Committee on Radio Astronomy Frequencies

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Report on Wind Farms and Radio Astronomy

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Executive Summary

Harvesting wind power for electricity generation is one of the few sustainable ways of power generation with minimal CO_2 emissions. The grave environmental and energy problems facing humanity on a global scale mean that all efforts to utilize sustainable energy sources ought to be supported. However, the special requirements of radio astronomical observatories could impose a restriction on the deployment of tall radio-reflecting structures, such as wind turbines, near radio telescopes. Nevertheless, this is likely to affect only a small fraction of the areas suitable for the location of wind turbines, and should therefore have a negligible impact on national or global wind power capacities.

Introduction

Radio astronomy and radio frequency interference

The radio signals from cosmic objects (stars, galaxies, etc.) that radio astronomers observe are extremely weak because the objects are very distant, often millions or billions of light years away from us. The large radio telescopes used are highly sensitive and routinely detect minute signals that have flux densities of the order of 1 mJy = 10^{-29} $Wm^{-2}Hz^{-1}$, which corresponds to the signal received from a UMTS mobile phone radiating 1 W at a distance of 40 million km (i.e. at approximately a hundred times the Earth-Moon distance).

Radio astronomical telescopes detect radio emission mainly in the forward direction, but it is impossible to avoid signal reception from most other directions. In technical terms, a radio telescope is highly directional with a very high 'gain' (typically 10^5 – 10^6) in the forward or 'main beam' direction. Astronomical radio antennas are however not pointed at low level terrestrial objects. Their sensitivity is so high, that they can even detect the radio part of the thermal spectrum of an object at ambient temperatures. Designers of radio telescopes take great pains to avoid receiving the thermal and other radiation from the local environment. However, a small fraction of it, about a million times smaller than what is received through the main beam can still find its way into the receiver. It is this ambient reception which is also the pathway for radio interference coming from all directions. Local interference sources can easily be a million times stronger than the signal from remote cosmic sources, but at the receiver they will appear to similar strength. Being the result of an ambient reception, their direction cannot easily be determined or avoided. One can only implement effective regulatory and preventive measures to keep local rfi below the detection threshold. Local means terrestrial in this context and can mean distances of hundreds of kilometres.

In order to detect distant cosmic radio sources, radio observatories require sufficient frequency bandwidth which is free of man-made radiation for a sufficiently long time (and that includes even weak and distant man-made sources). These very stringent requirements mean that radio telescopes are usually placed in carefully selected remote areas. Some countries, like the USA, Chile, Australia, and South Africa, have created large radio quiet zones around their current or future radio observatories, where human radio emissions are very strictly controlled. This is not an option in densely populated European countries, where the regulatory administrations attempt to coordinate the placement of radio transmitters so that they do not cause radio frequency interference (RFI) at the radio observatory.

Radio astronomers expend considerable money and time to avoid the creation of RFI on their sites by building shielded rooms for their electronic equipment, which is also carefully checked. The use of mobile phones and all other wireless equipment is forbidden, and regular interference surveys are undertaken in order to find any interfering equipment. However, all the efforts of regulators and radio astronomers are not always successful, as the example in Fig. 1, from Onsala Space Observatory (Sweden), shows.

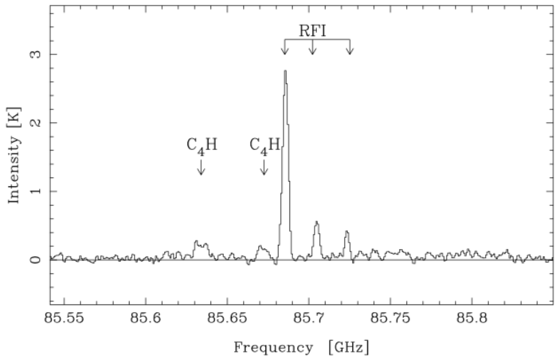

Figure 1: A spectrum observed with the Onsala 20 m radio telescope in Sweden. Spectra are used to detect and determine properties of, e.g., molecular gas surrounding old stars. In this case, the molecule being studied is C_4H. The radio signals from the molecular gas (the 'peaks' in the spectrum) are weak compared with the RFI. It is often impossible to separate the cosmic signal from RFI, which makes the observational data useless. The source of the RFI is unknown.

Another example, from the 100 m radio telescope in Effelsberg (Germany), is RFI that appeared in 2009, in a very important and protected frequency band for radio observations at ~1420 MHz (Fig. 2). The RFI is time variable, which makes it even more harmful, and its origin is still under investigation .

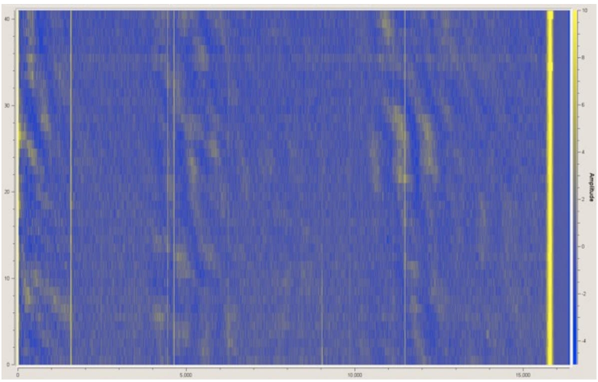

Figure 2: A spectrogram showing a pattern of time variable interference of unknown origin at ~1420 MHz. A wavy pattern is seen, which indicates reflections of a signal from an unknown transmitter by an unknown object. The amplitude of the signal is colour coded with frequency on the horizontal scale and time increasing on the vertical scale (data from Effelsberg, Germany, July 2009). The origin of this interference is still unknown.

International regulations

When combined with state-of-the-art signal processing and detection, a large radio telescope equipped with a cryogenically cooled radio astronomical receiver is much more sensitive than any industrial radio surveillance equipment. It will detect interference where other equipment shows only noise. Anything that can be detected with industrial radio equipment will almost certainly cause significant RFI in a radio telescope (note that a radio telescope is not very directional for local sources and therefore cannot easily be used to pin-point the origin of the interference). RFI can make sensitive radio observations impossible and the efforts to locate and neutralise the sources of RFI are great and can take a lot of resources that would otherwise be dedicated to scientific work. It is because of this that *preventive regulatory and technical measures are undertaken in consultation with radio astronomers* before a potentially disastrous situation arises.

Radio regulators recognised the outstanding protection requirements of radio astronomy as early as 1959, and devised a framework of international agreements and recommendations at the ITU[*] to that effect. Most important

[*] ITU: the International Telecommunication Union,

in this context is the recommendation ITU-R RA 769-2 which specifies limits of ambient radio power at a radio observatory above which harmful interference occurs. These limits are several orders of magnitude lower than the interference limits for other radio services such as broadcasting or mobile communications. Particular measures such as power limitation or minimum separation distances for transmitters from radio observatories have to be employed in order to keep the RFI power below the internationally agreed limits. The ESF* expert committee on radio astronomy frequencies (CRAF) is consulted on radio astronomical protection questions by regulatory administrations as a recognized member of the radio communication sector of the ITU. CRAF has observer status in CEPT†and participates in a consultative capacity in ECC‡ meetings.

Wind turbines

In the above context, the operation of wind turbines close to radio observatories is a new problem that has to be addressed. The recent and laudable national and European initiatives to increase the utilisation of wind power for electricity generation have given an incentive for the development of new possible sites for wind power generators. These now include areas closer to radio observatories. The impact of wind turbines on radio astronomical operations caused by their radio emissions and reflections is described in the next section.

As pointed out by the great Swedish scientist Svante Arrhenius as long ago as 1900, a rise in carbon dioxide in the atmosphere, which has already taken place and is continuing, will have a consequent rise in average global temperature with possible catastrophic consequences for mankind. It is also well known that without sufficient energy our civilization would collapse and certainly radio astronomy isn't conceivable without electricity. Consequently radio astronomers welcome the use of renewable sources for electricity generation. On the other hand, they still need to make sure that they can continue to observe without interference, thereby providing unique data for the understanding of the origin, the structure, and the future evolution of the universe. *A local planning process with rules that take account of the vulnerability of radio astronomical observatories, the expected radio emissions and reflections from a wind farm and its shielding by topography and distance is the rational solution to the question of how science can continue to provide answers for us without the destruction of the environment on which depend for survival*.

Sources of Radio Frequency Interference

Radio astronomy aims to perfect the detection of the very weakest signals from very distant radio sources, often billions of light years away. Any detectable radio emission of man-made origin can obscure these signals and constitutes RFI for a radio astronomer. The radio frequency range stretches (in broad terms) from ~10 MHz to above 100 GHz, and unique astronomical information is present throughout this frequency range.

In the past, radio astronomy suffered a great deal from interference from distant TV transmissions, direct broadcasting TV satellites, mobile satellite communication systems (IRIDIUM, still continuing) and navigational satellites (GLONASS). In addition to these 'remote' sources there are many diverse cases of local interference from radar transmitters, fixed radio links, electric trains, malfunctioning communications, TV equipment, industrial equipment and even electric cattle fences, that cause problems. The radio emission limits for industrial and consumer equipment have been created to ensure interference free operation for broadcasting and communication services. However the BS EN 61800-3:2004 document on 'Adjustable speed electrical power drive systems, Part 3: EMC requirements and specific test methods' draws attention to the fact that these limits are insufficient to protect domestic equipment from interference: (Section 6.4.3: 'Warning: In a domestic environment, this product may cause radio interference, in which case supplementary mitigation measures may be required.'). For radio astronomy the interference potential is much more severe and additional shielding or large separation distances are required for frequencies up to several GHz. *Hence the radio emission limits for industrial equipment do not take the higher requirements of radio astronomy into consideration*. Industrial equipment certified to CISPR-11 and CISPR-22 standards§ can therefore cause harmful RFI to radio astronomy (see figures 3 and 4). It is one of the reasons why radio astronomers have to make great efforts to shield their own electronic equipment.

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* ESF: European Science Foundation,

† CEPT: European Conference of Postal and Telecommunications Administrations

‡ ECC: Electronic Communication Committee of CEPT

§ CISPR = international committee on radio interference

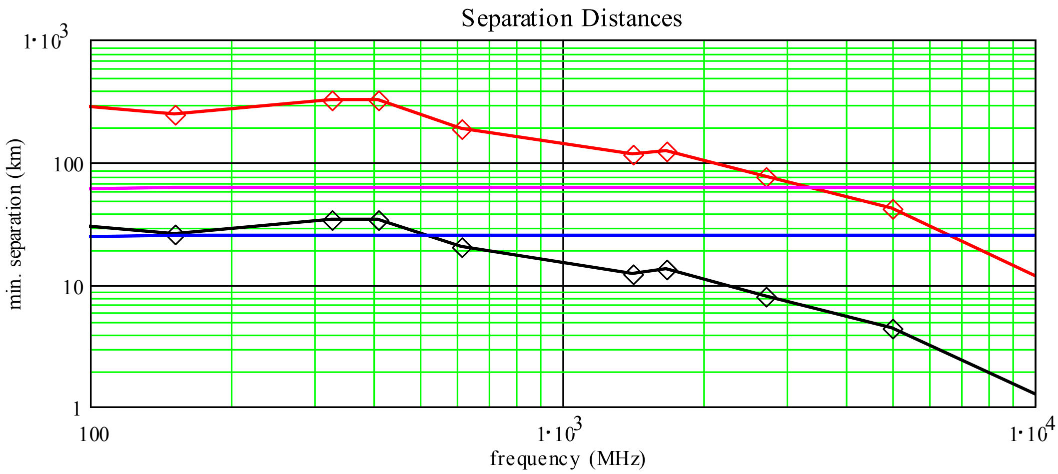

Figure 3: Free space separation distances between CISPR-11 electronic equipment and a radio observatory . Black: Minimum line of sight distance needed to shield a 50m high radio astronomical antenna from equipment at ground level as a function of frequency. Diamonds indicate radioastronomical bands. For ground-level (< 2-5 m) the local sub-urban clutter (buildings, trees etc.) can provide additional interference attenuation of about 20 dB . However separation distances of many km may be needed even in this case. Blue: optical horizon from a height of 50 m. Red: similar separation distances for an industrial emitter at a height of 100 m. Any equipment within the optical visibility range (mauve) of 61 km can become the source of significant interference.

The figure above illustrates why additional shielding of industrial emissions close to the radio telescope is needed. This can be achieved either by additional rfi suppression measures within the industrial plant, extra shielding or attenuation by the local topography or by a combination of various measures. Depending on the kind of terrain, the topographical attenuation can be very high (>30 dB) and it had traditionally been the resort of radio astronomers to select remote, preferably mountainous sites for their observatories. Regional planning restrictions then helped to prevent large scale industrial and other developments so that a low interference site could be maintained. But it becomes quite clear, that large structures, potentially emitting radio waves above the top of the local buildings and tress etc. significantly increases the range of possible interference and that can overcome the benefits of a remote location. Note that topographical attenuation (shadowing) will only reduce the interfering signals, but never fully suppress them. If they are strong enough, they can still be received, even when there is no optical line of sight to the transmitter.

Radio emission mechanisms potentially causing interference

a) Tall structures, such as wind power generators within the line of sight of a radio telescope, can function as primary (i.e. radio emission from the generator electronics, Fig. 2) and/or

b) secondary (i.e., by their reflection of more distant radio stations) transmitters of RFI.

In addition,

c) a large rotating structure close to a telescope can even modulate the near-field background signal of the telescope because of its periodically varying electrical characteristics. It can disturb the antenna pattern and present a variable source of thermal radio emission for low elevations of the radio antenna.

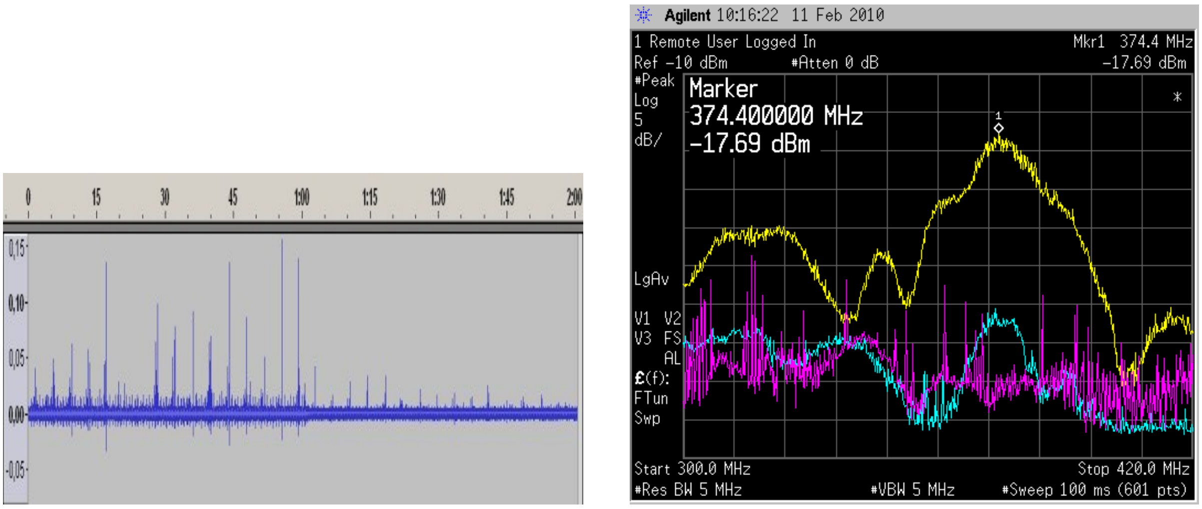

Figure 4: Radio emission detected from wind power plants.
Left*: Emission at 1420 MHz measured at a distance of 200 m from a wind turbine near Euskirchen (Germany). The horizontal scale shows time in minutes and seconds, and the receiver is pointing to the source for the first minute, then away for the second minute. The vertical scale shows the received radio power.*
Right*: Emission at 300-420 MHz detected at a distance of 1.5 km from a wind power station in Sardinia (Italy). The yellow trace shows the signal received in the direction of the wind farm and the blue and mauve traces show the signal received from directions orthogonal to the direction of the wind park. The characteristics of the emission is weather dependent and may originate from sparking or corona discharges of high voltage equipment associated with the wind farm.*

The scattering efficiency of wind turbines

The fact that wind turbines are potent reflectors of radio signals has been noted by other radio services and regulating authorities, in particular civil and military radar services, as well as operators of fixed radio links and TV broadcasting stations (see reports by EUMETNET 2006, ANFR 2008, ERA-AEGIS 2008, EUROCONTROL 2009, OFCOM 2009; references are given in Appendix 2). Individual wind power generators were found to have effective radio reflection cross sections (RCSs) for backscatter of 50000 m^2 at 435 MHz and 1600 m^2 at 1477 MHz. In intermediate (orthogonal) directions their RCSs were found to vary greatly between 50 m^2 and 6000 m^2, depending on frequency and orientation (ERA-AEGIS 2008). At higher frequencies, wind turbines with diameters of 39 m and hub heights of 40 m (i.e. much smaller than typical wind turbines built today) have been found to have RCSs of up to 5000 m^2 at 9000 MHz and up to 12000 m^2 at 15000 MHz (FOA 1999). Note for comparison that the total reflecting area of the largest European radio telescope, the 100 m dish in Effelsberg (Germany), is 7850 m^2. Reflections and diffraction cause false echos or non-detections (sky-blockage) for radar services. A 15 km range for impact assessment around primary air traffic control radars is therefore required by EUROCONTROL.

Weather radar

In the case of weather radar (which is used to locate rain, snow, hail, etc.), it has been proven that distant (71 km) wind turbine reflections of radiation emitted from the much weaker side lobes of the weather radar caused erroneous detections in the radar (EUMETNET 2006). The Nysted offshore wind farm south of the Danish island of Lolland is covered by 72 wind turbines, each with 70 m high blades. An example is shown in Fig. 5 below:

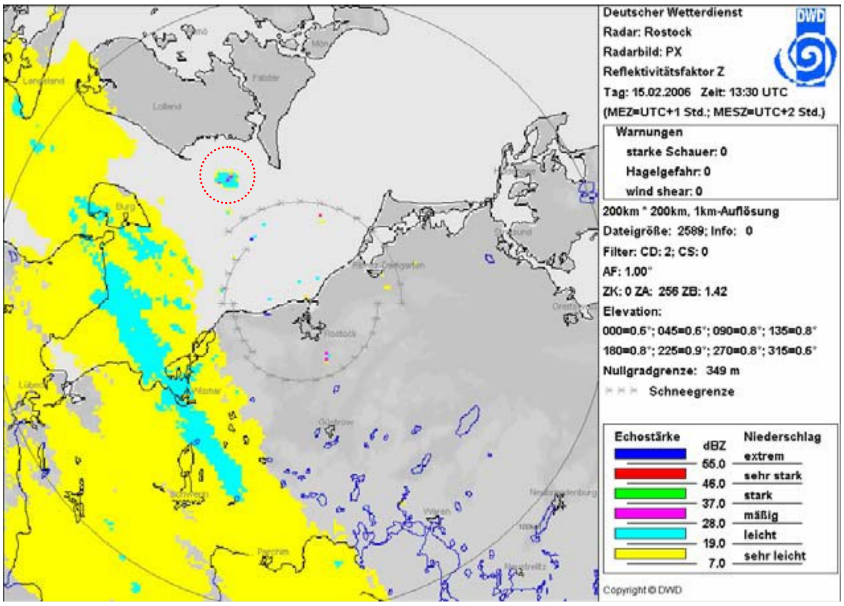

Figure 5: Reflectivity data from the Rostock weather radar showing the Nysted offshore wind farm (EUMETNET 2006). The location of the offshore wind farm is indicated by a red circle.

The 48 km distant Nysted offshore wind farm is usually visible during normal sea surface propagation of the radar beam from the Rostock Radar (EUMETNET 2006). Based on their measurements, EUMETNET has requested that:

i) no wind turbines should be deployed at distances from the radar antenna less than:
- 5 kilometres from C-band radars (≈ 6 GHz)
- 10 kilometres from S-band radars (≈ 2.3 GHz)

ii) projects of wind parks should be submitted to an impact study when they concern distances lower than:
- 20 kilometres from C-band radars
- 30 kilometres from S-band radars

The scattered radio signals from weather radars are, however, not simply lost. They create a variable and unpredictable background of radio interference!

CRAF and EUMETNET have recently submitted a document to ECC SE21 [Doc SE21(10)045] where, depending on frequency and design of the meteorological radar, *a separation distance between 42 and 102 km is required between a meteorological radar station and a radio observatory*. Propagation over mountainous terrain could shorten the distance in practice, but propagation over the sea will require larger protection radii. The report was accepted by the ECC. It should be pointed out that, although weather radars and radio astronomy do not operate at the same frequencies, the high power of radars and the consequent unavoidable out-of-band emission at radio astronomical frequencies mean that the above quoted separations are required for a direct line-of-sight path in order to comply with the ITU-R RA 769 interference thresholds for radio astronomy. A strong reflector can scatter radar signals from large distances, although the terrain (mountains) may shield the radio observatory from the primary transmitter, and these may be picked up as RFI. Whatever a radar station can detect is certainly also detectable by radio astronomy and a potential cause of interference!

Radio links

Procedures to coordinate point-to-point radio links have been set up and are used by regulators in order to avoid disturbance to the radio links themselves (e.g., OFCOM (UK) Wind farm coordination policy, TRANSFINITE 2010). Here regulators and operators aim to reduce the impact of

i) near field effects,
ii) intrusion into the Fresnel zones (the actual space occupied by the radio beams), and
iii) scattering or reflection

on the radio link itself . A 500 m wide exclusion zone around the point-to-point link path is needed in order to avoid interference to the link itself. However, the effects of wind farms can be measured at much greater separations than this from the link itself. An investigation of wind-farm-scattered signals from a point-to-point link near Euskirchen (Germany) has been made. The wind farm consists of 10 Enercon E53/800 wind turbines of diameter 53 m and hub height of 74 m. The distance between transmitter and wind farm was ≈ 8 km, the distance between the wind farm and the receiving antenna was ≈ 3.7 km, and the angle between the main lobe of the transmitter and the wind farm was ≈30 degrees (Fig. 6 and 7).

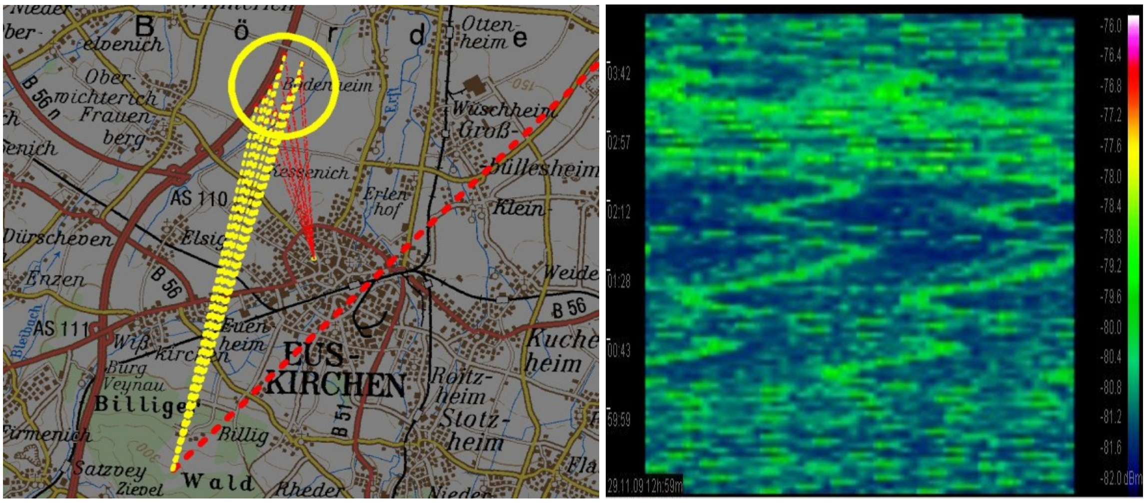

Figure 6: Scattering of point-to-point link sidelobe emission by a wind farm near Euskirchen (Germany) at a frequency of 4.4 GHz.
***Left**: Locations of the wind farm (yellow circle) and receiver in Euskirchem and the path of the link (dashed red line), Also shown are the paths to the individual turbines from the transmitter (dotted yellow) and the receiver (solid red).*
***Right**: Colour-coded spectrogram with 2,93 s per sweep of the received signals, showing reflections as a wavy intensity pattern, typically every 1.2 s between two blades, or 3.6 s per turn or 17 turns per minute (the rotational speed is variable, following the wind speed).*

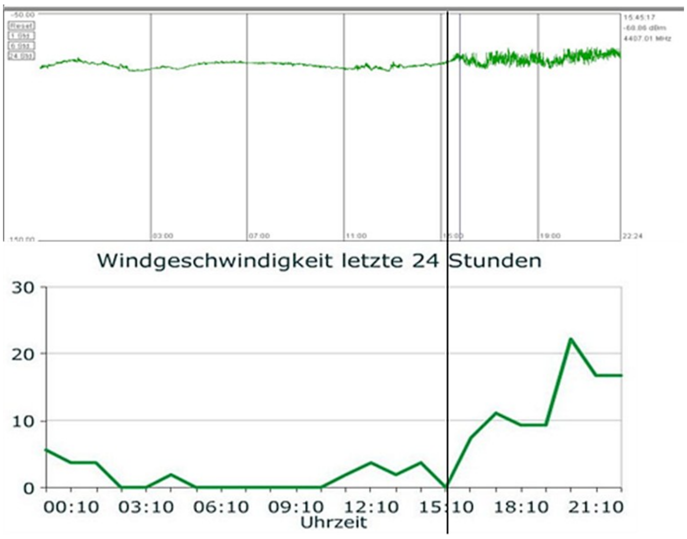

Figure 7:
***Bottom panel:** the local wind speed.*
***Upper panel:** the strength of the reflected signal. There is a clear increase in variability as a result of the wind farm beginning to operate when the wind speed exceeded the operational threshold.*

The receiving antenna was *not* a large radio telescope, but simply standard measuring equipment. The results show that even such equipment can detect the scattered signals when distances of several km are involved and when the link is not pointing at the wind farm. Note that the detected reflections are measured above the local background which may include some direct sidelobe emission from the fixed link and additional diffraction interference between direct and scattered radio power. It is clear that the characteristics of the scattered radiation are very complex. *TV broadcast*

UHF broadcast transmissions (470-862 MHz) are also known to be affected by tall structures and measures have had to be taken to avoid and remedy these effects (OFCOM 2009) for low-sensitivity (compared with a radio telescope) private TV receivers in an area of several km around a wind farm. Again, the radiation is strongly diffracted and scattered, which means that it may considerably increase the range of RFI from TV stations for a radio observatory.

Coordination

Sites of active services (radar, fixed link, broadcasting, mobile communication base station) are carefully coordinated by regulators to enable the coexistence between active services and radio astronomy. *Bringing strong radio reflectors or scatterers into the coordination zones may nullify the results of these efforts or require a complete reassessment of the coordination procedures for many frequency bands for all active services that can potentially cause interference to radio astronomy.*

International protection of radio observatories

The planning and operation of wind farms is subject to national and regional planning procedures. Radio observatories in Belgium, Germany, Italy. the Netherlands, Sweden, and the UK are currently involved in consultations with their regulating authorities, wind turbine companies, and governments in order to find suitable procedures and guidelines that will enable coexistence of wind farms and radio astronomical observatories. The matter is of great technical and legal complexity and has to be solved on a case by case basis for each country. *CRAF advises that no planning and operating permissions are given for wind farms within a radius of 25 -30 km (depending on terrain and propagation) around a radio astronomical observatory without a detailed impact assessment.* The assessment should take background, and primary and secondary effects into consideration for all frequencies at which the radio observatory operates, or is planned to operate in the near future. The detailed steps of the suggested procedure are given in **Appendix 1**.

CRAF sees its role as an accompaniment to this process, and is actively involved in devising guide lines that will enable a mutually beneficial coexistence of wind farms and radio observatories.

Appendix 1 - Generic Impact assessment procedure

This appendix outlines an assessment procedure developed by CRAF to estimate the effect of wind turbines on radio astronomical operations.

1. Calculate the effective path loss $\mathbf{L_b(p,f)}$ from the telescope to the site of the proposed structure for each frequency band using the methods (8a) of ITU-R P.452-12. As the proposed structure and the telescope both rise above the canopy of trees and they will not be located in urban areas, ground clutter corrections do not apply. However, for those cases where there is no direct line of sight because of elevated terrain between the observatory and the proposed structure, a careful path profile analysis according to Appendix 2 to Annex 1 of ITU-R P.452-12 has to be undertaken to include the sub-path diffraction losses. The calculated transmission losses should not be exceeded in p=0.05 of the time. For high frequencies one has to include atmospheric absorption. However, ducting-, tropo- and rain scatter propagation may be neglected.

2. If the antenna cannot point at the structure, then calculate the maximum side-lobe gain $\mathbf{G_{max}(f)}$= 32 - 25log(ϕ_{min}) of the antenna[1], which depends on the minimum relative elevation ϕ_{min} (given in degrees), in the direction of the new structure for each frequency. If the antenna can point at the structure, then use the full main beam gain of the antenna.

3. ITU-R RA. 769 gives a table of emission limits of continuum input power ΔP_H (table 1, column 7) for each radio astronomical frequency. Any emission from the site of the planned structure must be kept below the site limit of

$$\Delta P_{site} = \Delta P_H + \mathbf{L_b(0.05,f)} - \mathbf{G_{max}(f)}$$

4. Prepare a table of these emission limits for the proposed site and at the nominal height of the structure, one entry per radio astronomical frequency. giving centre frequency and bandwidth. Make estimates for neighbouring non-allocated frequency bands where signal limits may be higher by the amount of out-of-band rejection $\mathbf{G_{out}}$ or where ΔP_H is replaced by the intermodulation threshold $\mathbf{\Delta P_{IM}}$ of the receiver.

5. Planning and operating permissions should become subject to the adherence to the so derived limits. The operator has to prove beyond all reasonable doubt that his equipment will not exceed these emission limits through the sum of all emissions from
   a) direct emission $\mathbf{\Delta P_d(f)}$ from the plant and its control and power electronics including transmissions from power lines. It is the burden of the operator to prove that the equipment will stay within the operating constraints, by providing proper emission measurements of his equipment in the required bands.
   b) radiation $\mathbf{\Delta P_{scat}(f)}$ from other sources scattered by the turbine.

6. For the scattered radiation, the above means that in addition to the reflecting surface area $\mathbf{A_r}$, the reflection coefficients $\boldsymbol{\eta}\mathbf{(f)}$ of the structure and its materials at the specific frequencies must be known. Otherwise a perfect reflector will be assumed. Effective reflecting areas are of the order of 2-5000 m^2 for a typical wind power generator.

7. Measurements of the power flux densities $\mathbf{S_{site}(f,h)}$ (= pfd given in $dB(W/m^2)$ in all bands and at heights **h** up to the top of the structure have to be made by the administration or a certified consultant so that a statistically meaningful survey (i.e. $p < 5\%$ for a deviation from these levels for more than 2% of the time) of the ambient maximum signal levels $\mathbf{S_{ambient}(f)}$ and the band occupancy at the proposed planning location is available. Measurement are not required if suitable information on local pfd on bands that other services shared with radio astronomy can be provided by administrations.

8. For a proper assessment, these measurements should be performed at different heights h, and then an integration over the effective surface contributions with varying heights should be made, yielding the effective scattered power of

$$\mathbf{\Delta P_{scat}(f) = S_{ambient}(f) + 10 \cdot \log(\eta(f)) + 10 \cdot \log(A_r/m^2)}$$

   If measurements above a certain height are not feasible, then they can be performed at the maximum height available and scaled to the full height of the structure using the procedure described in ITU-R P. 1146. For heights above 30m, the value of 30m should be used.

9. **Compatibility means, that for all frequencies, f, the sum of direct and scattered emission stays below the interference limit at all considered frequencies for 98% of the time:**

a. $\mathbf{\Delta P_d(f) + \Delta P_{scat}(f)}$	<	$\mathbf{\Delta P_{site}(f)}$	(in band limit)
b. $\mathbf{\Delta P_d(f) + \Delta P_{scat}(f)}$	<	$\mathbf{\Delta P_{site}(f) + G_{out}}$	(out of band limit)
c. $\mathbf{\Delta P_d(f) + \Delta P_{scat}(f)}$	<	$\mathbf{\Delta P_{IM} + L_b(0.05,f) - G_{max}(f)}$	(out of band IM limit)

10. Radio astronomy is also vulnerable to powerful short duration pulses such as those emitted by radar facilities. In such cases, the ΔP_{site} of case 9b will have to be replaced by a pulsed detection threshold for regular observations.

11. The administration has to list the wind turbine site as a coordination location, where the limits derived above may not be exceeded when new transmitters are brought on-line elsewhere.

12. If there is to be more than one turbine, the cumulative effect of all structures will have to be considered.

Appendix 2 - Literature:

EUMETNET Report OPERA II WP 1.8 December 2006 at:
http://www.knmi.nl/opera/opera2/OPERA_2006_18_Impact_of_Wind_Turbines_on_Weather_Radars.pdf

ANFR (France) 2008 "Rapport CCE5 n°3 Perturbations du fonctionnement des radars fixes maritimes, fluviaux et portuaires par les eoliennes" at:
http://www.anfr.fr/fileadmin/mediatheque/documents/etudes/Rapport%20perturbations%20fonctionnement%20radars%20fixes%20maritimes%20fluviaux%20et%20portuaires%20par%20eoliennes.pdf

ERA-AEGIS Report for OFCOM (UK) 2008 on RF Measurement Assessment of Potential Wind Farm Interference to Fixed Links and Scanning Telemetry Devices at:
http://licensing.ofcom.org.uk/radiocommunication-licences/fixed-terrestrial-links/guidance-for-licensees/wind-farms/rf_measurement/)

EUROCONTROL (EU) 2009 Guidelines on How to Assess the Potential Impact of Wind Turbines on Surveillance Sensors at:
http://www.eurocontrol.int/corporate/gallery/content/public/event_docs/091123_windturb/Guidelines%20to%20assess%20potential%20impact%20of%20Wind%20turbines%20on%20sur%20sensors.pdf

OFCOM (UK) 2009 Tall structures and their impact on broadcast and other wireless services at:
http://licensing.ofcom.org.uk/binaries/spectrum/fixed-terrestrial-links/wind-farms/tall_structures.pdf

OFCOM (UK) Wind farm coordination policy at:
http://licensing.ofcom.org.uk/radiocommunication-licences/fixed-terrestrial-links/guidance-for-licensees/wind-farms/windfarm_coor_pol

TRANSFINITE (2010) Wind farms and Point to Point Fixed Links at:
http://www.transfinite.com

Doc SE21(10)045 2010 CRAF-EUMETNET Revision to section 9 (Radio astronomy) of PDN Report on radar spurious emissions (document SE21(10)27 Annex 5) available at: www.ero.dk

ITU Handbook on Radio Astronomy, 2nd ed., ITU, Geneva, (2003)

Recommendation ITU-R RA 769-2: Protection Criteria used for Radio Astronomical Measurements, ITU, Geneva (2003)

FOA Försvarets Forskningsanstalt (Sweden) 1999 Försvaret och vindkraften, huvudstudie radar (Dnr: 99-2936/L) (In Swedish; FOA is the Swedish Defence Research Agency)