The Coriolis force

ATM 316 Dynamic Meteorology I

October 21 2014

What we saw in the tank: summary

We rolled a ball on a (approximately) parabolic rotating plate. The motion looks very different in the inertial (classroom) and rotating (video screen) frames of reference.

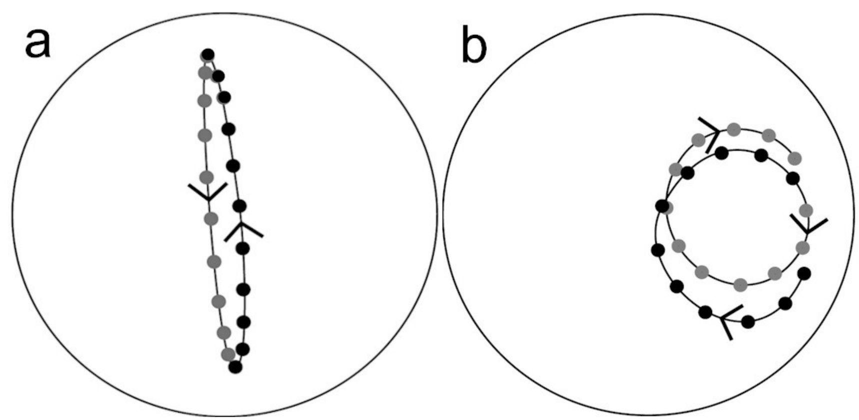


Figure 2: Trajectory of the puck on the rotating parabolic surface in (a) the inertial frame and (b) the rotating frame of reference. The parabola is rotating in an anticlockwise (cyclonic) sense.

The motion is “really” just straight lines, with balls oscillating up and down the sides of the plate. But when measured with respect to the rotating plate, the motion appears as circles.

These are known as “inertial circles”.

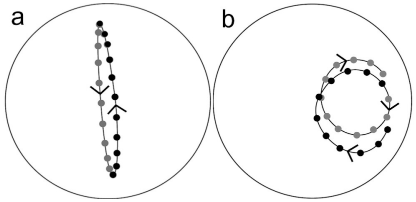


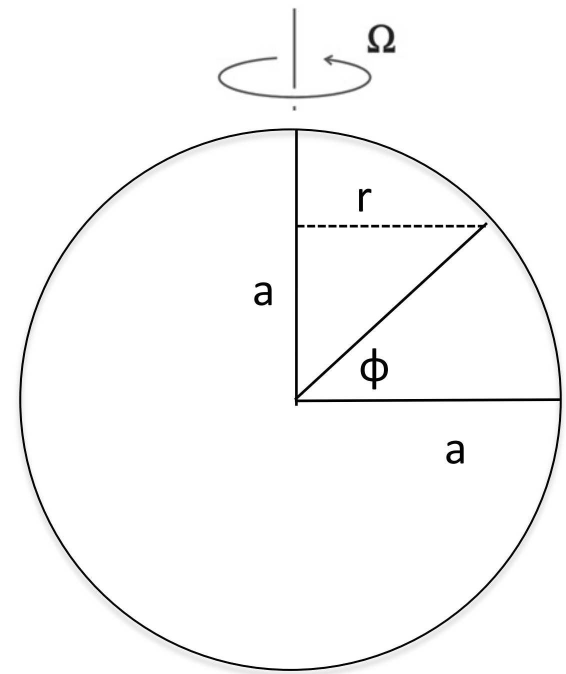
Figure 2: Trajectory of the puck on the rotating parabolic surface in (a) the inertial frame and (b) the rotating frame of reference. The parabola is rotating in an anticlockwise (cyclonic) sense.

Coriolis force and inertial circles

- The motion always **veers to the right** when viewed in the rotating frame.
- To account for this veering, we introduce an **apparent force** called the "**Coriolis force**" that always acts **90º to the right** of the (relative) motion.
- As we saw in lecture, the Coriolis force is really the "excess" centrifugal force associated with the *relative motion* of the ball compared to the rotating plate.
- Most of the centrifugal force due to the rapid rotation of the plate is **balanced by gravity**. This balance occurs because of the parabolic shape of the surface.
- Thus when we roll the ball across the plate, the only force acting in the horizontal direction is the Coriolis force. This is consistent with **clockwise circular motion** – the balls are continually accelerating to their right.

Relating the rotating table to the rotating Earth

Earth completes one rotation per day, so the rotation rate is
$\Omega = 2\pi / 1 \text{ day} = 0.73 \times 10^{-4} \text{ s}^{-1}$



Each fixed point on the Earth (including us!) is moving in a circular, anticlockwise path.

The azimuthal velocity due to Earth's rotation is
$V = \Omega r = \Omega a \cos \phi$
Where a = 6373 km is Earth's radius and ϕ is latitude
(the circles are smaller closer to the pole, where $\cos \phi$ approaches zero)

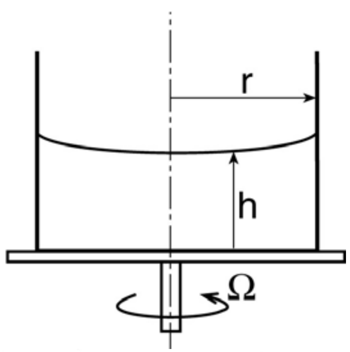
Here in Albany at ϕ = 42.7ºN, this works out to a speed of
$V = 341 \text{ m s}^{-1}$ = 763 miles per hour

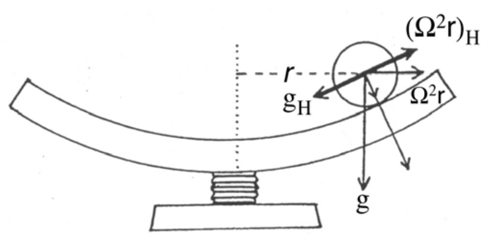
We are all moving very quickly around circular paths!

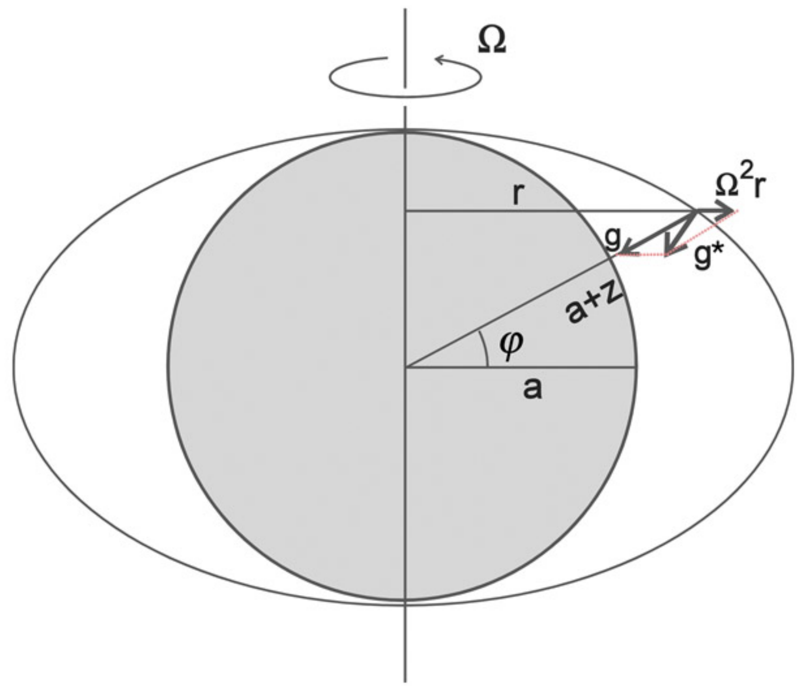
The wind speeds that we measure relative to the rotating Earth are usually much weaker.

The shape of rotating fluids: tanks and planets

Just as our water surface acquires a **parabolic shape** when rotating, it turns out that the Earth itself also **bulges out at the equator**. Rather than a perfect sphere, Earth is an “**oblate spheroid**”. The bulging is caused by Earth’s rotation.







Just like in the water tank, Earth’s surface is aligned **perpendicular to the vector sum of gravity** (acts toward center of Earth) **and centrifugal force** (acts radially outward from axis of rotation). There’s an “effective gravity” which is slightly modified by Earth’s rotation. “Effective gravity” points locally downward everywhere – but not exactly toward the center of Earth!

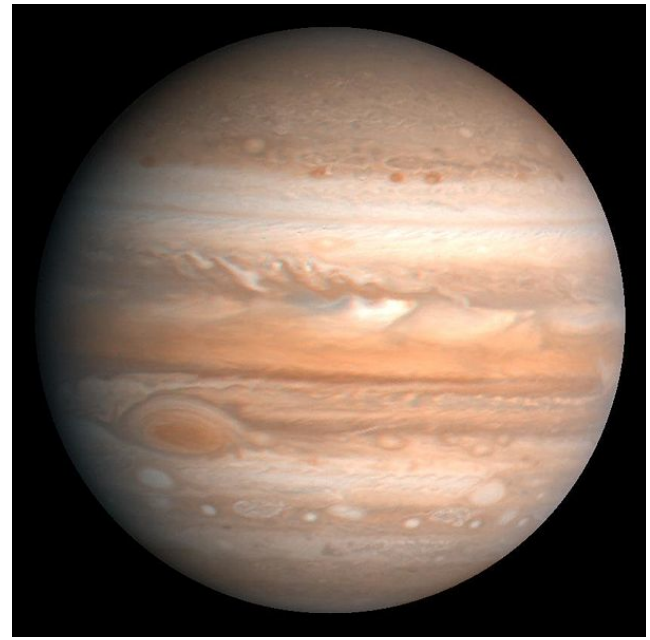
Compare equatorial bulge for two rotating planets:

Bulge = radius at equator minus radius at pole

Earth

(not to scale!)

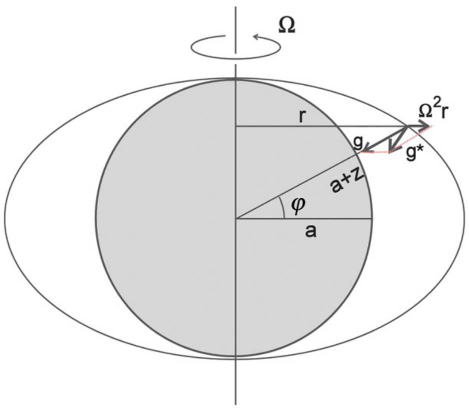
Jupiter



Average radius: 6373 km
Rotation rate: $\Omega = 2\pi$ / 1 day = $0.73 \times 10^{-4}\ s^{-1}$
Equatorial bulge = 21 km (0.3%)

Average radius: 69,000 km
Rotation rate: $\Omega = 2\pi$ / 9 hours = $1.9 \times 10^{-4}\ s^{-1}$
Equatorial bulge = 4640 km (6%)

Earth's bulge is tiny and not discernible by eye.
Jupiter's bulge is much larger, due to faster rotation and much larger planet size … but still barely enough to be seen by eye.



When we write down our equations of motion, we will combine the centrifugal force due to Earth's rotation with gravity into a single "effective gravity".

Then we can mostly forget all about the centrifugal force!

The surface of the oblate spheroid is "horizontal" and "flat" in the same sense that our parabolic plate was "flat" for a ball at rest in the rotating frame.

All that's left to think about is the "excess centrifugal force" due to the relative motion of the air: the **Coriolis force**!

The Coriolis force is always present and always acts 90º to the right of the wind vector.

One consequence**: if there are no other horizontal forces acting on a fluid** on Earth, it should move in inertial circles, just like our ball!

Inertial circles observed in the ocean

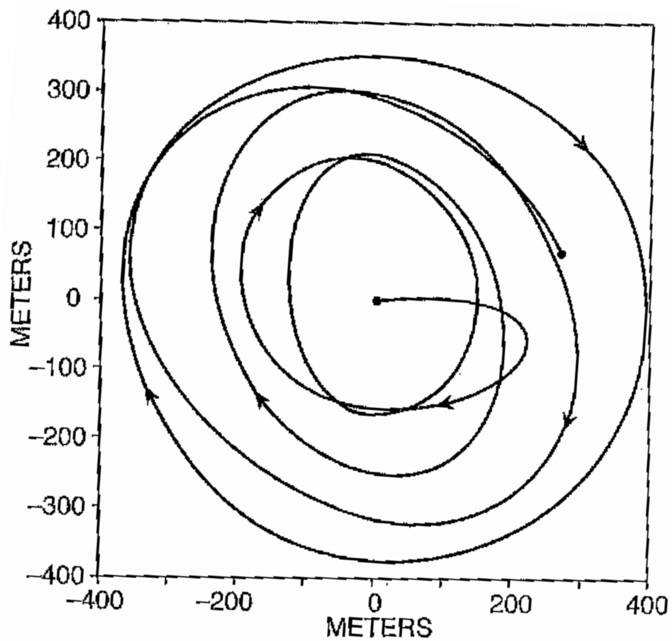


FIGURE 6.16. Inertial circles observed by a current meter in the main thermocline of the Atlantic Ocean at a depth of 500 m; 28°N, 54°W. Five inertial periods are shown. The inertial period at this latitude is 25.6 h and 5 inertial periods are shown. Courtesy of Carl Wunsch, MIT.

Marshall and Plumb 2008

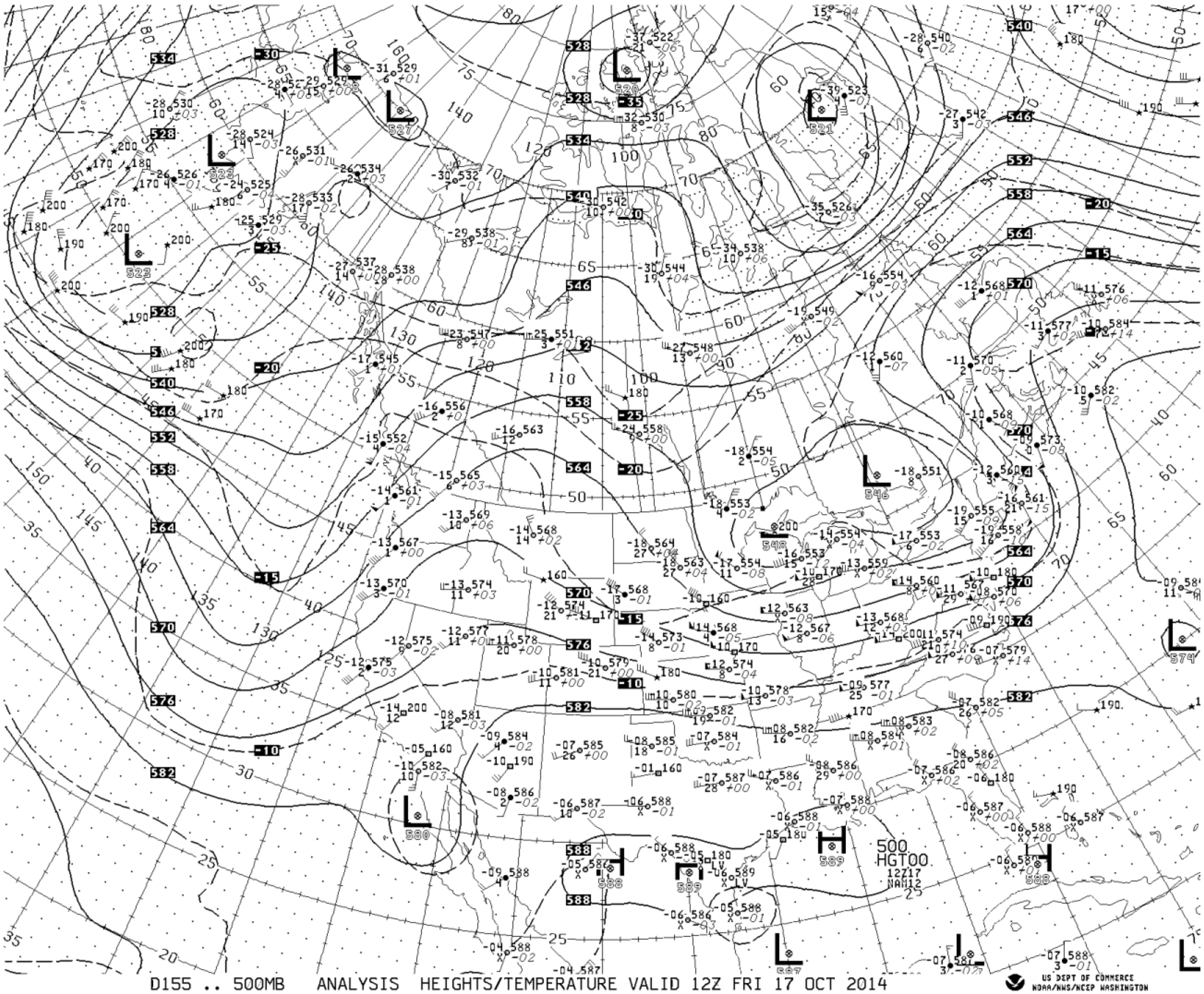
Water parcels can sometimes be observed to move in approximately circular paths in the ocean – just like the ball on the rotating plate.

Observations like these need to made at depth (here 500 m below the surface) to get away from the direct effect of winds and other disturbances.

Inertial circles are rarely seen in the atmosphere. Why?
We would need weak background winds that do not change for days at a time – this rarely happens.

However, the Coriolis force is incredibly important for understanding the atmosphere, as we will see…

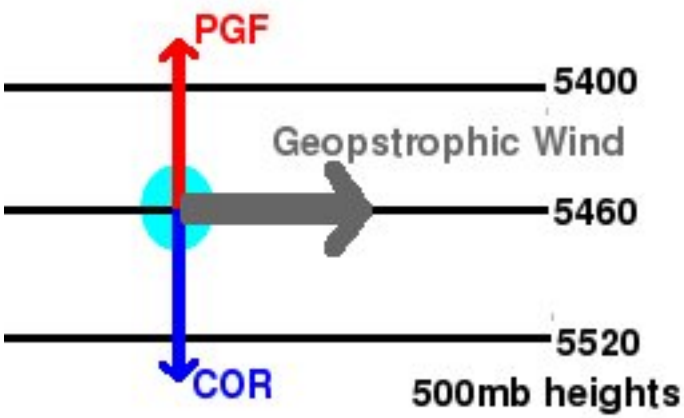
Weather maps (upper levels) show that winds are **nearly parallel to isobars**, with the **low pressure to the left**.



Why?

Geostrophic balance = balance between **horizontal PGF** (towards low pressure) and **Coriolis force** (90º to right of wind)

Low pressure



High pressure

Pressure gradient force tries to accelerate wind toward the low.

Coriolis tries to accelerate the wind to the right.

*The only way for these forces to balance (**net zero force)** is if the wind blows parallel to isobars as shown.*

Geostrophic balance is a very central concept in dynamic meteorology.

We will spend much of the rest of the semester talking about it!