Fingerprinting Airborne Volcanic Ash with Single Particle Polarimetry

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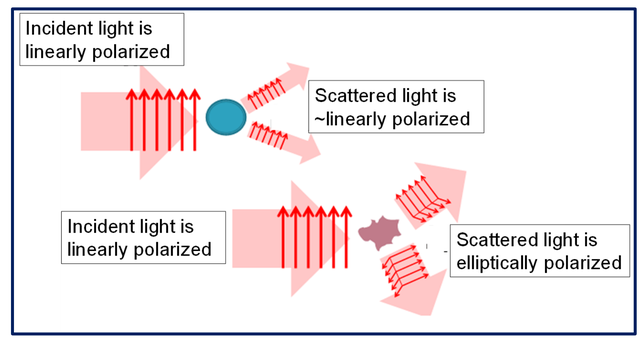
Overview

- Aircraft engines and air frames can suffer severe damage after encountering volcanic ash at mass concentrations > 1 mg m^{-3}.
- Serious degradation of aircraft engines can result from extended exposure to lower concentrations.
- There are no aircraft sensors currently capable of detecting the presence of ash in sub-visible quantities.

- Undetectable by eye..
- Undetectable by radar.
- Undetectable by satellite.
- Undetectable by passive sensors.
- Undetectable when mixed with clouds.
- Clear need for alternative technology.

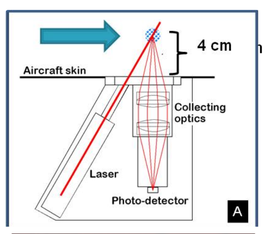
Single Particle Polarimetry

- The polarization state of light scattered by a particle depends on the structure of the particle and the angle of scattering.
- Light scattered from spherical particles approximately retains the same polarization state as the incident light.

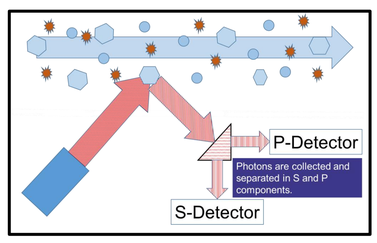


- Light scattered from non-spherical particles will change the polarization of the incident light by an amount proportional to the complexity of the particle structure.

Backscatter Cloudprobe with Polarization Detector (BCPD)



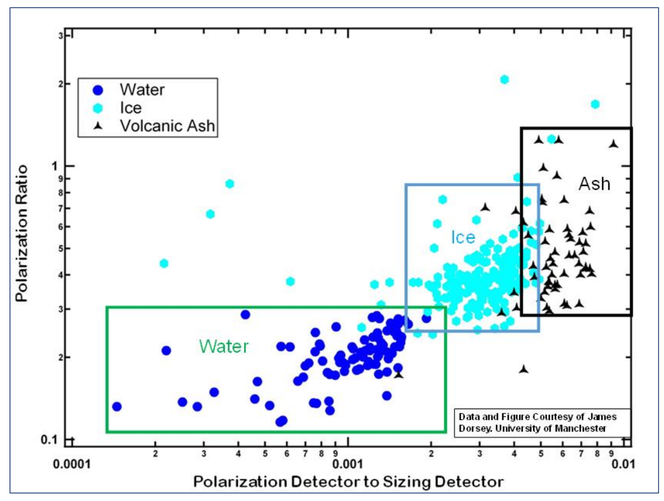
- The BCPD is a single particle optical spectrometer.
- The BCPD mounts inside the aircraft and projects a linearly polarized laser beam through a window.
- Particles that pass through the beam scatter light back through the window.

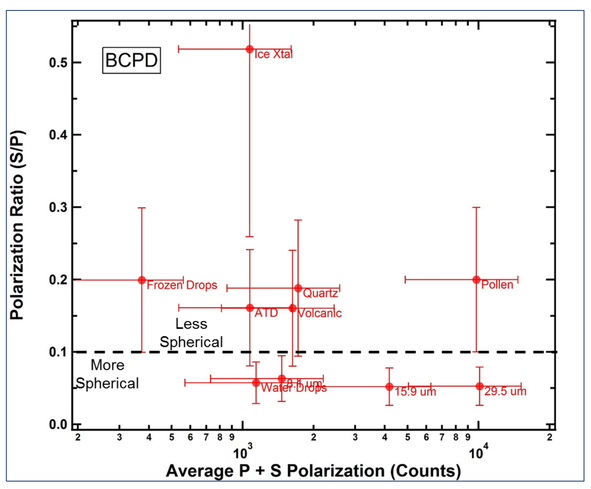


- The collected light is split into two components by a splitter.
- One component is passed through a filter with polarization perpendicular to the incident beam (S-detector)
- The other component is passed through a filter with polarization parallel to the incident beam (P-detector)

CAS-POL Measurements

- The Cloud and Aerosol Spectrometer with Polarization (CAS-POL) is a research prototype of the BCPD.
- It was flown on the UK Met Office BAE-146 over the North Atlantic in May, 2010 after the eruption of the Eyjafjallajökull volcano.
- Evaluation of the measurements in clouds and ash demonstrate that polarization measurements can separate water droplets, ice crystals and volcanic ash

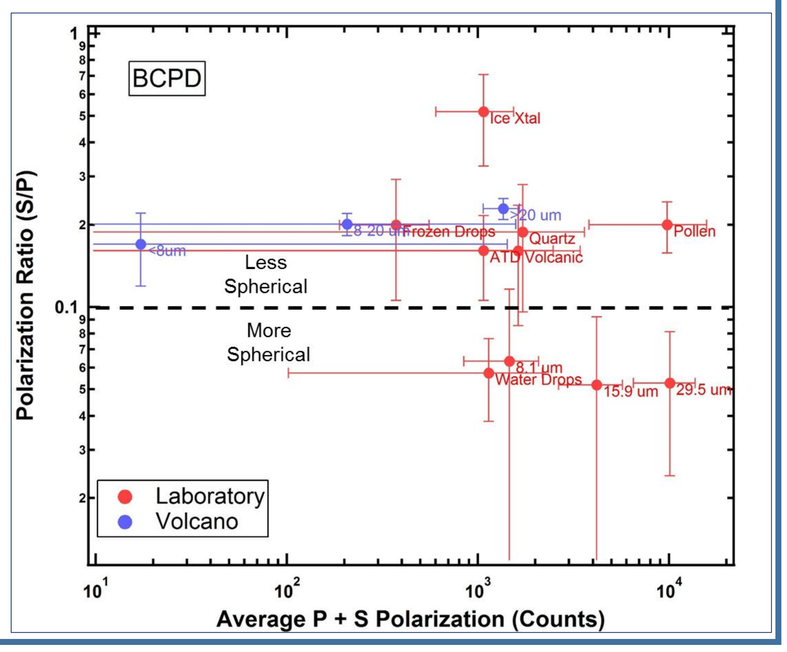




- Laboratory tests have been conducted to quantify the polarization response of the BCPD
- The polarization ratio (S/P) is sensitive to particle shape.
- Measurements were made of water droplets, ice crystals, volcanic ash and dust.
- There is a distinct separation in S/P between spherical and non-spherical particles.
- Droplets, ice and ash are well separated.

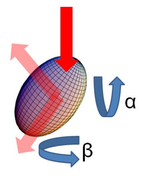
Volcanic Ash Plume Measurements

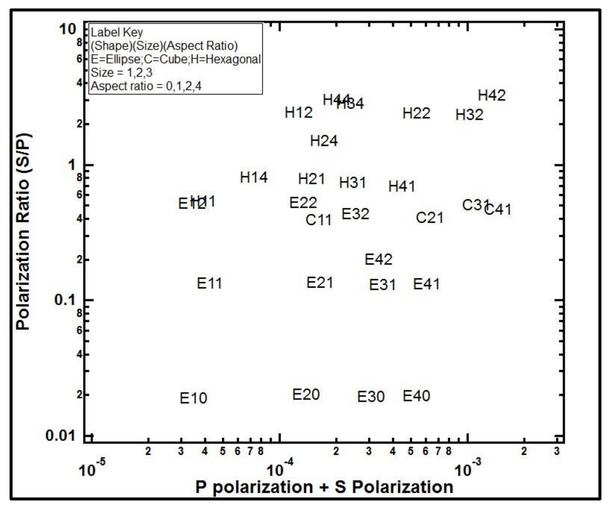
- Measurements were made with the BCPD in the Sakurajima volcano in Japan
- The polarization ratio (S/P) of the ash particles fit within the values expected from the laboratory measurements.
- The sensitivity of the mass concentration measurements is < 10 µg m^{-3}



Simulations

- Simulations that model the response to the BCPD to ellipsoids, cubes (salt) and hexagonals (ice crystals) are being conducted.
- Initial results suggest that crystal types can be quantified.





Summary, Conclusions and Ongoing Work

- There are currently no operational sensors for providing aircraft with in situ, real time volcanic ash detection.
- The Backscatter Cloudprobe with Polarization Detection (BCPD) is a compact, low power, light weight ash detector
- The BCPD can measure ash mass concentrations with a sensitivity of < 10 µg m^{-3}.
- The BCPD can differentiate volcanic ash, dust, water droplets and ice crystals.
- The BCPD has been extensively evaluated in the laboratory, icing wind tunnels and on multiple airborne platforms.
- The BCPD size range is currently being extended from 2-50 µm to 2-500 µm.
- A neural network system is being trained for real time, airborne recognition of ash, dust, droplets and ice particles.
- BCPD applications include: volcanic ash avoidance, high ice water alerts and detection of aircraft icing potential.