 minute averages, summed energetic particles | | | |
| Snowdon Summit (1085m) | 26/07/05-27/10/05 | 15.08±0.02 | 18.88±0.93 | 16.76±0.02 |
|                      | 2229 hourly averages, summed energetic particles | | | |

2.1 Ion production from cosmic rays

Cosmic ray ionisation increases with altitude, and, as expected, the highest telescope count rates were measured at Snowdon Summit, with significantly lower high-energy radiation detected at Marchlyn and Llanberis. The energetic particle count rates at Llanberis in 2005 and 2009 were 10.3±1.0 and 12.4±1.0 counts per hour, a statistically significant difference. This is likely to be related to solar activity, for which a simple proxy is sunspot number. There were (40±34) sunspots on average in July 2005 compared to (3±5) in July 2009 [8], consistent with the more active Sun deflecting cosmic rays away from Earth in July 2005, and preventing them from reaching the atmosphere.

The cosmic ray particles measured by the telescope are almost all muons (heavy electrons moving at relativistic velocities). The typical muon surface flux is a few hundred particles m\(^{-2}\)s\(^{-1}\)sr\(^{-1}\) [3], but the count rates recorded by our insensitive detectors are much lower. The ionisation caused by muons is 21cm\(^{-1}\) [9], but converting our count rates to volumetric ionization rates is not straightforward due to pressure and temperature related variations in muon production. The planned installation of a barometer and thermometer will permit further work on this.

The upper Geiger counter of the telescope always records a slightly (but statistically significant) higher count rate than the lower one, which persists when the tubes are swapped, Figure 1. This is unlikely to be related to natural radioactivity, since the two Geiger tubes are close together, and may be from lower-energy cosmic rays without sufficient energy to trigger both Geiger counters. The “soft component” is mostly electrons, and comprises 10% of the total cosmic rays at the surface [5].

3. Atmospheric ionisation and downwelling longwave radiation

Laboratory experiments showed that atmospheric cluster-ions can absorb radiation in the 9-12 \(\mu\)m range of the infra-red (IR) spectrum [10]. However, it has not been possible to detect any relationship
between atmospheric ionisation and the downwelling broadband IR radiation in clear sky at the Snowdon Summit site, due to atmospheric temperature effects modulating both the muon data and downwelling IR. Further measurements with a filter radiometer “tuned” to the ion absorption band did show a relationship between ionisation and atmospheric IR radiation [1].

4. Conclusions
Atmospheric ionisation measurements have been made at several sites in Snowdonia and in the South of England and have shown the variations expected with local geology, altitude and solar cycle. There was no clear link between ionisation and downwelling broadband radiation.

Beyond the scientific research aspect of this experiment, the Marchlyn data is made available to the general public on the Web. We intend to develop this website, including a Welsh translation, and produce data files so that school students can investigate simple aspects of atmospheric and particle physics for themselves. The equipment will be moved to the new Snowdon Summit building this summer to increase both the cosmic ray count rate and the impact of the measurements on the general public, who visit Snowdon in their thousands every year. The public engagement aspect of this work is currently funded by the Royal Astronomical Society and the work was previously funded by NERC and STFC. Technical assistance from J G Firth, C A Eley (RAL Space) and N T Clifford (Oxford University) is gratefully acknowledged.

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