# 1 Scientific challenges

As for every non-trivial problem, a number of questions remain which have not been convincingly answered yet. It is the purpose of this section to discuss a few of them. This list is necessarily incomplete.

## 1.1 Scattering theory

Although clear air scattering theory is quite well developed, it is nevertheless an area of active research, see Tatarskii and Muschinski (2001), Franke et.al. (2011) and Fritts et.al. (2011). This should not be very surprising, as the notoriuos turbulence problem is a part of the story. Difficulties are still noted with regard to the applicability of simplifying assumptions (eg. Fraunhofer vs. Fresnel approximation) see e.g. Tatarskii (2003) or Muschinski (2004). Another active research topic are the vertical velocity biases measured with radars, see Cheinet and Cumin (2011).

Bragg and Rayleigh scattering are the main atmospheric scattering processes for most RWP. Nevertheless, the problem of separating simultaneous contributions of particulate scatter and clear-air scatter - the so-called Bragg/Rayleigh ambiguity, a term coined by Knight and Miller (1998)- has not been practically resolved so far, although it would be possible by using two different frequencies, see Gage et.al. (1999). Statistical methods have also been proposed: William et.al. (2000). This is somewhat similar to the problem of target classification for cloud radars.

## 1.2 Clutter issues

The increasing interest in renewable energy has led to a rather rapid development of large wind turbine (WT) parks in many countries. The wind turbines used already exceed heights of 100 m for the nacelle and the propeller blades have diameters of more than 100 m, with a single blade weighting several 1000 kg. It is not surprising that solid structures of these dimensions are effective targets for many different radars, including air traffic control radars (Novak, 2009) and precipitation(weather) radars (Isom et.al., 2009 Hood et.al.,2010 and Toth et.al., 2011).

RWP are affected if the WT are located in the vicinity of a RWP. The specific problem for profilers is that the WT clutter echoes are caused by the side-lobes of the antennas, because the beam directions are always near-zenith. While this is generally advantageous due to the lower gain in the side-lobes in comparison to the main lobe (differences are usually 20-40 dB), the lower antenna gain is at least partially offset by the higher sensitivity of RWP compared to most other radars. Also, it is more difficult to estimate potential impacts because of the difficulties to estimate the antenna radiation pattern at angles about 90 degrees off boresight. This latter problem is made worse by the fact that the actual low elevation angle radiation pattern depends also on the properties of the surrounding landscape (orography, ground vegetation). This makes it virtually impossible to accurately calculate the antenna gain of a RWP in the direction of a wind turbine.

WT clutter contaminated spectra are characterized by a significantly greater spectral width compared to a clear air signal. This is due to the rotation of the propeller blades. The occurrence of WT clutter shows strong temporal variations which are not completely understood. It is speculated that a variety of factors, like the orientation and the dielectric properties of the blades as well as the magnitude of the backscattered signal in the main lobe have an influence on the relative strength of the WT clutter echo in comparison to the atmospheric echo.

Currently, no signal processing algorithm is able to suppress or filter out WT clutter. The only method that can be applied right now is the use of postprocessing data quality control. Further investigations are required for an better characterization of wind turbine clutter in order to find suitable measures to solve or at least to reduce the problem in signal processing. A reduction of side-lobes in the antenna radiation pattern would also be helpful, wherever this is possible.

### 1.3 Wind retrieval

Wind retrievals from Doppler-Beam-Swinging during non-homogeneous conditions (convective boundary layer, patchy precipitation). The homogeneity condition is obviously not always fulfilled, in particular not in a convective boundary layer (CBL), during strong gravity wave activity (Weber et al., 1992), in patchy precipitation (Adachi et al., 2005) or in complex terrain (Bingöl et al., 2009).

Embarrassingly, problems with 3-beam DBS wind profiler data obtained during with convection have even been noticed in NWP data assimilation (Cardinali, 2009). While the DBS assumptions are usually deemed to be correct for mean winds averaged over a longer time interval, it is not clear how long this time interval must be under different meteorological conditions. Cheong et al. (2008) have used data obtained with a volume-imaging multi-signal wind profiler in a CBL to show that for this particular case the assumptions inherent in the DBS method were valid for a wind field averaged over 10 minutes. This is the main reason why DBS RWP wind measurements are typically averages over 10-60 minutes. Moreover, it was found that the RMS error of RWP measurements can be significantly reduced by increasing the number of off-vertical beams in DBS.

In spite of these first results, more work is required to appraise the effects of this non-homogeneity and non-stationarity on the wind retrieval under various atmospheric conditions, especially in a well-developed CBL. Operational experience clearly shows that there are issues under such conditions. Recently developed antennas for RWP allow for more sophisticated scan-strategies to improve upon the simple DBS wind retrieval, so it would be very timely to address this question again.

## 2 Practical challenges

There are a number of issues that generate challenges in the operational application of a measurement method, although it would be no problem to resolve them from both a scientifical and technical point of view. However, there are always constraints imposed either by regulations or by available ressources.

### 2.1 Frequencies

A *conditio sine qua non* for the successful operation of radar wind profiler is the existence of uncontaminated frequency bands, as the high sensitivity of the RWP's make them vulnerable to any external in-band radio-frequency interference of sufficient strength. Frequency management is therefore an essential issue for operational networks. As more and more technical applications are using electromagnetic waves, the frequency spectrum has become a scarce resource. Effective protection of allocated frequency bands is paramount to maintaining and enhancing the quality of radar wind profilers and therefore an important task.

Wind profiler frequency allocations were on the agenda of the World Radiocommunication Conference 1997 (WRC-97), where the resolutions COM5-5, and Footnotes S5.162A and S.5.291A were accepted. In these documents, RWP frequency allocations are assigned for the bands 50 MHz, 400 MHz and 1000 MHz, depending on the ITU Region. Since then, the allocations have been constantly under pressure from other intended usage of these bands. For example, the European Radio Navigation Satellite Service GALILEO is going to use an L-band frequency range assigned to boundary-layer wind profilers. Compatibility studies were therefore necessary to ensure the best possible protection, see ECC Report 90

While the sharing of profiler frequency bands with other services is clearly inescapable, coexistence is often possible. Of advantage is the nearly vertical direction of the profiler beams, which naturally enhances the protection against horizontally propagating waves. For example, the 482 MHz RWP in Germany are operated in a frequency band that is primarily assigned to digital terrestrial television broadcasting (DVB-T) in UHF channel 22. With the exception of short-lived tropospheric ducting events, when TV signals can propagate over long distances up to 1000 km or more, the emissions of TV stations are no issue for the three 482 MHz wind profilers at Ziegendorf, Bayreuth and Lindenberg. However, RWP signal processing and quality control procedures needs to be set-up properly to eliminate all spurious non-meteorological data.

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