

Zonal Jets: An Overview

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Introduction

The term *jet*, when used in context with fluid dynamics, refers to an elongated flow of fluid or gas. The most famous jets that virtually any school child can identify give Jupiter its magnificent banded look. Earth's jets are not as striking as Jupiter's. Despite this, they play a crucial role in the dynamics of climate and weather. Classical physics provides ample explanation of the dynamics of jets forming from a nozzle. However, jets found in planetary fluid do not form from a nozzle. Planetary jets form from a number of boundary conditions. For example, a canyon can "funnel" fluid causing a jet like flow. The scope of this paper, however, concerns the β -effect, which is currently the most promising boundary condition shaping the formation of jets. Jets are often flows of mass that can extend for thousands of kilometers. Boundary conditions, particularly the β -effect, force the jets into bands which then flow continuously until a stronger force disrupts them, such as continental boundaries.

Basic Dynamics

Planetary fluid has different densities at different depths. Consequently, a density potential forms, which separates the fluid into different densities. All planetary fluids are constrained by vertical stratification of density. This trait allows fluid to flow in areas of constant density potential. Such zones are called isopycnal surfaces. So, if the Earth,

or arbitrary/fluid covered planet, were not rotating the fluid would flow freely in the isopycnal surfaces. No potential energy is gained or lost in such flow. (Admittedly, I'm disregarding thermodynamic effects at this point simply to identify all the components that cause jets). Fortunately, Earth and Jupiter rotate. Rotating spherical bodies covered in fluid are dynamically controlled by the Coriolis Effect. The Coriolis Effect determines the aforementioned β -effect, which occurs because fluids at different latitudes have different angular velocities. The Coriolis force prevails over the free-flowing ability of isopycnal surfaces because the Earth rotates faster (as does Jupiter) than large scale oceanic and atmospheric flows. As a result, in the presence of density stratification the Coriolis force forces the free-flowing fluid into parallel bands.

Thermodynamic effects contribute primarily in furthering the stratification of densities. Hot water is less dense than cold water so it rises and the colder water sinks. An example of this is the Gulf Stream, which takes the warm water from the Equator to the north of the Atlantic Ocean, and the North Atlantic Current, which runs at the bottom of the ocean and carries the cold water south. In this particular example, thermodynamic effects force the jets in a north-south-like direction rather than latitude directions. Hence, the Gulf Stream-North Atlantic Current "conveyor belt" depicts the importance of thermodynamic effects on jet formation.

Summary

Vertical stratification of density creates isopycnal surfaces (of constant density) where fluid is essentially free to flow. The Coriolis Effect causes the fluids at different latitudes to have different angular velocities, which gives rise to the β -effect. The β -effect overpowers the density stratification and forces the free-flowing fluids into parallel bands. These bands, which may persist for great distance and time, are the Zonal Jets, which are influential to climate and weather dynamics. Thermodynamic effects also play a crucial role in the creation of jets both as their direct cause (as in the case of the Gulf Stream- North Atlantic Current “conveyer belt”) and in assisting in stratification of density.

All the information provided above comes from Peter B. Rhines *Jets*, which was published by the American Institute of Physics in 1994.

