BAROTROPIC INSTABILITY OF PLANETARY POLAR VORTICES: LABORATORY ANALOGUES OF VENUS'S POLAR 'DIPOLE'?

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The polar vortices on Venus exhibit extremely rich dynamics, as recent observations by ESA's Venus Express spacecraft have revealed (Piccioni et al., 2007). They most often exhibit a double-lobed shape (the so-called 'Polar Dipole'), as first observed by NASA's Pioneer Venus spacecraft in the late 1970s (Taylor et al., 1980), but have recently been found to vacillate chaotically among 1-, 2- and 3-lobed configurations. Many factors have been invoked in developing a theoretical framework that could describe their bizarre dynamics. Different kinds of instabilities could arise at the edge of the polar vortices, where the wind shear between the circumpolar jet and the vortex interior is strongest. In the case of Venus, the possibility of barotropic instabilities in the polar jets has been supported by calculations made from radio occultation observations from Pioneer Venus (Newman et al., 1984), and by results of numerical models (Elson, 1982, Michelangeli et al., 1987, Limaye et al., 2009).

He we provide an overview of a range of laboratory experiments in rotating fluids that explore the occurrence and forms of fully developed, nonlinear barotropic shear instabilities over a wide range of conditions, including those relevant to Venus and other slowly rotating planets. Differential motion in the form of jets or shear layers is maintained in such experiments either by differentially moving horizontal boundaries (Frueh & Read 1999, Aguiar et al. 2010) or via a distribution of mass sources and sinks. Such systems enable reproducible experiments to be conducted under highly controlled conditions, within which the parametric dependence of features such as the preferred wavelength of equilibrated instability, onset of various forms of time-dependence etc. can be systematically investigated for direct comparison with theory. Full dynamical similarity with Venus's atmosphere is very difficult to achieve, but experiments in large tanks (with radii from 0.3 m to 6.5 m) have been carried out recently by the present team that allow conditions similar to those prevailing at Venus's south pole (such as large zonal Rossby number) to be approached. The experimental results show consistently that zonal shear flows at high Rossby number tend to favour low wavenumber disturbances developing in the analogue 'polar vortices', often with chaotic time-dependence, much as observed on Venus. Dye tracer visualisation is also found often to settle into striking 'S'-shaped patterns in flows dominated by wavenumber m=2. We further discuss the implications of these results for understanding Venus's atmospheric circulation.

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