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# VOLCANIC DISRUPTION

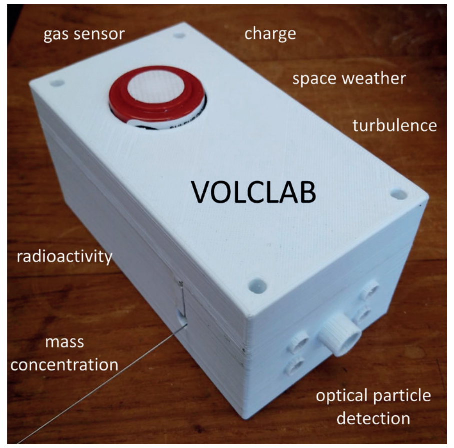
**The UK's Reading University has developed a sensor that measures the mass concentration of ash in the atmosphere, to help detect the presence and severity of plumes**

The closure of European airspace following the 2010 eruption of Eyjafjallajökull in southern Iceland is estimated to have cost US$200m/day, affecting 10 million passengers. New procedures have been put in place, in a bid to reduce the impact of future eruptions. One central requirement is the detection and measurement of volcanic ash in the atmosphere to provide the basic information from which subsequent dispersal in airspace can be predicted. To assess the potential hazard to aircraft, it is important to understand the mass concentration of ash in the atmosphere.

A new device has been developed to measure this directly, through the collection of ash on a detector carried by a weather balloon. This *in situ* sampling technique mimics aircraft exposure to ash, and forms part of an integrated suite of sensors designed to provide safe and rapidly deployed measurements in a hazardous situation.

During the Eyjafjallajökull eruption, a team from Reading University successfully used a weather balloon to obtain measurements of the volcanic ash plume above the UK, at a time when the predictions of the plume's existence over the UK were being challenged. This *in situ* information helped validate modeling studies predicting the motion of the plume, and also illustrated the potential of balloon-carried systems as readily deployed measurement platforms in hazardous situations.

Every day 3,000 weather balloons are launched across the world. This global measurement infrastructure is rarely used for anything other than measurement of temperature, relative humidity and position, from which thermodynamic quantities and upper level wind can be found. This satisfies the operational meteorological community, but greatly under-exploits the resources committed to making the radiosonde launches. Historically, radiosondes were used to investigate the spread of radioactivity, and some are used occasionally for stratospheric ozone measurements, but the lack of lightweight and compact sensors has hampered wider exploitation of radiosondes.




The device detects the conditions associated with eruptions

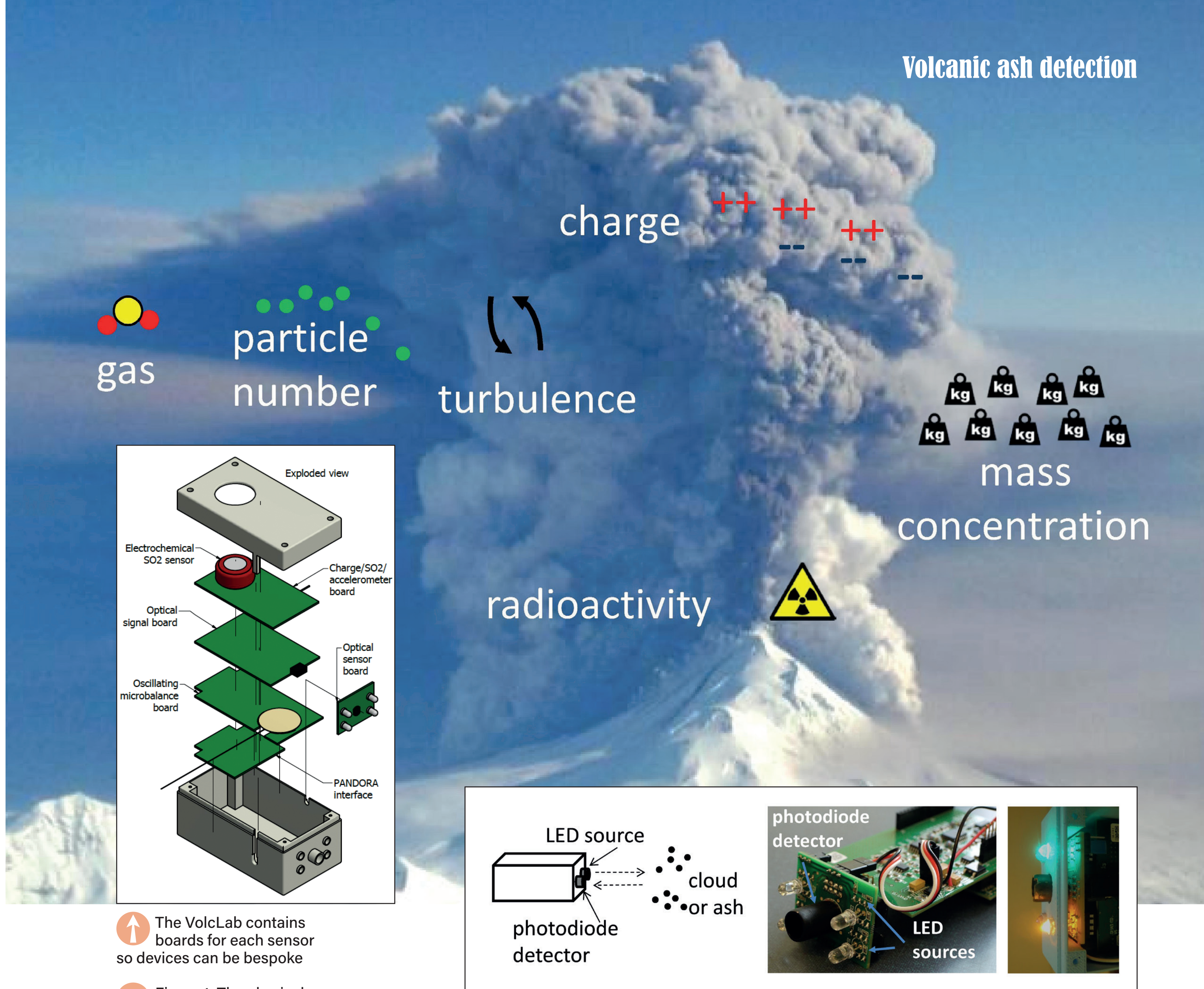
## VOLCLAB SOLUTION

Building on their experiences from the 2010 eruption, scientists at Reading have produced a new multiple sensor package – VolcLab – for *in situ* atmospheric measurements obtained through piggy-back operations on standard meteorological radiosondes. The VolcLab project, funded by the UK's Natural Environment Research Council, has developed technology for detecting material in the atmosphere associated with volcanic eruptions, which is also suitable for other hazardous situations and a wide range of atmospheric applications related to aircraft safety. Figure 1 shows the typical materials expelled during an eruption, either remotely or near the volcano itself. VolcLab has been designed for minimal user involvement, based on a plug-and-play approach. This extends the standard radiosonde measurements through making effective use of the experienced radiosonde staff available at remote sites.

As specific measurement needs will vary in every situation, the VolcLab package has been designed to be modular, enabling the sensors to be combined in different ways. A multiple-sensor approach adds confidence to the measurements, through the corroboration one sensor provides for another. The sensors are inexpensive and disposable, fitted within a lightweight 3D-printed enclosure strapped to the radiosonde. Each sensor is fitted on a carrier circuit board, which is stackable and fitted on an interface and power supply board at the base. This arrangement provides mechanical stability and the ability to quickly select a set of sensors for each application.








The VolcLab contains boards for each sensor so devices can be bespoke

Figure 1: The physical materials associated with a volcanic eruption

The optical sensor detects droplets and particles in the atmosphere using a high-intensity LED light and a photodiode detector and operates within the VolcLab enclosure

The set comprises an accreted mass sensor, a multi-wavelength optical sensor for detection of particles and droplets, a charge sensor, a turbulence detector, a radioactivity/energetic particle sensor and connections for a commercial electrochemical sensor, available for different gases. The base interface board is derived from the PANDORA (Programmable Analogue and Digital Operational Radiosonde Accessory) originally developed for Vaisala RS92 radiosondes, and used in more than 150 flights to date. It has now been extended to carry its own batteries and can be programmed to work with any radiosonde providing serial (XDATA) telemetry.

VolcLab carries an optical system that uses a photodiode to detect LED light scattered by droplets and particles. Four bright LED sources with different wavelengths are used with a common detector, enabling the retrieval of basic particle size information. This sensor works in both daylight and at night, and has been used successfully in many environments, including ground-based observations, as well as on balloon and unmanned aerial vehicle (UAV) platforms.

It has been tested with a range of aerosols, among them volcanic ash, salt and water droplets, detecting salt particles down to 1µm diameter. Tests of the sensor inside mountain clouds have shown good agreement in droplet concentration with commercial cloud droplet probes for cloud droplet diameters from 5-40µm.

## ASH CONCENTRATION

Determining the mass of ash present in a volcanic plume is an important requirement for aviation, useful in both plume modeling and hazard mitigation strategies. Direct measurements of ash mass are provided by an oscillating microbalance sensor in the VolcLab package, using a thin wire coated with adhesive as an ash collector. The wire is free to vibrate, and its resonant frequency varies with the mass of ash accreted. By measuring the wire's vibration frequency, the mass of ash collected can be determined, and, in turn, the mass concentration found. An onboard microcontroller is used to measure the resonant frequency accurately, using a combination of independent techniques. This direct collection method for mass determination does not require assumptions about the optical properties of the ash, such as the refractive index. To help in identifying a volcanic plume and distinguishing the collecting substance from ice (temperature data is also available), VolcLab also incorporates commercially available gas sensors, able to detect $SO_2$ or other gases often emitted geologically, depending on the specific sensor chosen.

Turbulence measurement has been included in the VolcLab package because of its effect on the diffusion and dispersal of volcanic plumes, but this capability clearly has wider aviation applications beyond volcanic ash emergencies.

## MEASURING TURBULENCE

According to some aviation accident databases, turbulence is responsible for half of all airliner accidents, with human factors, mechanical failures, and passenger illness accounting for the remaining half. Annually, in the USA alone, aircraft encounter moderate turbulence on 65,000 occasions and severe turbulence 5,500 times. These encounters cause about 40 fatalities and hundreds of serious injuries, lead to structural damage to planes, cause flight diversions and delays, and cost airlines between US$150m and US$500m.

The VolcLab package carries a three-axis accelerometer for determining the swing of the instrument package, which occurs when the carrier weather balloon encounters turbulence. More intense turbulence induces larger swings, generating a larger variance in the accelerometer measurements, particularly in the vertical axis accelerometer. Calibrations have been made against a Doppler lidar and a mesospheric-stratospheric-tropospheric (MST) radar, to allow the accelerometer data to be expressed using the standard meteorological turbulence measure of eddy dissipation rate. This enables the use of VolcLab turbulence observations in aviation safety and plume dispersion models.

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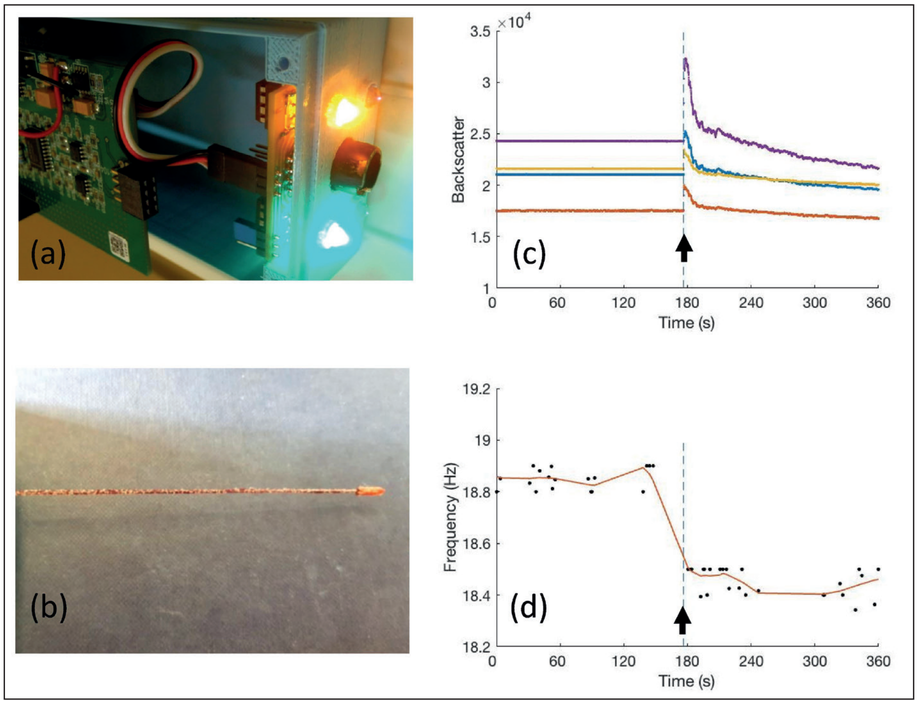
## CHARGED ASH PARTICLES

Electrification of volcanic plumes can lead, in intense cases, to visual displays of lightning, but smaller amounts of charge are almost always associated with particle plumes. The amount of charging depends on the chemical composition and physical properties of the particles emitted, such as size and shape. Charge was detected in the Eyjafjallajökull plume at over 1,000km (620 miles) from the source long after any initial charge would have decayed, indicating that the charge was being continuously generated. Plumes which readily electrify may cause additional hazards to aircraft, as, unlike lightning where the electrical effects are screened by the fuselage, the charged particles can enter the cabin or cockpit. The VolcLab charge sensor operates using a small sensing electrode, and has been demonstrated to be sufficiently sensitive to detect charge on layer clouds. Beyond charging from frictional effects and the fracture of rocks, a further possible source of charge in volcanic plumes is from natural radioactivity. For this reason, a radioactivity sensor has been included in the VolcLab package, using Geiger counter technology. This also has applications to detect particles entering the atmosphere during space weather events, and a more sophisticated sensor able to resolve the different energies associated with natural radioactivity and cosmic rays has been developed with counterparts in the University of Oxford's physics department.




Demonstration of (a) optical detector and (b) the oscillating wire ash collector, with (c) showing data from the detector and (d) the wire's change in vibration frequency

"According to some aviation accident databases, turbulence is responsible for half of all airliner accidents"

## OTHER POTENTIAL USES

VolcLab opens up a wide range of new measurement opportunities for investigating the spread of volcanic ash, but as the package is adaptable, it can also be deployed for other hazardous situations involving radioactivity or space weather. The cloud detector has general applications for identifying the presence of thin clouds without the time response issues associated with traditional thermodynamic radiosonde sensors, and the oscillating microbalance can also be used to measure ice accretion from super-cooled liquid water clouds. In addition, the extent of cloud electrification before a lightning strike can also be detected, together with the *in situ* measurement of turbulence. All these quantities can now be obtained in a value-added way by using VolcLab to extend the capabilities of existing radiosonde systems, without negative impact on the standard operational quantities for which the systems are funded and conventionally used. ∎