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Convection and magnetic field generation in the interior of planets (August Love Medal Lecture)

U.R. Christensen
Max-Planck-Institute for Solar System Research Katlenburg-Lindau (Germany)

Thermal convection driven by internal energy plays a role of paramount importance in planetary bodies. Its numerical modeling has been an essential tool for understanding how the internal engine of a planet works. Solid state convection in the silicate or icy mantles is the cause of endogenic tectonic activity, volcanism and, in the case of Earth, of plate motion. It also regulates the energy budget of the entire planet, including that of its core, and controls the presence or absence of a dynamo. The complex rheology of solid minerals, effects of phase transitions, and chemical heterogeneity are important issues in mantle convection. Examples discussed here are the convection pattern in Mars and the complex morphology of subducted slabs that are observed by seismic tomography in the Earth's mantle. Internally driven convection in the deep gas envelopes of the giant planets is possibly the cause for the strong jet streams at the surfaces that give rise to their banded appearance. Modeling of the magnetohydrodynamic flow in the conducting liquid core of the Earth has been remarkably successful in reproducing the primary properties of the geomagnetic field. As an examplefor attempts to explain also secondary properties, I will discuss dynamo models that account for the thermal coupling to the mantle. The understanding of the somewhat enigmatic magnetic fields of some other planets is less advanced. Here I will show that dynamos that operate below a stable conducting layer in the upper part of the planetary core can explain the unusual magnetic field properties of Mercury and Saturn. The question what determines the strength of a dynamo-generated magnetic field has been a matter of debate. From a large set of numerical dynamo simulations that cover a fair range of control parameters, we find a rule that relates magnetic field strength to the part of the energy flux that is thermodynamically available to be transformed into other forms of energy. This rules predicts correctly not only the magnetic field strength of planets with sufficiently simple dynamos (Earth and Jupiter), but also that of rapidly rotating stars.