A Rotating Air-Ring Model for Atmospheric Vortices and a Peripheral Drag Concept for Tornado Mitigation

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Abstract

This study introduces Latent Angular Momentum (LAM) as a heuristic parameter for understanding the intensification of rotating atmospheric vortices. Using a simplified air-ring model based on the conservation of angular momentum, we derive an analytical expression for tangential wind speed as a function of radial contraction and latitude. Model predictions yield physically plausible initial radii r_0 (approximately 217–220 km for intense hurricanes and 40–81 km for strong tornadoes), consistent with observational data from major storms. We further discuss how climate change may increase the initial radius of air masses drawn into cyclones, potentially leading to more intense vortices. Based on the LAM framework, we propose a novel conceptual tornado mitigation strategy — the External Wind (EW) method — which employs anchored sail-like parachutes (SLPs) to extract angular momentum in the peripheral region of a tornado, where intervention is energetically more favorable. Practical challenges, engineering requirements, and directions for future research are outlined.

Keywords: latent angular momentum, LAM, air-ring model, tornado mitigation, anchored sail-like parachutes, external wind method, vortex dynamics

1 Introduction

Tropical cyclones and tornadoes remain among the most destructive natural hazards worldwide, with their intensity and societal impact increasing in a warming climate. Traditional explanations of vortex spin-up rely heavily on the Coriolis force, a concept that can be challenging for non-specialists to visualize. An alternative and more intuitive perspective is offered by the principle of angular momentum conservation.

In this study we introduce Latent Angular Momentum (LAM) as a heuristic concept representing the rotational potential inherent in air masses co-rotating with the Earth. This latent quantity becomes manifest when radial contraction or expansion occurs, analogous to the release of latent heat during phase changes in thermodynamics. The LAM framework allows a transparent derivation of tangential wind speeds in vortices without explicit reference to the Coriolis parameter in the local rotating frame.

Recent high-resolution numerical simulations have significantly advanced our understanding of the multi-scale processes involved in tornadogenesis, particularly the origins and amplification of near-surface vorticity [10-12]. The present heuristic model aims to complement these detailed studies by providing a simple, analytically tractable framework focused on angular momentum conservation. The formation and intensification of atmospheric vortices have been extensively studied through both observational and numerical approaches [1, 2, 4, 9].

The objectives of this paper are sixfold:

(1) to present a thought experiment that illustrates the concept of LAM; (2) to derive tangential wind speed for an idealized contracting air ring; (3) to compare model predictions with observational data from intense hurricanes and tornadoes; (4) to examine possible effects of climate change on vortex intensity through changes in initial radius; (5) to propose a conceptual tornado mitigation strategy based on peripheral angular momentum extraction using anchored

sail-like parachutes; and (6) to discuss limitations of the model and outline directions for future research.

By combining a simple analytical model with a physically motivated mitigation concept, this work aims to contribute both to the didactic understanding of vortex dynamics and to the exploration of unconventional approaches for reducing the destructive potential of tornadoes.

2 Physical Model of Latent Angular Momentum

2.1 Thought experiment on a rotating platform

Consider a horizontal platform rotating with angular velocity Ω. A ring of mass m and initial radius r_0 rests on it (Fig. 1). In the laboratory frame, the ring's centre moves in a circle while the ring spins about its centre with angular velocity Ω. Its angular momentum is:

$$L_{\text{before}} = m r_0^2 \Omega \tag{1}$$

After levitation and contraction to radius $r < r_0$ (Fig. 2), angular momentum conservation gives:

$$L_{\text{after}} = m r^2 \omega = L_{\text{before}} \quad \Rightarrow \quad \omega = \Omega \cdot \frac{r_0^2}{r^2} \tag{2}$$

For an observer on the platform, the relative spin is:

$$\omega_{\text{rel}} = \omega - \Omega = \Omega \left(\frac{r_0^2}{r^2} - 1 \right) \tag{3}$$

Thus, contraction produces spin in the same direction as the platform. The work done during contraction converts into rotational kinetic energy. For example, with $r_0 = 1$ m and $r = 0.5$ m, Eq. (3) gives $\omega_{\text{rel}} = 3\Omega$.

Analogy with latent heat

The above thought experiment is idealized because it requires levitation, spontaneous contraction of the ring, and a constant distance from the central axis despite centrifugal effects. Nevertheless, it demonstrates that any object at rest in a rotating reference frame possesses **Latent Angular Momentum (LAM)**. For the ring on the platform, LAM is precisely the expression in Eq. (1): $L_{\text{lat}} = m r_0^2 \Omega$ – a physical quantity that exists but is not directly measurable until some change (such as contraction) occurs. This is analogous to latent heat in thermodynamics: energy that is present in a system but becomes apparent only during a phase transition. Therefore, spontaneous changes of motion in non-inertial systems may be understood through internal conservation laws (Eq. (3)) rather than solely through external forces.

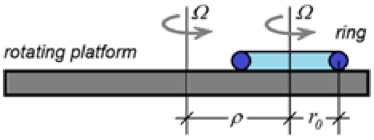

Figure 1: Ring on a rotating platform before contraction (laboratory frame).

2.2 Extension to a rotating sphere (Earth)

Place the ring on a smooth sphere rotating with angular velocity Ω (Fig. 3). At latitude ϕ, the local vertical component of Earth's rotation is $\Omega \sin \phi$. An observer in the local frame perceives the ring as stationary because their frame rotates with that component. The LAM about the local vertical is:

$$L_{\text{before}} = m r_0^2 \Omega \sin \phi \tag{4}$$

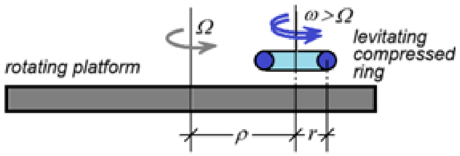

Figure 2: Levitating ring spontaneously contracts to a smaller radius and begins to rotate.

After radius change to r, conservation gives:

$$\omega = \left(\frac{r_0}{r}\right)^2 \Omega \sin\phi \tag{5}$$

The relative angular velocity (spin observed locally) is:

$$\omega_{\text{rel}} = \left(\frac{r_0^2}{r^2} - 1\right) \Omega \sin\phi \tag{6}$$

The tangential wind speed at radius r is:

$$v(r) = \omega_{\text{rel}} r = \left(\frac{r_0^2}{r^2} - 1\right) \Omega r \sin\phi \tag{7}$$

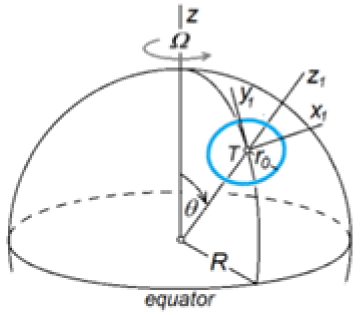

Figure 3: Latent rotation of a ring on a rotating sphere (local coordinate system).

3 Application to Atmospheric Vortices

3.1 Air ring model

We interpret the ring as an idealized air parcel. Equation (7) gives the tangential wind speed after contraction. Given measured v, r, and ϕ, the initial radius can be estimated:

$$r_0 = r\sqrt{\frac{v}{\Omega r \sin\phi} + 1} \tag{8}$$

Wind power density (W/m^2) is:

$$P(r) = \frac{1}{2}\rho_0 v(r)^3 \quad (\rho_0 = 1.225\,\text{kg/m}^3) \tag{9}$$

Figure 4 shows the tangential wind speed and power density for a vortex at $\phi = 25°$ with $r_0 =$ 300 km. As r decreases, wind speed increases rapidly, and power density even more dramatically ($\propto v^3$).

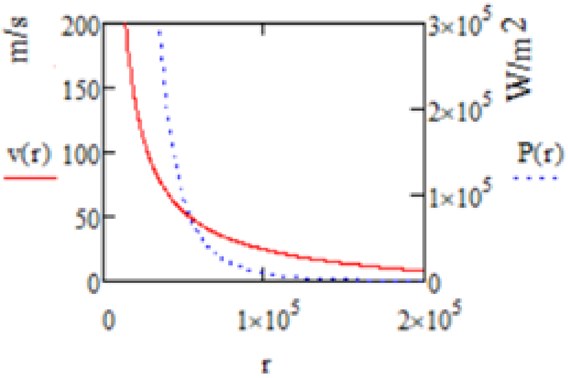

Figure 4: Tangential wind speed and power density (Eqs. (7) and (9)) at latitude 25° with initial radius 300 km.

3.2 From air ring to tropical cyclones and tornadoes

A large vortex can be understood as a multitude of concentric air rings. Before contraction, air masses are at rest relative to the local rotating frame, yet they possess LAM (Eq. (4)). Any vortex requires: a) initial angular momentum, b) an energy source. Earth's rotation provides a). Equation (7) shows that strong cyclones cannot form at the equator ($\phi = 0$). Formation is favored at 5°–20° latitude where ocean temperatures are conducive to cyclogenesis. These findings are consistent with previous studies on the environmental conditions favorable for cyclogenesis and tornadogenesis [3, 4].

4 Comparison with Observational Data

4.1 Model validation

Table 1 compares model predictions (initial radius from Eq. (8)) with real data. Computed r_0 values are approximately 217–220 km for the analyzed intense hurricanes and 40–81 km for the analyzed strong tornadoes. These values fall within physically plausible ranges, with hurricane results corresponding to the scale of the broader cyclonic circulation and tornado results consistent with the scale of the parent mesocyclone or environmental inflow.

Storm (year)	Max wind (km/h)	RMW (km)	Latitude	Power (kW/m^2)	Initial r_0 (km)
Patricia (2015)	345	9.5	15°N	539	220
Haiyan (2013)	315	7.5	11°N	410	217
Katrina (2005)	280	18.5	25°N	288	217
El Reno (2013)	475	2.1	35°N	1407	81
Joplin (2011)	322	0.8	37°N	438	40
Moore (1999)	484	0.8	35°N	1488	51

Table 1: Model validation against observational data. Sources: NOAA/NHC, JTWC, NWS. RMW = Radius of Maximum Wind.

The model performs particularly well for hurricanes, where the axisymmetric assumption is more applicable. For tornadoes, the computed r_0 values (40–81 km) likely represent the scale of the parent mesocyclone or the broader environmental flow from which angular momentum is drawn, rather than the tornado core itself. This interpretation is consistent with recent findings on the multi-scale nature of tornadogenesis and the importance of environmental vorticity sources [11,12].

4.2 Climate change impact

Warmer oceans may increase the initial radius r_0 of air drawn into cyclones. From Eq. (7), larger r_0 gives higher wind speeds at a given r. Figure 5 shows the tangential wind speed at $r = 30$ km for different r_0 at $\phi = 30°$. For $r_0 = 200$ km, wind speed is 171 km/h; for $r_0 = 300$ km, it rises to 390 km/h. Thus, continued warming may produce stronger, more frequent cyclones at higher latitudes, though this requires further investigation. This is in agreement with recent research linking anthropogenic ocean warming to increased hurricane intensity [5].

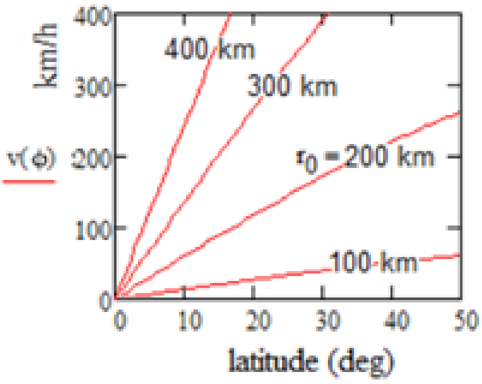

Figure 5: Tangential wind speed at $r = 30$ km from vortex centre for various initial radii r_0 (Eq. (7)) at latitude 30°.

5 Discussion

5.1 Role of LAM and model limitations

The Latent Angular Momentum (LAM) framework presented in this study offers a heuristic and didactic approach to understanding the spin-up of atmospheric vortices. By emphasizing conservation of angular momentum in a rotating reference frame and drawing an analogy with latent heat, LAM provides an intuitive bridge between large-scale planetary rotation and intense localized wind speeds, without requiring explicit invocation of the Coriolis force in the local frame.

Nevertheless, the simplified air-ring model has important limitations that must be clearly acknowledged. The model assumes frictionless radial inflow, perfect axisymmetry, conservation of LAM during contraction, and neglects vertical motions, environmental wind shear, and baroclinic effects. It treats the vortex as a single contracting ring (or a set of concentric rings) and does not explicitly account for the primary energy source — the release of latent heat from condensation — which sustains the radial inflow against friction.

For tropical cyclones, the axisymmetric assumption is reasonably applicable on scales of hundreds of kilometers. For tornadoes, the computed initial radii r_0 (40–81 km) likely represent the scale of the parent mesocyclone or the broader environmental flow from which angular momentum is drawn, rather than the tornado vortex itself. This is in line with recent numerical studies highlighting complex, non-axisymmetric processes and the role of near-surface vertical vorticity streaks in supercell environments [10,11l.

Despite these simplifications, the model reproduces observed wind speeds and yields physically plausible values of r_0, suggesting that the LAM concept can serve as a valuable conceptual bridge between large-scale rotation and intense local vortices, complementing the detailed vorticity budget analyses in high-resolution simulations [12,13]. The present heuristic model does not aim to replace comprehensive numerical simulations that include cloud microphysics and complex vorticity dynamics [2, 4].

5.2 Physical basis for peripheral angular momentum extraction

The total angular momentum of a rotating air mass at distance r from the vortex centre, measured in the inertial frame, is given by

$$L = mr\, v_{\text{inertial}} = mr\,(v + r\Omega \sin\phi) \tag{10}$$

where v is the magnitude of the relative (observed) tangential wind speed and $r\Omega \sin\phi$ is the peripheral speed due to Earth's rotation at latitude ϕ. A change in angular momentum due to a reduction in wind speed is then

$$\Delta L = mr\,\Delta v \tag{11}$$

Equation (11) reveals a key scaling property: to achieve the same reduction in total angular momentum ΔL, a much smaller velocity change Δv is required at large radii than near the radius of maximum wind (RMW). This makes the peripheral region of a tornado a physically attractive target for mitigation interventions (Figure 6).

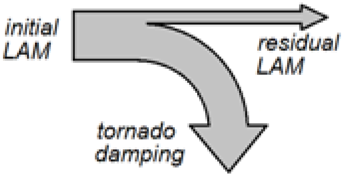

Figure 6: Tornado damping by the external wind method. Symbolic representation.

5.3 The External Wind Method with anchored sail-like parachutes

Based on the above scaling, we propose the External Wind (EW) method — a conceptual tornado mitigation strategy that uses networks of anchored sail-like parachutes (SLPs). In standby mode the parachutes lie flat. Upon detection of strong peripheral winds by a sensor network, individual units inflate and self-orient into the flow, generating significant drag that extracts angular momentum and transfers it mechanically to the ground via strong anchors (Figure 7).

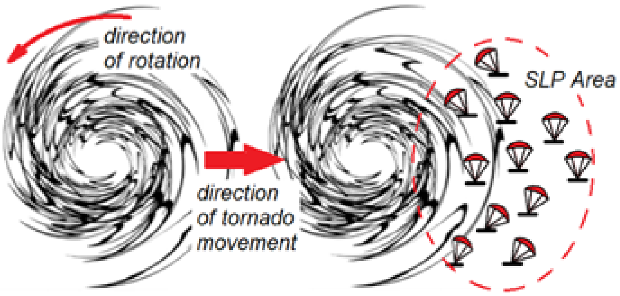

Figure 7: External wind method: tornado moving right encounters the protected area; sensors activate parachutes.

This approach operates at large radii where forces are expected to be more manageable and the leverage on the total angular momentum of the system is higher. Continuous extraction over a sufficiently large area could, in principle, reduce the angular momentum supplied to the inner core and thereby weaken the vortex. However, this remains a conceptual idea at an early stage.

5.4 Comparison with previous proposals

Previous mitigation concepts have included static walls (Coffer, 2021), which face prohibitive structural challenges due to extreme dynamic pressures near the vortex core, and balloon-based systems, which generally suffer from limited aerodynamic efficiency and poor directional control. The anchored SLP concept aims to offer higher drag, better self-orientation, and direct mechanical transfer of momentum to the ground.

Recent progress in understanding supercell tornadogenesis [12] as well as earlier conceptual studies [6] underscores the complexity of vortex intensification processes, further highlighting the need for innovative mitigation concepts that target peripheral angular momentum.

6 Future Work and Practical Challenges

To advance the concepts presented in this study, the following research directions and practical considerations are recommended:

- **Numerical validation of the LAM model** — Implementation of the air-ring concept within high-resolution numerical weather prediction (NWP) or large-eddy simulation (LES) models to test its robustness under realistic conditions including friction, moisture, and vertical motion.
- **High-fidelity CFD simulations** — Detailed computational fluid dynamics analysis of arrays of anchored sail-like parachutes interacting with a translating tornado-like vortex, with focus on optimal size, spacing, deployment height, and drag coefficients.
- **Scaled physical experiments** — Wind-tunnel or water-tank experiments to quantify momentum extraction efficiency and study self-orientation behavior of the parachutes.
- **Sensor network and control system** — Development of reliable, cost-effective sensor networks and automated activation systems capable of distinguishing dangerous peripheral flows from ordinary strong winds.
- **Materials and engineering challenges** — Selection of high-strength, durable materials (e.g., Kevlar, carbon fiber composites) capable of withstanding extreme winds and repeated deployment cycles.
- **Economic and environmental assessment** — Comprehensive cost–benefit analyses, life-cycle assessments, and ecological impact studies, including effects on wildlife and local ecosystems.
- **Targeted deployment strategies** — Identification of optimal locations for protection of critical infrastructure, schools, and hospitals, and integration with existing early-warning systems.
- **Extension of the LAM framework** — Application to other atmospheric vortices on Earth and potentially to rotating atmospheres on other planets.

Even a modest reduction in tornado intensity (for example, from EF5 to EF3) could result in substantial reductions in economic losses and human casualties. However, any real-world implementation of the External Wind method should only be considered after extensive modeling, experimentation, and close collaboration with severe-storms experts and emergency management authorities.

7 Conclusion

This study has presented Latent Angular Momentum (LAM) as a useful heuristic framework for understanding the spin-up of atmospheric vortices. Through a simplified rotating air-ring model, we have derived analytical expressions that relate tangential wind speed to radial contraction and latitude. The model successfully reproduces order-of-magnitude wind speeds and yields physically plausible initial radii for both intense hurricanes and strong tornadoes, supporting the relevance of angular momentum conservation on multiple scales. The analysis suggests that continued ocean warming may increase the initial radius of air masses participating in cyclonic circulations, potentially leading to stronger vortices in the future. Furthermore, the scaling properties of angular momentum imply that the peripheral region of a tornado offers an energetically favorable location for intervention. We have proposed the External Wind (EW) method utilizing networks of anchored sail-like parachutes (SLPs) as a conceptual approach to extract angular momentum at large radii, where modest reductions in tangential velocity can produce significant effects on the total angular momentum of the system. While this idea remains speculative and requires extensive further investigation, it represents a physically grounded alternative to previously considered static or balloon-based concepts. Key limitations of the present model, including its idealized assumptions and neglect of complex multi-scale interactions, have been clearly identified. Future work should focus on numerical validation, high-fidelity CFD simulations, scaled experiments, and comprehensive feasibility studies. In summary, the LAM concept not only offers an accessible educational tool for vortex dynamics but also opens new avenues for thinking about tornado mitigation. This work builds upon earlier observational and theoretical studies of tornado and hurricane dynamics [1, 8, 13]. We hope this work stimulates further theoretical, numerical, and experimental research into both the fundamental dynamics of atmospheric vortices and innovative strategies for protecting vulnerable communities.

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References

[1] Markowski P, Richardson Y (2014) What we know and don’t know about tornado formation. Physics Today 67(9):26

[2] Yao D et al (2019) Genesis, maintenance and demise of a simulated tornado. Atmosphere 10(5):236

[3] Armstrong R, Glenn J (2015) Electrical role for severe storm tornadogenesis. J Climatol Weather Forecasting 3(3)

[4] Fovell RG et al (2016) Influence of cloud microphysics. Meteorological Monographs 56:11.1

[5] Gilford DM, Giguere J, Pershing AJ (2024) Human-caused ocean warming has intensified recent hurricanes. Environ Res Climate 3(4):045019

[6] Coffer BE (2021) Would “tornado-preventing” walls work? E-J Severe Storms Meteorol 9(4):1–13

[7] Anonymous (2024) A proposal to fight tornadoes with multiple connected balloons. arXiv preprint arXiv:2410.12345

[8] Kurgansky MV (2025) Two-parameter model of intense atmospheric vortices. J Phys Conf Ser (in press)

[9] Tao D, Rotunno R, Bell MM (2020) Lilly’s model for steady-state tropical cyclone intensity. J Atmos Sci 77:3701–3720

[10] Dahl, J. M. L., and Fischer, J. (2023) On the origins of vorticity in a simulated tornado-like vortex. Journal of the Atmospheric Sciences, 80(5), 1225–1248.

[11] Markowski, P. M. (2024) A new pathway for tornadogenesis exposed by numerical simulations of supercells in turbulent environments. Journal of the Atmospheric Sciences, 81(3), 481–518.

[12] Fischer, J., Dahl, J. M. L., Coffer, B. E., et al. (2024) Supercell tornadogenesis: Recent progress in our state of understanding. Bulletin of the American Meteorological Society, 105(7), E1084–E1097.

[13] Rotunno, R. (2024) Recent developments in tornado theory and observations. Reports on Progress in Physics, 87, 114801.