New Wind Profiling Algorithms from Vaisala

Raisa Lehtinen[1], Ron Shellhorn[2], Aki Lilja[3]

[1]Vaisala Oyj, P.O. Box 26, FIN-00421 Helsinki, Finland, raisa.lehtinen@vaisala.com
[2]Vaisala Inc, P.O. Box 3659, Boulder, CO 80307-3659, USA, ronald.shellhorn@vaisala.com
[3]Vaisala Oyj, P.O. Box 26, FIN-00421 Helsinki, Finland, aki.lilja@vaisala.com

INTRODUCTION

With over 160 installations worldwide, Vaisala is a world leader in wind profiling radar technology. A strong research and engineering culture, commitment to continuous improvement, and technology infusion from acquisitions ensures that we will continue to provide our customers with the latest developments. Our long relationship with the world's leading wind profiling experts, such as the National Oceanic and Atmospheric Administration (NOAA) Laboratories in Boulder, Colorado, through a Cooperative Research and Development Agreement (CRADA) since 1991, provides a strong foundation for this effort. In 2006 Vaisala acquired Sigmet, a leading radar signal processor and application software manufacturer.

We have recently released new versions of the wind profiler LAP-XM® signal processing software. New features address clutter and interference problems with a Gabor transform filter, an intermittent precipitation algorithm and an improved quality control module. New products include a melting layer detection software and an experimental boundary layer top algorithm. There are also enhanced display and interfacing options, such as the integration of surface wind and temperature data from the Vaisala Weather Transmitter WXT520.

1. MELTING LAYER SOFTWARE

The melting layer is the vertical region of the atmosphere where frozen hydrometeors turn into liquid hydrometeors during precipitation. The detection of the presence and location of the melting layer is important for various applications, such as weather forecasting, hydrology, aviation and road safety, and flood emergency management. UHF wind profilers are capable of monitoring the melting layer by detecting the radar bright band, which provides a good estimate for the snow level, the height where snow or ice completely turns into rain.

The optional LAP-XM® Melting Layer Software LPS311 automatically detects precipitation events using vertical velocity and signal-to-noise ratio (SNR) thresholds, and then looks for bright band signatures in vertical velocity and SNR gradients. The module estimates the altitude of maximum SNR within the melting layer from spectral moments data using a consensus method described in [1]. The method has been further improved in collaboration with the authors. One of the advantages of the method is that no calibration of the radar reflected power is required. The SNR thresholds require some adjustment for different radar sampling parameters. Examples of usage can be found in [2].

2. BOUNDARY LAYER TOP DETERMINATION

The depth of the planetary boundary layer is an important parameter in air quality applications and in numerical weather models. The boundary layer is the lowest part of the atmosphere, which is directly influenced by the earth's surface, and where vertical mixing is strong. Wind profilers can detect the top of the daytime convective boundary layer by observing the maximum in the refractive index structure parameter Cn^2, which is directly proportional to range-corrected SNR.

The LAP-XM® Boundary Layer Module includes vertical velocity variance, spectral width, and SNR curvature and variance analysis to get a more robust estimate of the boundary layer depth. The module combines these parameters with a fuzzy logic technique, as described in [3]. The algorithm should be used with careful evaluation, as it has been mainly validated using summer-time data and a limited number of wind profilers. It is currently being tested by the authors in different geographical locations and in winter conditions.

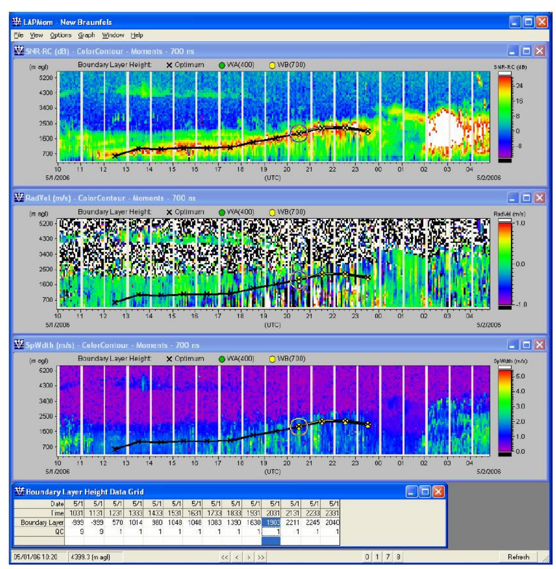

Figure 1. *LAPMom™ display showing the detected boundary layer top with a black curve, on top of time-height surface plots of spectral moments.*

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3. ENHANCED GRAPHICAL DISPLAY

LAPMom™ is a stand-alone application designed to graphically display spectral moments and/or Cn^2 data that are stored in LAP-XM® spectra or moments files, or Cn^2 text files. Doppler velocity, spectral width and SNR values from any antenna direction may be graphed in time and height.

LAPMom™ version 3 includes the ability to display the results from the boundary layer top module, and the optional melting layer module. Results can be viewed in a table format and in a graph. The results are most informative when displayed in the context of other spectral moments data. Figure 1 shows the boundary layer top estimates with a black curve, plotted on top of SNR, vertical velocity and spectral width. LAPMom™ enables the editing and manual quality-control of the boundary layer or melting layer heights, and saving the edited data. The software also allows various filtering and data reduction options, modification of text labels and axis properties, and the ability to print the graph and save it in several file formats.

4. MODIFIED WIND AND TEMPERATURE QUALITY CONTROL MODULE

Vaisala's Weber-Wuertz Quality Control Module [4] implements a method to evaluate the wind and virtual temperature data using time and height continuity of consensus data samples. Improvements have been made to the Weber-Wuertz quality control algorithm, including replacing the continuity check for radial beams with a continuity check for U, V and W wind components, and correcting code details that created discrepancies between NOAA FORTRAN and C source code versions.

In addition to the improvements to the algorithm, a two-step Weber-Wuertz procedure and an opposing beams consistency check have been implemented in cooperation with the German Weather Service (DWD). These features are used in the DWD profiler network.

The new algorithms have demonstrated to be especially effective for a 4 oblique beams measurement configuration, operating in a severely RFI contaminated environment.

5. INTERMITTENT CLUTTER FILTER USING GABOR FRAME EXPANSION

Vaisala is continuously developing LAP-XM® software to include new, beneficial algorithms and features. The Gabor Module implements an advanced method for the suppression of intermittent clutter in wind profiler time-series data. The method is intended especially for UHF profilers that experience significant problems during seasonal bird migration.

The module analyzes time series data using the discrete Gabor frame expansion, which forms a time-frequency presentation of the signal. This presentation is very useful in analyzing various clutter sources. Figure 2 demonstrates the difference between a clear air echo signal, which produces a persistent signal at one frequency, and a passing airplane, with a very strong short-lived frequency sweeping echo. The intermittent clutter signals can be separated and removed using the Hildebrand-Sekhon statistical filtering technique, applied to each frequency component separately.

Large flocks of birds produce semi-continuous strong echoes, such as in Figure 3, which overwhelm the underlying clear air signal so that the separation of signal components fails. The technique was further developed by adding a spectral width threshold for those situations where the clutter signal is too persistent for reliable removal. This algorithm from Lehmann and Teschke [5] was developed in cooperation with DWD (Deutscher Wetterdienst, German Weather Service).

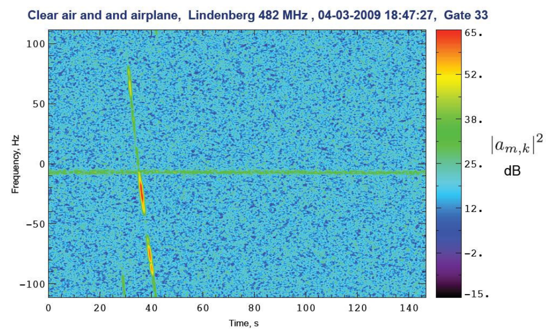

Figure 2. *Gabor frame expansion showing clear air signals and a frequency sweeping airplane echo (picture credits: DWD/Volker Lehmann).*

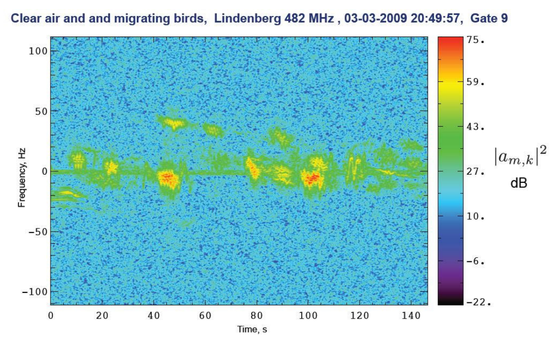

Figure 3. *Gabor frame expansion showing clear air signals and migrating bird echoes (picture credits: DWD/Volker Lehmann).*

6. INTERMITTENT PRECIPITATION ALGORITHM

A Doppler beam swinging (DBS) radar wind profiler is capable of producing good quality wind estimates in uniform precipitation. The contribution of the fall velocity of hydrometeors is determined and removed using either a vertical beam or the sum of two oblique beams. Problems arise when the precipitation echo is detected only in some beam directions, or only a part of the consensus averaging time. These changing conditions often cause the consensus average to fail or to produce erroneous results [6]. A precipitation detection algorithm has been added to the LAP-XM® software to improve the measurement in these situations.

The algorithm is implemented in the Consensus Wind Module, and consists of two parts: precipitation detection and modified consensus averaging. Radar dwells from the vertical beam are analyzed to find spectral peaks with range-corrected SNR above 60 dB and radial fall velocities exceeding 1.0 m s-1. These signals are flagged as originating from precipitation. The oblique beams of the measurement are then compared to the nearest-in-time vertical beam. If the SNR of a spectral peak exceeds 60 dB and the corresponding height in the nearest vertical beam has a precipitation flag, the oblique beam signal is flagged as precipitation. The radial velocity is also corrected for the vertical velocity component using the nearest vertical beam. The method is similar to the melting layer algorithm [1].

If the averaging period contains both precipitation and clear-air signals, the data points are divided into two populations accordingly, and the consensus algorithm [7] is applied to each group. The consensus threshold criteria are set less strict for the precipitation signals which are assumed to be stronger and more consistent. For each range gate, the reported wind is obtained from the population that passed consensus. During intermittent precipitation both groups may produce a valid consensus result. In this case, the group size is used as a factor for a weighted average.

7. OTHER NEW FEATURES

The LAP-XM® Weather Transmitter Interface Module enables the communication to the optional Vaisala WXT520 Weather Transmitter for configuration and gathering of surface wind and temperature information. The WXT520 is a surface weather measurement unit that measures wind velocity and direction, air temperature, pressure, relative humidity, and precipitation.

The weather transmitter is installed in proximity to the wind profiler, and accessed over a RS-485 serial connection. At intervals determined by user-selected configuration parameters, LAP-XM® queries the weather transmitter for the latest surface weather measurements. The surface wind and temperature data will be displayed as a first range gate in LAP-XM® wind and virtual temperature outputs. Other surface parameters can be configured to be included in the header information in text output files.

The XML Data Formatting Module writes wind and virtual temperature data in an Extensible Markup Language (XML) format. This general-purpose data-exchange format allows exploiting the data in a variety of applications. Wind profiler data integration to Vaisala AviMet® 5.1 aviation weather management system has been created using XML.

8. LOOKING AHEAD

Vaisala continues to explore new and innovative ideas for our wind profiler product line. The LAP®161 tropospheric wind profiler in is the most recent development in the evolution of Vaisala wind profiler instruments. The system topology is engineered to meet the requirements of the US National Weather Service for their Next Generation National Profiler Network (NGNPN). The system uses a distributed amplifier architecture which provides improved reliability, compliance with US frequency management regulations, and a lower first wind measurement altitude than was available in the US National Profiler Network (formerly Profiler Demonstration Network).

System reliability is enhanced using 12 transmit/receive (TR) modules, which reduce the likelihood of a single point failure interrupting profiler operation, and low power solid-state switching of delay lines for the phased array antenna. This eliminates the use of the unreliable high power electronic switches and finite-life mechanical switches that have been used in prior wind profilers.

Other ongoing development projects include a new signal processor scheduled for release in late 2009 and a concept study to produce solutions to the impending interference to boundary layer, 1290 MHz profilers, from Galileo satellites.

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