The Canadian O-QNet - a Relatively High-Density Windprofiler Network

W. K. Hocking[1], P. A. Taylor[2], N. Swarnalingan[1], P. S. Argall[1], S. Sharma[2], D. Tarasick[4], I. Zawadzki[3], F. Fabry[3], J. Barron[1], R. Mercer[1], Y. Zhang[1], P.Y. Li[2], A. Dehghan[1], G. Klaassen[2], N. Donaldson[4], E. Campos[4], M. Osman[1], R. Sica[1], H. Hangan[1], G. McBean[1].

[1]University of Western Ontario, Dept. of Physics and Astronomy, London, Ontario, N6A 3K7, Canada, whocking@uwo.ca
[2]York University, 4700 Keele Street, North York, Ontario, M3J 1Q3, Canada, pat@yorku.ca
[3]McGill University, Montreal, Quebec, Canada.
[4]Environment Canada, 4905 Dufferin St., Downsview, Ontario, M3H 5T4, Canada.

ABSTRACT

A network of over 10 relatively closely spaced VHF windprofiler radars is under construction in Ontario and Quebec, Canada. Using frequencies in the range 40 to 55 MHz, this network is interlinked by the internet and provides bufr format to the Canadian Meteorological Services and other interested parties on an hourly basis. Radars are separated by typically 150 km. The system presents horizontal winds, vertical winds, turbulence estimates, tropopause height determination, and scatterer anisotropy characteristics, from 400m to typically 14 km altitude. Five systems are currently active, and others are due on-line in the next 2 years. Current capabilities and future plans will be discussed.

1. INTRODUCTION

Improved knowledge of real-time upper level winds leads to better forecasting skill. In recent years, the number of radiosonde launch sites in Canada has been reduced, and in order to compensate for this, a new network of radars is being developed on a trial basis in the provinces of Ontario and Quebec. The radar network is called the O-QNet network (Ontario-Quebec Network). The proposed radar locations are shown in fig. 1. Additional radars near London, Ontario, and at McGill University in Montreal will also work with the other radars, although they were built prior to the availability of funding for this network.

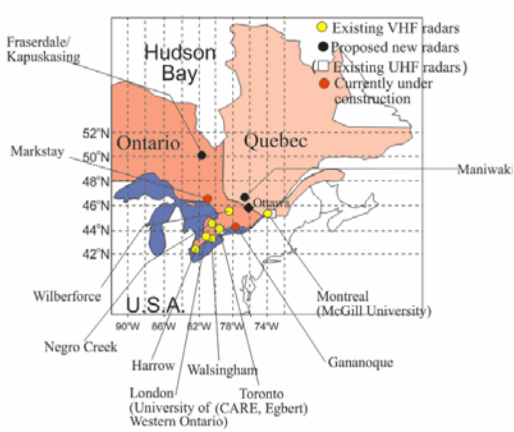

Figure 1. *Map showing locations of the O-Qnet radars.*

Fig. 2. shows a photograph of the VHF windprofiler at Negro Creek.

Figure 2. *Picture of the Negro Creek radar. This is typical of all the radars in the network.*

2. BASIC RADAR DESIGN

The radars use two groups of sub-arrays - a large one for Doppler measurements, and a smaller pair for lower level wind determinations (nominally referred to as "boundary-layer winds"). The larger one works above 1.5 to 2 km altitude, while the smaller one uses the spaced-antenna method to determine winds in the height region from 400m to 2 km. All radars in the network will have one of two main designs for the larger array, although frequencies will vary, depending on allocation by Industry Canada, and some minor design alterations may occur. All frequencies will be between 40 and 55 MHz, and generally in the range 40 to 50 MHz. The two different arrangements are designed to allow greater flexibility when adapting to local terrain.

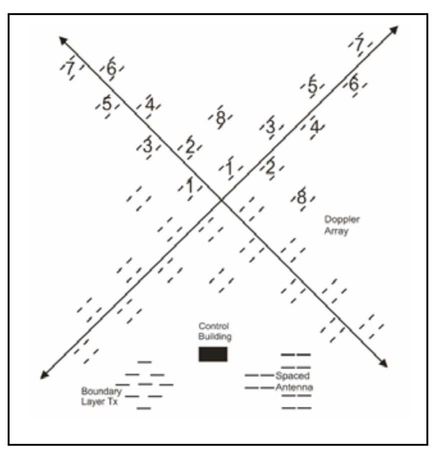

Figure 3. *Type I Antenna layout*

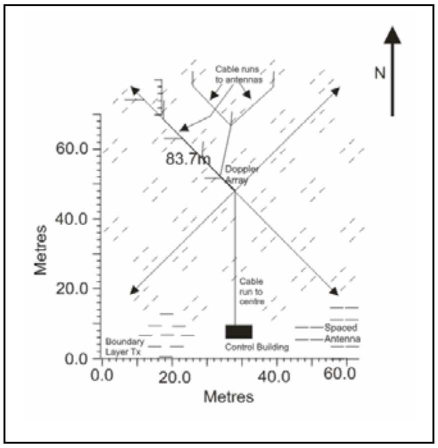

Figure 4. *Type II antenna layout.*

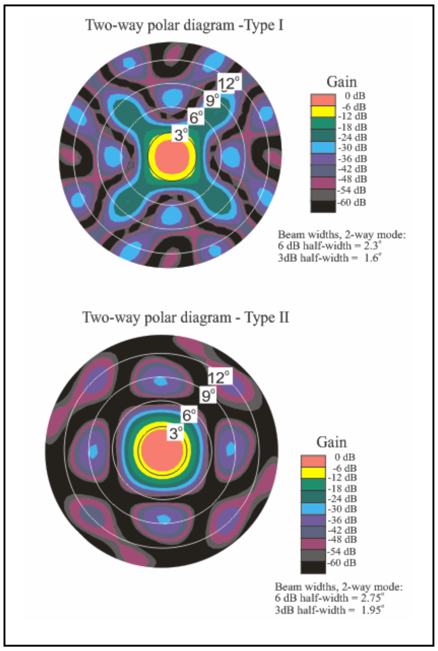

Figure 5. *Two-way polar diagrams for type I and type II radars.*

Fig. 3 shows the so-called "type-I" layout, and fig. 4 shows the "type II" layout. Each short line in the figures represents a 3-element Yagi-Uda antenna. Within the main Doppler arrays, the antennas are grouped in sets of 4, called quartets, and each quartet is separately fed by a low loss cable extending from the main control building, of length equal to an integral number of wavelengths. The small arrays near the bottom labeled "Boundary layer" antennas represent the boundary-layer radars, which use a bistatic principle. The principles of operation will be discussed later.

Type-I radars require more land, but produce a narrower main lobe of the polar diagram, and higher gain. They also produce stronger sidelobes, but these are not a serious contaminant as long as suitable software spectral processing (e.g. [1]) is used. Graphs of the polar diagrams of the radars are shown in fig. 5. Despite the higher sidelobes, the higher gain of the type I system in principle allows measurements to greater altitudes. The type II configuration is designed to be used when land availability is limited. The design has a slightly wider main beam than the first, and slightly lower gain. However, the quasi-irregular spacing of the quartets results in excellent sidelobe suppression, as can be seen in the polar diagram. The first option is used at McGill, London, Walsingham and Markstay, while the second is used at Harrow, Negro Creek, Egbert, Wilberforce and Gananoque. At Negro Creek, the type II format is slightly modified by bringing the quartets closer together by 17%, to permit the radar to fit on the limited available land.

3. NETWORK OBJECTIVES

The radars not only produce wind motions (both horizontal and vertical), but also routinely measure the strength of turbulence. This feature is not normally implemented in a network of this type. This will be important for studies of atmospheric diffusive transport at these upper levels, and also from the perspective of air traffic safety.

Our network is somewhat more tightly clustered than most other windprofiler networks (and much more tightly clustered than the existing radiosonde network), and will be sited in a geographically and meterorologically fascinating area, near the Great Lakes of North America. (Tornadoes, for example, are more common here than most other places in Canada, and lake breezes have very important effects on local meterorology).

We will work closely with the airlines of Canada, to examine the capabilites of these radars for improvement of airline safety (reduction of encounters with clear air turbulence) and for reduction in fuel costs by utilizing better flight planning strategies based on better knowledge of upper level winds.

We are keen to examine the potential for improvements by incorporating the data from this network into new computer models which take advantage of the latest advances in computer speed, parallel processing and storage capability. These models will cover a variety of grid scales, from eddy-scale simulations (which will take advantage of the high time resolution of these radars) to mesoscale models and beyond. We will especially be looking at the roles of gravity wave processes in these models, and once again the high temporal resolution will be important here.

We will also expand our studies to include topics like troposphere-stratosphere ozone and pollutant transport, in order to investigate upper atmosphere phenomena related to, among other things, global warming. Furthermore, knowledge of the upper level wind field will also be important for long-term studies of long-lived pollution transport.

4. WINDS ANALYSIS PROCEDURES

The radars use both Doppler and Spaced antenna procedures, alternating between the various modes. The Doppler procedures are relatively standard, as described by [1]. Cable phasing is used to steer the beam, and data are acquired after suitable super-heterodyning and subsequent digitization. A Fourier spectrum is formed using typically 30-40s of data, and then spectral fitting procedures are employed. Usually a Gaussian function is fitted, plus a noise offset. Weighted moments have also been employed, but are less reliable than spectral fitting. The spectral fitting also allows determination of spectral widths, which may in turn be used to calculate turbulent energy dissipation rates. Beams are steered successively in 4 different off-vertical directions, at 90 degree azimuth steps, with a zenith angle of 10.9 degrees. A vertical beam is also employed. The beam half-power half-widths in one-way mode are typically 2.1 to 3 degrees, depending on antenna configuration, and the 2-way beam-widths are of course equal to these widths multiplied by $\sqrt{2}$. Type 1 antenna configurations have the narrowest beam-width. Data are generally combined from all 4 off-vertical beams in order to produce a total wind vector. Usually hourly data are produced as "normal" outputs. However, for gravity wave studies and specialist events, other combinations of beam directions and sequences may be employed.

The spaced antenna mode uses a more unusual signal-processing procedure [2]. It employs a unique combination of Full Correlation Analysis and Imaging Doppler Interferometry. By transmitting on an antenna array separate to the receiver arrays, it is possible to sample the signal even before the pulse has finished transmitting, thereby allowing echoes to be sampled at the lowest possible heights. A key aspect of the analysis involves differentiating between atmospheric signal and signal associated with the effects of the transmitter pulse. It is often found that certain Doppler offsets, and particular phase combinations between different receivers, are unique to the chosen transmitter power amplifier and the chosen antenna configuration.

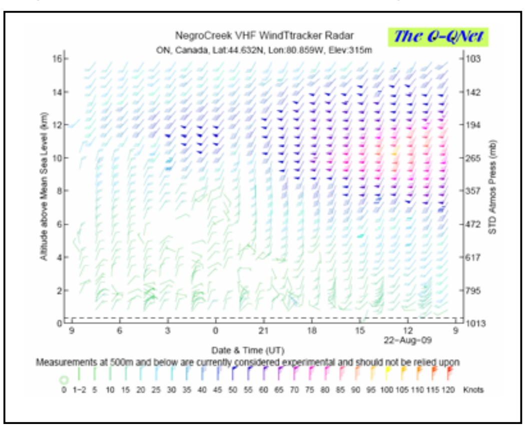

Figure 6. *Winds determined with the Negro Creek radar in August 2009. These are typical of data at all sites. Note that time runs from right to left.*

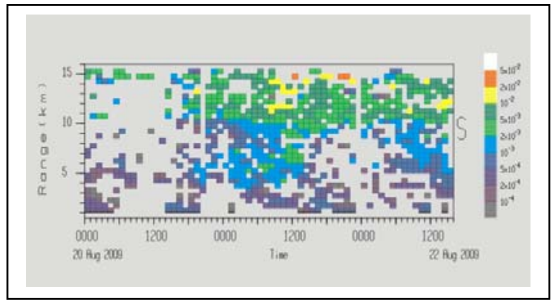

Figure 7. *Turbulent energy dissipation rates determined with the Negro Creek radar in August 2009.*

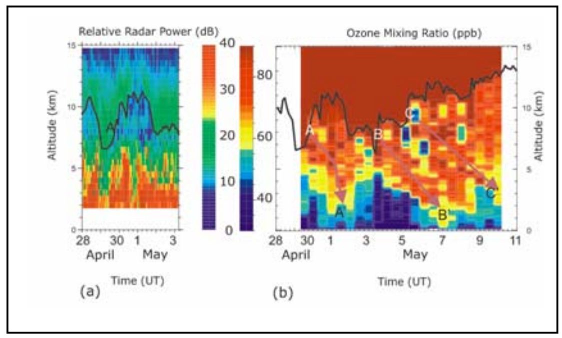

Figure 8. *(a) Plots of power as a function of height and time, showing a secondary maximum at 6-12 km (green). The lower edge of this marks the radar-tropopause, a good proxy for the real tropopause. (b) Ozone mixing ratio as a function of height and time, with the radar-tropopause superimposed. Intrusions of ozone are seen entering the troposphere from the stratosphere during periods of rapid tropopause ascent.*

By recognizing and eliminating these particular cross-spectral points, reliable estimates of wind speed and direction are possible, whereas previously (without this specialized filtering) no useful measurements were possible.

5. SAMPLE DATA

The radar determines a variety of atmospheric parameters. Various versions of the plots to be discussed in the following paragraphs can be found on publicly accessible web sites, to be given in the conclusions.

Fig. 6 shows typical winds determined with the Negro Creek radar. Magnitudes are colour-coded, as well as being indicated by wind-barbs. Upward wind-barbs indicate winds blowing toward the north, while horizontal ones pointing to the right indicate winds blowing toward the east. The figure shows one day of data from August 22, 2009.

Another important parameter determined with the radars is the turbulent energy dissipation rate. Examples of an intense turbulent event are shown in fig. 7, which shows downward intrusion of some strong upper level turbulence in August 2009.

Fig. 8 shows another special capability of the radar - namely its ability to monitor a proxy for the tropopause height. This is routinely displayed with these radars, but in this case, it is also used to demonstrate that rapid tropopause height-excursions can be associated with intrusions of ozone from the stratosphere into the troposphere, as reported by [3].

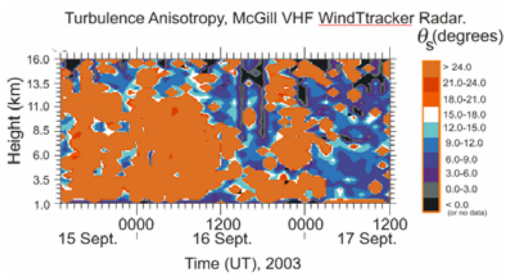

Figure 9. *The anisotropy parameter θ_s plotted as a function of height and time, recorded with the McGill VHF radar (from [4]).*

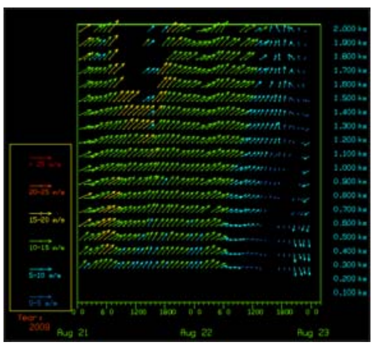

Figure 10. *Boundary layer winds measured with a UHF radar at the Egbert radar site.*

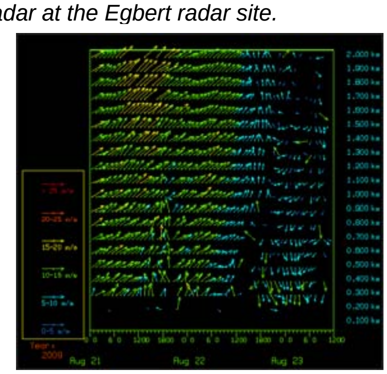

Figure 11. *Boundary Layer winds measured with a VHF radar of the O-QNet at the Egbert site, for the same height coverage, and similar time coverage to fig. 10. Note that the time axis extends 12 hours beyond that of fig. 10.*

Another important parameter relates to scatterer isotropy/anisotropy. The ratio of powers on the off-vertical and vertical beams can be converted to a parameter denoted as θ_s, which in turn relates to the average length-to-depth ratio of a "typical" scattering eddy. Large values of θ_s correspond to scatterers which are closer to isotropic, while small values correspond to scatterers which are stretched out horizontally relative to their vertical depth. Fig. 9 shows plots of θ_s as a function of time (from [4]). For the McGill radar, it has been found that when θ_s becomes large, it is indicative of convectively generated turbulence, and that this is often associated with precipitation. Indeed the onset of large values of θ_s often precedes the occurrence of rain in non-winter months, so that the anisotropy parameter can even be used as a forecast diagnostic for rain.

The capability of measuring winds down to 300-400m was also discussed earlier. Figs. 10 and 11 show simultaneous low level winds recorded with a UHF and a VHF profiler at the Egbert site. Note that the time axes do not quite coincide - the VHF data extends for an extra 12 hours. The radars are located within 400m of each other. The VHF data tend to be noisier since they are only recorded every 20 minutes (with the rest of the time devoted to upper level winds), wile the UHF system runs continuously in low level mode. The VHF system presents raw hourly averaged data: the UHF system uses a consensus averaging strategy to smooth the data, and so rapid changes in wind speed and or direction can at times be smeared out, while the VHF system catches rapid changes more accurately. In general, however, agreement is good.

6. CONCLUSIONS

The O-QNet is over half finished. System capabilities and important results to date have been reported, including some new parameters not traditionally reported with most radars. Websites for the current radars can be found at http://www.yorku.ca/oqnet/XXX/, where XXX is the name of the radar (Walsingham, Harrow, NegroCreek, Egbert or Wilberforce). All radars operate 24/7, and data are updated hourly.

REFERENCES

[1] Hocking, W.K., (1997), "System design, signal processing procedures and preliminary results for the Canadian (London, Ontario) VHF Atmospheric Radar", *Radio Sci*., **32**, pp. 687-706.

[2] Hocking, W.K., (2007), "Boundary Layer Winds with 50 MHz Radars – Comparison of Different Approaches", Proc. of the Eleventh International Workshop on Technical and Scientific Aspects of MST Radar, Gadanki, India, Dec 11-15, 2006, ed. V.K. Anandan, pp 284-287, publ. Macmillan India Inc.

[3] Hocking' W.K., T. Carey-Smith, D. Tarasick, S. Argall, K. Strong, Y. Rochon, I. Zawadzki, P. Taylor, (2007), "Detection of Stratospheric Ozone Intrusions by Windprofiler Radars", Nature, **450**, pp. 281-284.

[4] Hocking, A., and W.K. Hocking, (2007), "Turbulence anisotropy determined by Windprofiler Radar and its correlation with rain events in Montreal, Canada", J. Atmos. Oceanic Technology, 24, pp 40-51.