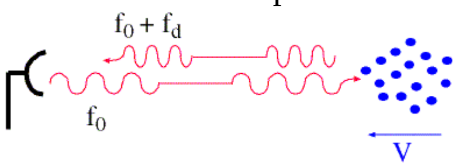
DOPPLER RADAR

Doppler Velocities - The Doppler shift

- Q: How does the radar get velocity information on the particles?



$f_0 = c/\lambda$ = transmitted frequency

f_d = Doppler-shifted frequency

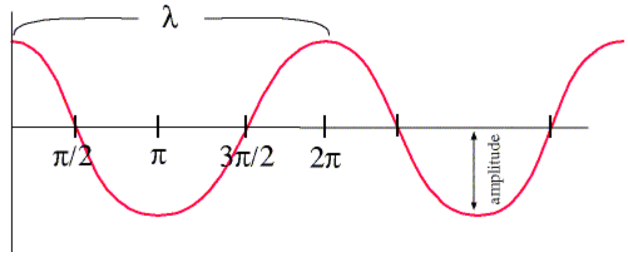
Note: $f_0 >> f_d$

- Measures a Doppler shift - change in frequency of radiation due to motion of scatterers

Total Distance to Target in Radians

The total distance (D) traveled by the wave is $2r$
The number of wavelengths (λ) in the total distance (D) is equal to $2r/\lambda$
We can also express D in terms of radians:
since 1 λ = 2π radians, then,

$$D = \left(\frac{2r}{\lambda}\right)2\pi \text{ radians}$$



Simple Example:

r = 10 cm then $D = 2r$ = 20cm
number of wavelengths in the total distance (D) is equal to $2r/\lambda$ = 20cm/10cm = 2 wavelengths
so, in terms of radians,

$$D = \left(\frac{2r}{\lambda}\right)2\pi = 2(2\pi) = 4\pi \text{ radians}$$

so phase of returned signal is:

$$\phi = \phi_o + \frac{4\pi r}{\lambda}$$

if $\phi_0 = 0$, then $\phi = 4\pi$

where

ϕ_o = phase of pulse sent out by radar
ϕ = phase of returning signal then

$$\phi = \phi_o + \frac{4\pi r}{\lambda} \quad (1)$$

differentiating (1) yields:

$$\frac{d\phi}{dt} = \frac{4\pi}{\lambda}\frac{dr}{dt} \quad (2)$$

Pulse-Pair Method

Take two consecutive pulses and measure the phase of the received pulses as shown in the schematic to the right -->>

Recall that: $$\frac{d\phi}{dt} = \frac{4\pi}{\lambda}\frac{dr}{dt} \quad (1)$$

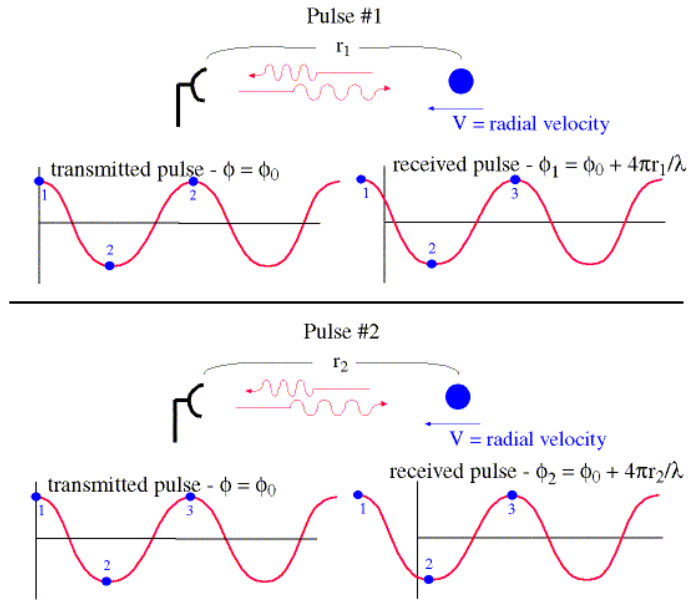
where $d\phi = \phi_2 - \phi_1$
dt = time between pulses
dr/dt = radial velocity of the target = V

so: $$v = \frac{\lambda}{4\pi}\frac{d\phi}{dt} \quad (2)$$

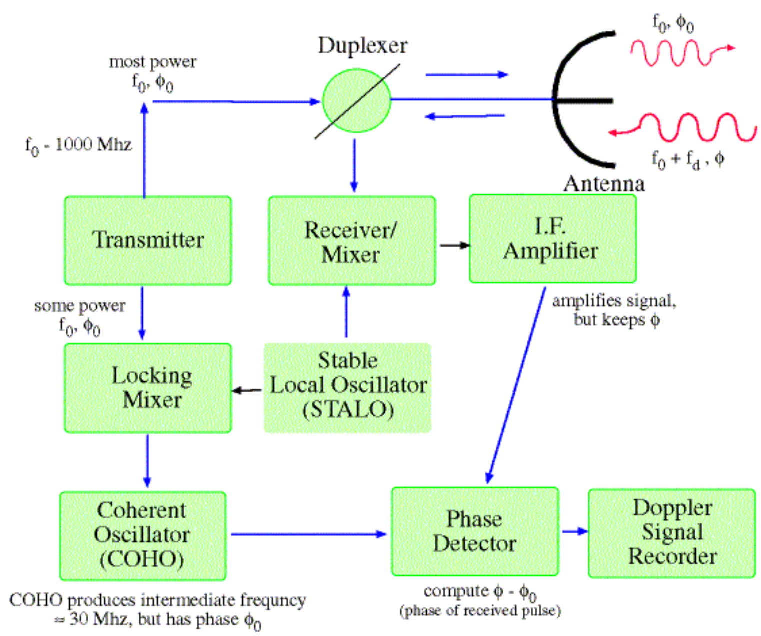
but $d\phi/dt$ is really the angular velocity = $\omega = 2\pi f_d$
So, (2) becomes:

$$v = \frac{\lambda}{4\pi} 2\pi f_d \quad \text{or:} \quad v = \frac{\lambda}{2} f_d$$

How does the radar then measure f_d?



Doppler Radar Block Diagram



Pulse-Pair Method

1) The transmitter produces a pulse with frequency f_0 and duration of τ.

2) Some power with frequency f_0 is mixed with a signal from STALO and is passed to COHO

3) COHO maintains ϕ_o of transmitted wave

4) Receiver/mixer mixes signal from STALO and received signal

5) Mixed signal is then amplified

6) Phases of original and received signals are differenced, i.e., compute $\phi_1 = \phi_0 - \phi$. This is the phase of pulse #1.

7) Repeat 1-6 above for successive pulses. This gives you $d\phi/dt$.

Nyquist Velocity

Q: What is the maximum Doppler-shifted frequency that can be unambiguously measured?

If you sample wave at the frequency of the wave (f_s=f), can't reconstruct it -->>

Need to sample the wave with frequency (f_s)of at least 2f. -->>

with a pulsed radar, then f_s = *PRF*. -->>

so *PRF* is greater than or equal to 2f.

or $f_{d\,max}$ = *PRF*/2

Nyquist Velocity, continued

Recall that:

$$f_d = \frac{2V_r}{\lambda} \qquad (1)$$

or:

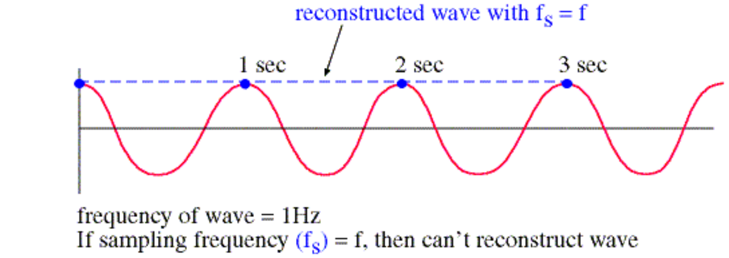
$$f_{d\,\max} = \frac{2V_{r\,\max}}{\lambda} \qquad (2)$$

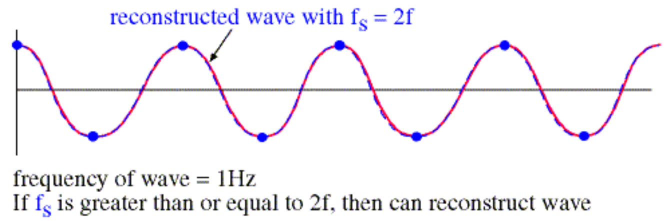
but:

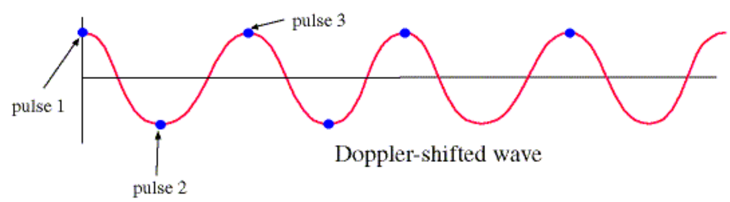
Velocity Folding

If a particle's radial velocity is outside the range of the nyquist interval, then the radial velocity will be **aliased, or folded**. This is called **velocity folding/aliasing.**

Example: if nyquist velocity is 25 m/s and the particle's radial velocity is -30 m/s, then it will fold over and the radar will interpret it as +20 m/s -->>







$$f_{\max} = \frac{PRF}{2} \qquad (3)$$

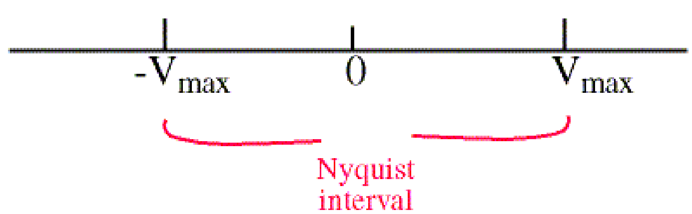
so equating (2) and (3) gives:

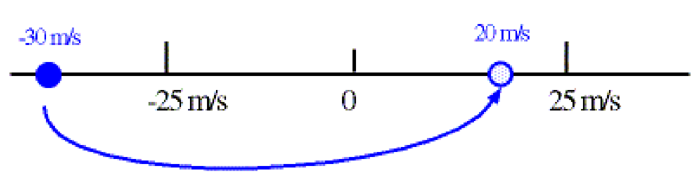
$$\frac{2v_{\max}}{\lambda} = \frac{PRF}{2} \qquad (4)$$

or:

$$v_{\max} = \frac{PRF\ \lambda}{4} \qquad (5)$$

example: if *PRF* = 1000 s^{-1} and λ = 10 cm, then V_{max} = 25 ms^{-1}





Relationship Between Nyquist Velocity and Unambiguous Range

We can now find a relationship between the Nyquist velocity (V_{max}) and the unambiguous range (R_{max}).

Recall that:

$$v_{max} = \frac{PRF\ \lambda}{4} \qquad (1)$$

Also recall from way back:

$$R_{max} = \frac{c}{2\,PRF} \qquad (2)$$

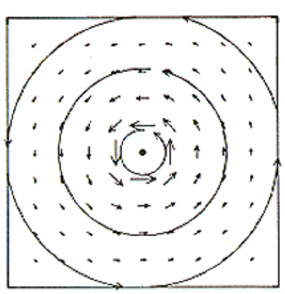
Eliminating the PRF from (1) and (2) gives:

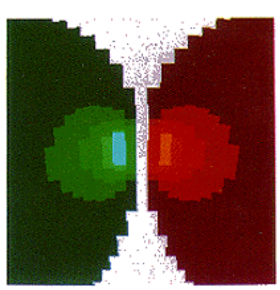
$$v_{max} = \frac{c\lambda}{8R_{max}}$$

So, to increase the Nyquist interval, one must decrease the unambiguous range and vice versa.

Single-Doppler Velocities - Beam Location above Ground

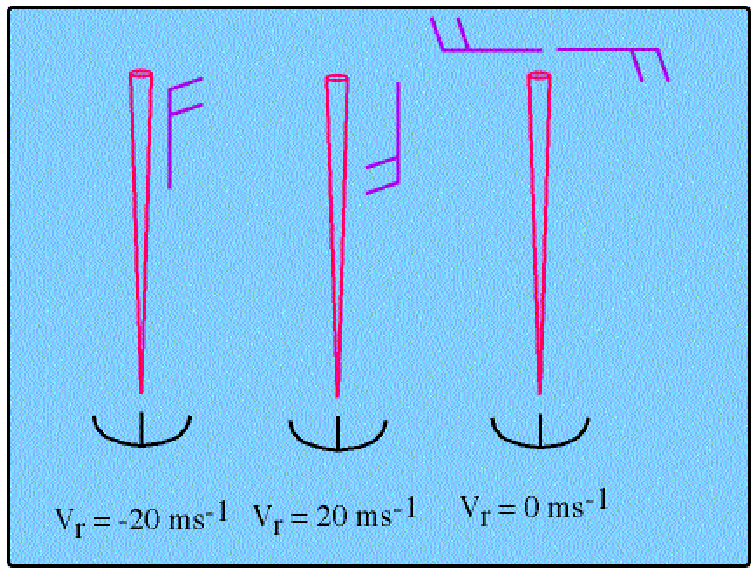
- When interpreting Doppler velocities, also keep in mind that the beam height above ground increases at larger ranges......-->>
- So, at larger ranges, you are not looking at the surface flow anymore
- Hence, single-Doppler velocity interpretation can be tricky...., so let's practice......

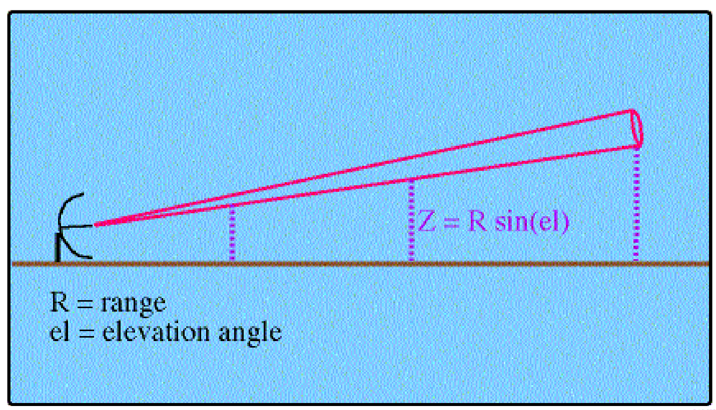


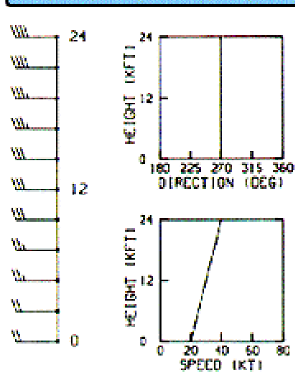


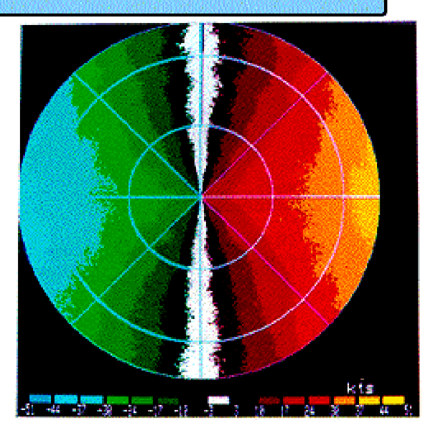
Introduction to Single-Doppler Velocity Interpretation

- A Doppler radar can only measure the component of the winds in a direction parallel to the radar beam
- the measured wind speed is called the radial velocity (V_r)
- see the examples to the right -->>
- note that zero radial velocity means either the winds are calm or the winds are moving in a direction perpendicular to the beam



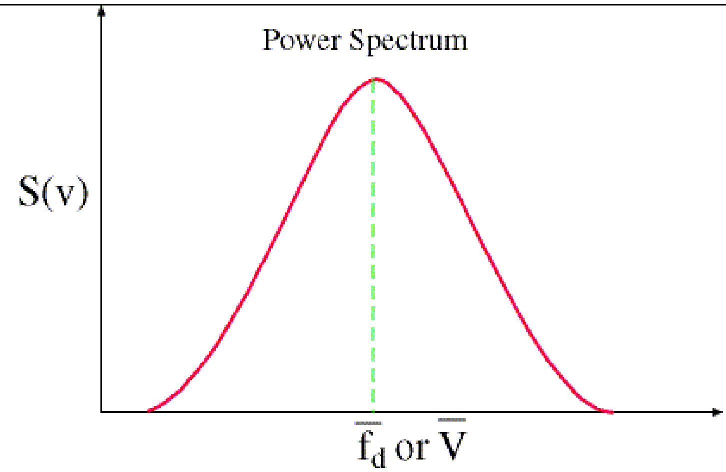






The Doppler power spectrum - Introduction

Because there are a large number of drops in a pulse volume, they will each provide their own backscattered power and Doppler shift.
One can then plot the Doppler power spectra of the data -->>
From the power spectra, one can derived the mean radial velocity and radar reflectivity factor:
$\overline{f_d}$ = mean Doppler-shifted frequency
$\overline{V}$ = mean radial velocity
S(v) = Backscattered Power
$\overline{P_r}$ = total average power = $\int_{-\infty}^{\infty} S(v)dv$ which is the area under the curve
Most radars do not keep the full Doppler spectrum, only
$\overline{f_d}$ and $\overline{V}$.



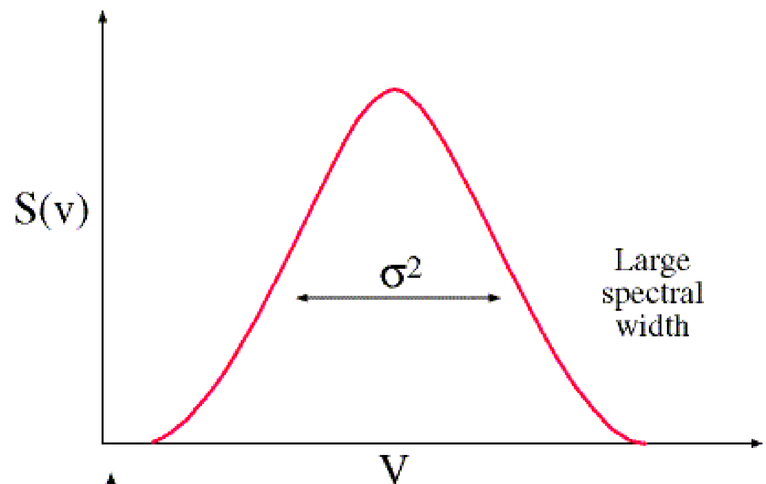
Spectrum Width

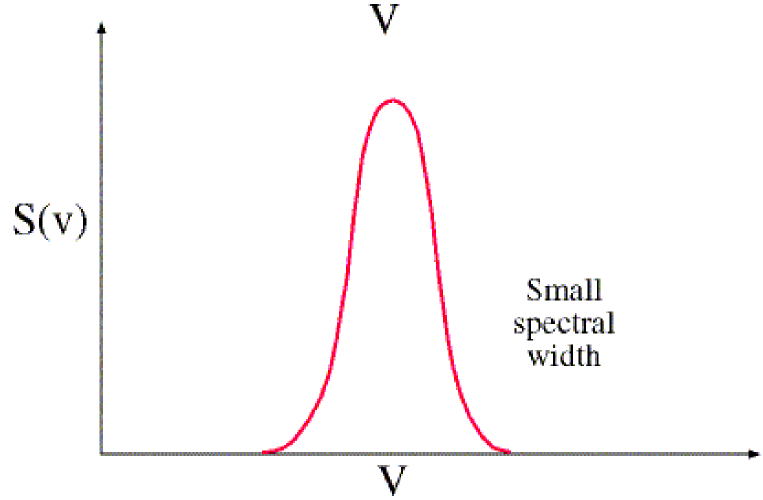
The width of the Doppler power spectrum can tell us more about the scatterers:

The spread of the Doppler power spectrum, referred to as the **spectral width,** is found by computing the variance. The spectral width depends on:

1. the spread, range of terminal fall speeds of the scatterers (more pronounced for rain than for snow)
   - spectra for rain
   - spectra for snow
2. turbulence of the air (upper levels in severe convection)
3. vertical wind shear (e.g., along a gust front)
4. antenna motion

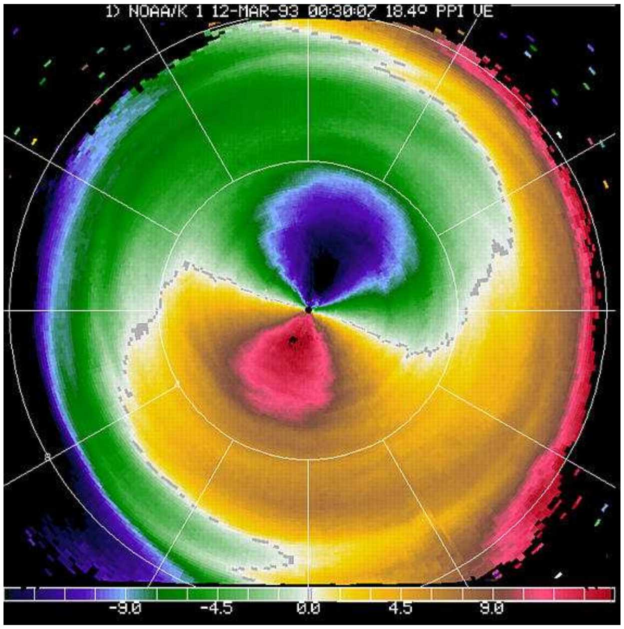
Then, the total spectral width is due to the sum of the aforementioned effects:

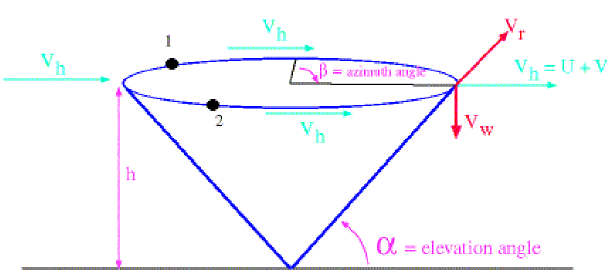


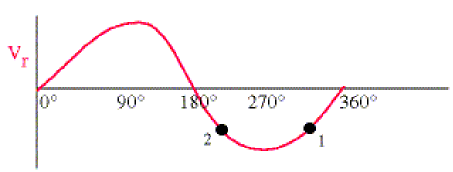


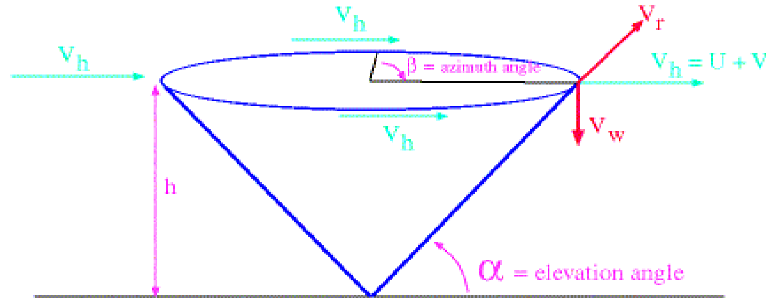
VADs (Velocity Azimuth Display)

- A method for retrieving 2-D wind profile (sounding) from the radial velocity field
- 88D produces these
- Assume a flow field that varies linearly
- perform a surveillance-type scan -->>

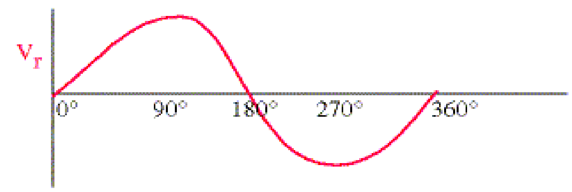








For a westerly wind:



V_r magnitude will be a sine wave

VADs (Velocity Azimuth Display)

At a given height (*h*), then the radial velocity is:

$$v_r = (U\sin\beta + V\cos\beta)\cos\alpha + V_w\sin\alpha$$

For a uniform flow field and assume V_w approximately = 0 then

$$v_r = (U\sin\beta + V\cos\beta)\cos\alpha$$

Have two unknowns (*U*,*V*), but one equation….

But, if you sample at two different points in your scan;

$$v_{r1} = (U\sin\beta_1 + V\cos\beta_1)\cos\alpha_1 (1)$$

$$v_{r2} = (U\sin\beta_2 + V\cos\beta_2)\cos\alpha_2 (2)$$

So, two estimates of V_r at two different points around the cone will give *U*,*V*

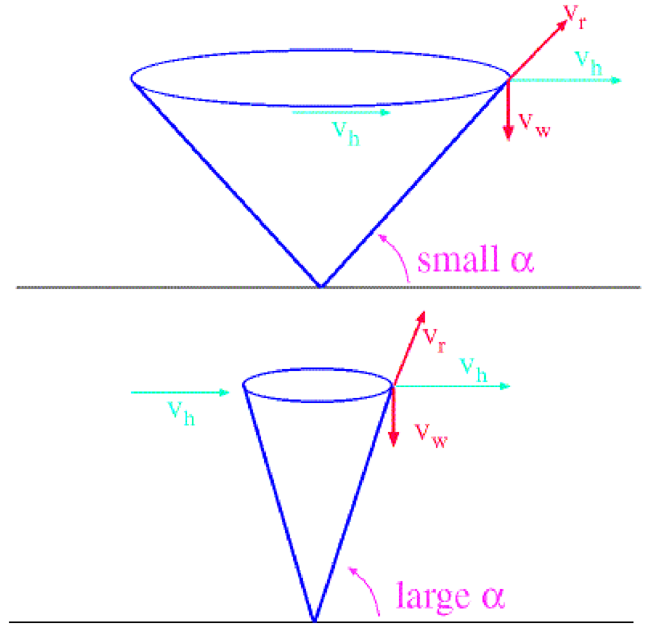
Actually sample around the entire cone, so you have an overdetermined system for finding *U*,*V*

VADs - Big and Small Cones

Cone size is an important consideration with VADs...

Big Cone (small α)
Advantages:
Disadvantages:

Small Cone (large α)
Advantages:
Disadvantages:



Dual Doppler - Introduction

Q: How can one determine the 3-dimensional wind field (U,V,W) from the radial velocities obtained from a Doppler radar?

A: Combine the radial velocity information from at least two radars using the **dual-Doppler methodology**

First, assume W = 0. then,

$$V_{r1} = (U \sin\beta_1 + V\cos\beta_1)\cos\alpha_1$$

$$V_{r2} = (U \sin\beta_2 + V\cos\beta_2)\cos\alpha_2$$

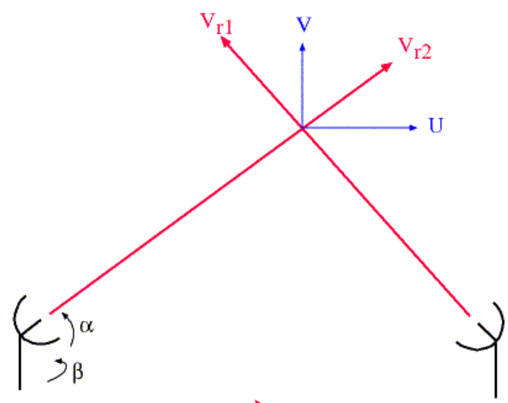
Solving for *U* and *V* gives:

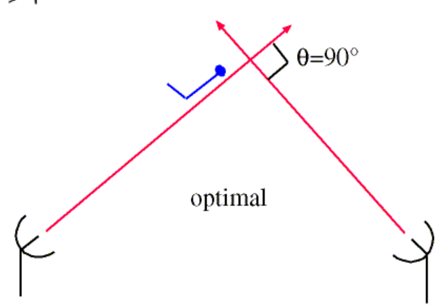
$$U = \frac{1}{\sin(\beta_1 - \beta_2)}\left[\frac{V_{r1}\cos\beta_2}{\cos\alpha_1} - \frac{V_{r2}\cos\beta_1}{\cos\alpha_2}\right]$$

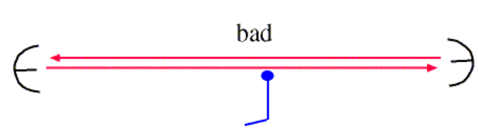
$$V = \frac{1}{\sin(\beta_1 - \beta_2)}\left[\frac{V_{r2}\sin\beta_1}{\cos\alpha_2} - \frac{V_{r1}\sin\beta_2}{\cos\alpha_1}\right]$$

W is found by using the continuity equation:

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} + \frac{1}{\rho} w \frac{\partial \rho}{\partial z} = 0$$





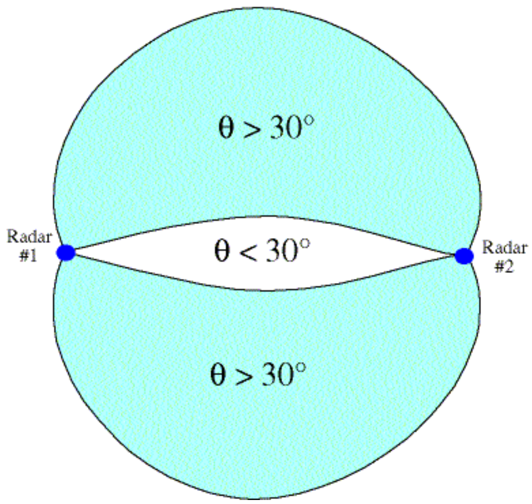


Dual Doppler - Lobes

Within the lobes, the beam intersection angle (θ) is greater than or equal to 30°

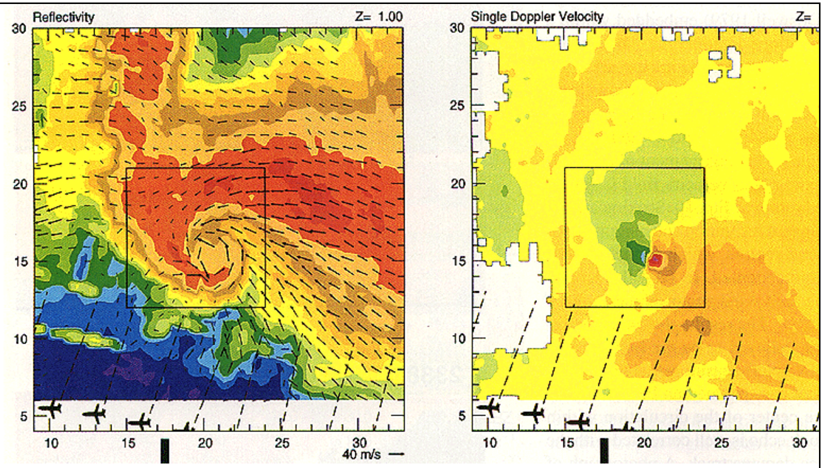
This is where you can retrieve useful dual-Doppler wind information

Dual-Doppler Lobes



Doppler Concepts

- components of a wave
  - wavelength
  - amplitude
  - phase
- Pulse-pair method for determining radial velocities
- Nyquist velocity/interval
- velocity folding
- relationship between Nyquist interval and PRF
- relationship between Nyquist velocity and unambiguous range
- Power spectrum
  - how to determine radial velocity and reflectivity from spectrum
  - factors governing width of spectra
  - information on scatterers based on spectral width data
  - difference between rain and snow



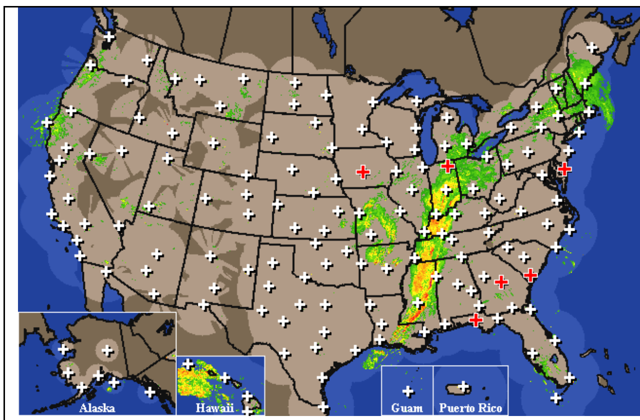
-
- vads:
  - assumptions made
  - sampling in a cone
  - adv/disadv of big/small cones
- Dual-Doppler technique:
  - number of radars required
  - optimal geometry
  - assumptions made
  - calculation of horizontal winds
  - calculation of vertical winds

NEXRAD

Next Generation Weather Radar (NEXRAD) makes conventional reflectivity observations and also uses the "Doppler effect" to measure motion of clear air and atmospheric phenomena within storms. NEXRAD comprises approximately 159 Weather Surveillance Radar-1988 Doppler (WSR-88D) sites throughout the United States and selected overseas locations. It does a PPI (Plan Positioning Indicator) scan at several elevations. **Clear Mode**: 5 elevation scans in 10 minutes. **Rain Mode**: 9-14 elev. Scans in 5 minutes.

DATA LEVEL	DESCRIPTION
LEVEL I	analog signals from the receiver, we are not interested in this stuff. Level I data is generated by the RDA
LEVEL II	three basic radar moments, base reflectivity, radial velocity, and spectral width. Level II data is generated by the RDA
LEVEL III	base products- produced with algorithms from the level II data generated by the RPG
LEVEL IV	base products- those products recorded on the PUP as selected by the operator

http://apollo.lsc.vsc.edu/classes/remote/ www.osf.noaa.gov



variable		value
wavelength		S band (10.0-11.1 cm)
frequency		2.8-3.0 GHz
Peak Power		750 kW
antenna diameter		8.5 m (28 ft)
beamwidth		0.95°
rotation rate		36° per sec
PRF		318-1304 s^{-1}
Pulse Length		1.57 and 4.7 microseconds
Gain		45 dB