REVIEW OF THE HISTORY AND FUTURE OF AUTOMATIC UPPER AIR SOUNDINGS

Aki Lilja, Jarmo Franssila, Petri Hautaniemi, Matti Lehmuskero

Vaisala Oyj, Vanha Nurmijärventie 21, FI-01670 Vantaa, Finland

ABSTRACT

Automatic sounding systems have been used for a quarter of a century for operational upper air observations. The first delivered systems have served for over 20 years and are operating the fourth type of radiosonde since their commissioning. Up to date, approximately 800.000 soundings have been performed with these systems, and the annual number of soundings will soon exceed 70.000. In this paper, we review the history of sounding automation, introduce one new automatic sounding system design, discuss its features and present some test results. The final part of the paper consists of considerations related to setting up, operating and maintaining automatic sounding systems in general.

INTRODUCTION

Continuous availability of high-quality upper air observation data is critical to both numerical weather prediction and human forecasting activities. In order to meet this need, a network of ca. 1300 upper air sounding stations is operated by the national meteorological institutes [1]. Today, the typical operational scheme is to perform two soundings per day, at 00 UTC and 12 UTC. In the future, it may be that the sounding times are adjusted to serve better the local forecasting needs, as numerical weather models can take in data outside these traditional synoptic time stamps.

Traditionally, soundings have been performed manually. The development and availability of radio navigation networks allowed to develop sounding systems that didn't need user intervention for the determination of the balloon trajectory and thus the wind profile [2]. This eventually led to the introduction of fully automatic sounding stations in the 1990's. Today, the global cumulative number of soundings performed by the fully automatic sounding stations is approximately 800.000.

HISTORY

Automatic systems for upper air soundings were introduced in the early 1990's [3]. The driver for the development of these systems was the expected need in the meteorological institutes to free personnel for other tasks than balloon filling and radiosonde launches. Globally available navigation systems, such as Omega and Loran networks removed the need for optical or radiofrequency based manual tracking of the balloons in the 1970's, making it possible to create sounding systems that are easy and straightforward to operate. Automation of the balloon filling and launch procedure was the next step in development.

Lilja A., Franssila J., Hautaniemi P., Lehmuskero M. *Review of the History and Future of Automatic Upper Air Soundings*.
TECO-2018, Amsterdam, the Netherlands. October 8th - 11th (2018).

Figure 1. *The first automatic sounding system, Vaisala AUTOSONDE, on display in 1992 WMO Technical Conference on Instruments and Methods of Observation in Vienna, Austria. The system was able to launch six RS80 radiosondes automatically.*

The first operational automatic sounding system, reporting synoptic messages regularly to the WMO Global Telecommunication System, was Swedish Meteorological and Hydrological Institute's Landvetter station that started automated operations in 1994. During the lifetime of this system, it has launched 4 different versions of radiosondes, as shown in Table 1. It's noteworthy that the system is still operational today, after 24 years of use. Such long operational lifecycles are possible with professional maintenance of the system and technical updates when new radiosonde models are taken into use.

Table 1. *History of radiosonde models used by the first fully automated synoptic sounding system. [4]*

Radiosonde type	Power on method	AUTOSONDE type designation	Years of operation
RS80-15N	Water activated battery	AS12	1994-2006
RS92-SGPW	Water activated battery	AS13	2006-2011
RS92-SGPA	Mechanical on-off switch, operated automatically	AS14	2011-2017
RS41-SG	Short-range wireless power-on circuit	AS15	2017-cont.

Figure 2. *The first automatic sounding system in synoptic use by a WMO member, SMHI's Landvetter upper air station. The system was installed and commissioned in 1994. The photograph was taken in April 1995.*

During 1990's, Vaisala was the only provider of automatic sounding systems and delivered 25 systems to 9 countries. In the following decade, radiosonde manufacturers from Japan, France, Korea and China presented their own automatic systems.

The annual number of installations was small during 2003-2008, but increased significantly after 2009. One possible reason for the increase is the world financial crisis 2007-2008, which seemed to cause significant pressure also to the public finances and eventually meteorological institutes' budgets. As a consequence, retiring sounding operators were not allowed to be replaced by new personnel headcount, and this lead to increased interest for automatic sounding systems. Another important motivation is to free workforce for other tasks in the meteorological institutes, such as infrastructure maintenance and forecasting. Typically, the site investment and maintenance costs of an automatic station are much lower than those for a manned sounding station, due to no need for buildings, balloon filling shelters, etc.

Currently, automatic sounding systems are in use in all continents, from Northern coastline of Alaska and Antarctic research stations to hot and dry Australian desert. Automatic systems have proven their operational capability in practically all climates.

The number of automatic systems has increased steadily during 2010's, and the large number of inquiries suggests that the automation of soundings is likely to continue in 2020's.

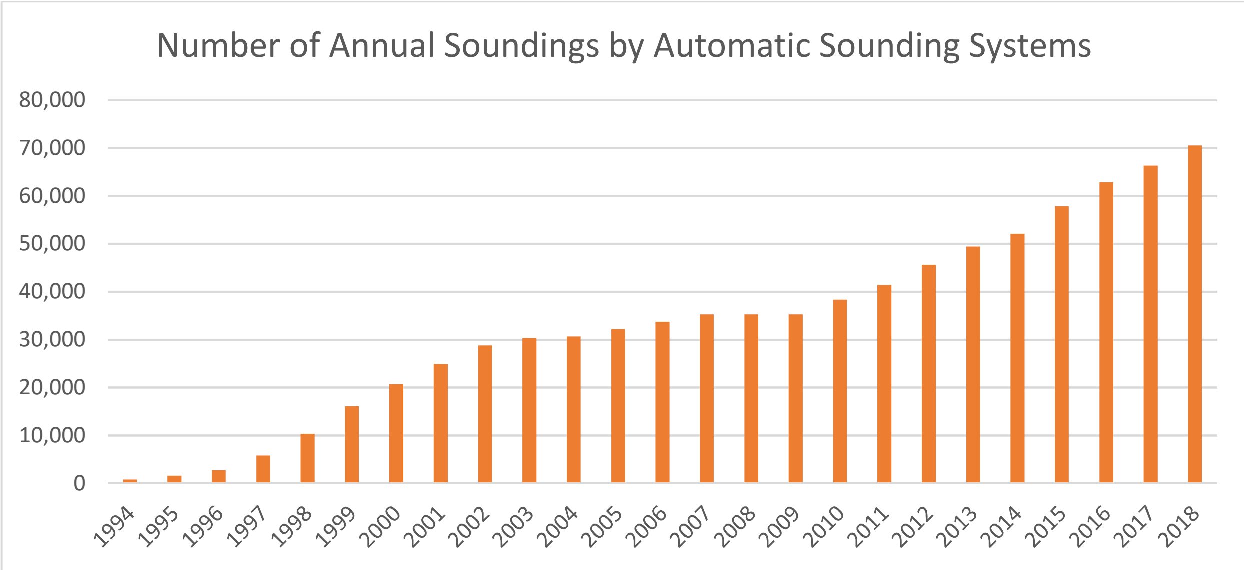

Chart 1. *The Number of annual soundings performed with automatic sounding systems 1994-2018. Test and demonstration systems are excluded. Vaisala estimates, based on GTS information and market information from public procurements.*

FUTURE

The newest design of an automatic sounding system is the new Vaisala AUTOSONDE AS41, which is designed for one-month automation of a typical sounding station. The system is able to launch 60 RS41 radiosondes fully automatically, without any user intervention. In practice, this kind of system needs to be visited once every four weeks, for half a working day at a time, in order to maintain twice-a-day synoptic sounding operation.

Figure 3. *The newest design of an automatic sounding system, the new Vaisala AUTOSONDE AS41. Pictures are from a test site in the coast of the Gulf of Finland.*

The new AS41 system has been tested in two test sites that have been purposedly selected from locations providing windy and harsh conditions: coast of the Gulf of Finland and western coast of Norway in Vestkapp. More than 1000 soundings have been performed in these locations to compare and test different design details that relate to reliablity of the system in general as well as performance in high wind conditions in particular.

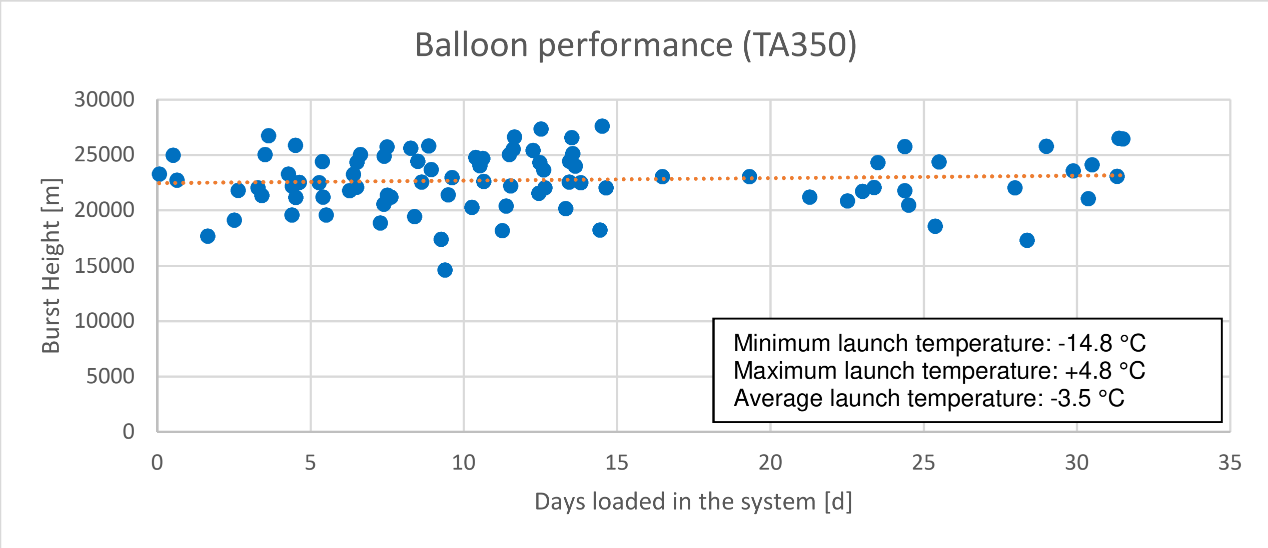

Chart 2. *Example test result: AS41 soundings; balloon burst heights with TA350 balloon type. Southern coast of Finland, January 1st – March 8th, 2018.*

The Vestkapp test site was founded and operated in cooperation with Norwegian Meteorological Institute, who used data from the successful test soundings in the same way as data from their other, operational AUTOSONDE systems. No errors or failures were found in using the data [5].

In addition to extended visit interval, an important requirement has been to create a system that fully takes into account the updated safety standards related to the use of hydrogen and the machine safety [6,7]. The new AS41 system maintains the original AUTOSONDE's design principle in that the balloon filling gas line never enters the container where the operator works, thus completely avoiding the risk of injury due to hydrogen explosion or helium suffocation. Occupational health and safety requires that there is a planned and safe route to access all elements that might require maintenance or repair during the lifecycle of the system. This is implemented by means of a fixed walkway designed as part of the system.

Figure 4. *Left: Example of an RS41 launch with the new Vaisala AUTOSONDE AS41 in high wind condition in Vestkapp, Norway (wind speed 20.6 m/s at launch). Right: Sounding data profile from the same flight.*

The radiosonde data produced by an automatic system should be of same quality to that of a manual system. In the AS41 system, this is achieved by receiving and processing the RS41 radiosonde data with exactly the same system (MW41) that is used in the manual stations. The radiosonde's humidity sensor is reconditioned and ground check performed during the automated launch preparation in order to ensure same performance as in manual stations.

In the case of an automated sounding network, it is desirable to have a very clear and concentrated situational view to the status of the network. In the case of Vaisala, this is possible by using the Vaisala Observation Network Manager NM10 system. It allows an instant view to the observation network's status, and can be connected to both AS41 and AS15 AUTOSONDE stations as well as to manual sounding stations. Observation network management is not, however, limited to that of sounding stations only. For this purpose, the NM10 system supports also monitoring and remote management of automatic weather stations, airport observing systems, weather radars, and lightning detection networks [8,9].

Eventually, as years and decades pass, automatic sounding systems need to be replaced or decommissioned. However, the new automatic system can make use of the existing infrastructure at the site, such as electricity, telecommunications, gas logistics, as well as in most cases the foundation structures of the previous automatic systems.

AUTOMATIC SOUNDING STATIONS – BEST PRACTICES

Setting up a new, automatic sounding station includes the following main phases:

- Sounding network operational requirements
- Site selection and infrastructure considerations
- Loading operations plan
- Maintenance plan

In this section, main considerations related to these phases are discussed, based on authors' experience in the field.

Sounding network operational requirements

In addition to accuracy requirements for temperature, humidity and wind, soundings network's operational performance is assessed based on data availability, latency, and burst height. One example of sounding network operational requirements are the EUCOS requirements [10]:

Table 2. *EUCOS requirements for upper air soundings.*

Requirement	Target
Data availability	95%
Achieving 100 hPa	97%
Achieving 50 hPa	95%
Timeliness HH+100 min	95%
Timeliness HH+50 min	75%

In addition, the extremes of the local climate need to be taken into account for the survivability of the system. Automatic systems are able to release balloons up to the storm wind speeds, which is often also the practical limit for successful manual launches. Regarding temperature the local extremes need to be considered. In case the operational temperature limits are exceeded, the system should return to fully operational status without site visit or user intervention.

Table 3. Example requirements related to environmental conditions for an automatic sounding station.

Requirement	Example specification (AS41)
Operating temperature range	-40 °C to +53 °C
Operating humidity range	0 to 100 %rh, condensing
Operating wind (max)	25 m/s
Surviving wind (max)	60 m/s

The most important individual part of a high-quality automatic sounding network is the radiosonde, which takes the measurements and provides the atmospheric data. The radiosonde must meet the needs for the reliability and measurement accuracy in order to provide the required data in a timely manner, with the required availability. In the case of Vaisala AUTOSONDE AS41, the radiosonde used is Vaisala Radiosonde RS41 [11,12,13].

There is an increased interest in adaptive soundings, which are initiated based on the forecasters' need on a situational basis. Automatic stations allow straightforward initiation of such soundings with a remote data connection. There is no need to engage any personnel at the sounding station, and the response time from the decision to the balloon launch can be easily reduced to less than 30 minutes.

Site selection and infrastructure

For installation and logistics purposes, the sounding station site needs to be accessible with a truck. A suitable site for the automatic soundings station allows for supply of electricity and telecommunications with a reasonable cost. Although some stations are using ISDN (64 kbps), a typical telecommunications connection consists of a broadband Internet connection (such as ADSL 2 Mbps) with a Virtual Private Network (VPN) tunnelling arrangement. This way, the automatic sounding system is connected to the host organization's LAN network in a cost effective manner. Backup Internet connection can be arranged with e.g. commercial, off-the-shelf 4g or similar wireless connectivity.

Figure 5. *Installation of an automatic sounding station with the help of a truck equipped with a crane. Part of the balloon launch equipment has been installed at site, before lifting the container.*

Electricity and telecommunications infrastructure are quite common requirements for any automatic weather observation equipment. An additional speciality in the case of upper air soundings is the need for the lifting gas for the balloons. Hydrogen would be preferred over helium due to cost reasons. The possibilities are:

- truck supply of helium bottle racks for the station
- truck supply of hydrogen bottle racks for the station
- hydrogen generator

The bottle rack solutions don't require any additional infrastructure other than the road access with a truck. Typically, the gas supply companies visit the site every six weeks and replace one of the gas bottle racks with a new one. Automatic gas rack selection changes the active rack when one of them becomes empty. It's possible to agree with the gas supply company that they perform the replacement without host organization's presence, given that they have been granted access to the premises for that purpose.

Hydrogen generators create hydrogen from water using electrolysis, proton exchange membrane (PEM) or other similar methods. These systems require electricity for their operation and preferably also telecommunications connection for the remote monitoring of those systems. An additional need is that of purified water for the system.

Loading operations and planning

Automatic sounding systems need to be resupplied with radiosondes and balloons. The required visit interval depends on the system's automation capacity, i.e., maximum number of automatic soundings between site visits, and the number soundings per day. The length of the visit on site and the travel costs in terms of personnel hours as well as car usage (or similar) need to be considered. With the newest systems, it suffices to send one person to the site for the period of half a working day, once every four weeks.

Some meteorological institutes have chosen to contract a person or a company nearby the station to perform the radiosonde and balloon loading to the station, in order to minimize the associated travel costs.

One consideration is the location of the radiosonde and balloon inventory for an automatic station. One practical possibility is to store some months' worth of supplies at the station itself, thereby removing the need to transport the goods during loading visits.

Maintenance

In broad terms, maintenance can be divided between planned, preventive maintenance and reactive, corrective maintenance.

The main items in the planned maintenance are annual maintenance visits, which include changing filters and other consumable parts of the system as well as thorough check of the system. During the monthly visits, basic cleaning, such as checking and cleaning for accumulation of snow, ice, dust or other dirt in the system can be performed.

Figure 6. *Corrective maintenance in progress at an automatic sounding station.*

No matter how reliable a system has been built to be, there will be also corrective maintenance needs during the lifecycle of a technical system. Suitable level of maintenance expertise can be built into the host organization, or alternatively the original supplier relied on for the repair operations. It's also possible to agree about a service contract that includes a number of corrective maintenance visits to the system as needed.

Another aspect of the corrective maintenance is the availability of spare parts. These are typically classified into three categories:

- spare parts stored at each site
- spare parts stored at a central depot location of the user organization
- spare parts ordered from the manufacturer as needed

Automatic sounding system providers are able to recommend sets of spare parts for each site and for the customer's central spare part depot. Some rare and/or surprising needs can be fulfilled by relying on the manufacturer's spare part delivery – especially in case those parts are not mandatory for the operation of the flights.

CONCLUSION

Automatic sounding systems have become mainstream part of national meteorological observation infrastructures. They have proven their usefulness in practically all climates, and are in operation in all continents. The number of installed systems and the annual number of soundings have increased steadily during 2010's, and these trends seem to continue in 2020's. The newest systems allow the user organizations to reduce both the number and length of visits to the automated sounding locations, thus helping them reduce costs, while maintaining high quality and reliable data provision for their forecasting operations.

REFERENCES

[1] Barrell S., Riishojgaard L. P., Dibbern J. *The Global Observing System*. In WMO Bulletin Vol 62 (1) - 2013.

[2] McBean G. A., Phillips D. J. *Comparison of Radar and Navaid Windfinding Systems*. Journal of Atmospheric and Oceanic Technology Vol. 3, pp 191-196 (March 1986).

[3] Kostamo P. *Advanced automation for upper-air stations*. WMO Instruments and Observing Methods Report No. 49 (TECO-92), pp. 104-107.

[4] Pia Bladh, Swedish Meteorological and Hydrological Institute, personal communication, and Vaisala archives.

[5] Terje Borge and Baard Meldal-Johnsen, The Norwegian Meteorological Institute, personal communication.

[6] ATEX Directive 2014/34/EU *Equipment for potentially explosive atmospheres*.

[7] Machinery Directive 2006/42/EC.

[8] Ojanperä O. *National Weather Observation Network at Your Fingertips: Software Solution for Monitoring, Management and Control*. Presentation given in Meteorological Technology World Expo 2015, Brussels, Belgium. October 14th (2015). Handout of the presentation available upon request.

[9] Ojanperä O., Shao J., Vuorio I., Brocklehurst H., Yin Jiang, Hongbo Zhuang, Ruiquan Gao. *Automated Statistical Model-based Spatial Data Quality Control*. TECO-2014, St. Petersburg, Russian Federation. July 7th-9th (2014). P1(40).

[10] Klink S., Hafner S., Kleinert T. *Observations Programme Management - EUCOS Quality Monitoring*. 1st Monitoring Workshop, Reading, United Kingdom. July 3rd-4th (2013).

[11] Survo P., Turunen M., Salo T., Jauhiainen H. *Vaisala Radiosonde RS41 – New sensing technologies for operational upper air measurements*. TECO-2014, St. Petersburg, Russian Federation. July 7th-9th (2014). 1(4).

[12] Survo P., Lehtinen R., Kauranen J. *SI traceability of Vaisala Radiosonde RS41 sounding data – calibration and uncertainty analysis*. TECO-2014, St. Petersburg, Russian Federation. July 7th-9th (2014). P2(7).

[13] Jauhiainen H., Survo P., Lehtinen R., Lentonen J. *Radiosonde RS41 and RS92 key differences and comparison test results in different locations and climates*. TECO-2014, St. Petersburg, Russian Federation. July 7th-9th (2014). P3(16).