African Easterly Waves and Convection: A Potential Vorticity Perspective

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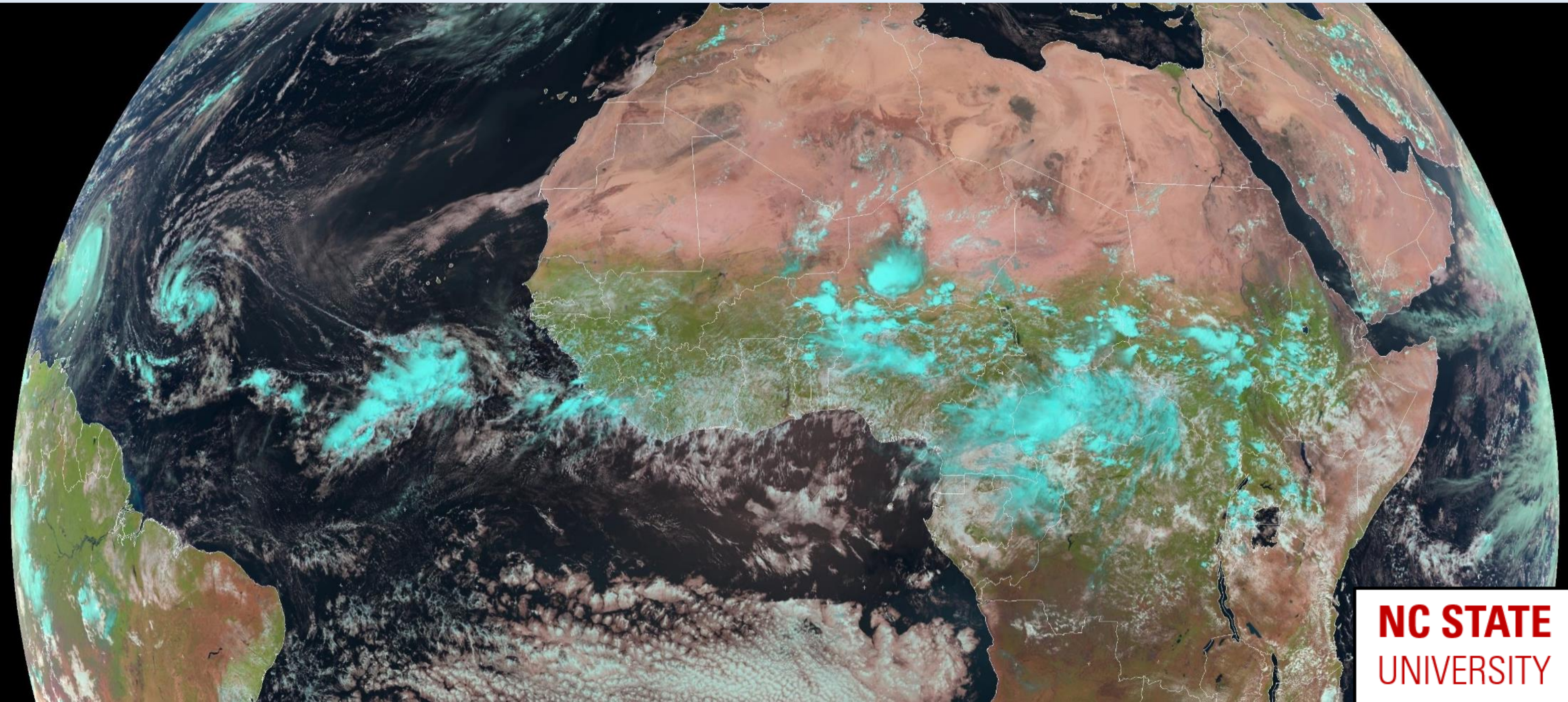

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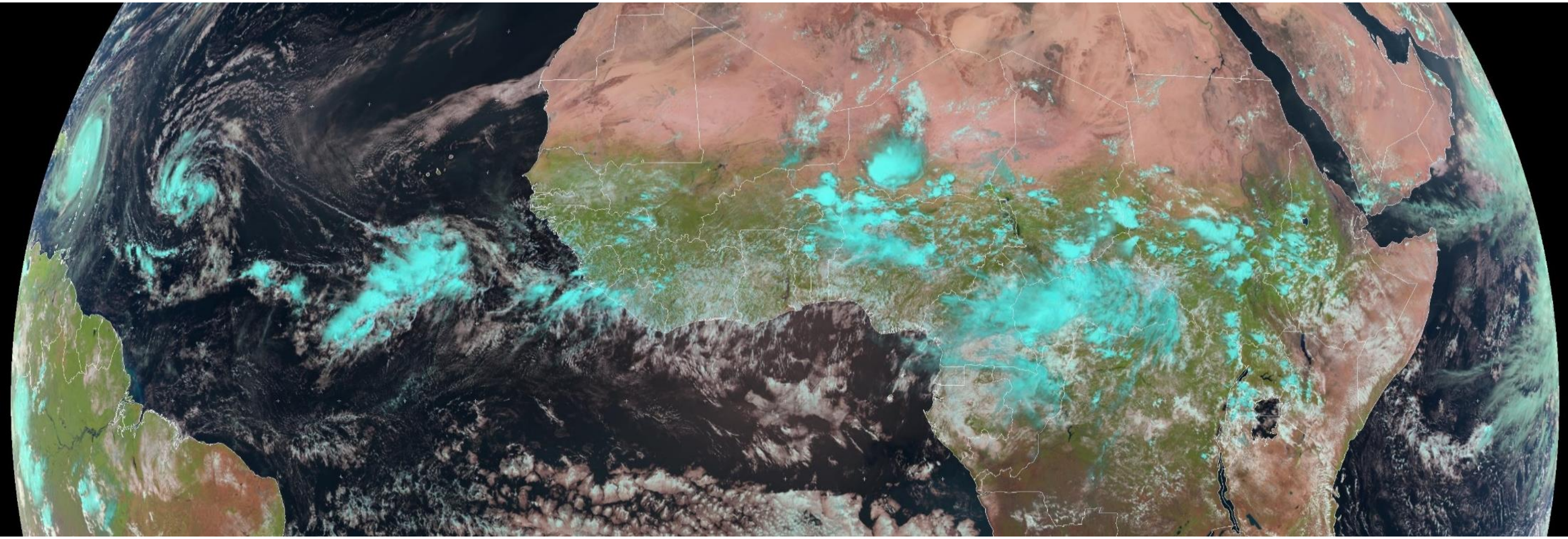
Background

- Early studies described AEWs as dry adiabatic waves (e.g. Burpee, 1972).
- Diabatic and adiabatic sources of energy are similar in magnitude (Berry and Thorncroft, 2012). Convection is important for the maintenance and growth of AEWS.
- Potential mechanisms of convective interaction include the Diabatic Rossby Wave (DRWs) mechanism (e.g. Moore and Montgomery, 2003).

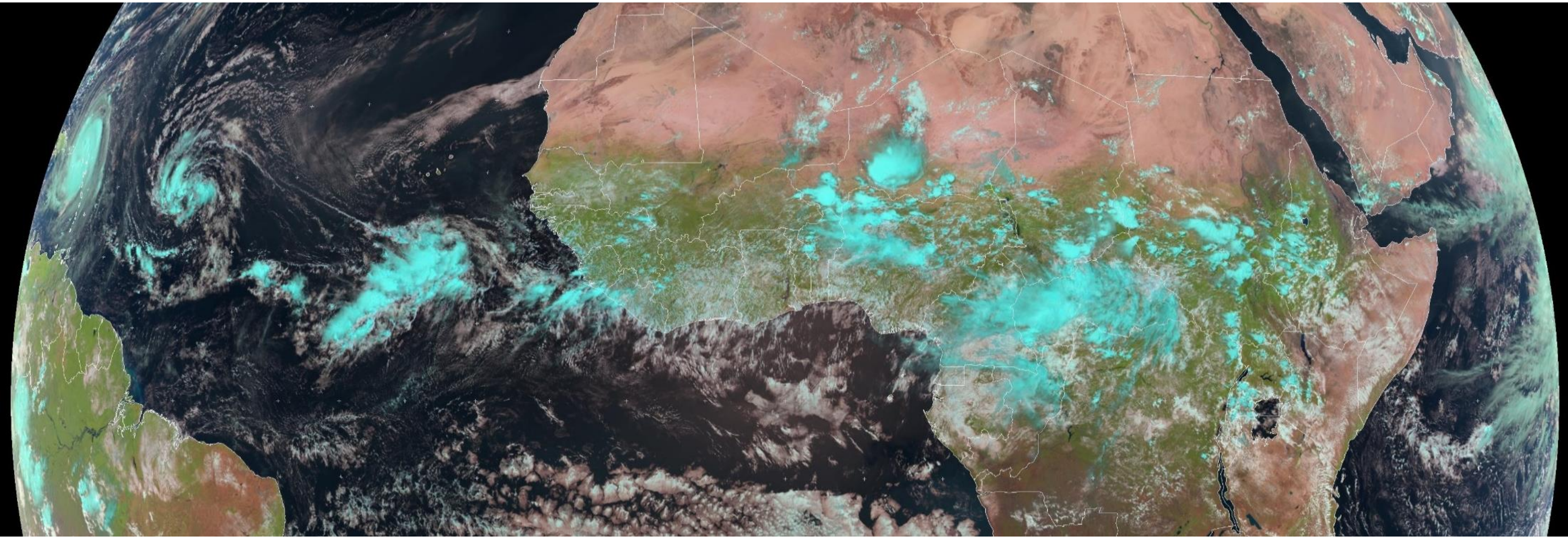


Research Questions

1) What is the role of convection in AEW dynamics?

2) What is the mechanism through which convection enhances AEWs?

3) What would AEWs look like, and how would they operate, in an atmosphere devoid of moist convection?



Simulations

Goal 1: Simulate AEWs with resolved convection

WRF simulations:

- ➢ 4km grid spacing
- ➢ No cumulus scheme
- ➢ Convection permitting

Two AEWs are simulated:

1) Sep. 2007
2) Aug. 2010; led to Hurricane Earl

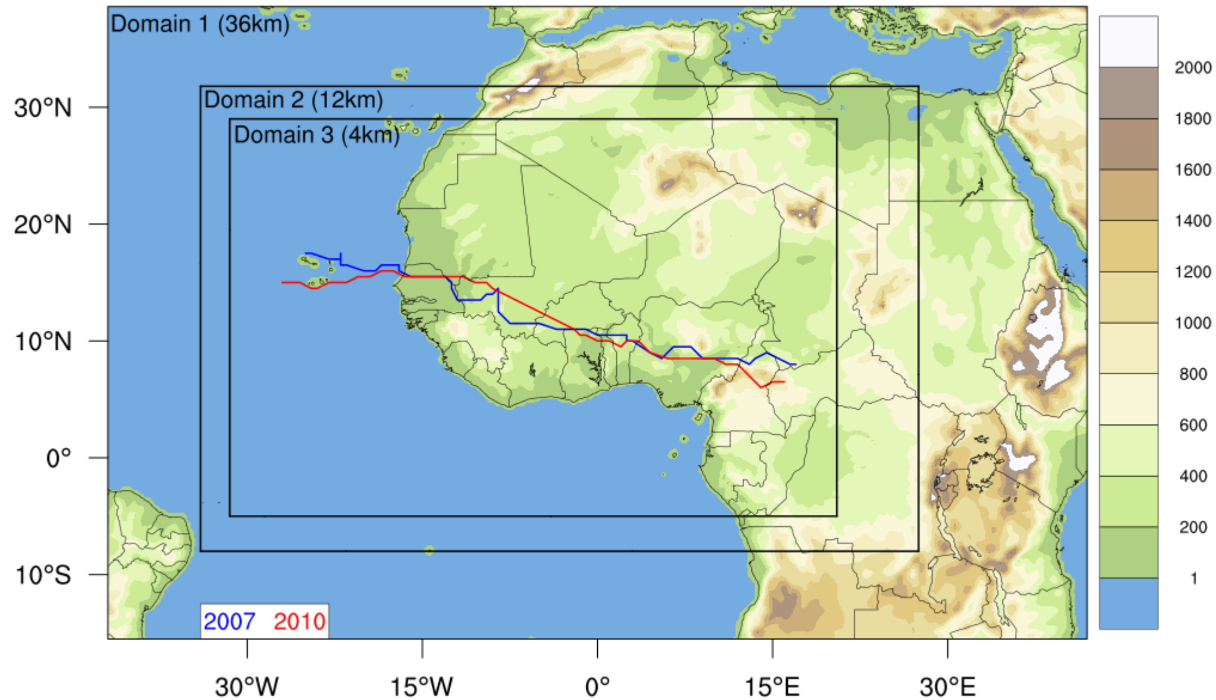


Figure: WRF domain and terrain with AEW control simulation tracks

Simulations

Goal 2: Remove convection or its effects from convection-permitting simulations of AEWs

Sensitivity studies to remove convection:

1) 50% mixing ratio in initial conditions
2) No microphysics (MP) heating

Control	50% Moisture	No MP Heating
2007-CTRL	2007-HLFQ	2007-NOMH
2010-CTRL	2010-HLFQ	2010-NOMH

Table: Summary of simulations and their abbreviations

PV and Circulation in Control simulations

- Quasi-balanced circulation in association with PV anomalies
- Match composite reanalysis AEWs (e.g. Kiladis, Hall, and Thorncroft, 2006)

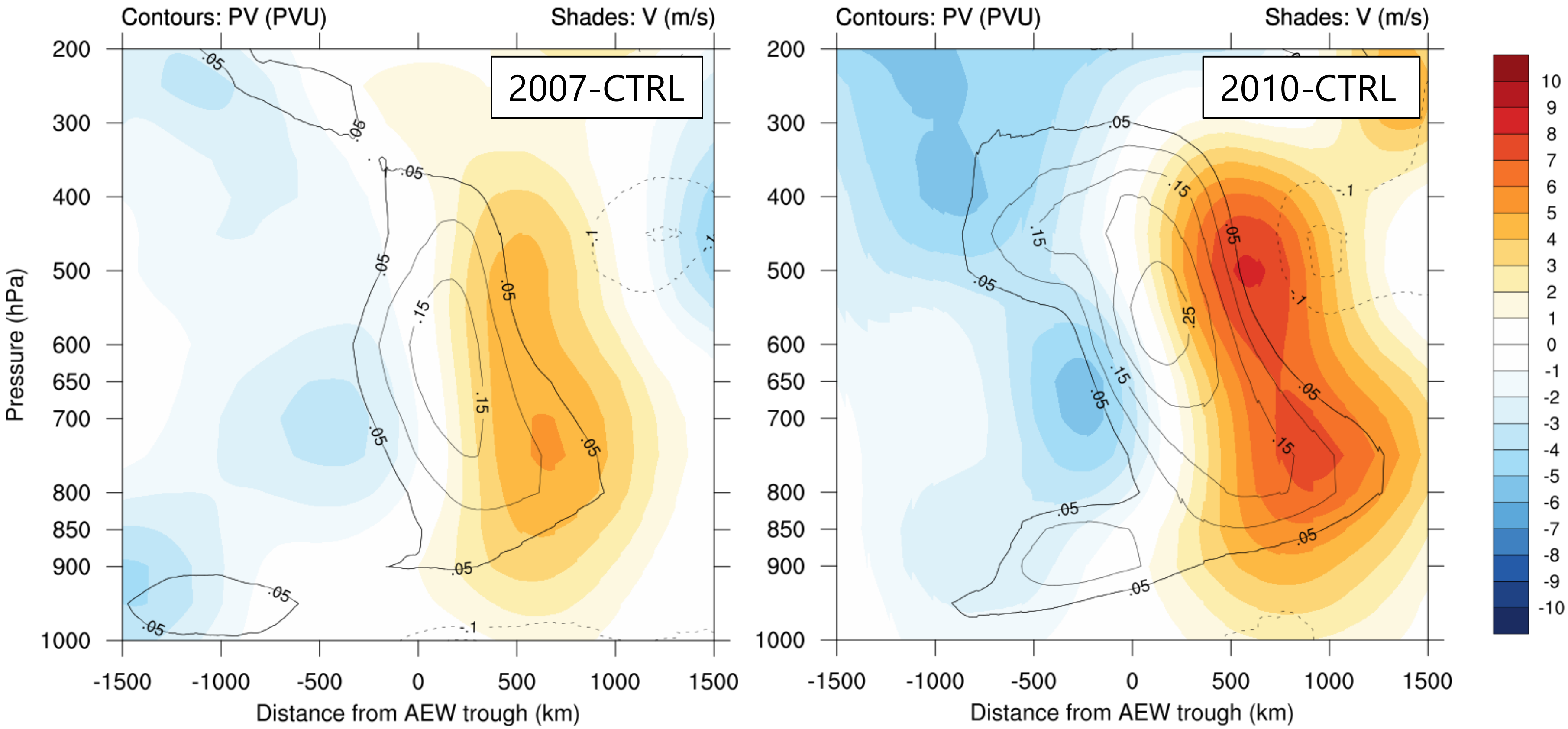


Figure: *Average longitude-pressure cross-sections following simulated AEWs.*

PV in all simulations

- 650hPa PV for control simulations maintains PV of 0.2 to 0.6 PVU
- Sensitivity studies all weaken to a PV below 0.2 within 2 days

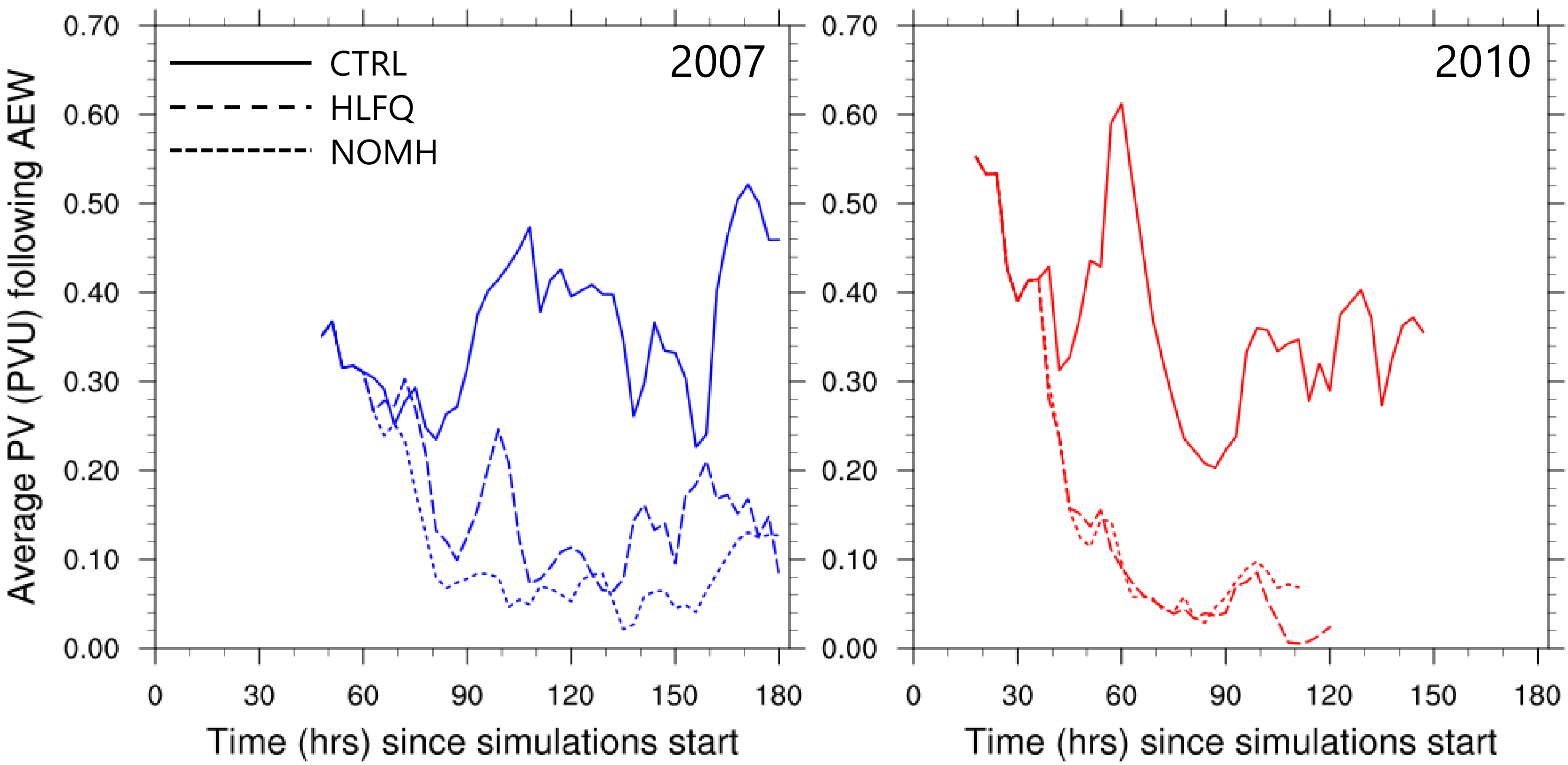


Figure: *Time-series of average 650hPa PV in 500km box following the AEW track center*

PV Budget

$$\underset{A}{\frac{\partial P}{\partial t}} = \underset{B}{-\vec{V}\cdot\vec{\nabla}P} \quad \underset{C}{-\,\omega\frac{\partial P}{\partial p}} \quad \underset{D}{-\,g\left(\vec{\eta}\cdot\vec{\nabla}Q\right)} \quad \underset{E}{-\,g\left(\vec{\nabla}\theta\cdot\vec{\nabla}\times\vec{F}\right)}$$

A: Local PV tendency

B: Horizontal PV advection

C: Vertical PV advection

D: Diabatic heating source

E: Frictional source

P = Potential Vorticity = -g(η·∇θ)
V = Horizontal Winds = u,v
ω = *vertical motion* = $\frac{\partial p}{\partial t}$
η = absolute vorticity
Q = diabatic heating rate
F = Frictional torque = F, G

PV Budget

A B C D E

$$\frac{\partial P}{\partial t} = \boxed{-\vec{V}\cdot\vec{\nabla}P} - \omega\frac{\partial P}{\partial p}\ \boxed{-\,g\left(\vec{\eta}\cdot\vec{\nabla}Q\right)}\ - g\left(\vec{\nabla}\theta\cdot\vec{\nabla}\times\vec{F}\right)$$

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PV Budget

$$\underbrace{\frac{\partial P}{\partial t}}_{A} = \underbrace{\boxed{-\vec{V}\cdot\vec{\nabla}P}}_{B} \underbrace{- \omega\frac{\partial P}{\partial p}}_{C} \underbrace{- g\left(\vec{\eta}\cdot\vec{\nabla}Q\right)}_{D} \underbrace{- g\left(\vec{\nabla}\theta\cdot\vec{\nabla}\times\vec{F}\right)}_{E}$$

$$-\vec{\bar{V}}\cdot\vec{\nabla}P' - \vec{V}'\cdot\vec{\nabla}P' - \vec{V}'\cdot\vec{\nabla}\bar{P} \longrightarrow \text{Advection of background PV by AEW}$$

Passive PV advection by mean flow

Non-linear advection

A: Local PV tendency

B: Horizontal PV advection

C: Vertical PV advection

D: Diabatic heating source

E: Frictional source

P = Potential Vorticity = -g(η·∇θ)

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PV Budget

A B C D E

$$\frac{\partial P}{\partial t} = \boxed{-\vec{V}\cdot\vec{\nabla}P} - \omega\frac{\partial P}{\partial p} - g\left(\vec{\eta}\cdot\vec{\nabla}Q\right) - g\left(\vec{\nabla}\theta\cdot\vec{\nabla}\times\vec{F}\right)$$

$$-\vec{\bar{V}}\cdot\vec{\nabla}P' - \vec{V}'\cdot\vec{\nabla}P' - \boxed{\vec{V}'\cdot\vec{\nabla}\bar{P}}$$

Advection of background PV by AEW

Dry Rossby Wave dynamics

Passive PV advection by mean flow

Non-linear advection

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Microphysical Heating in Control Simulations

- Deep convection is most prominent in the northerlies
- Stratiform convection is more prominent nearer wave center

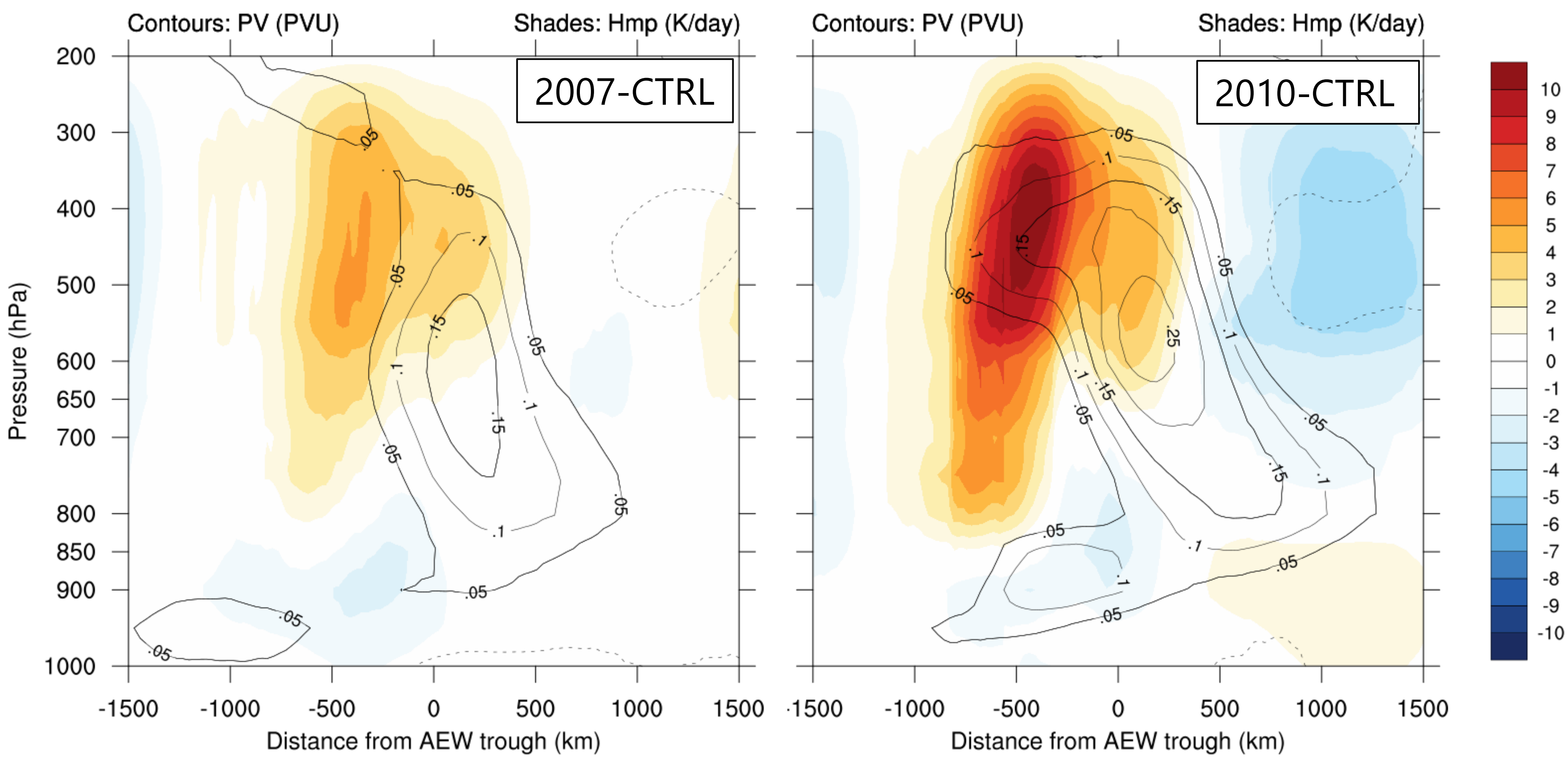

Figure: *Average longitude-pressure cross-sections of microphysical heating following simulated AEWs.*

Diabatic PV Tendency in Control Simulations

- In the northerlies, there is low-level positive diabatic PV tendency
- In the trough, there is also mid-level positive diabatic PV tendency

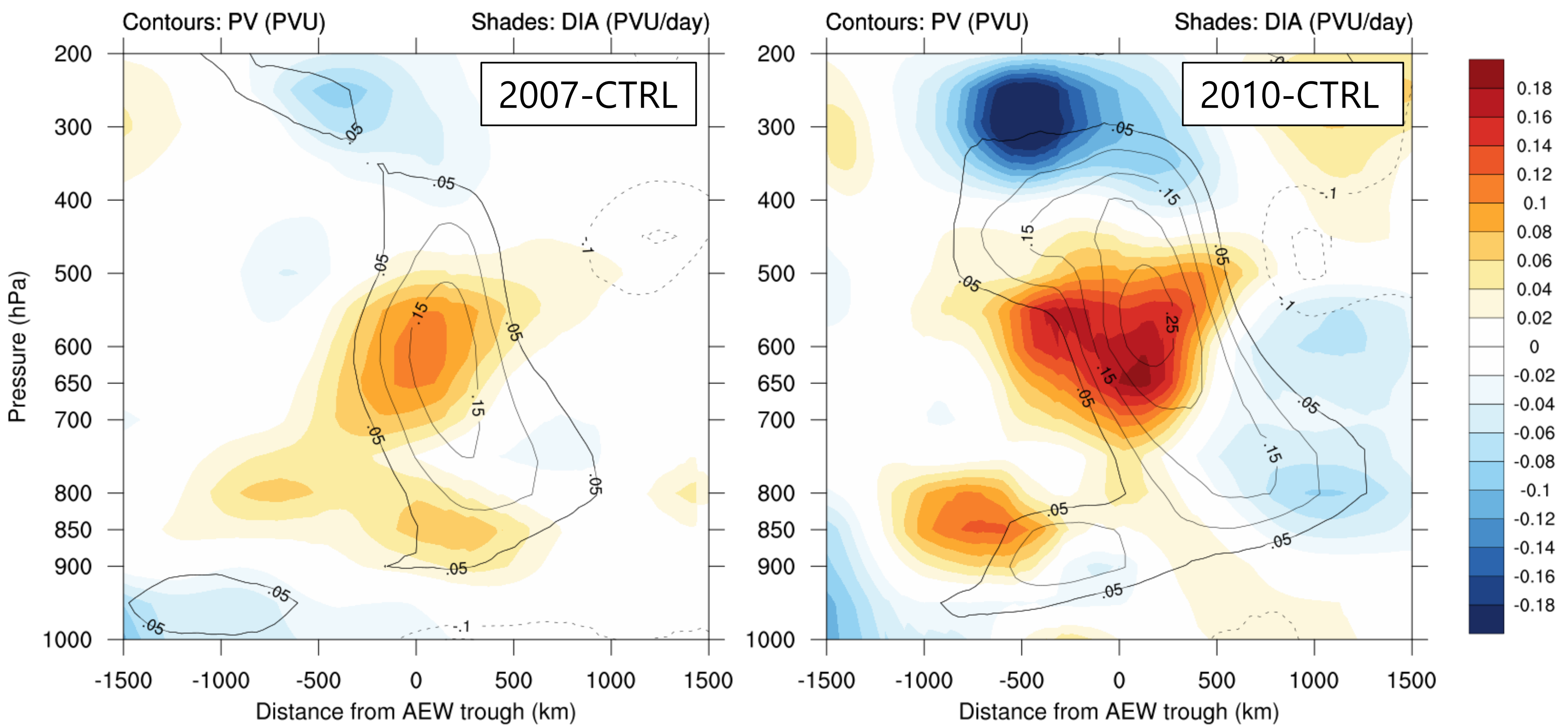

Figure: *Average longitude-pressure cross-sections of* $-g\left(\vec{\eta}\cdot\vec{\nabla}Q\right)$ *following simulated AEWs.*

Advective PV Tendency in Control Simulations

- Smaller but comparable in magnitude to diabatic tendencies

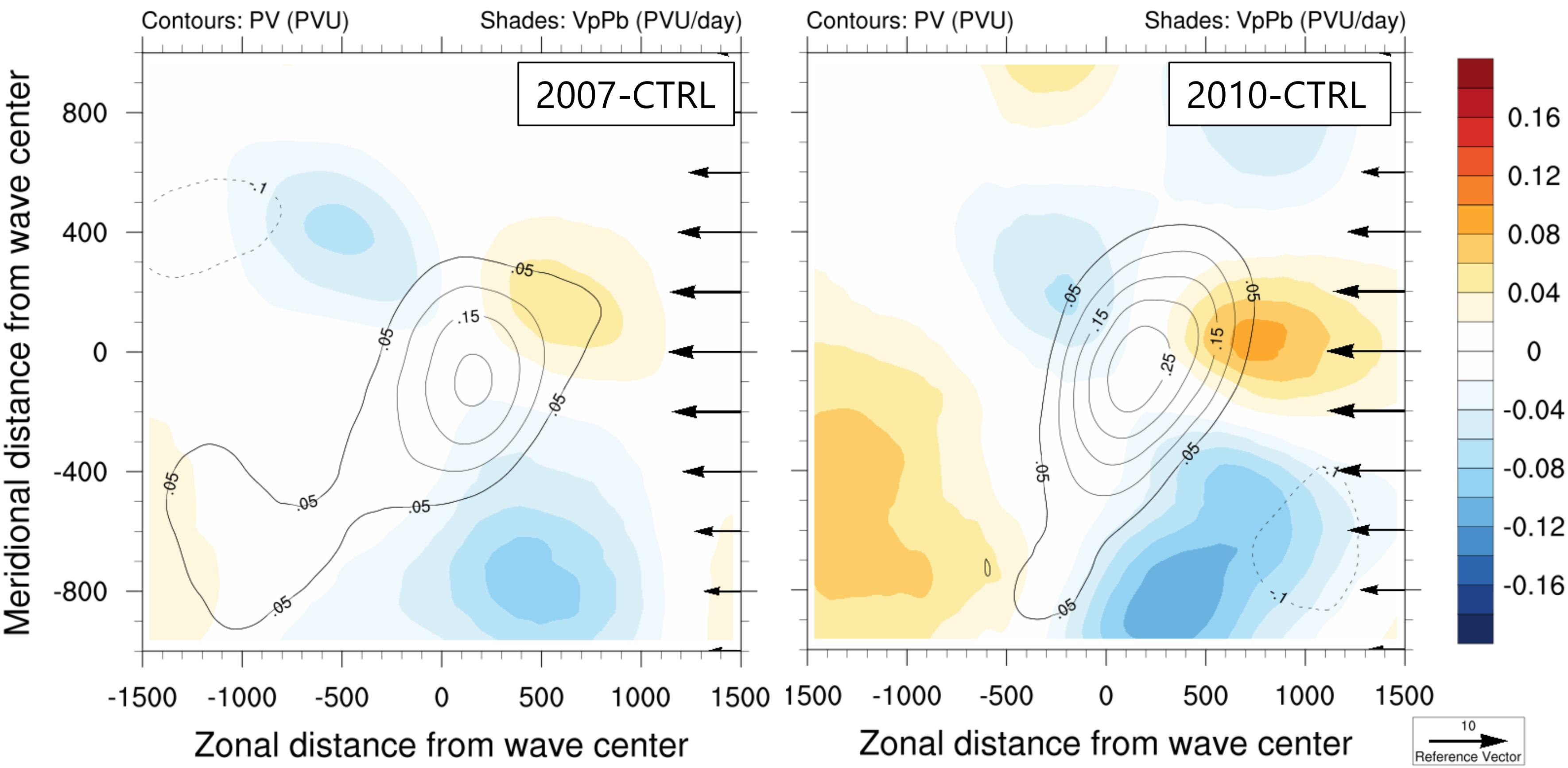

Figure: *Average latitude-longitude cross-sections of 600-700 hPa* $\vec{V}' \cdot \vec{\nabla}\bar{P}$ *following simulated AEWs.*

Advective PV Tendency in Control Simulations

- Smaller but comparable in magnitude to diabatic tendencies
- Checkerboard pattern of advective PV tendencies indicates phase-locked counter-propagating Rossby waves

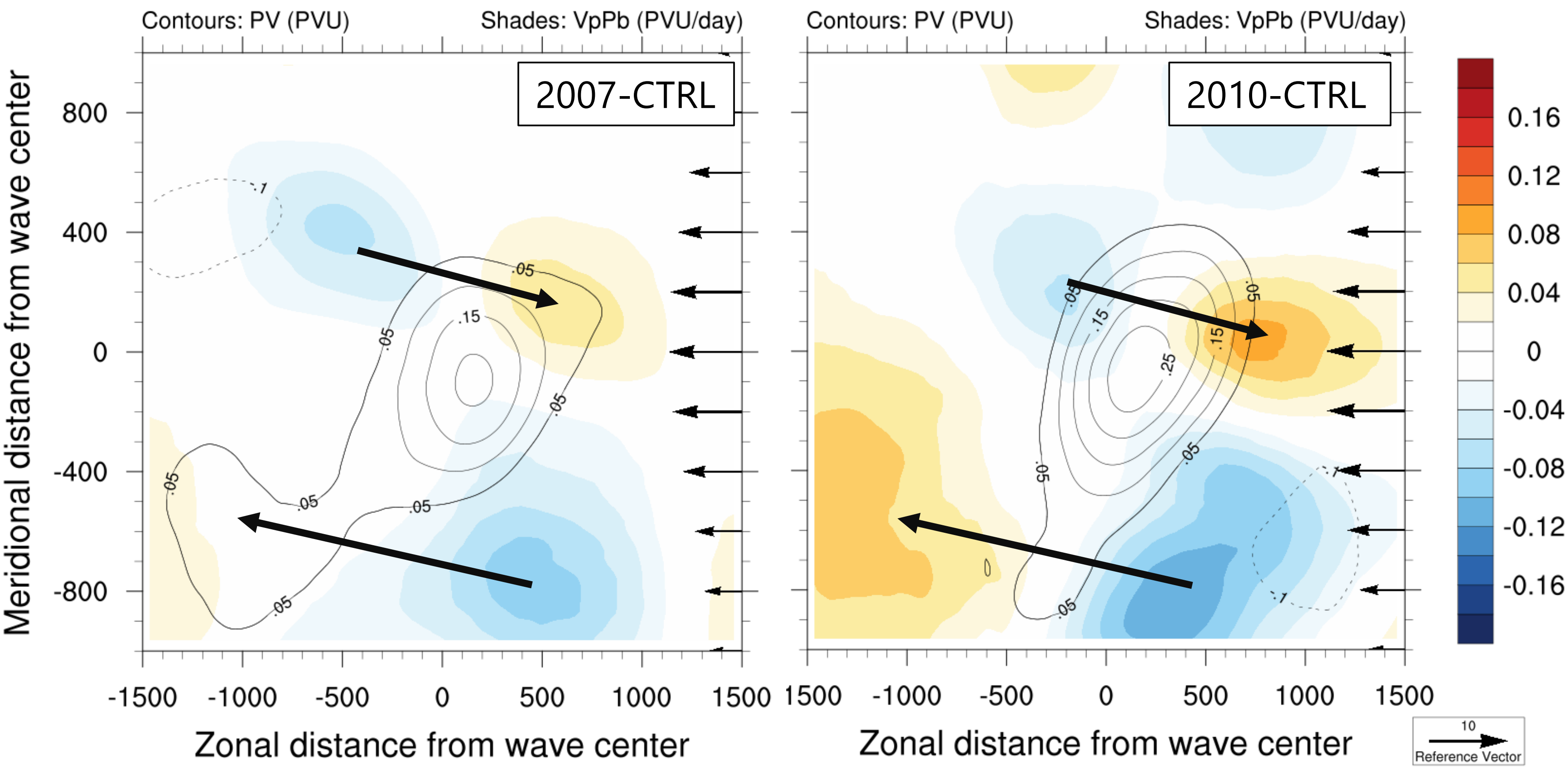

Figure: *Average latitude-longitude cross-sections of 600-700 hPa* $\vec{V}' \cdot \vec{\nabla}\bar{P}$ *following simulated AEWs.*

PV in Sensitivity Studies

- PV anomalies are limited to the upper-levels, especially when there is no microphysics heating
- Low/mid-level anomalies are small in the 50% moisture and non-existent in the no microphysics simulations

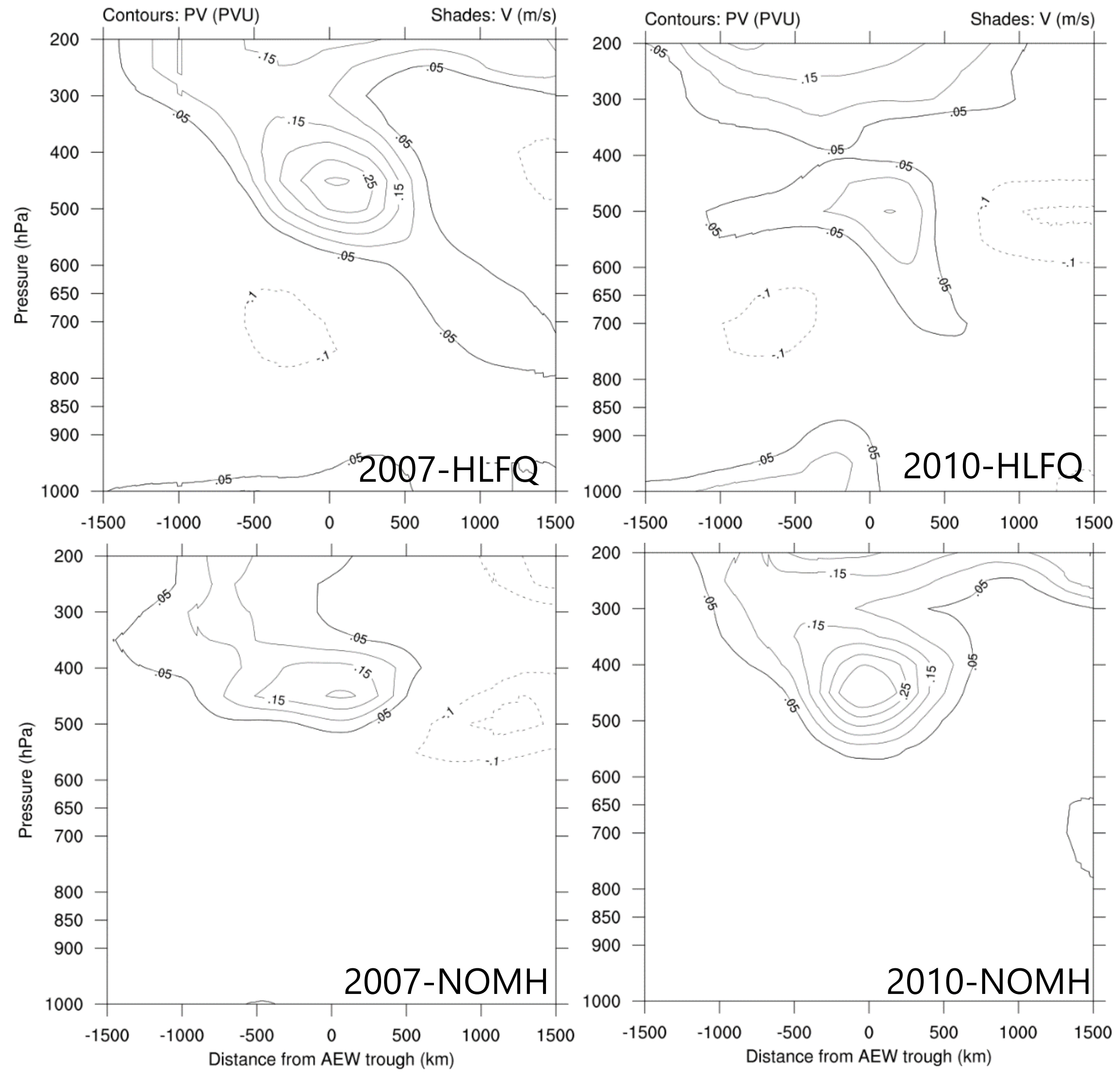

Figure: *Average longitude-pressure cross-sections of PV following simulated AEWs.*

Mechanisms in AEWs with no convection

- $\vec{V}' \cdot \vec{\nabla}\bar{P}$ tendencies are in quadrature with the PV anomaly

- This is representative of a neutral Rossby wave that is propagating via the advection of background PV by the AEW winds

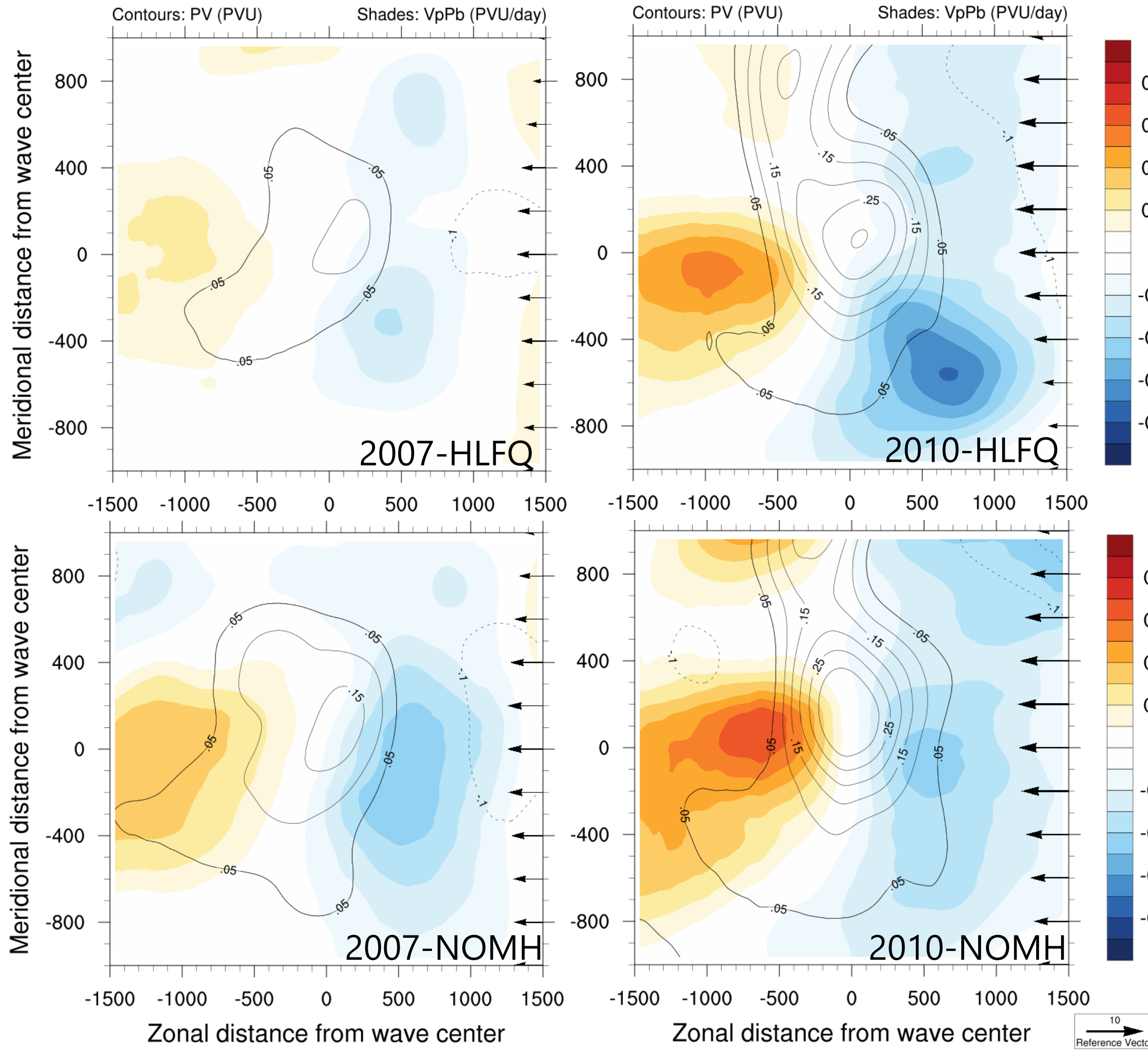

Figure: *Average latitude-longitude cross-sections of 600-700 hPa* $\vec{V}' \cdot \vec{\nabla}\bar{P}$ *following simulated AEWs.*

Summary

- In convection-permitting simulations, convection is essential for the maintenance of the AEW, especially in the low-mid levels
- In the northerlies there is deep convection that results in low-level positive PV tendency ahead of the existing PV anomaly
- In the trough there is stratiform convection that leads to mid-level positive PV tendency co-located with the existing PV anomaly
- Advective PV tendencies are comparable in magnitude with diabatic PV tendencies and produce phase-locked counter-propagating Rossby waves that can then grow through barotropic instability
- Without convection the PV anomaly is limited to above 500hPa and propagates through a neutral Rossby wave mechanism

Conclusions

Towards a complete model of an AEW

- Convection allows the PV and thus the circulation to build down - this has potential implications for tropical cyclogenesis
- The transition from deep convection to stratiform is essential for the growth of the AEW since this allows for the mid-level generation of PV
- Dry Rossby wave dynamics are still occurring in AEWs producing a pattern representative of a growing Rossby wave
- A potential model could be a combination of a dry Rossby Wave and a DRW

Future Work

- Compare and contrast energetics mechanisms with PV mechanisms
- Develop a model of AEW-convection interaction

Acknowledgements

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- NCAR CISL: Computational and Information Systems Laboratory. 2017. Cheyenne: HPE/SGI ICE XA System (University Community Computing). Boulder, CO: National Center for Atmospheric Research. doi:10.5065/D6RX99HX.
- Anantha Aiyyer
- Dylan White
- Gary Lackmann

- Poster 114 (Tuesday 3:30pm): The Interaction between Mesoscale Convective Systems and African Easterly Waves