of chemotherapy treatments. Kimchi-Sarfaty *et al*. found that P-glycoprotein inhibitors CsA and verapamil were less effective against proteins that were produced from haplotypes that consist of the polymorphic double (C1236T-G2677T, C1236T-C3435T, G2677T-C3435T) or triple (C1236T-G2677T-C3435T) variant combinations, suggesting that these protein products have altered conformations. Yet, C1236T and C3435T polymorphisms do not change the amino acid sequence of P-glycoprotein. The C1236T polymorphism changes a GGC codon to GGT at amino acid position 412 of the polypeptide (both encode glycine) and the C3435T polymorphism changes ATC to ATT at position 1145 (both encode isoleucine). However, both polymorphisms result in changes from frequent to infrequent codons and therefore may slow down the ribosome traffic at the corresponding mRNA regions. These alterations may thus affect the cotranslational folding pathway of P-glycoprotein, resulting in a different final conformation. Limited proteolysis and the use of a conformation-sensitive monoclonal antibody indeed revealed structural differences between the wild-type protein and the polymorphic haplotypes.

Artificial site-directed silent mutagenesis of synonymous codons (changing from infrequent to frequent) in certain genes also support the hypothesis that altered translation kinetics of mRNA might affect final protein conformation (*9*). However, until the study by Kimchi-Sarfaty *et al*., there had been no example demonstrating that naturally occurring variations in synonymous codons in a defined gene can give rise to a protein product with the same amino acid sequence but different structural or functional features. By demonstrating that this is indeed the case, the study opens up a new avenue of research and suggests that silent SNPs might contribute to development and progression of certain diseases. If this is the case, then silent SNPs should not be neglected in determining the likelihood of the development and progression of many diseases such as Alzheimer's disease, myopia (a disease leading to a refractive defect of the eye), and others that are strongly linked to SNPs. This knowledge should also be taken into account in personalized drug treatment and development programs.

References and Notes

1. C. Kimchi-Sarfaty *et al*., *Science* **315**, 525 (2007); published online 21 December 2006 (10.1126/science.1135308).
2. G. W. Beadle, E. L. Tatum, *Proc. Natl. Acad. Sci. U.S.A.* **27**, 499 (1941).
3. C. D. Anfinsen, *Science* **181**, 223 (1973).
4. K. Si *et al*., *Cell* **115**, 893 (2003).
5. J. Frydman, *Annu. Rev. Biochem*. **70**, 603 (2001).
6. I. J. Purvis *et al*., *J. Mol. Biol*. **193**, 413 (1987).
7. P. M. Sharp, T. M. Tuohy, K. R. Mosurski, *Nucleic Acids Res*. **14**, 5125 (1986).
8. B. Bukau, J. Weissman, A. Horwich, *Cell* **125**, 443 (2006).
9. A. A. Komar, T. Lesnik, C. Reiss, *FEBS Lett.* **462**, 387 (1999).

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ATMOSPHERES

The Jet-Stream Conundrum

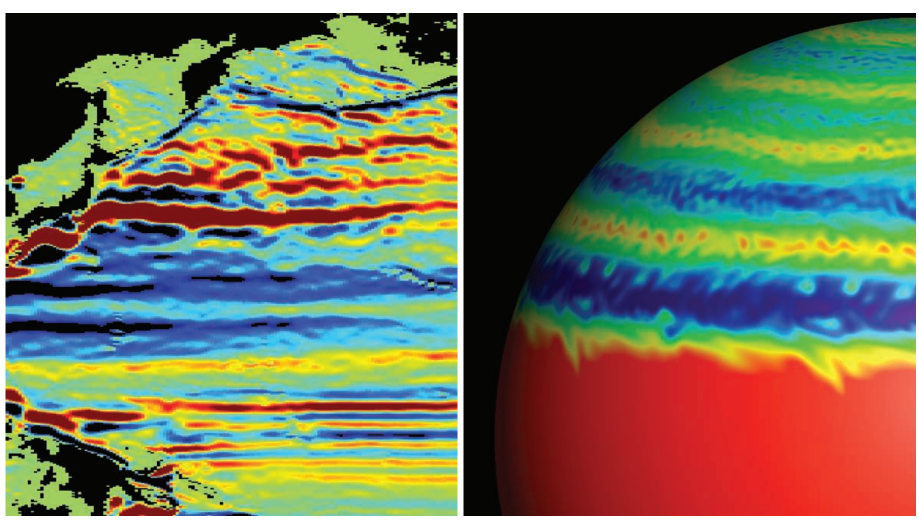
Fluid jets occur in Earth's atmosphere and oceans, and on other planets. A new theoretical view of jets has helped reveal why they form and how they interact with the surrounding fluid.

Mark P. Baldwin, Peter B. Rhines, Huei-Ping Huang, Michael E. McIntyre

Jet streams, or "jets" for brevity, are concentrated, intense, elongated flows that often contain most of the kinetic energy in a flowing fluid. They are pervasive features of Earth's atmosphere and oceans, where they transport heat, chemicals, and even biota such as krill, and they are also abundant on other planets (see the figure).

Jets are observed to occur spontaneously on rotating planets whenever stratified atmospheres or oceans are forced into turbulent motion. Yet there is a mystery as to why jets exist at all—why is there this propensity to concentrate energy and momentum? A second mysterious property of jets is that they can act as flexible material barriers, inhibiting mixing across their axes. The strongest eastward jets provide expressways for the transport of chemicals and biota along their axes but severely inhibit mixing across their axes. A new theoretical paradigm (*1*) explains the abundance of jets, in any planetary atmosphere or ocean, in a simple manner. The paradigm combines field theory with chaotic (turbulent) fluid motion; in doing so, it captures long-range interactions that are crucial for forming and stabilizing jets. It shows that mixing a fluid on a rotating planet will invariably produce jets and that the two mysteries, jet formation and the inhibition of mixing, formerly regarded as two separate phenomena, are intimately related to each other.

Both jet formation and the inhibition of mixing are completely enigmatic in terms of



Jets near and far. (Left) Map of east-west current speeds at 400-m depth, simulated by an eddy-resolving ocean model. Red and blue indicate eastward and westward flows. [Adapted from Richards *et al*. (*11*)] (**Right**) Snapshot of a simulation for Jupiter, with red and blue indicating eastward and westward flows. [Adapted from Heimpel *et al*. (*16*)]

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standard turbulence theory. In the standard paradigm, a turbulent flow puts fluid particles into random walks that cause local mixing everywhere. Mixing implies that any quantity carried with the flow, such as a chemical tracer, will eventually become uniformly distributed. However, this contradicts the observed inhibition of mixing across jet axes. For example, the stratospheric polar night jet has different chemical properties on either side of the jet axis, thereby containing the ozone hole (*2*). Furthermore, in the standard paradigm, momentum is locally mixed like a chemical tracer. If this were the case, jets would immediately begin to dissipate, again contradicting observation. One reason for the persistence of jets is that there are wave motions and long-range, nonlocal interactions; the latter are not considered in the standard paradigm. It is these long-range interactions that are best understood using field theory.

The new paradigm keeps the idea of mixing but combines it with the long-range interactions. All waves involve restoring forces like those in an elastic medium, and they give rise to subtle long-range effects—outside the scope of the standard paradigm—including long-range momentum transport by waves (radiation stresses).

Also among the nonlocal effects are simple fields somewhat like the electrostatic field of a positively charged atomic nucleus. An atom in its ground state consists of the nucleus and its electrostatic field, together with a quantum field described by Schroedinger's equation. The quantum field represents the electron orbitals, which are carried along with the atomic nucleus no matter how the nucleus moves, as long as it moves slowly enough.

The fluid analog to the nuclear charge that holds the atom together is a scalar field called the potential vorticity (PV). PV is a unified measure of actual or potential swirl or shear (including planetary rotation) and is carried with the flow like a chemical tracer (*3*). Strong, compact PV anomalies carry with them recognizable velocity, buoyancy, and pressure fields in the surrounding fluid, just as atomic nuclei carry electron orbitals (again provided that the motion is slow enough). These structures are the familiar pancake-like vortices of cyclones and anticyclones, from ordinary cyclonic depressions to Hurricane Katrina and Jupiter's Great Red Spot. Knowing the PV anomaly is enough to deduce the entire vortex structure, just as knowing the nuclear charge is enough to deduce the entire atomic orbital structure. The deduction of the vortex structure from the PV field is called PV inversion (*4*). The new paradigm comes from combining the turbulence-theoretic idea of mixing with the field-theoretic idea of PV inversion and from giving the two ideas an equal status.

Planetary rotation provides a vast reservoir of PV, with a south-north gradient that enables wave propagation. PV inversion allows us to deduce the velocity field corresponding to displacements of the fluid (and PV contours). For example, the velocity field corresponding to a large-scale east-west wave pattern causes the wave (called a Rossby wave) to propagate westward. The PV contours therefore behave somewhat like elastic bands, and it is this so-called Rossby elasticity of the PV gradient that supports the propagation of Rossby waves.

The key to understanding jets is that PV, not momentum, tends to behave like a tracer. It is therefore PV that is mixed when the fluid becomes turbulent. Mixing weakens the south-north PV gradients, reducing the Rossby-wave elasticity and encouraging further mixing. This positive feedback tends to make the mixing spatially inhomogeneous. Thus, strong mixing creates a profile in latitude of alternating steep and weak PV gradients, called a PV staircase. This staircase corresponds (through PV inversion) to thin, fast eastward jets located at the latitudes of the steepest PV gradients and strengthened elasticity. Furthermore, the strengthened elasticity there, together with the jet shear, strongly inhibit mixing across the eastward jets (*2*, *5*). Thus, the new paradigm explains both jet formation and the inhibition of mixing.

The new paradigm demonstrates how a rotating planet can concentrate energy and momentum into jets, with faster rotation yielding not just one jet but several or many (*5*–*7*). This scaling theory links the planet's radius, its rotation rate, and the turbulent kinetic energy level of the fluid to the scale and spacing of its jets. In accord with this theory, Earth's atmosphere has just one or two jets per hemisphere, whereas Jupiter and Earth's oceans have many (see the figure).

Several new planetary flight missions—including NASA's Mars Reconnaissance Orbiter, the European Space Agency's Venus Express, and NASA's planned Juno mission to Jupiter—are poised to provide detailed observations of extraterrestrial atmospheres. These observations are needed to understand, for example, Jupiter's Great Red Spot, which owes its persistence to the surrounding jets and Rossby waves (*8*).

Although the new paradigm helps us understand the mystery of jet formation and persistence, the emerging details of many jet-related phenomena in nature remain to be fully explored. Earth's atmospheric jets have shifted poleward by about 1° since 1979 (*9*), with corresponding shifts in climate zones. New data sets and high-resolution computer simulations have revealed a previously unknown set of mid-ocean jets (*10*–*11*) (see the figure) as well as velocity extremes within the Antarctic Circumpolar Current (*12*). The first hints of how Antarctic krill use the circumpolar jets are emerging, promising new insights into the life cycle and food-chain role of the krill (*13*, *14*).

There remain open questions with important implications for climate prediction. For example, the precise circumstances under which PV staircases form remains elusive. Quantitative predictions of devastating storms, of thermohaline shutdown, and of dislocations in ecosystems and in Earth's heat balance also require a more detailed understanding of jets.

References and Notes

1. The paradigm emerged at an American Geophysical Union Chapman Conference, "Jets and Annular Structures," held in Savannah, GA, 9 to 15 January 2006. The proceedings will be published in a special issue of the *J. Atmos. Sci.*, also available at www-mete.kugi.kyoto-u.ac.jp/yoden/research/Chapman_Web/ChapmanConference2006Jets.htm.
2. M. N. Juckes, M. E. McIntyre, *Nature* **328**, 590 (1987).
3. The Rossby-Ertel PV is the component of absolute vorticity normal to the stratification surfaces, divided by the mass per unit area enclosed between neighboring surfaces. When the surfaces move apart adiabatically, conservation of angular momentum can convert potential swirl into actual swirl, or actual shear, relative to the planet.
4. PV inversion is similar to finding the electric field due to a charge or the electron wave function of an atom. For a minimal tutorial, see www.atm.damtp.cam.ac.uk/people/mem/papers/ENCYC/epv-times.pdf
5. P. B. Rhines originated the idea of turbulently generated jets (*15*).
6. D. G. Dritschel, M. E. McIntyre, *J. Atmos. Sci*., in press, also at Web site in (*1*).
7. T. J. Dunkerton, R. K. Scott, *J. Atmos. Sci*., in press, also at Web site in (*1*).
8. S. Shetty, X. S. Asay-Davis, P. S. Marcus, paper presented at the American Physical Society annual meeting of the Division of Fluid Dynamics, 19 to 21 November 2006, Tampa Bay, Florida, U.S.A. (*1*).
9. Q. Fu *et al*., *Science* **312**, 1179 (2006).
10. H. Nakano, H. Hasumi, *J. Phys Oceanogr*. **35**, 474 (2005).
11. K. J. Richards *et al*., *Geophys. Res. Lett.* **33**, L03605, 10.1029/2005GL024645 (2006)
12. C. W. Hughes, N. A. Maximenko, personal communication.
13. B. A. Fach, J. M. Klinck, *Deep-Sea Res. Part I Oceanogr. Res. Pap.* **53**, 987 (2006).
14. B. A. Fach, E. E. Hofmann, E. J. Murphy, *Deep-Sea Res. Part I Oceanogr. Res. Pap.* **53**, 1011 (2006).
15. P. B. Rhines, *J. Fluid Mech.* **69**, 345 (1975).
16. M. Heimpel, J. Aurnou, J. Wicht, *Nature* **438**, 193 (2005).

17. We thank M. Allison, Y. Hayashi, B. Harris, P. H. Haynes, B. J. Hoskins, W. A. Robinson, D.W.J. Thompson, G. Vallis, and S. Yoden for discussions, and NSF and NASA for funding the Chapman Conference. M.P.B. was supported by NSF's Climate Dynamics Program (under the U.S. CLIVAR Program), NOAA's Office of Global Programs, NASA's Supporting Research and Technology Program for Geospace Sciences, NASA's Living with a Star Program, and NASA's Oceans, Ice, and Climate Program.

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