The Non-traditional Coriolis force drives Westward tilts in Multiscale Theories and Laboratory Experiments of Tropical Dynamics

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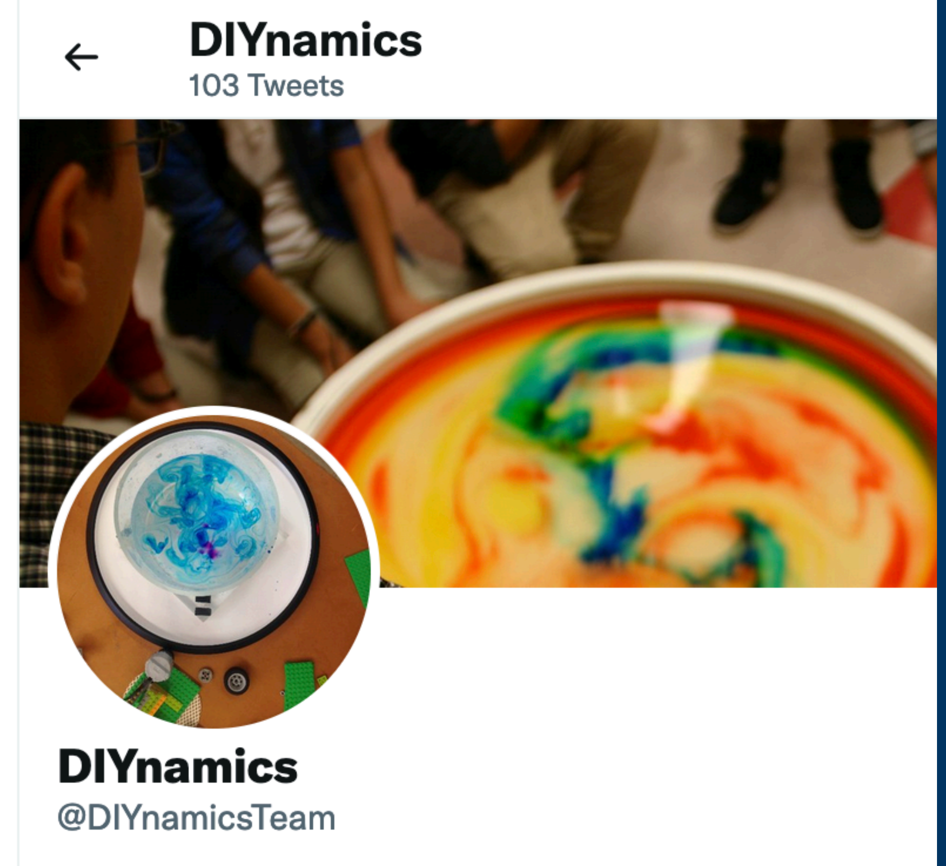

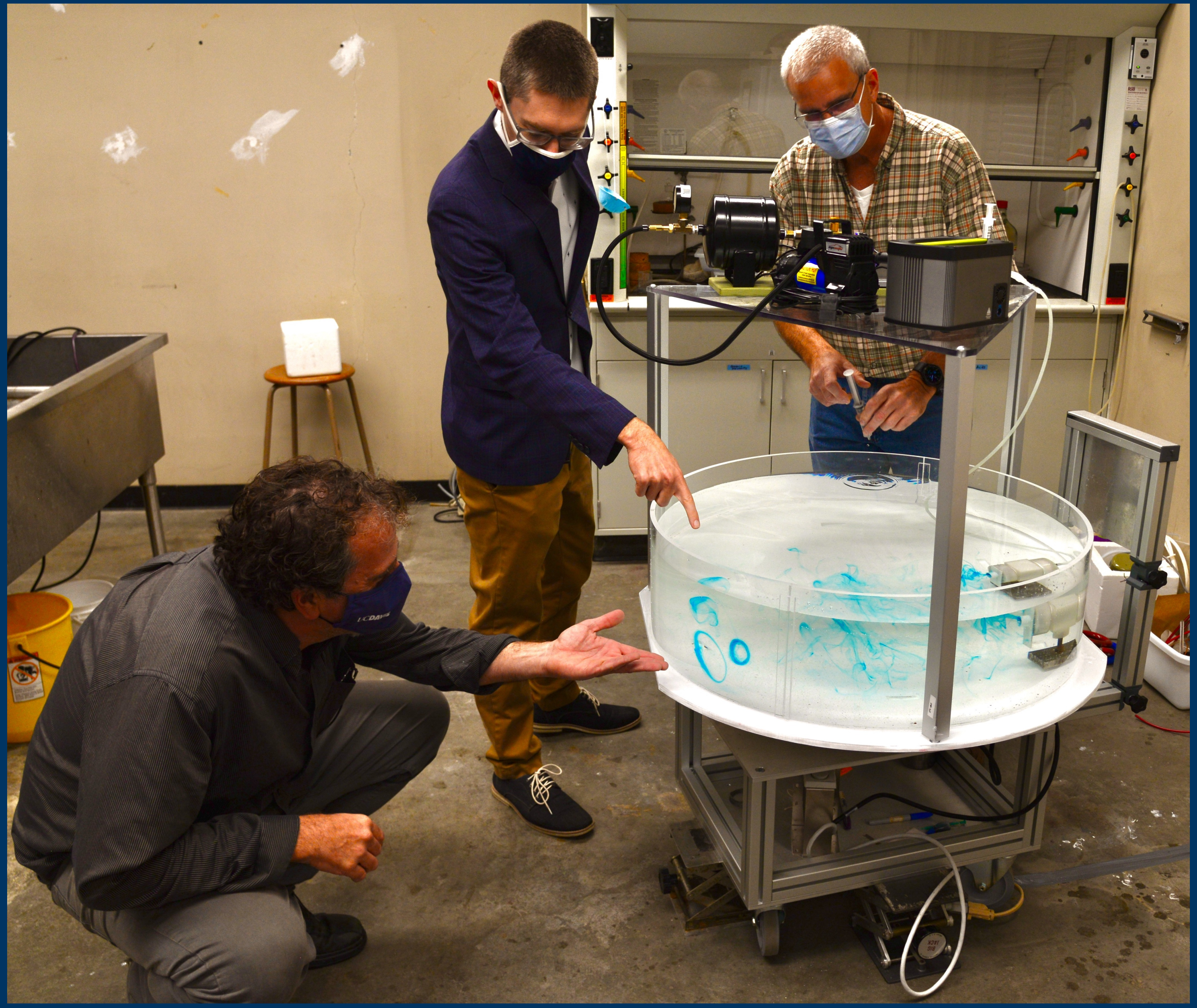

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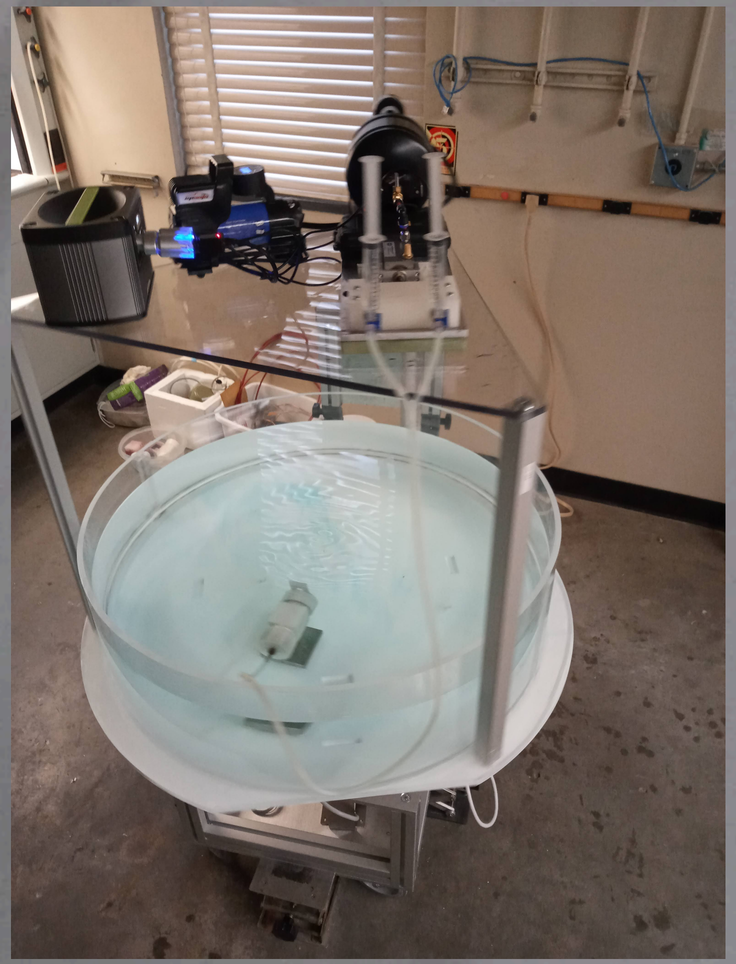


- Counterclockwise rotating tank
- 36 second period
- Seen from above
- 12 cm depth of water
- Horizontal injection of toroidal vortices
- Water + Methyl blue
- 4 pairs of vortex rings

IPESD + MJO

The Multiscale Models of Tropical Dynamics

- J.A.B. & Majda (early 2000s) on the MJO
- Majda & Klein (2003)

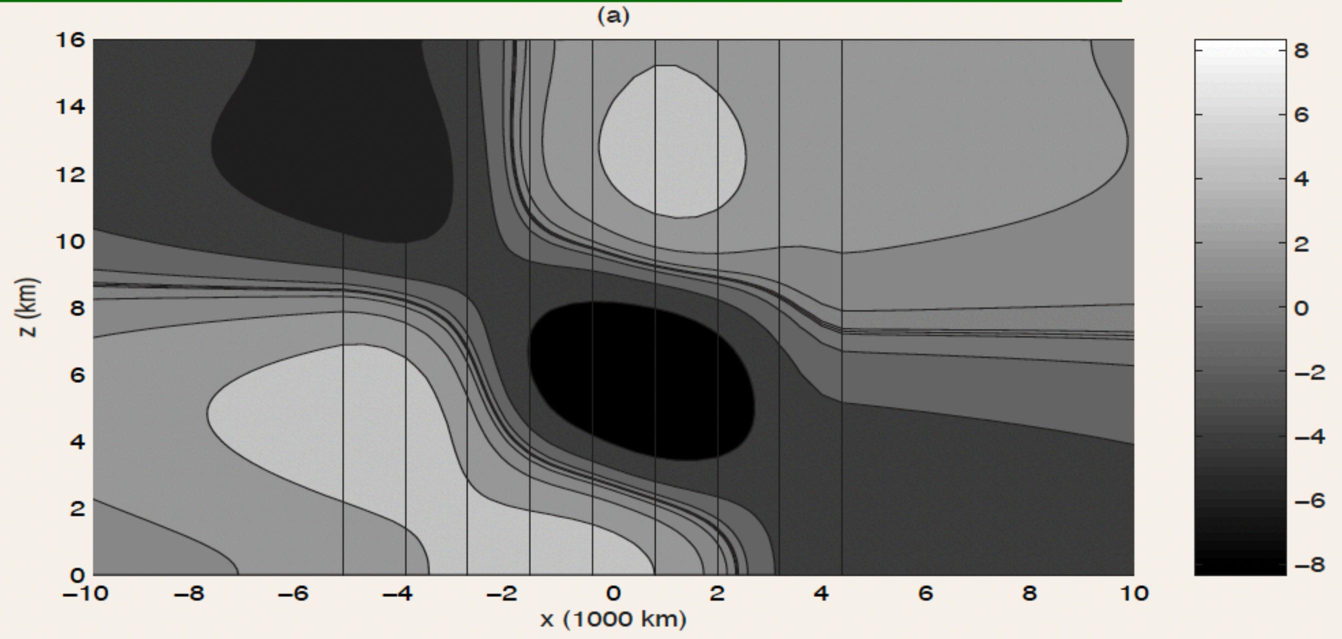
- The multi scale models are a multiscale system of PDEs wherein diabatic heating on the synoptic scale drives the large scale circulation

$$
\begin{aligned}
\overline{U}_t - y\overline{V} + \overline{P}_X &= F^U - d_0\overline{U} \\
y\overline{U} + \overline{P}_y &= 0 \\
\overline{\Theta}_t + \overline{W} &= F^\theta - d_\theta\overline{\Theta} + \overline{S}_\theta \\
\overline{P}_z &= \overline{\Theta} \\
\overline{U}_X + \overline{V}_y + \overline{W}_z &= 0
\end{aligned}
$$

$$
\begin{aligned}
F^U &= -\overline{(v'\,u')}_y - \overline{(w'\,u')}_z \\
F^\theta &= -\overline{(v'\,\theta')}_y - \overline{(w'\,\theta')}_z
\end{aligned}
$$

Equatorial MJO model: Winds above the equator

- Lower troposphere congestus heating in the east
- Westward tilted anvil superclusters in the west



- Vertical/Westward tilted convection (w’u’) is essential, but unexplained

Dynamics of Non-rotating Updraft Tori

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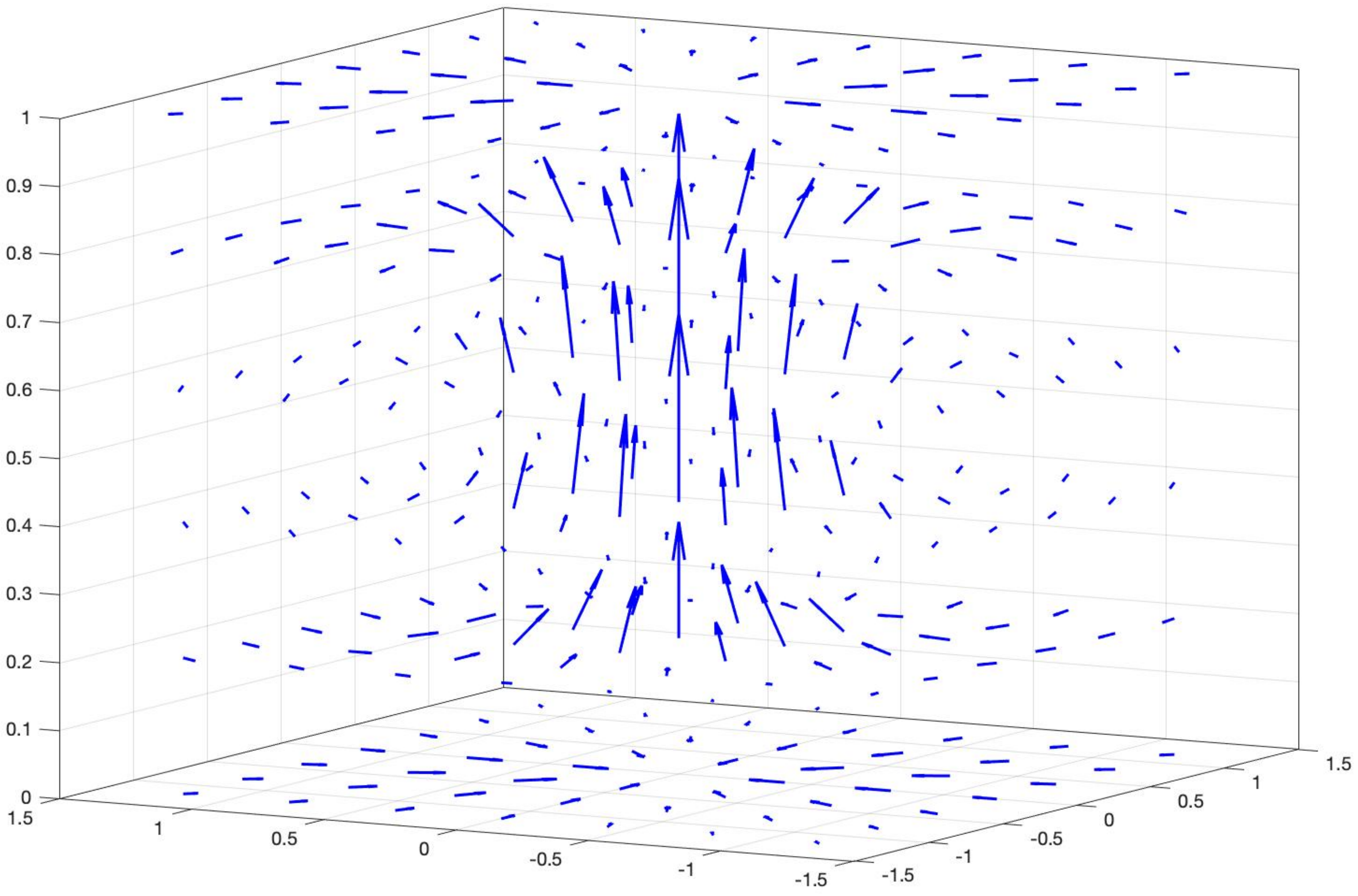
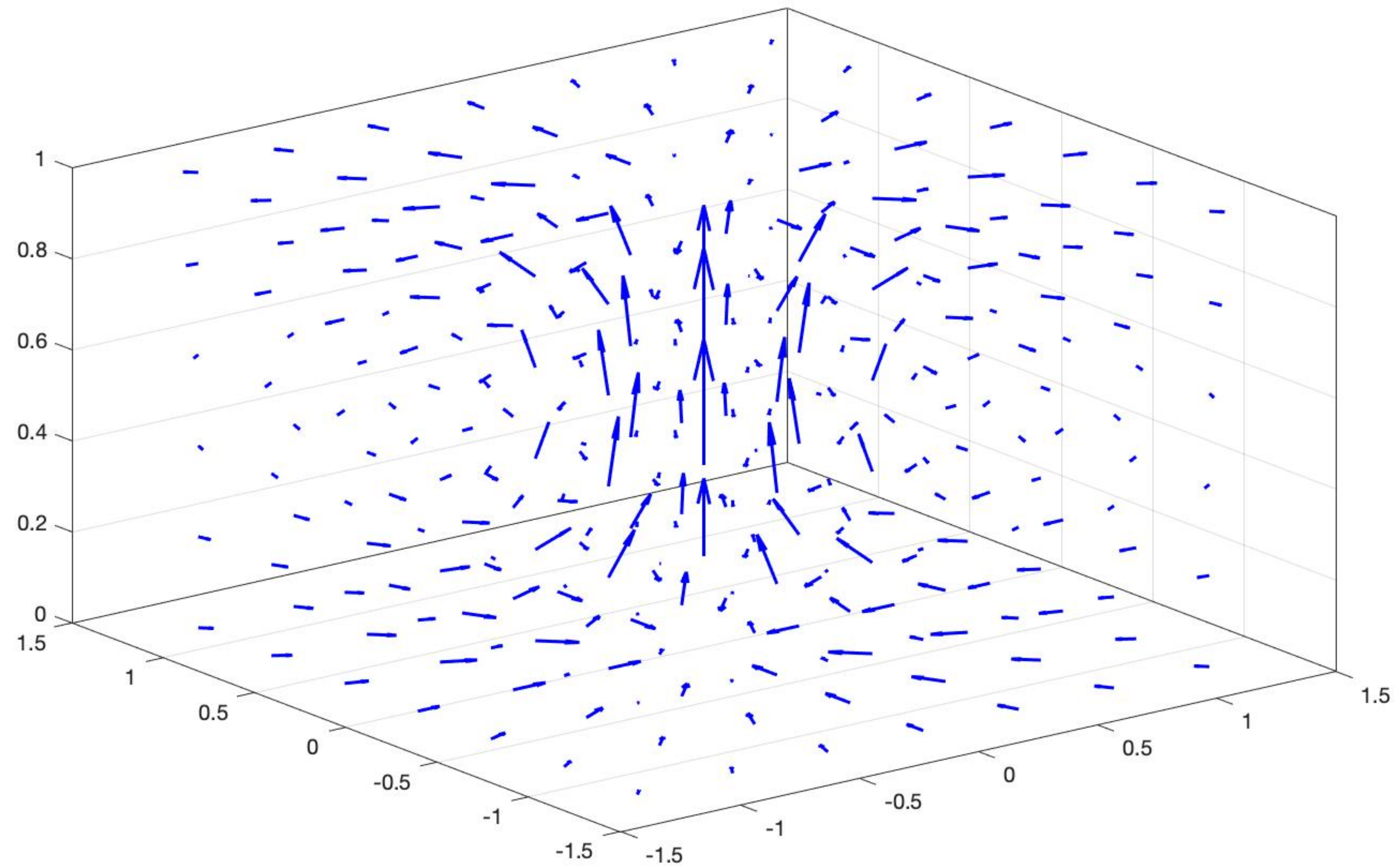
- w/ Igel, we are developing dynamical convective models consisting of poloidal circulations
- poloidal circulations are tori





Some Other DoNUT Talks/Posters

- A25D-1709: The Divergence-free Net Coriolis Force creates Vertical Geostrophic Balance and Westward tilted Atmospheric Convection
- NG33A-06: The Non-Traditional Coriolis Terms and Their Impact on the Convective Weak Temperature Gradient
- A22A-08: Modeling Tropical Convective Clouds and Circulations with the DoNUT

- Focus in these talks is in using the DoNUT (or a conceptually simplified version) to understand the impact of physics on convective circulations.

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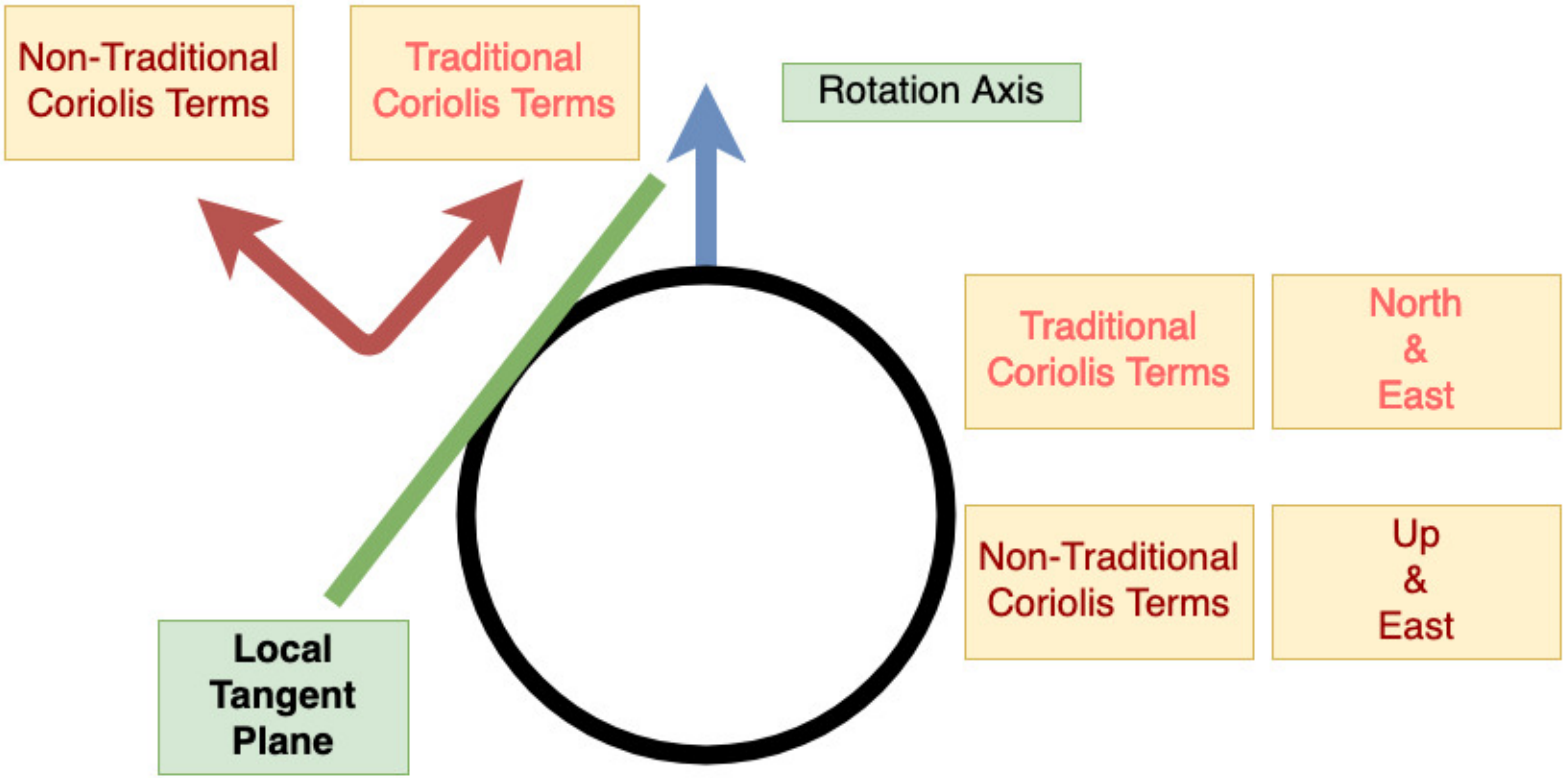
The Coriolis Force

The traditional simplification and the non-traditional terms



The Coriolis Force

The traditional simplification and the non-traditional terms

- The non-traditional terms are underlined
- The traditional terms vanish at the equator
- The non-traditional terms are negligible (and rightfully neglected) for flows which are horizontally much larger than the height of the troposphere
- The non-traditional terms, NCT, are significant for convective scale flows at the equator.
- Igel & B., JAS, 77, 2020

$$\frac{Du}{Dt} + \frac{\partial p}{\partial x} = 2\Omega_0 \sin(\phi)v - \underline{2\Omega_0 \cos(\phi)w}\,,$$

$$\frac{Dv}{Dt} + \frac{\partial p}{\partial y} = -2\Omega_0 \sin(\phi)u\,,$$

$$\frac{Dw}{Dt} + \frac{\partial p}{\partial z} = \underline{2\Omega_0 \cos(\phi)u} + B\,.$$

The Net Coriolis Force

Using the Leray projection to determine the pressure

- The net Coriolis force is the divergence-free force resulting from the pressure gradient in the Leray projection

$$\vec{F} = -\nabla p - 2\vec{\Omega} \times \vec{u}, \qquad \nabla \cdot \vec{F} = 0 \qquad \vec{F} \cdot \hat{n} = 0 \quad \text{on rigid boundaries,}$$

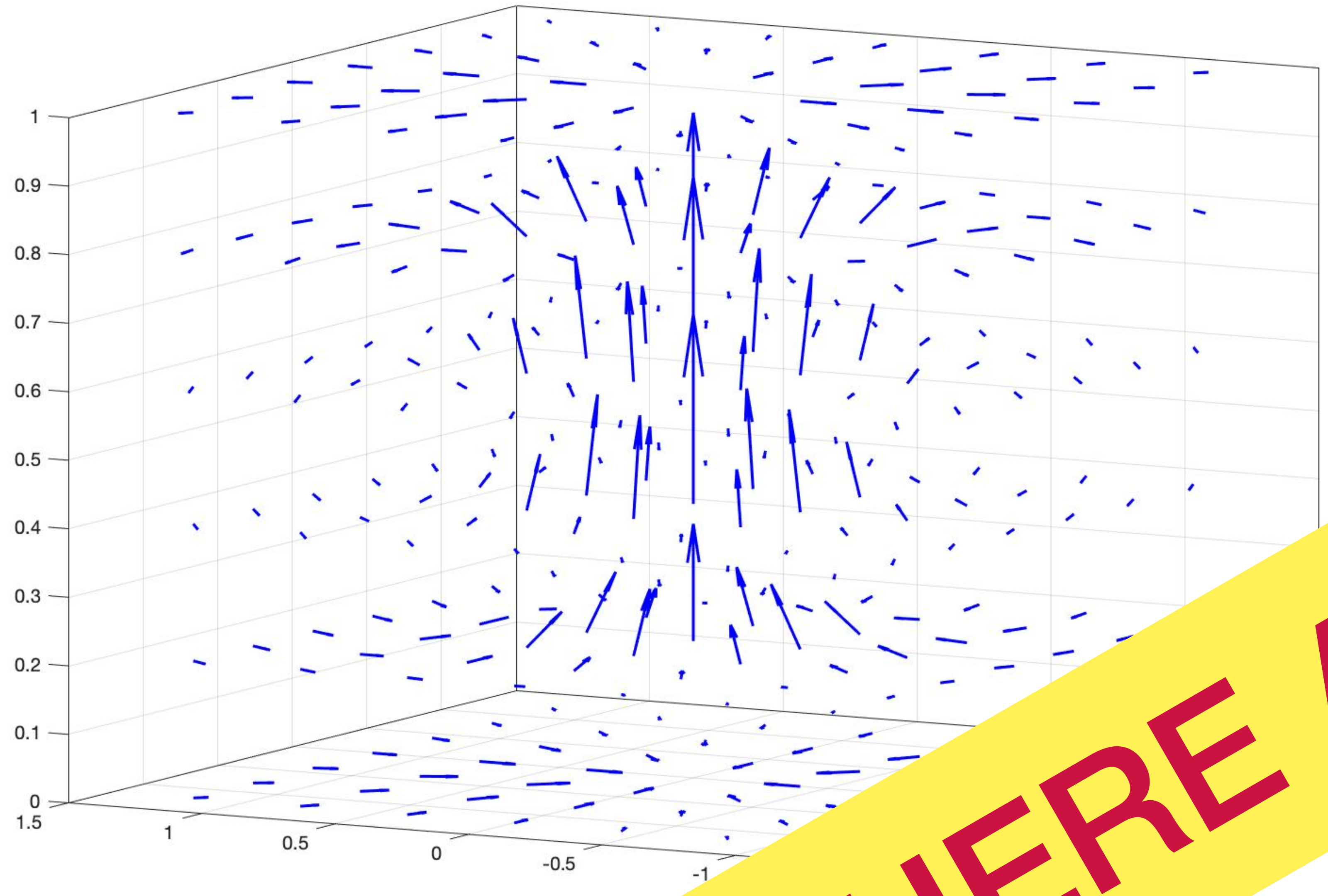
- Using the Leray projection we can compute the pressure and net force

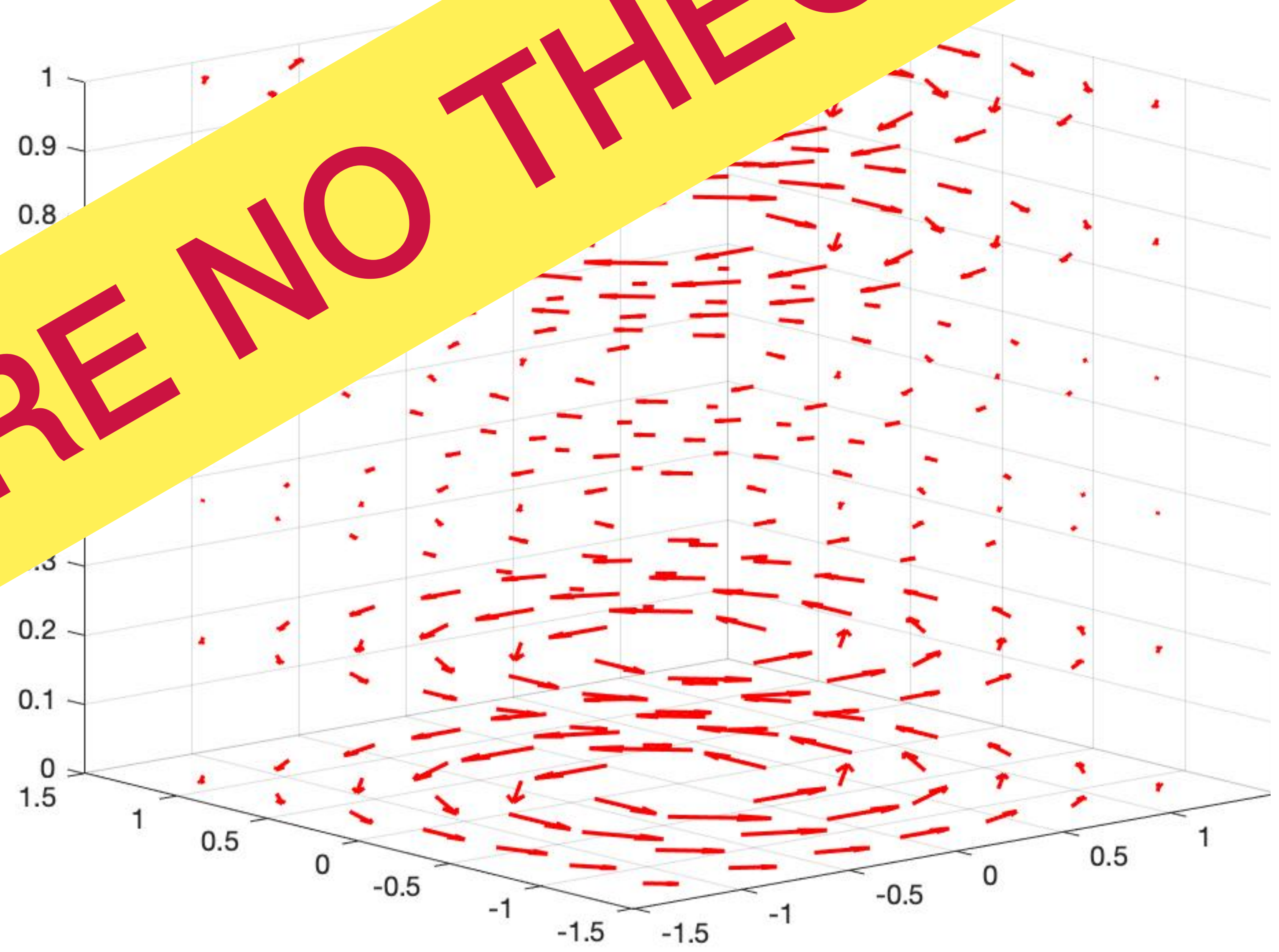
$$\nabla^2 p = 2\vec{\Omega} \cdot \vec{\omega},$$
$$\hat{k} \cdot \nabla p = 2\left(\vec{u} \times \vec{\Omega}\right) \cdot \hat{k}, \quad \text{on} \quad z = 0.$$

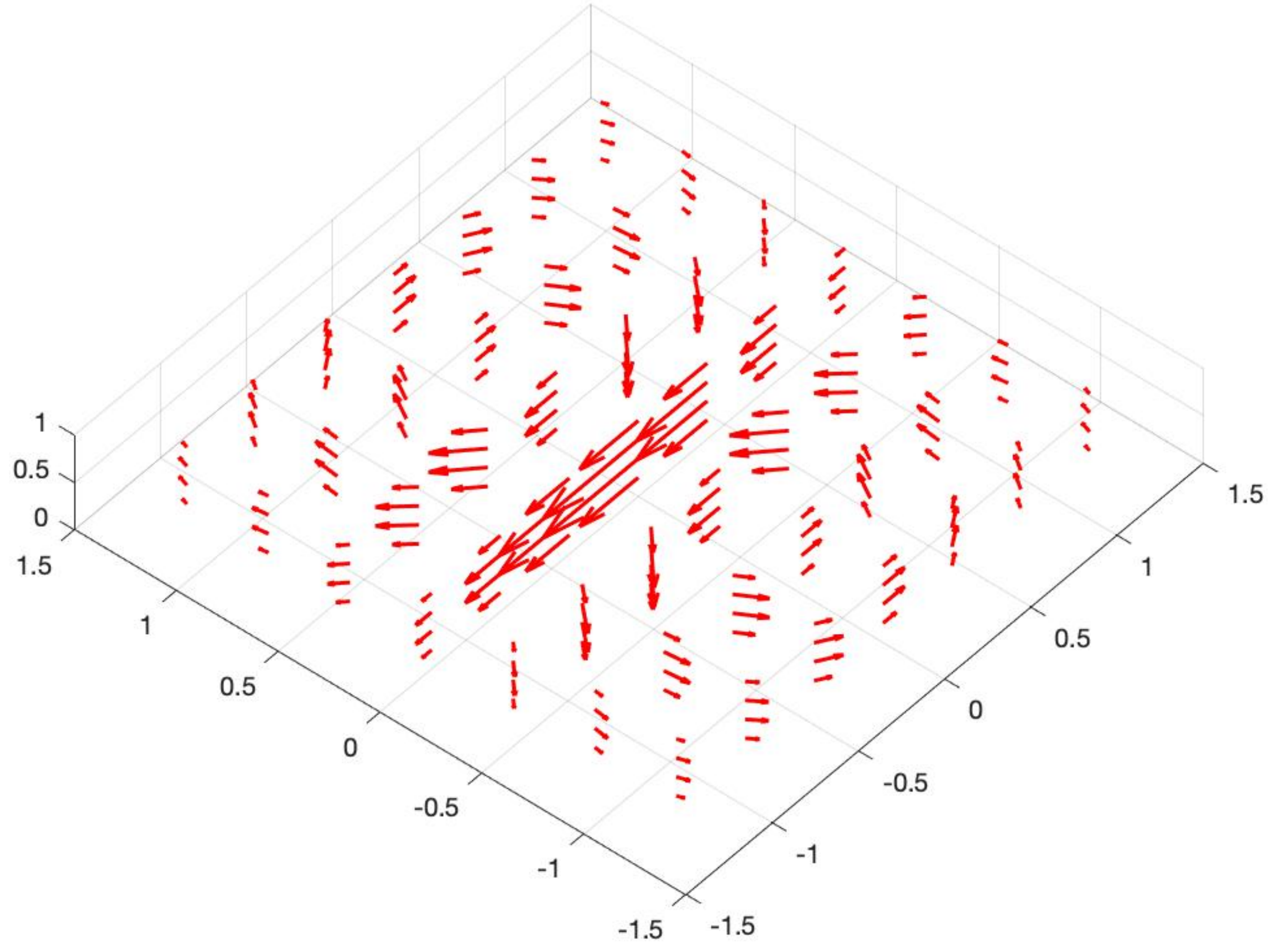
Theorem: The vertical component of the net Co... orce is identically zero for Poloidal Fl...

Consequence: The pressure is computed as ... vertical integral

THERE ARE NO THEOREMS AT AGU!!







Theorem: The vertical component of the net Coriolis Force is identically zero for Poloidal Flows

Consequence: The pressure is computed as a simple vertical integral

$$p = -2\Omega_0 \cos(\lambda) \int_z^\infty u(x, y, z')\, dz';$$

$$\Phi = \int_z^\infty \phi(x, y, z')\, dz'.$$

$$\vec{F}_{\mathrm{TCT}} = -2\Omega_0 \sin(\lambda)\, U\, \hat{\theta}$$

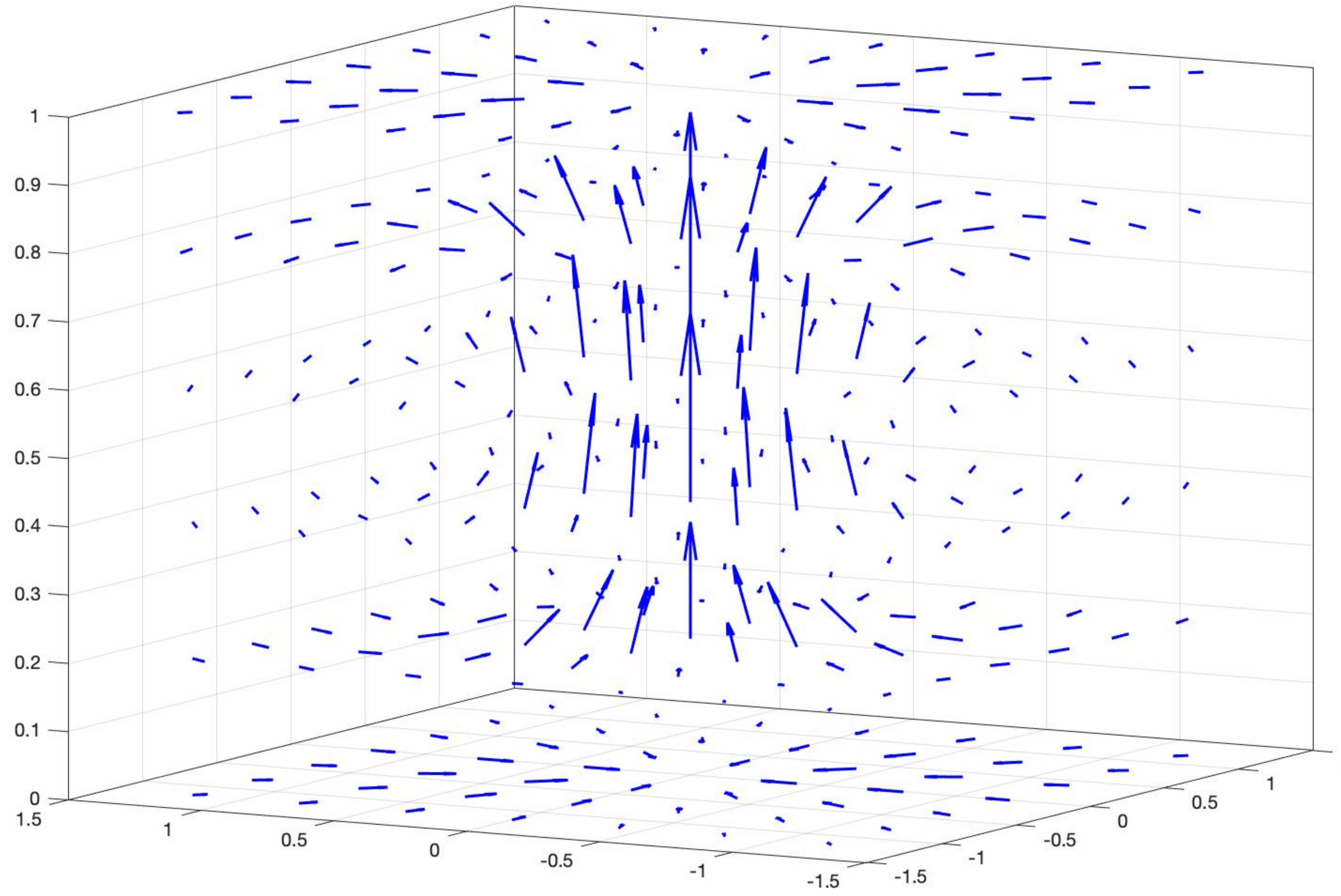
$$\vec{F}_{\mathrm{NCT}} = 2\Omega_0 \cos(\lambda) \left[\Phi_{yy}\, \hat{i} - \Phi_{xy}\, \hat{j} \right]$$

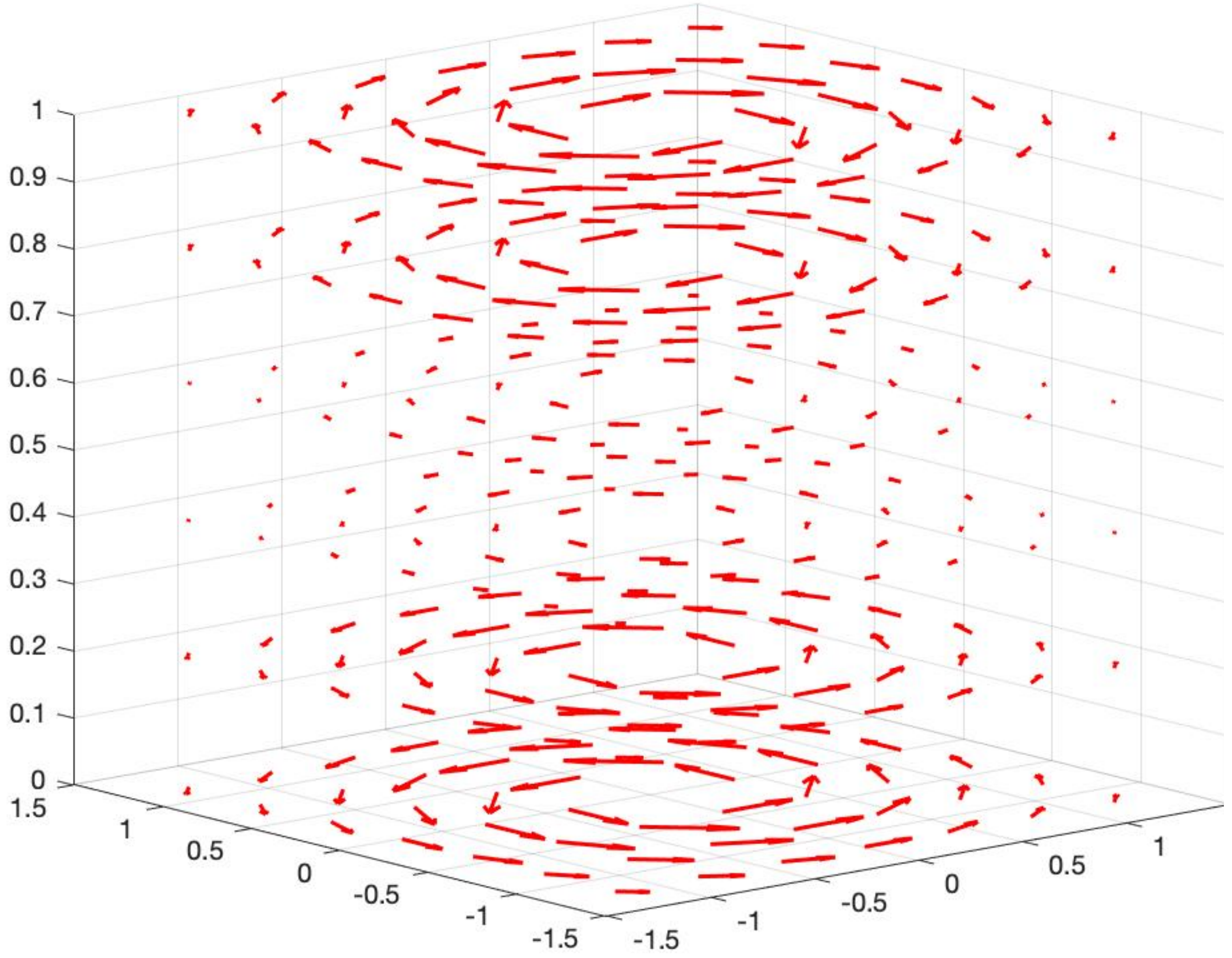
Tropical Cyclogenesis

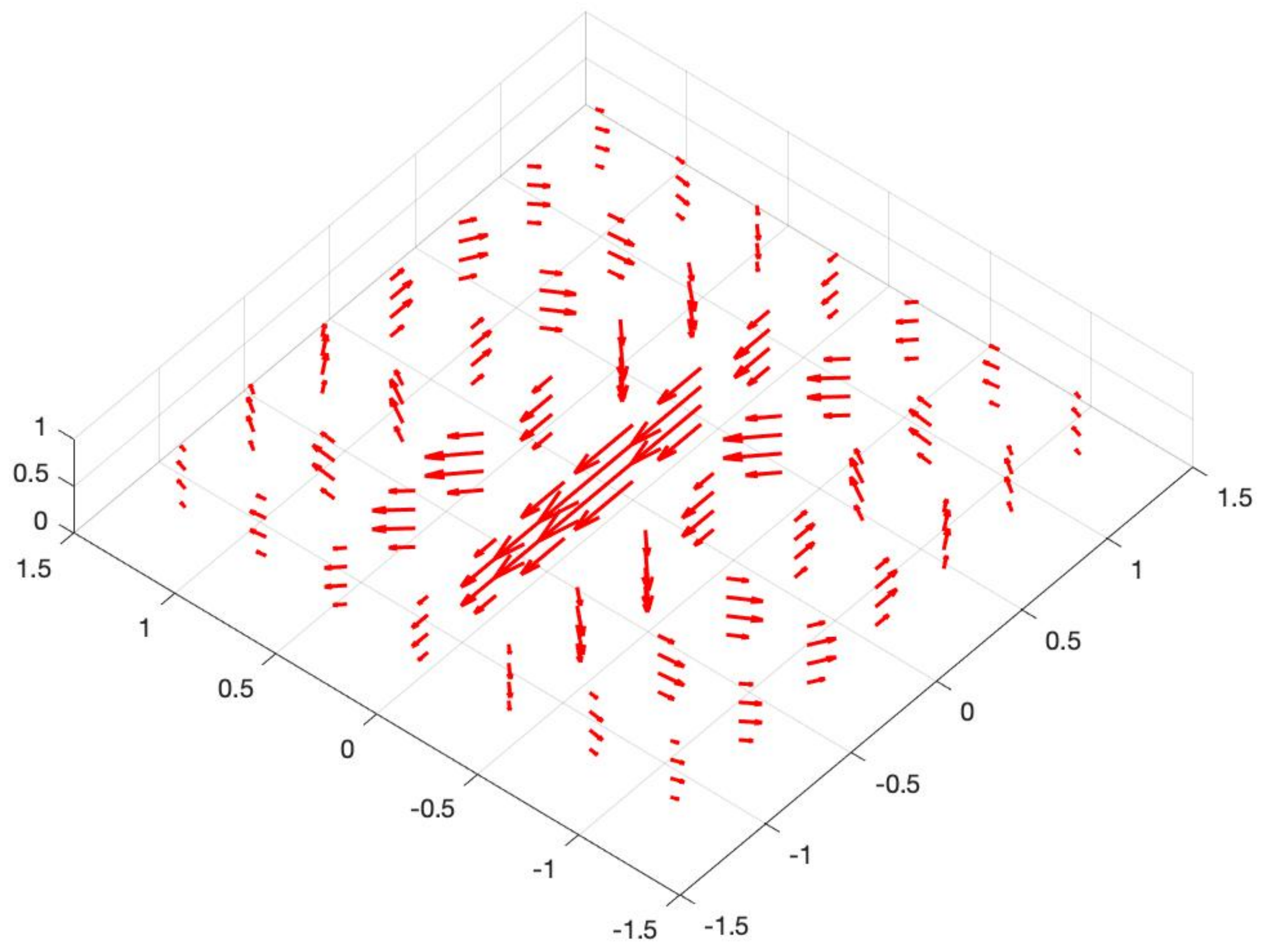
MJO-genesis?

Theorem: The vertical component of the net Coriolis Force is identically zero for Poloidal Flows

Consequence: The pressure is computed as a simple vertical integral

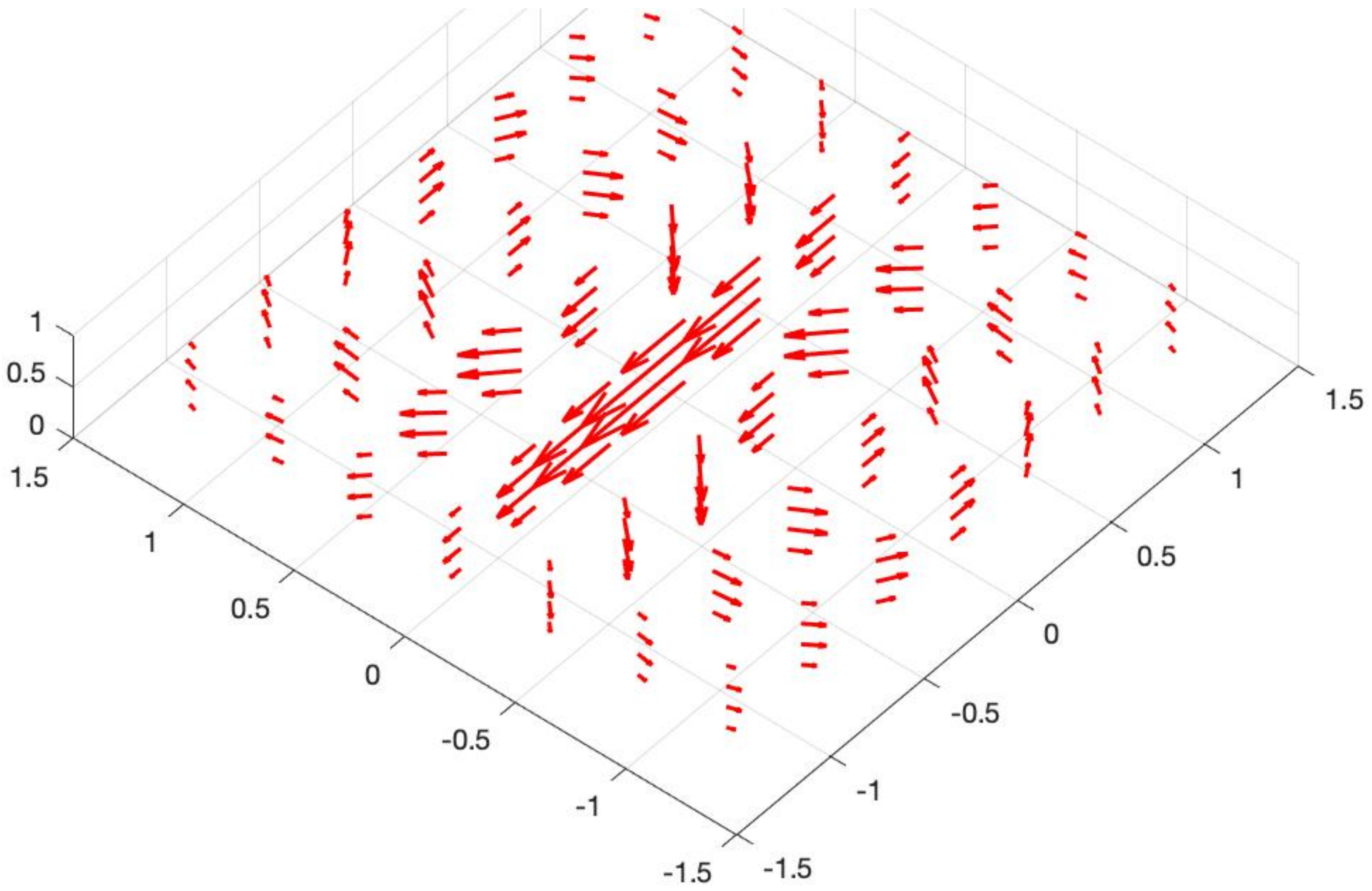


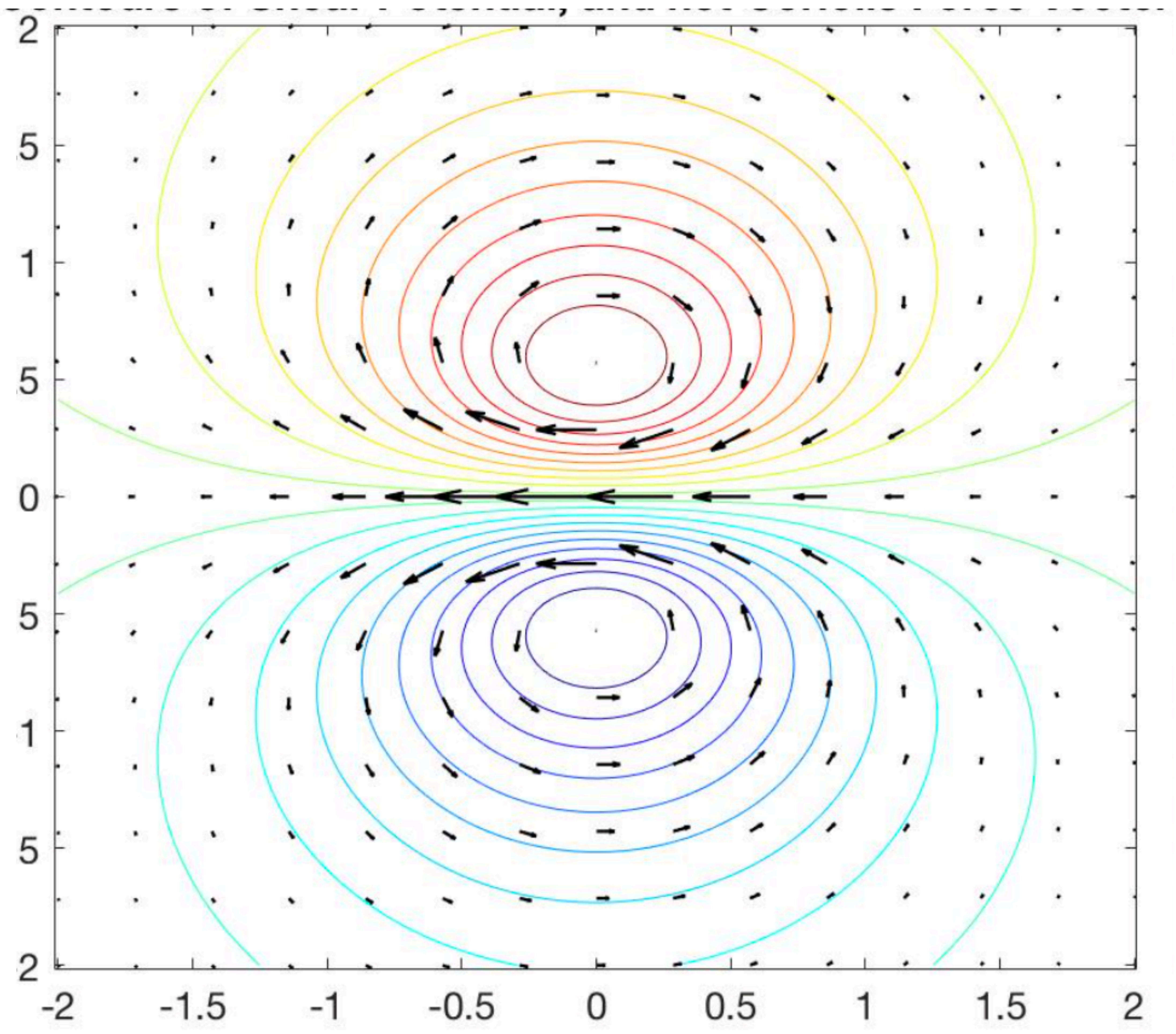




The Net NCT for Poloidal flows

Westward in the up flow, eastward in the down flow



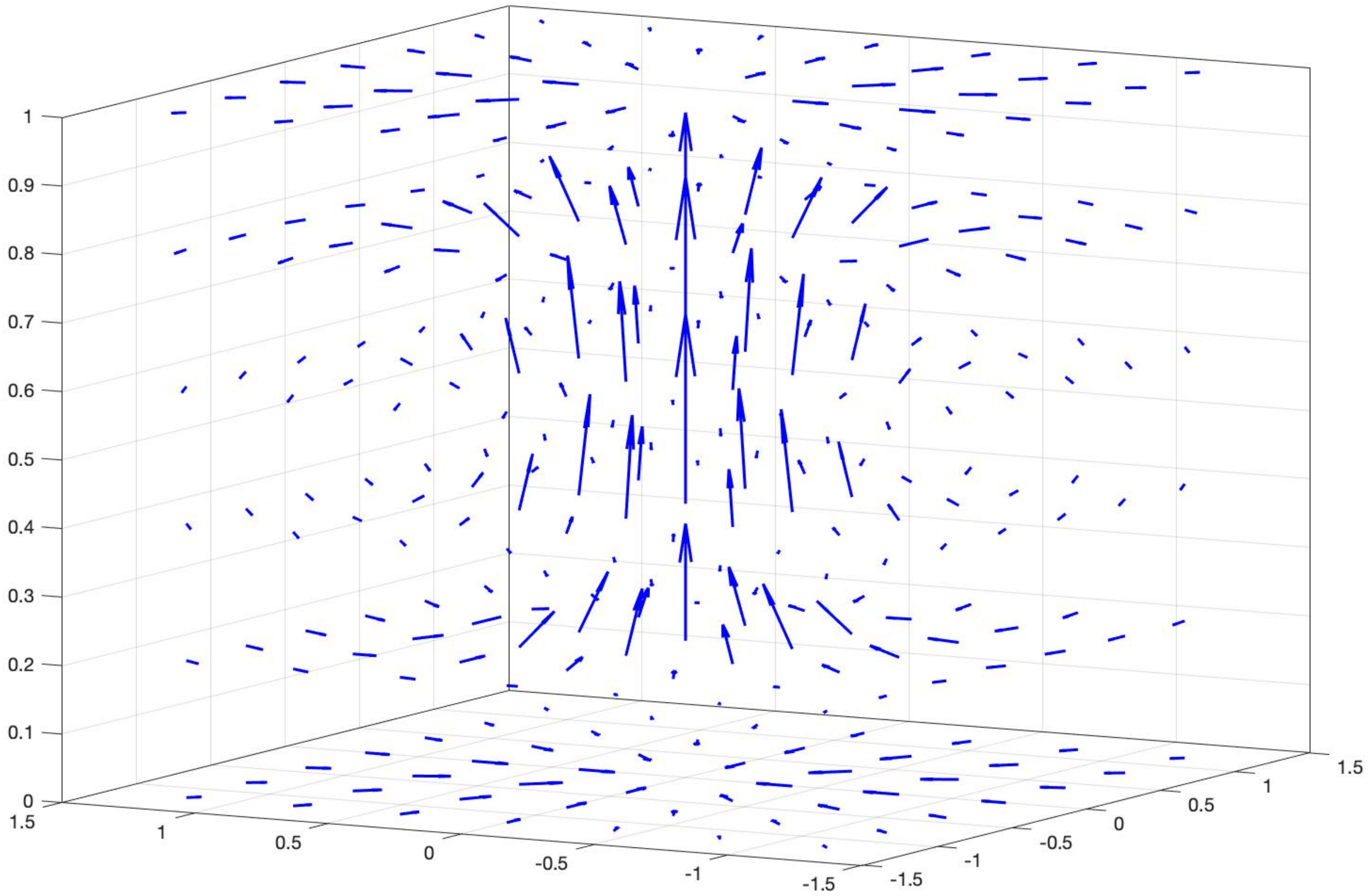


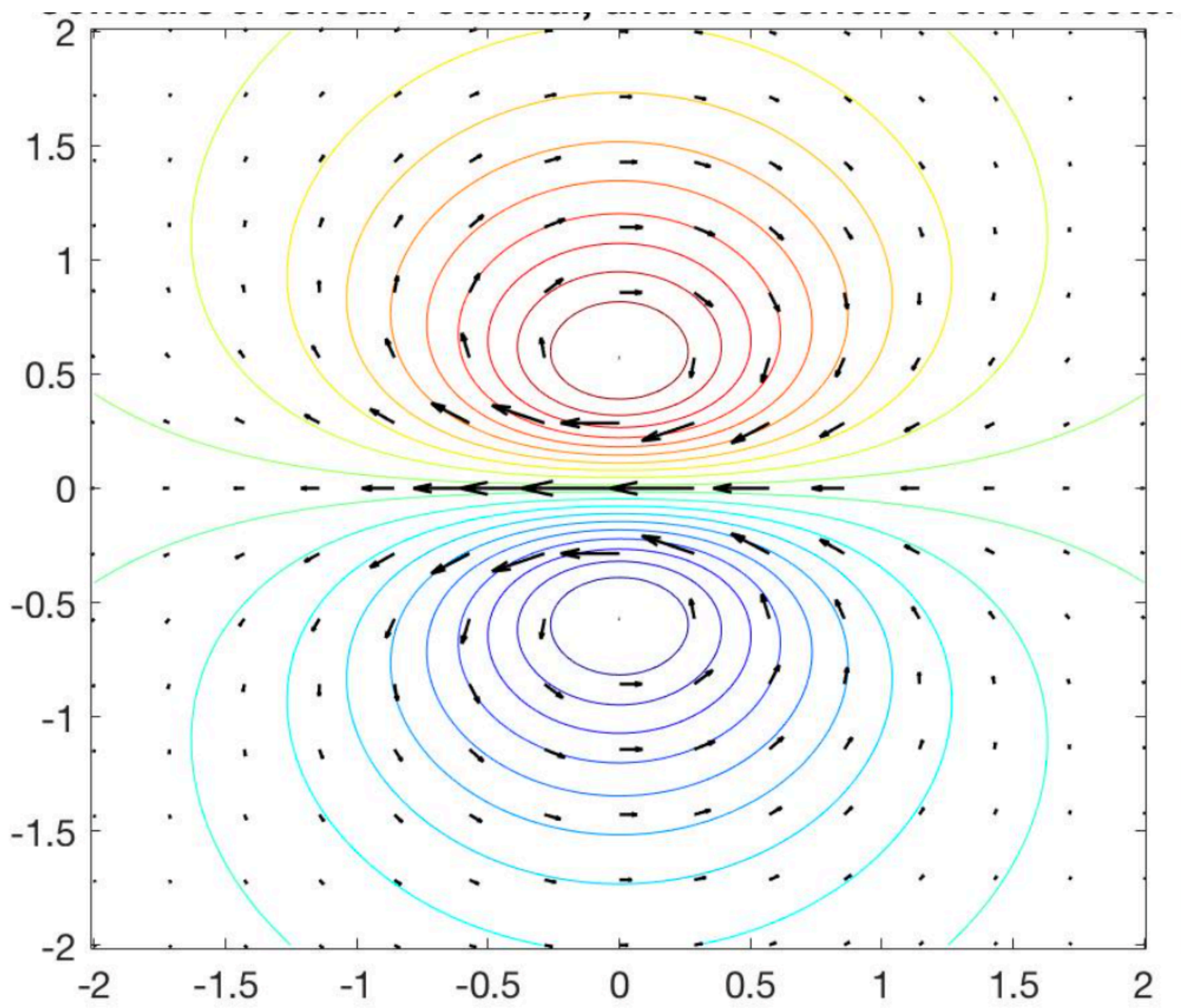
Vertical Upscale Flux of Zonal Momentum

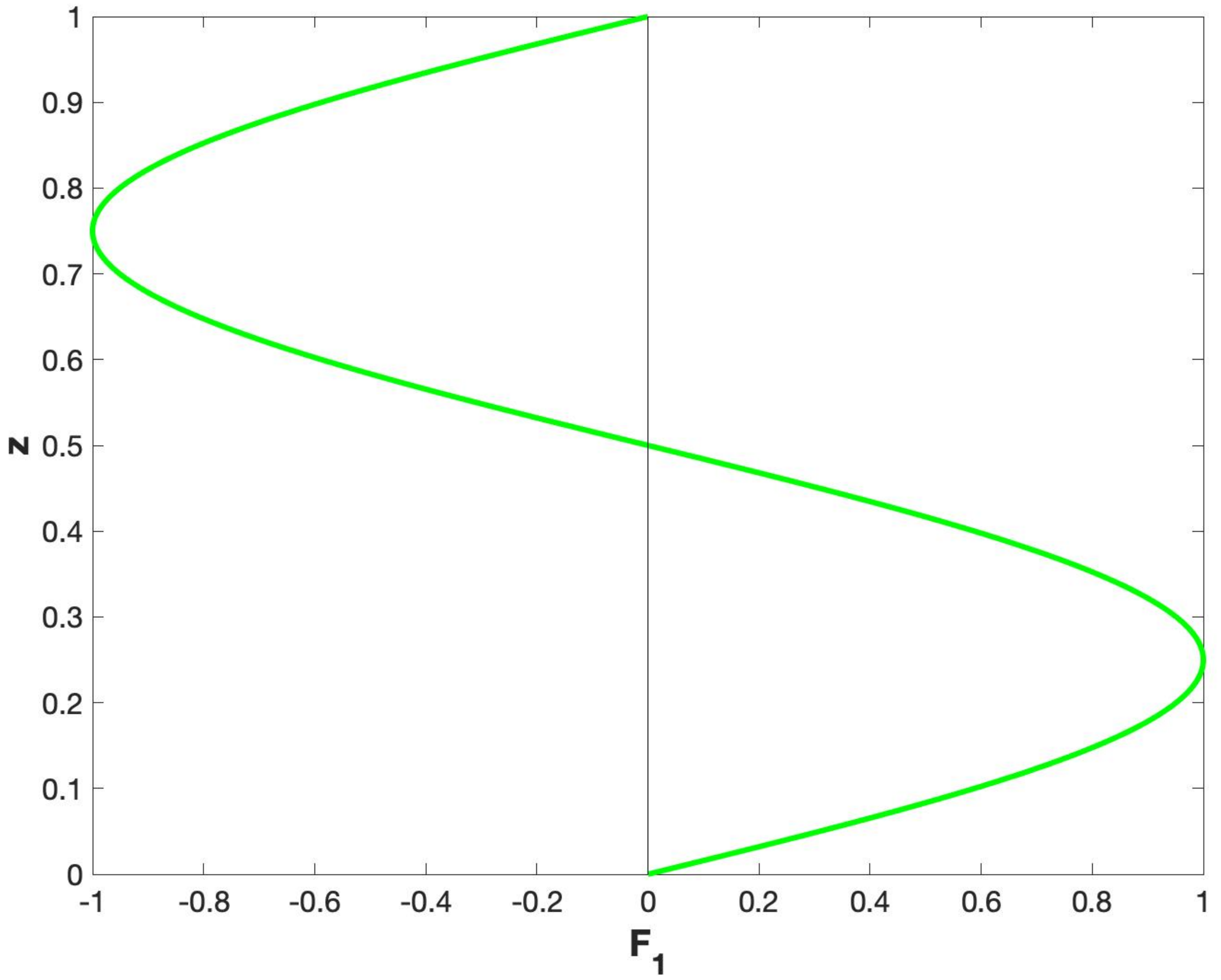
Lower tropospheric westerlies, upper tropospheric easterlies

$$\vec{F} = -\left(\overline{uw}\right)_z \hat{i}$$

$$\overline{F}_1 = \frac{f}{H}\left(\frac{\Omega}{D}\right)\left(\frac{S_0^2}{\Gamma^2}\right)\sin\left(\frac{2z}{H}\right)$$







The DoNUT circulation + Net Non-Traditional Coriolis force provide the vertical upscale fluxes of zonal momentum which were needed in the Multiscale MJO Models of Majda & B.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Equatorial Non-Traditional Coriolis Force
IPESD + MJO
Large Scale Lower tropospheric Westerly Wind