SMS 303: Integrative Marine Sciences III

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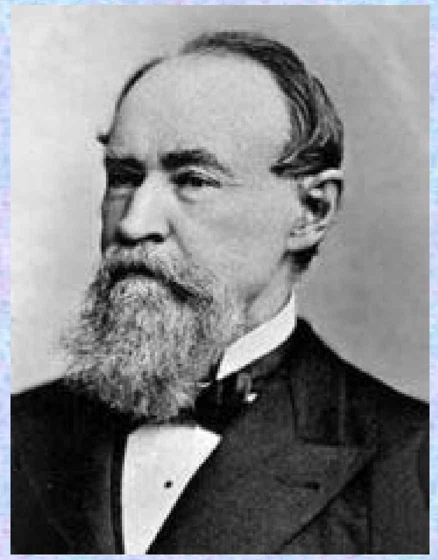
- 5 weeks & topics: ~~Diffusion~~, ~~mixing~~, Coriolis, waves and tides.



William Ferrel (1817-1891)

BBC take on Coriolis

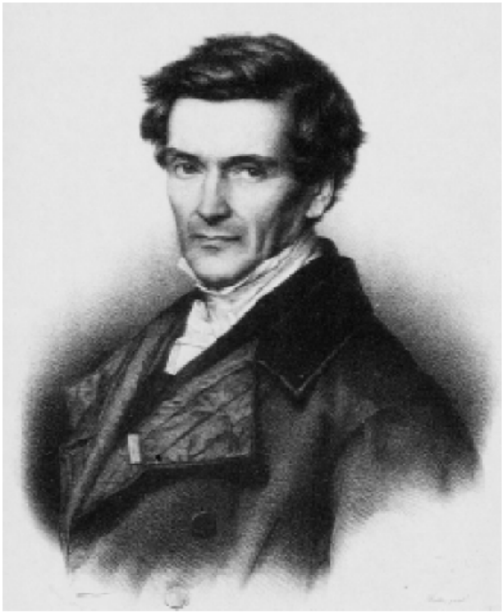


FIG. 5. Gaspard Gustave Coriolis (1792–1843).

From: Persson, 1998, BAMS

Real and fictitious forces on a rotating planet

Newton's 1^{st} law of motion:

Every object in a state of uniform motion tends to remain in that state of motion unless an external force is applied to it.

Corollary: if you want to change an object's trajectory you need to apply force.

Q: how can one throw a curve-ball? How can you bend it like Beckham?

This law is for motion with respect to a non-moving reference frame – called *inertial* frame of reference.

When we measure motion on the Earth we do it relative to a *rotating* reference frame. If we are to predict where a ball will go we need to take this rotation into account.

Real and fictitious forces on a rotating planet

What happens when you sit on a merry-go-round that begins to spin?

Assume you are held in place to the merry-go-round. What happens if you throw a ball to somebody?

[Movie](http://www.youtube.com/watch?v=mcPs_OdQOYU)

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How different does it seems for an observer that is not rotating?

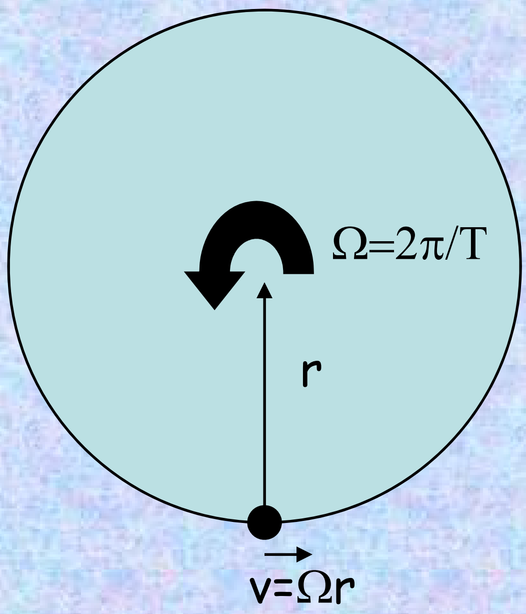
Analysis of the merry-go-round:

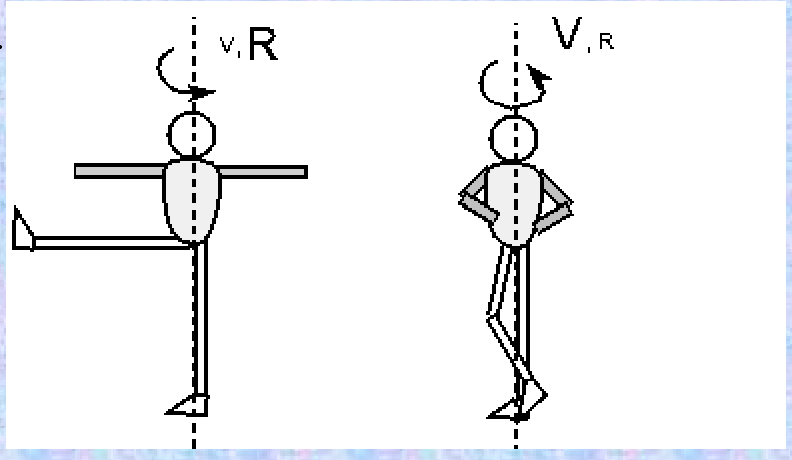
Angular momentum: mv x r=mωr^2

When the ball is pushed in/out r changes.

If r is shortened v needs increase (to conserve angular momentum) → →added rotation relative to the merry-go-round (think about an ice skater).

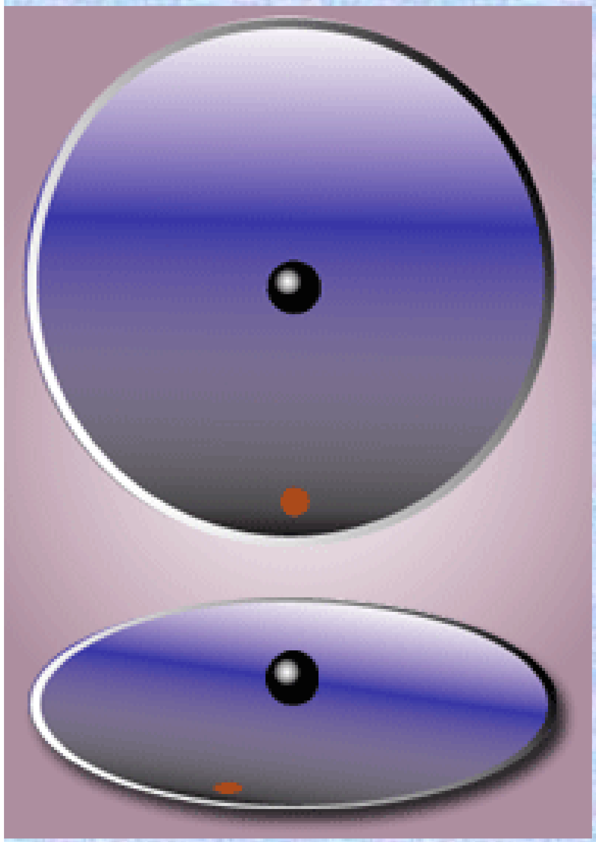
In addition the position of the observer is changed.



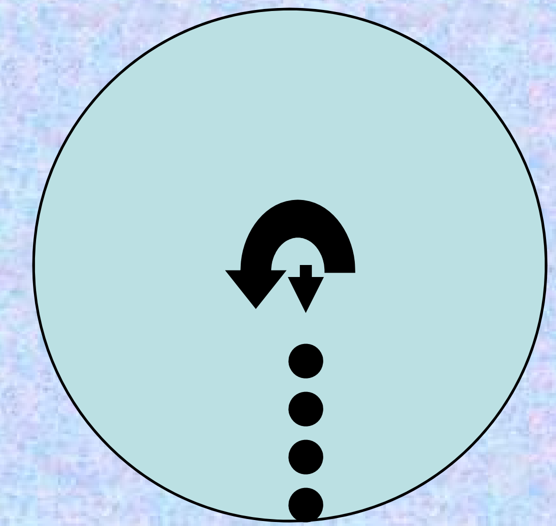


www.astronomynotes.com/ evolutn/s12.htm

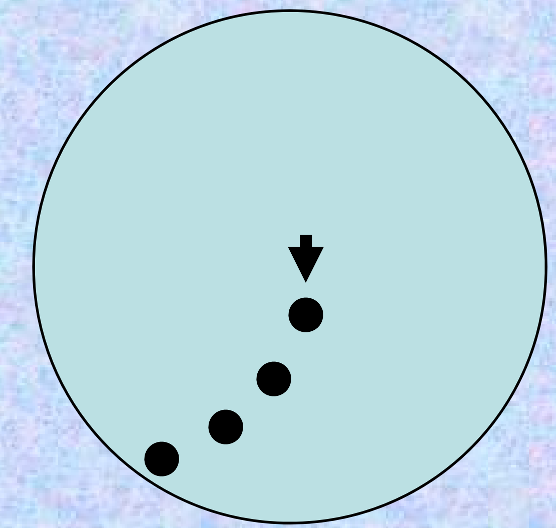
Analysis of merry-go-round:



Inertial frame:

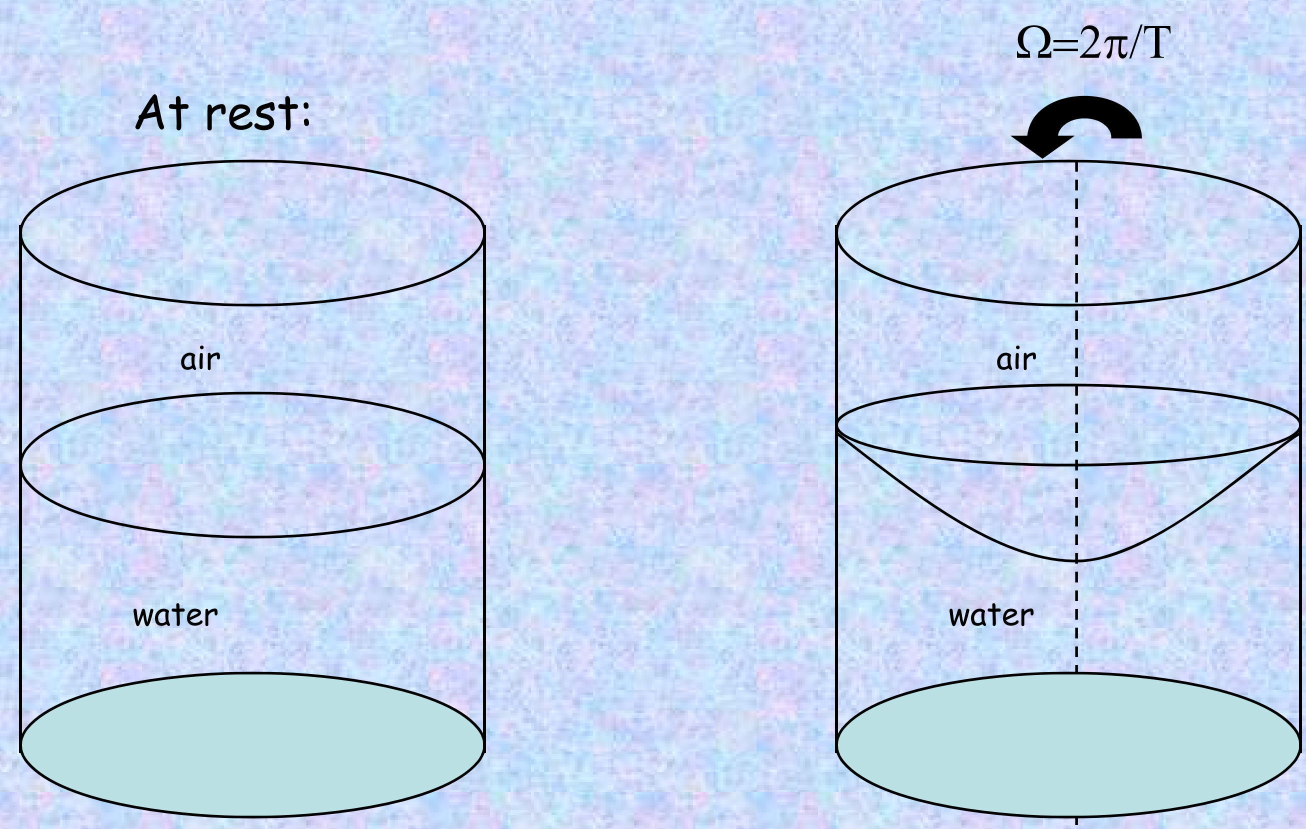


Rotating frame:



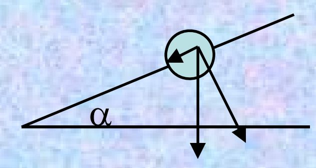
An apparent force (apparent to a rotating observer) is present (Coriolis).

The *geopotential* surface: fluid at rest in a rotating frame.



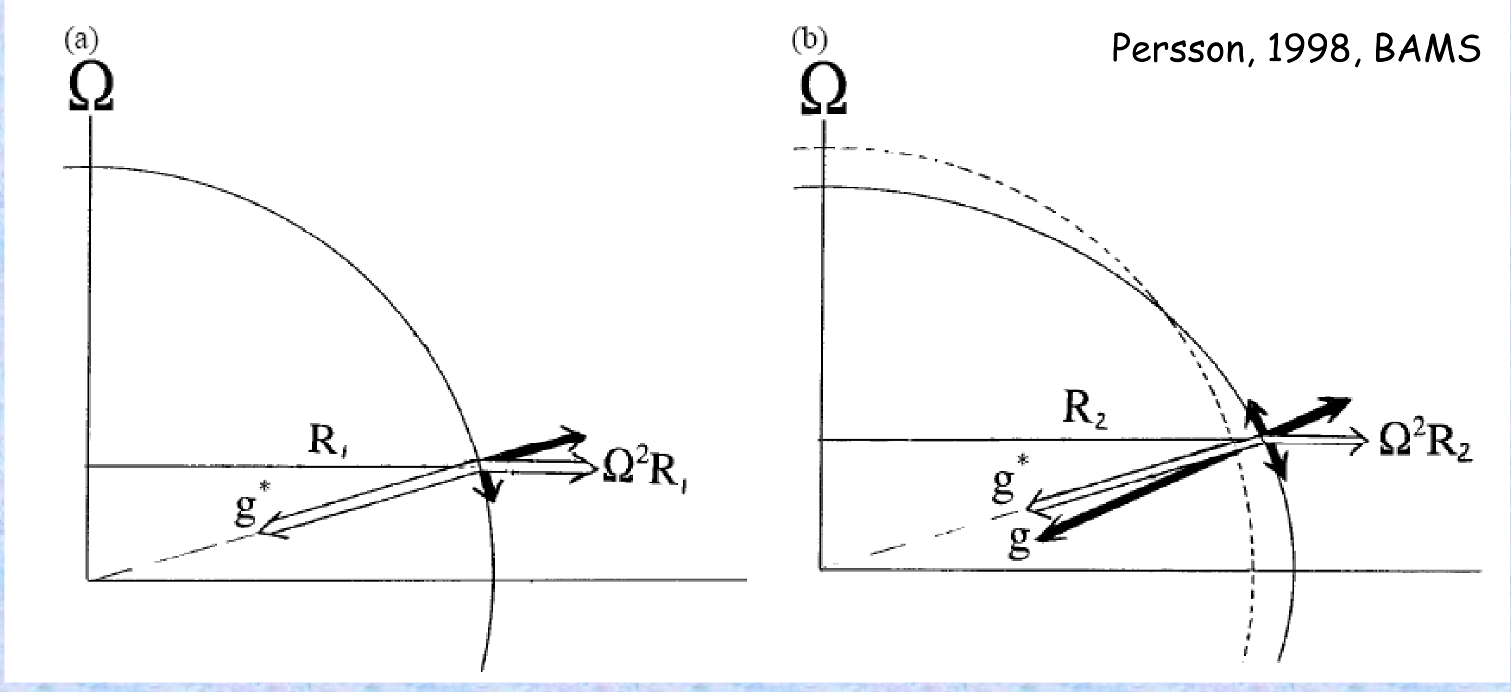
Gravity provides the centripetal force necessary for fluid rotation:

$g\sin\alpha=\Omega^2 r\cos\alpha \rightarrow \tan\alpha=dh/dr=\Omega^2 r/g \rightarrow h(r)=h_0+\Omega^2 r^2/(2g)$



The geopotential of a 3-D planet:

The balance of forces for a particle at rest on the Earth (e.g. rotating thousands of miles per day):



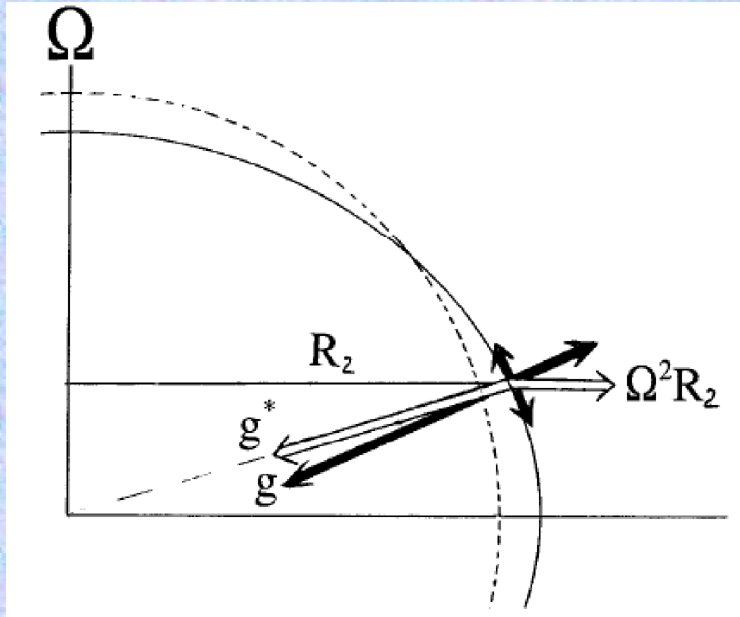
Persson, 1998, BAMS

Spherical Earth: tangent components are not balanced.

Ellipsoidal Earth: tangent components are balanced for mass at rest relative to the Earth.

Geopotential: a surface on which particles are at rest (all forces are balanced).

How can we explain the deflection of the trajectory in the E-W direction:



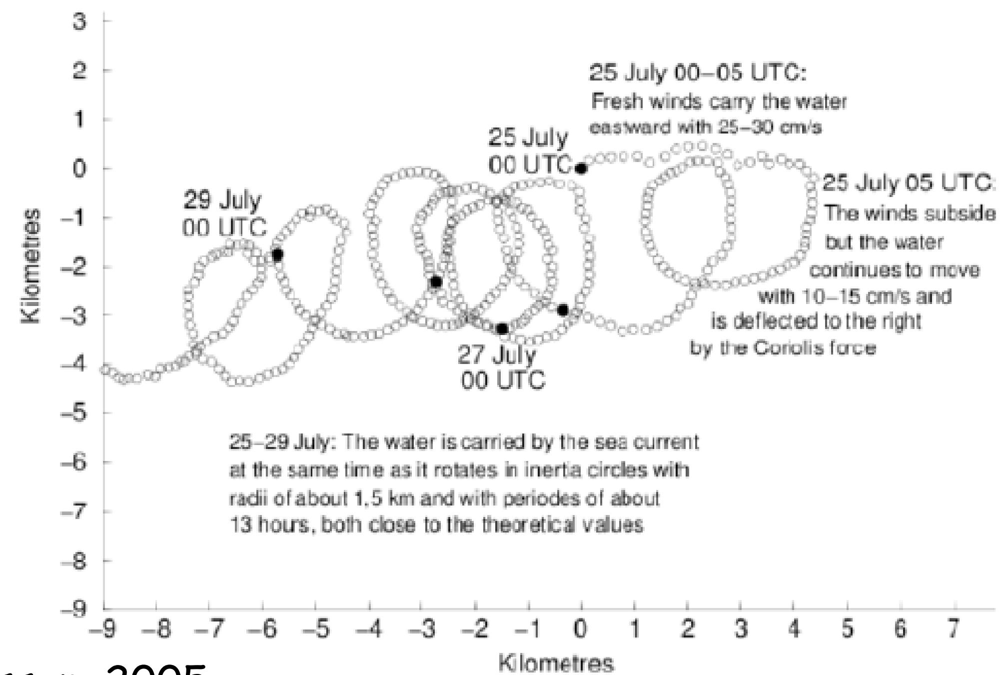
A centripetal force is needed to hold for a particle at rest ← gravity.

If the particle has velocity at the same direction as the Earth rotation (e.g. increasing the centripetal component needed) a net equatorial force will act on it.

If the particle has velocity opposite the direction of the Earth rotation (e.g. decreasing the centripetal component needed) a net poleward force will act on it.

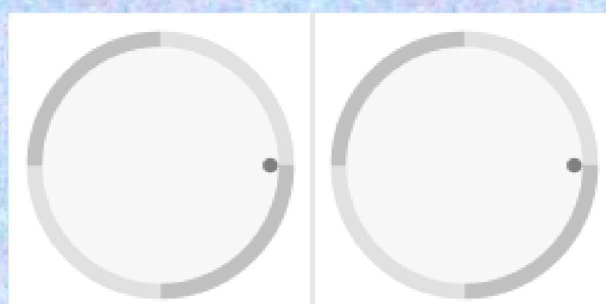
What happens if we push a parcel of water from rest?

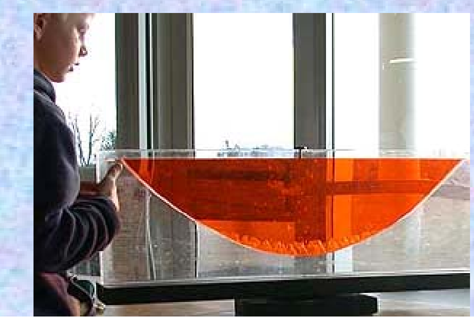
Inertial oscillations:



Persson, 2005

Drifting buoys set in motion by strong winds tend, when the wind has decreased, to move under inertia and follow approximately inertia circles—in the case of steady ocean currents, cycloids. The example is taken from oceanographic measurements taken in summer 1969 in the Baltic Sea just southeast of Stockholm (Courtesy Barry Broman at the oceanographic department at SMHI).





Real and fictitious forces on a rotating planet

Forces affecting motion of fluids as viewed from an inertial frame:

1. Gravity (directed towards the center of gravity).
2. Centripetal force (directed towards to center of curvature).
3. Pressure gradient (directed from high to low pressure).
4. Friction (slows velocity without affecting direction).

Forces affecting motion of fluids as viewed from a rotating frame:

1. Gravity (directed towards the center of gravity).
2. Centripetal force (directed towards to center of curvature).
3. Pressure gradient (directed from high to low pressure).
4. Friction (slows velocity without affecting direction).

and:

5. Coriolis 'force' (directed at 90degree to the motion).

Two effects on the Earth proving we are on a rotating planet:

I. Foucault's pendulum (demo)

http://www.physclips.unsw.edu.au/jw/
foucault_pendulum.html#animation

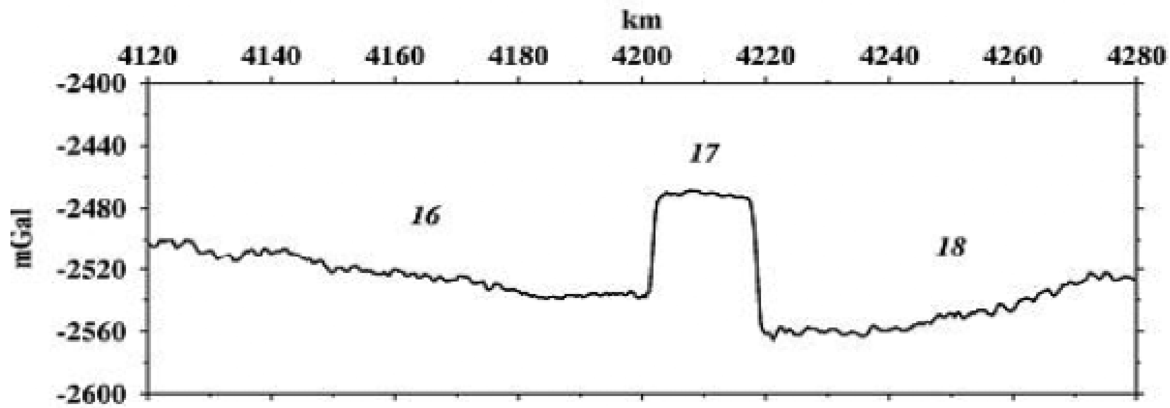
Present at the poles but not equator

Period = (Earth period of rotation)/sin(latitude)

II. The Eötvös Effect:

Present at the Equator but not the poles

From Persson, 2005:



The Eötvös effect measured by a French research vessel in the South Indian Ocean. The ship is first moving slowly in a westerly direction (16), then faster westward (17), and finally slowly eastward (18). The units on the y-axis indicate gravity and are inversely proportional to the ship's weight. Figure courtesy of Dr Helen Hebert, Laboratoire de Détection et de Géophysique, Bruyères-le-Chatel, France.

A common misconseption wrt Coriolis:

It controls the direction water drains in the bath or toilet.

When is Coriolis important?

I. Small spatial scales: motions with time scales on the order of the Earth's rotation period.

II. Small spatial scales: motions with large speeds (e.g. fast velocity)- e.g. a finite effect (O(1cm)) can be shown for a baseball.

III. Large spatial scales + short time scales - e.g. missiles.

Forces acting on fluids on Earth and their balance

On horizontal motion (perpendicular to the local gravity) the following forces apply:

Pressure gradient.

Wind stress.

Friction.

Coriolis.

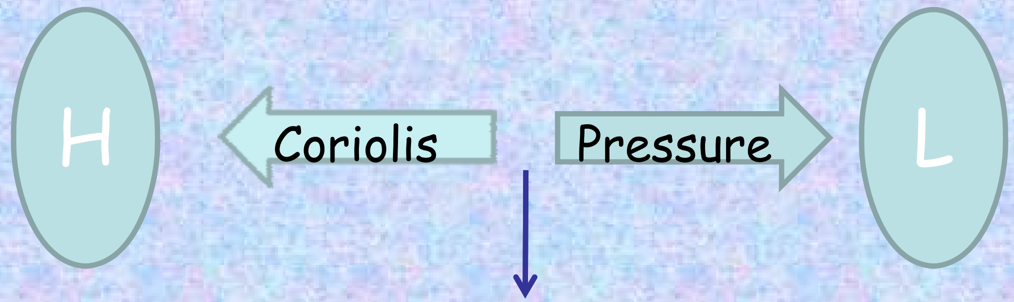
Centripetal acceleration (e.g. tornado).

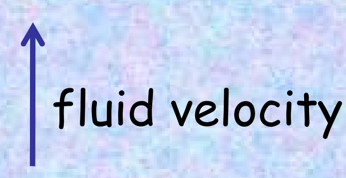
Newton: Acceleration=(sum of all forces)/mass

Assuming we can neglect acceleration, lets look at some balances:

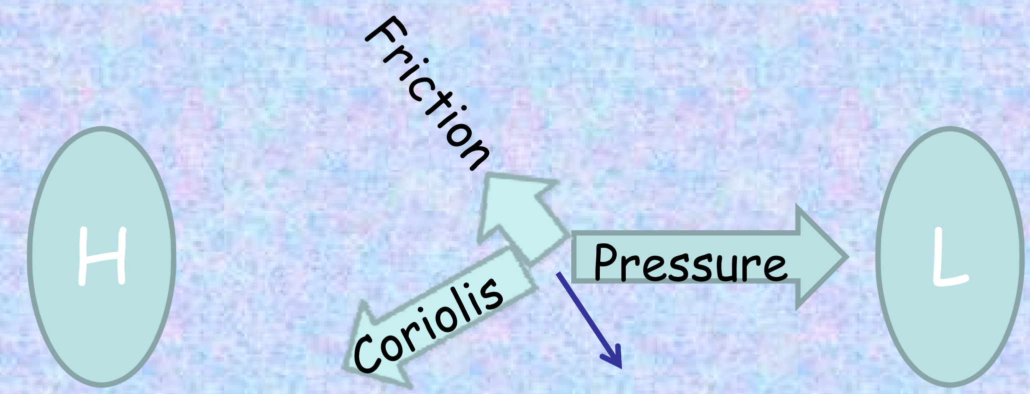
I. Coriolis = pressure gradient

Geostrophy





II. Coriolis = pressure gradient + friction




Icelandic low (Wikipedia):

→ Ekman's spiral dynamics

The Coriolis or deformation radius

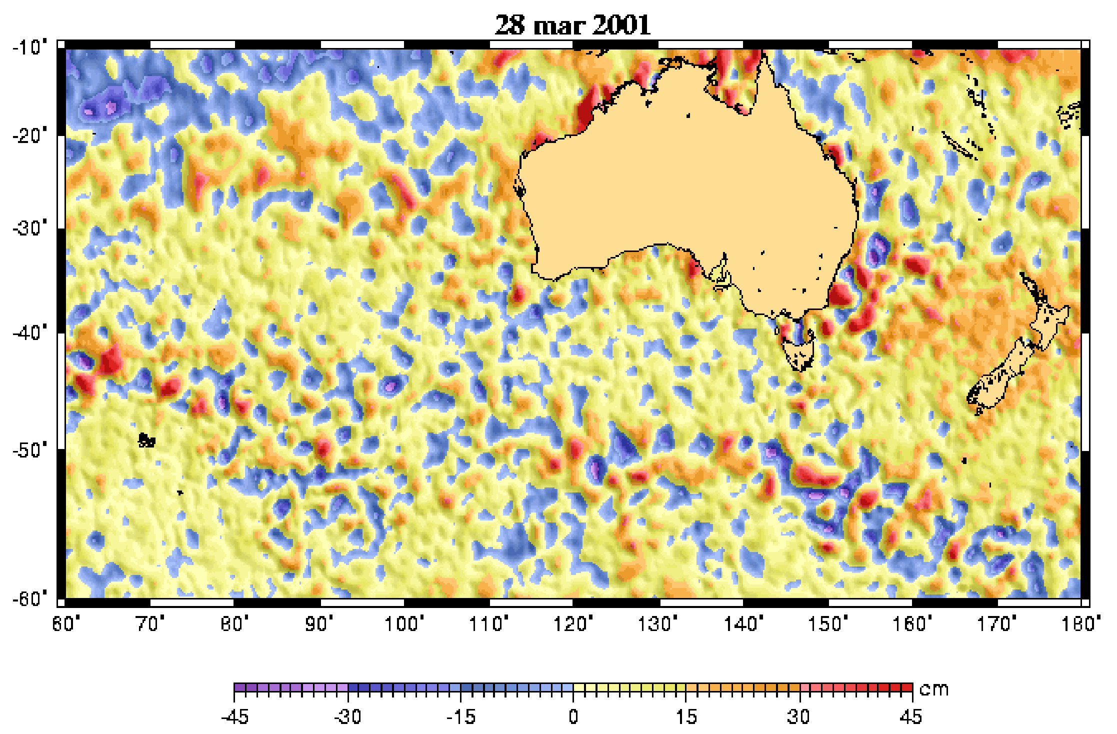
The oceans are forced primarily by winds which have systems of O(100kms) and time scales of O(5days).

Coriolis force sets the scale for many energetic horizontal motions which for non-stratified fluid is:

$$L \equiv \frac{\sqrt{gH}}{f}$$

While for the ML it is:

$$L \equiv \frac{\sqrt{g\,\Delta\rho/\rho_0\,H_{ML}}}{f}$$



http://www.aviso.oceanobs.com/en/applications/ocean/mesoscale-circulation/multisensors/altimetry-and-buoys/index.html

Implications: atmospheric scales are larger (factor of 10) than oceanic. Scales shorten as we move to poles.

Summary

Things look different on a rotating platform.

For next week: homework and reading.

5min break.

Meet at the SMS lab on the 4th floor.