

OF POOR QUALITY

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Polar Vortex Dynamics

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Recent work with high resolution, one-layer numerical models of fluid flows resembling those in the real stratosphere has suggested that:

1. The interiors of strong cyclonic vortices like the Antarctic polar vortex may be almost completely isolated laterally from their surroundings - perhaps even completely isolated, under some circumstances;
2. By contrast, material near the edge of such an isolated region can easily be 'eroded' (or mixed one-sidedly) into the surrounding region;
3. The erosion characteristically produces extremely steep gradients in isentropic distributions of potential vorticity (PV) and of other tracers, possibly down to horizontal length scales of a few kilometres only. Such length scales may occur both at the edge of the main polar vortex and in smaller features outside it, such as thin filamentary structures, produced by the erosion process.

These results (for more details see Juckes and McIntyre 1987, '88) seem likely to be relevant to the Antarctic ozone problem. For example, point 1 would be especially relevant if it were turn out that the chemistry of the ozone hole is sensitive to 'contamination' e.g. from nitric oxides that might enter the polar vortex from outside. Point 3 might be relevant to the interpretation of high-resolution tracer observations. It is important to ask, therefore, to what extent the qualitative features just listed might carry over to the real stratospheric vortex and its surroundings.

Several modelling studies are currently in progress at Cambridge, involving work by D.G.Dritschel, P.H.Haynes, and W.A.Norton, using the computing resources of the U.K. Universities' Global Atmospheric Modelling Project. These aim to go beyond the earlier work and establish a hierarchy of models that will thoroughly test the robustness of the foregoing conclusions. Results to date will be reported on, including, it is hoped, some high resolution, fully three-dimensional, baroclinic polar-vortex simulations. Further details are given in two posters by Dritschel and Haynes submitted concurrently with this presentation.

One interesting result is a tendency for isentropic distributions of PV to exhibit a particularly steep 'cliff' at the outermost edge of the main vortex. This feature appears highly characteristic of the erosion process, at least when the vortex is disturbed mainly from outside, or by a planetary-scale wave only, as in model simulations to date. However, the real Antarctic vortex might be significantly stirred within its interior as well, making the isolated core region more nearly homogeneous than it might otherwise be, a circumstance that would also have chemical implications. A possible mechanism is stirring by the action of anticyclonic, tropopause-level PV anomalies associated with the observed "mini-holes" in column ozone, if and when these move underneath the main vortex. Such anomalies could induce synoptic-scale circulations in the air within the isolated vortex core above them, without requiring any material transport across the edge higher up, eg on the 420K isentropic surface.

The prediction of thin filaments and steep gradients (point 3) is physically reasonable; there is no reason to suppose that the real atmosphere has any pre-existing 'eddy diffusivity', like the artificial eddy diffusivities used in numerical models, that would smooth such features. These features are part of the physical mechanism that causes what might appear in a coarse-grain statistical description to be an 'eddy diffusivity'.

Indeed, the one-sided nature of 'erosion' of material from the edge of a strong vortex revealed by the numerical models provides a typical illustration of how deceptive the standard idea of 'mixing' and 'eddy diffusion' can be. It is always possible, of course, to define an eddy viscosity or tracer diffusivity by dividing an eddy flux by some mean gradient, but this idea may draw attention away from the fact that such quantities exhibit an extreme degree of spatio-temporal inhomogeneity in many naturally-occurring fluid flows. For instance as one crosses the edge into the polar vortex the eddy diffusivity must drop suddenly to zero, or to extremely small values, insofar as it can be defined usefully at all. It may rise again as one crosses into the interior.

From a theoretical-dynamics point of view one of the most striking aspects of flows like these is a tendency to exhibit a mixture of 'wavelike' and 'turbulent' characteristics in closely adjacent or overlapping regions. The distortions of the (edge of the) main polar vortex are an example of 'Rossby waves', and the surrounding region an example of two-dimensional turbulence or, in this context, 'Rossby-wave surf'. The interacting regions -- a sort of highly inhomogeneous 'wave-turbulence jigsaw puzzle'-- poses one of the biggest challenges facing dynamicists today. Results from the Antarctic may provide some unique clues to the solution of this puzzle, and hence an opportunity to make fundamental advances in dynamics as well as chemistry.

References

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