Organised wind chaos on Jupiter

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Scientists from the Max-Planck Institute for Solar System Research, the University of Alberta in Edmonton, Canada, and the University of California Los Angeles, have now presented a new three-dimensional computer model that successfully describes and explains all important characteristics of the banded flows on Jupiter. The simulations suggest that the wind system may reach as deep as 7000 km into the planet's atmosphere.

Driving forces are smaller, turbulent flows that are organised into the banded form by the planet's curvature and rotation. The computer model also explains why there are two jet classes: strong and wide jets near the equator, but narrow and weak wind belts at higher latitudes. The reason is hidden deep in planet, where immense pressures cause the atmosphere to take on a metallic state. (Nature, November 10, 2005)

Jupiter, the largest planet of our solar system, offers a fascinating view. A number of Bands of different coloured clouds seem to embrace the planet like belts. These bands mirror a system of extremely strong and stable jet winds, blowing both in easterly and westerly directions. Comparisons between the measurements of the VOYAGER mission in 1979 and the recent CASSINI spacecraft show that the system remained nearly unchanged. The winds alternate direction in accordance with the clouds: they blow eastward on the equator-facing side of the dark belts, and westward on the pole-facing side. The strongest jet is centred on the equator and blows with a speed of up to 170 meter per second in easterly direction. The jets can be separated into two classes. Stronger, broader winds are grouped around the equator while the jets are higher latitudes are generally weaker and narrower.

The team of researchers from Germany, Canada, and the USA has presented the first computer simulation that models all important characteristics of Jupiter's wind system and explains its origin. Two groups of models for the dynamics of Jupiter's atmosphere can be distinguished: shallow and deep models. Supporters of the shallow approach apply techniques developed in meteorology on Earth to Jupiter's atmosphere. Because the Earth's atmosphere is very thin compared to the planet's radius, its spherical form can be approximate with a simplified layer, which allows the computer simulations to run considerably faster. The respective models successfully produce several banded winds but fail otherwise: The equatorial jet, the strongest on Jupiter, blows in the wrong direction, and the distinction into the two classes is missing, all jets are similar.

In the 1970s Friedrich Busse, Professor Emeritus at the University of Bayreuth, Germany, developed the first deep dynamical model . He pointed out that there is an important difference between Jupiter's and Earth's atmospheres: Earth's atmosphere is bounded by the planets rocky surface. Jupiter, on the other hand, is a gaseous planet. There simply is no bottom that could restrict the winds to a thin layer.

Jupiter's atmosphere mainly consists of hydrogen and helium. The atmospheric pressure increases with depth. At some point, the hydrogen molecules are pressed so close together that they form a metallic, electrically conductive state. Jupiter's strong magnetic field prevents any faster movement in the electrically conductive deeper regions by a mechanism that also works in an eddy current brake. This limits the fast jet flows to the outer 10 percent of the planet's radius.

Based on the ideas by Friedrich Busse, the new computer models the dynamics of this outer layer which still comprises 7000 km in depth. The computer program has been developed by Johannes Wicht at the Max Planck Institute for Solar System Research in Katlenburg-Lindau, Germany, and simulates the convection-driven fluid flow in a rotating spherical shell. The results offer a novel insight into how and why Jupiter's wind system has developed.

On earth, weather dynamics is driven by the heat coming from the sun. On Jupiter, however, heat emerging from inside the planet plays a larger role. This powerful energy source primarily drives small-scale turbulent convective motion. But the dynamics of fluids in rotating systems – like planets – exhibit some particular characteristics: these systems prefer flows which do not change along the axis of rotation. Convective motions, like tornadoes on earth, therefore try to organise themselves into cylinder-shaped columns. The cylindrical geometry is in conflict with the spherical shape of the planet.

The spherical curvature hardly affects smaller, turbulent vortex structures. There is, however, a particular vortex size where its influence becomes as important as the convective forcing. This theoretically-derived size is known as the Rhines length, after Peter B Rhines, a professor at the University of Washington, Seattle. When a vortex diameter reaches the Rhines length, the planet's curvature starts to organize the convective kinetic energy into the jet winds. The Rhines length therefore determines not only the width but also the number of jets that fill the planetary surface.

But why are there two different classes of jets? The computer models also provide insight into this question, and confirm the theoretical principle also proposed in the article in Nature. Jet winds around the equator reach right through the planet spanning northern as well as southern hemisphere. This is not possible at higher latitudes where the winds are in contact with the electrically conductive gas region. Here, the stronger curvature of the inner boundary helps to organize the turbulent convection. When incorporating this effect into a redefined Rhines length theory, simulation, and observation all agree: these jets are narrower than, and belong to a different class as, those around the equator.

Source: Max-Planck-Gesellschaft