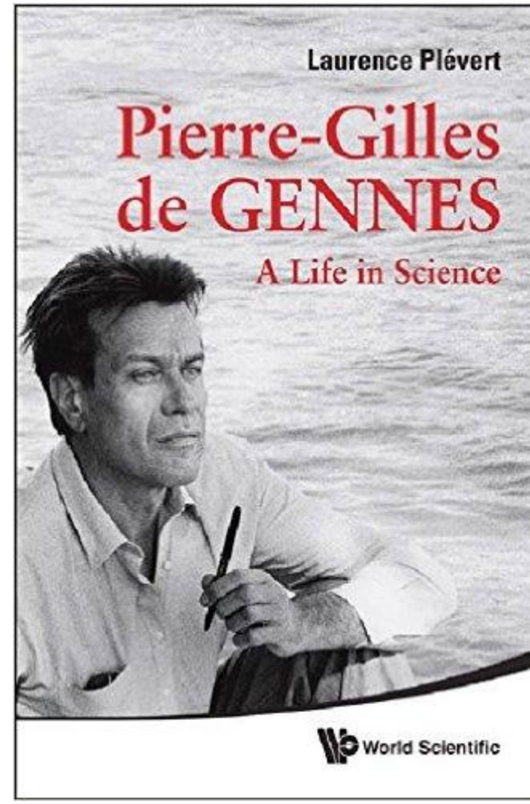
Dynamic meteorology without tears

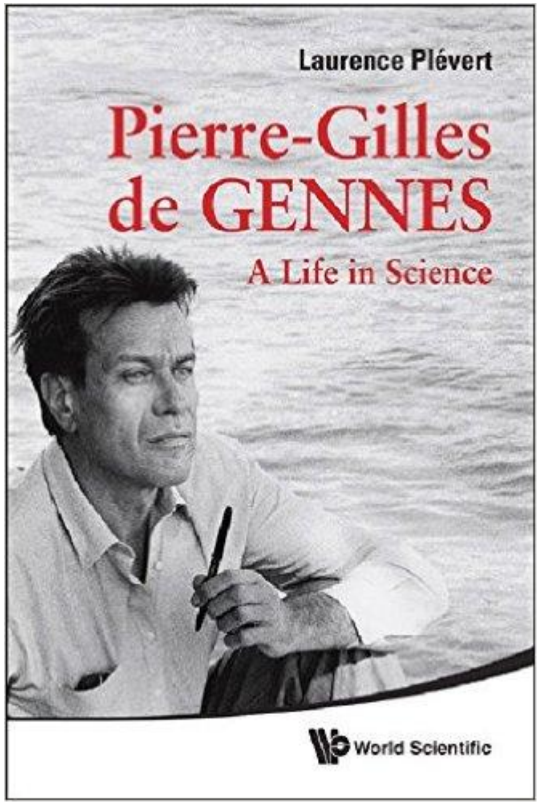
Part I: Common misinterpretations in dynamic meteorology

Пьер Жиль де Жен (фр. *Pierre-Gilles de Gennes*; 24 октября 1932, Париж — 18 мая 2007, Орсе) — французский физик, лауреат Нобелевской премии по физике в 1991году «за обнаружение того, что методы, развитые для изучения явлений упорядоченности в простых системах, могут быть обобщены на жидкие кристаллы и полимеры». Де Жен известен прежде всего тем, что открыл структуру, положившую начало производству ЖК-дисплеев. За множество фундаментальных открытий многие научные круги называют де Жена «Ньютоном нашего времени».



Пьер Жиль де Жен (фр. *Pierre-Gilles de Gennes*; 24 октября 1932, Париж —

“The easiest thing in physics is the mathematics, the difficult bit is what it means”



плеев. За множество фундаментальных открытий многие научные круги называют де Жена «Ньютоном нашего времени».

Some common misinterpretations:

1. The Foucault pendulum
2. The Coriolis effect (The Trade winds)
3. Acceleration in a constant pressure field
4. Ageostrophic winds without friction
5. Kinetic and potential energy conversion
6. Streamlines versus trajectories
7. Air passing over a mountain conserving PV

The mathematics is mostly correct, but the physical interpretation is often incomplete, misleading or erroneous

1. The Foucault Pendulum (1851)

Because of the Earth's rotation the plane of swing of the pendulum turns during the day.

It makes one full revolution in **24h (23h 56 m)/sin (latitude)**

This means: **24**h at the Poles, **30**h in Paris, **48**h in Casablanca and

∞h at the equator (no turning)

. . . but the common explanation, with a pendulum over a rotating turntable, implies the same turning period everywhere – 24h (23h56m) - which is only valid at the Poles

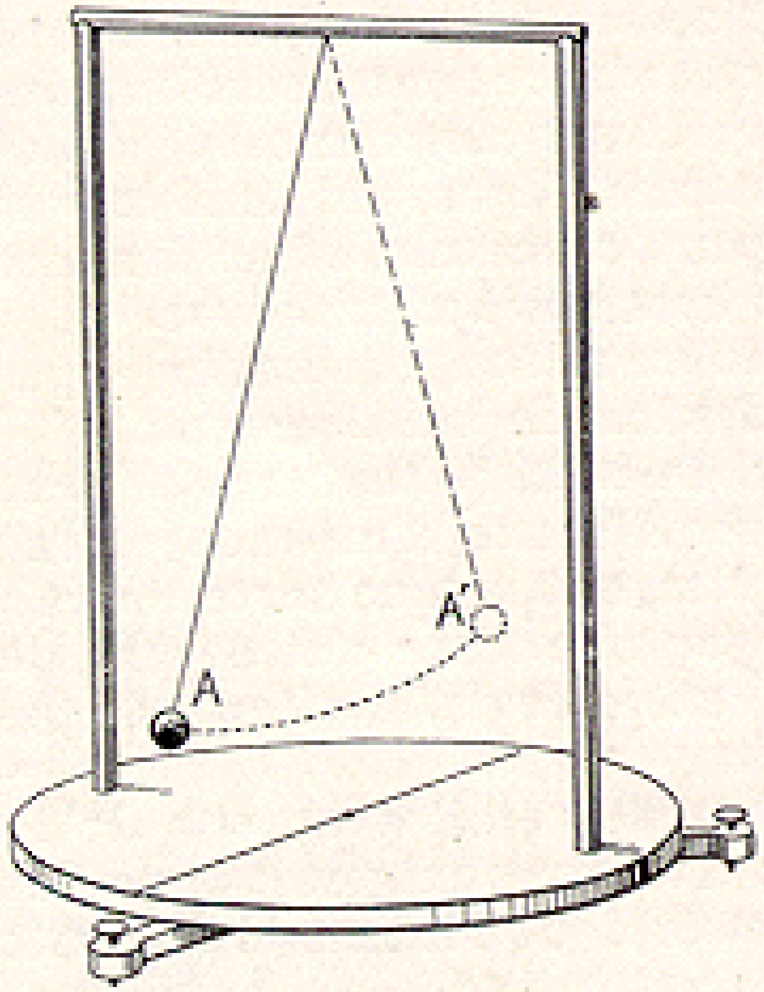
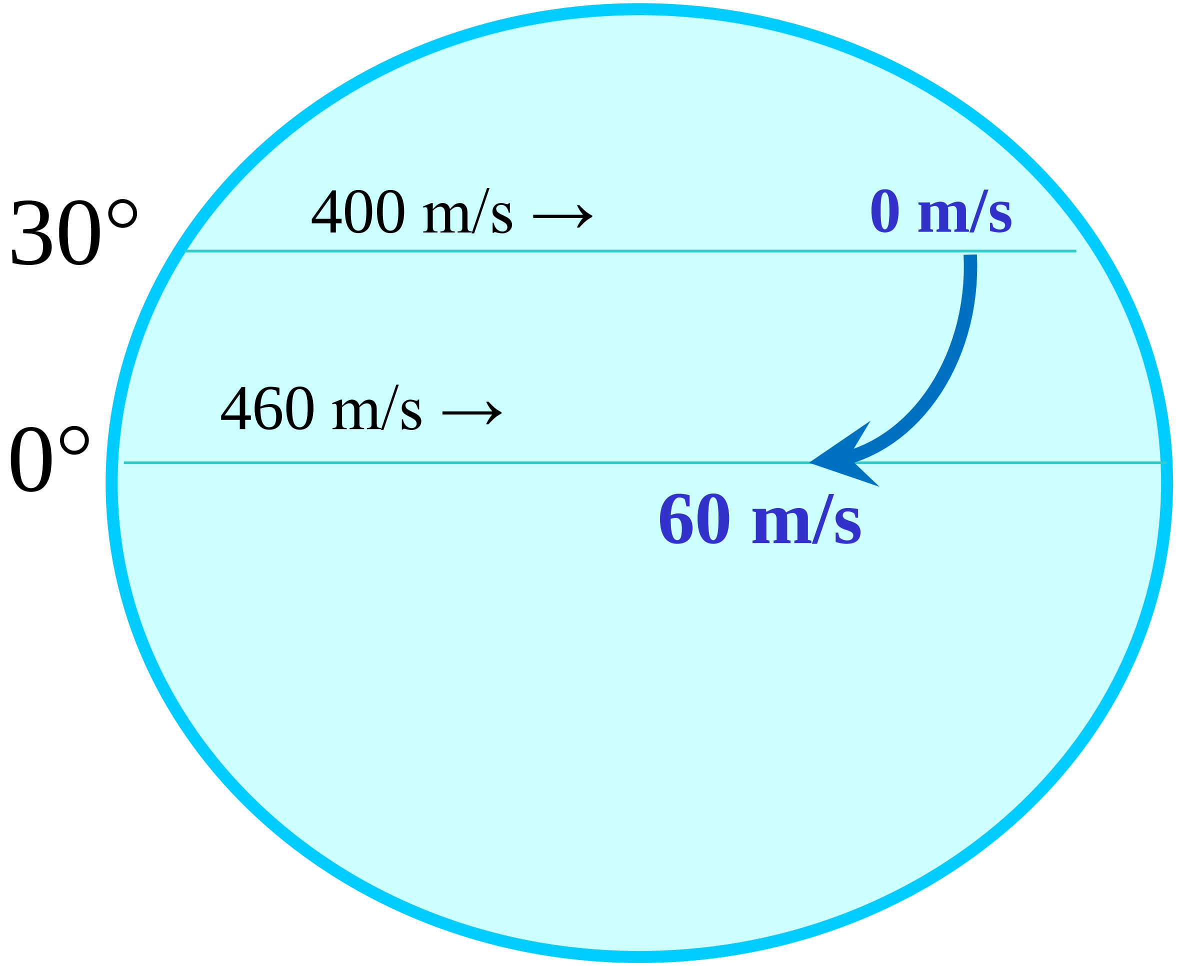


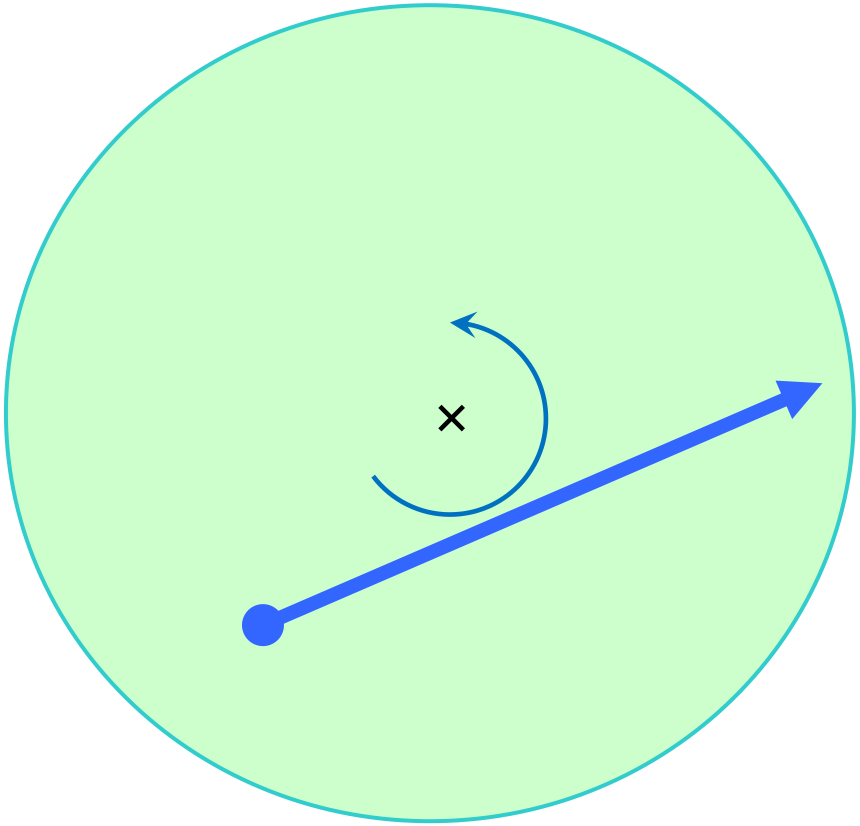
FIG. 19. — Principe de l'expérience du PENDULE DE FOUCAULT.

2. The Coriolis Effect

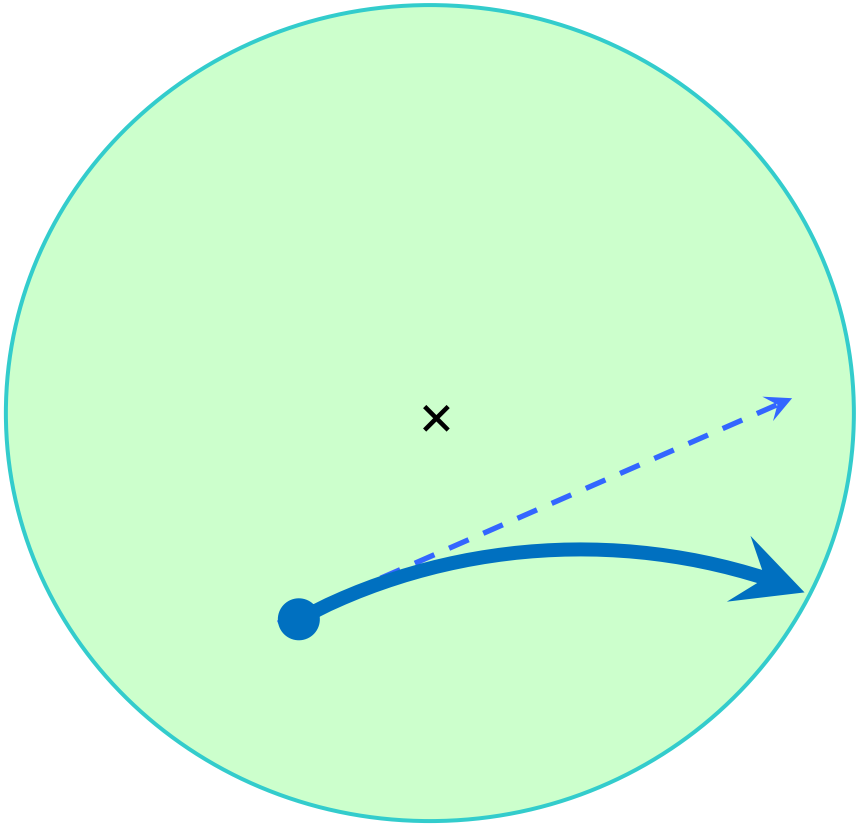


A popular, but very erroneous explanation of the Coriolis effect on a rotating planet, assuming the winds conserve their absolute velocity – **which they do not!**

Another popular, but erroneous explanation of the Coriolis effect



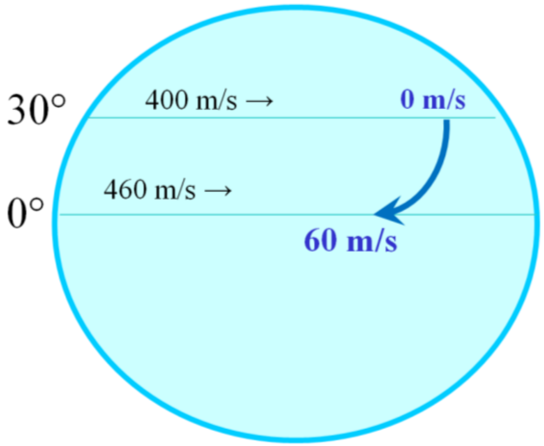
Seen from **outside** the carousel



Seen from **inside** the carousel

But the Coriolis force is not alone, there is also **the centrifugal force**

But if the two erroneous assumptions are mathematically combined, as is done in many textbooks, **one gets the correct result**



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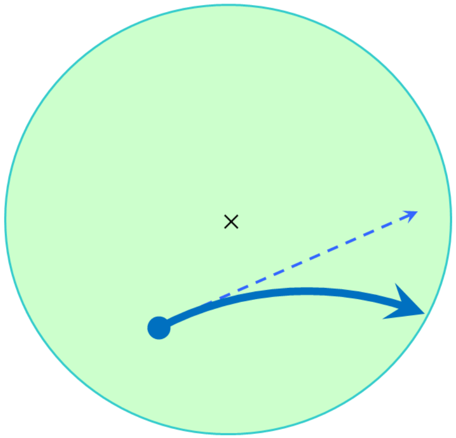

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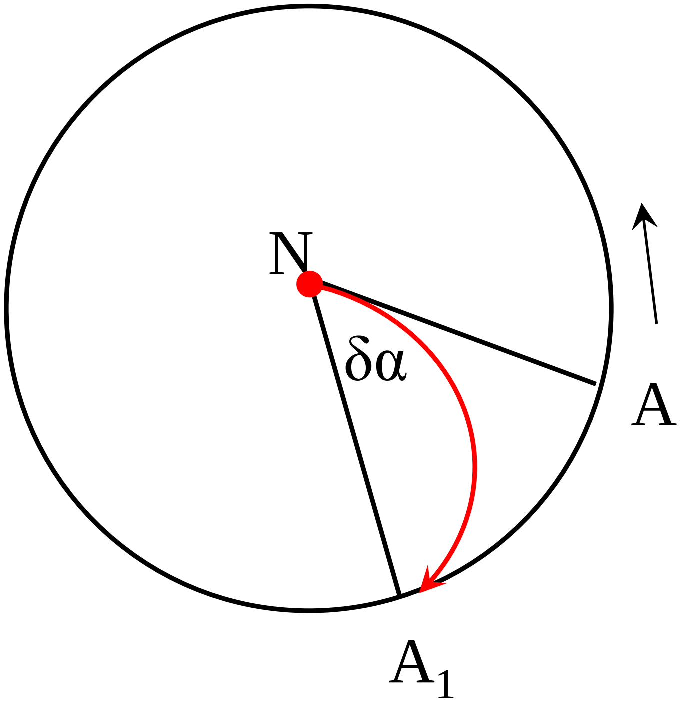


The derivation combines the previous erroneous assumptions: that the absolute velocity is conserved (left) and that on a rotating carousel only the Coriolis force is active (right)

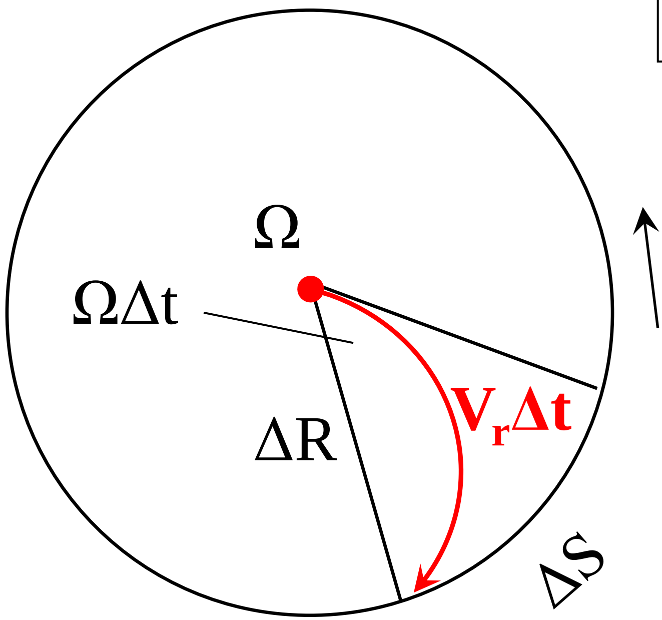
This very easily understood, but erroneous, derivation of the Coriolis force appears in two different versions

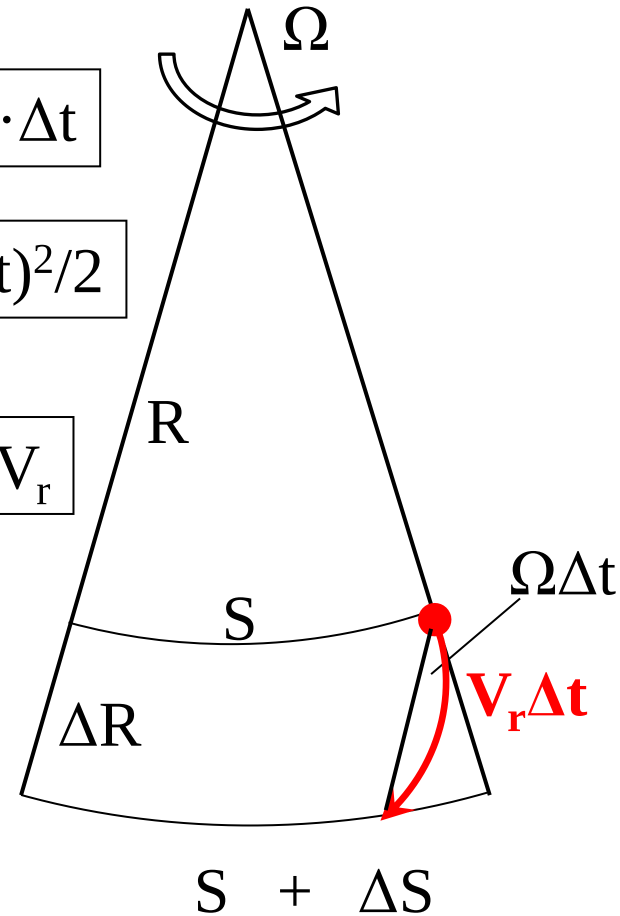
acc = sideways acceleration (Coriolis effect)

$$\Delta S = \Omega \cdot \Delta t \cdot V_r \cdot \Delta t$$

$$\Delta S = acc \cdot (\Delta t)^2/2$$

$$acc = 2\Omega \cdot V_r$$





One of them is found in at least two Russian textbooks in dynamic meteorology

Министерство высшего и среднего специального образования РСФСР

ЛЕНИНГРАДСКИЙ ГИДРОМЕТЕОРОЛОГИЧЕСКИЙ ИНСТИТУТ

И. И. МЕЛЬНИКОВА, В. М. РАДИКЕВИЧ

ДИНАМИЧЕСКАЯ МЕТЕОРОЛОГИЯ

(учебное пособие для океанологов)

Под редакцией профессора Д. Л. Лайхтмана

ЛЕНИНГРАД
1974

Отклоняющая сила вращения Земли (сила Кориолиса)

Отклоняющая сила вращения Земли представляет дополнительную инерционную силу, действующую на частичку воздуха, движущуюся относительно поверхности Земли. Сила Кориолиса (названа по имени французского механика Густава Гаспара Кориолиса, впервые рассчитавшего эту силу) возникает за счет вращения Земли. Если бы Земля не вращалась, то путь частицы воздуха от полюса до экватора был бы NA (рис. 3), в результате вращения Земли частица попадает в точку A_1, $NA_1 = c \cdot dt$ (где c — скорость частицы). За время dt Земля повернулась на угол $\delta\alpha = \omega dt$.

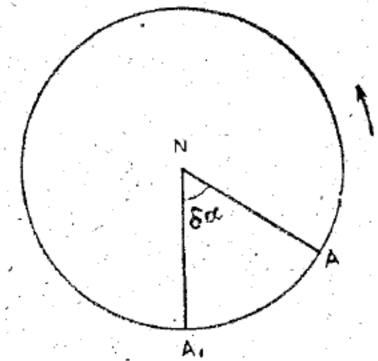


Рис. 3. Траектория движения частицы от полюса к экватору.

Для малых dt мало $\delta\alpha$ и можно считать

$$AA_1 = NA_1 \cdot \delta\alpha = c\omega (dt)^2.$$

С другой стороны, для равномерно-ускоренного движения

$$AA_1 = \frac{1}{2} a \cdot (dt)^2,$$

где a — ускорение за счет вращения Земли или ускорение Кориолиса.

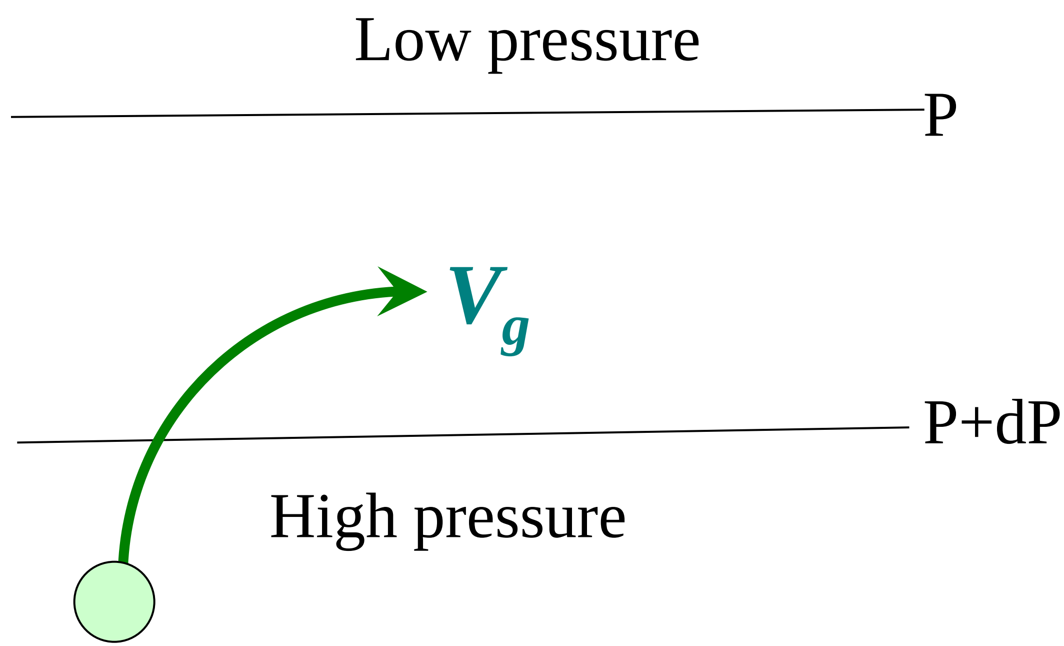
Из сравнения выражений для AA_1 получаем

$$a = 2\omega \cdot c, \qquad (2.2.4)$$

3. Acceleration of the wind in a constant pressure field

$$\frac{du}{dt} - fv = 0$$

$$\frac{dv}{dt} + fu = -\frac{\partial P}{\rho \cdot \partial y}$$



The common textbook (erroneous) interpretation gives an image of a smooth "well behaved" approach to geostrophic balance

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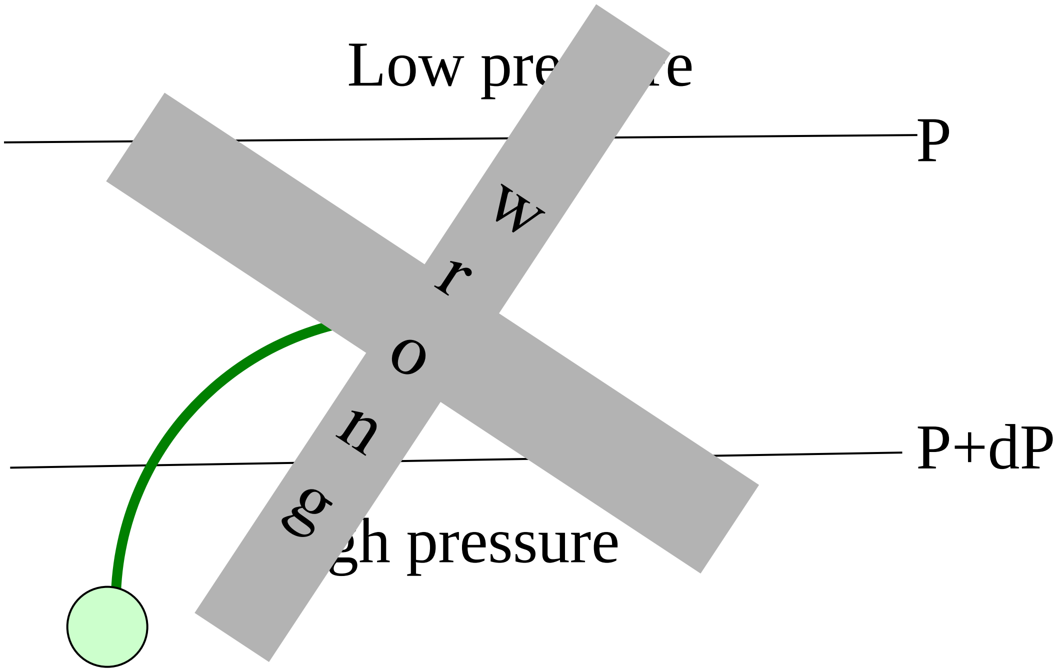
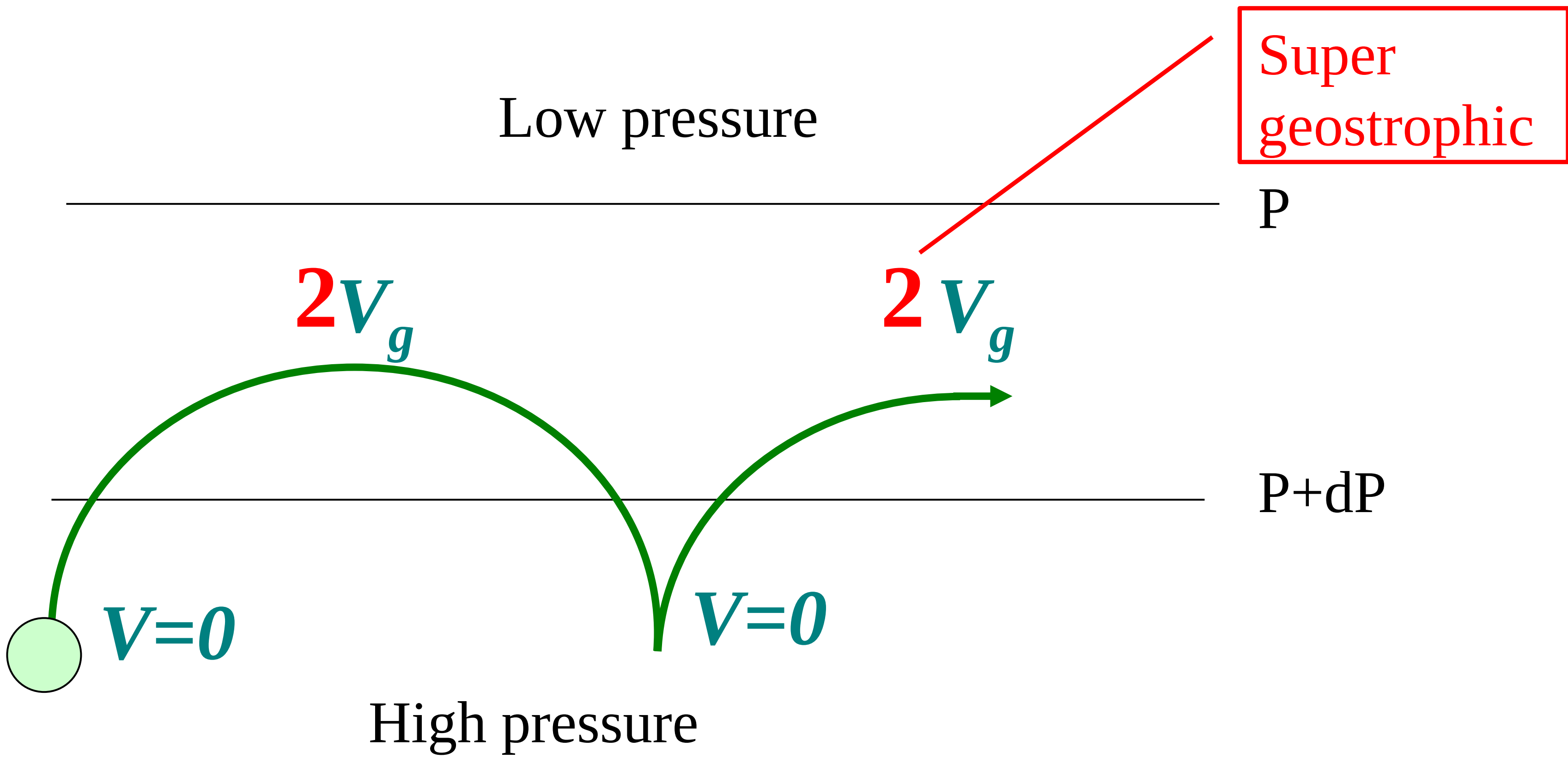


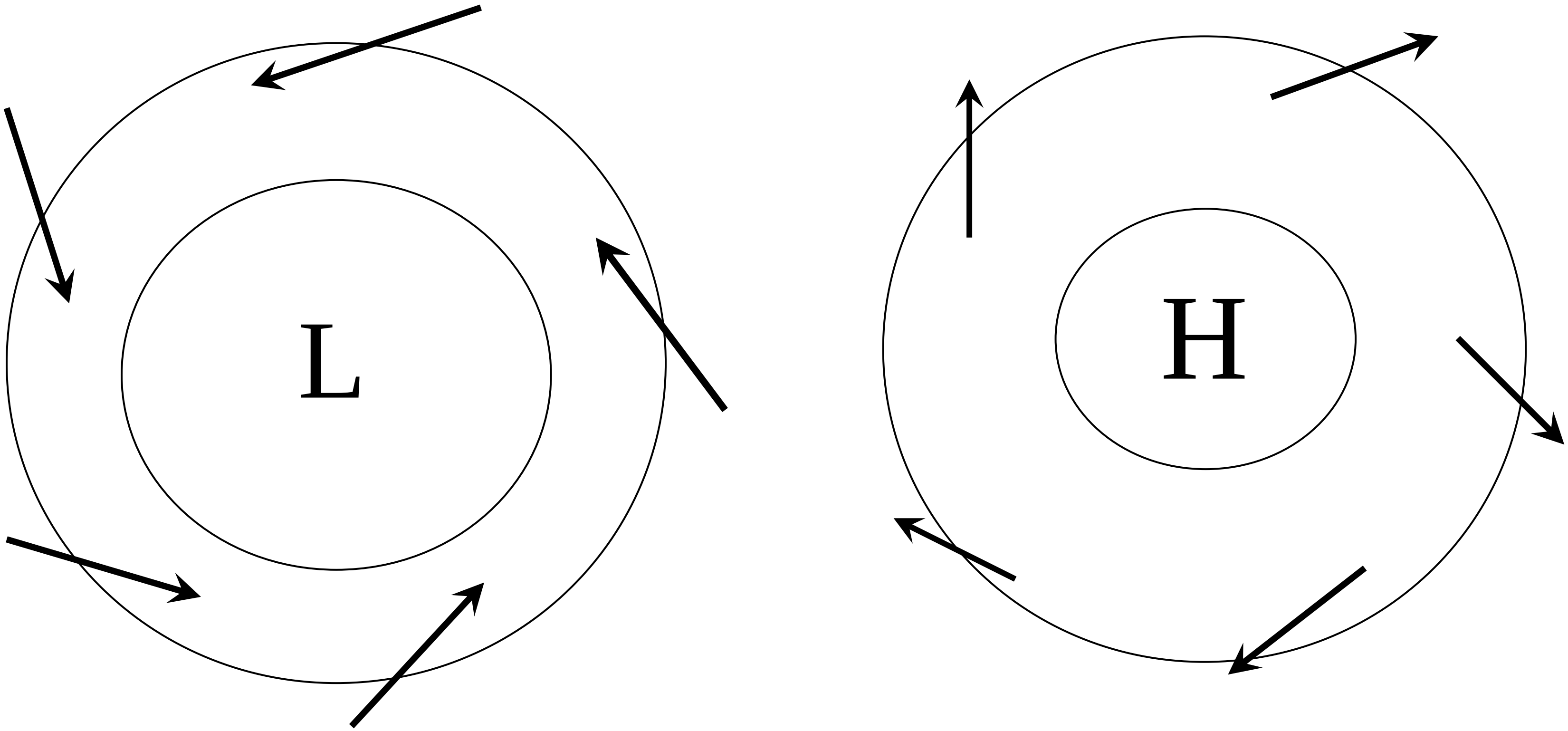
The common textbook (erroneous) interpretation gives an image of a smooth “well behaved” approach to geostrophic balance

The real image looks more like a case of "road rage" when the super geostrophic winds turn to the right

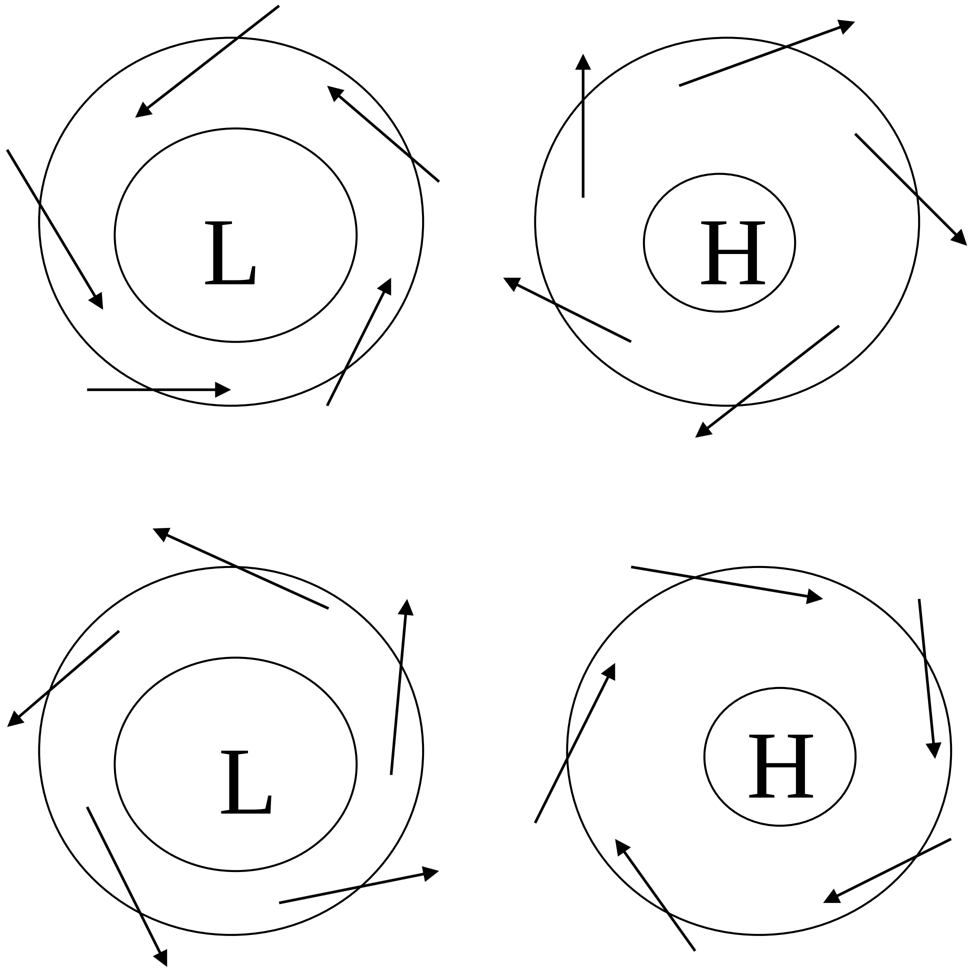


This is no "playing with mathematics" but the basis for an understanding of different types of jet streams

4. Typical relations between isobars and winds in the friction layer



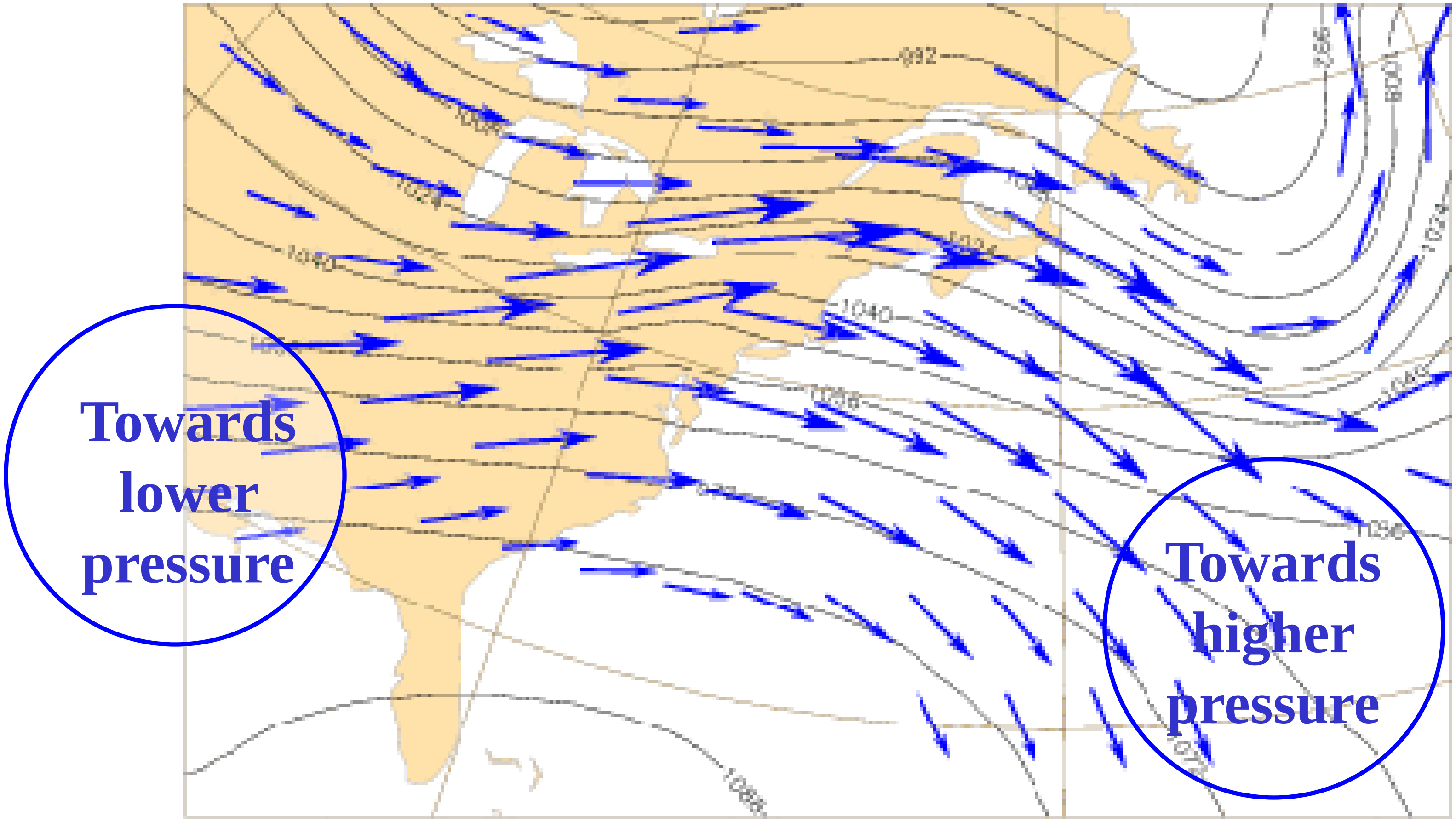
Typical relations between isobars and winds <u>above</u> frictional layer



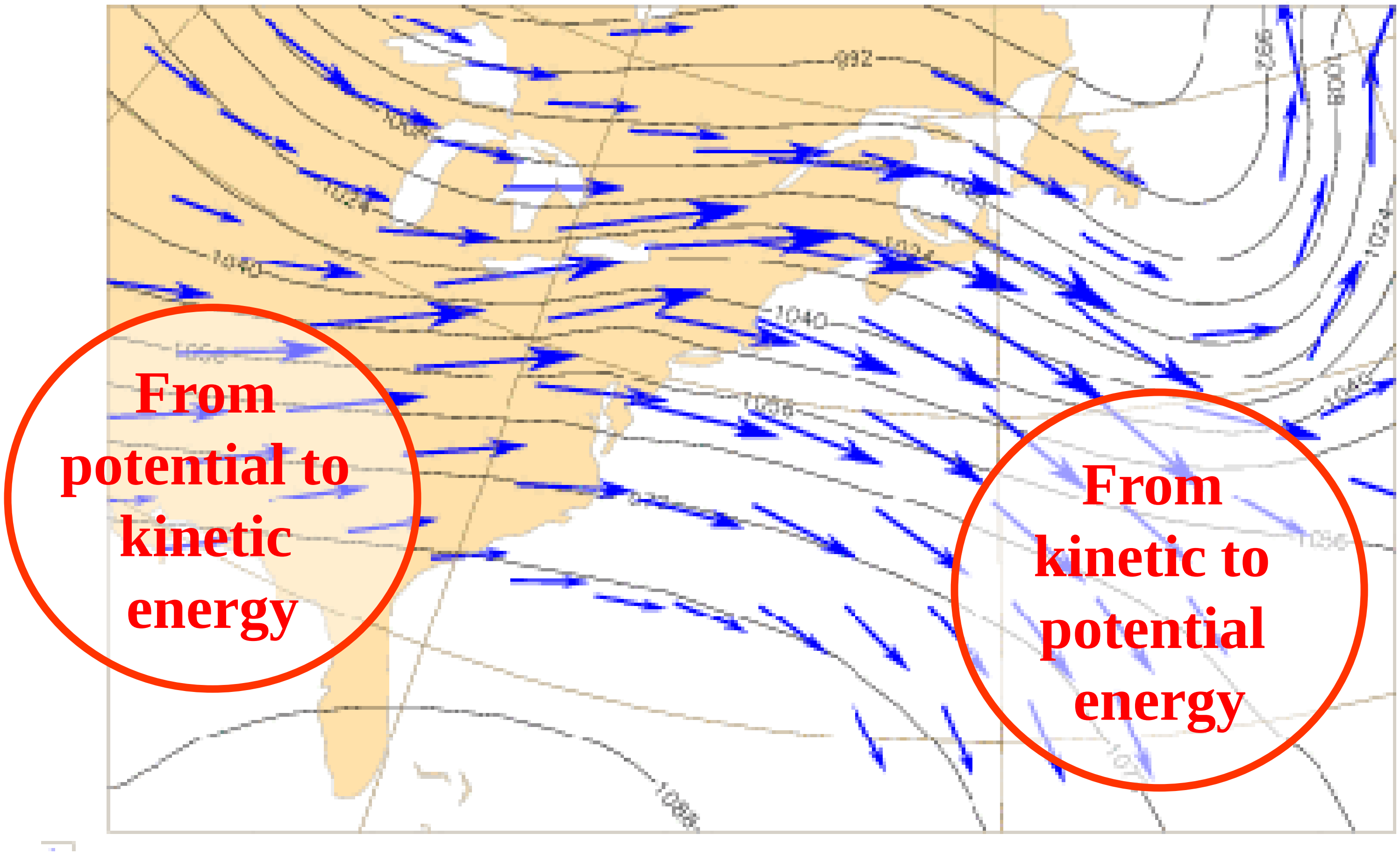
As in the friction layer but not because of friction

Under frictionless conditions inertia can deflect the wind in the opposite direction

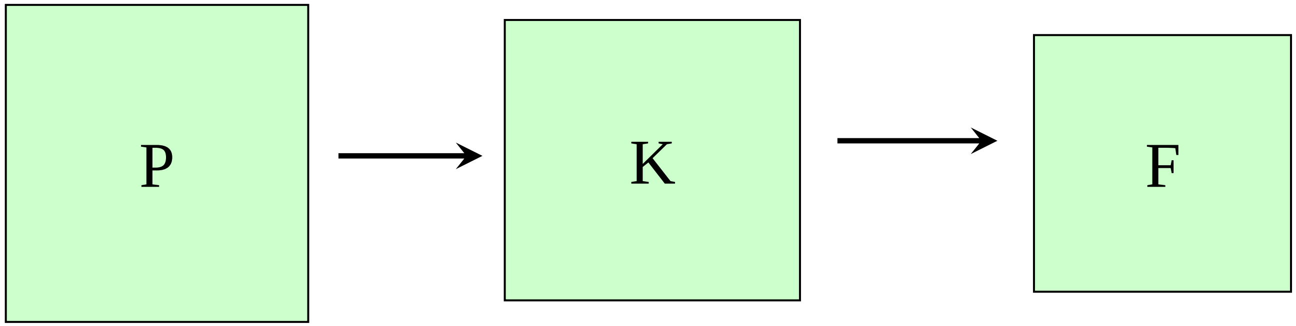
Ageostrophic winds in a jetstream



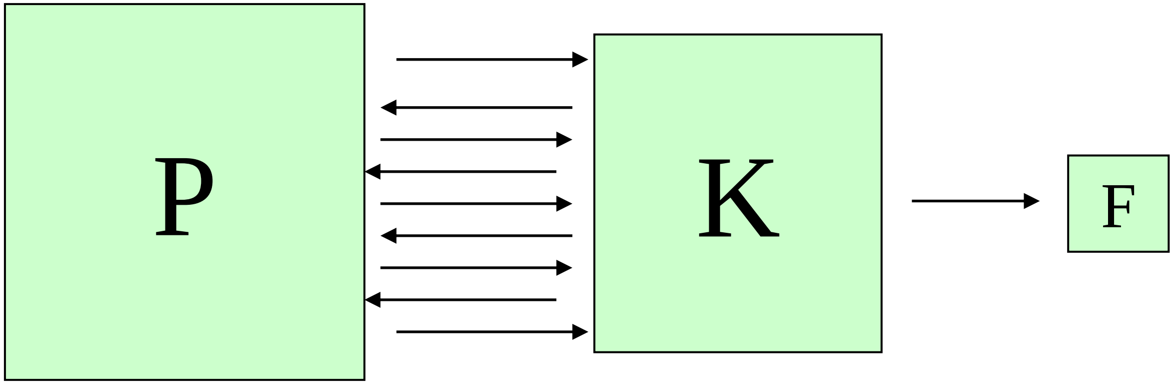
5. The typical energy conversions



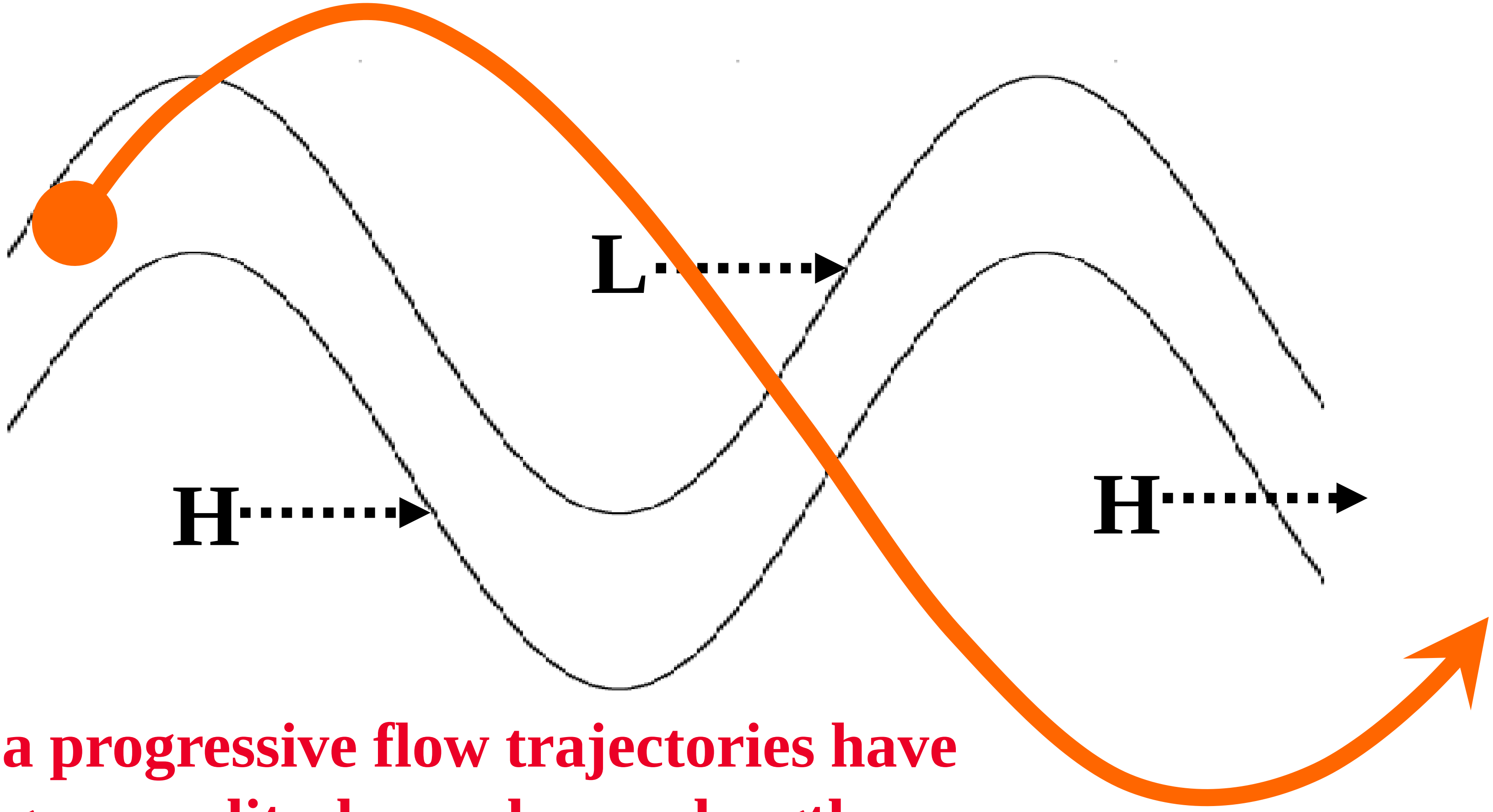
The energy budget should not



be confused with the continuous energy conversions

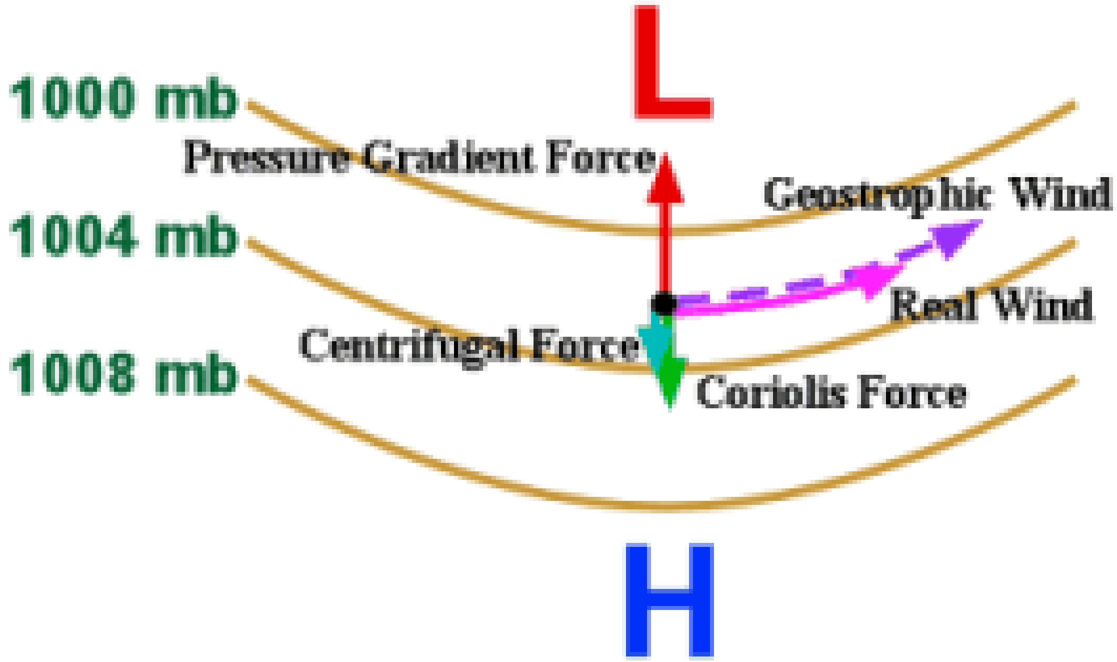


6. Stream lines and trajectories



In a progressive flow trajectories have larger amplitudes and wave lengths

A common error is to relate the curvature in the **gradient wind balance** to the streamlines and not to the trajectories

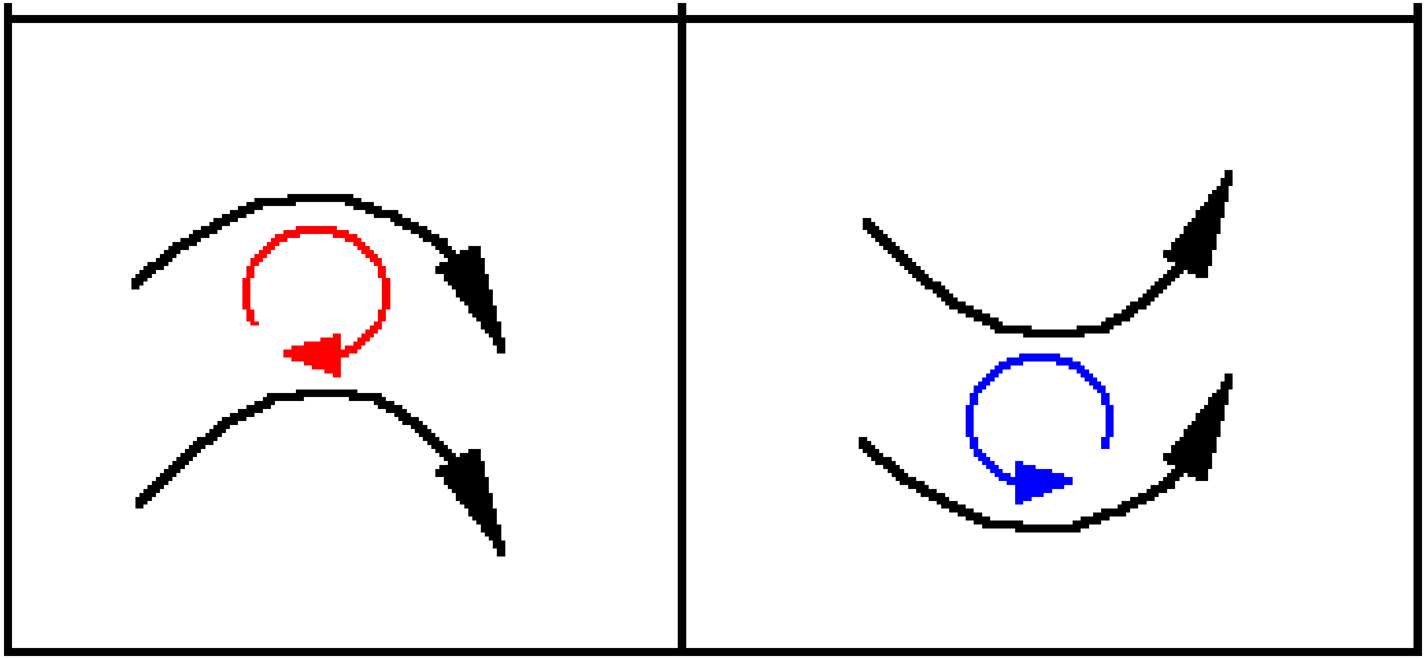


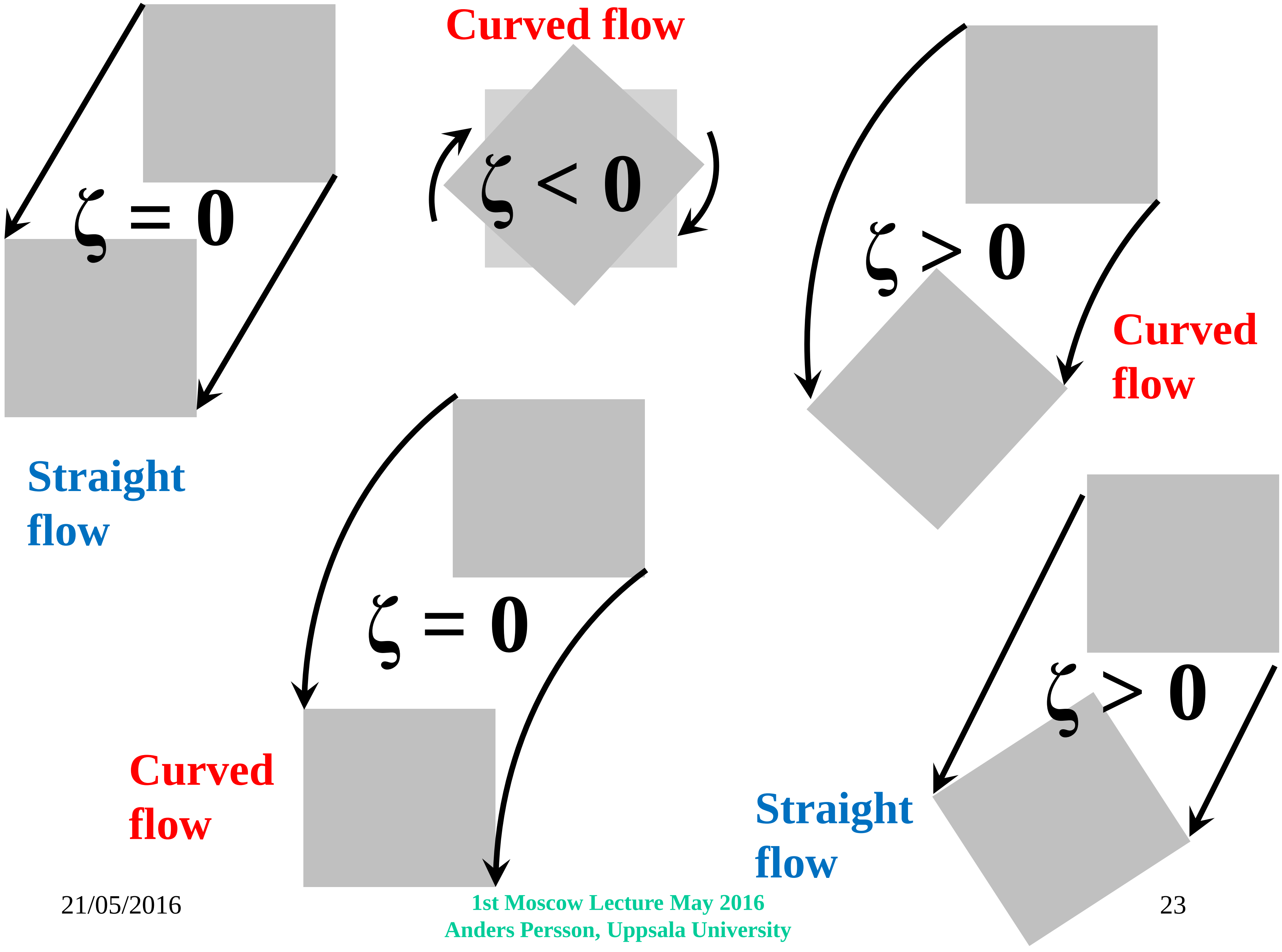
Even C.G. Rossby committed this error (in 1939)

A similar error is done with vorticity. It does **not** depend on the curvature of the streamlines

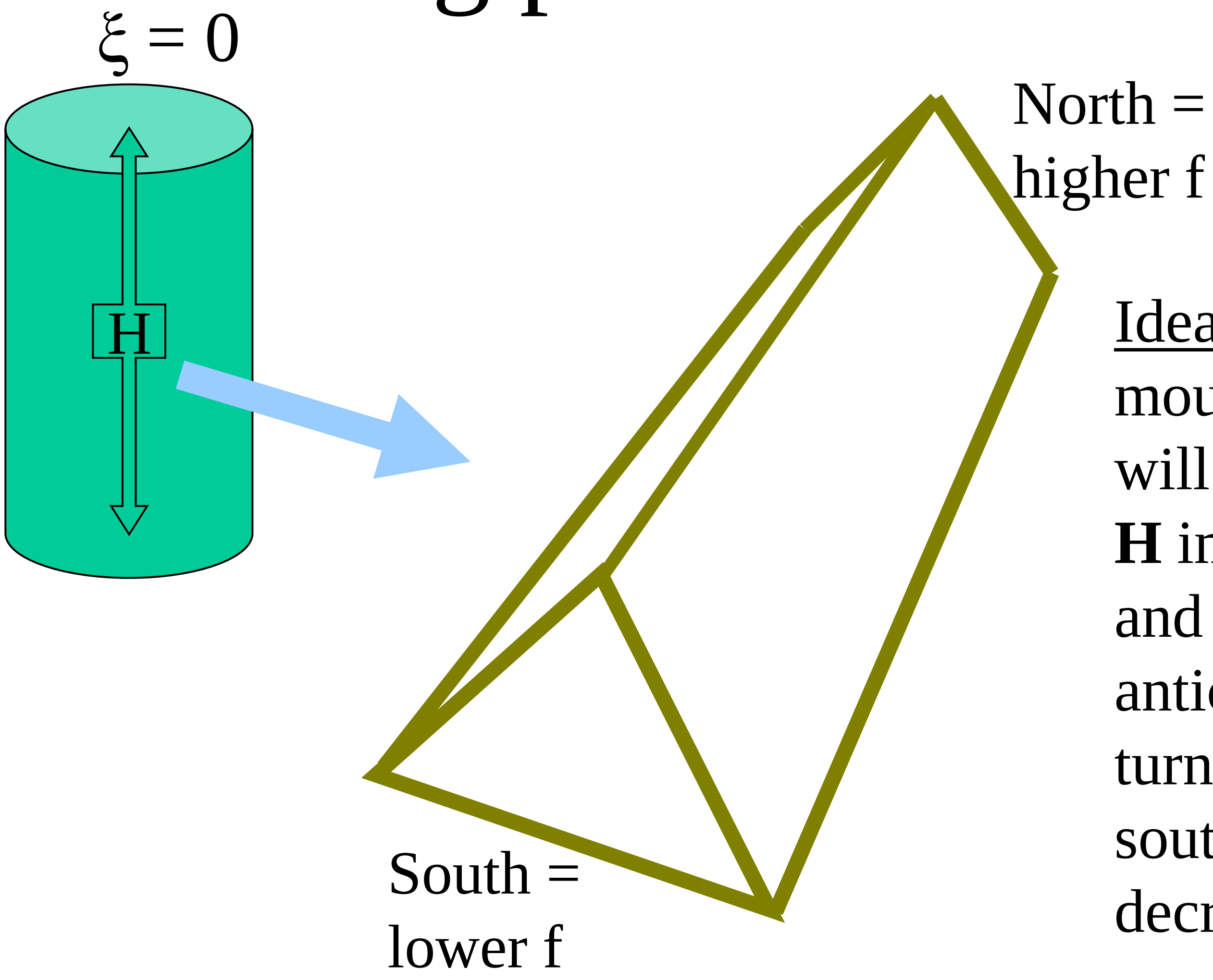
Negative vorticity???

Positive vorticity???



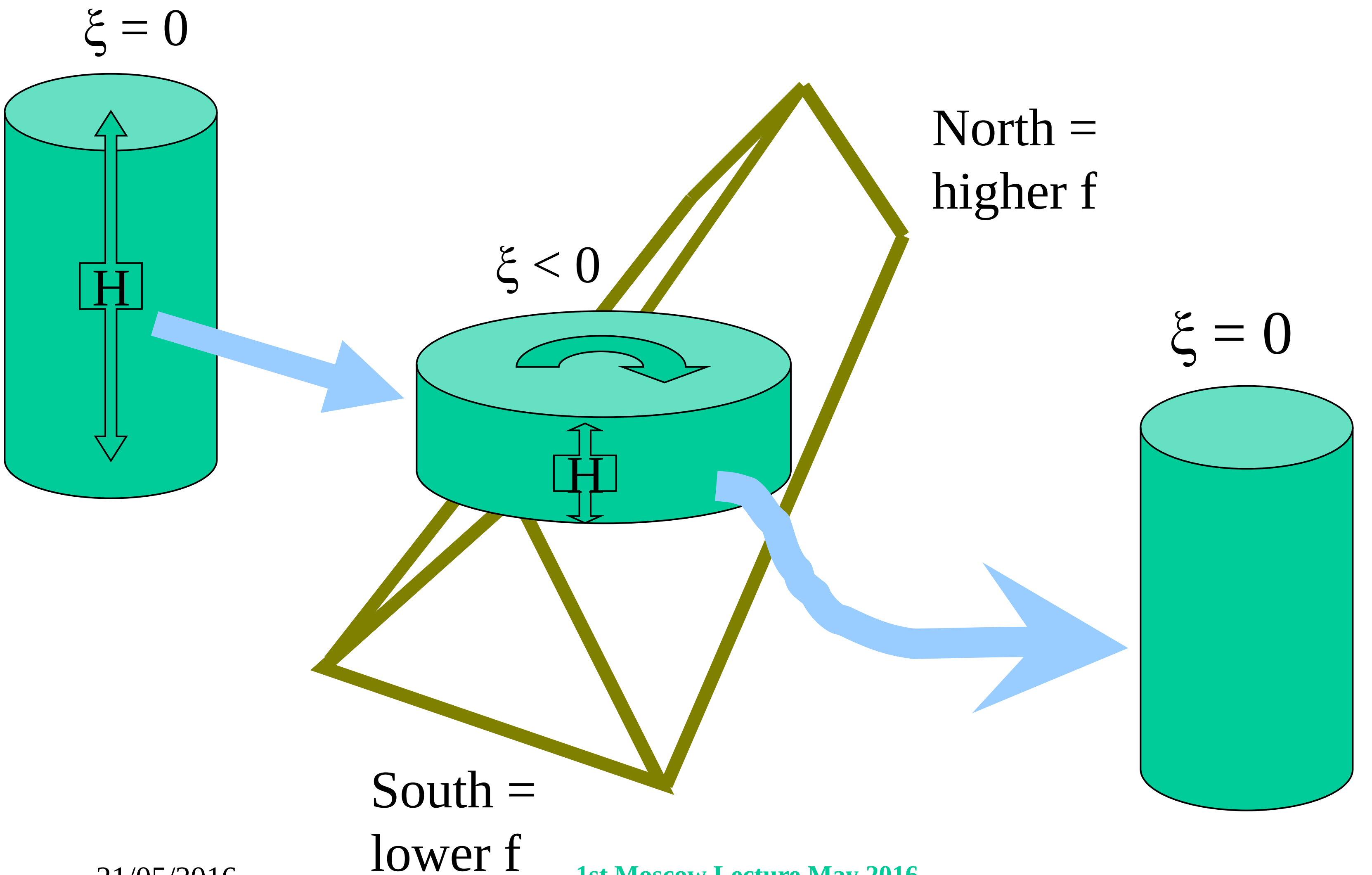

Curved flow
$\zeta = 0$
$\zeta < 0$
$\zeta > 0$
Curved flow
Straight flow
$\zeta = 0$
Curved flow
$\zeta > 0$
Straight flow

7. Air passing a mountain conserving potential vorticity $PV = \frac{\xi + f}{H}$



Idea: When passing the mountain the column will shrink. Decrease in **H** implies decrease in **ξ** and therefore anticyclonic flow turning the column southwards which decreases **f**

The air column shrinks and conserving PV becomes more anticyclonic and turns south



James R. Holton, *Atmospheric Sciences Department, University of Washington, Seattle, Washington*

Stationary Planetary Waves, *Bull. Amer. Meteor. Soc.*, **74**, 1735-1742.**1993**

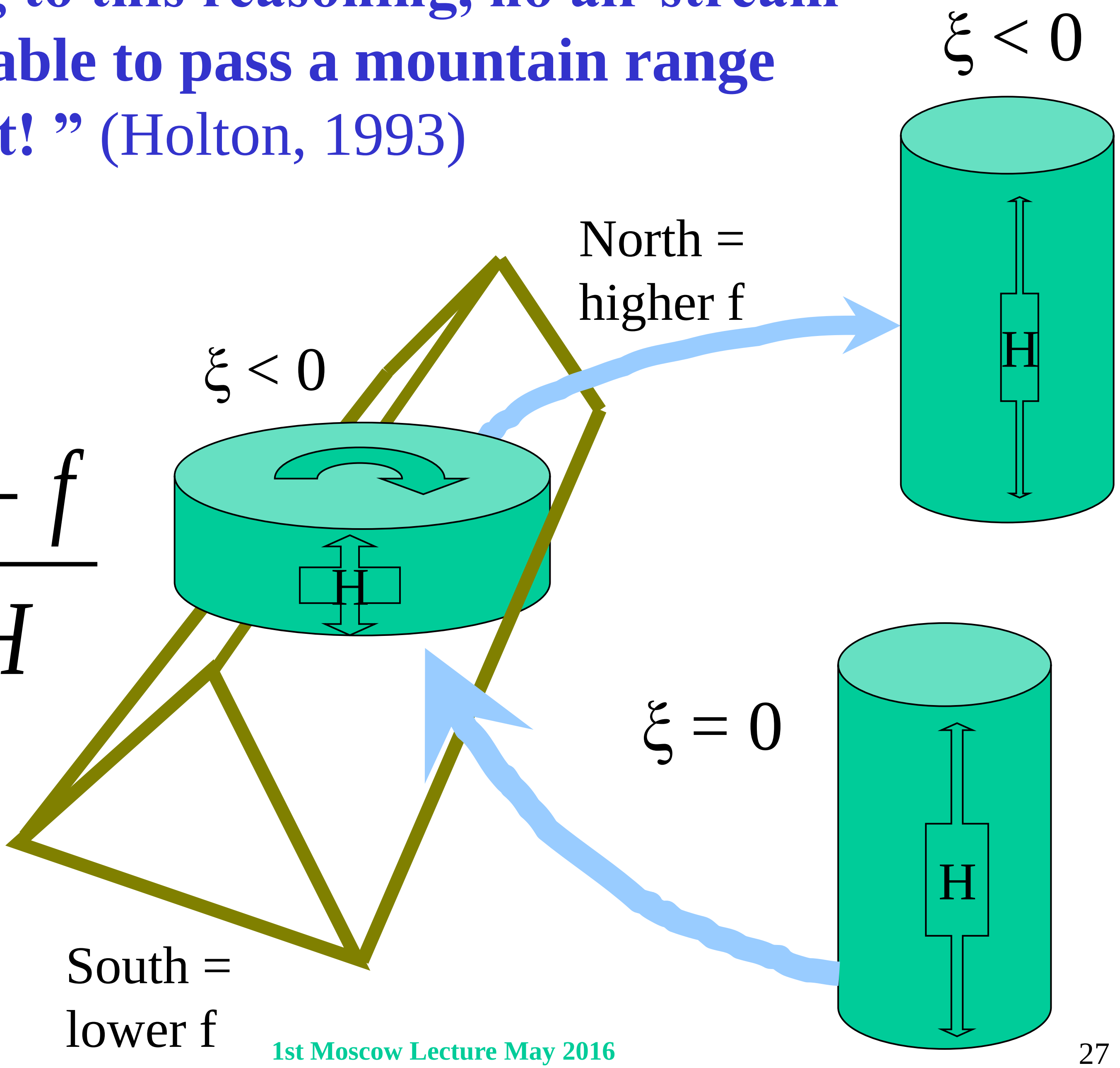
”…Although this conceptual model seems to work well for westerly flow over topography, an attempt to apply it to easterly flow quickly leads to an absurdity.

…According to this reasoning, no air stream will ever be able to pass a mountain range from the east!

Since the standard conceptual model does not work for easterly flow it is reasonable to ask whether it is appropriate for westerly flow….”

…According to this reasoning, no air stream will ever be able to pass a mountain range from the east! ” (Holton, 1993)

$$PV = \frac{\xi + f}{H}$$



“Since the standard conceptual model does not work for easterly flow it is reasonable to ask whether it is appropriate for westerly flow….” (Holton, 1993)

4.5 | Shallow Water Equations

There has to be a universal rethink how we teach dynamic meteorology

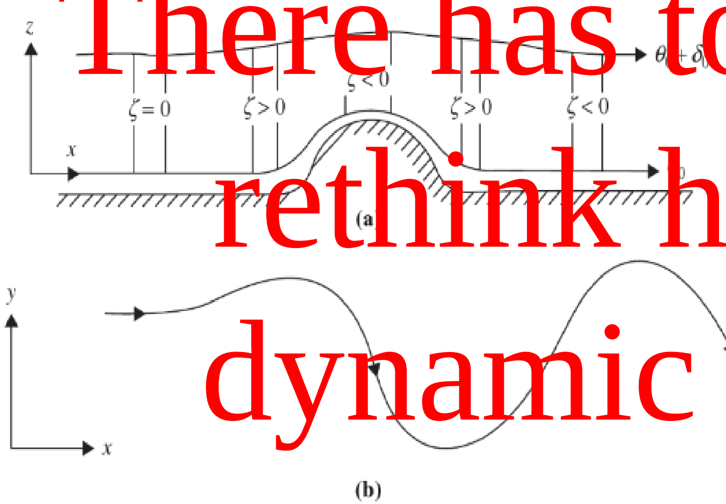


FIGURE 4.11 Schematic view of westerly flow over a topographic barrier: (a) the depth of a column as a function of x and (b) the trajectory of a parcel in the (x, y) plane.

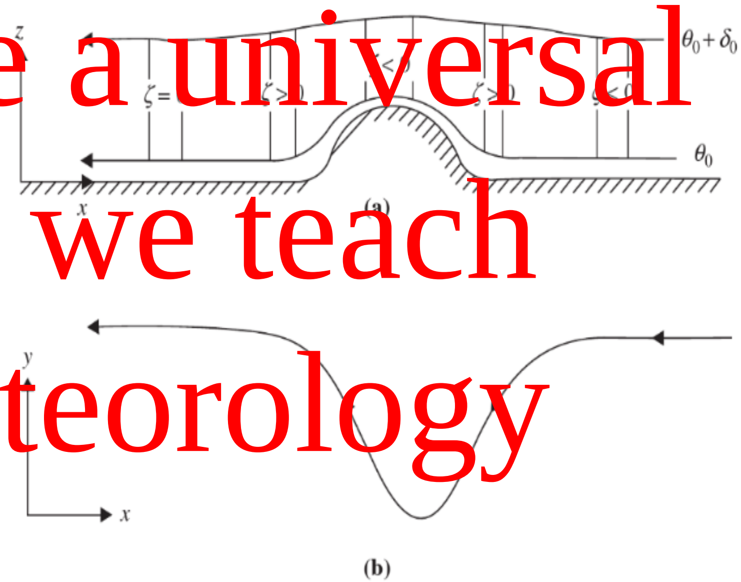


FIGURE 4.12 As in Figure 4.11, but for easterly flow.

But in Holton’s own books the erroneous explanation remains (above from the 2005 Holton-Hakim 5th edition)

End