Session IR1 - Inverse Turbulent Cascade, Vortex Dynamics and the Creation of the Planetary Zonal Flow.
INVITED session, Wednesday morning, November 17
Grand I and II, The Westin Seattle

[IR1.01] How the Inverse Turbulent Cascade and Vortex Dynamics Create Planetary Zonal Flows

Philip S. Marcus (UC -- Berkeley)

The analogies between pure--electron plasmas and geophysical fluid flows that are quasi--2--dimensional due rotation and/or stratification are well--known. The formation of vortices, their interactions and persistence along with their tendencies to both filament and merge are the subject of many fluid experiments and numerical simulations and have analogies in plasma experiments. The hallmark of two--dimensional turbulence is the inverse cascade of energy from small to large scales. Here we are interested in finding if the inverse energy cascade along with our usual notions of vortex dynamics can be used to explain the large--scale structures of the atmospheres of Jupiter and Saturn which are dominated by long--lived east--west (zonal) flows. Little is known about what sets their velocity scales or their length scales (i.e., the number of zones on each planet). Typically, the energy--containing modes in a turbulent flow span a range of scales, and in the rare cases that there are coherent features, their lengths are usually determined directly by the boundaries or the forcing length scales. Even turbulence in geophysical flows show this trait: the scale of granulation on the Sun (due to turbulent convection cells) is set by the depth of the convective zone; Jupiter's long--lived vortices, such as the Red Spot, are set by the widths of the local zonal flows in which they are situated. By examining a simple forced/dissipated flow we show that the widths of zonal flows are determined by a subtle combination of the forcing and dissipation and not set by boundary conditions or by the length scale of the forcing. We show that under a wide variety of conditions a turbulent flow without east--west winds forms via a inverse energy cascade and that zonal flows (with a single dominant length scale) form only for a small set of parameters. We present a simple theory which determines these parameter values and which also provides scaling laws for the zones' velocities and widths. Thus we are able to adjust the widths and strengths of the zonal flows by changing the forcing and dissipation rates. We show that the coherent and the incoherent parts of the energy spectrum obey different scaling laws and we explain why. We show how two different physical effects lead to two superposed scaling laws in the energy specrum, one of which is the usual Kolmogorov scaling while the other results in a steeper spectrum and dominates at large scales. We discuss the implications for Jupiter, compare the numerical experiments with similar ones carried out previously by others, and show how one could build a laboratory experiment that would form jovian--like winds with two easily adjustable control parameters that determine their widths and strengths.

Part I of program listing