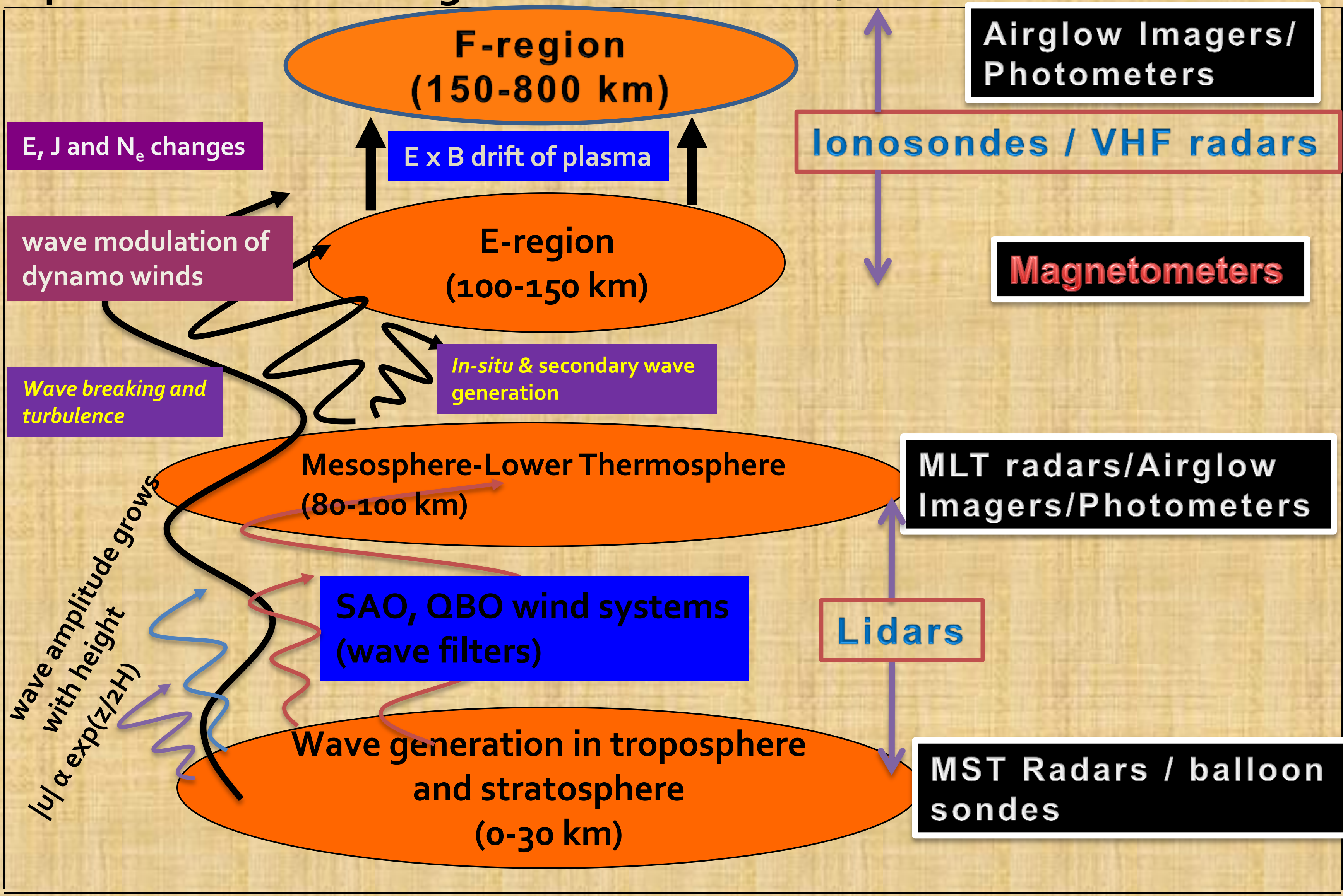
Atmospheric Coupling Processes – Investigation by radio and optical remote sensing and in-situ balloon/rocket sondes



Observational Techniques

- **In-situ**

  -Balloon-borne Radiosondes

  -Rockets

  -Satellites

- **Ground-based**

  -Radars

  -Lidars

We will discuss only about ground-based radar techniques here

Ground-based radio methods

- ***CATEGORY 1*: PASSIVE – receive only**

(Riometer, Scintillation/GPS receiver (TEC monitors)

- ***CATEGORY 2*: ACTIVE – transmit and receive**

RADARS – Atmospheric/Ionospheric

Mechanisms determining radar returns

- **Reflection and Refraction processes**

  -Bending of HF radio waves as they propagate through the ionosphere and reflection occurs where wave frequency matches plasma frequency (e.g., ionosonde)

  -Reflection from stable horizontal weakly ionized structures in the mesosphere

- **Scattering process**

  -Scattering from thermally induced density fluctuations in ionization (e.g., Incoherent Scatter Radar, 95-500 km)

  -Scattering from field-aligned irregularities in ionosphere (e.g., Coherent radars directed perpendicular to geomagnetic field at HF or VHF frequencies)

  -Scattering from turbulence-induced fluctuations in ionization in mesosphere (MF, HF, VHF radars, 75-100 km)

Bragg Scatter

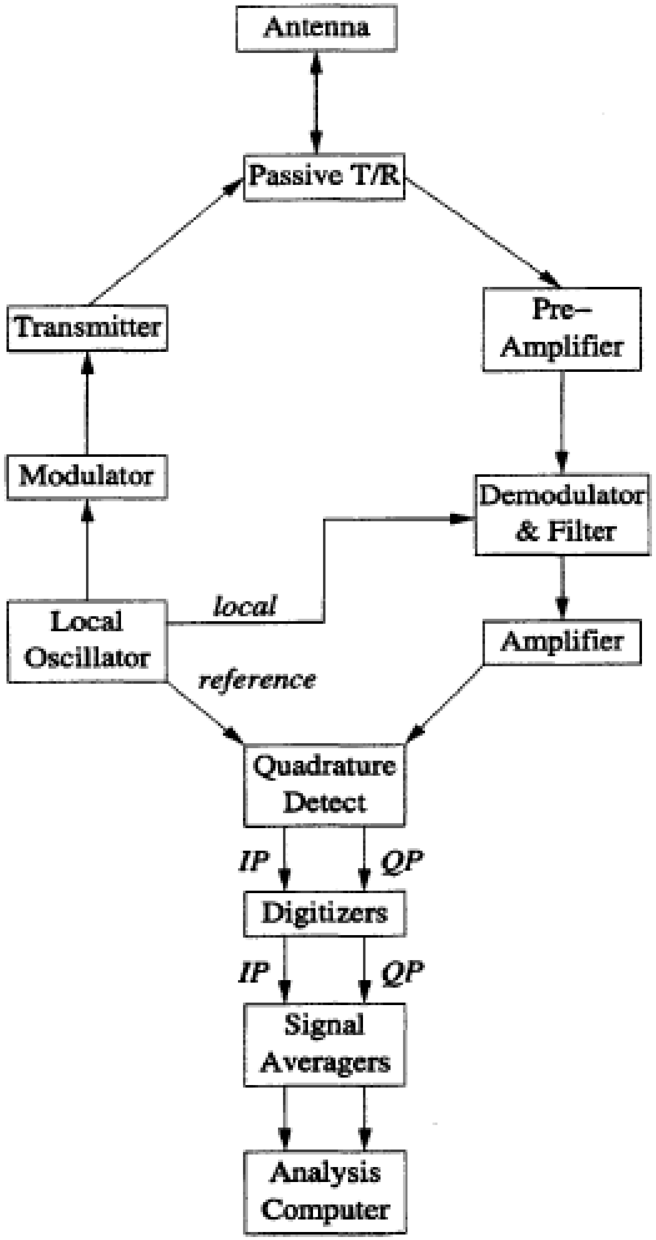
- Irregularities with a spectrum of scale sizes scatter radio signals.
- Radar of a certain wavelength detects scattered signal returns from fluctuations in refractive index with sizes that are ½ the radar wavelength – this is referred to as **Bragg Scatter**.

  (e.g., a 50 MHz radar with a wavelength of 6 m, would detect structures of 3 m scale size irregularities)

Atmospheric Radars

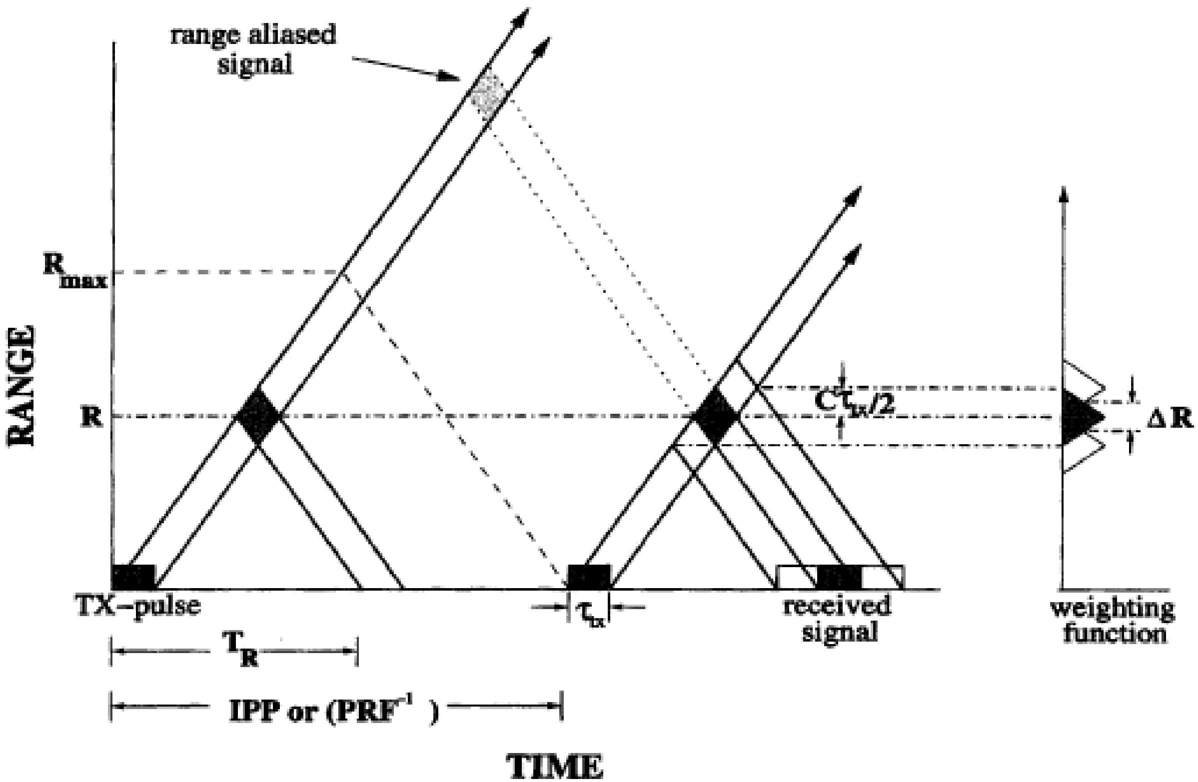
- **Medium frequency (MF) radars**
  - **-Frequency in the range 2-3 MHz**
  - **-Winds in the height region 70-100 km (day) and 80-100 km (night)**
- **Meteor radars**
  - **-Frequency in the range 30-50 MHz**
  - **-Winds in the height range 80-105 km**
- **MST radars**
  - **-Frequency of ~50 MHz**
  - **-Winds in the height range 2-20 km & 60-80 km (day)**
- **Incoherent Scatter Radars**
  - **-Arecibo operates at 430 MHz**

Radar Fundamentals



- Master oscillator
- High-power transmitter
- Antenna(s)
- Low-noise receiver
- Amplifier
- Complex (amplitude and phase) receivers
- Digitisers, signal averagers
- Digital storage and analysis
- Pulse operation

Pulsed Radar Operation



- **Range determined by time-of-flight of pulse, $R=cT_R/2$**
- **Range resolution, $\Delta R=c\ \tau_{Tx}/2$**

Radar Scattering

- Echoes come from vertical gradients in refractive index of air, *n*
- For frequencies > 30 MHz:

$$n = 1 + 0.373\frac{e}{T^2} + 77.6 \cdot 10^{-6}\,\frac{p}{T} - 40.3\frac{N_e}{f^2}$$

- Require fluctuations in
  - Humidity, *e*
  - Temperature, *T*
  - Electron density, N_e
- Scale of of fluctuations or irregularities ~λ/2
  - ~3 m at 50 MHz and ~75 m at 2 MHz

Radar Scattering

- Nature of irregularities is not well known
  - Isotropic turbulence
  - Sharp steps ("Fresnel irregularities")

$$P_r = \frac{\pi P A \alpha \Delta R}{64 R^2} \eta \quad \text{(Volume scatter)}$$

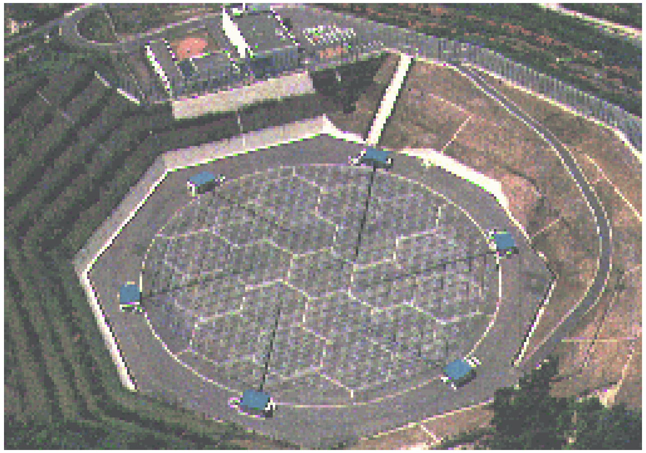
$$P_r = \frac{P A^2 \alpha}{4 \lambda^2 R^2} |\rho|^2 \quad \text{(Fresnel reflection)}$$

- Strength of scatter depends on strength of turbulence, η or on Fresnel reflection coefficient, ρ
- *PA* is a "figure of merit" for a radar
  - *P* is average transmitted power
  - *A* is antenna area

MST Radars

Equatorial Atmospheric Radar (EAR) Sumatra, Indonesia (0º), Indian MST Radar, Gadanki

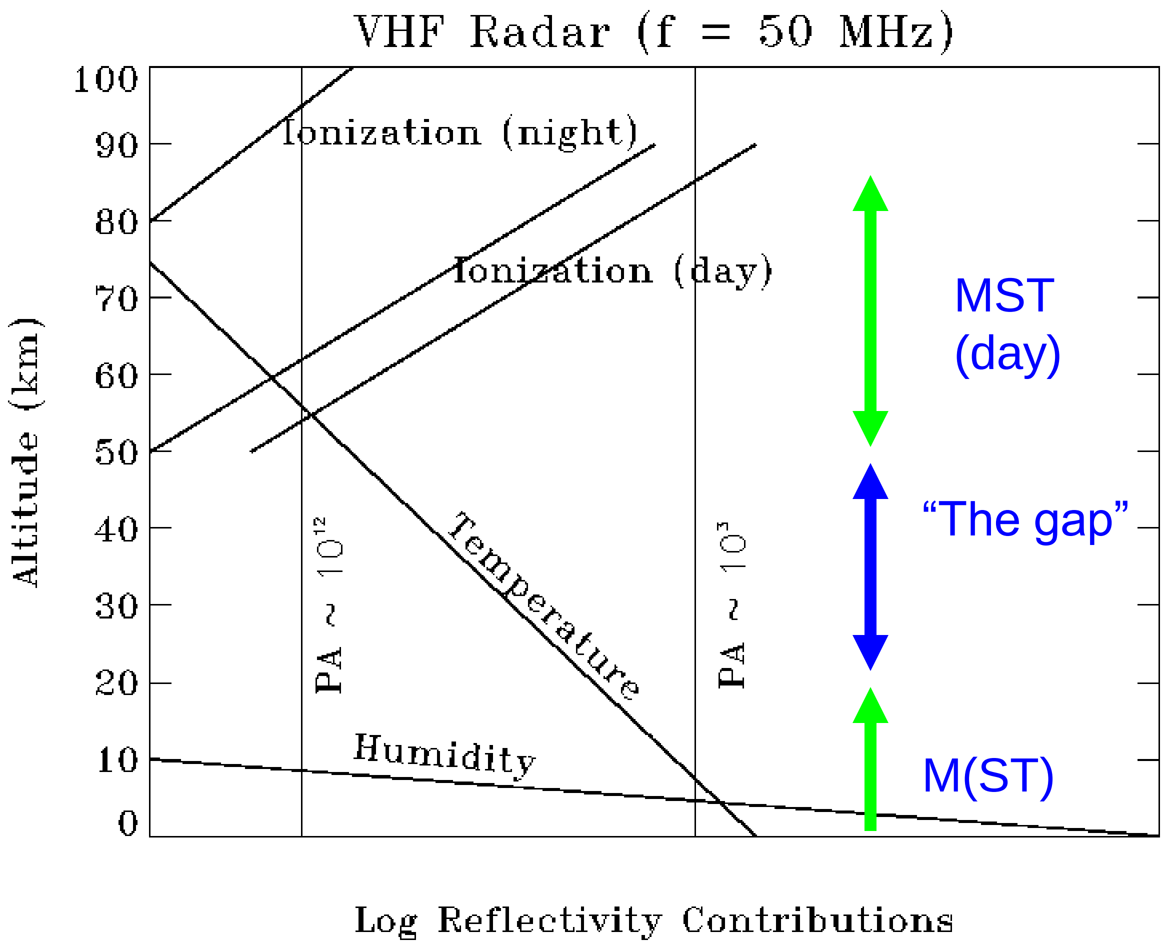
Versatile and powerful systems for studying atmospheric dynamics with excellent time and height resolution



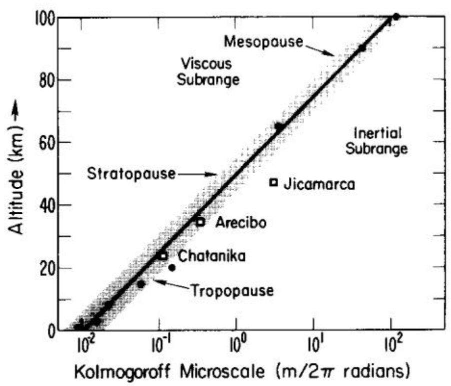
MU radar, Kyoto, Japan (35ºN)

Jicamarca Observatory, Peru (12ºS)

Performance of MST Radars



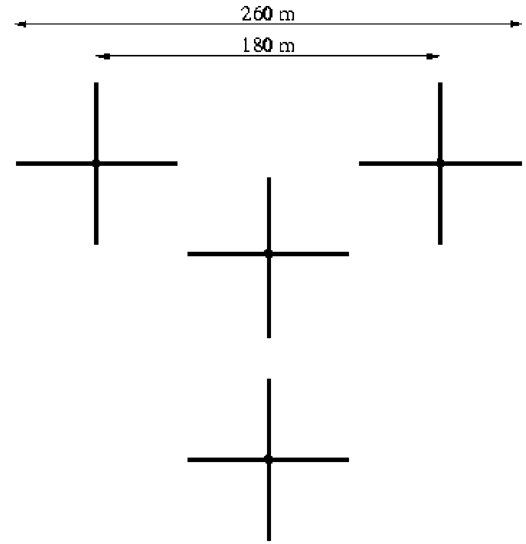
- For good height coverage need:
  - Large *PA* product
  - Strong turbulence
- Mesospheric scattering intermittent in time and space



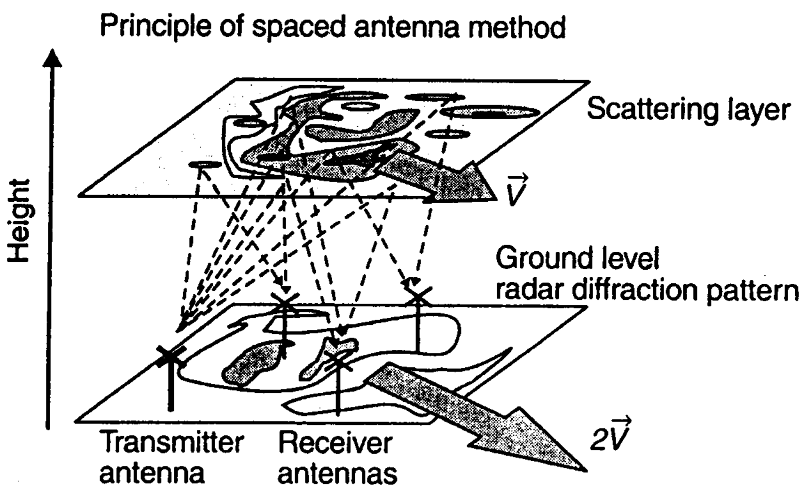
Intense turbulence required to generate mesospheric irregularities

MF Radars

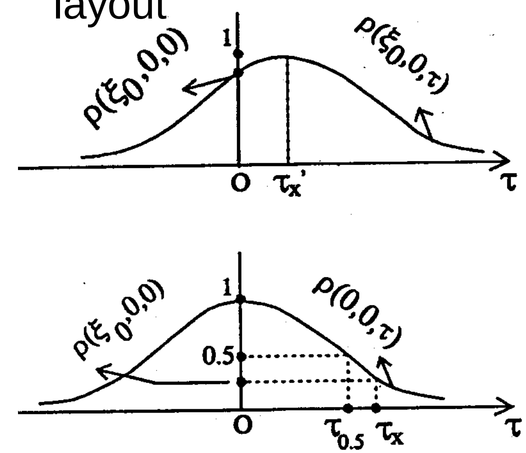
- Strengths
  - Moderate to good range and time resolution
    - range ~ 2 - 4 km
    - time ~ 2 - 5 min
  - Good height coverage
    - 60 - 100 km (day)
    - 80 - 100 km (night)
  - Low power, inexpensive to set up and run
  - Reliable continuous operation
- Use spaced-antenna technique to determine wind velocity
  - Measure motion of diffraction pattern across ground by sampling at 3 spaced antennas
- Measurement of turbulence motions



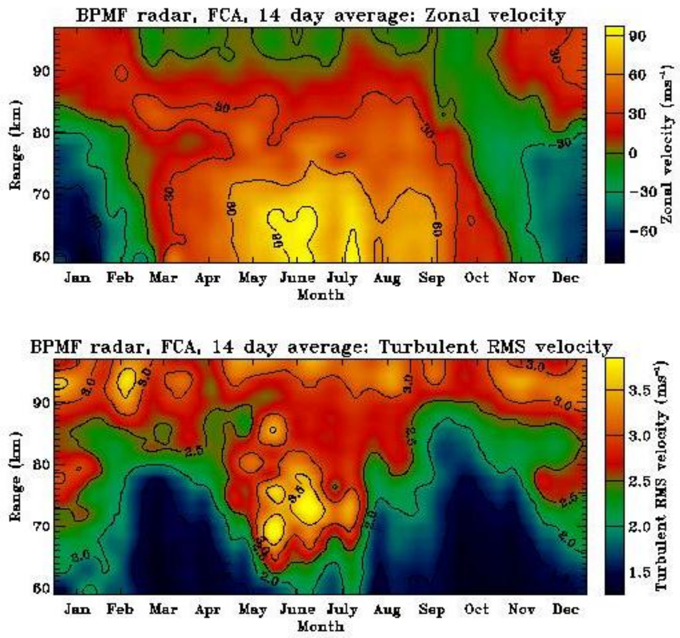
Typical antenna layout



(After Hocking, 1997)



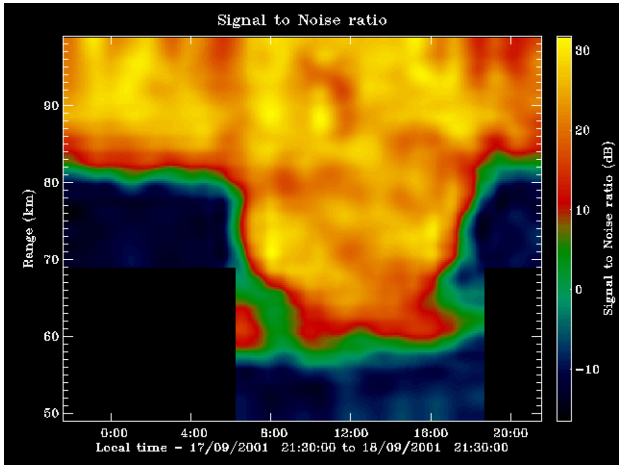
Correlation analysis (After Briggs, 1984)



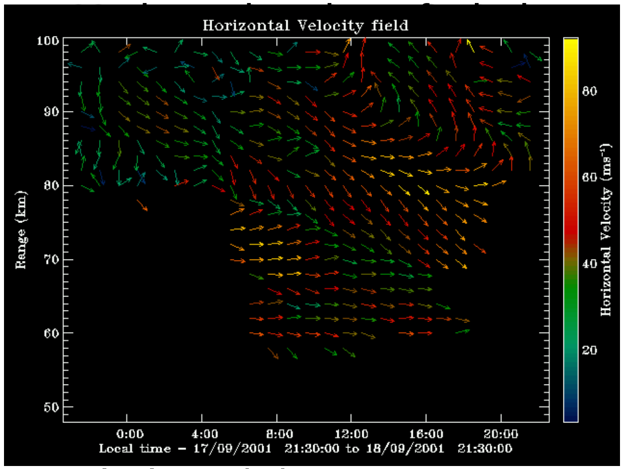
MF radar observations, Adelaide, 1999

Limitations

- Small antennas, wide beams. This means that height resolution can degrade if angular scatter is wide (> 10 deg)
- Total reflection occurs near 100 km at MF. This represents an upper limit to the technique during daytime
- Group retardation near midday causes incorrect heights to be measured above about 95 km

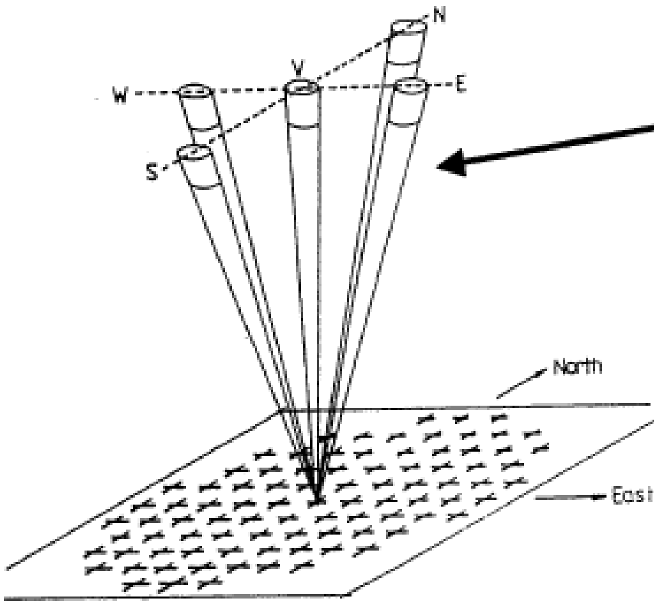


SNR 18/9/2001

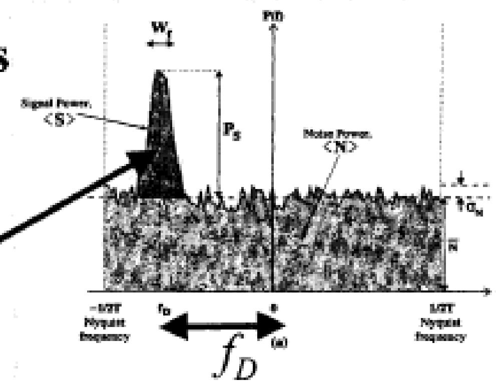


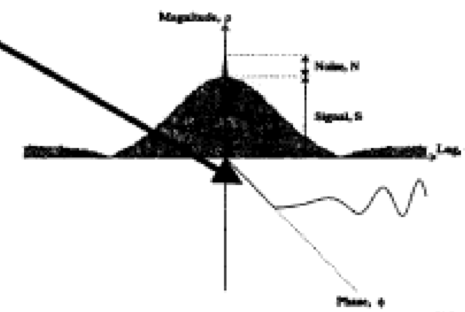
Winds 18/9/2001

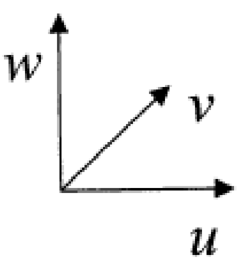
Doppler Winds



- Phase antennas to point beams in different directions
- Measure Doppler shift of returned echoes to measure radial velocity, v_r
- Spectral widths provide information about strength of turbulence







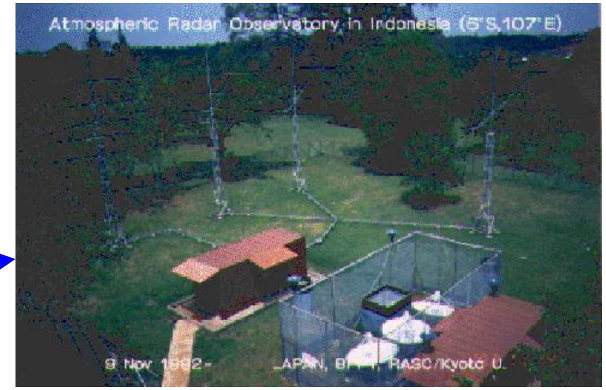
$$v_r = -\frac{\lambda}{2} f_D$$

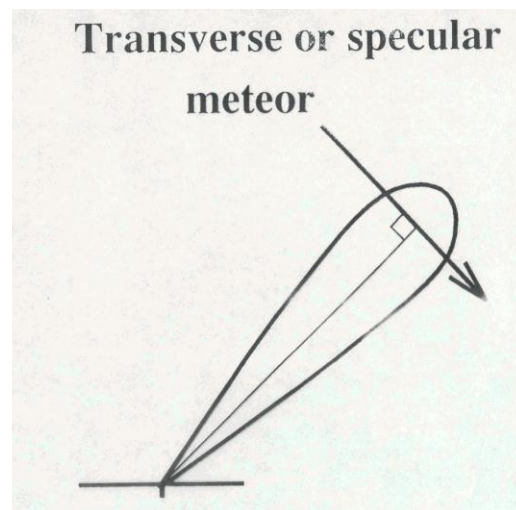
$$v_r = u \sin\phi \sin\theta + v \cos\phi \sin\theta + w \cos\theta$$

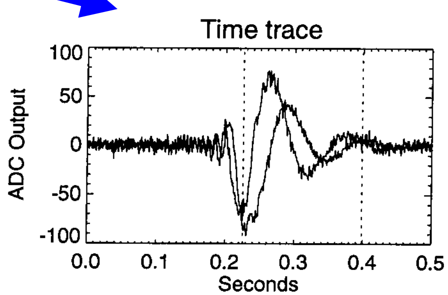
where $U = (u, v, w)$

Meteor Techniques I

- Frequency ~30-50 MHz
- Reflections from randomly occurring meteor trails
- Two techniques:
  - broad-beam method with interferometer to locate meteor
  - Narrow-beam radar (often ST radar)
- Line-of-sight velocities measured from Doppler shift of trail







Meteors II

- Strengths
  - Reliable
  - 24-h observations
  - Continuous long-term observations for long period winds and tides
  - It is possible to infer T'/T from the diffusion of the trails
- Limitations
  - Large diurnal variation of echoes
  - Large spatial average
  - Height coverage 80 - 105 km