Suggestions for upgrading the pilot balloon network in West Africa and elsewhere in the tropics

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Abstract

Based on experience during the 2006 NAMMA field program we provide some recommendations for improving the pilot balloon network over the West Africa region. These range from relatively straightforward suggestions as to adjusting the launch time to maximize sounding height, to improved efforts to maintain the equipment and train observers. The supply of gas for balloon inflation is probably the largest logistical problem, followed by quality control of the data. The paper concludes by suggesting that the fastest way to upgrade the sounding network over Africa is to make it independent of National Meteorological Services and place it under an independent body that would oversee all aspects of its operation – for the benefit of Numerical Weather Prediction and climate monitoring objectives. The reasons for this seemingly drastic action are presented.

Introduction

The National Aeronautics and Space Administration (NASA) – African Monsoon Multi-disciplinary Analysis) (AMMA) field program (NAMMA hereafter) was carried out in West Africa and over the eastern tropical Atlantic during August and September 2006 to improve our understanding of the genesis of tropical storms over this region. The main focus was on the contribution of Saharan dust and African easterly wave variability to downstream cyclogenesis over the Atlantic Ocean.

The primary components of the NAMMA were the NASA DC-8 research aircraft and meteorological radars based in the Cape Verde Islands at Praia and near Dakar, Senegal. However, a small effort was supported to upgrade the sounding network in countries of West Africa, specifically Mali, Mauritania, Senegal, and Guinea. The objective was to improve the synoptic specification of the African waves leaving the continent to help plan the DC-8 flight missions and to support studies to describe the upstream tropical wave structure prior to cyclogenesis over the Atlantic.

Because of the limited funds available, the effort mostly involved trying to bring the existing pilot balloon network over the region up to its former status. The pilot balloon network in West Africa has been in place for more than 50 years, and in the past the network was characterized by relatively frequent observations (often 4-times daily) and with high spatial density (more than 20 stations in West Africa). However, the pilot balloon network has decayed in recent decades. Unfortunately it is difficult to describe this decay in detail because many of the observations have not transmitted in real-time and many, perhaps most, have still not been digitized and made available in digital archives.

This paper summarizes our experiences, highlights the main problems, and then suggests where the future may lie with regards to the African pilot balloon network. More information on our NAMMA activities may be found at:

http://www.nssl.noaa.gov/projects/pacs/web/NAMMA/e_introduction.html

Our group spent 30 days trying to re-establish the pilot balloon network in Senegal, Mauritania, Mali and Guinea, prior to the start of NASA aircraft operations in mid-August 2006. Our effort succeeded in improving the operation of two sites in Mali, one in Guinea and two in Mauritania, but was unsuccessful in Senegal. There were very many problems with equipment, gas supply, communications, and motivation, that prevented a quick solution to the network's problems – which had developed over many years. Many small details of the effort to improve the network in West Africa prior to the NAMMA activities are described in an informal report that can be found at:

http://www.nssl.noaa.gov/projects/pacs

This provides the flavor of what can happen in an effort that in retrospect allowed too little lead-time and was short of resources. Despite our considerable experience in working in Latin America, we were not fully prepared for the conditions we encountered in West Africa.

Although this paper was motivated by our NAMMA experience, one of the authors (MD) has been involved with pilot balloon activities in Latin America for more than 15 years, the last 10 involving the PACS-SONET project (see the project's web site for more information at: http://www.nssl.noaa.gov/projects/pacs). In addition, it should be noted that the material discussed below is relevant to many regions of the tropics, not just Africa.

Suggestions for improving the pilot balloon network in West Africa

Our experience with the seriously decayed pilot balloon network we found during NAMMA-2006 does not mean that these observations should be abandoned. In the relatively cloud free environment of the region there would be considerable benefit to having a relatively dense upper wind network. The intensity of tropical waves cannot be adequately described from the current sounding network over the region; the small scale of the vorticity features cannot be well-resolved from the radiosonde network alone.

Reducing the pilot balloon network's major deficiencies – unavailability of gas and poor data quality being the two most obvious problems, is an urgent need. In principle, the gas supply problem can be dealt with by either 1) importing gas cylinders from a central source where it can be produced inexpensively (Europe or the US) or 2) using new technology gas generators to generate on demand the gas needed for balloon inflation. A system now being tested (http://www.hydrogenpowerinc.com/index.html) appears to be less expensive to purchase than current caustic soda generators, easier to maintain, and similarly economical. The unavailability of an inexpensive and convenient hydrogen source to inflate balloons in remote locations is the most important logistical problem blocking a significant upgrade of the pilot balloon network over the region.

To improve data quality of pilot balloon observations requires regular maintenance of the theodolites (which is seriously lacking from our NAMMA experience) and calculation of the winds with computer software that displays and interactively corrects the raw angle data if errors are detected. Currently winds are either computed with a special slide rule or more commonly, a hand-held calculator. Unfortunately, no error-detection is possible with these procedures. With the computer, raw angles are entered and the winds are immediately calculated. A keypunching mistake or an incorrect reading from the theodolite cannot be easily detected (or corrected). With a simple program we installed during NAMMA on available personal computers, the raw angles are displayed and the observer can interactively correct any apparent errors. Winds are immediately recalculated and displayed upon changing an angle value and the observers quickly learns to identify and correct errors – and improve their capability to make more error-free observations. An online tutorial and documentation, together with the program, can be found at: http://www.nssl.noaa.gov/projects/pacs/web/CORRIGE/index.shtml. However, the software is intuitive and can be understood in only a few minutes - though practice is important.

If balloon inflation gas, a good-condition theodolite, and a personal computer with the suitable data correction software are available, then high quality pilot balloon observations can be made. However, there are some further steps that need to be taken to improve the overall efficiency of a pilot balloon network in Africa (or anywhere else in the tropics). These are outlined below:

1) *Select suitable sites.* Most pilot balloon sites are located at airports in keeping with the original intent to aid in determining winds for aviation purposes. However, if the observations are to contribute to initializing numerical weather prediction (NWP) models they much reach as high a level as possible. The sites should thus be located in regions with the least cloudiness. Today this can be estimated from satellite, but in practice this has not been done. In the tropics the mean cloudiness can vary over short distances **(Fig. 1).** For example, coastal sites are very often cloud-free during afternoon hours due to sea-breeze related subsidence. A high pilot balloon sounding is much more likely to be obtained at such a site than one only 20 km inland. Similarly, valleys are usually much less cloudy than surrounding mountains during the afternoon hours. While pilot balloon measurements in valleys or along sea coasts may yield measurements that are unrepresentative of the “undisturbed” environment (away from the topography or coasts) below the level of the topography or perhaps 1 km above sea level in the case of the sea breeze zone, the relative lack of clouds in such environments (permitting soundings to perhaps 10 km instead of 1 km) will generally far outweigh the disadvantage of such sites.

Obviously, pilot balloon sites must have observers, communications and electrical power (for the computer). However, almost any surface observatory has sufficient staff to make pilot balloon observations, and these can be relatively easily adapted to make pilot balloon observations (hereafter “pibals”). Training such staff to make pibals has been done many times over in the PACS-SONET project, and does not require specialized personnel.

2) *Launch at times of minimum cloudiness.* Modern NWP data assimilation systems do not need observations at rigidly-fixed times, though that may often be desirable. It is more important for synoptic upper-air analysis to have a high pibal that is off-time than a short observation that is at a standard synoptic hour. We observed during NAMMA that one site

had consistently made pibals with candles, that were followed for no more than about 10 minutes, when waiting 1 hour would have allowed daylight observations that could be tracked for much longer. Likewise, the best hours for pibals over tropical land areas is before the boundary layer starts to convect through a deep layer and produce cumulus clouds that may prevent following of the balloon. Usually, about 30 minutes to an hour after sunrise is best – a balance between better visibility (sufficient sunlight – but rarely will the balloon disappear in the sun's glare at these low sun angles) and a stable boundary layer (no cumulus due to convection). The morning stable boundary layer is important in minimizing the uncertainty of the calculated winds due to the assumed constant ascent rate of the balloon. During the late morning, with a strongly heated PBL, the balloon may

Figure 1. *Southern Ghana on Jan 31 2007 at about 1330 local time. 1) indicates clear region associated with subsidence over and around Lake Volta while 2) shows clearing associated with subsidence behind sea-breeze front. Arrows indicate wind direction (approximate). Such cloudiness patterns need to be considered when planning a pilot balloon network.*

be carried aloft at a higher (or lower) ascent rate that that assumed in the calculation, affecting the calculated winds. In the afternoon, the best observations are generally possible about 30 minutes before sunset – a balance between the dissipation of cumulus and weakening turbulent motions formed from the daytime heating of the PBL and the need to have enough sunlight to track the balloon for at least 30 minutes. If the skies are clear and a 50 minute sounding is anticipated, the balloon should be launched with enough time to track it in daylight – but just barely so.

3) Consider the cost of pilot balloon observations in the overall budget of an NMS.

Most NMS's rarely publicize their budgets – at least the details. If they did it would be easier for independent evaluation of whether the costs in operating their observational networks were optimal. Rarely are questions asked such as: What is the best way to spend the available funds? How can the best forecast be obtained for the available funds? What observations, or mix of observations, will have the greatest positive impact on the forecast (whether it be subjective or based on NWP output)? Often a radiosonde station will take a large potion of the observing budget. The cost of one GPS radiosonde observation may be approximately equal to the monthly salary of a staff member in many Meteorological Services in Africa. On the other hand, the cost of operating a pilot balloon station is very roughly 10% that of a radiosonde station. Is it better to operate 10 pilot balloon stations or one radiosonde station? Or one radiosonde observation every other day and 5 pibal observations daily? How important is the temperature and humidity information from the radiosonde compared with the wind information? All of these questions are rarely asked – and even more rarely answered.

4) Consider an adaptive sounding network.

All countries in West Africa have a distinct dry season. An NMS should consider whether the frequency of soundings should be the same all year or whether some sites might be operated seasonally. For example, during the dry season it might be less important to specify the moisture field and thus radiosonde observations might be reduced. Or, non-GPS radiosondes (roughly half the cost of GPS-sondes) could be used to obtain the thermodynamic data and winds obtained by tracking the radiosonde balloon with a theodolite. The savings could be used to fund additional pibal observations.

Seasonal operation might permit more sites to operate during the period of higher priority. However, it might be very difficult to determine what period is most important for forecasting. The rainy season might be the most obvious answer, but in some countries dust outbreaks may be more important, and in others heat waves. In any case it would be a useful exercise for any NMS to develop such a set of forecasting priorities. Unfortunately, what might make economic sense for country "A" might be bad for country "B" downstream of "A". A very complicated issue.

5) Improve observer and forecast staff training to ensure effective use of the observations

Most upper air observations made in developing countries are underutilized in their country of origin. Consider that a single radiosonde observation in Senegal or Mali might cost the equivalent of 2 weeks or more of a forecaster's salary. Yet in the weather forecasting office at Dakar or Bamako only a few minutes are likely spent to be spent looking at the observation, and perhaps the upper-air analysis carried out by a synoptic analyst takes another 10 minutes. Even if 1 hour is spent examining the observation in the context of helping to generate a weather forecast (a significant overestimate from our observations) this hour still amounts to only several dollars in a forecaster's or analyst's time. Roughly 100 times more is spent on the observation than on the effort to use the information. Of course, a number of countries may use the same observation for their own purposes, and the observation hopefully makes a positive impact in NWP products that later become available to the different countries. Nonetheless, more could be done at the point of origin with more sophisticated analysis procedures.

Part of the problem of under-utilization of information lies in the technical preparation of the meteorological staff in the forecast office. Without relatively advanced meteorological education this situation is unlikely to change. Thus, a major effort – certainly similar amounts to the observational cost of upper-air observations, should go into education and training activities. The observer staff should not be neglected – a motivated and knowledgeable observer is essential to the quality of a pilot balloon observation and regular feedback from the forecast office can serve to motivate observers or minimize the likelihood of observations being missed. It is fair to say that this feedback is generally lacking in most African meteological observing networks.

In fairness to the Meteorological Services in Africa, many are not as deficient as suggested above. And those that have serious problems are not alone. Many meteorological services in Latin America, which are more familiar to the author, have similar problems. To varying degrees all meteorological services can identify with the concerns described above.

An alternative perspective regarding future radiosonde and pilot balloon activities in Africa

The ASECNA[1] has overseen radiosonde observations in many former French colonies in Africa since their independence. This is a realistic recognition that each country, by itself, might not be able to maintain the meteorological networks needed for civil aviation purposes. This arrangement appears to have worked well, and the current radiosonde network is thus somewhat insulated from the economic difficulties of meteorological services in any of the particular countries.

Our original impression was that the problems with maintaining the sounding network in West Africa (both radiosonde and pilot balloon) was due primarily to the non-participation of the individual meteorological services in operating the sounding network. We believed that if each country was individually responsible for making the observations, and then used them for forecasting, they would individually see the value of the observations and help support the sounding network. ***It is not clear that this is the best strategy.***

Our experience in attempting to upgrade the sounding network in West Africa during NAMMA suggests that a radiosonde network for Africa should be operated by a organization that would be essentially *independent* of national meteorological services. Such an organization should have authority to establish and operate sounding sites based on the overall benefit to numerical weather prediction on a regional or global scale. Recommendations from an "oversight committee" – preferably composed of scientific personnel and others familiar with the value and impact of such observations for NWP (rather than representatives from individual meteorological services) would be used to

[1] Acronym for French-led agency, based in Dakar, that oversees aviation activities in former French colonies in Africa and Madagascar.

specify the blend of observations, specific sites, and frequency of operation of such stations. Input from National Meteorological Services would be sought, but should not determine the operational decisions.

While somewhat radical, our suggestion is similar to what ASECNA is already doing today in much of West Africa. It is similar to what the US National Weather Service does in the Caribbean Sea region during hurricane season, in supplementing the radiosonde observations of different countries. And it is also exactly what the NOAA-funded PACS-SONET project did for approximately 10 years in Latin America with pilot balloon observations (which motivated our African work).

It makes little sense to have some countries, because of their favorable economic status, establishing many stations while their neighbors cannot afford – or choose not to support, any sounding stations. And it will be *very difficult* to convince all countries in Africa to agree to financially support a radiosonde and pilot balloon network of uniform density for weather forecasting purposes. This would put a major burden on geographically large, but

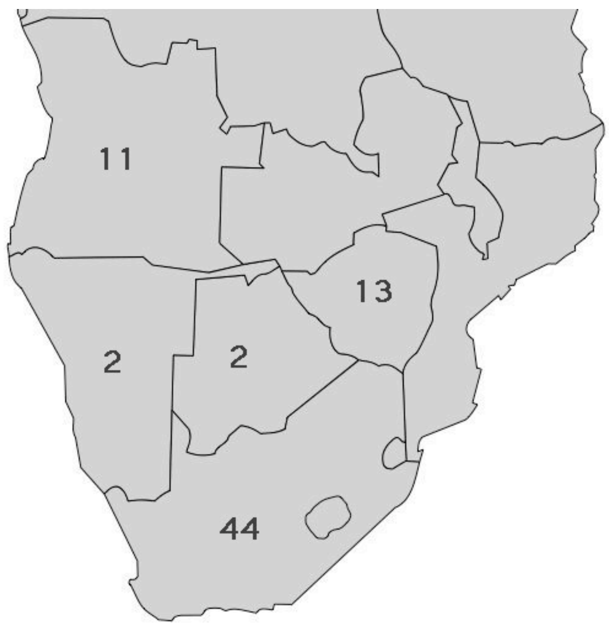

Fig 2. *Problem of obtaining a uniform network when a large-economy country (South Africa, 44 million people) is bordered by two geographically-large countries with small economies (Botswana, Namibia, 2 million people each). The small countries have an observing network "financial burden" many times larger than South Africa.*

relatively poor countries **(Fig. 2).** Very few countries will be willing to support radiosonde observations in a neighboring country that chooses not to make such observations (**Fig. 3**). Perhaps the most feasible solution to establishing an adequate and more nearly uniform network over the continent is to support the network with external funds, and to then run the network for the purposes of NWP and climate monitoring, and essentially independent of the host countries. In this sense the network would be little different than a multinational corporation. Today, satellite observations are provided to Africa by EUMETSAT and the US distributes satellite imagery and NWP output regionally and globally through the Internet. Thus, there is no essential reason that atmospheric sounding observations must be made by a National Meteorological Service, if they can be more effectively carried out by another organization.

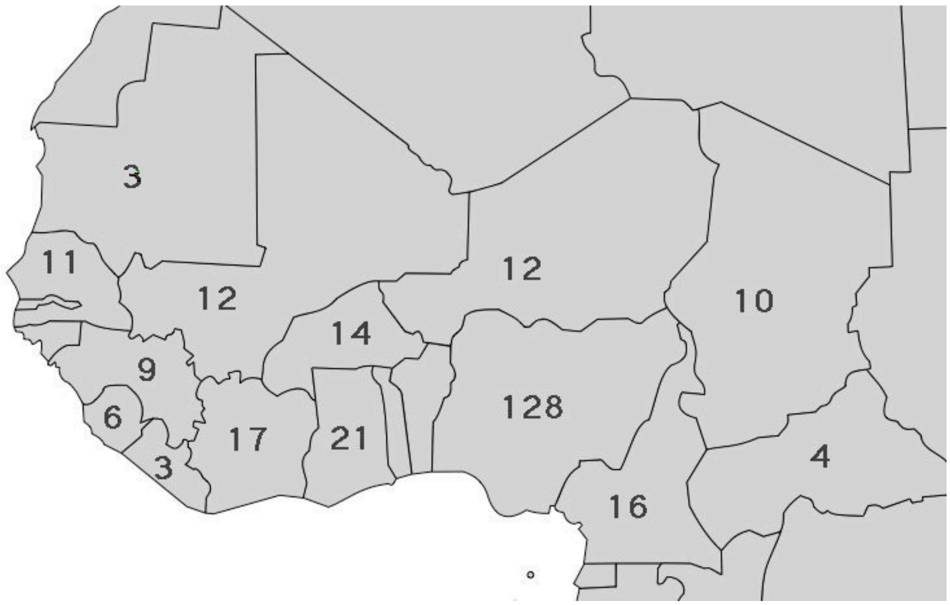

Fig. 3. *The problem of Nigeria and its neighbors. Nigeria can afford substantial meteorological network, but weather often originates from bordering and upstream countries – Niger, Chad, Cameroon and CAR – all quite small economies. Should it pay for observations in these countries? Likewise should Senegal pay for observations in Mali and Mauritania?*

Having an independent organization contracting individuals to make the soundings might well increase the likelihood of reliable observations. Observers could be paid a reasonable salary - proportional to the importance of their work (as opposed to the relatively low salaries of workers in many NMS's – whose salaries are controlled by overall governmental regulations that cannot easily be changed). Observers could also be rotated periodically from remote locations to more central locations, or perhaps even internationally. Such an organization would essentially be a meteorological service, but focused on making and distributing the upper-air observations. It would ensure a more uniform distribution of stations, and maximal impact on continental and global-scale numerical weather prediction.

The obvious question is how to fund such an independent organization. A simple formula is not proposed here. But it might not be dissimilar to any number of United Nations organizations. Absolutely key would that scientific, technical, and organizational oversight be provided, in large part, from meteorologists and technical support staff from developed countries with good meteorological infrastructure.

If establishing an organization to oversee and operate such a sounding network over much of Africa sounds too complicated, the alternative is to make mutual aid arrangements with many of the approximately 53 countries that comprise Africa and then to somehow enforce the operation of these stations. This appears to have been the historical approach for the past 40 years. Considering the historical trend of soundings over Africa during the past 40 years, it is clear that this procedure hasn't worked, and that an alternative strategy is in order.

The possible existence of such an internationally-funded organization to make radiosonde soundings does not mean that individual countries could not operate their own sounding networks. If the basic sounding network was perceived as not sufficiently dense for good limited area forecasts, an individual NMS could always fund its own stations. And the operation of surface stations for climate monitoring, the main function (in terms of personnel) of many Meteorological Services in Africa today would still remain under NMS direction.

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