Tornadic Vortex Signature (TVS) Produced by Constrained Pulsing Inertial Oscillation (PIO) Model

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Abstract. The TVS on Doppler radar indicates a midtropospheric vortex of Rossby number $\mathrm{Ro} \approx 1000$ that develops in a supercell storm shortly before a tornado descends. This paper shows how the PIO model, which was first described at the 1991 AGU Spring Meeting, could produce a TVS.

Introduction. Although the TVS is an important precursor to a tornado [1], it is not easily explained by the conventional splitting-storm model of supercell storms [2]. The PIO model [3] is a strongly nonlinear vortex solution of the inviscid fluid dynamic equations in the middle troposphere. In this model, inertial flow is organized into a radial oscillation that is coupled to a compressible vertical draft. A supercell storm corresponds to one pulse of the oscillation.

Figure 1 shows core-average values of dimensionless (primed) vertical vorticity ζ' = Ro (Rossby number), vertical draft speed ω', buoyancy B', and draft radius α' plotted versus time τ' for Ro_{max} = 10. For larger values of Ro_{max}, the pulses become narrower. As shown, spin-up occurs when the average draft is downward. This downdraft is cylindrical, and compressibility makes it contract. The contraction induces a convergent flow in the middle troposphere that spins-up the mesocyclone with help from the Coriolis force.

Constrained PIO. The draft is driven by buoyancy. For high values of Ro, the positive buoyancy required to support the PIO is 8-times greater than the negative. However, the positive and negative limits of buoyancy available from latent energy are approximately equal. We take these limits to correspond to a temperature excess ΔT in the range $(-12\ \mathrm{K} \le \Delta T \le 12\ \mathrm{K})$ and constrain the PIO accordingly, as shown in Fig. 2.

Development of TVS. This constraint causes the model to deviate from the ordinary PIO, as follows: Since buoyancy drives the vertical speed w, the average downdraft is prolonged relative to that in the PIO, as shown in Fig. 3. This prolonged downdraft causes prolonged contraction and spin-up, as shown in Figs. 4 and 5. The resulting Rossby number Ro exceeds the value 1000 that is a typical for a TVS.

Pressure deficit. The ordinary PIO has no pressure deficit in the core. However, the constraint causes a central pressure deficit Δp to develop, as plotted versus t in Fig. 6. At maximum spin-up, Δp = 47 mb at 1 km height above mean sea level. This computed value compares with the highest recorded pressure deficit in a mesocyclone of 34 mb [1].

Detection. According to the constrained PIO model, a TVS is produced by a prolonged average downdraft in a supercell storm. If such a downdraft could be detected, perhaps by radar and lidar from a satellite, tornado prediction could improve.

Modification. The ordinary PIO model does not produce a TVS. In the constrained PIO model, a TVS is produced by a deficit in the positive buoyancy that latent heating can provide. If this missing buoyancy could be supplied -- possibly by beaming-in energy -- the prolonged downdraft would be cut short before a TVS develops. Similarly, by promoting transition to an average updraft, an existing tornadic vortex could be made to expand and spin down. Of course, these modifications could increase the production of hail.

Conclusions. The constrained PIO model provides an explanation for the development of a tornadic vortex in the middle troposphere within a supercell storm. This explanation also has implications for early detection of a developing tornadic vortex and dissipation of an existing one.

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References.

[1] R. P. Davies-Jones, Tornado dynamics. Thunderstorm Morphology and Dynamics, Second Edition. E. Kessler, Ed. Vol. 2. Thunderstorms: A Social, Scientific, and Technological Documentary, Univ. of Oklahoma Press. London (1986) 197-236.

[2] C. Church, D. Burgess, C. Doswell, and R. Davies-Jones (Eds.), The Tornado: Its Structure, Dynamics, Prediction, and Hazards. Geophysical Monograph 79. American Geophysical Union (1993).

[3] R. C. Costen and L. V. Stock, Inertial oscillation of a vertical rotating draft with application to a supercell storm. NASA TP-3230 (1992) with 8-minute video supplement available.

Figure 1. Typical PIO ↓

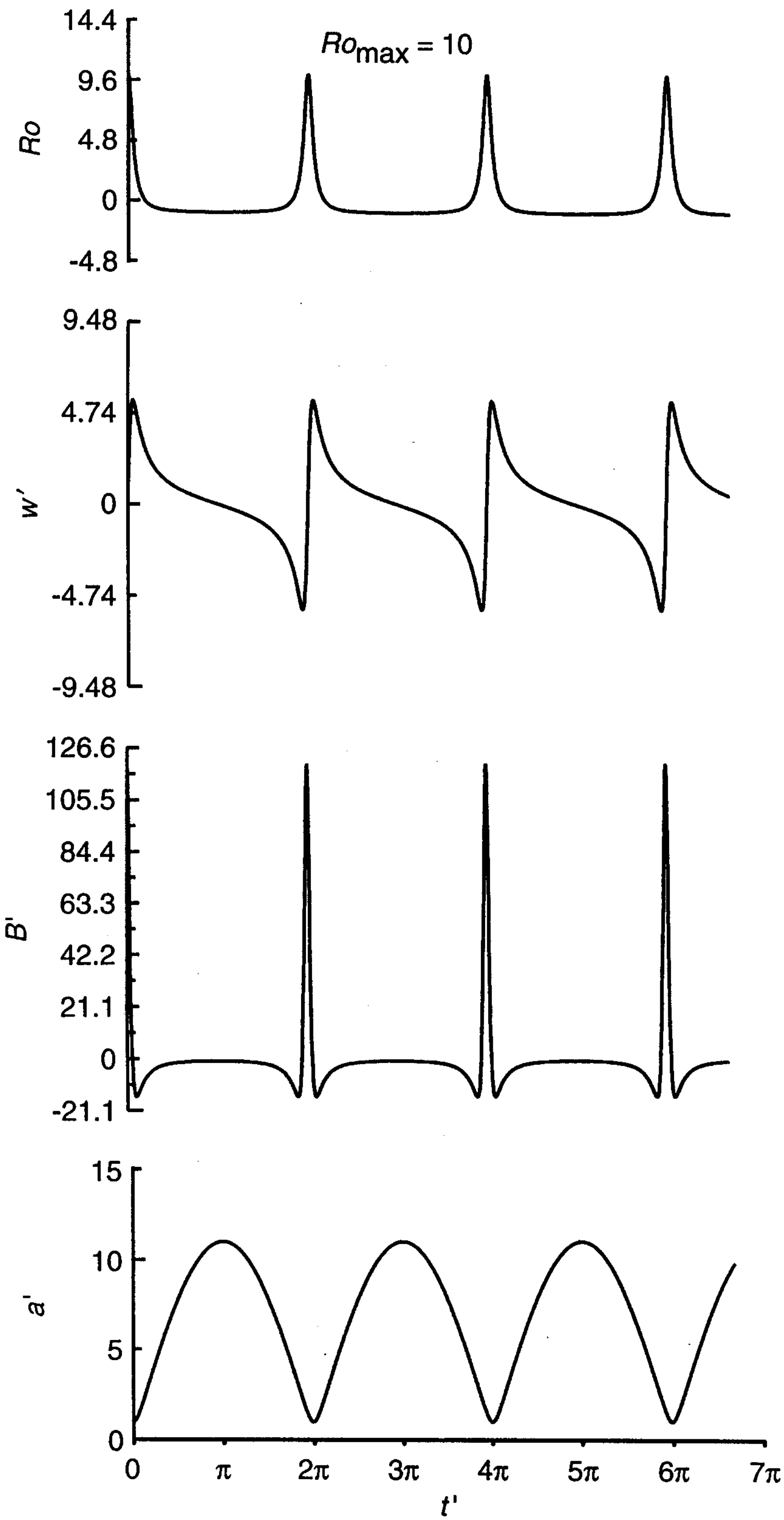

Figure 2. Buoyancy vs. time ↓

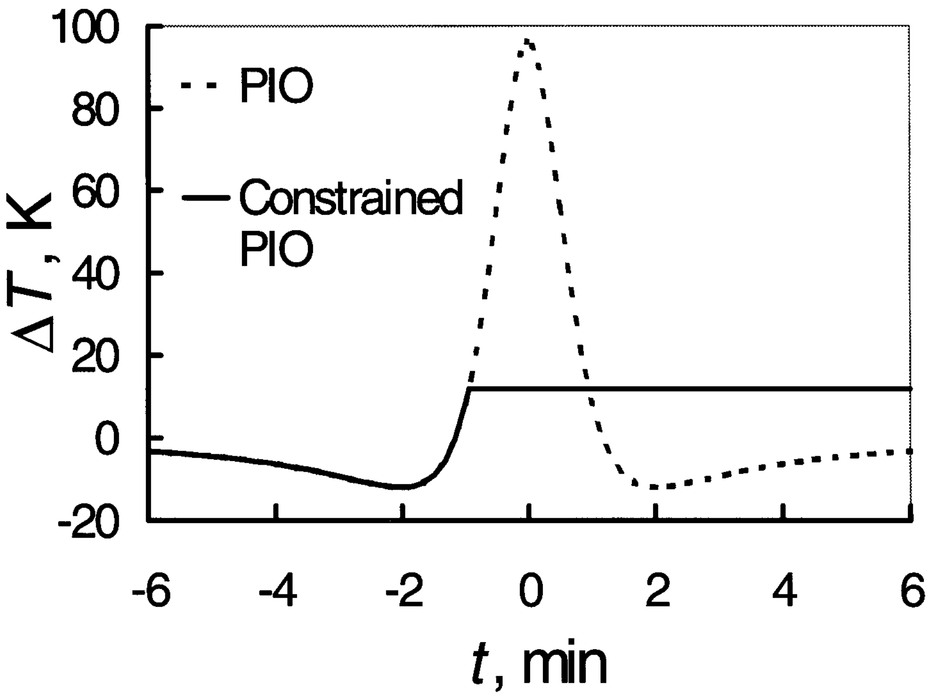

Figure 3. Average draft speed ↓

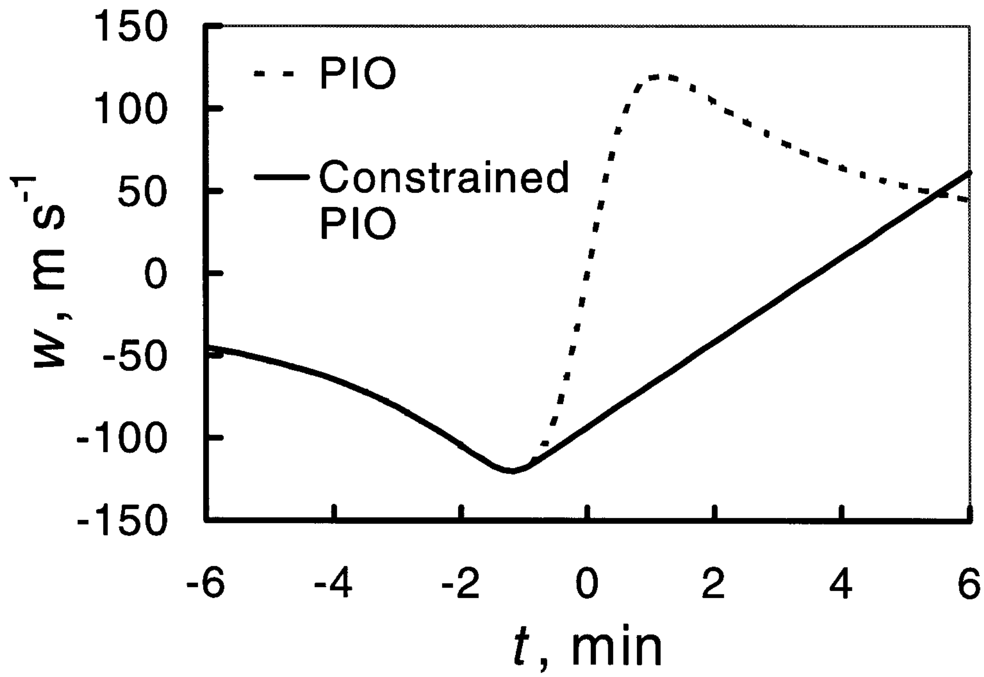

Figure 4. Core radius ↓

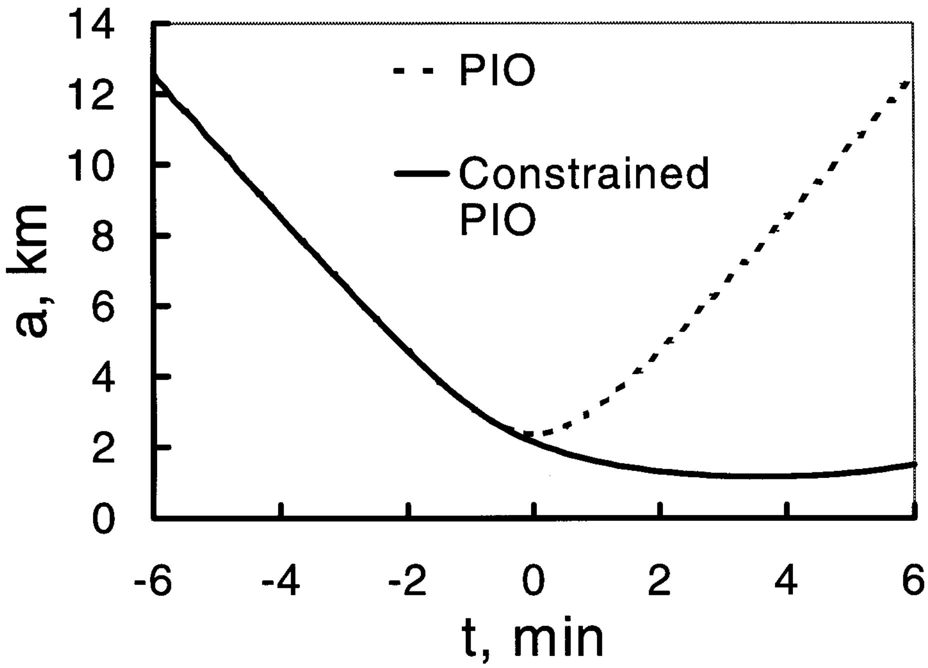

Figure 5. Vertical vorticity ↓

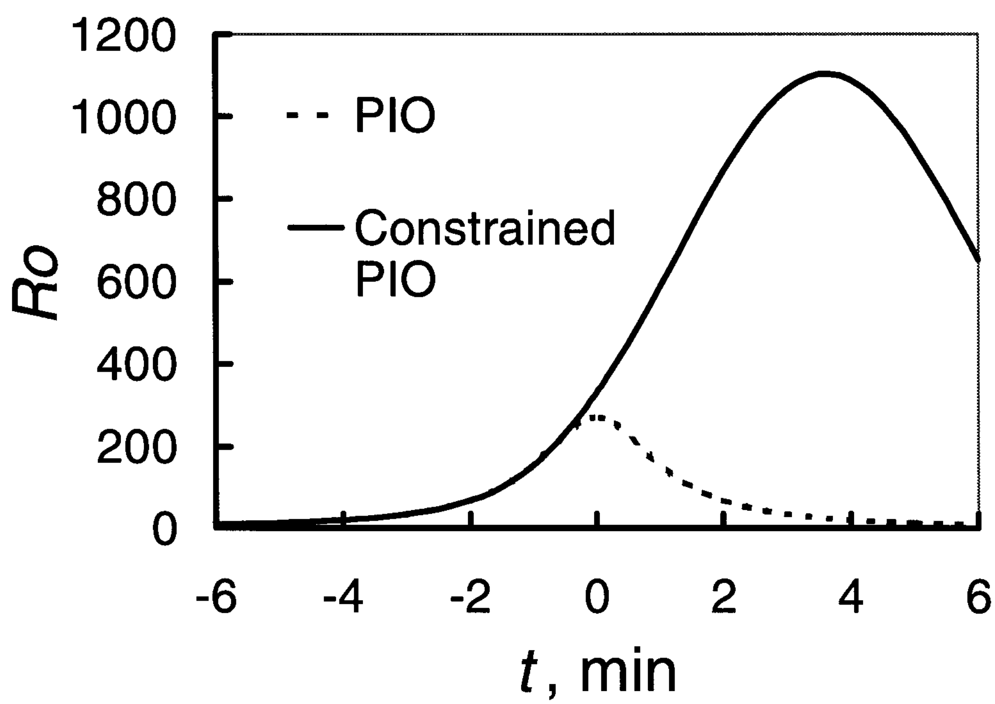

Figure 6. Central pressure deficit ↓