A charge emitter for use in evaluating aircraft rainfall enhancement

Journal of Physics: Conference Series

PAPER • OPEN ACCESS

A charge emitter for use in evaluating aircraft rainfall enhancement

A charge emitter for use in evaluating aircraft rainfall enhancement

Nicoll, K.A.[1], V. Escobar-Ruiz[1], R.G. Harrison[1], M.H. Ambaum[1], A.A. Alkamali[1,2]

1. Department of Meteorology, University of Reading, UK
2. Department of Research and Weather Enhancement, National Center of Meteorology, United Arab Emirates

Corresponding Author: k.a.nicoll@reading.ac.uk

Abstract. Charging of droplets is known to influence their properties and interactions, such as through modifying their evaporation, collisions or stability. Introducing additional charge into a droplet system, such as a natural fog or cloud may therefore provide a route to modify its behaviour. As aircraft are already used in rainfall enhancement activities by some national meteorological services, adapting their existing delivery systems to include charge release provides a convenient method with which to pursue this. Rainfall enhancement aircraft typically carry an array of under-wing tubes into which cloud seeding agents (e.g. salt or silver iodide) are contained in flares which are loaded pre-flight. Our approach for a charge release system is to construct a stand-alone device able to fit within an existing flare housing, to provide controlled release of ions by corona emission. The "flare emitter" device is battery powered and able to release either polarity of corona ions. It contains a programmable microcontroller (Arduino Nano) able to operate in a fixed sequence and record data to an internal memory card at 10Hz. Monitoring systems for the corona emission voltage and current are included, as well as environmental sensors for pressure, temperature and relative humidity.

1. Introduction

Charge is known to modify the behaviour of aerosol particles and droplets in atmospheric air. Water droplets in fogs and clouds become charged naturally by the attachment of atmospheric ions, which are produced by galactic cosmic rays and radioactivity from Earth's surface. Previous research has suggested that charge influences droplet collisions (through affecting the droplet collision efficiency) and evaporation [1], [2], leading to a change in the droplet size distribution. Artificially enhancing charge in fogs and clouds may therefore provide a method of influencing droplet processes, with potential applications in the fields of rainfall enhancement or fog dispersal. Traditional rainfall enhancement schemes typically involve chemical methods, where silver iodide or salt particles are released into clouds from manned aircraft. Charge generation by ionisation provides a method which minimises chemical residues and removes the need to carry a heavy payload which must be replenished after each flight.

Recent research has attempted to investigate the effects of charge on droplets directly, by artificially adding ions to clouds and fogs. Measurable changes in fog droplet diameter have been demonstrated [3], following active release of charge from bipolar ionisers during near surface fog at a site in the south-west of the UK. Artificially introducing charge into clouds above the surface, however, is a more complex affair - involving airborne platforms or, at the least, an installation of emitter masts. Our previous research has developed compact bipolar ionisers which can be flown on small Unmanned Aerial Vehicles (UAVs), and flown into low altitude cloud or over fog layers [4]. The UAV is instrumented with one positive and one negative ioniser, mounted beneath the wings, with ionisers switched on and off under manual control from the UAV pilot. UAV flights over an electric field mill have demonstrated a clear change in electric field during ion emission from the aircraft [5]. Subsequent UAV flights in fog demonstrated a change in the radiative properties of the fog during ion emission periods, as measured by downward-looking radiation sensors onboard the aircraft [5].

In this paper we discuss the development of a new charge emitter, which has been designed to fly on manned aircraft, as part of the existing cloud seeding infrastructure of the National Centre for Meteorology (NCM) in the United Arab Emirates (UAE). The UAE carries out a regular programme of cloud seeding flights with its King Air aircraft (Figure 1(a)), which is instrumented with a rack of NaCl (salt) loaded seeding flares (Figure 1(b)). The conventional seeding flares are burned in flight, releasing the seeding particles into convective clouds. By developing charge emitting instrumentation to fit within the existing seeding flare tubes (Figure 1(c)) it is possible to routinely fly such instrumentation without further adapting the aircraft structure. This makes it possible to study effects of charge on cloud droplet behaviour in much more detail and more conveniently than previously.

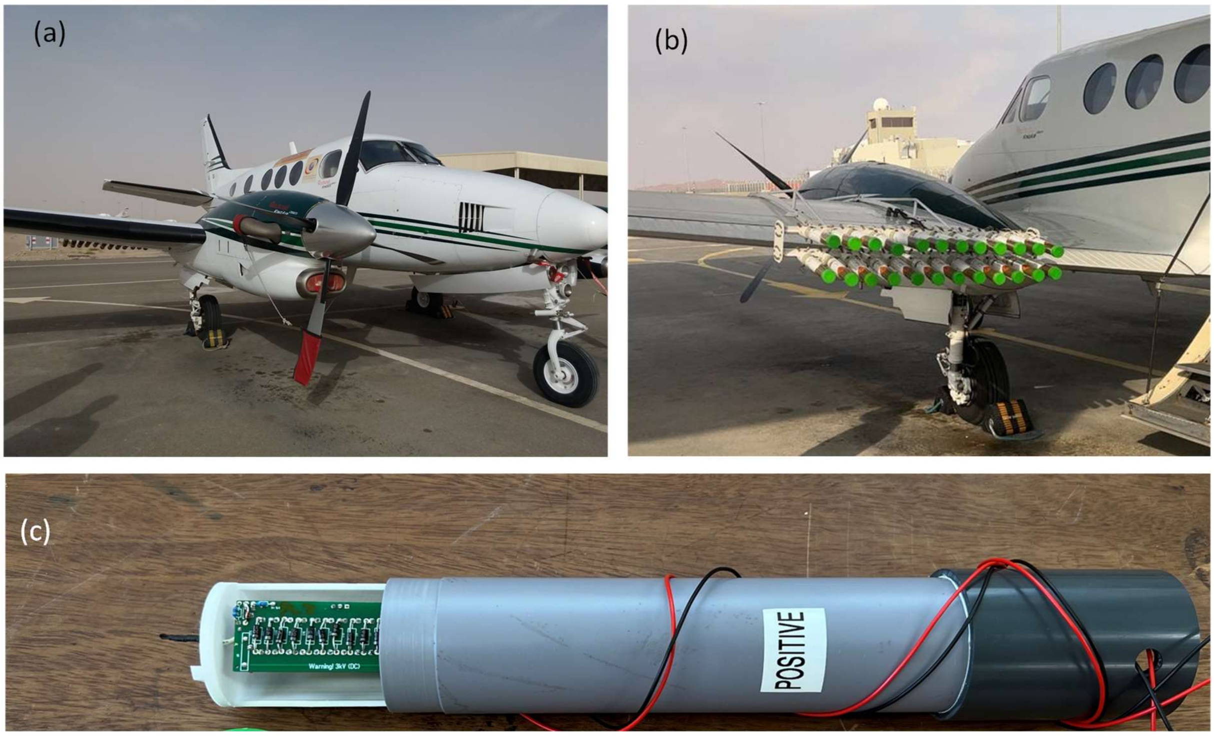

Figure 1. (a) King Air aircraft flown by NCM for cloud seeding missions. (b) Flare seeding rack on the wing of the King Air, loaded with 24 seeding flares. (c) "Flare Emitter" housed inside existing seeding flare tube.

Section 2 of this paper describes the design of the charge emitter flare, section 3 outlines a novel method to monitor the corona current using a Light Emitting Diode (LED), and section 4 contains conclusions and future work.

2. Flare Emitter design

Design of the Flare Emitter is constrained by the existing flare mounting tubes, which are of fixed dimensions (a cylinder of length 270mm and 55mm diameter). An electrical signal from the aircraft electrical supply is used to ignite the conventional seeding flares, but it is of unknown capability, so internal batteries are indicated as a power supply for the Flare Emitter. Physically, the Flare Emitter needs to be robust to the vibration it will encounter on the aircraft, and a range of hostile environmental conditions including water and ice. The Flare Emitter electronic systems required have therefore been built within their own housing, using rigid 3D printed materials to anchor the circuit boards. This housing fits within the existing flare mounting tube. Figure 2 (a) and (b) shows the design of the 3D printed housing, with the battery compartment indicated. The housing contains grooves to secure the circuit boards, and the high voltage circuit boards (i.e. for the voltage multiplier) are deliberately housed at the opposite end of the tube from the sensitive electronic systems (such as the controller) to minimise issues with charge build up and interference.

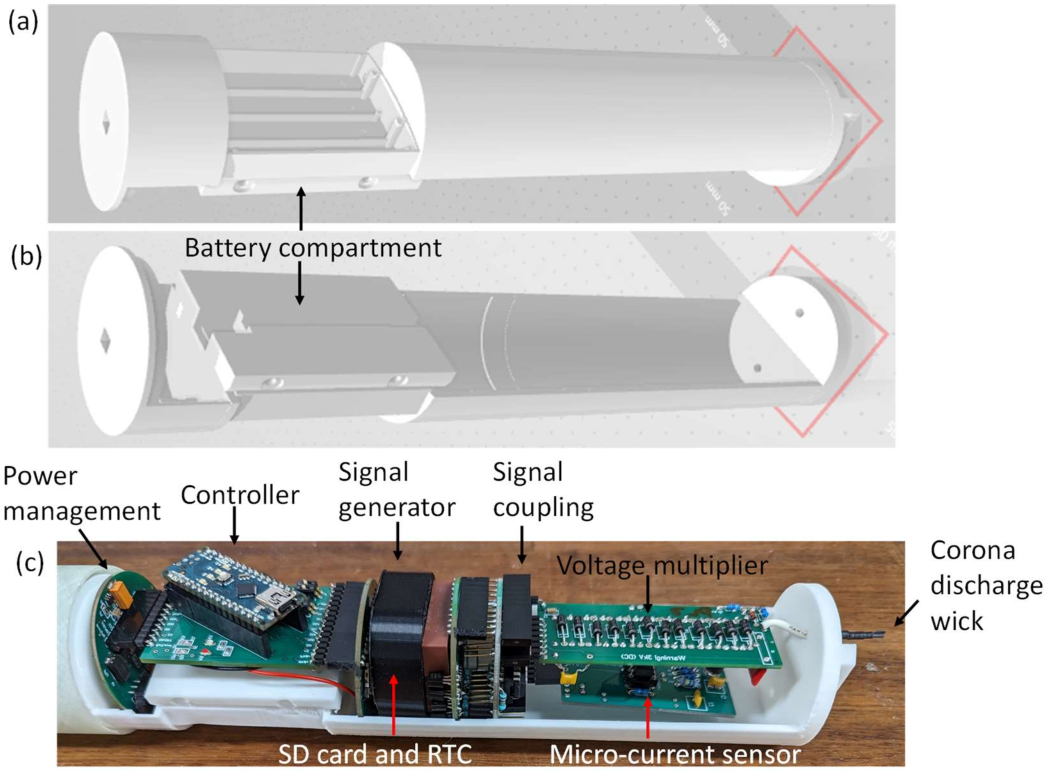

Figure 2. (a) and (b) Image of design of 3D printed housing for the Flare Emitter. (a) shows the design from underneath, and (b) from the above. (c) shows the internal circuit boards within the Flare Emitter, including the battery compartment highlighted in (a) and (b), which is located underneath the controller.

The Flare Emitter works by corona discharge from a carbon fiber brush emitter held at high voltage (see e.g. [4]). The amount of charge released is proportional to the current supplied to the corona emitting wick and is measured by monitoring the current flow (described in more detail in section 3). A block diagram of the electronic systems developed is shown in Figure 3.

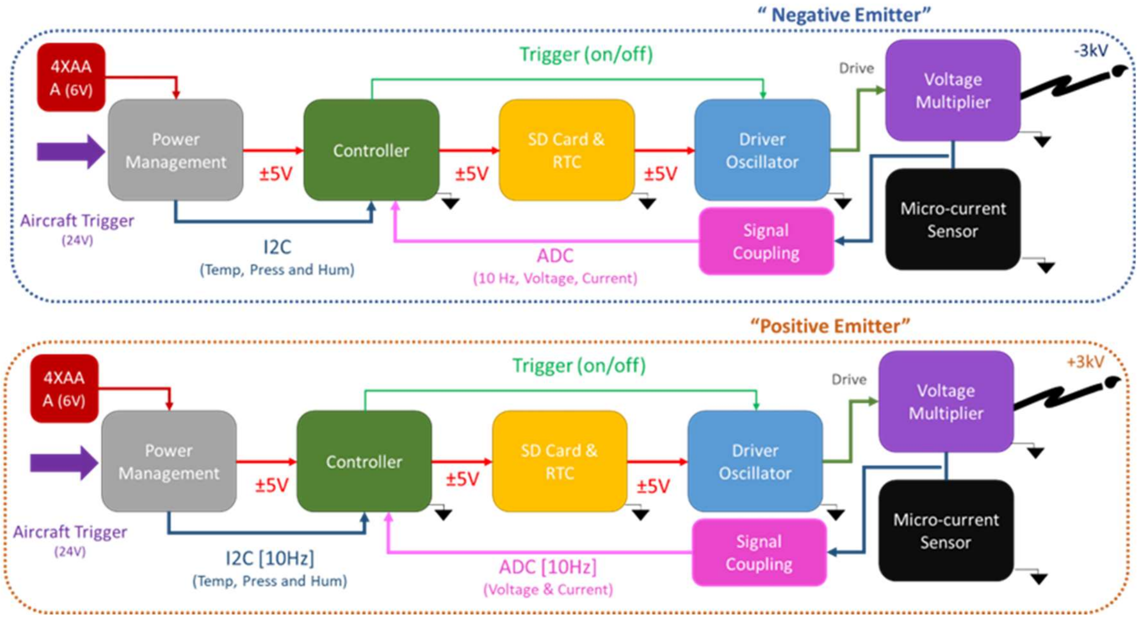

Figure 3: Flare Emitter system. Negative emitter (within blue dotted box) and positive emitter (within orange dotted box). The Power Management (grey box) system has an aircraft voltage trigger circuit, and hosts a BME280 sensor for monitoring pressure, temperature, and relative humidity ("PTU"). The Controller (green box) is integrated with an Arduino Nano to monitor the BME280 PTU variables, the operating voltage and current of each emitter at 10Hz. The SD Card & RTC (yellow box) consist of a real time clock to timestamp data to an SD Card circuit for data logging. In the high voltage part of the system, the Driver Oscillator generates a signal to feed a transformer, followed by a Cockroft-Walton voltage multiplier to generate ±3 kV. (Either polarity can be obtained). Finally, the micro-current sensor determines the release rate of ions from the emitter into the nearby air.

Each Flare Emitter (shown in Figure 2(c)) consists of multiple systems: 1) power management, 2) controller, 3) SD card and real time clock, 4) driver oscillator, 5) voltage multiplier and discharge wick, 6) micro-current sensor, and 7) signal coupling. Several of these systems are located on their own individual circuit boards, mounted by stackable connectors and housed within the bespoke 3D printed outer casing which fits within the seeding flare tube. Flare Emitters produce single polarity ions, with negative charge emitters and positive charge emitters housed in separate seeding tubes. The Flare Emitters are designed to be switched on and off from the 24V aircraft power supply, with batteries to power the corona stages. This is achieved using a 6V supply from 4×AAA batteries, using a DC-DC converter to 5V and -5V for the controller and emitter circuitry. The controller is an Arduino Nano, which, using the I2C protocol, obtains the BME280 sensor measurements of pressure, temperature and relative humidity as well as monitoring battery levels, corona operating voltage and corona current at 10 Hz. The information is logged to a microSD card, which is intended to be downloaded after every flight. The driver oscillator circuitry consists of several elements: an oscillator, a transformer (VTX-121-3015-206 6V to 230V) and a voltage multiplier. This generates a regulated ±3 kV with the polarity chosen depending on emitter. The operating voltage is monitored through a 1 GΩ:1 MΩ potential divider, recorded via the Analogue to Digital Converter of the Arduino Nano. This divided voltage also provides voltage regulation, by comparison with a reference voltage, to maintain a steady voltage on the corona discharge electrode. The sixth stage comprises an innovative isolated corona micro-current sensor (described in Section 3) to determine the rate of delivery of ions from the emitter to the atmosphere, which is returned to the controller system and logged via the SD card. Finally, the seventh stage is a coupling circuit to transfer to the controller the measurements related to the emitter operating voltage and the generated current.

An example of some of the parameters measured by the Arduino Nano on the Flare Emitter is shown in Figure 4. Upon receiving the 24V triggering pulse, the charge emitter is switched on for 1 minute, and data is monitored for a further minute before the system switches off. Two triggering periods are shown in Figure 4. The corona emission voltage (high voltage output from the voltage multiplier) is shown in Figure 4(a) for both the positive (red) and negative (blue) emitters, The positive emitter corona voltage is considerably larger (+3.4kV), than the negative emitter corona voltage (-2.2kV), due to the higher threshold onset voltage required for positive corona.

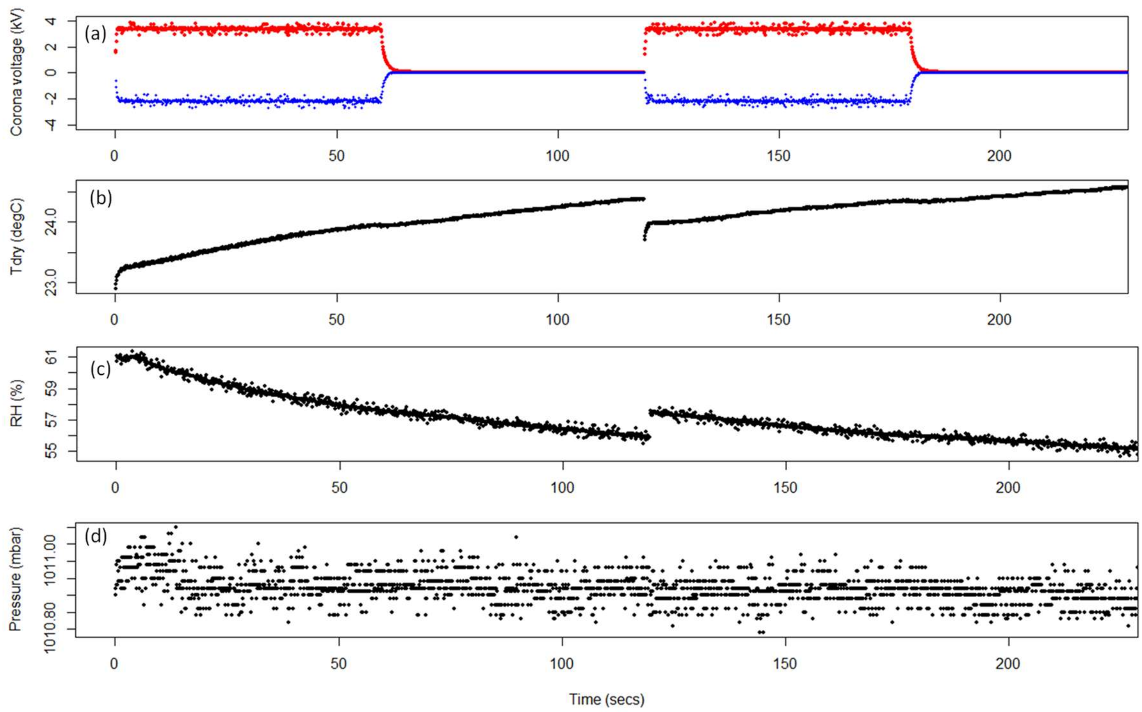

Figure 4. Example of data output from Arduino Nano during Flare Emitter laboratory tests. (a) Corona voltage from voltage multiplier stage (red = positive emitter, blue = negative emitter), (b) temperature, (c) Relative Humidity (RH), and (d) pressure as measured by the BME280 Sensor.

3. Corona current measurement

Measurement of the corona current is required at the high voltage output of the voltage multiplier stage of the emitter (±3 kV). Such measurements are typically achieved using large common mode electronics or by floating the measuring electronics at the high voltage with optical isolation [6]. The physical constraints of the seeding flare tube made implementation of these conventional and relatively complex approaches difficult. Using a high efficiency LED as a passive sensor to determine and telemeter the current offers a simpler method, as the brightness of the LED varies with the current flowing [7]. A high efficiency infra-red LED-photodiode optocoupler pair is implemented here to measure the expected corona currents of around 1 μA. The lower halves of the LED/photodiode pair were painted black, to exclude external light, and they were mounted facing each other, but not touching, within black heat-shrink tubing (Figure 5).

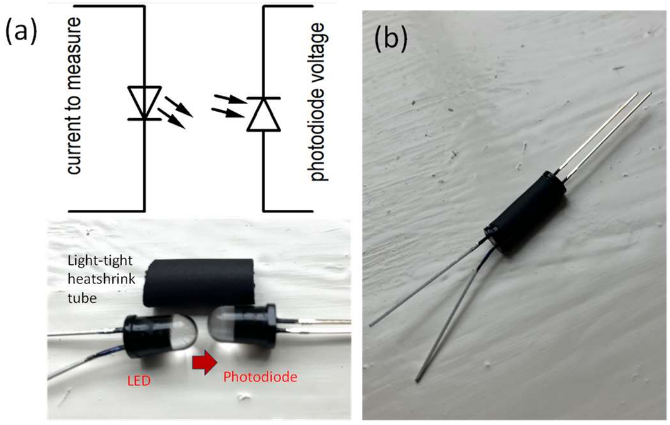

Figure 5. (a) Concept of LED-photodiode optocoupler pair (top) and photo of implementation, with the lower half of the components painted black, and the heat-shrink tube. (b) The LED/photodiode optocoupler pair are mounted facing each other, but not touching to maintain high voltage isolation, within the black heat-shrink tubing. (Parts used - LED: OSI3NA5111A; Photodiode: SFH213).

The relationship between the forward current of the LED (I_f) and open circuit voltage of the photodiode (V_{PD})is shown in Figure 6 (a). The current-voltage characteristics of the optocoupler pair show a very large response of V_{PD} to I_f for the small values of I_f likely to be encountered in the Flare Emitter. An analogue electronics compensation system has been developed to allow this range to be more effectively measured, based on using matched LED-photodiode optocouplers [8]. The compensated ("linearised") response is plotted in Figure 6(b) which shows reduced sensitivity at small values of I_f and increased sensitivity at greater values.

To test the response of the optocoupler to corona current, a separate series of experiments were devised using a negative ionizer as a corona source (discussed in detail in [8]). The isolated optocoupler current measurement method showed a typical uncertainty of about 0.2uA (for a corona current of 1-1.3 uA) when compared with a resistive method [8].

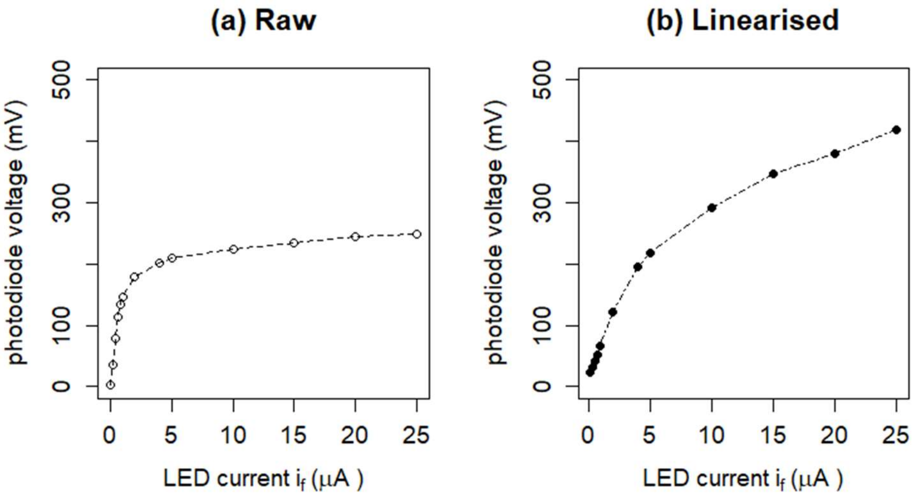

Figure 6. Current-voltage characteristics of an optocoupler pair (consisting of a OSI3NA5111A LED and SFH213 photodiode) facing each other in a light-tight tube, with the LED driven, for testing, from a constant current source. (a) Response of a single LED/Photodiode optocoupler pair. (b) Compensated response using an additional optocoupler LED/photodiode pair and analogue signal processing electronics.

4. Conclusions and future work

This paper describes the development of an atmospheric charge emitter (known as the Flare Emitter), designed to fit within the existing cloud seeding flare tubes of an operational cloud seeding aircraft. The Flare Emitter is controlled by a programmable microcontroller, with the corona emission voltage and current monitored and logged to SD card for analysis after a flight. Environmental parameters of pressure, temperature and humidity are also recorded.

Following the laboratory testing of the charge emitters reported here, real world use of the charged emitters on board the King Air aircraft are shortly to occur. This will provide a unique opportunity to fully test the operation of the charge emitters with an aim of ultimately investigating the effects of charge on cloud droplet behaviour.

Acknowledgements
This material is based on work supported by the National Center of Meteorology, Abu Dhabi, UAE under the UAE Research Program for Rain Enhancement Science (UAEREP).

References
[1] Harrison, RG, & MH Ambaum 2008 *Proceedings of the Royal Society A: Mathematical, Physical and Engineering Sciences*, *464*(2098), 2561-2573.
[2] Khain, A, V Arkhipov, M Pinsky, Y Feldman, & Y Ryabov, 2004 *Journal of Applied Meteorology and Climatology*, *43*(10), 1513-1529.
[3] Harrison, RG, GJ Marlton, MH Ambaum, & KA Nicoll 2022 *Physical Review Research*, *4*(2), L022050.
[4] Harrison, RG, KA Nicoll, DJ Tilley, GJ Marlton, et al 2021 *Journal of Atmospheric and Oceanic Technology*, *38*(1), 63-75.
[5] Harrison, RG, KA Nicoll, GJ Marlton, DJ Tilley & P Iravani 2022 *Geophysical Research Letters*, *49*(19), e2022GL099827.
[6] Band, A, & J Unguris 1997 *Review of scientific instruments*, *68*(1), 250-251.
[7] Argiro, S, DV Camin, M Destro & CK Guerard 1999 *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment*, *435*(3), 484-489.
[8] Harrison, RG, Escobar-Ruiz, V, Nicoll, KA, & Ambaum, MH (2023). Isolated corona current monitoring using a compensated light-emitting diode as an unpowered sensor. *Review of Scientific Instruments*, *94*(9).