Electrical charge measurements in clear and cloudy conditions from fixed wing UAVs

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Charge generation in air

- Charge is ubiquitous in the atmosphere – not just in thunderstorms
- Charge created by radioactivity from Earth’s surface, and cosmic rays from outside solar system

- Air ions formed cluster with water molecules, to generate small (or cluster) ions
- Ion concentrations in surface atmospheric air depends on aerosol concentrations, but concentrations are typically 100 to 500 cm$^{-3}$
Ion-aerosol attachment

- Ions collides with aerosol particles and droplets => charging
- Charging has potentially important implications for:
  - Long range transport of dust/volcanic ash
  - Cloud microphysical processes (= production of rain, lifetime of clouds)

- Processes affected by charge:
  - particle-particle collisions (coagulation)
  - particle collection by droplets (scavenging)
  - droplet evaporation
  - freezing of droplets
  - droplet-droplet interactions (collision and collection)

Typical ion diameter = 1nm \( (10^{-9} \text{m}) \)
Typical aerosol diameter = 1µm \( (10^{-6} \text{m}) \)

Ion-particle attachment

aerosol particle carries net charge of +2
Charging of layer clouds

- Global electric circuit current flows through layer clouds


- Horizontal cloud (and aerosol) layers cause charge separation from the sharp conductivity transition at cloud edges

- Local space charge density depends on vertical conduction current (of ions) and the sharpness of the cloud edge

→ Cloud edge charge
Charged cloud instrumentation

Charge sensor
- Spherical electrode and electrometer
- Measures current induced by changing electric field (i.e. displacement current)

Cloud droplet sensor
- Backscatter device
- Uses ultrabright LEDs as source and photodiode as receiver in an open path device
- Light source is modulated to allow signal recovery despite background light variations
- Multiple channels to allow size discrimination


Harrison, R.G. and K.A. Nicoll, Active optical detection of cloud from a balloon platform, Rev. Sci. Instrum., 85, 066104, 2014
Cloud droplet sensor characterisation

- Comparison with DMT Cloud Droplet Probe (CDP) number concentration shows very good agreement for droplets > 5µm diameter

- Relationship between backscatter and CDP Liquid water content (LWC) found for 20µm droplets

- Current work underway to derive droplet size information from backscatter
Cloud and aerosol campaign

- 2 week campaign in August 2015
- Mace Head, Ireland
- Skywalker X6 UAV (1.5m wingspan, 1kg payload)
- 4 different aircraft with various payloads including aerosol, turbulence, cloud + charge
Charged cloud measurements

- 20 flights through different cloud layers (often multiple ascents and descents and temporal sampling)
- Clear identification of cloud from cloud and charge sensors
- All clouds sampled were charged

11\textsuperscript{th} August, flight 23
Multiple ascents through cloud

Multiple profiles through long lived stratocumulus cloud layer

Cloud backscatter to liquid water content (LWC) (IR channel)
Mace head charged cloud measurements

11/08/16
13:00
Flight 23

- Comparison of two different flights 3 hours apart
- Very little change in cloud droplet profile or cloud charge

11/08/16
15:54
Flight 25
Fair weather charge measurements

09/07/15  13:20 LT  Lannemezan, France

10/07/15  11:38 LT
Charge and aerosol profile
Lannemezan, France

09/07/15 13:20 LT

Charge is affected by same turbulent processes that transport aerosol and water vapour, therefore expect profiles to be similar.

Total aerosol number counts across all size bins from Optical Particle Counter (0.3-3 µm)

Strong temperature inversion acts as a lid to charge, water vapour and aerosol transport.
Charge and aerosol profile

Mace Head, Ireland 17/08/15

- Cases where no significant inversion exists show close relationship between charge and aerosol profiles

Mace Head, Ireland 22/08/15

- Turbulence data from nose mounted probe also available
Summary

• Charge can serve as a useful tracer for both cloud and aerosol layers as well as boundary layer top location

• Ongoing measurements are characterising the typical charge values within cloud and aerosol layers in order to inform modelling studies of charge effects on microphysical processes

• Further analysis of charge data in clear air will look at relationships between:
  - Boundary layer stability
  - Turbulence and surface heat flux

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Calibration of optical droplet detector

- Transmission and backscatter experiments performed simultaneously

- Transmission signal \( I(t) \) related to optical extinction \( \xi \)

\[
I(t) = I_0 \exp[-\xi(t)d]
\]

d = path length

- Visual range calculated from extinction:

\[
X = -\frac{\ln \varepsilon}{\xi}
\]

\( \varepsilon \) = visual contrast factor = 0.05
\( \xi \) = extinction
\( X \) = visual range

\[ \begin{array}{c}
| \text{extinction (km}^{-1} \text{)} | \\
\hline
0 & 50 & 100 & 150 & 200 & 250 \\
\hline
\hline
\end{array} \]

\[ \begin{array}{c}
| \text{visual range (m)} | \\
\hline
0 & 10 & 20 & 30 & 40 & 50 \\
\hline
\hline
\end{array} \]

\[ \begin{array}{c}
| V_p/LED (mV mA}^{-1} \text{)} | \\
\hline
10 & 15 & 20 & 25 \\
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\hline
\end{array} \]
Atmospheric flights of optical droplet detector

- Measurements made during a daylight sounding through a stratocumulus layer of stratocumulus about 400 m thick, with cloud base at 1200 m.

![Graph showing relative humidity and temperature](image)

**Standard thermodynamic detection** (coarse indication of cloud position and poor threshold RH value)

**Active cloud detector** using ultra-bright LED light source shows sharp cloud boundaries