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Weather Balloons and Radiosondes

By Cdr Mike Channon OBE RN

Recent events between the USA and China involving seemingly guided balloons, carrying surveillance instruments manoeuvring over sensitive American territory, caused a major political incident when one was shot down over US territorial waters, off the coast of South Carolina, by a US fighter jet on 4 February this year. China claimed it was merely a weather balloon gathering meteorological data. The resulting speculation on the true purpose of the balloon made for good reading in newspapers at the time (and interesting conversations in my local village pub). However, this article is not a judgement piece about clandestine surveillance or spy balloons, subjects about which I am singularly unqualified to write. This article is about weather balloons, the radiosondes they carry, the data they gather and how that information is used by meteorologists around the world. I will also include some experiences of METOC schoolies in using these instruments.

Weather balloon launched from Hong Kong, March 1981.

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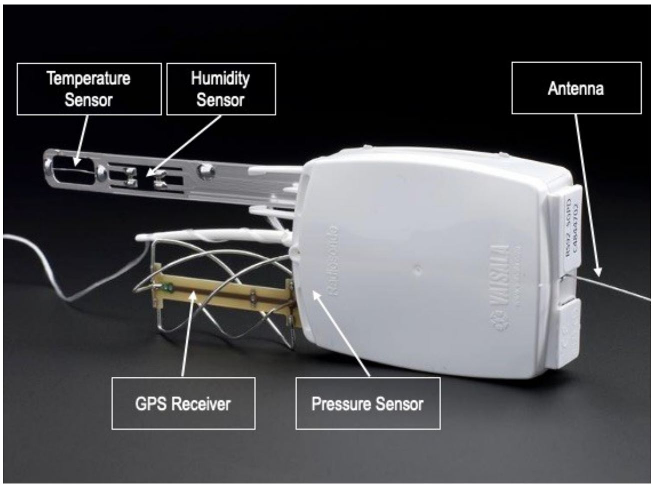
Weather Balloons

A weather balloon is a high-altitude device, that carries a small, expendable package, called a radiosonde, which sends back information that profiles the atmosphere. They are filled with either hydrogen (lower cost) or helium (safer) and they can reach heights exceeding 40,000 m prior to bursting. The balloons are generally made of latex and the maximum altitude to which the balloon ascends is determined by its diameter and thickness. When released at the surface, they typically measure about 1.5 m in diameter and, due to the decreasing air pressure, expand in size during ascent, to as much as 8 m in diameter. A balloon ascends at about 300 m per minute and may take as long as two hours before bursting. Depending on the winds aloft they may travel one or two hundred miles from the release point. A small parachute is used to ensure the whole device sinks slowly to the surface after bursting, although very lightweight radiosondes may rely on the burst balloon remnants to provide sufficient drag. In some countries, radiosondes contain a prepaid mailing bag and instructions on what to do if you find one.

In the USA about 18% of the radiosondes sent up each year are found and returned to be reused. Switzerland claims to recover and re-use more than 60% of the devices that it launches. However, it is inevitable that a great many of the radiosondes launched worldwide will end up littering the land and marine environments. It is somewhat ironic that the very instruments that gather essential data for climate change research are also a significant polluter. Finnish company, Vaisala, supplies meteorological technology to around 150 countries and is working to produce weather balloons and radiosondes that have less environmental impact. Organic latex is being used for balloons, polystyrene has been replaced by cardboard and they are working on biodegradable radar reflectors, parachutes and strings.

Radiosondes

Today's radiosondes are battery-powered telemetry instruments that measure several atmospheric variables and transmit them by radio at established frequencies (typically 403 or 1680 MHz) to a ground receiver. Modern radiosonde systems measure or calculate altitude, pressure, temperature, relative humidity, wind (both speed and direction) and geographical position (latitude/longitude). Ground computers and meteorologists analyse the information at the various altitudes.



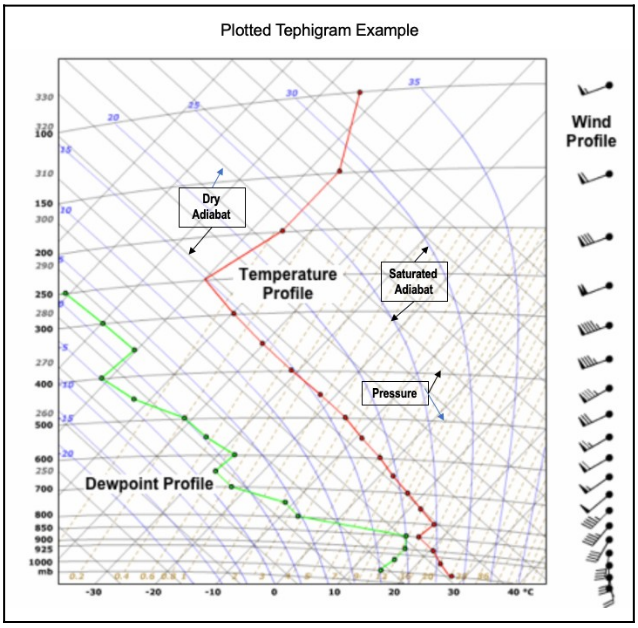
A Modern Radiosonde

(Adapted from a photograph Copyright: Science Museum, London)

Radiosondes are launched all over the world at regular intervals, their information shared with all nations as part of international agreements under the auspices of the World Meteorological Organisation (WMO). They determine real time upper air conditions which are then used by meteorologists and computer models for weather forecasting. There are over 1300 radiosonde sites worldwide, most launching twice a day at standard times. The UK launches radiosondes four times daily (an hour before 00, 06, 12, and 18 GMT, now referred to as UTC (Coordinated Universal Time) from six launch sites spread throughout the UK. The US National Weather Service launches radiosondes twice daily (an hour before 00 and 12 UTC) from 92 stations spread throughout the USA.

The raw upper air data is also routinely processed by supercomputers running numerical models. Forecasters can view the data in a graphical format, plotted on thermodynamic diagrams such as Skew-T log-P diagrams (USA), Tephigrams (UK, Canada) and Emagrams (Europe). Thermodynamic diagrams are principally used to demonstrate how behaviours of materials, typically fluids (like our atmosphere), respond to variations in pressure and temperature. The ones named above are basically variations of the same diagram using slightly different coordinate transformations.

It is beyond the scope of this article to give an in-depth description of these diagrams but the UK tephigram, also used by Royal Naval meteorologists, evolved from the original name T-Φ gram after its axes of T (temperature) and Φ (entropy).



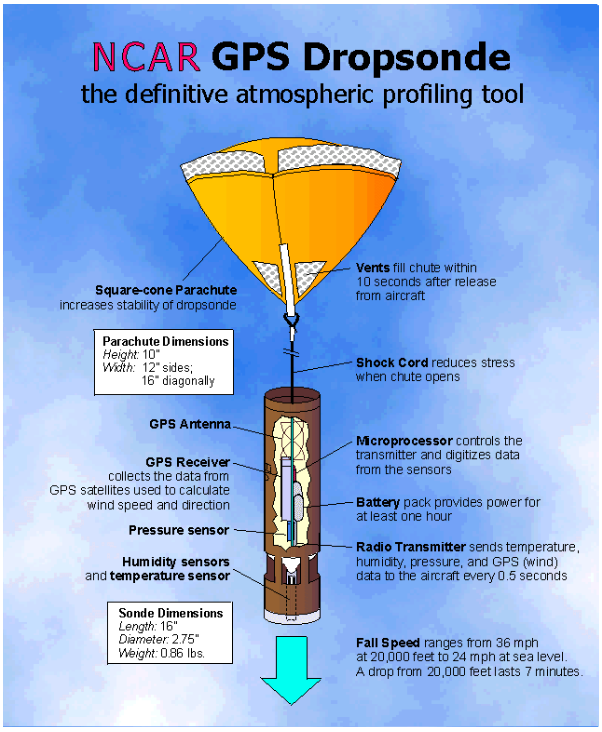
A Tephigram depicting a Plotted Radiosonde Ascent
"The source of this diagram is the COMET® Website at http://meted.ucar.edu/ of the University Corporation for Atmospheric Research (UCAR), sponsored in part through cooperative agreement(s) with the National Oceanic and Atmospheric Administration (NOAA), U.S. Department of Commerce (DOC). ©1997-2023 University Corporation for Atmospheric Research. All Rights Reserved."

A trained meteorologist can interpret the above diagram and assess the convective stability and the convective available potential energy. The wind barbs plotted on the side of the chart indicate the wind strength and direction at different heights. Cloud bases and tops plus regions where aircraft condensation trails (contrails) occur can be calculated. Additionally, the location of any radar/radio ducts can be identified and either exploited or avoided in tactical scenarios.

Dropsondes

Weather balloons are not the only means of transporting radiosondes aloft. Kites and rockets have been utilised, but aircraft are the most common platforms that are used. A dropsonde is an expendable weather reconnaissance device created by the US National Center for Atmospheric Research (NCAR), designed to be dropped from an aircraft at altitude over water to measure (and therefore track) storm conditions as the device falls to the surface. Like balloon carrying radiosondes, dropsondes contains a GPS receiver, along with pressure, temperature, and humidity (PTH) sensors to capture atmospheric profiles and thermodynamic data. It typically relays this data to a computer in the aircraft.

Dropsonde instruments are the only method to measure the winds and barometric pressure through the atmosphere and down to the sea surface within the core of tropical cyclones. The data obtained are usually fed via radio into supercomputers for numerical weather prediction, enabling forecasters to better predict the cyclone effects and intensity.



A diagram of an NCAR GPS Dropsonde
(Public Domain)

While I was serving in Hong Kong in 1981, I was fortunate enough to be invited to the US Joint Typhoon Warning Center (JTWC), at that time located in Guam. In advance of my visit, I was also invited to take a flight into a typhoon should there be one in the area. Unfortunately (or fortunately depending on one's point of view) there was no typhoon near enough to warrant a flight during my visit, but I did take a ground tour of a USAF 54th Weather Reconnaissance Squadron (WRS), WC130 (Hercules) aircraft at Andersen Air Force Base, Guam.

The 54th WRS aircraft (see photo on the next page) and crew were known as the "Typhoon Chasers". When airborne the 5-person crew comprised: pilot, co-pilot, Combat Systems Officer (CSO), Aerial Reconnaissance Weather Officer (ARWO) and a weather loadmaster as the dropsonde operator. The CSO acts as the mission commander. The ARWO is the flight meteorologist and takes over as the Flight Director when the WC-130 enters the tropical cyclone.

"Typhoon Chaser" WC-130 Aircraft, Guam
(Personal photograph of ©Mike Channon. All rights reserved.)

Surprisingly, these aircraft were not specially strengthened or reinforced for flying into typhoons, but they were very well instrumented. Typically, they would fly into storms with a spiralling flight path to minimise wind shear turbulence. The target entry height was the 700 millibar (mb) level (roughly 10,000ft) for typhoons with mean one-minute sustained winds greater than 96 knots (3 or above on the Saffir-Simpson Scale). Once they penetrated the eye or main core of the storm, they would release their dropsonde. They would also penetrate the storm core at lower and higher levels and take measurements using sensors on the aircraft.

ARWO desk in the WC-130
(Personal photograph of ©Mike Channon. All rights reserved.)

The 54th WRS was deactivated in 1987, but the 53rd WRS, known as the "Hurricane Hunters", is still operational today, based at Keesler Air Force Base, Mississippi. It has 10 WC-130 aircraft aligned under the 403rd wing of the US Air Force Reserve Command (AFRC). Their area of responsibility is midway through the Atlantic Ocean, then west to the Hawaiian Islands, although they have also been tasked to fly into typhoons even further west in the Pacific Ocean on occasion.

Apart from tropical cyclones, the 53rd WRS also performs winter storm weather reconnaissance off both coasts of the United States between 1 November and 15 April. These missions are flown at the WC-130's service ceiling of 30,000 ft (9,100 m), which subjects them to turbulence, lightning and icing. The crews collect data ahead of these weather systems, by dropping small drifting weather buoys.

Atmospheric Soundings by METOCs in the Royal Navy

Weather balloons can be launched from large aviation-capable Royal Naval ships. The data collected are used by RN forecasters and shared with the WMO via the UK Met Office. In the 60s, 70s and early 80s, RN radiosondes were less sophisticated than today, lacking GPS receivers and so needed to be tracked by radar to determine the upper winds for flying operations. Sondes to determine upper winds only, using balloons with radar reflective covers, were known as rawinsondes (Radar Wind Sondes).

Profiles of the atmosphere provide information crucial to weather forecasting. RN ships operating in coastal waters would access local radiosonde ascents from nearby civil stations and gain relevant information without launching their own balloons. However, in data sparse areas like open oceans the requirement to launch weather balloons from ships had increasing importance.

Weather balloon launch, 1965.
(Source: Public Domain)

Unfortunately, launching weather balloons from aircraft carriers can be problematic. Even if the weather conditions are conducive for balloon preparation and sonde handling, the Captain and Commander Air may be understandably reluctant to alter course or pause flying operations to facilitate a balloon launch. Another major factor was that many ship met offices may not have their own dedicated radar, so to determine upper winds they would have needed to request the use of an operational radar for a sufficient time slot to track the rawinsonde.

The following remarks of forecasting in HMS *Ark Royal* (R09) in 1978 are provided by Cdr John Hartley (RNIO 1967–1996).

- *Data were transmitted from the radiosonde by radio in Morse code, the recording of which by ear and pen was very labour intensive and onerous for the met office staff.*
- *The helium stowage was on the stern of the ship, directly under the round-down of the flight deck and hence just below the flight path of recovering aircraft (see photo below) prohibiting its access during flying operations. This location was also subject to more movement in moderate to rough sea states than in other areas of the ship.*
- *There was no clear or dedicated area from which to launch the balloons and sondes.*

HMS *Ark Royal*
(Helium stowage area within the yellow box)
(Source: MOD Public Domain)

HMS *Invincible*, 1982
Source: Navy News© (www.royalnavy.mod.uk/news-and-latest-activity/navy-news).

Wartime situations can cause their own unique problems. For example, during the Falklands War, Argentina and some other South American nations, ceased sharing their real time meteorological data so denying the RN ships information normally crucial to operations. Recent conversations with the METOC Commander who was in HMS *Invincible* during that conflict, revealed that, at times, meteorological information was very sparse.

Compounding the problem, it was decided by the Command that launching weather balloons with radar reflective covers created a risk of giving away the ship's position, limiting their use as an information source. The experienced forecasting team on board often had to use single observer forecasting techniques to assess the observed weather parameters in situ, glean what they could from various intelligence sources and get frequent debriefs from pilots with respect to upper air wind speeds and any other useful meteorological data observed during flying operations.

HMS *Invincible* Met Office, 1981
(Source: Navy News© www.royalnavy.mod.uk/news-and-latest-activity/navy-news)

It is a testament to the METOC specialisation, that despite many of the difficulties described above, a professional service was always provided by knowledgeable, well-trained forecasters supported by some of the most talented senior and junior ratings in the RN. The close relationships enjoyed by METOC teams was second to none. They most certainly would have appreciated the modern automated radiosondes, satellite imagery and other improvements in meteorological data availability and data gathering that their HM successors in the RN no doubt utilise today.

Current and Future Considerations

The current focus on climate change has increased the importance of having a large global network of meteorological reporting stations. Unfortunately, in less developed parts of the globe, which often have high vulnerability to impacts of extreme weather events, there is an increasing paucity of surface and upper-air observations, presumably due to affordability and global socio-economic effects. Recently the WMO stated that there was "*a dramatic decrease of almost 50% from 2015 to 2020 in the number of radiosonde flights and/or observations, the most important type of surface-based observations for weather prediction and climate analysis"* and furthermore "*now has poorer geographical coverage*". Over the last two decades, some 82% of the countries in Africa have experienced severe (57%) and moderate (25%) reduction in radiosonde ascents. This has resulted in a global effort to "plug the data gap" in the decade ahead and halt a further deterioration in the observation networks.

There is much ongoing research to improve the ability of meteorological satellites to deliver vertical atmospheric profiles. Satellites offer excellent global coverage of the atmosphere from space whereas radiosonde data are sparse over the oceans and in certain countries as highlighted in the previous paragraph. However, satellites still cannot provide all the meteorological measurements that soundings by radiosonde devices can. Radiosonde data remain crucially essential in providing the real time ground truth and validation of this research. Atmospheric soundings by radiosonde will always be essential and the requirement for them can only increase as time goes on.

The importance of radiosonde data to numerical models run by supercomputers has been mentioned throughout this article. An underlying concern of the modellers is that the sonde may drift long distances during the 90 to 120-minute flight, and this can introduce problems into the model initialisation. In general, this does not appear significant except locally in jet stream regions of the stratosphere. In these cases, drones would be a good solution as they have precise control over their location and can compensate for drift.

Weather drones are thus likely to be the radiosondes of the future. They can act as mobile weather observing stations and be sent to precise locations where data are needed. They could also solve the radiosonde littering problem. However, they currently have their limitations. They cannot reach the high-altitude areas that balloons are capable of. Present rotary-wing weather drones can only operate at heights up to 6000 m. Fixed wing drones can fly considerably higher but would likely be prohibitively expensive to use for routine weather observations. Improvements in drone technology will, however, increase their capabilities in the future. Current weather drones are robust enough to handle strong winds in storms, are equipped with heated rotors to ward off icing and even have emergency parachutes.

Weather drones are not yet used routinely to support National Meteorological and Hydrological Services mainly because they are subject to ongoing negotiations covering Unmanned Aerial Vehicles' (UAVs) access to airspace and compliance with airspace regulations. They are also not quite compliant with the technological development needed to meet the WMO requirements. However, it is only a matter of time before such aspects are resolved. Of course, having guided weather drones carrying increasing payloads of data gathering instruments, could create further political incidents with accusations of spying, which is precisely where this article started!

Information sources:

Wikipedia
National Oceanic and Atmospheric Administration (NOAA) website
53rd Weather Reconnaisance Squadron Hurricane Hunters website
COMET MetEd (www.meted.ucar.edu)
Science Direct (www.sciencedirect.com)
Cdr Bob Young (RNIO 1964-1991)
Cdr John Hartley (RNIO 1967-1996)

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