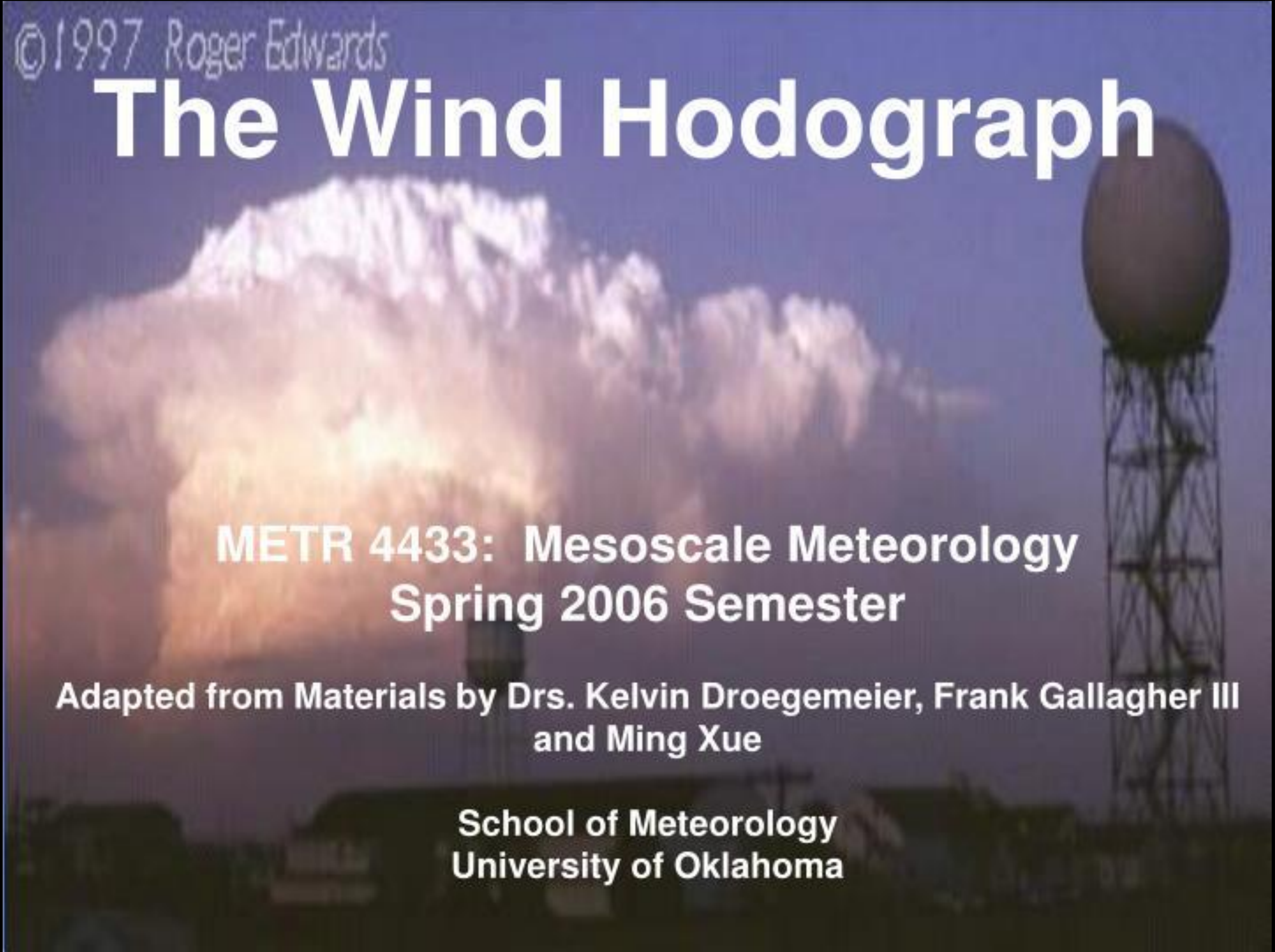


The Wind Hodograph

METR 4433: Mesoscale Meteorology
Spring 2006 Semester

Adapted from Materials by Drs. Kelvin Droegemeier, Frank Gallagher III and Ming Xue

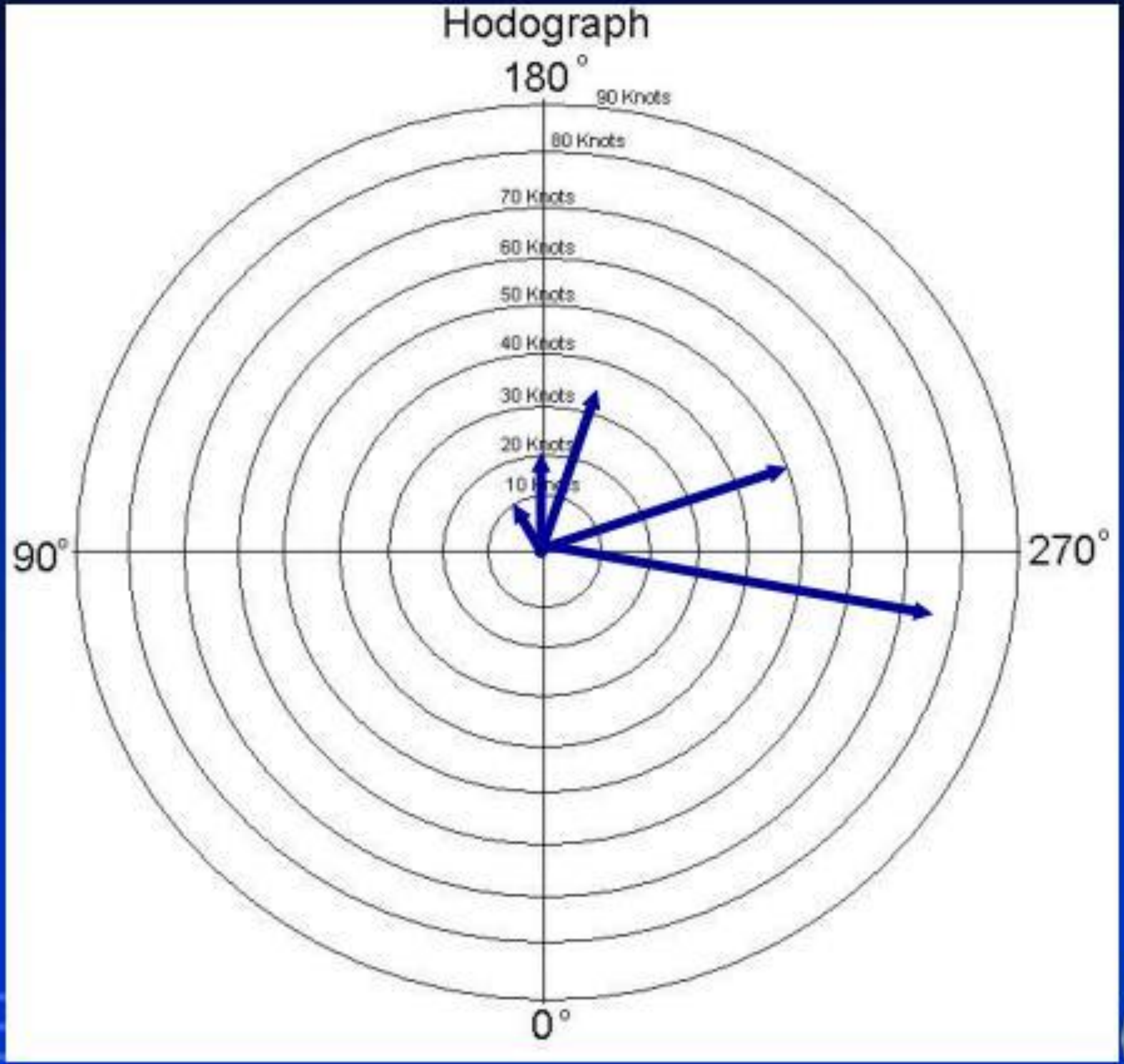
School of Meteorology
University of Oklahoma

Wind Hodograph

- A wind hodograph displays the change of wind speed and direction with height (vertical wind shear) in a simple polar diagram.

- Wind speed and direction are plotted as arrows (vectors) with their tails at the origin and the point in the direction toward which the wind is blowing. This is backward from our station model!!!

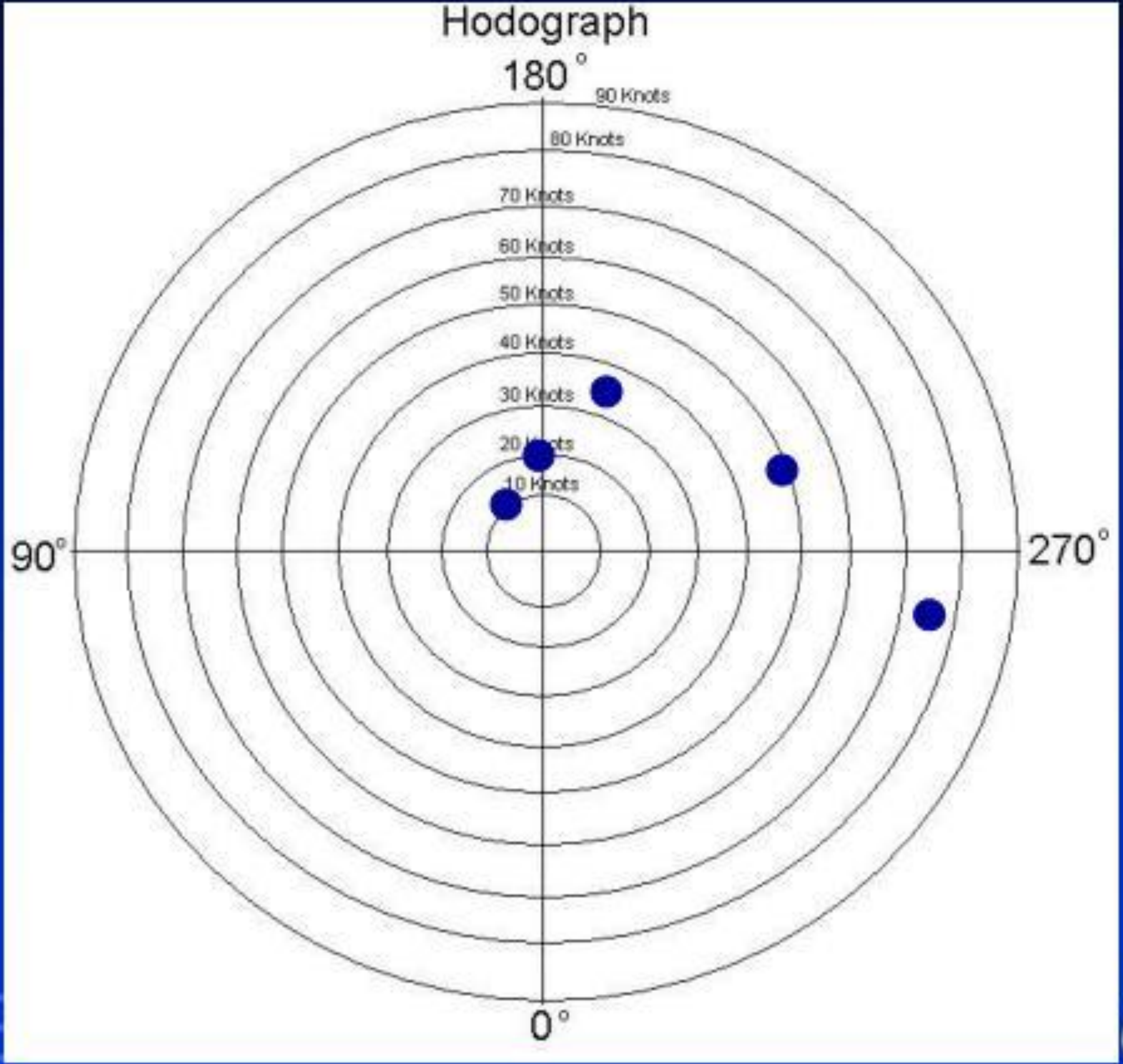
Hodograph -- Example



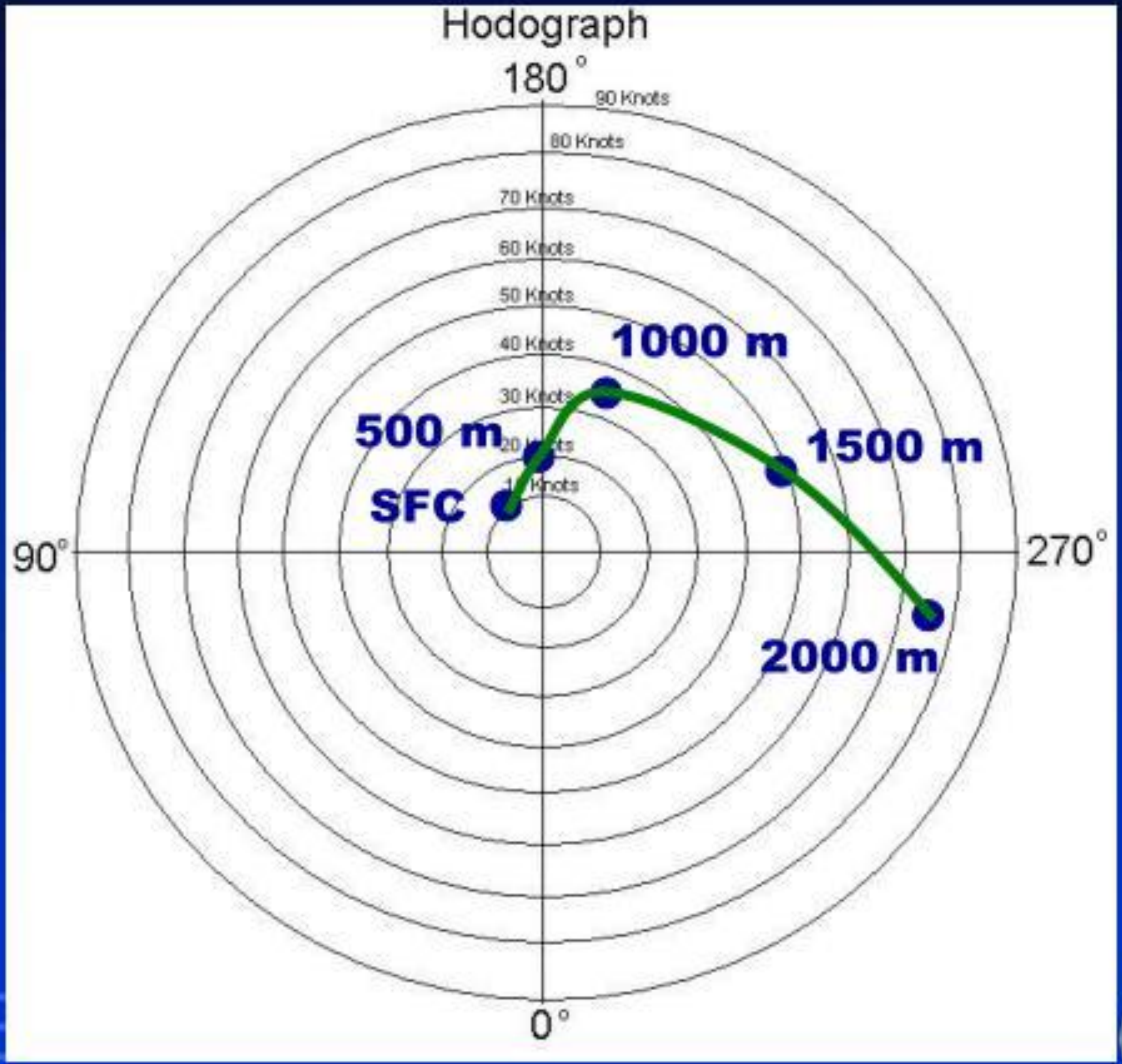
Hodograph

- The length of the arrows is proportional to the wind speed. The larger the wind speed, the longer the arrow.
- Normally only a dot is placed at the head of the arrow and the arrow itself is not drawn.
- The hodograph is completed by connecting the dots!

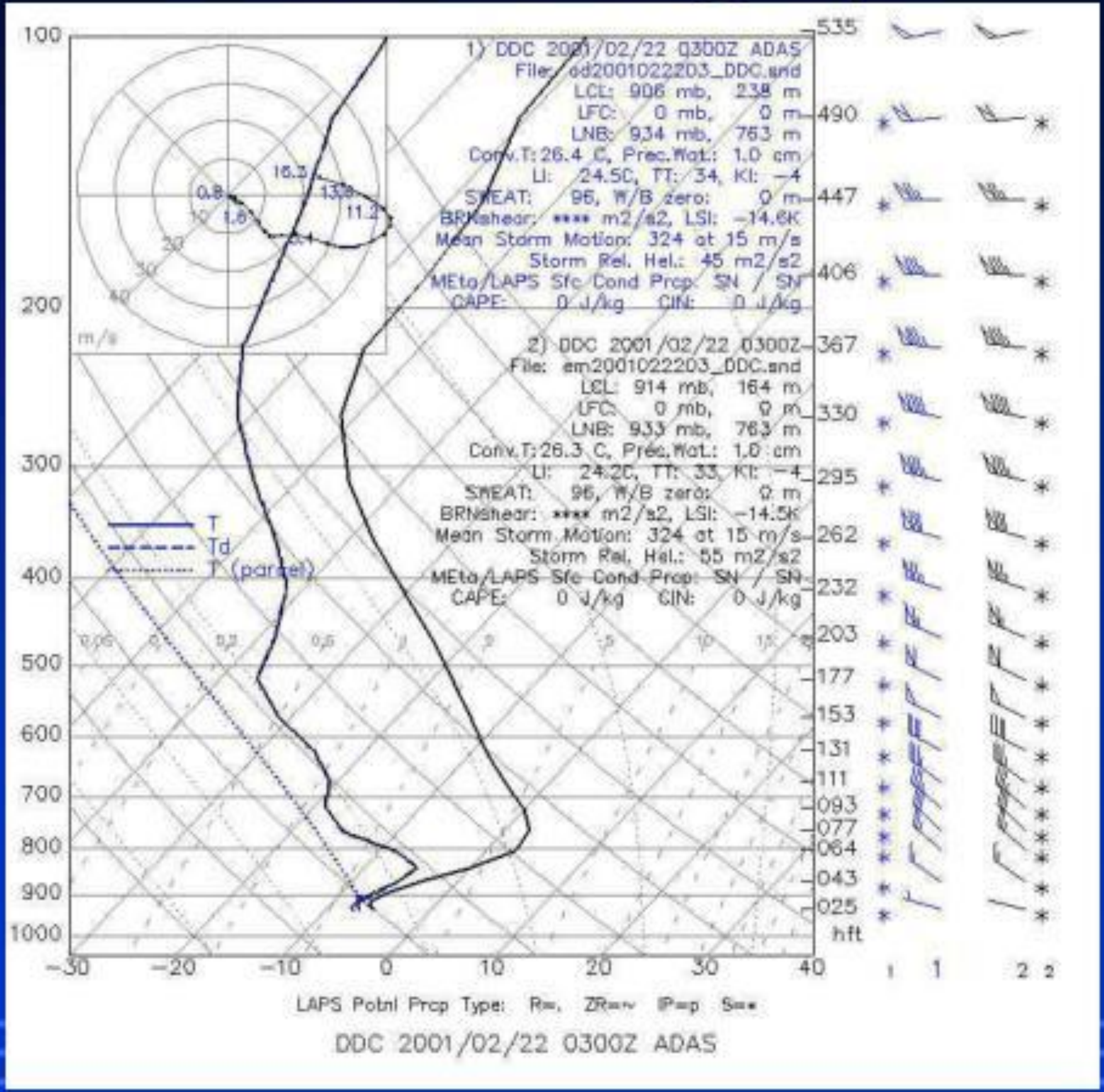
Hodograph -- Example



Hodograph -- Example



Real Hodograph



Hodograph

- Why Draw a Hodograph?
  - We don't have to look through a complex table of numbers to see what the wind is doing.
  - By looking at the shape of the hodograph curve we can see, at a glance, what type of storms may form.
    - » **Air Mass (garden variety) storms**
    - » **Multicellular Storms**
    - » **Supercell Storms**
    - » **Tornadic Storms**
  - The shear on a hodograph is very simple to determine, as is the horizontal vorticity
  - This allows us to assess helicity and streamwise vorticity (later)

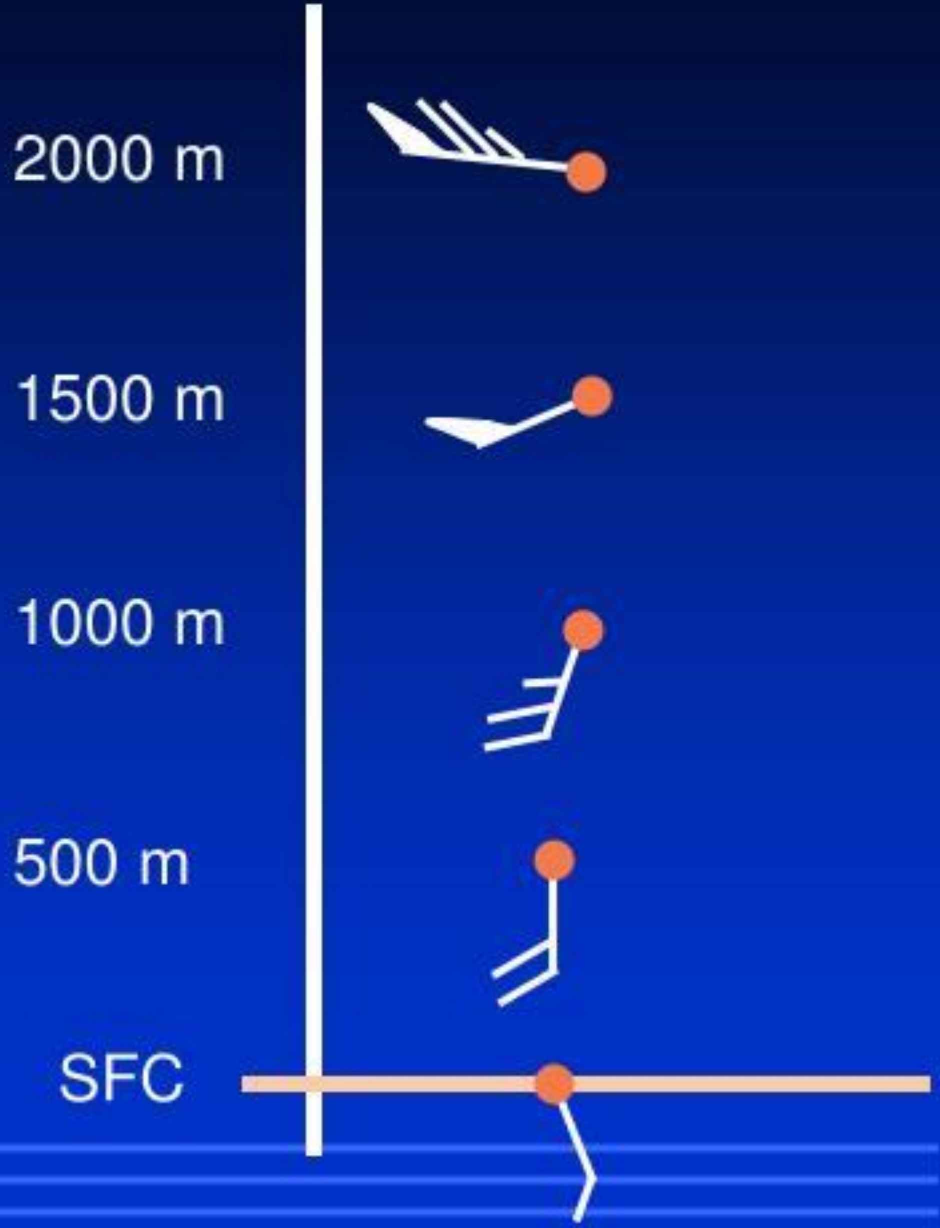
Hodograph -- Example

Height (MSL)	Direction	Speed (kt)
250 m (SFC)	160	10
500 m	180	20
1000 m	200	35
1500 m	260	50
2000 m	280	75

Just by looking at this table, it is hard (without much experience) to see what the winds are doing and what the wind shear is.

Hodograph -- Example

- Let us plot the winds using a station model diagram.
- This is better but it is time consuming to draw and still is not that helpful.



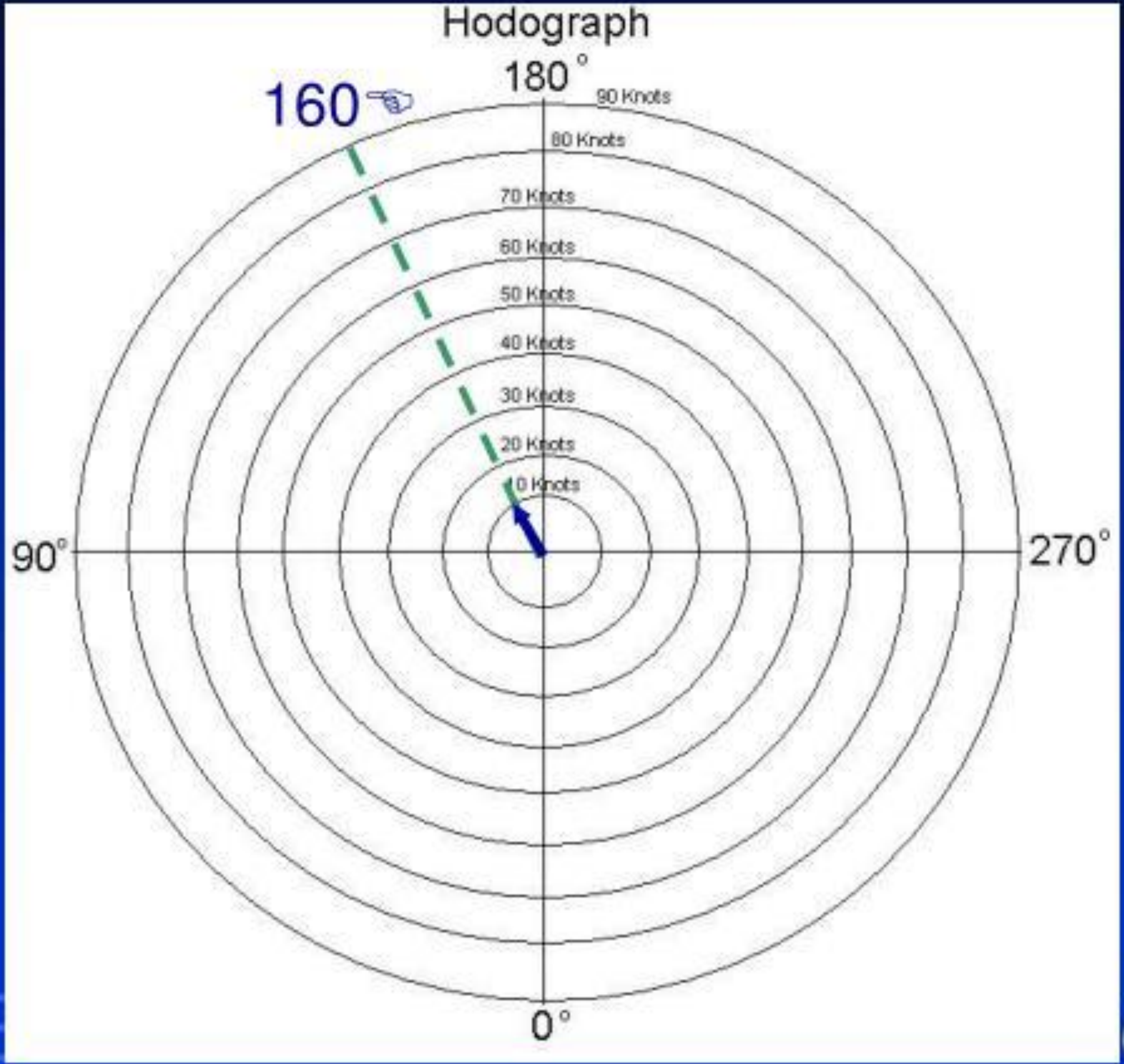
Hodograph -- Example

- Let us now draw the hodograph!

Let us draw the surface observation.
160º at 10 kts

Since the wind speed is 10 kt, the length of the arrow is only to the 10 knot ring.

The direction points to 160º.



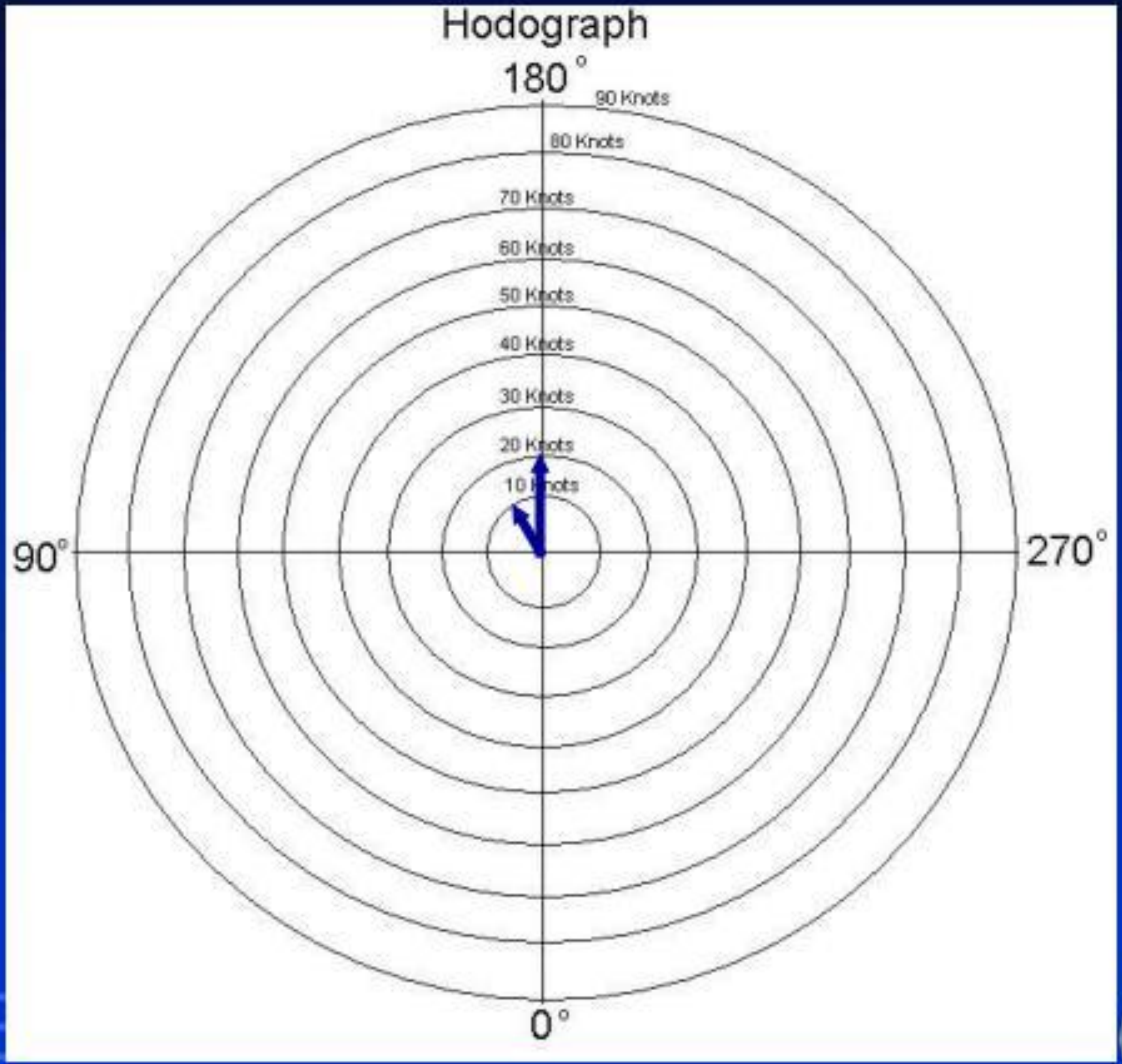
Hodograph -- Example

- Let us now draw the 500 m observation.

Let us draw the 500 m wind observation: **180º at 20 kts**

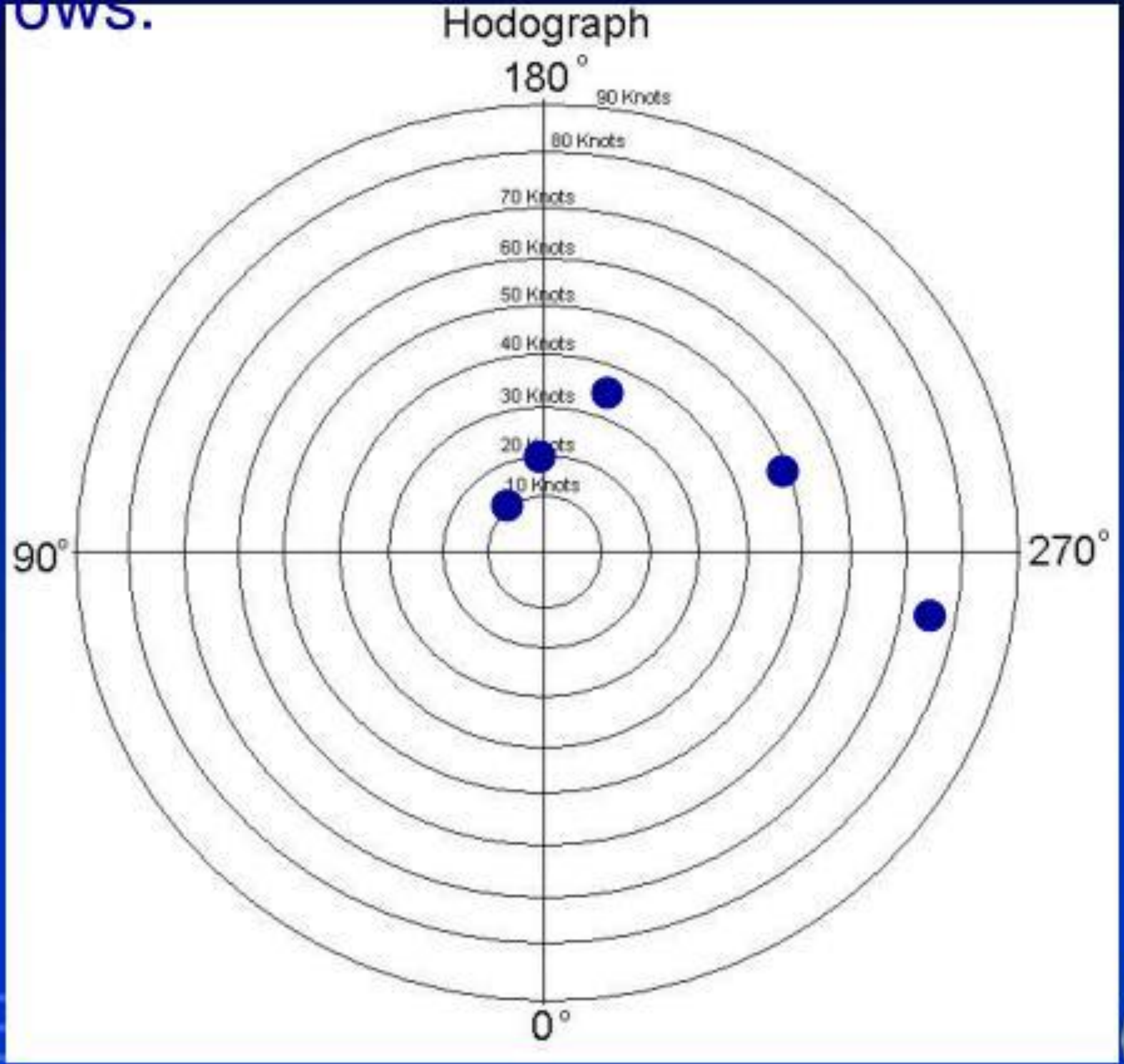
Since the wind speed is 20 kt, the length of the arrow is only to the 20 knot ring.

The direction points to 180º.



Hodograph -- Example

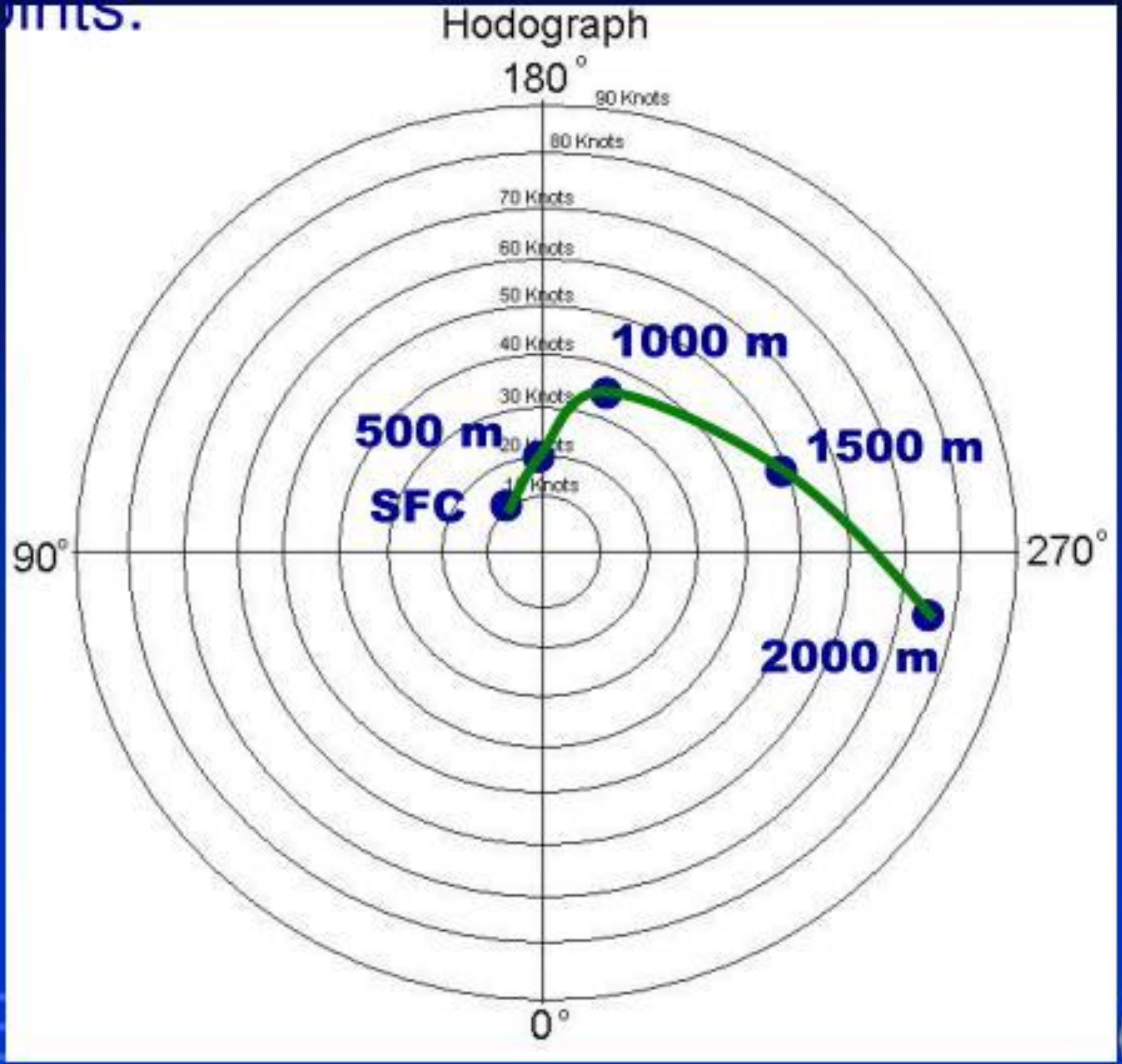
- We now place dots at the end of the arrows then erase the arrows.



Hodograph -- Example

- We then connect the dots with a smooth curve and label the points.

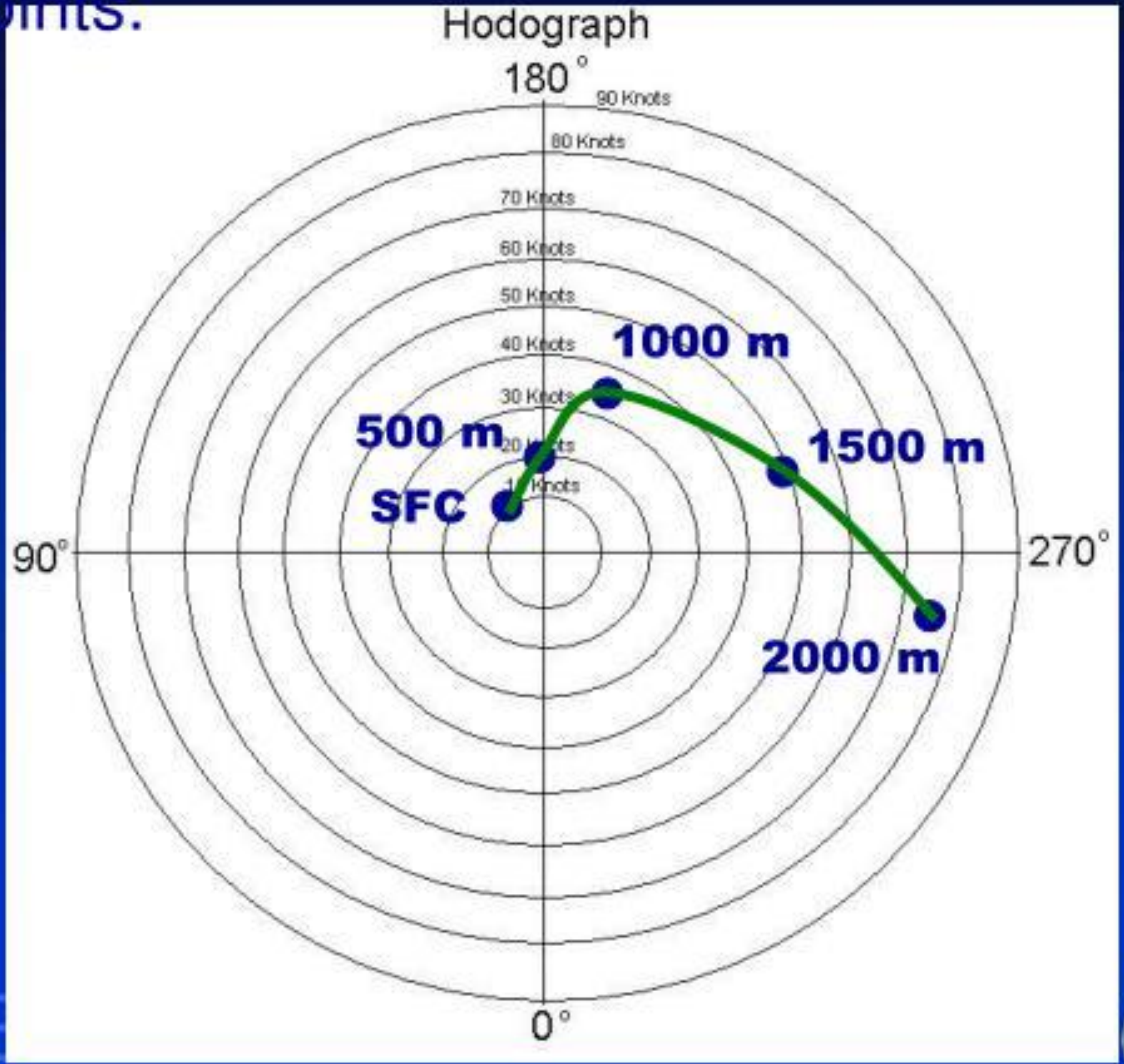
This is the final hodograph!!!



Hodograph -- Example

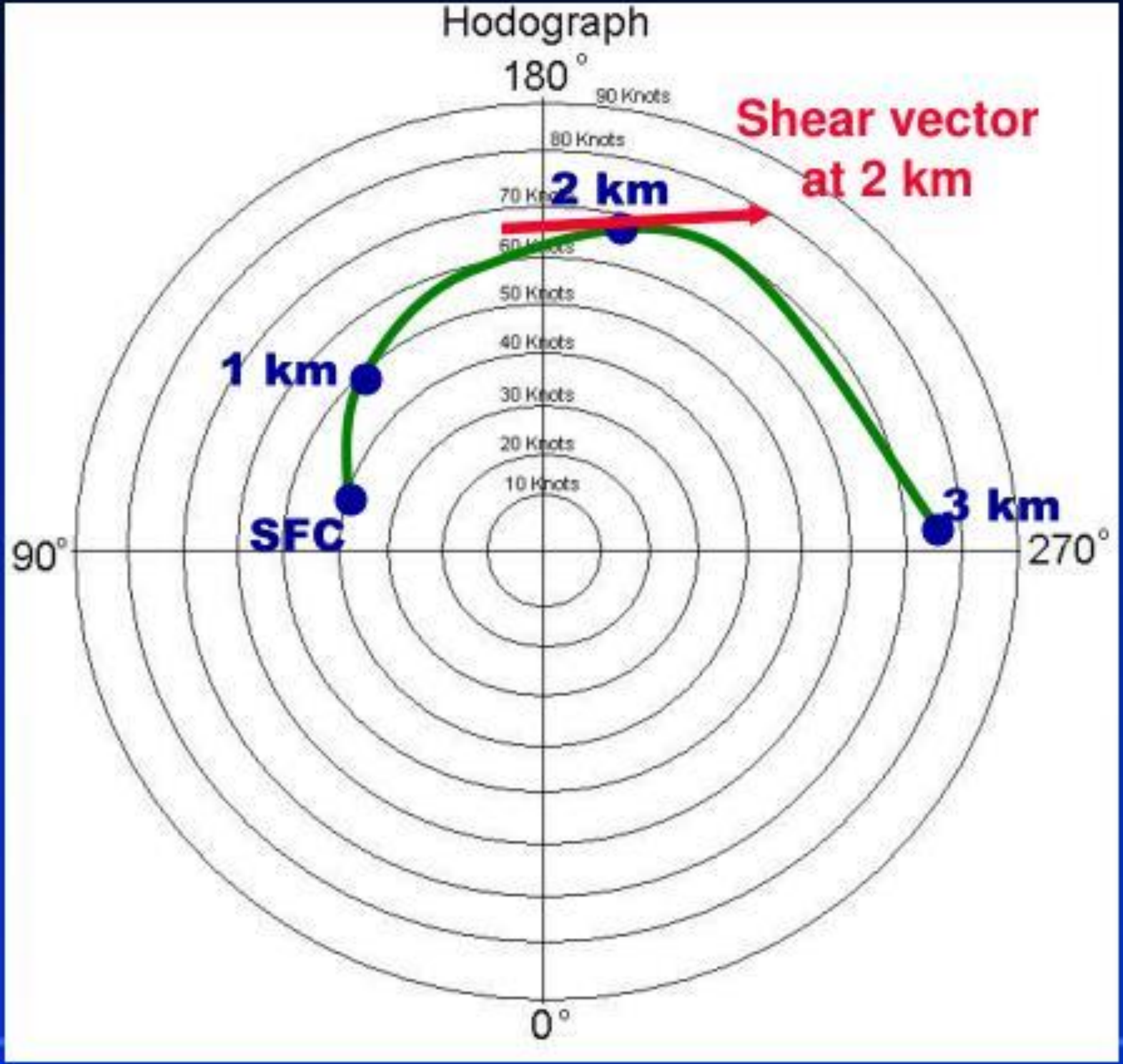
- We then connect the dots with a smooth curve and label the points.

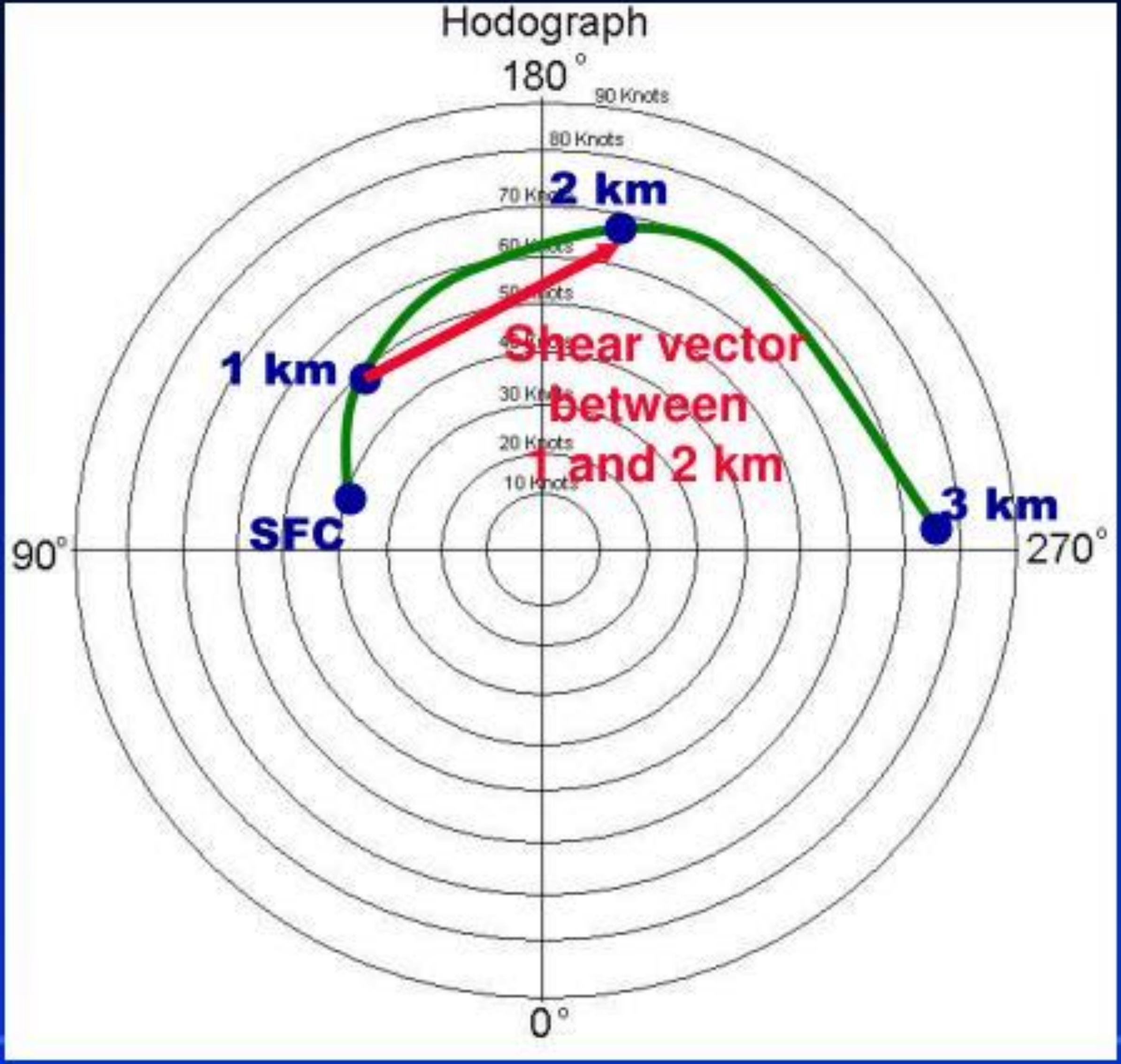
This is the final hodograph!!!



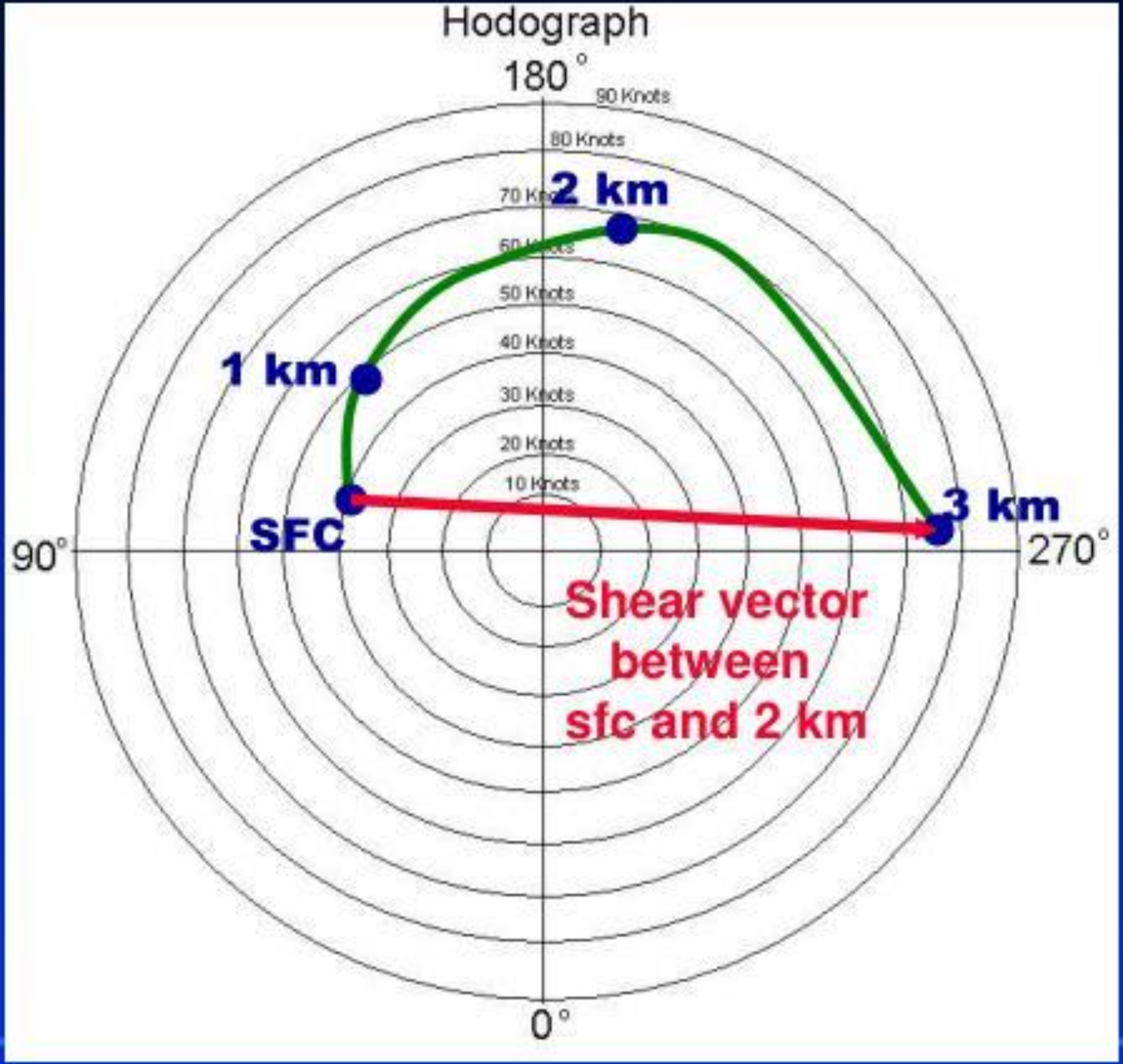
Determining the Wind Shear

- The wind shear vector at a given altitude is tangent to the hodograph at that altitude and always points toward increasing altitudes
- The vector shear between two levels is simply the vector that connects the two levels
- Makes assessing the thermal wind vector (location of cold air) trivial!!
- The average shear throughout a layer is very useful in forecasting storm type


Hodograph
180°
90 Knots
80 Knots
70 Knots
60 Knots
50 Knots
40 Knots
30 Knots
20 Knots
10 Knots
Shear vector
at 2 km
2 km
1 km
SFC
3 km
90°
270°
0°



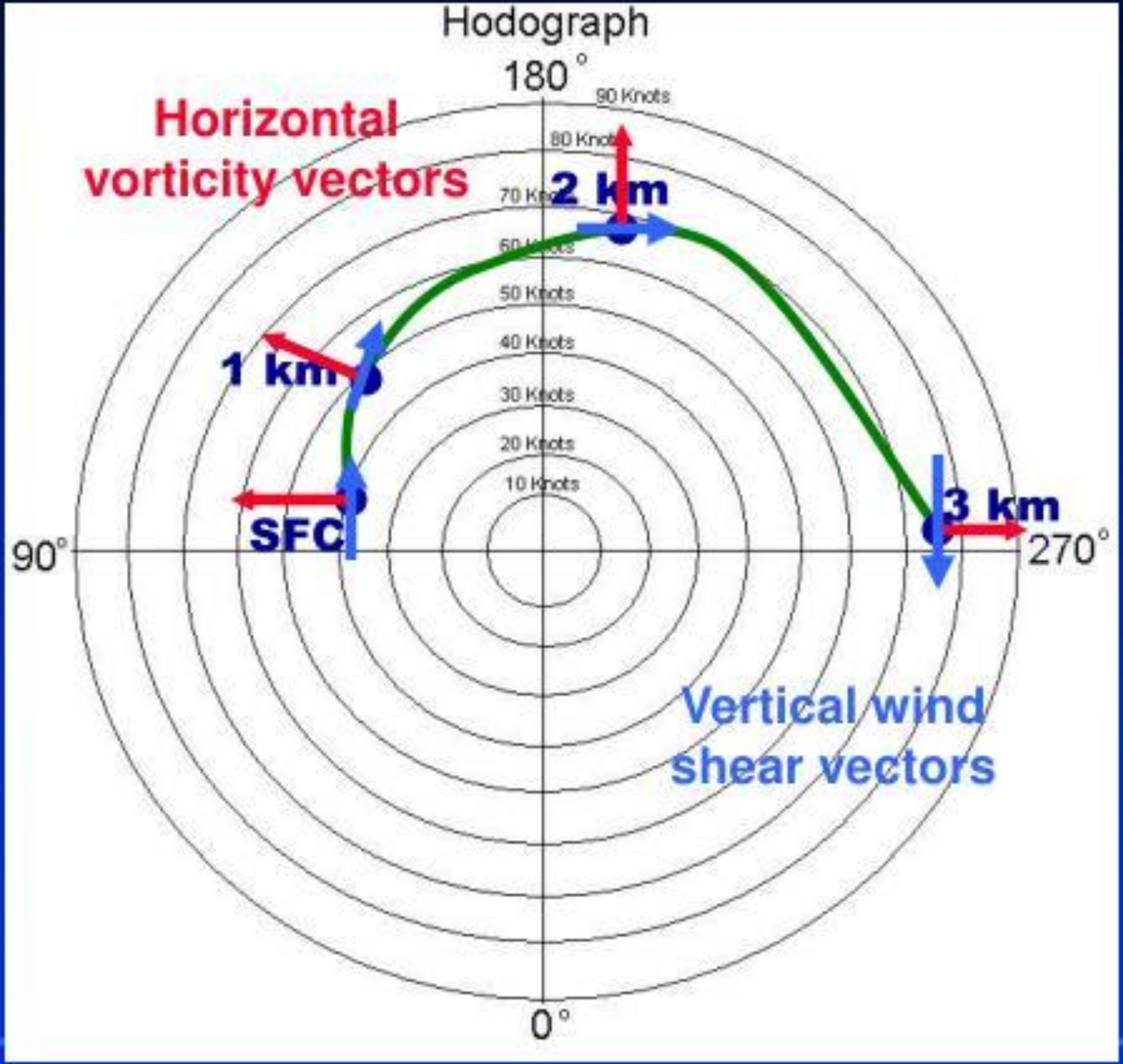
Hodograph
180°
90 Knots
80 Knots
70 Knots
60 Knots
50 Knots
30 Knots
20 Knots
10 Knots
2 km
1 km
SFC
3 km
Shear vector
between
1 and 2 km
90°
270°
0°



Hodograph
180°
90 Knots
80 Knots
70 Knots
60 Knots
50 Knots
40 Knots
30 Knots
20 Knots
10 Knots
2 km
1 km
SFC
3 km
90°
270°
0°
Shear vector
between
sfc and 2 km

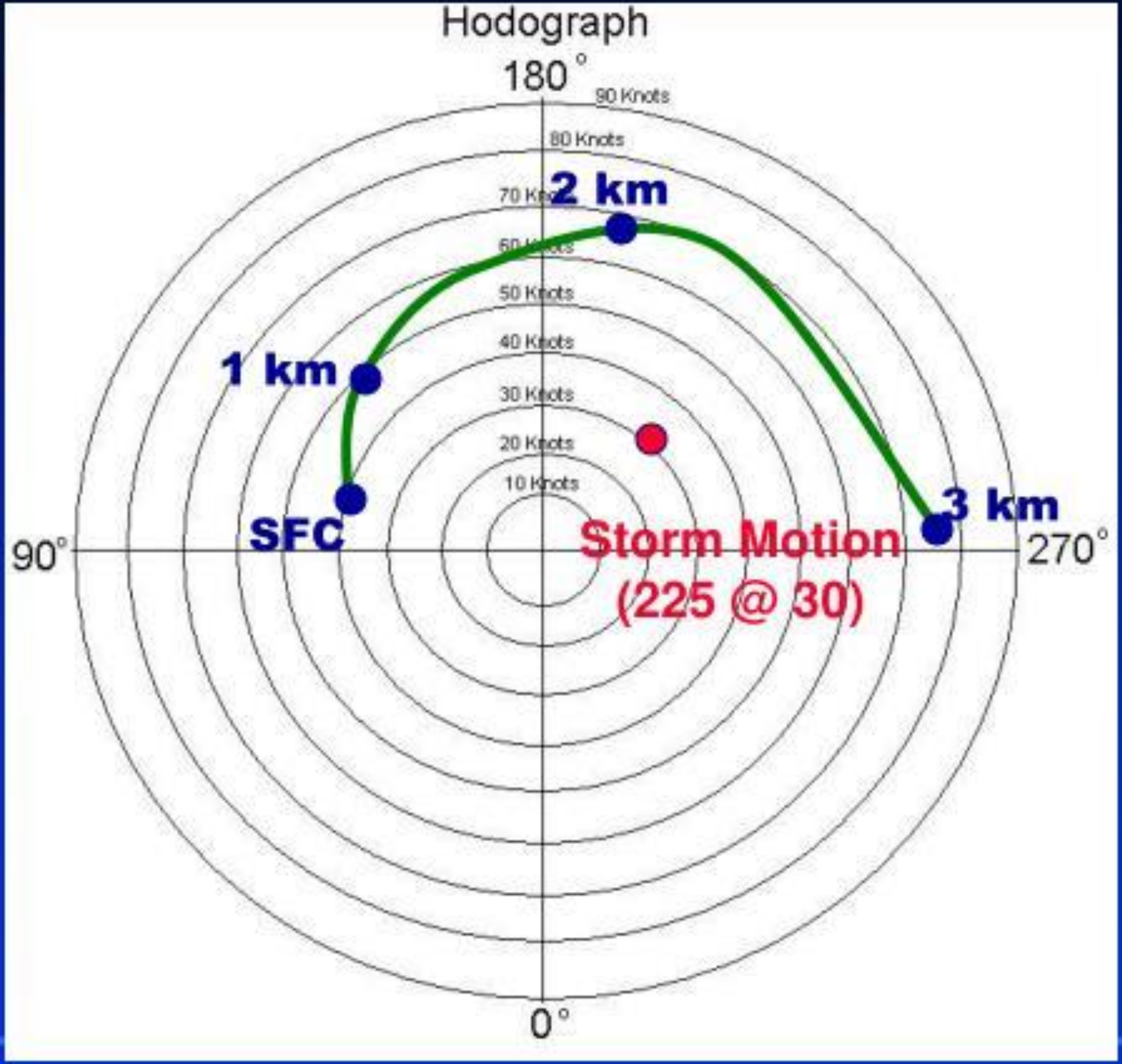
Determining Storm-Relative Winds

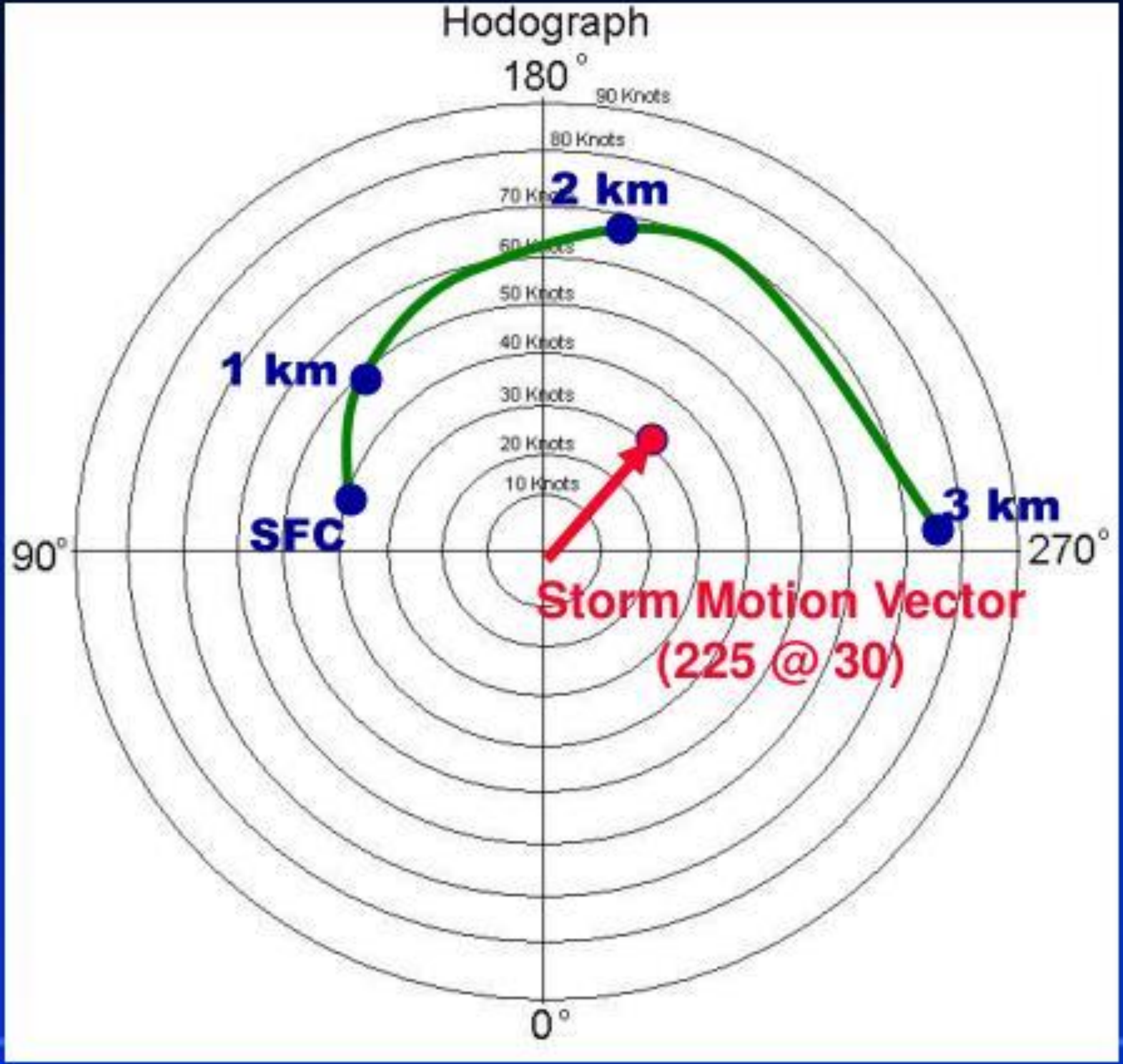
- We can determine the S-R winds on a hodograph very easily given storm motion
- Storm motion is plotted as a single dot


Hodograph
180°
90 Knots
80 Knots
70 Knots
60 Knots
50 Knots
40 Knots
30 Knots
20 Knots
10 Knots
Horizontal vorticity vectors
2 km
1 km
SFC
3 km
90°
270°
0°
Vertical wind shear vectors

Determining Storm-Relative Winds

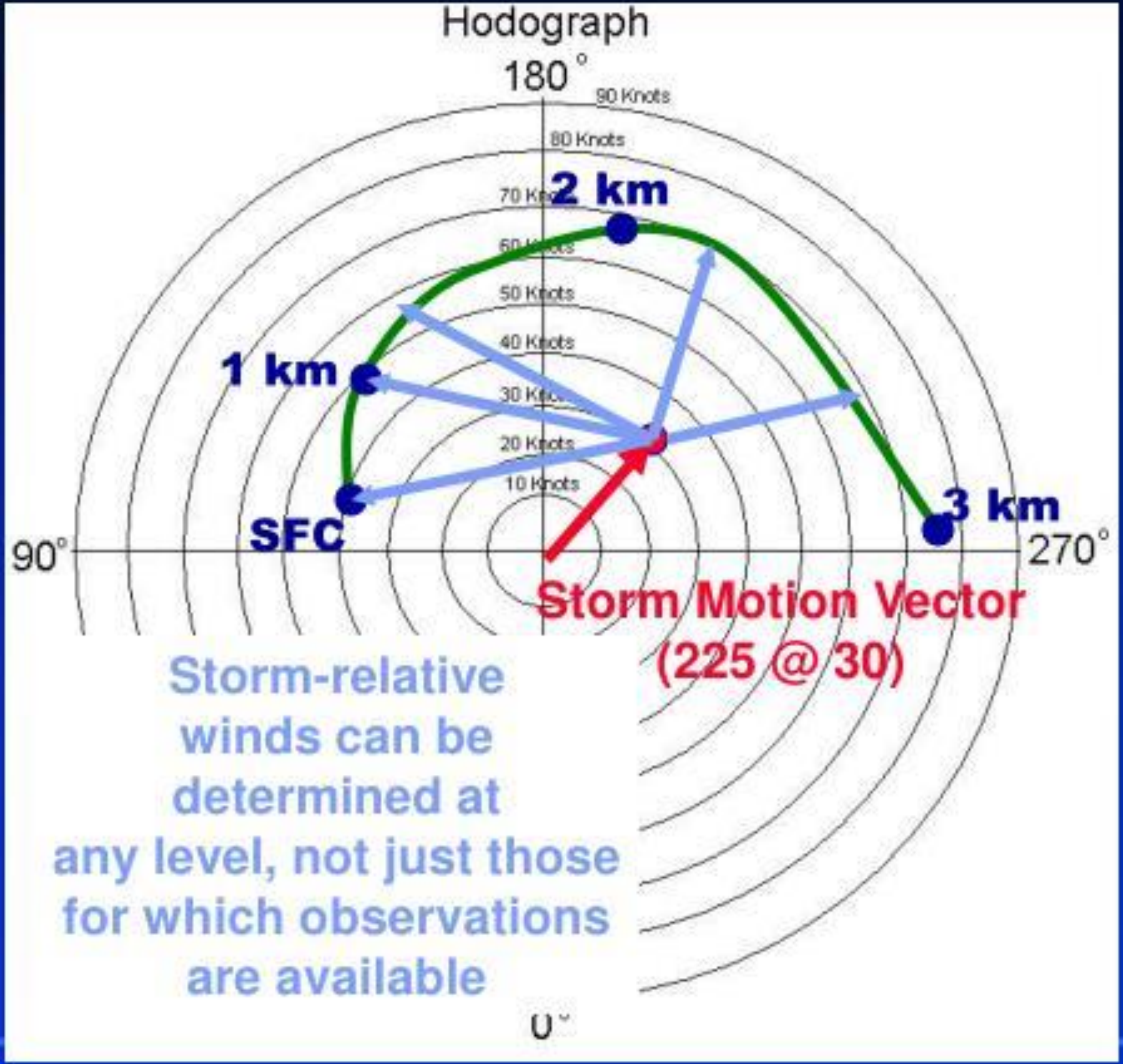
- We can determine the S-R winds on a hodograph very easily given storm motion
- Storm motion is plotted as a single dot


Hodograph
180°
90 Knots
80 Knots
70 Knots
60 Knots
50 Knots
40 Knots
30 Knots
20 Knots
10 Knots
2 km
1 km
SFC
3 km
Storm Motion
(225 @ 30)
90°
270°
0°


Hodograph
180°
90 Knots
80 Knots
70 Knots
60 Knots
50 Knots
40 Knots
30 Knots
20 Knots
10 Knots
2 km
1 km
SFC
3 km
90°
270°
0°
Storm Motion Vector
(225 @ 30)

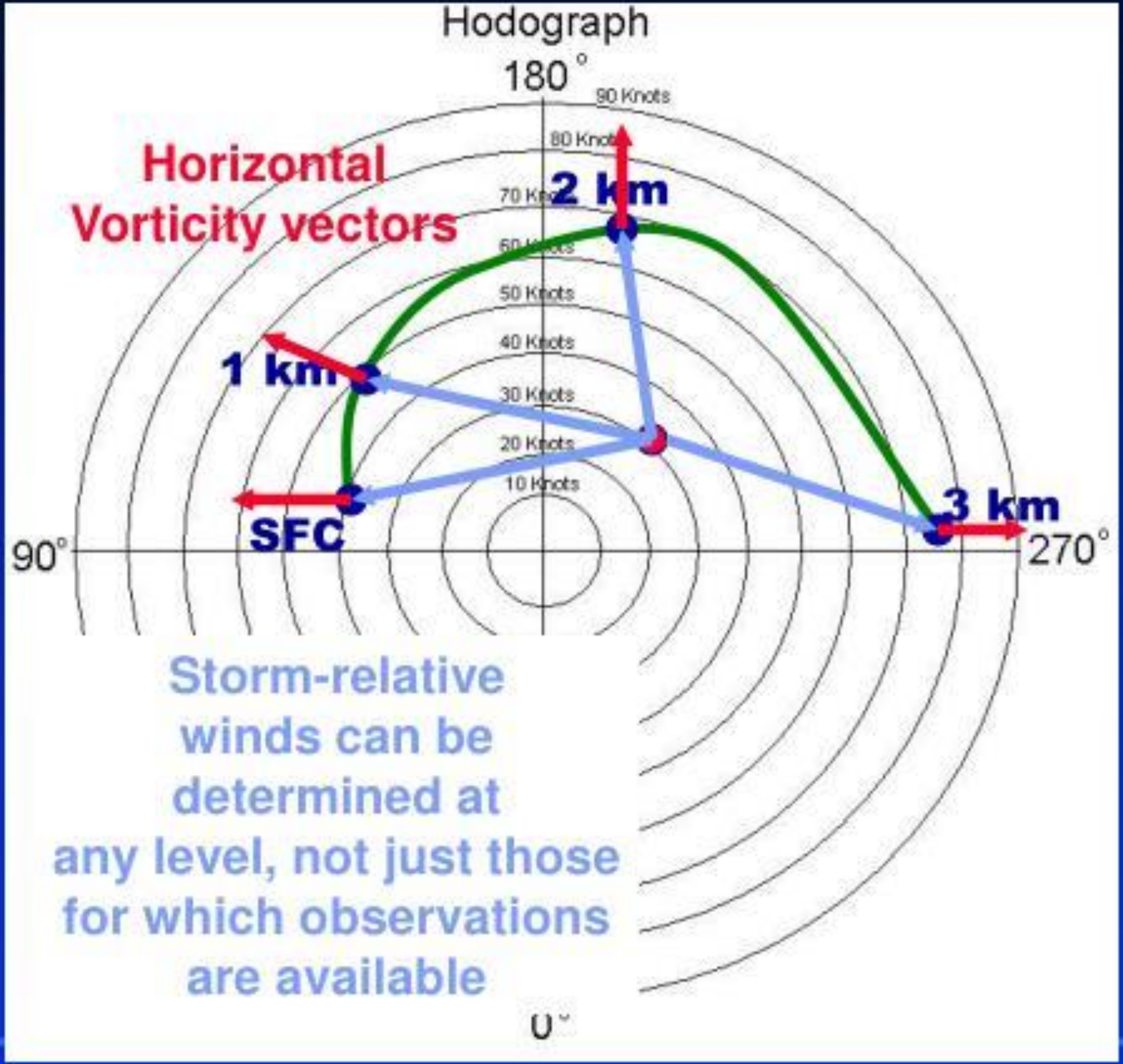
Determining Storm-Relative Winds

- We can determine the S-R winds on a hodograph very easily given storm motion
- Storm motion is plotted as a single dot
- The S-R wind is found easily by drawing vectors back to the hodograph from the tip of the storm motion vector


Hodograph
180°
90 Knots
80 Knots
70 Knots
2 km
60 Knots
50 Knots
40 Knots
1 km
30 Knots
20 Knots
10 Knots
SFC
3 km
90°
270°
Storm Motion Vector
(225 @ 30)
Storm-relative
winds can be
determined at
any level, not just those
for which observations
are available
0°

Use of Storm-Relative Winds

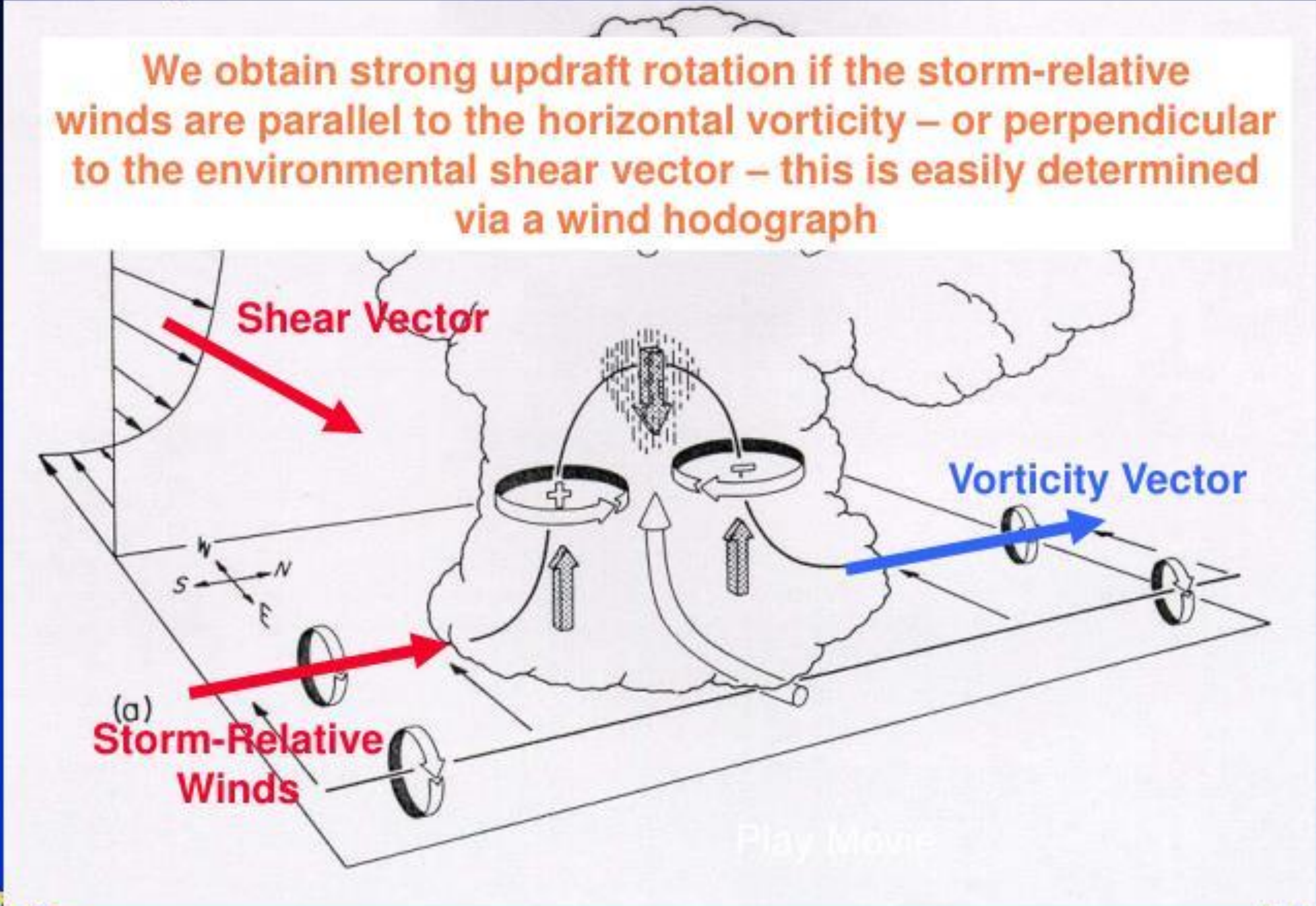
- Why do we care about the S-R winds?
- Remember, only the S-R winds are relevant to storm dynamics
- In the case of supercell updraft rotation, we want to see an alignment between the S-R winds and the horizontal vorticity vector
- This is easily determined on a hodograph



Storm-relative winds can be determined at any level, not just those for which observations are available

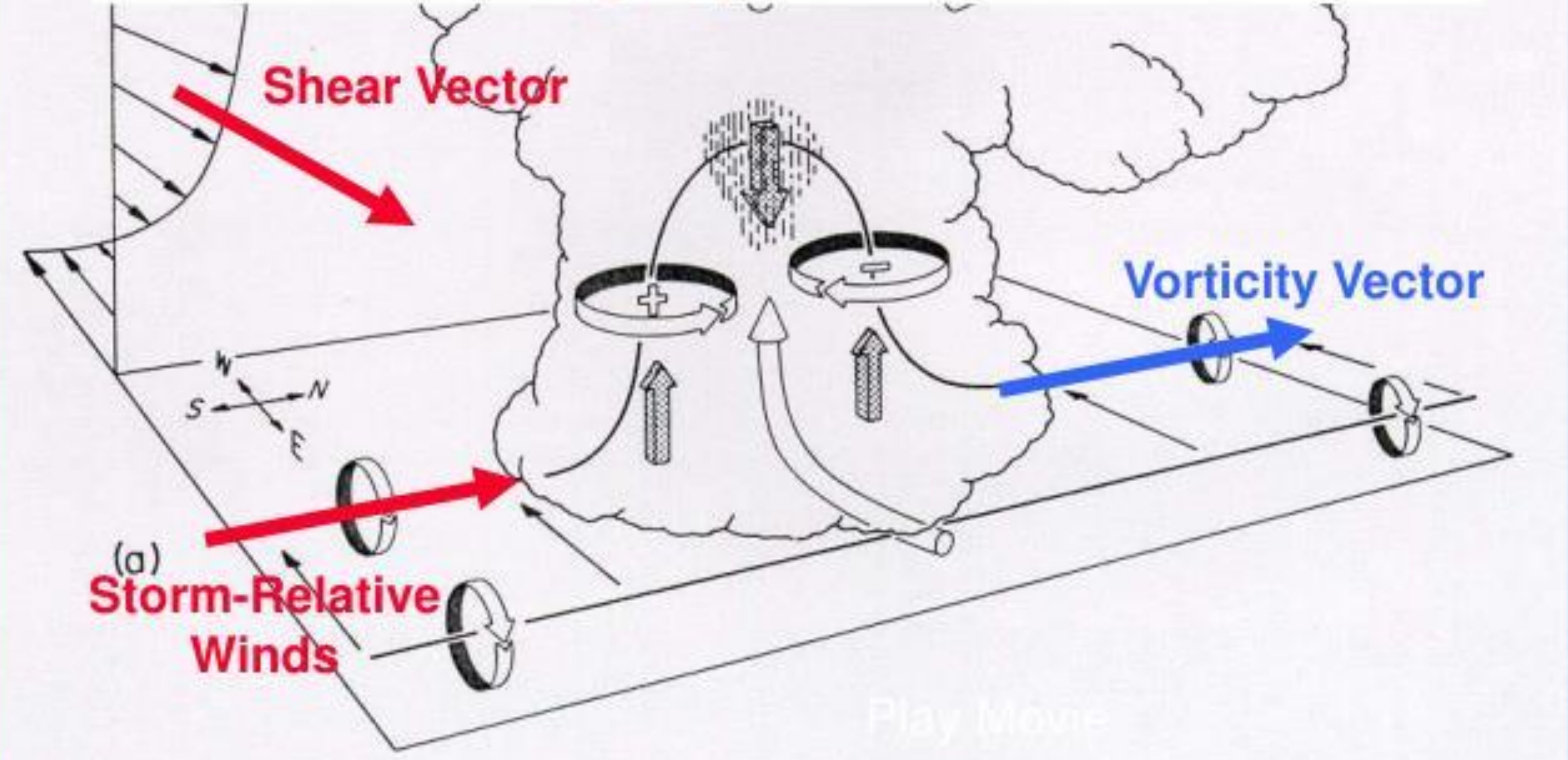
Importance of Storm-Relative Winds

We obtain strong updraft rotation if the storm-relative winds are parallel to the horizontal vorticity – or perpendicular to the environmental shear vector – this is easily determined via a wind hodograph



Importance of Storm-Relative Winds

Note that low pressure exists at the center of each vortex and thus "lifting pressure gradients" cause air to rise from high to low pressure, enhancing the updraft beyond buoyancy effects alone



Estimating the Potential For Updraft Rotation

- Ingredients
  - » Strong storm-relative winds in the low-levels (at least 10 m/s)
  - » Strong turning of the wind shear vector with height (90 degrees between the surface and 3 km)
  - » Strong alignment of the S-R winds and the horizontal vorticity – to develop rotating updrafts
  - » All of this can be quantified by a single quantity- the Storm-Relative Environmental Helicity

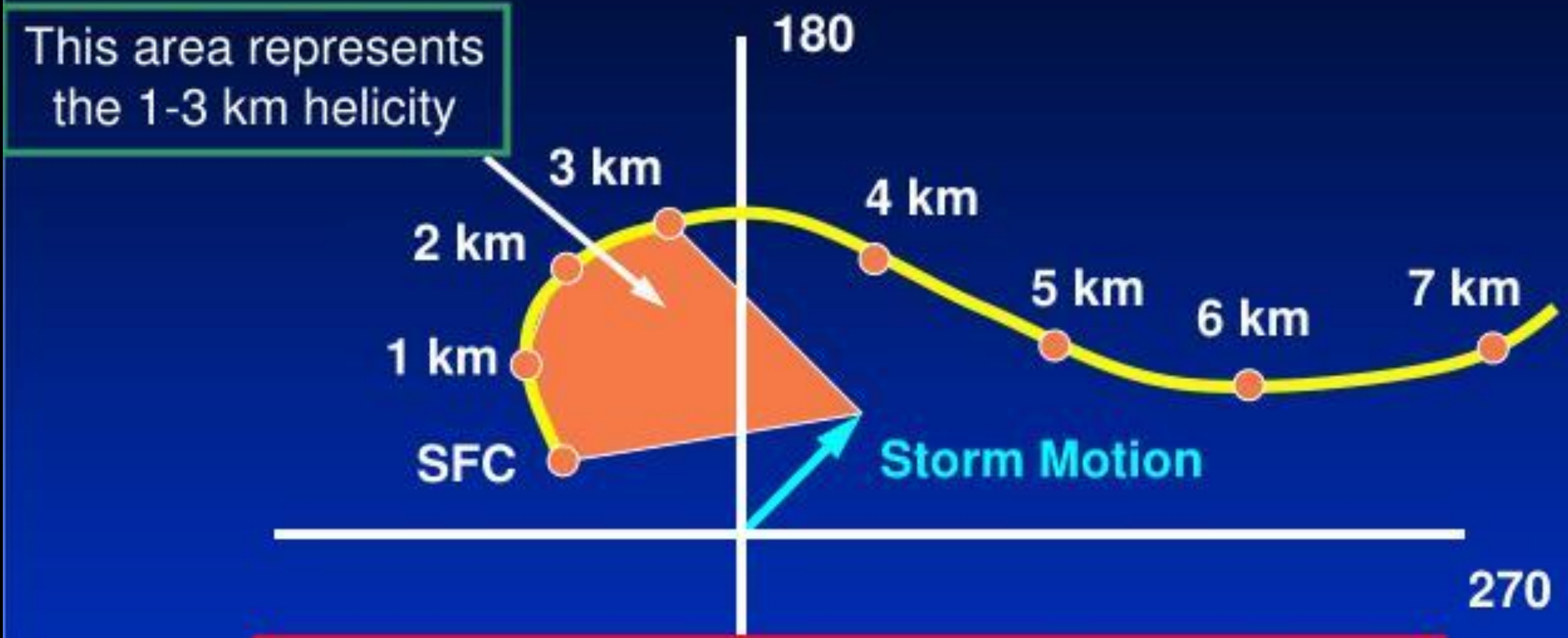
Storm Relative Environmental Helicity

- SREH -- A measure of the potential for a thunderstorm updraft to rotate.
- SREH is typically measured over a depth in the atmosphere:
  - 1 to 3 km
  - 0 to 4 km
- A good helicity estimate depends on accurate winds and storm motion data

Storm Relative Environmental Helicity

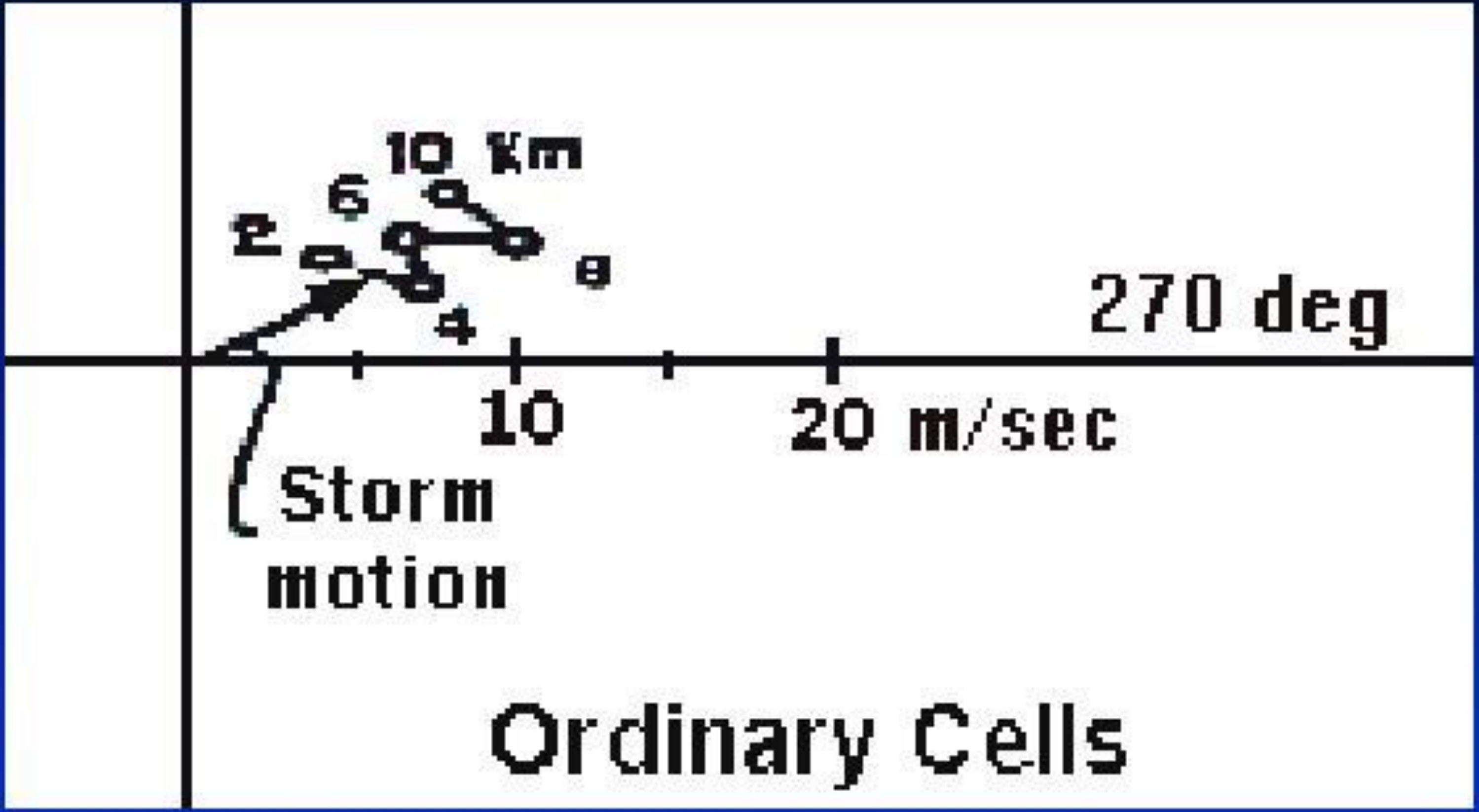
- SREH is the area swept out by the S-R winds between the surface and 3 km
- It includes all of the key ingredients mentioned earlier
- It is graphically easy to determine

Storm Relative Helicity



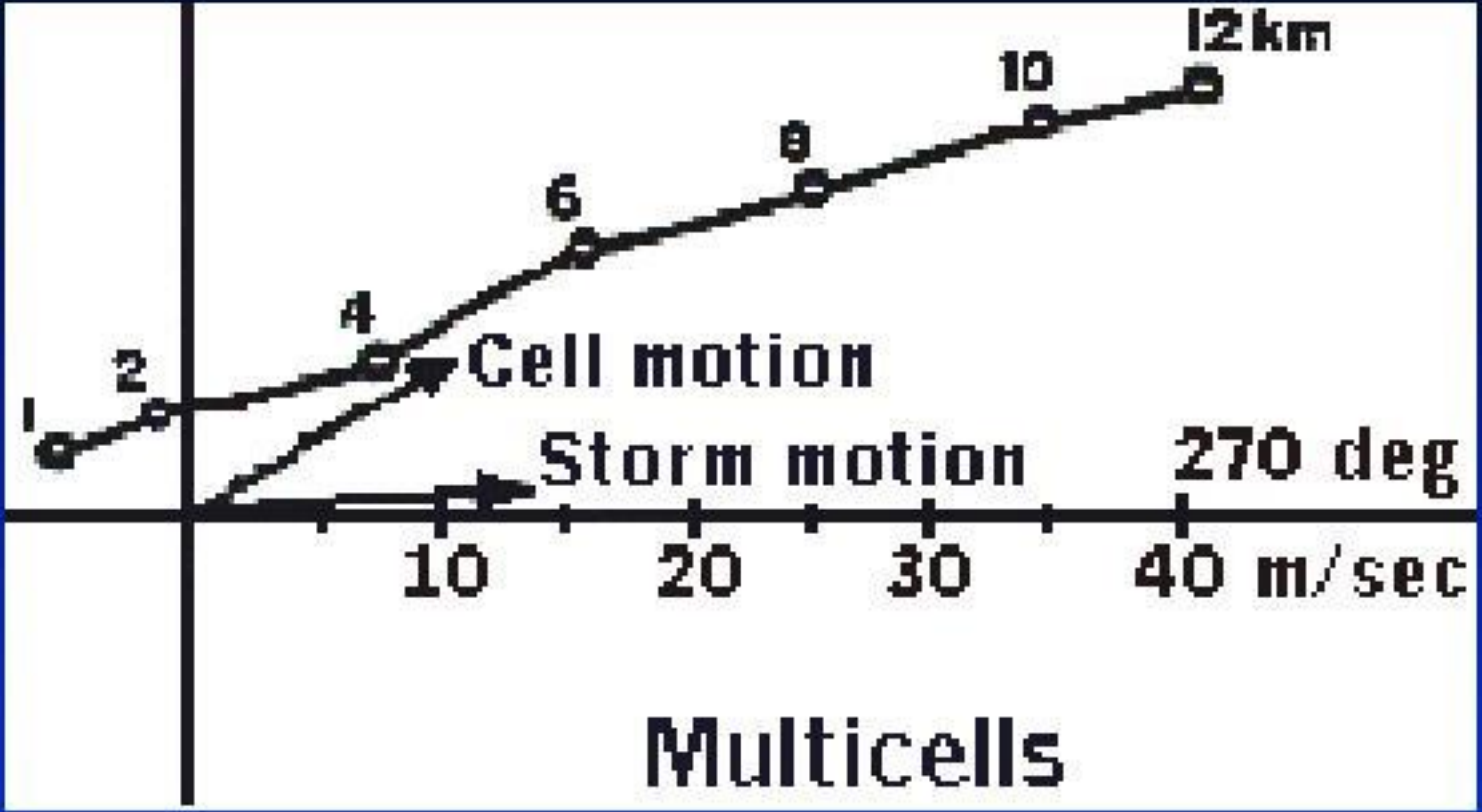
SREH	Potential Tornado Strength
150 - 300 $m^2 s^{-2}$	Weak
300 - 500 $m^2 s^{-2}$	Strong
> 450 $m^2 s^{-2}$	Violent

Typical Single-Cell Hodograph



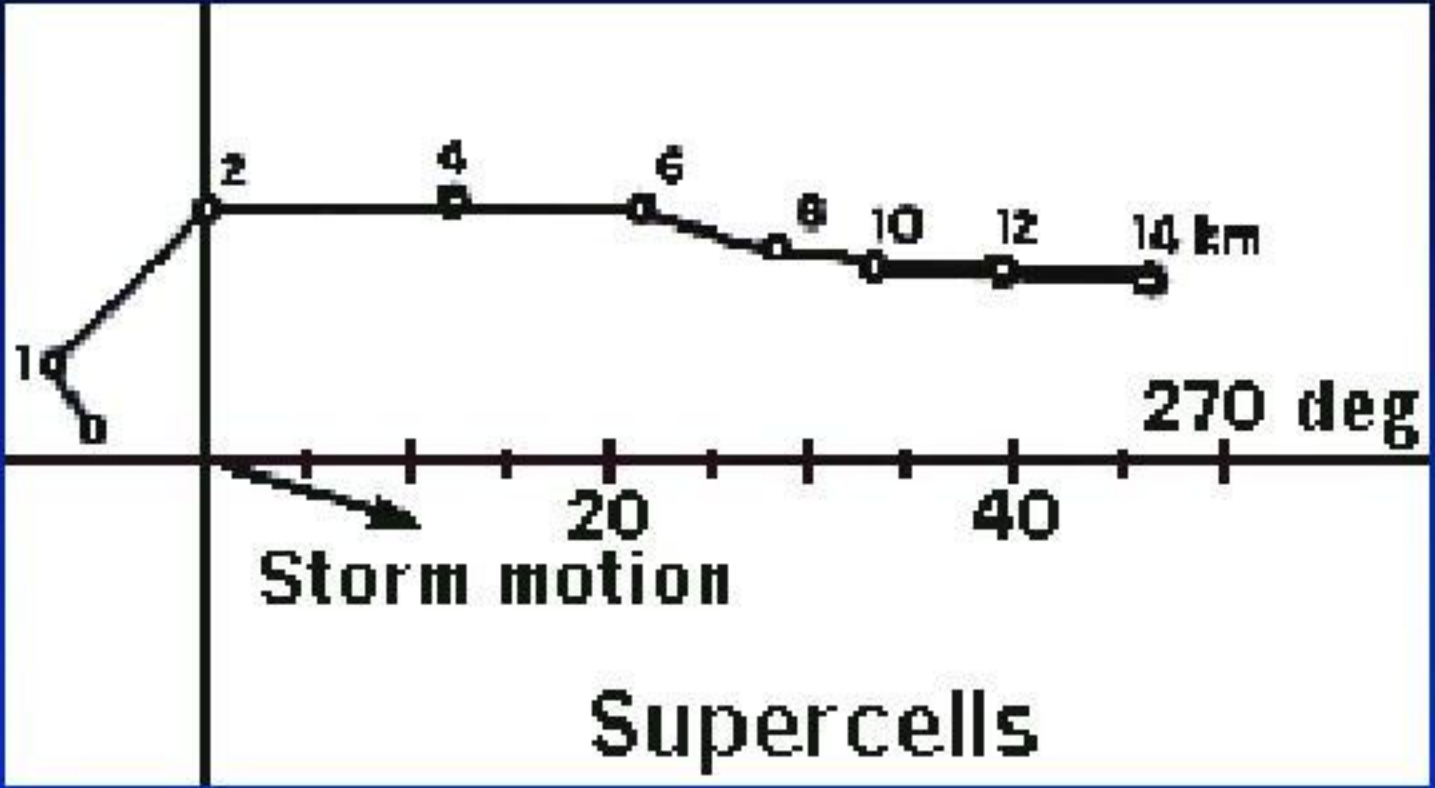
- Weak shear, weak winds

Typical Multicell Hodograph



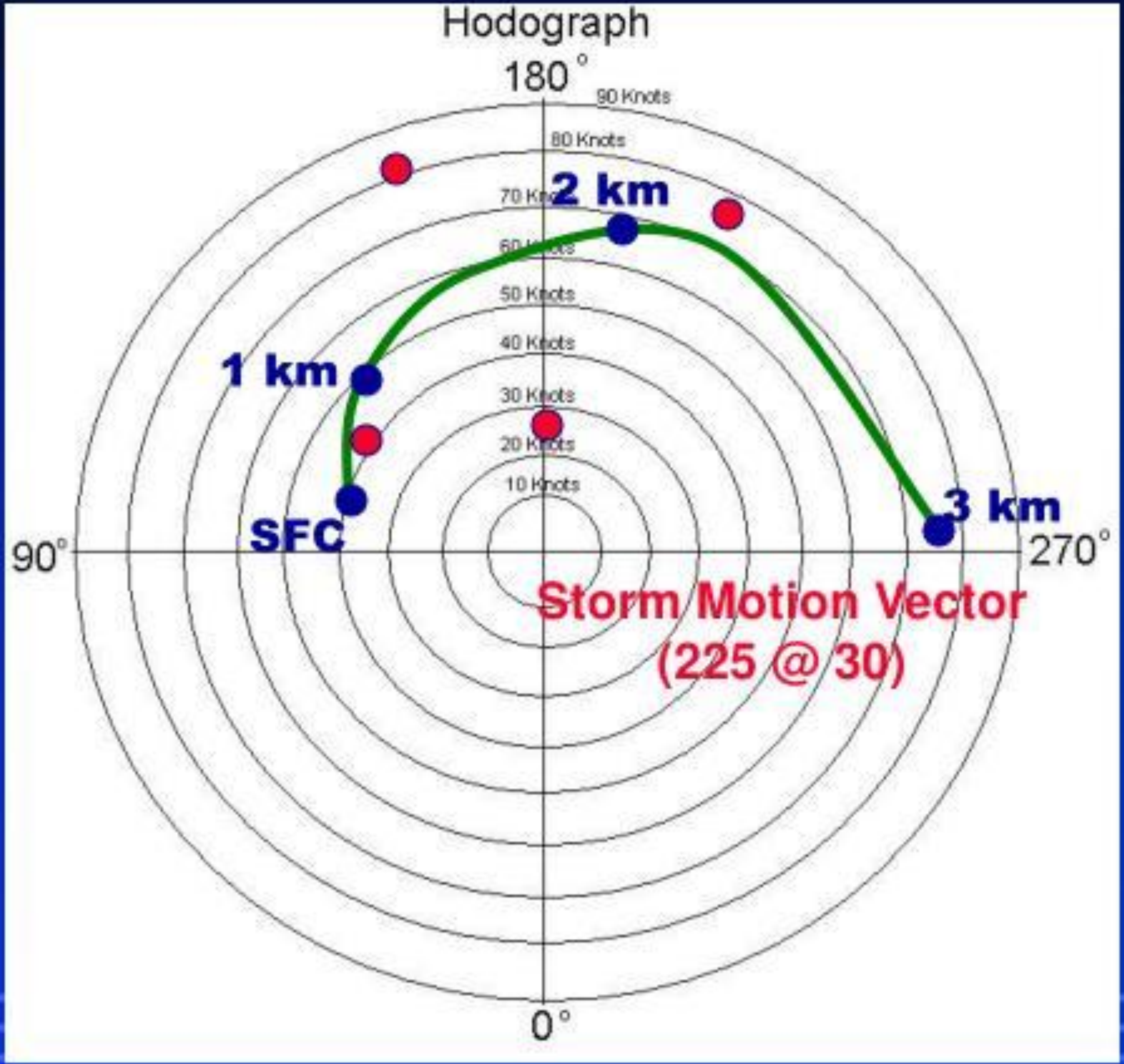
- Somewhat stronger winds and shear, with S-R winds providing mechanism
- Hodograph is essentially straight, especially at low levels

Typical Supercell Hodograph



- Strong wind, shear vector turns with height, strong S-R winds
- Note curved shape of hodograph at low levels

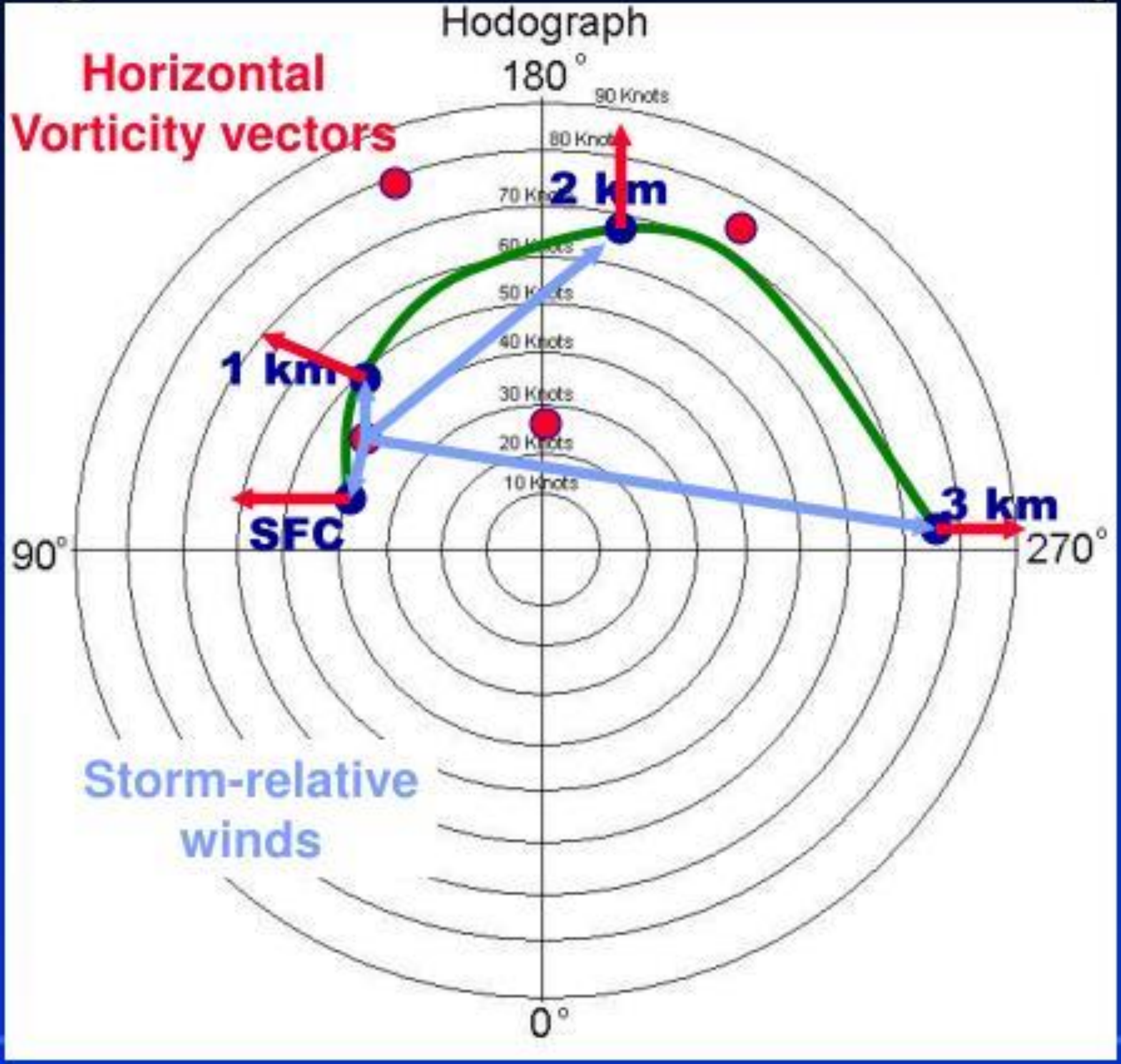
Which Storm Motion Produces a Strong, Cyclonically-Rotating Supercell?



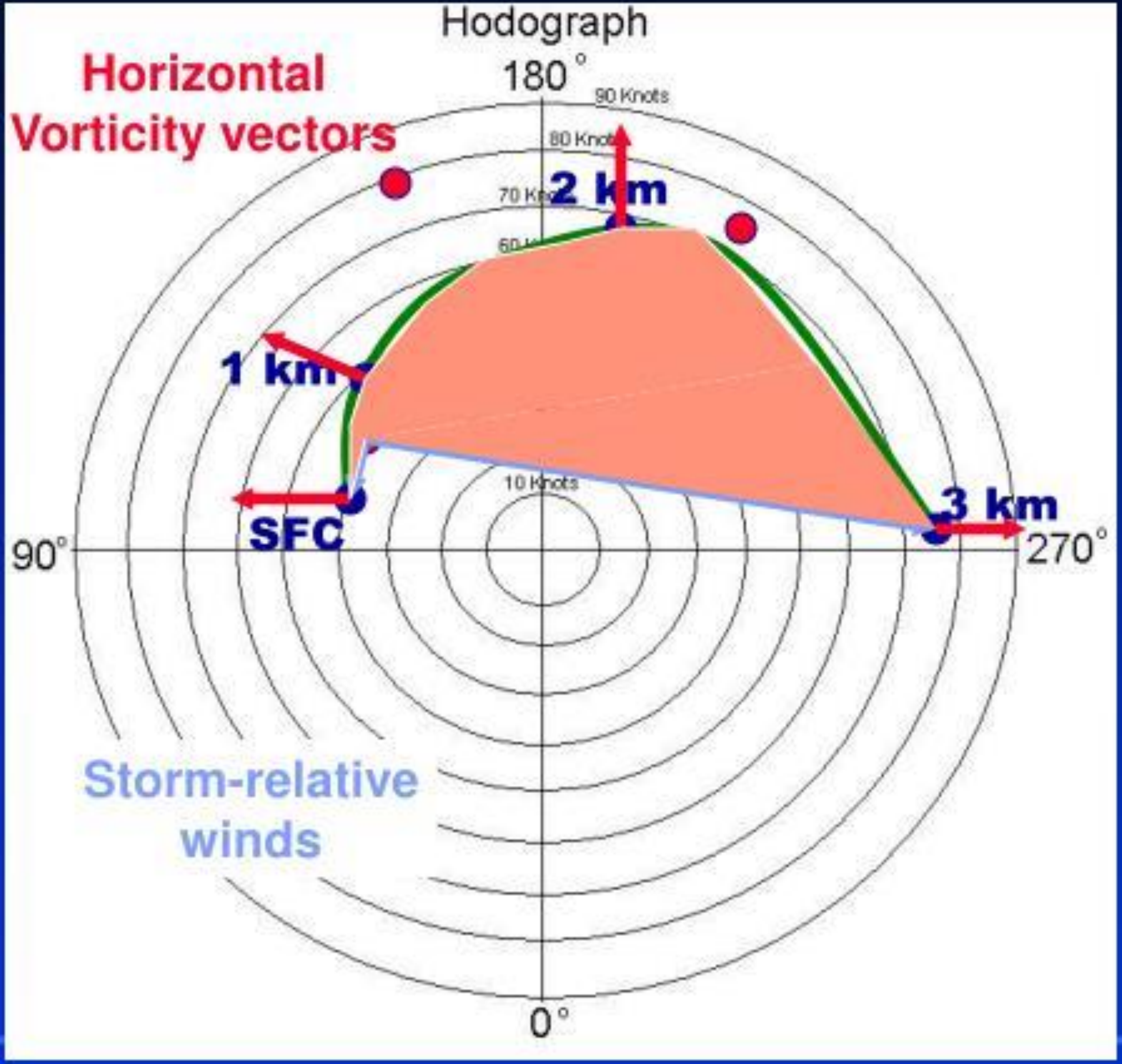
Estimating the Potential For Updraft Rotation

- Ingredients
  - » Strong storm-relative winds in the low-levels (at least 10 m/s)
  - » Strong turning of the wind shear vector with height (90 degrees between the surface and 3 km)
  - » Strong alignment of the S-R winds and the horizontal vorticity – to develop rotating updrafts

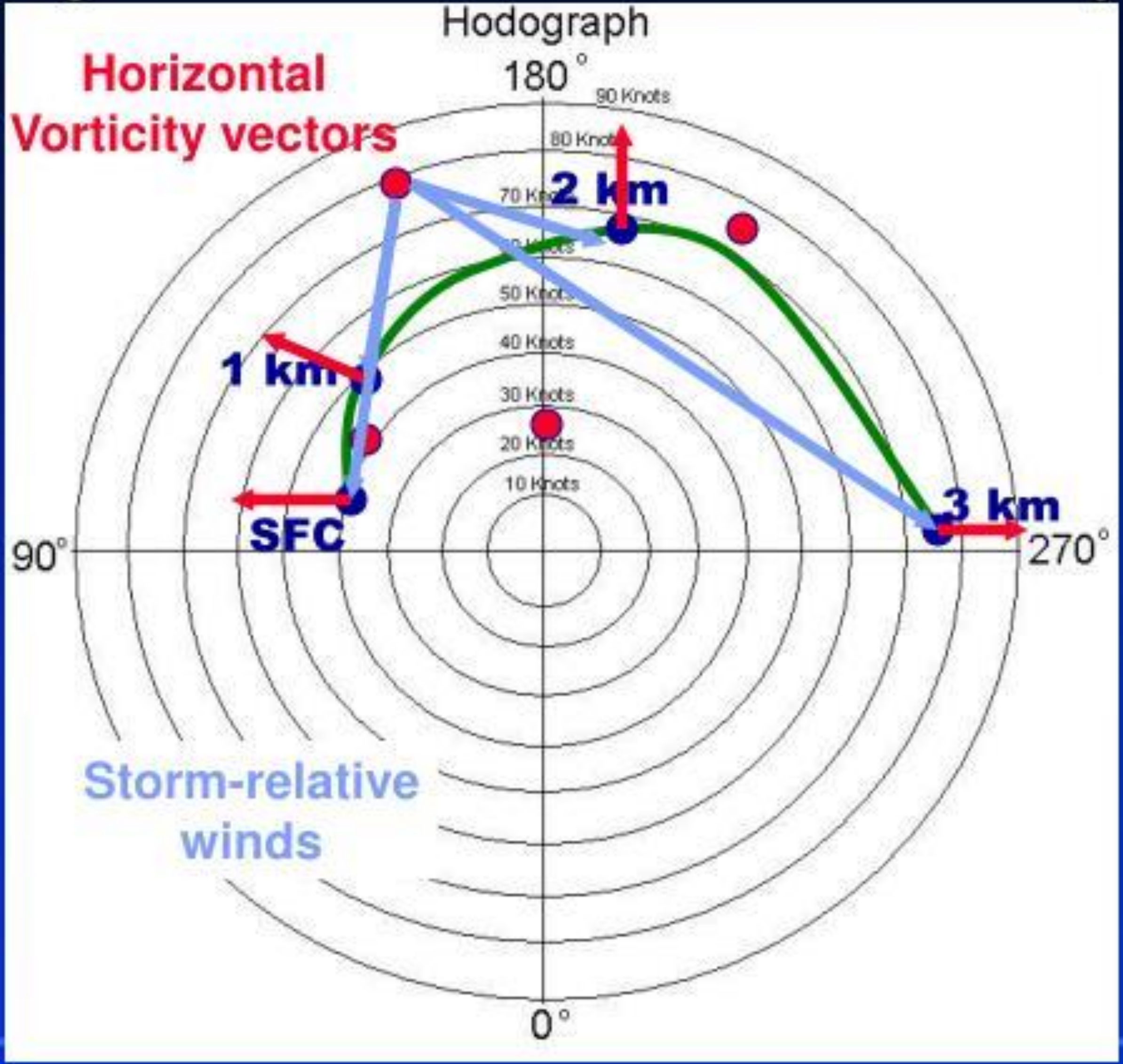
Speed of S-R Winds
Alignment of S-R Winds and Vorticity



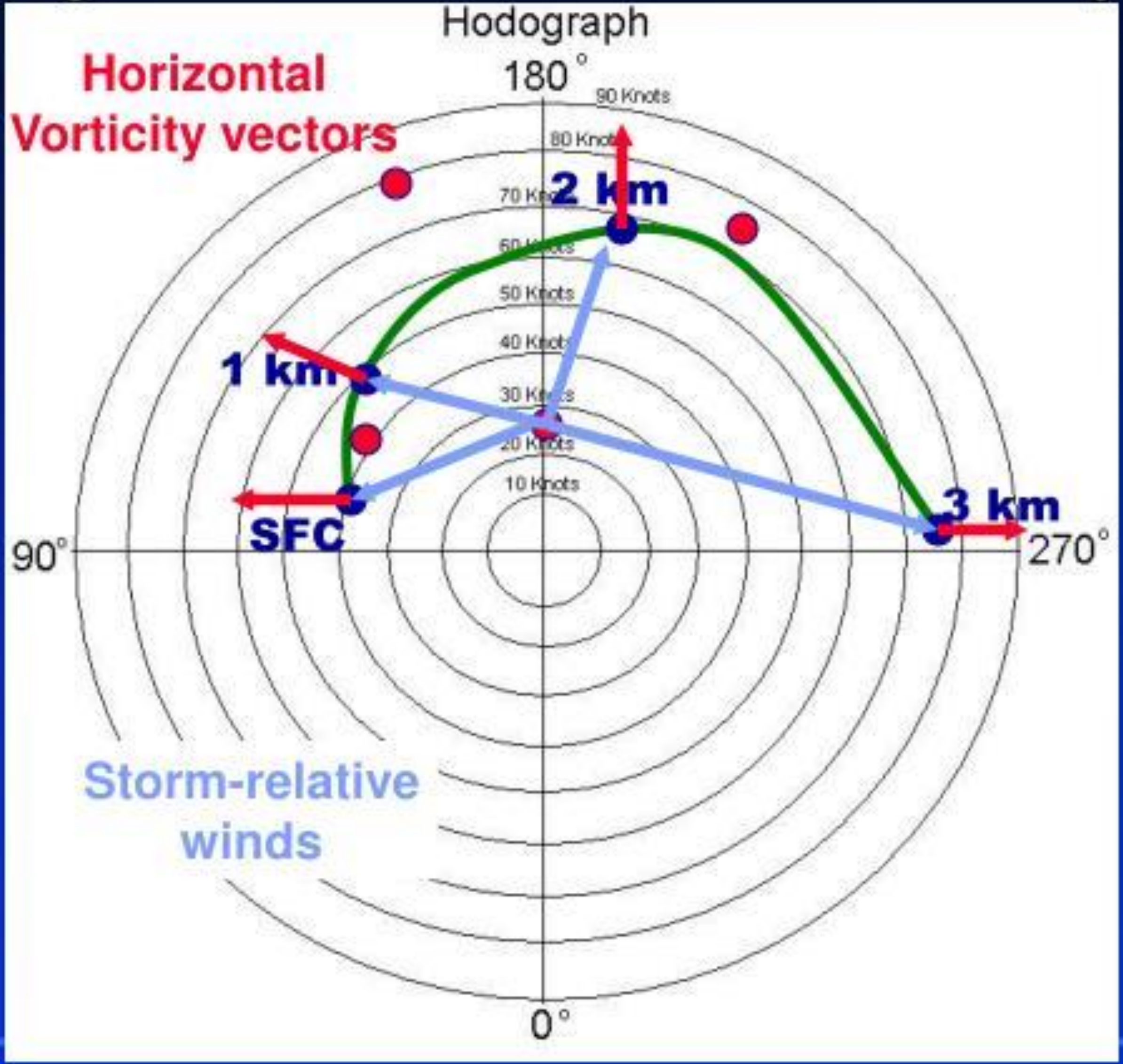
Storm-Relative Environmental Helicity



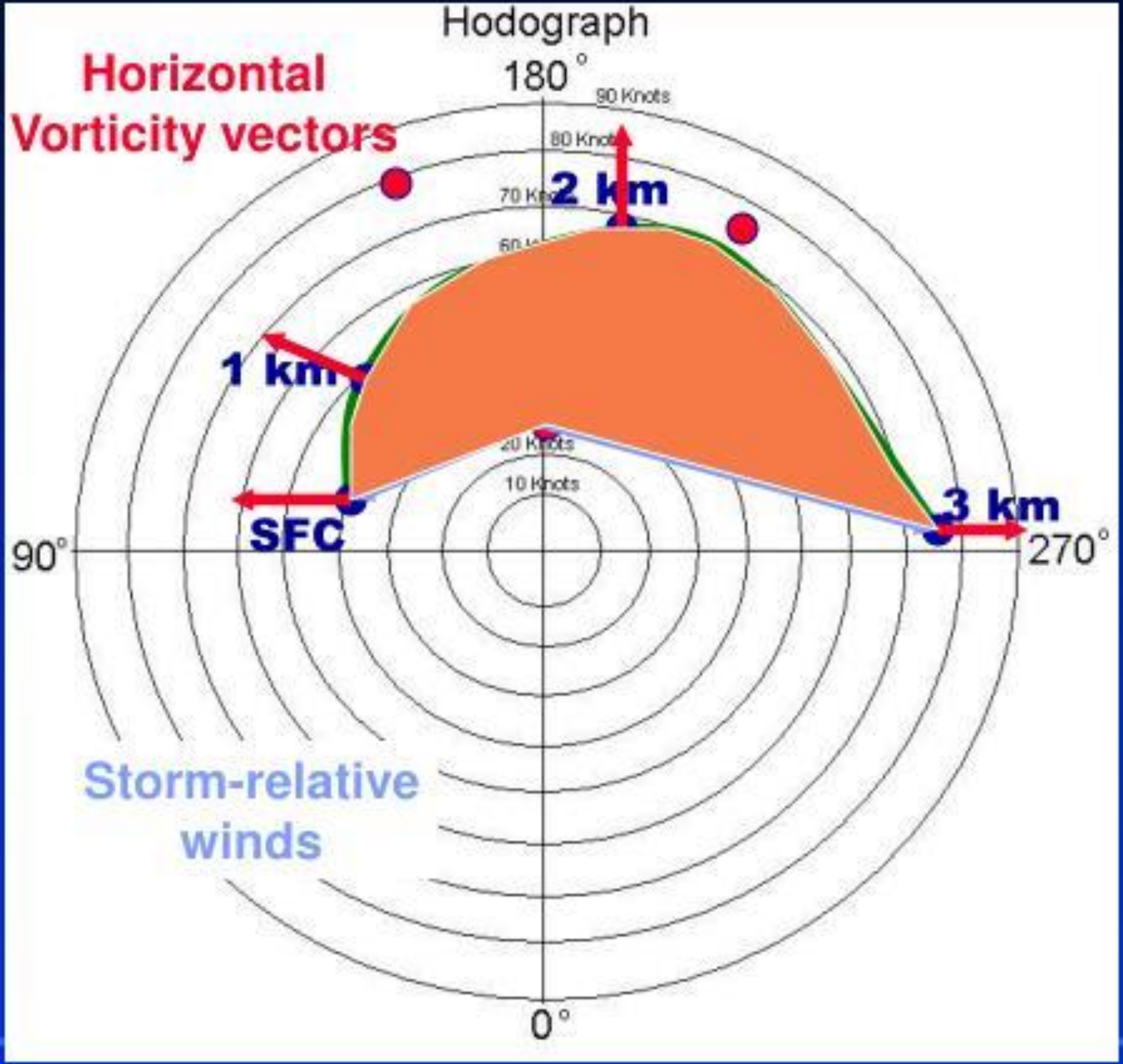
Speed of S-R Winds
Alignment of S-R Winds and Vorticity



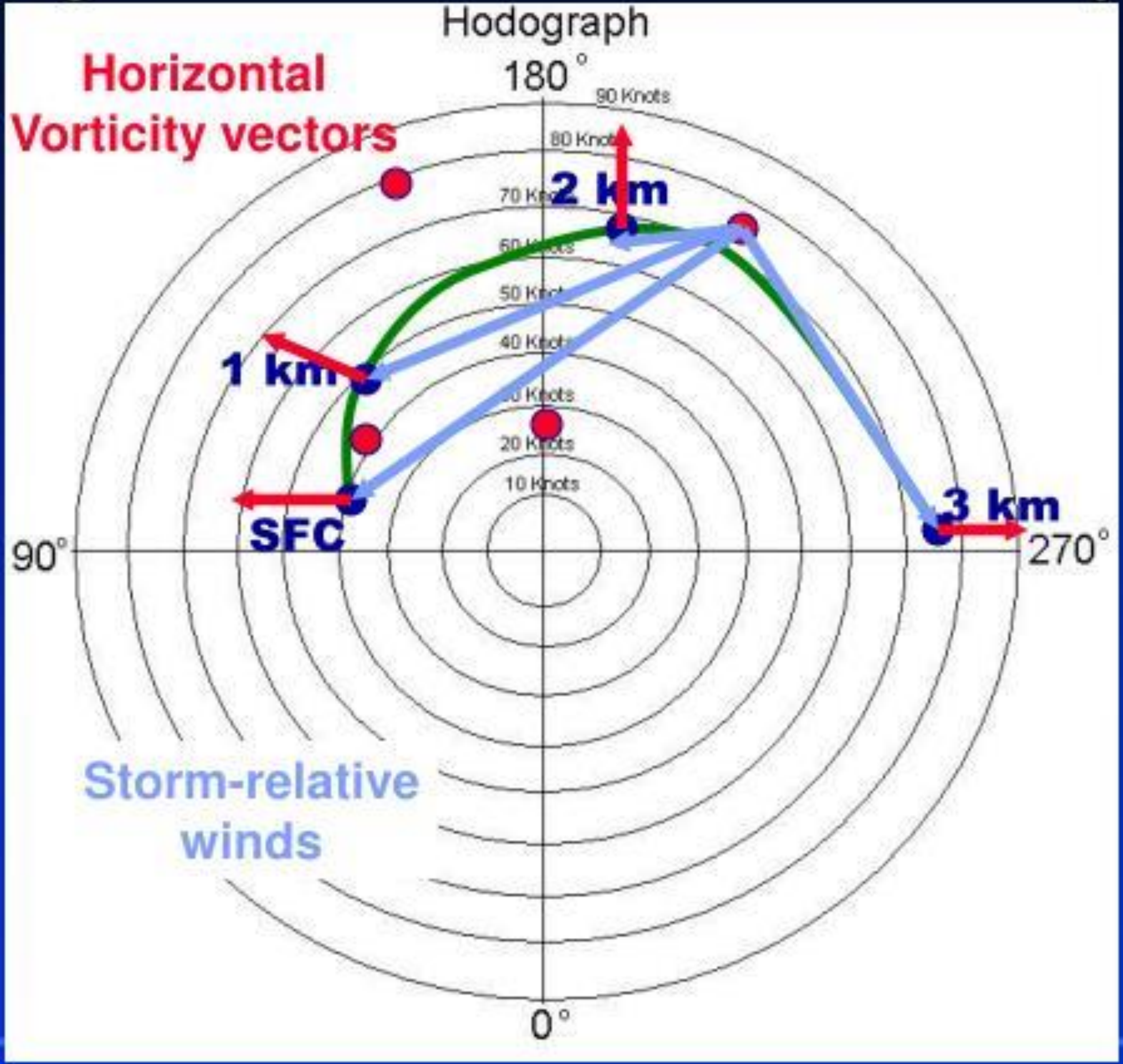
Speed of S-R Winds
Alignment of S-R Winds and Vorticity



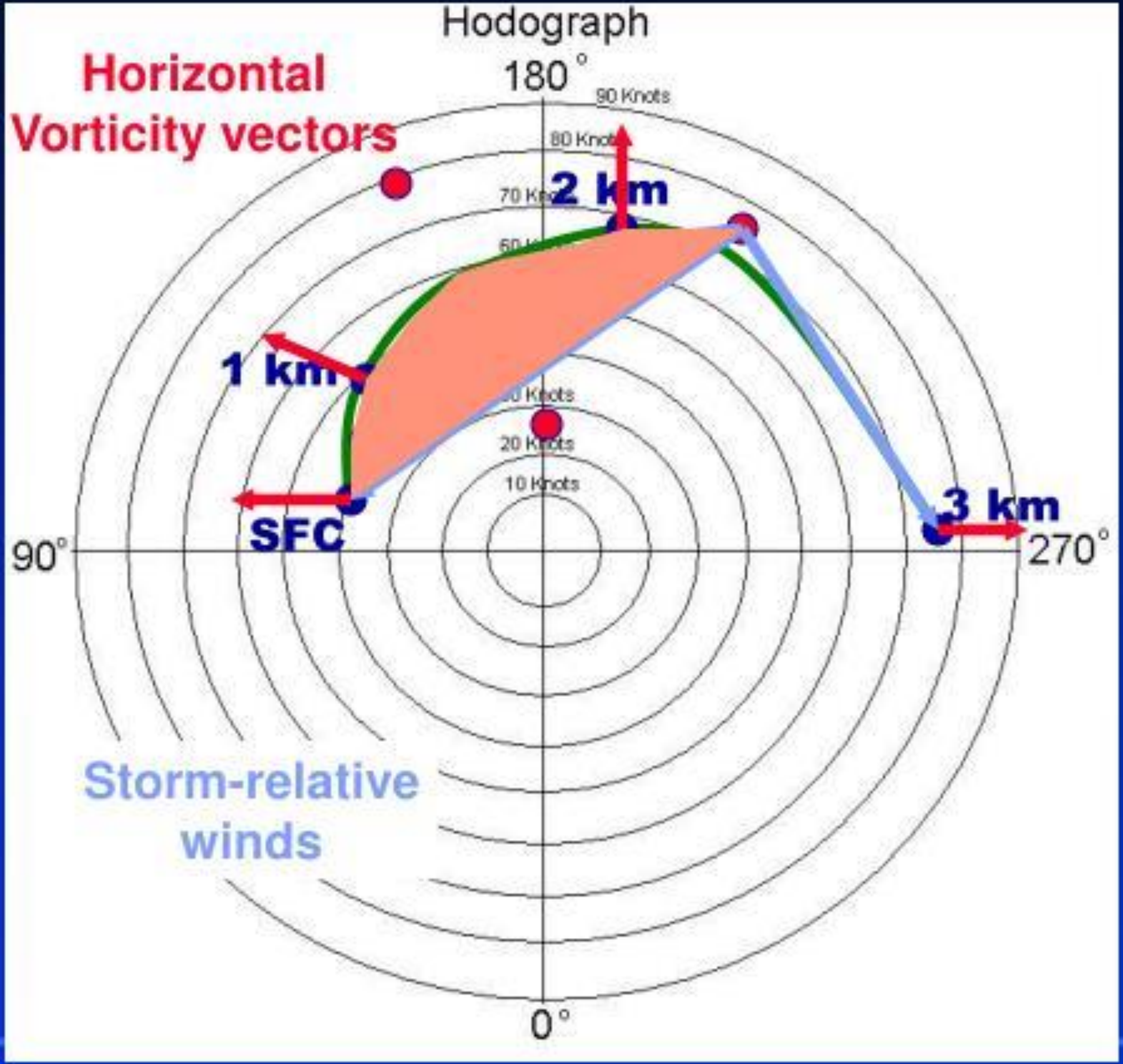
Storm-Relative Environmental Helicity



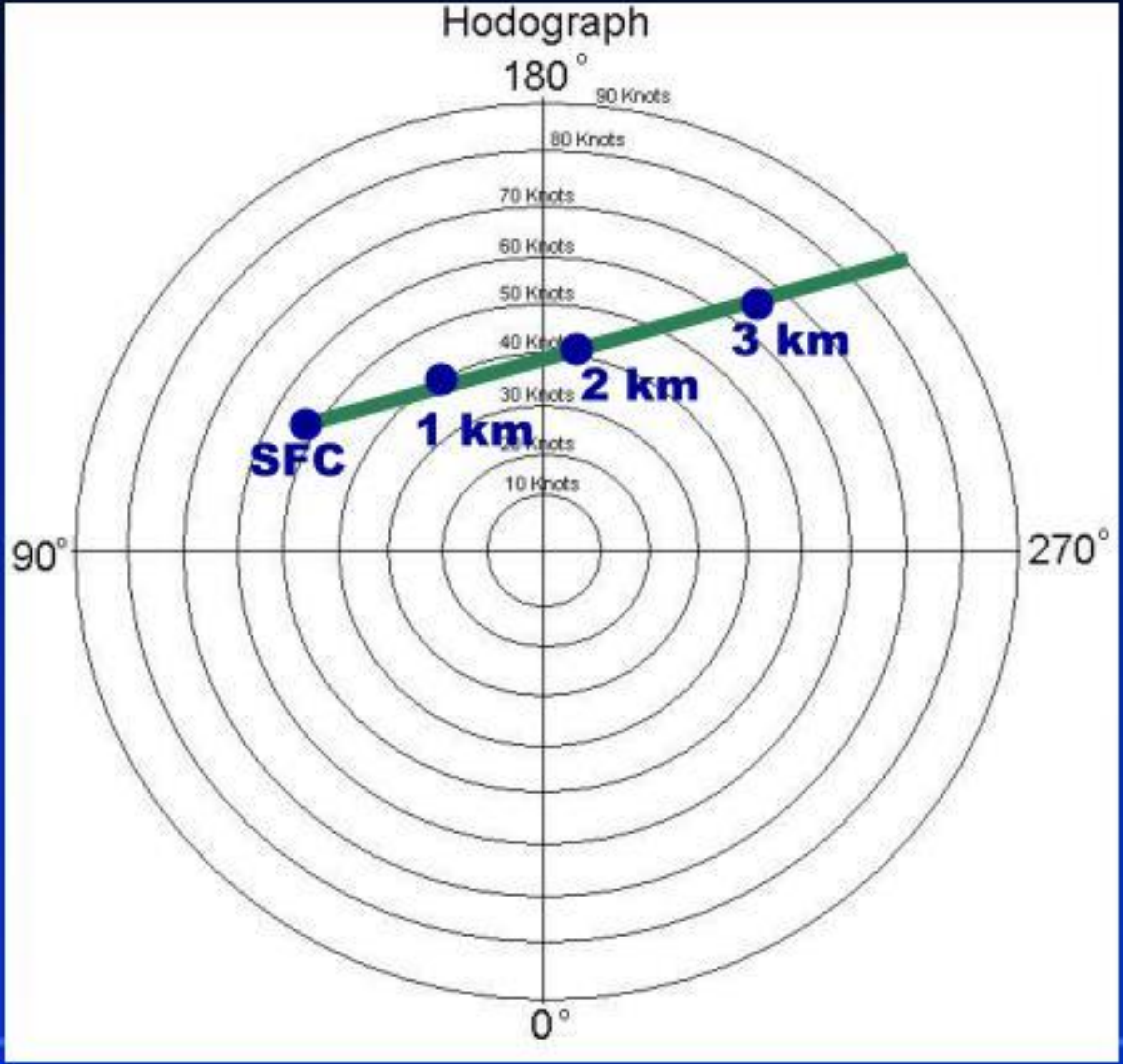
Speed of S-R Winds
Alignment of S-R Winds and Vorticity



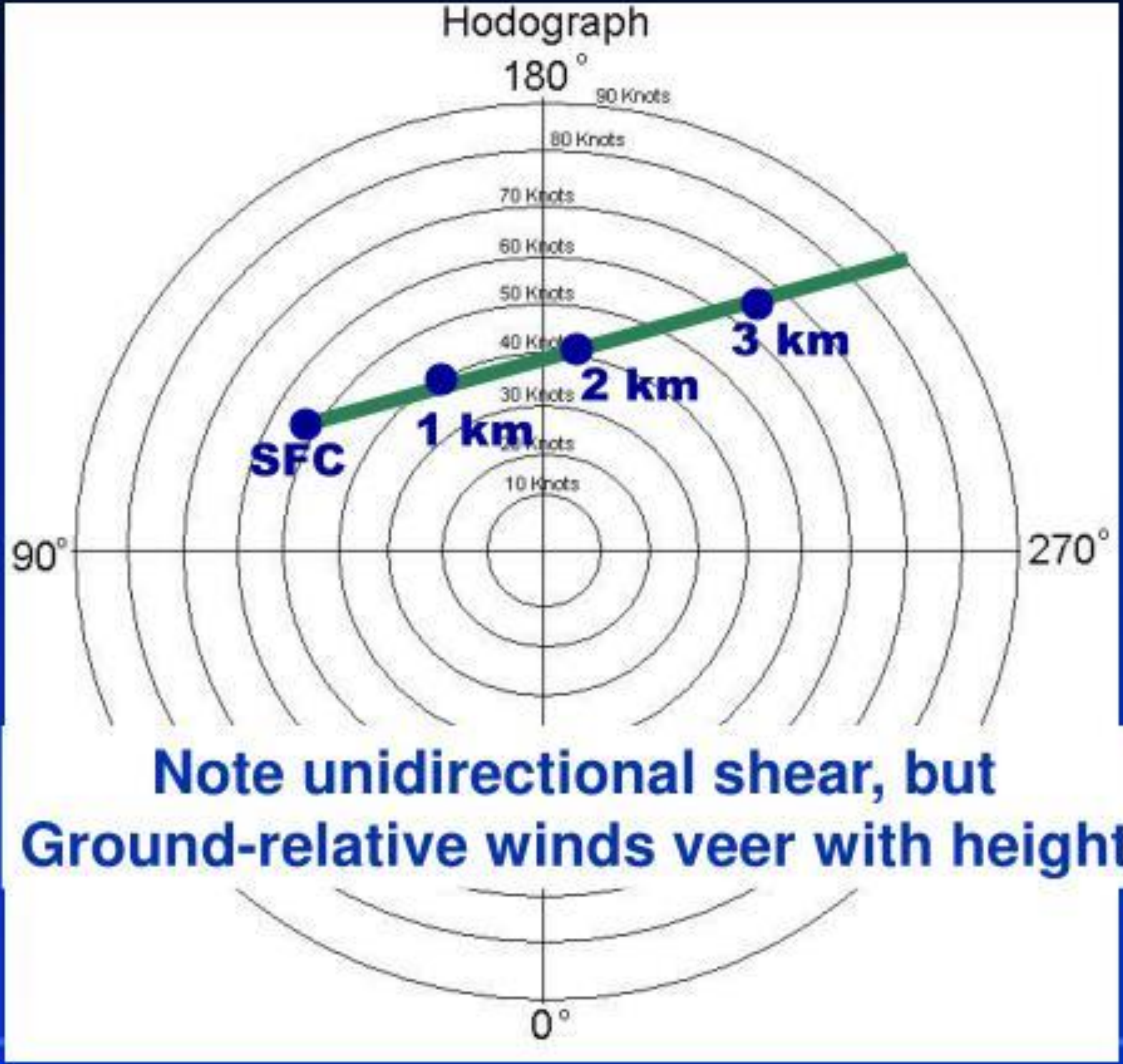
Storm-Relative Environmental Helicity



Making an Optimal Hodograph

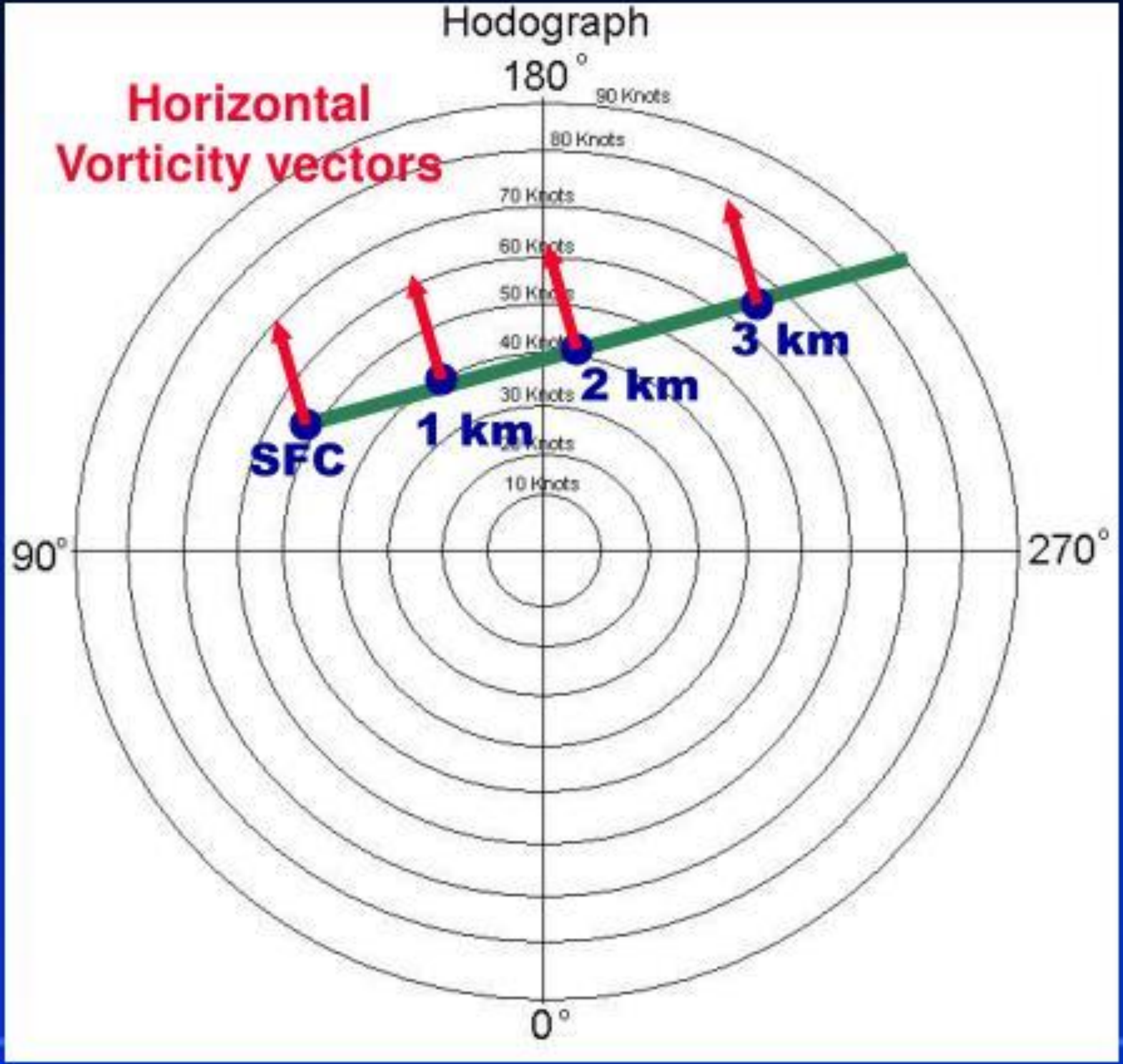


Making an Optimal Hodograph

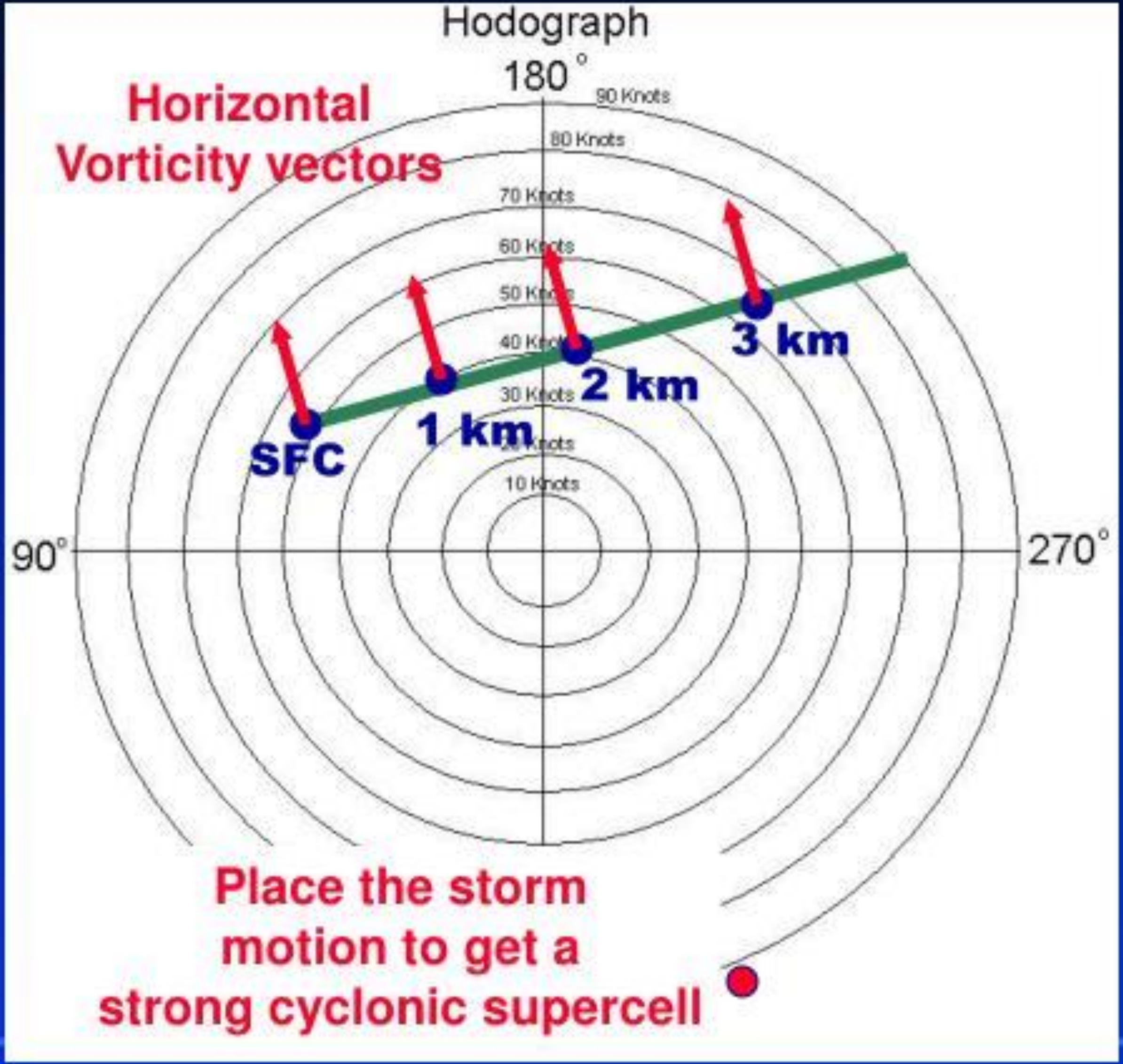


Note unidirectional shear, but Ground-relative winds veer with height

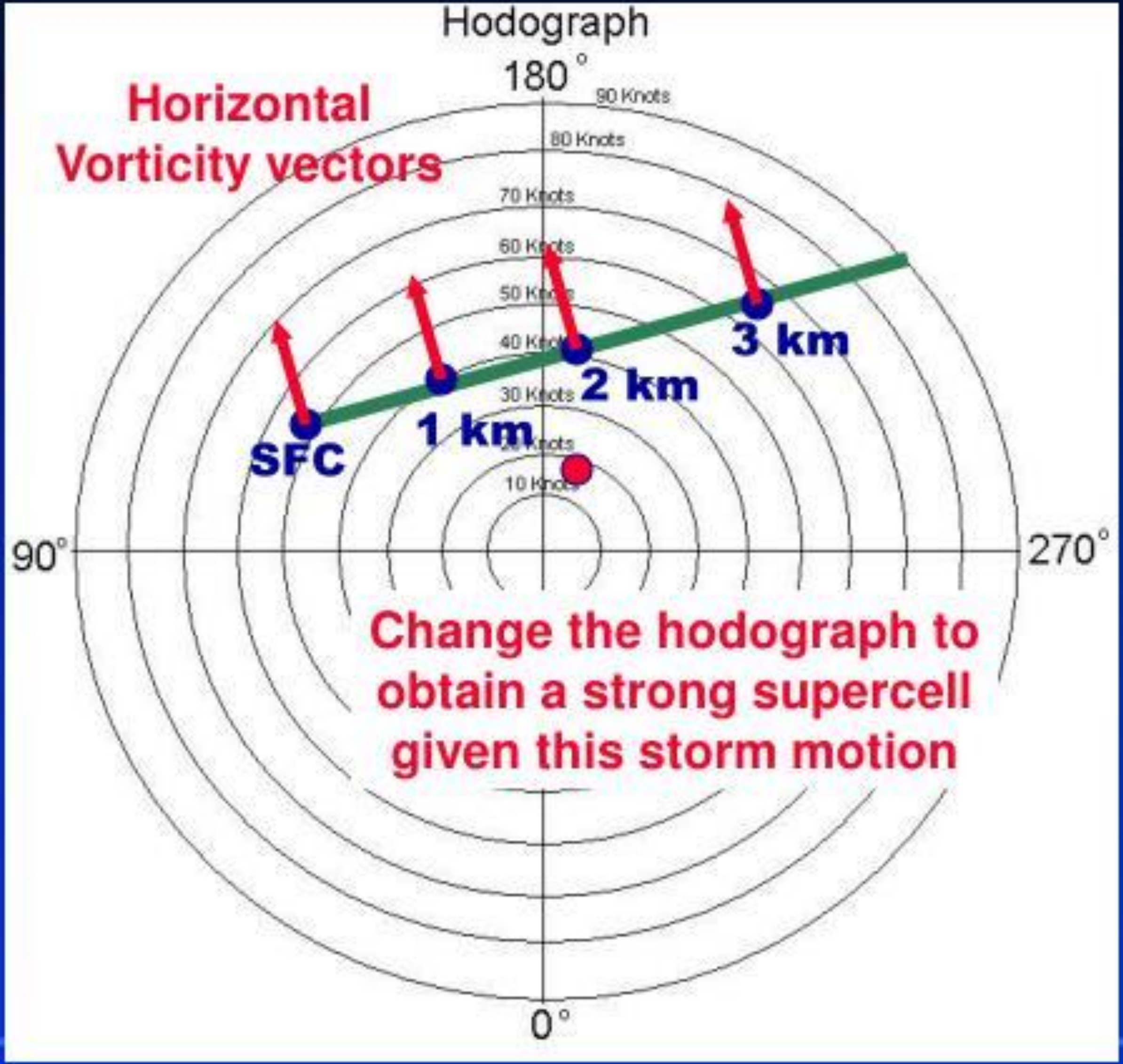
Making an Optimal Hodograph



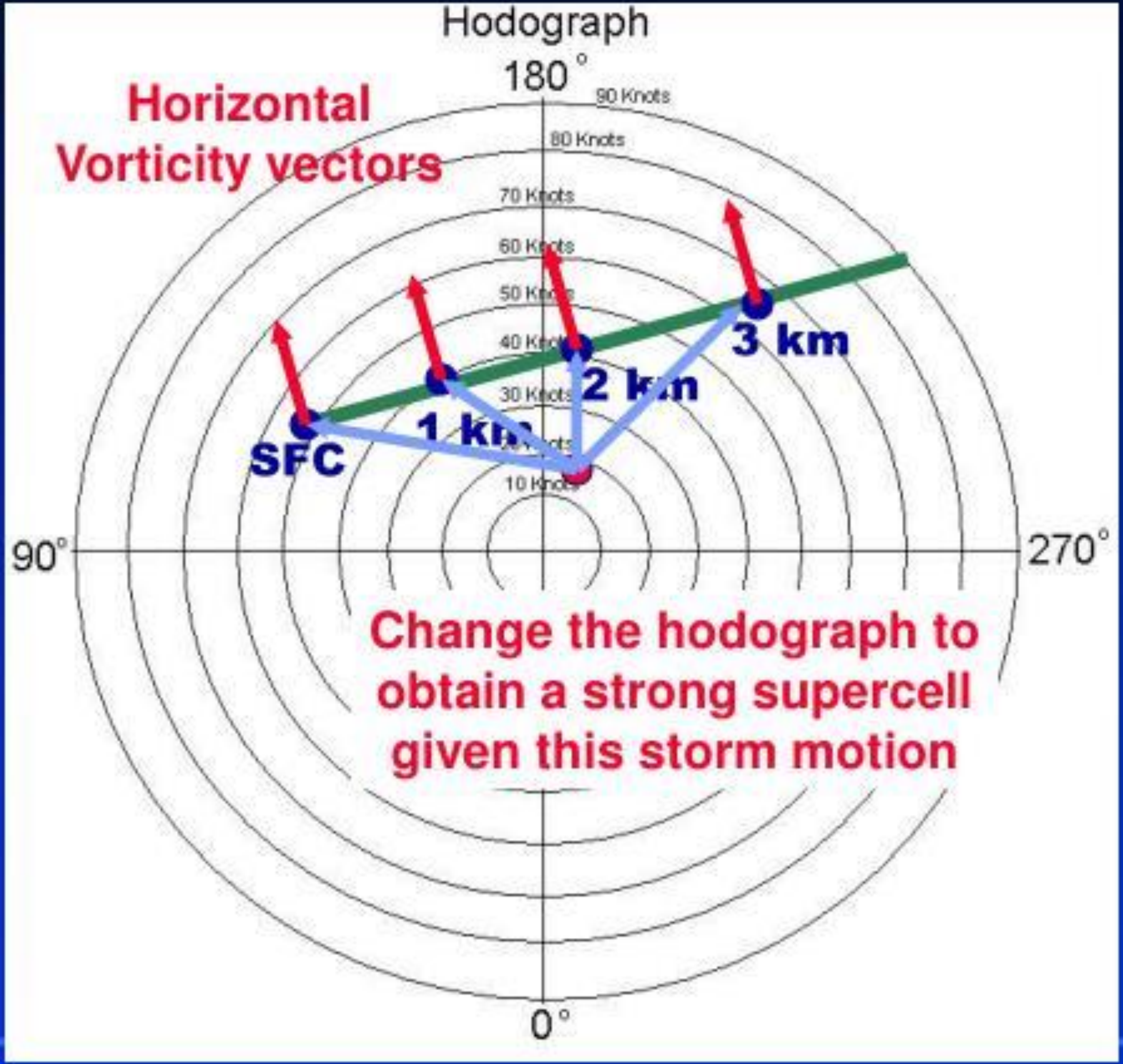
Making an Optimal Hodograph



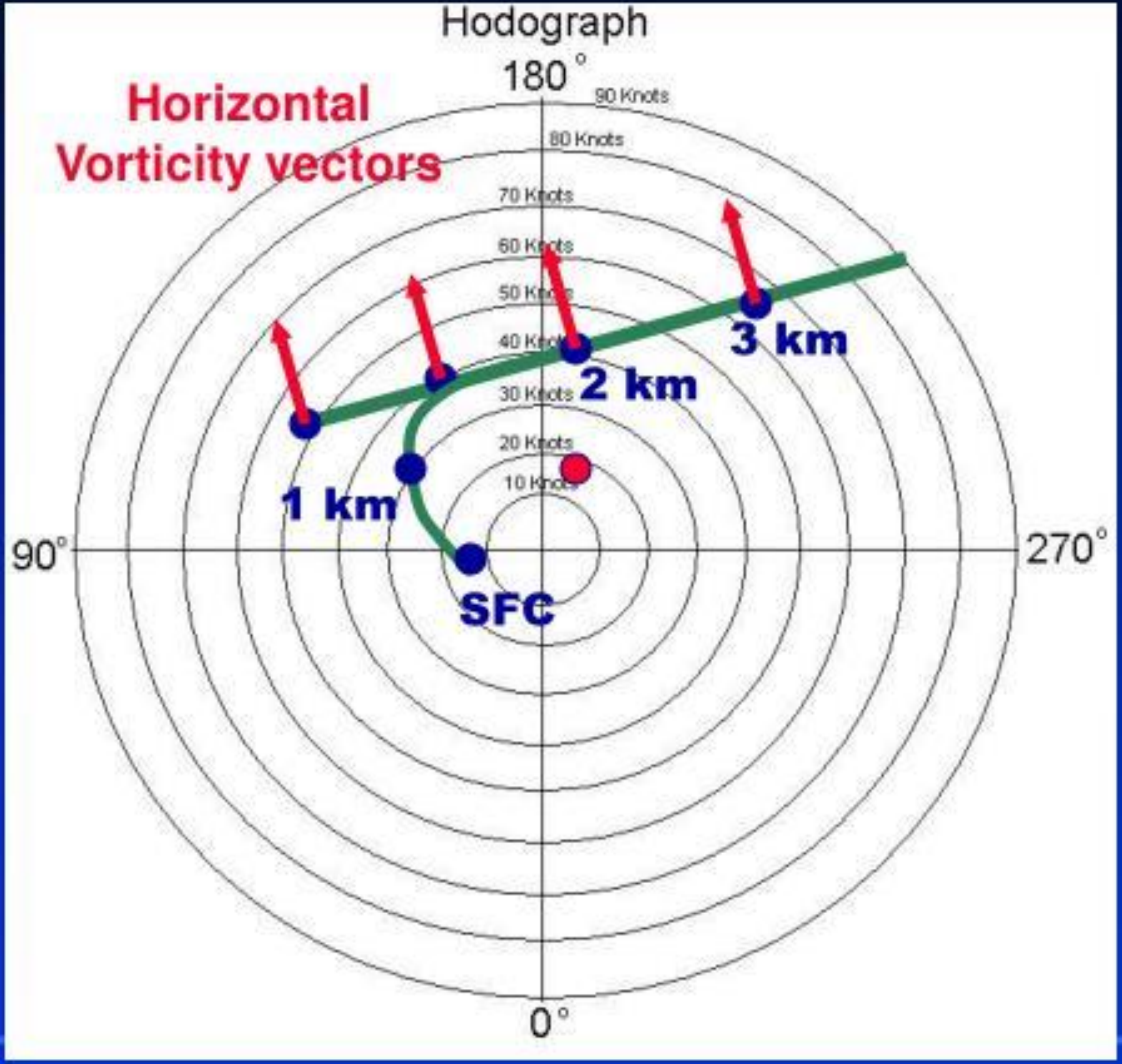
Making an Optimal Hodograph



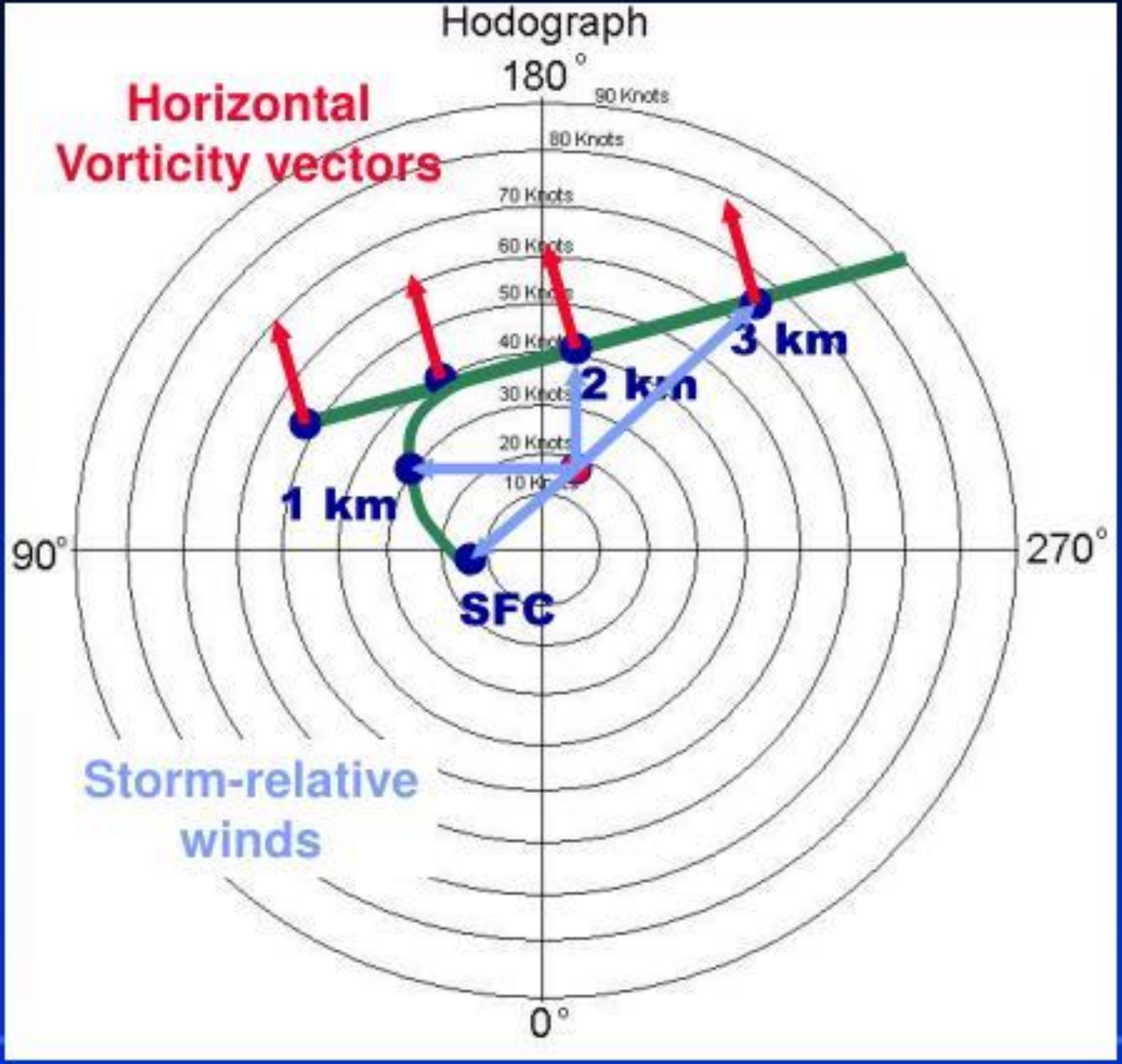
Making an Optimal Hodograph



Making an Optimal Hodograph



Making an Optimal Hodograph



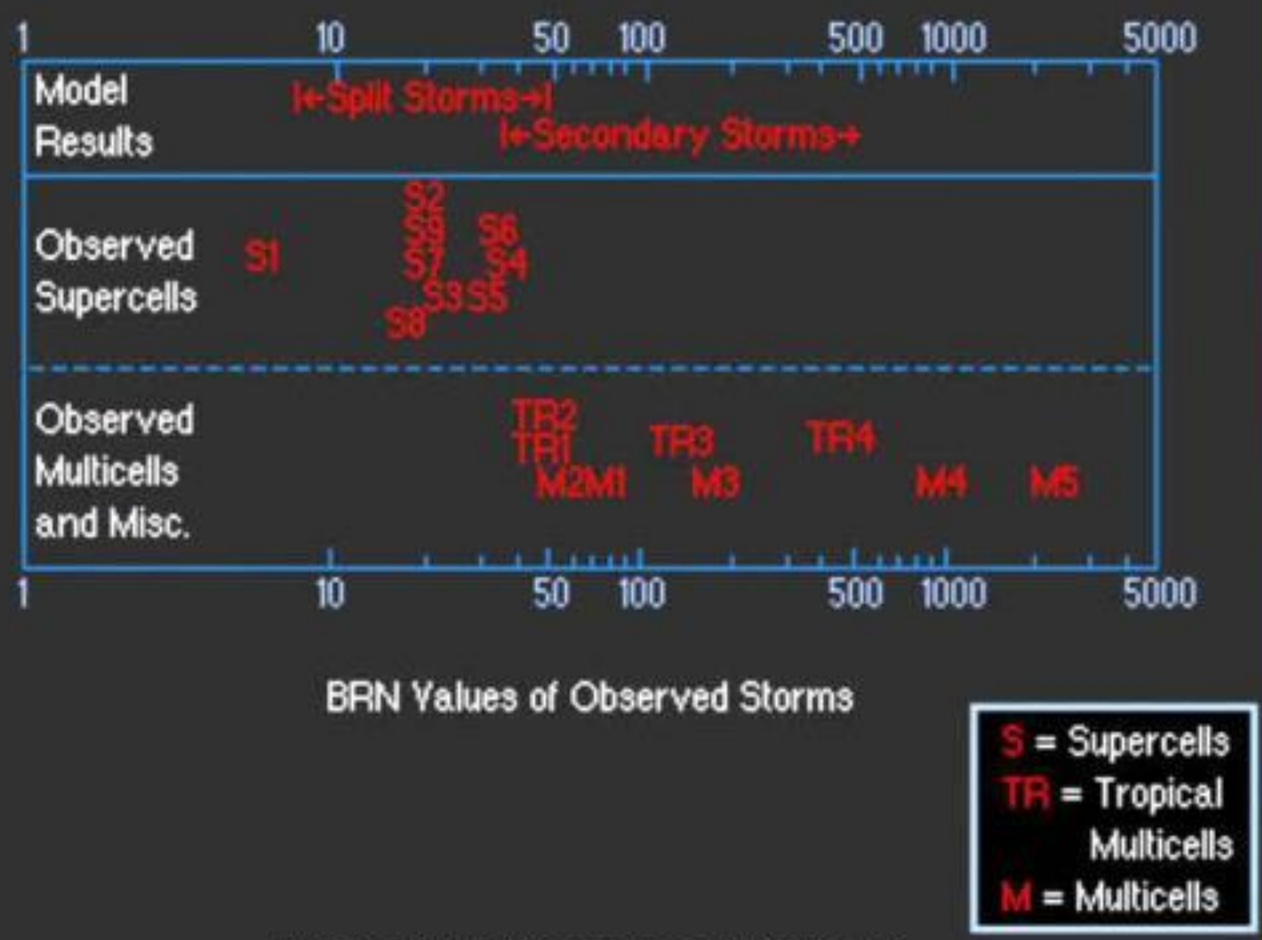
Predicting Thunderstorm Type: The Bulk Richardson Number

$$BRN = \frac{CAPE}{S^2}$$

$$where\ S^2 = \frac{1}{2}(\bar{u}_{6000} - \bar{u}_{500})^2$$

- Need sufficiently large CAPE (2000 J/kg)
- Denominator is really the storm-relative inflow kinetic energy (sometimes called the BRN Shear)
- BRN is thus a measure of the updraft potential versus the inflow potential

Results from Observations and Models



Adopted from Weisman and Klemp, 82.

General Guidelines for Use

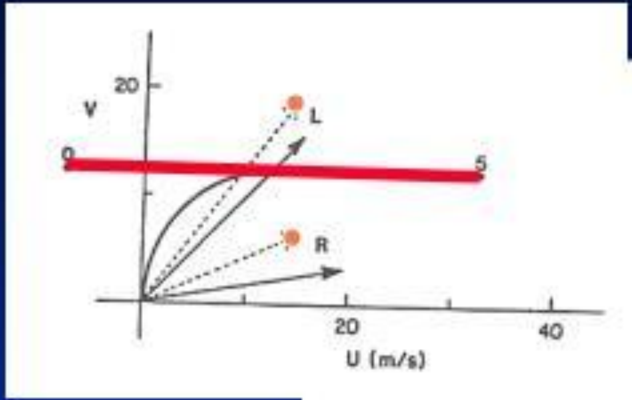
$$Supercells \ for \ 5 \le BRN \le 50$$

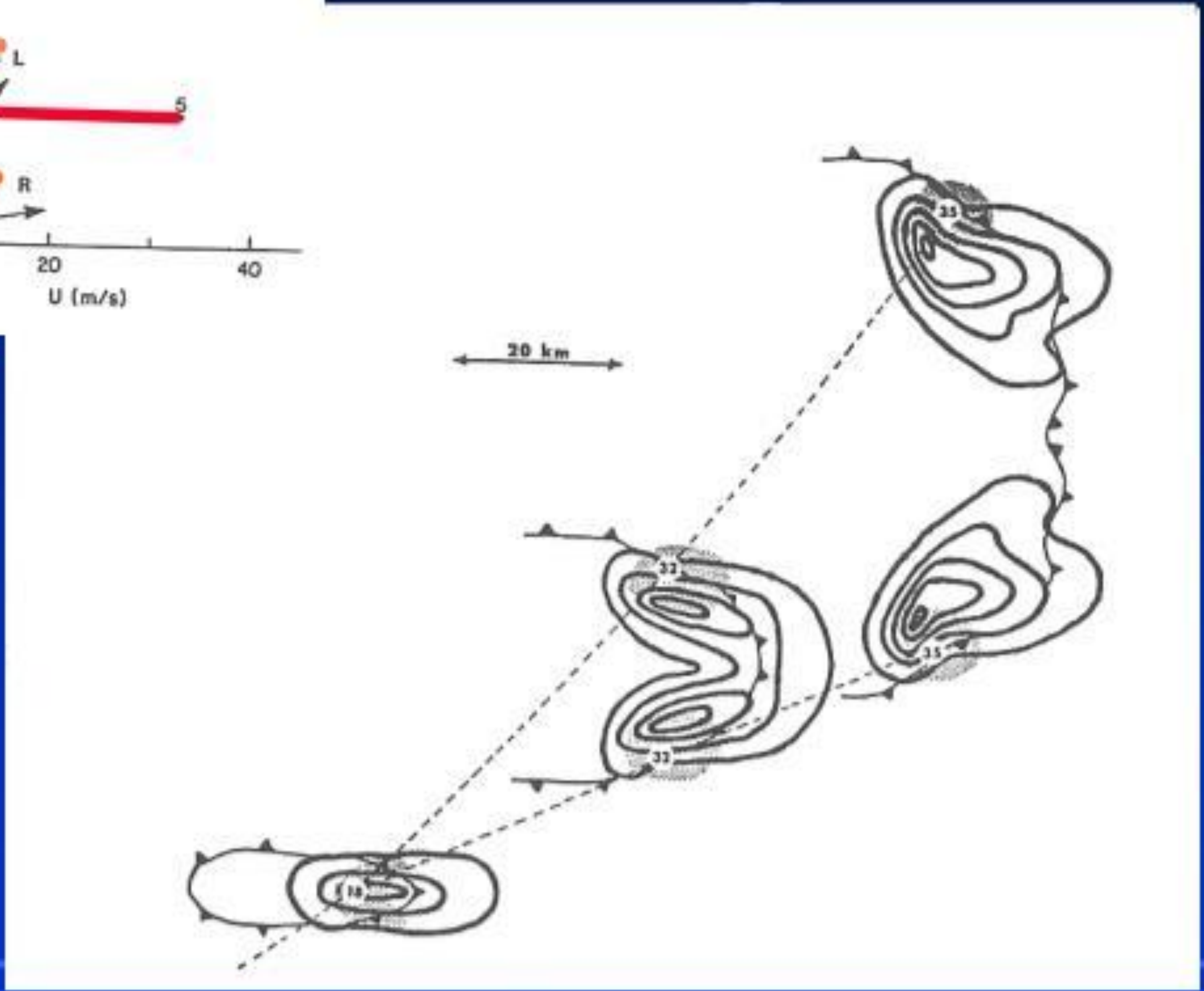
$$Multicells \ for \ 35 \le BRN \le 400$$

Selective Enhancement and Deviate Motion of Right-Moving Storm

- For a purely straight hodograph (unidirectional shear, e.g., westerly winds increasing in speed with height and no north-south wind present), an incipient supercell will form mirror image left- and right-moving members

Straight Hodograph



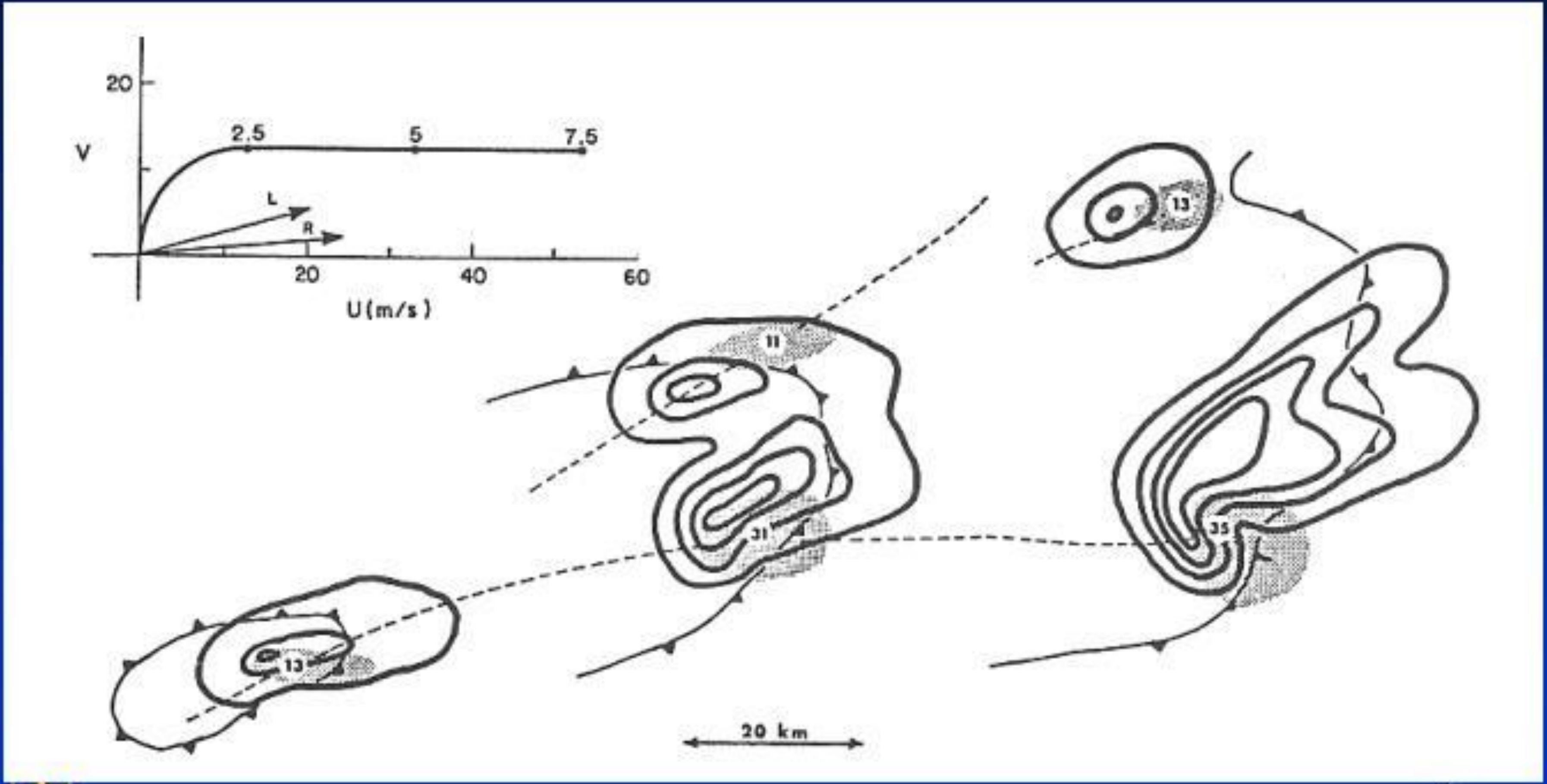


Weisman (1986)

Selective Enhancement and Deviate Motion of Right-Moving Storm

- For a curved hodograph, the southern member of the split pair tends to be the strongest
- It also tends to slow down and travel to the right of the mean wind

Curved Hodograph – Selective Enhancement of Cyclonic Updraft



Weisman (1986)

Obstacle Flow – Wrong!

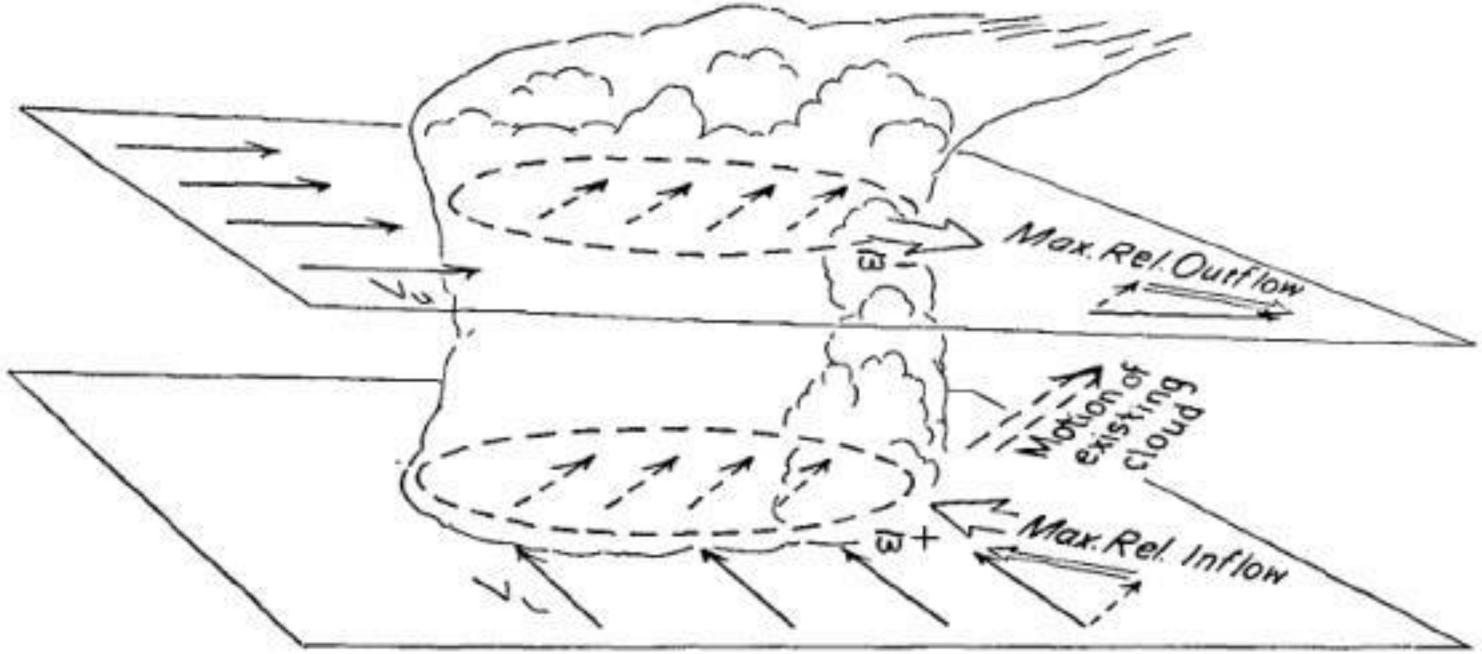
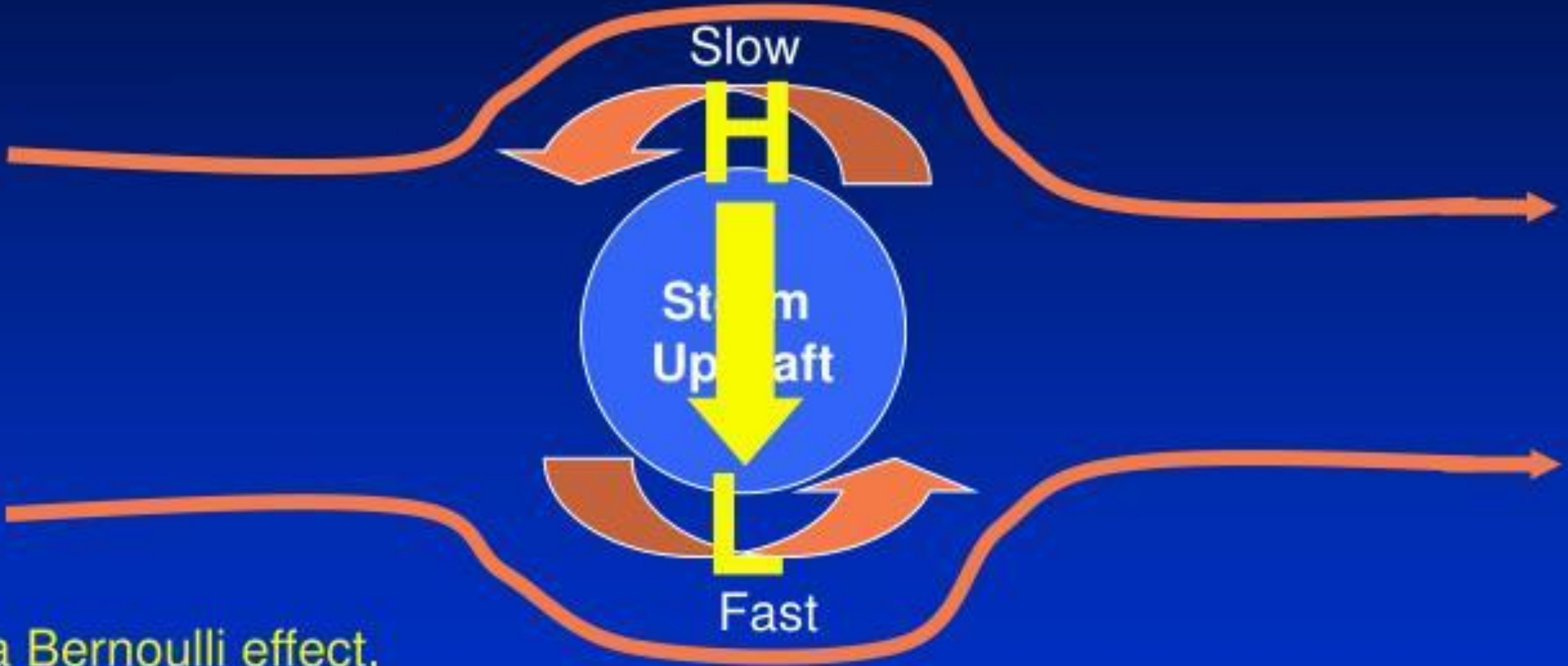


FIG. 6. Sketch of convective storm in environment wherein wind veers with height. See text (after Newton, 1960).

Magnus Effect – Wrong!



Via Bernoulli effect,
low pressure located where
flow speed is the highest, inducing a pressure gradient force
that acts laterally across the updraft

Newton and Fankhauser (1964)

Linear Theory of an Isolated Updraft

- Using the linear equations of motion, one can show that

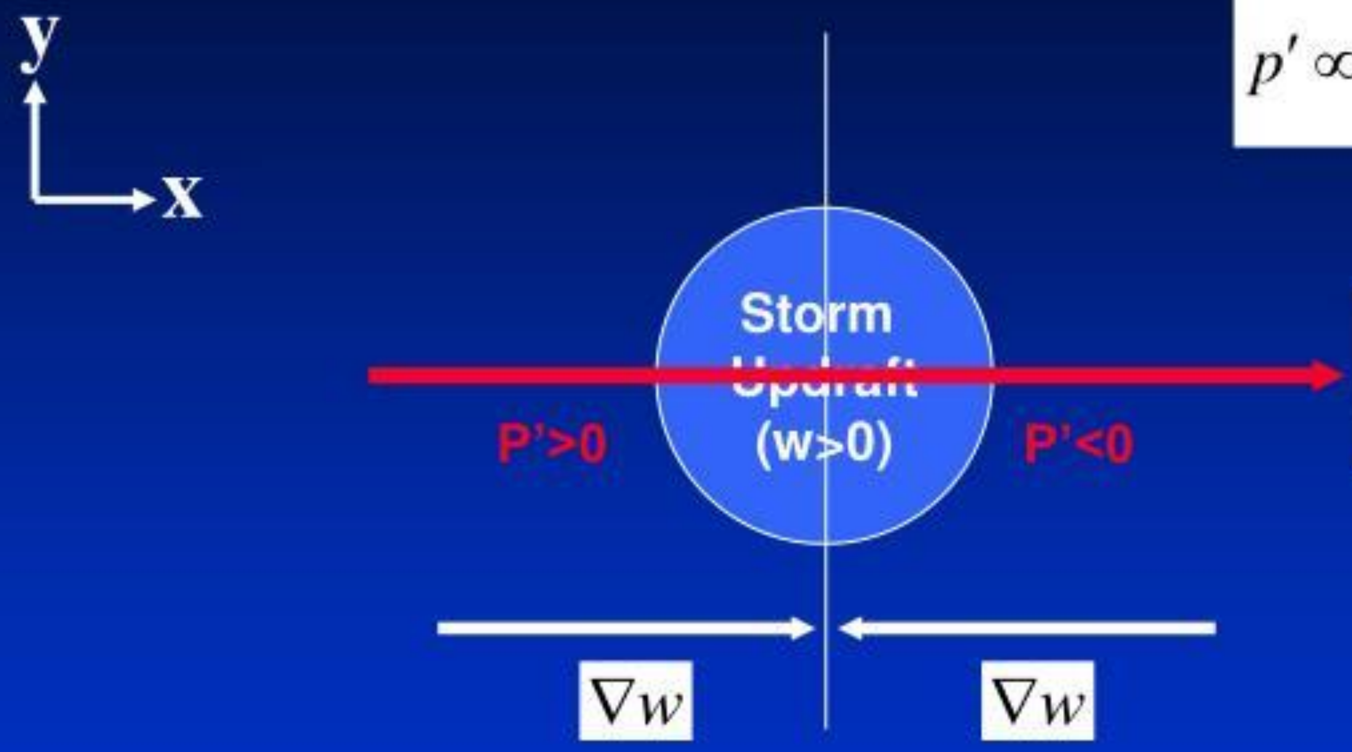
$$p' \propto \frac{\partial \vec{V}_{env}}{\partial z} \cdot \nabla w$$

- …where p' is the pressure perturbation, w is the updraft and vector v is the environmental wind
- This equation determines where pressure will be high and low based upon the interaction of the updraft with the environmental vertical wind shear

Rotunno and Klemp (1982)

Linear Theory of an Isolated Updraft

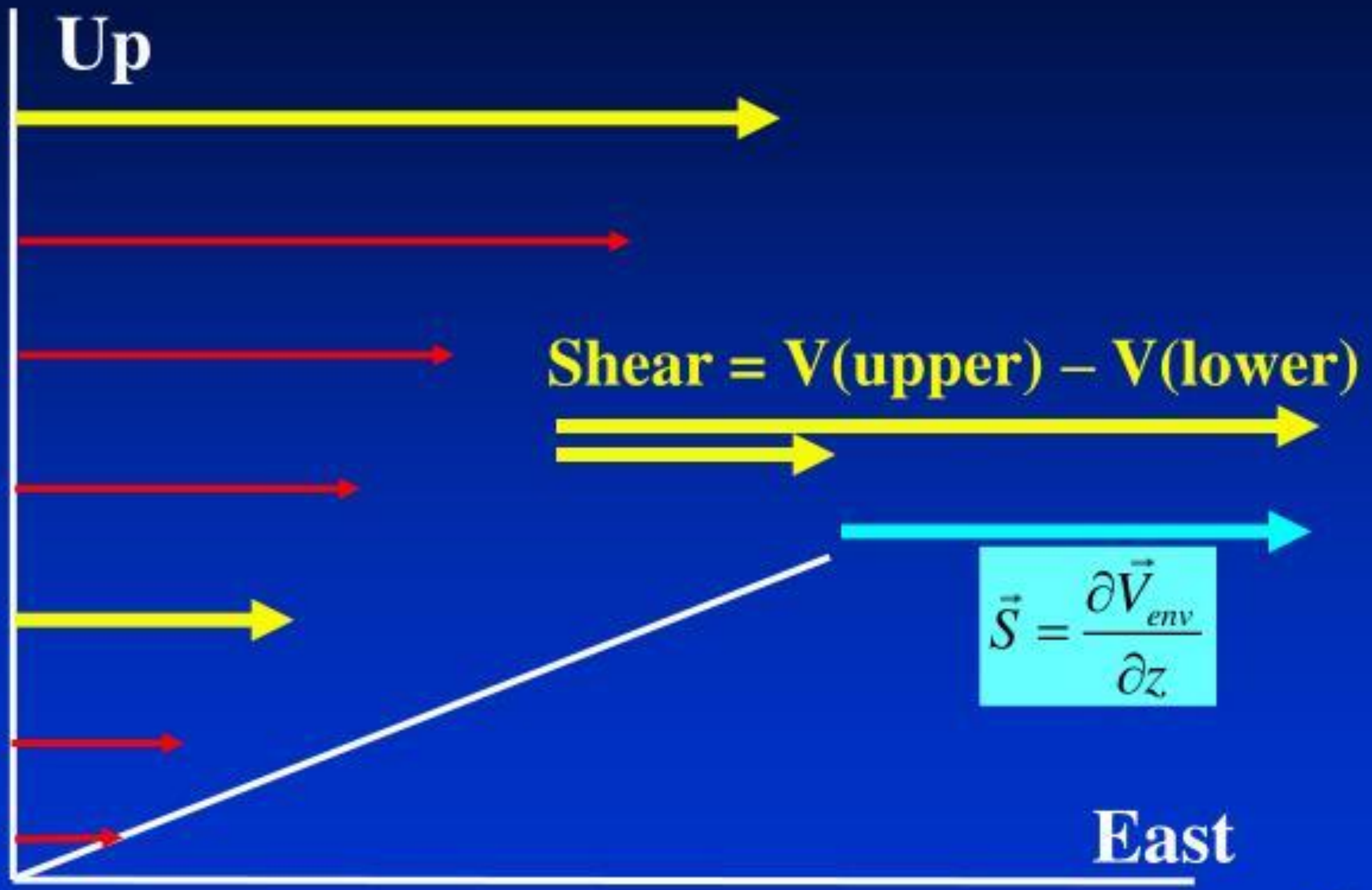
$$p' \propto \frac{\partial \vec{V}_{env}}{\partial z} \cdot \nabla w$$



$$\vec{S} = \frac{\partial \vec{V}_{env}}{\partial z}$$

Rotunno and Klemp (1982)

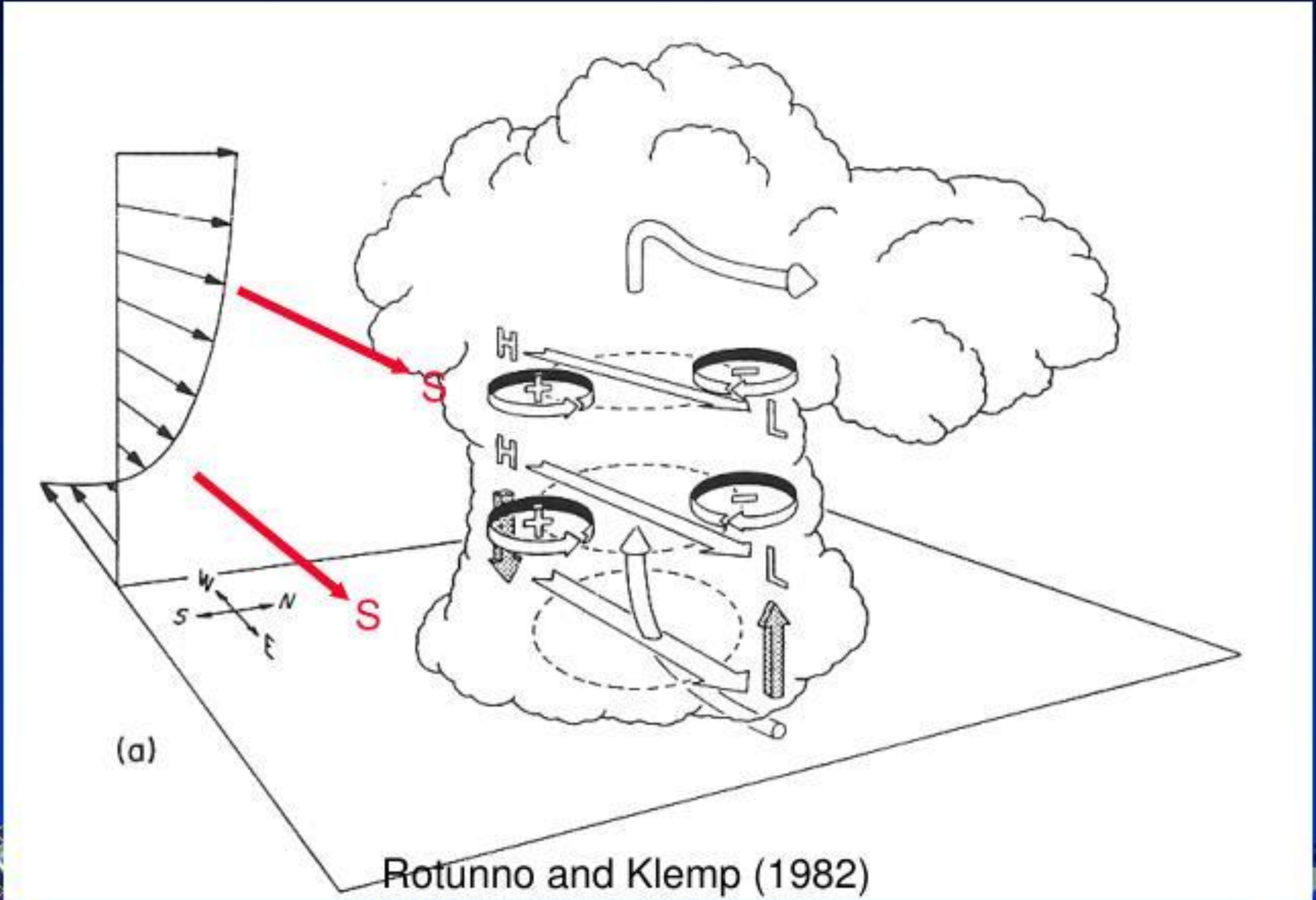
Vertical Wind Shear



Unidirectional Shear (Straight Hodograph)

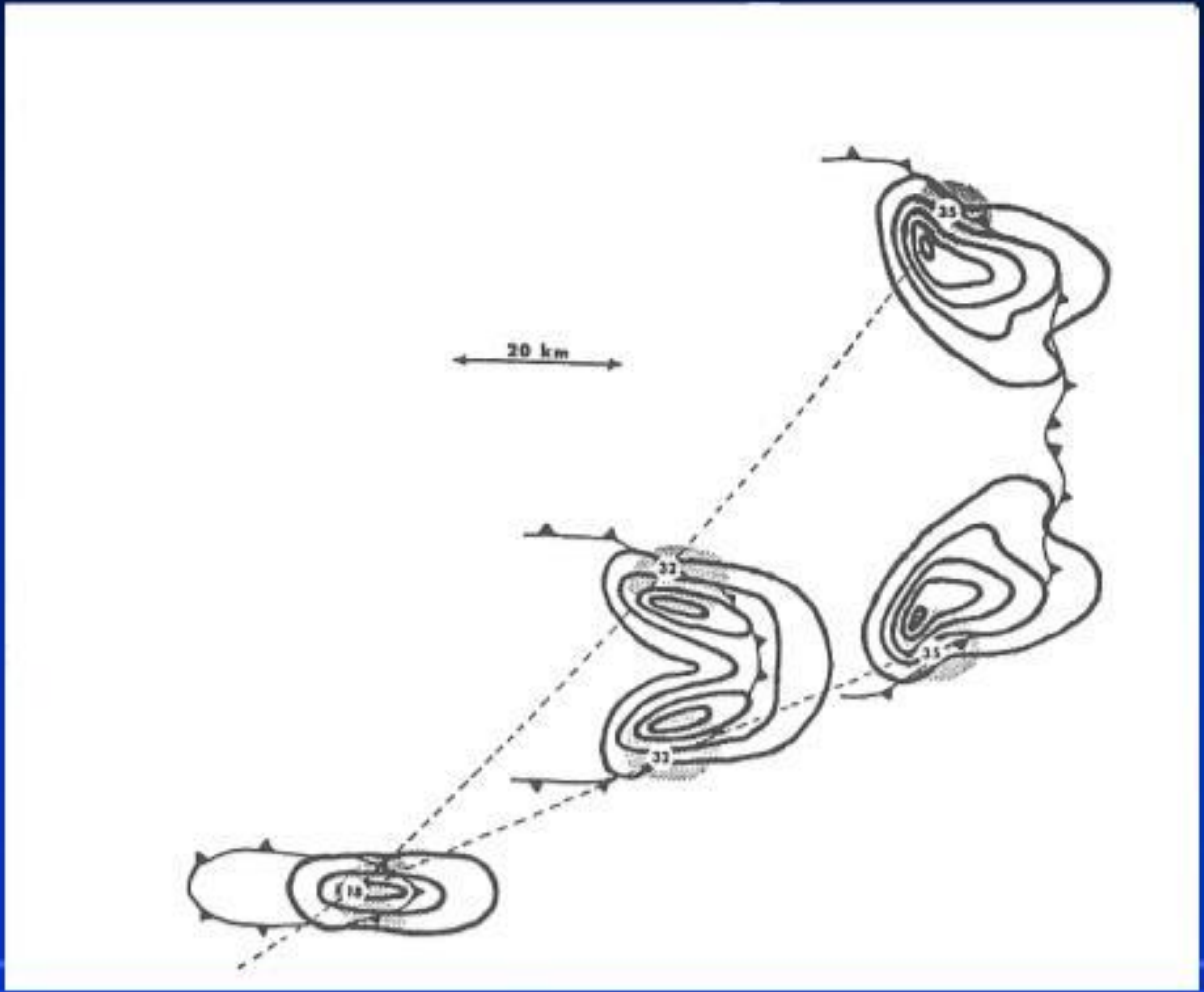
- Note that if the shear vector is constant with height (straight hodograph), the high and low pressure centers are identical at all levels apart from the intensity of w

Straight Hodograph



Rotunno and Klemp (1982)

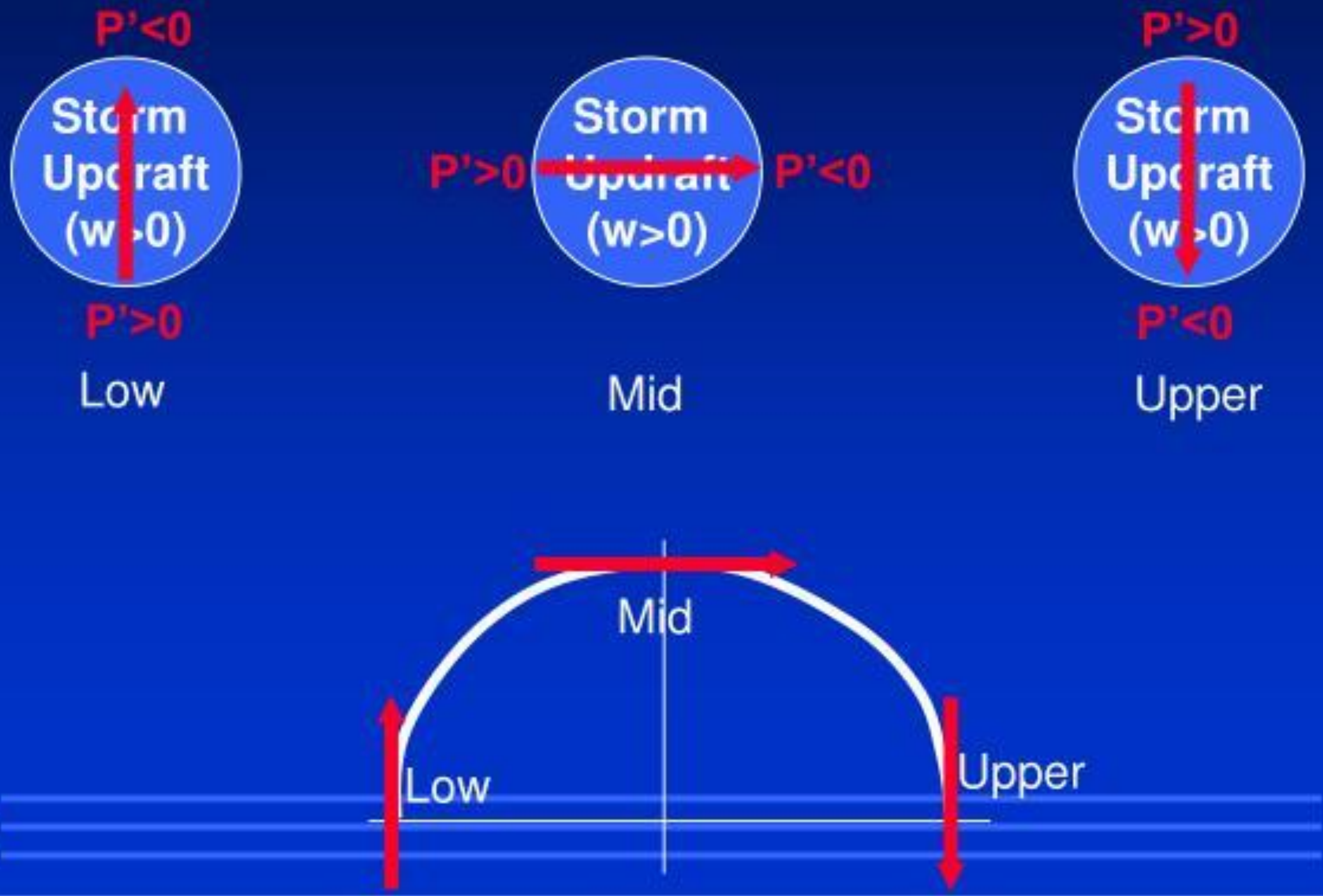
Straight Hodograph



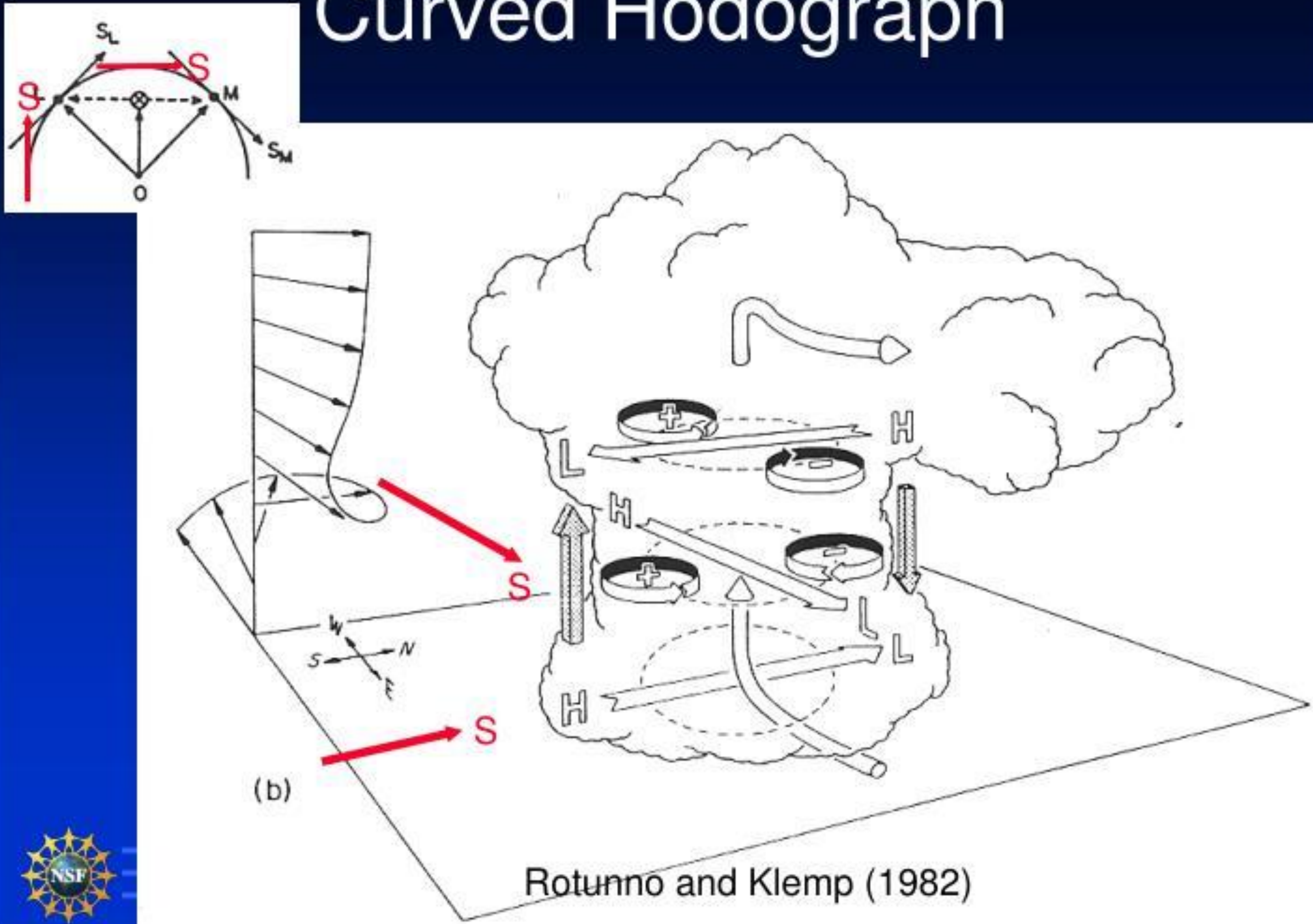
Weisman (1986)

Turning Shear Vector

- Note that if the shear vector turns with height (curved hodograph), so do the high and low pressure centers

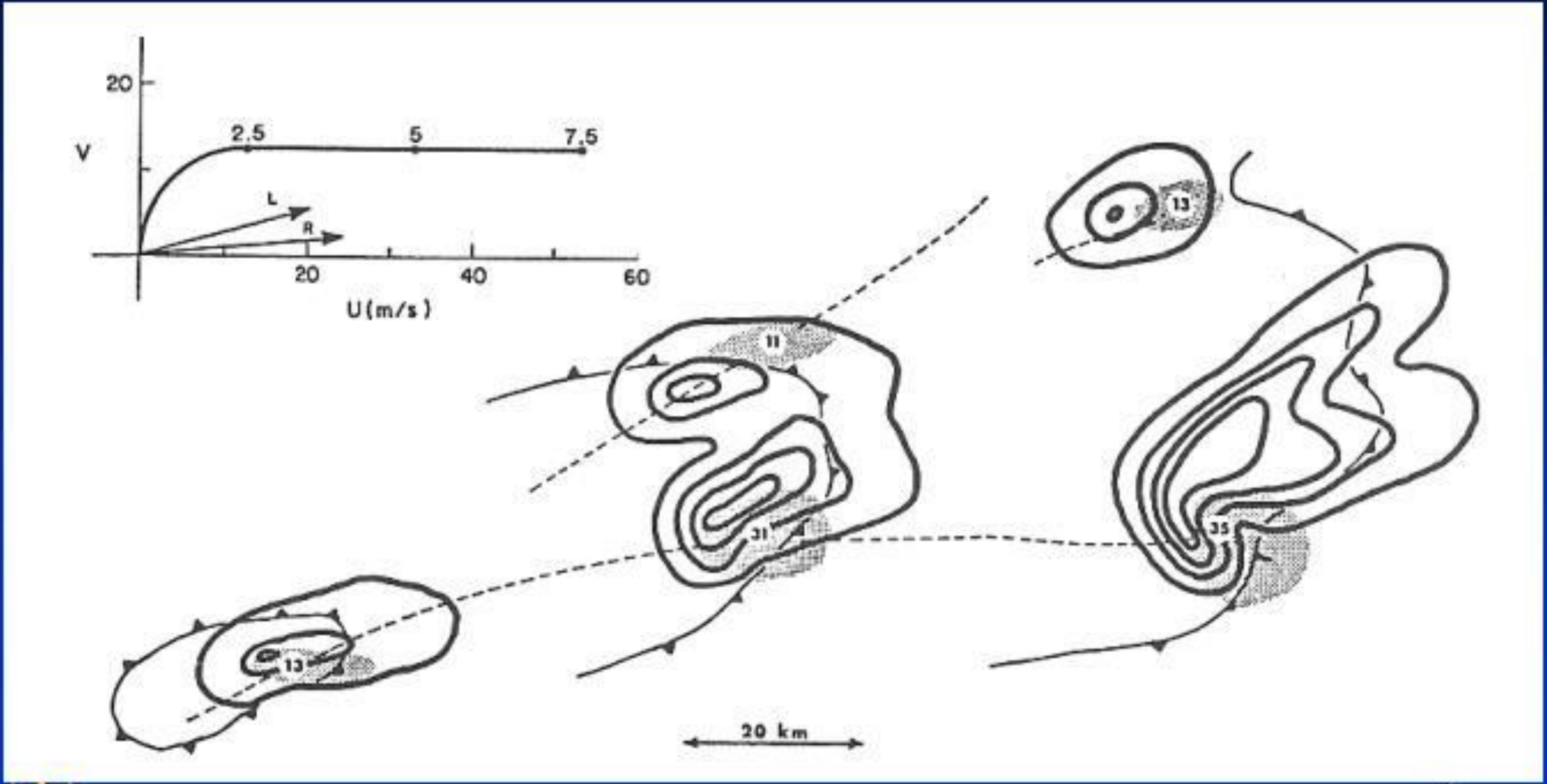


Curved Hodograph



Rotunno and Klemp (1982)

Curved Hodograph – Selective Enhancement of Cyclonic Updraft



Weisman (1986)

Real Example!