Prof Giles Harrison – Research Themes

This is a summary of findings from papers I have led or collaborated on, derived from the full list . The papers primarily concern investigations[1] related to

- Atmospheric electricity (AE)
- Measurements and Instrumentation
- Eclipse meteorology

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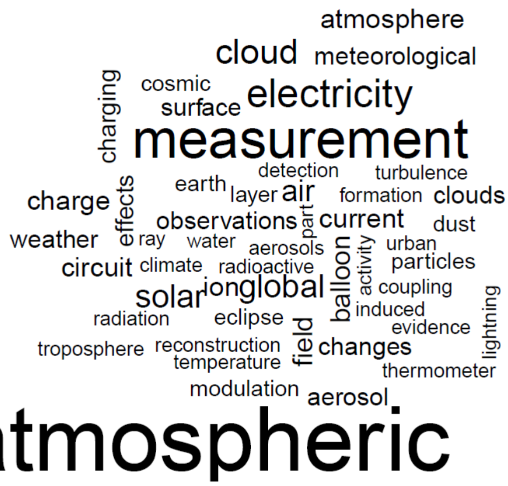

The **Atmospheric electricity** work is driven to understand relationships between atmospheric electricity and meteorological processes. It includes research on clouds, air pollution, cosmic rays, space weather, volcanic plume electrification and historical data recovery. Some planetary atmosphere properties have also been investigated.

Our **Measurements and instrumentation** work includes the design and development of new sensors, detectors and related electrometry instrumentation, and the use of meteorological measurement systems, especially weather balloons and surface observations.

Solar eclipses keep happening… the **Eclipse meteorology** work has led to a special issue of *Philosophical Transactions*, publications on the eclipse wind, and the National Eclipse Weather Experiment (NEWEx). It is currently focused on turbulent fluxes.

I have also written general or less technical pieces intended more for **Outreach**.

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[1] Atmospheric Electricity and Eclipse work were recognised in the Institute of Physics' Appleton Medal, and the Measurements work in the European Geosciences Union's Huygens Medal.

Atmospheric Electricity

Topic	Findings and contribution	Comment
Climate		
Atmospheric electricity and internal climate variability	The global circuit is a central concept in atmospheric electricity, originated by the Nobel Prize Winner CTR Wilson[1]. It links charge separation in disturbed weather with distant fair weather regions, with current flow throughout the atmosphere. **I wrote about its likely relationship with climate change in 1997** [2] , and developed this theme further in a review paper[3]. We discovered a link between the global circuit and internal climate variability, occurring through the El Niño Southern Oscillation (ENSO) [4]. This is present in data recovered from measurements made in both hemispheres during the 20th Century [5]. **These findings provide confirmation that the global circuit is consistently embedded in the climate system**	 The ENSO findings have been independently explained by modelling of changes in the positions of global thunderstorms.
Cosmic rays, clouds and climate	There have been many suggestions that cosmic rays can affect clouds, which is an incompletely explored question in atmospheric electricity. **We summarised possible physical mechanisms in a paper in *Science*** [6], through ion influenced particle formation, or cloud edge charging. The first (ion) route is now established to be minor[7],[8], but the second, through cloud edge charging, remains to be fully evaluated. We have shown that some cloud properties show similarities with cosmic ray variations[9][10], during Forbush decreases[11] and when there is regular rapid cycling in cosmic rays[12]. **Charging on layer cloud boundaries results from current flowing in the global circuit, which physically links space weather changes into lower atmosphere clouds**. Separately, we have found indications[13,14] that **space weather contributes to influences on lightning rates**.	

Clouds		
Cloud edge charging	Theory indicates that the upper and lower edges of layer clouds should acquire electric charge from the global circuit current, but with limited real-world evidence. To demonstrate this experimentally, we first established that the current does flow through droplet layers[15] and clouds[16]. With specially designed balloon-carried sensors[17] we showed, first, that the base of layer clouds is charged[18] and then that the top was charged, in multiple locations globally[19]. For low clouds, the cloud base charge can even be sensed in surface measurements[20]. **These results confirm charging of upper and lower boundaries of layer clouds is a global phenomenon**.	
Turbulence in charged layer clouds	For thin layer clouds, using surface and in-cloud measurements, we observed that surface-sensed changes in their electrical properties occurred before observed cloud base changes[21]. This can be explained by turbulence affecting the cloud top charge, before the effects of those changes propagated to the cloud base[22]. This is **further evidence for layer cloud boundary charging, showing charge is intrinsic to the cloud and follows cloud motions arising through turbulence.**	
Charge effects on clouds	Charge may influence how clouds develop because of its effect on droplet interactions[23]. For charged water droplets, evaporation is inhibited, facilitating droplet formation at reduced water supersaturation compared with an equivalent neutral droplet[24]. Collection processes are affected by charging[25] which may influence rainfall generation[23], which has also been investigated in simulations of turbulent situations[26]. We have shown that rainfall in the 1960s appears modified by the ionisation then released into the atmosphere[27] . **This shows that fundamental cloud droplet processes can be influenced by charge.**	
Fog and charge	Air's electrical properties often change before fog becomes evident visually[28], to **provides a new basis for nowcasting of fog**[29]**.**	Fog prediction in Phys.org

	Fogs are electrical active regions of the lower atmosphere, as fog droplets readily collect charge, which may influence their lifetimes behaviour due to reduced evaporation or modifying collision rates[30]. By releasing charge into fog from an overflying robotic aircraft, we observed a small increase in the reflectivity of the fog[31], likely to be due to changes in the droplet size distribution. **This shows a new way to influence natural droplet systems, by charge release.**	
Aerosol		
Aerosol charging	Atmospheric aerosol particles are almost always slightly charged, due to the imbalance in the properties of positive and negative ions[32]. Radioactive aerosols – particles formed from, or containing radioisotopes - can become appreciably charged when their self-charging rate exceeds the discharge rate from diffusing ions[33]. One consequence is that radioactive aerosol particles are more effectively scavenged by water droplets from the atmosphere than neutral particles[34]. **Our theory predicts the charge on radioactive aerosols, and has been experimentally verified in the French Nuclear Industry.** The ion-aerosol topic and its application to clouds and climate is summarised in a review paper[35].	"Our results therefore confirm the theoretical studies carried out by Clement and Harrison…"
Volcanic plumes and lightning	Many plumes, and especially those of dusts, are charged[36]. This allows charged volcanic plumes can be sensed as they pass over an electric field sensor[37]. These aspects were considered in a review paper on volcanic lightning[38], subsequently well-cited. Surprisingly, a volcanic plume came to us, and in a rapidly published paper, **we reported charged volcanic ash particles aloft**[39].	Making urgent measurements National Geographic on Eya plume
Dust charging	We have investigated dust charging in several ways, using radiosondes which showed the ease with which electrification occurs aloft[36], a surface measurement network monitoring charged dust[40], and the sea breeze from the Arabian Gulf to provide a regular and repeatable disturbance of dust leading to strong electrification[41]. Dust devils have	Saharan plume *Physics World*

	also been investigated in desert conditions using simple instrumentation[42]. We also responded to a Saharan dust plume over Reading, with surface observations and a sounding[43]. The surprising long range transport of dust remains unexplained although electrification looks unlikely to be a factor[44]. **Charging through triboelectrification seems a ubiquitous property of atmospheric dust.**	
Electrical Environment		
Planetary AE	I have worked on some planetary AE topics, including reviewing what is known about the (dusty) electrical environment of Mars[45], and, drawing on findings for terrestrial clouds[9], **likely cosmic ray effects in Neptune's clouds**[46] **and Uranus** [47] This shows common variability in two planetary atmospheres driven through energetic particle modulation by their host star.	Neptune - *Weatherwatch*
Atmospheric ionisation and space weather	I developed a new Geiger tube system for modern radiosondes[48], facilitating a series of ionisation profiles in the troposphere and stratosphere in different solar conditions, in which the stratospheric maximum values show a strong correlation with surface neutron monitor measurements[49]**. During space weather disturbances, extra ionisation was unexpectedly observed in the lower atmosphere** [27]**,** implying a source of otherwise unnoticed energetic charged particles[27].	American physical Society
Obtaining properties of the global circuit	The global circuit has been investigated by modelling[50], and its properties inferred by observations. **Storage of charge by layer clouds has been shown to modify properties of the global circuit**[51]**.** Global circuit properties have been observed empirically using volcanic lightning data, including for system's time constant[52]. **This shows the system's time constant is 5 to 10 mins: the global circuit is therefore actively sustained on that timescale.**	Summary
Earthquake precursors	Changes in the ionosphere have been observed before some earthquakes, but how the coupling from the surface to the ionosphere occurs has been elusive. Our ALICE mechanism[53] (Atmospheric	Evidence for D region coupling

	Lithosphere–Ionosphere Charge Exchange) can explain this. Our original paper suggesting this global circuit mechanism[54] was **short-listed for the 2010 Lloyds Science of risk prize.**	
Data		
Standardising fair weather measuring conditions	Weather perturbs atmospheric electricity[55],[56], so data selection is needed to minimise local effects if a global signal is to be retrieved. **Our modernised criteria for identifying fair weather conditions are becoming widely used**[57] yielding high quality atmospheric electricity data using automated weather sensors.	
Recovering atmospheric electricity data	Recovering historical measurements complements modern measurements. The available data was greatly boosted by my discovery of a neglected dataset of UK atmospheric electricity measurements[58]. This made new investigations possible of the global circuit[59],[60]. I have explored the historical measurements approaches used at Eskdalemuir[61] and Lerwick[62] and the data is now becoming widely available[63]. **This dataset is one of the longest atmospheric electricity series anywhere, underpinning global circuit and climate investigations.** To provide the classical data of the daily variation in atmospheric electricity, known as the Carnegie curve, I reanalysed measurements from the original voyages with, unusually at the time, the data provided in full[64], together with an investigation into the differing sources for the Carnegie curve[65]. **This comparative reference data is widely used**[66]**.** From working in archives**, I found a new source of eighteenth-century aurora data**[67] **also including thunder day records**[68]**.**	Data is being keyed through the Citizen Science Atmelect project at Zooniverse. Why use data from Shetland? Guardian *Weatherwatch*
Smoke pollution reconstruction	Smoke influences local atmospheric electricity measurements. We have used the retrieved archive measurements from Kew[69], due largely to	Eiffel Tower work reported in *Nature*.

	CTR Wilson and Lord Kelvin[70] **to reconstruct smoke pollution at Kew for the entire twentieth century**[71]**.** Smoke pollution has also been inferred for nineteenth century Paris[72], and, using measurements from a rod above a house in Knightsbridge, a double-diurnal cycle in pollution can be identified in Georgian London air[73], well before the traffic to which the variation is generally now attributed. **These smoke pollution retrievals provide data for studying environmental change.**	

Measurements and Instruments

Surface air temperature	Assessing the accuracy of conventional air temperature measurement has been a long-running research theme, for example through the development of an accurate fine wire thermometer system[74] and designed sensitive signal processing with exceptionally small sensor excitation current[75]. Operating this sensitive thermometer alongside a standard Stevenson screen (SS) has shown that the SS generally works well, but **when the wind is light there is** - **a slow SS registration of temperatures** [75], - **generally poorer accuracy** [76]. The daily minimum temperature is often affected by light winds. Also, SS thermometers very occasionally generate anomalously warm daily maximum temperatures (up to 1.5˚C) at low solar angles in winter and anomalously cool overnight minima under clear skies[77]. **Poor SS time response damps extreme temperatures, for example underestimating daily maxima** [78].	UoR piece on thermometer screens "Harrison clearly explains the basic physics of the interaction of a temperature sensor with flowing air and ...predicts ...the radiative error of a thermometer depends on the square root of the diameter of the sensor and inversely on the square root of the air speed past the sensor"
Surface humidity	The uncertainties caused by **variable ventilation effects also affect humidity measurements using a psychrometer**, with a correction proposed [79] which is becoming more widely used	Correction of Chinese humidity data
Radiosonde sensors	Radiosondes are an underused as a measurement platform in broader atmospheric science, as they are rarely equipped with sensors beyond those for the standard thermodynamic properties needed in meteorology**.** I suggested **specialised radiosondes for investigating cloud electrical properties**, which proved even more useful for a much wider range of measurements[80]. A particular feature of our radiosonde adaptations is their suitability for use by non-specialists at remote locations, due to simplified connectivity [81,82]. I	"...Harrison plans his own experiments using weather balloons..." *New Scientist*, 11 July 1998

	have worked on many sensors for different measurements, including electric charge[17], solar radiation[83] and cloud detection [84] which works even in daylight. A collector using a vibrating wire[85] as the sensing element shows promise for quantifying atmospheric supercooled water and direct measurements of volcanic ash. **Profiles of energetic particles have also been obtained using Geigersondes**[48]**.** Through an art-science project carrying a camera on a balloon, the instability of an ascending radiosonde became very obvious, leading to methods – initially a magnetometer[86] – to detect the platform's motion. This developed into a three-dimensional magnetometer[87] motion sensor, calibrated alongside a lidar, and then accelerometers to **directly record the atmospheric turbulence encountered. The local acceleration can be many times that of gravity,** especially near jet boundaries.[88]**.** **These sensors underpin atmospheric soundings of turbulence, radiation, ionisation, cloud charge and dust particles.**	 The magnetometer turbulence measurements helped interpret NASA's data from Titan's atmosphere.
General instruments	I have designed and demonstrated many general instruments and sensors, such as for measuring wind speed using a kite[89], and determining the freezing temperature of a suspended water drop[90]. This work has also included barometers[91,92], using ultrasound in measuring humidity[93], a stable radiometer amplifier[94] and repurposing an infra-red LED for isolated corona current measurements [95].	Over 30 papers in the *Review of Scientific Instruments* Kites as sensors
Aircraft charge emission	**We have developed methods to emit charge into fogs and clouds**, using extensively instrumented UAV platforms[96] and crewed aircraft[97] . The crewed aircraft emitter device fits in existing flare housings already provided on specialised cloud-seeding aircraft.	Editors Highlight: SciLight
Electrometry		
Small currents	**I have worked on compact and inexpensive sensors able to measure the tiny electric currents typically encountered in atmospheric electricity**, all	

	derived from this first design[98]. Calibration methods[99] have also been developed to avoid high-grade laboratory instrumentation. A logarithmic response current amplifier[100,101], exploiting the non-linear response of a LED has also proved useful in atmospheric soundings, as ion currents can vary over orders of magnitudes.	
Charge	Charge and current measurement are closely linked. For biological and meteorological applications, **we developed a Faraday cup charge measurement system** with a built-in picoammeter**,** allowing use with an **ultrasonic levitator to suspend objects** [102]**.** It includes a novel calibration approach which avoids the need for laboratory instruments.	
Electric field	Electric fields in the atmosphere are generally sensed using a field mill. A miniature and compact self-calibrating[103] version has been developed for environmental and eventual radiosonde use.	
Electrometer	Electrometers are sensitive current or voltage measuring devices, and often expensive and unsuitable for environmental use**. Several low current electrometer designs have been based on the floating input stage principle** I described[104], for measuring the potential on a long wire antenna[105] for calibrating field mills arrangements, and for high voltage[106].	

Eclipse Meteorology

Meteorological eclipse effects	Solar eclipses provide predictable changes in solar radiation forming **a natural atmospheric experiment**[107], allowing associated atmospheric changes to be modelled, predicted and observed.	
Eclipse wind	In both the 1999 and 2015 we observed wind changes[108] associated with a total and partial eclipse[109]. These support early suggestions of eclipse-induced circulation changes.	"these findings support the hypothesis…expected from the Aplin&Harrison 2003 theory…and are more likely to be correct than the original Clayton 1901 model"
Solar radiation	To test radiosondes' use in measuring solar radiation above cloud layers, a **coordinated release of instrumented radiosondes** from Reading, Lerwick Reykjavik successfully gave solar radiation measurements to compare with theory[110].	
Power generation effects	Eclipses allow transient stresses on the power grid to be evaluated, even in partial eclipses[111]. This emphasises that **reductions in solar generation cannot be mitigated with wind generation** from the same region, as the wind will also be reduced.	

Outreach papers

Storm Ciarán	The low pressure associated with the passage of this storm reduced the boiling point of water around breakfast time in the UK[112].	Guardian Welt
Eclipse met	My chapter in the interdisciplinary Eclipse and Revelation describes the range of weather-related effects arising from a solar eclipse.	"In his elegant and informative chapter meteorologist Giles Harrison explains… (*Nature Physics* review)
Hunga-Tonga pressure wave	I analysed and described the Reading pressure data[113] which contained multiple pressure pulses from the volcanic pressure wave circling Earth. The Reading data was included in a paper in *Science[114]*.	UoR press release *Science* front cover
Carrington event	The data recovered from the 1859 solar flare[115] – the Carrington event – has been turned into sound ("sonified").	https://www.loudnumbers.net/carringtonevent
Simple barometer	I described construction of a simple but accurate barometer[92], able to be built for less than £10, with the microcode provided.	
Air temperature	In *"Shall I compare thee to a summer's day?…",* we explained the science behind measuring air temperature accurately[116].	Victorian technology still accurate
The NEWEx experiment	For the 2015 partial solar eclipse, we encouraged folk to record cloud and temperature changes, to compare them against predictions and recordings from existing measurement networks. There was effective national engagement[117] generating useful science data [118].	BBC report on NEWEx
Asperitas cloud	*Asperitas* was officially recognised in the 2017 World Meteorological Organisation's Cloud Atlas, following the Cloud Appreciation Society (CAS)'s campaign. Our associated paper with the CAS described the observations and a possible formation mechanism[119].	EOS

Chaos machine	We described how chaotic behaviour could be replicated using an analogue computer, with equations originally devised to describe the atmosphere.	Elektor Article1 Article2
Anthropogenic snow	Snow formed from industrial plumes can fall in urban areas, without a conventional weather forecast warning of it[120].	Guardian
Atmospheric electricity sensor	Based on instrumentation developed for our research work and frequent requests from schools, we provided the description and details of a simpler version for educational use[121].	

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