

Models of the Great Red Spot

SIR—We note that the experiments of Sommeria *et al.*¹ and the numerical simulations of Marcus² are not acceptable models of Jupiter's Great Red Spot (GRS) because their approach does not meet the necessary conditions.

Necessary conditions for an adequate model of the GRS-like vortices include: (1) cyclonic–anticyclonic asymmetry — almost all large, long-lived vortices in the jovian and saturnian atmospheres are anticyclones (including the GRS vortex)^{3,4}; (2) large radii, a , of the vortices (the characteristic length of the velocity gradient) relative to the barotropic Rossby–Obukhov radius, r_R (for a vertically homogeneous fluid) or the baroclinic Rossby radius, r_i (for an inhomogeneous fluid); for example, for the GRS, $a \approx 5,000$ km (ref. 5), $r_i = 1,000$ – $1,500$ km (refs 3,5), and $a \gg r_i$. (Here $r_R = (gH)^{1/2} / \Omega \sin \varphi$, where g is the acceleration due to gravity, H the thickness of an atmosphere, and φ is the latitude; $r_i \approx (1/5-1/4) r_R$ in real atmosphere.)

Conditions (1) and (2) correspond to the 'intermediate geostrophic' (IG) regime of the Rossby vortex motion ($a > r_R$). Both of them were satisfied in our experiments^{6,8} (see ref. 3 for review). In refs 1 and 2, a method of vortex production that allows generation only of cyclones and eliminates generation of anticyclones was used, not satisfying condition (1). In addition, the model fluid used has no free surface (it is contained between rigid lids), thus corresponding to a regime with $r_R \rightarrow \infty$ and, hence $a \ll r_R$, r_i ('quasi-geostrophic' (QG) approximation, $a < r_R$), not satisfying condition (2).

We produced^{13,6,8} a long-lived monopole IG Rossby anticyclonic soliton and so obtained a laboratory model of the jovian GRS driven by smooth counterstreaming fluid flows. We also showed that the long-lived Rossby soliton exists only when it has a sufficiently large amplitude and involves captured particles, that is, the Rossby soliton is a real vortex. Regarding cyclones, we showed that they were only generated by the counterstreaming cyclonic flows under the condition of extremely strong velocity shear, similar to conditions necessary for the existence of jovian cyclonic 'barges' (14° N).

The vortex Rossby soliton concept allows us to interpret satisfactorily the principal properties of the GRS: its anticyclonic polarity, its size, its rotation speed and its steady westward drift, its generation by counterstreaming flows (existing in jovian atmosphere) and its uniqueness along the whole perimeter of Jupiter. In agreement with this concept, there is a large, long-lived vortex in Jupiter's Northern Hemisphere (19° N) which corresponds to the GRS of the

Southern Hemisphere (22° S): like the GRS, it is an anticyclone, it drifts westward with a speed of 2.5 m s^{-1} and has a size $a > r_i$. Because of its physical similarity to the GRS it is called the Little Red Spot⁹.

An essential part of our results is represented incorrectly in ref. 1: we did observe the merging of vortex Rossby solitons under their mutual collisions. This phenomenon is in good agreement with the observed properties of the GRS and with the theory of the vortex (not 'purely wave') Rossby soliton; it also agrees with the computer work⁴. This phenomenon is in qualitative disagreement with the first ('purely wave') soliton theory of the GRS¹⁰; the latter uses the QG approximation ($a < r_i$) and does not agree with the GRS observations.

Our results are not affected by viscosity because, under the conditions of our experiments^{6,7}, the characteristic decay time of the IG Rossby anticyclone is about 20–25 s (ref. 11); hence, it is an order of magnitude greater than the vortex turnover time (≈ 2 s). The point is that, in the presence of a free surface, the viscous lifetime (τ_{visc}) of the IG Rossby vortex is much greater than the Ekman time (τ_E), because^{11–13} $\tau_{\text{visc}} = \tau_E (1+F)$, where the Froude number, $F = a^2/r^2$, is much larger than unity for the IG regime. We predict that Neptune's Great Dark spot discovered recently¹⁴ is an anticyclone.

However, we must say that independent of the above, the experiments of Sommeria *et al.*¹ seem to be very impressive from a hydrodynamical point of view.

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MARCUS AND SOMMERIA *ET AL.* REPLY—The theory and experiments of Antipov *et al.*^{6–8} are in the intermediate geostrophic regime, and ours^{1,2} are in the quasi-geostrophic. Both IG and QG are special cases of single-layer shallow-water theory but the approximations are mutually exclusive, and the dynamics of long-lived vortices are different for the two regimes. Thus the issue is whether the GRS is QG or IG — we argue it is QG based on Voyager observations.

The distinction between IG and QG depends on the size of the baroclinic (inner) Rossby radius r_i . For scales of motion larger than r_i , the IG rather than the QG approximation is appropriate. Estimations of r_i near the GRS range from 500 to 5,000 km; hence, because the GRS is 12,000 km by 26,000 km, several

authors⁴ conclude the GRS must be IG. Voyager data, however, show that the GRS velocity is mostly in a thin, large diameter, annular region. The correct length scale to compare with r_i is the half-width of this annulus, approximately 2,000 km, which is the characteristic scale l over which the velocity varies. A careful comparison of Voyager data with numerical solutions of full shallow-water equations yields^{15,16} $2,000 \text{ km} \leq r_i \leq 3,000 \text{ km}$; hence, the QG approximation for the GRS is justified. The numerical solutions also show that the potential vorticity q can be approximated to within 15% by the QG expression $q = Q[(f+\omega)^{-1} \nabla \cdot (f^{-1} \nabla gh) - gh(fr)^{-2}]$, where ω and Q are the vorticity and potential vorticity of the zonal velocity, h the height of the upper surface of the vortex not including the zonal component, f the Coriolis parameter and g the effective gravity. Our simulations show that QG vortex dynamics are *insensitive* to the value of r_i . Therefore, experiments with a rigid lid ($r_i = \infty$) simulate GRS dynamics.

We showed¹² that a large QG vortex can form from the turbulent merging of smaller vortices. The resultant large vortex (which is not a soliton) has approximately uniform q (which forces $l \approx r_i$) and a quiet interior with v and vorticity increasing exponentially until they peak in an annular strip of thickness $2r_i$ at the vortex's edge. This is a very good description of the GRS. By contrast, an IG Rossby soliton is gaussian with vorticity and angular velocity peaked at its centre⁴.

Antipov *et al.* emphasize that the GRS is anticyclonic, as in IG theory, whereas QG vortices are cyclonic or anticyclonic. Their use of IG theory to explain the GRS's anticyclonicity is not compelling because another explanation is then needed for the majority of jovian vortices: most of the > 100 vortices observed by Voyager have $l \leq R \leq 1,300$ km, where R is the vortex radius. Even if r_i were as small as 1,300 km, these vortices would be QG — yet 90% are anticyclonic⁷. Thus, physics beyond the shallow-water approximations is needed to explain the anticyclonicity.

Antipov *et al.* argue that westward drifts of the GRS (-3.5 m s^{-1}) and Little Red Spot (-2.5 m s^{-1}) support IG-soliton theory because QG vortices remain stationary with respect to the local zonal flow, whereas IG solitons drift westward at the Rossby drift velocity: $-4.6/(1,000 \text{ km})^2 \text{ m s}^{-1}$ at the latitude of the GRS. Drift speeds of jovian vortices are measured with respect to System III coordinates, but there are uncertainties of at least $\pm 5 \text{ m s}^{-1}$ in determining the velocity of the deep zonal flow with respect to System III. Thus, the vortex drift speeds are all zero within the observational uncertainty. Williams and Wilson¹⁸ appeal to the uncertain zonal velocity to salvage their IG soliton model of the White Oval BC, which drifts eastward at 4 m s^{-1} . Note

that with $r_1 = 1,500$ km, the IG-soliton GRS drift speed would be 10 m s^{-1} which is outside $-3.5 \pm 5 \text{ m s}^{-1}$.

Our experiments and simulations show that in a turbulent QG shear flow, vortices grow and are sustained by merging. Similarly, 24 mergers of vortex pairs in the same zone were observed by Voyager¹⁷. Antipov *et al.* also observed merging, but merging *per se* occurs in a wide variety of flows. The mergers Antipov *et al.* observed were not in a turbulent shear flow and not in the regime where they observed a persistent solitary vortex (refs 3,6–8 describe merging of transient vortices generated by a rotating disk in a laminar flow). The striking feature of the vortices on Jupiter and in our experiments is their persistence in the presence of turbulence. In a rapidly rotating tank, there is fast dissipation. The vortices of Antipov *et al.* survive longer than the Ekman friction time because the fluid layer is locally thicker at the vortex. In the surrounding thin fluid layer, however, the turbulence is strongly damped by Ekman friction. Thus, the vortices of Antipov *et al.* are laminar.

Although we disagree with Antipov *et al.*'s identification of the GRS as an IG soliton, we are fascinated by their experiments and would like to understand them better. Measurements of vortex size and shape as a function of fluid depth and shear strength would be helpful.

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Ubihomologous homology usage

SIR—The body of scientific ideas often grows faster than the vocabulary available for its expression, but the imprecise use of the word 'homology' in molecular biochemistry to mean 'sequence similarity' is unnecessary and can be obstructive because the two concepts conveyed by the single word are related¹.

The tendency in biology to assign homology to various generalizable associations manifests itself further in immunology, where the word 'homologous' takes on at least two additional meanings. In one sense, 'homologous' is used, largely in molecular immunology but also in other areas, to describe the relationship of an antibody with its naturally eliciting antigen, and stands in contrast to heterologous. By this definition, the combining site of anti-bovine serum albumin antibody is homologous with bovine serum albumin and heterologous with bovine myoglobin. Thus, 'homology' implies a causal physiological link, usually in association with a high degree of structural complementarity. (It does not refer to the structural complementarity itself.)

Unfortunately, this is not the only meaning of homology in immunology. 'Homologous', in its broad sense, also refers to the relationship of an antigen to an immunogenic host of the same species. Bovine serum albumin (BSA) is thus homologous to cows but heterologous to rabbits. Is rabbit anti-bovine serum albumin antibody, then, homologous or heterologous to BSA? Many immunologists would say the answer depends upon the context in which the question is asked, and that the intention would be readily understood by anyone working in the field.

The terminological ambiguity increases in more complicated cases. Suppose an immunologist is investigating two chemically distinct forms of bovine serum albumin, BSA₁ and BSA₂. He immunizes a rabbit with BSA₁ and finds that some of the antibodies elicited react with BSA₂. What are the relationships of BSA₁ and BSA₂ to these antibodies? Some molecular immunologists might say BSA₁ is the homologous antigen whereas BSA₂ is a heterologous antigen, even though BSA₁ and BSA₂ are from the same species and, in this more general biological sense, are both heterologous to the antibodies.

Alternatively, suppose a cow is immunized with rabbit serum albumin and the antibodies found to react with BSA. Such results have often been observed². Is BSA in this instance a heterologous antigen? And what of the relation between rabbit anti-BSA antibody and the antibody it elicits in a cow? Would the eliciting and elicited antibodies in this case be referred to as heterologous? As antibodies produced by different species, they are. As an antibody–antigen pair, they are not.

The potential for confusion in the description of antibody–antigen reactions also arises in that of cellular receptor–antigen interactions.

Although immunologists generally recognize the terms as they apply in their own field, for the sake of consistency throughout immunology and biology, the terminology needs to be clarified.

We propose that the use of the words homologous and heterologous in biology be reserved for the indication of suggestion of common phylogenetic ancestry or the lack thereof. Relationships among and within species may be aptly described by such terms as allogeneic, xenogeneic and syngeneic as in xenogeneic graft, allogeneic antigen (or simply 'alloantigen'). As for the relationship between antibody and antigen or between receptor and antigen, we suggest the introduction of two new terms: homoligous (homo-LYE-gous) and heteroligous (hetero-LYE-gous), the former referring to an eliciting elicited–ligand–receptor pair and the latter to a pair lacking the causal link and describable in terms of degree of cross-reactivity.

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All shook up

SIR—The recent experiments¹ (see ref. 2), in which a spinning gyroscope apparently loses weight, have an obvious flaw: anyone who has seen components travelling on a vibration-feed conveyer will have doubts about weighing vibrating objects.

Gyroscopes contain spinning material and so must vibrate. Given that gyroscope bearings are imperfect, the vibration could consist of a linear movement followed by a return movement — at a slightly different speed. This asymmetric vibration will interact with the damping mechanisms in the weighing device. For example, mechanical friction would be less for the faster movement. So pivot bearings in a balance could exert a thrust on the gyroscope being weighed. The mystery is no more.

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■ See also S.H. Salter's fuller description of this effect on page 509 of this issue.