A Viable Alternative for Conducting Cost-Effective Daily Atmospheric Soundings in Developing Countries

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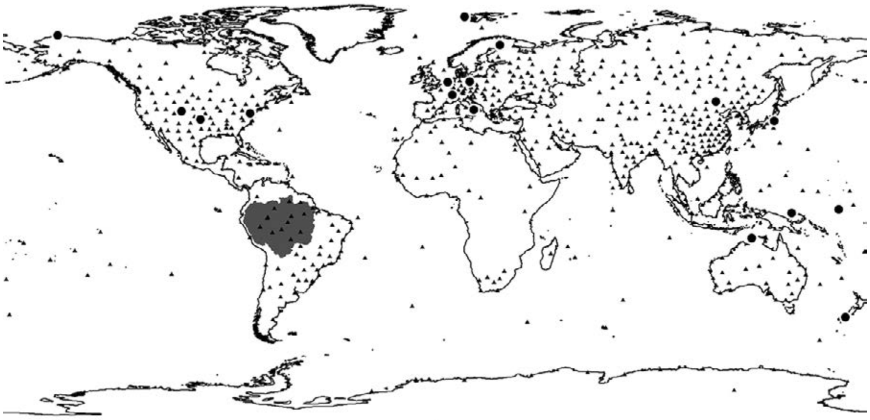

FIG. 1. Global positions of operational sounding stations (▲), including GRUAN stations (●), as recorded by the WMO in Feb 2011. The Amazon basin is represented by the gray area.

THE IMPORTANCE OF ATMOSPHERIC SOUNDINGS. While accuracy and coverage of satellite imagery have improved markedly in recent years, radiosonde-collected data still provide us with the most detailed measurements of the troposphere (i.e., the lower part of the atmosphere where most hydrological atmospheric processes occur) due to their fine vertical resolution (i.e., 5–10 m). However, instrument biases (temperature, relative humidity, pressure, wind direction, and wind speed) are compounded in the tropics by relying on sparse sampling of data. Figure 1 shows the locations of operational sounding stations from the Global Climate Observing System (GCOS) upper-air network (GUAN) as recorded by the World Meteorological Organization (WMO) in February 2011. The figure illustrates the scarcity of sounding stations, particularly in developing countries compared to other parts of the globe.

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WHY SO FEW MEASUREMENTS IN DEVELOPING COUNTRIES? The primary factor accounting for the lack of sounding data availability is, quite simply, cost. Budgets allocated to soundings in developing countries of Africa and South America are often limited or a minute part of a bigger budget. This results in the inability of a vast majority of developing countries to comply with the standards set by the WMO in their 2007 revision of the WMO Convention originally published on 11 October 1947.

Here, we take as an example the Instituto de Hidrologia, Meteorologia y Estudios Ambientales (IDEAM), which, as the governmental institute for meteorological and hydrological services of Colombia, is responsible for recording the climate at a national level. In 2011, the meteorological station of the IDEAM in Leticia (WMO #80398), based in the southern tip of the Colombian Amazon and hence in charge of recording meteorological data on global water vapor regulation in a critical region, received funding for a total of only 119 flights, whereas the

WMO-recommended number is 730 flights a year (i.e., two flights a day).

As of 2011, only 50% of the South American GUAN stations transmitted regular reports. This lack of data is further highlighted by the GCOS goal for establishing a reference network for upper-air climate observations (GRUAN) as an extension to GUAN. GRUAN standards are more rigorous than that of GUAN and aim at addressing historic biases in the data. Of the 15 initial GRUAN sites, none were in South America. There is a current plan for expansion, as the importance of monitoring the Amazon is recognized; however, the budgets to support this research have not yet materialized.

CURRENT RADIOSONDE TECHNOLOGIES.

Improvement in sensor accuracy has been made over the years, but the standards for long-term climate studies require even higher accuracy and more rigorous documentation of instrument changes in order to reduce temporal and spatial inhomogeneity. Formed to provide long-term, high-quality, accurate climate data, the WMO's GRUAN program is working toward correcting these issues. The 2010 WMO evaluation of radiosonde performance quantitatively ranked radiosonde technologies against GRUAN requirements. The three companies with the highest average score—and hence the closest to meeting these overall standards—are Vaisala (Finland), Lockheed Martin Sippican (United States), and GRAW (Germany).

All three manufacturers have pricing levels that depend on the volume of the radiosondes being acquired. Assuming that a) the sondes are being acquired by a large agency such as the WMO or a national weather institute, and b) a quantity corresponding to two flights a day per year is being ordered, the price is on average $155 per sonde. Here, we do not consider the cost of shipping, which may or may not be included in the sonde cost. For new stations, or stations that are changing equipment, additional charges will result from buying the corresponding receiving device or ground station (i.e., used in the collection of the data radio-transmitted by the sonde), which ranges from $12,500 to $80,000.

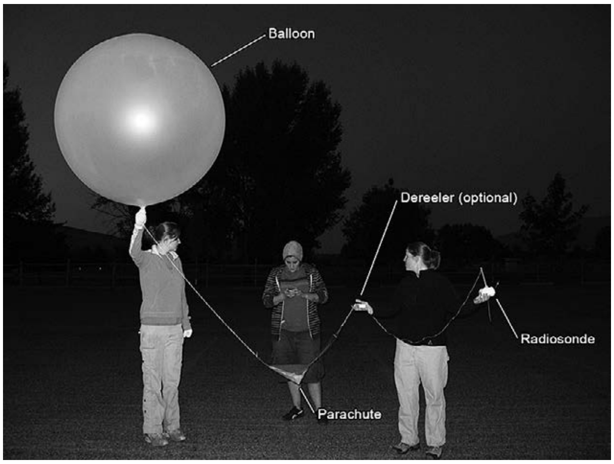

Fig. 2. Setup of the GRAW sounding equipment for a flight.

Considering only well-established sounding stations, and therefore discounting the costs of the receiving devices and infrastructure, each station will spend approximately $113,150 per year on sondes alone in order to meet WMO standards. We only focus here on sonde costs such as balloon size, type of lifting gas, and the decision to use dereelers and/or parachutes, which are determined by each individual sounding station, making costs vary considerably in addition to the purchase of the radiosondes (see Fig. 2). Costs of sondes increase by as much as 35% when quantities of supplies decrease.

POSSIBLE ALTERNATIVE: GLIDERSONDES.

An alternative to lower the costs of conducting daily sounding operations would be to have the radiosonde be reused. Indeed, once the balloon has been launched it is often impossible to get the equipment back; the sonde can drift tens of kilometers away. The issue of recovering the radiosonde becomes even more prominent in parts of the globe where topography, land cover, and lack of highway infrastructure render retrieving a fallen sonde difficult (e.g., the dense vegetation of the Amazon rain forest).

With this objective in mind, the development of a new technology was initiated in 1997 by the National Severe Storms Laboratory (NSSL, United States): the radiosonde would *glide* back to a designated landing point. This recoverable system involves the lifting of a miniature plane (the "glidersonde") using the same balloon and lifting gas method as that of a regular sounding flight. Once the balloon reaches its upmost altitude and pops, the plane free-falls until stabilizing and then glides back to a designated point using an onboard GPS and flight navigation computer.

It is important here to note the difference between a glider and other unmanned aircraft systems (UAS) such as aerosondes. In contrast with glidersondes, aerosondes have no need for a balloon system for transport before release, as they power their own ascent and descent. Unfortunately, such UAS do not adhere to GRUAN standards, which require the radiosonde to reach an altitude of 30,000 m, whereas many UAS designed for atmospheric sampling work in the lower atmosphere, typically up to 5,000 m. Although we make a distinction between a glider and a UAS based on data requirements, aviation agencies do not make such distinctions, and all systems are classified as UAS, commonly referred to as drones.

A recent glider model developed by GPSBoomerang (New Zealand), the "DataBird" (see Fig. 3), has shown promising results with regard to the possibility for its use by national weather stations. The DataBird has a wingspan of 63.5 cm, weighs 270 g, and can carry payloads up to 330 g (WMO recommended radiosondes weigh between 90 g for the GRAW DFM-09 and 290 g for the Vaisala RS92). Total weight of the equipment necessary for a flight amounts to approximately 700 g when including the dereeler and balloon. There are two main advantages of these specifications. First, costs for its uplifting using hydrogen or helium will not be significantly higher than that of radiosondes flights whose total weight usually ranges between 90 g and 1,050 g. Second, no additional infrastructure is required for data collection, as this system can fit within existing balloon launch procedures.

The DataBird is capable of ascending up to an altitude of 35 km and coming back within a 100-m radius of a predetermined landing site (www.gpsboomerang.com). A maximum of 39 alternative landing sites can be programmed for the glider to decide "on the fly" which to descend to depending on the site's proximity and ease of access on the basis of winds. Furthermore, no-fly zones can be determined in order to minimize any risks of flying into an airport's airspace or another country.

Two case studies, published on the manufacturer's official website, describe the field testing of the glidersonde when released at altitudes of 10 and 20 km. The most complete (datawise) of the two flights shows that the DataBird took 85 min to reach an altitude of 20 km with an average ascending rate of 3.9 m s^{-1}, and took 97 min to reach its landing site with an average descent rate of 3.4 m s^{-1}. Averaged over the two case studies, the glider's descent takes about 1.34 times more time than its ascent. Winds registered during these field tests range between 3.7 and 25.0 m s^{-1} (i.e., gentle breezes to strong gales). Although such results are promising, the DataBird has not yet been tested by any third party or described in formal literature, most certainly due to the fact that GPSBoomerang discontinued its manufacturing because of issues related to the earthquake that hit New Zealand in 2011.

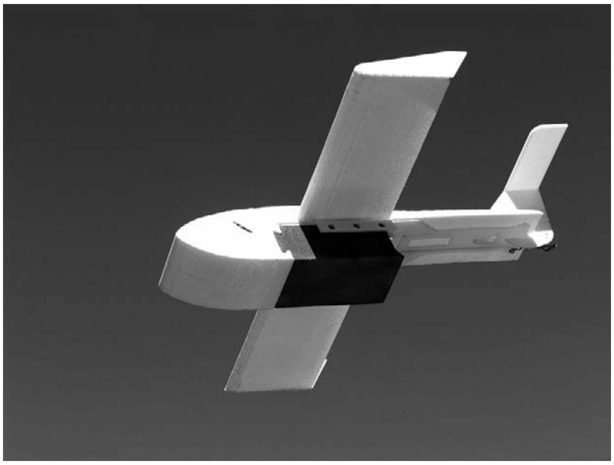

Fig. 3. The DataBird glidersonde model developed by GPSBoomerang.

Glidersonde devices are still prototypes and are therefore not readily available on the commercial market. Other than the lack of funding and the possible reluctance of radiosonde manufacturers to cooperate if their market share should decline, a major issue currently impeding their development is strict air-space restrictions. The United Nations Agency governing the International Civil Aviation Organization (ICAO) sets standards and regulations necessary for aviation safety, security, efficiency, and regularity among its 191 member states. Under the ICAO standards and regulations, a Certificate of Authorization (COA) and a UAS operator certificate are required for flying UAS. However, laws on the use of UAS vary from nation to nation.

Strict air-space restrictions are exemplified in the United States with Federal Aviation Administration (FAA) regulations: a COA or a Special Airworthiness Certificate (SAC) are often imperative but difficult to obtain, as glidersondes fall under the same category as drones. A 2012 FAA article states that "already, the agency has achieved the first unmanned aircraft systems milestone included in the 2012 FAA reauthorization—streamlining the process for public agencies to safely fly UAS in the nation's airspace." However, "this COA process is not available to private companies. They must apply for a SAC or Experimental Certificate, which only allow crew training and research, and exclude flying for profit." (Rayleigh 2013) Colombia has adopted the same policy where existing certification, operation, and maintenance of UAS in other member states is currently being evaluated in order to establish requirements for universities and companies developing projects for academic and/or research purposes only.

Both countries are consistent with current development of UAS regulations but, by creating avenues only for public institutions, market availability of glidersonde technology becomes extremely limited. However, other member states, such as Brazil, Mexico, and New Zealand, are virtually unregulated, making these potentially viable testing grounds for UAS development by private companies. However, it may not be cost-effective to travel to other countries for UAS evaluation based on flight regulations; it is important to recognize that the availability of equipment and its testing for data collection are mutually exclusive due to flight restrictions and project location.

FUTURE DEVELOPMENTS. To conclude this review, we underline two major issues that currently hamper the development and commercialization of the glidersonde technology: 1) how to have reusable radiosondes while keeping the market viable for sonde manufacturers, and 2) the need for permits that are difficult to obtain for flying glidersondes.

We propose an alternative consideration to address the first issue, namely that of providing users with reusable equipment while maintaining manufacturers' market share. One way to achieve this is to develop glidersonde systems that fit current radiosonde models and have the radiosondes be reusable for the number of flights needed to break even on the cost of the glider, plus make an additional cost savings over the disposable radiosondes.

For example, a package of six DataBird modules, capable of going into the stratosphere, cost approximately $5,850. Including costs of radiosonde sensor reconditioning and battery replacement, this would require each module to complete ten flights with one reusable radiosonde to break even with current radiosonde costs and realize an additional 4.6% cost savings [10 radiosondes: $155 × 10 = $1,550; one glider, one reusable radiosonde, and reconditioning of the sonde: $975 + $155 + (9 × $38.75) = $1,478.75]. Here we are describing equipment being sold as a one-piece module composed of the glider and its radiosonde; we are not yet considering a glider on which the radiosonde can be replaced. By first introducing this module on the market, one can probe for the reaction of the end-users to this change and assess its effects on sales. If the reaction is positive, it will then become possible to gradually increase the number of soundings each glider can achieve and have the radiosonde be replaced. For example, one glider can be used with two radiosondes (20 flights), then with three radiosondes (30 flights), etc. Savings will then climb to a striking 65% each time 10 flights are completed using the same glider as used for the previous 10 flights [same glider, new reusable radiosonde and reconditioning costs: $0 + $155 + (9 × $38.75) = $503.75]. In this way, assuming that the total budget spent on soundings remains identical, the amount of data collected increases while maintaining the sales levels of the sonde providers.

Applying this to our example, and assuming one DataBird module will be used for 50 flights, the IDEAM of Leticia would have been able to collect approximately 2¼ times the amount of atmospheric data in 2011 with the same budget. Even taking the other extreme of replacing the glider every 10 flights, savings are realized. For a station with a yearly average sonde budget of $113,150, flights would increase from 730 to 765 per year, which in turn would increase data collection by 4.8%. Although this may seem to be a small percentage, when major meteorological events such as severe flooding (e.g., that of the Amazon Basin in 2012 or Hurricane Sandy off the U.S. Atlantic coast) are considered, these extra days of soundings, which increase temporal resolution of the data, will positively affect forecast accuracy. The increase in flights could also lead to a greater spatial resolution of the data when savings are being used to supply sondes to new sounding stations.

An advantage for well-established stations, such as that in Leticia, Colombia, is that sonde launches are considered part of the meteorologist's regular duties and therefore no additional personnel costs are incurred with added launches, as the glider does not need a trained, active operator working a separate ground station; the DataBird is designed to be out-of-the-box ready for a single operator, thus integrating smoothly into typical radiosonde operations. We therefore also assume no added costs over regular station operations for balloons, lifting gas, dereelers, etc. Furthermore, following the GPSBoomerang case studies that show an uncertainty of approximately 100 m in the accuracy of landing location under varying wind conditions, it can be assumed that costs incurred in the retrieving of the fallen glidersonde should not significantly affect budgets if alternative landing sites are chosen wisely.

This still does not mean that the manufacturer makes any additional profit from the whole experience. However, it could be hypothesized that such properties of reusability will attract more occasional users who do not especially use the radiosondes for recording climatological variables for a national institute but rather for their own purposes (e.g., universities, NGOs), as well as to convince national weather institutes to use their product. Glidersonde technology is not new and has shown promising results, meaning that costs of development and testing should be kept at reasonable prices. Furthermore, recovering the sonde reduces the environmental impact caused by the nonbiodegradable equipment of the radiosonde. It is important to stress that the environmental impact from the loss of radiosondes should not be considered lightly. Using this cleaner-technology aspect of glidersondes over radiosondes is also a robust marketing strategy, as governmental institutions are being pushed to stick to international environmental legislation for conducting scientific research while diminishing impact on the environment. To summarize, the glidersonde manufacturer should benefit from an increase in clients because

- the company's products are less expensive and can achieve more in terms of data collection;
- the company explores a new technology and as such could be a potential leader in that market; and
- the company will be considered as more environmentally friendly than others on the market.

All this said, a few important concerns still need to be addressed in order for this technology to be reliable to the end users and as such viable to the glidersonde manufacturer (e.g., all savings will ultimately be eliminated if the glidersonde is lost in operation). More testing of the glidersonde technology needs to be undertaken in order to answer concerns such as: Can the glider come back from large distances (i.e., 150 km from the landing site)? Will the sensors resist the temperature of the upper troposphere and be able to work again (excluding the routine reconditioning) or will more expensive sensors need to be used? Could glidersondes be used in urban areas?

To address the second issue of overly strict aviation regulations, it is imperative to broaden interagency and private industry cooperation. In our consideration of GRUAN standards for radiosonde data, it is important to consider GRUAN as an international collaboration. The addition of a UAS to the GRUAN system would benefit from a similar approach to international consistency. The ICAO document on UAS states: "Close adherence to the guidance material will facilitate later adoption of Standards and Recommended Practices and will ensure harmonization across national and regional boundaries during this development phase. [. . .] Therefore, every effort should be made amongst contracting States to collect data in a coordinated manner and share it openly to expedite the development of international civil aviation standards." It would therefore be best if glidersonde technology for GRUAN standards met the ICAO ruling on UAS to make requirements uniform.

For that reason, we support international collaborative efforts similar to that of GRUAN for glidersonde development, and underscore the necessity of an avenue to address private availability of the COA/SAC and license processes. We also stress the unique need for a glider technology that can be seamlessly integrated into current sounding systems rather than the popular notion of fully automated UAS that require licensed technical operators and their own ground station. It should be clearly understood that the technology and acquired datasets are equally beneficial for all involved parties (i.e., interagency and private industry).

To conclude, we urge cooperation in the development of an operational glidersonde system and in the collection of more extensive and continuous data over areas—such as the Amazon basin—that are of vital importance to global climate. Climate models are critically important and powerful tools with which most predictions are currently achieved, and we strongly believe their simulation and prediction performances will benefit from refined atmospheric datasets. However, as long as our observed data remains uncertain, so will our model predictions.

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