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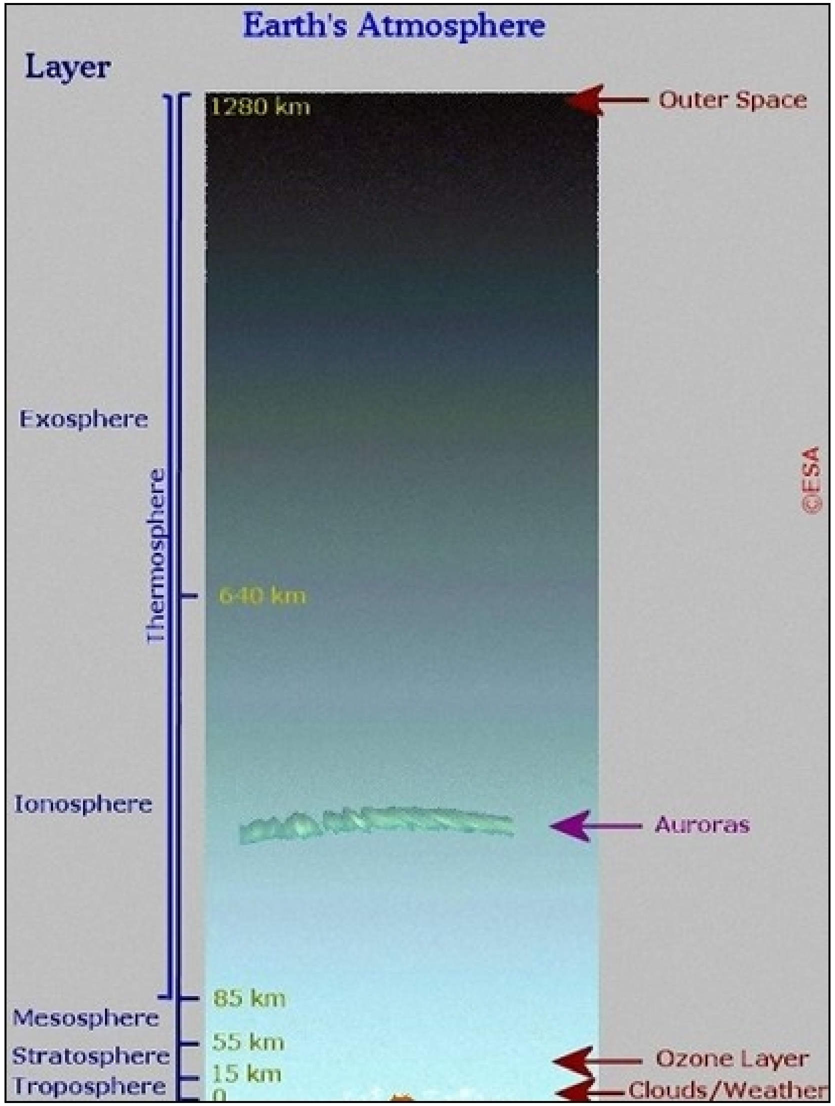
Radar measurements

FYS 3610

Photo: Tony Van Eyken

Radars

A radar transmit a radio pulse (pulse code), and receives the returned ”echo” sometime later.



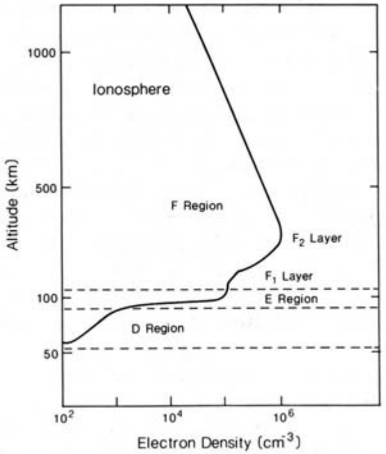
Radiowave propagation

- It can be deduced that a radio signal is reflected in the ionosphere when it’s frequency f is equal to the local plasma frequency fp, where

$$f_{pe} = \sqrt{\frac{n_e \cdot e^2}{2\pi\varepsilon_0 m_e}}$$

- To a good approximation, $f_{pe} = 9000 \cdot \sqrt{n_e}$ Hz , when n_e is in [cm^{-3}]

- The peak electron density in the ionosphere is ~ 10^6 cm^{-3} (i.e· 10^{12} m^{-3}).
- This gives that $f_{pe} \leq 12$ MHz



Inchoerent Scatter Radars (ISR)

- The ISR uses frequencies well above the the plasma frequency in the atmosphere.
- Typical frequencies used are from 50 MHz and up (to 2 GHz). Such waves are almost unattenuated by the ionosphere, and pass through almost unaffected into space.
- (Absorbtion is inversely proportional to the frequency of the signal, and has it's maximum i the D-layer).
- **Therefore it is the small amount of energy scattered by the ionospheric electrons which is detected by the ISR method.**
- Since the scattered signal is very weak, very powerfull transmitters are used ($P_T \sim 10^6$ W, $P_R \sim 10^{-15}$ W).

ISR – density measurements

- The radio signal is transmitted in pulses. The range from the radar to the echoing region is determined by

$$2s = v \cdot t \Rightarrow s = \frac{v \cdot t}{2}$$

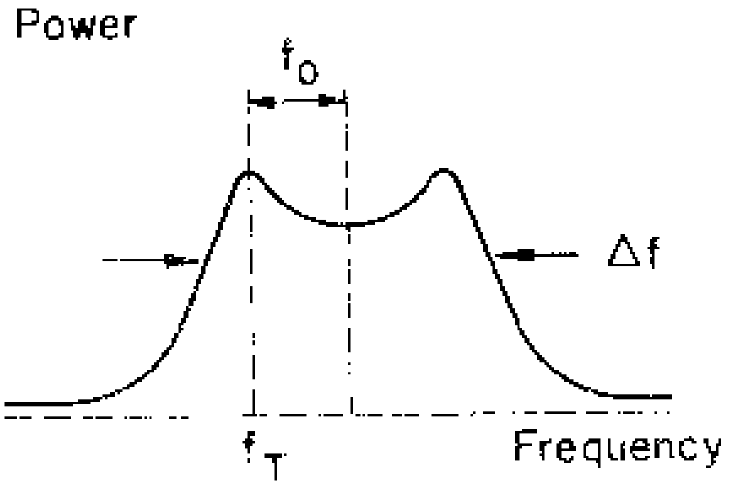
- **The power in the returned signal is proportional to the electron concentration in the volume irradiated**. This stems from the fact that each electron incoherently radiates back a small amount of the incident energy. **The electric field in the transmitted wave causes the electrons encountered by the radar pulse to oscillate, resulting in radiaton of a signal at almost the same frequency** (Thomson scattering).

ISR – velocity measurements

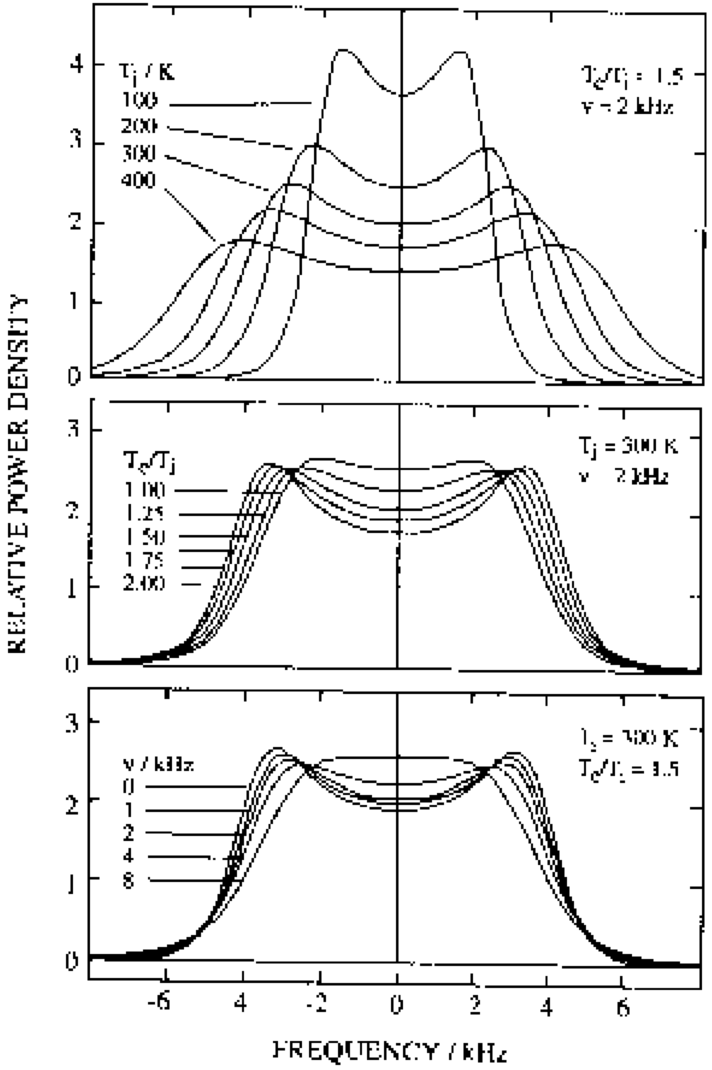
- The electrons are in thermal motion, and hence the backscattered signal is Doppler shifted from the incident frequency. This gives information about the radar line of sight velocities of the scattering electrons.
- As long as the neutral density is much larger than the electron density (low ionisation), the electrons will follow the movements in the neutral gass, and the radar measurements can be used for studying the dynamics in the atmosphere.

ISR – Doppler spectrum due to scattering from thermal fluctuations in the ion line

- Number density ~ power/area under the curve.
- The width Δf determines the ion temperature Ti.
- T_e / Ti determined from the intensity of the ”wings”/shoulders in the spectrum.
- The frequency shift f_o from the transmitt frequency f_T gives the mean ion velocity.



ISR – Doppler spectrum



ISR – Doppler spectrum explanation

An incoherent scatter radar echo comes from a very large number of electrons. These are not stationary, but rather in random thermal motion. Thus the echo will not be at a single frequency, but a range or spectrum of frequencies near the transmitter frequency. As the temperature increases, the average velocity of the electrons increases, and the range of velocities increases. Put another way, the width of the spectrum increases. The width of the spectrum is then a measure of the temperature of the ionosphere, and the incoherent scatter radar functions as a thermometer. In fact, there are two temperatures in the ionosphere. When an electron is removed from an atom, the remaining atom, which is now missing an electron, is known as an ion. The ion gas may have a different temperature from the electron gas. As a result of electrical interactions between the ions and electrons, the width of the spectrum measures the ion temperature. However, the spectrum usually has two peaks, or wings/shoulders, and the height of these shoulders measures the electron temperature. The electron/ion mixture is known as a plasma, and in addition to the thermal motions, the entire plasma is usually in motion. In other words, there is a plasma wind. As a result, the entire spectrum will be shifted instead of being centered on the transmitter frequency. Thus an incoherent scatter radar also functions as a wind speed meter.

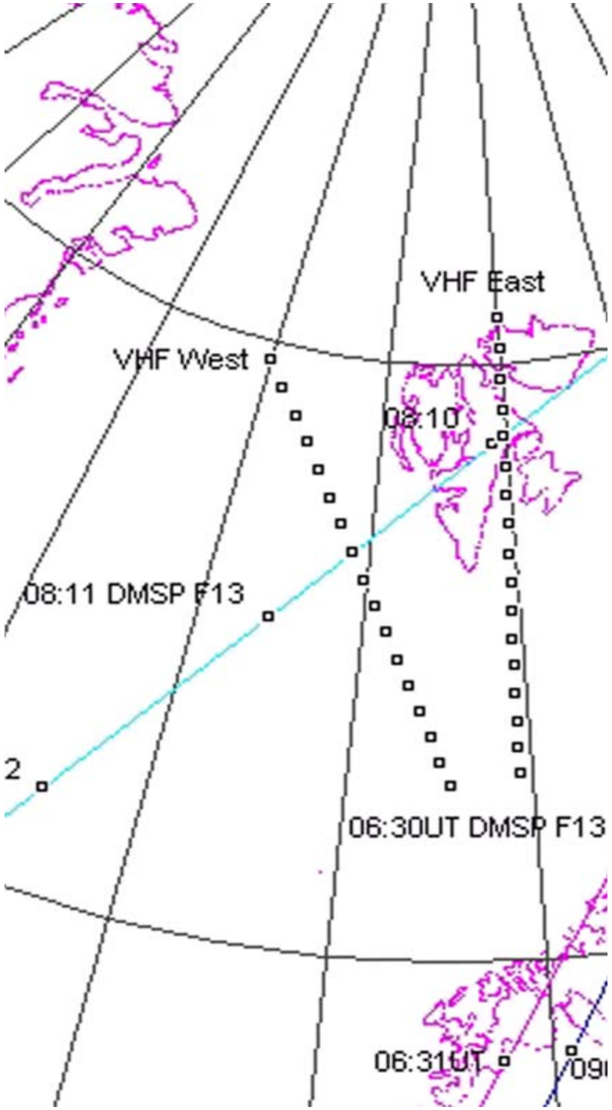
EISCAT Scientific Association

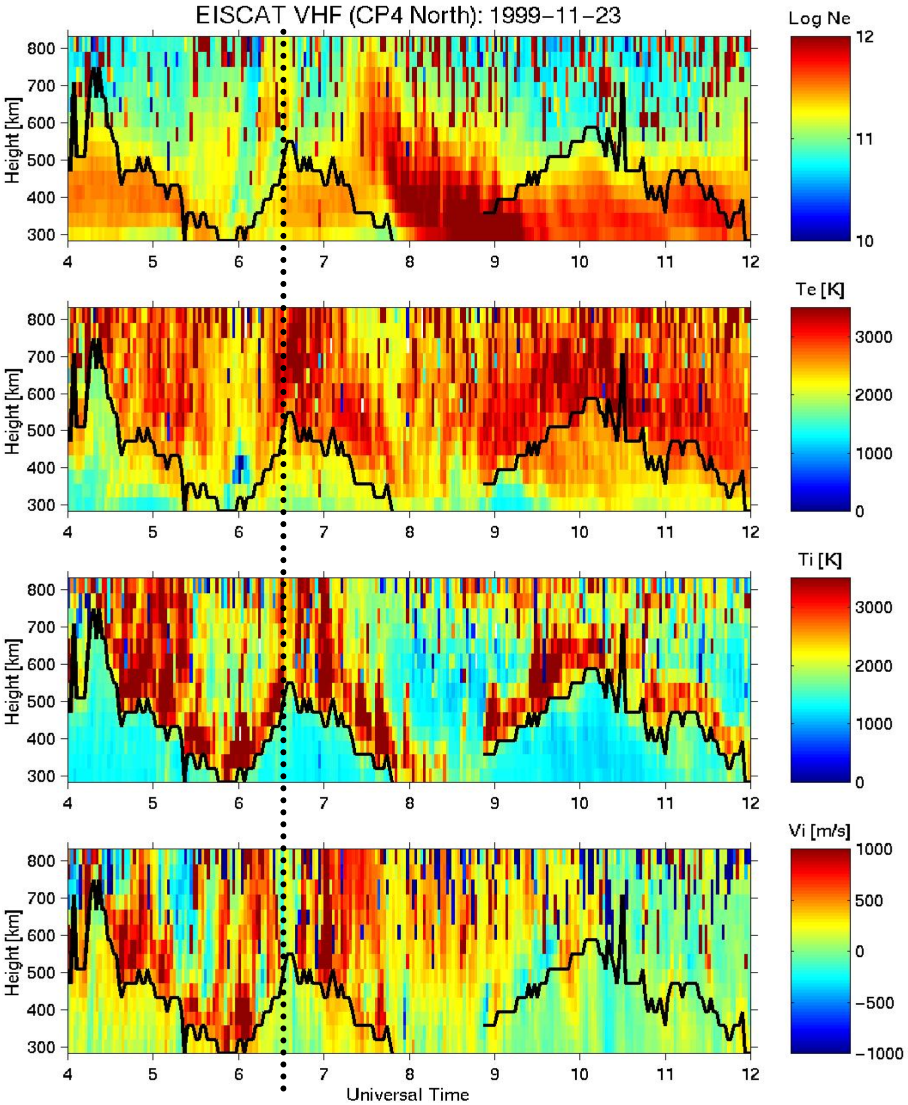
Three Incoherent Scatter Radar Systems:

- **Tromsø VHF (224 MHz)**
- **Tromsø UHF (933 MHz)**
- **EISCAT Svalbard Radar (500 MHz)** - dual antenna system

Associated countries:
Germany, France, Finland, Japan, Norway, Sweden, UK.

China from 1 Jan 2006

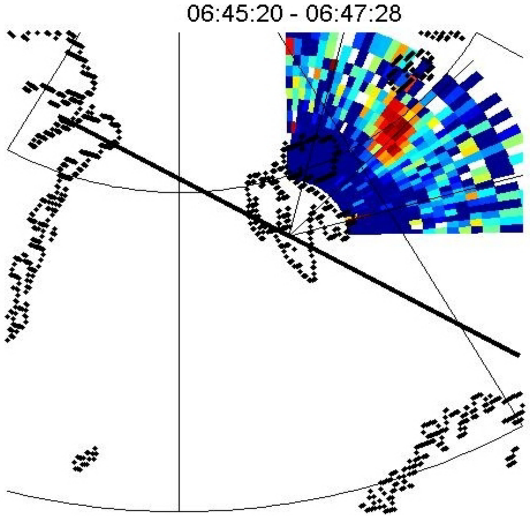


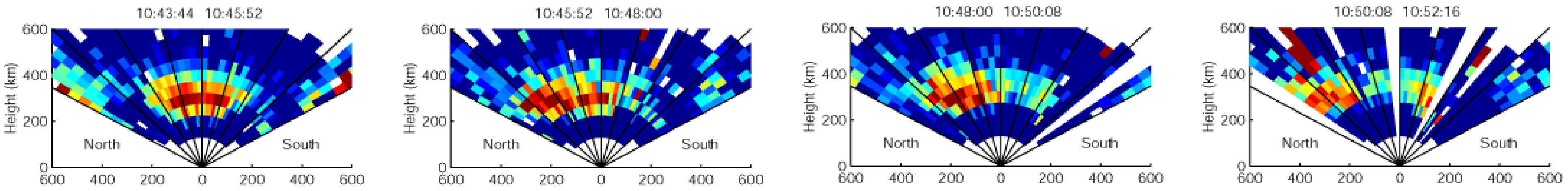


Moen at al., 2004

Mapping of electron density patches by EISCAT Svalbard Radar

- Developed fast sweep modes for mapping and tracking of density patches
- For both elevation and azimuth-sweeps the windshield-wiper motion is repeated every 128 seconds, and data is sampled every 3.2 seconds at a range resolution of 50 km.
- Steep density gradients may in a worst case scenario cause serious problems for GPS navigation





Poleward drifting electron density patch at a speed of ~1 km/s

Coherent Scatter radar

- In the troposphere and stratosphere changes in the index of refraction is mainly attributed to changes in temperature and the content of water vapor.
- In the ionosphere the density of free electrons determine the index of refraction.
- The radio signals are scattered from irregularities or gradients in the atmospheres index of refraction (n).
- $n = c / v$

c = velocity in vacuum, v = velocity in the medium

Coherent radar– backscatter targets

- The scattering wavelength is one half the transmitted wavelength, meaning that backscatter occures when the irregularities have a size of approximately on half the radar wavelength (constructive interference).
- Example:

A medium frequency radar operating at 10 MHz . This gives a wavelength of

$$\lambda = \frac{c}{f} = \frac{3 \cdot 10^8 m/s}{10 MHz} = 30m$$

This means that this radar will give backscatter when the irregularities are in the size of ~ 15 meters.

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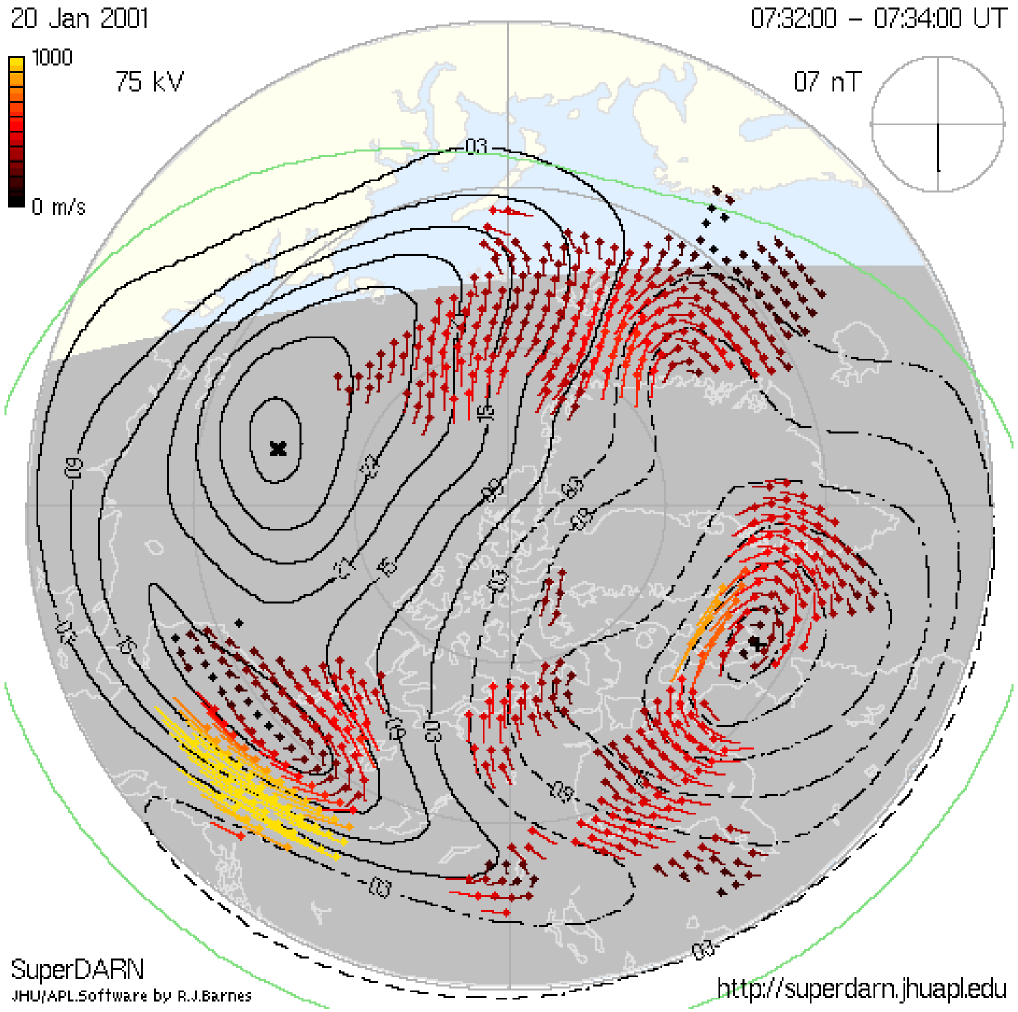
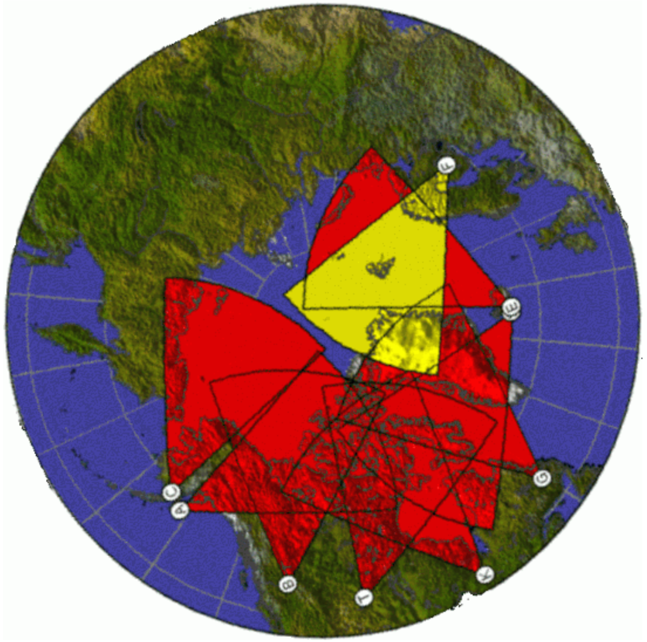
SuperDARN Radars

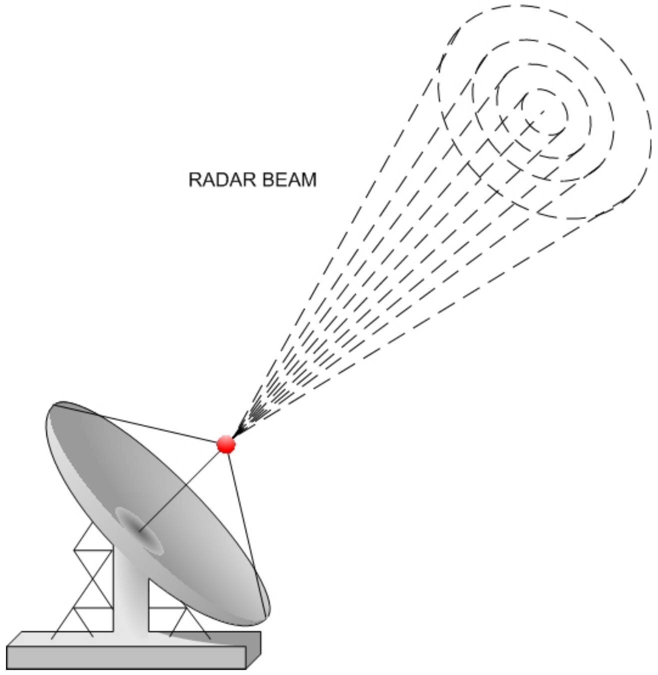




A network of HF radars that monitors the high-latitude ionosphere.

Radar Beam

- As pulses travel away from the antenna; the beam takes on a cone-like appearance and expands in all directions.
- This expansion or *beam broadening* increases pulse volume.



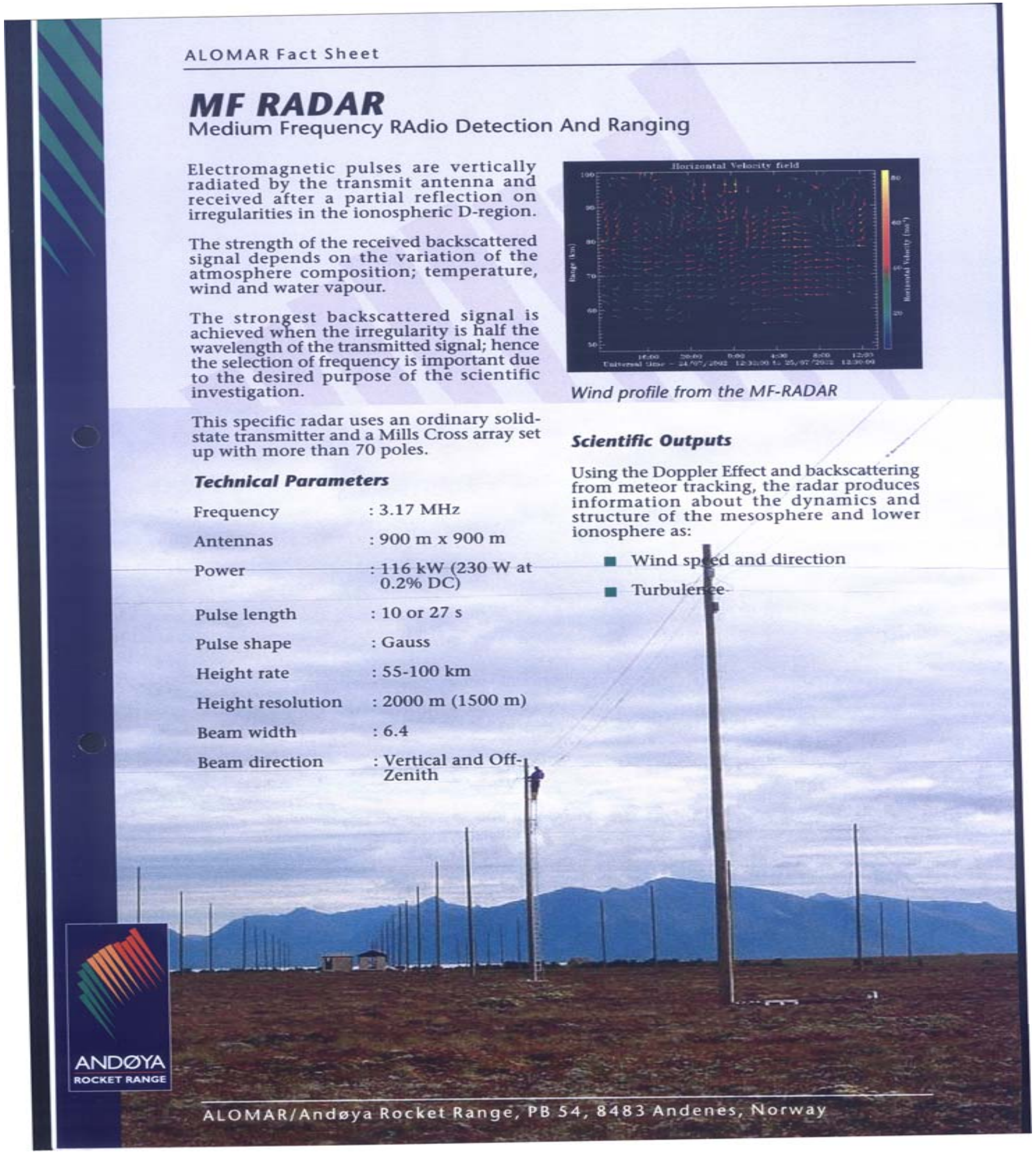
Beam width (opening angle) :

$$\varphi = k \cdot \frac{\lambda}{D}$$

Where k is a numeric factor (k ~ 1) and D is the antenna aperture.

Radar Beam

- While the amount of power within a pulse is determined by its length and remains constant, power density decreases with distance. This occurs because the pulse’s fixed amount of energy is spread over a greater area (pulse volume) as the beam broadens.
- The further a pulse travels, the weaker and less effective it becomes due to increased pulse volume.
- **Radars with small beam widths are necessary to provide good target resolution.**
- **Height resolution / spatial resolution of a radar depends on the pulse length !**



ALOMAR Fact Sheet

MF RADAR

Medium Frequency RAdio Detection And Ranging

Electromagnetic pulses are vertically radiated by the transmit antenna and received after a partial reflection on irregularities in the ionospheric D-region.

The strength of the received backscattered signal depends on the variation of the atmosphere composition; temperature, wind and water vapour.

The strongest backscattered signal is achieved when the irregularity is half the wavelength of the transmitted signal; hence the selection of frequency is important due to the desired purpose of the scientific investigation.

This specific radar uses an ordinary solid-state transmitter and a Mills Cross array set up with more than 70 poles.

Technical Parameters

Frequency : 3.17 MHz
Antennas : 900 m x 900 m
Power : 116 kW (230 W at 0.2% DC)
Pulse length : 10 or 27 s
Pulse shape : Gauss
Height rate : 55-100 km
Height resolution : 2000 m (1500 m)
Beam width : 6.4
Beam direction : Vertical and Off-Zenith

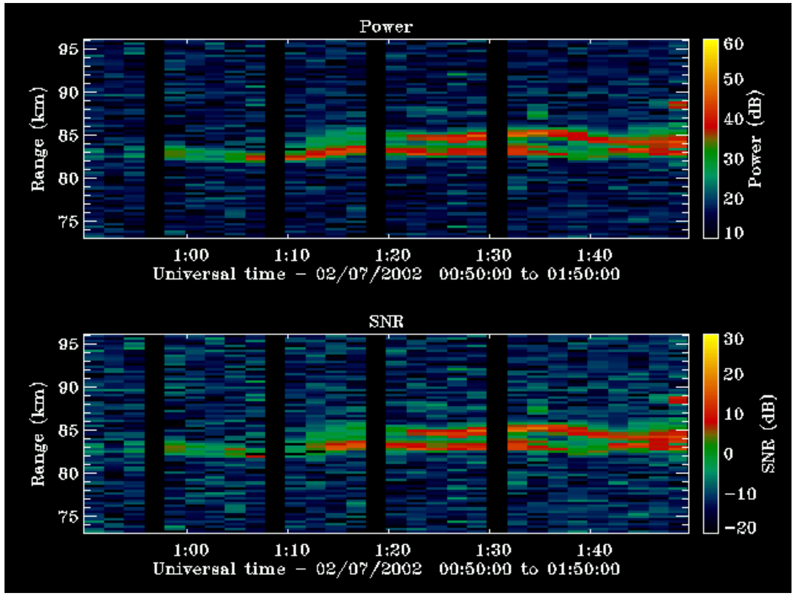
Wind profile from the MF-RADAR

Scientific Outputs

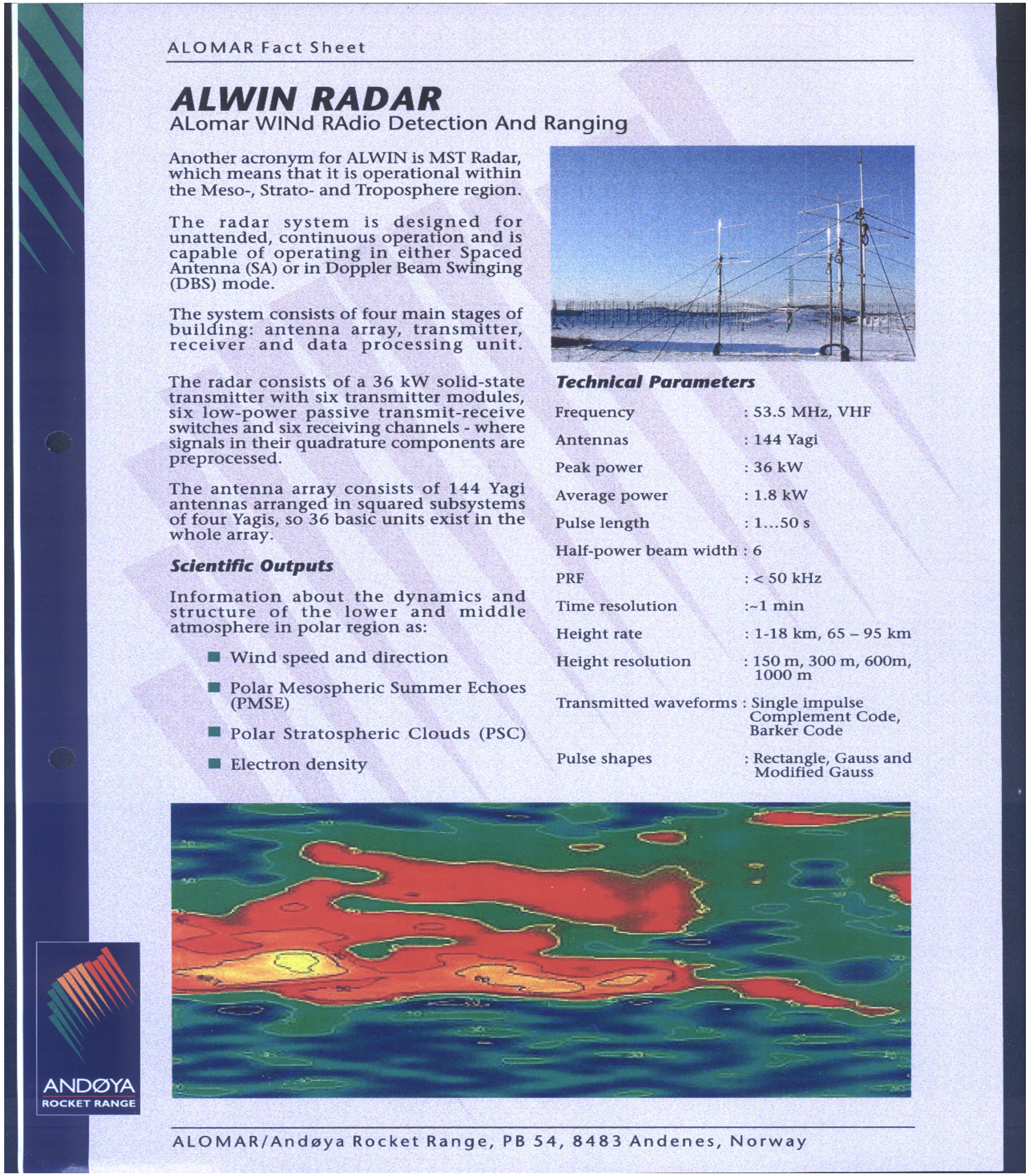
Using the Doppler Effect and backscattering from meteor tracking, the radar produces information about the dynamics and structure of the mesosphere and lower ionosphere as:

- Wind speed and direction
- Turbulence

ALOMAR/Andøya Rocket Range, PB 54, 8483 Andenes, Norway



ALWIN radar measurements of NLC (noctilucent clouds)



ALOMAR Fact Sheet

ALWIN RADAR

ALomar WINd RAdio Detection And Ranging

Another acronym for ALWIN is MST Radar, which means that it is operational within the Meso-, Strato- and Troposphere region.

The radar system is designed for unattended, continuous operation and is capable of operating in either Spaced Antenna (SA) or in Doppler Beam Swinging (DBS) mode.

The system consists of four main stages of building: antenna array, transmitter, receiver and data processing unit.

The radar consists of a 36 kW solid-state transmitter with six transmitter modules, six low-power passive transmit-receive switches and six receiving channels - where signals in their quadrature components are preprocessed.

The antenna array consists of 144 Yagi antennas arranged in squared subsystems of four Yagis, so 36 basic units exist in the whole array.

Scientific Outputs

Information about the dynamics and structure of the lower and middle atmosphere in polar region as:

- Wind speed and direction
- Polar Mesospheric Summer Echoes (PMSE)
- Polar Stratospheric Clouds (PSC)
- Electron density

Technical Parameters

Frequency	: 53.5 MHz, VHF
Antennas	: 144 Yagi
Peak power	: 36 kW
Average power	: 1.8 kW
Pulse length	: 1...50 s
Half-power beam width	: 6
PRF	: < 50 kHz
Time resolution	:~1 min
Height rate	: 1-18 km, 65 – 95 km
Height resolution	: 150 m, 300 m, 600m, 1000 m
Transmitted waveforms	: Single impulse Complement Code, Barker Code
Pulse shapes	: Rectangle, Gauss and Modified Gauss

ANDØYA
ROCKET RANGE

ALOMAR/Andøya Rocket Range, PB 54, 8483 Andenes, Norway