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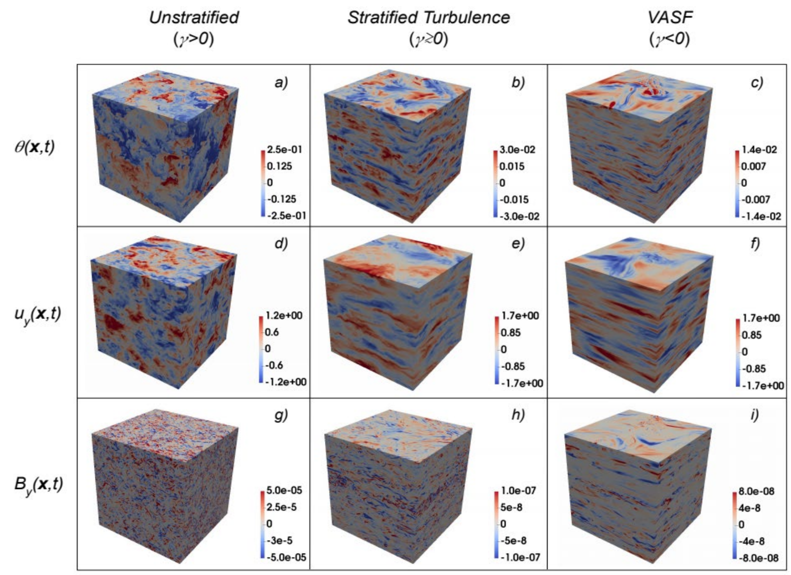
Understanding Turbulence in Earth's Atmosphere Helps Unlock Mechanisms of Magnetic Field Generation Inside the Sun

Instability conditions for magnetic field growth in stratified turbulence are found to be satisfied in the Sun using novel simulations and scaling analysis.



Snapshots of turbulent temperature (top row), velocity (middle row), and magnetic fields (bottom row) for increasing gravitational strength (columns left to right). Left most column has no gravity, middle column has moderate gravity similar to conditions in the Sun, and right column has overly-strong gravity leading to a regime called the viscously-affected stratified-flow regime (VASF).

The Science

Despite its importance in determining space weather, we still do not completely understand how large-scale magnetic fields on our Sun's surface are generated. Previous studies overlooked the role of small-scale magnetic fields that contribute important non-linear effects, which can initiate or suppress the generation of large-scale fields – to understand a "nonlinear" effect, imagine the feedback cycle between predator and prey populations.

New research combines recent theoretical advances in understanding turbulence in the Earth's atmosphere and supercomputer plasma simulations to uncover the instability conditions necessary for the exponential magnification of small scale magnetic fields in the Sun. We find the Sun is unstable to these nonlinear effects, opening a promising line for future research for understanding solar dynamics.

The Impact

This research ties together details of how gravity-affected turbulence inside the Sun drives solar magnetic activity, which directly links to space weather. Space weather regularly causes damage to satellite electronics and can even disrupt city power grids during strong solar storms. (You might well know how thunderstorms on Earth can knock out power; well, thunderstorms in the Earth's magnetosphere can do much worse.) Our findings help understand observations throughout our solar system.

Summary

The same turbulence present high in the Earth's atmosphere, which creates the turbulence you might have encountered in plane flights, is also present inside the Sun. Known as stratified turbulence due to its tendency to create horizontal layers, the turbulence is asymmetric because gravity restricts vertical fluid displacements from equilibrium while allowing free horizontal motions.

The new numerical calculations build on recent research of stratified turbulence in Earth's atmosphere and apply it to conditions in the Sun, whose fluid is a conducting gas of charged particles known as a plasma. We ran plasma simulations with background stratification and initialized with a weak magnetic field, modeling a patch of turbulence inside the Sun. Analysis of the simulations revealed scaling relations of the instability criterion for small-scale magnetic field generation. The scaling relations are between dimensionless numbers (e.g. the Reynolds and Froude numbers), and so calculating their expected values in the Sun reveals that the stratified turbulence is unstable to exponential small-scale magnetic field growth. The explosive growth saturates when the energy in the magnetic field is comparable to the kinetic energy in the turbulence. The resulting small-scale fields have important effects on the generation of large-magnetic fields, which are primarily responsible for the coronal mass ejections and solar flares that lead to space weather around the Earth.

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Publications

V. Skoutnev, J. Squire, A. Bhattacharjee. "Kinematic Small Scale Dynamo in Stably Stratified Turbulence". Submitted to *The Astrophysical Journal* (2020).