

A tabletop model of atmospheric turbulence

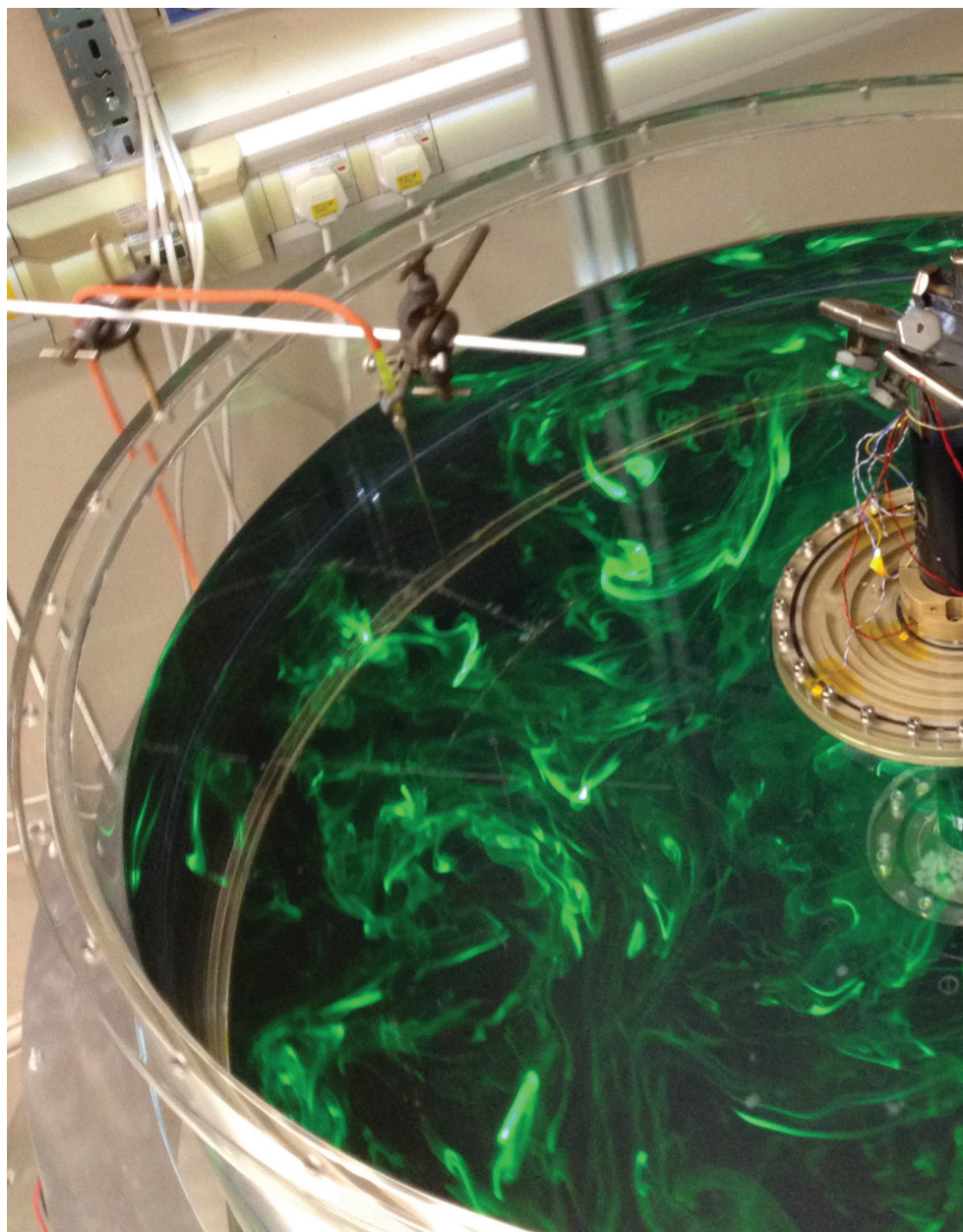
A meter-sized lab experiment offers new insight into how energy is transferred between turbulent flows of different sizes, from small eddies to large-scale weather events.

By **Sarah Wells**

Contributing to damaging weather events such as polar vortices, midlatitude storms, and tropical cyclones, turbulent flow in Earth's atmosphere plays a large role in climate dynamics. Atmospheric turbulence can be understood, in part, by its kinetic-energy spectrum, which describes energy cascades between eddies of different length scales. The scales can range from tens of meters to thousands of kilometers, and energy flow between the eddies contributes to weather events such as tornadoes or large, merging storms.

Yet how to describe the underlying processes that create the atmospheric structure has been a long-standing subject of debate among atmospheric scientists. Theories based on idealized or simplified conditions predict a flatter spectrum for large length scales and a steeper drop-off for small length scales, whereas observational data from aircraft show the opposite. Now Peter Read from the University of Oxford and colleagues have created a scaled-down, tabletop model of Earth's atmosphere that can realistically

Inside a tank filled with a dyed solution of water and glycerol, turbulent eddies of different length scales are generated through the use of variables like the speed of rotation and differences in temperature. (Photo courtesy of H el ene Scolan.)



re-create those atmospheric energy dynamics more accurately than previous models.¹ Such experiments can offer a new understanding of the kinetic-energy spectrum and of large-scale turbulence on Earth and other planets.

Despite its small stature, the team's model emulates large-scale, planetary atmospheres by exhibiting comparable values for key dimensionless parameters derived from the rotation speed, fluid density and viscosity, system size, and

other properties. The model consists of a meter-wide tank filled with a water-glycerol mixture, and it features a heated ring at the bottom of the tank and a cooling plate at the top surface of the fluid to imitate the effects of solar radiation at the equator and radiative atmospheric cooling at high latitudes. The researchers rotate the fluid system at speeds between 0.5 and 10 revolutions per minute to account for Earth's rotation. The model also includes a cone-shaped

floor to imitate how the effect of Earth's rotation depends on latitude. Altogether, the temperature differences in the fluid and rotation of the tank generate convective motion that creates turbulence. The team visualizes the turbulence by using a camera mounted above the tank to capture the motion of particles seeded in the fluid, which can be seen in the figure.

The researchers use that velocimetry data to compute the kinetic-energy spectrum of the tank turbulence and find that its dependence on length scale more closely agrees with observational data captured by aircraft than with the idealized calculations. They also use the velocimetry data to calculate the cascade of vorticity, a measure of atmospheric fluid rotation that's important for weather forecasting. The team found that whereas energy largely cascades from small to large length scales, the cascade of vorticity goes in the opposite direction and dominates at both large and small length scales. That observation helps explain the steep slope of the energy spectrum observed at large length scales, but the exact mechanism that connects these opposite cascades is still being explored, Read says.

The team plans to use the model to study how the kinetic-energy spectrum might look different for gas giants and other planets that have atmospheres unlike Earth's. For example, using faster rotation speeds and greater variations in the tank's fluid depth can create effects similar to parallel jet streams, which are connected to the generation of zonal banding on Jupiter and Saturn. PT

Reference

1. S.-S. Ding et al., "Stratification-dependent enstrophy-controlled regime in geostrophic turbulence," *Phys. Rev. Lett.* **136**, 114101 (2026).

