Prof Giles Harrison – Research Themes

Research Overview

The atmosphere is electrically active at all scales, from charged cloud droplets to the global atmospheric electric circuit connecting thunderstorms worldwide. My research seeks to understand how electrical processes interact with weather, climate and environmental change, and how these processes can be observed through novel instrumentation and long-term measurements. The research, with co-workers, combines fundamental atmospheric physics, environmental observations and instrumentation development, with many projects linking all three aspects through common questions concerning electrical processes in the atmosphere

Applications and Impact

Outcomes from the research have contributed to:

- Climate-quality meteorological observations.
- Atmospheric observation standards.
- Environmental electrostatics.
- Fog and cloud modification studies.
- Citizen science and public engagement.
- Historical environmental reconstruction.
- Weather and climate outreach.

Key Contributions

- Demonstrated links between atmospheric electricity and climate variability.
- Established cloud-edge charging as a global atmospheric phenomenon.
- Developed a broad suite of atmospheric instrumentation, including sensors for cloud charge, ionisation, turbulence, radiation and environmental electrometry.
- Advanced the understanding of uncertainty in meteorological observations.
- Recovered and exploited unique long-term atmospheric electricity datasets.
- Investigated electrostatic modification of natural droplet systems.

Scientific Question 1 - How is atmospheric electricity linked to climate, weather and space weather?

Why this matters

The global atmospheric electric circuit links thunderstorms, fair-weather regions and the ionosphere. Understanding whether it responds to climate variability or solar influences is central to determining whether atmospheric electricity is an active component of the Earth system.

Key Findings

Atmospheric electricity and climate variability

- Demonstrated links between atmospheric electricity measurements and ENSO variability.
- Showed that atmospheric electrical measurements contain signatures of multidecadal climate variability.
- Provided evidence that the global atmospheric electric circuit is embedded within the climate system.

Space weather influences

- Investigated links between cosmic rays, clouds and atmospheric electricity.
- Found evidence for space-weather influences on lightning occurrence.
- Identified responses in atmospheric ionisation to energetic particle events.

Global-circuit properties

- Quantified electrical storage within the atmosphere.
- Developed new methods for obtaining properties of the global electric circuit, including its time constant.

Current Research

- Lerwick atmospheric electricity dataset.
- Historical atmospheric electricity records.
- Climate variability using atmospheric electrical measurements.
- Space-weather influences on lower-atmosphere processes.

Scientific Question 2 - Does electric charge influence clouds, fog and precipitation?

Why this matters

Cloud droplets are naturally charged. If electrical effects alter droplet behaviour they may influence cloud formation, precipitation and potentially climate.

Key Findings

Cloud electrification

- Demonstrated that layer-cloud boundaries carry electrical charge globally.
- Established current flow through layer clouds.
- Showed that cloud charging responds to turbulence.

Cloud microphysics

- Demonstrated that droplet charge influences evaporation and collision processes.
- Investigated mechanisms by which charge may alter precipitation development.
- Identified evidence that atmospheric ionisation may modify rainfall.

Fog electrification

- Showed that electrical properties change before visible fog formation.
- Demonstrated charge effects on fog droplet populations.
- Established new possibilities for electrically based fog monitoring.

Current Research

- FAAM aircraft measurements.
- Charged-droplet physics.
- Fog and cloud charge interactions.

Scientific Question 3- How can atmospheric measurements be improved?

Why this matters

Reliable environmental observations underpin weather forecasting and climate monitoring.

Key Findings

Air temperature measurements

- Quantified limitations associated with Stevenson screen ventilation.
- Demonstrated effects of sensor response times on observed temperature extremes.
- Developed methods for assessing measurement uncertainty.

Humidity measurements

- Identified ventilation-related biases in psychrometer measurements.
- Proposed corrections now being incorporated into major datasets.

Reference observations

- Contributed to improving understanding of climate-quality meteorological observations.

Current Research

- Climate Reference Site.
- Temperature measurement standards.
- Humidity dataset correction.
- Long-term climate observations.

Scientific Question 4- What new instruments are needed to observe the atmosphere?

Why this matters

Many atmospheric processes remain poorly observed because suitable instrumentation does not exist.

Key Findings

Atmospheric sounding systems

- Developed radiosonde systems for cloud charge measurements.
- Developed measurements of atmospheric ionisation using Geigersondes.
- Developed cloud, radiation and turbulence sensors for balloon platforms.

Electrometry

- Designed compact current and charge measurement systems.
- Developed low-cost electrometers and field mills.
- Created calibration methods suitable for field deployment.

Environmental electrostatics

- Developed airborne charge-emission systems for UAVs and crewed aircraft.
- Developed instrumentation for charged-droplet studies and environmental applications.

Current Research

- Charged-droplet instrumentation.
- Atmospheric electricity sensor development.
- Environmental electrostatics.
- Charge-emission

Scientific Question 5- What can long-term observations tell us about environmental change?

Why this matters

Environmental processes often operate over decades. Historical data provide unique opportunities for detecting long-term variability and change.

Key Findings

Atmospheric electricity archives

- Recovered and digitised Lerwick and Eskdalemuir datasets.
- Reanalysed Carnegie observations.
- Developed modern approaches for identifying fair-weather conditions.

Environmental reconstruction

- Reconstructed historical smoke pollution from atmospheric electrical observations.
- Recovered historical auroral and meteorological records.
- Used atmospheric electricity measurements to investigate past climate variability.

Current Research

- AtmosElec citizen-science project.
- Lerwick data recovery and analysis.
- Environmental reconstruction from historical observations.
- Climate variability and long-term change.

Natural Atmospheric Experiments

Solar Eclipses

Solar eclipses provide predictable perturbations to atmospheric forcing and are natural experiments for studying atmospheric processes.

Contributions

- Discovery and interpretation of eclipse-induced wind changes.
- Coordinated international weather-balloon observations.
- Investigation of eclipse-related turbulent flux changes.
- National Eclipse Weather Experiment (NEWEx).

Scientific Question 1 - How is atmospheric electricity linked to climate, weather and space weather?		
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], developing 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 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 global circuit current flow, which physically links space weather changes into lower atmosphere clouds**.	
Planetary AE	I have worked on some planetary AE topics, including the (dusty) electrical environment of Mars[13], and, drawing on findings for terrestrial clouds[9], **likely cosmic ray effects in Neptune's clouds**[14] **and Uranus** [15]. This shows common variability in two planetary atmospheres driven through energetic particle modulation by their host star.	Neptune - *Weatherwatch*
Space weather and atmospheric ionisation	A new Geiger tube system integrated with meteorological radiosondes[16] has given repeatable ionisation profiles in the troposphere and stratosphere in different solar conditions. Despite ad hoc launch times, the stratospheric maximum values correlate well with simultaneous surface neutron monitor measurements[17]**. Notably, during space weather disturbances, extra ionisation was unexpectedly detected in the lower atmosphere** [18]**,** implying a source of otherwise unnoticed energetic charged particles[18]. Separately, we have found indications[19,20] that **space weather influences lightning rates**.	American physical Society
Obtaining properties of the global circuit	Global circuit properties have been inferred from observations and modelling[21]. **Storage of charge by layer clouds modifies global circuit properties** [22]**.** The time constant has been obtained empirically using volcanic lightning data[23]. **This is 5 to 10 mins: the global circuit is therefore actively sustained on that timescale.**	Summary
Electrical processes in the lower atmosphere		
Volcanic plumes and lightning	Many plumes, and especially those of dusts, are charged[24]. This allows charged volcanic plumes can be sensed as they	Making urgent measurements

	pass over an electric field sensor[25]. These aspects were considered in a review paper on volcanic lightning[26], subsequently well-cited. Surprisingly, a volcanic plume came to us, and in a rapidly published paper, **we reported charged volcanic ash particles aloft**[27].	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[24], a surface measurement network monitoring charged dust[28], and the sea breeze from the Arabian Gulf to provide a regular and repeatable disturbance of dust leading to strong electrification[29]. Dust devils have also been investigated in desert conditions using simple instrumentation[30]. We also responded to a Saharan dust plume over Reading, with surface observations and a sounding[31]. The surprising long-range transport of dust remains unexplained, although electrification looks unlikely to be a dominant factor[32]. **Charging through triboelectrification is a widespread property of atmospheric dust.**	Saharan plume *Physics World*
Coupling between Earth's surface and the atmosphere		
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[33] (Atmospheric Lithosphere–Ionosphere Charge Exchange) can explain this. Our original paper suggesting this global circuit mechanism[34] was **short-listed for the 2010 Lloyds Science of risk prize.**	Evidence for D region coupling

Scientific Question 2 - Does electric charge influence clouds, fog and precipitation?		
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[35] and clouds[36]. With specially designed balloon-carried sensors[37] we showed, first, that the base of layer clouds is charged[38] and then that the top was charged, in multiple locations globally[39]. For low clouds, the cloud base charge can even be sensed in surface measurements[40]. This **confirms charging of upper and lower boundaries of layer clouds as 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[41]. This can be explained by turbulence affecting the cloud top charge, before the effects of those changes propagated to the cloud base[42]. 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[43]. For charged water droplets, evaporation is inhibited, facilitating droplet formation at reduced water supersaturation compared with an equivalent neutral droplet[44]. Collection processes are affected by charging[45] which may influence rainfall generation[43], which	

	has also been investigated in simulations of turbulent situations[46]. We have shown that rainfall in the 1960s appears modified by the ionisation then released into the atmosphere[18] . **This shows that fundamental cloud droplet processes can be influenced by charge.**	
Fog and charge	Air's electrical properties often change before fog becomes apparent visually[47,] to **provides a new basis for nowcasting of fog[48].** 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[49]. By releasing charge into fog from an overflying robotic aircraft, we observed a small increase in the reflectivity of the fog[50,] likely to be due to changes in the droplet size distribution. **This shows a new way to influence natural droplet systems, by charge release.**	Fog prediction in Phys.org
Aircraft charge emission	**We have developed methods to emit charge into fogs and clouds**, using extensively instrumented UAV platforms[51] and crewed aircraft[52] . The crewed aircraft emitter device fits in existing flare housings already provided on specialised cloud-seeding aircraft.	Editors Highlight: SciLight

Scientific Question 3- How can atmospheric measurements be improved?		
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[53] and designed sensitive signal processing with exceptionally small sensor excitation current[54]. 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 slower registration of temperatures** [54]**,** - **generally poorer accuracy** [55]**.** The daily minimum temperature is especially affected by light winds. 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[56]. The SS time response is poorly known, and falls outside the World Meteorological Organisation's recommendations. Poor SS time response **damps extreme temperatures, underestimating daily maxima** [57]. It also affects statistics derived from exceedances of temperature thresholds, such as the count of Tropical Nights[58].	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 [59] which is becoming more widely used in datasets.	Correction of Chinese humidity data
Climate reference observations	Understanding instrumentation uncertainty naturally leads to development of climate-quality observations. Current work includes development of the Reading Climate Reference Site, intended to provide high-quality reference measurements and support investigations of long-term environmental change.	
Scientific Question 4- What new instruments are needed to observe the atmosphere?		
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[60]. A particular feature of our radiosonde adaptations is their suitability for use by non-specialists at remote locations, due to simplified connectivity [61,62,]. I have worked on many sensors for different measurements, including electric charge[37], solar radiation[63] and cloud detection [64] which works even in daylight. A collector using a	"...Harrison plans his own experiments using weather balloons..." *New Scientist*, 11 July 1998

	vibrating wire [65] as the sensing element shows promise for quantifying atmospheric supercooled water and direct measurements of volcanic ash. **Energetic particle profiles have been obtained using measurements from our Geigersondes[16].** 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[66] – to detect the platform's motion. This developed into a three-dimensional magnetometer[67] motion sensor, calibrated alongside a lidar, and then with accelerometers to **directly record the atmospheric turbulence encountered. The local acceleration can be many times that of gravity,** especially near jet boundaries.[68]. **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 general instruments and sensors, such as for measuring wind speed using a kite[69], and determining the freezing temperature of a suspended water drop[70]. This work has also included barometers[71,72], using ultrasound in measuring humidity[73], a stable radiometer amplifier[74] and repurposing an infra-red LED for isolated corona current measurements [75].	Over 30 papers in the *Review of Scientific Instruments* Kites as sensors
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[76]. Calibration methods[77] have also been developed to avoid high-grade laboratory instrumentation. A logarithmic response current amplifier[78,79], exploiting the non-linear response of a LED has 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** [80]**.** 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[81] 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[82], for measuring the potential on a long wire antenna[83] for calibrating field mills arrangements, and for high voltage[84].	"Our results therefore confirm the theoretical studies carried out by Clement and Harrison..."
Scientific Question 5- What can long-term observations tell us about environmental change?		

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[85]. This made new investigations possible of the global circuit[86,87]. I have explored and summarised the historical measurements approaches used at Eskdalemuir[88] and Lerwick[89], making the forgotten data more widely available[90]. **This dataset is amongst 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 used provided in full[91], together investigating the differing sources for the Carnegie curve[92]. **This comparative reference data is widely used[93].**	Data is being keyed through the Citizen Science Atmelect project at Zooniverse. Why use data from Shetland?
Standardising fair weather measuring conditions	Weather perturbs atmospheric electricity[94,95], 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 have become widely used[96]** yielding high quality atmospheric electricity data using automated weather sensors.	
Smoke pollution reconstruction	Smoke influences local atmospheric electricity measurements. We have used the retrieved archive measurements from Kew[97], due largely to CTR Wilson and Lord Kelvin[98] **to reconstruct smoke pollution at Kew for the entire twentieth century[99].** Smoke pollution has also been inferred for nineteenth century Paris[100], and, using	Eiffel Tower work reported in *Nature*.

	measurements from a rod above a house in Knightsbridge, a double-diurnal cycle in pollution can even be identified in Georgian London air[101], well before the traffic to which the variation is generally now attributed. **These smoke pollution retrievals provide data for studying environmental change.**	
Historical aurora and weather records	A bonus from working in archives was chancing upon **a new source of eighteenth-century aurora data**[102] **also including thunder day records**[103]**.**	
Natural Atmospheric Experiments		
Meteorological eclipse effects	Solar eclipses provide predictable changes in solar radiation forming **a natural atmospheric experiment**[104], allowing associated atmospheric changes to be modelled, predicted and observed.	
Eclipse wind	In both the 1999 and 2015 we observed wind changes[105] associated with a total and partial eclipse[106]. These are consistent with 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"
Turbulent fluxes	Switching of turbulent fluxes by an eclipse allows unique investigations near to the surface[107].	
Solar radiation	To test radiosondes' measurements solar radiation, a **coordinated release of instrumented radiosondes** from Reading, Lerwick and Reykjavik successfully gave solar radiation measurements above cloud layers [108].	
Power generation effects	Eclipses allow transient stresses on the power grid to be evaluated, even in partial eclipses[109]. This emphasises that **reductions in solar generation cannot be mitigated with**	

	wind generation from the same region, as the wind is typically also reduced.	

Engagement, Impact and Citizen Science		
Research communication		
Storm Ciarán	The low pressure associated with the passage of this storm reduced the boiling point of water around breakfast time in the UK[110].	Guardian Welt
Air temperature	In *"Shall I compare thee to a summer's day?…",* we explained the science behind measuring air temperature accurately[111].	Victorian technology still accurate
Hunga-Tonga pressure wave	I analysed and described the Reading pressure data[112] which contained multiple pressure pulses from the volcanic pressure wave circling Earth. The Reading data was included in a paper in *Science*[113].	UoR press release *Science* front cover
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)
Anthropogenic snow	Snow formed from industrial plumes can fall in urban areas, without a conventional weather forecast warning of it[114].	Guardian
Citizen Science		
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[115] generating useful science data [116].	BBC report on NEWEx
AtmosElec	Citizen-science project supporting recovery and digitisation of historical atmospheric-electricity observations, enabling new investigations of climate variability from long-term datasets.	Guardian *Weatherwatch*
Public Engagement		
Asperitas cloud	*Asperitas* was officially recognised in the 2017 World Meteorological Organisation's Cloud Atlas, following the Cloud	EOS

	Appreciation Society (CAS)'s campaign. Our associated paper with the CAS described the observations and a possible formation mechanism[117].	
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
Carrington event	The data recovered from the 1859 solar flare[118] – 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[72], able to be built for less than £10, with the microcode provided.	
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[119].	

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