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Potential solar influence on clouds through atmospheric electrical coupling

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Abstract

This work reviews the evidence for the effect of the Global Atmospheric Electric Circuit on clouds, including a discussion of charge-influenced cloud microphysical processes. New cloud edge charging observations from balloon borne sensors using a radiosonde system are presented, demonstrating the typical magnitude and vertical distribution of charge present in layer clouds.

1. Introduction

Clouds play a major role in the radiation budget of the Earth's climate system. Links postulated between solar activity and clouds have therefore attracted attention and controversy. Observing and quantifying the suggested physical mechanisms coupling solar variability with clouds and climate is therefore an important contribution to this discussion. One potential route by which clouds may respond to solar influenced variations in high energy particle emissions is via the Global Atmospheric Electric Circuit. This arises as a result of the current flow in the global circuit, which causes electrification at the upper and lower edges of extensive layer clouds. A vertical conduction current flow, J_z, is always present globally in fair weather, which is strongly modulated by solar activity. It effectively couples solar changes down through the lower atmosphere to the surface. Electrification of cloud droplets can have implications for cloud microphysical processes, and potentially provides one source of variability in the macroscopic properties of clouds.

2. Charge production at cloud edges

Charge is continually generated at the edges of layer clouds due to vertical ion current flow through the vertical air conductivity gradient caused by the cloud [1]. The conductivity gradient arises due to ion-droplet attachment inside the cloud, which reduces the conductivity, σ, inside the cloud compared to it's clear air value. The gradient in conductivity creates a vertical gradient in electric field, E_z, at the cloud edge. Gauss' law of electrostatics relates the vertical gradient in electric field to space charge density, ρ, through

$$\frac{\rho}{\varepsilon_0} = \frac{dE_z}{dz} \qquad (1),$$

where ε_0 is the permittivity of free space, generating positive space charge at the cloud top and negative charge at the base. Assuming Ohm's law ($J_z = \sigma E_z$), space charge can be expressed in terms of J_z as

$$\rho = \varepsilon_0 J_z \frac{1}{\sigma^2} \frac{d\sigma}{dz} \qquad (2).$$

Equation (2) demonstrates that the cloud edge charge is dependent on a number of factors, including the vertical current density, controlled by the global electric circuit; the local conductivity (altitude and solar cycle dependent); and the vertical conductivity gradient, which is mostly determined by the cloud droplet profile. Cloud edge electrification clearly also requires J_z to pass continuously through the droplet region, which has been demonstrated to occur with extensive cloud layers [2].

3. Cloud microphysical implications

Charge on cloud edges is quickly transferred to cloud droplets, influencing several cloud microphysical processes. Droplet-particle interactions are thought to be influenced by charge via the electro-scavenging mechanism [3]. Charged aerosol particles are more likely to be scavenged by water droplets than neutral ones, enhancing freezing in supercooled cloud layers if the aerosol particle is an ice-nuclei. Droplet activation is also thought to be influenced by charge by reducing the amount of supersaturation of water vapour required for the droplet to grow [4]. Droplet-droplet interactions can also be influenced by charge as theory demonstrates that collision efficiencies for small droplets (<5μm) can be substantially enhanced when only a few electron charges are present on the droplets [5]. Typical droplet charges required to influence the various processes detailed above varies from a few electronic charges, e, for droplet-droplet interactions, to several hundred e for droplet activation. Therefore knowledge of typical droplet charges present in layer clouds is essential to assess which cloud microphysical processes are most likely to be affected by charge.

4. Charged cloud measurements

In-situ cloud charge measurements have been made from a free balloon platform from Reading, in the UK. The specially developed PANDORA data acquisition system [7], allows specialist sensors to be flown alongside meteorological radiosondes, with data transferred to ground at 1Hz, synchronous with the pressure, temperature and relative humidity measurements made by the radiosonde. Charge measurements have been made alongside cloud measurements from two specially developed disposable, lightweight sensors. The charge sensor comprises a small spherical electrode, connected to a sensitive electrometer circuit, which measures the current flowing to the electrode. This is based on a previous approach [6]. The charge device is self calibrating, with a known calibration current applied to the measuring electrode every 180 seconds. The cloud droplet detector employs an optical backscatter method of cloud droplet detection, utilising two ultrabright LEDs as the light source and a VTB8440B photodiode as the receiver. Light which is backscattered from cloud droplets is reflected by the droplets into the photodiode receiver. An example of data from an instrumented balloon flight is shown in Figure 1 which depicts a flight through an extensive layer of stratiform cloud over Reading.

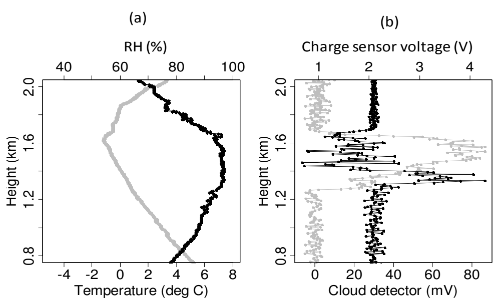

Figure 1. Measurements from a balloon flight through a layer cloud over the southern UK. (a) Temperature (grey) and relative humidity, RH (black) as measured by the radiosonde. (b) Voltage output of cloud droplet sensor (grey) and charge sensor (black).

The location of the cloud edges are shown very clearly by the cloud droplet detector (Fig. 1 (b), grey line), which shows the sharp transition between clear and cloud air over a distance of approximately 50m. Measurements from the charge sensor (Fig. 1 (b)) show the presence of charge within the cloud layer, coincident with the cloud edge. Utilising the method detailed in [6] the space charge, ρ, within the cloud layer is found to range from ±150 pCm^{-3}. Using a combination of the data measured by the cloud droplet detector and charge sensor, the charge per cloud droplet can be roughly estimated and was found to range from -96 to 65e.

5. Summary and Conclusions

The use of a multisensor charge and cloud package, which is flown alongside standard meteorological radiosondes, demonstrates the presence of charge on layer cloud edges, as predicted by theory, and allows an estimate of the typical charges present on cloud droplets to be derived. The cloud edge charge observed is sufficient to influence various cloud microphysical processes including droplet-droplet interactions and electro-scavenging, which may have implications for macroscopic cloud properties.

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