by Keri Nicoll and Giles Harrison

RISING TO THE CHALLENGE

Research radiosonde high-altitude systems

Sometimes, such as during the eruption of a volcano, manned aircraft cannot be used for vertical profiling. A UK university is developing cost-effective balloon-borne sensors that can take to the sky whatever the weather

Balloons have been used as a tool for atmospheric research for many years, to which the discovery of atmospheric layering, cosmic rays and the charge structure of thunderstorms are due. Although there have been significant advances in technology and miniaturization of electronics over recent decades, the use of balloons for scientific research has declined, and vertical profiling is often undertaken with large manned aircraft, despite the advantages of balloon-based instruments over aircraft for cost and in that there is no requirement for flight plans in advance.

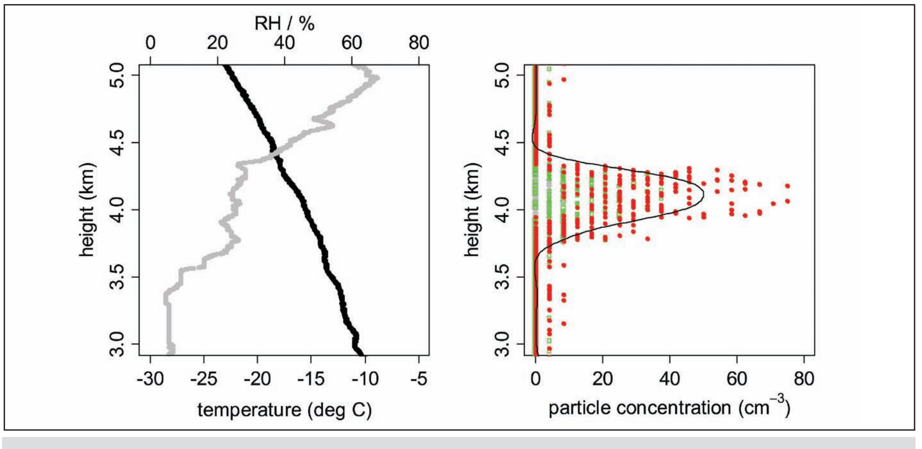
A radiosonde is a meteorological instrument flown on a free lift balloon, which measures various meteorological parameters and sends the data back to ground in real time, via a radio transmitter. Radiosondes provide a very cost-effective method of making high-resolution vertical profiles, including measurements in close proximity to the surface. Despite this, and the proliferation of modern miniature sensor technologies, the number of commercially available meteorological sensors that are capable of being flown on a balloon is small. The University of Reading, UK, continues to develop a range of meteorological balloon-borne sensors that are lightweight and low-cost – essential properties of a non-recoverable instrument. These include turbulence sensors, Geiger counters, charge detectors, and, in conjunction with the University of Hertfordshire, aerosol particle counters, which have been flown to sample a variety of atmospheric phenomena including clouds, volcanic plumes, and Saharan dust.

Achievements using radiosondes

Balloon-carried sensors have been instrumental in some of the key discoveries about the atmosphere. After more than 200 instrument ascents by day and night, Leon Teisserenc de Bort in 1902 reported a temperature discontinuity at about 11km, dividing the atmosphere into layers, which he named the troposphere and stratosphere. Balloons were also pivotal in the discovery of cosmic rays, made by Victor Hess in 1912. Hess flew three different ionization chambers on manned balloons and determined the extra-terrestrial and non-solar origin of cosmic rays.

Research radiosondes have also provided a safe method for probing the internal structure of thunderstorms, a violent environment in which few aircraft dare to fly. The tripolar electrical structure of thunderstorms was established by Simpson and Scrase in 1937, from measurements of electric field by an instrument called an 'alti-electrograph', flown on a radiosonde platform. More recent balloon measurements of thunderstorm electrification have been made by Maribeth Stolzenberg, Thomas Marshall and David Rust at the University of Mississippi, who have made many soundings of electric field through a variety of convective situations, including thunderstorms, mesoscale convective systems, and severe supercells. The electric field sensor consists of two 15cm diameter aluminum spheres containing the electronics, transmitter and batteries, which rotate in vertical and horizontal planes, allowing the vertical and horizontal components of the electric field and its polarity to be determined. The sensors were flown alongside a Vaisala dropsonde, suspended ~20m below the balloon to avoid any effects of balloon charging. Their measurements show that the charge structure of individual thunderstorms is variable and can be much more complicated than the simple dipole/tripole conceptual model of the gross structure of thunderstorms that is normally assumed.

Despite the impressive pedigree of radiosondes for fundamental atmospheric research, and their almost universal availability within the upper air networks of national meteorological services, they are widely under-exploited as a scientific research tool. One of the reasons is that the



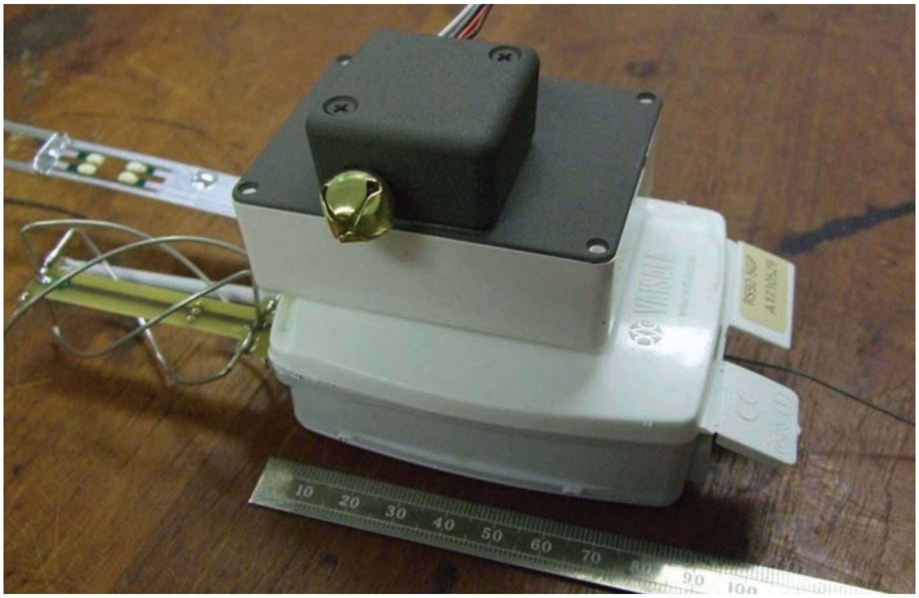
Above: Vertical profiles of an instrumented radiosonde flight through the Eyjafjallajökull volcanic ash plume, launched from Stranraer, Scotland on April 19, 2010. A 600m thick layer of ash particles was detected at ~4km altitude using a balloon borne particle counter developed by the Universities of Hertfordshire and Reading. See http://iopscience.iop.org/1748-9326/5/2/024004 for full paper.


On the day of the flight through the volcanic ash cloud the sky looked very clear from the ground, however a distinct layer of ash 600m thick was detected at 4km altitude

"The balloon flight took place during the flight ban when UK airspace was closed, and demonstrated the usefulness of instrumented balloons in locations deemed too dangerous for manned aircraft to fly"

standard quantities routinely measured by radiosondes are conventionally restricted to pressure, temperature, relative humidity, and upper air winds. An exception is ozone, which is one of the very few non-thermodynamic quantities to be routinely measured by radiosondes around the globe, using an electrochemical sensor technique.

Additionally, regular long-term measurements of cosmic rays from a radiosonde-based platform have been made by the cosmic ray group at the Lebedev Physical Institute in Russia. Measurement of cosmic rays using balloon-borne Geiger counters began in 1957 at Murmansk, and continues to the present day, to investigate the modulation of cosmic rays by solar activity. For little extra cost and no additional receiving equipment, existing



Above: An RS92 radiosonde instrumented with a charge sensor (right) and aerosol particle counter (left). The specially developed data acquisition system allows the extra sensor data to be transmitted back to the surface over the radio link, synchronously with the standard meteorological data measured

Left: The charge sensor developed at the University of Reading, attached to the Data Acquisition System and Vaisala RS92 radiosonde

daily weather balloon flights can clearly provide a new network of scientific measurements, permitting research into a wide range of properties of the lower atmosphere such as atmospheric turbulence, cloud, aerosol properties, electric charge, radioactivity and atmospheric chemistry.

Atmospheric research

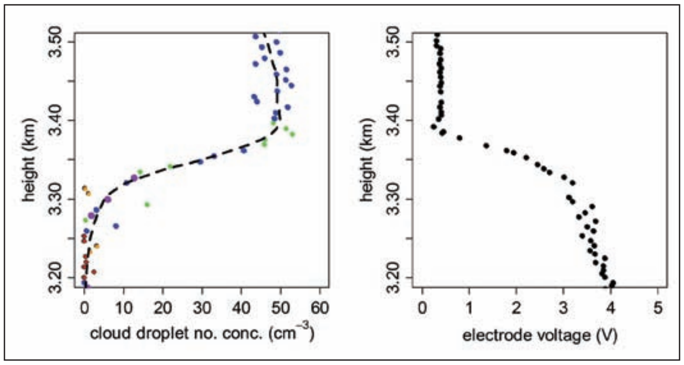
As commercially available radiosondes generally transmit only the standard measured parameters back to ground, additional circuitry is required to acquire, process and transmit data from specialist sensors. A data acquisition system (DAS) has been developed at the University of Reading, for use with the Vaisala RS92 digital radiosonde.

The DAS provides a standard measurement and mounting infrastructure for additional radiosonde science sensors for the RS92, which is widely used in Europe, including operationally by the UK Met Office. The system is programmable, providing additional analog and digital data channels, allowing a variety of specialist sensors to be connected. Data from the DAS is transmitted at 1Hz and received at the ground using the standard Vaisala receiver and Digicora system, with no further equipment necessary. Several different types of balloon-borne sensors have been developed at Reading, and flown successfully using this data acquisition and retrieval system.

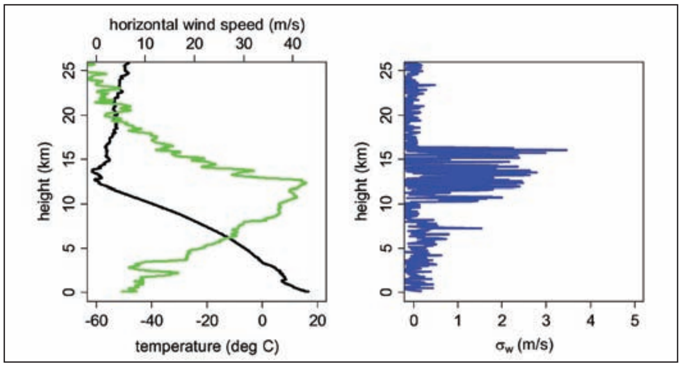
Turbulence measurements

Vigorous atmospheric motions present a hazard to commercial aircraft, and although lidar and acoustic techniques provide effective measurement techniques, in situ measurements of turbulence from radiosondes provide additional information inexpensively. The disposable turbulence sensor developed uses orthogonal geomagnetic field sensors (magnetometers), to detect rapid motion during the balloon flight. The variability in each magnetometer channel is used to detect motion, which is an approach relatively robust to periods of poor radio signals and thermal drift.

As well as sensing potential atmospheric hazards, information obtained from this technique has already been applied in understanding the turbulent motion of the Huygens planetary probe descending to Saturn's moon, Titan (see www.nasa.gov/mission_pages/cassini/media/cassinif-20070828.html for more details).



Above: Left – cloud droplet number concentration at the base of the cloud. Right – voltage on the charge sensor electrode as it descended through the cloud. The change in electrode voltage at cloud base indicates the presence of charge in this region. Theory predicts that stratiform clouds should be charged at their upper and lower edges



Above: Left - vertical profiles of temperature (black) and horizontal wind speed (green) measured by the standard sensors on a Vaisala RS92 radiosonde. Right – vertical profile of variability in vertical wind speed measured on the same flight by the Reading turbulence sensor – note the more detailed structure in the turbulence sensor data than from the horizontal wind speed inferred from GPS measurements made by the RS92

HISTORY OF RADIOSONDES

Radiosondes provide a reliable and inexpensive means of obtaining high-resolution information about the vertical structure of the atmosphere, and are launched regularly from more than 800 locations around the world. Nowadays, data from radiosondes is mostly used operationally for weather forecasting; however, the very first upper air measurements provided fundamental information on atmospheric structure. Kites, and later, manned balloons, were used in some of the earliest soundings, such as that of Joseph and Jacques Montgolfier in 1783; however, lack of oxygen for the balloon operators limited the altitude of their ascents to only a few kilometers.

The invention of small short-wave radio transmitters in the late 1920s led to the first unmanned instrumented balloons, which were able to transmit data back to the surface. These were pioneered by the French scientists Pierre Idrac and Robert Bureau, who coined the now familiar term of 'radiosonde'.

Cloud droplet properties

The 1950s saw a large number of instrumented balloon flights measuring atmospheric electrical parameters, and there are new research interests in atmospheric electricity requiring similar measurements. One need is to investigate the role that charge plays in droplet interactions in non-thunderstorm clouds. A sensitive, inexpensive, lightweight charge sensor has been developed at the University of Reading, which has been flown through more than 20 stratiform clouds. The charge sensor consists of a spherical electrode connected to an electrometer circuit, which measures the voltage on the electrode. The electrode responds to direct impacts from electrified particles, as well as induced currents from changing electric fields. Results show that stratiform clouds are charged, particularly near the upper and lower edges.

Volcanic aerosol

Aerosol particles in the atmosphere are of ever increasing importance to atmospheric researchers, which was emphasized by the eruption of the Eyjafjallajökull volcano in Iceland during April and May 2010. A balloon-borne aerosol particle counter, developed at the Universities of Hertfordshire and Reading, was launched through the volcanic plume on April 19 from Stranraer, Scotland. The aerosol particle counter measures particle size and concentration using light scattered from particles drawn into a sampling chamber by an air pump. Particles are detected in five different size bins from 0.6-10.6µm. The balloon flight took place during the flight ban when UK airspace was closed, and demonstrated the usefulness of instrumented balloons in locations deemed too dangerous for manned aircraft to fly. A 600m thick layer of ash was detected at 4km altitude, with a maximum particle concentration of 100cm^{-3}, and mean particle diameter of 1.4µm.

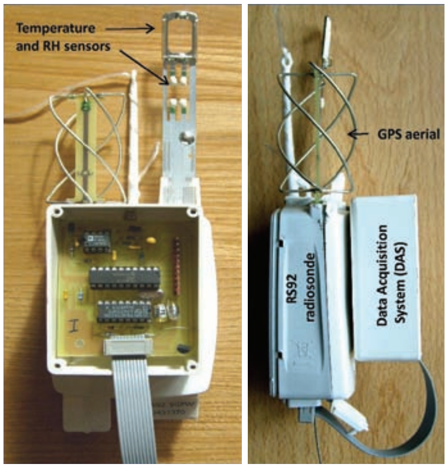
Saharan dust

The characterisation of atmospheric dust is another area that has been investigated using instrumented radiosondes. Dust particles contribute to the radiative balance of the atmosphere by scattering and absorbing radiation, therefore it is important to understand the transport of dust throughout the atmosphere. Observations hint that dust particles can sometimes become vertically aligned, possibly due to electrical effects, which can alter the transfer of solar and terrestrial radiation through a dust layer. It is therefore useful to determine whether elevated layers of dust are substantially electrically charged, for which balloons provide a suitable measurement platform.

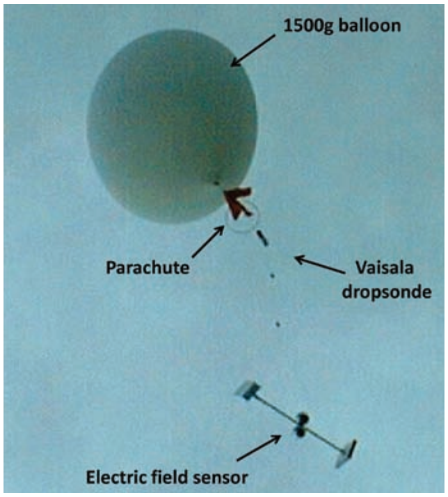
The Saharan desert is the largest producer of mineral dust on Earth, therefore a good location to investigate atmospheric dust is the Cape Verde islands, just off the west coast of Africa, which are frequently afflicted by Saharan dust outbreaks. In the summer of 2009, several instrumented balloon ascents were made from Sal, Cape Verde, through elevated layers of dust. These research radiosondes were instrumented with the DAS, charge sensor and aerosol particle counter. Two of the balloon flights measured large concentrations of dust particles in layers up to 4km altitude, which coincided with increased levels of charge, showing that the elevated dust layers were electrically charged.

Future plans

The continued use of the long-established radiosonde as a research tool is limited only by the availability of suitable inexpensive sensors. Consequently, the development of novel types of balloon-borne meteorological sensors will continue at the University of Reading, such as solar radiation sensors, cloud droplet sensors and an electric field mill. The university's simplified standard approach to carrying additional sensors on the RS92 already provides the existing operational radiosonde network with a range of specialised sensors, opening a new network of scientific measurements. ∎



Above: The Data Acquisition System (DAS) developed at the University of Reading to interface additional sensors to the Vaisala RS92 radiosonde. The DAS allows data from additional sensors to be sent across the radio link synchronous with the standard meteorological parameters measured by the RS92 (P,T,U and GPS).



Above: Balloon developed at Reading, and flown successfully using this data acquisition and retrieval system

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