nature geoscience
SUPPLEMENTARY INFORMATION
DOI: 10.1038/NGEO2601

Simulation of deep-seated zonal jets and shallow vortices in gas giant atmospheres

Moritz Heimpel[1*], Thomas Gastine[2], Johannes Wicht[2]

[1]University of Alberta, Department of Physics, Edmonton, Alberta, T6G 2J1, Canada,

[2]Max Planck Institute for Solar System Research, 37077 Göttingen, Germany

[*]To whom correspondence should be addressed; E-mail: mheimpel@ualberta.ca

October 8, 2015

In contrast to the stability of the outer boundary jet structure over time, vorticity and entropy at the outer boundary of our model exhibits strong time variability. To show this time variability six movies are included as supplementary material. Three perspectives, from the equator, north pole and south pole, are included for the entropy and radial vorticity at the outer spherical surface. The movies span 58 rotations of the model planet. The time series in Figure S1a shows that the surface vorticity and entropy are anticorrelated. Cooling of the surface occurs when vortex activity increases. Vortices are spawned by thermal plumes deep in the convective region. Plume fluid ascends through the convective region and impinges upon the thin stably stratified layer, in which entropy and temperature increase toward the surface. Thus a plume lifts cool subsurface fluid to the heated outer surface. The ascending fluid thus diverges and is spun into a relatively cool anticyclonic vortex by the Coriolis force. This explains the superficially counterintuitive result that our plume-induced anticyclones are cool, as can be seen in Figure S2. The correspondence between global and regional entropy and vortex activity is also evident. In Figure S2a a lack of vortex activity in the southern hemisphere coincides with high surface entropy. However as a period of strong vortex activity occurs, as seen in the high southern latitudes in Figure S2b and S2c, the region cools significantly.

 DOI: 10.1038/NGEO2601

Also included as Supplementary Information are six movies of entropy and radial vorticity at the outer spherical surface of the model. There is a pair of movies in 3 different views: an equatorial view, a North polar view and a South polar view. The colour scales for entropy and radial vorticity are the same as those in Figure S2. Corresponding to the time scale of Figure S1, the movies each cover the first 58 rotation. Thus, the content of Figure S2a shows up about half way through the movie. Projections in the movies are orthographic.

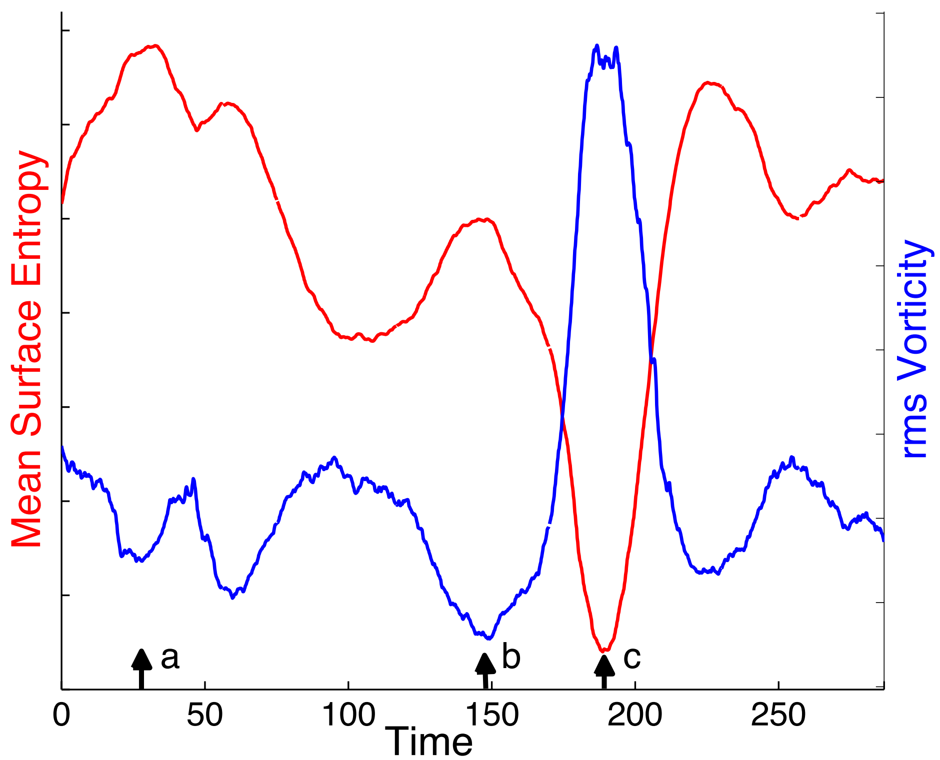

Figure S1: Plot of mean surface entropy and root mean square (rms) radial vorticity (a). The time scale represents 286 rotations of the model planet. The labels a, b and c refer Figure S2, which shows entropy and radial vorticity at the outer spherical surface for three different snap shots in time.

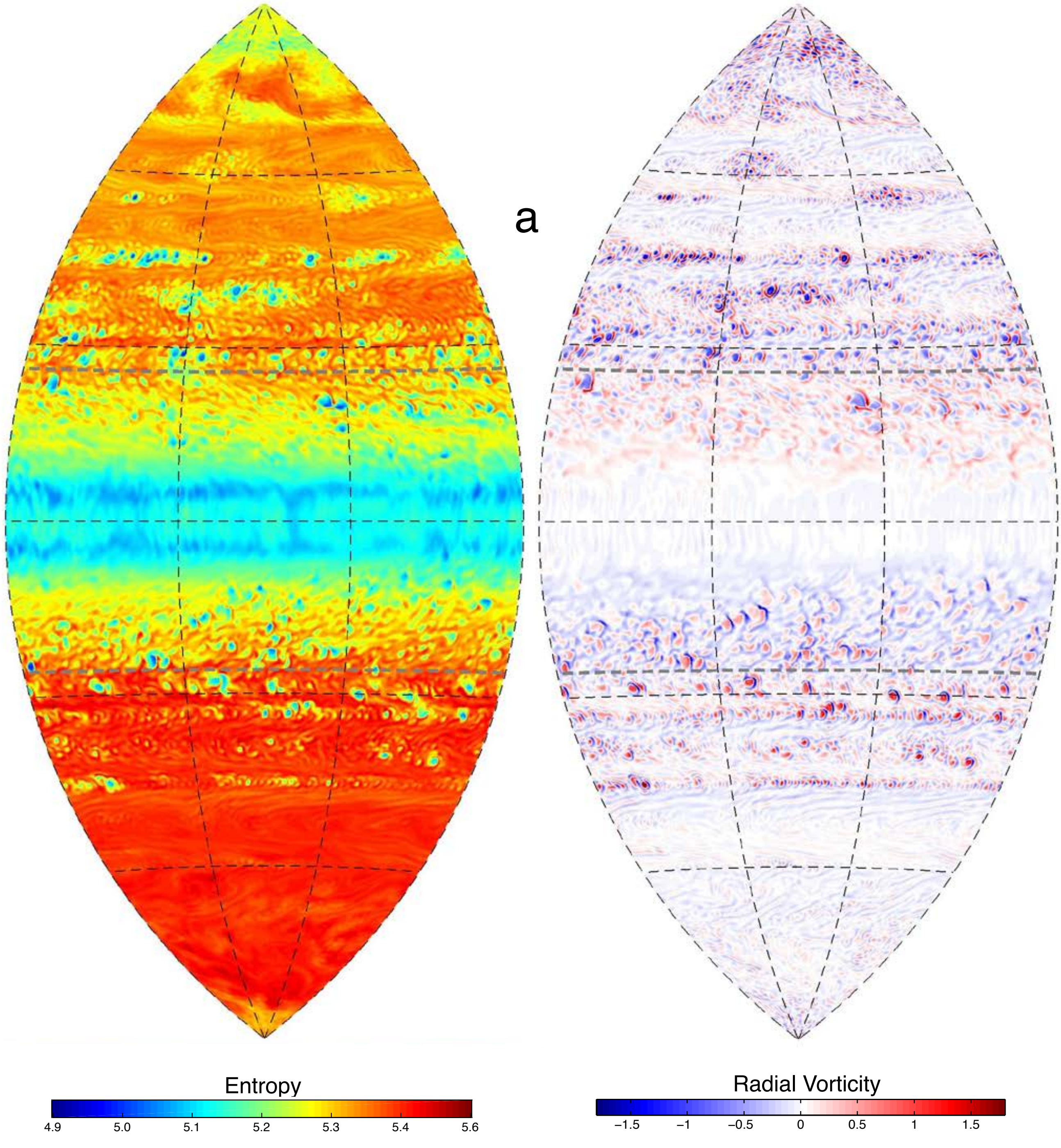

Figure S2a: Entropy (left side of image pair) and radial vorticity (right side if image pairs) for the snapshot in time (a) marked in Figure S1. One-quarter of a full sphere is displayed in Aitoff projection. Periodic boundary conditions on the bounding meridional planes give four-fold symmetry. Cyclonic (anticyclonic) radial vorticity is red (blue) in the northern hemisphere and blue (red) in the southern hemisphere. Heavy dashed lines at northern and southern latitudes $\cos^{-1} 0.9 = 25.8°$ mark the location of the tangent cylinder (TC) at the outer boundary. Larger vortices tend to form in the first and second anticyclonic shear zones poleward of the TC (see also Figure 3 in the main paper). Entropy is in model units. Radial vorticity is in units of planetary angular velocity Ω.

 DOI: 10.1038/NGEO2601

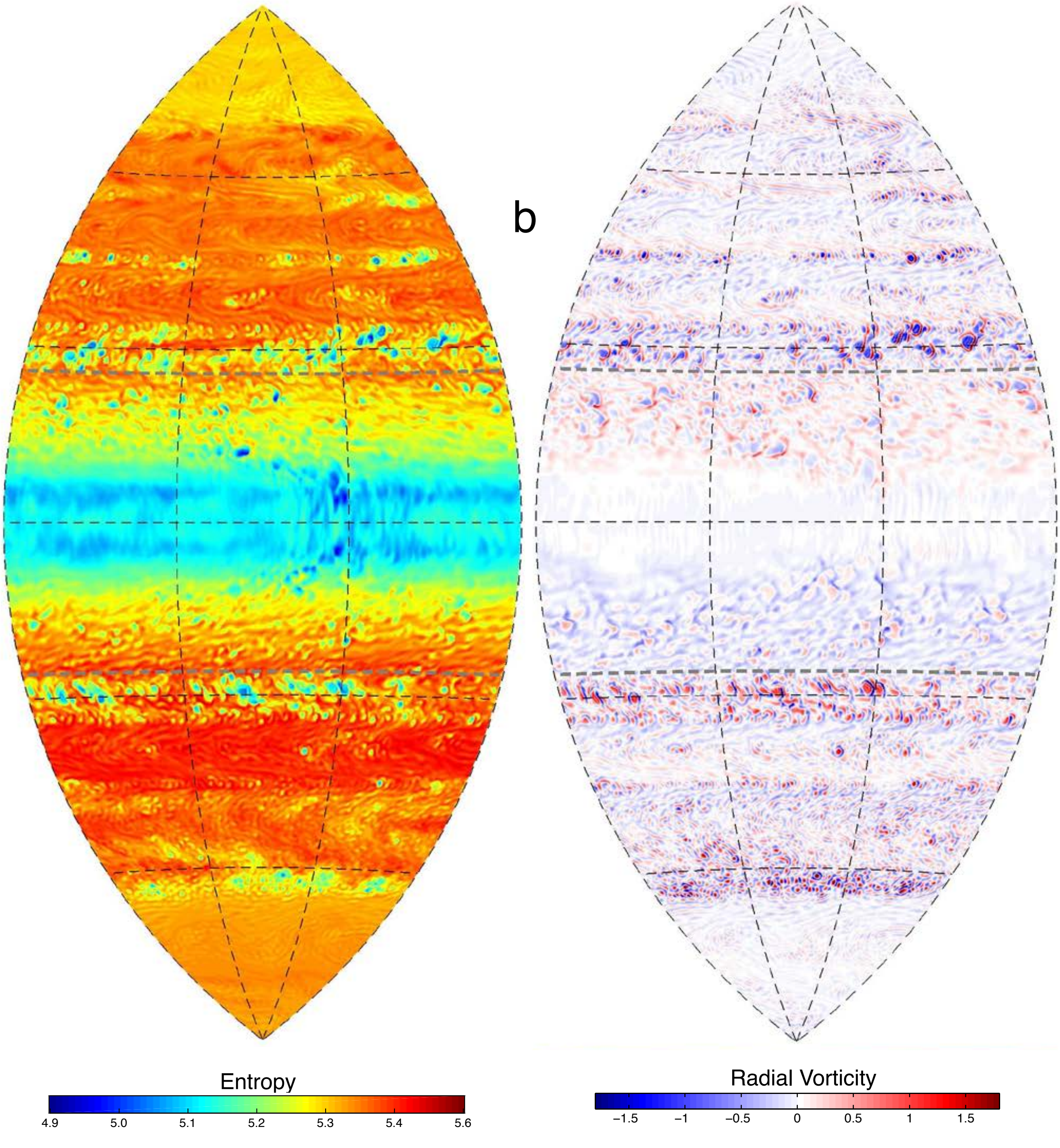

Figure S2b: Similar to Figure S2a, but for time snapshot b.

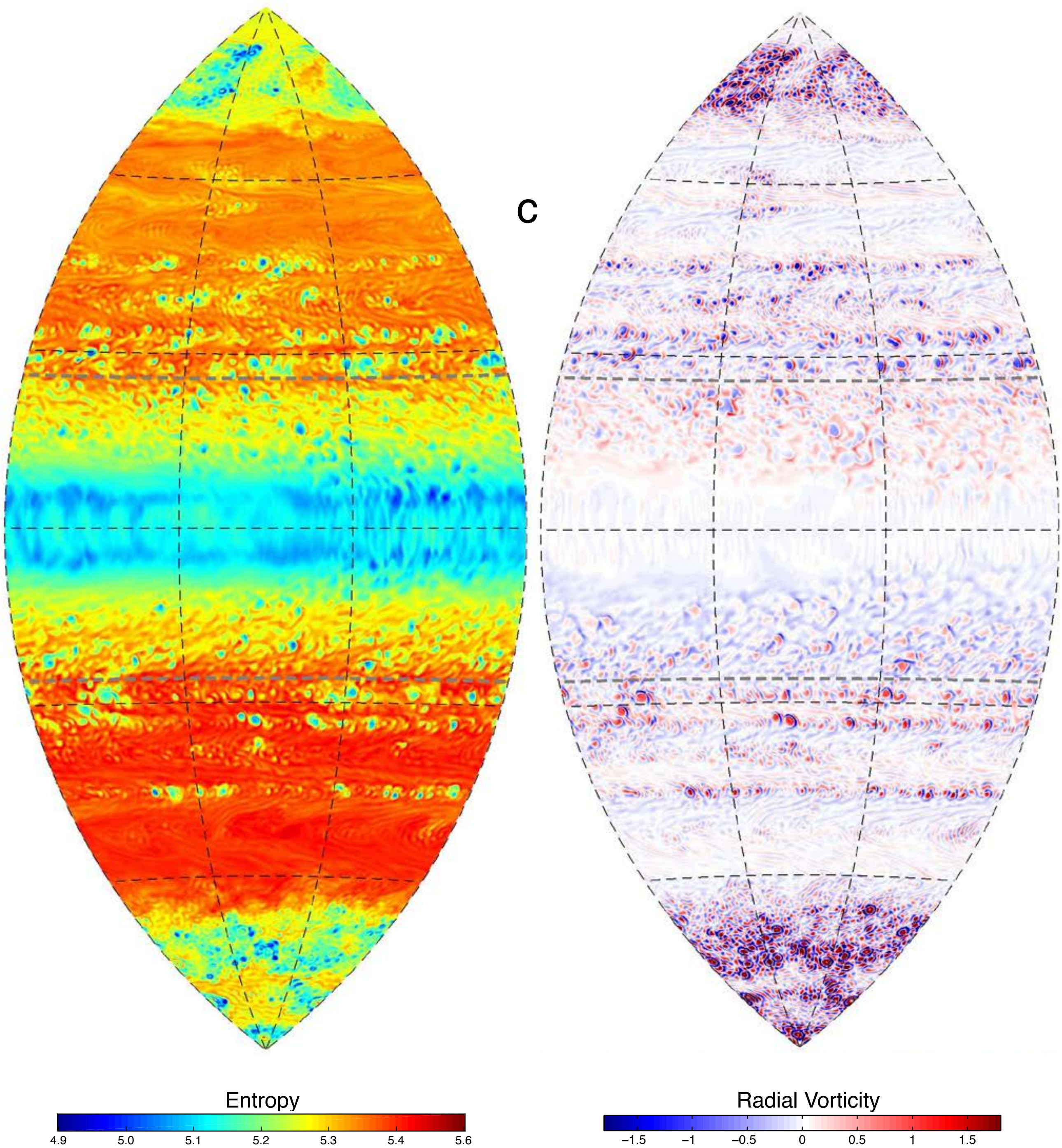

Figure S2c: Similar to Figure S2a, but for time snapshot c.