Geophysical Research Abstracts, Vol. 8, 09872, 2006
SRef-ID: 1607-7962/gra/EGU06-A-09872
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Numerical simulation of atmospheric flows using vorticity confinement techniques

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Recently, Tripoli et al., 2004 demonstrated the ability of vorticity confinement techniques (Steinhoff, 1994) to dramatically enhance the ability to numerically simulate a waterspout condensation funnel observed over the Tyrrhenian Sea. Although the technique produced realistic looking waterspout vorticies when applied to a micro-scale simulation, there was little theoretical justification presented to defend its use, there was no guidance on the proper setting of parameters determining the strength of the confinement term and there was no attempt to determine the limits of its applicability over different scales and types of atmospheric flow problems. In this paper, the vorticity confinement technique is demonstrated to have both a physical justification, based on idealized vortex studies and a numerical justification based on the differing behavior of flow systems under increasing inertial stability. Under increasing inertial stability, atmospheric flows become inertially balanced and long lived as energy is trapped from cascading downscale. Under weak inertial stability flows become isotropic and energy cascades downscale. Numerical model filters are designed to remove the unresolved and poorly resolved scales. This can be justified for flows smaller than the Rossby radius of Deformation, but less so for flows that tend to be balanced such as gradient or cyclostrophic flows. Hence numerical filters and implicit filtering of a numerical advection scheme will act to erode balanced flows erroneously. It will be shown in this talk that the addition of a vorticity acceleration to the equations of motion acts to oppose erosion of inertially stable flow regimes by numerical smoothing. It will also be shown, that vorticity confinement can be formulated to precisely target filtering of balanced flows increasing the accuracy of the procedure. In addition, it is shown that the inclusion of this term in larger scale flows, such as the simulation of fronts and cyclones, can greatly benefit from this procedure and pick up accuracy

similar to that demonstrated for the waterspout problem.