EPSC Abstracts
Vol. 6, EPSC-DPS2011-1118, 2011
EPSC-DPS Joint Meeting 2011

The gravity signature of internal dynamics on Jupiter, Saturn, Uranus and Neptune

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Abstract

A key question regarding the circulation on the giant planets is how deep do the zonal flows observed at the cloud level extend into the interior. The upcoming Juno mission to Jupiter and extended Cassini mission to Saturn will perform close flybys of these planets enabling them to measure high-order gravity harmonics, which can give information about the depth of the circulation. Here, we systematically determine the gravity signature for a variety of plausible flow configurations, with the goal of determining what constraints can be placed on the flow field from spacecraft determination of the gravity field. For this analysis we use a mix of models including potential-theory models; an anelastic deep general circulation model simulating the fluid motion on the planet and the resulting density perturbations; and a thermal-wind analysis in which we use the observed surface winds and extend them into the interior while varying the depth of the flow along angular momentum surfaces. The latter approach allows a systematic study of the relation between the depth of the winds and the resulting gravity field. For Jupiter the signature of deep winds will appear at gravity harmonic J10 and beyond, which is likely to be measurable by Juno. On the other planets the gravity signature of the circulation is expected to appear at even lower harmonics due to their lower masses, stronger surface winds, and the fact that they have fewer, wider jets (in latitude) than Jupiter. The extreme case is Neptune where if the zonal winds are deep enough they can affect even J4. On Saturn, these results for the lower harmonics can potentially constrain the recent uncertainty in the exact rotation period. We discuss the results for each of the giant planets, the physical constraints they give about the circulation and implications for the Juno and Cassini missions.