Kinematics of the Wind Field

Meteorology 411 – Iowa State University – Week 3

Bill Gallus

Kinematics vs Dynamics

- What is the difference?
- Kinematics is a description of the wind field
- Dynamics explains cause/effect

Taylor Series expansion

- Any wind field can be defined using a Taylor series expansion about a point (x,y):

$$u(x,y) = u(x_0,y_0) + \partial u/\partial x\,(x-x_0) + \partial u/\partial y\,(y-y_0)$$

$$v(x,y) = v(x_0,y_0) + \partial v/\partial x\,(x-x_0) + \partial v/\partial y\,(y-y_0)$$

In other words, a wind at any point, like Ames, can be written as the wind in a different place, like Des Moines, plus gradients times distances between the 2 sites

More mathematical manipulation….

- From that equation, it can be shown that all wind fields possess 3 quantities which describe them:

$\delta = \partial u/\partial x + \partial v/\partial y$ -> horizontal divergence (the expansion [>0] or contraction of air parcels

$\zeta = \partial v/\partial x - \partial u/\partial y$ -> relative vorticity (vertical component) which is counterclockwise (>0) or clockwise spin.

Other parameter…

$D_1 = \partial u/\partial x - \partial v/\partial y$

$D_2 = \partial v/\partial x + \partial u/\partial y$

These are the 2 components of Deformation (the changing shape of an air parcel)

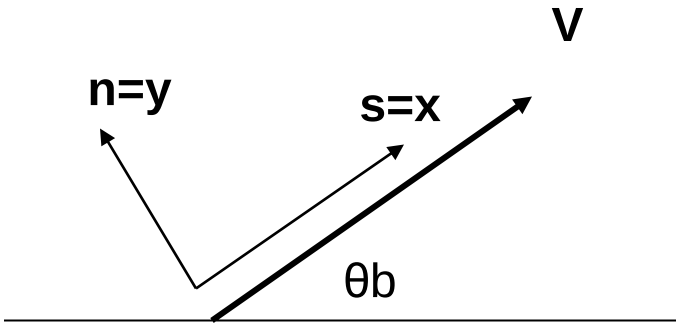
We usually ignore deformation in synoptic meteorology because it is more complicated to discuss, except in frontogenesis discussions where it is extremely important!

Natural Coordinate system

- To better understand divergence and vorticity, we use a natural coordinate system…

$u = V\cos\theta_b$

$v = V\sin\theta_b$



Convert cartesian expressions for divergence and vorticity to be valid in natural coordinates

$\partial u/\partial x = \partial V/\partial s * \cos 0 - V*\sin 0 = \partial V/\partial s$

$\partial v/\partial x = \partial V/\partial s * \sin 0 + V*\cos 0*\partial \theta_b/\partial s = V\ \partial \theta_b/\partial s$

$\partial u/\partial y = \partial V/\partial n$

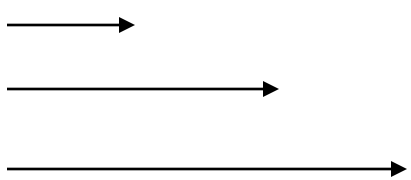
$\partial v/\partial y = V\ \partial \theta_b/\partial n$

Think about what these terms represent…

$\partial V/\partial s$ – stretching ($\partial V/\partial s > 0$) or shrinking of air parcel in direction of wind

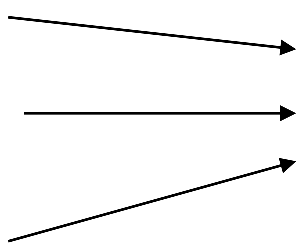
$\partial \theta_b/\partial s$ – counterclockwise (>0) or clockwise curvature

$\partial V/\partial n$ – positive or negative lateral shear

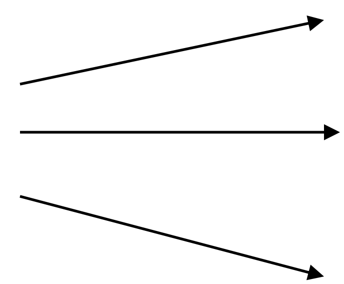


Meanings (cont)

$\partial\theta_b/\partial n$ – diffluence (>0) = flowing apart of streamlines, or confluence (<0) = flowing together



confluence



diffluence

Divergence in Natural Coords

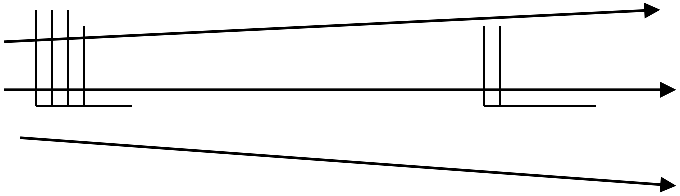
- So, divergence becomes..

$$\delta = \partial V/\partial s + V\ \partial \theta b/\partial n$$

Changes in wind speed along a streamline

Confluence or diffluence

Usually these terms cancel out so we can't eyeball divergence/convergence on a map.



Vorticity in Natural Coords

$$\delta = V\ \partial\theta b/\partial s - \partial V/\partial n$$

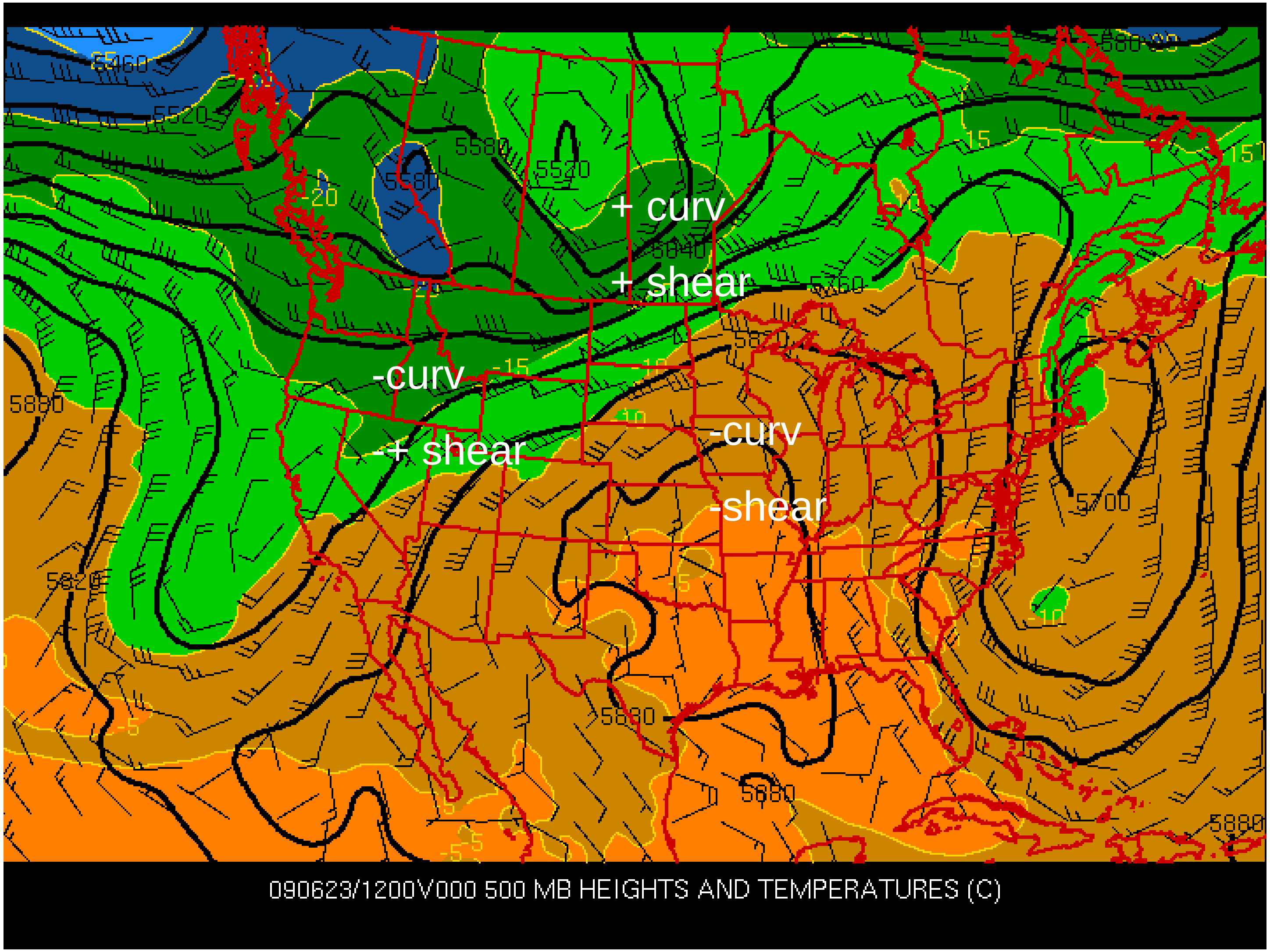
Curvature vorticity

Shear vorticity

We can write the curvature term as V/R_t, where Rt is the radius of trajectory, and is >0 for cyclonic motion and <0 for anticyclonic motion

Do these terms tend to cancel out like the ones for divergence?

Consider typical map…



Thus, the two terms do NOT necessarily cancel out for vorticity

Thus, vorticity maxima are usually in the trof and north of the jet stream, while minima are in the ridge south of the jet stream

Absolute vorticity includes the effect of the Earth's spin

$\eta = \zeta + f$

Since $f = 2\Omega\sin\varphi$, and is positive in N. Hemisphere, η is positive everywhere there

How do we compute these quantities?

- To use meteorological degrees and get correct component values, use
- $U = - |V| \sin \theta$
- $V = - |V| \cos \theta$

- Usually, finite difference approximations are used to estimate spatial derivatives. If possible, use centered differences. Since our wind obs are not usually on an even grid, we also end up having to estimate/average/interpolate