# *The electricity of extensive layer clouds*

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# The electricity of extensive layer clouds

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## Introduction

Luke Howard's classification of clouds occurred at a time when electrostatics was an especially fashionable topic, both as a study and for entertainment (Schiffer, 2003). It is therefore perhaps not surprising that, in his *Seven Lectures on Meteorology*, Howard mentions 'the electric fluid' playing a role in the formation of cirrus,

> *Vapour then being present, and condensation by change of temperature admitted, we have only to call in the air of a third element, the Electric fluid, to account for the peculiar appearances of the Cirrus cloud* (Howard, 1837).

The equivalence between the electricity of laboratory machines and the charges in clouds was appreciated from the time of Benjamin Franklin, motivating early investigations in atmospheric electricity, such as James Glaisher's use of an electrometer on his mid-nineteenth century balloon flights (Glaisher, 1862).

Whilst thunderstorm electrification has been a dominant research topic in atmospheric electricity, all clouds encounter mobile atmospheric charges released by natural ionisation, and hence can acquire a small net charge as a result. Here, recent experimental investigations into the electrification of extensive layer clouds are summarised.

## The global circuit

The work of two further historical scientists provides a useful framework for this discussion. These are, firstly, Lord Kelvin, who provided Glaisher's balloon electrometer and pioneered instrumentation for continuous recordings of atmospheric electrical changes (Aplin and Harrison, 2013), and, secondly, C.T.R. Wilson, Nobel Prize winner for the cloud chamber and contributing a lifetime of work on atmospheric electricity (Harrison, 2011). These two individuals had contrasting interpretations on the electricity of the atmosphere. Despite observing considerable variability, Kelvin regarded the phenomena as fundamentally electrostatic, whereas, following the discovery of the electron, Wilson saw the need for current flow, inferring therefore that atmospheric electricity was somehow electrodynamic. This ultimately led to Wilson's key insight, of the global atmospheric electric circuit concept (Wilson, 1929).

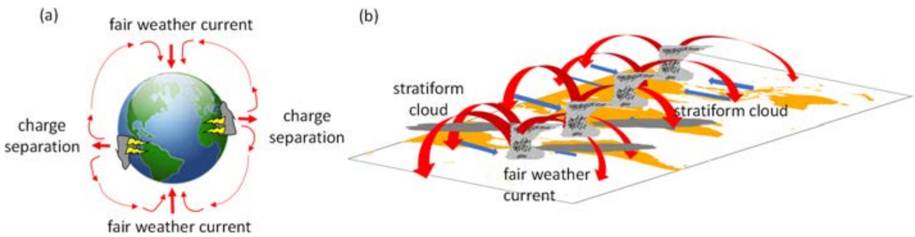


*Figure 1. (a) Representation of the global atmospheric electric circuit. Charge separation in disturbed weather regions leads to current flow around the planet, which returns to the surface in fair weather regions. (b) Conceptual picture of global circuit current flow, with regions of extensive stratiform cloud present.*

The global circuit essentially provides an explanation for, electrically speaking, 'what comes down must have gone up'. It argues that charge separation in the disturbed weather regions of rain and thunder sustains the currents observed at some distance away where there is no charge separation, known as fair weather[1] regions (Figure 1a).

An important supporting aspect for the Wilson perspective was the agreement between the diurnal variation seen in the active area of land thunderstorms as determined from thunderday data, and current flow in the global circuit, originally reported by Whipple and Scrase (1936). Such a close correlation was, however, indicative rather than confirmatory (Harrison, 2020). Establishing the vertical charge structure of thunderclouds was a critical mechanistic aspect (Williams, 2009), ultimately resolved experimentally through carrying a new recording instrument (the 'alti-electrograph') through thunderclouds by a sounding balloon. The consequences of these findings were carefully explained in *Weather* (Simpson, 1949).

The global circuit is one of meteorology's many conceptual frameworks, such as the Hadley Cell or Brewer–Dobson circulation. Whilst such descriptions are expressly intended to minimise detail, they can nevertheless provoke related further questions, especially with the added context of modern data sources and satellite imagery. For example, as Figure 1(b) shows, the abundance of layer cloud (e.g. covering 20% of the low latitude oceans, Schneider *et al*., 2019) leads to the conclusion that current flowing in the global circuit must sometimes encounter layer clouds, with some associated charge transfer to the cloud droplets.

Experiments have shown that the fair weather current – which consists of

[1]In atmospheric electricity, 'fair weather' refers to a situation with negligible local weather effects on the electrical conditions, and especially without electrically active convection. There is no relationship implied with the presence or absence of fair weather cumulus clouds, but more than three-eighths cumuliform cloud of any form would violate the usual atmospheric electricity fair weather criteria (Harrison & Nicoll, 2018).

molecular cluster ions formed by natural radioactivity and cosmic rays – continues to flow through droplet and cloud layers (Bennett and Harrison, 2009; Nicoll and Harrison, 2009). Hence, although extensive layer clouds do not locally generate charge separation by convection, they may nevertheless interact with fair weather electric current flow. Figure 2 shows a simplified picture of global circuit current flow in which a branch of the global circuit passes through extensive layer clouds.

The global circuit current is affected by internal climate variability (e.g. the El Niño Southern Oscillation), and external influences associated with space weather.

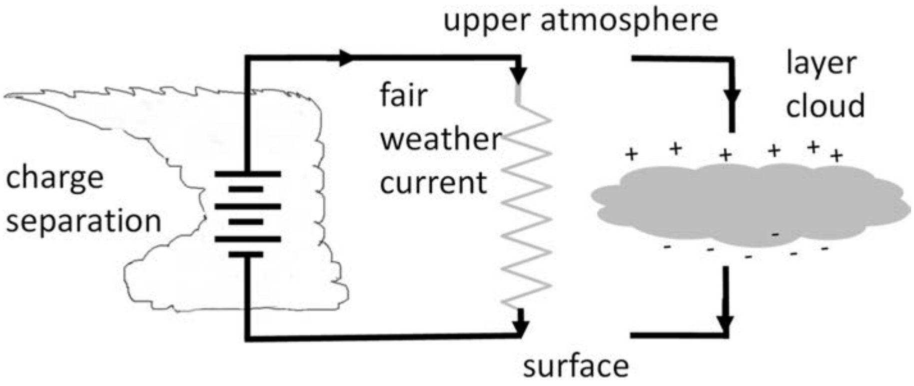


*Figure 2. Global electric circuit, showing current flow out of the charge-separating regions, returning through the electrical resistance of the distant, fair weather, atmosphere. In some cases, the current will return through extensive layer clouds.*

## Experimental observations

As mentioned, cluster ions are always present in air and are responsible for the finite electrical conductivity of air. Such cluster ions are collected by water droplets, hence liquid water clouds become regions of reduced electrical conductivity compared with that of cloud-free air. This has the consequence that the horizontal boundary between clear air and cloudy air also represents a transition in the electrical conductivity. With a positive current flowing downwards, and taking a solely electrostatic perspective (i.e. neglecting motion within the cloud), positive space charge accumulates at cloud top and negative charge at cloud base (see also Figure 2). The charge is proportional to the global circuit current and inversely proportional to the distance over which the cloud to clear air transition occurs (Gunn, 1956; Tinsley, 2008; Nicoll and Harrison, 2010). Fog provides some intuition for the length scales involved (see Figure 3), and, although there is variability, even window-gazing during commercial aircraft flights suggests horizontal cloud edges can be very abrupt, especially at the upper boundary.

*Figure 3. Examples of lower (left panel, Chicago, Illinois, 22 June 2014) and upper (right panel, Selsley, Gloucestershire, 12 October 2014) fog boundaries.*

As extensive layer clouds are relatively common globally, and the global circuit current is always present, layer cloud electrification is therefore also expected to be common. Two experimental approaches have been taken to investigate whether this is really the case, firstly, using surface measurements beneath low-level stratiform cloud, and, secondly, from in situ measurements using modified radiosondes.

### *Surface measurements*

Charge in the base of clouds can affect the electric field at the surface beneath. Figure 4 shows an example of surface atmospheric electric field changes associated with a low-level stratiform cloud, found by soundings to be about 300m thick (Harrison *et al*., 2019). Turbulent fluctuations in the cloud base, as observed using a ceilometer (Figure 4a), are reproduced closely in the atmospheric electric field (Figure 4b). Such a close correlation between measured quantities can arise when the same physical property is sensed with different methods, in this case the change in the cloud varies the position of the cloud base charge.

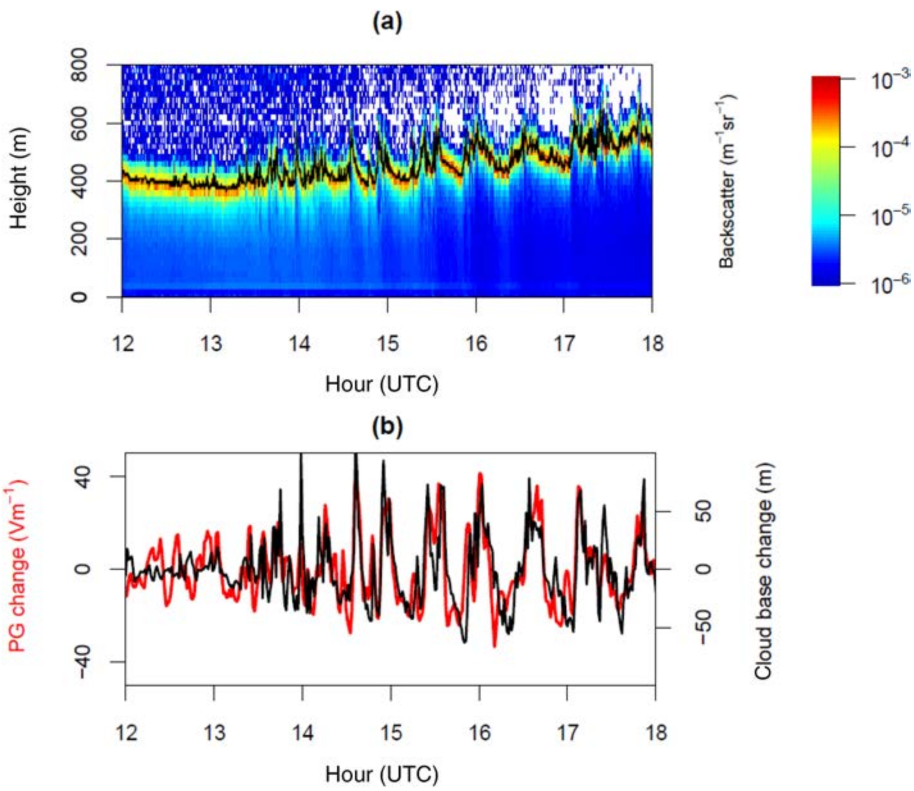


*Figure 4. (a) Ceilometer backscatter observations of slow dynamical changes in the cloud base of low-level stratiform cloud at Reading (19 March 2015). Black line shows retrieved cloud base height. (b) High-pass filtered cloud base (black line) and atmospheric electric field changes (red line, measured as the potential gradient [PG]) at the surface beneath.*

## *Balloon soundings*

Meteorological radiosondes routinely provide vertical soundings of solely thermodynamic properties and wind, but, despite their long use for ozone measurements (Brewer and Milford, 1960) and in resolving the thunderstorm charge problem mentioned earlier (Simpson and Scrase, 1937), they are under-exploited as general measurement platforms. Miniaturised electronics can now allow many additional sensors to be carried without compromising the standard meteorological data, such as for cloud electricity measurements (Harrison, 2022). To investigate the electrical properties of stratiform clouds, the upper and lower boundaries must be accurately identified. The time response of the capacitance-based relative humidity sensors is insufficient to achieve this at typical radiosonde ascent speeds, hence an optical backscatter system has been specially developed using a high brightness light-emitting diode source and phase-locked photodiode detector (Harrison and Nicoll, 2014). The special sounding package also includes a sensitive charge detector (Nicoll, 2013) and can be deployed wherever the standard radiosonde equipment exists.

Figure 5 shows soundings made through layer clouds at Halley, Antarctica, on two consecutive days in February 2015. Although the thermodynamic profiles (Figure 5a and d) appear similar, the optically determined cloud boundaries differ considerably. The charge profiles (Figure 5c and f) are also different, with the greatest charge present in the case with the greatest backscatter contrast across the cloud boundary. The upper and lower charges in this case are positive and negative, respectively.

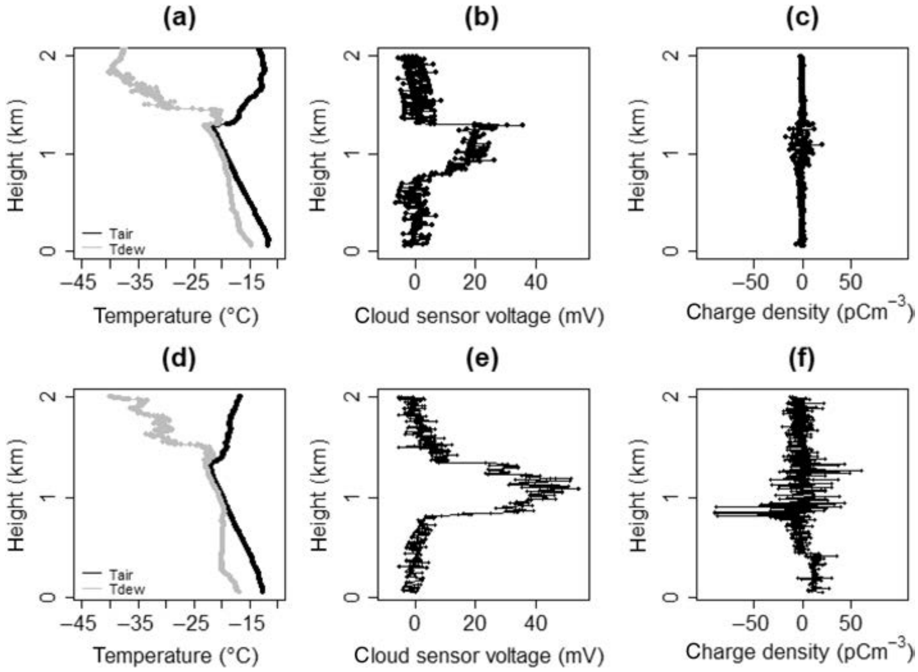


*Figure 5. Vertical profiles through a long-lived stratiform cloud at Halley, Antarctica, on 20th (a–c) and 21st (d–f) February 2015. (a,d) The thermodynamic information (air temperature and dew point temperature), (b,e) the response of the optical cloud sensor (with cloud sensor voltage proportional to backscatter received) and (c and f) the measured charge density (1 pC m$^{-3}$ = 6.3 elementary charges per cm$^{-3}$).*

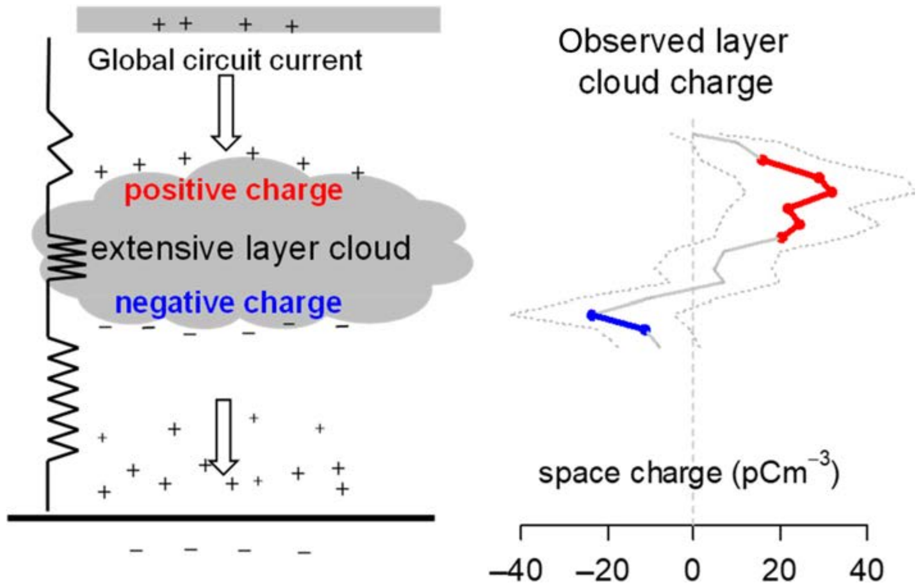


*Figure 6. Left panel: conceptual picture of the electrical structure of extensive layer clouds, with the relative resistances of cloud and clear air regions depicted by compressed and stretched, respectively, resistor symbols. Right panel: average of charge measurements at layer cloud edges normalised by cloud thickness, from soundings made in Antarctica, Finland and the UK (modified from Nicoll and Harrison, 2016; Harrison, 2022).*

## Charge on water drops

After combining many measurements from multiple sites globally, including supercooled and warm stratiform clouds, Figure 6 shows the average charge profile (Nicoll and Harrison, 2016). This clearly demonstrates that the electrostatic expectations for extensive layer clouds are reasonable, and hence that cloud drop electrification in stratiform clouds is likely to be a global phenomenon.

Charged drops have some surprising properties. Highly charged drops can only sustain charge up to a maximum value – the Rayleigh limit – above which the drop becomes unstable and explosively disintegrates (Rayleigh, 1882). At lesser charges, Rayleigh found experimentally that the collision and coalescence processes were affected (Strutt, 1879). Charge also affects droplet evaporation (Ambaum, 2021). An important aspect is that water drops are polarisable, hence, unlike point charges, two drops of the same polarity can attract when they are close to each other. This may have implications for the coalescence of drops, even when only small charges are carried. Simulations of droplet interactions which include turbulent flow show that, for certain size combinations, enhancement of collisional growth can occur (Ambaum *et al.*, 2022).

Awareness of the cloud base charge in stratiform cloud has provoked investigations of whether there are any resulting effects, observable directly or indirectly (Harrison and Ambaum, 2013). Figure 7 shows atmospheric electrical measurements made at the high latitude sites of Sodankyla, Finland (Figure 7a) and Halley, Antarctica (Figure 7b), which demonstrate a similar variation to the standard Carnegie curve, well established as due to the global atmospheric electric circuit current. During the polar night at both sites, when no strong thermally driven diurnal cycle is expected,

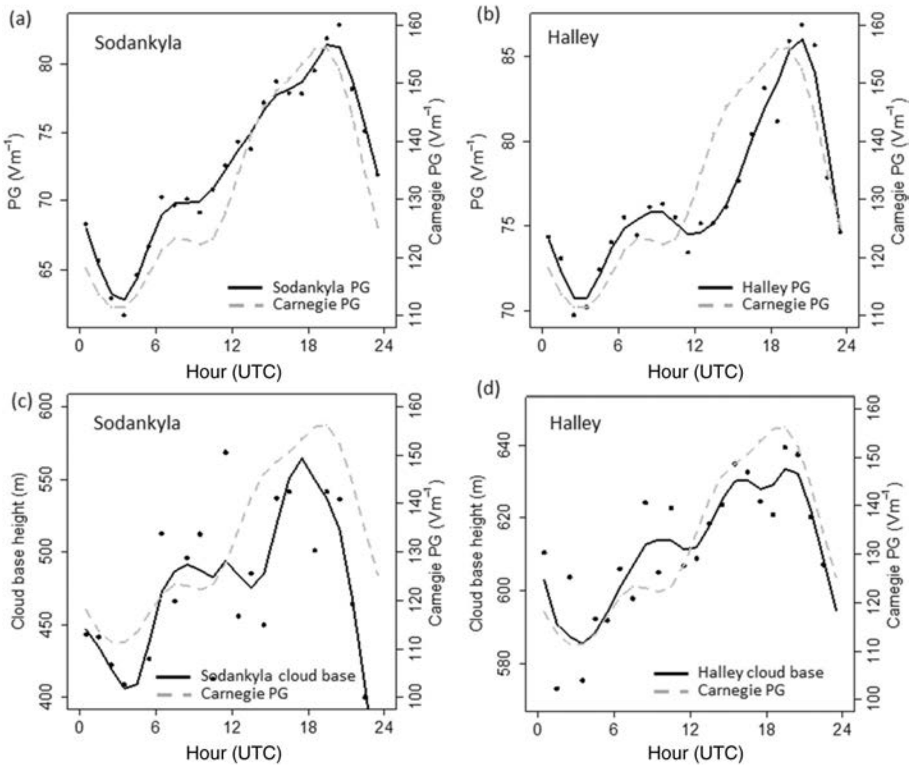


*Figure 7. (a,b) Diurnal variation in potential gradient (PG) at Sodankyla (June 2017–May 2020; $0 < PG < 1000 Vm^{-1}$) and Halley (2015–2017; $0 < PG < 300 Vm^{-1}$). (c,d) Diurnal variation in cloud base height at Sodankyla (2006–2012; <4000m) and Halley (2003–2020; <2000m) during polar night conditions. The grey dashed curve shows the standard diurnal variation in PG measured by the Carnegie (Harrison, 2013).*

laser ceilometer data demonstrate a daily variation in cloud base height which follows a similar form (Figure 7c and d). As the lower cloud edge charge is known to be proportional to the global circuit current, this raises the possibility that charge effects on cloud microphysics migh be related to the cloud base changes.

## Conclusions

Luke Howard's suggestions of electrostatic influences on clouds were not firmly based in experimental atmospheric science, but they nevertheless remain thought-provoking, not least his words on Nimbus,

> *… in which minute drops constituting cloud…are by a change in their electrical state made to coalesce, and descend in drops of Rain* (Howard, 1837),

which were written well before the experimental work of Rayleigh on charged drops. From the modern perspective, it seems fair to conclude that all clouds, not just thunderclouds, are charged to a greater or lesser extent: there are also good reasons to conclude that extensive layer clouds will always carry charge.

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## Data availability

Much of the material is from cited articles, but Halley and Sodankyla PG data are available from the GloCAEM database (http://data.ceda.ac.uk/badc/glocaem/data/). Cloud base data for Sodankyla was provided by the Finnish Meteorological Institute (https://litdb.fmi.fi/), and, for Halley, from the British Antarctic Survey. Sounding data for Figure 5 are at https://doi.org/10.17864/1947.000420.

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# When clouds raise an eyebrow – the case for a new supplementary cloud feature '*Supercilium*'

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Since it was first published in 1896, the *International Cloud Atlas*[1] has provided an internationally agreed standard for the observation and reporting of cloud types. It uses the familiar Linnaean system of nomenclature (*Stratus, Cumulus*, etc.), as first proposed by Luke Howard in his '*Essay on the Modification of Clouds*' in 1803 (Hamblyn, 2002; Howard, 2011). Howard's system was later adopted as the official international classification scheme by the World Meteorological Organization (WMO).

Over the past century and a quarter since its initial publication, the *International Cloud Atlas* has undergone occasional revisions (Hamblyn, 2002). The most recent version of the Atlas, published online in 2017 (WMO, 2017) underwent the greatest number of changes in its history. This followed considerable evidence gathered by academics and citizen scientists during the first two decades of the twenty-first century aided by the rapidly emerging and widespread use of smartphones and digital photography, particularly in the case of the new supplementary feature *asperitas* (Harrison *et al*., 2017). In total, the WMO accepted 12 revisions to the 2017 version of the Atlas, comprising 1 new cloud species (*volutus*), 5 new supplementary cloud features (*asperitas, cavum, murus, cauda* and *fluctus*), 1 new accessory cloud type (*flumen*)

*Figure 1.* Altocumulus 'supercilium' *(unofficial name, across centre and lower part of photograph) spotted over the Sangre de Cristo Mountains, New Mexico (USA), on 17 January 2022. There is also some* Altocumulus lacunosus *(top and right) and cloud iridescence (top right). (© Marc Davey.)*

[1]There had been a *Wolken-Atlas* (Cloud Atlas) published six years earlier by Hildebrandsson *et al.* (1890).