Review of progress in the development of operational upper air technology.

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This paper provides a brief review of progress with operational Upper Air Technology, considering radiosonde systems, wind profilers, microwave radiometers and GPS water vapour.

1. Introduction

The main aim of many operational meteorological services at the present time appears to be reducing expenditure on ground based upper air measurements. Radiosonde consumable prices are generally considered as too high, although in real terms they may not have increased very much, given the very large improvement in measurement, processing and transmission technology applied in the latest systems.

The latest radiosonde designs produce measurements of much better quality than earlier designs, so it becomes more important to follow the manufacturer's guidance on preparation in order to ensure the best quality measurements. Modern hydrogen generators appear more reliable in operation than predecessors and can readily generate enough hydrogen to fill even large balloons (1200g) so that it should be practical to fly large balloons at a reasonable number of sites in the tropics without excessive expenditure.

Ground based remote sensing offers the chance of measurements at very high temporal resolution at a given site, for instance modern wind profilers and microwave radiometers can produce observations at 10 minute intervals compatible with the traditional sampling periods of surface measurements. Thus, in terms of number of observations per day the systems appear good value for money, if the operational meteorological services have a use for this number of measurements.

However, are these systems largely developed with research interests in mind and not operational applications? Is current development taking the systems towards improved usefulness for research or improved suitability for operations?

Are operational meteorologists hindering progress by failing to agree on suitable specifications for future observing systems? or by failing to provide the long-term investment in terms of skilled staff with expert meteorological insight who can work with the manufacturers developing equipment?

With a system like GPS water vapour measurements, large amounts of research have been taking place, but the system is not yet really used operationally by many meteorological services. This is probably because ingesting the measurements into existing numerical weather prediction models has produced results with varying success. In some countries the magnitude of benefits achieved has not yet justified the considerable costs that can be associated with accessing GPS data in near real time.

Currently most operational upper air wind and temperature measurements from large commercial aircraft are close to radiosondes measurements in quality. In the US relative humidity measurements are starting to become available in real time operations. On the other hand aircraft measurements are not available and will not be available from a large number of sites where upper air observations with high vertical resolution are required.

Thus, radiosondes and ground-based vertical sounding still have a viable future. On the other hand, network planners should take into account that the ground-based systems could lose commercial viability or face even more price increases in the future if the market size for the systems remains relatively small (wind profilers?) or the current market size is drastically reduced (radiosondes).

2. Progress with radiosondes

Modern radiosonde systems are much more sophisticated systems than the best radiosondes in use 20 years ago.

The best systems now have small temperature sensors that have rapid time constants of response so solar heating in the daytime is less than about 1 K at 10 hPa, and a simple correction scheme can be expected to produce temperatures with final errors less than 0.5 K in all circumstances. The use of aluminised sensors eliminates strong coupling to the infrared radiation fields allowing relatively uniform sensor performance around the world, independent of temperature structure. The temperatures at night from the better radiosondes should agree at all levels to within about 0.3 K.

Errors in height/ pressure used to be the limiting factor in stratospheric temperature in the tropics , but this can now be overcome by using GPS height measurements, see the results from the WMO Radiosonde Comparison in Mauritius. Thus, GPS radiosondes should no longer need to use a pressure sensor and this should lead to a reduction in the cost of GPS radiosondes.

Up to ten years ago the better quality radiosondes would only give consistent comparison results in dry conditions and very few worked reliably at temperatures lower than -40 deg C. In wet conditions very large persistent errors of greater than 20 per cent relative humidity were often found above cloud. Now, nearly all modern radiosondes are using capacitative relative humidity sensors. These can give reproducible relative humidity measurements down to temperatures of -70 deg C [height 14 km in the tropics]. Some of these modern radiosondes can now produce reliable relative humidity measurements in both wet and dry conditions.

Wind measurements with the new generation of code correlating GPS wind systems are much more accurate than any of the earlier operational wind systems. The capability of GPS radiosondes has been improved so that systems are now available that synchronise rapidly during radiosonde preparation with minimal requirement for exposure outside before launch.

The new generation radiosonde transmitters are much more stable in frequency and as such cannot be criticised by the ITU for wasting radiofrequency spectrum. This also leads to very good data reception in the ground system with relatively low power radiosonde transmissions.

Ground systems associated with GPS radiosondes have become so small that it is easy to transport them around with minimal time necessary for installing an upper air station.

At this time a large scale changeover to the new generation radiosondes is starting to occur in the global network. This has caused problems since although the radiosondes are much superior to the earlier radiosondes; many customers are reluctant to pay the cost associated with upgrading. In this situation it is clear that the main manufacturers need to upgrade to modern components and manufacturing technology to minimise the cost of production. On the other hand, the customer cannot be expected to endlessly pay out for upgrades in equipment, particularly when the equipment was purchased as perfectly adequate only a few years ago. Thus, it is to be hoped that suitable arrangements can be made which minimise the costs involved to both manufacturer and customer.

A second problem involves those countries that do not wish to buy from the main commercial manufacturers, but wish to use national resources to produce radiosondes. Monitoring results for the global radiosonde network readily demonstrate that these countries lag behind in radiosonde measurement performance, particularly with respect to relative humidity measurements and in some case even with temperature. The continued existence of this very large gap in observing system performance is a major obstacle to progress in upgrading the global radiosonde network. Unfortunately, any actions to remedy the problem have not yet been effective. There remains a challenge to CIMO to devise better methods of encouraging progress, since this is not a problem caused by insufficient technical capability in the nations concerned.

2. Wind profilers and Doppler weather radars

The use of operational wind profilers has been expanding most rapidly in Asia where since 2001 Japan has installed a network of 31 profilers observing from near the surface to about 5 km in dry conditions and 8 km in precipitation [Ishihara, 2005], see Fig. 1(a) and (b) This network operates well and delivers the measurements required, i.e. wind in the lower and middle troposphere, for numerical weather prediction in Japan. The frequency used is in the range 1300-1375 MHz. Fig.1 (c) shows an example of wind measurements on a day when the centre of a typhoon passed close to one of the small island wind profiler sites, with winds as high as 60 ms^{-1} reported at a height of 1.5 km. Given that wind profilers can operate well in these conditions as long as the power supply and communications can be maintained, it is surprising that more systems are not deployed for observing conditions in these types of storms in other parts of the world.

In contrast to Japan, the main new wind profiler developments in Europe have been in operational systems designed to observe from near the surface to heights above the tropopause. In Germany 2 new generation profilers, operating at around 482 MHz

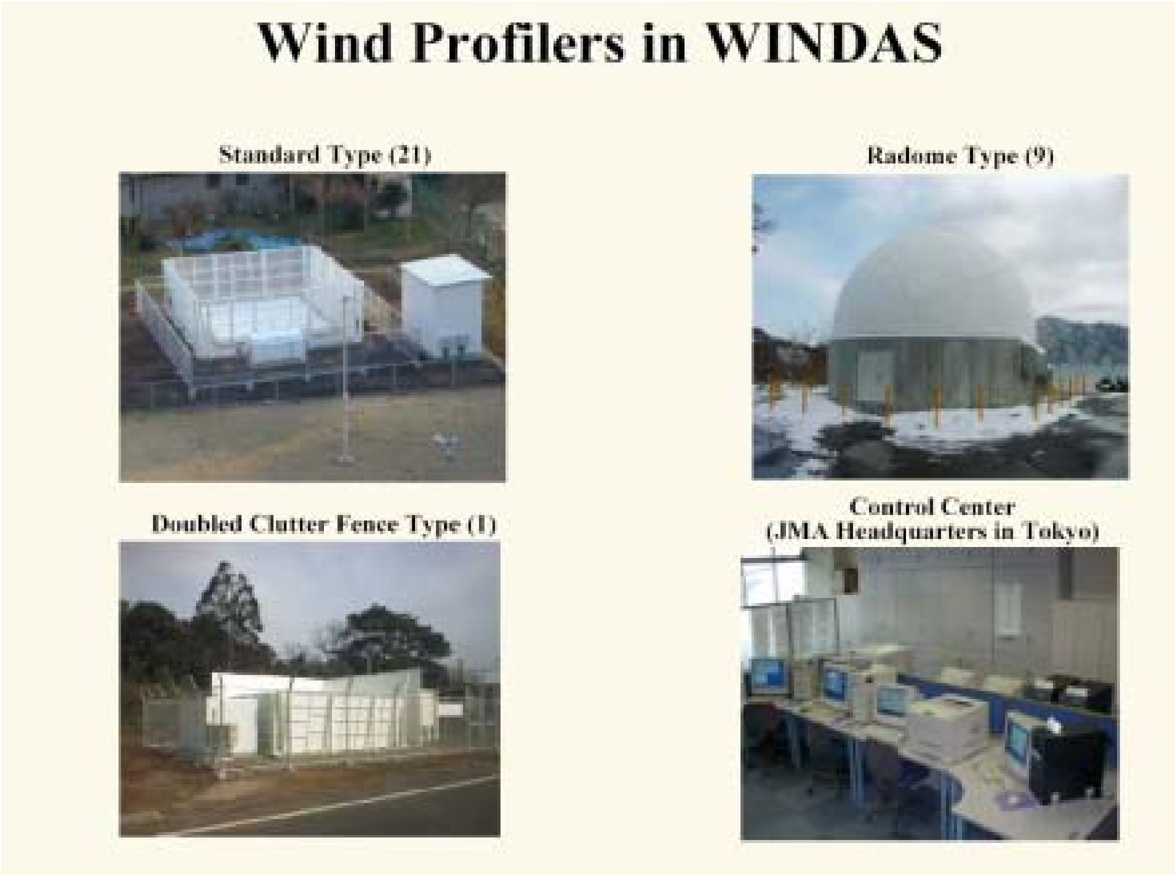

Fig.1(a). Different types of wind profiler installation in the JMA wind profiler network plus the control centre in Tokyo, extracted from Ishihara [2005]

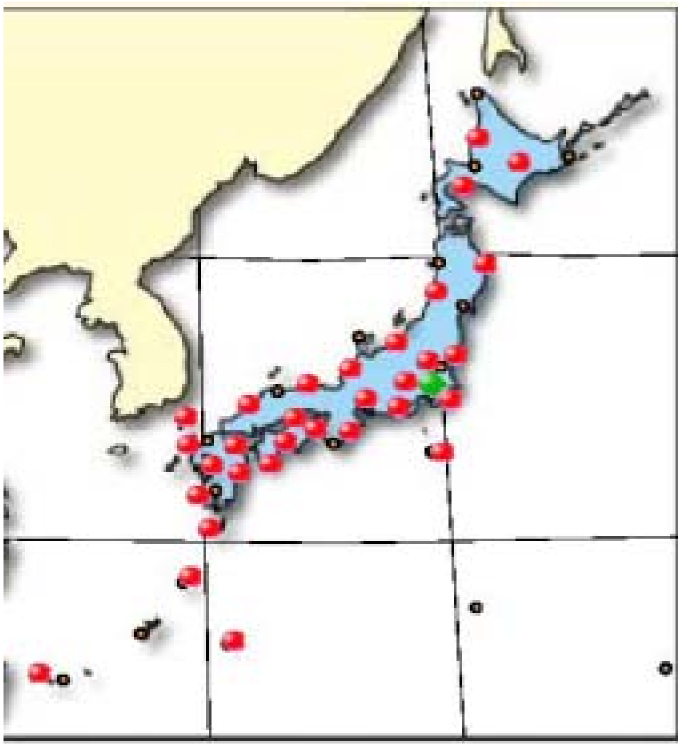

Fig.1(b) Map of wind profiler sites in the WINDAS network , extracted from Ishihara[2005]

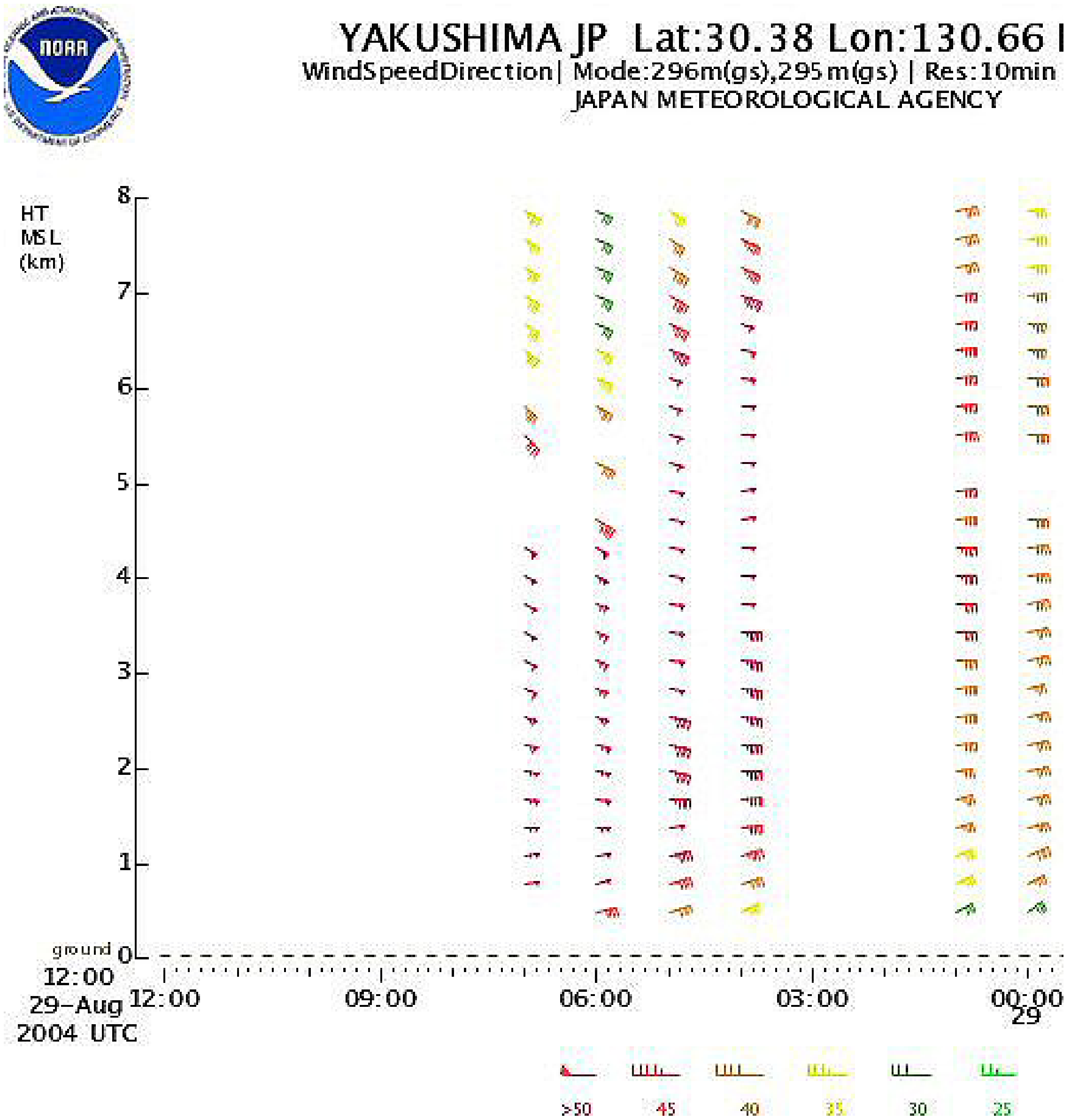

Fig.1 (c) Wind profiles measured by JMA wind profiler as typhoon approaches mainland Japan on 29 August 2004, extracted from NOAA-NPN archive.

have been installed and are in satisfactory operation, see Fig.2 (a) for a picture of the system at Nordholz. The measurement coverage in the vertical in the upper mode of this system can be seen in Fig.2 (b). The winds at 12 km show plenty of variation during the day, and these variations will become more important as numerical weather prediction attempts to represent smaller scales of atmospheric motion. Of course, if there are plenty of aircraft flying over the area day and night then expenditure on a profiler with this capability may not be justified. The profilers in Germany have excellent signal to noise characteristics and probably represent close to optimum in the measurement quality that can be obtained from an operational wind profiler, see Fig.3.

Fig.2(a) Deutsche Wetterdienst 482 MHz wind profile +RASS installed at Nordholz.

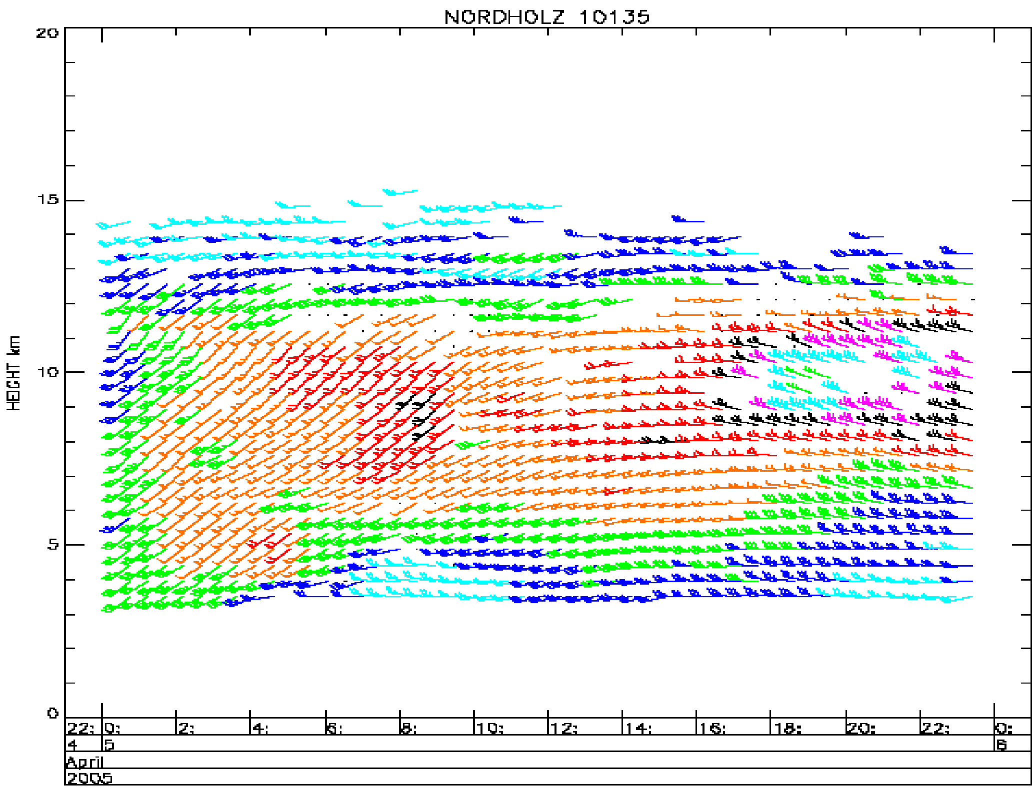

Fig.2(b) WINPROF[CWINDE] hub monitoring display of time-height display for winds from 5 April2005

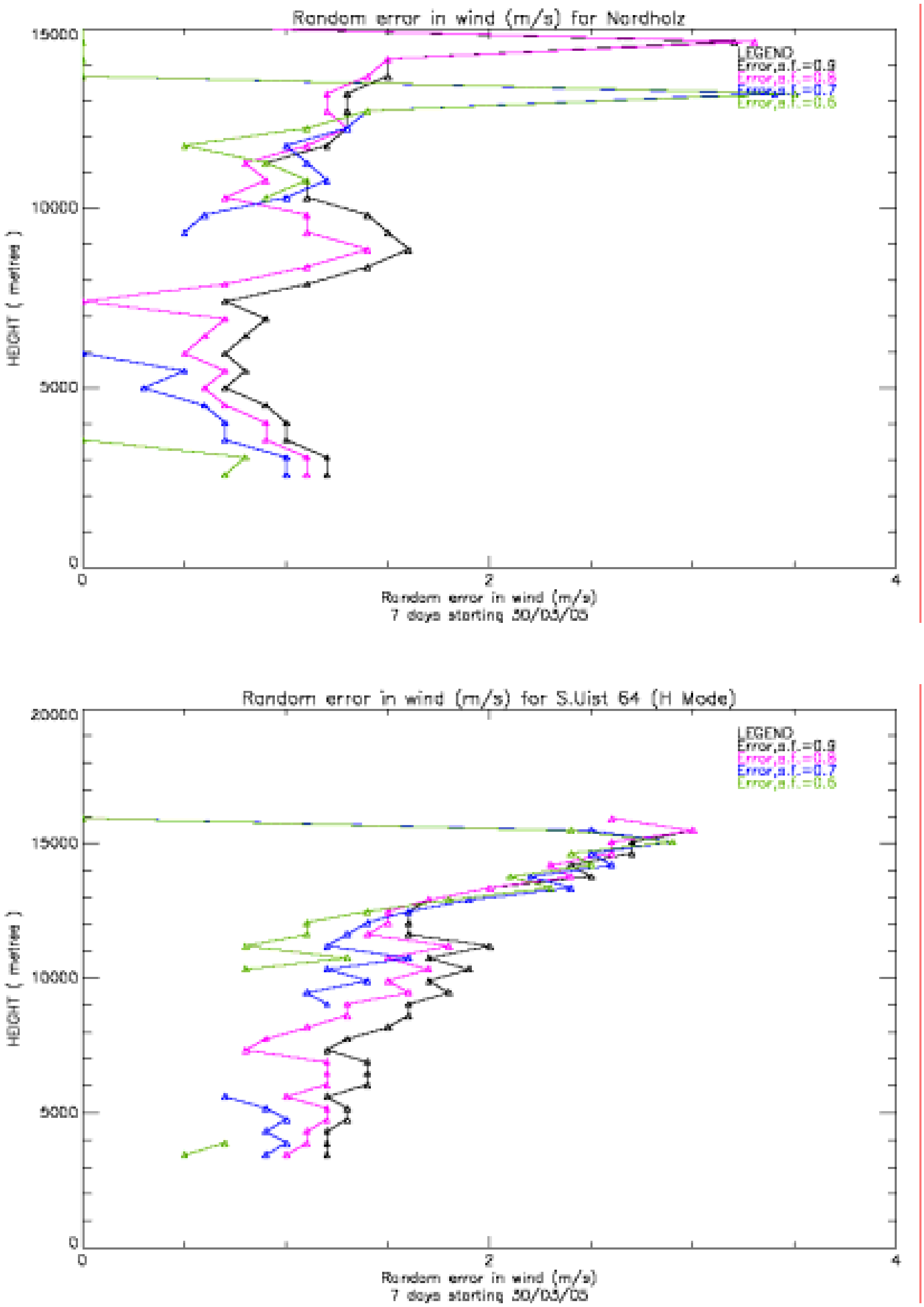

Fig.3 Comparison of random error estimates from the Nordholz [Germany] and South Uist [UK] wind profilers produce by the WINPROF [CWINDE] monitoring hub.

Fig.4 Operational wind profiler observing at 64 MHz on the island of South Uist.

Fig.4 shows a profiler installed with a similar purpose to the systems in Germany, but with a more tolerant specification on acceptable wind error. This is on an island to the west of the Scottish mainland, where in wintertime there can be extremely violent storms. Although much of the internal electronics and software is similar to the systems in Germany, a different antenna design was chosen because of the need of the antenna system to be very resilient against corrosion from driven rain, with the system very close to the sea. Although the concrete foundation for the Yagi antenna was expensive, the overall cost of this system was much less than the systems in Germany. Even so, it is still very expensive and will require a very strong business case to justify expenditure on many more systems. At 64 MHz, it has been found essential to use multipeak identification software in processing the results from the Doppler spectra, whilst this type of software is not required with the Germany systems. Thus, although the UK and Germany tried to keep to a similar specification for these wind profilers, in practice the systems have diverged because of the different operating conditions. The UK system has less ongoing problems with radiofrequency sharing, but the German systems having fewer problems with ground clutter.

Fig 5(a) shows an alternative solution to the more expensive wind profilers , where a 1290 MHz system is deployed at Zurich airport by MeteoSuisse for a development project. This system has been assembled from spares available to MeteoSuisse and Deutsche Wetterdienst, with a clutter screen devised by Meteo Suisse, avoiding the expensive option of purchasing the manufacturers clutter screen.

Fig.5(a) Temporary installation of Meteo Suisse-DWD wind profiler at Zurich airport.

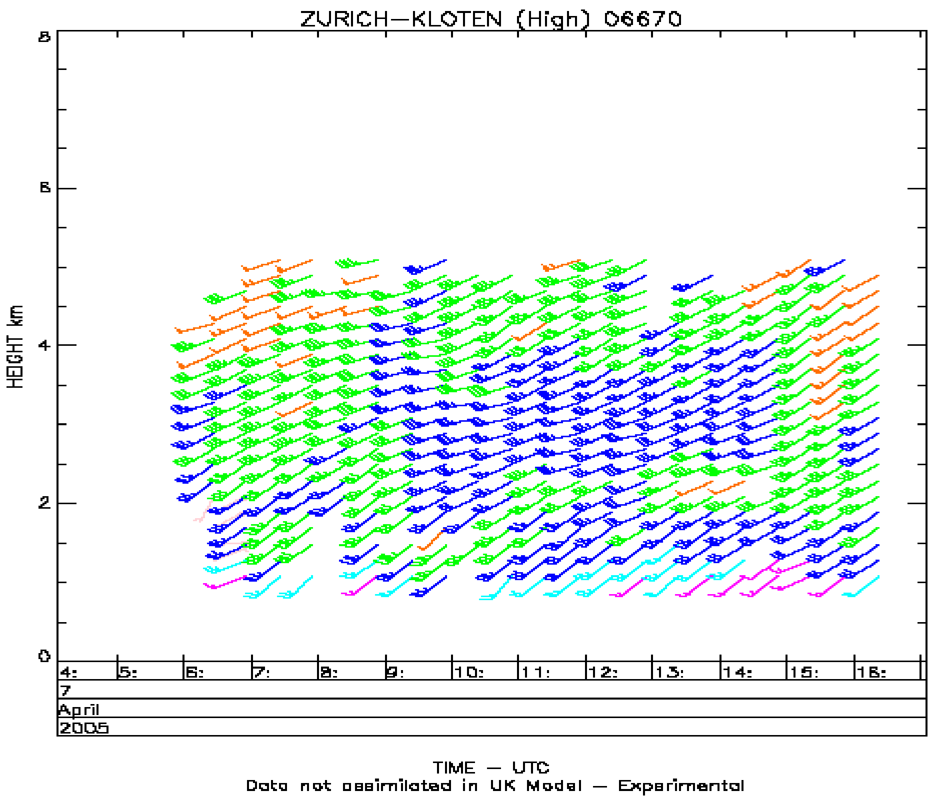

Fig.5(b) WINPROF[CWINDE] hub monitoring display of time-height display for Zurich winds from 7 April2005

The wind measurements at Zurich are again of acceptable quality, random errors of 2 ms^{-1}.

In the US, the conversion of wind profilers in the NOAA-NPN from 400 to 449 MHZ continues. It is unfortunate that some countries are still trying to design new wind profilers operating in the 400 to 406 MHz band. This design of new systems was specifically forbidden by the ITU when granting the current allocations for wind profilers.

NOAA is making efforts also to assimilate winds from at least 80 cooperating sites (with different types of profilers, as in Europe). A new 449 MHz profiler intended to be cheaper than the full scale NPN profilers and only observing at heights up to 8 km has already been supplied to a limited number of sites.

Are wind profilers only to be used for measuring at heights below aircraft cruise levels in future, or are there sufficient locations where observations will be required to heights above 12 km to justify economic production of the larger systems? What is the necessary accuracy requirement for acceptable observations?

The costs of some of these large profiler systems are coming close to the cost of modern Doppler weather radar. Fig.6 shows VAD wind outputs from weather radar in Finland

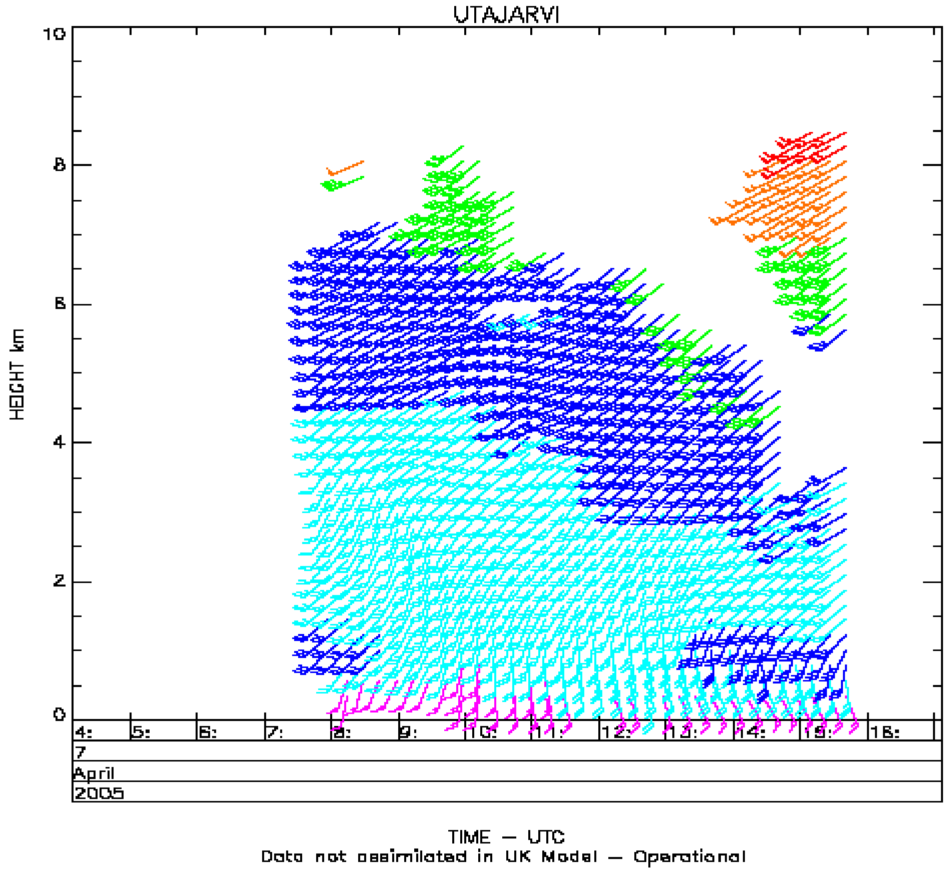

Fig.6 WINPROF[CWINDE] hub monitoring display of time-height display for Utajarvi winds on 7 April 2005. Here the failure to assimilate the data in the UK model is not related to poor measurement quality on this day.

Network planning for the future also needs to take into account the availability of winds from Doppler weather radar systems. These radar winds are now being used in numerical weather prediction.

3. Microwave radiometers

RASS systems provide a method of measuring profiles of virtual temperature in the atmosphere, but in many countries it is difficult to find sites where the noise from the systems is not accepted by the local population or the noise attracts attention to the position of the ground based remote sensing installation and then vandalism occurs.

Multichannel microwave radiometers have been available for ground based remote sensing of temperature and water vapour for many years. They offer the option to measure temperature in the lower troposphere, integrated water vapour plus an indication of the vertical structure of relative humidity in the lower troposphere, liquid water in cloud and some indication of cloud base height if an upward pointing infrared radiometer is incorporated with the system. As with wind profilers, the cost of radiometers was not cheap. However, in recent years efforts have been made to design the systems so they can be manufactured in a more cost-effective manner, and the prices have fallen significantly.

In late 2004 two systems were compared in Camborne, both being able to observe the atmosphere sufficiently quickly to resolve the effects of cloud moving rapidly over the observing site. Fig.7 shows how the scan rates of the Radiometrics MP3000 have increased since January 2002. Radiometers with this observing capability were not available commercially five years ago.

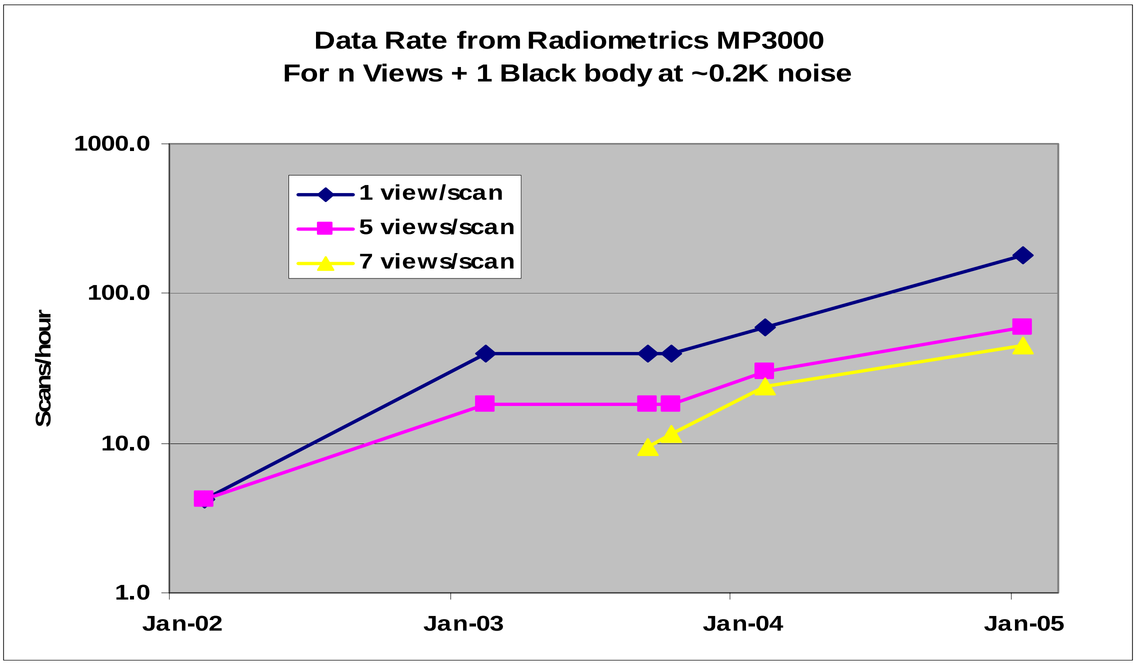

Fig.7 Increase in the scan rates available with the Radiometrics MP3000 microwave radiometer.

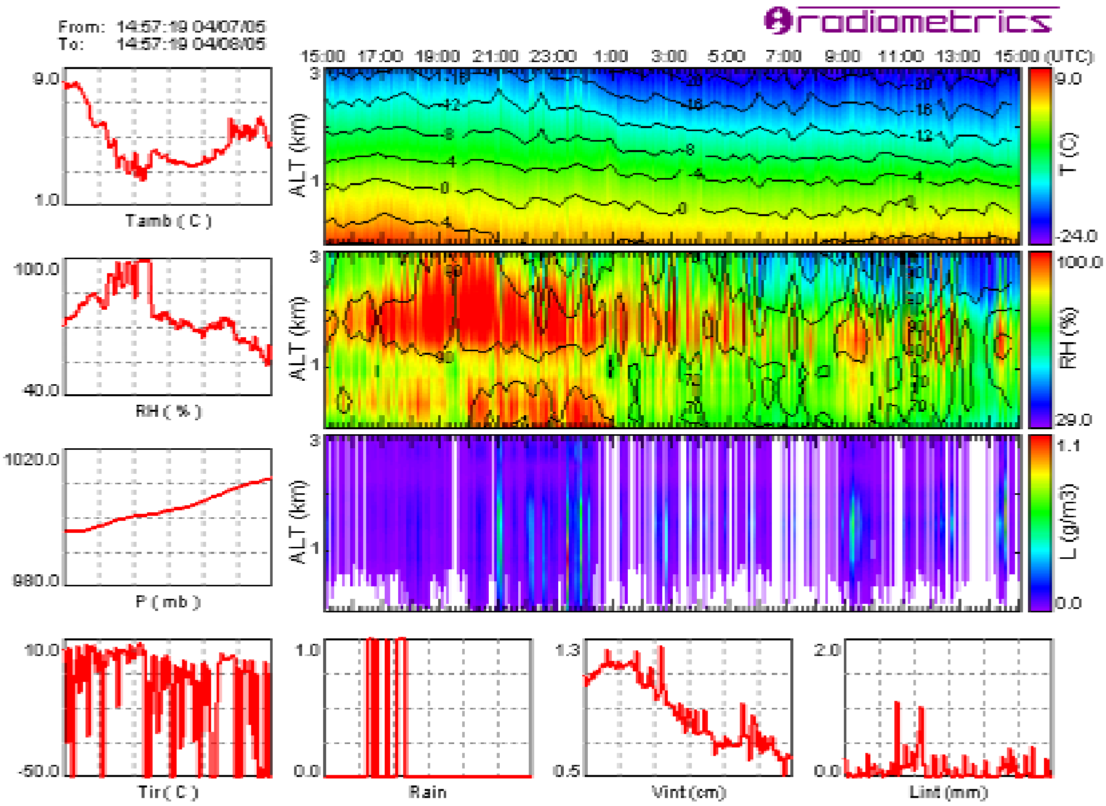

Fig. 8 Time height displays of high resolution temperature , relative humidity and cloud measurements observed at Camborne during a 24 hour period from 14.57 on 07 April 2005 [long displays, upper right side]. Displays against time in[other boxes working anticlockwise from top left hand side are surface temperature, surface relative humidity, pressure, infrared temperature, presence of rain, integrated water vapour, and total liquid water in cloud..

The comparison at Camborne identified problems in calibration and noise with the two radiometers, but it is expected that these will be rectified before further tests this year. Both systems seem to be able to make measurements in situations with drizzle and light rain where earlier radiometers could not produce reliable measurements.

4. GPS measurements of integrated water vapour

Whilst there are several Internet sites where real time measurements of integrated water vapour can be accessed there are relatively few countries where the system has been handed over from the scientists to be run as a standard part of operational observing. The COST 716 project in Europe looked at the use of the data and produced estimates of the true costs of setting up an operational system, see Elgered et al [2004]. Costs of installing the sensors are not negligible for a closely spaced network, and even where large number of sensors have been installed for other purposes it may be difficult to get cheap real time access to the sensors for operational purposes. In the UK there was a relatively small network of GPS sensors during the COST 716 demonstration, but in the last year this has increased as a consequence of a memorandum of understanding between the Met Office and the Ordnance Survey, the UK government mapping agency. The Ordnance Survey are installing sensors on some Met Office automatic weather station sites and in return are getting access to real time data from the whole of the mapping agency network . Fig.9 shows an example of the coverage of IWV that is now being processed in real time for the Met Office.

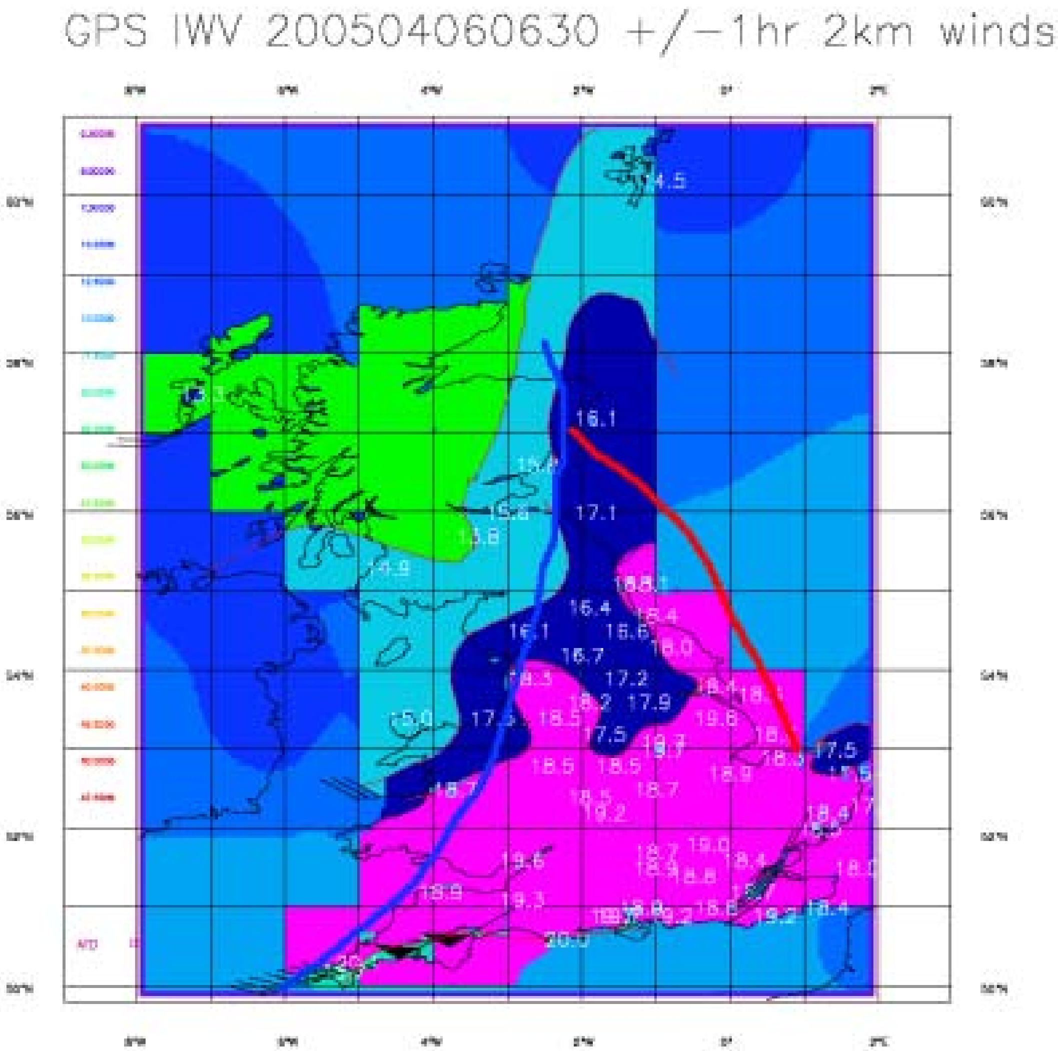

Fig. 8 IWV field averaged over one hour derived from about 70 sites across the UK, mostly owned by the Ordnance Survey, processed in collaboration with IESSG, Nottingham University. This plot was derived in real time, with a delay of about 30 minutes after the end of the sample period. IWV values are contoured at 2 kg. m^{-2} intervals wind, with the winds taken from the UK wind profilers at 2 km.

It is probable that to obtain most benefit from the water vapour measurements it is necessary to ensure that the atmospheric motions on the scales observed with the GPS system are accurately represented in the model. Thus, it will be essential that upper winds are available on the necessary scales and assimilated correctly.

In summary GPS water vapour measurements are not as cheap as was originally claimed. However, it does seem apparent that useful information for meteorology can be obtained at suitable cost by negotiating sharing arrangements with other government agencies. If these systems are to be used in the tropics it may be necessary to organise centralised regional processing and distribution of the data in future.

References:

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Ishihara, M.(2005) Wind Profiler network of Japan Meteorological Agency: document 4.3.2, CIMO Expert team on Remote Sensing Upper-Air Technology and Techniques, 16-17 March, Geneva, available on WMO web site: http://www.wmo.int/web/www/IMOP/IMOP-home.html