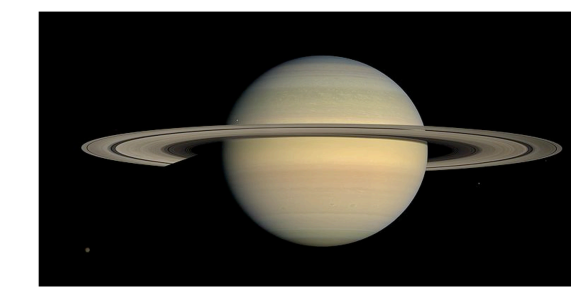
The Meteorology of Giant Planets Revealed Through Automated Cloud Feature Tracking



David S. Choi and Adam P. Showman
Department of Planetary Sciences, University of Arizona

Abstract

We examine the meteorology of the giant planets using our automated cloud feature tracker. Through pattern recognition and correlation optimization, our software returns a dense, regular grid of wind vectors.

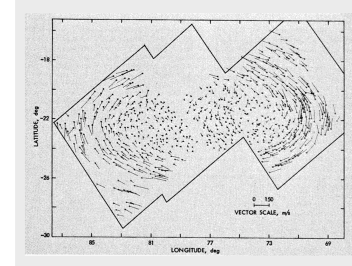
We measured the winds within Jupiter's Great Red Spot (GRS) and uncovered its distinctive "hollow" structure, its counter-rotating interior, and a newly discovered cyclonic ring around its periphery. This cyclonic ring suggests the presence of a thermally indirect, downwelling secondary circulation at the periphery of the GRS.

We also analyzed a time-series of images of Jupiter's White Ovals. Over a decade, the system has evolved from three discrete, white anticyclones to one reddish vortex (Oval BA). Our measurements revealed a modest, non-uniform acceleration of the flow within Oval BA coincident with the coloration event, and areas of organized cyclonic circulation in seemingly turbulent regions near these anticyclones.

We have also directly measured the power spectrum of the turbulent kinetic energy present within Jupiter's atmosphere. Our results provide evidence consistent with an inverse cascade of energy from small to large scales that may fuel Jupiter's impressive jet streams and vortices.

Finally, our analysis of VIMS near-infrared images of silhouetted clouds in Saturn's atmosphere demonstrated that the measured latitudinal zonal wind profile is largely similar to previous measurements utilizing visible-wavelength images. This result, accompanied by a statistical analysis of the imaged cloud features, yields constraints on the vertical structure and latitudinal temperature gradients of Saturn's atmosphere.

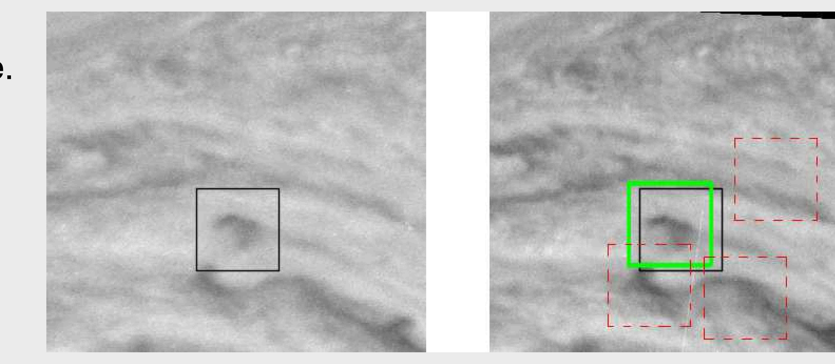
Methodology



Mitchell et al. (1981)

Manual cloud tracking:
- is a straightforward technique.
- can be challenging in certain conditions.
- results in an irregular arrangement of wind vectors.
- is limited to the inherent resolution of the images.

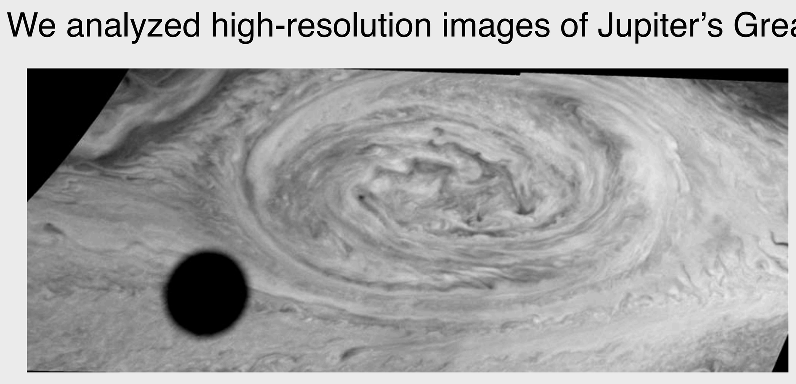
Automated cloud tracking:
- returns orders of magnitude more wind vectors, all arranged in a regular grid for easy analysis.
- is objective and repeatable, and returns results where manual feature tracking may be challenging.
- is limited to image pairs with a relatively short time interval. [features cannot deform too much]
- can yield spurious results in certain areas that must be manually removed.



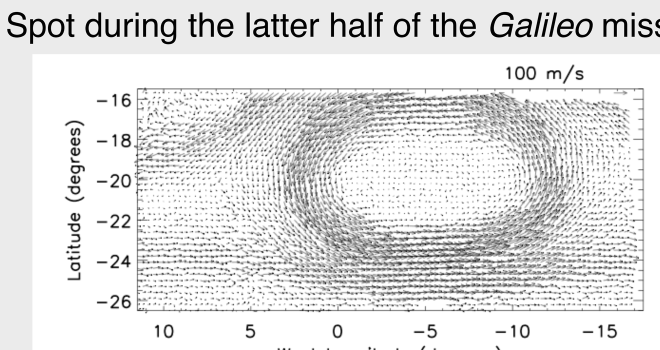
Our algorithm extracts a basis portion of an image at some initial time (black box, left). Then, it systematically extracts numerous comparison portions from a later image (right), and calculates the one with the highest cross-correlation score (green box, right) and rejects those with lower cross-correlation scores (dashed red boxes, right). The spatial displacement between the comparison portion with the highest cross-correlation score and the basis portion is the foundation for the velocity measurement, which our software defines to be located at the center of the basis portion.

Jupiter's Great Red Spot

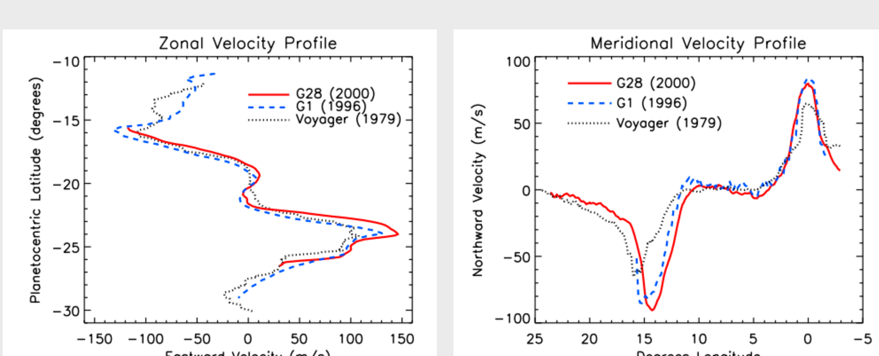
We analyzed high-resolution images of Jupiter's Great Red Spot during the latter half of the *Galileo* mission.



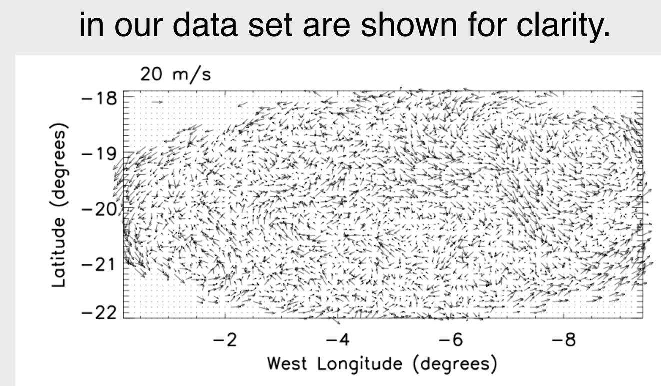
One of the analyzed mosaics (resolution 12 km/pix).



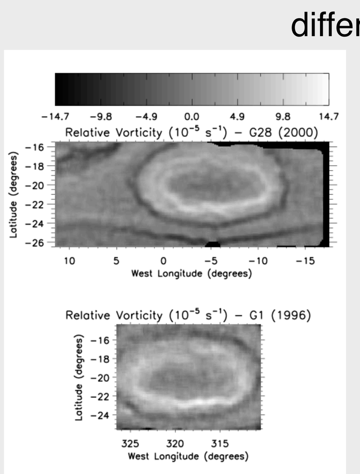
GRS Wind Velocity Map. Only ~10% of the vectors in our data set are shown for clarity.



Zonal and meridional wind profiles of the GRS from different data sets.

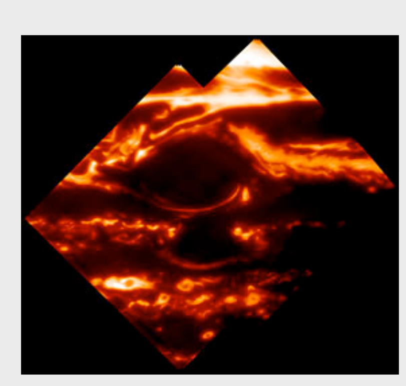


GRS Center Wind Velocity Map, showing coherent flows and recirculating currents. All vectors are shown.



(left) Relative vorticity map of the GRS. Note the cyclonic ring at the periphery of the vortex. This is the first time, to the best of our knowledge, that such a ring has been observed around the GRS, and matches bright rings observed spectroscopically (right).

Both rings imply a thermally indirect circulation, where air rises in the interior of the vortex, outflows to the outer regions, and sinks at the periphery, producing evaporation of cloud condensibles.

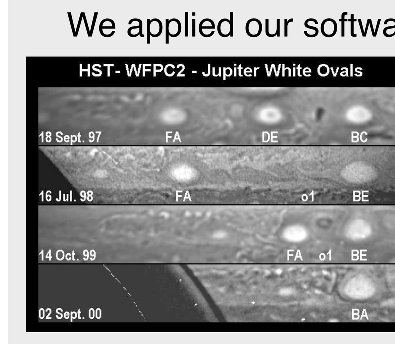


Credit: Imke de Pater, Michael Wong (UC Berkeley); Al Conrad (Keck), and Chris Go (Cebu, Philippines)

Reference: Choi, D. S., D. Banfield, P. Gierasch, and A. P. Showman (2007). Velocity and vorticity measurements of Jupiter's Great Red Spot using automated cloud feature tracking. *Icarus*, 188, pp. 35–46. doi:10.1016/j.icarus.2006.10.037.

Jupiter's White Ovals and Oval BA

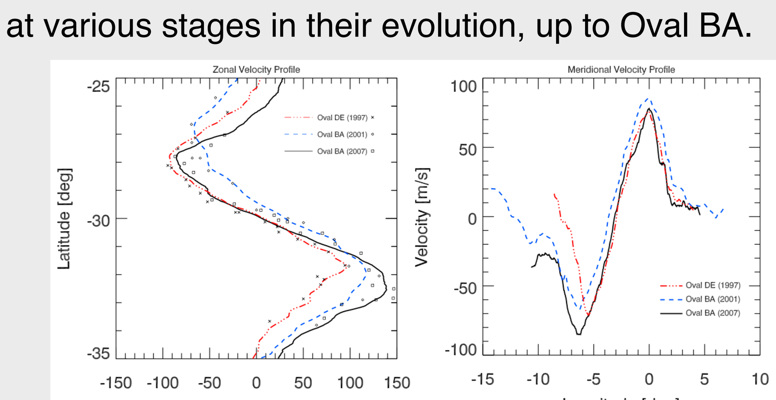
We applied our software to images of the White Ovals at various stages in their evolution, up to Oval BA.



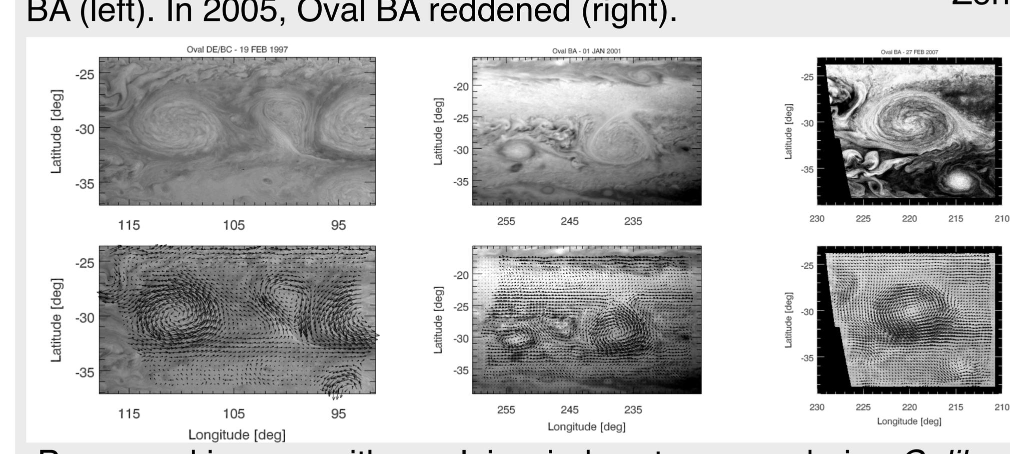
Credit: HST/NASA/ESA

Credit: NASA, ESA, I. de Pater, and M. Wong (UC Berkeley)

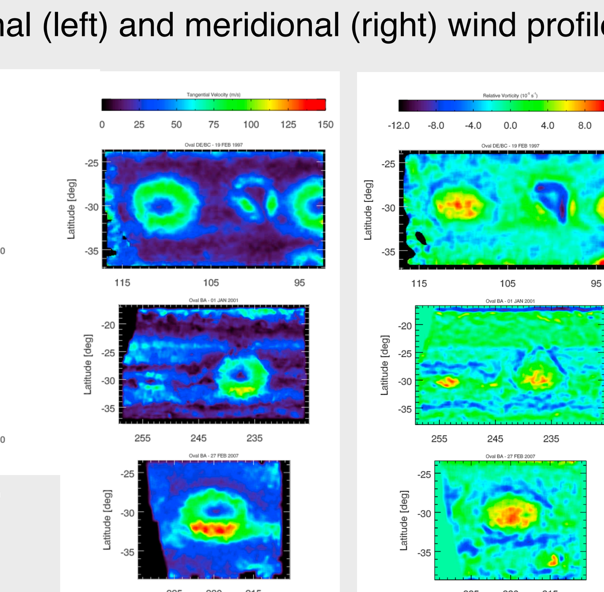
The White Ovals existed for most of the 20th century, until mergers created a large, white anticyclone, Oval BA (left). In 2005, Oval BA reddened (right).



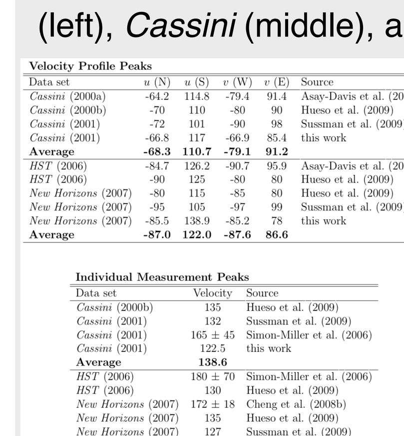
Zonal (left) and meridional (right) wind profiles

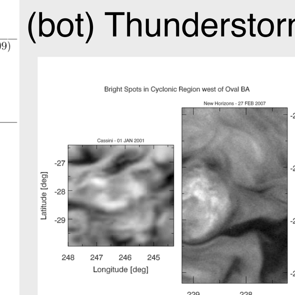


Processed images with overlain wind vector maps during *Galileo* (left), *Cassini* (middle), and *New Horizons* (right)



Velocity (left) and relative vorticity (right) maps





(left) Comparison of studies.
(bot) Thunderstorm candidates.

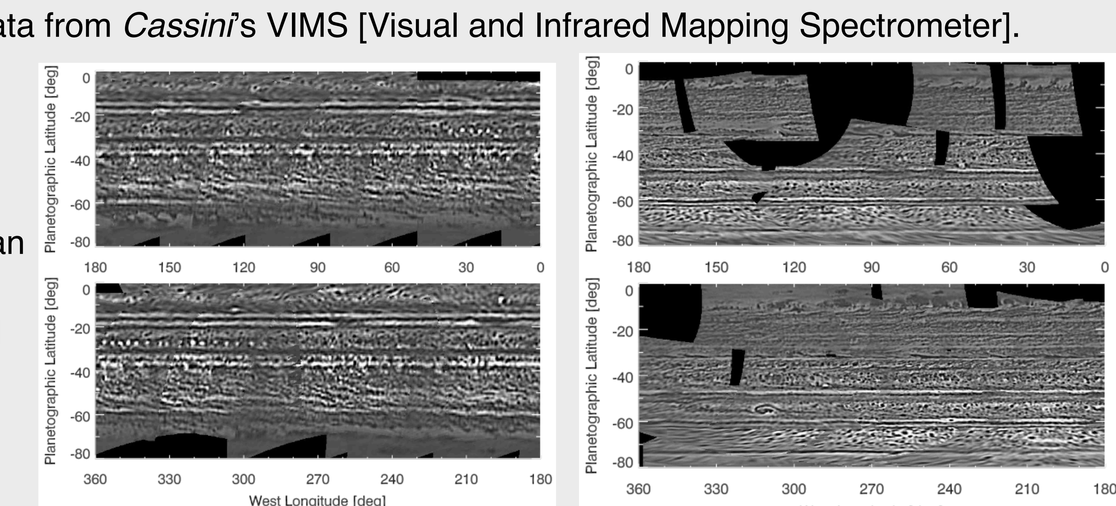
Overall, we show evidence supporting a moderate change in the dynamics of Oval BA before and after its color change. Oval BA also had an anomalous shape that affected its dynamical evolution. Cyclonic regions adjacent to the vortex may have some involvement with Oval BA's dynamics.

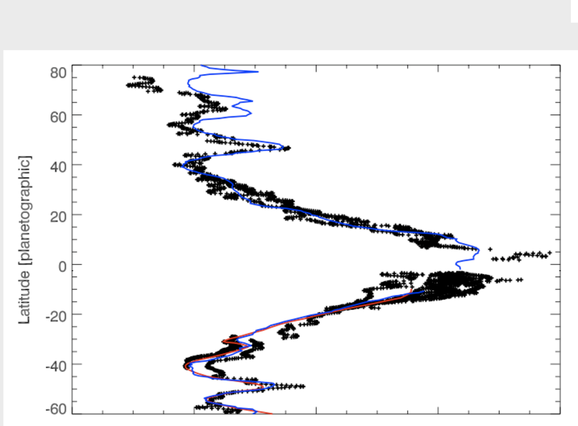
Reference: Choi, D. S., A. P. Showman, and A. R. Vasavada (2009). The Evolving Flow of Jupiter's White Ovals and Adjacent Cyclones. *Icarus*. doi:10.1016/j.icarus.2009.10.013. in press.

Saturn revealed with VIMS

We analyzed near-infrared data from *Cassini*'s VIMS [Visual and Infrared Mapping Spectrometer].

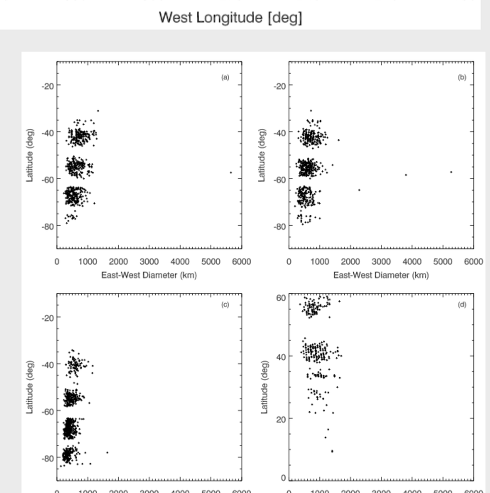
5-micron mosaics of Saturn's northern (left) and southern (right) hemispheres. This spectral band can probe deeper layers of the atmosphere as they are silhouetted against the planet's thermal background.

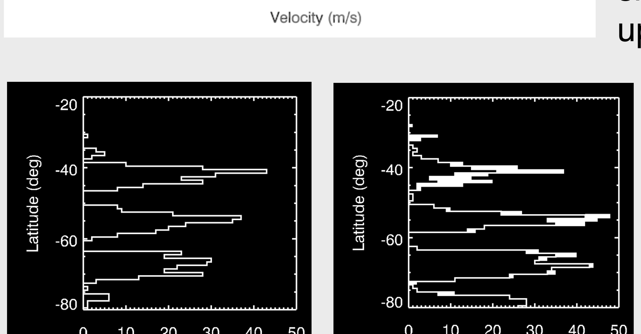


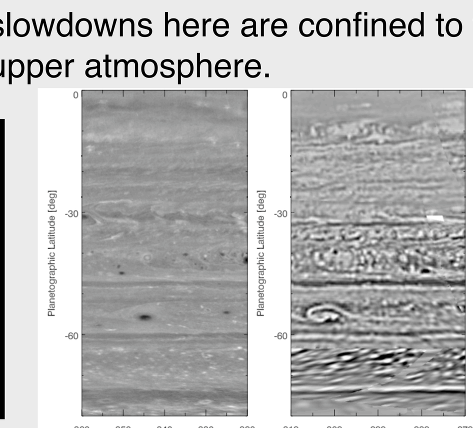


Zonal Wind Profile:
Blue - *Voyager*
Red - *Cassini* (ISS)
Black - *Cassini* (VIMS)

Note the overall general match. Also note high velocity measured at equatorial jet stream, implying that previous measurements of slowdowns here are confined to the upper atmosphere.







Plot of Spot Feature Diameter vs. Latitude, showing a slight trend of decreasing size with latitude, suggesting that the Rossby deformation radius may help control size.

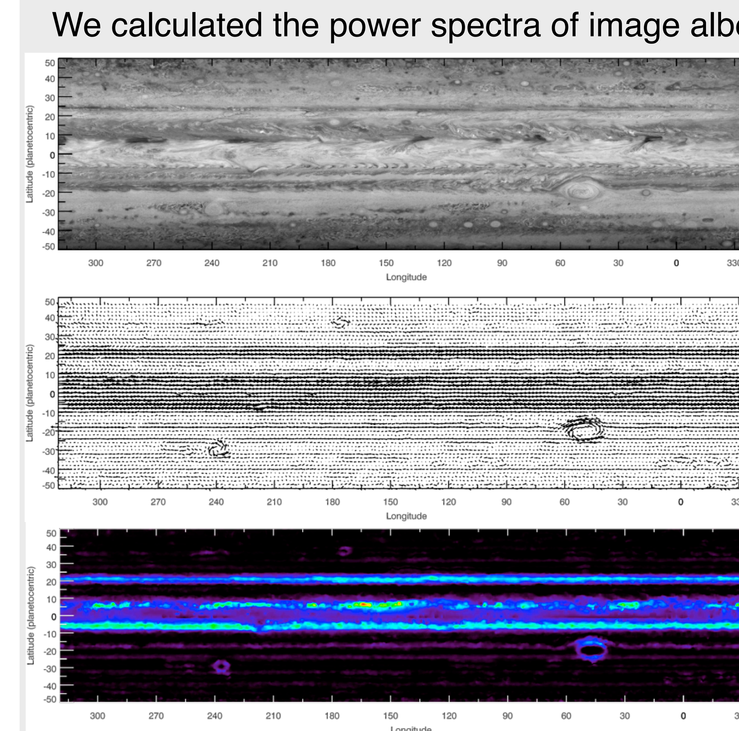
(left) Number of Spot Features vs. Latitude, VIMS. (middle) Number of Spot Features vs. Latitude, ISS. Unfilled: Light spots/clouds, Filled: dark, low-albedo spots. (right) Comparison between VIMS and ISS mosaics.

Results imply that either VIMS and ISS are observing a single cloud deck, or that there are constraints on latitudinal temperature gradients and vertical wind shears if cloud decks are independent.

Reference: Choi, D. S., A. P. Showman, and R. H. Brown (2009). Cloud features and zonal wind measurements of Saturn's atmosphere as observed by *Cassini*/VIMS. *Journal of Geophysical Research* (*Planets*), 114, p. 4007. doi:10.1029/2008JE003254.

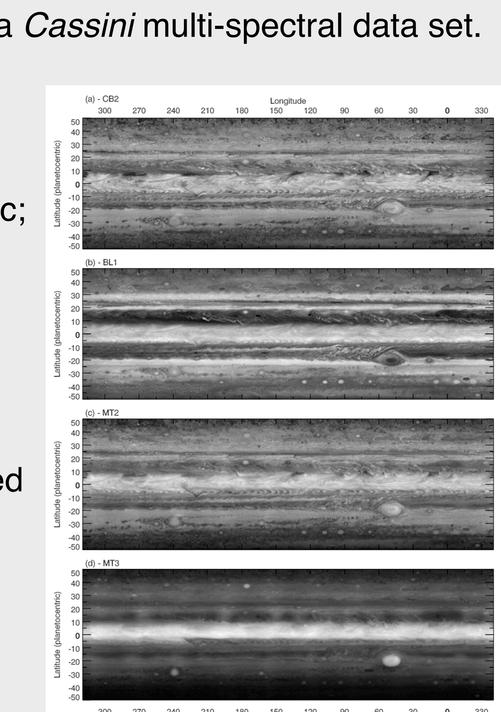
Power Spectra of Jupiter's Atmosphere

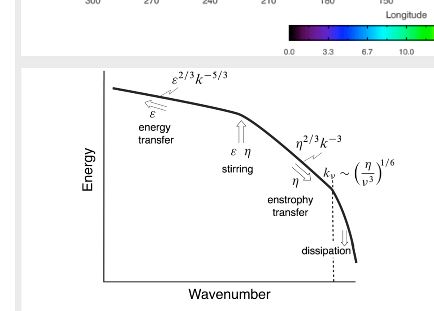
We calculated the power spectra of image albedos and kinetic energy from a *Cassini* multi-spectral data set.



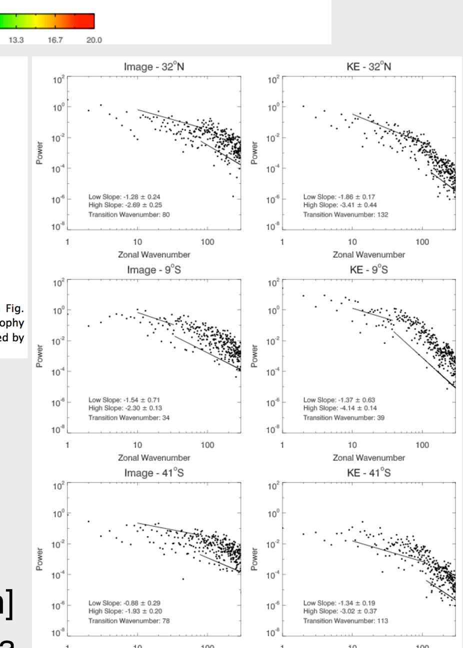
[Left, from top to bottom] Near-infrared image mosaic; wind-vector map; kinetic energy map

[Right, from top to bottom] Image mosaics using different filters: near-infrared (756 nm); visible blue (455 nm); moderate methane (727 nm); strong methane (889 nm)





Vallis, 2006

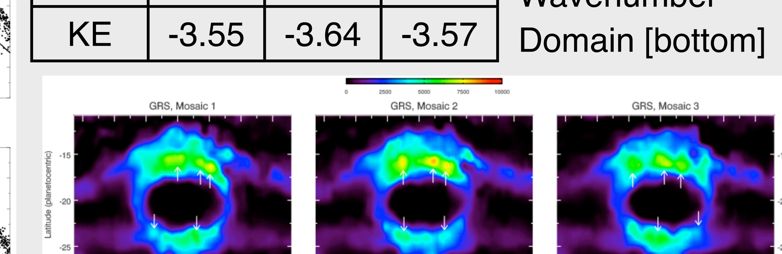


(top) Theoretical power spectrum of 2D turbulence. (right) Example image albedo [left column] and kinetic energy [right column] power spectra from our data.

	1	2	3
Image	-1.20	-1.26	-1.17
KE	-1.39	-1.43	-1.35

	1	2	3
Image	-2.37	-2.38	-2.40
KE	-3.55	-3.64	-3.57

Average Zonal Power Spectra Slopes, All Latitudes: Low Wavenumber Domain [top], High Wavenumber Domain [bottom]



Time-dependent eddies within GRS flow collar

Overall, we return evidence consistent with the presence of an inverse energy cascade in the atmosphere, which may transfer energy from small-scale eddies driven by, say, eddies, to large-scale flows such as the jet streams and large vortices. We also demonstrate that the power spectra of image albedos and kinetic energy derived from a common imaging data set are distinct.

Reference: Choi, D. S. and A. P. Showman (2010). Power Spectra of Jupiter's Cloud Albedos and Kinetic Energy from *Cassini*. In preparation.

Future Work

Future Projects:
- 2D Power Spectra of Wind Vector Maps
- Construction and continual analysis of full-longitudinal wind vector maps for Jupiter and Saturn.
- Observational analysis and numerical simulations of Jovian 5-micron hotspots
- Application of software to stereo imaging data sets to extract topography

Future Algorithm Improvements:
- Accounting for shear and rotation in the tracked cloud features; improvement of algorithm utility.
- Optimization of code subroutines and algorithms.
- Automated selection of correlation box size parameters.
- Neural network integration, parallel processing

Acknowledgements

We thank Ashwin Vasavada, Robert H. Brown, Andrew Ingersoll, Anthony del Genio, Augustin Sanchez-Lavega, Xylar Asay-Davis, Amy Simon-Miller, Peter Gierasch, and Don Banfield for discussions that improved the work presented in this poster.

This research was supported by NASA's Planetary Atmospheres program, the NASA Earth and Space Sciences Fellowship program, and the University of Arizona TRIF Imaging Fellowship.

We thank the CPS International School of Planetary Sciences for a generous travel grant.

Header Image Credit: NASA/JPL/SSI