INTEROPERABILITY IN UPPER AIR SOUNDING SYSTEMS

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1. Introduction

The WMO Executive Council has requested that the Secretary General investigate the feasibility of interoperability in upper-air sounding systems. This topic was first addressed in a paper delivered by InterMet to the WMO Technical Conference on Meteorological and Environmental Instruments and Methods of Observation (TECO 2005, Bucharest).[1]

The purpose of this paper is to summarize and update the TECO paper, and to discuss whether interoperability can be extended to 403 MHz GPS type sounding systems.

2. Definitions

Upper-air sounding systems consist of two primary elements: a radiosonde that measures and transmits meteorological data, and a ground station that receives the telemetry and processes it into met data products. Ground stations are long-lived, high-cost systems permanently installed at synoptic sounding sites. Radiosondes are low-cost disposable sensors consumed in the process of making upper-air soundings.

For the purposes of this paper, “interoperability” is defined as the ability of an upper-air ground station to employ radiosondes made by multiple manufacturers, including, but not limited to, the manufacturer of the ground station.

An interoperable ground station must deliver the met data products generated by the radiosonde in a manner that is transparent and unbiased.

3. 1680 MHz RDF Systems

InterMet has been building interoperable 1680 MHz RDF systems since 1987. 27 systems are currently installed at synoptic sites in 20 countries. InterMet’s RDF systems are currently compatible with seven radiosondes built by three manufacturers (Table 1.)

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Table 1: RDF Compatibility

System	Sonde Manufacturer	Sonde Type
iMet-1500 / 1600 / 1700	L-M Sippican	Mark-II
iMet-1500 / 1600 / 1700	L-M Sippican	B-2
iMet-1500 / 1600 / 1700	India Meteorological Department	Mark-IV
iMet-1500 / 1600 / 1700	InterMet	iMet-1-BI
iMet-2000	L-M Sippican	Mark-IIA
iMet-2000	InterMet	Model 3010
iMet-2000	InterMet	iMet-1-BB

Figure 1 shows the iMet-2000 and iMet-1500 systems. The 2000 is a 2-meter, high gain system designed for fixed installations within a radome. The 1500 is a smaller, lower gain system with a 1.2-meter dish designed for mobile or fixed installations.

Figure 1: iMet-2000 and 1500

The iMet-1700 was introduced in 2005 as a lower cost, fixed-installation version of the 1500. The iMet-1600 is a hybrid system that integrates 1680 MHz RDF capabilities with 403 MHz GPS through a single PC operating system. The RDF capabilities of the 1500, 1600 and 1700 systems are functionally identical, and are compatible with the same radiosondes.

InterMet's RDF systems are also described as "dual-mode", which means they can use RDF or 1680 MHz GPS radiosondes. Hybrid and dual-mode operations will not be covered in this paper.

4. 1680 MHz RDF Technical Issues

Upper-air sounding systems consist of five main elements:

- Radiosonde / Transmitter
- Antenna(s) / Receiver(s)
- Signal Processing System (Decoder)
- System Computer
- Meteorological Operating System

Figure 2 shows a system diagram for an RDF type system.

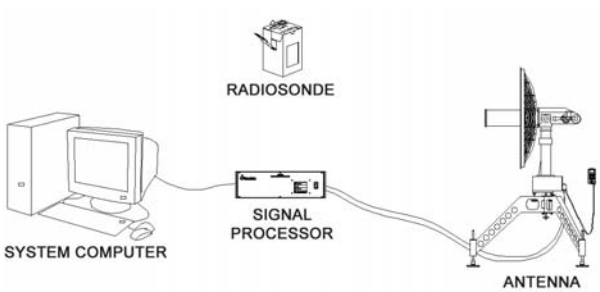

Figure 2: RDF Upper Air Sounding System

Radiosonde / Transmitter

RDF radiosondes collect pressure, temperature and humidity (PTU) and use proprietary schemes to encode the data before transmission. To be compatible with the InterMet antenna, the sonde transmission bandwidth requirement can be no greater than 1,000 KHz. Power output should be equal to or greater than 19.1 dBm (depending on the bandwidth requirement) to achieve maximum range.

Antenna / Receiver

RDF systems use a directional antenna that includes an integrated 1680 MHz receiver. The antenna tracks the sonde and receives the coded PTU message as an AM or FM signal. Tracking data is passed directly to the System Computer where wind speed and direction are calculated. PTU data is independent of the antenna. Wind calculations require antenna data as wells as PTU data from the radiosonde.

Signal Processing System (Decoder)

The Signal Processing System (SPS) receives the coded data stream from the antenna over a coaxial connection. The iMet-2000 uses a 10.7 MHz frequency while the iMet-1500 uses demodulated baseband. The SPS has its own power supply, which is connected to the system UPS.

The PTU data stream is decoded in the SPS using the same proprietary scheme that coded the data within the radiosonde. The methodology does not need to be disclosed by the sonde manufacturer.

The SPS passes the decoded PTU data to the System Computer over an RS 232 serial data connection.

System Computer

The System Computer is a commercial PC or laptop running the Microsoft operating system. The only special hardware requirement is the availability of two serial ports. This requirement can be met with the use of serial cards or USB converters.

Meteorological Operating System

The iMetOS Meteorological Operating System is installed on the System Computer. This code provides four functions:

- Antenna control and system status
- Met data processing and editing
- Report generation and graphics
- Communications

For interoperability, the iMetOS needs to correctly apply any sonde-specific processing required after the signal is decoded in the SPS. The most common is Solar / IR corrections based on the time of the flight, location of the site and/or cloud cover codes. A particular sonde's PTU sensors may also require proprietary functions to apply calibration coefficients, statistically smooth the data or make other corrections.

To protect proprietary information, the SPS logic could be upgraded to make the solar/infrared corrections, as well as any other corrections and smoothing. Alternatively, proprietary data corrections could be provided as compiled software executables with defined inputs and outputs. This would allow InterMet to include the necessary code while protecting the proprietary functions.

iMetOS must also correctly describe the sonde being flown in the TEMP and PILOT messages. Sonde type, wind finding method and whether or not any solar correction has been made are included in the 31313 code.

The processing of standard met messages, graphic outputs, etc. is well defined and relatively straightforward. Once the PTU data is decoded and processed, there are no longer any sonde-specific aspects and the information can be consistently displayed, edited and reported.

Interoperability

Interoperability has been achieved in the InterMet RDF systems by means of the SPS and the iMetOS Meteorological Operating System. The SPS is provided by the sonde manufacturer who also provides any sonde-specific processing code for integration into the iMetOS. If the operator switches to a new radiosonde, the SPS is swapped out for the model compatible with the new sonde. Selection of the appropriate software is made through a drop-down menu in iMetOS.

Compatibility

InterMet is confident its systems can fly any 1680 MHz RDF radiosonde. The most difficult technical challenges have come from adapting to obsolete sonde characteristics such as the requirement for a 5 ¼" floppy drive to input calibration coefficients for the L-M Sippican B-2 radiosonde. This problem is eliminated in the Mark-II, which writes the calibration coefficients directly into the radiosonde's EPROM with no processing required in the System Computer. In general, the more recent the sonde's design, the more easily it can be integrated and used as part of an interoperable system.

5. Field Experience

InterMet has installed RDF systems in Tanzania and Namibia as part of the WMO GUAN program. The Tanzania system was evaluated by an international expert team in October, 2004 which provided valuable lessons for the implementation of interoperable systems. [2]

Technically, the team concluded that the wind data produced by the InterMet RDF system was satisfactory when compared with results from a Vaisala RS92 GPS system. It was also found that the iMetOS was not correctly applying the necessary solar corrections for the L-M Sippican radiosonde that was being flown. The software was also not properly identifying the sonde and was not properly coded for the appropriate WMO region.

The team also found that the observers from the Tanzanian Met Dept. had not received adequate training for a site that had not made flights for many years. The observers had also not received proper instructions for how to transmit standard met messages to the international data sites.

The software errors have been corrected but point to the necessity for close communications between the sonde and ground station vendors. It is essential that the vendors keep each other informed of potential changes to the hardware or software that may require corresponding modifications to maintain system integrity. It is also important that the ground station vendor assume full responsibility for integrated system operations and to provide a single point of contact for operators.

The Namibia installation (and a subsequent project in Zimbabwe) established a tentative commercial model that defines the respective roles of the ground station and sonde vendors. Under the method used for these sites, the sonde supplier provides both the disposables and the SPS as part of the sonde contract. The ground station manufacturer is the system integrator and provides all other hardware and software elements. Commercial issues are discussed in more detail in Section 8 below.

In India, ten iMet-1500 systems have been making synoptic observations since 2003 using the IMD MK-IV radiosonde. The IMD is currently making test flights with L-M Sippican Mark-II sondes and is working with the WMO to implement the Mark-IIs at four sites to be included in the GUAN. Conversion to the Mark-II radiosonde will require no hardware or software changes to the iMet-1500 systems.

6. 403 MHz GPS Technical Issues

Figure 3 shows a system diagram for a 403 MHz GPS type sounding system.

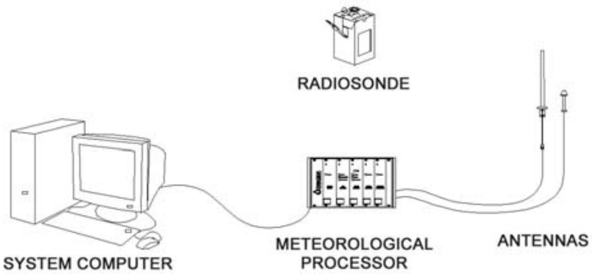

Figure 3: GPS Upper Air Sounding System

Although the diagram looks similar to the RDF version (Figure 2), there are important distinctions that make interoperability much more challenging.

Antennas

403 MHz GPS systems employ two antennas, one for differential GPS and the second for reception of the 403 MHz (UHF) telemetry. In some systems, a third UHF antenna is added to improve overhead coverage. Unlike RDF systems, the receivers (GPS and UHF) are located in the Meteorological Processor (MP), which takes the place of the SPS used in RDF systems. Both the GPS and UHF antennas include Low Noise Amplifiers (LNAs) to boost the signals sufficiently to travel over coaxial cables to the receivers in the MP.

GPS antennas are generally standardized components that can be used with any GPS receiver. Unfortunately, the UHF antennas are not at all standardized, which presents a major barrier to interoperability. Table 2 describes the antenna types currently in use and attempts to characterize their suitability for interoperability.

Table 2: UHF Antenna Types

Manufacturer	UHF Antenna	Interoperable
InterMet	Omnidirectional Dipole	Yes
Sippican	Yagi	Unknown
Modem	Omnidirectional Dipole with optional auxiliary for overhead flights	Dipole: Yes Auxiliary: Unknown
Vaisala	Omnidirectional Dipole (RB22) or Directional (RB21)	Dipole: Yes Directional: Unknown
Graw	Omnidirectional Dipole with helix auxiliary for overhead flights	No: switching circuit required in receiver
Meisei	Omnidirectional	Yes
Meteolabor	Helix	Unknown

For interoperability comparable to what has been described for RDF systems, the GPS and UHF antennas would have to be standardized so they could be used with standard receivers. Alternatively, system vendors would have to provide Interconnect Diagrams (ICDs) so their antennas could be used with MPs made by other vendors. Active UHF antennas that require both power and switching logic will be the most difficult to accommodate.

Meteorological Processor

The Meteorological Processor (MP) used with GPS systems is significantly more complex than the SPS used with RDF systems. The MP typically includes the following hardware elements:

- UHF Receiver
- GPS Receiver
- Decoder
- Power Supply
- Data Converter

The MP is in many ways the heart of a 403 MHz GPS ground system. It is the highest cost element as well as the most specialized. The receivers are designed specifically for the UHF and GPS antennas, which determine both the complexity of the receivers and the number of input connectors.

System Computer

The System Computer for GPS systems is a commercial PC or laptop with no special hardware requirements. The MP and any peripheral equipment (such as ground check systems) are connected via USB ports.

Meteorological Operating Software

The Meteorological Operating System in a GPS system provides the same basic functions as in RDF applications:

- Antenna control and system status
- Met data processing and editing
- Report generation and graphics
- Communications

The main difference with the RDF example comes from the wind finding calculations. In RDF systems, wind finding and PTU are independent. The sonde controls PTU and the ground station manages wind finding. In GPS systems, wind finding and PTU both originate in the sonde and must be controlled by proprietary software.

Many GPS sondes also require a cable interface to program transmitter frequencies and/or provide sensor recalibration before launch. These interfaces also require proprietary software, which suggests that the sonde vendor will have to provide the Met Operating System.

7. Interoperability

Interoperability is achieved in RDF systems by swapping out a relatively low cost SPS and adding whatever software is required in the meteorological operating system to handle any sonde-specific processing. The high-cost system elements (tracking antenna, cabling, system computer, met software) remain in place.

Applying the same model to GPS type systems is not possible due to the incompatibility of the UHF antennas and the need to install the sonde manufacturer's proprietary software in the System Computer. What this implies is that all hardware other than the System Computer (and possibly the GPS antenna) will have to be swapped out in order to accommodate a new radiosonde. This is almost indistinguishable from providing a completely new ground station.

8. Commercial Issues

1680 MHz RDF

Interoperability has been successfully demonstrated in RDF systems. The commercial model calls for the operator to purchase the ground station from one vendor and the sonde and SPS from another. The ground station remains permanently installed while the SPS depends on the sonde in use.

In order to encourage sonde vendors to develop interoperable models, it might be useful for the SPS to be provided as a loan, which would be returned if the operator switched to another sonde. This would reduce the amortization cost of the SPS resulting in a lower sonde price. Alternatively, the operator could purchase the SPS outright, further reducing the sonde price.

As described in the TECO paper[3], the use of interoperable RDF systems can result in ten-year life cycle operating costs that are between 30% and 37% below comparable GPS systems.

403 MHz GPS

In the RDF model, the high cost ground station elements remain in place and only the relatively inexpensive SPS is swapped when a new sonde is introduced. In the GPS case, the MP, Meteorological Operating System and UHF antennas must all be swapped. As noted above, this comprises almost the entire ground station.

Even if the UHF antennas could be standardized, the cost of the MP remains significantly higher (approximately 3 to 5 times) than that of an SPS. To calculate the impact of this on competitive sonde tenders, we can assume that the cost of the SPS or MP is going to be amortized across the number of sondes sold. Assuming that the recurring cost for an SPS is $3,500 compared with $10,500 for an MP, Table 1 calculates the one-year amortization for sites flying one or two sondes per day.

Table 3: 1-Year SPS/MP Cost Amortization

Type	Sondes per Year	Cost per Sonde
SPS ($3,500)	365	$9.58
MP ($10,500)	365	$28.76
SPS	730	$4.79
MP	730	$14.28

Additional costs for providing UHF antennas along with installation and cabling will increase the amortization. The commercial implications of this are that a sonde vendor offering an interoperable package of disposables, MP and software will be at a distinct disadvantage to the vendor who controls the ground station. This could be mitigated by multi-year contracts or the recycling of previously used (fully depreciated) MPs.

9. Conclusions

Interoperability of 1680 MHz RDF systems has been well established in multiple countries using sondes from three manufacturers. The transaction costs of switching sondes are relatively low, encouraging competition in sonde re-orders.

Interoperability in 403 MHz GPS systems is difficult to define since the highest cost elements of the GPS ground station will have to be replaced when sondes are switched. This will result in transaction costs that will give the established vendor a significant (but not insurmountable) advantage.

End Notes

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[1] "Universal Upper Air Sounding System", Rodney D Wierenga Ph.D., Frederick A. Clowney, International Met Systems, 2005

[2] "Dar-es-Salaam Demonstration Test of IMS 1600 Integrated Upper Air System". J. Nash, R Smout, M Smees (U.K.), C. Bower (U.S.), 2005

[3] "Universal Upper Air Sounding System", pp 5-6