RECOMMENDATION ITU-R SA.1165-1

# TECHNICAL CHARACTERISTICS AND PERFORMANCE CRITERIA FOR RADIOSONDE SYSTEMS IN THE METEOROLOGICAL AIDS SERVICE

(Question ITU-R 144/7)

(1995-1997)

The ITU Radiocommunication Assembly,

*considering*

a) that upper-air meteorological measurements carried out by radiosondes are an essential element of the World Weather Watch Programme of the World Meteorological Organization (WMO);

b) that many defence services deploy radiosonde systems in order to support a variety of operations, independent of the World Weather Watch Programme;

c) that many radiosonde systems are now used for local and regional monitoring of atmospheric pollution conditions and also for tracking the trajectories of hazardous discharges from natural or man-made disasters;

d) that radiosonde systems operating in the meteorological aids (MetAids) service have unique radiocommunication requirements;

e) that these requirements affect assignments and other regulatory matters;

f) that radiosondes in the MetAids service are flown on balloons and rockets and may operate with stations located on land or ships;

g) that other types of radiosondes in the MetAids service are dropped from aircraft and operate with stations located on aircraft;

h) that performance objectives for transmissions to and from radiosondes must be consistent with the attendant functional requirements and with the performance limitations associated with the systems and frequency bands in which the requirements will be fulfilled;

j) that performance objectives for representative systems operating in the MetAids service are intended to provide guidelines for the development of actual systems that must operate in a frequency sharing environment;

k) that performance objectives for particular systems may be determined using the methodology similar to that described in Recommendation ITU-R SA.1021;

l) that performance objectives are a prerequisite for the determination of interference criteria,

*recommends*

**1** that the characteristics described in Annex 1 be taken into account in connection with frequency assignments and other technical and operational regulatory matters concerning MetAids systems and their interaction with other services;

**2** that MetAids systems have the performance objectives specified in Table 1.

TABLE 1

**Performance objectives for links in the meteorological-aids service**

| Frequency band (MHz) and receiver platform and antenna | Function and transmitter platform and antenna | Modulation and bandwidth | Receiving antenna elevation angle (degrees) | Practical maximum range (km) | Minimum $C/(N + I)$ (dB) | Transmitter power (dBW) | Maximum transmitter altitude (km) | Required link availability (%) |
|---|---|---|---|---|---|---|---|---|
| 400.15-406<br>Land or ship based receiver | Direct data readout from balloon-borne radiosonde | FM<br>280-480 kHz | From 0 to 90 | 300 | 12 | –6.0 | 36 | 99 |
| 400.15-406<br>Aircraft based receiver | Direct data readout from descending dropsonde | FM digital<br>20 kHz | From –3 to –90 | 350 | 12 | –8.2 | 20 | 99 |
| 400.15-406<br>Balloon-borne receiver | Ranging signal reception at balloon-borne receiver | FM<br>300 kHz | From –3 to –90 | 250 | 12 | 3.0 | Ground based | 99 |
| 1 668.4-1 700<br>Land based receiver high gain antenna | Direct data readout from balloon-borne radiosonde | AM<br>–40 dBc: 0.5 MHz<br>–50 dBc: 1.0 MHz | From 3 to 90 | 250 | 12 | –6.0 | 36 | 99 |
| 1 668.4-1 700<br>Land based receiver high gain antenna | Direct data readout from balloon-borne radiosonde | FM<br>180 kHz | From 3 to 90 | 250 | 12 | –6.0 | 36 | 99 |

ANNEX 1

# 1 Introduction

## 1.1 Daily meteorological operations

Radiosondes are mainly used for *in situ* upper air measurements of meteorological variables (pressure, temperature, relative humidity, windspeed and direction) in the atmosphere up to an altitude of 36 km. The radiosonde measurements are vital to national weather forecasting capability (and hence severe weather warning services for the public involving protection of life and property). The radiosondes and associated tracking systems provide simultaneous measurements of the vertical structure of temperature, relative humidity and wind speed and direction over the full height range required. The variation of these meteorological variables in the vertical contains the majority of the critical information for weather forecasting. The radiosonde systems are the only meteorological observing systems able to regularly provide the vertical resolution that meteorologists need for all four variables. Identification of the heights where sudden changes in a variable occur is vital. Thus, it is essential that continuity of reliable measurements is sustained throughout the deployment cycle of the radiosonde.

The observations are produced by radiosondes carried by ascending balloons launched from land stations or ships or dropsonde deployed from aircraft and carried by a parachute. Radiosonde observations are carried out routinely by almost all countries, two to four times a day. The observations are then circulated immediately to all other countries within a few hours. The observing systems and data dissemination are all organized under the framework of the World Weather Watch Programme of WMO.

Thus, the radiosonde network provides the primary global source of real-time *in situ* measurements. WMO Regulations (Manual on the Global Data-Processing System (GDPS)) require that MetAids measurements should be made and circulated to all GDPS centres worldwide at national, regional and global levels for numerical weather prediction. The observations are required at a horizontal resolution of less than or equal to 250 km, by the year 2005 with a frequency of observation of from one to four times per day. This is required as a reasonable achievable target for radiosonde systems, worldwide. However, the numerical weather prediction models will actually require upper air observations every one to three hours at a horizontal resolution from 50 to 100 km by the year 2005, depending on whether the forecast is for the globe or for a more limited region. These observations are to be provided from a variety of observing systems, chosen according to the needs of the national administration, including MetAids measurements, wind profiler radar measurements or satellite measurements.

The radiosonde observations are essential to maintain stability in the WMO Global Observing System (GOS). Remotely sensed measurements from satellites do not have the vertical resolution available from radiosondes. Successful derivation of vertical temperature structure from these satellite measurements usually requires a computation initialized either directly from radiosonde statistics or from the numerical weather forecast itself. In the latter case, the radiosonde measurements ensure that the vertical structure in these forecasts remains accurate and stable with time. In addition, the radiosonde measurements are used to calibrate satellite observations by a variety of techniques. Radiosonde observations are thus seen to remain absolutely necessary for meteorological operations for the foreseeable future.

## 1.2 Monitoring climate change

Large worldwide changes have occurred in atmospheric temperature and ozone in the last 20 years, with many of the largest changes taking place at heights between 12 and 30 km above the surface of the Earth. The changes are large enough to cause concern about safety of future public health. Routine daily radiosonde observations to heights above 30 km identify the distribution in the vertical of the changes that occur and hence allow the causes of the changes to be evaluated. Ozone sonde measurements to similar heights determine the vertical distribution of the ozone depletion that now appears to be occurring in both Southern and Northern Hemisphere winter and spring. Many countries are now flying ozone sondes at least three times per week during these seasons to monitor developments.

Successful sampling of climate change requires the use of radiosondes with established systematic error characteristics. The requirement for continuity in the time series of upper air measurements worldwide means that new radiosonde designs are only introduced into operation after several years of intensive testing, both in the laboratory and in the free atmosphere

### 1.3 Defence use

In all countries with the infrastructure to support modern defence operations (on land or at sea) radiosondes are used in significant numbers by the defence. This use is not decreasing with time, since with modern automation it is now much easier to successfully operate mobile battlefield systems and shipboard systems without highly skilled operators and a large amount of supporting equipment. Civilian radiosonde operations have to accommodate the defence use and this expands the radio-frequency spectrum required for radiosonde operations. This is particularly critical when defence launch sites are within 150 km of the civilian launch sites.

### 1.4 Other users

Other radiosonde systems may be deployed independently of the main civilian meteorological organization by national research institutes. Specific investigations will include environmental pollution, hydrology, radioactivity in the free atmosphere, significant weather phenomena (e.g. winter storms, hurricanes, thunderstorms, etc.) and investigation of a range of physical and chemical properties of the atmosphere.

## 2 Characteristics of radiosonde operation

Civilian radiosonde observations are carried out worldwide to provide the observations necessary for daily weather forecasting. The standard observations are nominally performed at 0000 and 1200 UTC, but the actual launch times vary according to national practice and in some cases will be at least three-quarters of an hour earlier than the nominal time. The launch may also be up to two hours later than nominal if there are problems with preparation of the radiosonde prior to flight, if local air traffic regulations limit launch times or if there is a malfunction during the initial flight. Intermediate observations at 0600 and 1800 UTC are also performed routinely in several countries.

The radiosonde networks are implemented and operated by national meteorological services in compliance with recommended practices and procedures internationally agreed upon by WMO. The current number of radiosonde stations reporting regularly is about 900. About 800 000 radiosondes are launched in a year in association with the WMO network and it is estimated that about another 400 000 radiosondes are used for defence use and specialized applications. The current level of radiosonde use does not adequately meet meteorological requirements due to operational costs.

Additional radiosondes and dropsondes are launched periodically, often from temporary sites using mobile systems in response to abnormal weather or requirements for testing.

## 3 Radio-frequency spectrum used in WMO operations

### 3.1 Results from WMO survey

Table 2 presents estimates of the radio frequency used at civilian radiosonde stations reporting information daily for WMO meteorological operations. This information is based on recent WMO survey. The survey results are grouped into regions to illustrate the variation in use worldwide. More detailed information is available from the WMO Catalogue of Radiosondes and Upperwind Systems in use by Members. Proposals for band segmentation would have to take account of the fact that bands internationally allocated to MetAids on a primary basis are not available to this service in all countries. For instance, in Australia, at least half of the 400.15-406 MHz frequency band is currently not available to the national weather services for MetAids operations.

TABLE 2

**Summary of radio frequency use for radiosondes for daily civilian operations**

| Region | Total Number of sites | Number of sites using 400 MHz | Number of sites using 1 680 MHz | Number of sites using 1 780 MHz |
|---|---|---|---|---|
| Europe and Western Russia | 214 | 111 | 11 | 92 |
| Asia and Eastern Russia | 265 | 159 | 32 | 74 |
| Africa | 65 | 53 | 12 | – |
| North America | 174 | 50 | 122 | 2 |
| South America and Antarctica | 64 | 50 | 12 | 2 |
| Australia and Oceania | 87 | 65 | 22 | – |
| Ship systems | 25 | 16 | 1 | 8 |
| Overall | 894 | 504 | 212 | 178 |

1 680 MHz systems are mainly operated by or supplied from United States of America and Japan. Russia and some states with cooperating arrangements use 1 780 MHz. These countries are expected to move away from this frequency in order to be compatible with equipment available from other countries. Most 400 MHz systems have been installed within the last decade. The main exceptions are some of the systems in Asia where much older broad band transmitter systems are still in use.

Both 1 680 MHz and 400 MHz are used for defence radiosonde operations.

Table 3 indicates the types of upper wind measurement system used in each region. For ease of interpretation the types have been compressed into three categories.

Navigational aids (NAVAID) windfinding systems that are highly automated and rely on international radiolocation signals to track the radiosonde. These will all be 400 MHz systems:

– primary tracking radars, where position is measured independent of any response from the radiosonde. These will also be 400 MHz systems;

– radiotheodolites or secondary radars, where tracking depends on a combination of directional measurements from the launch site combined with either a height measurement from the radiosonde or a transponder response to pulses transmitted from the ground station. These systems are a combination of broad band systems at 400 and 1 780 MHz, together with the 1 680 MHz systems;

– NAVAID, primary radar and radiotheodolite systems may be used for defence systems. Shipboard applications will usually use NAVAID systems.

TABLE 3

**Summary of windfinding type used for civilian radiosonde operations**

| Region | Total number of sites | Number of sites using NAVAID | Number of sites using primary radar | Number of sites using radiotheodolite or transponder system |
|---|---|---|---|---|
| Europe and Western Russia | 214 | 86 | 24 | 104 |
| Asia and Eastern Russia | 265 | 37 | 21 | 207 |
| Africa | 65 | 41 | 11 | 13 |
| North America | 174 | 50 | – | 124 |
| South America and Antarctica | 64 | 31 | 2 | 31 |
| Australia and Oceania | 87 | 22 | 43 | 22 |
| Ship systems | 25 | 16 | – | 9 |
| Overall | 894 | 283 | 101 | 510 |

## 3.2 Radio-frequency spectrum occupied in Europe

In Western and Northern European areas the radiosounding station network is dense, with stations operated for routine meteorological operations, environmental monitoring and a variety of defence operations. Most of the radiosondes are operating in the 400.15 to 406 MHz band. The actual radio-frequency spectrum currently occupied during a year by a civilian radiosonde network in North-West Europe was reviewed in late 1995 and is shown in Fig. 1. In several areas, the civilian stations are within 150 km of defence sites. In one particular country, the civilian radiosondes use 400 MHz transmitters with a typical frequency change during flight of 10 kHz, although in a small number of flights changes in frequency may be as large as ±100 kHz. These radiosondes are selected by the manufacturer for higher stability performance and a premium added to the purchase price.

In the example shown, defence radiosondes were using 400 MHz before the civilian radiosondes were moved from 28 MHz in 1990. The civilian frequencies shown in Fig. 1 were chosen to accommodate the existing defence use. This spectrum occupation is typical for the larger countries in Western Europe.

In 1995, procurement of some additional defence MetAids equipment took place in the same country that requires a spectrum occupation of about 4 MHz somewhere between about 1 678 and 1 686 MHz.

## 3.3 Radio-frequency spectrum occupied in the United States of America

The civilian weather service in the United States of America is currently the main user of the 1 680 MHz MetAids bands. US defence systems and some research users utilize the 400 MHz band. Though the weather service MetAids are allocated in the bands covering 1 668.4 to 1 700 MHz, Fig. 2 shows how the band is currently utilized. Through effective coordination with other users of the band, interference is avoided by limiting the use of MetAids to a much smaller portion of the band. The remaining portion of the band used by MetAids is necessary to support transmitter drift, dual flights, second releases and interference between adjacent stations.

FIGURE 1

**Estimate of radio-frequency spectrum occupied during a year by a typical civilian radiosonde network in North-west Europe**

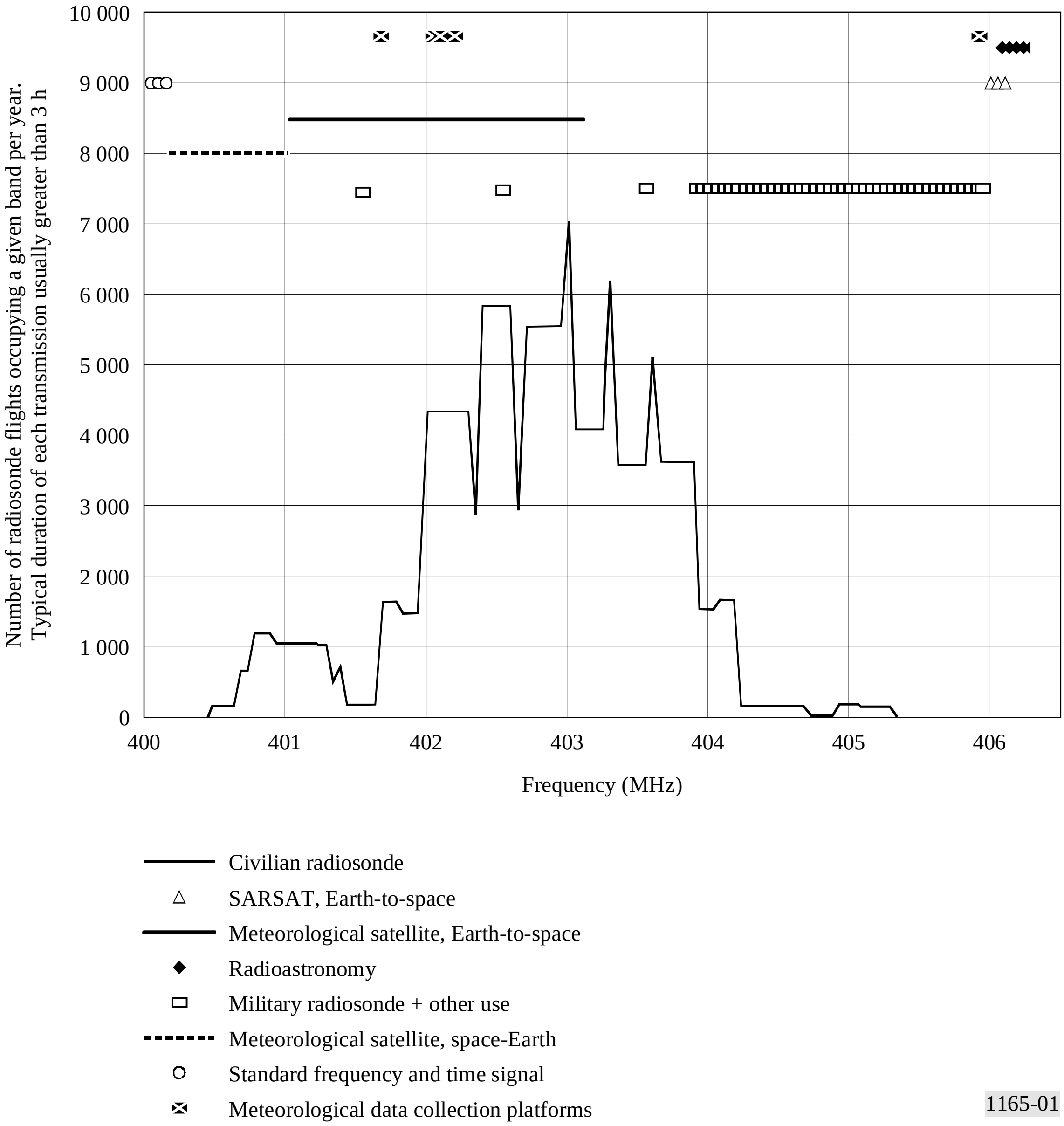
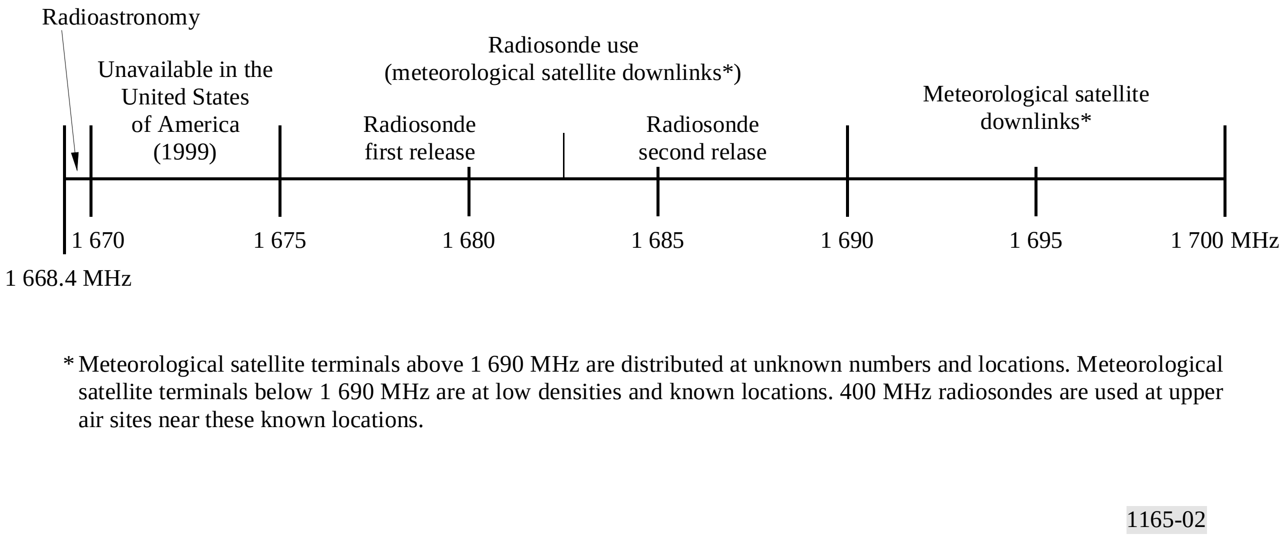


FIGURE 2

**Current United States usage of the MetAids bands 1 668.4 to 1 700 MHz**




The use of radiosondes in the band 400.15 to 406 MHz in the United States of America has recently been surveyed and confirms that large numbers of systems are deployed by the defence. At least another 40 systems are used by universities or other United States agencies. Some of these systems are deployed in groups at smaller spacing in the horizontal than 250 km, supporting long-term investigations at national scientific sites.

The United States Defence authorities have indicated in future they will require 12 channels within the band 401 to 406 MHz and it is estimated that at least another 4 channels will be required for other agencies. The weather services operate one operational station in this band at Wallops Island, (Virginia) to avoid interference in the 1 680 MHz band with one of the main meteorological satellite CDA facilities, located close to the radiosonde station.

TABLE 4

**Summary of radio frequency use of radiosondes in the band 400.15 to 406 MHz for users other than those in World Weather Watch Programme based in the United States of America**

| | Omega NAVAID | Loran NAVAID | Total |
|---|---|---|---|
| United States defence in the United States of America | 294 | 81 | 375 |
| United States defence overseas | 62 | 3 | 65 |
| Other United States users | 4 | 40 | 44 |
| Totals | 360 | 124 | 484 |

# 4 Operational requirements

Apart from accuracy, the chief features required in radiosonde design are reliability, robustness, small weight, small bulk and small power consumption. Since a radiosonde is generally used only once, it should be designed for production at low cost. Ease and stability of calibration are also important factors. A radiosonde should be capable of providing data over a range of at least 200 km and operating in a temperature range from −90 °C to +60 °C. Since the voltage of a battery varies with both time and temperature, the radiosonde must be designed to accept the variations without exceeding the accuracy and radio-frequency drift requirements. The associated ground equipment should not be unduly complicated or require frequent highly skilled maintenance. It is preferable, however, to keep the radiosonde itself as simple as possible, even at the expense of complication in the ground equipment, since failure of the latter is more readily corrected and since the costs of flight equipment should be kept to a minimum.

The major limitation of the radiosonde observation is the cost. In the Organization for Economic Co-operation and Development (OECD) countries one radiosonde observation costs about 400 ECU, from the total costs about one fourth is the cost of the radiosonde. The cost structure is noteworthily different in developing countries, where the cost of the radiosonde is the most important element. As meteorological data requirements are global, some developed countries are donating systems and part of the radiosondes for some developing countries with a view to sustained upper-air observations. There is therefore a strong requirement for keeping the radiosonde price as low as possible in order to ensure the continuation of the observations vital to operational meteorology, including its aspects related to the protection of life. In the total cost of the radiosonde the sensors and wind finding represent the major part, whereas the transmitters are intentionally kept as simple as possible, hence maintaining a low total price. Transmitter costs represent about 15-35% of the current radiosonde electronic equipment costs.

The ascent time of a full radiosounding is about 90 min, and the descent time is about half of the ascent time if a parachute is used. The radiosonde is usually still transmitting while descending. The maximum range of the proper reception of the radiosonde is about 200 to 350 km. The ascent speed is about 5 m/s and the trajectory depends on the prevailing wind conditions. In general, within an area of radius about 400 to 650 km around the radiosounding station the same downlink frequency cannot be used. In high density areas, more than ten radiosonde operators are located within the effective area of one radiosonde.

In Western and Northern European areas the radiosounding station network is dense. In addition meteorological and environmental monitoring and research activities and defence force related users are sharing the frequency band with the synoptic observations. Coordination between radiosonde operators is required to prevent interference between the radiosondes of different stations.

# 5 Future trends

It is expected that radiosonde operations will need to continue in both the 403 and 1 680 MHz MetAids bands. The following factors are likely to influence the national choice of the system in use.

## 5.1 Very strong upper winds

The average strength of upper winds varies with geographical location. Japan and many of the coastal areas of North-West Europe have very much stronger winds on average between the surface and heights of 16 km than much of the rest of the Northern Hemisphere. The situation becomes more serious for radiosonde operations in North-West Europe since at higher latitudes the winds between 16 and 30 km may often be even stronger than in the lower layers for much of the winter. Thus, the radiosondes must regularly be tracked at ranges well in excess of 150 km at very low elevation angles. These strong wind conditions can persist for several weeks and significant gaps will appear in climate records if the radiosonde data at upper levels cannot be received during this time.

Wintertime observations are very important for ozone depletion investigations and it is vital that as much information as possible is obtained at upper level from the radiosondes/ozone sondes used in these conditions. For this reason, the superior reception provided at 403 MHz is considered essential for radiosonde operations in these conditions. This is true whether NAVAID or primary radar tracking is used to measure the upper winds.

Therefore, for sites which regularly experience high wind speeds, the use of the 400 MHz MetAids band is preferable for two reasons. First, the propagation characteristics of 400 MHz produce greater link reliability at long distances. Second, multipath is a limitation to radiotheodolite accuracy at elevation angles near the horizon. Thus, the use of a NAVAID based system at 400 MHz, even at the possible high cost of global positioning systems (GPS), is essential for accurate wind measurements in these harsh conditions.

## 5.2 Manpower efficiency resulting from highly automated systems

A large number of national weather services around the world moved to NAVAID windfinding (Omega or Loran-C) at 403 MHz in the last decade. This was to improve the manpower efficiency of their operations. The additional cost of the NAVAID windfinding radiosonde was outweighed by the large efficiency savings associated with single-man operations and major reductions in maintenance to the ground system. In the United States of America, the cost of having a maintenance person on-site to respond to maintenance and repair needs is not critical since the person is also responsible for many other tasks and must be available anyway.

It should be noted that the cost of the codeless GPS radiosondes currently under development has not yet stabilized, being typically twice as large as the present Omega and Loran NAVAIDs. However, when the technology becomes more mature and production numbers are higher, this price level may stabilize to about 30% to 50% higher than the present NAVAID prices. Operation of the other conventional terrestrial NAVAID systems is expected to cease between 1997 and 2001 in most of the world. Thus, it is possible that some countries currently using 403 MHz may return to radiotheodolite operations at 1 680 MHz if the cost of the GPS radiosondes are significantly higher than the present NAVAID radiosondes. GPS radiosondes at 403 MHz will have to be used where upper winds are very strong on a regular basis. Continued use of Loran radiosondes is possible in areas of the world where Loran operations will continue.

The use of NAVAID windfinding with radiosondes operating in the 1 680 MHz band is under study by some manufacturers.

## 5.3 Low radiosonde cost

Use of the 1 680 MHz bands is desirable in countries where the occurrence of high wind situations is low and/or there is a concern over the cost of using future GPS-based radiosondes in the 400 MHz MetAids band. Reduction in the spectrum available to MetAids systems may require the development of systems with more stable transmitters and smaller bandwidth than currently used. The costs of development of the new systems will increase the price of the radiosondes and it may take several years before the benefits of the economies of large scale production can be passed on to the user.

Radiosondes used for meteorological operations with radiotheodolites or primary radars are the most basic design, leading to the lowest cost per unit. Though the procurement of a more complex ground station results in a higher initial cost, there may be cost savings realized in the yearly operating costs when large numbers of radiosondes are procured and manpower costs are not critical.

## 5.4 Independence from international NAVAID systems

Some countries may also have a national requirement for upper air sounding systems to be capable of operation independent of international NAVAID systems. International NAVAID systems may not be available during times of emergency. In that situation, use of radiotheodolites in the 1 680 MHz bands or primary radars at 403 MHz are viable options.

### 5.5 Possible improvements to spectrum occupation from improved radiosondes

Recently, Western European countries operating dense networks have been forced to either use crystal controlled transmitters or specially selected stable transmitters to support routine operations. This improved efficiency in spectrum use has taken place within the last decade.

A major transition in MetAids windfinding is occurring in the 1997-1998 time frame, due to the termination of the Omega radionavigation system. This windfinding function must be replaced by another method.

One choice is to transition to a GPS-based windfinding system. While it is not clear today what the exact characteristics of these systems will be, it is expected that the GPS windfinding radiosondes are likely to have reduced bandwidths (as low as 200 kHz if operators can afford the cost, and possibly eventually as low as 60 kHz, if required in very dense networks where costs are already much higher than average). The performance of these GPS radiosondes will meet or exceed that of current radiosondes.

Some regions of the world will convert to (or in some cases still use) Loran-C. While there will be less of a cost than in going to GPS, extremely dense network operation (i.e., 100 km spacing) will be difficult due to the large bandwidth of Loran-C radiosondes.

Furthermore, other regions of the world that use very broad-band radars for windfinding are being encouraged by the WMO to implement narrower band systems because of the need to share the radio spectrum with other systems.

1 680 MHz systems have not been used in networks with such close spacing and the equivalent developments in transmitter stability have not yet been required of the major suppliers. Thus, some improvement in efficiency of spectrum use is possible in this band, given that the changes can be introduced on a time-scale that does not lead to a significant cost increase in the radiosondes supplied.

Any proposal for band segmentation would have to take account of the fact that bands internationally allocated to MetAids on a primary basis are not available to this service in all countries. For instance, in Australia, at least half of the 400.15-406 MHz frequency band is currently not available to the national weather services for MetAids operations.

Other methods to reduce spectral occupancy include digital transmissions which are under investigation.

## 6 Radiocommunication characteristics of current radiosonde systems

Radiosonde systems perform *in situ* measurement of the atmospheric pressure, temperature and relative humidity (PTU). The wind speed and direction is determined using either a NAVAID method or radio direction finding (RDF) measuring the azimuth and elevation angle of the radiosonde in respect of the receiving antenna. The data downlink from the radiosonde to the ground receiving station is at the 400 MHz band in NAVAID, and at the 1 680 MHz band in RDF radiosondes. The Omega VLF and Loran-C signals are relayed to the ground receiver using a simple translator.

For 1 680 MHz radiosondes, signal losses of greater than 10 s will generally cause loss of ground receiver tracking. A radiosonde whose track is lost will only rarely be re-acquired so track is lost even if the interfering signal goes away. The radio receiver will track the strongest amplitude signal in its instantaneous bandwidth (1.3 MHz). When winds are very strong, wind velocity is sometimes measured using a transponding radiosonde. The radiosonde receives ranging signal near 400 MHz from the ground station and retransmits the pulse train at 1 680 MHz.

The radiosonde transmitting antennas are quarter wave length monopoles.

## 6.1 Transmitter characteristics

TABLE 5

**Radiocommunication characteristics of 400 MHz radiosonde transmitters**

| | |
|---|---|
| Tuning range (MHz) | 400.15-406 |
| Maximum drift in flight (kHz) | ± 800 |
| Nominal output power (dBW) | –6.0 |
| Maximum antenna gain (dBi) | 2 |
| ITU-R emission type | F9D |
| Modulation | FM |
| Modulating PTU signal (kHz) | 7-10 |
| Deviation of the PTU signal (kHz) | 45 ± 15 |
| Deviation caused by the VLF/Loran-C signal relay link (kHz) | 100/300 |
| Occupied bandwidth with Omega VLF (kHz) (–40 dBc level) | 280 |
| Occupied bandwidth with Loran-C (kHz) (–40 dBc level) | 480 |
| Occupied bandwidth with GPS (kHz) (–40 dBc level) | 200 |
| Equivalent information rate of the PTU signal (bit/s) | 1 200 (1) |
| Equivalent information rate of the PTU and GPS signal (bit/s) | 2 400 |
| Out-of-band emission (dBc) | < –43 |

(1) The information transmission rate is intended to indicate the actual data rate transferred from the radiosonde to the ground receiver. Because of the current modulation techniques used by radiosonde systems, further study is needed to estimate these values.

TABLE 6

**Radiocommunication characteristics of 1 680 MHz radiosonde transmitters**

| | | |
|---|---|---|
| Tuning range (MHz) | 1 668.4-1 700 | 1 668.4-1 700 |
| Maximum drift in flight (MHz) | ± 4 | ± 4 |
| Nominal output power (dBW) | –6.0 | –6.0 |
| Maximum antenna gain (dBi) | 2.0 | 2.0 |
| ITU-R emission type | A9D | F9D |
| Modulation | AM, 100% | FM |
| Modulating PTU signal (kHz) | 0.7-1.0 | 7-10 |
| Deviation | Not applicable | 45 ± 15 |
| Windfinding | Detection of the reception angles | Detection of the reception angles |
| Occupied bandwidth | –40 dBc: 0.5 MHz<br>–50 dBc: 1.0 MHz | 180 kHz |
| Information rate (bit/s) | 1 200 | 1 200 |
| Out-of-band emission (dBc) | < –43 | < –43 |

## 6.2 Ranging signal

Determining the position of the radiosonde with a 1 680 MHz radiotheodolite (RDF) is very sensitive to azimuth and elevation angle, and when elevation angles are small (below 10° to 15°) height measurement (and hence slant range) errors may become very large. This situation typically occurs during the winter when very strong upper level winds carry the radiosonde far downwind. To cope with this situation, a 403 MHz ranging system is used to provide the range to the sonde as an additional variable (often replacing elevation angle in the computation of position) for more accurate position calculation.

The ranging adjunct generates a 75 kHz sine wave signal. The ground station transmitter amplitude modulates a 403 MHz carrier with the 75 kHz signal and transmits it to the radiosonde. The 403 MHz signal is demodulated on the radiosonde, and the 75 kHz signal is used to modulate the 1 680 MHz down link signal. The ranging adjunct on the ground station then compares the phase difference between the original 75 kHz signal and the signal returned by the sonde. This phase difference is used to calculate the slant range to the radiosonde. Table 7 gives the typical characteristics of the ranging adjunct which is added to the RDF systems.

TABLE 7

**Technical characteristics of the radiosonde ranging adjunct**

| Parameter | Value |
|---|---|
| Ground Station ( uplink transmitter): | |
| – Transmitter output power (W) | 25 |
| – Emission bandwidth (kHz) | 180 |
| – Modulation | MA |
| – Antenna Gain (dBi) | 12 |
| – Antenna 3 dB beamwidth (horizontal × vertical) | 17 × 45 |
| – Polarization | Vertical |
| Radiosonde Ranging Receiver (uplink receiver): | |
| – RF bandwidth, 3 dB (MHz) | 8.0 |
| – IF bandwidth, 3 dB (kHz) | 250 |
| – Antenna gain (dBi) | 1.3 |
| – Antenna 3 dB beamwidth (horizontal × vertical) | 360 × 60 |

## 6.3 Receiving antennas

Typical characteristics of currently used antennas are:

TABLE 8

**Characteristics of 400 MHz antennas**

| Type | Omnidirectional (dipole, ground plane) | Directional corner reflector, six corners |
|---|---|---|
| Frequency range (MHz) | 397-409 | 400-406 |
| Horizontal gain (dB) | Omnidirectional | 8 |
| Vertical gain (dB) | Omnidirectional | –3 |
| Amplifier NF (dB) | < 3.5 | < 2.5 |
| Amplifier gain (dB) | 13 | 20 |

TABLE 9

**Characteristics of 1 680 MHz antennas**

| Type | Phased array | Conical scanned |
|---|---|---|
| Frequency range (MHz) | 1 660-1 700 | 1 660-1 700 |
| 3 dB beamwidth (degrees) | 20 horizontal | 8.8 |
| | 15 vertical | |
| Gain (dBi) | 16 minimum | 28 |
| Side lobe attenuation (dB) | > 20 to the direction of specular ground reflection on flat terrain when elevation > 14° | 15 at ± 60° from boresight |
| Sensitivity (dBm) | –110 RF input 12 dB $S + N/N$ | –97 (tracking) |
| Automatic gain control (dBm) | Dynamic range –110 … 0 | |
| IF bandwidth, PTU measure (kHz)<br>– Tracking (MHz) | 300<br>Not applicable | 180<br>1.3 |