Quantitative Assessment of Improved Spectral Moments Selection Algorithms on an Operational 64 MHz Clear-Air Doppler Wind Profiler

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Abstract

In May 2003 the UK Met Office installed a tropospheric radar wind profiler on South Uist Island in the Outer Hebrides, Scotland, in conjunction with its upper-air modernization program. The wind profiler was acquired to provide upper-air data in conjunction with the decommissioning of a WMO radiosonde station at Stornoway, Scotland.

The Met Office's development team undertook extensive operational reliability and data quality verification program prior to transferring the system to the production branch and declaring the system "operational". This verification program generated an abundant data set that was used to assess several signal processing techniques that have been emerging from the research community over the past several years.

This paper discusses the evaluation methodology and contrasts data quality and system performance between widely used Profiler Online Processing (POP) software, which was originally developed by the National Oceanic and Atmospheric Administration (NOAA), the Swiss Federal Institute of Technology (ETH) developed multiple peak picking algorithm (MPP) and the National Center for Atmospheric Research (NCAR) developed Improved Moments Algorithm (NIMA).

Wind Profiling Radar

The Met Office, in support of observational upper-air measurements, acquired the Vaisala LAP®-12000 Doppler wind profiler used in this evaluation. The profiler was designed to function remotely and reliably under the extreme environmental conditions of South Uist Island, and deliver 90% data recovery to altitudes of at least 12 km. The wind profiler operates at 64 MHz and is the first Vaisala manufactured VHF wind profiler system deployed within Europe.

The system integrates the Vaisala digital IF receiver and LAP®-XM software with antenna and final amplifier subsystems produced by ATRAD, PTY (Adelaide, Australia). The antenna array (Figure 1) is composed of 144 Yagi-Uda antennas with a footprint of approximately 1100 m^2. The digital IF electronics, beam steering unit, T/R switches, high voltage power supply and final amplifiers are housed in two electronics cabinets located inside an environmentally controlled facility (Figure 2). The final amplifier, which consists of six vacuum-tube modules, operates at a maximum 3% duty cycle producing an maximum average transmit power of 1.8 kW.

Data Collection

The Met Office collected data used for this evaluation from 15 to 20 August 2003. The wind profiler was operated in two modes with 30-minute consensus averaging. The low mode utilized 36 range gates from 1000 to 6200 meters altitude and employed 150-meter vertical resolution. The high mode utilized 30 range gates from 3400 to 16000 meters and used 400-meter resolution. Averaged spectral data from the wind profiler were continually archived during this period.

Thirty-three independent radiosonde soundings were also collected during the same period by the Met Office at nominal two-hour intervals between 0530 and 1500 hours daily and used as verification data. The rawinsonde data were collected from a site located approximately five kilometers from the wind profiler using a Vaisala MARWIN ground station and RS-90 radiosondes.

Figure 1 LAP®-12000, 64 MHz antenna array

Figure 2 LAP®-12000 Profiler Electronics

The wind profiler data collected during the evaluation period is presented in Figure 3. Comparison data periods used in the evaluation are also illustrated in Figure 3 as vertical white (radiosonde) and red (wind profiler). The data gap on August 17, 2003 resulted from an AC Mains power problem that was promptly corrected, allowing data collection to continue without further incident.

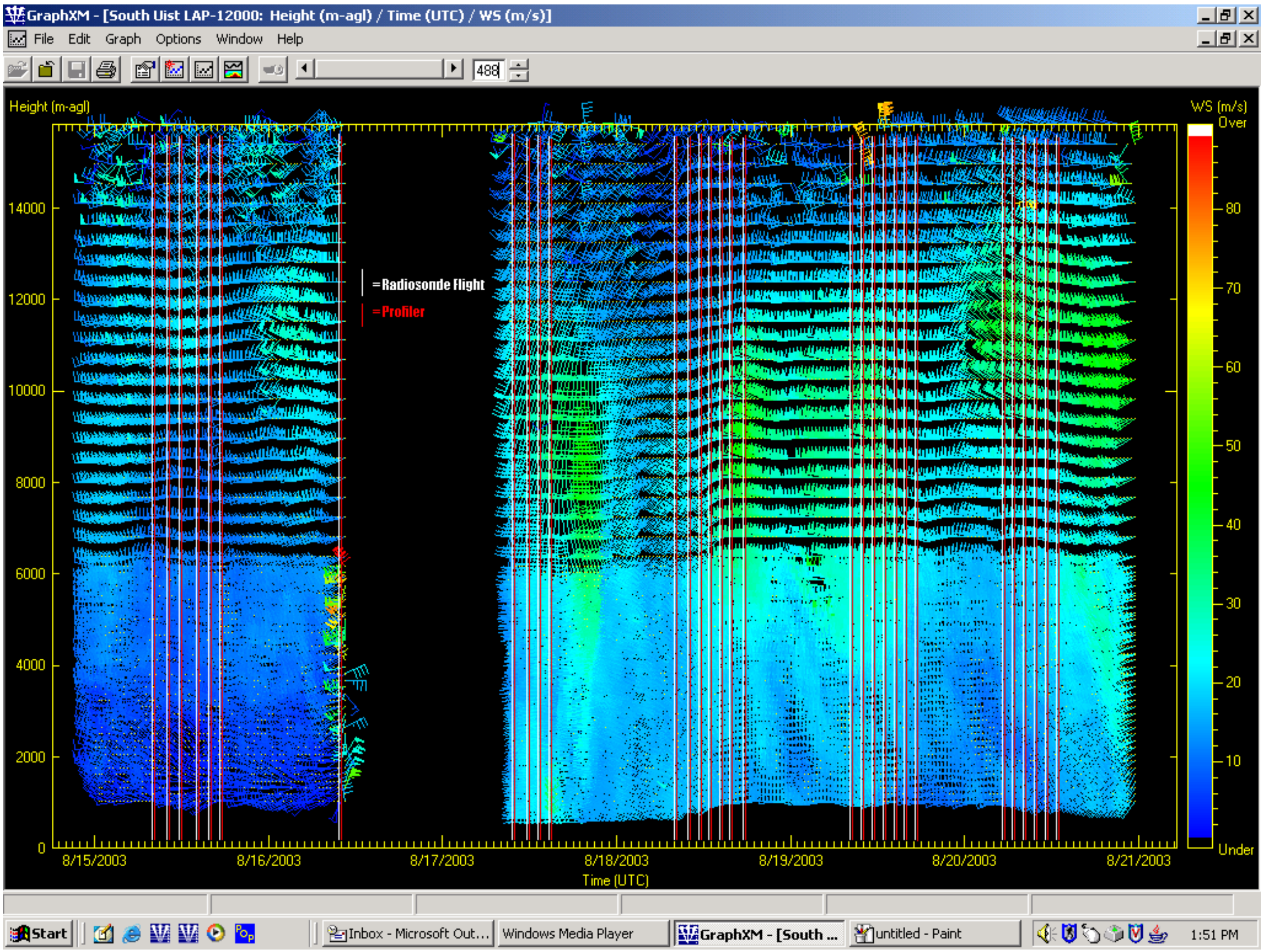

Figure 3 Wind Profiler data shown with radiosonde sounding periods used in the evaluation. Low and high mode wind profiler data are superimposed.

Signal Processing

Spectral data collected during the experiment were processed off-line with three different moments algorithms to compare the quality and availability of their result. The algorithms analyze the power spectra to estimate the noise level, the Doppler velocity and width of the atmospheric echo signal. These parameters are called the moments of the radar spectrum. The Doppler velocities estimated with each algorithm are converted into (u, v, and w) wind components and then into wind speed and direction for each measurement altitude with a standard procedure.

Cornish[1] and Woodman[2] describe a widely used moments selection method for averaged spectra. This method was used in the NOAA developed Profiler Online Processing (POP), and is a standard module in Vaisala wind profiler software LAP®-XM. Estimates of the noise level are calculated using Hildebrand-Sekhon method[3]. The strongest signal in the spectrum is assumed to originate from the atmospheric signal. The moments (power, Doppler velocity and width) of this signal are estimated using an integration method.

The ETH Multiple Peak Picking algorithm (MPP)[4] is an enhanced spectral analysis tool to increase data recovery and to discard wrong signals from radar data. The algorithm uses time and height continuity scores to select the best atmospheric echo candidates, and identifies 2-dimensional echo profiles with a fuzzy logic iteration process. Examples comparing the POP and MPP moments selection with stacked spectra are presented in Figure 4 and Figure 5. The MMP algorithm was developed at ETH and further improved in Vaisala, including an RFI interference detection algorithm. MPP is an alternative processing method available in Vaisala wind profiler software LAP®-XM. The MPP method is configurable, but a default configuration parameter set was used in this analysis.

The NCAR Improved Moments Algorithm (NIMA)[5] is a stand-alone program, which uses mathematical analysis, fuzzy logic synthesis, and global image processing algorithms to mimic human experts' ability to identify atmospheric signals in the presence of contaminants. Results from NIMA are presented with a confidence value indicating the plausibility of the result. NIMA is configurable and can be tuned to optimize performance for a given profiler site. For users who wish to use this moments processing method, Vaisala offers a NIMA network workstation.

Evaluation Methodology

The radiosonde winds were used to compare the profiler winds produced by POP, MPP, and NIMA moments processing techniques. High and low mode data were segregated and independently evaluated. Radiosonde data were averaged in height to correspond to the 150-meter and 400-meter resolutions of the wind profiler data.

Differences in wind speed and wind direction of 5 m/s and 40°, respectively, between the radiosonde and profiler data were identified as "outliers", and were removed from this comparison as an objective quality control. Root-mean square (RMS) and data recovery statistics were computed to evaluate performance differences between POP, MPP, and NIMA. A 0.5 confidence level threshold was used to define NIMA-derived winds in this analysis[6].

MPP Data Recovery Results

Figure 6 through Figure 9 present data recovery plots for POP and MPP-derived validated winds for both low and high mode, respectively.

Low Mode

Figure 6 shows the percent data recovery rate for low mode with and without implementation of MPP. Overall, POP signal processing produced relatively high data recovery rates within the low mode. The only significant data recovery reduction was observed above 5.5 km, at the uppermost levels of low mode.

Figure 7 presents the data recovery changes between POP and MPP moments processing. While MPP produced small data recovery reductions in approximately 17% of the measured range gates, 50% of the range gates experienced 5% or higher data recovery increases. This increase was most pronounced at the uppermost range gates where data recovery increased to as much as 15%. This illustrates that the MPP algorithm improved signal processing over POP, especially in its ability to extract winds in regions of weaker atmospheric returns.

High Mode

The effect of MPP moments processing is more pronounced in high mode, where weak signal returns are more typical, and where this data set included some strong RFI disturbances. Figure 8 and Figure 9 show that data recovery improvements were observed in 93% of the range gates. The improvements ranged from 5% within the lower portion of this mode to as high as 40% at 15 km. These data clearly demonstrate the MPP algorithm superior moment processing compared to POP and its ability to extend the system's 90% data recovery performance to 14 km, beyond the 12 km specification.

MPP RMS Analysis Results

RMS values of the wind speed, v- and u-component for both POP and MPP moments processing are presented in Figure 10 for both high and low mode. This figure shows that MPP improved the overall measuring accuracy of the wind measurements over POP in virtually all of the data stratifications. Figure 11 shows that magnitudes of the improvements are quite small, however, with a maximum RMS error reduction of 0.073 m/s in low mode.

Figure 12 and Figure 13 show the RMS improvements of the u-component, v-component and wind speed, respectively, as a function of altitude for both low and high modes. Interestingly, the largest reduction of RMS values due to MPP occurs at the altitudes coinciding with the contribution by the MPP algorithm to increased data recovery. This analysis shows that MPP improves overall data recovery without sacrificing measuring accuracy, a feature that has been observed in other moments signal processing techniques where expert-based interpolation schemes are sometimes employed.

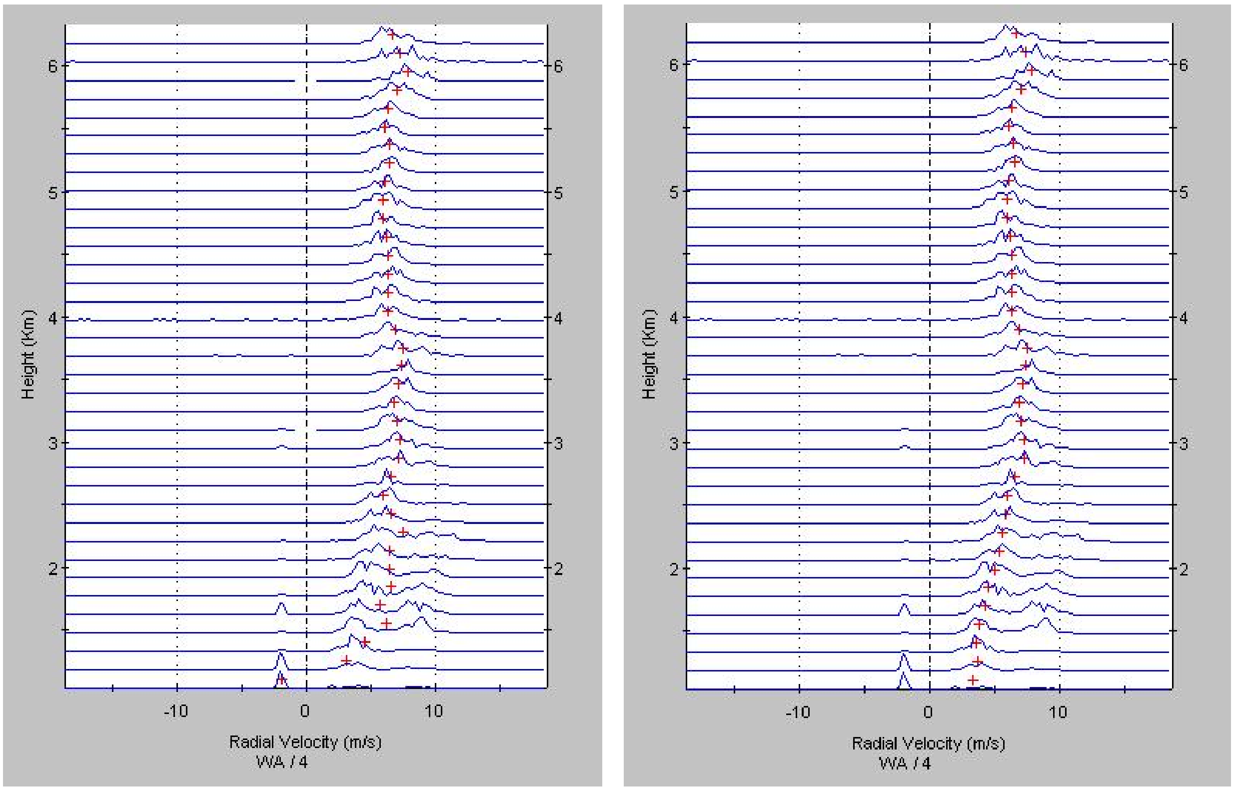

Figure 4 Stacked power spectra examples from the low mode. POP estimates of the radial velocities (left) are disturbed by interfering signals from precipitation below 2.5 km. MPP estimates (right) use continuity conditions to find the most plausible profile.

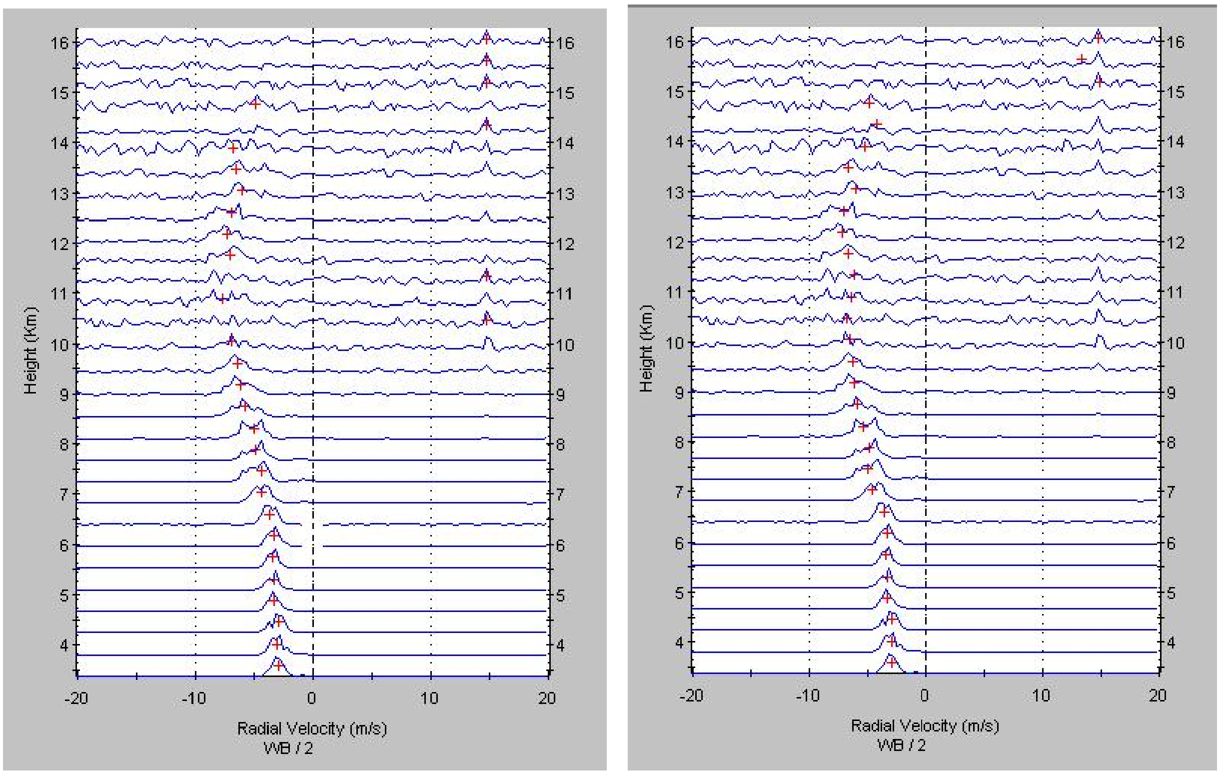

Figure 5 Stacked power spectra, example from the high mode. POP estimates of the radial velocities (left) are disturbed by RFI signals above 10 km. MPP estimates (right) are able to recover the correct profile up to higher altitudes.

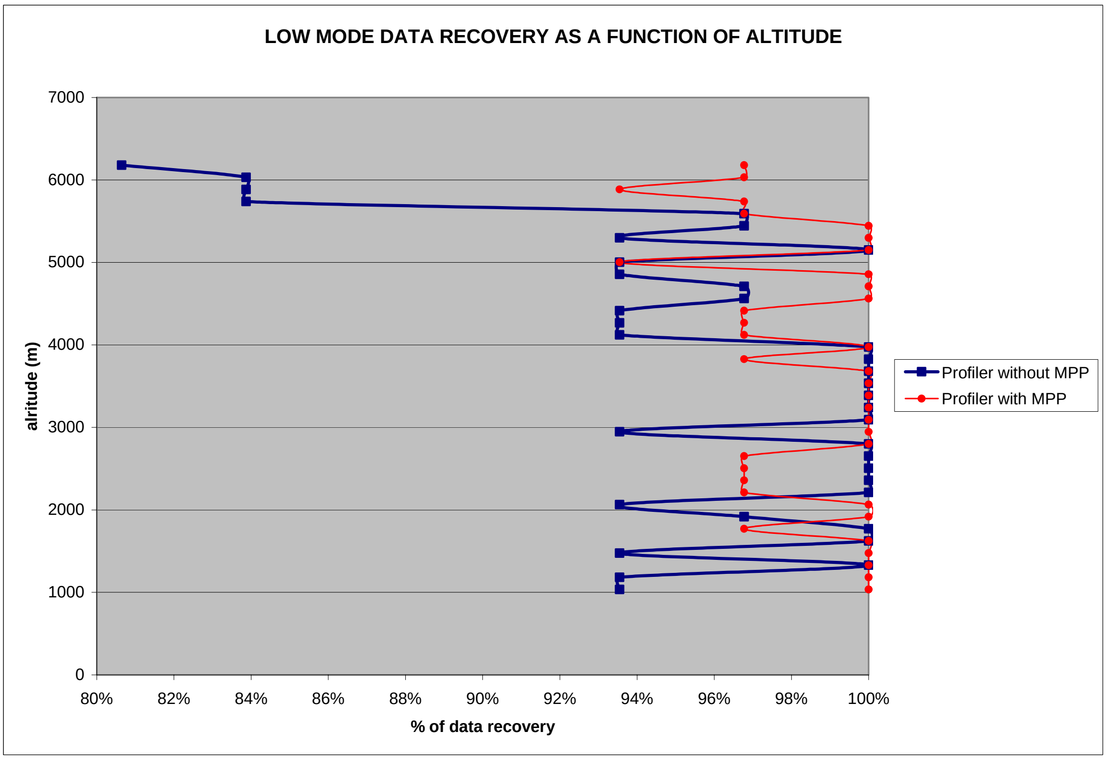

Figure 6 Percent data recovery as a function of altitude for MPP and POP-derived winds for low mode.

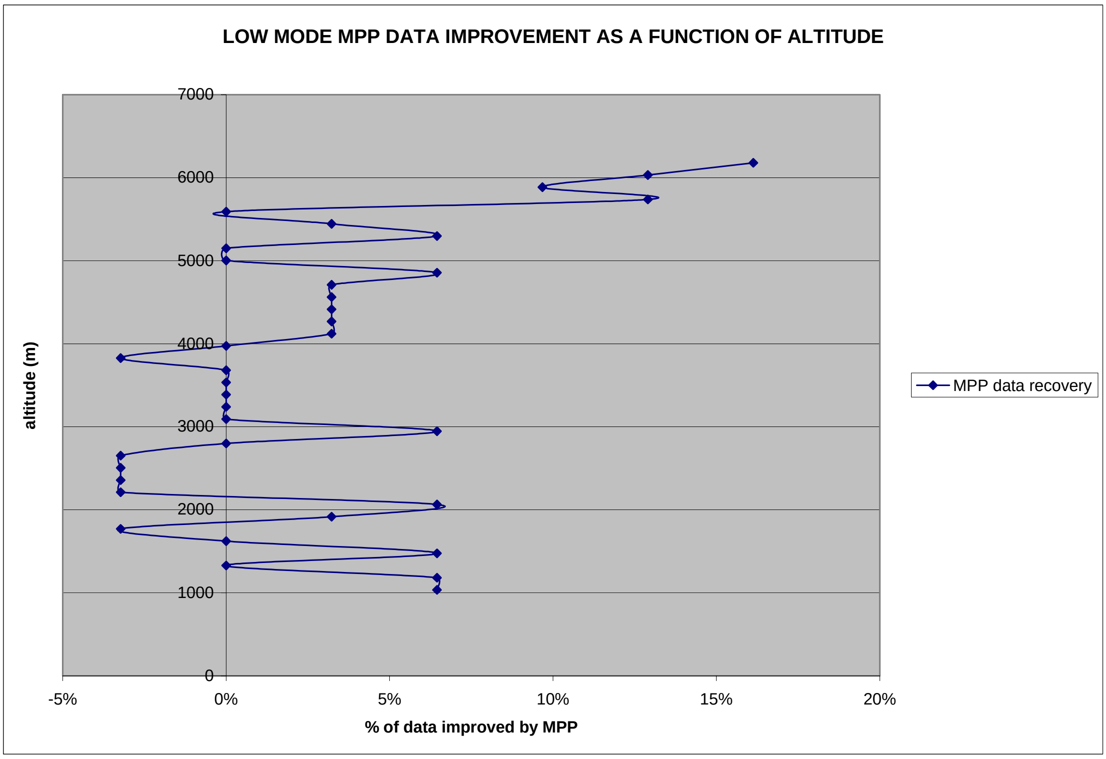

Figure 7 Data recovery differences as a function of altitude between MPP and POP-derived winds for low mode. Positive values indicate superior MPP performance.

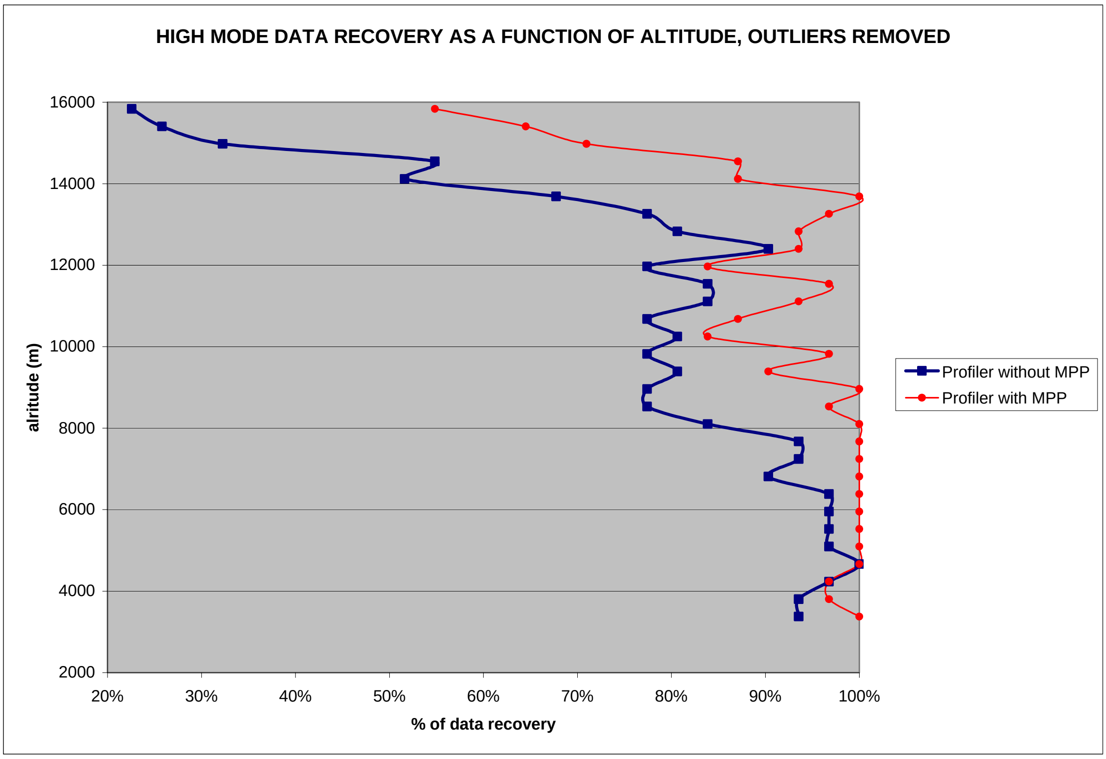

Figure 8 Percent data recovery as a function of altitude for MPP and POP-derived winds for high mode

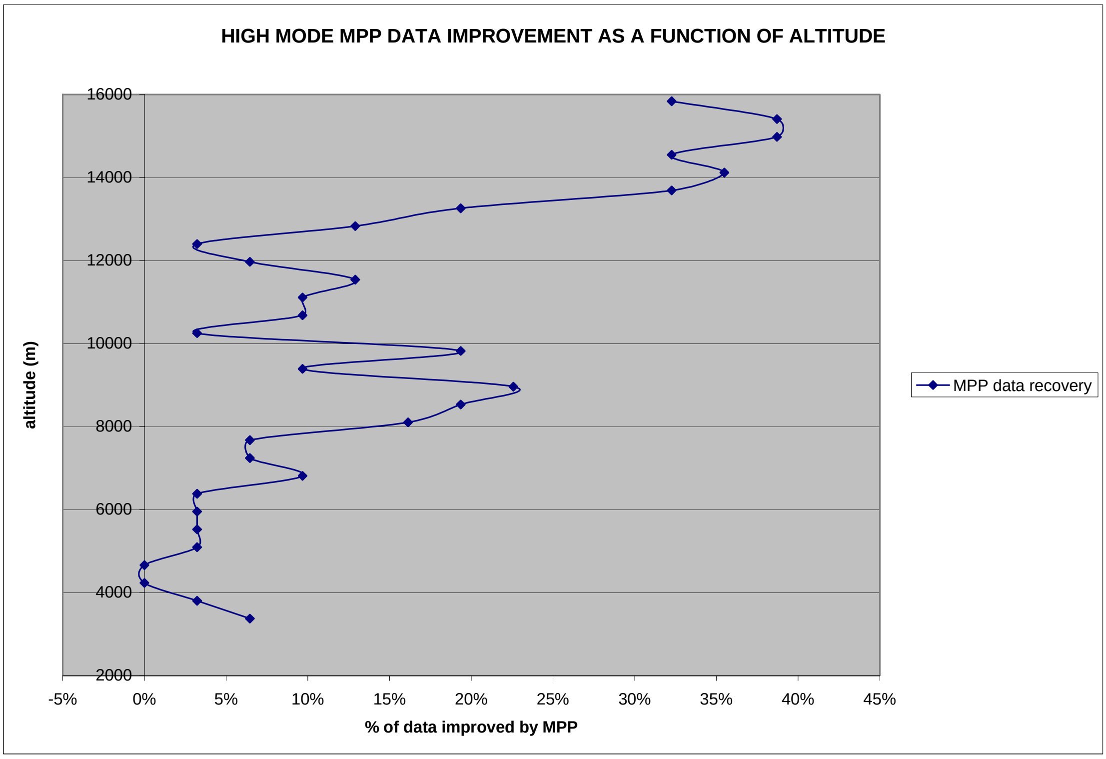

Figure 9 Data recovery differences as a function of altitude between MPP and POP-derived winds for high mode. Positive values indicate superior MPP performance.

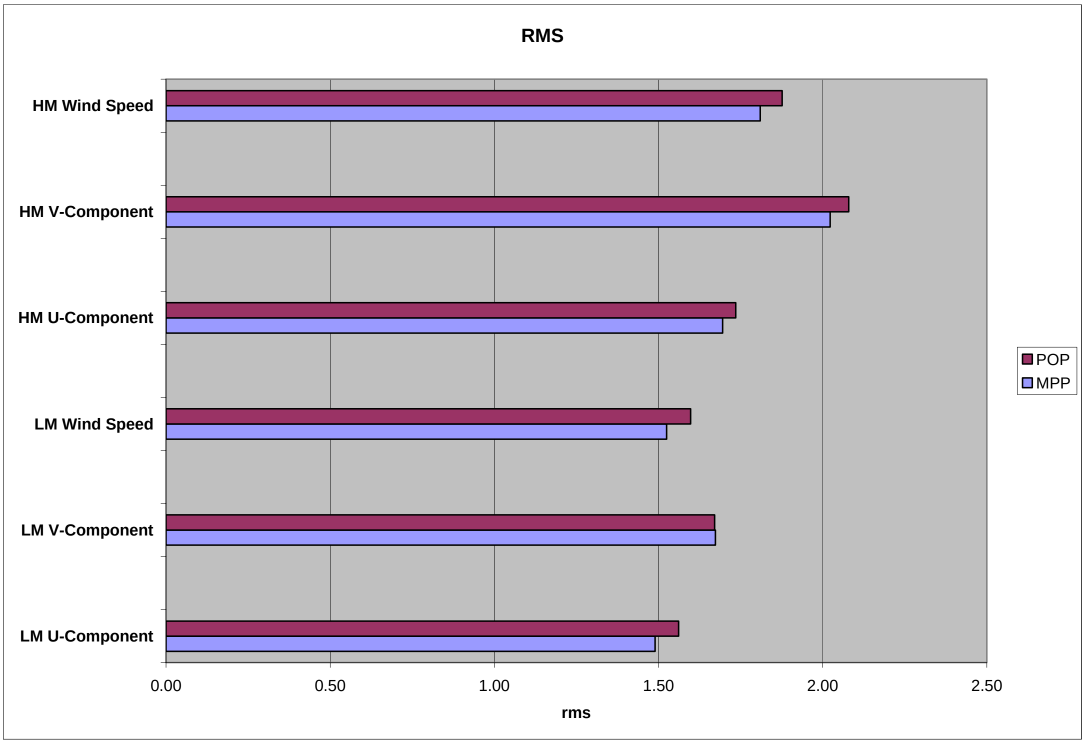

Figure 10 RMS values of wind speed and wind components (v and u) for both POP and MPP-based signal processing techniques. Both high mode (HM) and low mode (LM) are presented, units in m/s.

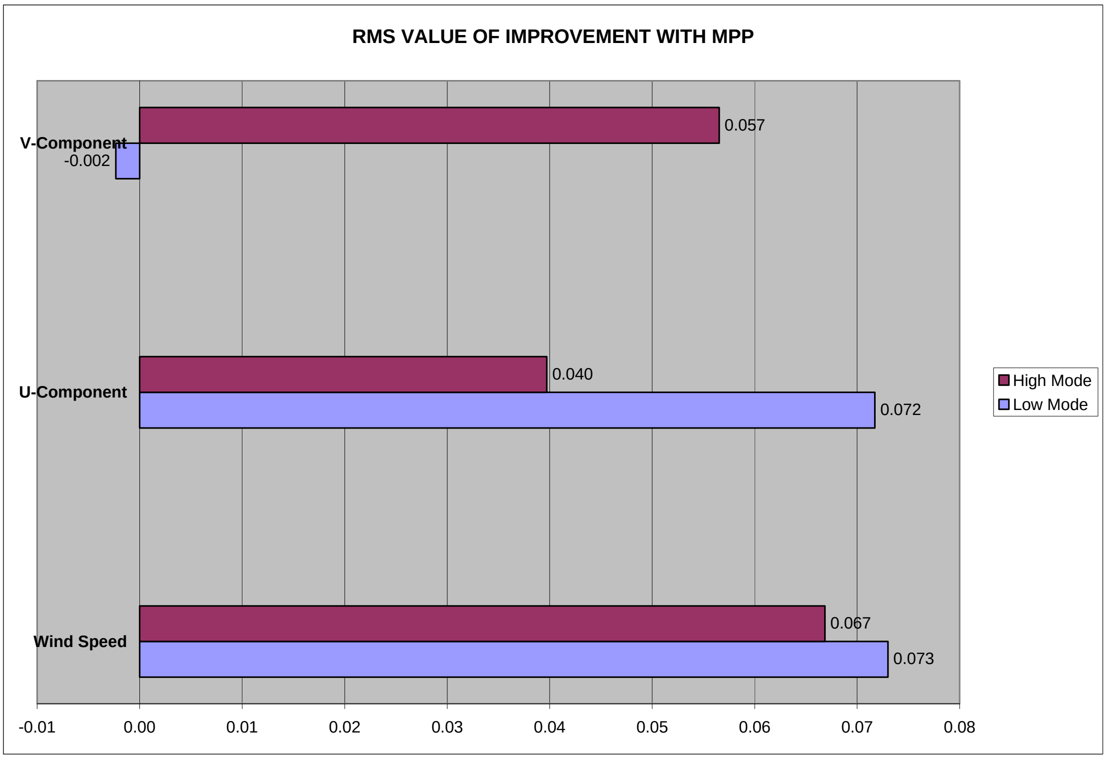

Figure 11 RMS differences between POP and MPP-based signal processing for wind speed and wind components. Positive values indicate superior MPP performance. High and low modes are presented.

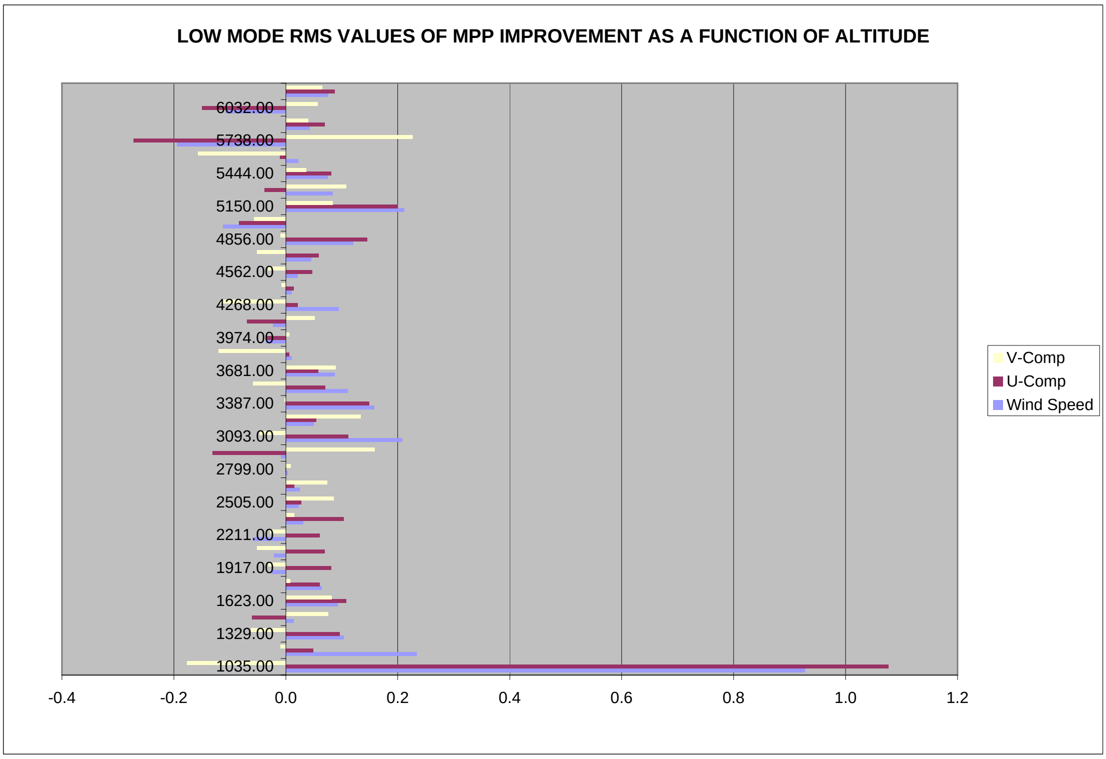

Figure 12 Low mode RMS differences between POP and MPP for each range gate. Positive values indicate superior MPP performance. Data are provided for v and u wind components and for total wind speed in m/s.

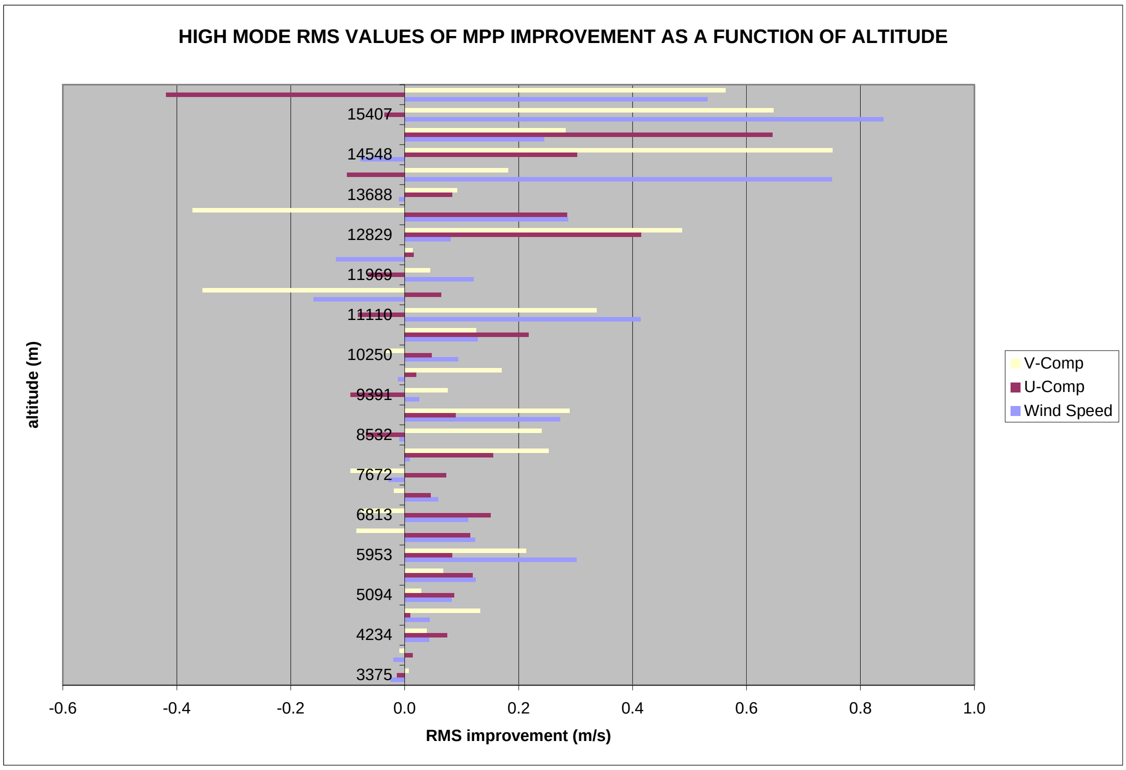

Figure 13 High mode RMS differences between POP and MPP for each range gate. Positive values indicate superior MPP performance. Data are provided for v and u wind components and for total wind speed in m/s.

Conclusions

The MPP moments algorithm is observed to increase overall data recovery rates over the original POP method, especially within the uppermost altitudes where weak atmospheric returns are typically observed. As a result, the LAP-12000 system's 90% data recovery performance increased to 14 km from the originally specified 12 km. MPP-based wind accuracy's were found to be slightly higher than those produced by POP, leading us to conclude that MPP improves overall wind profiler performance, and does not sacrifice data quality for improved altitude performance as has been observed in recently developed signal processing techniques.

Since this experiment, the Met Office has changed to profiler sampling parameters for operational use. The highest gate of the low mode was reduced from 6km to 5km and the beam sequence uses four beams, off zenith directions only. The sampling uses a 12 minute consensus period.

The MPP algorithm is now being used operationally on the South Uist wind profiler and has shown a significant improvement in the wind measurements during precipitation and in the presence of strong ground clutter or RF interference. However, operational monitoring has identified one or two days per month, notable in winter conditions, where the current MPP configuration does not select the correct atmospheric signal for some interval. Further investigation of these instances is being conducted under a collaboration agreement between the Vaisala and the Met Office.

At the time this preprint was prepared, analysis of the NIMA signal processing had not been completed. The poster that will be presented at TECO 2005 will include our NIMA results and contrast NIMA with the MPP moments processing.

Acknowledgements

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[6] Personal correspondence with Corinne Morse; NCAR.