Coriolis and the Red Spot

The power of a pseudoforce

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Since the discovery of Jupiter's Great Red Spot some 3 centuries ago[1], scientists have pondered on the forces that drive and sustain it. Similar unresolved questions arise from a similar weather system on Neptune. This article proposes a simple solution.

The Coriolis effect is generally dismissed by scientists as a pseudoforce, an illusion that occurs when a body moves relative to a rotating surface. This has led to Coriolis being ignored by all but meteorologists and even then its treatment is fairly limited.[2]

An aspect of Coriolis that has been largely overlooked is the force differential between points separated by latitude. The rotational velocity of the Earth at the equator is 464 metres per second relative to space, the decrease in the circumference of the earth as you move north or south meaning that the velocity also decreases. It is 434 m/s at latitude 20°, 401 m/s at 30°, 355 m/s at 40° down to zero at the poles. These velocities are localised as all objects at the same latitude are travelling at the same speed relative to space and are therefore stationary relative to one another. Things become interesting when you consider the difference in velocity between two lines of latitude. For example, a body at latitude 30° is moving 46 m/s faster than one at latitude 40°. The difference between the velocities is calculated by:-

$$V = \frac{D \pi [\cos(N) - \cos(F)]}{T}$$

D is the diameter of the planet (12,760km for the Earth)
T is the rotational period (time) in hours (24 for the Earth)
N is the latitude nearer the equator
F is the latitude further from it.
V is the velocity in k/ph - divide by 3.6 for m/s.[3]

A velocity differential between points of latitude means that there is a net energy that is capable of manifesting itself in a body spanning those points (the *Coriolis Differential Force* - CDF).[4] It is tiny where the separation is a few metres, but becomes significant as

distances increase. For example, the velocity difference between latitudes 30° and 31° is 4.1 m/s. It follows that a hurricane forming across these latitudes has winds on the equatorial side that are being pushed 4.1 m/s faster than those on the side further from the equator.[5] This is small by comparison with the ultimate wind velocities, but it is enough to act as a catalytic or activating force that determines the direction of rotation of a developing vortex. It also explains why hurricanes rotate in an anti-clockwise direction in the Northern Hemisphere and clockwise in the Southern Hemisphere. (see fig. 1).[6]

An extreme example of the force at work is seen in Jupiter's Great Red Spot. Jupiter has an equatorial diameter of 142,796 km and a sidereal rotation period of 9.925 hours. This results in a rotational velocity relative to space in the equatorial upper atmosphere of 45,200 kph or 12,556 m/s. With the Red Spot at 10° south and spanning around 10° of latitude the differential velocity is 567 m/s, easily explaining its high winds. In this case the CDF accounts for the bulk of the energy without needing to consider the comparatively small thermal forces that occur on a planet with an average temperature of -123°C. It also accounts for the longevity of the Great Red Spot [1] as the CDF is much more stable than the thermal currents that contribute to much of the atmospheric movement on Earth. Fig.2 is a cloud density image of the Great Red Spot [2] showing a higher density / cloud height (blue) in the equatorial regions, principally in the north western quadrant. This is consistent with CDF origins. Similar vortices have been spotted on Neptune and Uranus by the Hubble Space Telescope and various other NASA probes. It is suggested that they too have similar origins[6].

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[1] First observed by Giovanni Cassini in 1665.

[2] See for example *An Introduction to Thermal-Fluid Engineering*, Z. Warhaft, C.U.P. at p.153. Here the "force" is taken at a single point. As the force is localised its energy is only quantifiable relative to space. Otherwise an ice skater would break the World Land Speed Record.

[3] This formula is designed for a sphere, so the terrestrial velocities in this paper are fairly accurate as the Earth is only slightly elliptical (ellipticity=0.0034). Figures for Jupiter are indicative only as Jupiter is flattened at the poles and quite paunchy around the equator (ellipticity=0.0649).

[4] The name was coined by the author to avoid confusion with the "Coriolis Effect" and similar names that are used in the literature to describe rotational effects at single points.

[5] The differential velocity does not equate to wind velocity as it takes no account of physical constraints such as drag and the inefficiencies of kinetic energy transfer through a fluid. Apart from velocity figures, no attempt has been made to quantify the CDF in this article due to the multiple variables involved. The size of terrestrial vortices depends on the primary forces that create them. General vortex energy equations are inaccurate as they assume uniform energy in the vortex cone whereas the CDF drops in a non-linear fashion from the equatorial side to zero at the non-equatorial side. Added to this are drag factors resulting from internal turbulence.

[6] Photographs by NASA's Gallileo probe. See NASA's Digital Image web site.