RADAR METEOROLOGY
Lecture 6 part 2

Christine Unal
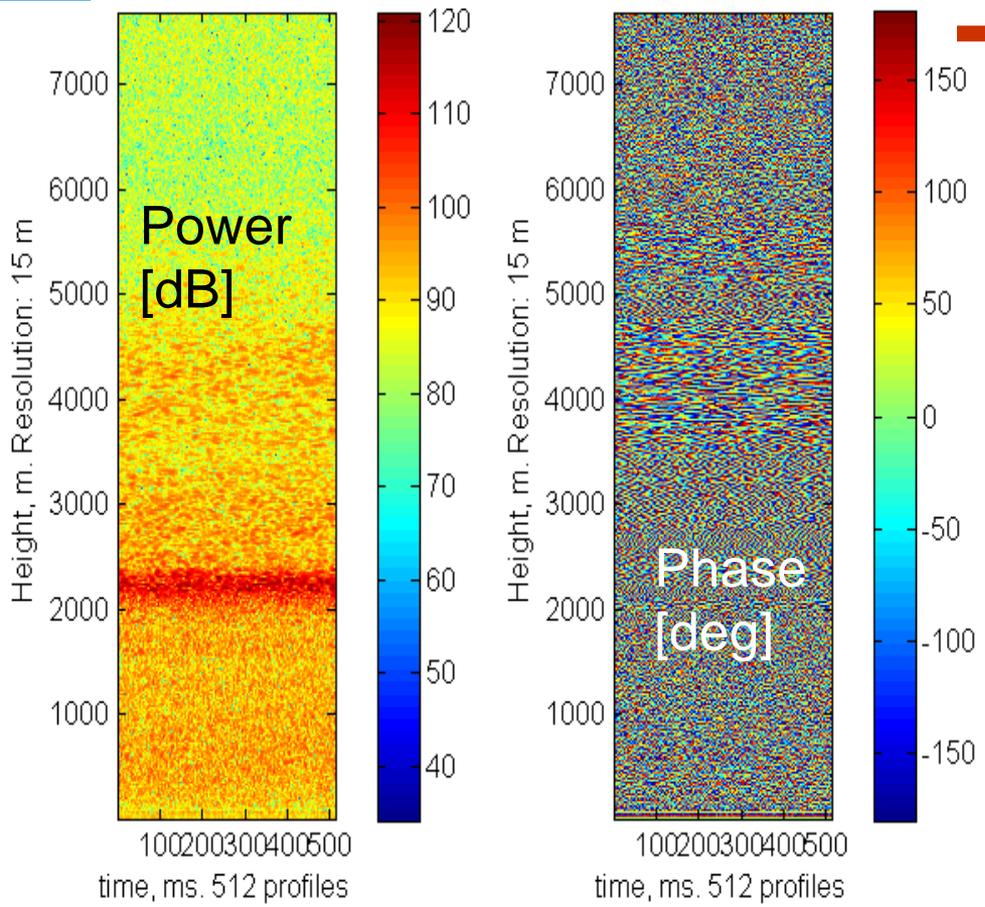
Examples at large elevation angles
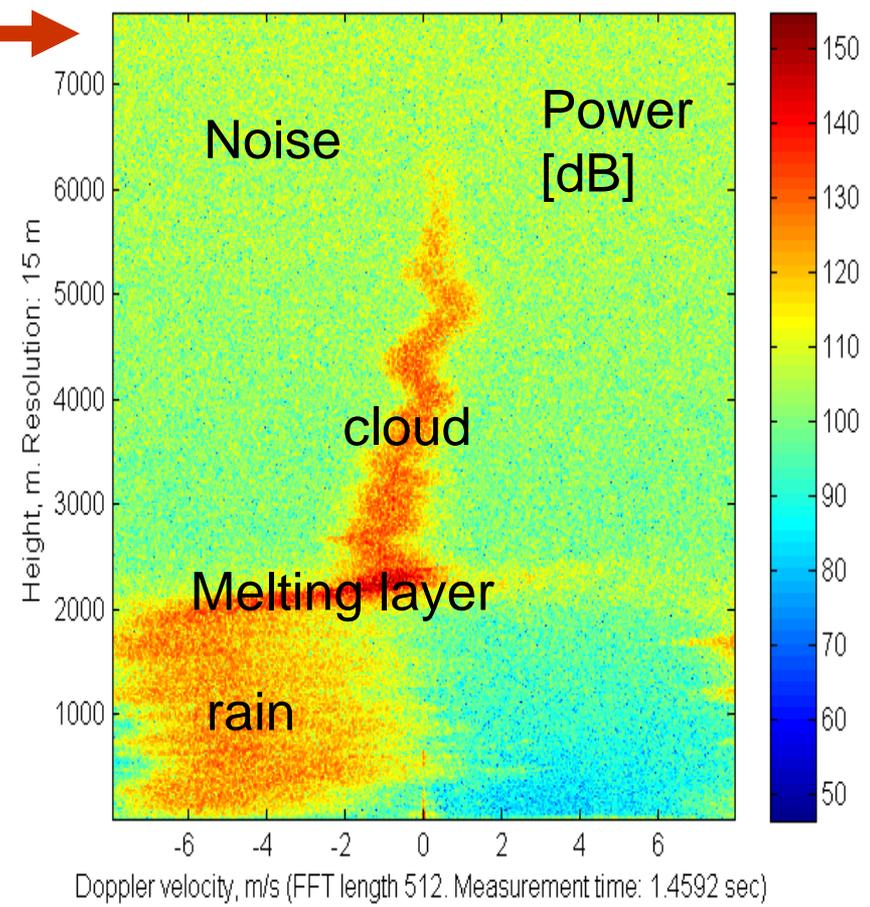
Atmospheric Remote Sensing

Raw radar signal and Doppler spectra

Time series of complex signal (V) for each range bin (~s)

Fast Fourier Transform

Complex Doppler spectra for each range bin: spectrogram

Power [dB]

Phase [deg]

Noise

Power [dB]

cloud

Melting layer

rain

time, ms. 512 profiles

time, ms. 512 profiles

Doppler velocity, m/s (FFT length 512. Measurement time: 1.4592 sec)

Example of near-vertical profiling radar

TU-Delft TARA radar

COPS 1 July 2007
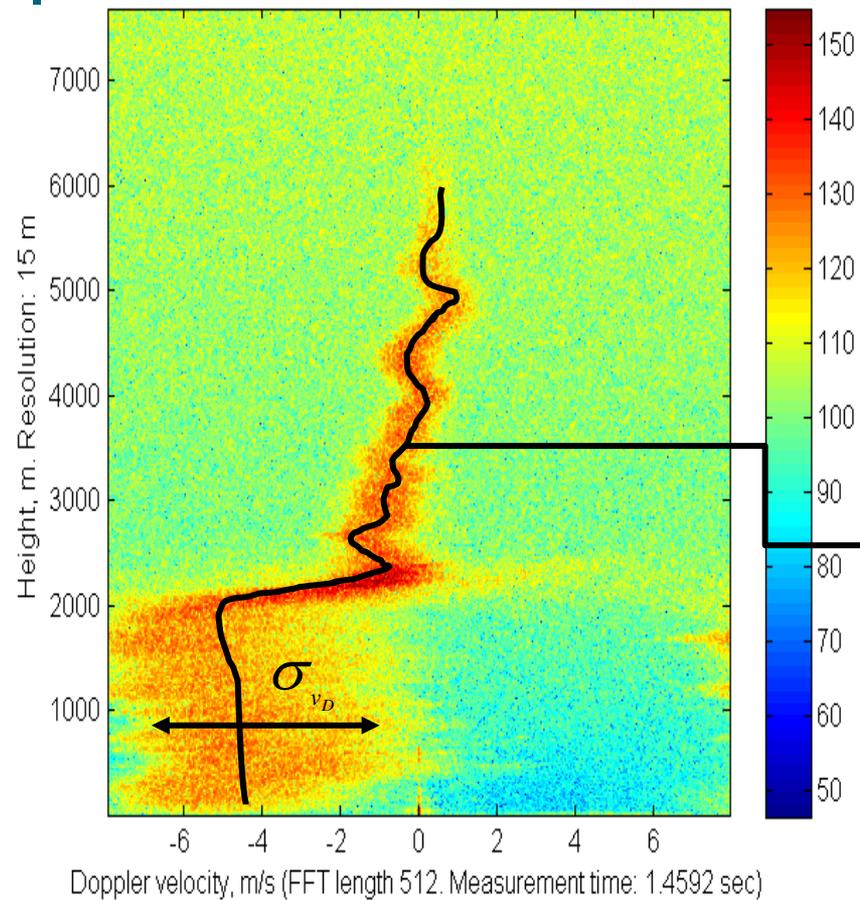
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Atmospheric Remote Sensing

Interpretation of the Doppler velocity
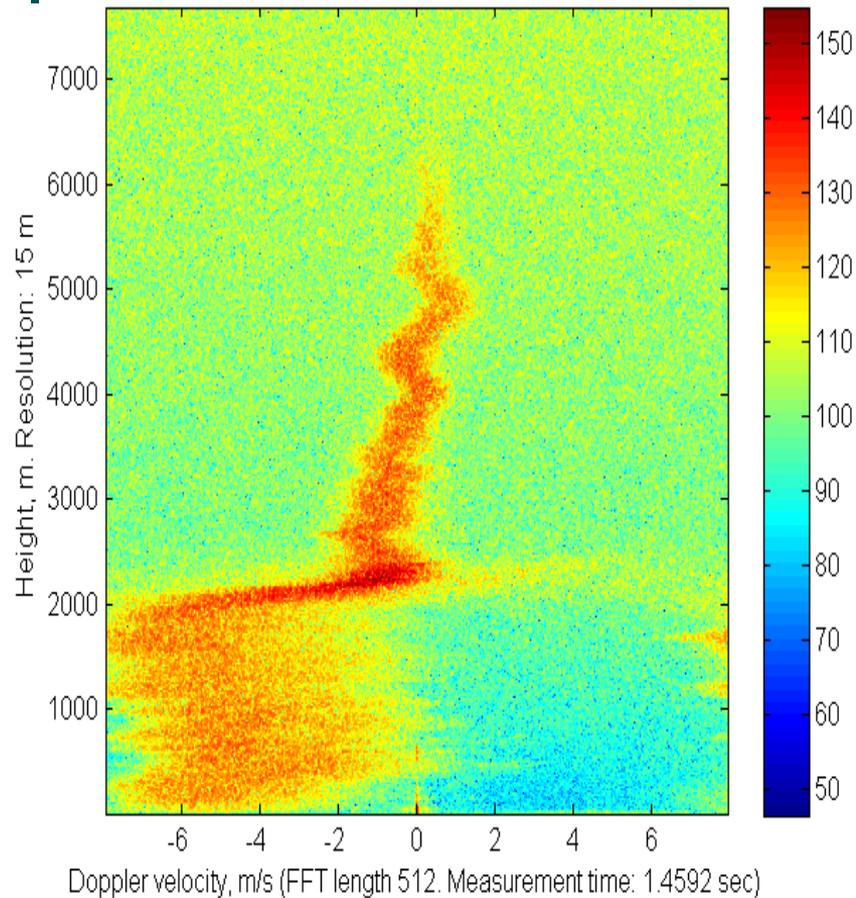
The Doppler velocity contains a large component of the <u>fall velocity</u> of the hydrometeors and a component of the wind (<u>horizontal</u> and vertical)

Example of near-vertical profiling radar ($\alpha = 75^o$)

Atmospheric Remote Sensing

$$P = \int P(v)\,dv$$

$$v_D = \frac{1}{P} \int v P(v)\,dv$$

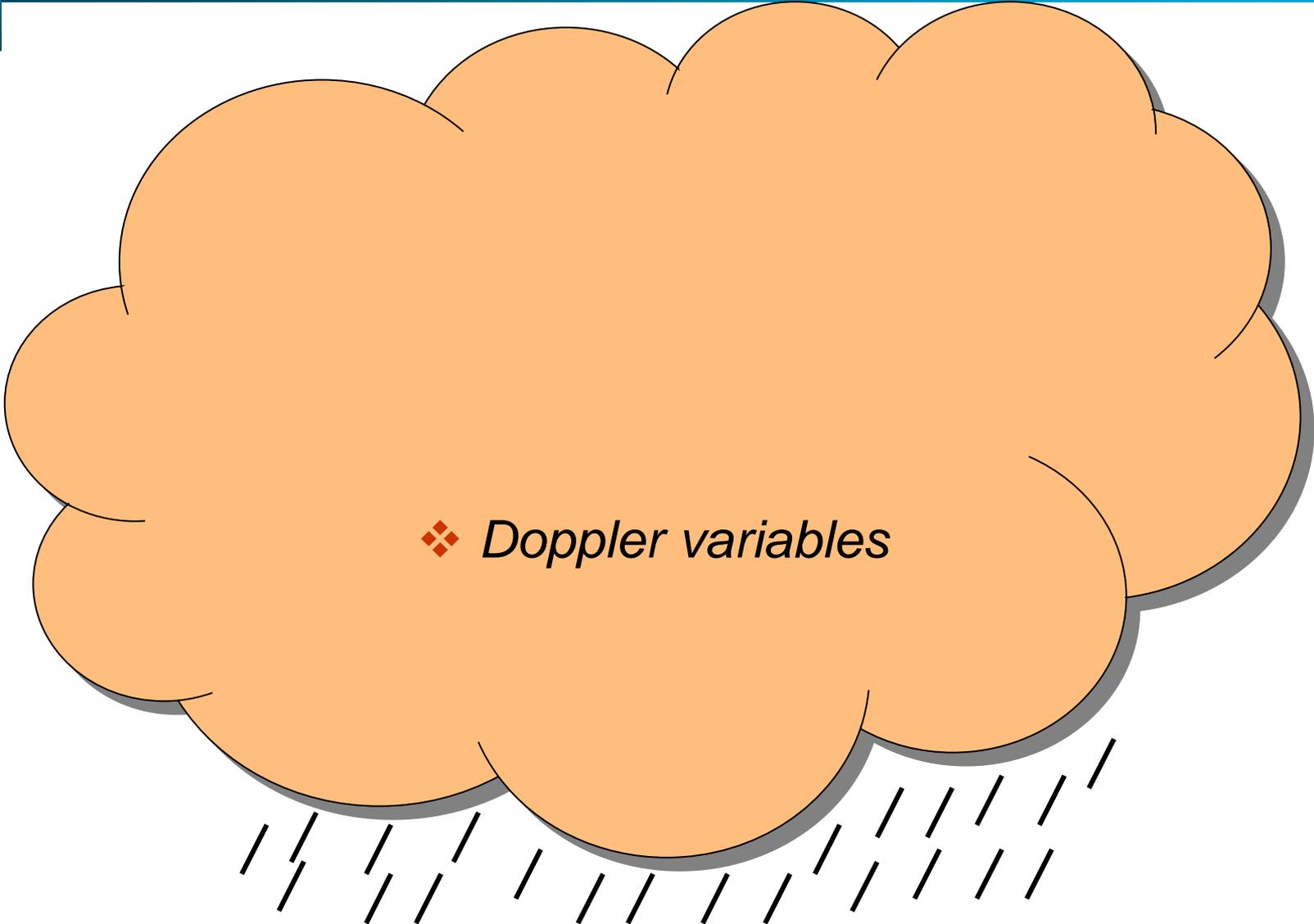$$\sigma_{v_D} = \sqrt{\frac{1}{P} \int (v - v_D)^2 P(v)\,dv}$$

v_D

for every height

after extracting the spectrogram of hydrometeors
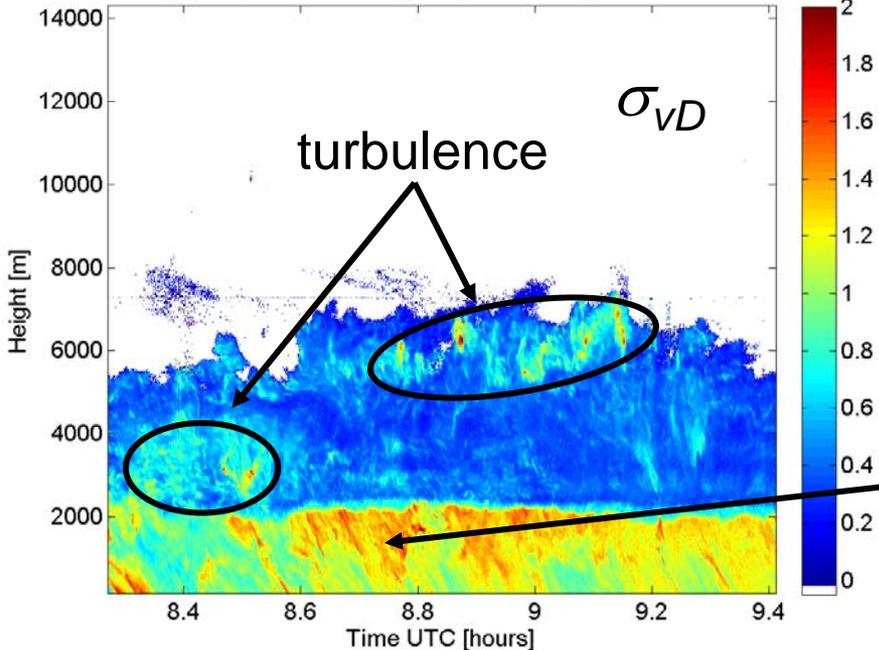
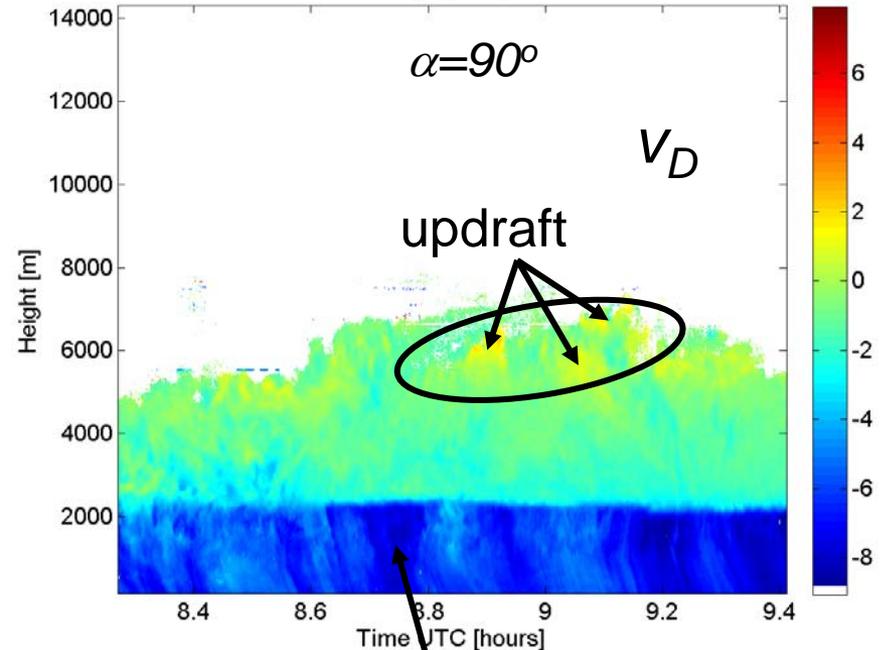Example of near-vertical profiling radar ($\alpha = 75^o$)

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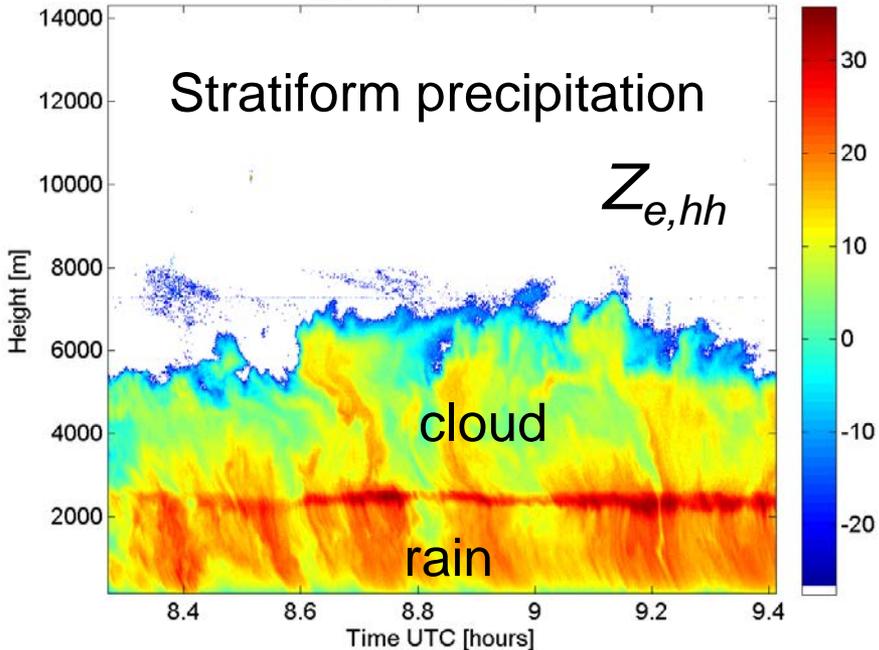**Atmospheric Remote Sensing**

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Contents

❖ *Doppler variables*

Reflectivity [dBZ] EL=75 deg. D20070807

Stratiform precipitation

$Z_{e,hh}$

cloud

rain

Vertical velocity [m s^{-1}] D20070807

$\alpha=90^o$

v_D

updraft

increased fall velocity

Doppler spectrum width [m s^{-1}] EL=75 deg. D20070807

σ_{vD}

turbulence

From cloud to rain: modulus of vertical Doppler velocity and Doppler spectrum width increases (contrast). A strong vertical wind and turbulence may change this.

increased Doppler spectrum width

TU-Delft TARA radar

Atmospheric Remote Sensing

Doppler variables (rain)

For an analytical expression, we need

a model for the raindrop size distribution

$$N(D) = N_0 \exp(-\Lambda D)$$

a model for the fall velocities of raindrops

$$v_f(D) = 9.65 - 10.3\exp(-0.6D)$$

$$v_f(D) = 3.78D^{0.67} \qquad \text{approximation } 0.5 < D \text{ [mm]} < 5$$

Atmospheric Remote Sensing

mean Doppler velocity

$$v_D \approx -\left(\frac{\rho_0}{\rho}\right)^{0.4} \sin(\alpha)\left[9.65 - 10.3\left(\frac{\Lambda}{\Lambda + 0.6}\right)^7\right] + v_0$$

radial wind

ρ: *air density, depends on altitude*

Radar looking direction

mean fall velocity (altitude=0 m)

"mean" dropsize

$$\langle v_f \rangle_z = \frac{1}{z}\int v_f(D)D^6 N(D)\,dD$$

using exponential dropsize distribution

Doppler spectrum width

$$\sigma_{v_D} \approx \sqrt{\left(\frac{\rho_0}{\rho}\right)^{0.8}\sin^2(\alpha)\cdot(10.3)^2\left[\left(\frac{\Lambda}{\Lambda + 1.2}\right)^7 - \left(\frac{\Lambda}{\Lambda + 0.6}\right)^{14}\right] + \sigma_0^2}$$

turbulence

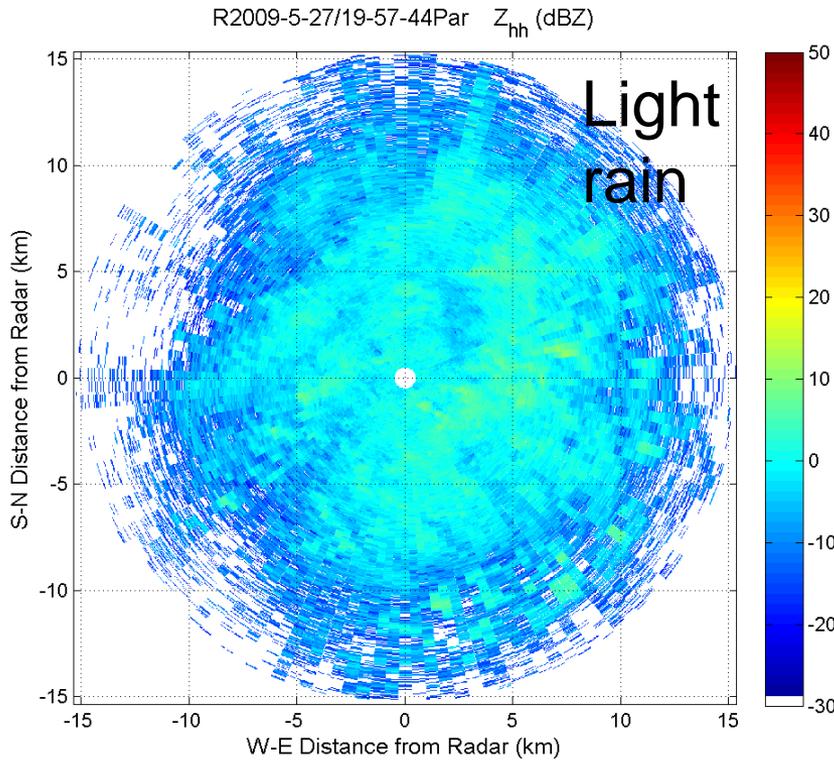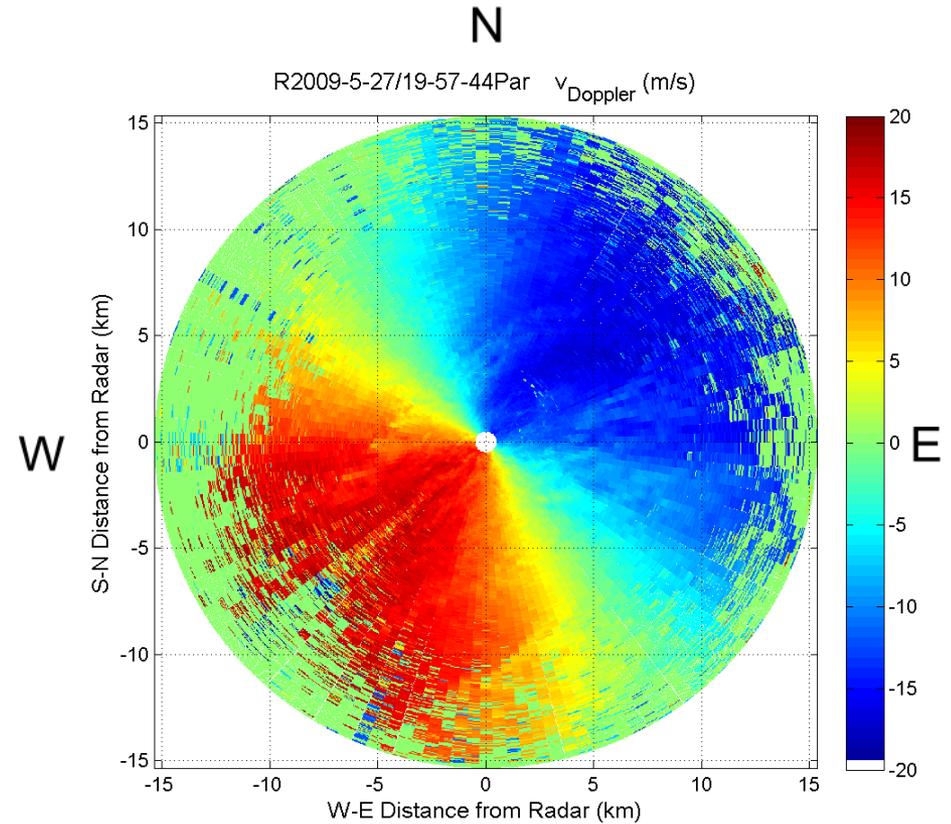**Atmospheric Remote Sensing**

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❖*Horizontal wind estimation (low elevation angles)*

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Atmospheric Remote Sensing

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Weather radar measurement example (PPI)

IDRA, Doppler-polarimetric X-band, TU-Delft

Reflectivity factor

Mean Doppler velocity

What is the wind speed and direction?

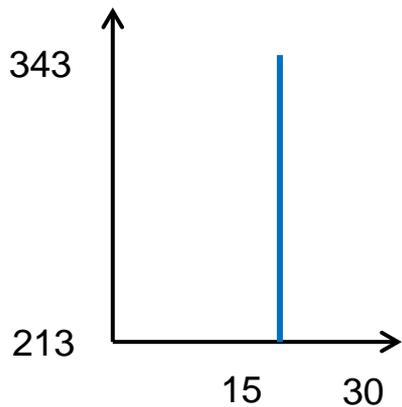The wind direction is the direction from which comes the wind
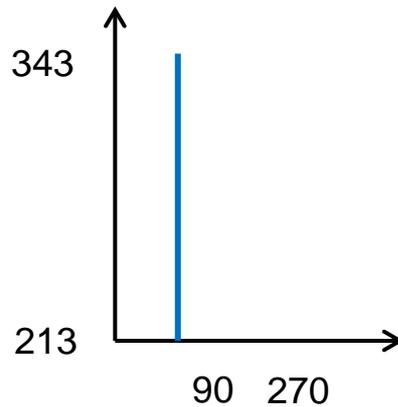
Weather radar measurement example (PPI)

$R_{max} = 15 \cdot 10^3$ m and $\alpha = 0.5^0$
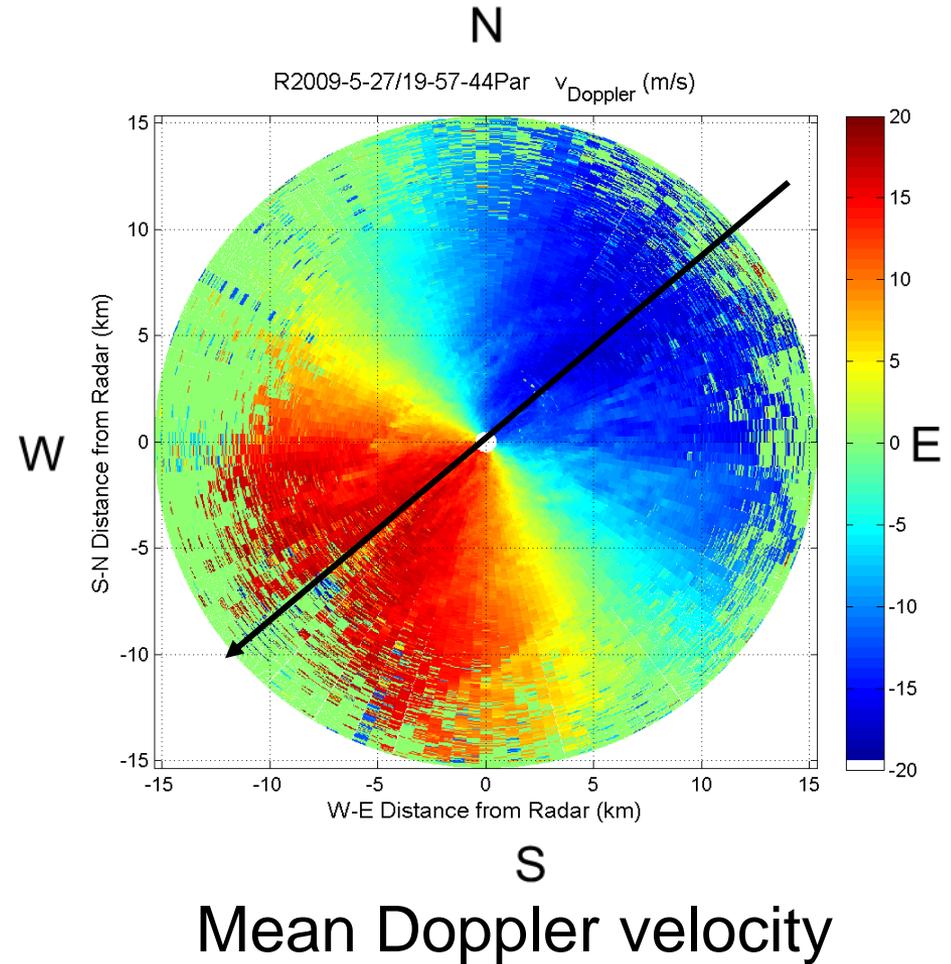
$h_{max} = 213 + R_{max}\sin(\alpha) = 343$ m

Radar placed at the top of the meteorological tower at Cabauw

Mean Doppler velocity

North-East wind direction with wind speed 15-20 ms⁻¹

R2009-5-27/19-57-44Par Z_{hh} (dBZ)

Light rain

R2009-5-27/19-57-44Par $v_{Doppler}$ (m/s)

wind

IDRA

$\alpha = 0.5^o$
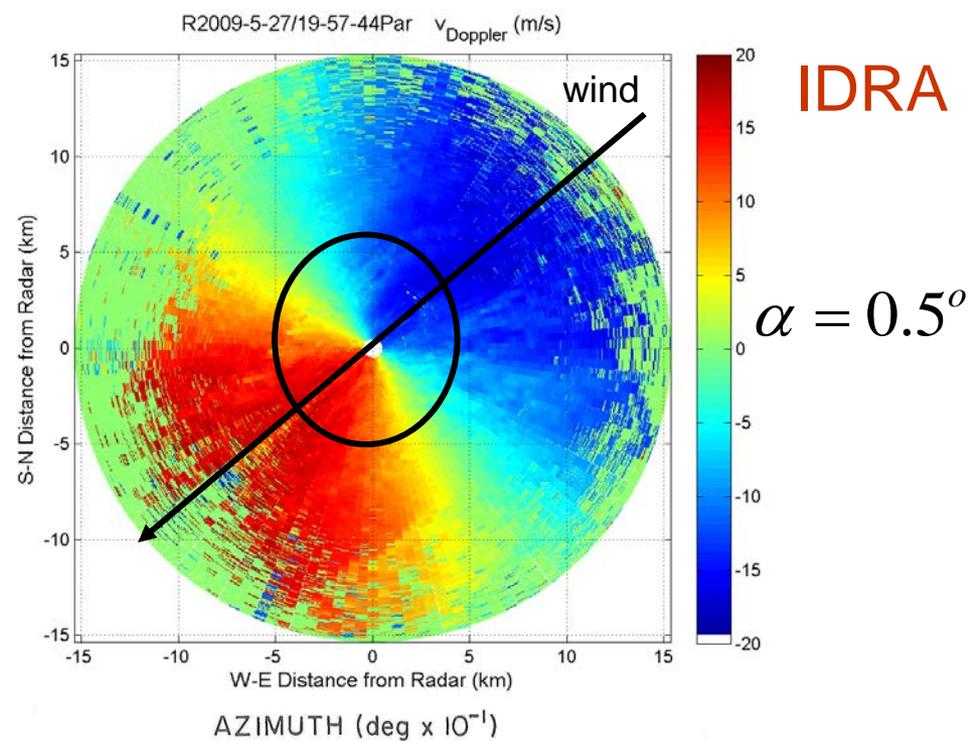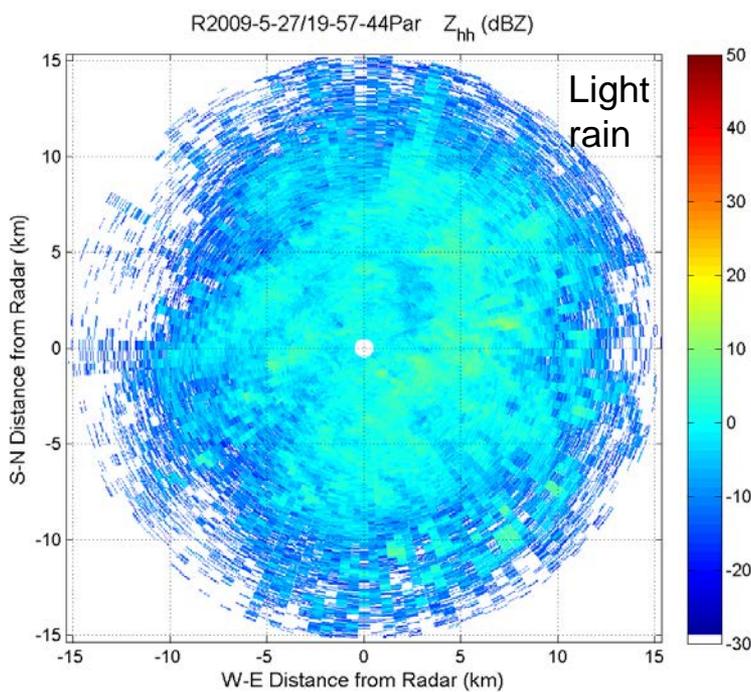
Horizontally uniform wind

At a specific height (range)

radial velocity = sine/cosine function of azimuth

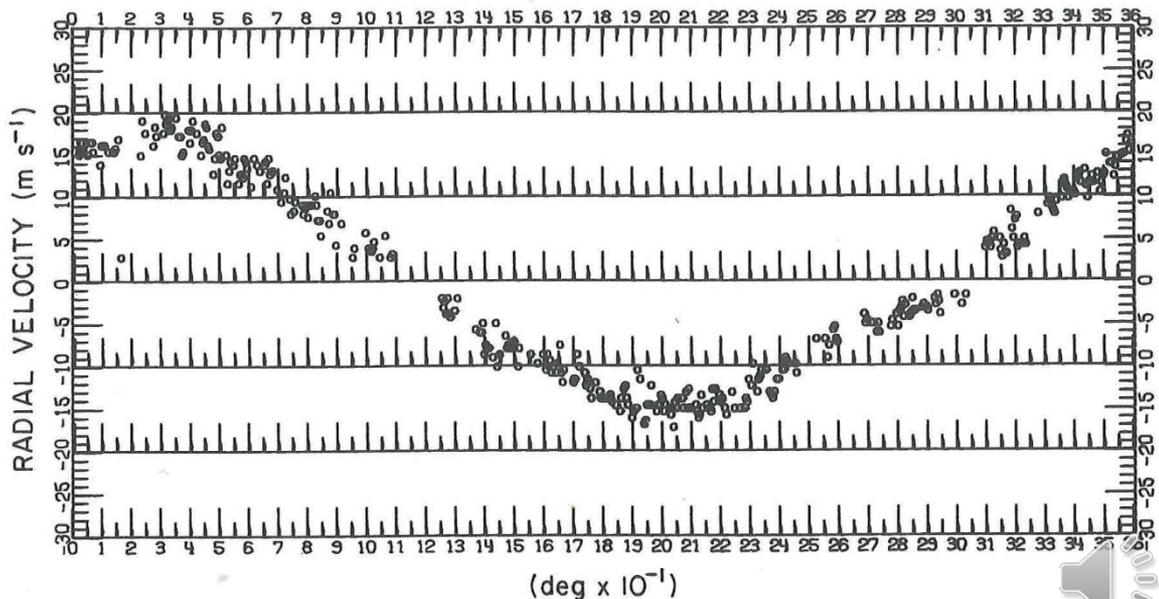Doviak and Zrnić, Doppler radar and weather observations, Fig. 9.9

AZIMUTH (deg x 10⁻¹)

Fig. 9.9 Radial velocity at a range of 40 km versus azimuth of the Cimarron radar, 1411–1414 C.S.T., 27 April 1977. The elevation is 0.5°.

Horizontal wind estimation

AZIMUTH (deg x 10⁻¹)

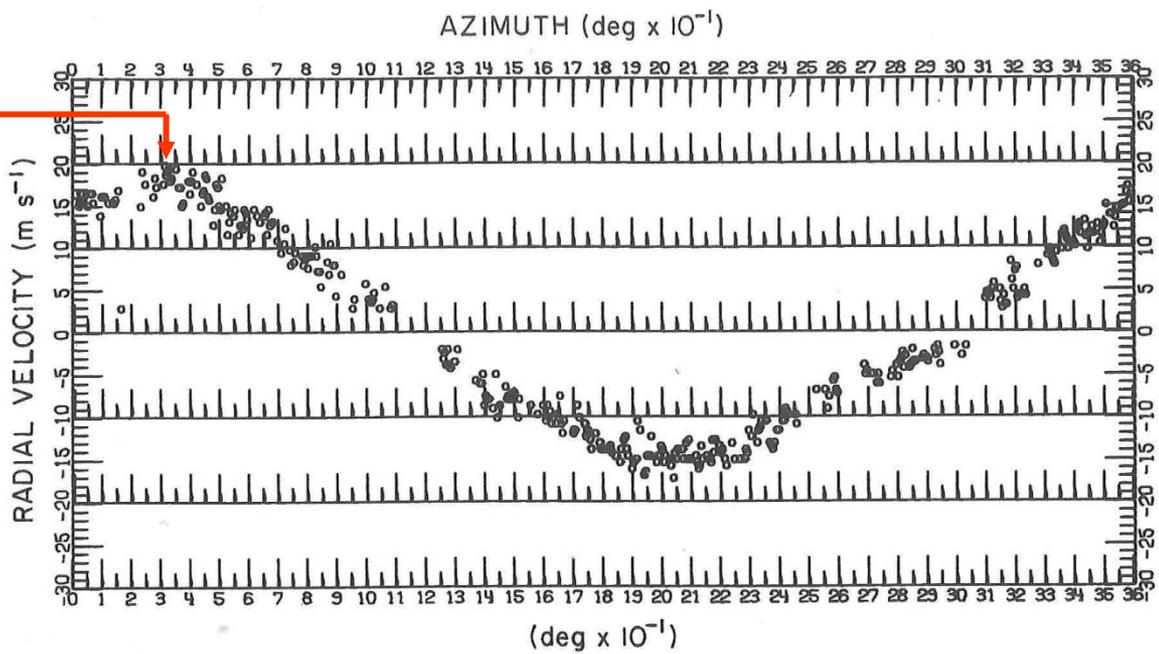**Fig. 9.9** Radial velocity at a range of 40 km versus azimuth of the Cimarron radar, 1411–1414 C.S.T., 27 April 1977. The elevation is 0.5°.

At a specific height (range)

$$v_D(\phi) = (w + v_f)\sin\alpha + v_H\cos\alpha\cos(D - \pi - \phi)$$

velocities $\alpha \approx 0$ angles

v_D measured Doppler velocity ϕ azimuth (related to North)

v_H horizontal wind speed α elevation

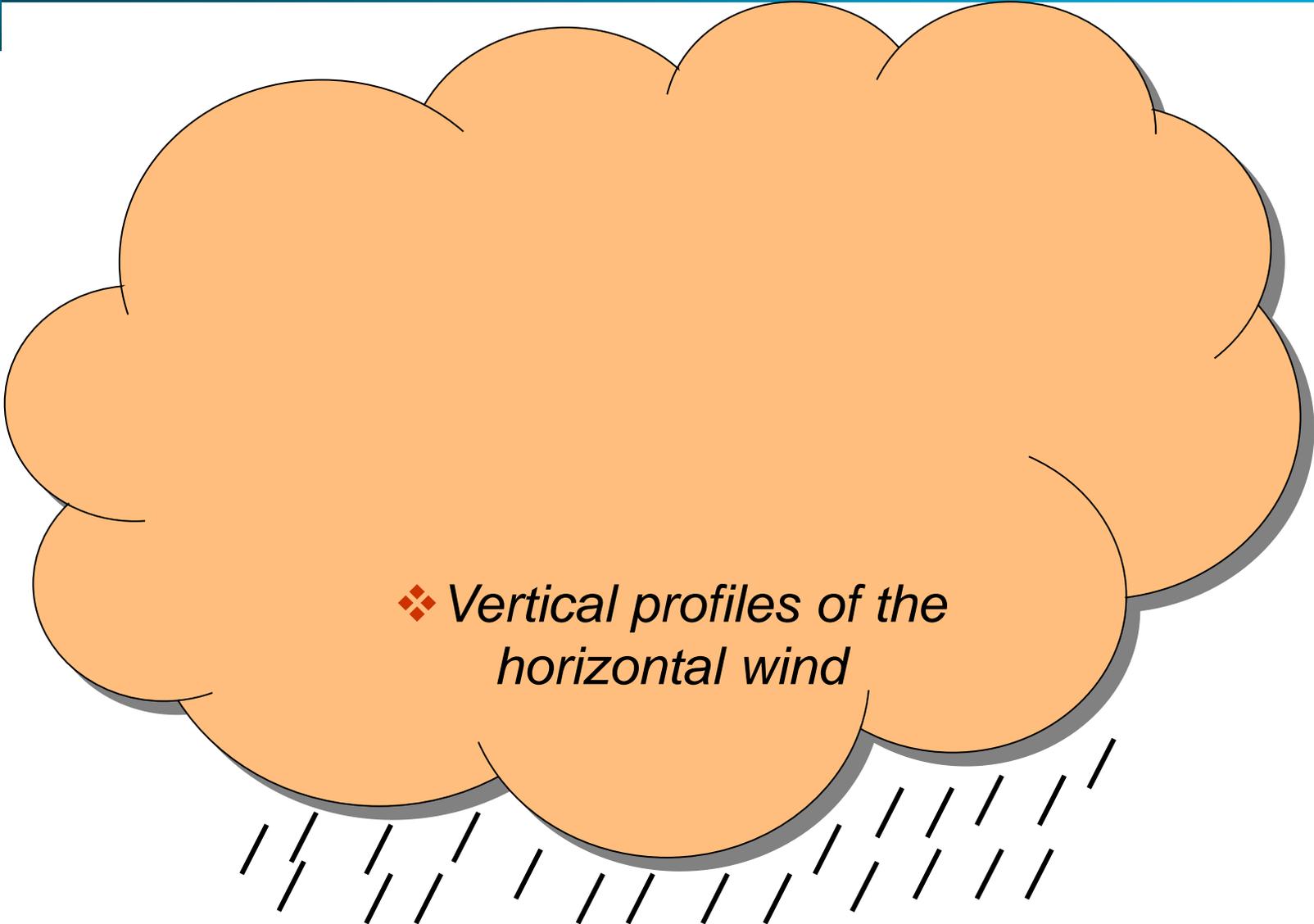w vertical wind velocity   D horizontal wind direction (North)

v_f fall velocity
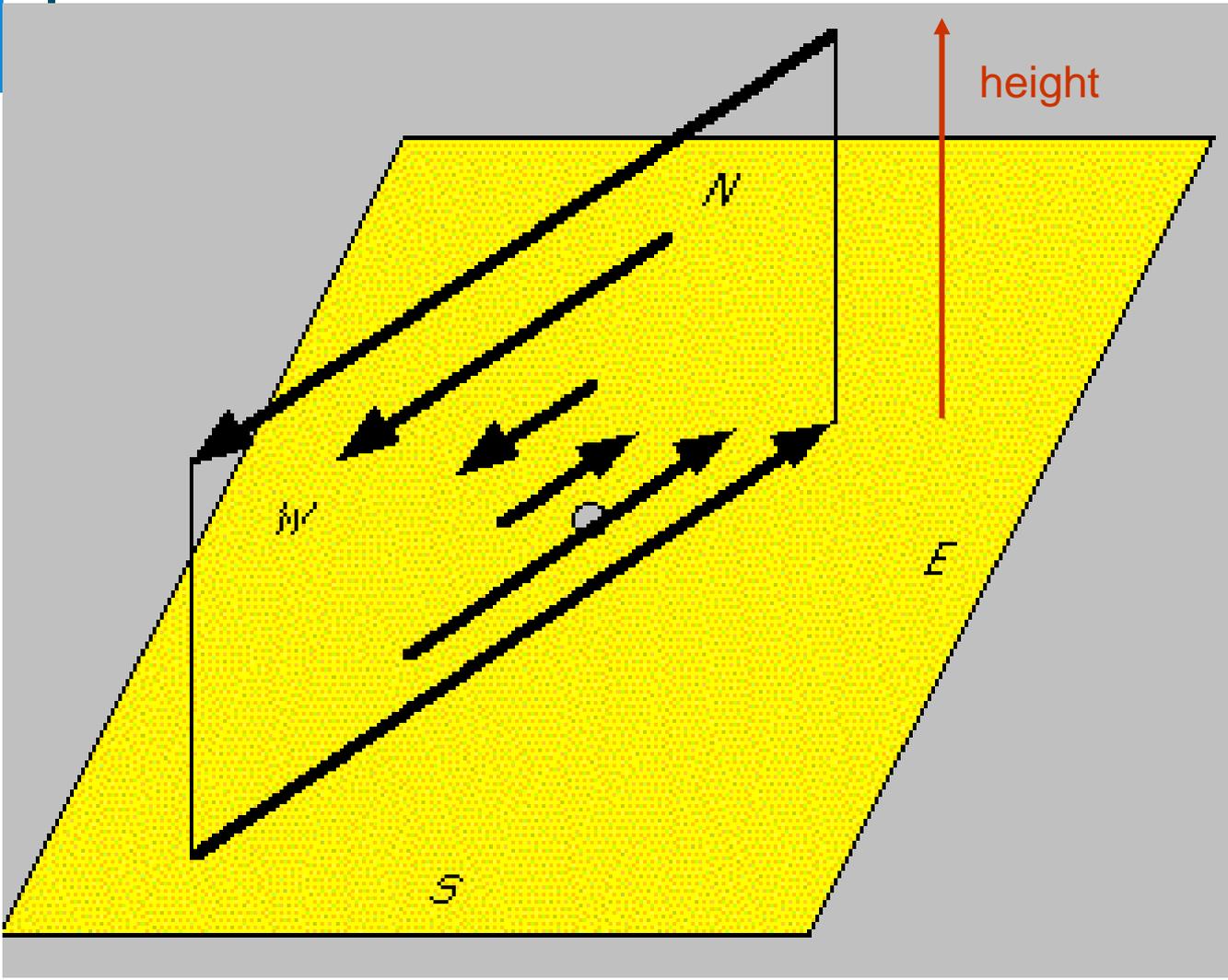
Precipitation

❖ horizontally uniform wind at fixed range

❖ vertical wind cannot be estimated

❖ the complete measurement of Doppler velocity versus azimuth is not always fully available

Contents

❖ *Vertical profiles of the horizontal wind*
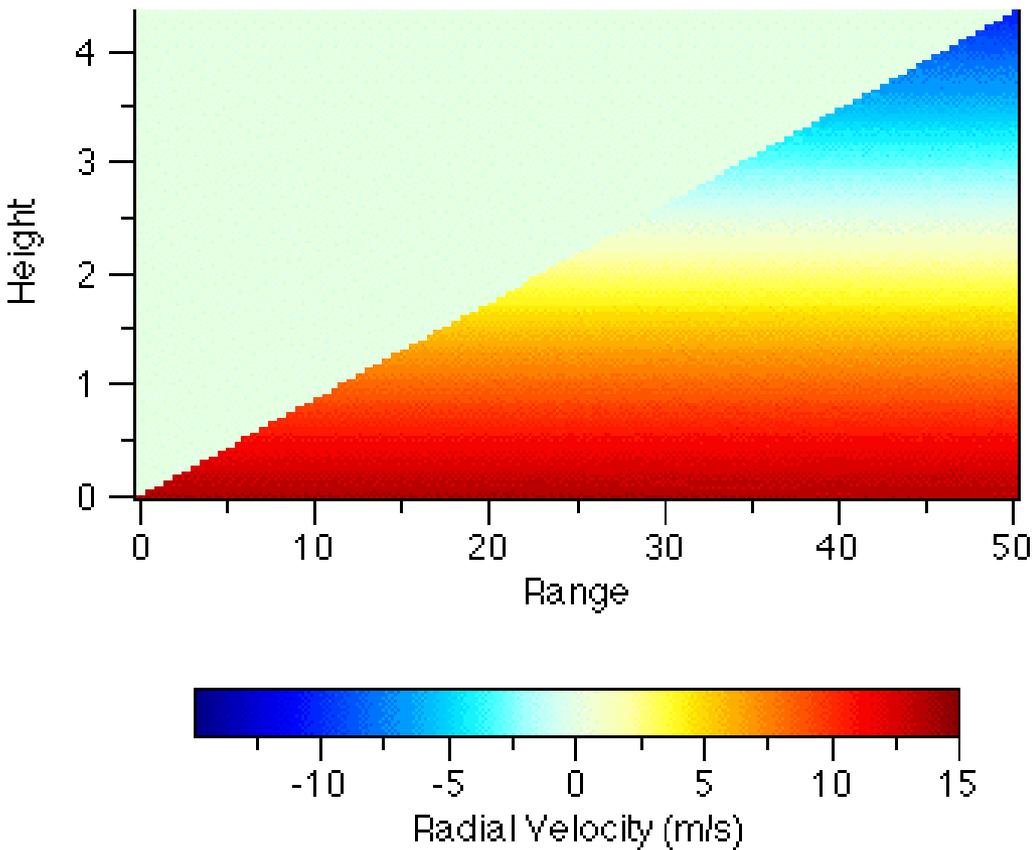
TU Delft
Delft
University of
Technology

Wind profile

from South-West to North-East

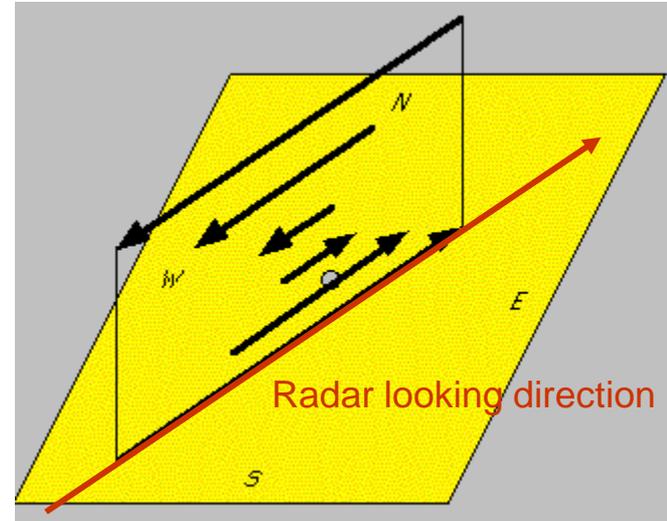Wind direction= direction from which the wind comes from

Mean Doppler velocity: RHI

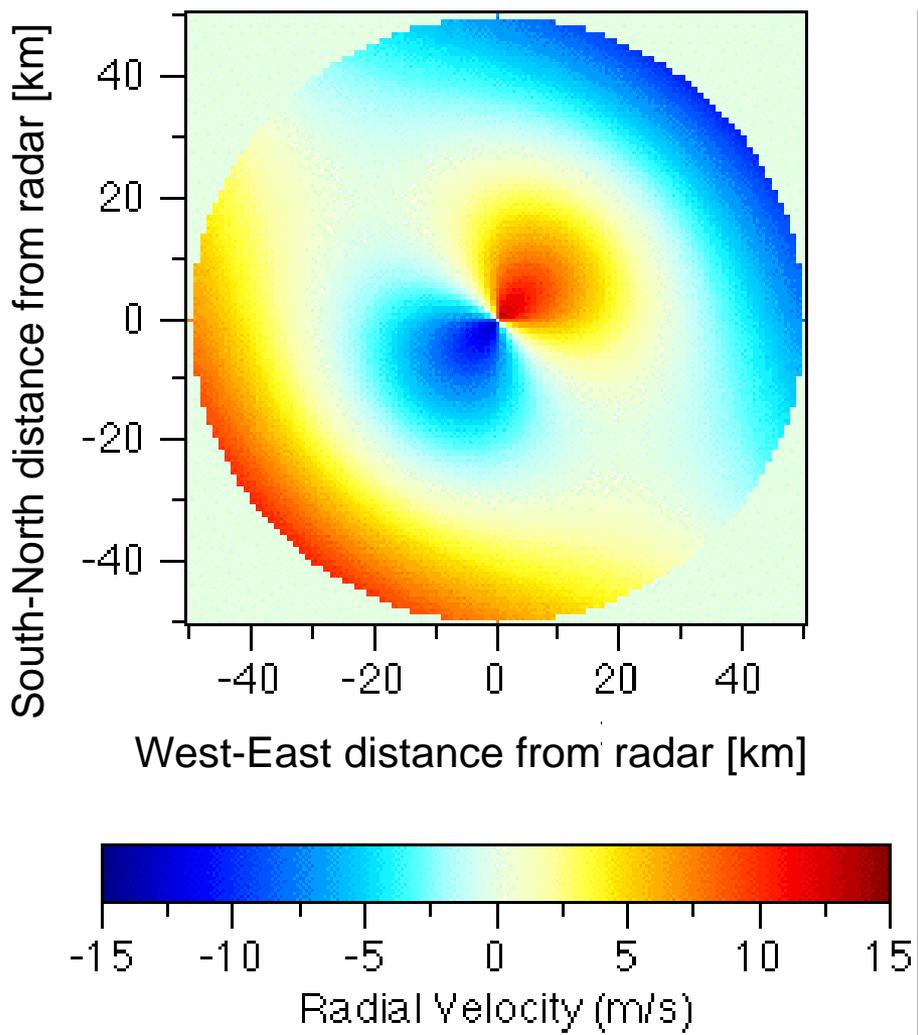elevation scanning $\qquad 0 \le \alpha \le \alpha_{max}$

RHI

Range **H**eight **I**ndicator

Fall velocities: low values

Radar looking direction

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Velocity azimuth display (VAD)

South-North distance from radar [km]
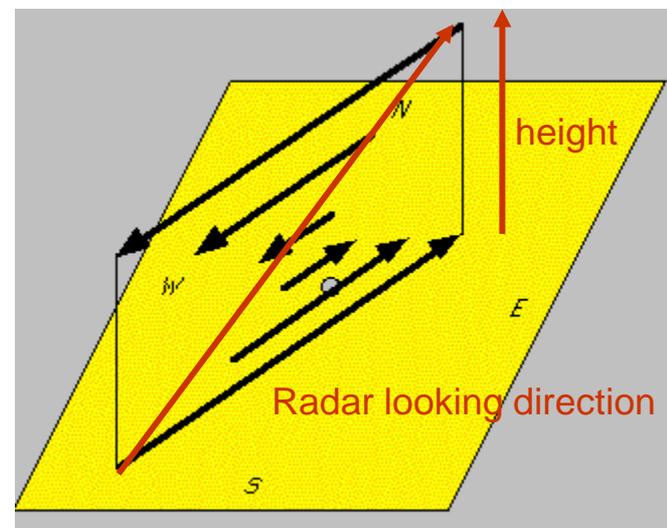
West-East distance from radar [km]

Radial Velocity (m/s)

$$\alpha = \alpha_{max}$$

PPI

Plan Position Indicator

Fall velocities: low values

height

Radar looking direction

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ATMOS

$$\alpha = 0^o$$

South-North distance from radar [km]

West-East distance from radar [km]

Radial Velocity (m/s)
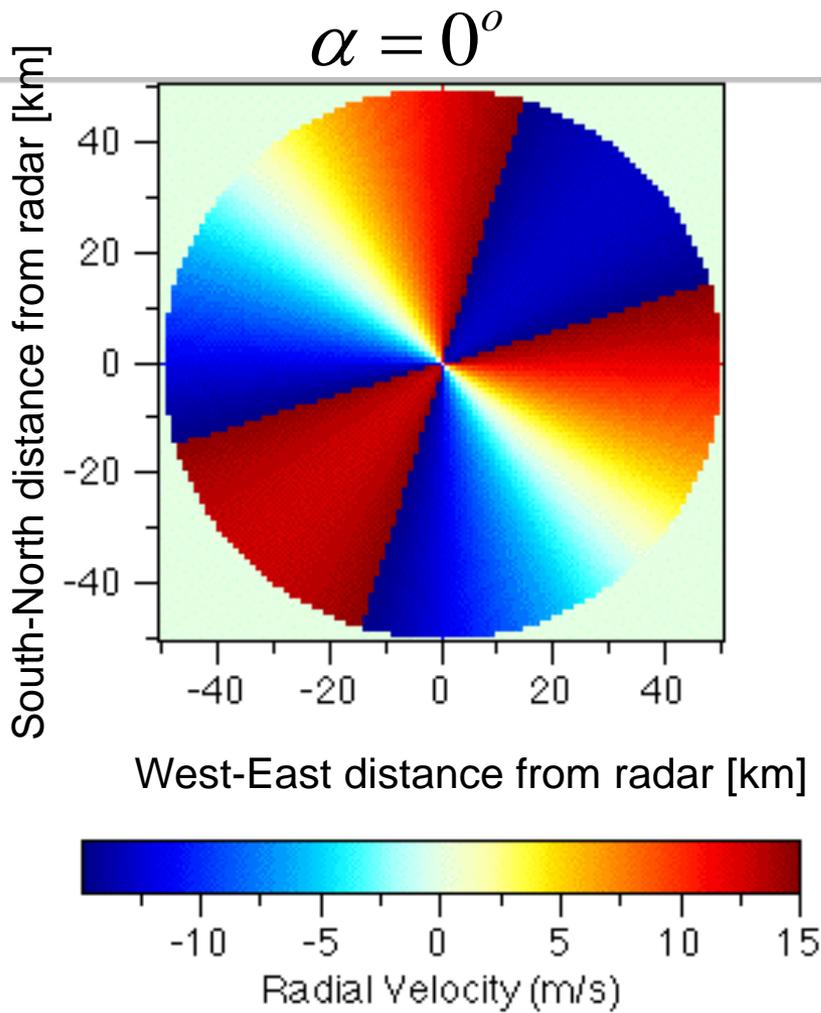
What is wrong here?

Fall velocities: low values

Radar looking direction

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Velocity azimuth display (VAD)

$$\alpha = 0^o$$

South-North distance from radar [km]

West-East distance from radar [km]

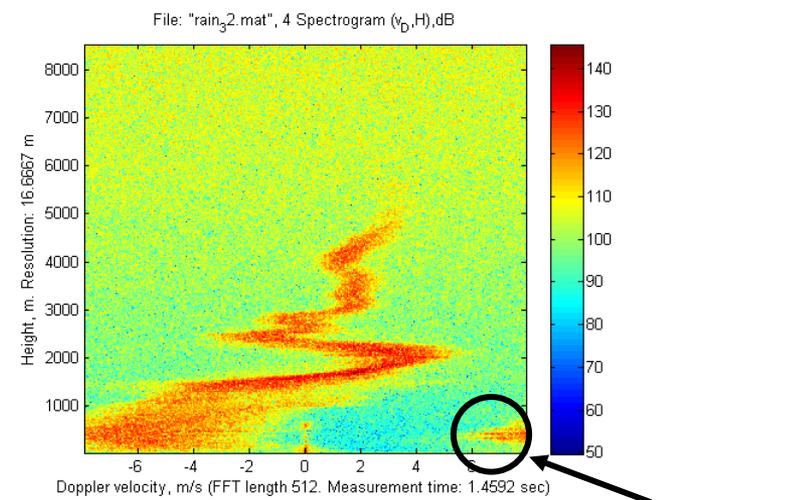Radial Velocity (m/s)
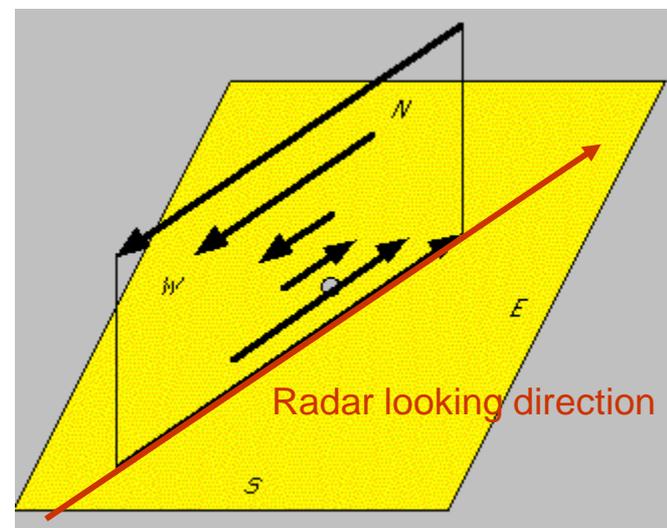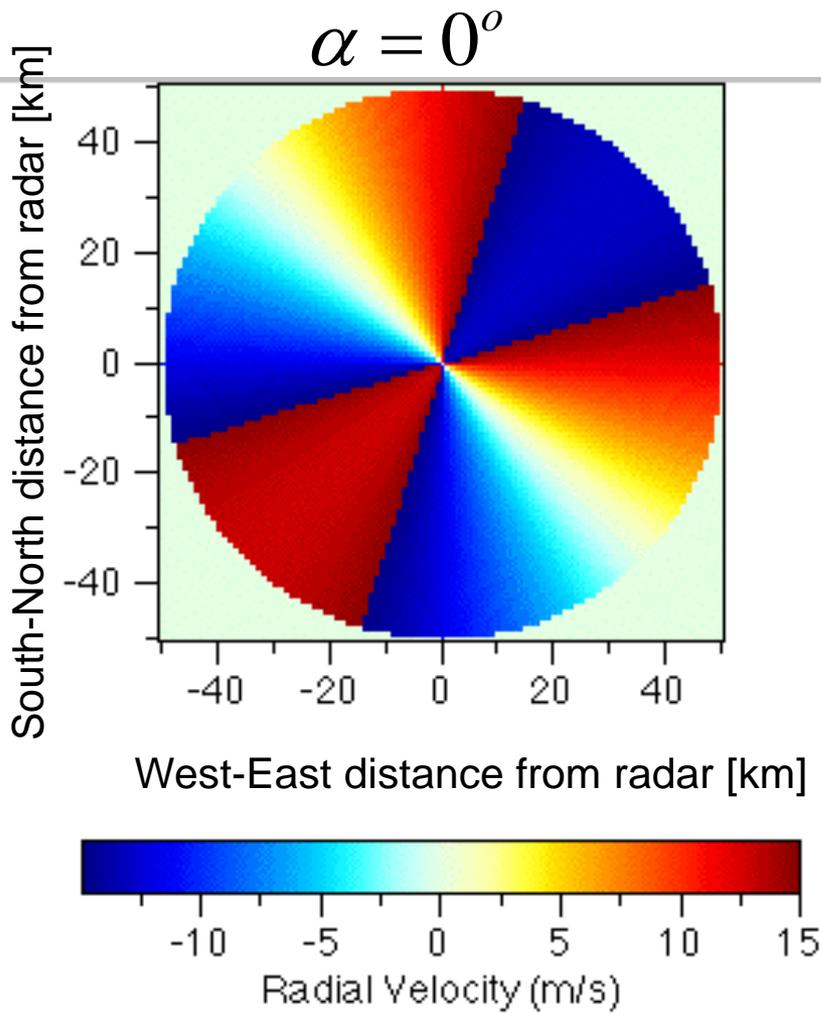
Windspeed increases

Maximum unambiguous Doppler velocity too small

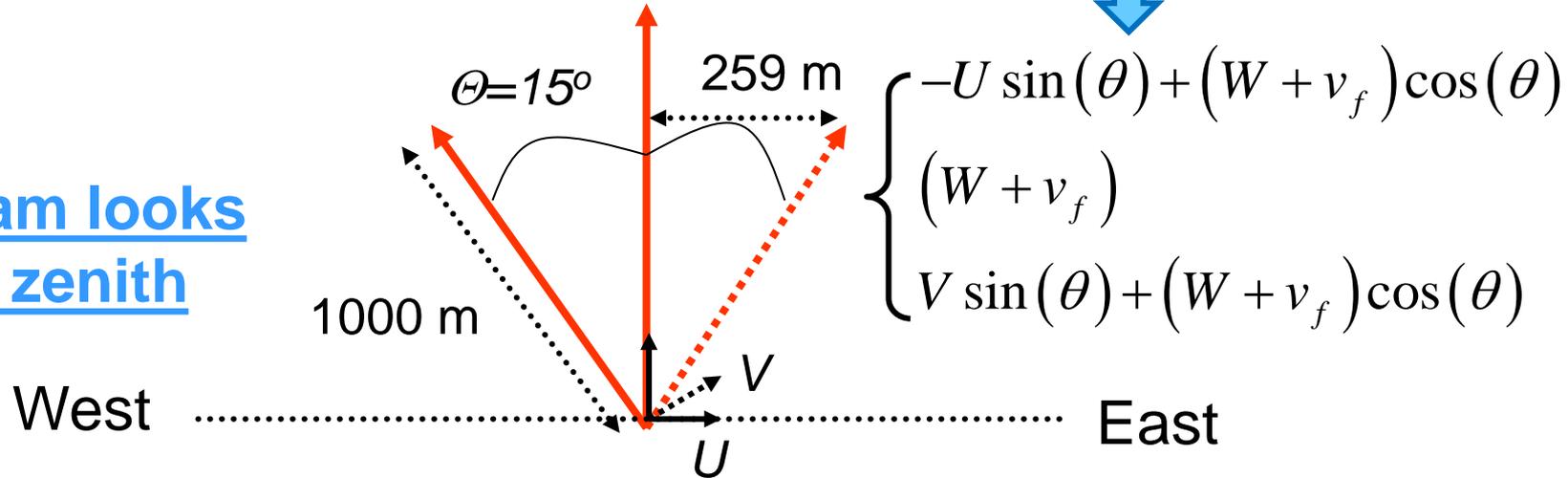$$\varphi_{\max} = \pm\pi \qquad v_{\max} = \pm\frac{\lambda}{4T_0}$$

File: "rain_3 2.mat", 4 Spectrogram (v_D,H),dB

Height, m. Resolution: 16.6667 m

Doppler velocity, m/s (FFT length 512. Measurement time: 1.4592 sec)

Doppler aliasing

Radar wind profiler

a set of 3 mean Doppler velocities

One beam looks at the zenith

$\Theta = 15^o$

259 m

1000 m

$$\begin{cases} -U\sin(\theta) + \left(W + v_f\right)\cos(\theta) \\ \left(W + v_f\right) \\ V\sin(\theta) + \left(W + v_f\right)\cos(\theta) \end{cases}$$

West

East

V

U

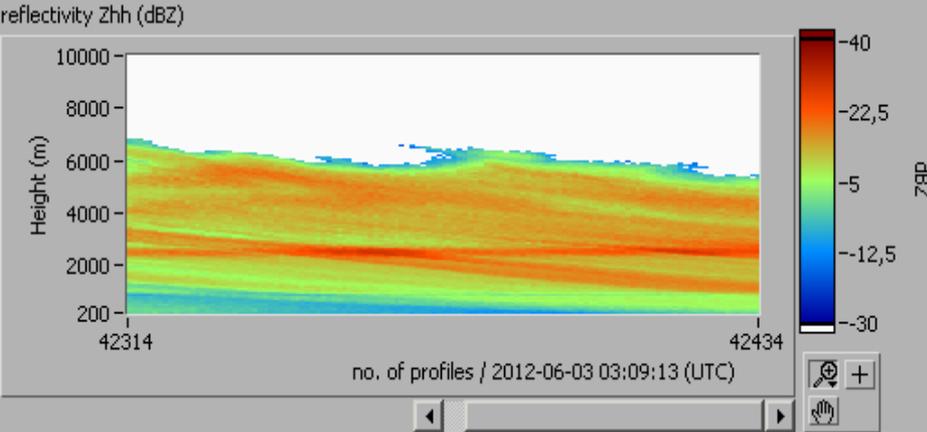Do the measurements in three directions to obtain the three-dimensional wind vector (V, U, W)

V: horizontal wind component South-North
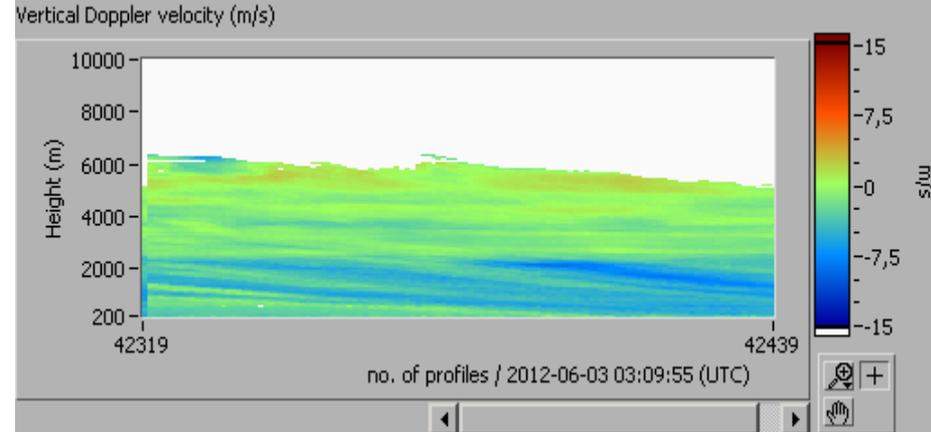U: horizontal wind component West-East
W: vertical wind

Assumption: the 3 beams probe the same medium (microphysical and dynamical) at fixed height
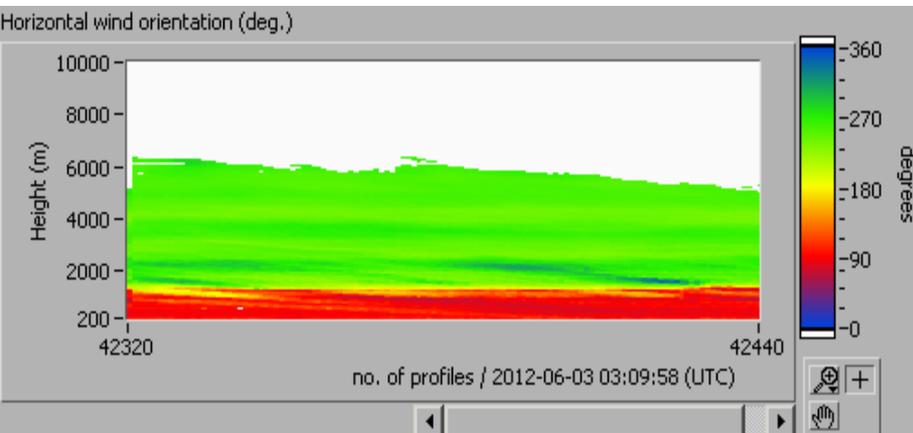
Equivalent reflectivity [dBZ]

Vertical Doppler velocity [m s⁻¹]

$$v_D = W + v_f$$

Notice the difference of about 180 deg in wind direction

Elevation = 75 deg.   *http:/ftp.tudelft.nl/TUDelft/irctr-rse/tara*

Horizontal wind direction [deg]

$$\tan D = \frac{U}{V}$$
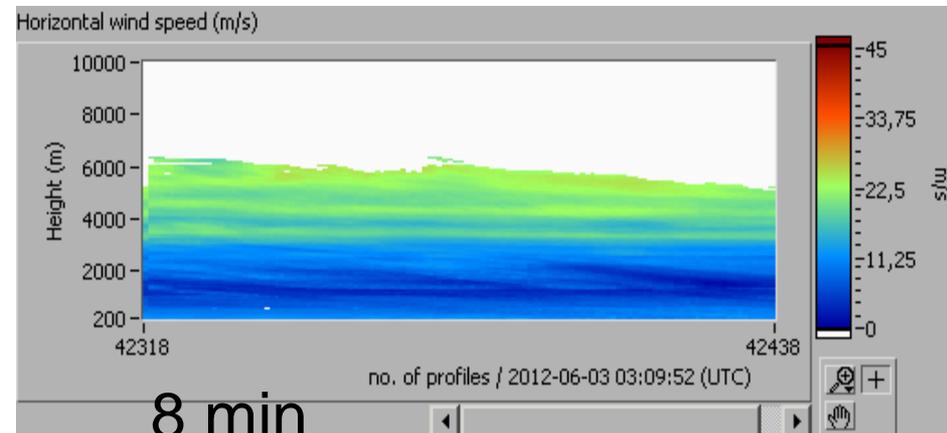
8 min

Horizontal wind speed [m s⁻¹]

$$v_H = \sqrt{U^2 + V^2}$$

Precipitation

❖ 10-min averaging may suppress the contribution of turbulent effect, small time variations, Doppler velocity variance

❖ cannot calculate the vertical wind unless the microphysics is known (fall velocity of the particles)

❖ the 3 beams may probe precipitation with different microphysical properties (different fall velocities)

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