by Giles Harrison, Keri Nicoll, Graeme Marlton & Paul Williams

MOON'S A BALLOON

Balloon-borne measurements for Earth weather and space weather

Radiosondes are under-exploited as atmospheric science platforms, but new technologies can expand the information gathered


Photo: NOAA

Radiosondes are on the up. Using lightweight, inexpensive, low-power, disposable sensing techniques, meteorological radiosondes can now provide cloud and space science measurements well beyond the traditional thermodynamic parameters.

Balloon-carried instruments and sensors have a long and distinguished history in atmospheric science. From the early manned ascents of the Montgolfier brothers and later pioneering aeronauts in the 19th century, key discoveries on the structure and behavior of the atmosphere have emerged through balloon exploration technologies.

Modern meteorological radiosondes are launched many times daily in a coordinated way globally, but other than the few used to measure ozone, hardly any measure anything more than the traditional meteorological quantities of temperature, pressure and humidity. As miniature sensing packages they provide the basic infrastructure – power, telemetry and position information – for a wide range of other important atmospheric measurements. These sensing opportunities come at a greatly reduced cost compared with aircraft platforms, particularly as the launch and receiving equipment is already available at very many sites worldwide.

New low-cost sensing technologies can greatly improve the range of meteorological measurements obtained by standard radiosondes. For example, at the Meteorology Department of the University of Reading, advanced sensors are now in routine use to detect clouds optically and to identify turbulent regions in the atmosphere, which are potentially dangerous to aircraft. The optical and motion-sensing technology adds little to the cost of the radiosonde, which in many cases is being launched anyway, but greatly enhances the information obtained. These research-led methods already provide improved identification of cloud over the traditional thermodynamic measurements, together with directly sensed information on vigorous convection and clear-air turbulence not otherwise available.

Hazardous conditions

Radiosondes are by their nature automatic devices, so are ideally suited for use in hazardous situations. This has long been recognized (see Figure 1 overleaf for an example of radiosonde measurements safely monitoring the radioactive debris cloud from a nuclear bomb) but it is still surprisingly little exploited.

The European flight disruption due to the Eyjafjallajökull and Grimsvötn volcanoes in 2010 and 2011 proved just how

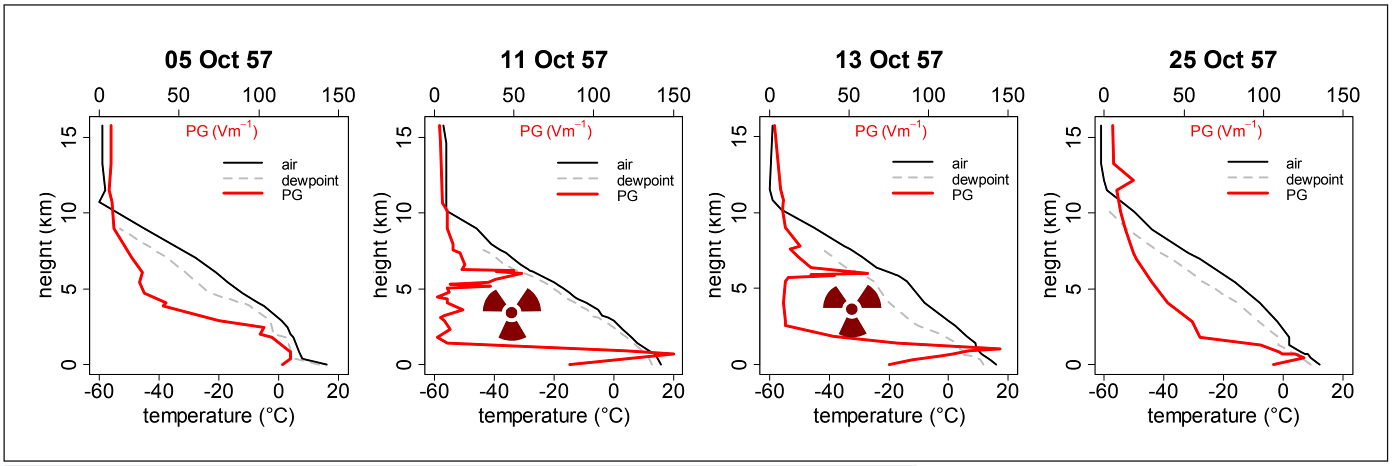


Figure 1: Sequence of radiosonde measurements through radioactive clouds over Belgium, during nuclear bomb testing in 1957. The radioactive plume region between 2km and 6km aloft is marked on October 11 and 13, as identified by potential gradient measurements (PG, red line), an atmospheric electrical parameter highly sensitive to radioactivity. The black and gray lines show the air and dewpoint temperatures respectively

useful the radiosonde platform could be in hazardous conditions, through balloon soundings providing some of the first ash concentration measurements made aloft during the 2010 flight ban crisis. (Self-charging of the Eyjafjallajökull volcanic ash plume, Environ Res Lett 5 024004, 2010.)

Cloud is conventionally inferred from radiosonde relative humidity (RH) measurements. Although such thermodynamic measurements have improved greatly in recent decades, the slow time response of the RH sensors can be a problem, particularly at low temperatures. A new disposable optical sensor developed at the University of Reading enables accurate determination of cloud layers from measurement of solar radiation. The constant movement of the radiosonde generates high variability in clear air conditions (where the position of the solar sensor with respect to the sun is important), but low variability beneath and inside cloud (where the radiation is diffuse and isotropic, hence the sensor becomes insensitive to changes in direction). This can be seen from Figure 2, which shows a radiosonde flight through a layer of stratocumulus cloud. Beneath and inside the cloud, the solar radiation is low (Figure 2b), with small variability. As the sensor exits the cloud at 1.75km, the solar radiation and variability increase as the sensor enters clear air above. Such an optical approach may identify thin clouds otherwise missed, through its improved high-resolution measurements of cloud boundaries compared with relative humidity measurements alone.

Balloon sensors

A standard radiosonde cannot measure turbulence, although its meteorological data can be used to infer regions of the atmosphere where the air is unstable and could be turbulent. Instead, two disposable sensors newly developed at the University of Reading are being used to measure the movement of radiosonde packages and to directly determine the strength of any turbulence.

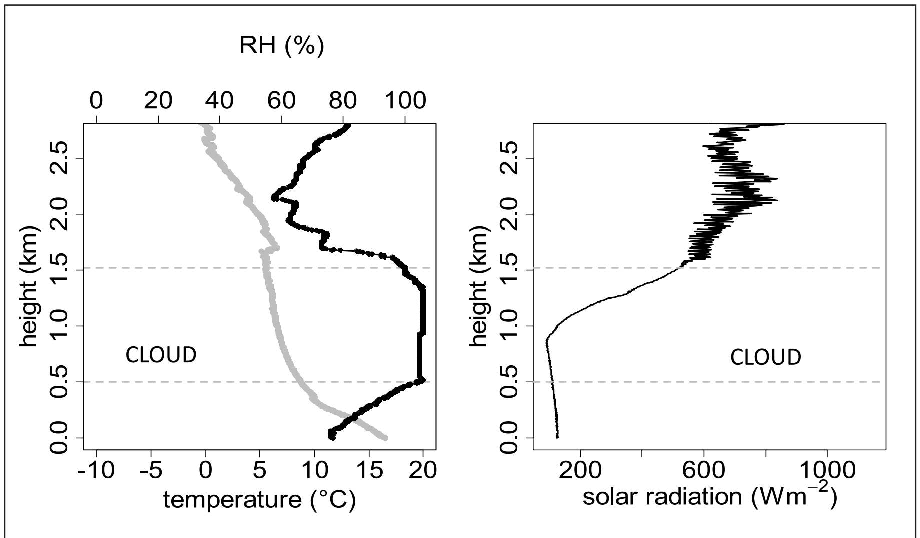


Figure 2: Measurement of solar radiation through a stratocumulus cloud, from a radiosonde flight from the University of Reading. (a) Standard meteorological measurements of temperature (gray) and relative humidity (RH, black); (b) solar radiation as measured by an optical solar radiation sensor developed at the University of Reading. (From: 'Balloon-borne disposable radiometer for cloud detection', *Review of Scientific Instruments 84, 025111, 2012*)

HALL EFFECT

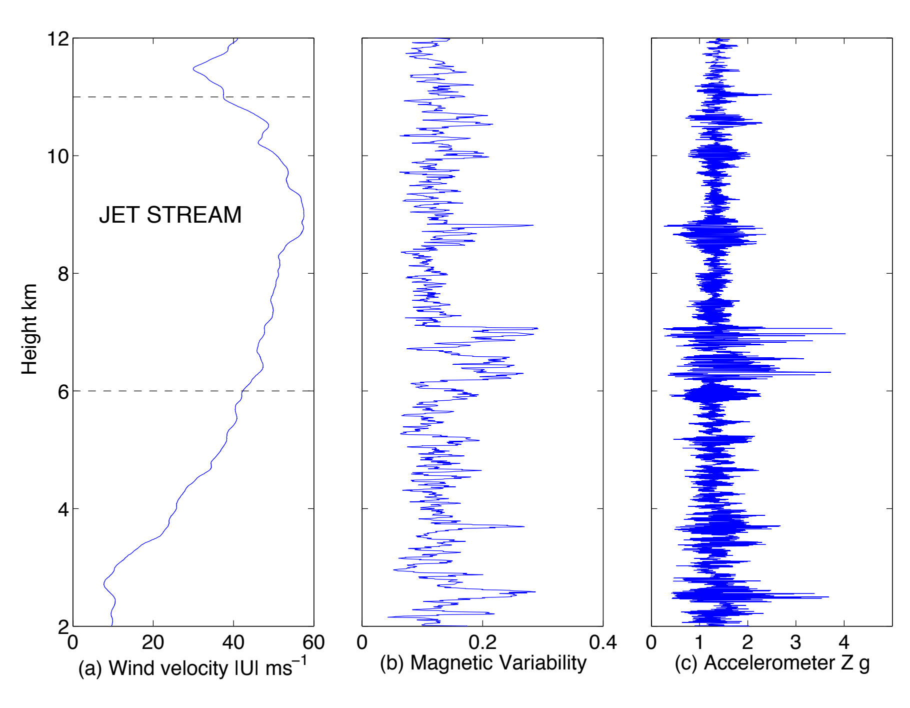
If an electric current flows through a conductor in a magnetic field, the magnetic field exerts a transverse force on the moving charge carriers, tending to push them to one side of the conductor. The Hall effect is most evident in a thin flat conductor. Using this a buildup of charge at the sides of the conductors will balance the magnetic influence, producing a voltage between the two sides of the conductor. This measurable transverse voltage is called the Hall effect after the man who discovered it in 1879: E H Hall.

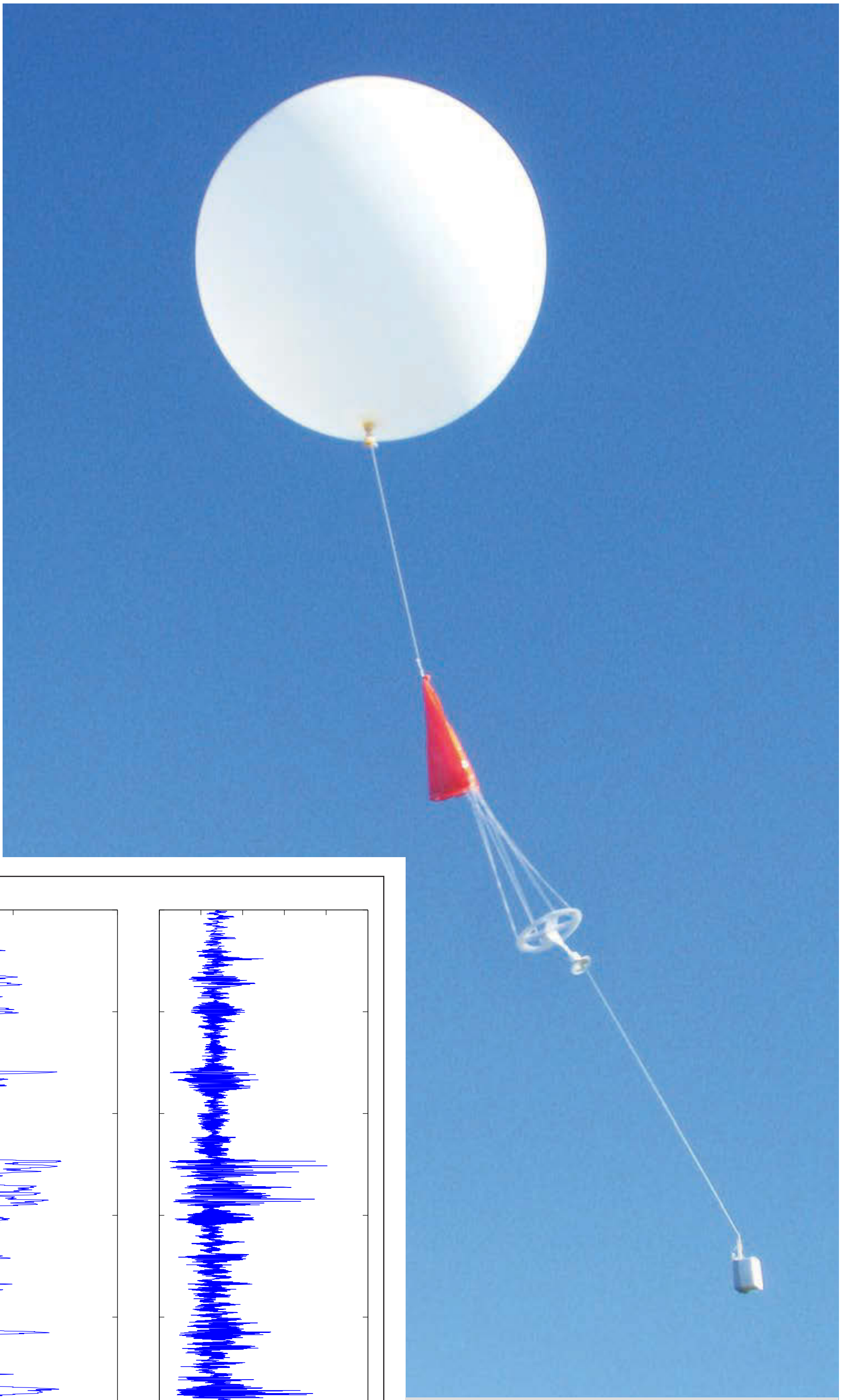
The first sensor uses the Hall effect to measure the orientation of the balloon package in relation to the Earth's magnetic field (see *In situ* atmospheric measurements using the terrestrial magnetic field – a compass for a radiosonde, *Journal of Atmospheric and Oceanic Technology, 23, 517-523*). The second sensor uses an accelerometer to measure the 3D acceleration experienced by the balloon package. Figure 3 shows that the magnetic sensor and the accelerometer both detect turbulent air at the lower boundary of a jet stream. The two sensors, combined with a solar radiation sensor, enable clear-air turbulence to be distinguished from in-cloud turbulence. Ascents such as these are providing information vital to improving our understanding of atmospheric turbulence, predicted to become more intense as the climate changes ('Intensification of winter transatlantic aviation turbulence in response to climate change', *Nature Climate Change*, 3(7), 644-648).

Space weather

Beyond aircraft protection, space weather is increasingly recognized as a hazard to

Figure 3: Radiosonde ascent encountering a jet stream around 9km. (a) Horizontal wind velocity as measured by GPS location, together with measurements from (b) the Hall effect sensor (relative units) and (c) the acceleration sensor, which both detect a region of turbulence at the bottom edge of the jet





Nearly all routine radiosonde launches occur 45 minutes before the official observation time of 00:00 UTC and 12:00 UTC

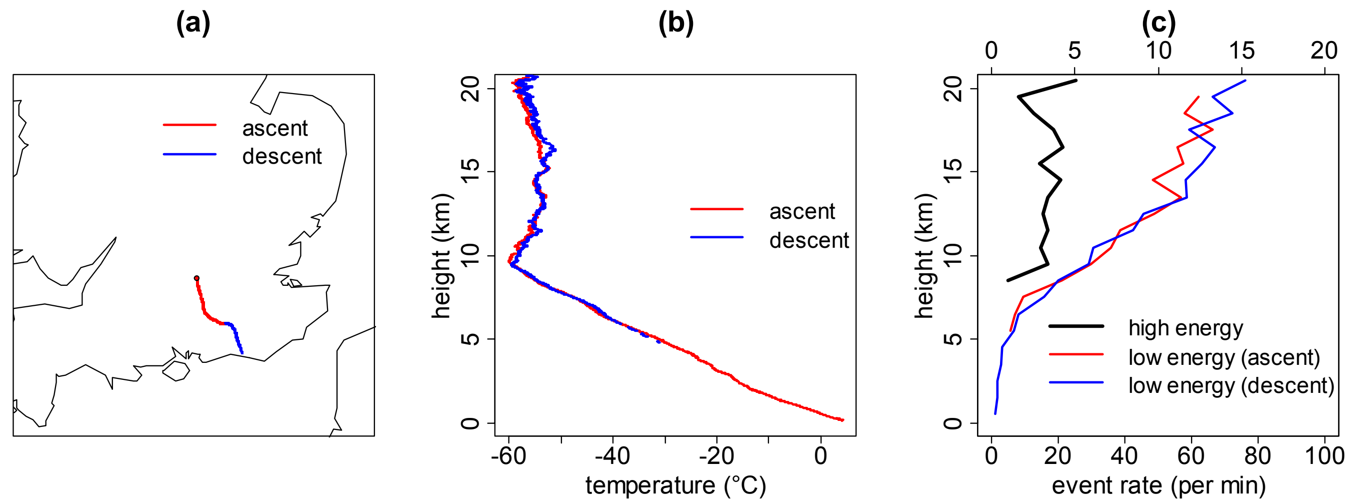


Figure 4: Space weather measurements of high and low energy particle event rate made during a radiosonde flight from the University of Reading. The standard meteorological data – (a) trajectory and (b) temperature – is unaffected by the particle sensor (c)

society's technological systems, and consequently the effects of energetic particles on the upper atmosphere – with a potential implication for weather and climate – present a new area in which scientific knowledge needs to be developed and intensive monitoring may ultimately become beneficial.

Airborne cosmic ray monitoring exploiting routine meteorological balloons now presents a cost-effective method for detecting high-energy particles entering the lower atmosphere.

As more national meteorological services become responsible for space weather forecasting, the synergy with their existing use of radiosondes in conventional weather forecasting seems likely to be adopted more widely. Figure 4 shows an example of space weather measurements of high-energy particles made using a standard radiosonde to provide power and telemetry. The meteorological data is still obtained in the standard manner, and the standard GPS information is also useful for further interpretation of the space weather sensors.

RETRIEVING THE SCIENCE MEASUREMENTS

The University of Reading radiosonde measurement system uses a simple and rapid method of attachment to the host radiosonde, employing a single box containing the interfacing electronics and, in many cases, the necessary sensors as well.

This device, the Programmable Analog and Digital Operational Radiosonde Accessory (Pandora) has already been tested at a UK Met Office radiosonde launch site, and no detrimental effects were found on the radiosonde's standard meteorological data. (Results reported in 'Programmable data acquisition system for research measurements from meteorological radiosondes', *Review of Scientific Instruments* 83, 036106, 2012.)

Software has also been developed to enable the sensor data telemetered to be easily extracted with the meteorological data for further processing.

System deployment

One reason why the radiosonde has seen so little use as a workhorse for measurements of air pollution, cloud properties, aircraft hazards and space weather may be a perceived difficulty in obtaining and deploying the additional sensors needed, or even worries about a possible threat to the quality of the standard meteorological measurements.

At the University of Reading the radiosonde science program initially concentrated on the sensing technologies – for example the measurements of ash and dust aloft – but it has also pioneered a plug-and-play approach to allow existing radiosonde flights to be used simply with additional sensor packages (see *Retrieving the Science Measurements*, above). This straightforward methodology, combined with data-retrieval software, is particularly well suited to the occasional use of such equipment by inexperienced staff, but has also been in long-term use as part of a research measurement program. This adjacent sensor approach has been thoroughly compared against standard radiosondes carrying no extra sensors, and the published results show no appreciable difference between this and meteorological data from the enhanced radiosonde.

In summary, new sensors integrated simply with existing radiosonde systems open up a wide range of atmospheric monitoring and measurement applications. ▮

The authors, Giles Harrison, Keri Nicoll, Graeme Marlton and Paul Williams, are all with the Department of Meteorology, University of Reading, UK. See http://environmentalresearchweb.org/cws/article/opinion/50353