Atmospheric Dynamics

دانشگاه رازی

Lecture 1

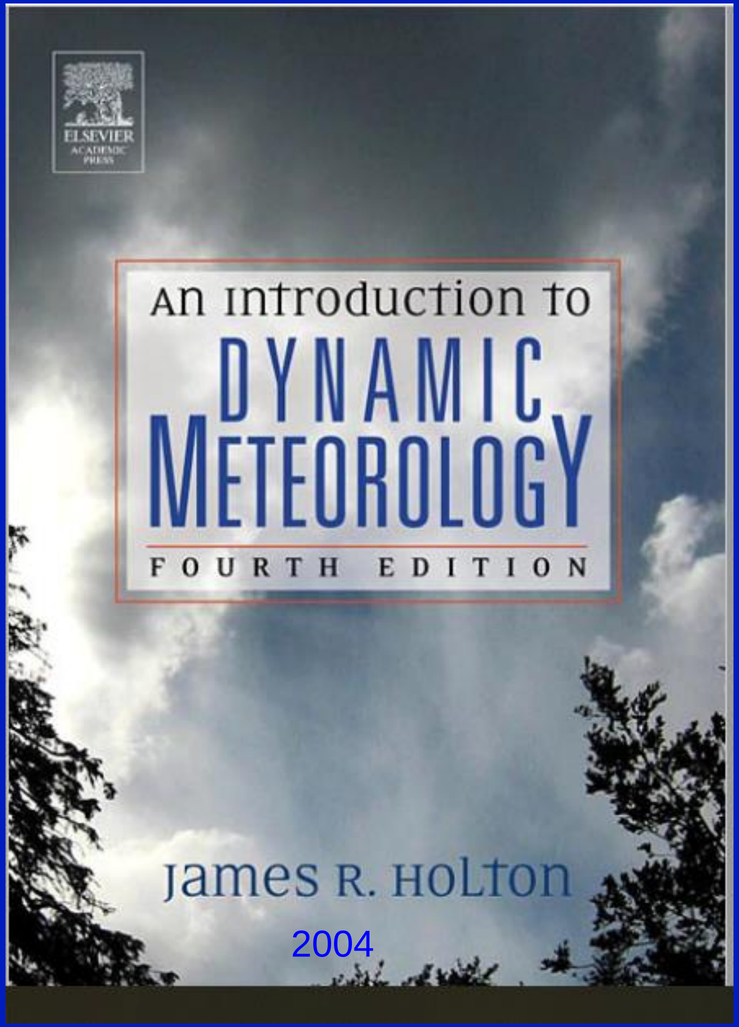
Sahraei

https://sci.razi.ac.ir/~sahraei

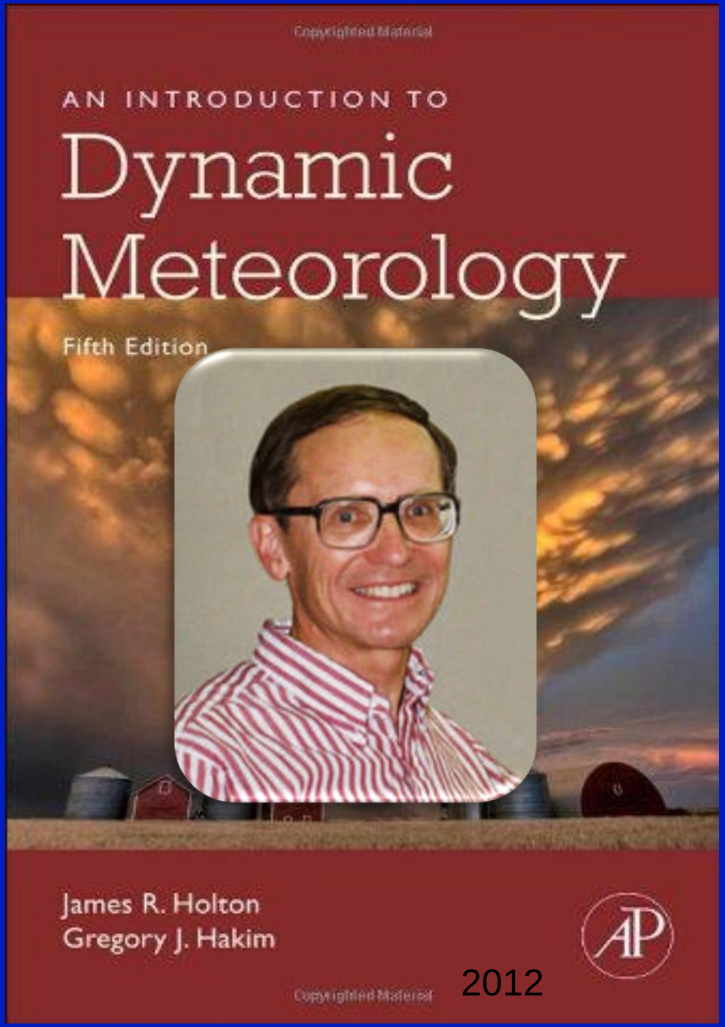
فهرست منابع:

1. *Holton, J.R., 2004: An Introduction to Dynamic Meteorology. Academic Press, 535 pp.*
2. *Holton, J.R., and G. J. Hakim, 2013: An Introduction to Dynamic Meteorology. Academic Press, 532 pp.*
3. *Pedlosky, J., 1987: Geophysical Fluid Dynamics. Springer Verlag, New York, 624 pp.*
4. *Gill, A., 1982: Atmosphere-Ocean Dynamics. Academic Press, 662 pp.*
5. *Andrews, D.G., J.R. Holton, and C.B. Leovy, 1987: Middle Atmosphere Dynamics. Academic Press, 489 pp.*
6. *Hoskins, B. J., and I. N. James, 2014: Fluid Dynamics of the MidLatitude Atmosphere. John Willey & Sons, Ltd, 408pp.*
7. *Vallis, G. K., 2006: Atmospheric and Oceanic Fluid Dynamics: Fundamentals and Large-Scale Circulation. Cambridge University Press, 737pp.*
8. *Zdunkowski, W., and A. Bott, 2003: Dynamics of the Atmosphere. Cambridge University Press, 742pp.*

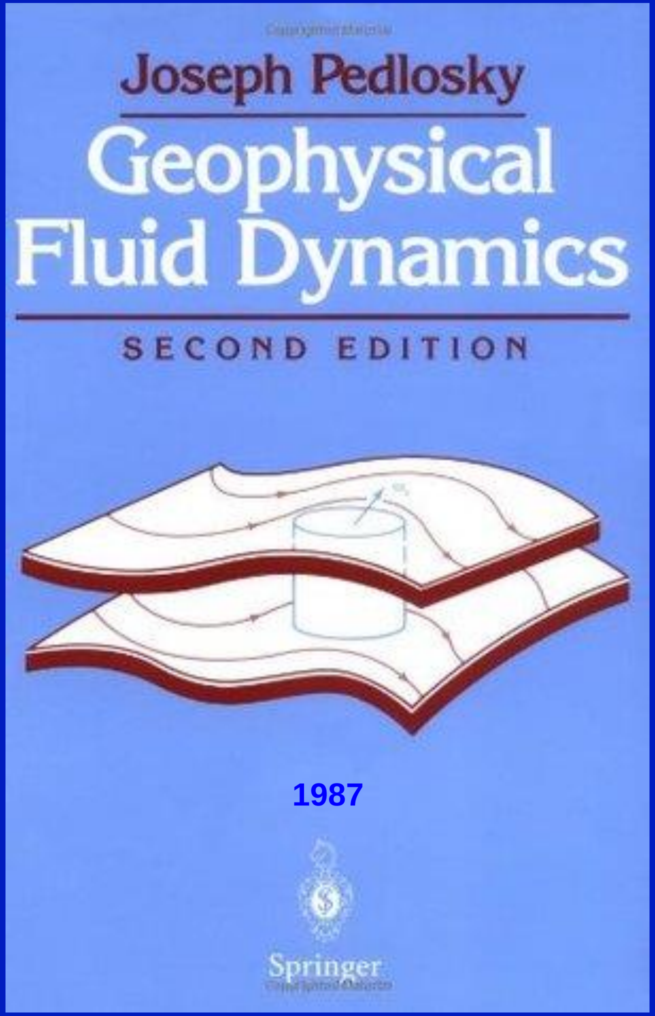
References

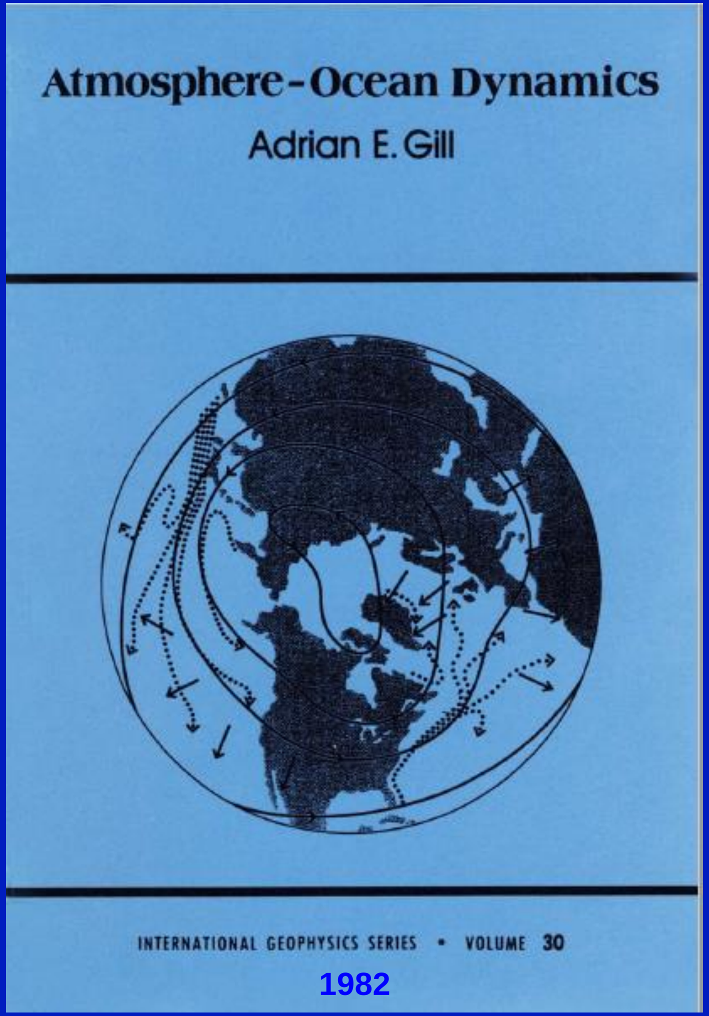


2004



2012


Joseph Pedlosky
Geophysical Fluid Dynamics
SECOND EDITION
1987
Springer


Atmosphere-Ocean Dynamics
Adrian E. Gill
INTERNATIONAL GEOPHYSICS SERIES • VOLUME 30
1982

Assessment

عنوان درس به فارسی: دینامیک جوّ

عنوان درس به انگلیسی: *(Atmospheric Dynamics)*

تعداد واحد: ۳

نوع واحد: نظری

نوع درس: تخصصی

تعداد ساعت: ۴۸ ساعت

پیش‌نیاز: دینامیک شاره های ژئوفیزیکی

همنیاز: -

آموزش تکمیلی عملی: دارد O ندارد ● سفر علمی O کارگاه O آزمایشگاه O سمینار O

اهداف کلی درس: آشنایی با حرکت‌ها و گردش‌های جوّی و پایداری یا ناپایداری آن‌ها.

سرفصل درس: ۴۸ ساعت نظری

فصل اول - حرکت‌های مقیاس‌همدیدی

ساختار مشاهداتی گردش‌های برون‌حاره‌ای، نظریه شبه‌زمینگرد، معادلات شبه‌زمینگرد تکانه، تاوایی، گرایش ارتفاع ژئوپتانسیلی، تاوایی پتانسیلی و سرعت قائم؛ گردش آزمینگرد، مدل ایده‌آلی یک آشفتگی کژ فشار.

فصل دوم - نوسانات و امواج جوّی

روش پریشیدگی، انواع موج ساده (امواج صوتی و گرانی آب کم‌عمق)، امواج گرانی درونی، امواج لختی خالص، امواج گرانی-لختی، تنظیم به توازن زمینگرد، امواج کوهستان، امواج راسبی، امواج راسبی فشارورد آزاد، امواج راسبی واداشته زمینگان.

فصل سوم - ناپایداری‌های دینامیکی

ناپایداری هیدرودینامیکی، ناپایداری کژفشار در مدل دو لایه‌ای فیلیپس،معادلات انرژی در مدل دو لایه‌ای، ناپایداری کژفشار در جوّ با چینه‌بندی پیوسته،قضیه ریلی در ناپایداری کژفشار، مدل ایدی و مدل چارنی، ناپایداری فشارورد.

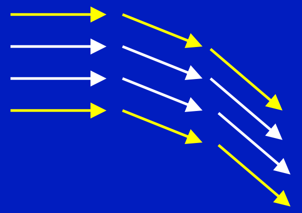
فصل چهارم - دینامیک جوّ میانی

ساختار و گردش جوّ میانی، گردش میانگین مداری جوّ میانی، انتشار قائم امواج سیاره‌ای،گرمایش‌های ناگهانی پوشن‌سپهری، امواج در پوش‌سپهر استوایی، نوسان شبه دوسالانه،انتقال ردیاب‌های جوّی.

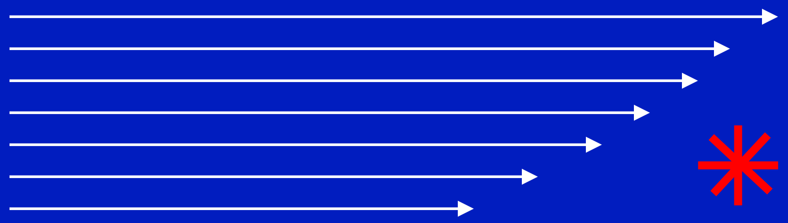
Vorticity

Vorticity is the microscopic measure of spin and rotation in a fluid.

Vorticity is defined as the curl of the velocity: $\nabla \times \vec{V}$



Wind direction varies → clockwise spin



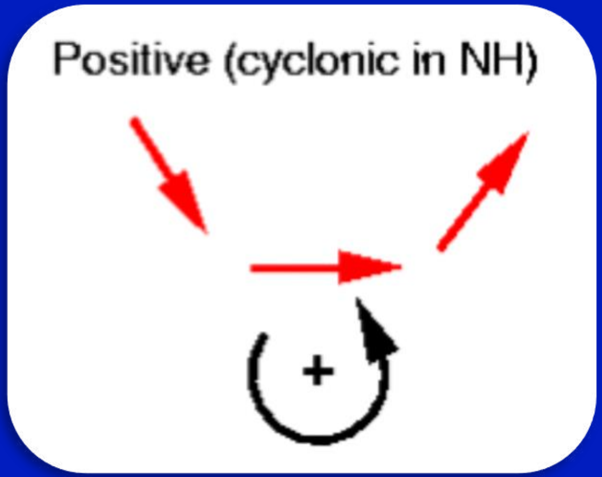
Wind speed varies → clockwise spin

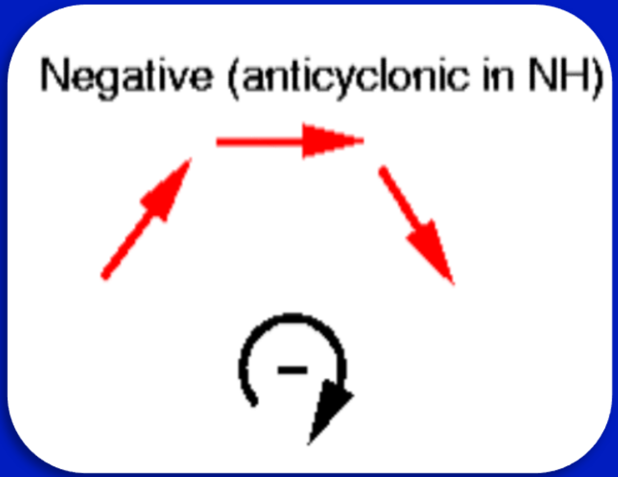
Absolute vorticity (inertial reference frame): $\vec{\omega}_a \equiv \nabla \times \vec{V}_a$

Relative vorticity (relative to rotating earth): $\vec{\omega} \equiv \nabla \times \vec{V}$

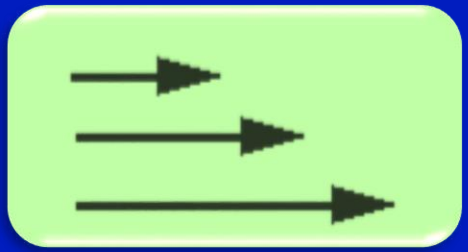
Vorticity

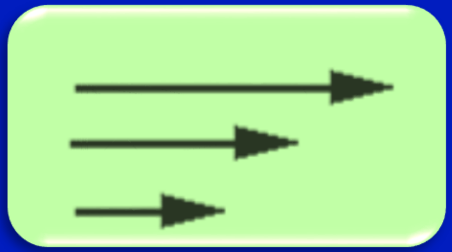
Curvature vorticity





Shear vorticity





Expansion of relative vorticity into Cartesian components:

$$\nabla \times \vec{V} = \begin{vmatrix} \hat{i} & \hat{j} & \hat{k} \\ \frac{\partial}{\partial x} & \frac{\partial}{\partial y} & \frac{\partial}{\partial z} \\ u & v & w \end{vmatrix}$$

$$\nabla \times \vec{V} = \left(\frac{\partial w}{\partial y} - \frac{\partial v}{\partial z} \right) \hat{i} + \left(\frac{\partial u}{\partial z} - \frac{\partial w}{\partial x} \right) \hat{j} + \left(\frac{\partial v}{\partial x} - \frac{\partial u}{\partial y} \right) \hat{k}$$

For large scale dynamics, the vertical component of vorticity is most important.

The vertical components of absolute and relative vorticity in vector notation are:

$$\zeta = \hat{k} \cdot \left(\nabla \times \vec{V} \right)$$ relative vorticity

$$\eta = \hat{k} \cdot \left(\nabla \times \vec{V}_a \right)$$ absolute vorticity

From now on, vorticity implies the vertical component (unless otherwise stated.)

The absolute vorticity is equal to the relative vorticity plus the earth's vorticity. Since the earth's vorticity is

$$\hat{k}\cdot\left(\nabla\times\vec{V}_e\right)=2\Omega\sin\phi=f$$

then

$$\zeta=\frac{\partial v}{\partial x}-\frac{\partial u}{\partial y} \quad \text{and} \quad \eta=\frac{\partial v}{\partial x}-\frac{\partial u}{\partial y}+f=\zeta+f$$

For large scale circulations, a typical magnitude for vorticity is

$$\zeta\approx\frac{U}{L}=10^{-5}\ s^{-1}$$

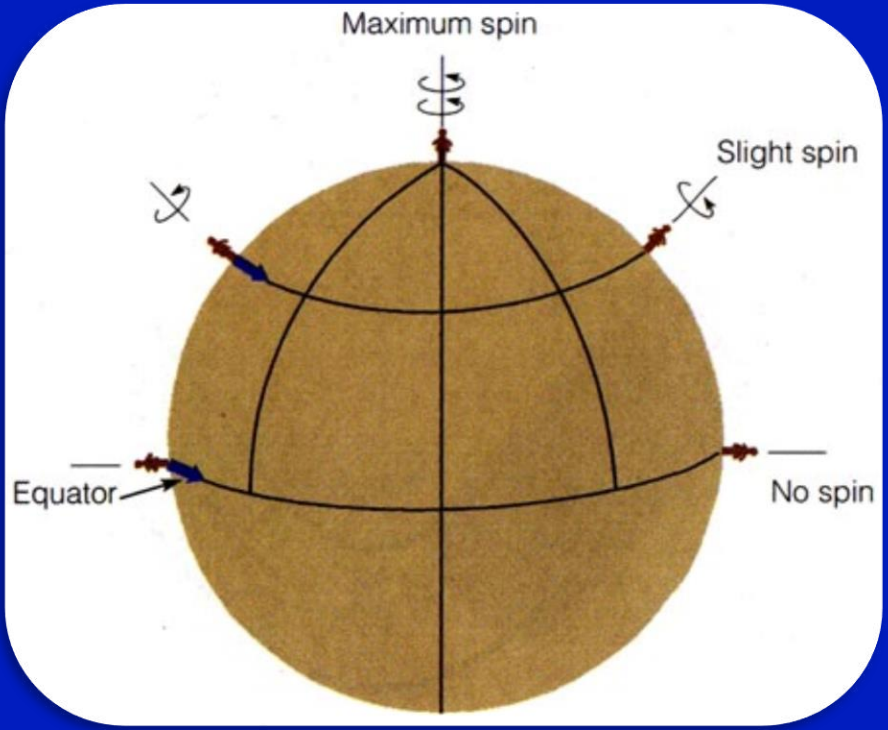
$$\eta = \zeta + f$$

Planetary Vorticity is spin produced by earth's rotation

$$f = 2\Omega \sin\phi$$

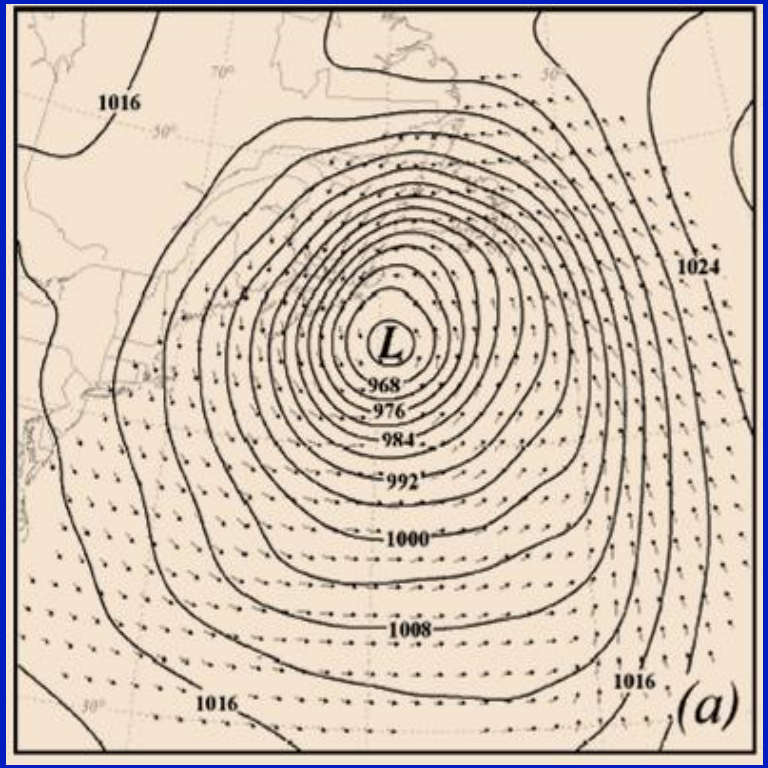
Component of earth's rotation oriented around local vertical

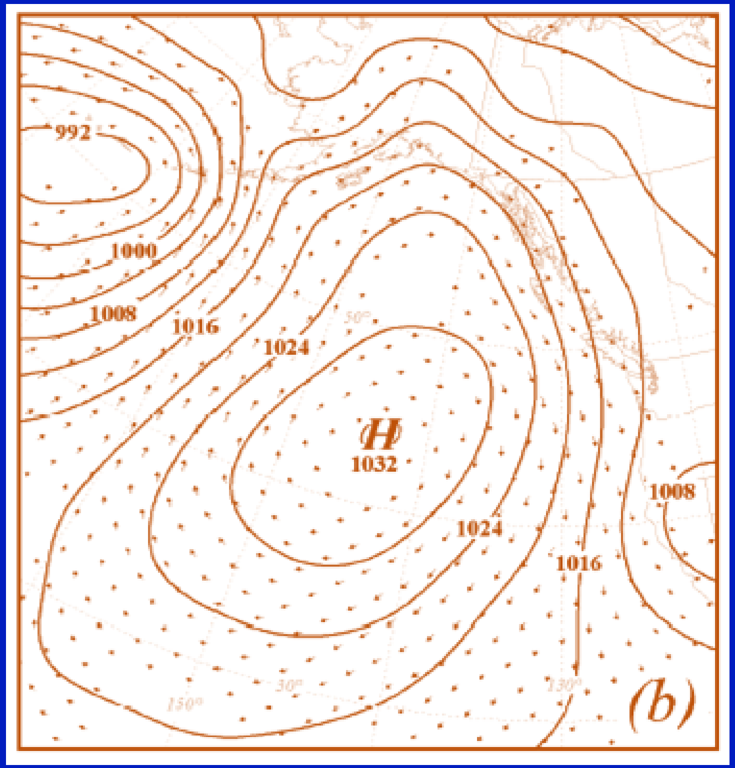
Always positive in Northern Hemisphere 0 at equator, increases northward



FLUID ROTATION

Circulation and Vorticity





Circulation and Vorticity

Two primary measures of rotation in a fluid

By convention, both circulation and vorticity are positive in the counterclockwise direction.

(cyclonic in the Northern Hemisphere)

Circulation:
Macroscopic measure of rotation for a finite area of the fluid = integration of the tangential component of velocity around a closed path

Vorticity: The tendency to spin about an axis; Microscopic measure of rotation at any point in the fluid

Circulation: The tendency for a group of air parcels to rotate.

If an area of atmosphere is of interest, you compute the circulation.

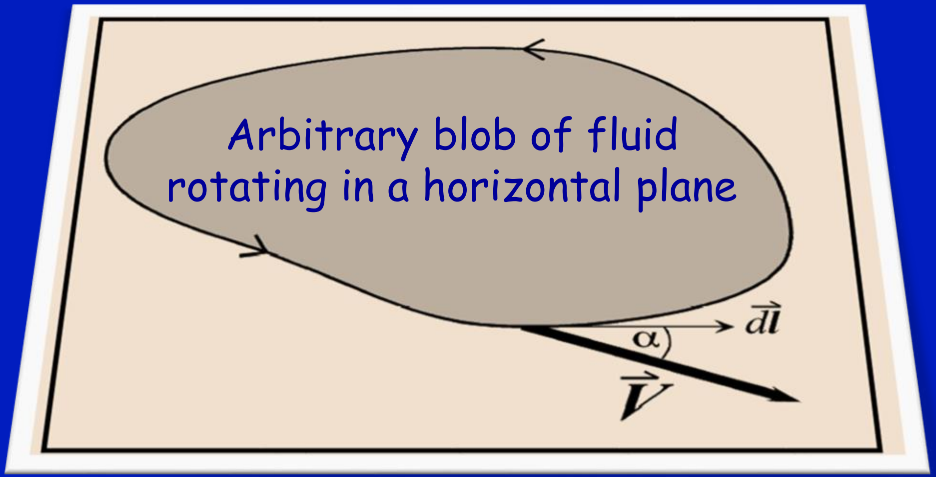
Vorticity: The tendency for the wind shear at a given point to induce rotation.

If a point in the atmosphere is of interest, you compute the vorticity

THE CIRCULATION THEOREM

The circulation, C, about a closed contour in a fluid is defined as the line integral evaluated along the contour of the component of the velocity vector that is locally tangent to the contour:

$$C = \oint \vec{V}.d\vec{l} = \oint |V| \cos\alpha \, dl$$



Where $\vec{l}(s)$ is a position vector extending from the origin to the point s(x, y, z) on the contour C,

$d\vec{l}$ represents the limit of $\delta\vec{l} = \vec{l}(s+\delta s) - \vec{l}(s)$ as $\delta s \to 0.$

Hence, as indicated in Fig., $d\vec{l}$ is a displacement vector locally tangent to the contour.

By convention the circulation is taken to be positive if $C > 0$ for counterclockwise integration around the contour.

That circulation is a measure of rotation is demonstrated readily by considering a circular ring of fluid of radius R in solid-body rotation at angular velocity about the z axis.

In this case, $\vec{U} = \vec{\Omega} \times \vec{R}$, where $\vec{R}$ is the distance from the axis of rotation to the ring of fluid.

Thus the circulation about the ring is given by

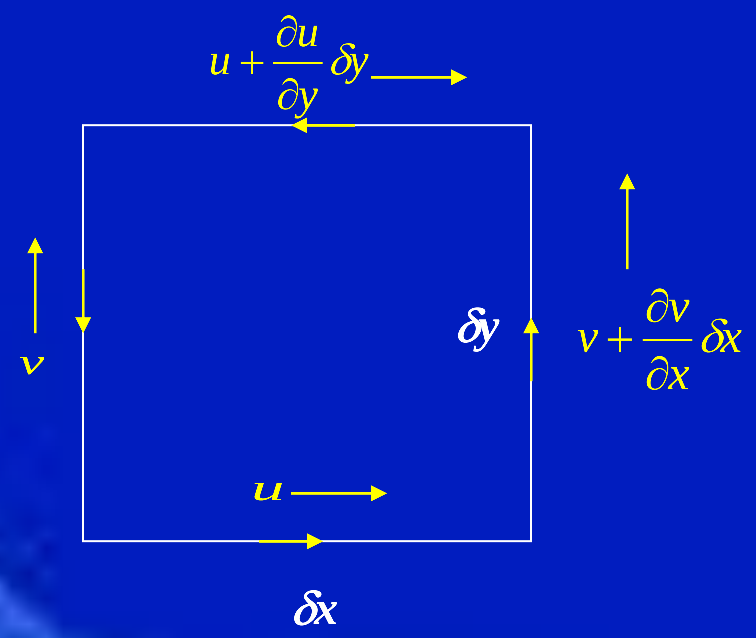
$$C = \oint \vec{V}.d\vec{l} = \int_0^{2\pi} \Omega R^2 d\lambda = 2\Omega\pi R^2$$

In this case the circulation is just 2π times the angular momentum of the fluid ring about the axis of rotation.

Alternatively, note that $C/(\pi R^2) = 2\Omega$ so that the circulation divided by the area enclosed by the loop is just twice the angular speed of rotation of the ring.

Circulation and Vorticity

The relationship between relative vorticity and circulation can be seen by considering the following expression, in which we will define the relative vorticity as the circulation about a closed contour in the horizontal plane divided by the area enclosed by that contour, in the limit as the area approaches zero.



$$\zeta = \lim_{A\to 0}\frac{\oint \vec{V}\cdot d\vec{l}}{A} \qquad C=\oint u\,dx+v\,dy$$

Evaluating $\vec{V}\cdot d\vec{l}$ for each side of the rectangle yields the circulation:

$$\delta C = u\,\delta x + \left(v+\frac{\partial v}{\partial x}\delta x\right)\delta y - \left(u+\frac{\partial u}{\partial y}\delta y\right)\delta x - v\,\delta y$$

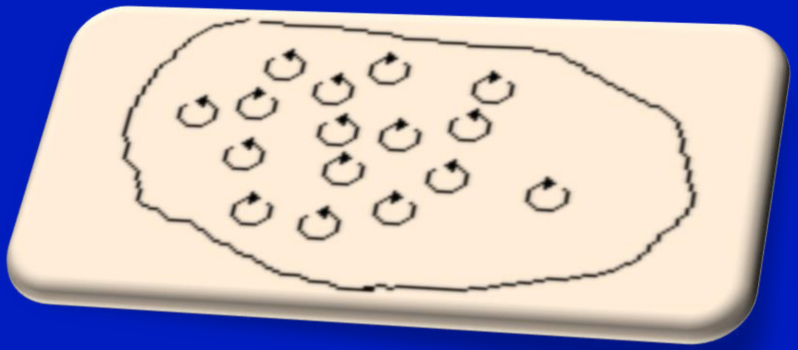
$$\delta C = \left(\frac{\partial v}{\partial x}-\frac{\partial u}{\partial y}\right)\delta x\delta y \qquad \delta A = \delta x\delta y$$

$$\frac{\delta C}{\delta A} = \left(\frac{\partial v}{\partial x} - \frac{\partial u}{\partial y} \right) = \zeta = relative\ vorticity$$

Circulation, Vorticity, and Stokes Theorem

In more general terms the relationship between vorticity and circulation is given simply by Stokes's theorem applied to the velocity vector:

$$\oint \vec{V}.d\vec{l} = \iint_A (\nabla \times \vec{V}).\hat{n}dA$$



Here A is the area enclosed by the contour and n is a unit normal to the area element dA (positive in the right sense).

Thus, Stokes's theorem states that the circulation about any closed loop is equal to the integral of the normal component of vorticity over the area enclosed by the contour.

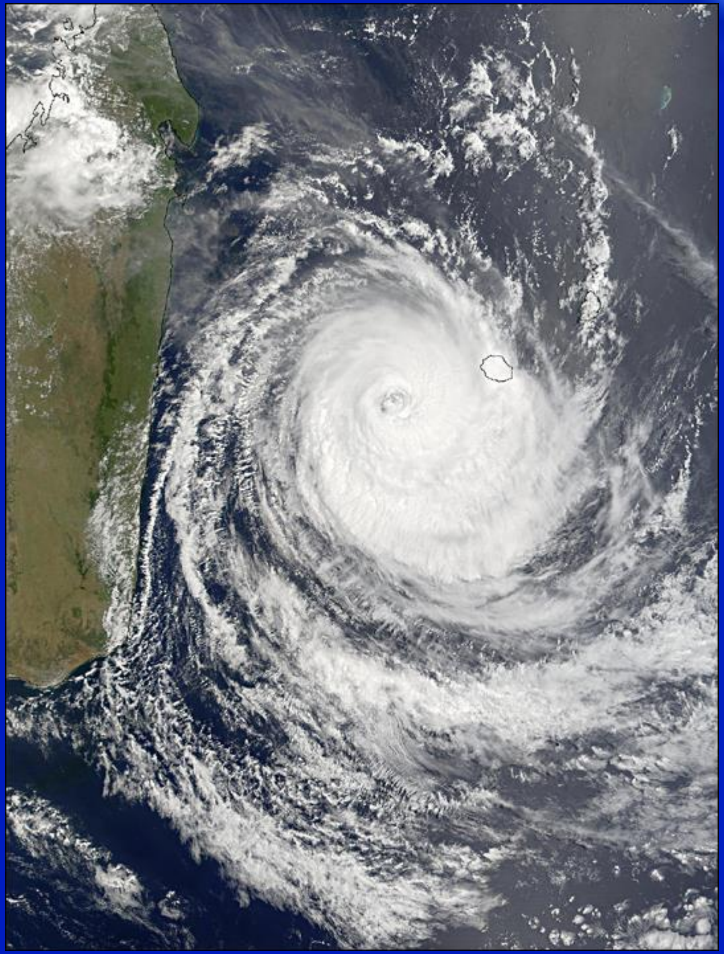
Hence, for a finite area, circulation divided by area gives the *average normal component of vorticity in* the region.

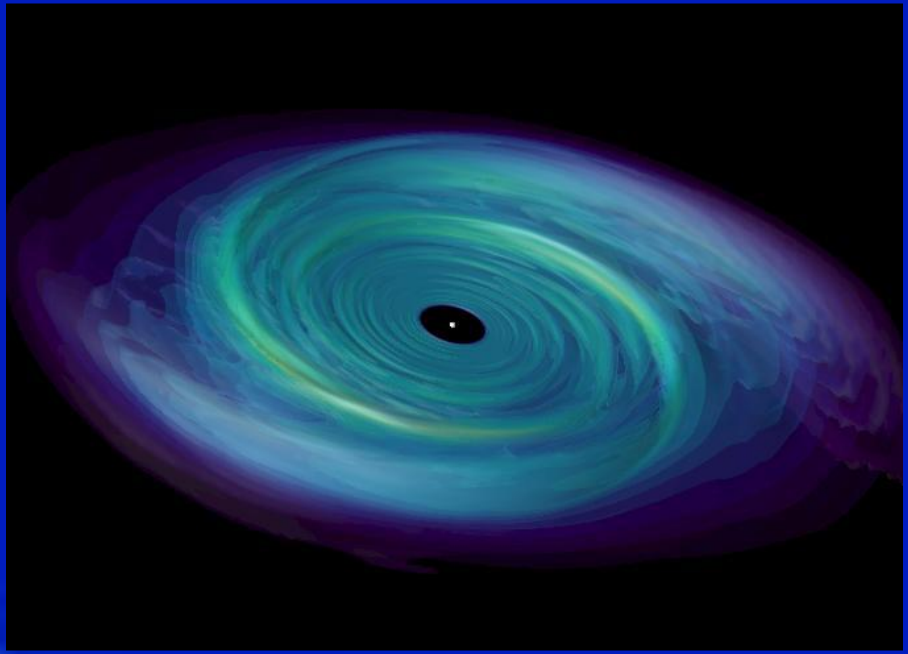
As a consequence, the vorticity of a fluid in solid-body rotation is just twice the angular velocity of rotation.

Vorticity may thus be regarded as a measure of the local angular velocity of the fluid.

Applications:

Cyclones & Tornado's



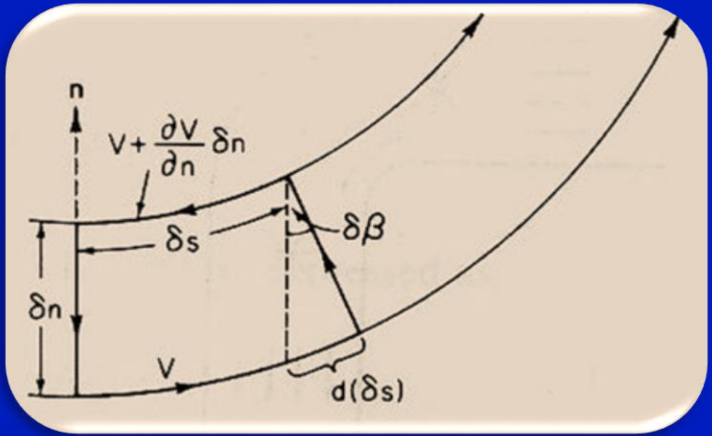


Vorticity in Natural Coordinates

Using natural coordinates can make it easier to physically interpret the relationship between relative vorticity and the flow.

To express vorticity in natural coordinates, we compute the circulation around the infinitesimal contour shown below.

$$\delta C = V[\delta s + d(\delta s)] - \left(V + \frac{\partial V}{\partial n}\delta n \right)\delta s$$



From the diagram, $d(\delta s) = \delta\beta\,\delta n$, where $d\beta$ is the angular change in wind direction in the distance ds.

$$\delta C = \left(-\frac{\partial V}{\partial n} + V\frac{\partial \beta}{\partial s} \right)\delta n\,\delta s$$

Or in the limit $\delta n \delta s \rightarrow 0$

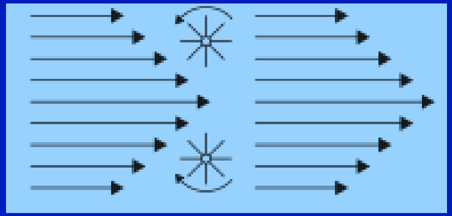
$$\zeta = \lim_{\delta n, \delta s \rightarrow 0} \frac{\delta C}{\delta n\,\delta s} = \boxed{-\frac{\partial V}{\partial n} + \frac{V}{R_s}}$$

where R_s is the radius of curvature of the streamlines

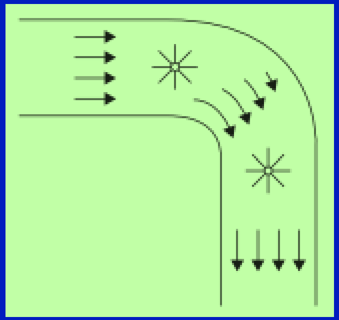
Vorticity in natural coordinates: $\zeta = -\dfrac{\partial V}{\partial n} + \dfrac{V}{R_s}$

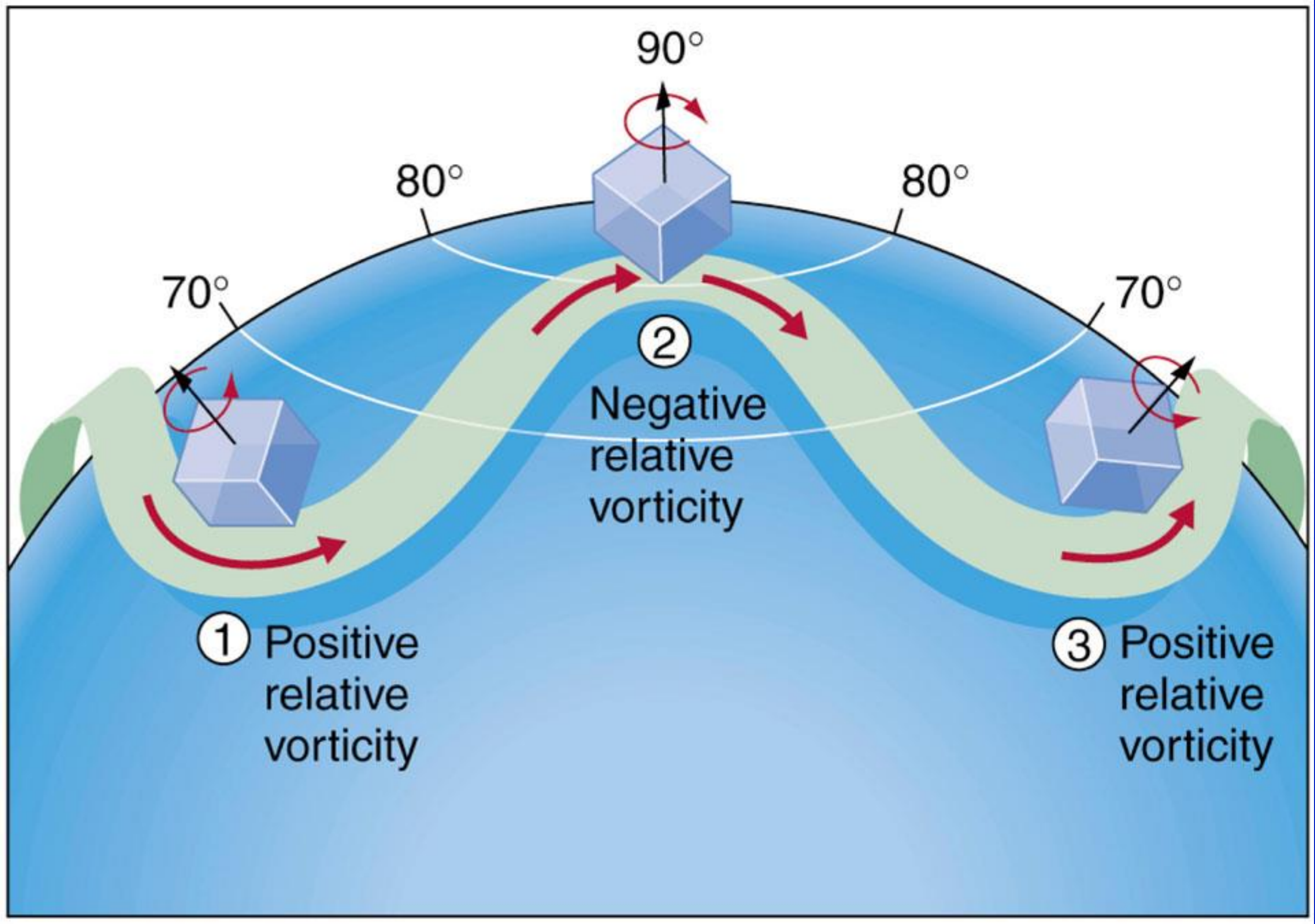
It is now apparent that the net vertical vorticity component is the result of the sum of two parts:

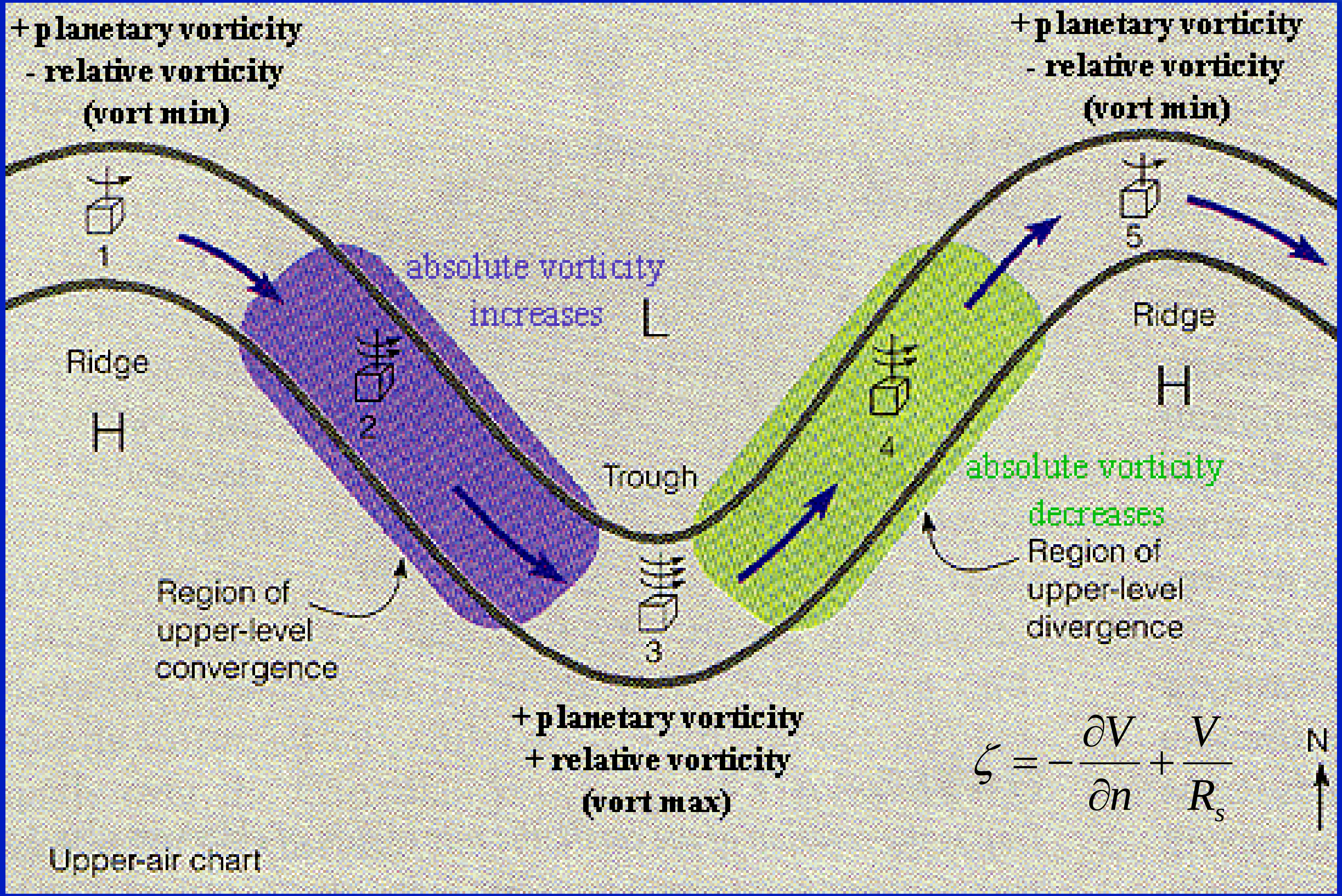
$-\dfrac{\partial V}{\partial n}$ The rate of change of wind speed normal to the direction of flow, which is called the shear vorticity.



$\dfrac{V}{R_s}$ The turning of the wind along a streamline, which is called the curvature vorticity.

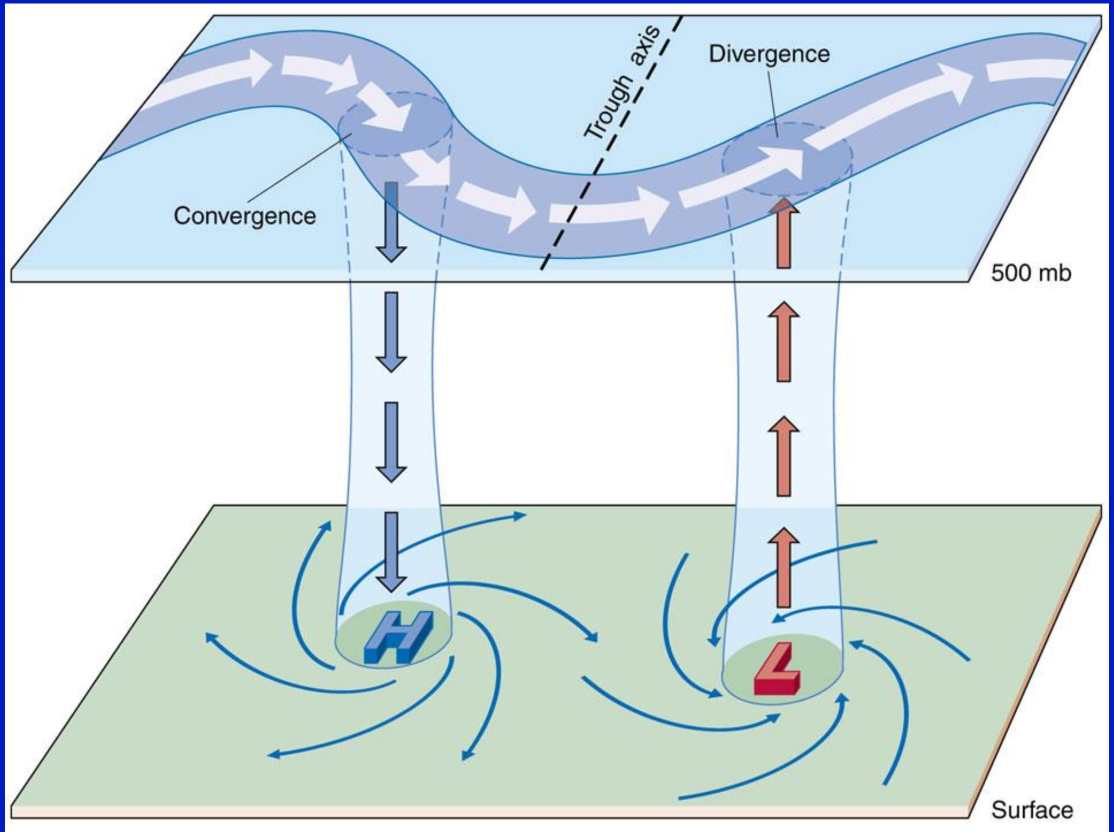


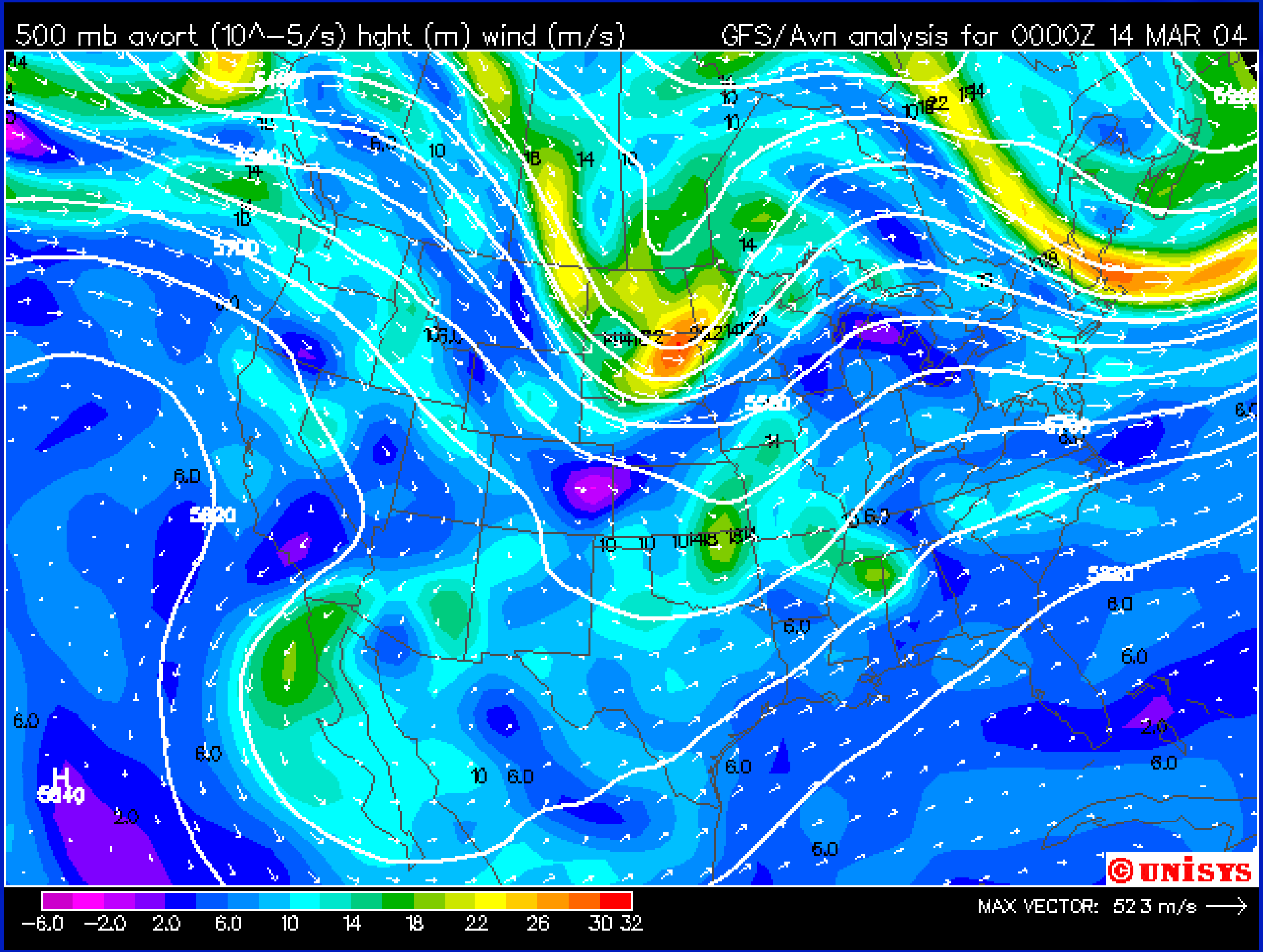

90°
80°
80°
70°
70°
2 Negative relative vorticity
1 Positive relative vorticity
3 Positive relative vorticity



Vorticity Maximum: Along the trough axis to left of the strongest flow. Both shear and curvature terms are positive.

Vorticity Minimum: Along the ridge axis to right of the strongest flow. Both shear and curvature terms are negative.

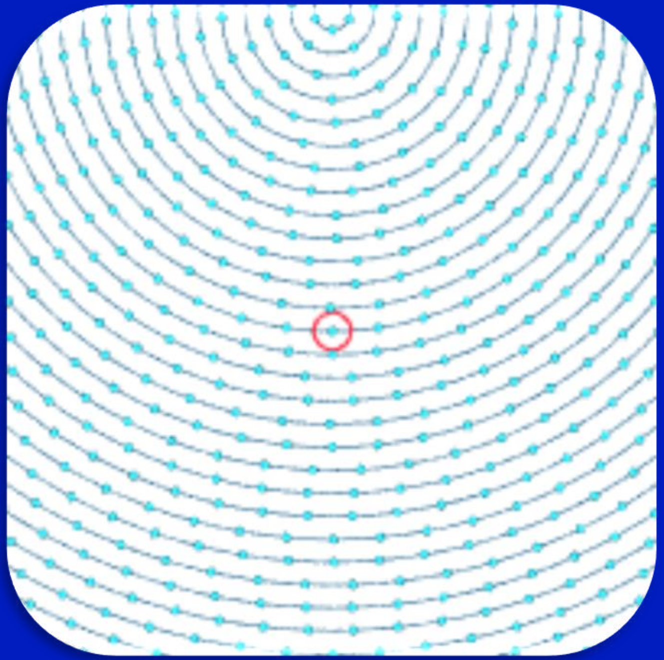

Trough axis
Divergence
Convergence
500 mb
H
L
Surface



Absolute vorticity = $\zeta + f$

In a mass of continuum that is rotating like a rigid body, the vorticity is twice the angular velocity vector of that rotation.

This is the case, for example, of water in a tank that has been spinning for a while around its vertical axis, at a constant rate.



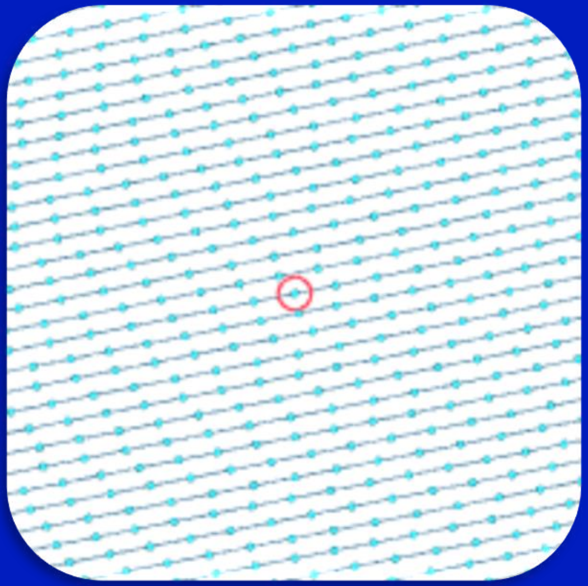
Rigid-body-like vortex

$$v \propto r$$

The vorticity may be nonzero even when all particles are flowing along straight and parallel pathlines, if there is shear (that is, if the flow speed varies across streamlines).

For example, in the laminar flow within a pipe with constant cross section all particles travel parallel to the axis of the pipe; but faster near that axis, and practically stationary next to the walls.

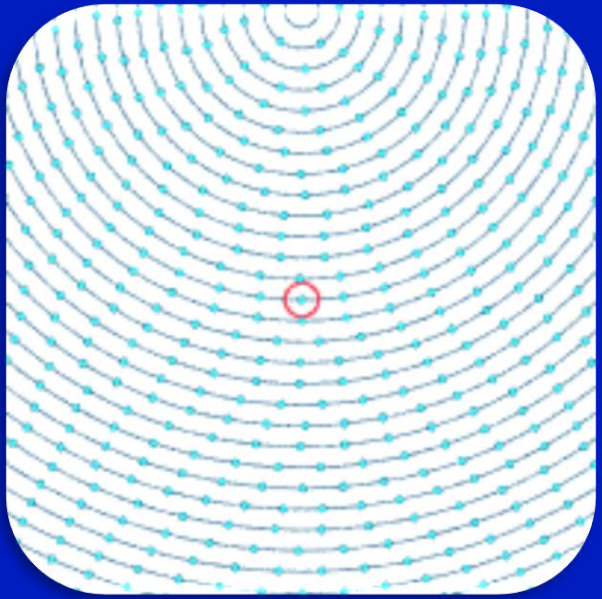
The vorticity will be zero on the axis, and maximum near the walls, where the shear is largest.



Parallel flow with shear

Conversely, a flow may have zero vorticity even though its particles travel along curved trajectories.

An example is the ideal irrotational vortex, where most particles rotate about some straight axis, with speed inversely proportional to their distances to that axis. A small parcel of continuum that does not straddle the axis will be rotated in one sense but sheared in the opposite sense, in such a way that their mean angular velocity *about their center of mass* is zero.



Irrotational vortex
$v \propto 1/r$