Shallow versus deeply forced atmospheric dynamics. Y. Kaspi[1]

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Atmospheric dynamics on exoplanets span a wide range of dynamical regimes. Particularly, the dynamics can be distinguished between atmospheres driven by shallow forcing from their parent star, and deep atmospheres driven by internal convection. Using idealized general circulation models (GCMs) we will compare the physical mechanisms controlling the dynamics in each of these circulation regimes, with examples from the observed circulation on the solar-system planets. One focus will be on the effect of the planetary rotation rate on the jet structure and meridional heat transport [1].

For terrestrial type atmospheres we use idealized GCMs which use the traditional shallow dynamics approximations and in which the upper atmosphere is relaxed to a temperature profile determined by the distance and angle to the parent star. For deep atmospheres we use an anelastic GCM we developed, based on the MITgcm non-hydrostatic dynamical core, but not limited to a thin spherical shell allowing therefore studying deep compressible dynamics. This model has an internal thermodynamical adiabatic structure based on interior structure models of giant planets, which we use as a template to study a wide-range of planetary climates [2]. Equatorial superrotation appears on both types of atmospheres; we will discuss possible mechanisms leading to equatorial superrotation, both due to shallow horizontal eddy momentum flux convergence, and due to eddy momentum flux convergence driven by internal columnar convection. We will show how angular momentum constrains the properties of the interior flow, and how the compressibility affects the depth to which atmospheric circulation may extend.

The depth of atmospheric circulation is a key question for understanding the structure, evolution and energetics of such planets. This topic will be in the frontier of solar-system planetary research in the next decade as two of NASA's space missions, Juno and Cassini, will probe the deep dynamics of Jupiter and Saturn via high order gravity measurements. We show that while low order gravity harmonics are dominated by the oblateness of the planet, high order harmonics (n>10) have a strong signature by the density perturbations arising from the flow field [3]. We use the dynamical relations between the fluid velocity and the dynamical density gradients to give relations between the measurable gravity signal and the depth of the circulation [4]. On Neptune sized planets with deep atmospheres, the gravity signature of internal dynamics can appear even at low gravity harmonics. We show that for the particular case of Uranus and Neptune, due to the broad strong atmospheric jets on these planets, current knowledge of the fourth zonal gravity harmonic, J4, allows to constrain their dynamics to the uppermost 0.4% of the mass on Uranus and 0.2% on Neptune. This means that effectively the fast observed jets are confined to a relatively thin weather-layer (as in the terrestrial case) despite the fact that the atmosphere extends continuously into the planets' fluid interior.

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