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WIND PROFILERS - A STATUS REPORT
(JANUARY 1989)

prepared for the Rapporteur for Profilers to the Working Group on the Global Observing System (GOS) of the Commission for Basic System (CBS) of WMO

by

Hans Richner, Zurich

October 1989

Wind Profilers 551.508.59

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Abstract

After a short description of the operating principles of wind profilers, the characteristics of these instruments are presented for three different operating frequencies. The main part of the report deals with system-related properties which must be considered when planing a continent-wide network, and with the most important open problems. Observing techniques for temperature which could complement wind profilers in the future are mentioned. After a summary of the worldwide activities in wind profiling, an estimation of the operating costs, and recommendations for further literature, some important conclusions and recommendations conclude the report.

Zusammenfassung

Nach einer kurzen Beschreibung des Funktionsprinzips von Windprofilern werden die Charakteristiken dieser Geräte für drei verschiedene Betriebsfrequenzen geschildert. Der Hauptteil des Berichtes diskutiert systembezogene Eigenschaften, die vor allem bei der Planung eines kontinentalen Netzes zu beachten sind, und die wichtigsten noch offenen Fragen. Messsysteme zur Erfassung der Temperatur, die Windprofiler dereinst ergänzen könnten, werden kurz erwähnt. Nach einer Darstellung der derzeitigen weltweiten Aktivitäten auf dem Gebiet der Windprofiler, einer Abschätzung der Betriebskosten und Hinweisen auf weitere Literatur, werden abschliessend die wichtigsten Folgerungen und Empfehlungen formuliert.

Résumé

Après une courte description du principe de fonctionnement du profileur de vent, les caractéristiques de cet instrument sont présentées pour trois fréquences opérationnelles. La partie principale de ce rapport discute des propriétés de ce système qui doivent être considérées dans la planification d'un réseau continental et, d'autre part, des plus importantes questions encore ouvertes. Les systèmes pour la détermination de profils de température qui pourraient compléter les profileurs de vent dans le futur sont aussi mentionnés. Après un résumé des activités relatives aux profileurs de vent actuellement en cours dans le monde, une estimation des coûts opérationnels et des indications bibliographiques, le rapport se termine par quelques importantes conclusions et recommandations.

Riassunto

Dopo una breve descrizione dei principi di funzionamento dei Wind Profiler, vengono presentate le caratteristiche di questi strumenti per tre frequenze operazionali. La parte principale del presente rapporto si occupa delle proprietà inerenti il sistema, che devono essere considerate nella pianificazione di una rete a scala continentale, focalizzando pure i problemi che restano tuttora aperti. Vengono accennate pure le tecniche d'osservazione della temperatura che possono essere introdotte a complemento dei wind profiler. Vengono inclusi: in riassunto sulle attività a livello mondiale per quel che riguarda questa tecnica, una stima dei costi di gestione di un simile impianto, dei suggerimenti sulla letteratura esistente. Il rapporto termina con alcune conclusioni importanti e delle raccomandazioni.

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1. Introduction

Wind profilers are vertically oriented pulsed doppler radars working in the range from 30 to 1200 MHz. By analyzing the signals scattered back by turbulent elements in the atmosphere (at higher frequencies also by hydrometeors), the velocity of the air along the beam can be determined. By deflecting the beam slightly (typically 15° from the vertical) first in the east-west, then in the north-south direction, the horizontal components of the air motion can also be obtained, consequently, wind vectors can be measured three-dimensionally. The atmosphere is sufficiently turbulent to allow measurements to be made routinely to an altitude of around 15 km with an economically sized radar.

Thus, wind profilers are remote sensing systems which - depending on their operation frequency - can produce wind data for heights from a few tens of meters above ground to up to several tens of kilometers. The time resolution of these systems is very high; it takes typically ten minutes to produce one complete profile.

2. The basic types of wind profilers

Although a variety of frequencies are being used for wind profiling, most instruments work in one of three frequency bands. These are located near 50, 400 and 1000 Mhz. The selection of frequency determines the performance characteristics and the antenna size to a large extent; Table 1 shows some details.

3. Profilers in operation

At present, about 40 wind profilers are worldwide in operation. Most of these systems operate in a research mode as independent single stations. It seems that only two wind profiler networks have been or are being operated over an extended period of time; both are in the United States: The Colorado Network and the Pennsylvania State University Network.

Until November 1988, the Colorado Network consisted of five stations operating on frequencies of 50 MHz (three stations), 405 MHz (one station), and 915 MHz (one station). The 50 MHz stations are separated by about 180 km. The Pennsylvania State University Network consist of a triangle formed by three 50 MHz profilers separated about 140 km and a mobile 404 MHz system. For a rather limited time, a small network was established in France in the framework of a research program related to fronts. This system included the French bifrequency instrument which operates on 961 and 45 MHz simultaneously.

Table 1: Typical characteristics of the different wind profiling system families.

shortest pulse duration:	1 microsec
pulse shape:	optimized for minimum bandwidth
antenna gain:	typ. 30 dB
antenna beamwidth:	typ. 5°
sidelobe attenuation:	typ. 20 dB at 0...30°
	typ. 40 dB at > 60°

	50 MHz	400 MHz	1000 MHz
range	3 - 30 km	500m-trop.	0.1 - 3 km
height resol.	150 m	150 m	75 m
antenna type	yagi array or co-co	yagi array or co-co	dish
antenna size	100m x 100m	10m x 10m	3m x 3m
peak power	500-1000 kW	15-40 kW	5 kW
duty cycle	4 %	4 %	4 %
mean power	20-40 kW	0.6-1.6 kW	0.2 kW
bandwidth	1 MHz	1 MHz	2 MHz
spacing	300 km	100 km	(local)

As mentioned, wind profiling is still in a research phase. However, at Ponape (Christmas Island) a 50 MHz system is operated in what might be called a semi-operational mode. Its wind data are included both in the analyses for the NMC and the ECMWF models. Two other 50 MHz systems - one operated by NASA at Kennedy Space Flight Center, the other operated by the U.S. Air Force at White Sands Missile Range - were installed primarily for furnishing wind data to be used operationally.

In the technology of wind profilers, there is nothing basically new. Much of the experience gathered in radar meteorology could be transferred to wind profilers. However, the most important factor which made wind profilers so interesting as an operational tool are the vast possibilities in modern digital signal processing. It is in this area where much progress was made in the past years, but there is undoubtedly still much room for further improvements. Based on the experience gathered in the operation of the existing experimental systems, significant improvements in the signal processing are likely to be made. A second area where further progress is still possible is in the design of the antenna systems. In particular, it seems that the phased array antennas can be improved with respect to sidelobe attenuation and beamwidth.

Despite occasional difficulties with some of the systems, it has been convincingly demonstrated that the two networks as well as single-site systems are capable to reliably observe the vertical wind profile with high time and space resolution. These data allow insight into the dynamic structure of the atmosphere which are unprecedented in quality and resolution.

4. Factors affecting the definition of a network

The definition of an optimal profiler network depends, of course, very much on the needs of tomorrow's operational activities of the weather services. Nevertheless, there are indications as to what requirements will have to be fulfilled which - when combined with the properties of the instruments - give an idea of a possible network configuration.

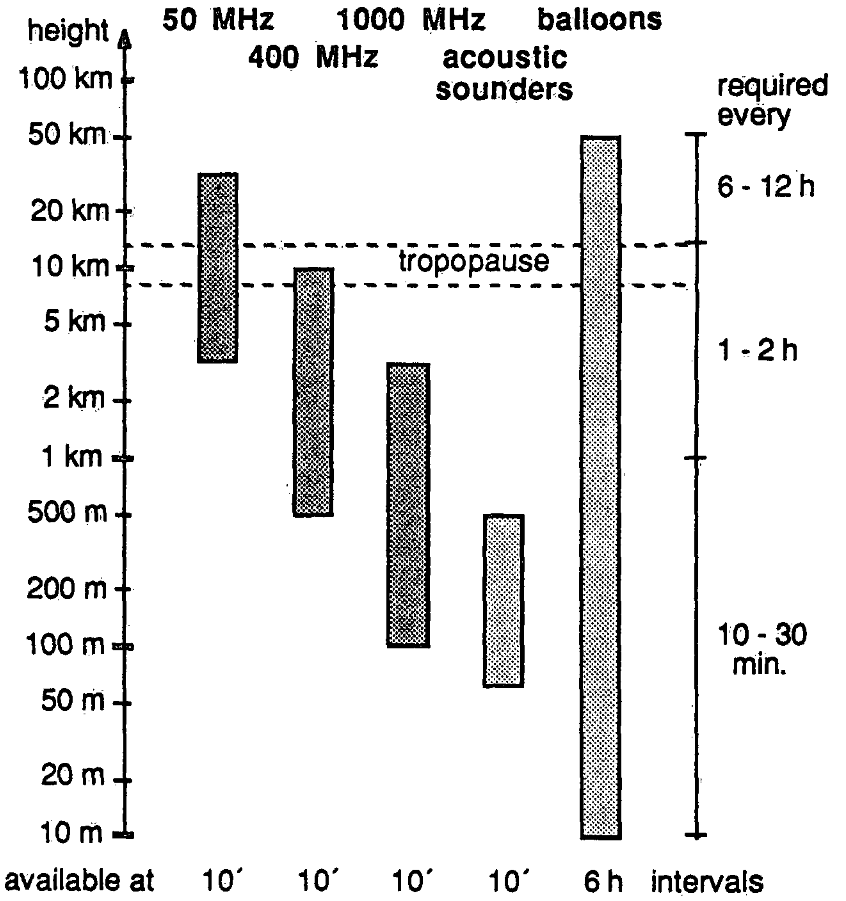

Figure 7: Height ranges of different wind profiling systems. See text for explanations of the labelling.

Fig. 1 depicts typical height ranges of the wind profiler systems in the three frequency ranges mentioned. For comparison, also the height ranges for acoustic sounders and for balloons are indicated. The time intervals given on the right side of the figure represent typical values between which updates of wind profiles are required for operational forecasting purposes on the respective scales. The time indications given at the bottom show typical intervals at which profiles from the different system are available.

Since the technology for determining temperature and humidity profiles by remote sounding is far less developed than that for observing wind profiles, it is safe to assume that radiosondes will have to be used also in the foreseeable future. Consequently, for general, operational meteorological purposes there is presently no urgent need for 50 MHz wind profiling systems observing stratospheric winds. The radiosondes which will still have to be launched for temperature and humidity measurements can report these winds at the time intervals required with little additional costs. Nevertheless, 50 MHz system should be further developed so they will be ready for deployment as soon as improved remote sensing techniques for temperature and humidity will be available, i.e., as soon as radiosoundings can be replaced by remote observations.

In the troposphere and around the tropopause, winds are required at much shorter intervals than in the stratosphere because the persistence of the dynamic situation is much smaller than in the stratosphere. Typical intervals for the initialization for mesoscale models are 1 to 2 hours. Balloon-based wind observations at such high frequencies are not possible, therefore, 400 MHz wind profilers seem to be a suitable tool for mesoscale forecasting; synoptic scale analysis certainly can also benefit from more frequent observations of the wind field in this height range. The capabilities of 400 MHz systems in terms of time resolution actually exceed the present requirements of mesoscale applications except for diagnostic purposes in special applications such as monitoring wind fields for, e.g., aviation purposes.

For observations in the boundary layer finally, 1000 MHz profilers are ideal. They offer a height range well suitable for determining wind profiles for aviation and pollution control purposes combined with an excellent time resolution. Apart from the very expensive scanning doppler radars (which, up until now, are not being used operationally), they seem to be a promising low-level wind shear detection system although it must be realized that the horizontal resolution of single instruments is virtually zero, i.e., it is only the wind field directly above the profiler which can be observed.

A future wind profiler network could, therefore, consist of a basic array of 400 MHz systems. Should the use of radiosondes at some later time be discontinued, this basic network could be upgraded by 50 MHz profilers, however, since the spatial variability of winds in the stratosphere is much lower than in the troposphere, the spacing between the 50 MHz instruments could be a multiple of the spacing of the 400 MHz array. (Due to its size, siting a 50 MHz antenna will become a serious problem in densely populated regions.) In areas such as airports, heavily polluted urban agglomerations etc, the basic 400 MHz network could be complemented or made denser by short-range 1000 MHz systems. It seems very unlikely that continuous coverage of, say, a whole country by 1000 MHz systems will be feasible in the foreseeable future.

However, neither this kind of theoretical reasoning nor the operation of single wind profilers will ever be able to demonstrate the real capabilities of wind profiling networks. There is an absolute necessity for full scale demonstration networks because only these can produce the data needed to investigate the effects of high density wind data in numerical models.

In parallel, modelers should be encouraged to carry out observing system simulation experiments (OSSEs) in order to learn more about the reaction of particular models to increased data input. Some OSSEs published so far demonstrate clearly that decreasing the grid size (and, consequently, increasing the number of grid points) is likely to result in a much poorer performance of the model. There is some danger that such results could lead to the quick conclusion that additional wind data will not be able to improve the forecasting skills.

5. Other profiling systems

In the Federal Republic of Germany, wind profiling systems have been developed which operate around 1000 MHz in a FM-CW mode (instead of pulsed mode as used in the great majority of other instruments). These low power systems have also been combined with acoustic sounders for determining wind profiles practically from the ground on upwards. Such a system was recently operated on a research vessel in the Arctic.

In France, profiling systems are being tested which are basically a combination of a 50 and a 1000 MHz instrument. From the characteristics of the respective systems it is clear that such a combination should be able to cover a very large height range.

It seems that the RASS (radio acoustic sounding system) has come to new life in connection with the wind profilers. In these systems, the temperature profile is derived from the velocity of sound. This velocity is obtained by following a "wave packet" of sound (emitted from a classical echo sounder or sodar) with an electromagnetic wave (produced by a profiling radar). Excellent agreement between temperature profiles measured by radiosondes and RASS have been reported from the U.S. up to about 5 km. It is obvious that this new success of RASS is mainly due to the fact that nowadays much more sophisticated procedures for determining the doppler shift are available; RASS systems of the seventies employed only very simple techniques requiring rather high signal-to-noise ratios in the back-scattered signals.

6. Outstanding problems

One of the most serious problems connected presently with wind profiling is not a technical or scientific, but an administrative issue, namely the *frequency allocation*. Frequency spectrum is limited and overcrowded, and it is understandable that frequency allocating authorities are not at all happy with requests for the operation of high powered transmitters which, in addition, require large bandwidth because of their pulsed operation. It seems to be desirable to find an international solution by which one common frequency in each of the three bands mentioned is allocated in all countries. By doing this, a minimum of the spectrum will be used, interference problems across national borders will be minimized, and the costs of the instruments (which can be standardized for one frequency) can be kept reasonable.

There are indications that television broadcasting in the band 47 to 68 MHz will be discontinued in Europe. In fact, in the United Kingdom, broadcasts in this range have ceased already. In the Federal Republic of Germany, a 50 MHz profiler is being operated successfully (now for nearly ten years) in the gap between the sound and color carrier of an active (!) television channel. No harmful interference was observed which is attributed to the fact that the profiler radiates primary vertically while television transmitters radiate horizontally. As favorable as this situation might seem, the frequency allocating authorities have designed plans for the future use of this part of the spectrum which do not include wind profilers. Quite obviously, they are or were not aware of the needs of the wind profiling community.

The band 401 to 406 MHz is already allocated for meteorological aids, consequently, many authorities feel that wind profilers should be operated in this region. However, as investigations in the United States have demonstrated, the probability of interference between wind profilers and certain satellite systems in this frequency range is high. The ARGOS service relays environmental data at 401.65 MHz, the GOES data collection system operates in the range 401.7 to 402.0 MHz and SARSAT (Search and Rescue Satellite Aided Tracking) communicates at 406.05 MHz. However, harmful interference is likely to occur only when the satellite is within a defined angle from the profiler zenith, consequently, in the U.S. it has been decided to temporarily cease transmissions under such circumstances. Thus, wind profilers and satellite systems work in a sort of time sharing mode. Some interference has also to be expected with the radiosondes which are operated on a regular basis by most national weather services, experiments related to this problem are currently under way in Finland and Switzerland.

Alternatively, without significant loss of height range, it would be possible to operate the 400 MHz family of profilers in a television channel between 470 and 500 MHz; much in the same way as a 50 MHz research profiler can be operated in a television channel. Such allocations were, e.g., proposed by the Finnish authorities.

1000 MHz wind profilers represent the most cost-effective tool for a continuous monitoring of the wind profile in the boundary layer. Also, they have a high capability for monitoring potentially hazardous winds in airport areas. The frequency range 960 to 1215 MHz is reserved on a world-wide basis for aeronautical radionavigation including "any directly associated ground-based facilities" (Radio Regulations, Art. 8, Sect. IV, No. 709). It seems justified and logical that part of this frequency range should be made available for profiler operation.

In the U.S., a licence for the operation of the 400 MHz demonstration network on a common frequency has been issued by the FCC, other profilers are licensed individually. In Europe, the operation of experimental systems has only been allowed (often after tedious negotiations) on individual and non-interference bases. In a concerted action, most of the countries participating in the COST74 project have filed a request with their national frequency allocating authority (generally the PTT) for spectrum in all the three bands mentioned. At the same time, ICAO was approached because only this organization can decide on the use of the 1000 MHz band (just below the band assigned for aviation purposes, practically all frequencies are occupied by cellular telephone). COST74 also asked CIMO of WMO to support its requests by making use of the existing connections between WMO and the International Telecommunication Union (ITU). A similar support was asked from the Secretary General of WMO by a number of national Permanent Representatives. As the European Commission EC establishes closer and more efficient links to international organizations, it is hoped that the issue can be brought directly to the attention of ITU and CEPT (Conférence Européenne des Administrations des Postes et Télécommunications, in Europe probably the most important organization for this issue). As a result of the numerous interventions on national levels, the PTTs have put this problem on the agenda of CEPT already, and discussions have taken place.

It is obvious that only a strong international coordination of the requests for frequency allocation will be successful. While such a coordination among continents might not be absolutely necessary for the 50 and 400 MHz systems, for the 1000 MHz systems only a truly global solution is realistic due to the global assignment and use of spectrum assigned for aviation purposes.

7. Major projects related to wind profiling

In the Central U.S., NOAA is just beginning to establish an operational wind profiler network consisting of 30 stations spaced by about 400 km. The prototype is now undergoing acceptance tests; it is planned that the network will be fully operational in about three years. By complementing existing observation platforms, the network is to evaluate and assess operational applications such as sub-synoptic numerical weather prediction, local-scale analysis and forecasting schemes, and integration with other weather observing systems.

While in the U.S. the establishing of a demonstration network by NOAA is well under way, the situation in Europe is complicated by the fact that a cooperation among the many countries and its authorities must be realized before a network of any appreciable size can be erected. In 1987, France initiated the COST 74 project related to wind profiling and bearing the title "Implementation of an European research project on the utilization of UHF/VHF radar wind profiler networks for improving weather forecasting in Europe". (COST projects are cooperate research projects within the European Community which are open to all European nations.) Up until now, Belgium, the Federal Republic of Germany, Finland, France, Italy, the Netherlands, Portugal, Spain, Switzerland, and the United Kingdom participate officially and are represented in the Management Committee.

The objectives of the current activities of COST 74 can be grouped into technical and application-related aspects. The former include the problem of frequency allocation, the use of complementary systems, intercomparison techniques, and co-operation with industries. The latter deal with the use of profiler data in numerical models, the use of profilers other than in analysis and forecasting models, recommendations regarding formats for transmitting profiler data, and finally, recommendations for an European network.

Outside the U.S. and Europe, research projects related to wind profiling are under way mainly in Australia, Japan, Peru, Puerto Rico, and Taiwan. From here as well as from the other places where wind profilers are operated, significant contributions to the technology and use of wind profilers in operational and research applications have been and are being made. So far, no plans for establishing demonstration networks in any of theses countries were announced.

8. Cost effectiveness of wind profilers

At this stage it is certainly too early to make make a sound statement on the cost effectiveness of wind profilers. Nevertheless, within COST74 an evaluation which is still under way indicates that the costs for four wind profiles per day (as now obtained from radiosondes) should be just about half of the present costs. In these present costs, only the expenses were counted which are in addition to the expenses for obtaining pressure, temperature, and humidity profiles. Since the operational costs of a wind profiler are low compared to radiosounding stations, all the additional wind profiles (one about every ten minutes) would be virtually free!

Some skepticism towards these first conclusions might be appropriate, but it is unlikely that the costs of wind profiles from profiling radars will exceed those for profiles from radiosondes. In this connection it must be emphasized that there is no intention to actually replace radiosondes by wind profilers in the near future; this direct comparison of the costs was made for demonstration purposes only.

9. Literature

There is already a vast number of papers dealing with technical and operational aspects of wind profilers. Recently two conferences have taken place for which Extended Abstract Volumes were printed: In May/June 1988, AMS, NCAR, and NOAA organized a symposium "Lower Tropospheric Profiling: Needs and Technology" to critically review and evaluate scientific need, and assess current and projected technologies (copies of the Extended Abstracts are available from NCAR, P.O. Box 3000, Boulder, CO 80307, U.S.A.). In March 1989, the COST74 Management Committee organized the "First European Wind Profiler Workshop" in Versailles which dealt with the various problems associated with the implementation of a network for operational purposes (copies of the Extended Abstracts are available from Météorolgie Nationale, SETIM, B.P. 202, F-78195 Trappes Cedex, France).

For both conferences, full reviewed papers were or will be published. A special issue of the *Journal of Atmospheric and Oceanic Technology* was devoted to papers given at the Symposium on Lower Tropospheric Profiling. Full papers given at the First European Wind Profiler Workshop, will be published in a special issue of *Meteorologische Rundschau* in late 1989.

NOAA Experimental Research Laboratories produce a publication called "Profiler Forum" which briefly informs on current activities and discusses new literature on the subject. "Profiler Forum" is an occasional bulletin originating in the Profiler Program of NOAA. Inquiries should be sent to Lorrain Kaimal, Profiler Program, R/E/FS3, 325 Broadway, Boulder, CO 80303. From this address, also a complete bibliography related to wind profiling is available.

In the U.S., the National Weather Service, Office of Meteorology, has published an "Assessment Plan for the Use of Wind Profiler Technology in NWS Operations" discussing primarily meteorological and systems-engineering points of view. An internal report giving a detailed account on "Current U.S. Profiling Efforts" by A. Kaplan can be obtained from NOAA National Weather Service, Silver Spring, Md. 20910, U.S.A.

The COST74 Management Committee has produced a number of documents related to specific questions such as frequency allocation, operation costs etc. Copies of these documents can be obtained from the national representative of COST74 or directly from Dr. H. Hasenjaeger, Secretary COST74, CCR-JRC, Physics Division, I-21020 Ispra, Italy.

10. Conclusions and recommendations

Based on the experienced gathered so far, the following recommendations to WMO as a internationally active, coordinating institution can be made:

1. WMO must actively support the requests of its member countries for frequency allocations using all its possibilities. It is evident that frequency allocation is by far the most significant single problem in the entire context of wind profiling! It should be remembered that the Secretary General of WMO can contact directly the International Telecommunication Union (ITU) and explain the needs for frequency spectrum by the meteorological community. The cooperation between these two international agencies has been regulated and published as WMO No. 60, "Agreements and working arrangements with other international organizations" (World Meteorological Organization, Geneva, 1983, p. 49 to 52).

2. An international data exchange between profiler sites will become necessary on different levels of the data processing (raw doppler and associated data along profiler beams, maximum resolution wind data, significant wind data, etc.). In order to arrive at common international formats as early as possible, the advice and support of all institutions involved in meteorological data networks will be necessary.

3. WMO should encourage and support intercomparisons of wind profiling instruments. Such intercomparisons should be carried out with different types of profilers but also with classical, say balloon-based, equipment.

4. Investigations on the impact which wind data from a profiler network will have on models, must commence now; the needs and wishes of the data users are not yet known. WMO should encourage and support OSSEs as well as numerical experiments using real profiler data from demonstration networks.

5. In order to facilitate the exchange of information between the different research groups active in wind profiling and related modelling activities, WMO should support workshops and conferences in particular on an intercontinental level.

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