1.11 UPPER AIR RAWINSONDE OBSERVATION USING AN INTEGRATED GPS/RDF RECEIVING SYSTEM

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1. INTRODUCTION

The advent of GPS wind-finding technology in the 1990's divided the world of upper air sounding into two camps: GPS systems transmitting in the 403 MHz band and radio direction finding (RDF) systems using the 1680 MHz band. Advantages of 403 GPS systems are a lower initial investment for ground stations and the relative ease of use. Negatives to date are a high failure rate due to GPS dropouts, and the high cost of disposables. These factors have raised the cost of GPS rawinsonde operations, contributing to a decline in active sites and a reduction in upper air data available for meteorologists and climatologists.

International Met Systems has developed a 1680 MHz upper air sounding system that can operate in RDF, GPS or GPS/RDF redundant modes using the 1680 MHz band. The InterMet system uses a tracking antenna combined with an integrated data processing platform and a family of compatible and improved radiosondes to deliver superior performance at a lower operating cost. This approach is designed to significantly reduce flight failures due to GPS failures by providing an improved GPS receiver with redundant RDF wind-finding that fills in for GPS in situations where the GPS data is lost. The system offers the further advantage of allowing user selection of low-cost RDF radiosondes whenever their use is compatible with local upper air conditions. By eliminating lost flights and allowing a mix of high and low cost radiosondes, the InterMet approach aims to reduce the life cycle cost of upper-air observation stations, while giving users maximum flexibility and performance.

Prior to the availability of electronic navigation aids, upper air sounding required the use of optical or radio theodolites to calculate wind speed and wind direction. The introduction of Omega and Loran-C made it possible to measure wind using position fixes at the radiosonde.

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With the increasing affordability of GPS receivers, it appeared that GPS wind-finding would become the standard for upper air soundings. In response, upper air equipment manufacturers introduced a number of GPS based sounding systems transmitting in the 403 MHz meteorological band. These systems deliver high quality wind data but experience two significant problems:

- High failure rates due to GPS dropouts
- GPS receiver costs higher than expected

Having the GPS receiver located in the radiosonde introduces a potential cost driver into the disposable part of the sounding system.

Uncoded GPS receivers being used in some radiosondes offer lower cost but inconsistent reception of data because uncoded GPS receivers have significantly lower gain than coded receivers. Coded receivers offer better reception, but at a higher cost.

High failure rates combined with high radiosonde costs have contributed to a decline in active synoptic sounding sites, particularly in developing countries with severely limited operating budgets. The rapid adoption of 403 MHz GPS systems left site operators with no alternative but to reduce the number of flights since these systems are only able to operate with GPS radiosondes.

2. RDF RECONSIDERED

RDF sounding systems perform best when used at low latitudes where the light upper air winds mitigate the multipath problems encountered at low tracking angles under high wind conditions. 403 MHz GPS systems overcome this weakness but sacrifice RF gain and maximum range.

In 1999, The U.S. National Weather Service requested proposals for an upper air tracking antenna that would use GPS radiosondes operating in the 1680 MHz frequency band. A proposal to adapt its IMS-1500 antenna was submitted by InterMet and selected by the NWS.

The tracking antenna is now known as the Telemetry Receiving System, or TRS. The TRS 1680 MHz tracking antenna increases tracking range and RF gain and keeps upper air operations in the same frequency band in use by the previous NWS systems.

Although InterMet originally intended to use GPS as its sole wind-finding methodology, it became clear that the system's RDF capabilities could add additional benefits. Unlike 403 MHz GPS systems, the TRS is capable of independently generating wind data with the elevation and azimuth angles measured by the TRS and the PTU data measured by the radiosonde. Although the angle and PTU data are not needed for GPS wind-finding, the fact that the angles are used to control pointing of the antenna at the radiosonde offered the possibility of using the TRS in a dual-mode with both GPS and RDF radiosondes.

3. DUAL-MODE SYNOPTIC OBSERVATION

The first advantage of a dual-mode GPS/RDF system is the availability of redundant RDF wind data. By constantly monitoring GPS data transmissions, the system computer can quickly detect problems with the GPS signal. These can be caused by a radiosonde hardware failure or by atmospheric conditions limiting GPS reception. If loss of GPS data is detected, RDF wind data can be used to complete the flight, or fill in accurate wind data until good GPS data resumes. This feature could eliminate lost flights caused by GPS reception problems.

It is noted that the TRS radiosonde includes an atmospheric pressure sensor, as well as temperature and humidity sensors. The three of them can be used to compute geopotential height, which can be converted to geometric height. Height above the WGS-84 reference ellipsoid is provided by GPS. Each TRS site has a GPS base station that is used with the GPS in the radiosonde to differentially correct the GPS measurements. The GPS measurements can be corrected to read geometric height above the geoid, or mean sea level. From the dual-mode perspective, the existence of PTU sensors means that GPS dropouts will not result in the loss of wind data. The availability of two independent height measurements may offer additional benefits for meteorologists and researchers.

The third advantage of dual-mode operation is the ability to use non-GPS radiosondes when atmospheric conditions permit. The decision to use a GPS radiosonde or a non-GPS radiosonde can be based on site location, time of the year or local conditions. This gives users the ability to employ a disposable that can be less than half the cost of a GPS radiosonde. The PTU sensors used in all InterMet radiosondes are identical so the decision on which model to use will not affect the quality or consistency of the data.

4. TRS AND 1500 RADIOTHEODOLITES

InterMet has been under contract with the National Weather Service since 1999 to manufacture the Telemeter Receiver System (TRS) as part of the Radiosonde Replacement System (RRS) program. In addition, we have upgraded our IMS-1500 antenna incorporating key elements of the TRS. The TRS and IMS-1500 are shown in Figure 1.

Figure 1: TRS (Left) and IMS-1500 Antennas

Figure 2 shows the Control Display Unit (CDU) used by both systems. It controls antenna tracking and receiver functions. The CDU is menu driven and housed in a lightweight rectangular metal casing. The width of the casing is such that it is easily held in one hand. An LCD display is mounted in the upper section of the face of the casing. Each CDU incorporates a keypad on the lower section of the face of the casing for numeric and functional operations plus a set of direction controls for slew/level control. The CDU display is a 120 x 64 pixel LCD with backlighting. The keypad consists of 15 keys and 4 direction control keys. The keys are made of molded silicon. They have a full tactile feel and a beep accompanies each keystroke.

Figure 2: CDU

The main TRS and IMS-1500 characteristics are summarized in Table 1.

Table 1: Main Characteristics

TRS	**1500**
1680 MHz	1680 MHz
Installs in radome	Installs in radome or outdoors
2 m fiberglass dish	1.25 m alum rod dish
Solid state scanner	Solid state scanner
Left hand polarized	Vertical polarized
Processor controlled analog receiver	Digital receiver
Max alt – 42 Km	Max alt – 35 Km
Max slant range – 250 Km	Max slant range – 200 Km
UPS – 10 minutes	UPS – 60 minutes
NWS workstation controls antenna	System computer controls antenna
NWS workstation displays weather data	System computer displays weather data

The TRS is designed to operate with a GPS radiosonde; the IMS-1500 is designed to operate in the RDF mode. With a GPS radiosonde, wind is measured by the GPS receiver in the radiosonde. In the RDF mode, wind is calculated using PTU data from the radiosonde together with antenna measurements of the elevation and azimuth angles from the antenna to the radiosonde.

5. ANGLE ACCURACIES

The pointing angle accuracy requirement for the TRS and IMS-1500 for accurate wind calculations is 0.5 degrees RMS in azimuth and elevation with a resolution of 0.001 degrees. Figures 3 and 4 show the measured azimuth and elevation angles on a flight overlaid on the calculated angles from the GPS data. The curves with steps are the TRS measured angles. Because of the high accuracy of the GPS (2 m), it can be used as "truth" when calculating pointing angles. The azimuth and elevation mean errors are 0.0. The azimuth and elevation standard deviations are 0.3 and 0.1 degrees, respectively. The GPS measurements were used for boresighting the TRS, resulting in mean errors of zero.

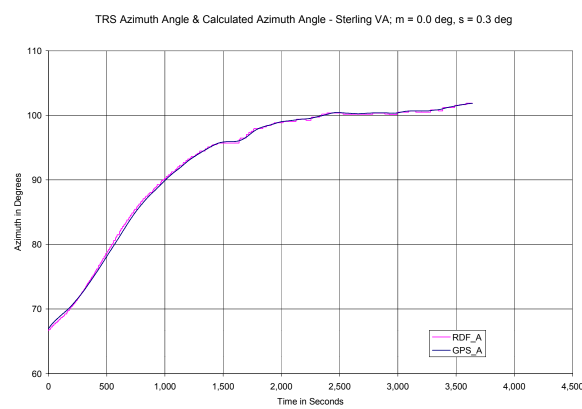

Figure 3: TRS Azimuth Pointing Error

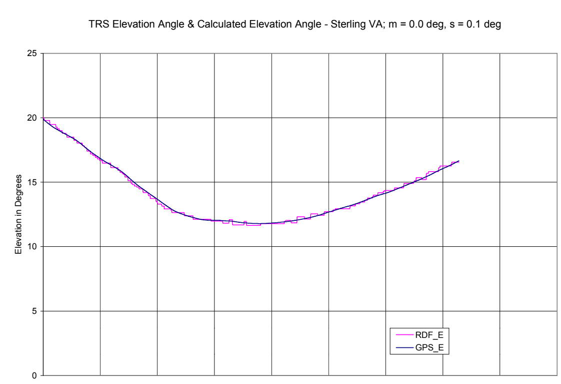

Figure 4: TRS Elevation Pointing Error

6. RDF VERSUS GPS RADIOSONDES

RDF sounding systems perform best when used at low latitudes where the light upper air winds mitigate the multipath problems encountered at low tracking angles under high wind conditions. Because of the high cost of GPS radiosondes, it may be economical to use GPS radiosondes under high wind conditions and use the RDF approach when the winds are low. The TRS could be used this way.

The following is a comparison of annual cost using GPS versus RDF radiosondes. The cost of a 403 system using GPS radiosondes is compared to a TRS system using a mix of RDF and GPS radiosondes. The selection of the mix could be done daily, by season of the year and by region in the world. Costs that are essentially the same, such as the cost of balloons, lifting gas, utilities, and met technicians are ignored. The basic cost model is shown in Table 2.

Table 2: Cost Model

Description	**Range**
10 yr straight line depreciation of initial capital cost	\$3500 (403 GPS) \$10000 (1680)
Maintenance at 2.5% of orig cost per year	\$875 (403 GPS) \$2500 (1680)
GPS less RDF radiosonde cost differential	\$50 to \$100
Flight per year	365 or 730
Lost GPS flights	0 to 30 %

From this cost model, the fixed relative costs and variable relative costs can be computed as shown in Tables 3 and 4.

Table 3: Fixed Relative Costs

Description	**TRS Antenna**	**403 Antenna**
Original Cost	\$100K	\$35K
Years Deprec	10	10
Annual Maint	2.5%	2.5%
Total	**\$12500**	**\$4375**

Table 4: Variable Relative Costs

Description	**All RDF \$**	**All GPS \$**	**All GPS 10% Loss - \$**
RS Cost	70	120	120
\$/yr –365 flts/yr	25550	43800	48180
\$/yr –730 flts/yr	51100	87600	96360

Adding the appropriate fixed and variable costs gives the total relative costs for the 403 system, the 1680 GPS system and the 1680 RDF system. See Tables 5, 6 and 7, respectively. In these tables, the cost per flight is calculated by dividing the total cost by the number of flights per year.

Table 5: Total Relative Costs for 403 System

Descript	**All GPS**		**All GPS 10% Loss**	
	Total \$	**\$/Flt**	**Total \$**	**\$/Flt**
\$/yr –365 flts/yr	48175	132	52555	144
\$/yr –730 flts/yr	91975	126	100735	138

Table 6: Total Relative Costs - 1680 GPS System

Description	**All GPS**		**All GPS 10% Loss**	
	Total \$	**\$/Flt**	**Total \$**	**\$/Flt**
\$/yr –365 flts/yr	56300	154	60680	166
\$/yr –730 flts/yr	100100	137	108860	149

Table 7: Total Relative Costs - 1680 RDF System

Description	**All RDF**	
	Total \$	**\$/flt**
\$/yr –365 flts/yr	38050	104
\$/yr –730 flts/yr	63600	87

Figures 5 and 6 compare the 403 system using all GPS radiosondes to the 1680 system using a mix of GPS and RDF radiosondes with a range of RDF radiosondes from 0 to 100%. Figure 5 shows the comparison with no lost flights due to GPS dropouts. Figure 6 shows the costs with 10% loses in both the 403 and 1680 systems. In each figure, the 403 lines are horizontal since they use 100% GPS (0% RDF). The 1680 end points at 100% (0% RDF) and 100% RDF are from Tables 5 and 6. The break-even points are 23% RDF with 730 flights/year and 45% for 365 flights per year. For 10% GPS loses, the break even points are 18% RDF with 730 flights/year and 36% for 365 flights per year.

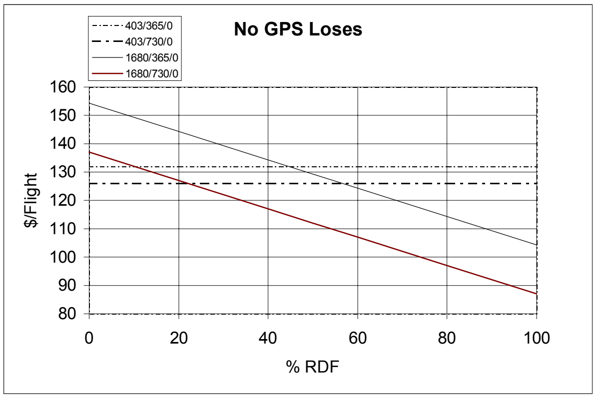

Figure 5: RDF Vs GPS Costs – No GPS Loses

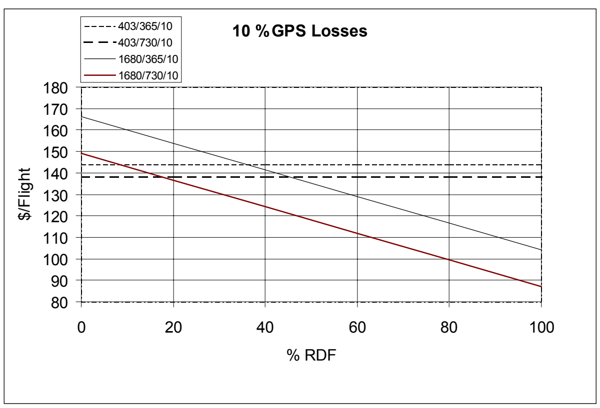

Figure 6: RDF Vs GPS Costs – 10% GPS Loses

Additional combinations of cost differences, percentages of GPS loses, and whether or not GPS is lost with the 1680 system are shown in Table 8. It is noted that the 1680 GPS receiver is a coded receiver with a much greater signal-to-noise ratio than non-coded receivers and is not likely to have loses like the 403 GPS receiver, which is uncoded. The NWS has 102 sites that will use the TRS or IMS-1500, which could use GPS or RDF radiosondes. Table 8 shows the NWS cost savings under various conditions if 50% of the flights are GPS and 50% are RDF. The NWS cost savings range from $100,000 to $6,700,000.

Other combinations can be computed using the data given above. The costs for antennas and radiosondes can be changed and additional trade-offs can be made as desired.

Table 8: Additional Cost Combinations

GPS Less RDF RS $ Diff	% Loss of GPS	1680 GPS RS Loss Too	365 flts/yr		730 Flts/yr	
			Cost Sav per Flt - $	NWS Sav per Yr - $M	Cost Sav per Flt - $	NWS Sav per Yr - $M
50	0	Yes	3	0.1	14	1.0
50	10	Yes	9	0.3	20	1.5
50	30	Yes	21	0.8	32	2.4
100	0	Yes	28	1.0	39	2.9
100	10	Yes	36	1.3	47	3.5
100	30	Yes	53	2.0	64	4.8
50	0	No	3	0.1	14	1.0
50	10	No	15	0.6	26	1.9
50	30	No	39	1.5	50	3.7
100	0	No	28	1.0	39	2.9
100	10	No	45	1.7	56	4.2
100	30	No	79	2.9	90	6.7

7. CONCLUSIONS

The InterMet tracking antennas allow synoptic sites to use GPS radiosondes under high wind conditions and use RDF radiosondes under all other conditions. This approach offer significant cost savings over current GPS systems.