AN EXPLANATION OF THE PERSISTENCE OF THE GREAT RED SPOT OF JUPITER

(Letter to the Editor)

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Abstract. An argument is given basing the persistence of the Great Red Spot of Jupiter on compensation of the natural decay of vorticity by collision with a portion of the vortices shed by the South boundary of the South Tropical Zone. The latter are deviated northward by Coriolis acceleration. The GRS itself is regarded as a Rankine vortex with a central depression revealing the coloration of a layer below.

Although there have been several attempts to explain the observational feature of the Jovian atmosphere known as the Great Red Spot (Giersch and Stone, 1968; Hide, 1961, 1963; Ingersoll, 1969, 1970; Stone and Baker, 1968) (GRS) it seems that none have been able to adduce reasons for its relatively long persistence. Discovery of the GRS which is located in the South Tropical Zone (STZ) is usually attributed to Giovanni Domenico Cassini (sketched in 1672, 1691) which would make it about 300 yrs old. Recent work by the NASA Voyager team (Ingersoll and Cuong, 1980; Ingersoll et al., 1980a, b; Maxworthy and Mitchell, 1980; Mitchell et al., 1980) has led to reported kinematic viscosity estimates of the order of $10^7$ m$^2$ s$^{-1}$ which for a vortex of the size of the GRS would yield a decay time of about 6 days.

The decay of vorticity $\xi$ with kinematic viscosity $\nu$ may be approximated as a solution of the cylindrically symmetric diffusion equation given on p. 542 of Milne-Thompson (1955)

$$\frac{\partial \xi(r)}{\partial t} = \nu \frac{\partial^2 \xi(r)}{\partial r^2},$$

with solution

$$\xi = \frac{K}{2\nu t} e^{-r^2/4\nu t},$$

where $K$ is the strength of the vortex.

This corresponds to the assumption that the vortex is decaying with no mechanism available for the replenishment of vorticity. Here an attempt to adduce such a mechanism from established principles of hydrodynamics will now be made. The view pursued here is that the GRS is not due to a Taylor column which has drawn the objection of being associated with a solid subsurface feature for which there is little if any evidence. On the contrary it is here suggested that the GRS is a Rankine vortex (Milne-Thompson, 1955; p. 340) with a central depression revealing the coloration of a layer below the surface. For a Rankine vortex Bernoulli's Theorem yields a surface shape

$$z = \begin{cases} \frac{\omega^2 a^4}{2gr^2} & r > a \\ \left(\frac{\omega^2 a^2}{g}\right)(1 - \left(\frac{r^2}{2a^2}\right)) & r \leq a \end{cases}$$


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with a maximal depression on the vortex axis given by

$$z_{\text{max}} = \frac{\omega^2 a^2}{g}$$

(4)

where $\omega$ and $a$ are angular velocity and radius of the vortex while $g$ is the gravitational acceleration and $z$ is the depth of the vortical depression as a function of $r$ the axial distance.

For a Rankine vortex of the size of the GRS the maximal depth would be about 140 km. It is sometimes taken as fact that the GRS is elevated rather than depressed on the basis of evidence for upward flow in the zones (where the atmosphere is about 4° K warmer than in the adjacent belts) but the velocities of this upflow are much smaller than the circulatory velocities of the GRS so that the possibility of a depression should not be hastily discounted.

The mechanism here invoked to offset the natural decay of vorticity depends upon the following assumptions:

(1) Vortices are continually produced at the zone/belt boundaries and those generated at the South STZ boundary have the same (counter-clockwise) sense as the GRS vorticity.

(2) Coriolis effect moves all vortices generated at the South STZ boundary across the STZ to the North boundary except those within a section of the South boundary roughly 90% of the GRS major axis and longitudinally immediately preceding it.

(3) These latter vortices from the South boundary will collide with the GRS and their cumulative vorticity will then balance out the loss of vorticity due to decay.

The transport of vortices from a portion of the STZ South boundary to the GRS is attributed to Coriolis effect which deviates them from initial motion along a circle of latitude northward. Only about 11% of those generated at the South boundary will collide with the GRS contributing to restoration of its vorticity while the remainder will simply transit the STZ from South to North boundary. The horizontal component $a_H$ of the Coriolis acceleration is given in terms of $\omega_4$ the angular velocity of Jupiter and of its radius $R_4$ and the latitude $L$

$$a_H = \omega_4^2 R_4 \sin (2L)/2$$

(5)

for a vortex moving along a circle of latitude. Taking

$$R_4 = 71398 \text{ km } = \text{ equatorial radius}$$

$$\omega_4 = 0.633 067 \text{ radians hr}^{-1}$$

with $L_1 = 20.9^\circ S$ and $L_2 = 26.3^\circ S$ as the STZ boundaries one has from (5) for $L_1$ an $a_H = 9536.25 \text{ km hr}^{-2}$ and for $L_2$ an $a_H = 11365.95 \text{ km hr}^{-2}$ which yields an average $a_H = 10451.10 \text{ km hr}^{-2}$. Since the linear width of the STZ is $W_{STZ} = 6729 \text{ km}$ one finds the average time to transit the STZ under such a Coriolis acceleration to be

$$t_{STZ} = \sqrt{2W_{STZ}/a_H} = 1.14 \text{ hr},$$