Exo-Climatology

Collaboration: University of Exeter & Exeter Met Office.

We are modifying the Global Circulation Model (GCM) of the UK Met Office, called the Unified Model (UM) which is used for Numerical Weather Prediction (NWP) and Climate Research on the Earth, to model the dynamical structures of 'Hot Jupiter' atmospheres. Comparing predictions from this model with observations from the Sing & Pont HST survey will allow us to:

(i) Investigate the efficiency of heat advection
(ii) Determine importance of deep circulation patterns
(iii) Test veracity of assumptions and initial conditions

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Process: UM: Earth ➡ 'Hot Jupiter'?

To apply the UM, currently configured for Earth, to 'Hot Jupiters' requires adjustment of the model forcing and domain (for instance modeling higher temperature and pressure regimes). More realistic modeling of exoplanets also requires adjustment of some of the physical mechanisms (for instance inclusion of a more appropriate Equation of State, EOS, and Radiative transfer scheme).

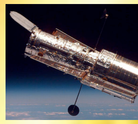
Heng et al (2011), provide a progression of temperature forced benchmarks, from Earth-like conditions to that of 'Hot Jupiters'.

1, Held-Suarez (Dynamical Core test)
2, Tidally-Locked Earth (Zonally Asymmetric Temperature)
3, 'Shallow' Earth (Temperature Inversion)
4, 'Shallow' Hot Jupiter (High Temperatures)
5, Deep Hot Jupiter: HD209458b6 (High Pressures)

We then include more detailed physics.

6, Realistic Exoplanets (Radiative Transfer, EOS, Composition)

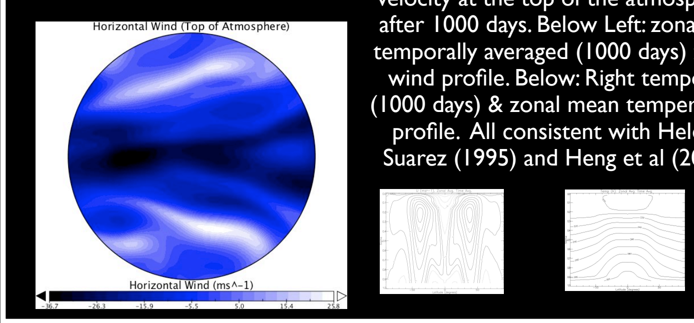
Goal:



Observational constraints will then be available from the HST survey, lead by David Sing, comprising eight 'Hot Jupiter' targets covering a range of estimated temperatures. We aim to model each target successfully observed using our modified UM.

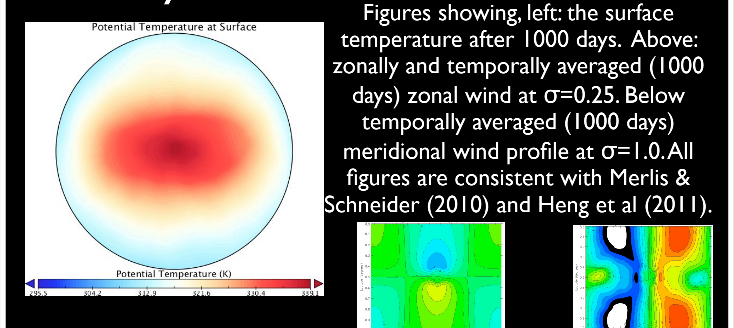
Wasp 12-2800K
Wasp 19-2319K
Wasp 17-1860K
Hat 1-1500K
Wasp 6-1340K
Hat 12-1080K
Wasp 39-1368K
Wasp 31-1285K

1, Held-Suarez



Figures showing, left: the horizontal wind velocity at the top of the atmosphere after 1000 days. Below Left: zonally & temporally averaged (1000 days) zonal wind profile. Below: Right temporal (1000 days) & zonal mean temperature profile. All consistent with Held & Suarez (1995) and Heng et al (2011)

2, Tidally-Locked Earth

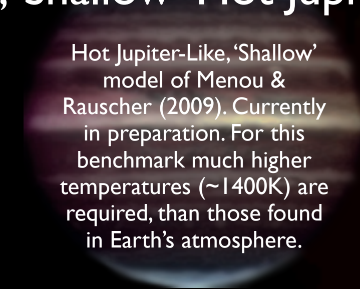


Figures showing, left: the surface temperature after 1000 days. Above: zonally and temporally averaged (1000 days) zonal wind at σ=0.25. Below temporally averaged (1000 days) meridional wind profile at σ=1.0. All figures are consistent with Merlis & Schneider (2010) and Heng et al (2011).

3, 'Shallow' Earth

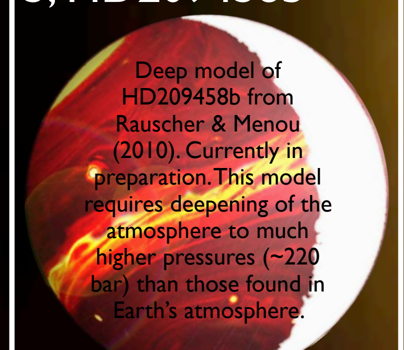
Earth-Like, 'Shallow' model of Menou & Rauscher (2009). Currently in preparation. This model requires inclusion of a temperature inversion at the tropopause, i.e. a more realistic stratosphere.

4, 'Shallow' Hot Jupiter



Hot Jupiter-Like, 'Shallow' model of Menou & Rauscher (2009). Currently in preparation. For this benchmark much higher temperatures (~1400K) are required, than those found in Earth's atmosphere.

5, HD209458b



Deep model of HD209458b from Rauscher & Menou (2010). Currently in preparation. This model requires deepening of the atmosphere to much higher pressures (~220 bar) than those found in Earth's atmosphere.

6, Realistic Exoplanets

Once the temperature forcing benchmarks are complete we must then include treatments of the detailed physics within 'Hot Jupiter' atmospheres. This will include a Radiative Transfer scheme, adjustments to the EOS and composition, the inclusion of the main opacity sources (such as: H_2O, CH_4, VO, CO, TiO, NH_3), and the inclusion of deep atmosphere convection.

Why UM?

-Validated -Robust -Supported -Fast -Flexible
Full Navier-Stokes Equations:
(i) No hydrostatic equilibrium assumption
(ii) No Shallow Fluid assumption
(iii) No Traditional assumption

Exoclimes 2012, Aspen