Extra-solar planetary atmospheres and interiors

Conference or Workshop Item

Extra-solar Planetary Atmospheres and Interiors

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Summary:
This project aims to bring together models of both the atmospheric circulation and interior structure and apply them to close-in gas giant exoplanets, with the intent of producing information that can be used to inform and interpret observations. To this end, an atmospheric model has been modified, and an interior model is being adapted. Scans through parameter space are being performed with the atmospheric model to validate the modifications.

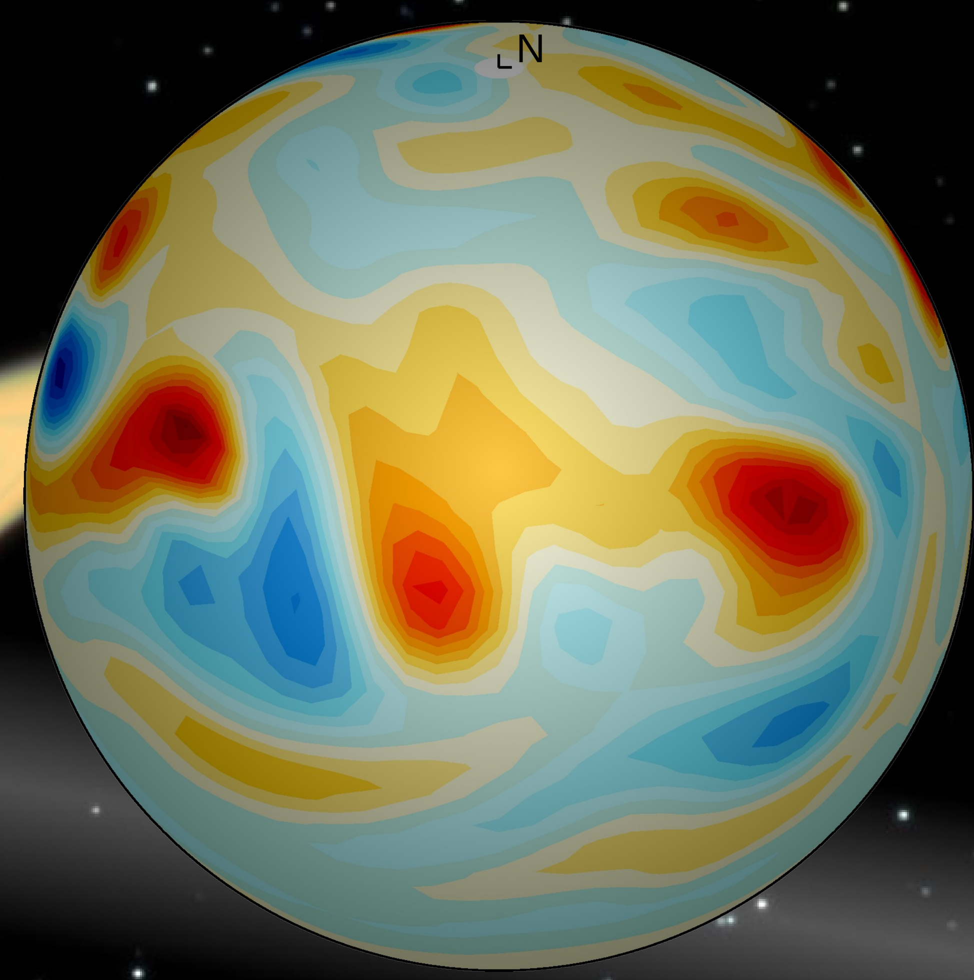
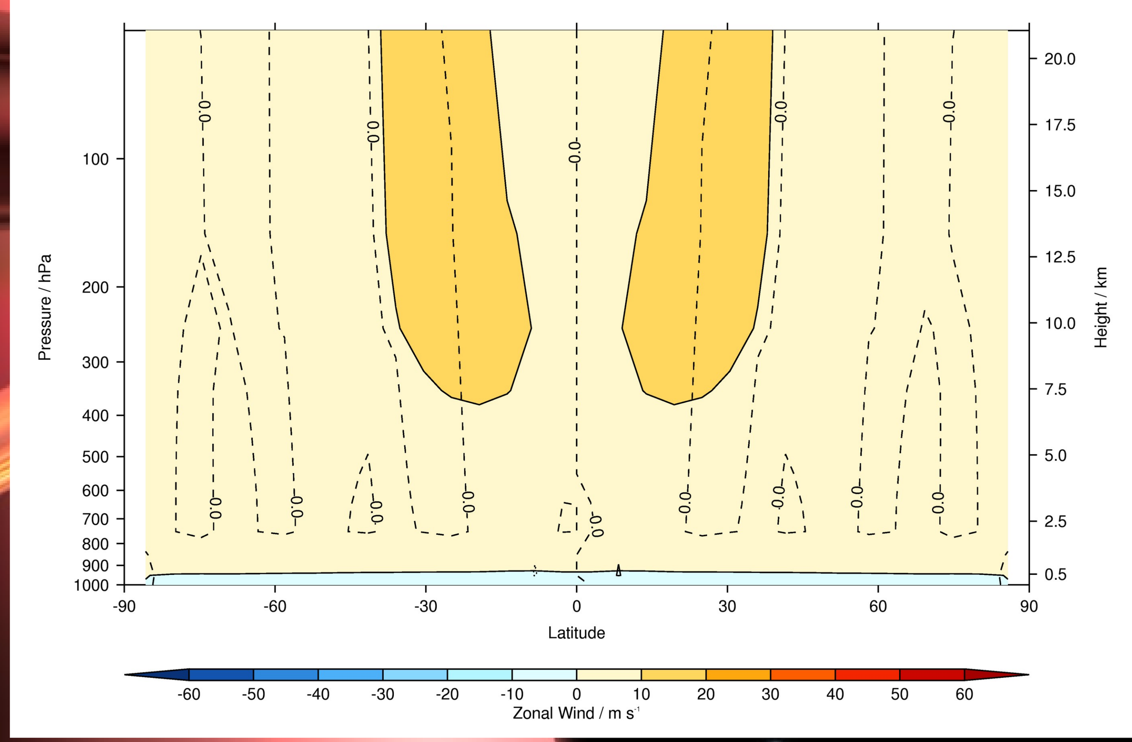


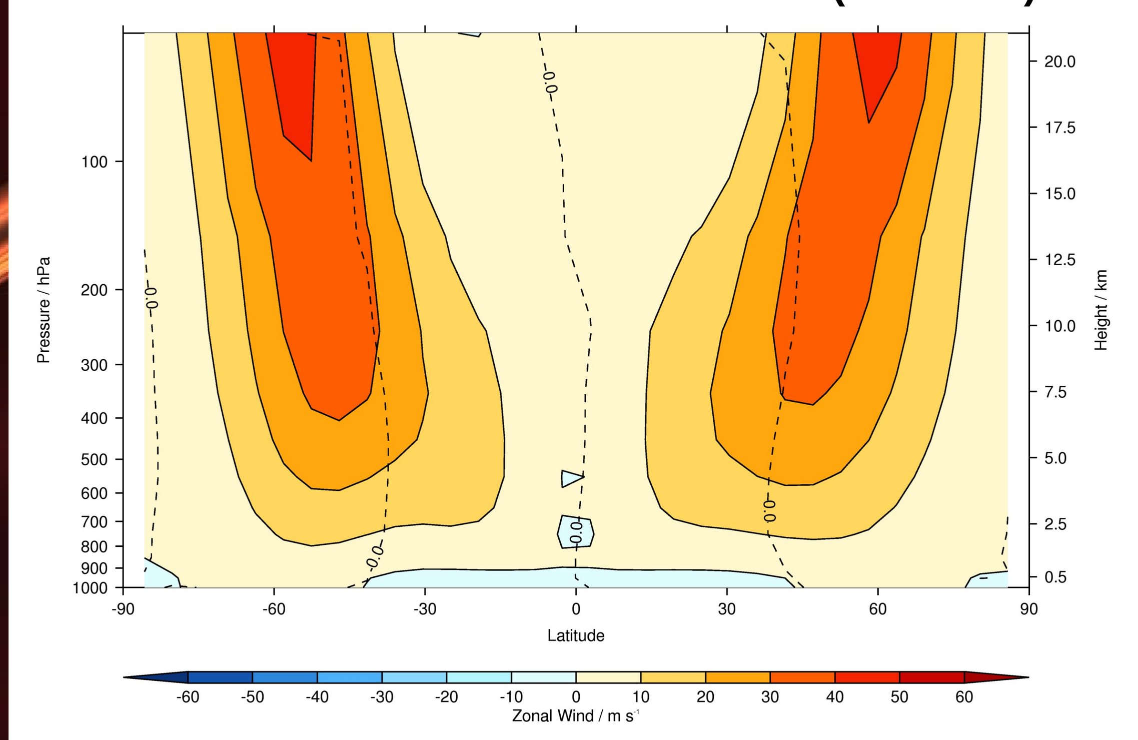
Image shows vorticity displayed on a sphere for a run using Earth parameters at T42 resolution

Models:
The atmospheric model used is PUMA[1], maintained at the University of Hamburg and based on the Reading spectral model. The atmosphere is modelled as a thin spherical shell under the hydrostatic approximation, and the hydrostatic primitive equations are solved.

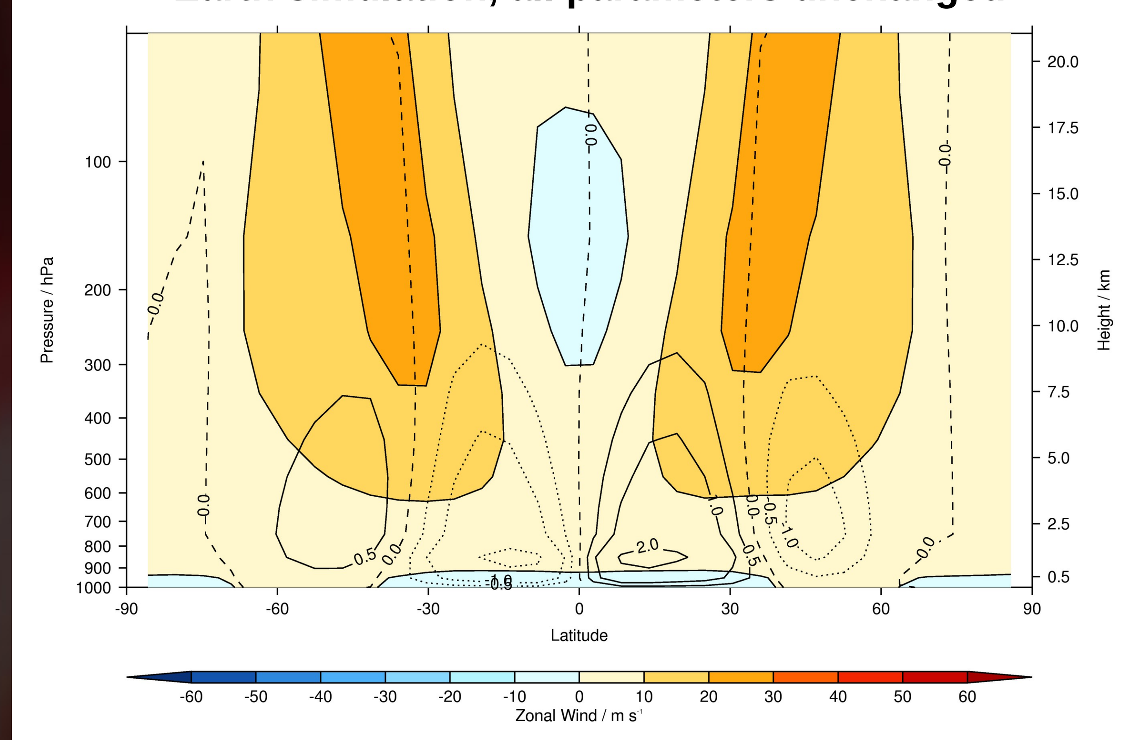
Earthlike simulation at 2x rotation rate



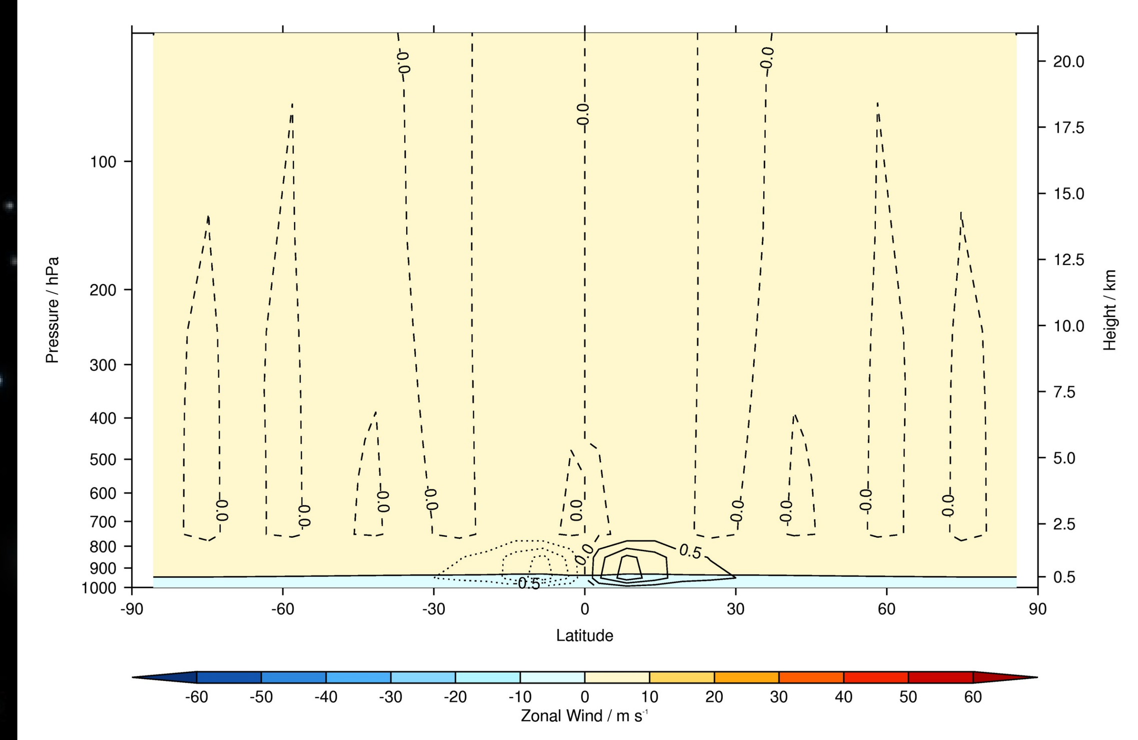
Earthlike simulation at Martian radius (½ Earth's)



Earth simulation, all parameters unchanged

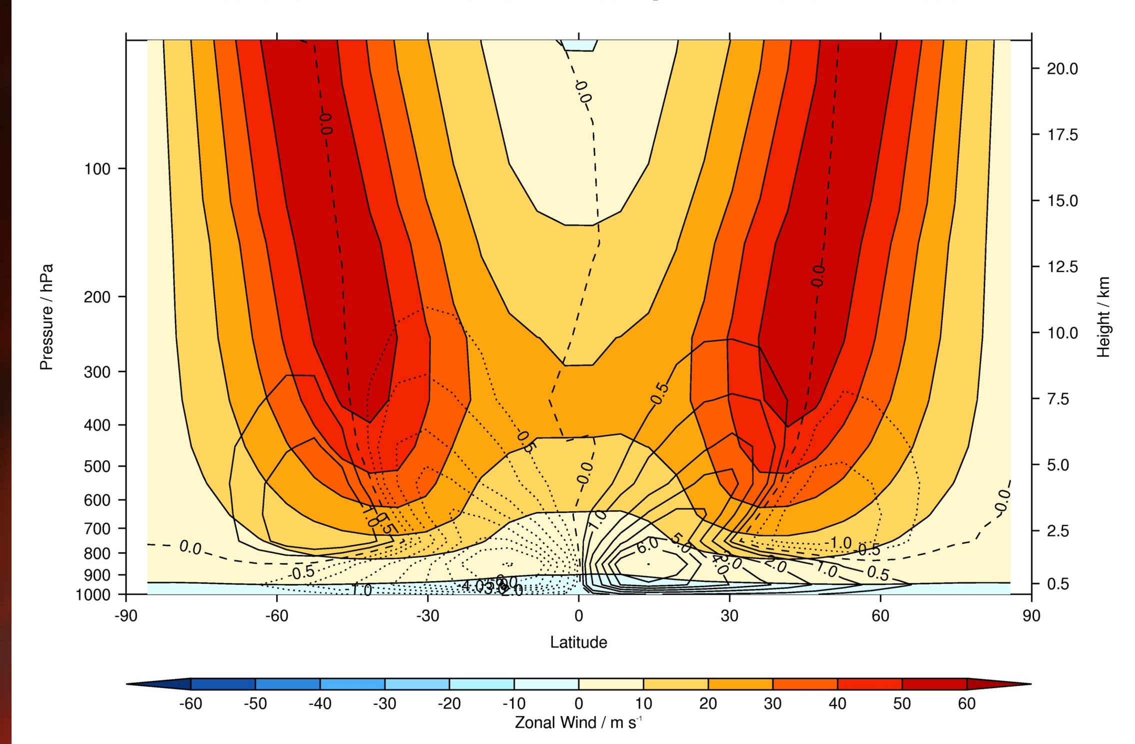


Earthlike simulation at 4x Earth radius

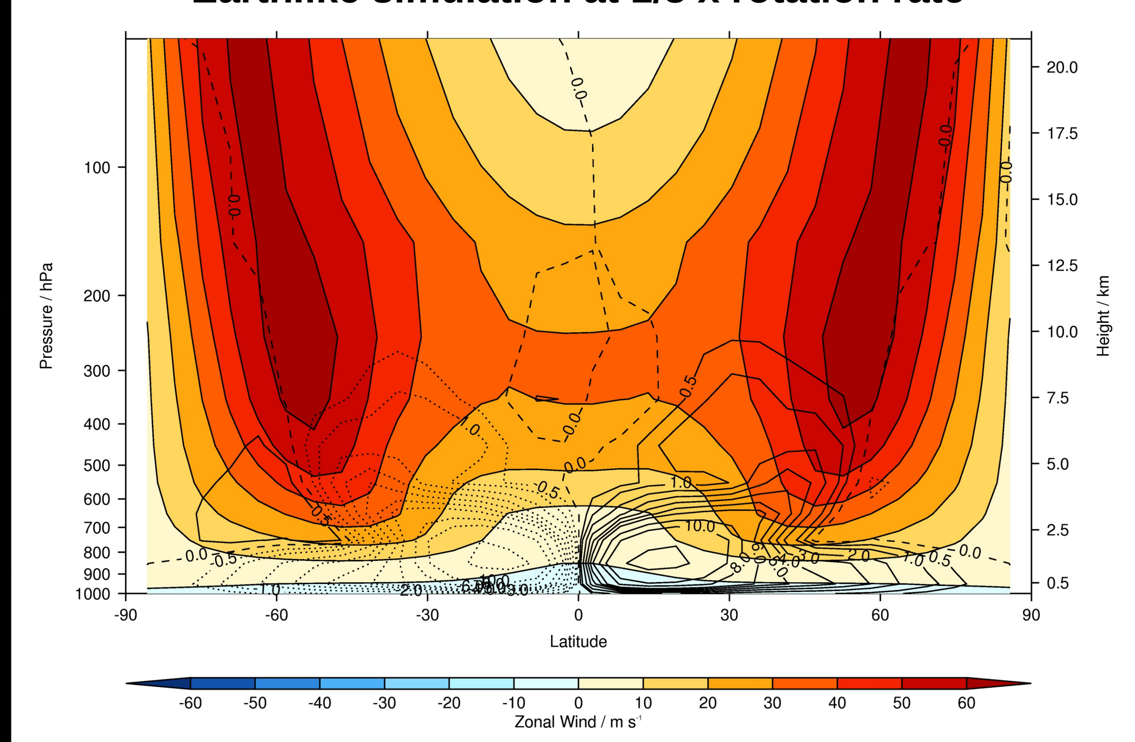


Originally designed for Earth, PUMA has been modified in this project to allow other planets to be studied.
An interior model is also under development, scaling down a model for low-mass stars and brown dwarfs. This is based on an expanded and upgraded version of the code by Mazzitelli[2].

Earthlike simulation at 1/4 x rotation rate



Earthlike simulation at 1/8 x rotation rate



Results:
The graphs depict results from the testing of the modified PUMA. Each plot shows:
- Zonal wind (filled contours)
- Mean meridional circulation (overlaid, unfilled. Units: 10^{13} kg s^{-1}; dotted contours negative)

Parameters varied:
- Planetary rotation rate: decreases from top to bottom
- Planetary radius: increases from left to right
- All other parameters held constant

"Earth" is displayed at the intersection

Conclusions:
PUMA has carried out preliminary scans through parameter space. As the rotation rate, Ω, decreases, the jets and Hadley cells expand towards the poles, demonstrating the predictions of the Held-Hou model[3], which gives the poleward extent of the Hadley cells as proportional to 1/Ω. Super-rotation also becomes apparent.
For a smaller planet, the jet velocity is seen to increase, again as predicted, as the wind at higher latitudes is given as proportional to 1/a, where a is the radius of the planet.

Outlook:
The next stage will involve focusing the model toward the specific characteristics of a small number of chosen exoplanets. In parallel, the development of an interior model for these planets will continue. Although the models cannot be directly coupled, a link will be formed via the boundary conditions, using the output of each model to inform input to the other.

References:
Fraedrich et al (2005) "The portable university model of the atmosphere (PUMA): Storm track dynamics and low-frequency variability" Meteorologische Zeitschrift, Vol. 14, No. 6, 735-745
Mazzitelli (1989) "The core mass at the helium flash: influence of numerical and physical inputs" ApJ, 340, 249-255
Held & Hou (1980): "Nonlinear Axially Symmetric Circulations in a Nearly Inviscid Atmosphere" J. Atmos. Sci., 37, 515–533

Background image: NASA artist's impression of planet Epsilon Eridani b