Cassini observations reveal a regime of zonostrophic macroturbulence on Jupiter

Supplementary Material

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1 List of raw image pairs

Tables S1 and S2 list the raw image pairs used in the analysis, from the image list in Vasavada et al. (2008). All use the CB2 filter.

2 Parameters for the PATCH step

The parameters for the PATCH1 step (smoothing and interpolation) in the CIV procedure are listed in the table. This is the final step in the first CIV stage (translation) before the velocity is refined by rotation and deformation of the correlation box. Details about the PATCH1 step and each of these parameters can be found in Sect. 11 of Coriolis Platform / LEGI (2013).

Parameter	Value	Description
rho	1	Thin plate spline smoothing parameter (Coriolis Platform, 2011)
max dev	2	Vectors further than this away from the smoothed field are removed
subdomain size	600	Thin plate spline domain size (Coriolis Platform, 2011)
nx	100	Number of output x grid points
ny	50	Number of output y grid points

3 Fields for days 1, 3, and 4

Figures S1–S4 show equivalent plots to the fields shown in the main document, but for days 1, 3, and 4. The plots for day 2 are shown in Fig. 3 of the main document.

4 Number of filtered velocity vectors

Figure S5 shows the number of filtered velocity vectors used to calculate the velocity in each mosaic grid box, for each of the four days.

5 Velocity errors

Figures S6 and S7 show the estimated random error in the mosaiced u- and v- velocity components.

6 Zonal diagnostics for varying grid spacing

Figures S8 and S9 show the zonal mean diagnostics for the different latitudinal grid spacings.

7 Example vorticity field with pointing uncertainty

Figure S10 shows one of the vortcity fields where 1.0° uncertainty was introduced into the position of each individual image pair before they were combined into the global mosaics.

8 Velocity datasets

The velocity field and error mosaics produced by cloud tracking as described in Sect. 3 of the main text are included as supplementary data file `U_V_wERR_050_centric_civ2_master.tgz`. This zipped tar archive contains the following files, one for each day:

```
U_V_wERR_day1_050_centric_civ2_master.dat
U_V_wERR_day2_050_centric_civ2_master.dat
U_V_wERR_day3_050_centric_civ2_master.dat
U_V_wERR_day4_050_centric_civ2_master.dat
```

The files contain the zonal and meridional velocity fields, along with their 1σ errors. Each data file is a single column of numbers. Apart from the first two lines (which are integers) all numbers are real values with 13 decimal places. The format of each data file is as follows:

1. Number of longitude points M [1 number].
2. Number of latitude points N [1 number].
3. Value used in fields to represent missing data [1 number].
4. List of longitude points (°E) [M numbers].
5. List of latitude points (°N) [N numbers].
6. Eastward (zonal) velocity ($\mathrm{m\,s^{-1}}$) [$M \times N$ numbers]. The order is
   lat 1 lon 1
   lat 1 lon 2
   lat 1 lon 3
   ...
   lat 1 lon M
   lat 2 lon 1
   lat 2 lon 2
   lat 2 lon 3
   ...
   lat 2 lon M
   ...
   lat N lon M
7. Northward (meridional) velocity ($\mathrm{m\,s^{-1}}$) [$M \times N$ numbers]. Ordered as eastward velocity.
8. Error in eastward velocity ($\mathrm{m\,s^{-1}}$) [$M \times N$ numbers]. Ordered as eastward velocity.
9. Error in northward velocity ($\mathrm{m\,s^{-1}}$) [$M \times N$ numbers]. Ordered as eastward velocity.

Should the reader want to check the values are loaded correctly, they are shown in the following figures:

Field	Day 1	Day 2	Day 3	Day 4
Velocity	S1a	3a	S1b	S1c
Zonal velocity error	S6a	S6b	S6c	S6d
Meridional velocity error	S7a	S7b	S7c	S7d

References

Coriolis Platform, 2011. Thin plate spline. http://coriolis.legi.grenoble-inp.fr/spip.php?article73 (retrieved 11.06.12).

Coriolis Platform / LEGI, 2013. Help for Uvmat, http://servforge.legi.grenoble-inp.fr/projects/soft-uvmat/wiki/UvmatHelp (retrieved 11.10.13).

Limaye, S. S., 1986. Jupiter: New estimates of the mean zonal flow at the cloud level. Icarus 65, 335–352.

Porco, C. C., West, R. A., McEwen, A., Del Genio, A. D., Ingersoll, A. P., Thomas, P., Squyres, S., Dones, L., Murray, C. D., Johnson, T. V., Burns, J. A., Brahic, A., Neukum, G., Veverka, J., Barbara, J. M., Denk, T., Evans, M., Ferrier, J. J., Geissler, P., Helfenstein, P., Roatsch, T., Throop, H., Tiscareno, M., Vasavada, A. R., 2003. Cassini imaging of Jupiter's atmosphere, satellites, and rings. Science 299, 1541–1547.

Vasavada, A. R., Porco, C., the Cassini imaging science team, 2008. NASA Planetary Data System: Cassini Cylindrical-Projection Maps near Jupiter Closest Approach. http://pds-atmospheres.nmsu.edu/Jupiter/CassiniMaps.txt.

Table S1: Raw images used for the northern hemisphere.

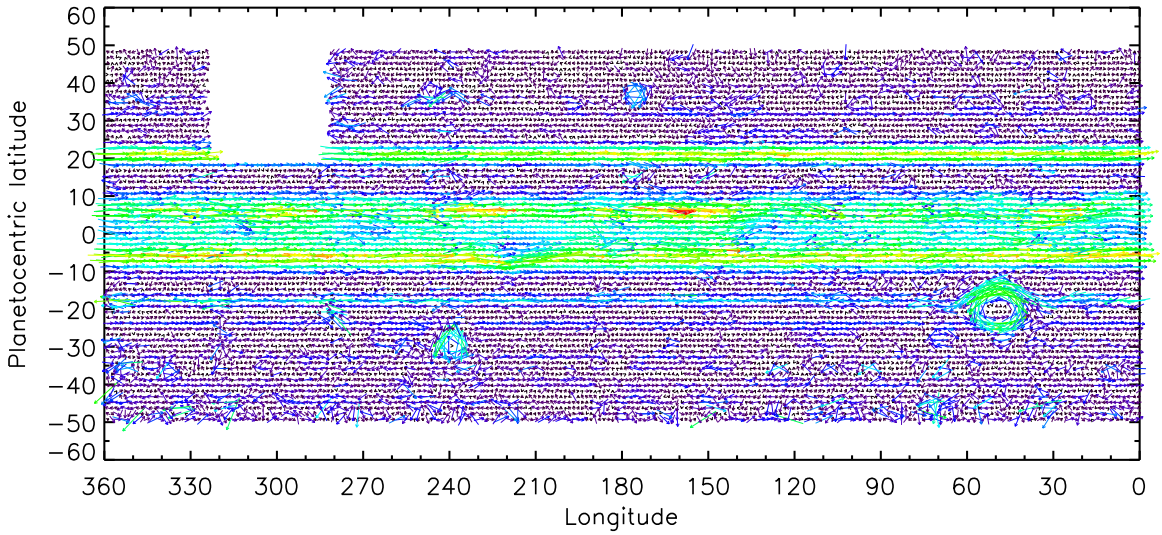
Day	Image 1	Image 2	First image 2000-Dec date & time	Second image 2000-Dec date & time	Separation (mm:ss)	Overlap central pixel (System III W longitude)
1	n1355233441	n1355237227	11th 13:32:34	11th 14:35:40	63:06	208.75
	n1355237227	n1355241013	11th 14:35:40	11th 15:38:46	63:06	246.85
	n1355248585	n1355252371	11th 17:44:58	11th 18:48:04	63:06	1.05
	n1355252371	n1355256157	11th 18:48:04	11th 19:51:10	63:06	39.15
	n1355256157	n1355259943	11th 19:51:10	11th 20:54:16	63:06	77.25
	n1355259943	n1355263729	11th 20:54:16	11th 21:57:22	63:06	115.35
	n1355263729	n1355267515	11th 21:57:22	11th 23:00:28	63:06	153.45
	n1355267515	n1355271301	11th 23:00:28	12th 00:03:34	63:06	191.55
2	n1355271301	n1355275087	12th 00:03:34	12th 01:06:40	63:06	229.60
	n1355275087	n1355278873	12th 01:06:40	12th 02:09:46	63:06	267.65
	n1355278873	n1355282659	12th 02:09:46	12th 03:12:52	63:06	305.75
	n1355282659	n1355286445	12th 03:12:52	12th 04:15:58	63:06	343.85
	n1355286445	n1355290231	12th 04:15:58	12th 05:19:04	63:06	21.95
	n1355290231	n1355294017	12th 05:19:04	12th 06:22:10	63:06	60.05
	n1355294017	n1355297803	12th 06:22:10	12th 07:25:16	63:06	98.10
	n1355297803	n1355301589	12th 07:25:16	12th 08:28:22	63:06	136.15
	n1355301589	n1355305375	12th 08:28:22	12th 09:31:28	63:06	174.25
3	n1355305375	n1355309161	12th 09:31:28	12th 10:34:34	63:06	212.35
	n1355309161	n1355312947	12th 10:34:34	12th 11:37:40	63:06	250.45
	n1355312947	n1355316733	12th 11:37:40	12th 12:40:46	63:06	288.55
	n1355316733	n1355320519	12th 12:40:46	12th 13:43:51	63:06	326.60
	n1355320519	n1355324305	12th 13:43:51	12th 14:46:57	63:06	4.65
	n1355324305	n1355328091	12th 14:46:57	12th 15:50:03	63:06	42.75
	n1355328091	n1355331877	12th 15:50:03	12th 16:53:09	63:06	80.85
	n1355331877	n1355335663	12th 16:53:09	12th 17:56:15	63:06	118.95
	n1355335663	n1355339449	12th 17:56:15	12th 18:59:21	63:06	157.05
	n1355339449	n1355343235	12th 18:59:21	12th 20:02:27	63:06	195.10
4	n1355343235	n1355347105	12th 20:02:27	12th 21:06:57	64:30	233.60
	n1355347105	n1355350891	12th 21:06:57	12th 22:10:03	63:06	272.10
	n1355350891	n1355354677	12th 22:10:03	12th 23:13:09	63:06	310.15
	n1355354677	n1355358463	12th 23:13:09	13th 00:16:15	63:06	348.25
	n1355358463	n1355362211	13th 00:16:15	13th 01:18:43	62:28	26.15
	n1355362211	n1355365978	13th 01:18:43	13th 02:21:30	62:47	63.95
	n1355365978	n1355369821	13th 02:21:30	13th 03:25:33	64:03	102.20
	n1355369821	n1355373607	13th 03:25:33	13th 04:28:39	63:06	140.55

Table S2: Raw images used for the southern hemisphere.

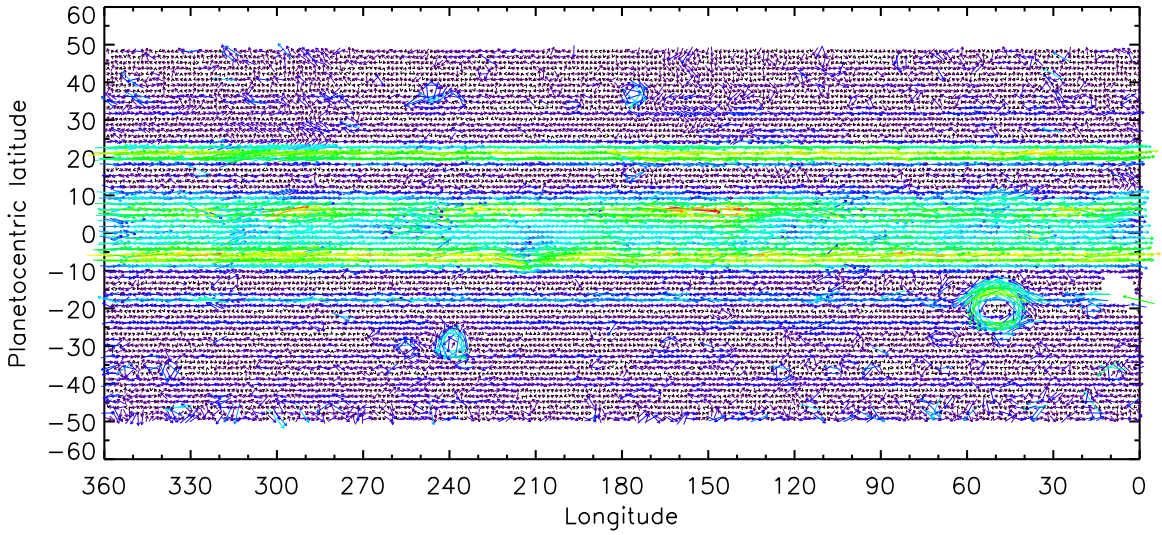
Day	Image 1	Image 2	First image 2000-Dec date & time	Second image 2000-Dec date & time	Separation (mm:ss)	Overlap central pixel (System III W longitude)
1	n1355233845	n1355237631	11th 13:39:18	11th 14:42:24	63:06	212.75
	n1355237631	n1355241417	11th 14:42:24	11th 15:45:30	63:06	250.85
	n1355241417	n1355245203	11th 15:45:30	11th 16:48:36	63:06	288.95
	n1355245203	n1355248989	11th 16:48:36	11th 17:51:42	63:06	327.05
	n1355248989	n1355252775	11th 17:51:42	11th 18:54:48	63:06	5.15
	n1355252775	n1355256561	11th 18:54:48	11th 19:57:54	63:06	43.25
	n1355256561	n1355260347	11th 19:57:54	11th 21:01:00	63:06	81.35
	n1355260347	n1355264133	11th 21:01:00	11th 22:04:06	63:06	119.40
	n1355264133	n1355267919	11th 22:04:06	11th 23:07:12	63:06	157.45
	n1355267919	n1355271705	11th 23:07:12	12th 00:10:18	63:06	195.55
2	n1355271705	n1355275491	12th 00:10:18	12th 01:13:24	63:06	233.65
	n1355275491	n1355279277	12th 01:13:24	12th 02:16:30	63:06	271.75
	n1355279277	n1355283063	12th 02:16:30	12th 03:19:36	63:06	309.85
	n1355283063	n1355286849	12th 03:19:36	12th 04:22:42	63:06	347.95
	n1355286849	n1355290635	12th 04:22:42	12th 05:25:48	63:06	26.00
	n1355290635	n1355294421	12th 05:25:48	12th 06:28:54	63:06	64.05
	n1355294421	n1355298207	12th 06:28:54	12th 07:32:00	63:06	102.15
	n1355298207	n1355301993	12th 07:32:00	12th 08:35:06	63:06	140.25
	n1355301993	n1355305779	12th 08:35:06	12th 09:38:12	63:06	178.35
3	n1355305779	n1355309565	12th 09:38:12	12th 10:41:18	63:06	216.45
	n1355309565	n1355313351	12th 10:41:18	12th 11:44:24	63:06	254.50
	n1355313351	n1355317137	12th 11:44:24	12th 12:47:29	63:06	292.55
	n1355317137	n1355320923	12th 12:47:29	12th 13:50:35	63:06	330.65
	n1355320923	n1355324709	12th 13:50:35	12th 14:53:41	63:06	8.75
	n1355324709	n1355328495	12th 14:53:41	12th 15:56:47	63:06	46.85
	n1355328495	n1355332281	12th 15:56:47	12th 16:59:53	63:06	84.95
	n1355332281	n1355336067	12th 16:59:53	12th 18:02:59	63:06	123.00
	n1355336067	n1355339853	12th 18:02:59	12th 19:06:05	63:06	161.05
	n1355339853	n1355343639	12th 19:06:05	12th 20:09:11	63:06	199.15
4	n1355343639	n1355347598	12th 20:09:11	12th 21:15:10	65:59	238.10
	n1355355143	n1355358929	12th 23:20:55	13th 00:24:01	63:06	352.95
	n1355358929	n1355362570	13th 00:24:01	13th 01:24:42	60:41	30.30
	n1355362570	n1355366357	13th 01:24:42	13th 02:27:49	63:07	67.65
	n1355366357	n1355370295	13th 02:27:49	13th 03:33:27	65:38	106.50
	n1355370295	n1355374081	13th 03:33:27	13th 04:36:33	63:06	145.35

Figure S1: Velocity fields $\mathbf{u} = (u, v)$. The vectors are subsampled by a factor of 3 in both directions (i.e. are 1.5° apart). The colour scale is the same for each day. Figure 3a in the main document contains the plot for day 2.

(a) Day 1



(b) Day 3



(c) Day 4

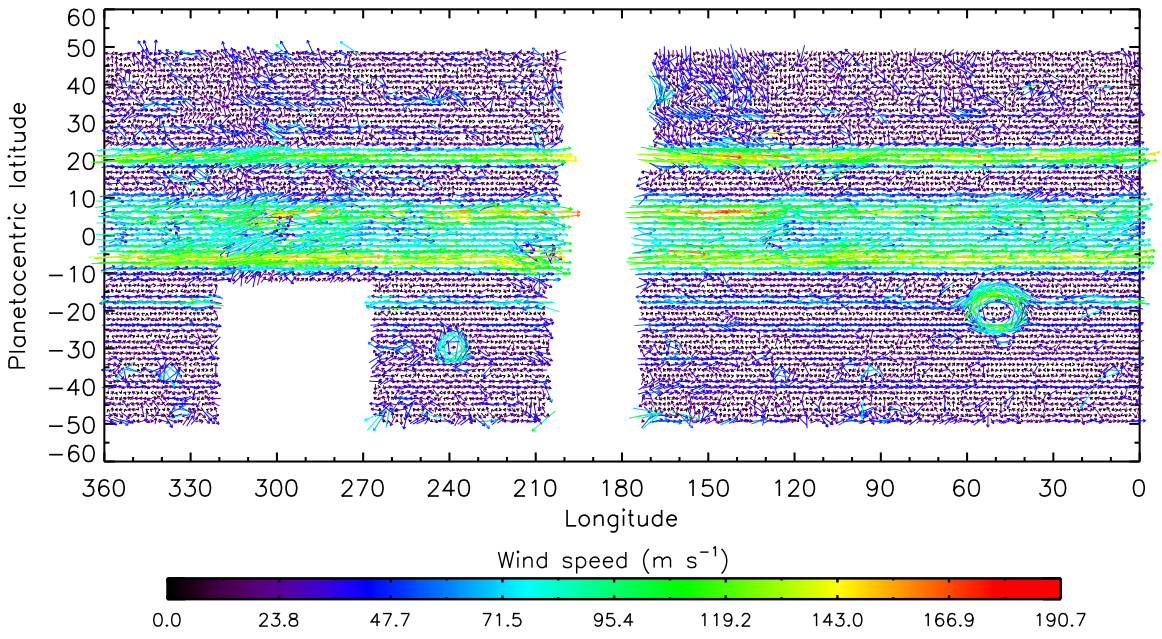
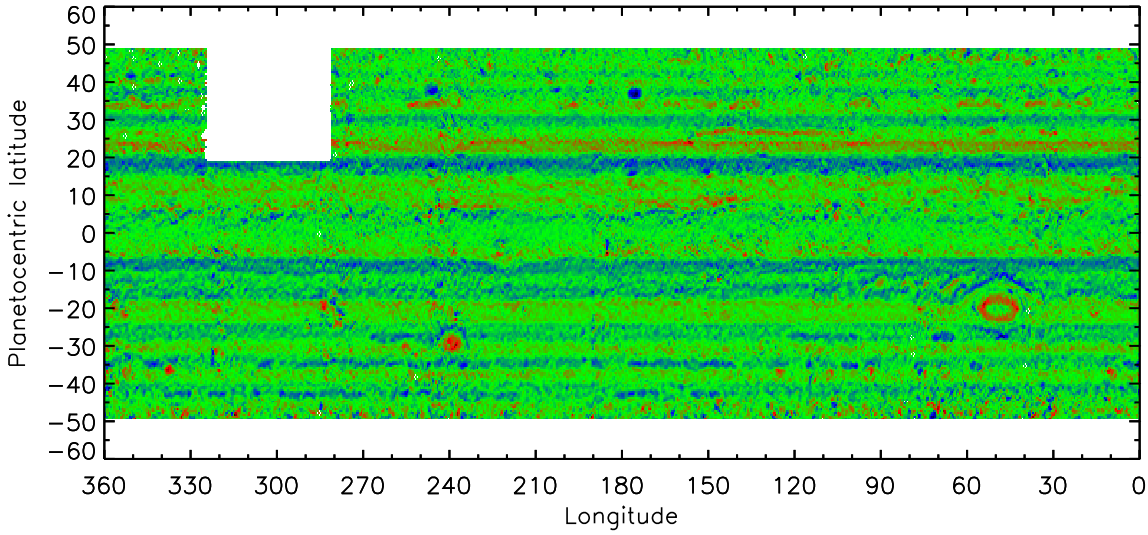
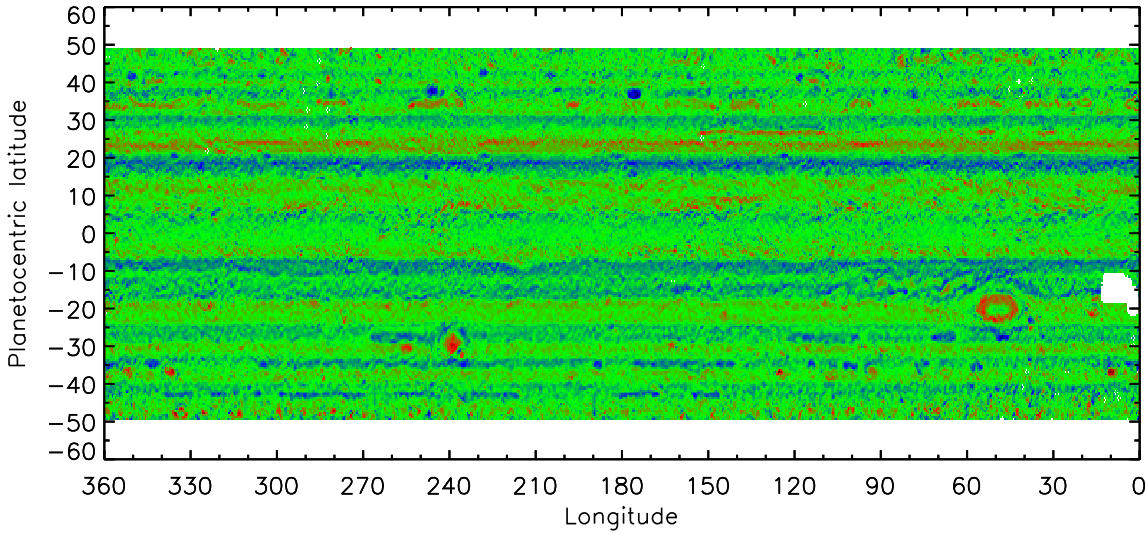


Figure S2: Relative vorticity $\nabla \times (u, v)$. The colour scale is the same for each day. Figure 3b in the main document contains the plot for day 2.

(a) Day 1



(b) Day 3



(c) Day 4

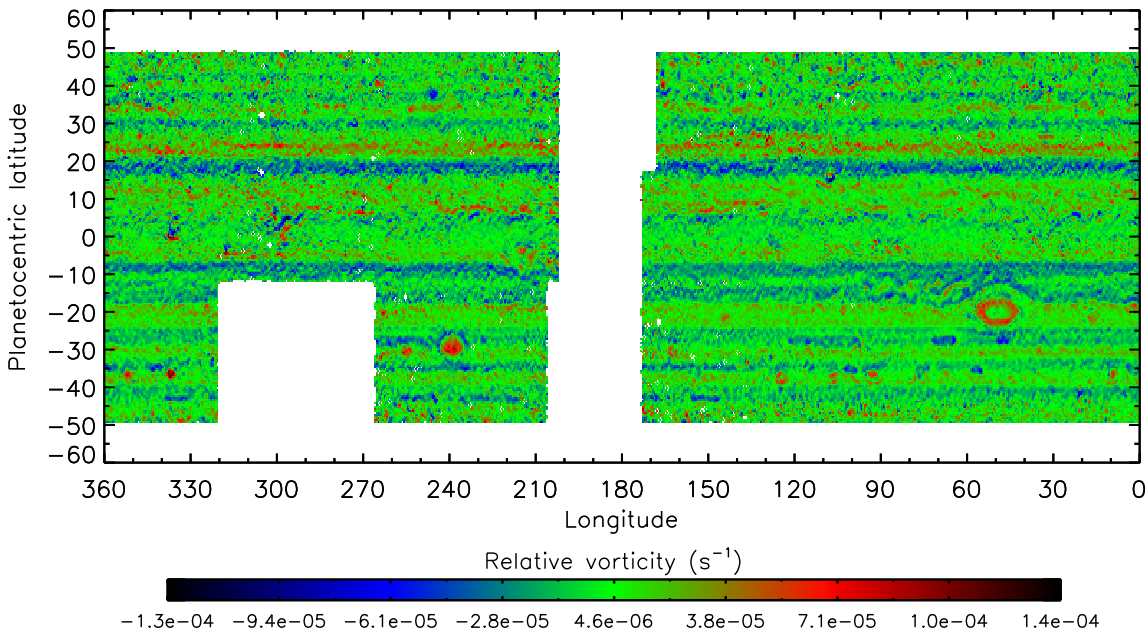
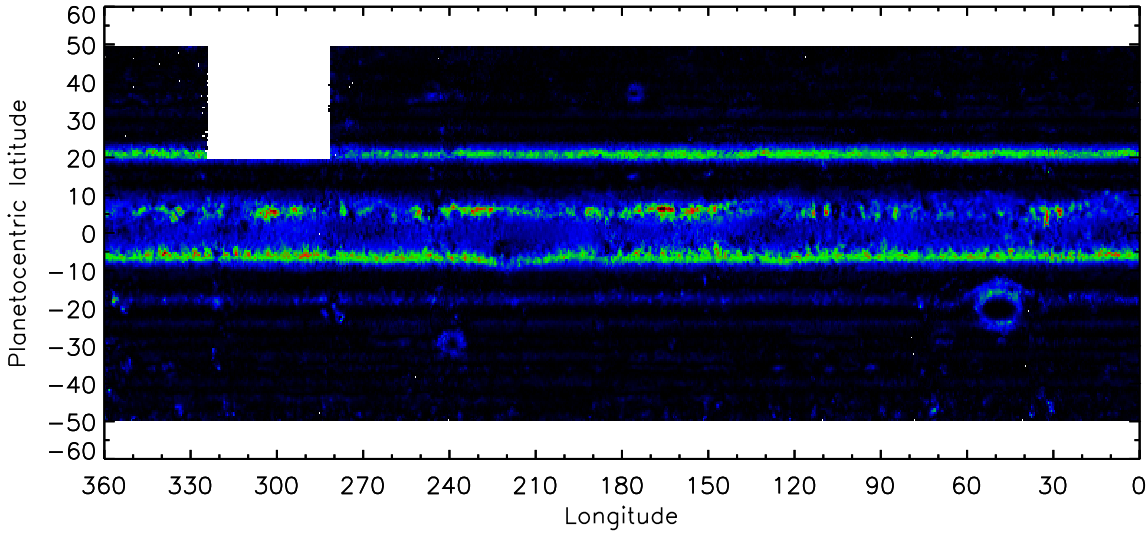
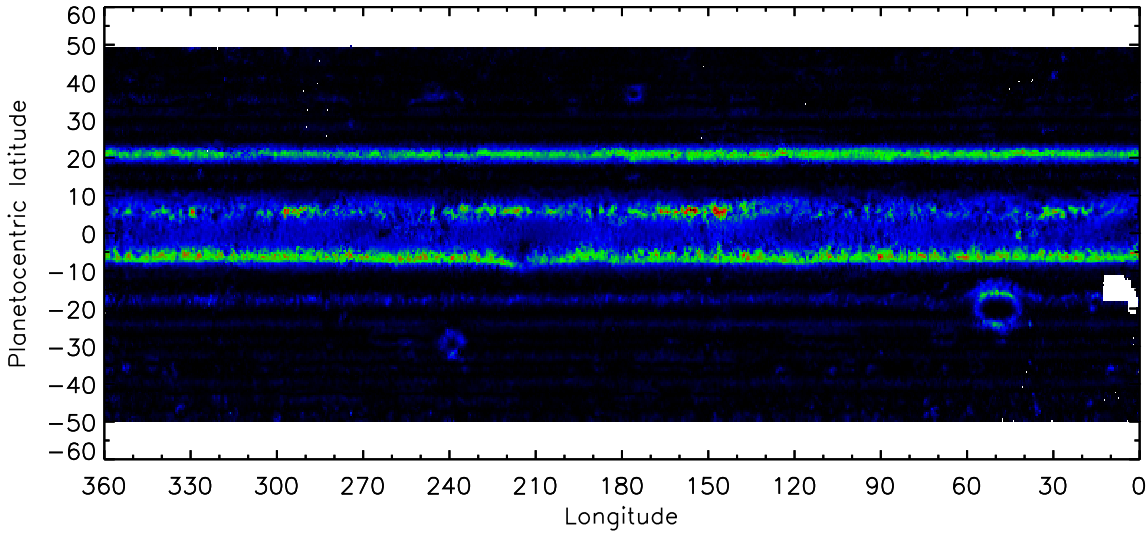


Figure S3: Total kinetic energy $|\mathbf{u} \cdot \mathbf{u}|/2$. The colour scale is the same for each day. Figure 3c in the main document contains the plot for day 2.

(a) Day 1



(b) Day 3



(c) Day 4

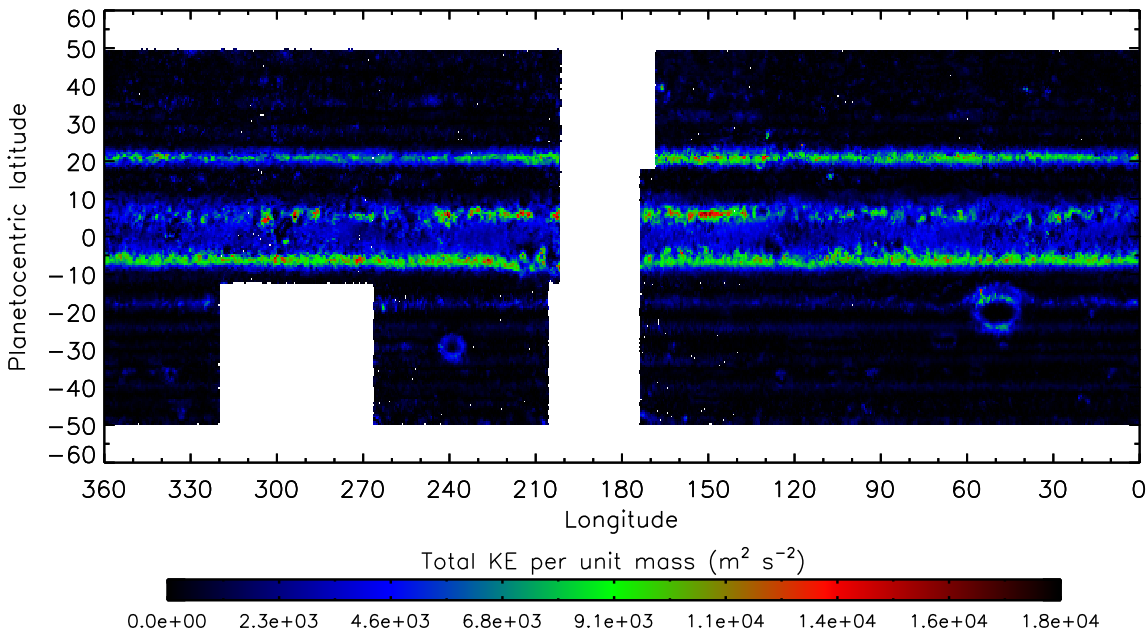
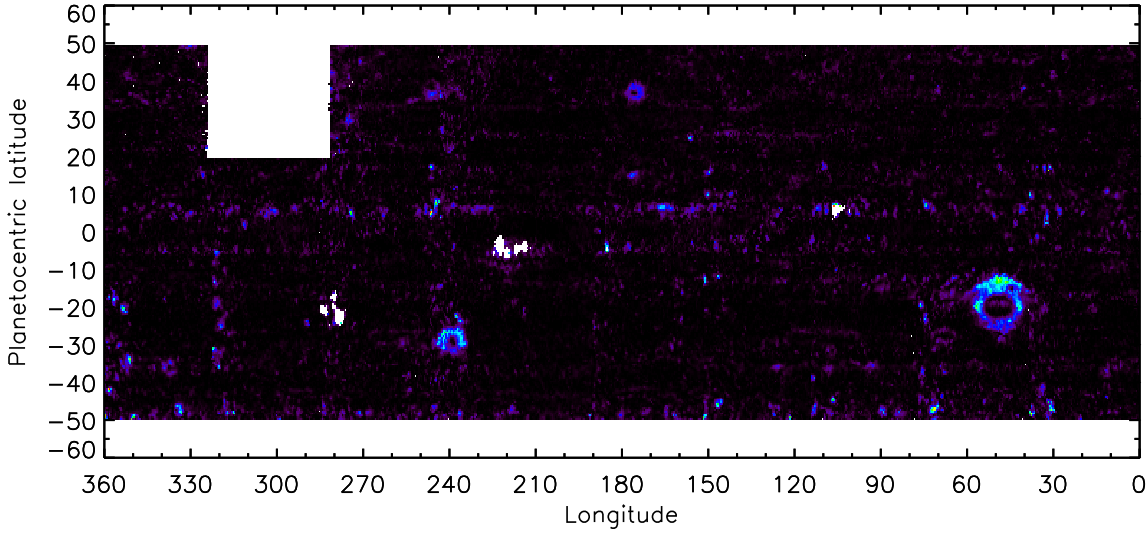
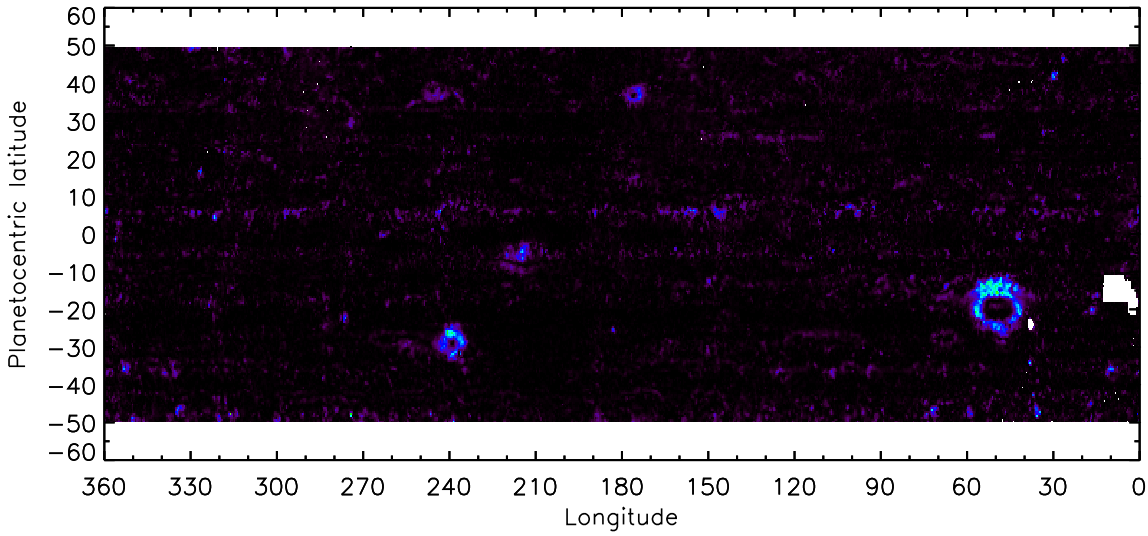


Figure S4: Eddy kinetic energy $|\mathbf{u}-\overline{\mathbf{u}}|^2/2$. To improve colour contrast we manually removed a few regions with errors above the 99th u-velocity percentile (regions are indicated in the subcaptions), and restricted the maximum value to 10^4 m^2 s^{-2}. The colour scale is the same for each day. Figure 3d in the main document contains the plot for day 2.

(a) Day 1. Points removed near 20°S 280°W, 5°S 220°W, and 5°N 105°W.



(b) Day 3. Points removed near 25°S 40°W.



(c) Day 4. Points removed near 0°N 335°W, 5°N 300°W, 15°N 110°W, and 40°N 40°W.

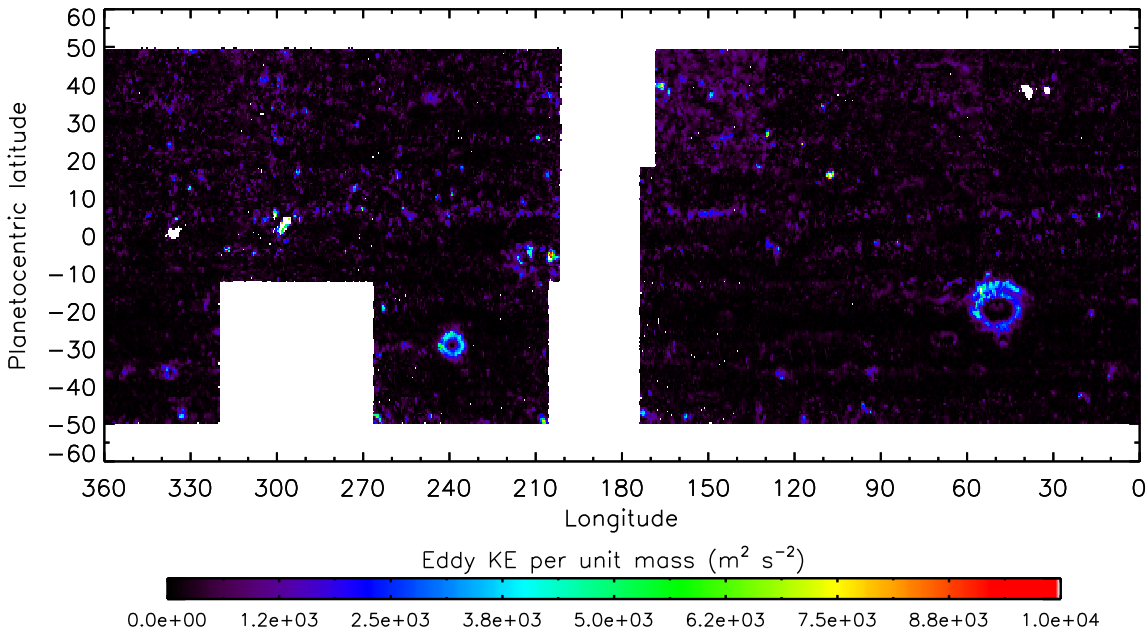
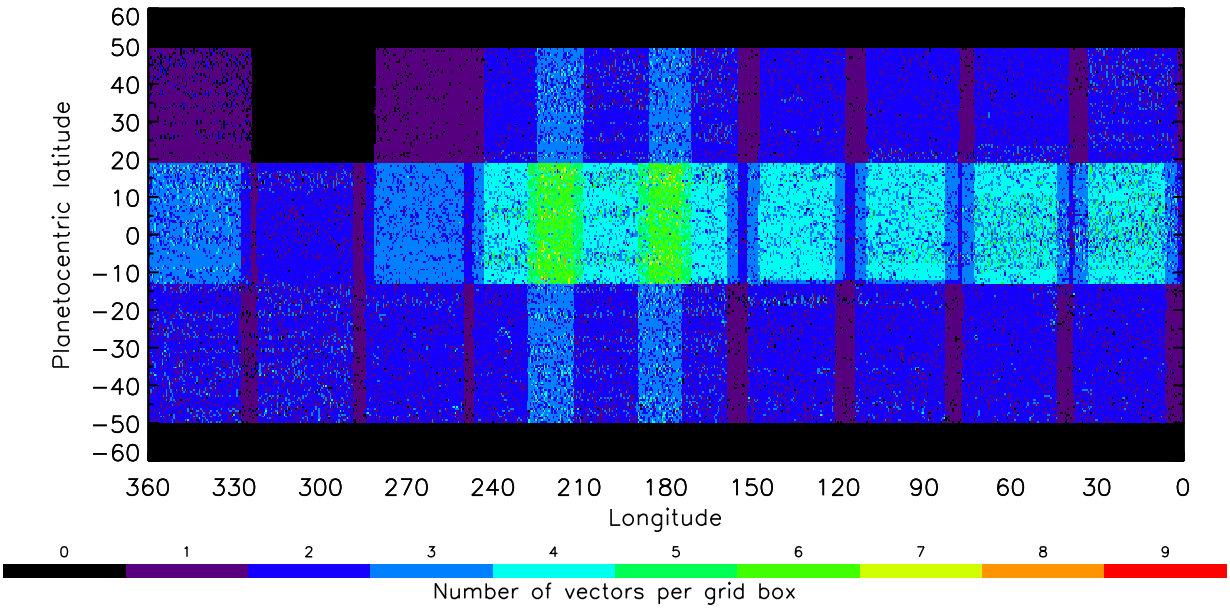


Figure S5: Number of filtered velocity vectors in each mosaic gridbox spanning (λ_i, ϕ_j) to $(\lambda_i+\delta\lambda, \phi_j+\delta\phi)$. Note the colour scale is different for each subfigure.

(a) Day 1



(b) Day 2

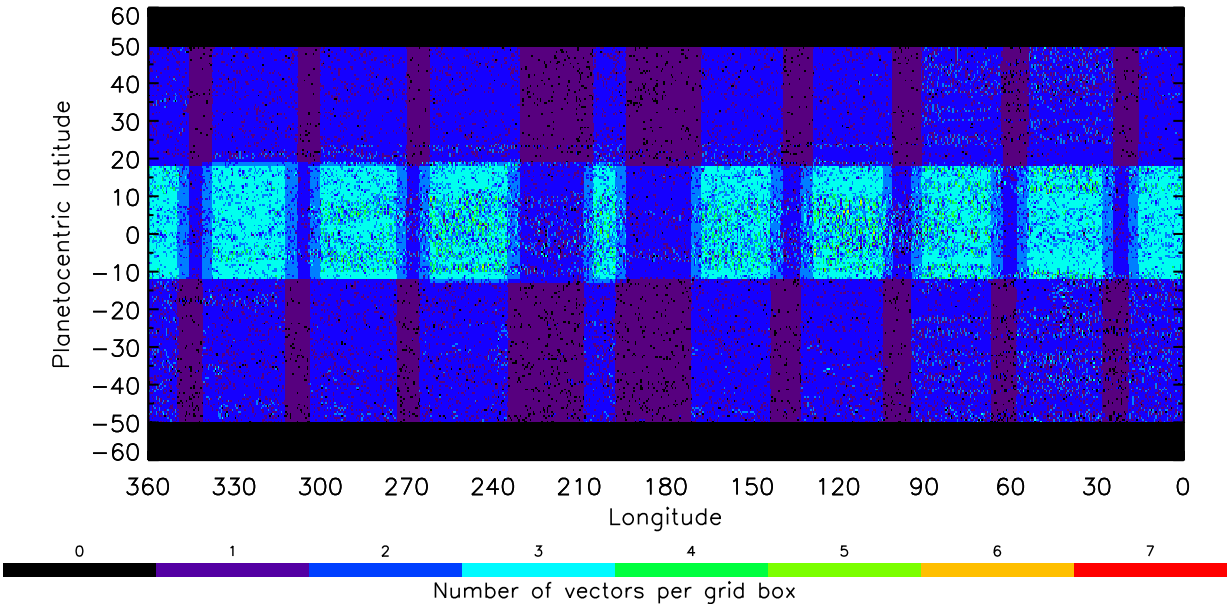
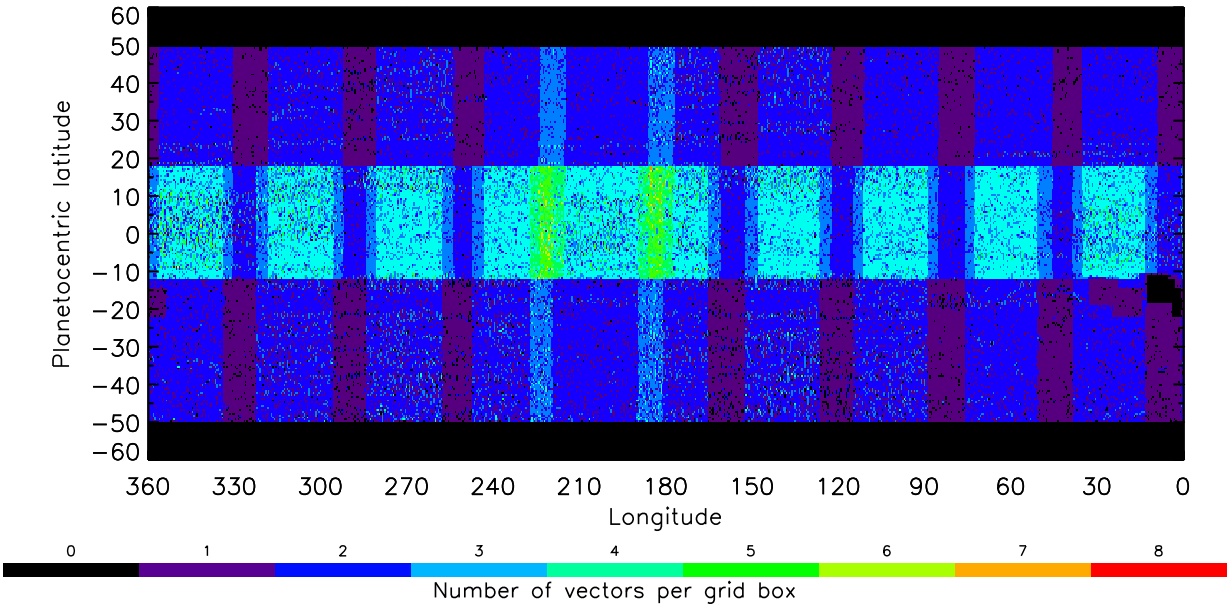


Figure S5: continued.

(c) Day 3



(d) Day 4

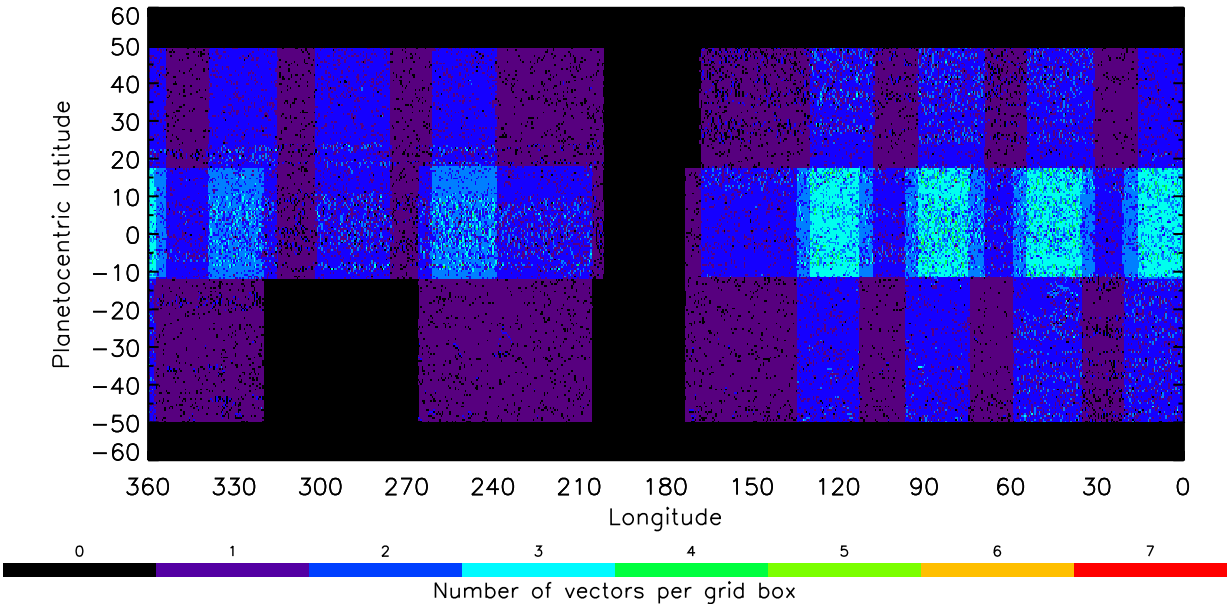


Figure S6: Estimated random error in u (zonal) velocity component. The maximum in the colour scale is the 99th percentile of the error distribution; points with error in the top 1% are coloured white to preserve the contrast at the low end of the scale. The maximum u error over the four days is $129\,\mathrm{m\,s^{-1}}$. The colour scale is the same for each day.

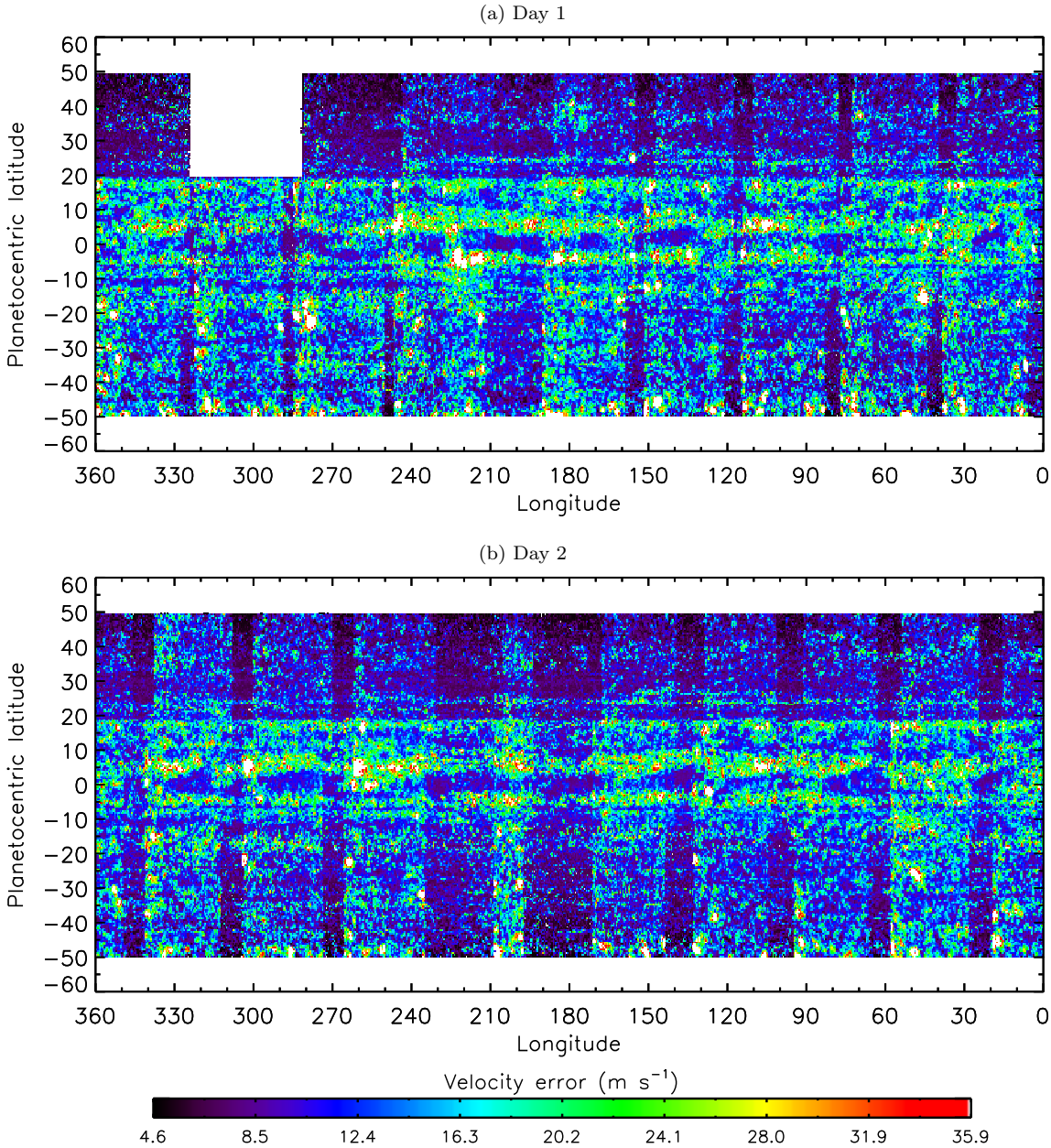
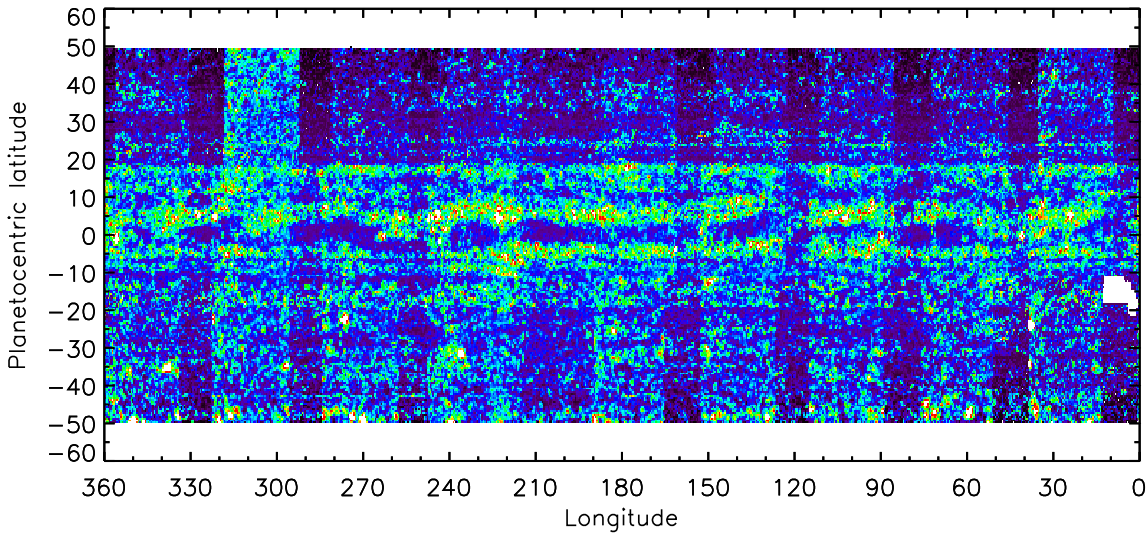


Figure S6: continued.

(c) Day 3



(d) Day 4

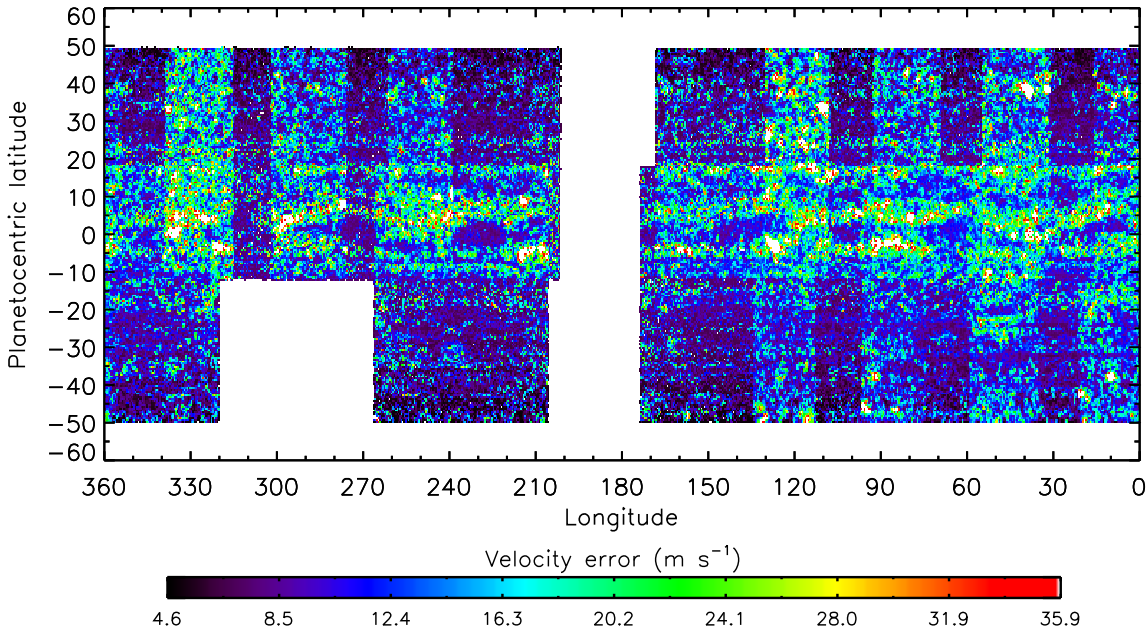


Figure S7: Estimated random error in v (meridional) velocity component. The maximum in the colour scale is the 99th percentile of the error distribution; points with error in the top 1% are coloured white to preserve the contrast at the low end of the scale. The maximum v error over the four days is $66\,\mathrm{m\,s^{-1}}$. The colour scale is the same for each day.

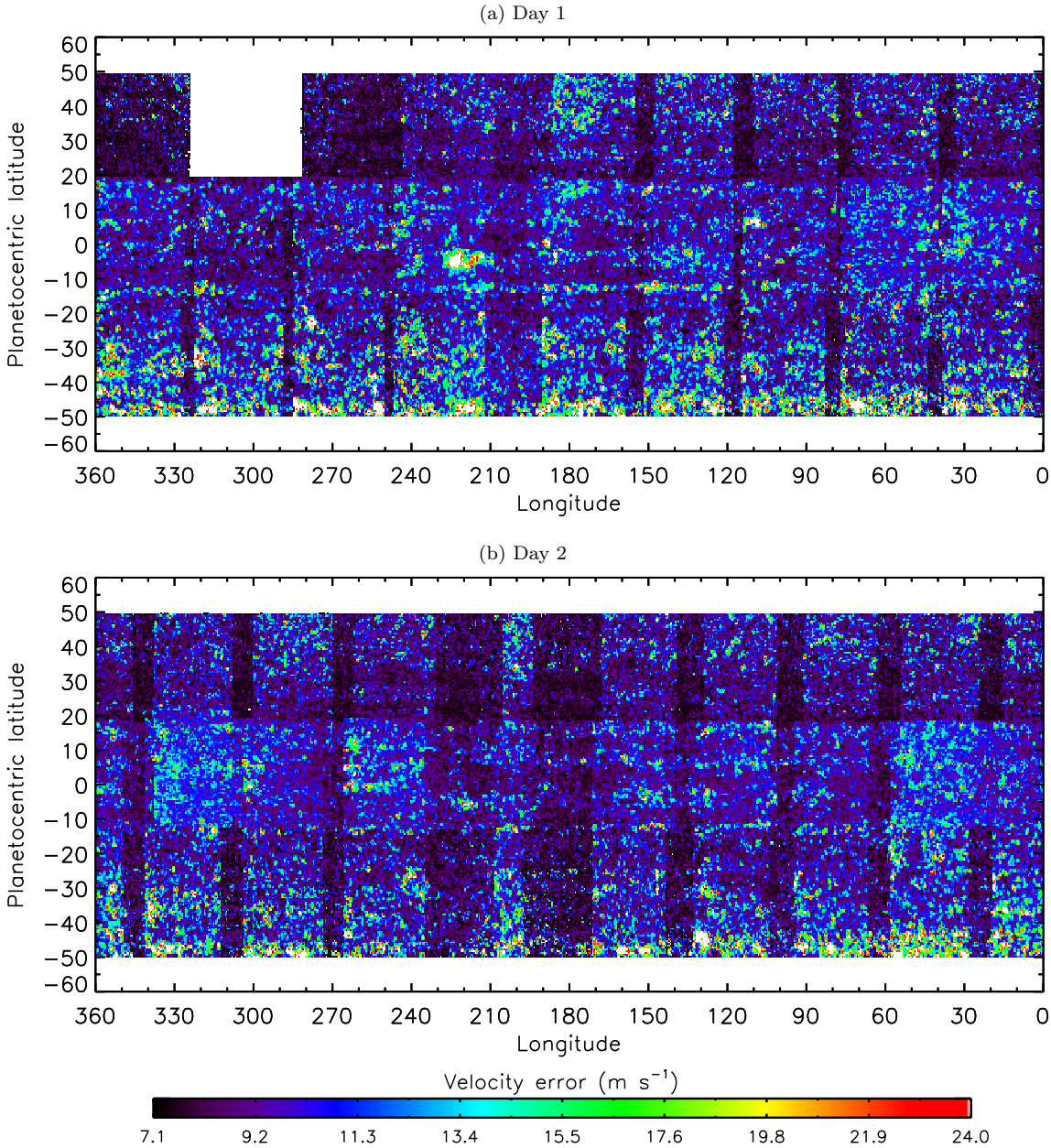
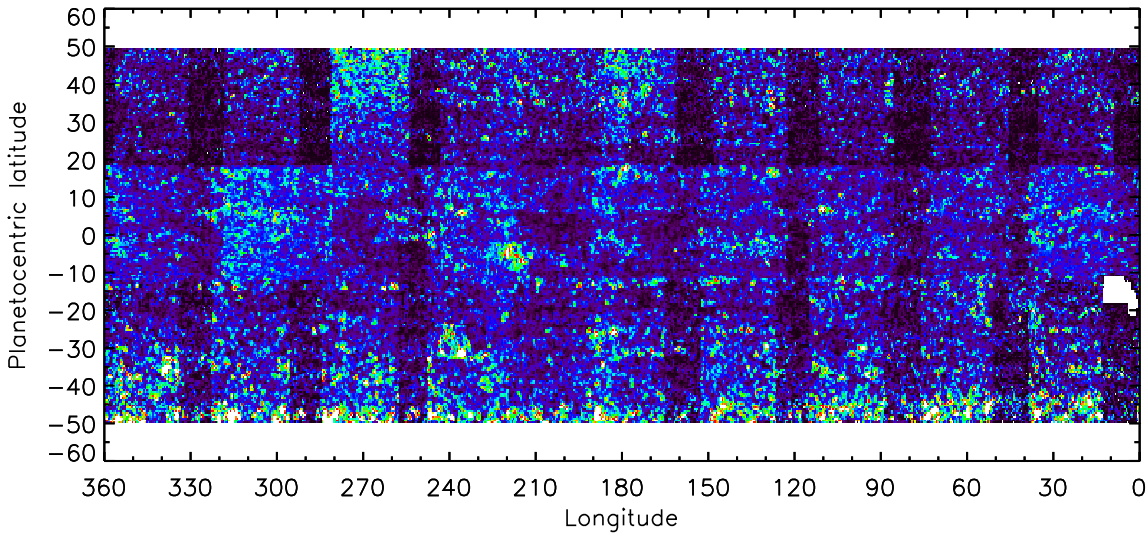


Figure S7: continued.

(c) Day 3



(d) Day 4

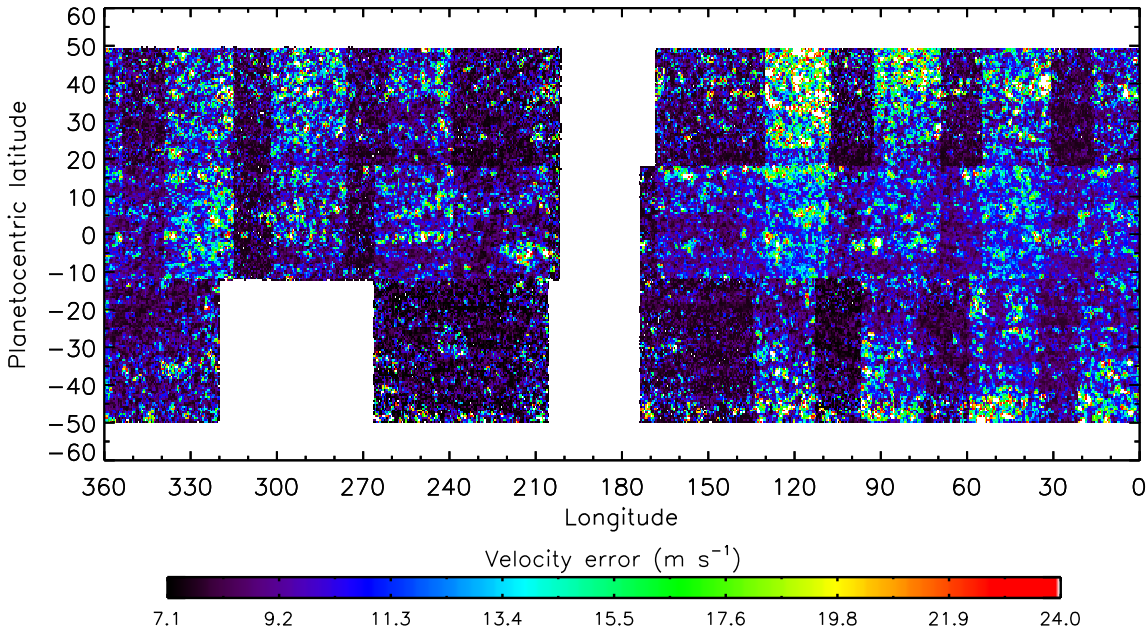


Figure S8: Zonal mean zonal velocity $\overline{u}$ for different latitudinal grid spacings, calculated by binning the filtered velocities (not the mosaiced fields). The dotted line is from Porco et al. (2003), and the dashed line is from Limaye (1986).

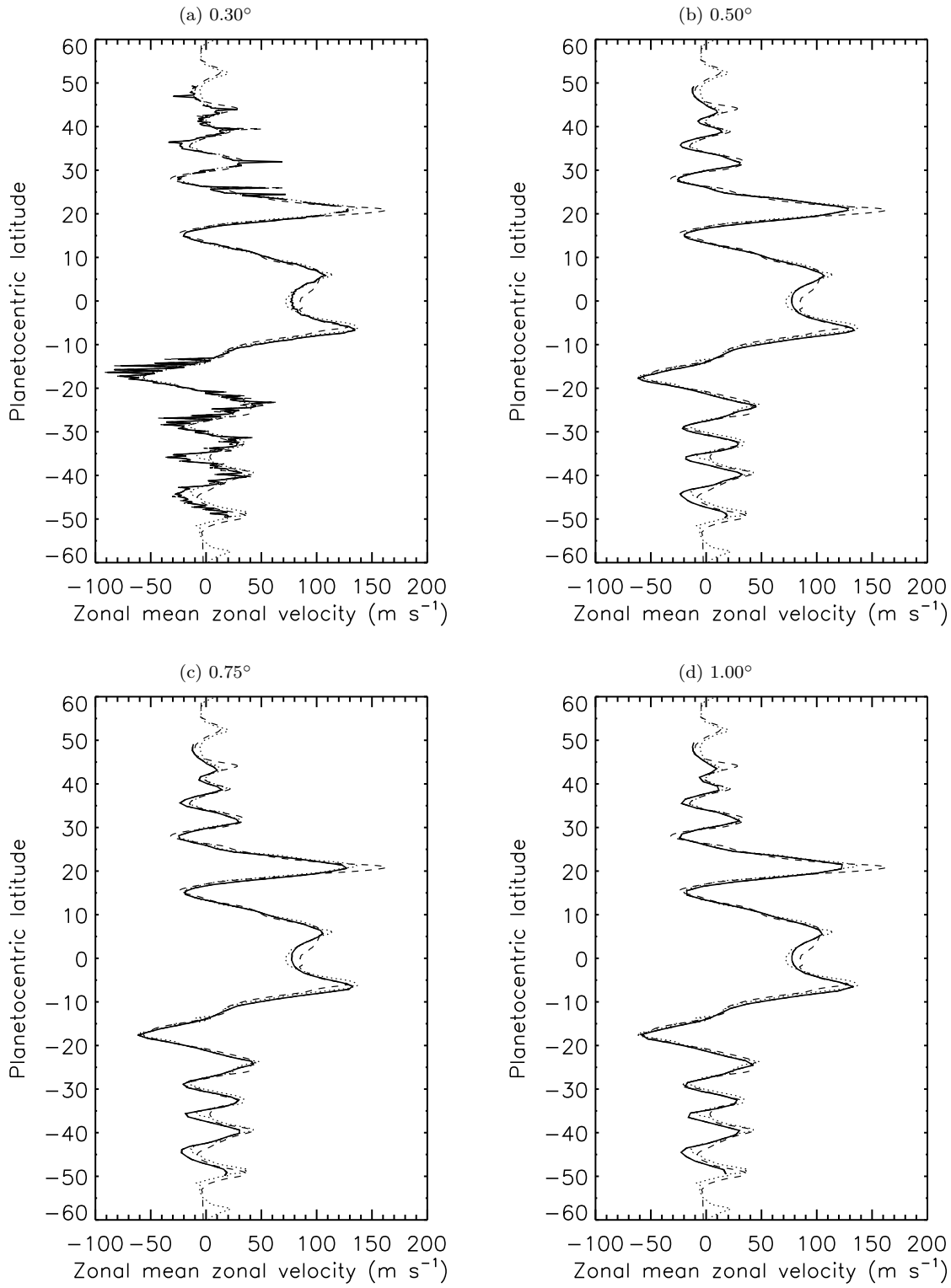
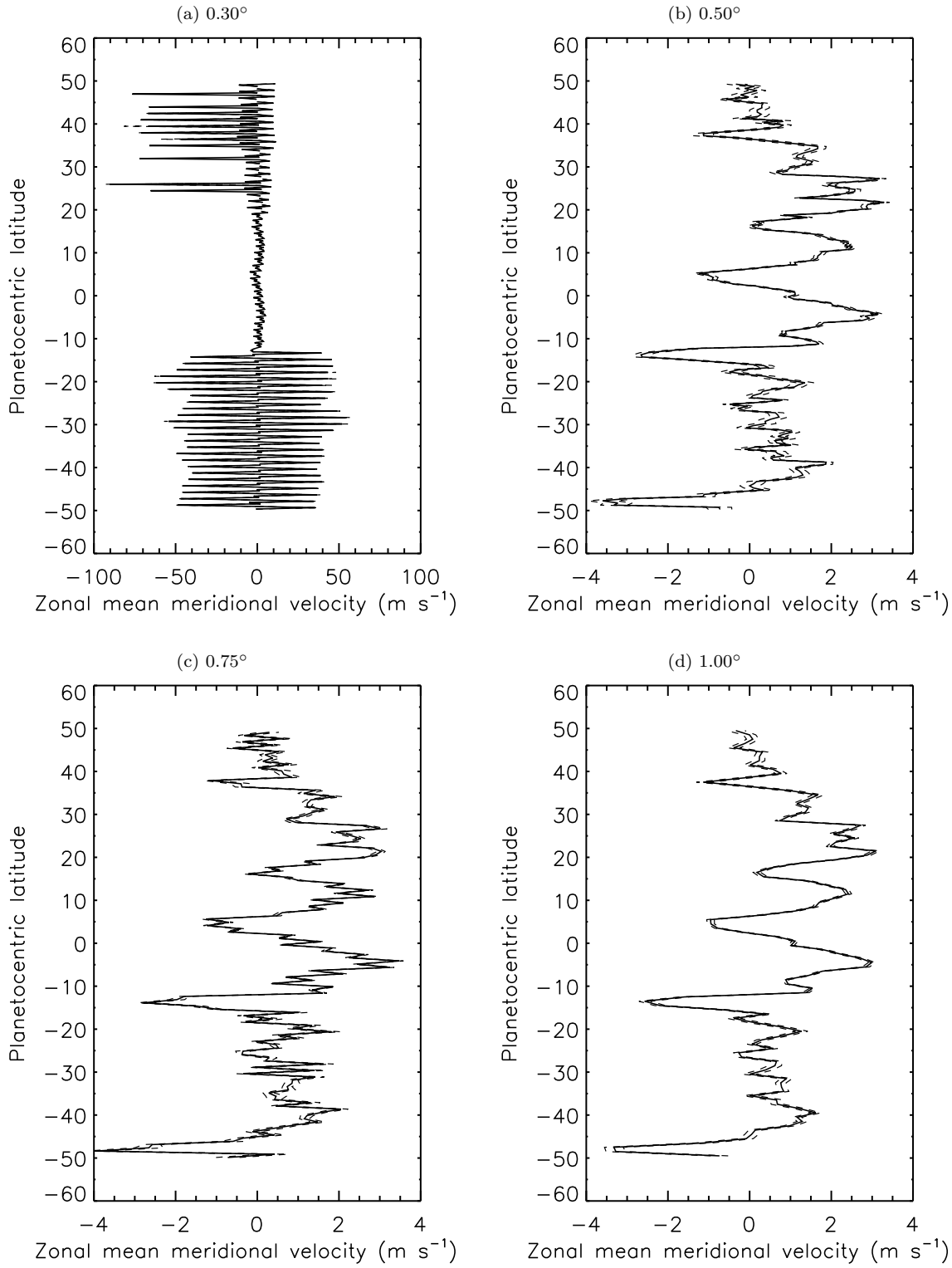


Figure S9: Zonal mean meridional velocity $\overline{v}$ for different latitudinal grid spacings, calculated by binning the filtered velocities (not the mosaiced fields). Dashed lines show ± one standard error from the mean.



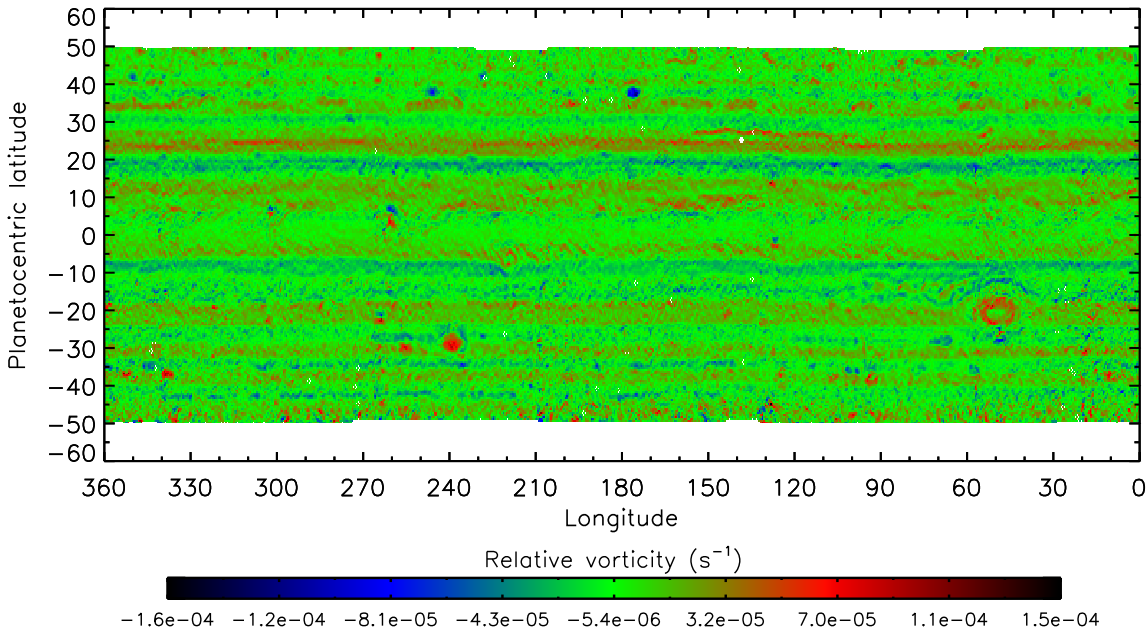


Figure S10: Relative vorticity field for day 2, with an uncertainty of 1.0° introduced into the position of individual image pairs before they were combined into the mosaic.