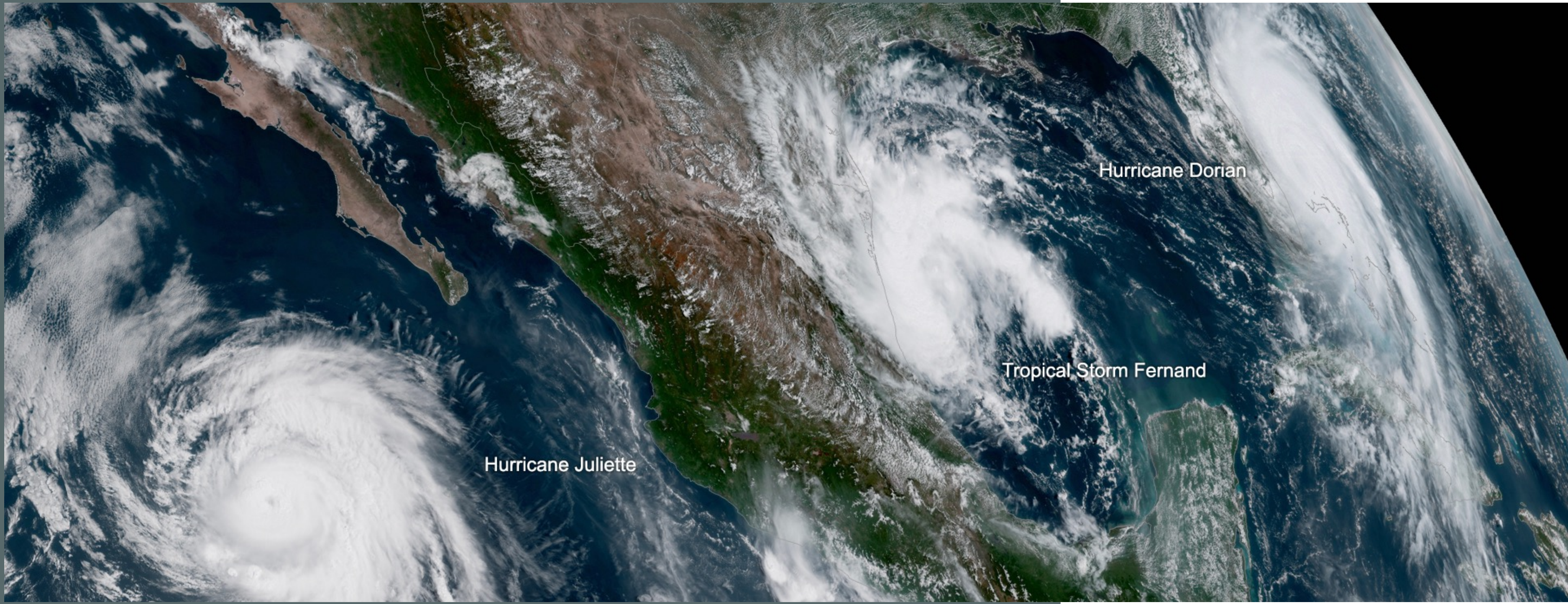


PC: https://www.nesdis.noaa.gov/news/three-storms-brewing-hurricane-season-heats

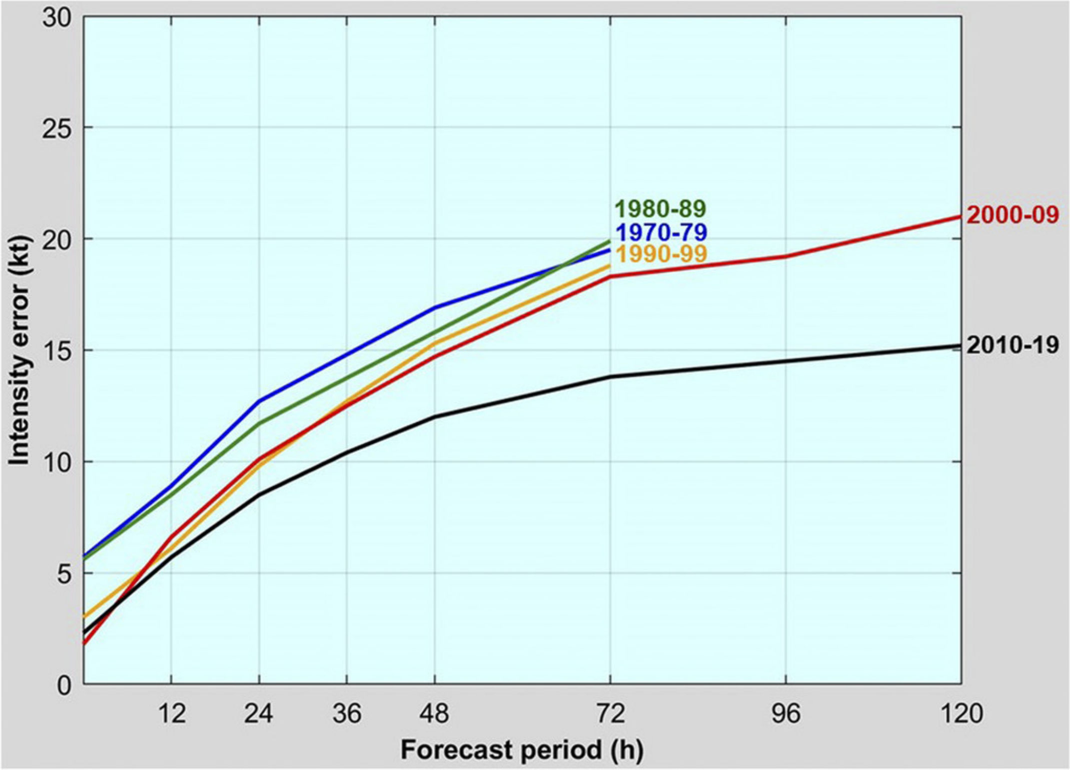
Investigation of Relationships Between Tropical Cyclone Structure and Intensity Change

Eleanor G. Casas[1,2,3], Michael M. Bell[1]

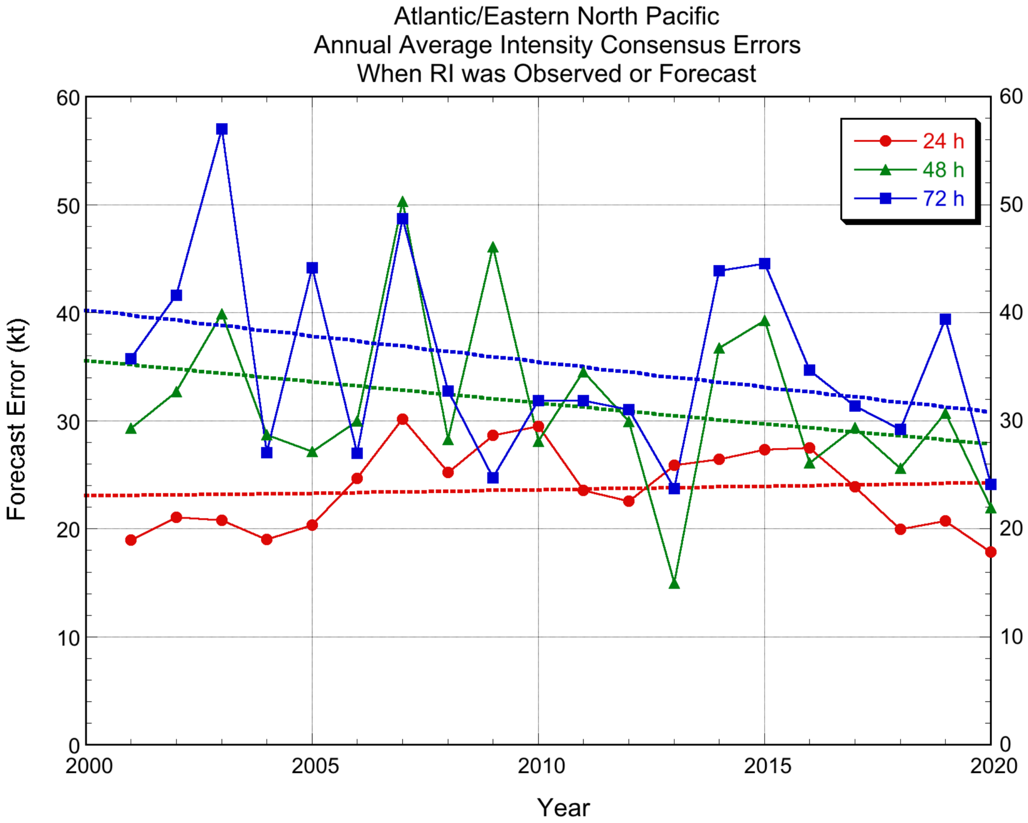
HFIP Seminar
08/02/2023

[1]Colorado State University,
[2]Naval Postgraduate School,
3Millersville University

Forecasting RI remains a challenge



Cangialosi et al. (2020)



DeMaria et al. (2021)

When the external environment is favorable, intensification rates depend more on internal dynamics

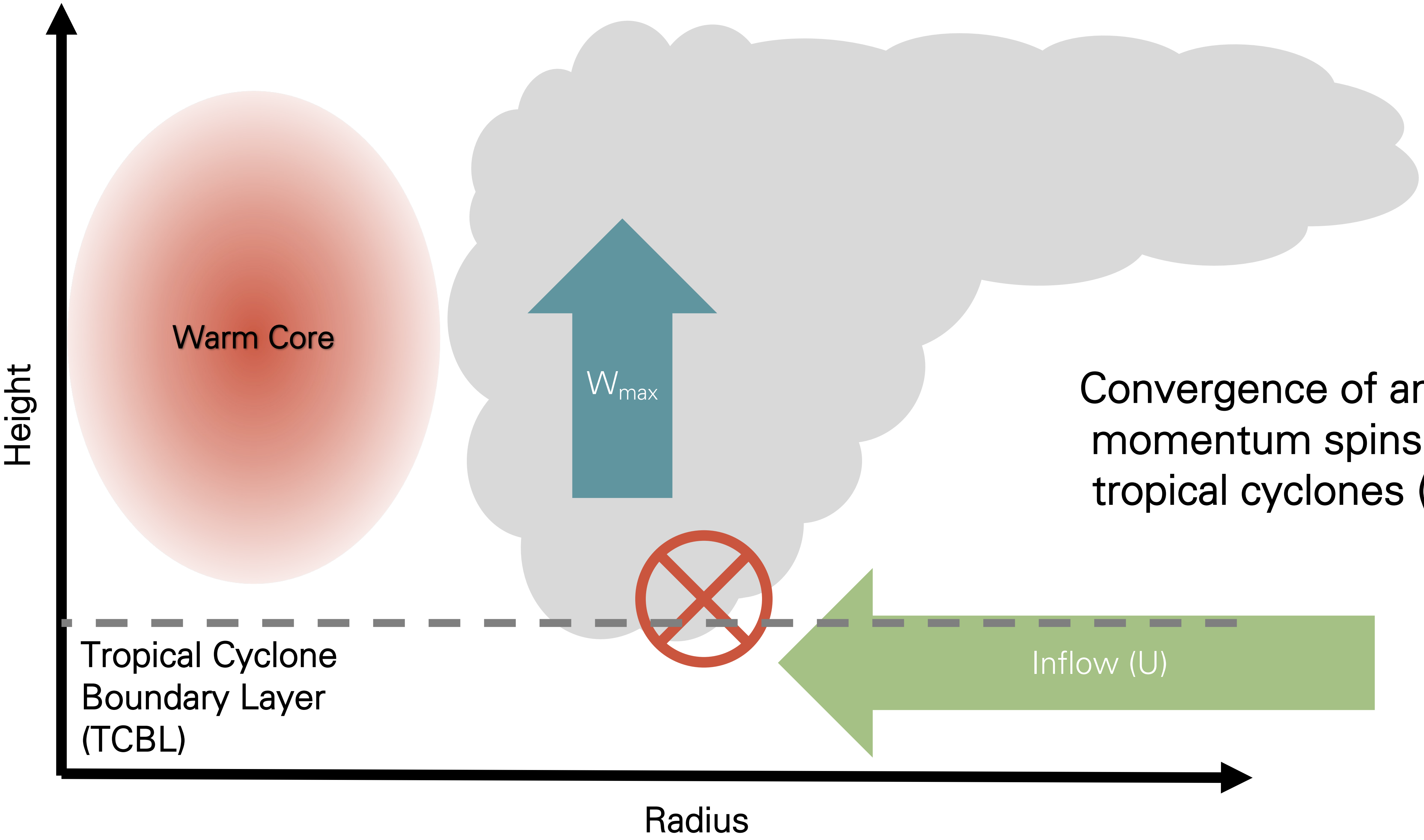
RI = 30 kt within 24 hr

External Environment

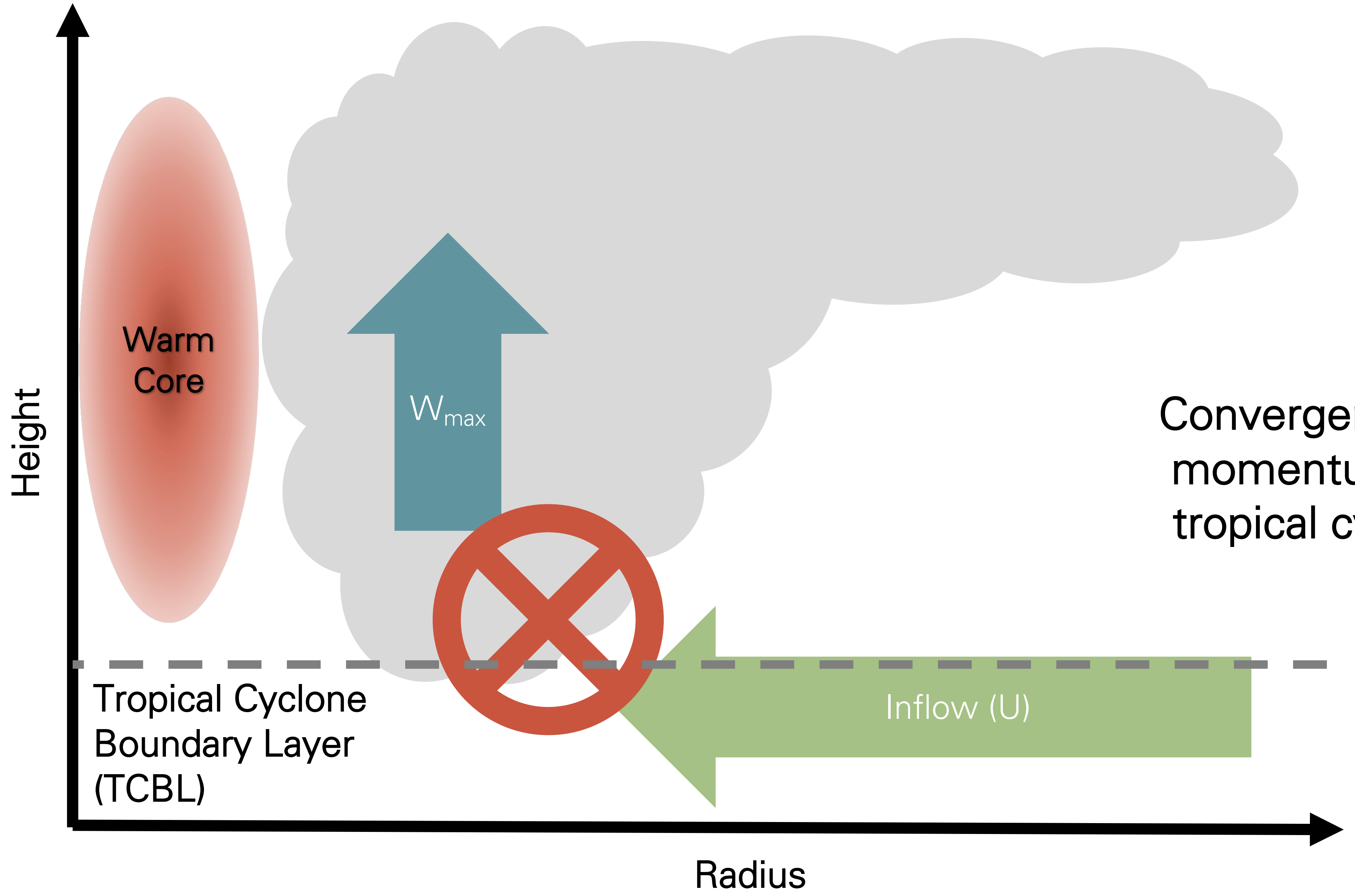
- Sea Surface Temperatures ↑
- Vertical Wind Shear ↓
- Environmental humidity ↑

Internal Dynamics

- Heating Efficiency in the Balanced Vortex Model
- Convection Organization
    - Updraft location within Radius of Maximum Wind (RMW)

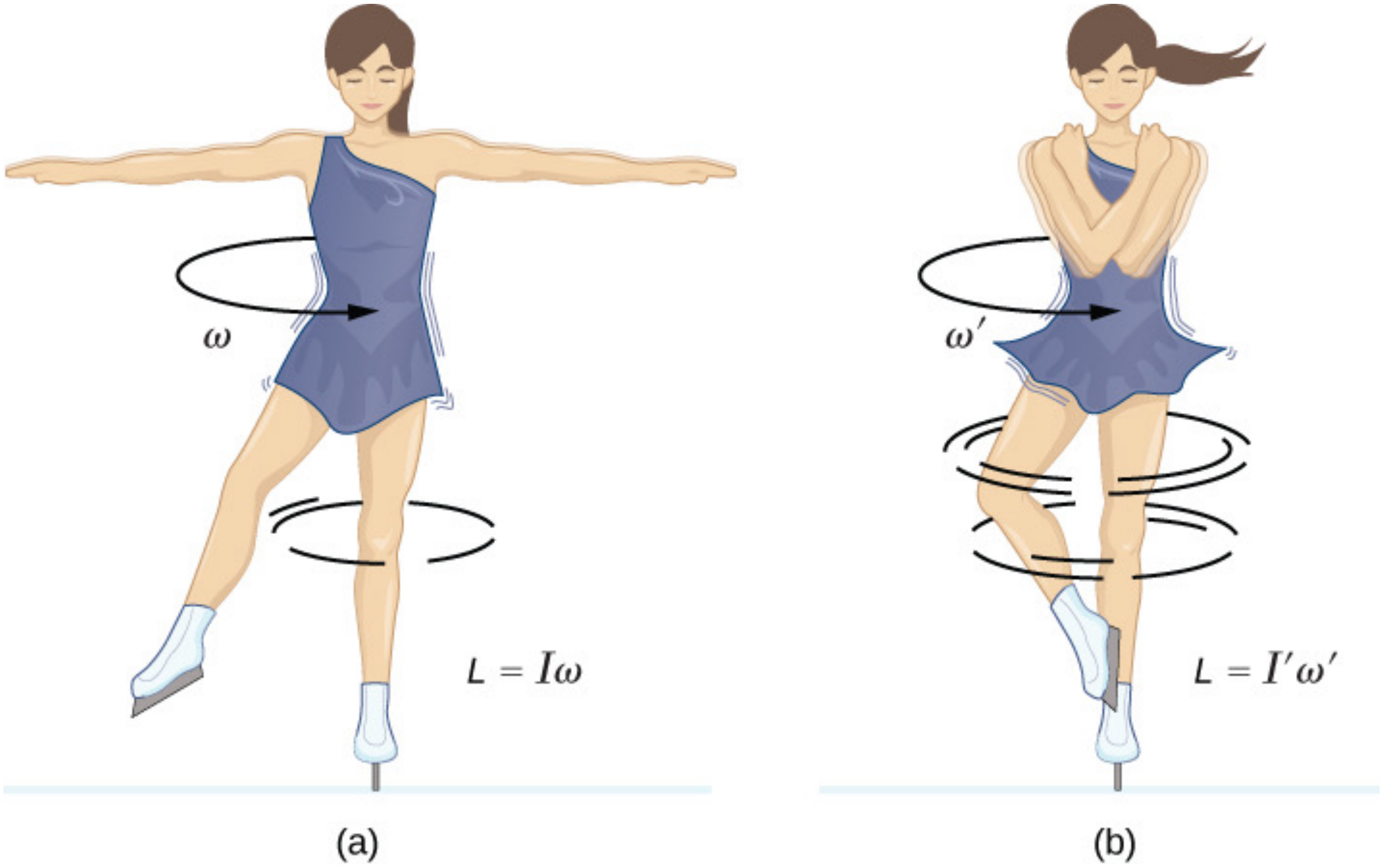


Convergence of angular momentum spins up a tropical cyclones (TCs)



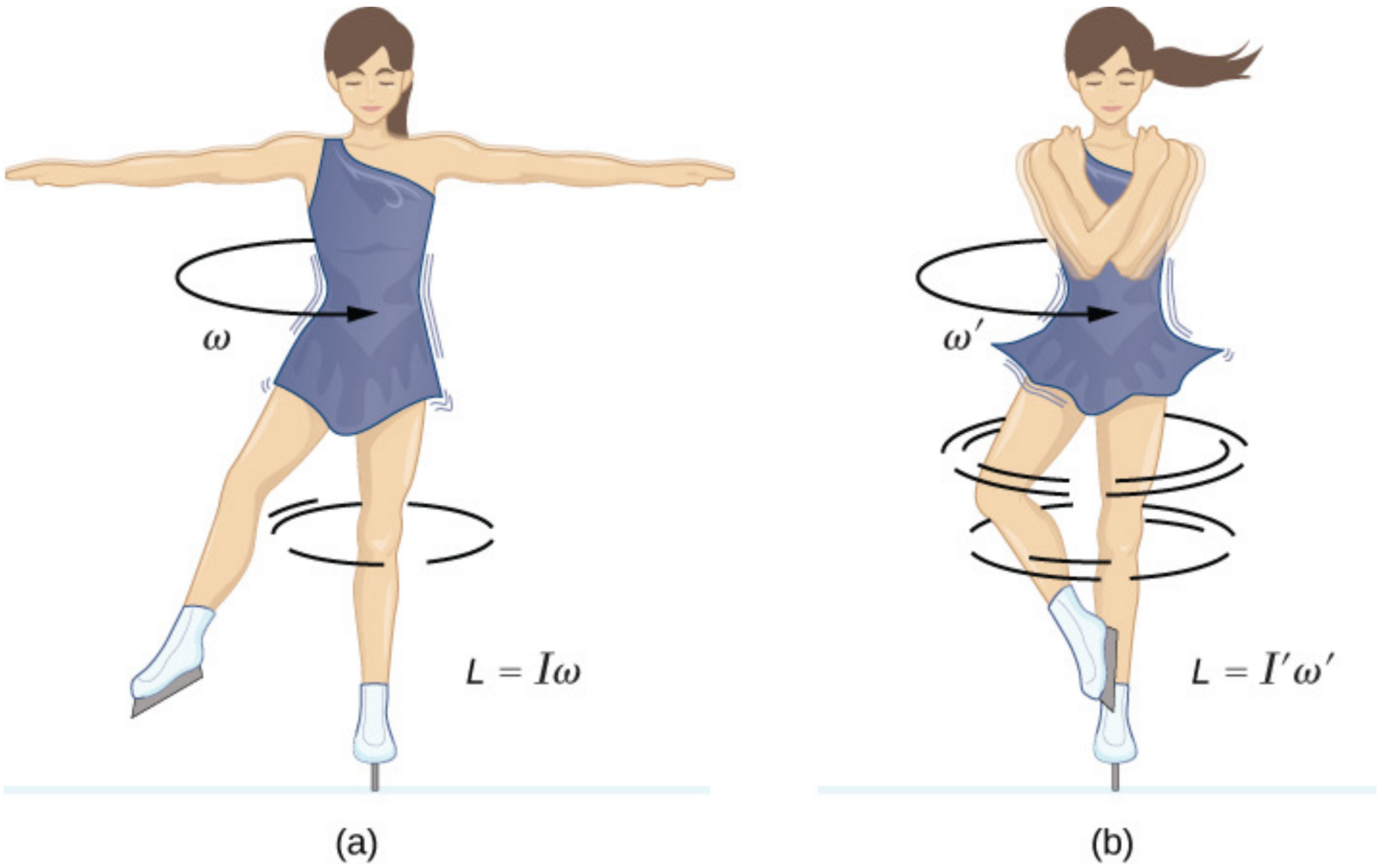
Convergence of angular momentum spins up a tropical cyclones (TCs)

Hurricane (TC) intensification is often likened to the “ice skater” analogy



PC: https://courses.lumenlearning.com/suny-osuniversityphysics/chapter/11-2-conservation-of-angular-momentum/

But does intensification *require* contraction?



PC: https://courses.lumenlearning.com/suny-osuniversityphysics/chapter/11-2-conservation-of-angular-momentum/

But does intensification *require* contraction?

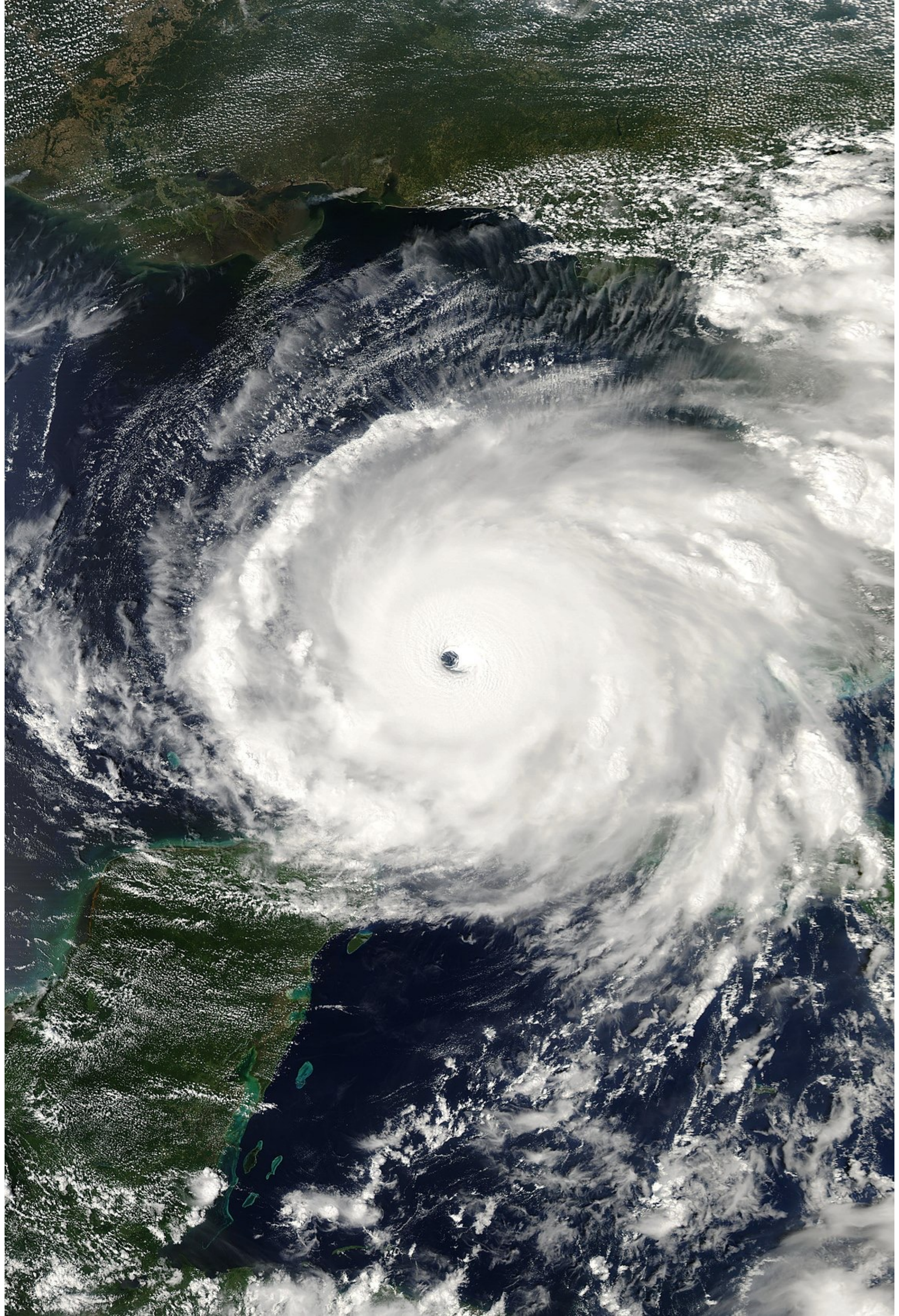
$$\frac{d\mathrm{RMW}}{dt} = -\frac{(\partial/\partial r)(\partial V/\partial t)}{\partial^2 V/\partial r^2}\bigg|_{\mathrm{RMW}}$$

"It remains unclear how typical it is for the RMW to reach a steady state prior to peak intensity, as opposed to following the existing paradigm, where peak intensity is coincident with the end of contraction. "

Stern et al. (2015)

PC: https://courses.lumenlearning.com/suny-osuniversityphysics/chapter/11-2-conservation-of-angular-momentum/

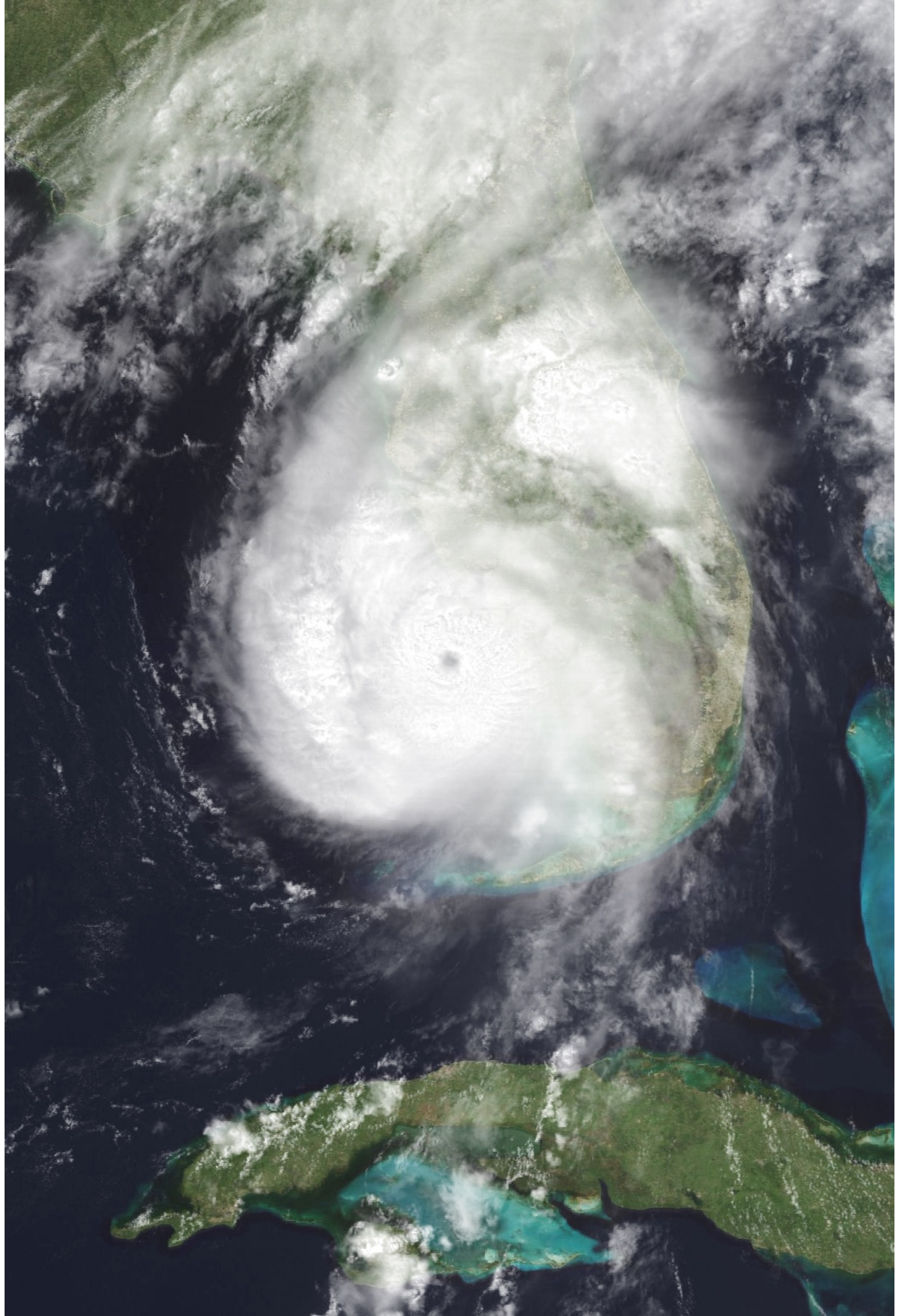
Sep. 21, 2005



Hurricane Rita

PC: https://en.wikipedia.org/wiki/Hurricane_Rita

Aug. 13, 2004

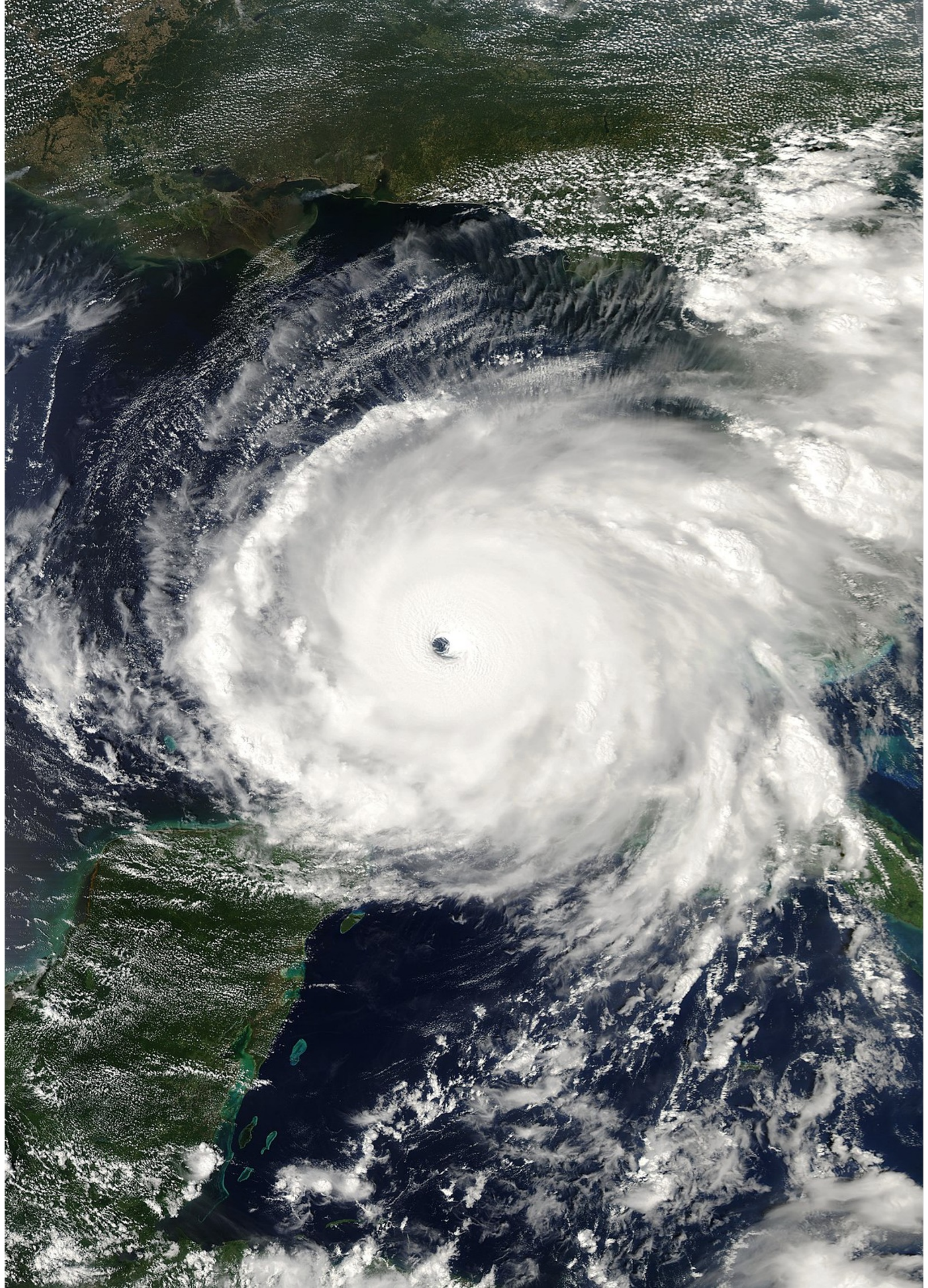


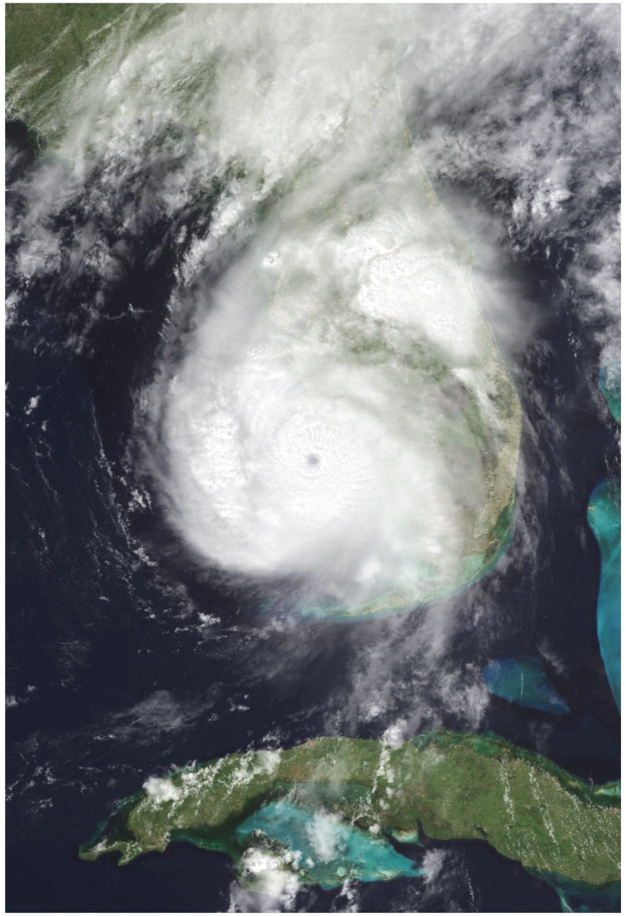
Hurricane Charley

PC: https://en.wikipedia.org/wiki/Hurricane_Charley

Size of Florida Panhandle is Constant

Rita



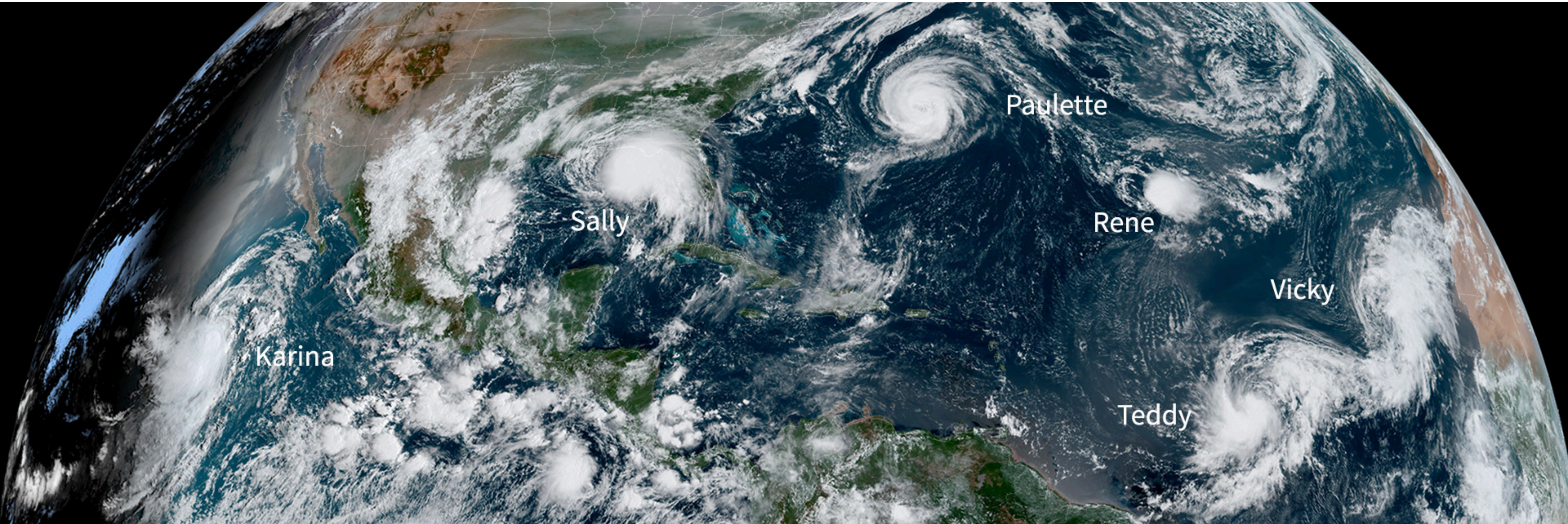


Charley

Research Goal

How does hurricane structure and intensity matter for intensification rates?

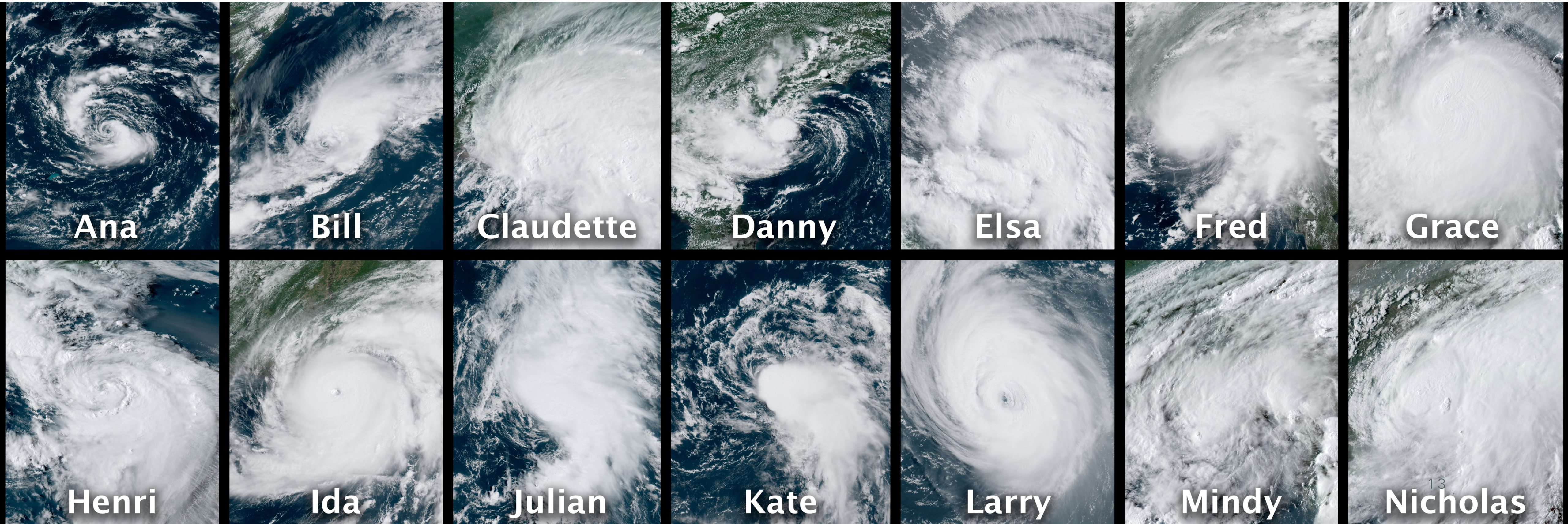
PC: https://www.nesdis.noaa.gov/news/six-tropical-systems-swirl-around-two-oceans



First Step

How would you classify the intensity and size of a hurricane?

PC: https://www.nesdis.noaa.gov/news/the-2021-atlantic-hurricane-season-glance



Outline

Part 1:
Developing the framework

Part 2:
Developing the initial profiles

Part 3:
What happens?

Part 4:
Why?

Outline

1: Utilize an EOF analysis to create orthogonal intensity/size axes

Part 1: Developing the framework

Part 2: Developing the initial profiles

Part 3: What happens?

Part 4: Why?

Outline

1: Utilize an EOF analysis to create orthogonal intensity/size axes

2: Reconstruct semi-realistic idealized profiles from EOF axes

Part 1: Developing the framework

Part 2: Developing the initial profiles

Part 3: What happens?

Part 4: Why?

Outline

1: Utilize an EOF analysis to create orthogonal intensity/size axes

2: Reconstruct semi-realistic idealized profiles from EOF axes

3: Utilize idealized profiles in axisymmetric CM1

Part 1: Developing the framework

Part 2: Developing the initial profiles

Part 3: What happens?

Part 4: Why?

Outline

1: Utilize an EOF analysis to create orthogonal intensity/size axes

2: Reconstruct semi-realistic idealized profiles from EOF axes

3: Utilize idealized profiles in axisymmetric CM1

4: Utilize idealized profiles in slab- and height-resolved TCBL models

Part 1: Developing the framework

Part 2: Developing the initial profiles

Part 3: What happens?

Part 4: Why?* (one explanation)

Part 1: Developing the Intensity-Size Phase Space

Outline

1: Utilize an EOF analysis to create orthogonal intensity/size axes

Part 1: Developing the framework

Part 2: Developing the initial profiles

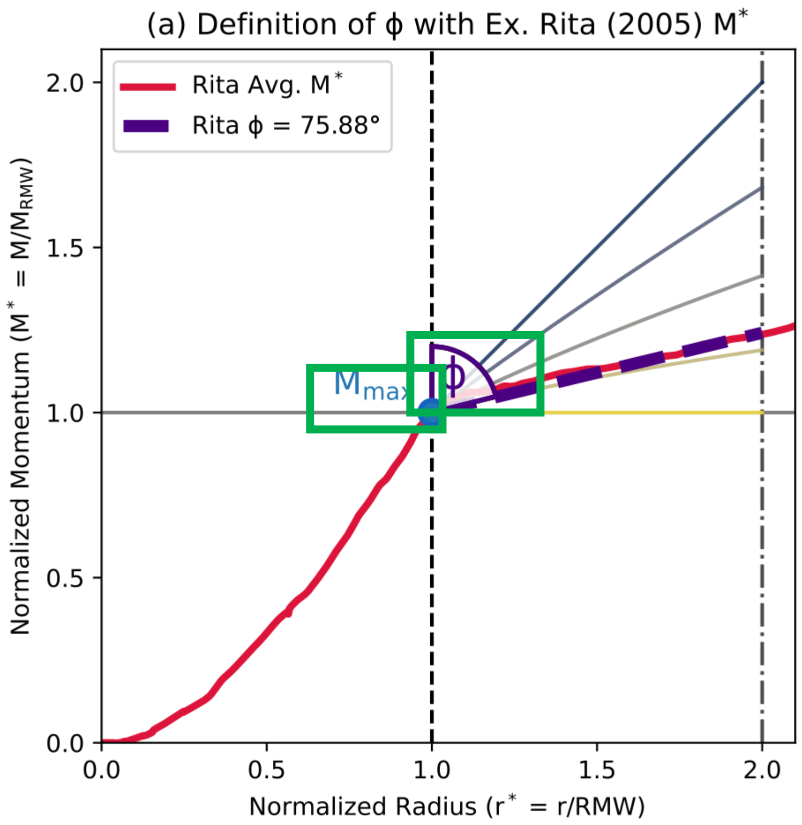
Part 3: What happens?

Part 4: Why?

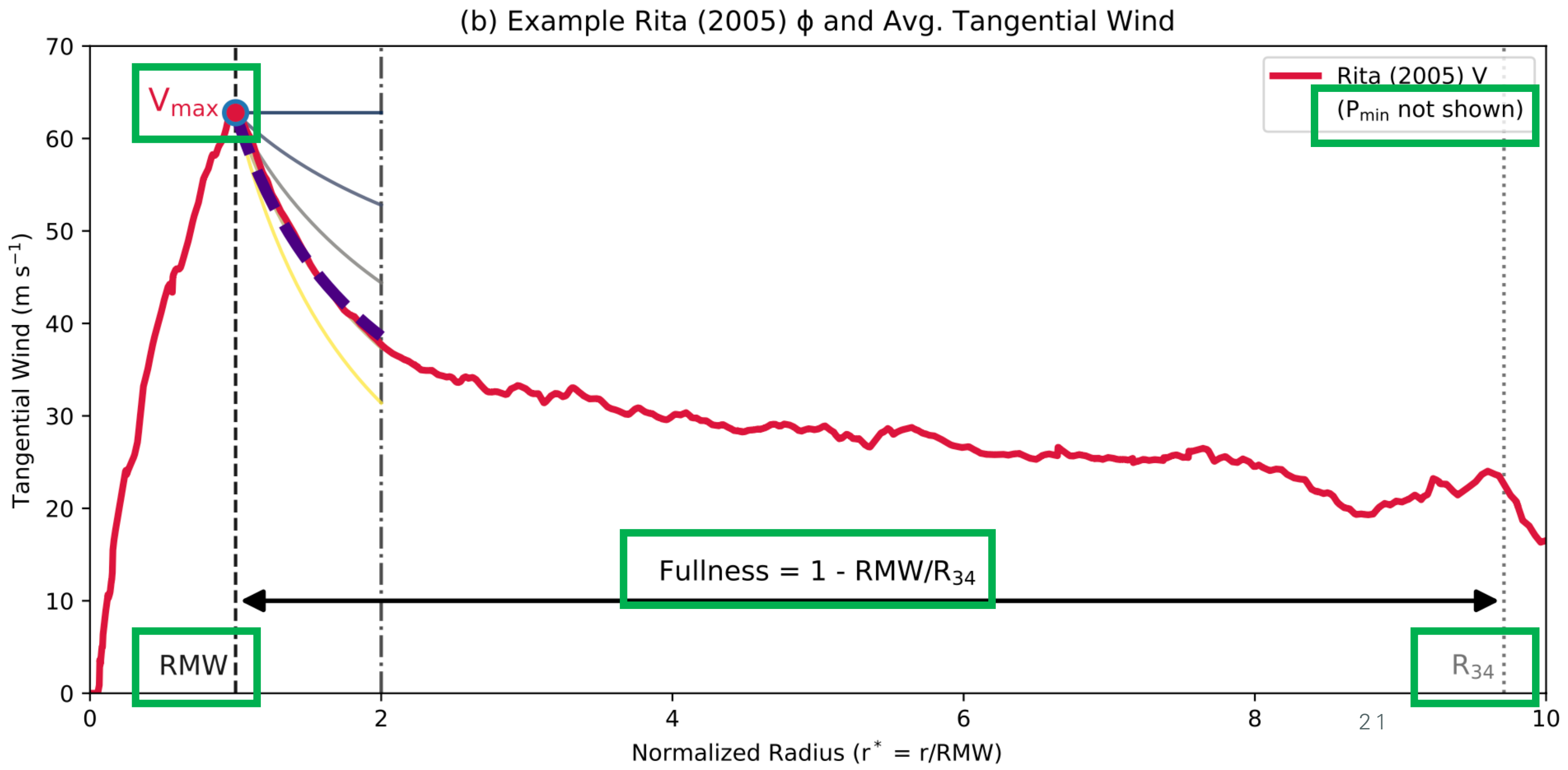
We have computed an EOF on 7 commonly observed aircraft observations and Best Track estimates

Ex: Hurricane Rita (2005) near peak intensity

Normalized Angular Momentum



Flight-level Tangential Wind



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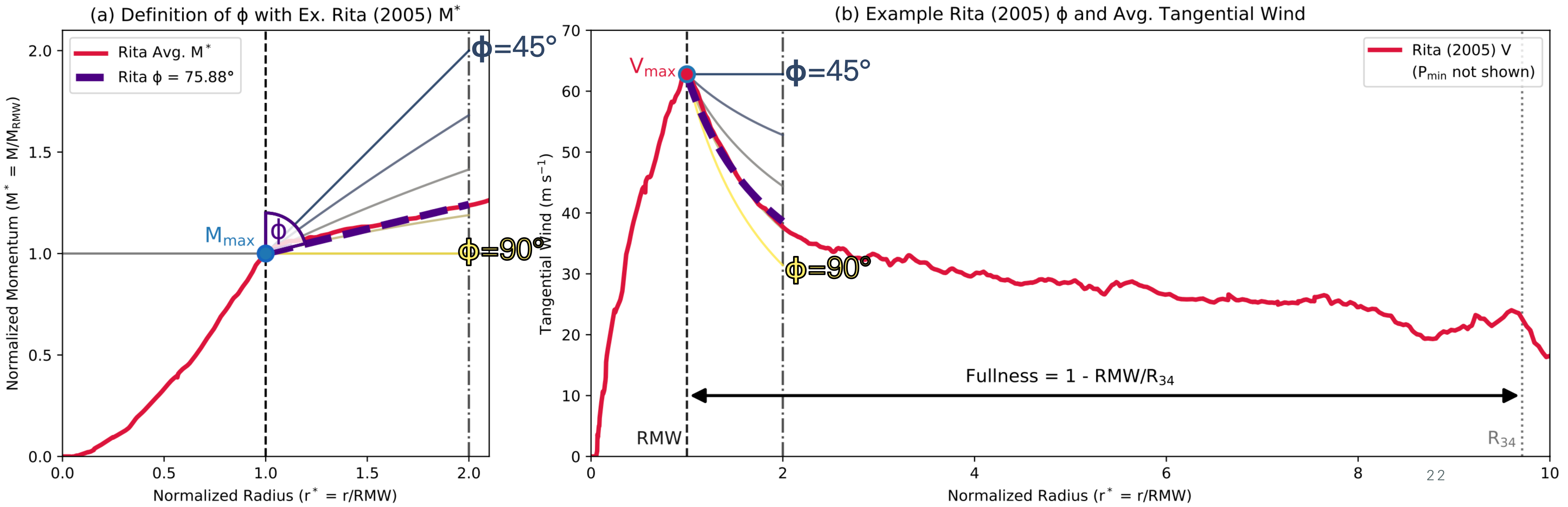
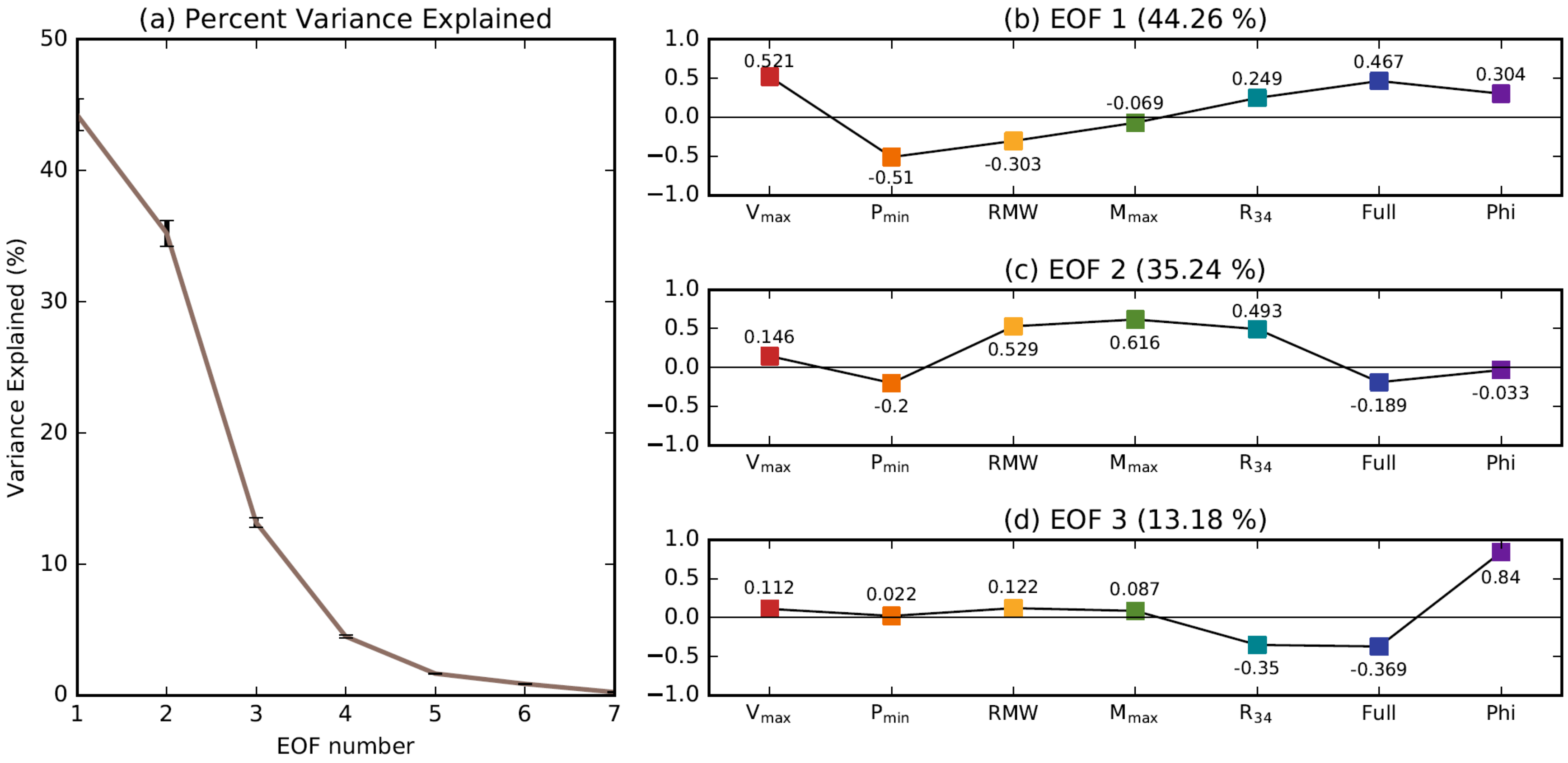


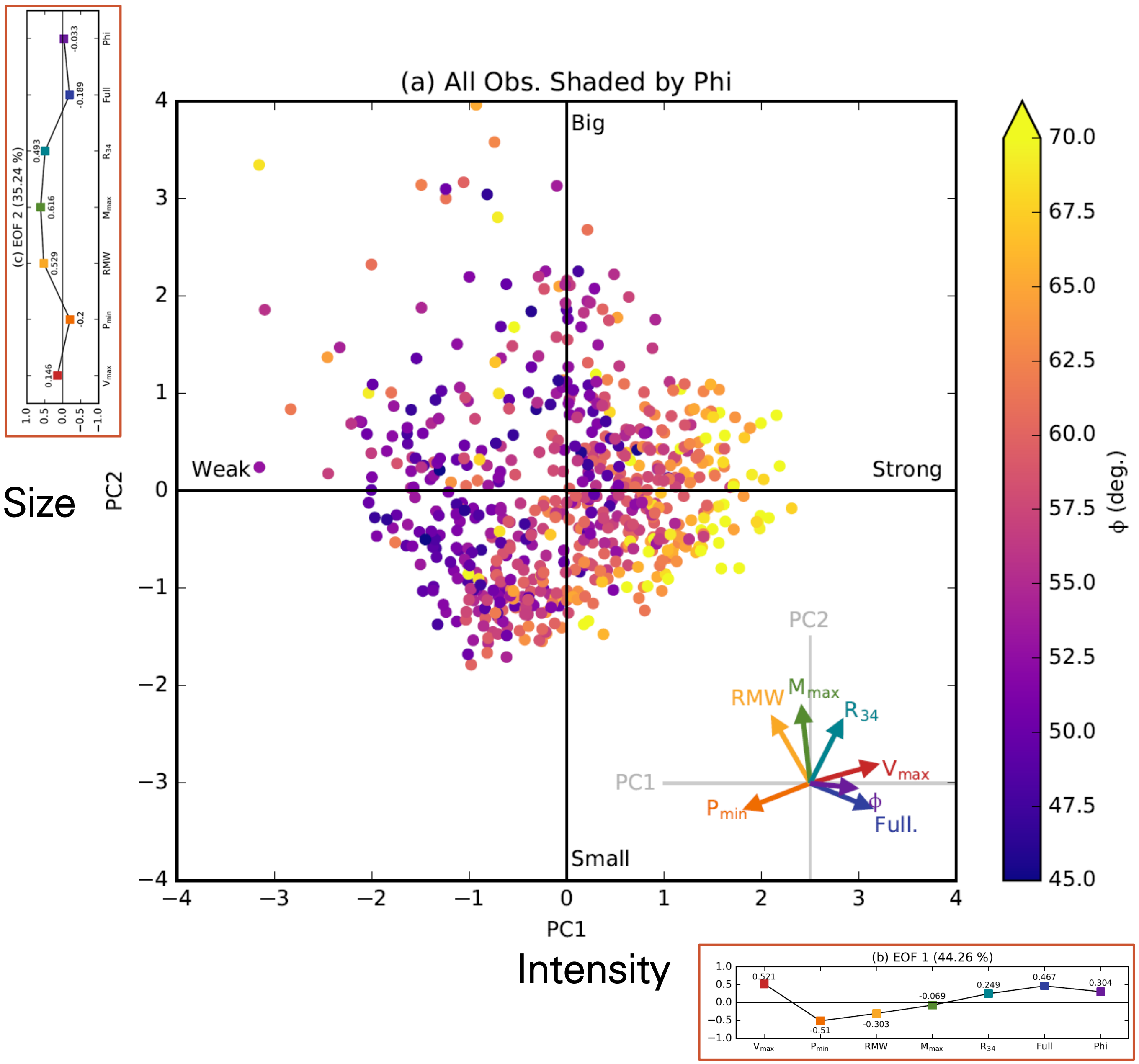
The Resulting EOF Structures



TC Intensity

TC Size

TC Maturity (Mostly Phi)



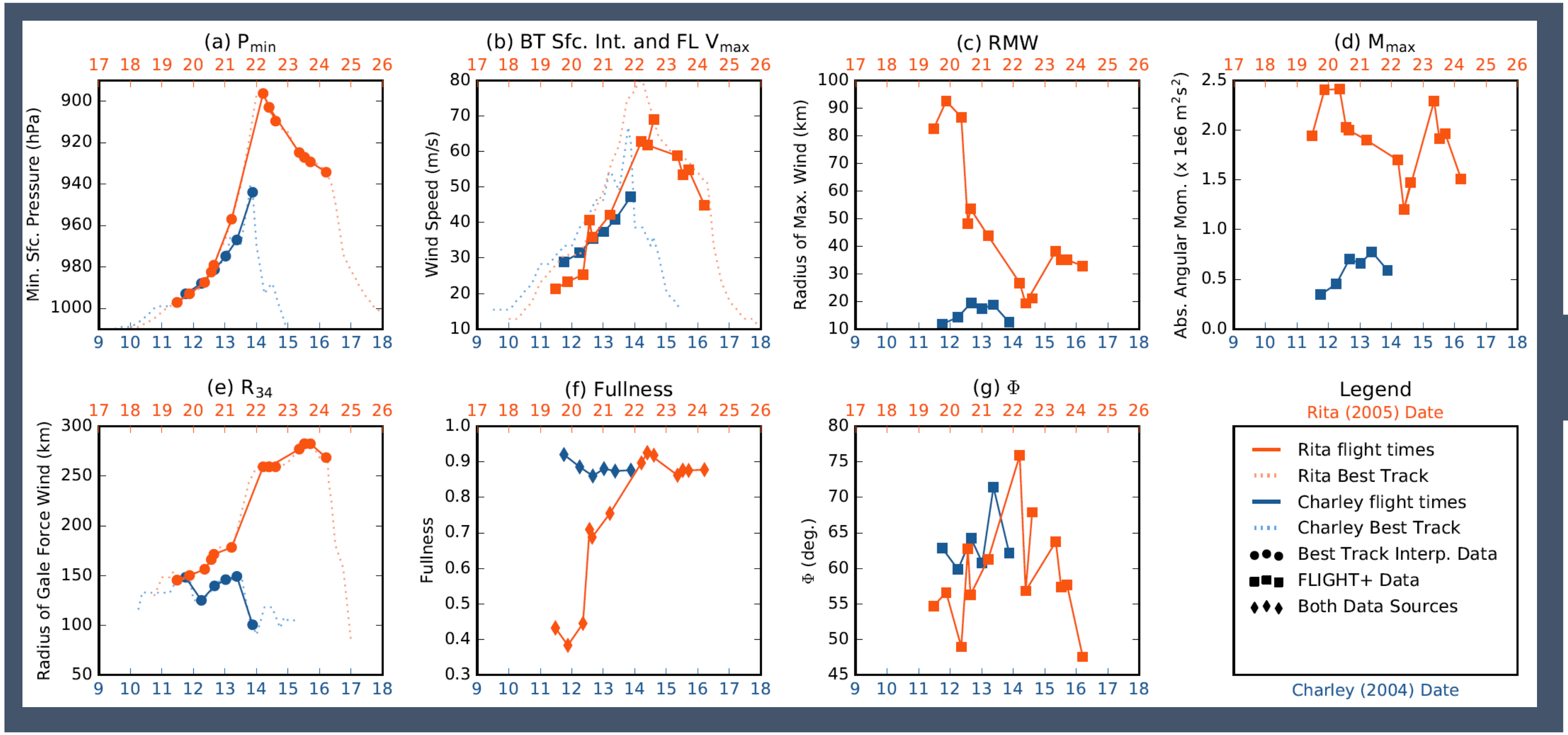
Using the EOF Framework

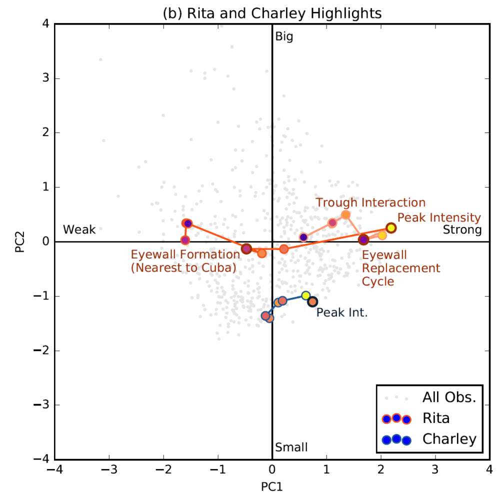
Phi is most closely aligned with the intensity axis

M_{max} is most closely aligned with the size axis

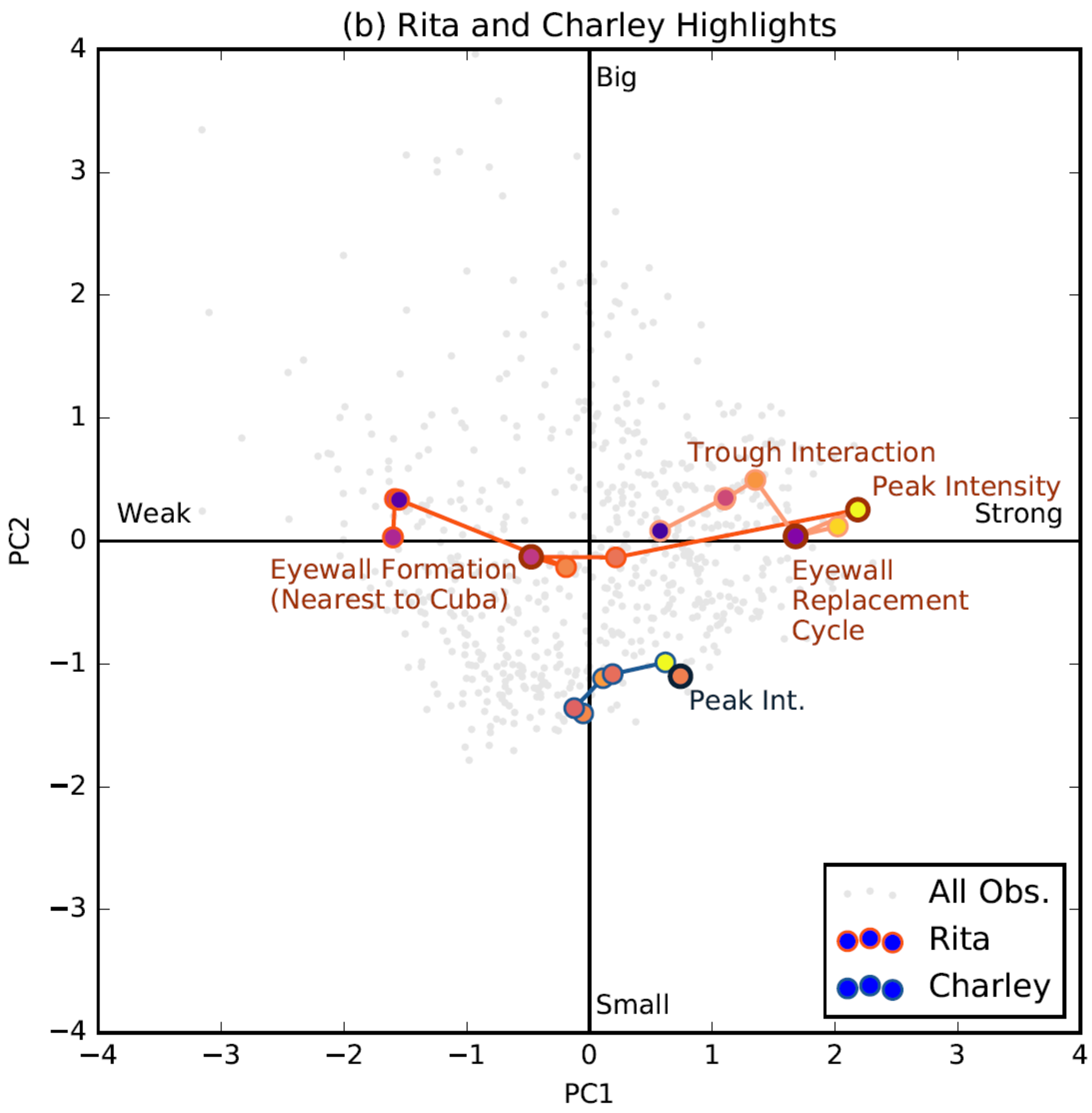
The (Weak, Big) quadrant has the largest outliers

Example Observational Comparison





Rita (2005) and Charley (2004)



Enlarged Observations

This framework easily allows us to see that:

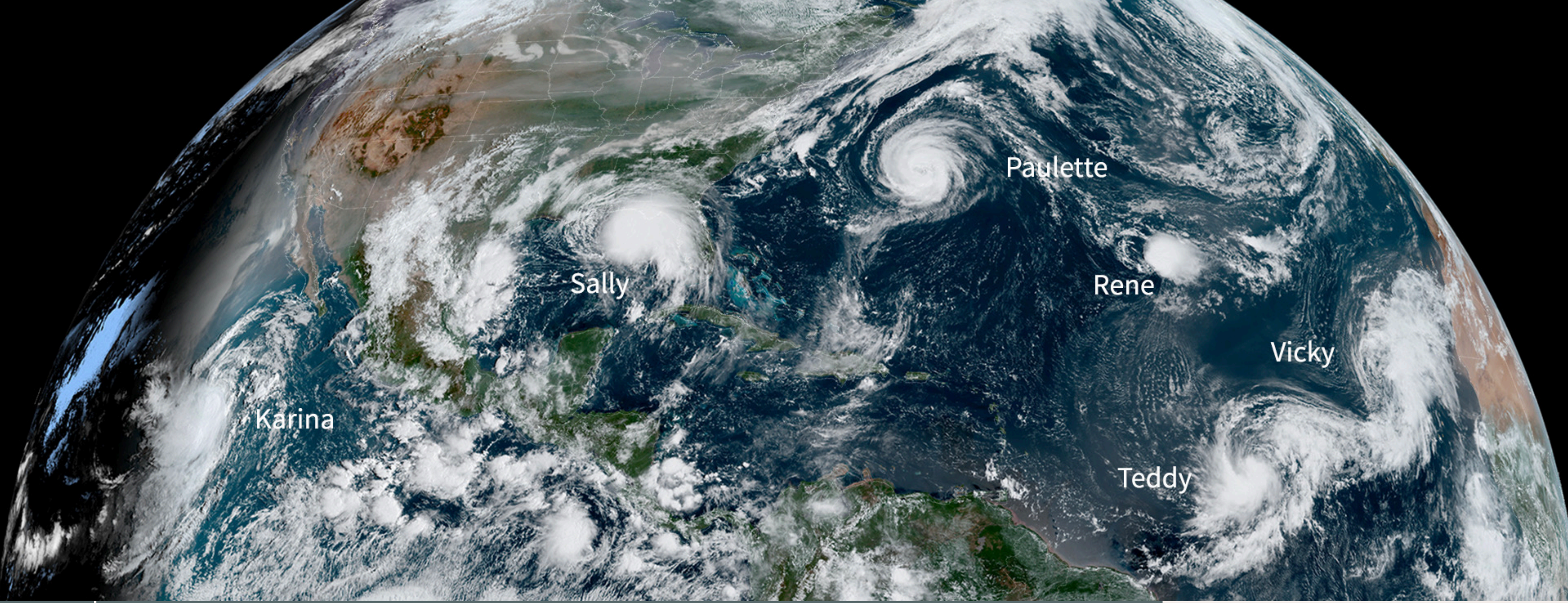
- Rita is considered an average-sized hurricane that contracted at first and expanded later on
- Charley is an extremely small hurricane that grew a bit

Part 1 Summary

This study was recently published in JGR: Atmospheres! Casas et al. (2023)

An Intensity and Size Phase Space for Tropical Cyclone Structure and Evolution

Doi: [10.1029/2022JD037089](10.1029/2022JD037089)



Part 2: Assessing TC Variability & TCBL Responses

Outline

1: Utilize an EOF analysis to create orthogonal intensity/size axes

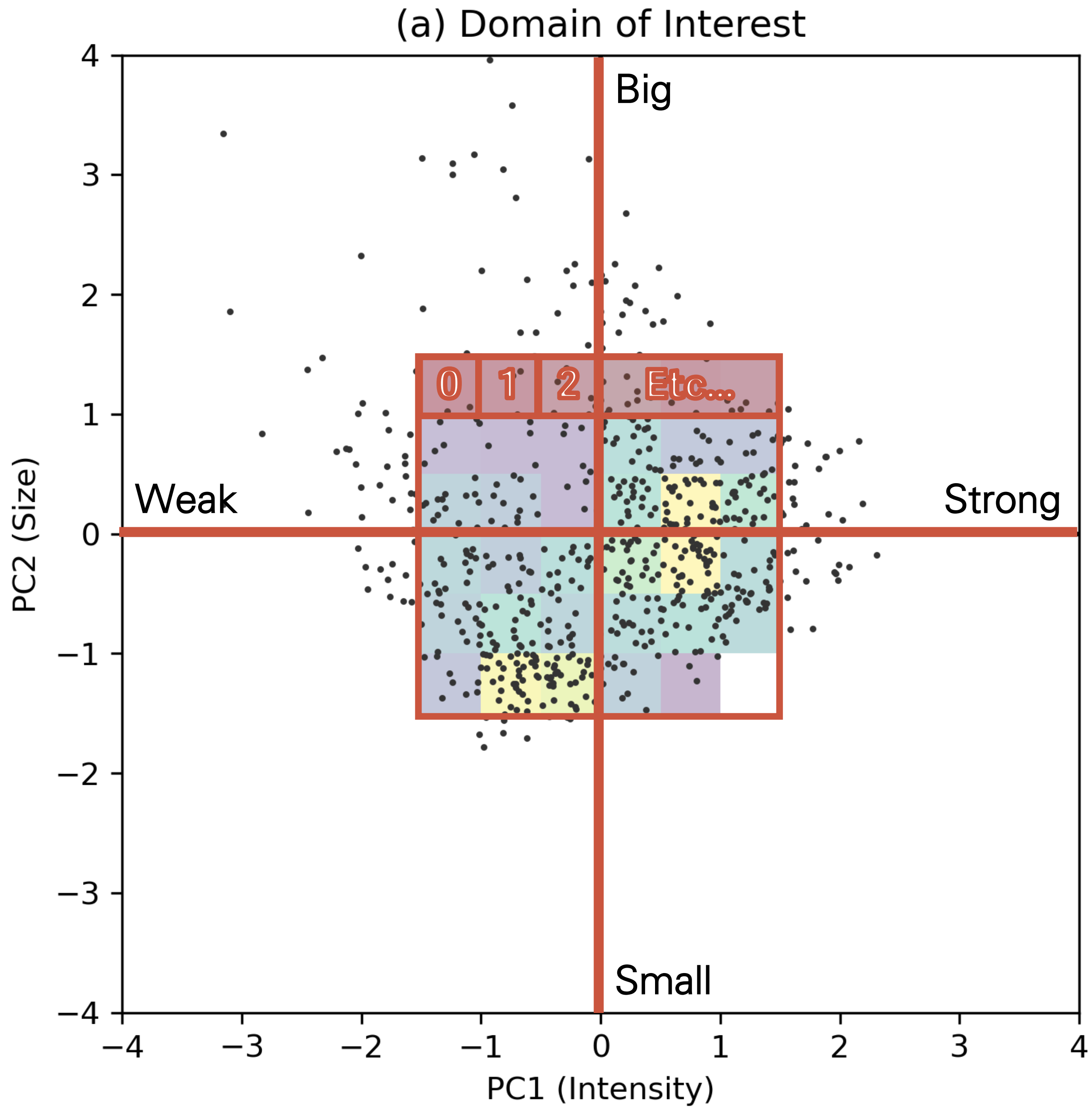
2: Reconstruct semi-realistic idealized profiles from EOF axes

Part 1: Developing the framework

Part 2: Developing the initial profiles

Part 3: What happens?

Part 4: Why?

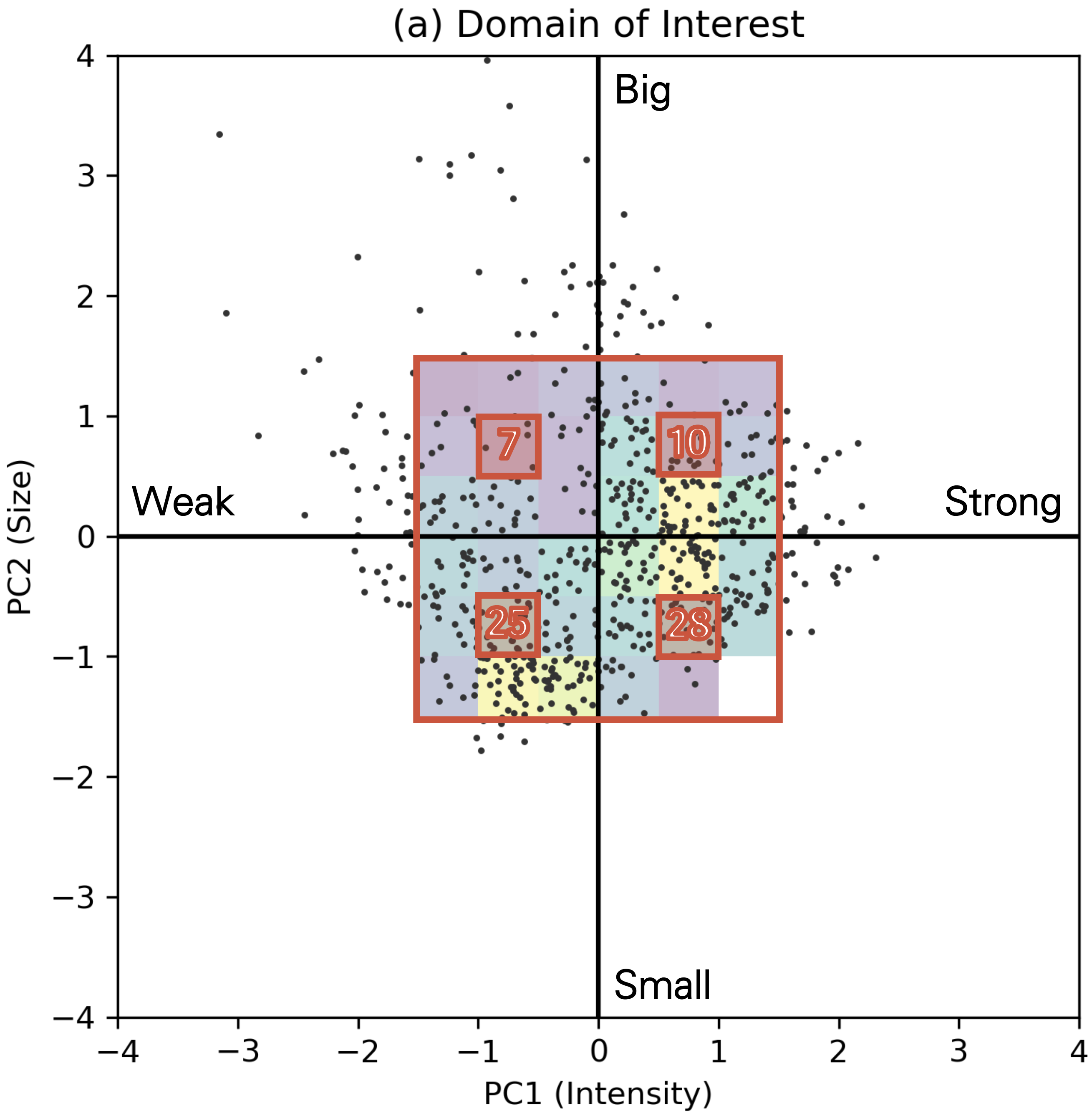


Methods Pt. I

Develop the EOF

1. Define an EOF, where:
    1. PC1 = Intensity
    2. PC2 = Size
2. Domain of interest is between -1.5 to 1.5 with bins of 0.5x0.5

(shading denotes number of obs. within bin)



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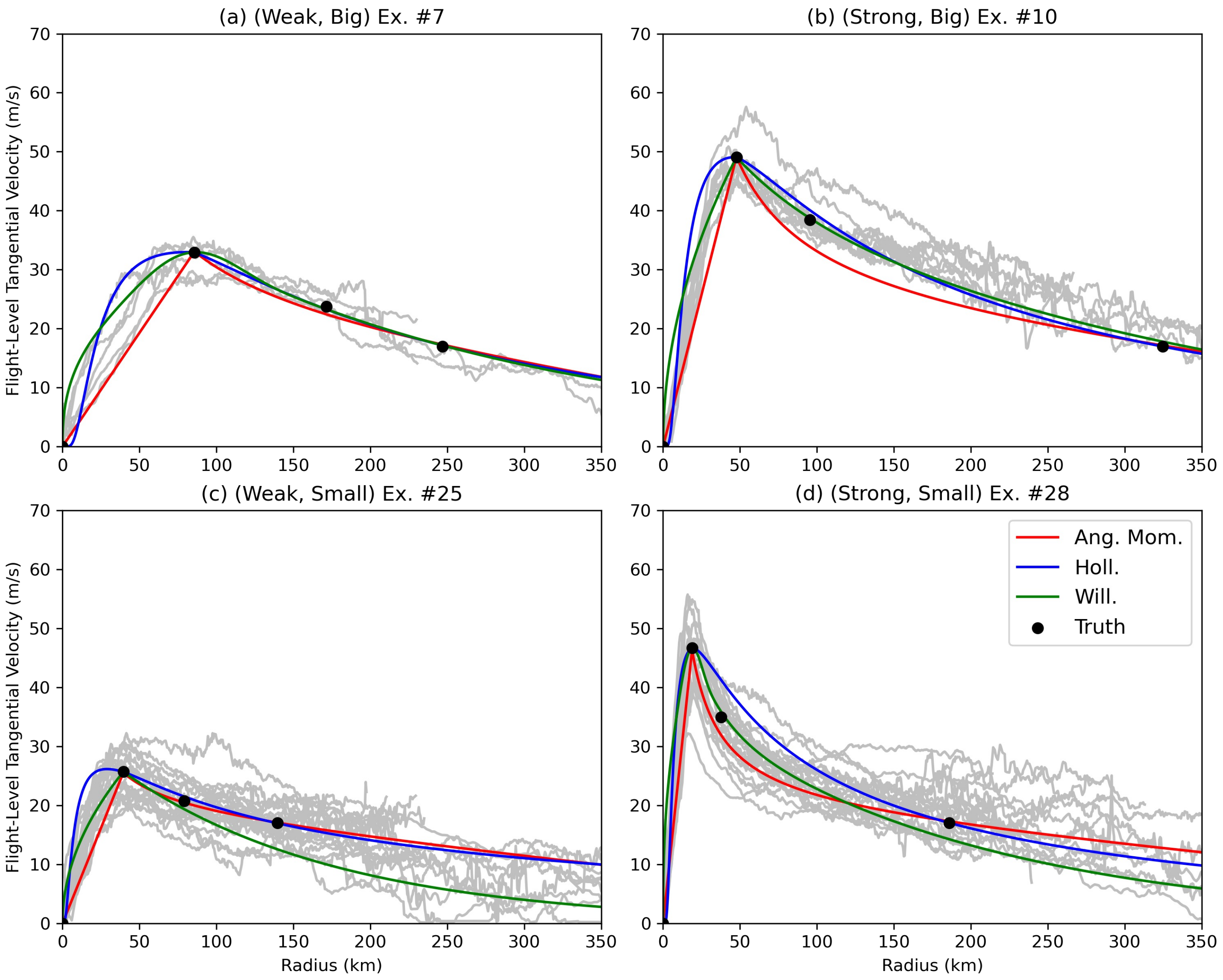
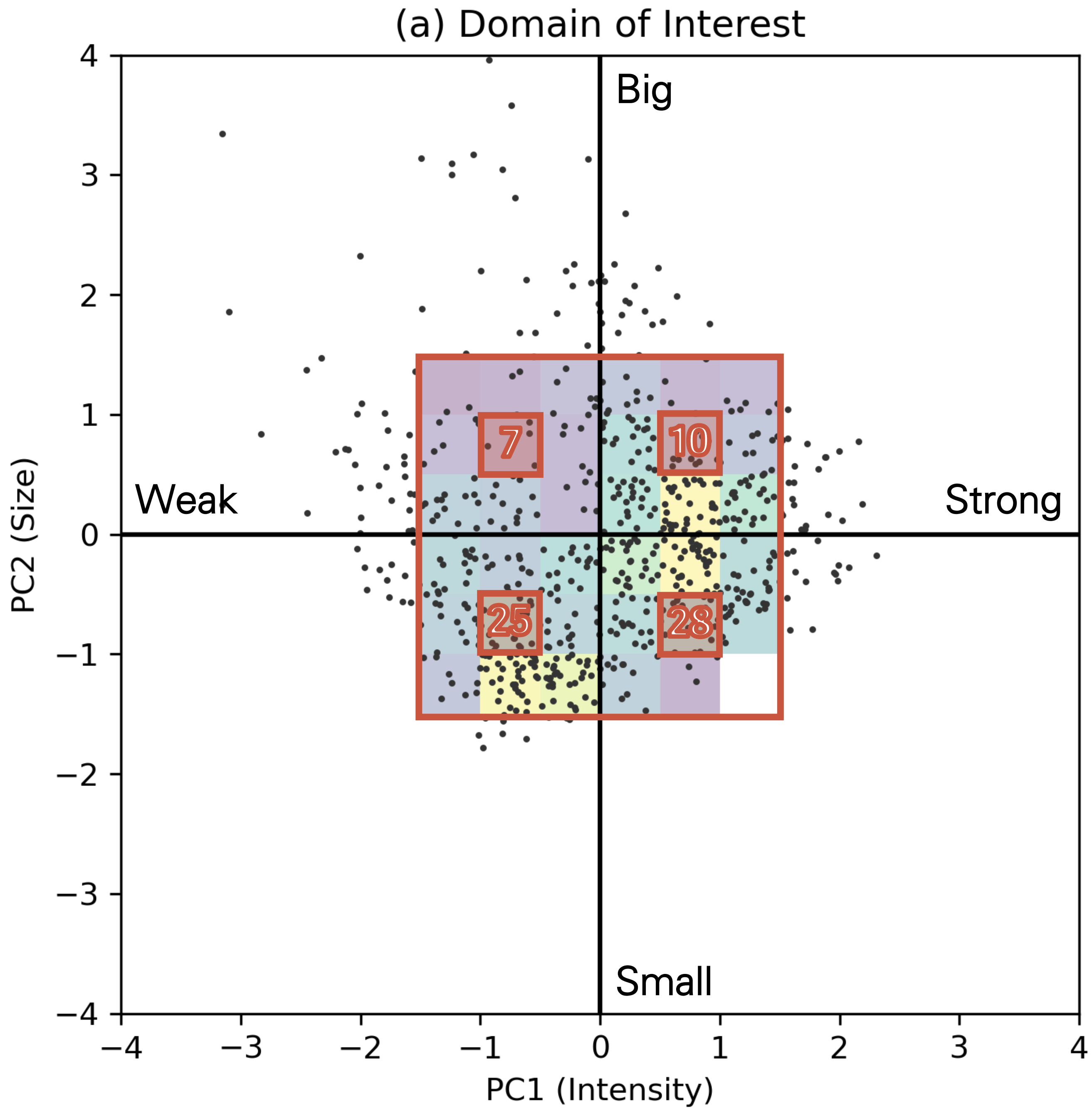


Methods Pt. II

Create the Bogus Vortices

1. Develop initial bogus vortices from bin averages and an assumption of a linear decay of normalized angular momentum from the RMW to R34 (for the red profiles)

Only red tangential wind profiles used in this study



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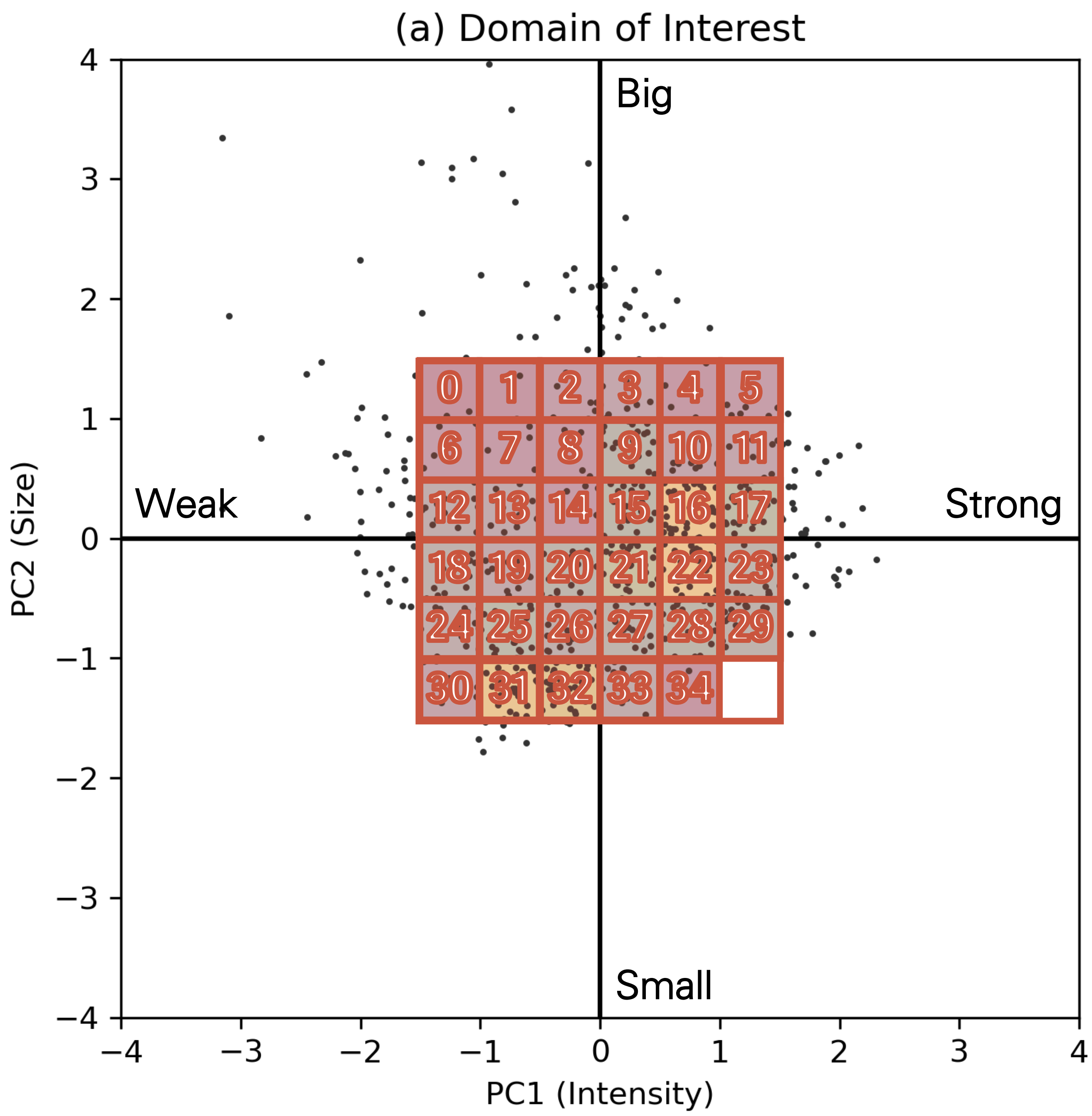


Methods Pt. III

Run axisymmetric CM1

1. Use all 35 red profiles to initialize the axisymmetric version of CM1
    1. All conditions aside from initial structure are identical

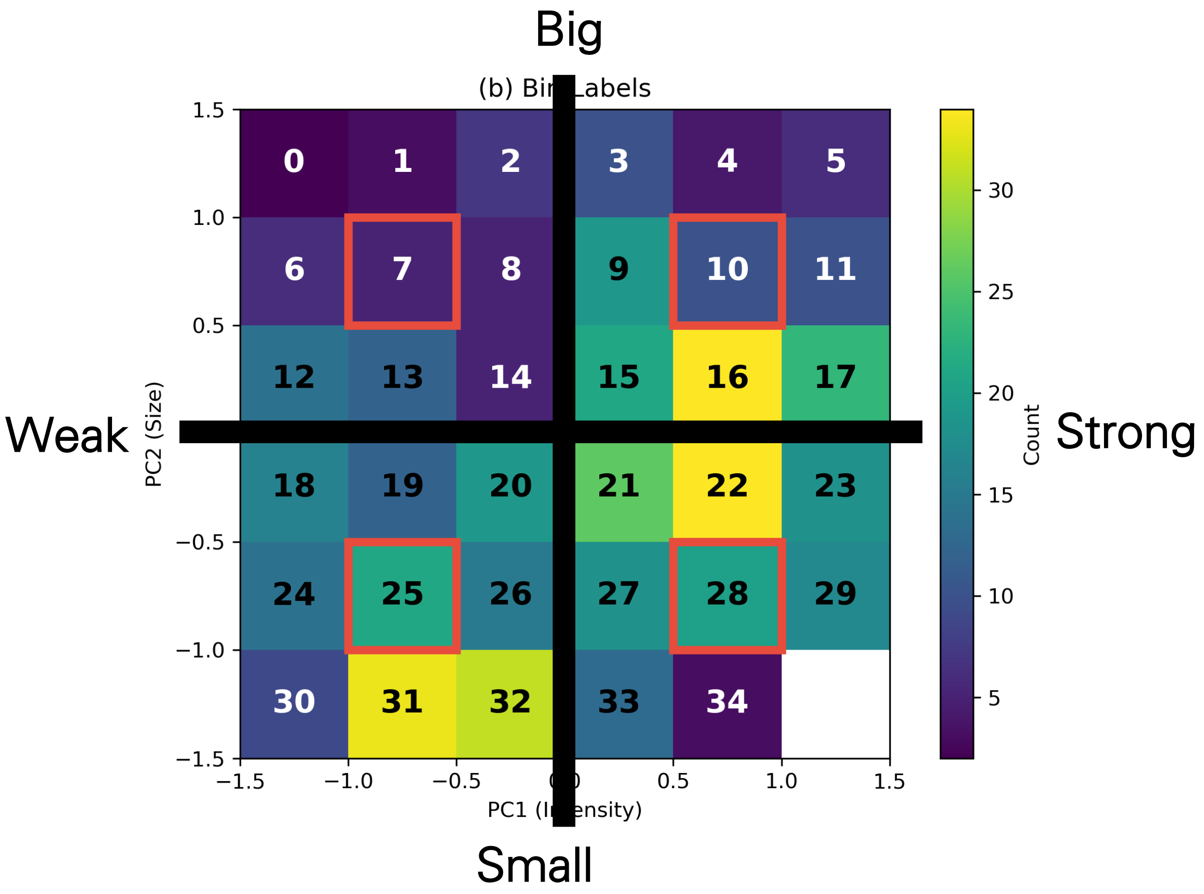
Introducing Color Key

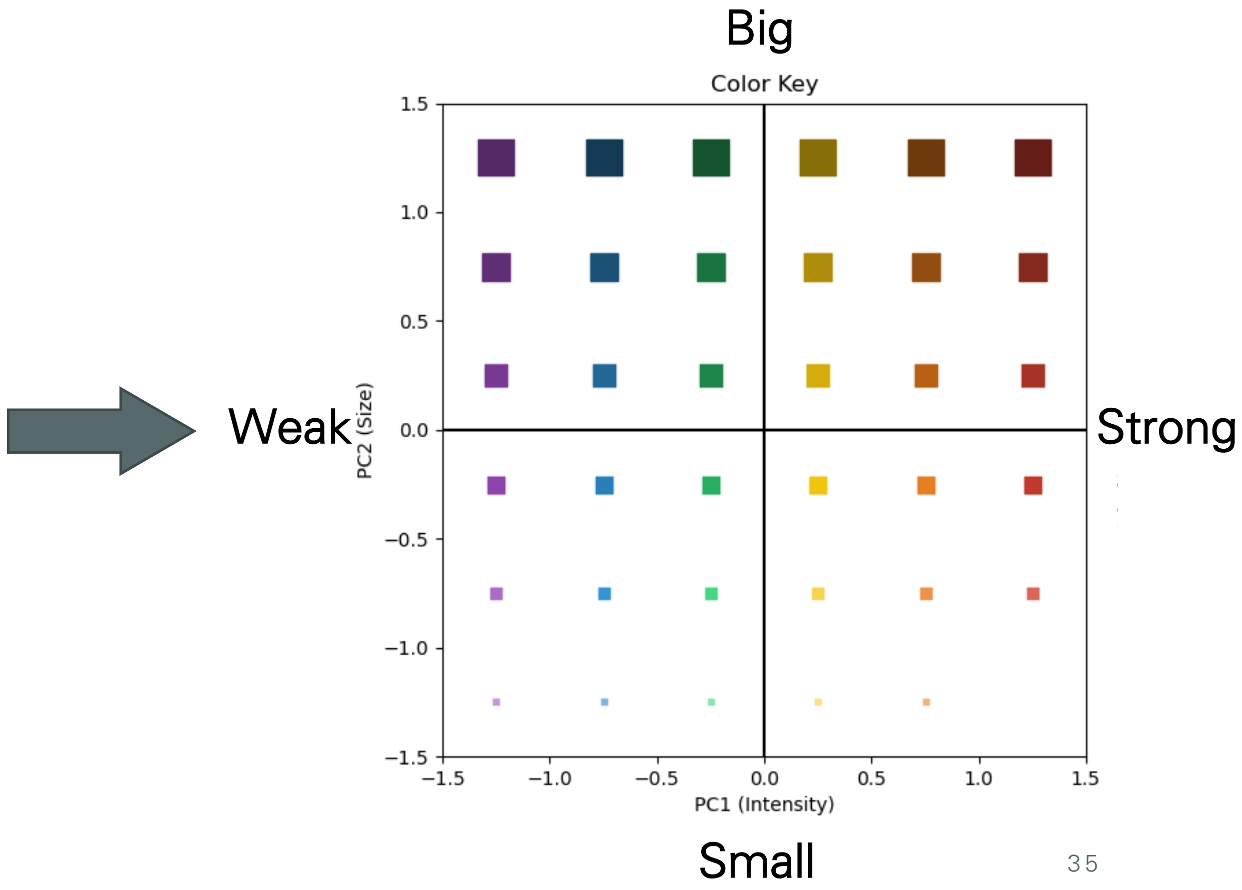
Hue of points represents PC1

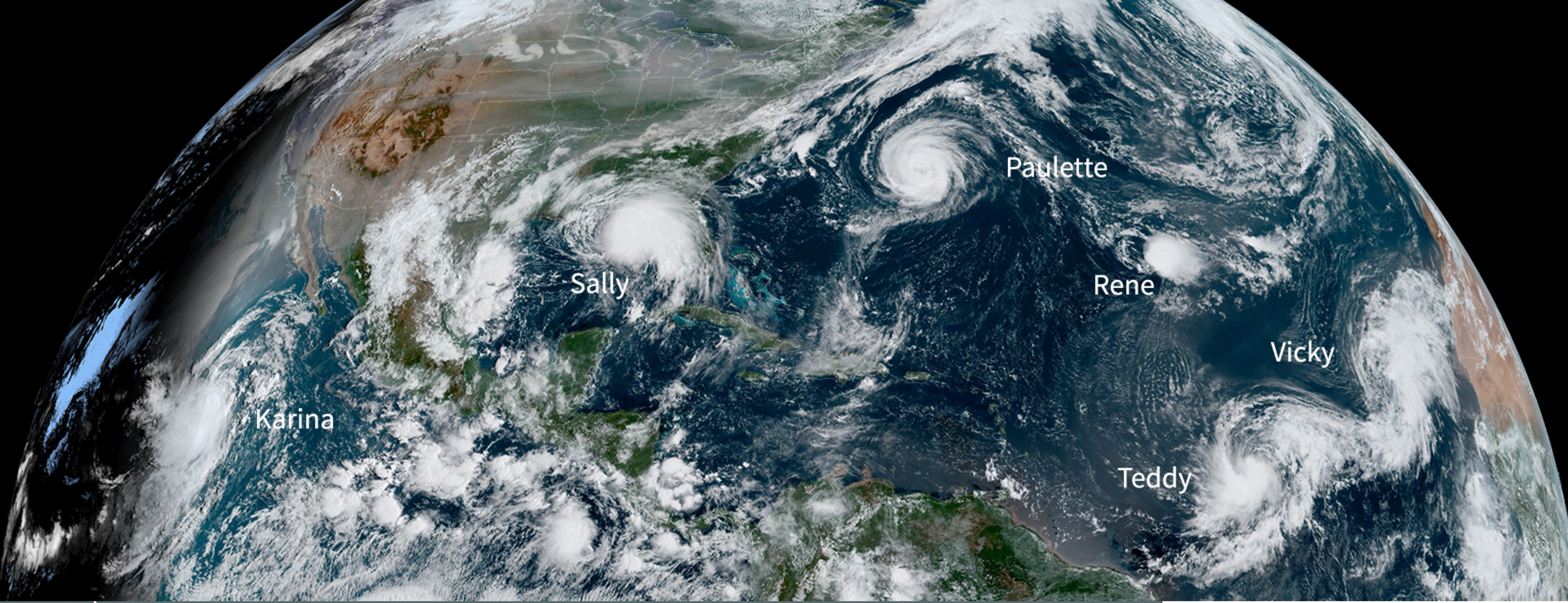
(cool colors = -PC1; warm colors = +PC1)

Size/Shading represents PC2

(small/light = -PC2; big/dark = +PC2)







Part 3: Investigating Structure and Intensity Impacts on RI

Outline

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2: Reconstruct semi-realistic idealized profiles from EOF axes

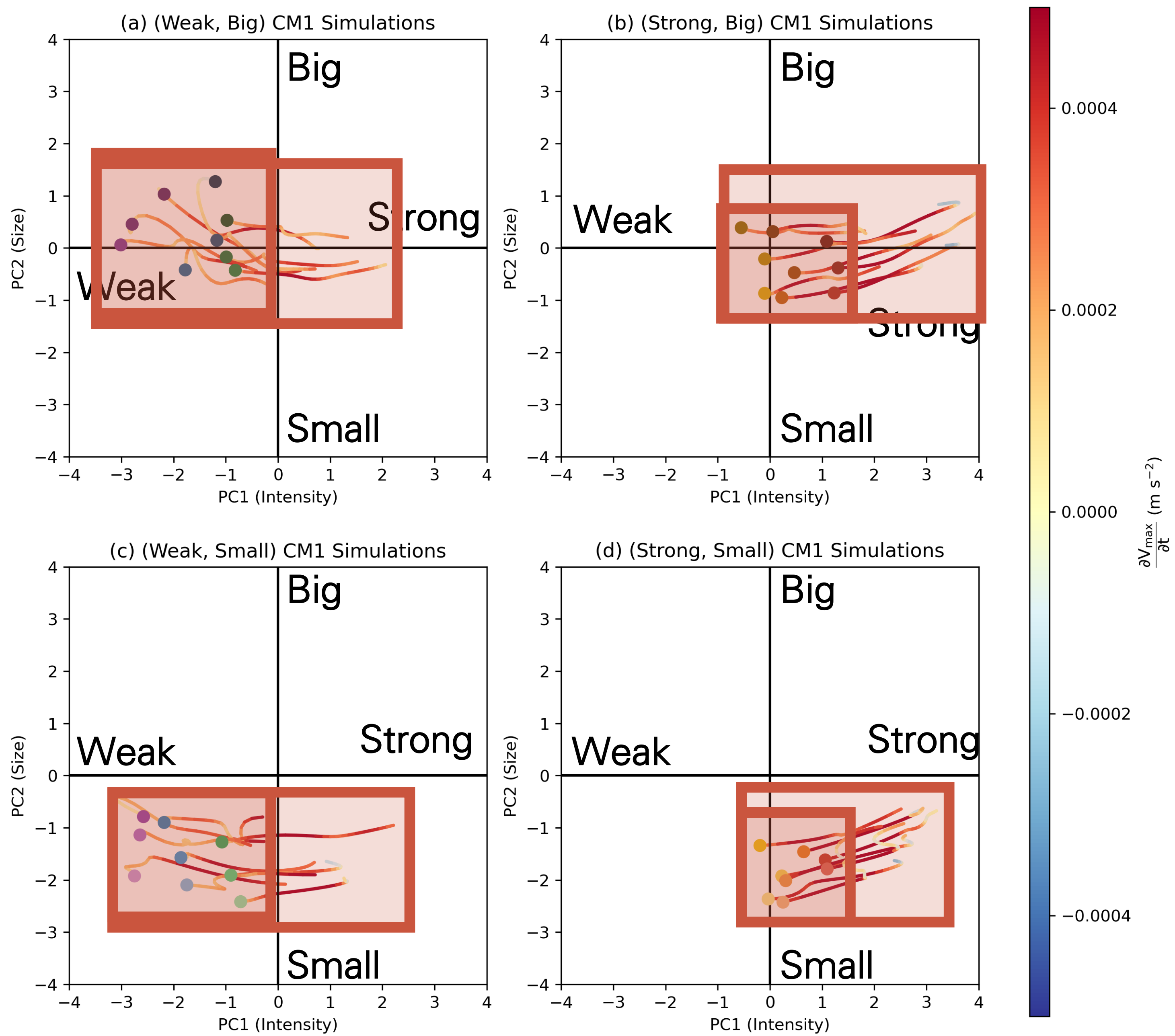
3: Utilize idealized profiles in axisymmetric CM1

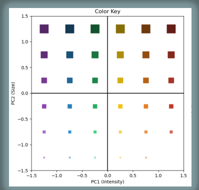
Part 1: Developing the framework

Part 2: Developing the initial profiles

Part 3: What happens?

Part 4: Why?



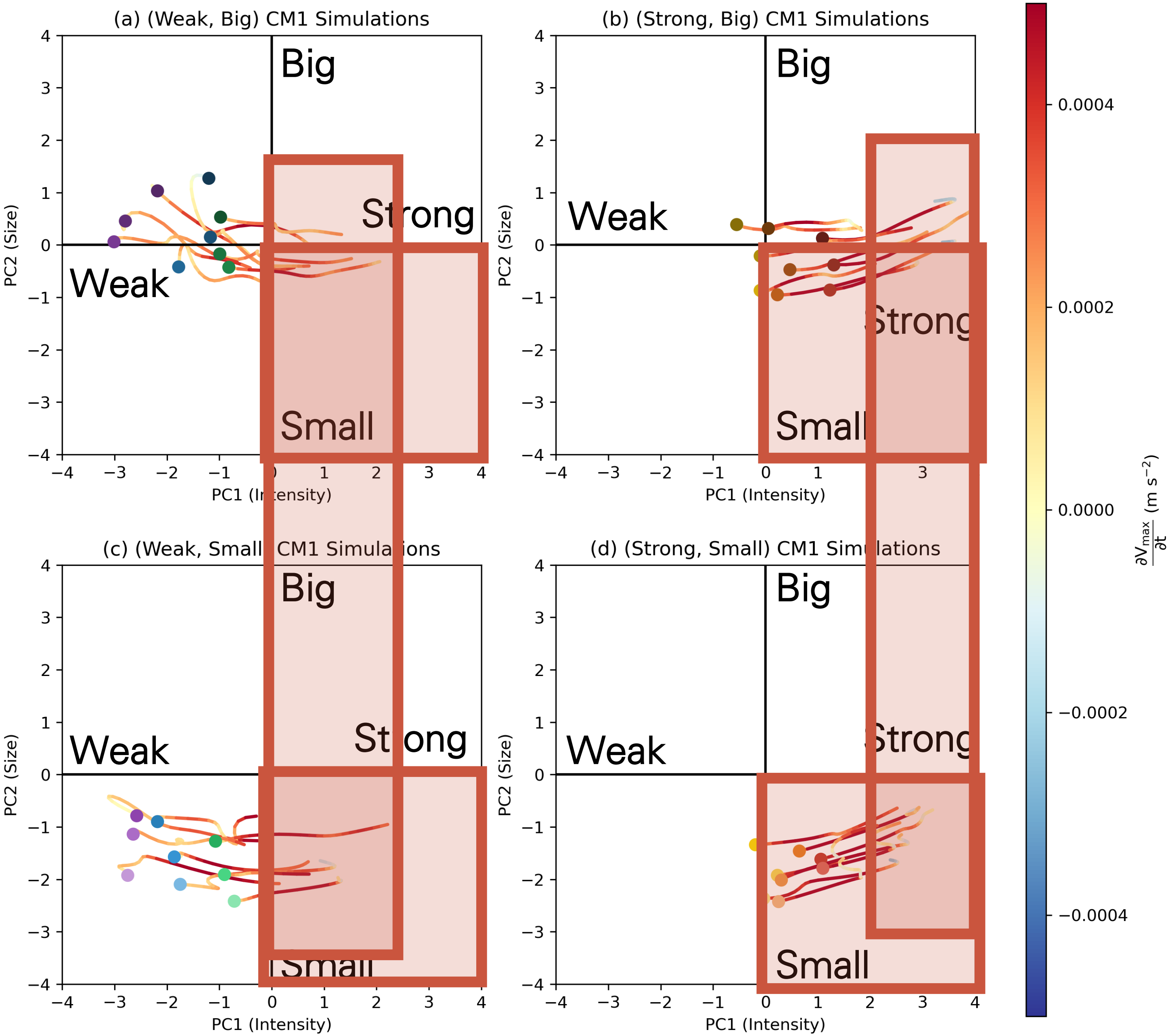


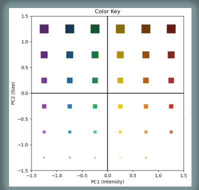
Intensification Rates 0-24 hr after RI Onset

Points denote RI onset

Lines span from 0-24 hr after RI Onset

Shading = instantaneous intensification rate of Vmax



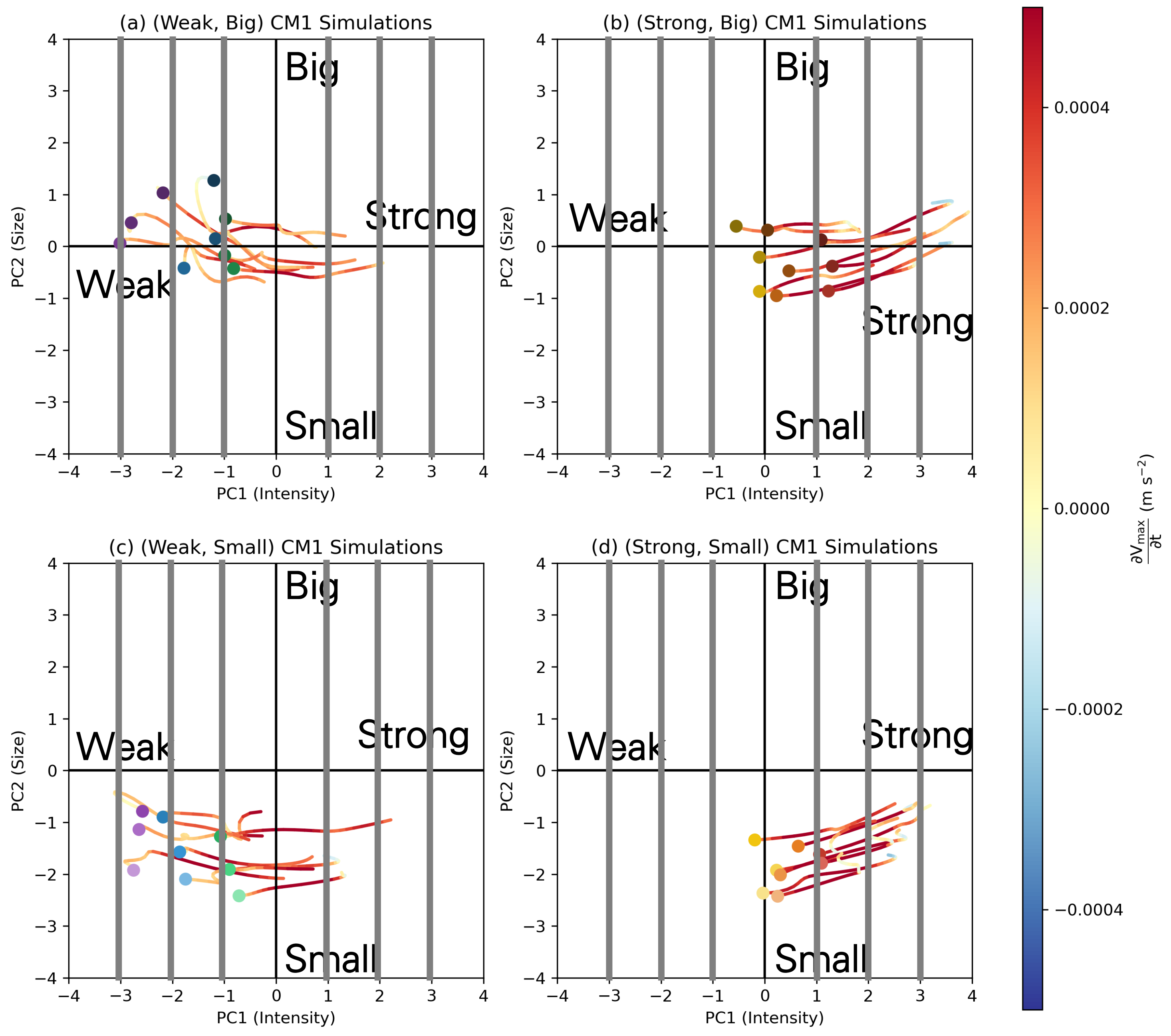


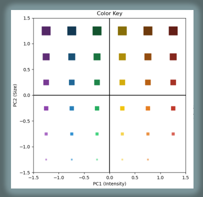
Intensification Rates 0-24 hr after RI Onset

Big TCs reach higher peak intensities than small TCs

The initially weak TCs had not yet reached their peak intensities within 24 hrs

There is a suggestion that the intensification rates tend to be fastest in the (Strong, Small) quadrant regardless of starting condition





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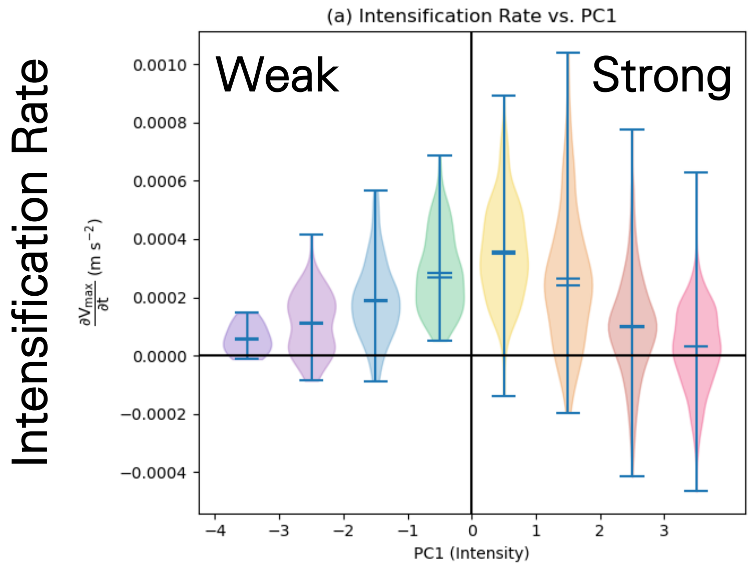


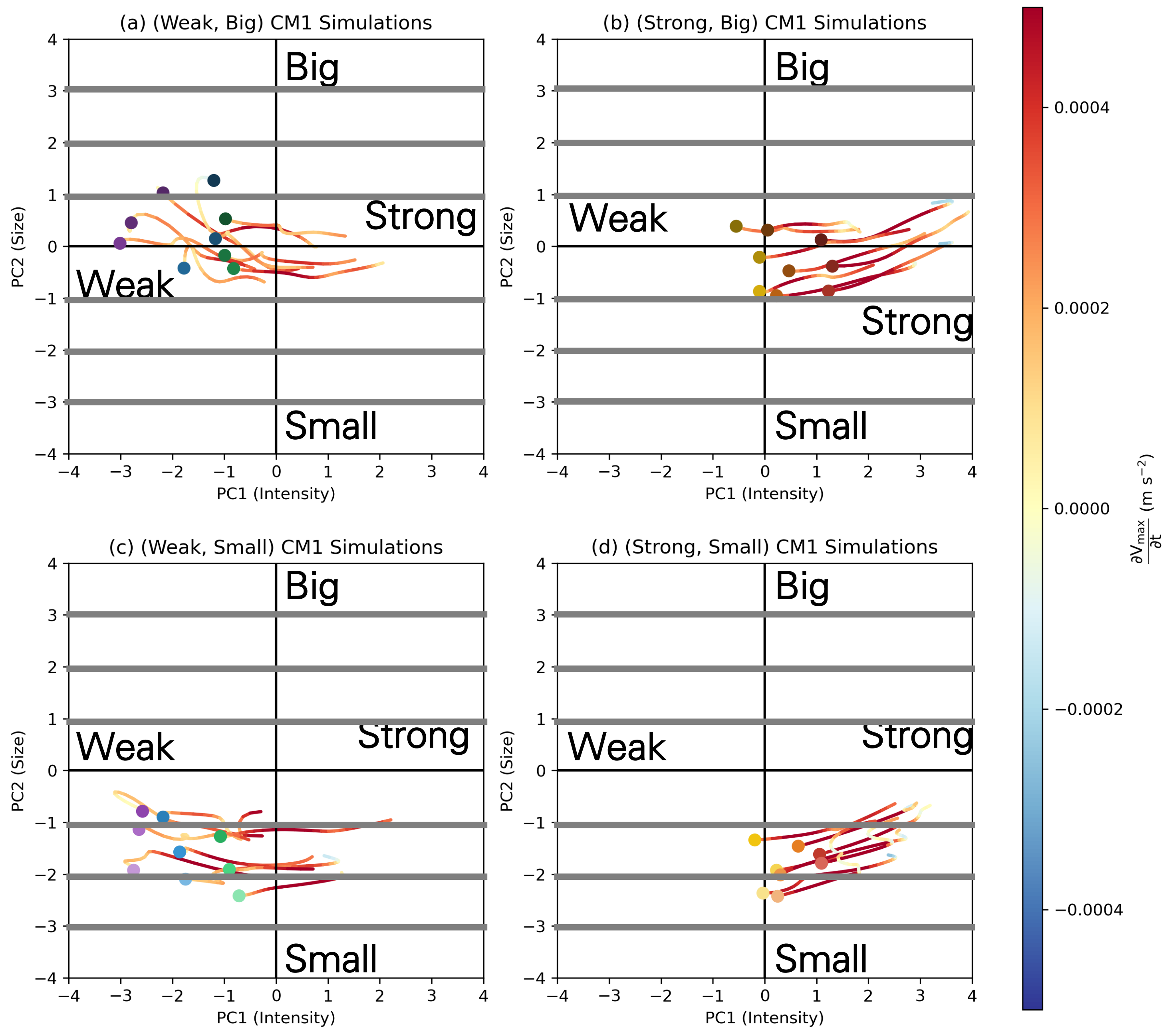
PC1- Intensity

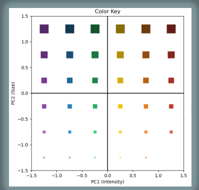
PC2-Size

Rates of Change 0-72 hr after RI Onset

Maximum instantaneous intensification rates keep increasing even after TCs reach above average intensities

(The fastest rates occur just before TCs reach quasi-steady state)





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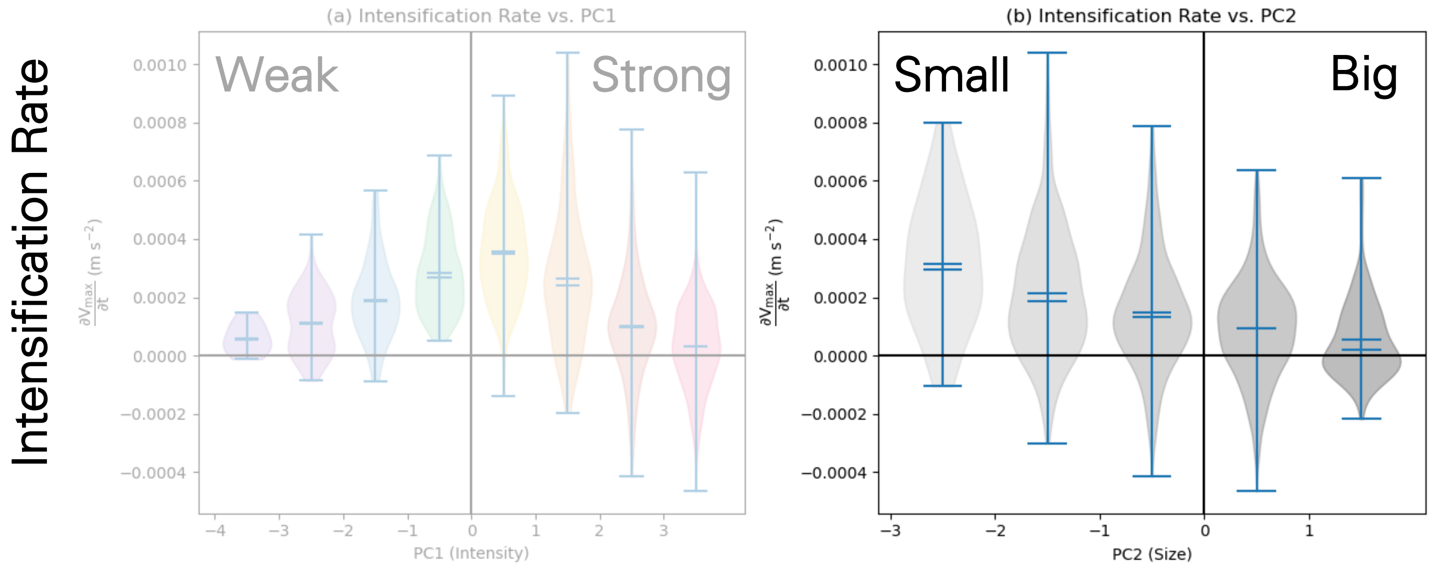


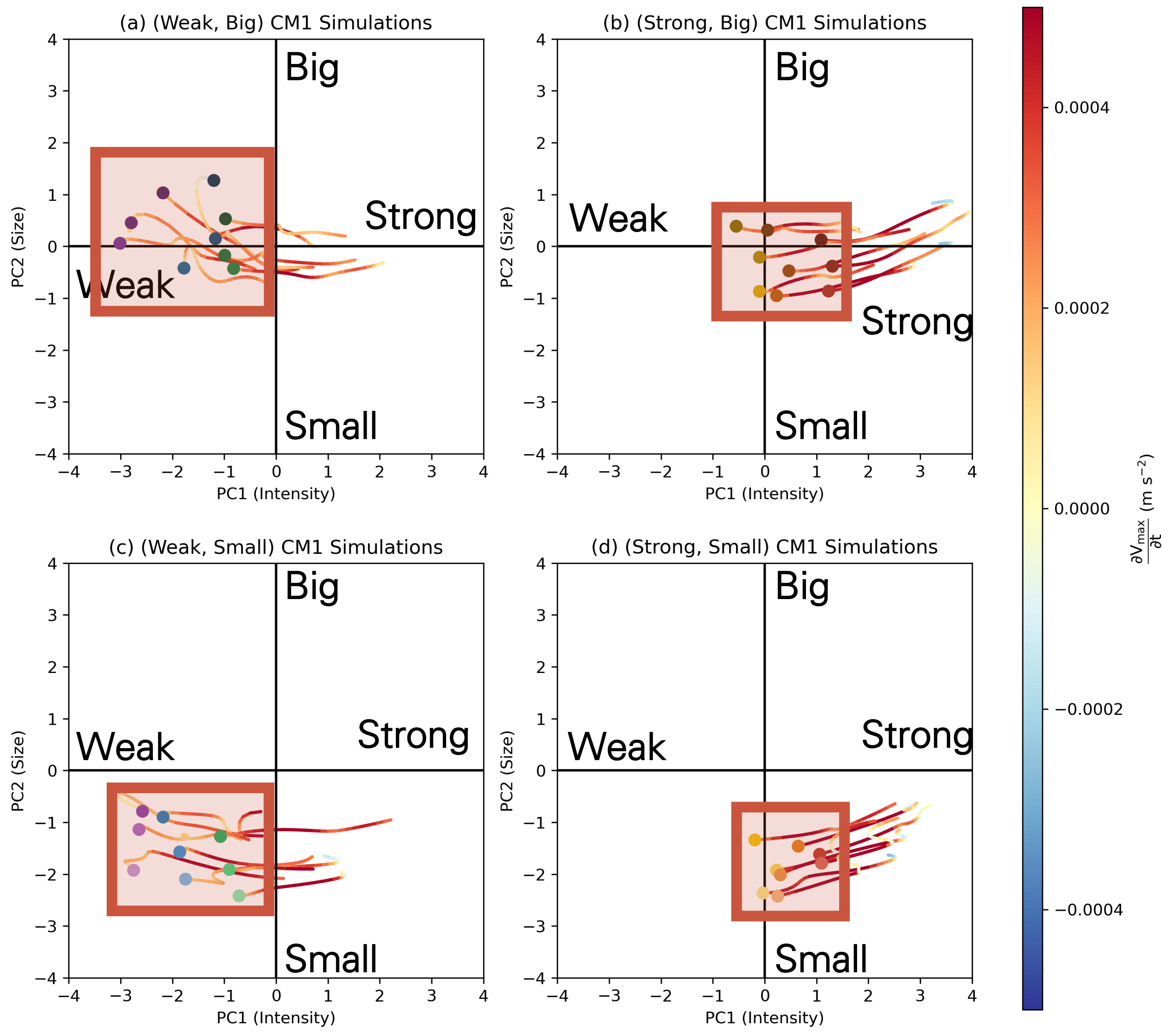
PC1- Intensity

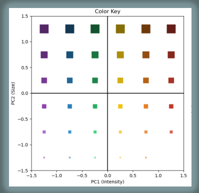
PC2-Size

Rates of Change 0-72 hr after RI Onset

Small TCs are associated with slightly faster intensification rates

Now let's examine how RI varies as a function of initial intensity and size



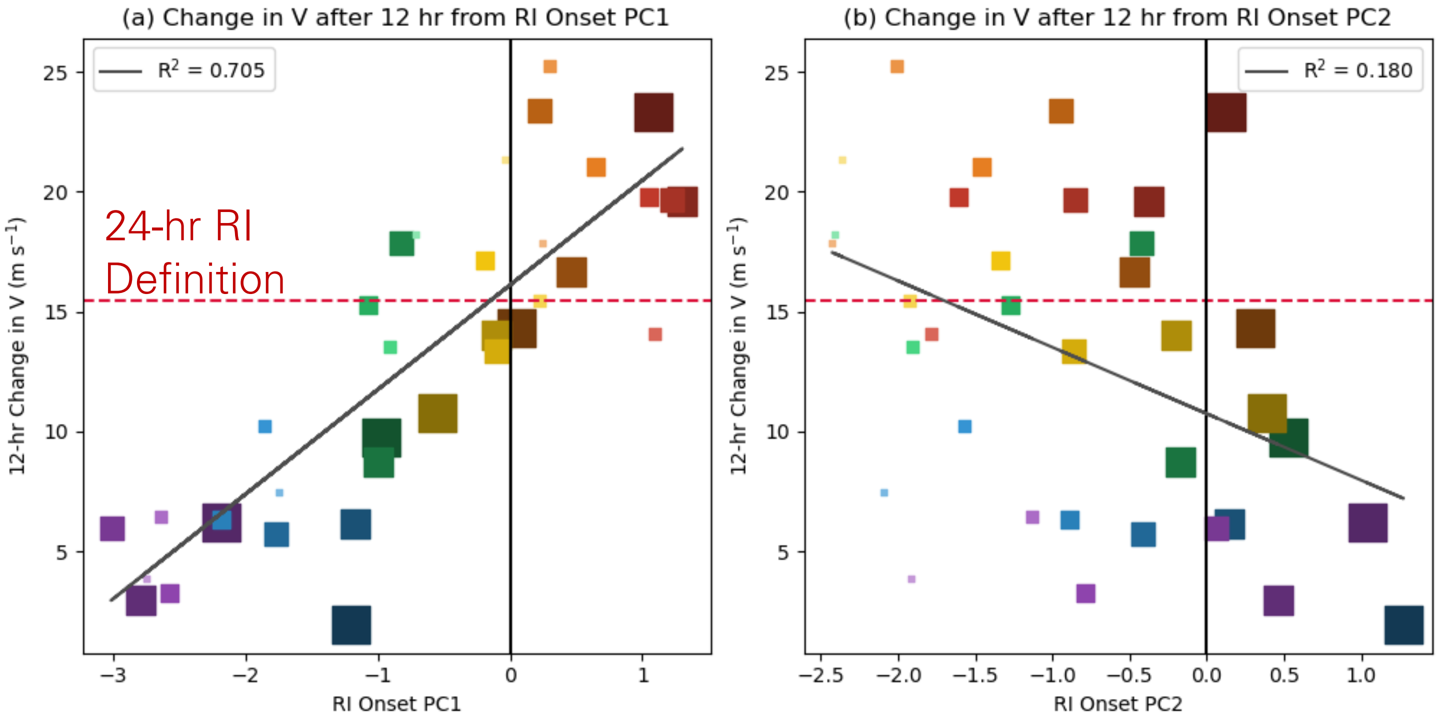


Intensification Rates 0-24 hr after RI Onset

We'll compare how Vmax changes as a function of PC1 and PC2 at RI Onset

Change in Vmax 12 hours* after RI Onset

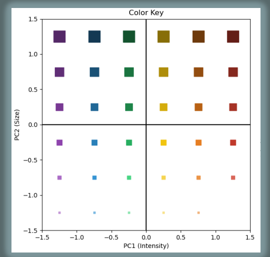
Weak Strong Small Big



PC1- Intensity at RI Onset

PC2-Size at RI Onset

*The relationship from 0-24 hr after RI Onset was weaker because the most intense TCs reached their quasi-steady intensities

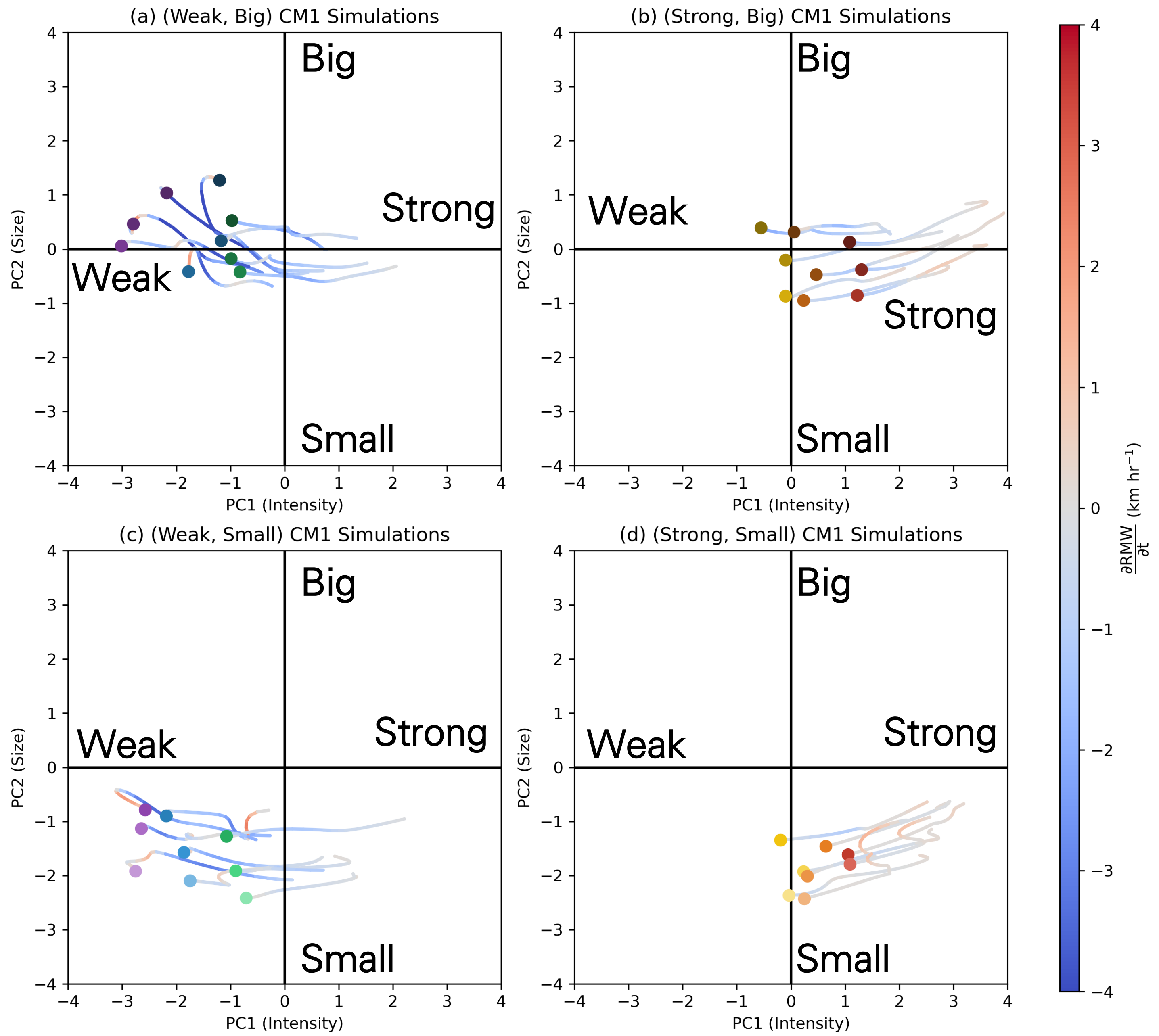


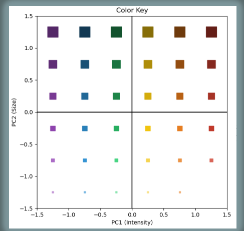
Change in Vmax 12 hr after RI Onset

There is a surprisingly linear relationship with Vmax

The initial rate of RI depends more on the intensity at RI Onset than the size

The more intense a TC is at RI Onset, the faster it could intensify within 12 hours in an ideal environment

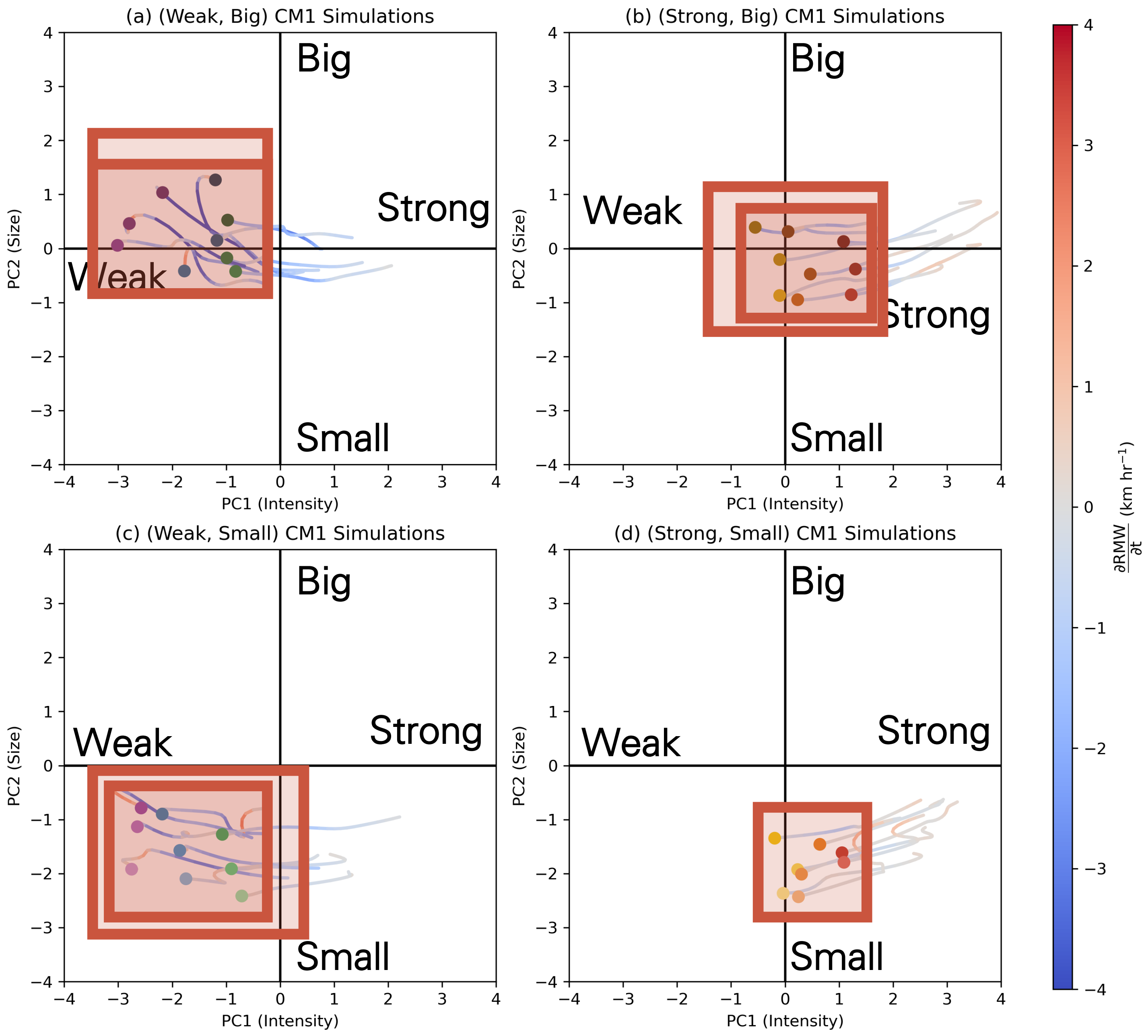


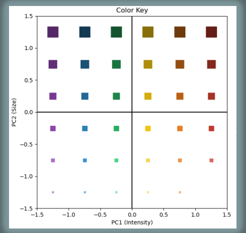


RMW Contraction Rates 0-24 hr after RI Onset

Blues = RMW contraction

Reds = RMW expansion





RMW Contraction Rates 0-24 hr after RI Onset

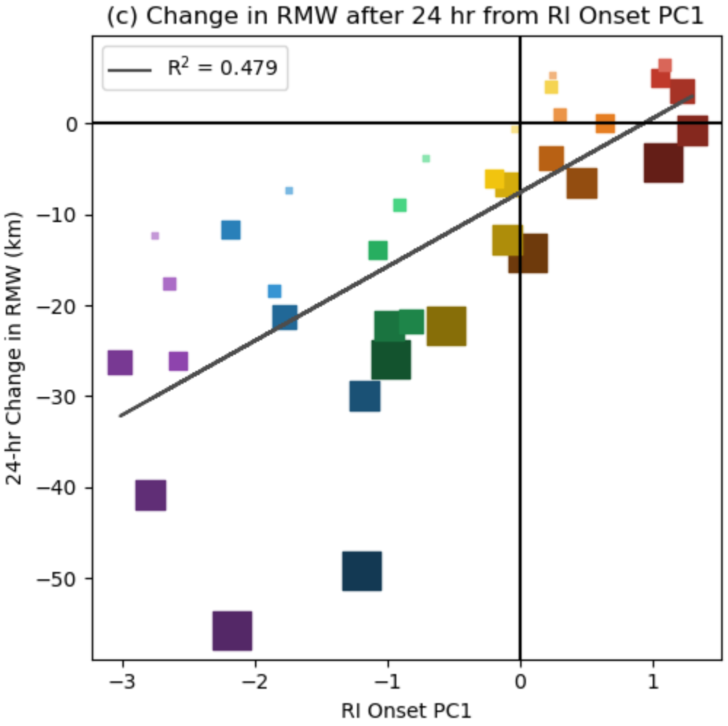
RMW Contraction rates are strongest in (Weak, Big) quadrant

Weak, small TCs experience more contraction than strong, big TCs

RI can occur with or without changes in RMW

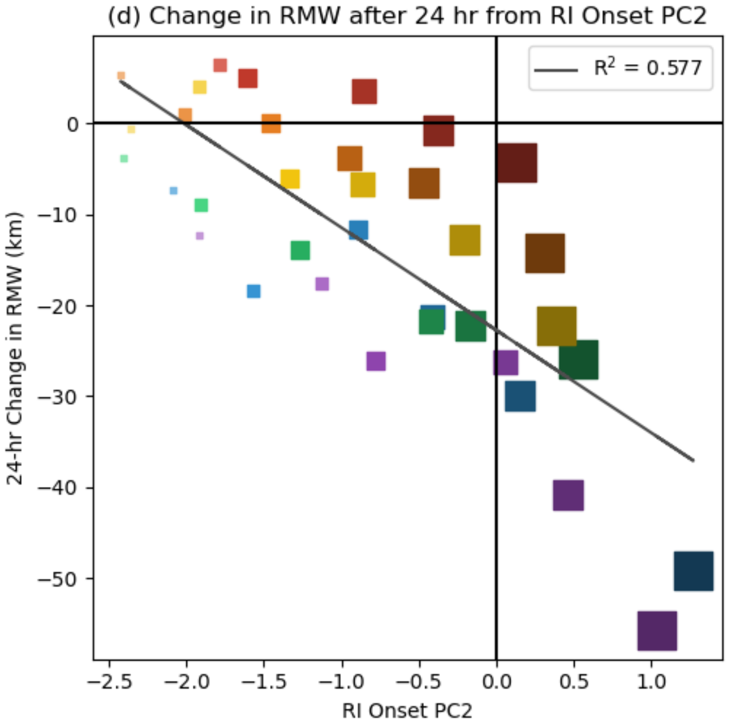
Change in RMW 24 hours* after RI Onset

Weak | Strong



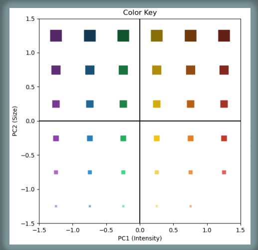
PC1- Intensity at RI Onset

Small | Big



PC2-Size at RI Onset

*The relationship from 0-12 hr after RI Onset was weaker because the largest TCs were still rapidly contracting

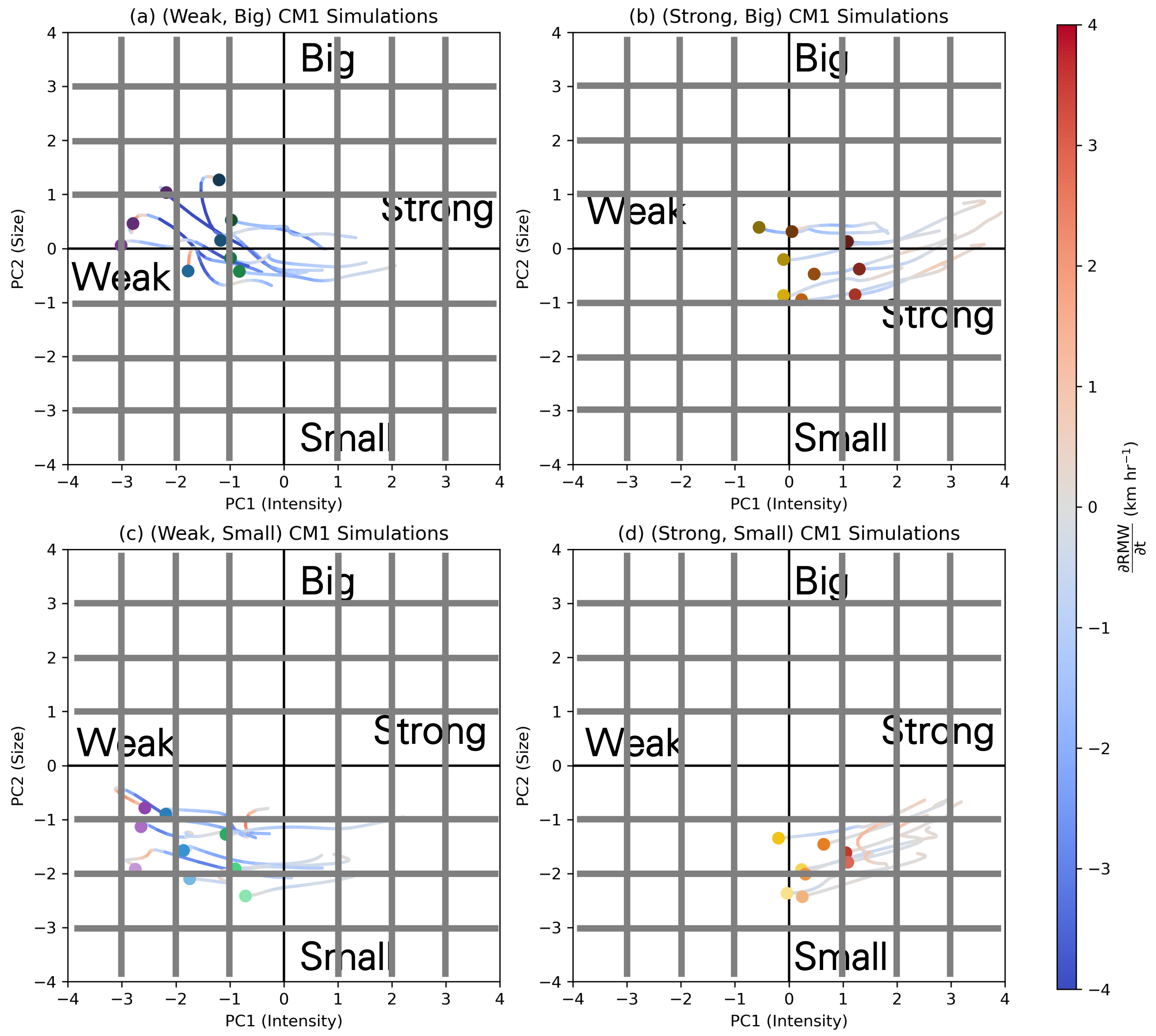


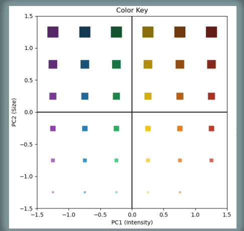
Change in RMW 24 hr after RI Onset

The amount of RMW contraction depends on both intensity and size at RI Onset

Size at RI Onset has a stronger linear relationship

The TCs that had initially slower RI rates were undergoing larger changes in RMW



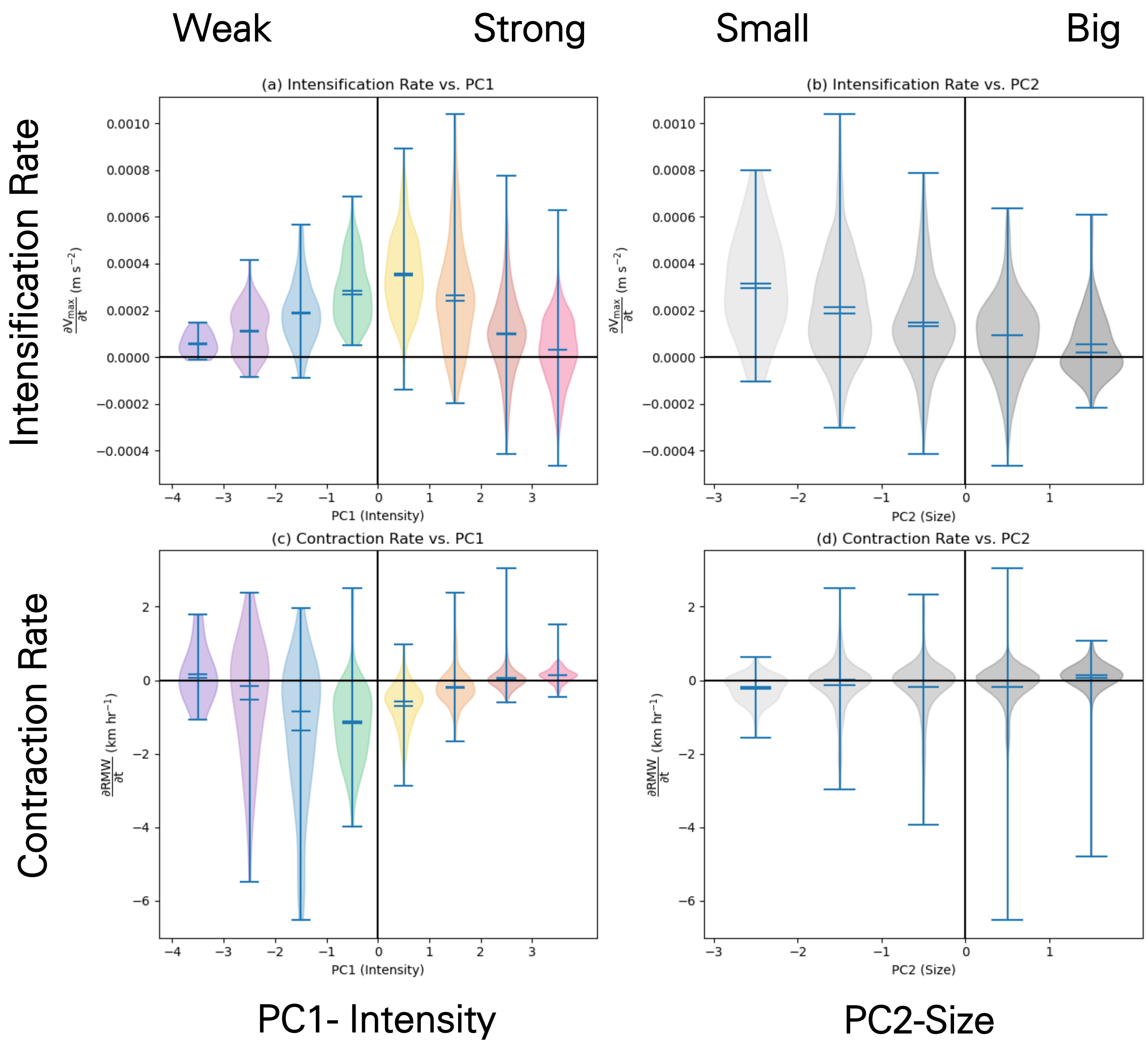


RMW Contraction Rates 0-24 hr after RI Onset

RMW Contraction rates are strongest in (Weak, Big) quadrant

Weak, small TCs experience more contraction than strong, big TCs

RI can occur with or without changes in RMW



Rates of Change 0-72 hr after RI Onset

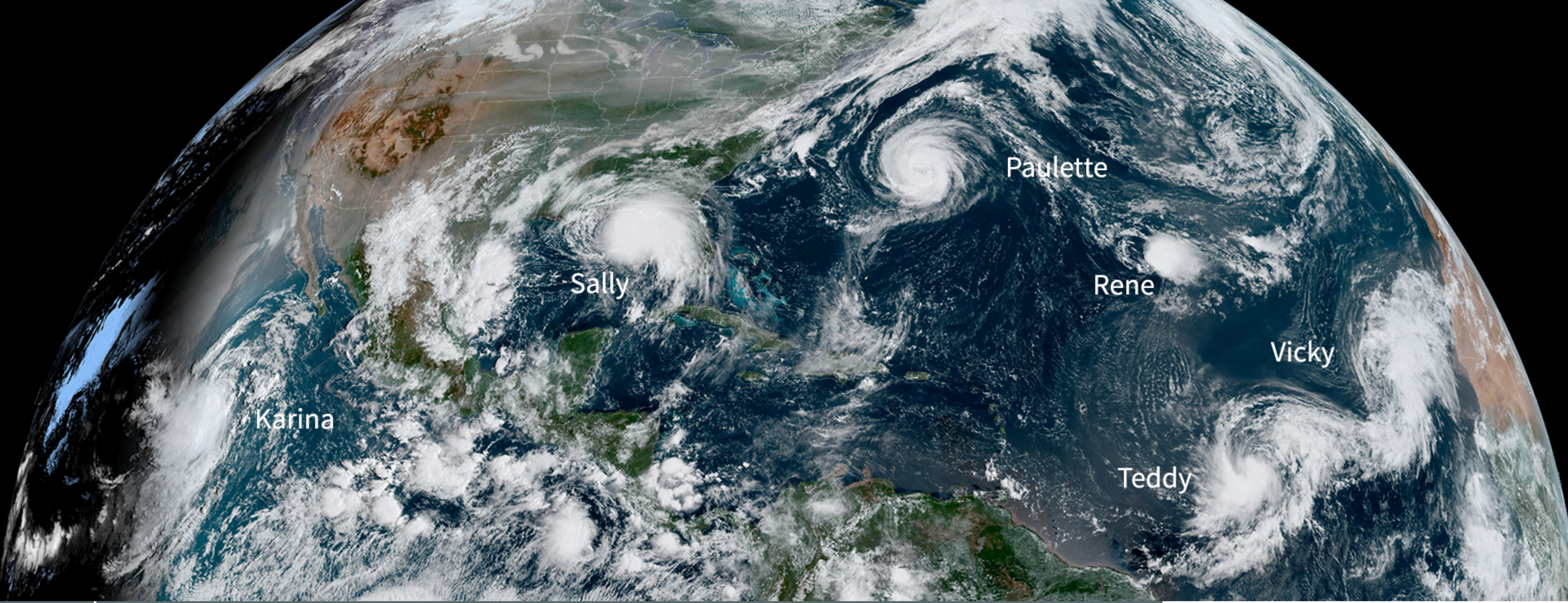
Intensification rates keep increasing until just before TCs reach quasi-steady intensity

RMW Contraction rates peak at below average intensities

Part 3 conclusions

The more intense a TC is at RI Onset, the faster it could intensify within 12 hours in an ideal environment

The fastest RMW contraction rates occur prior to the fastest intensification rates



Part 4: Investigating TCBL effects on intensification vs. contraction

Outline

1: Utilize an EOF analysis to create orthogonal intensity/size axes

2: Reconstruct semi-realistic idealized profiles from EOF axes

3: Utilize idealized profiles in axisymmetric CM1

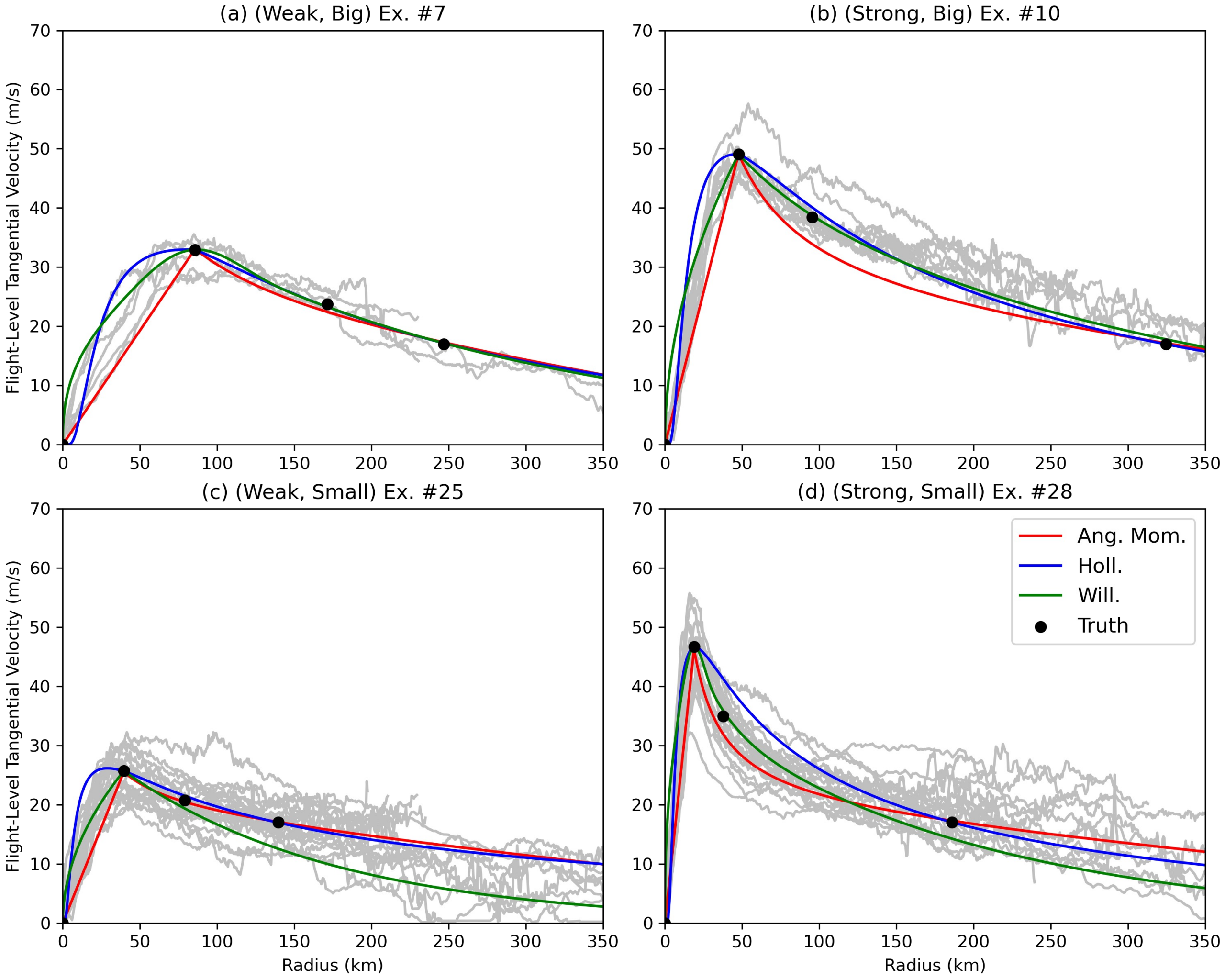
4: Utilize idealized profiles in slab- and height-resolved TCBL models

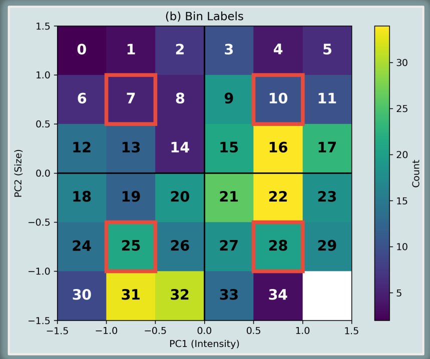
Part 1: Developing the framework

Part 2: Developing the initial profiles

Part 3: What happens?

Part 4: Why?* (one explanation)

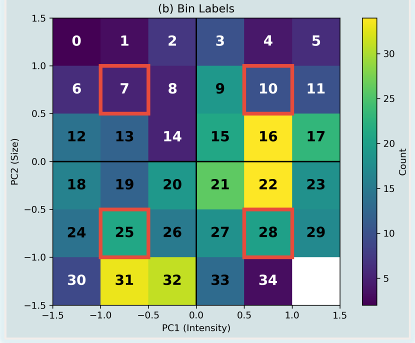




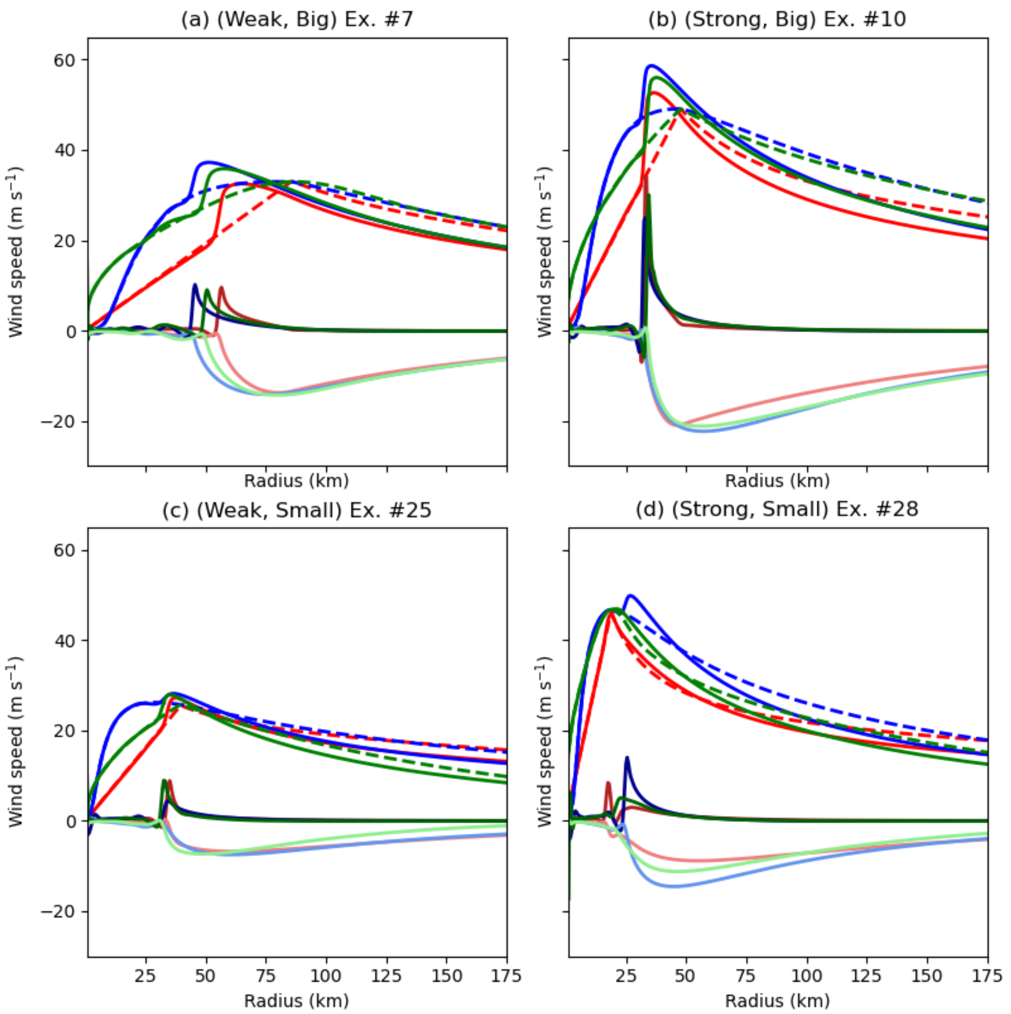
Methods

1. Use **all three** sets of simplified profiles in slab TCBL model
2. Use only red profiles in height-resolved TCBL model

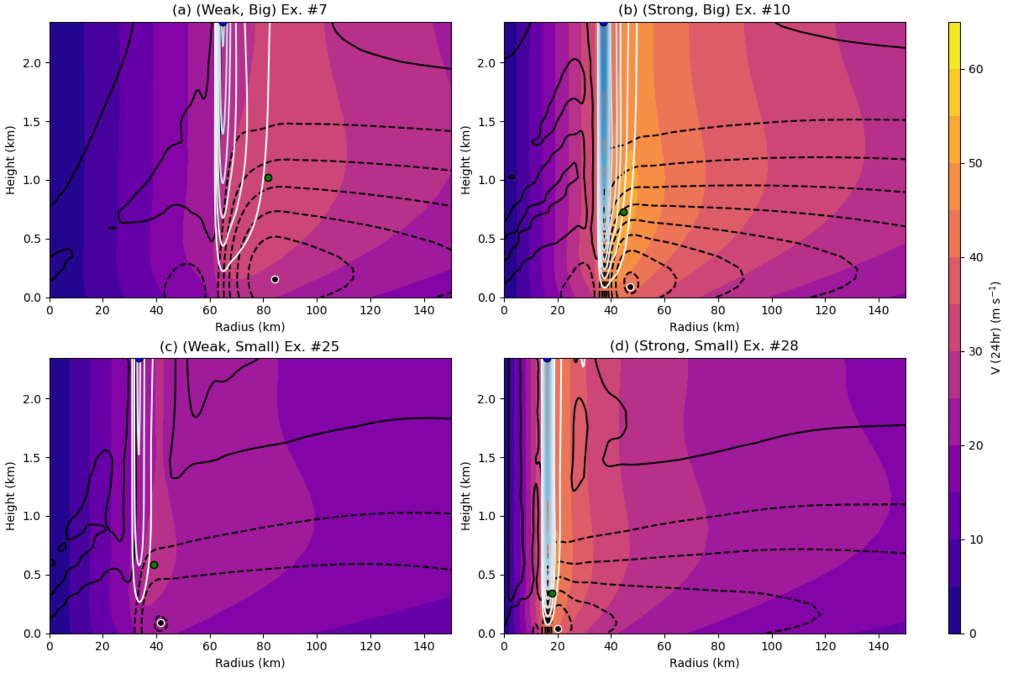
Example Profiles from Each Quadrant



Slab TCBL



Dashed = initial profile
Solid = quasi-steady profile



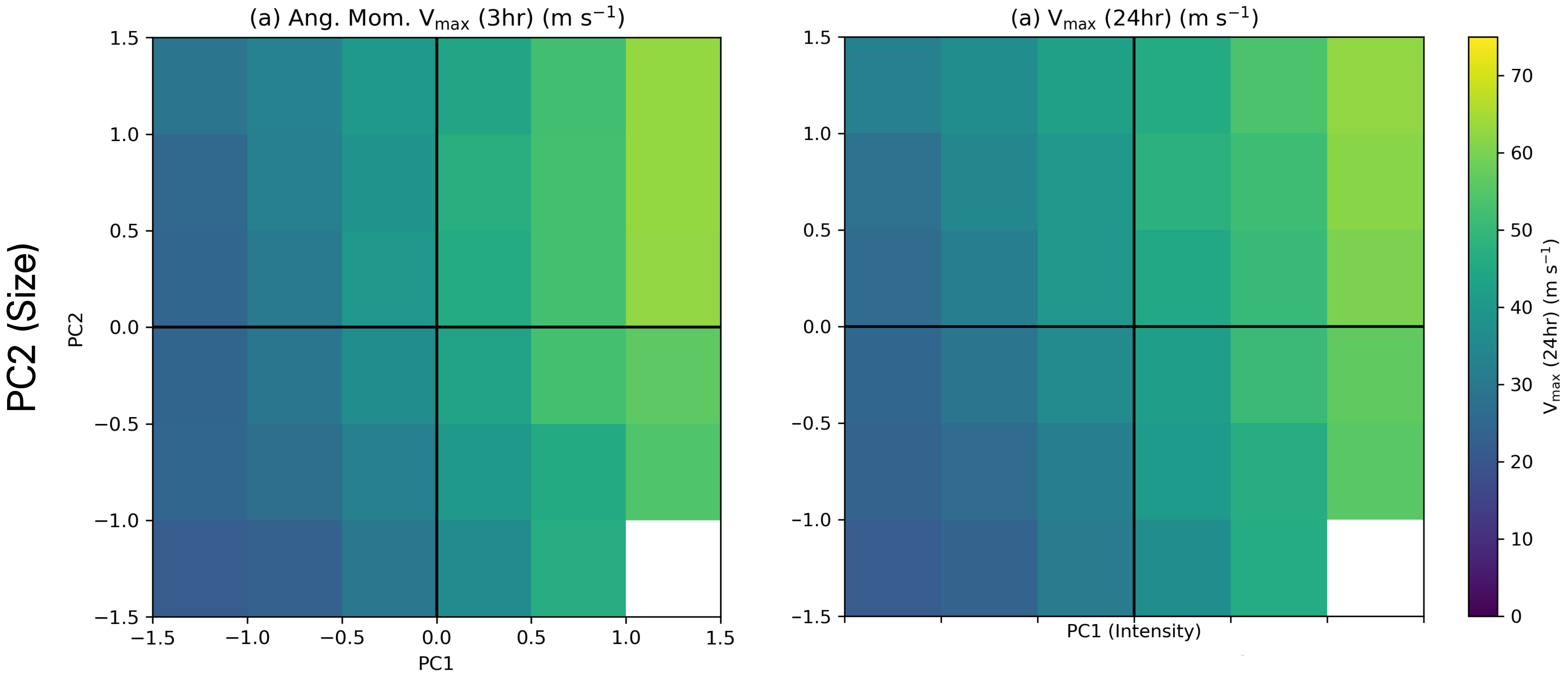
Quasi-steady profiles shown

Height-Resolved TCBL

Tangential Wind (V_{max}) ⊗

Slab TCBL

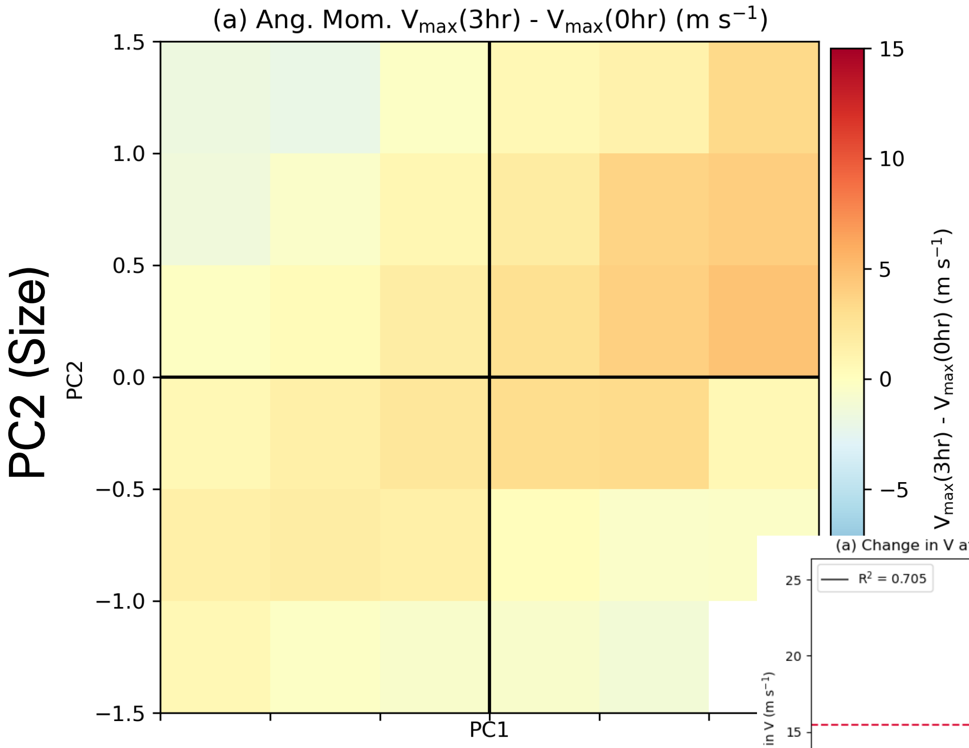
Height-Resolved TCBL

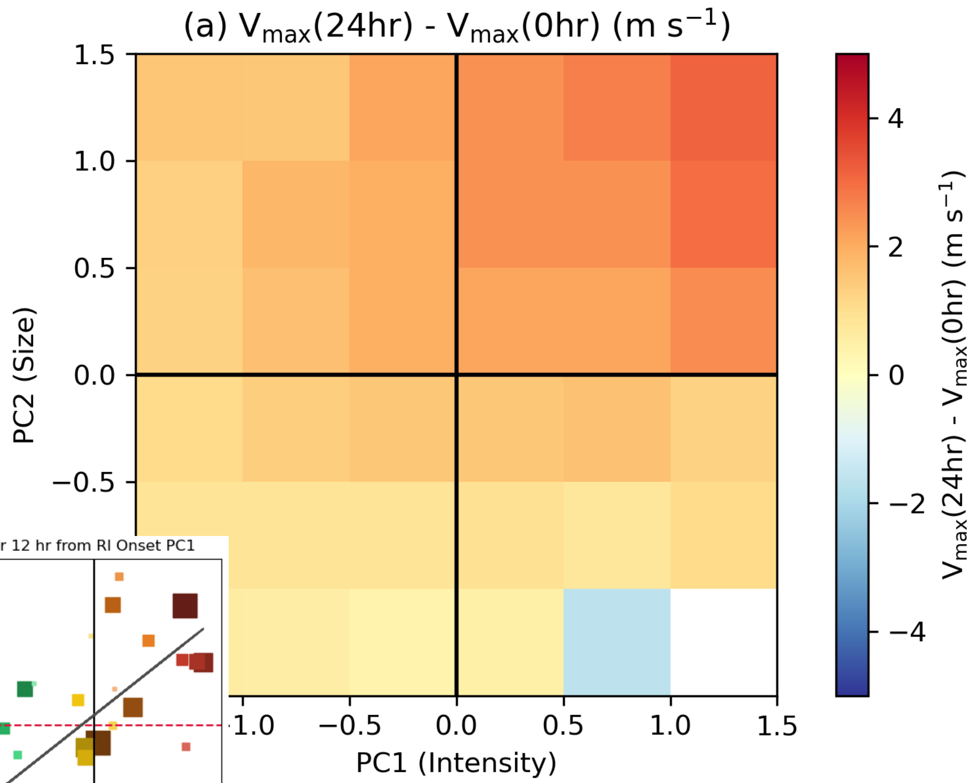


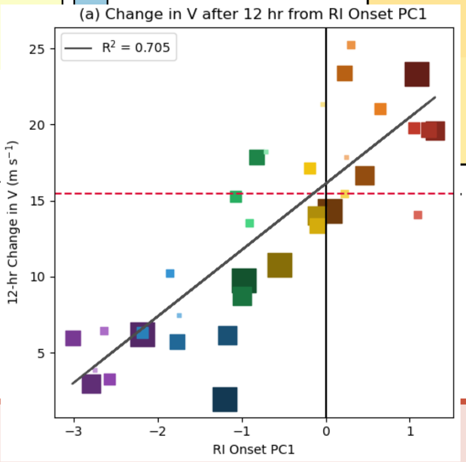
PC1 (Intensity)

Strong, Big TCs have the largest V_{max}

Supergradient Wind ($V_{max[steady]}$ - $V_{max[initial]}$)







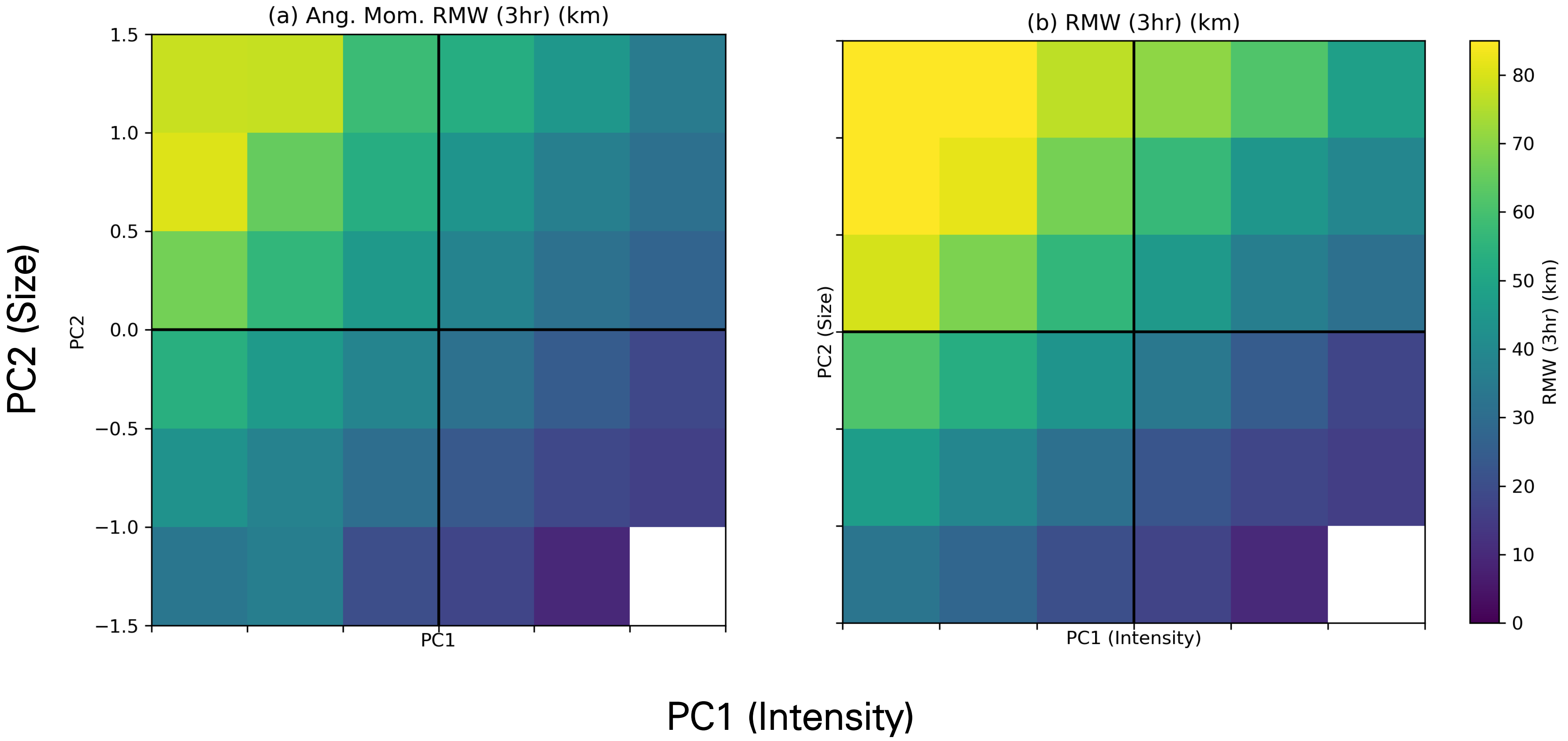
Slab TCBL

Height-Resolved TCBL

Strong, Big TCs have the largest supergradient winds

Radius of V_{max} (RMW)

Slab TCBL



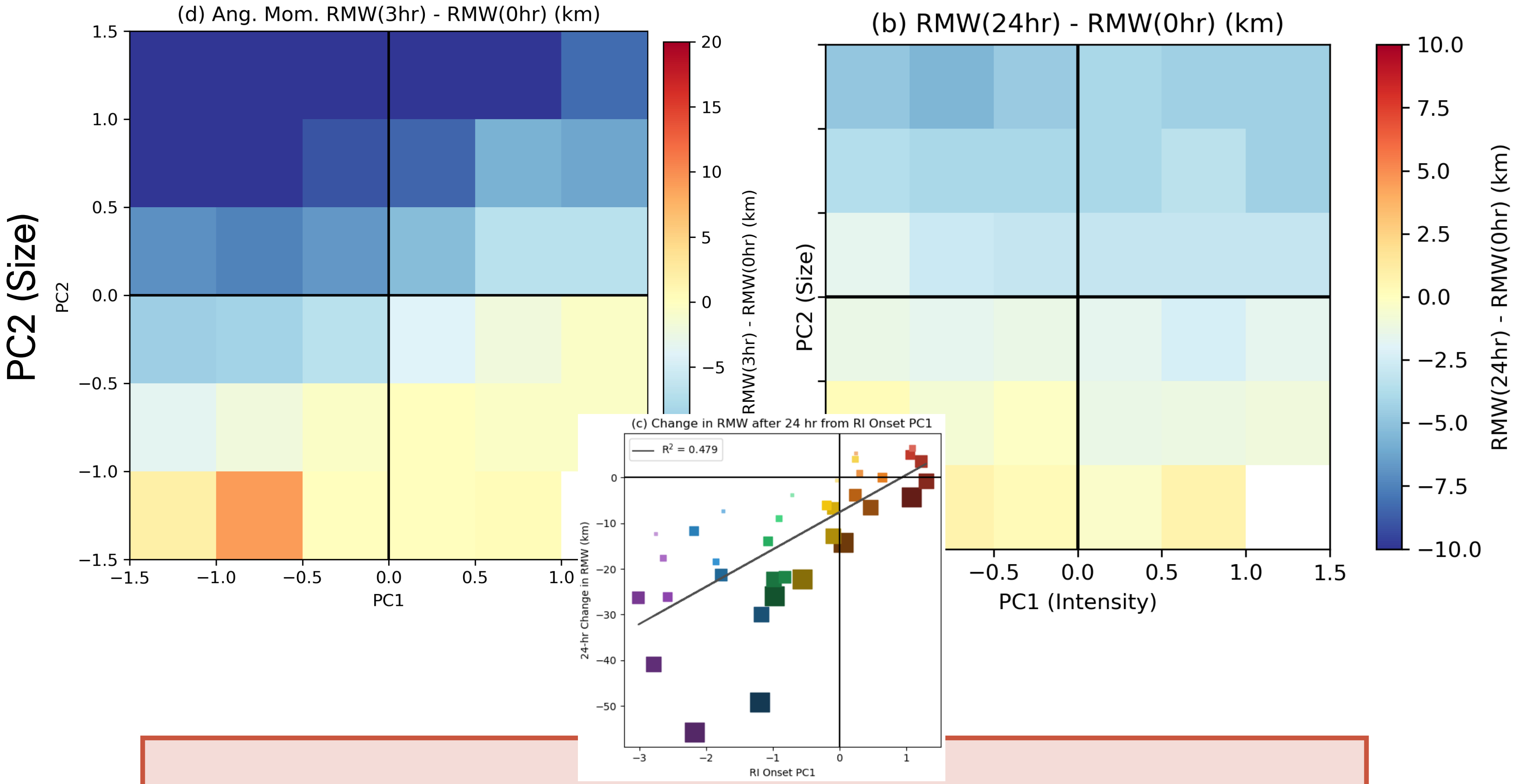
Height-Resolved TCBL

Weak, Big TCs have the largest RMW

Change in RMW ($RMW_{[steady]} - RMW_{[initial]}$)

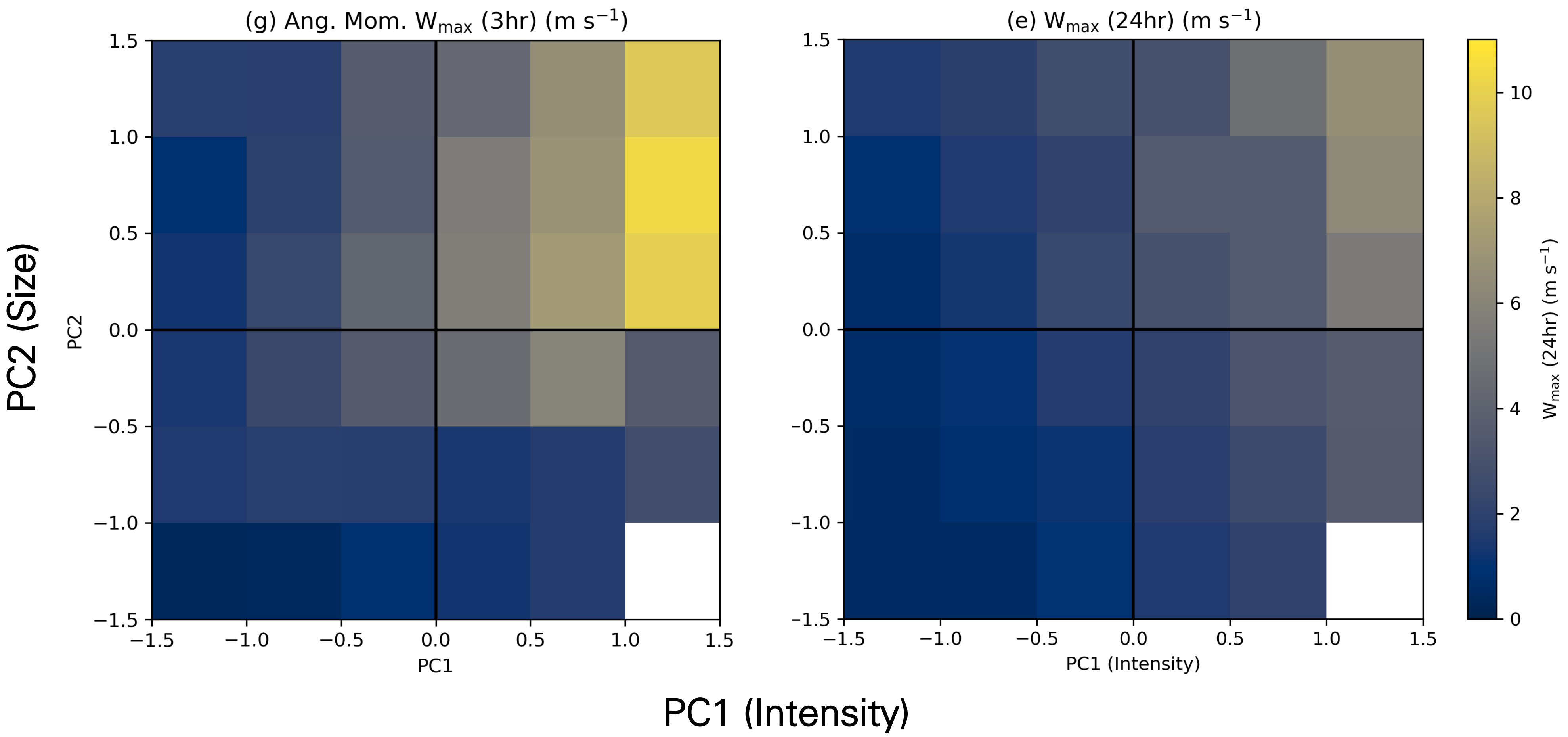
Slab TCBL

Height-Resolved TCBL



Weak, Big TCBLs contracted the most

Vertical Wind (W_{max}) ↑

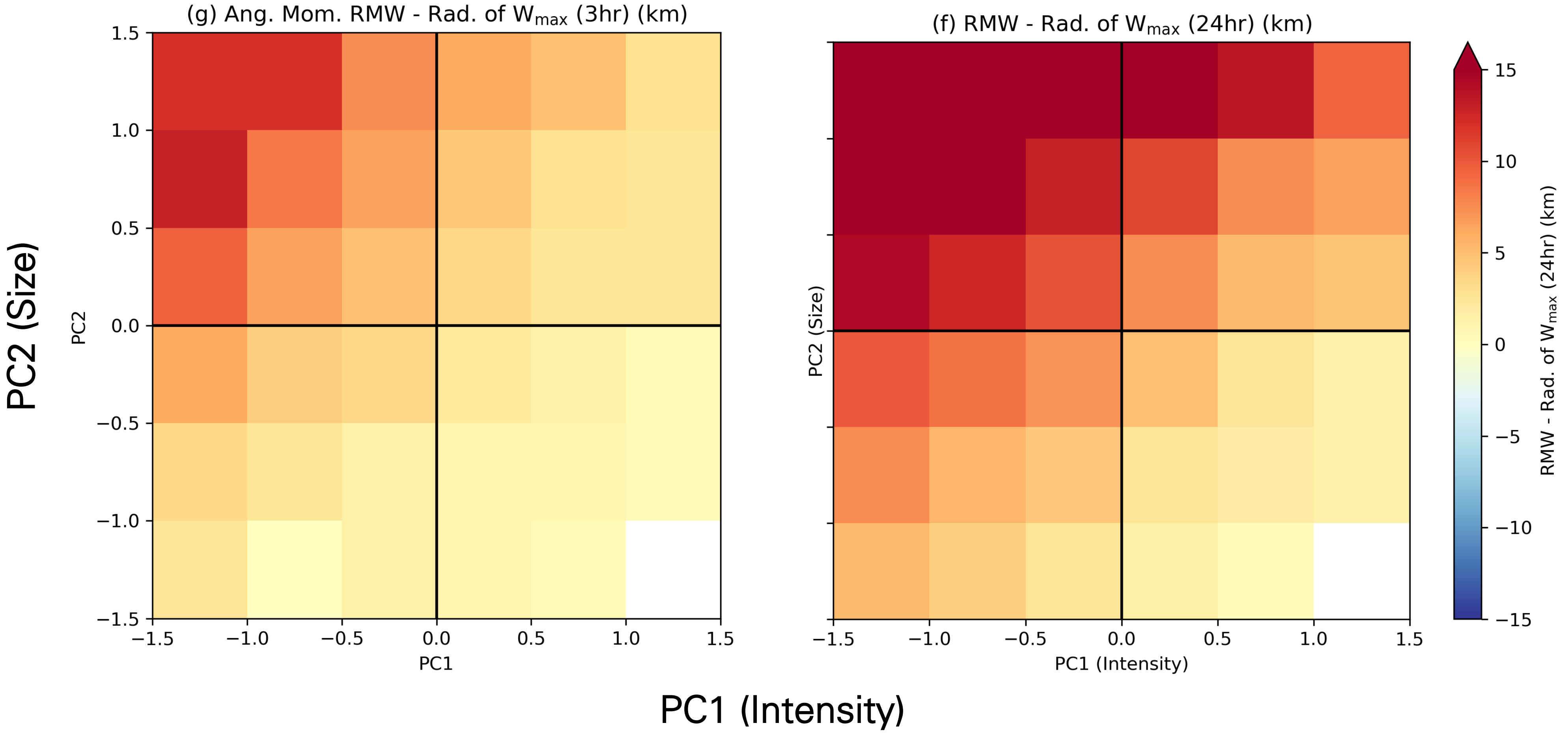


Strong, Big TCs have the largest W_{max}

Slab TCBL

Height-Resolved TCBL

Radius of V_{max} - Radius of W_{max} (RMW - RMWW)



Slab TCBL

Height-Resolved TCBL

Weak, Big TCs have the largest gap between RMW and RMWW

Partial Recap

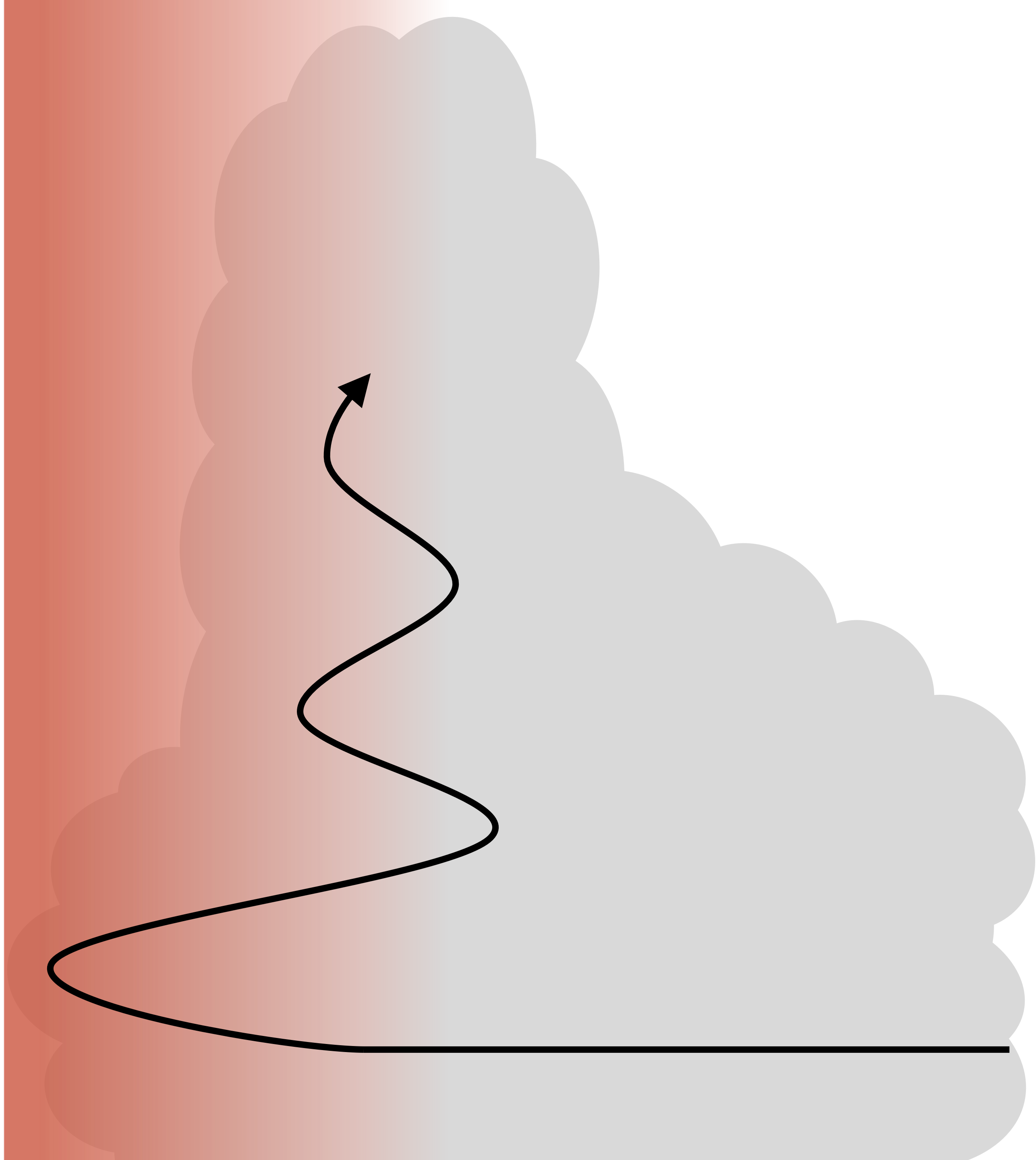
Strong, Big TCs appear to "amplify" the most

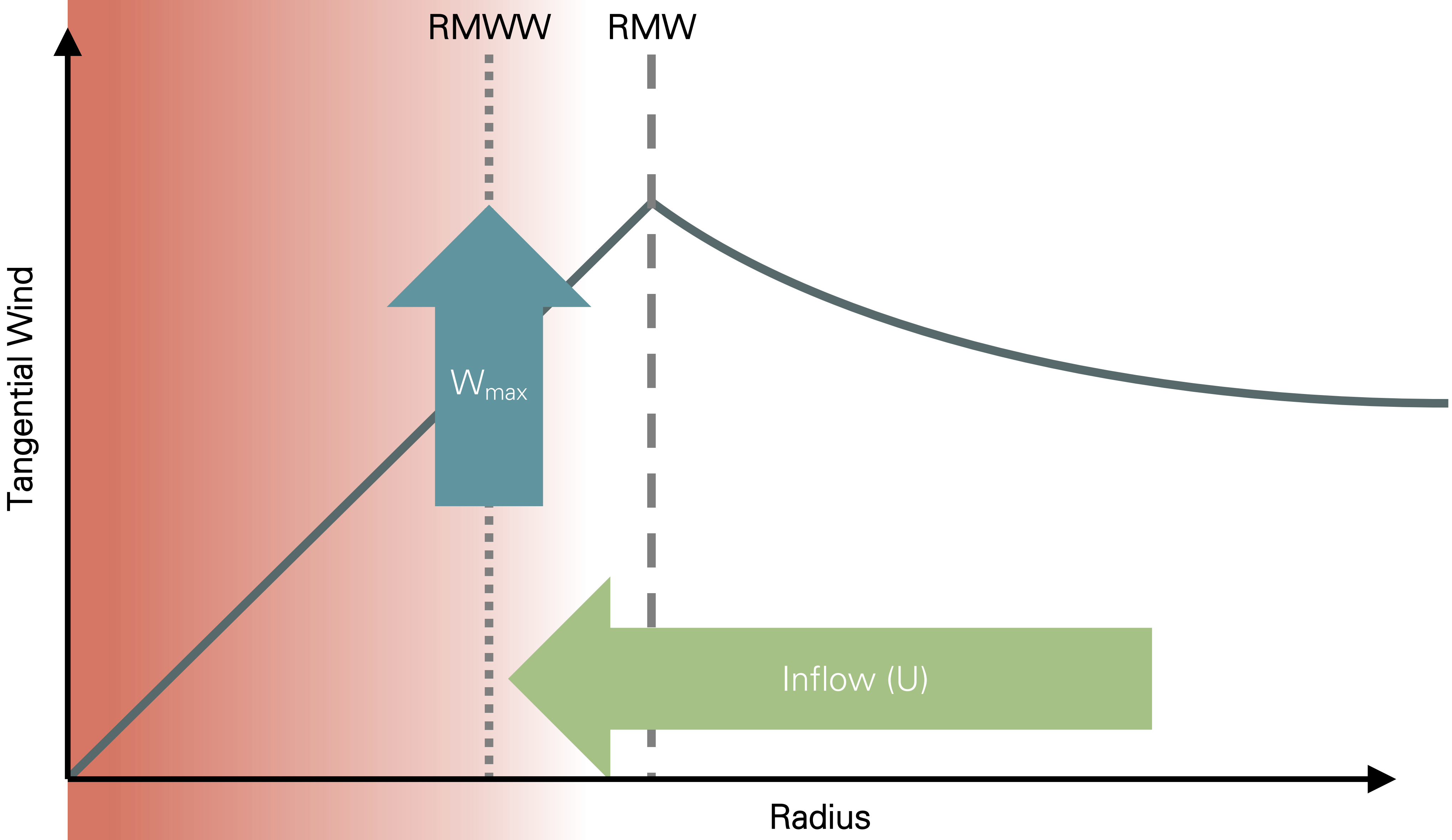
The initially strongest wind speeds become the largest supergradient winds

Weak, Big TCs appear to contract the most

The initially largest RMWs contract the most and have the largest gap between the RMW and RMWW

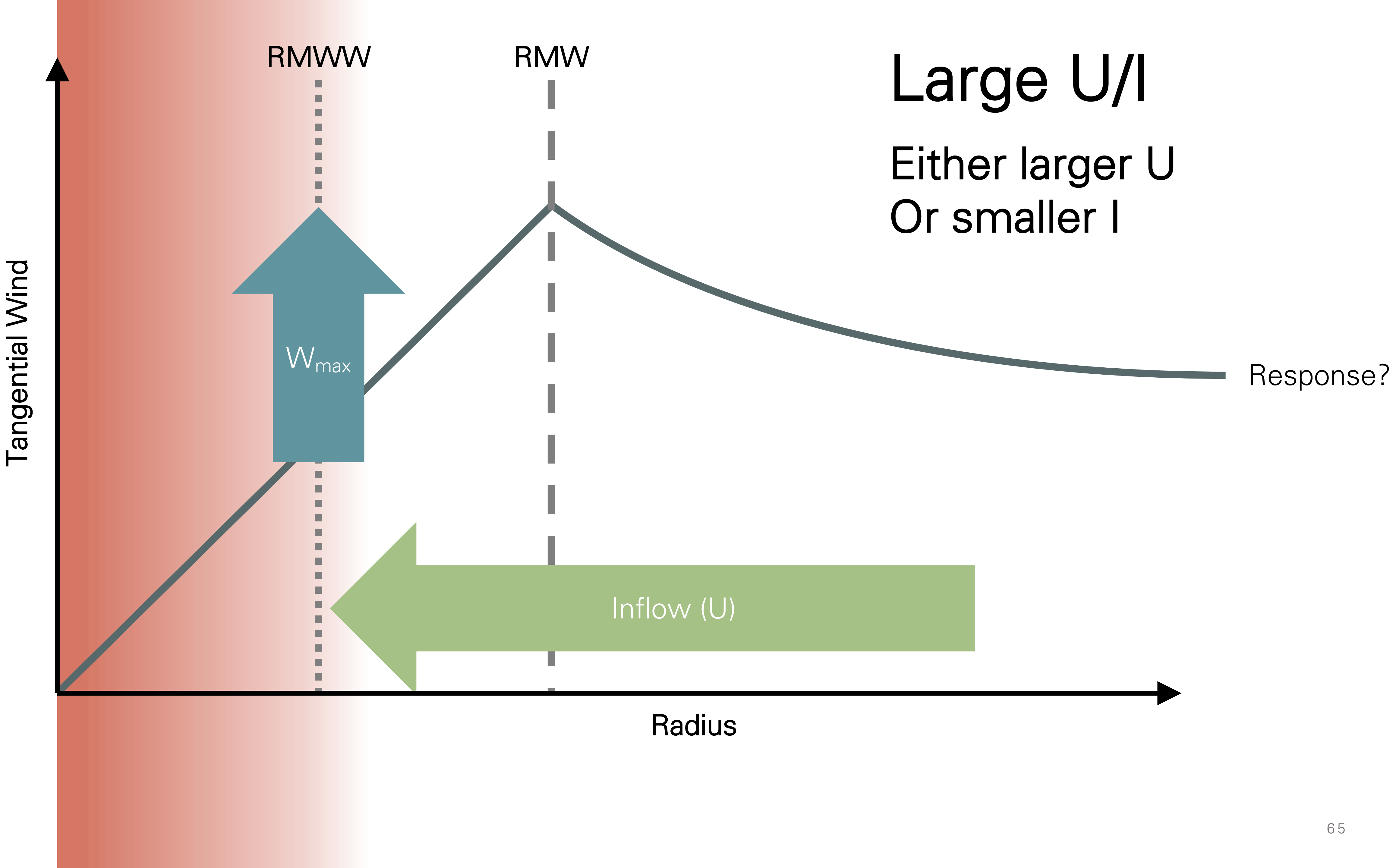
“Inertial Stability” (I)

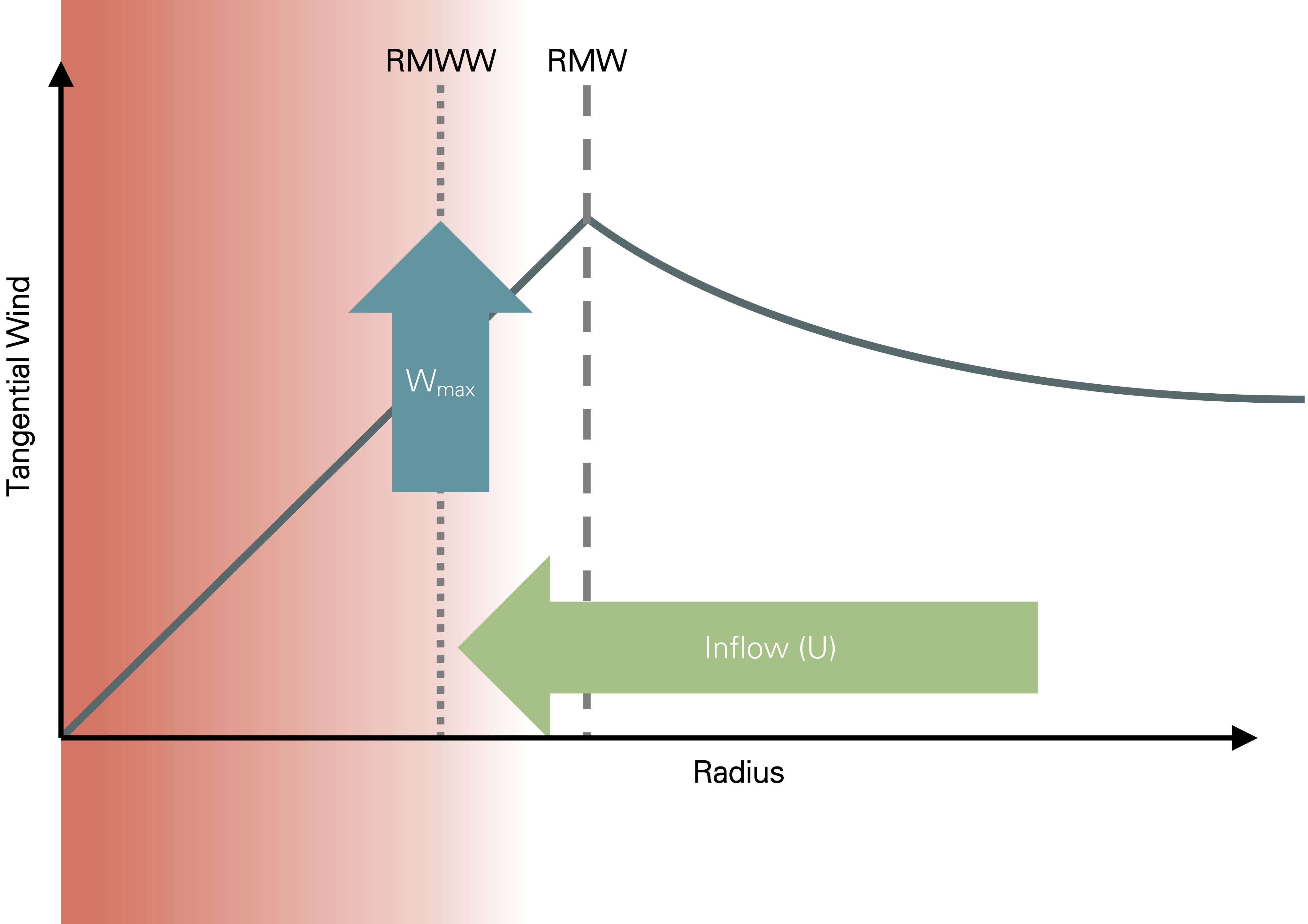



RMWW
RMW
Tangential Wind
W_{max}
Inflow (U)
Radius

Large U/I

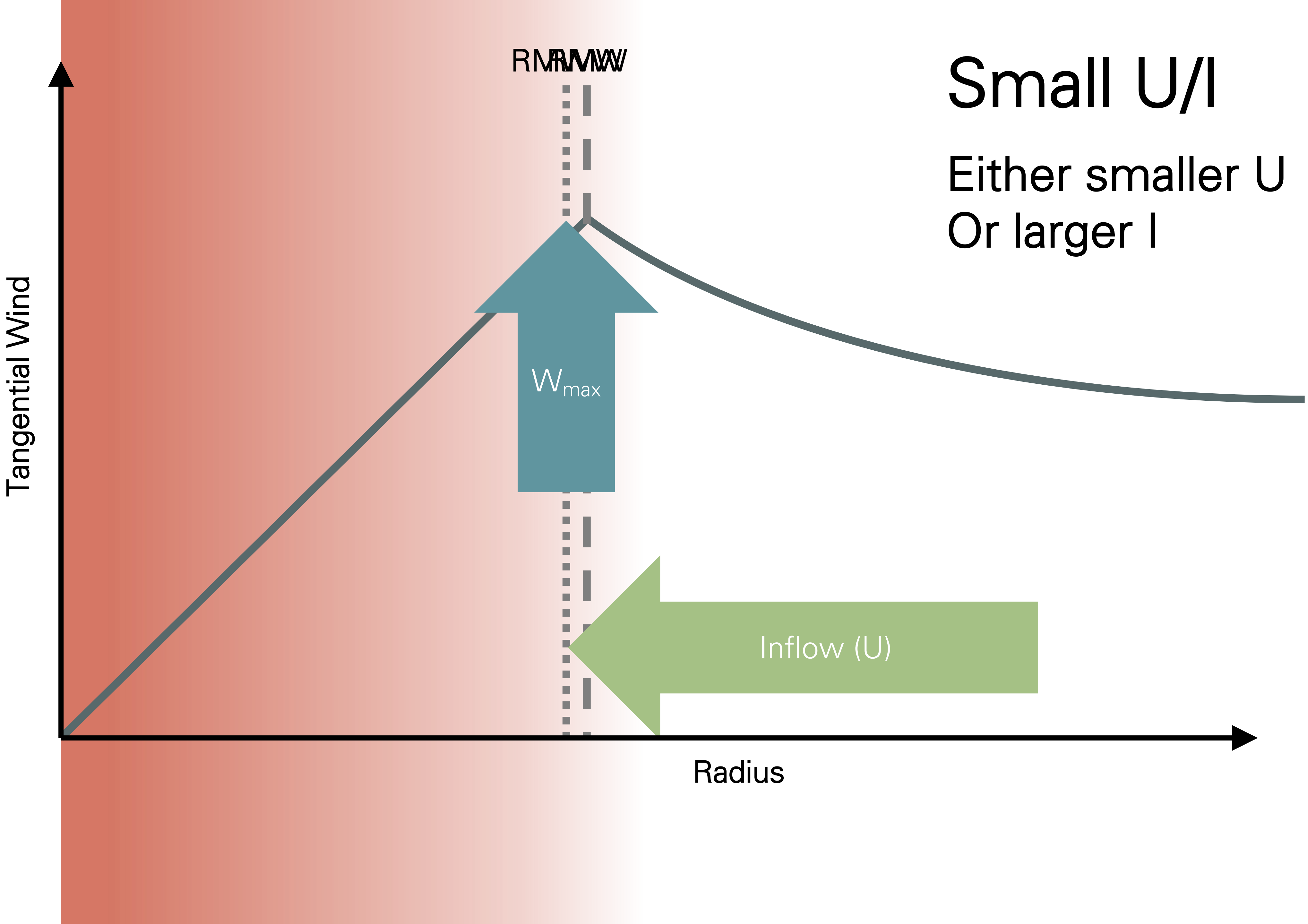
Either larger U
Or smaller I



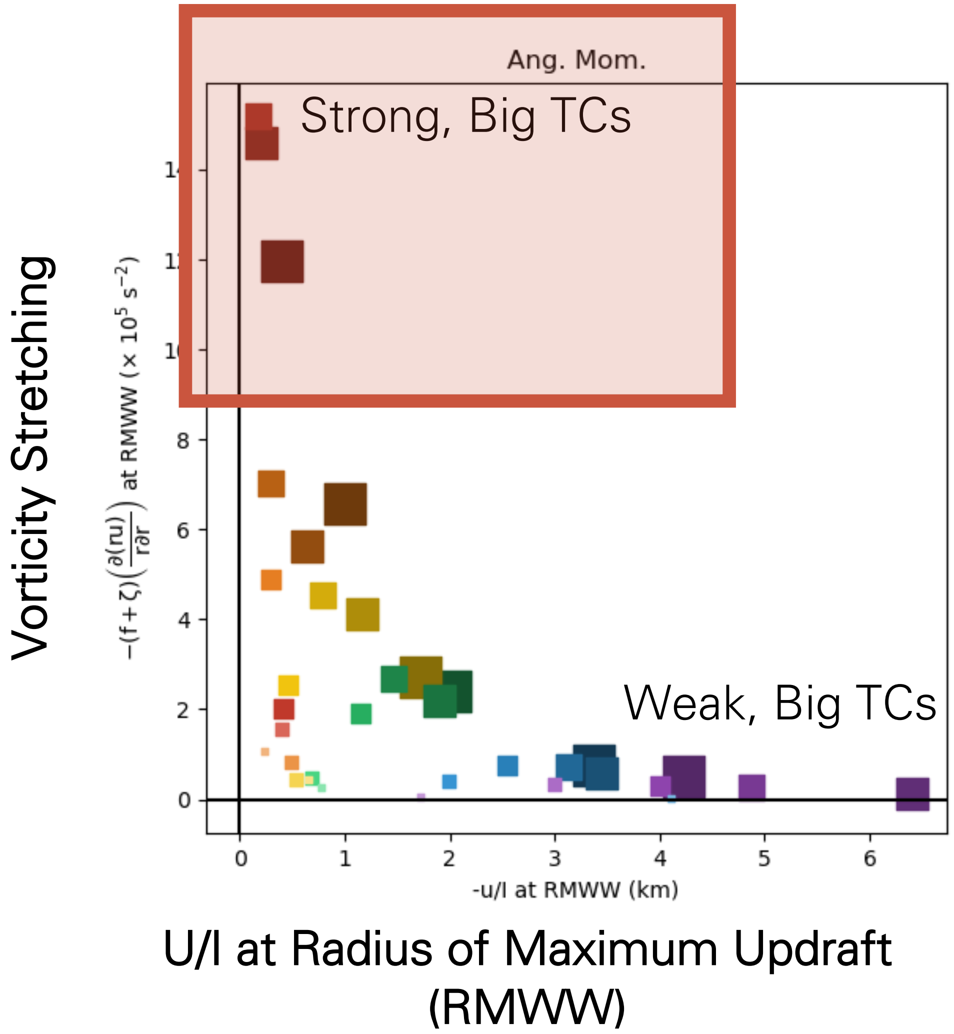

RMWW
RMW
Tangential Wind
W_{max}
Inflow (U)
Radius

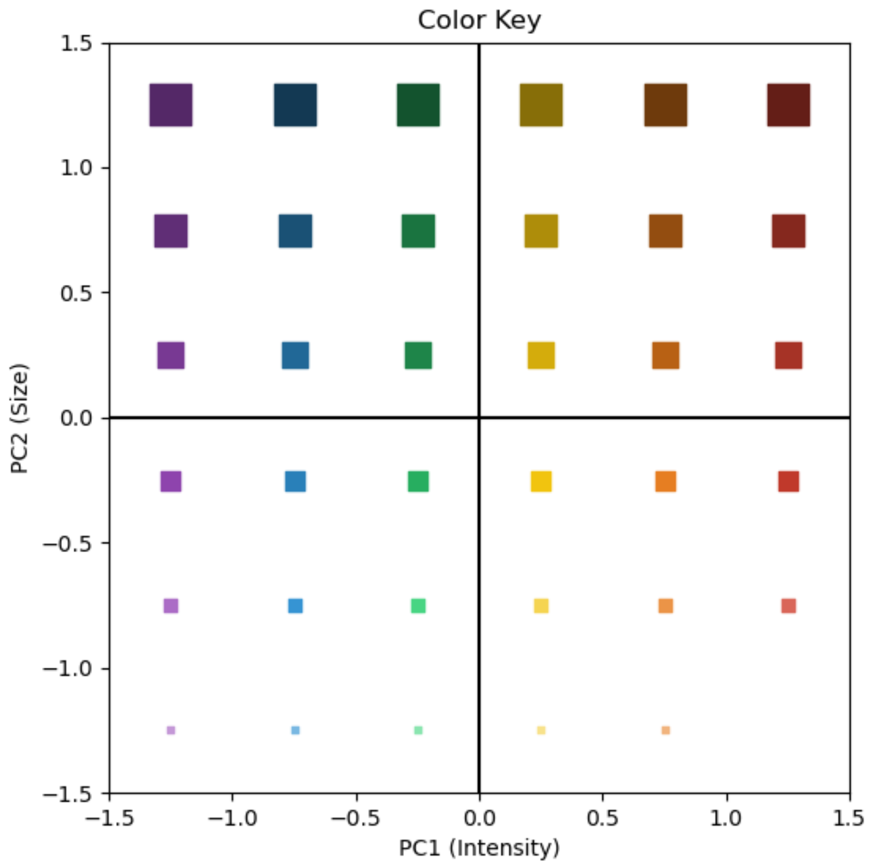
Small U/I

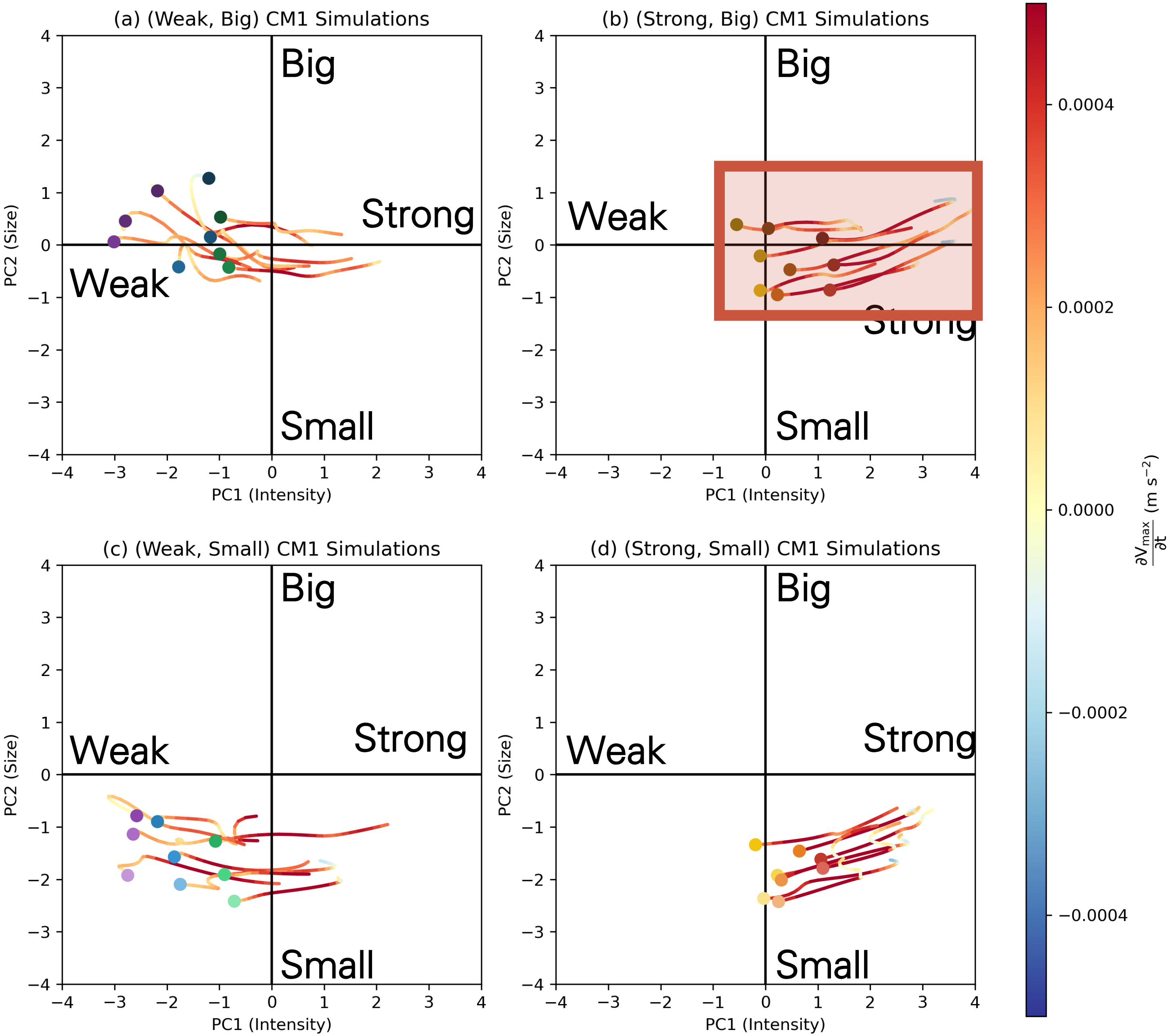
Either smaller U
Or larger I

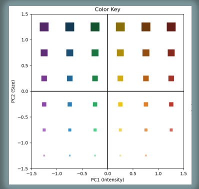


Small U/I is associated with more vorticity stretching in strong, big TCs







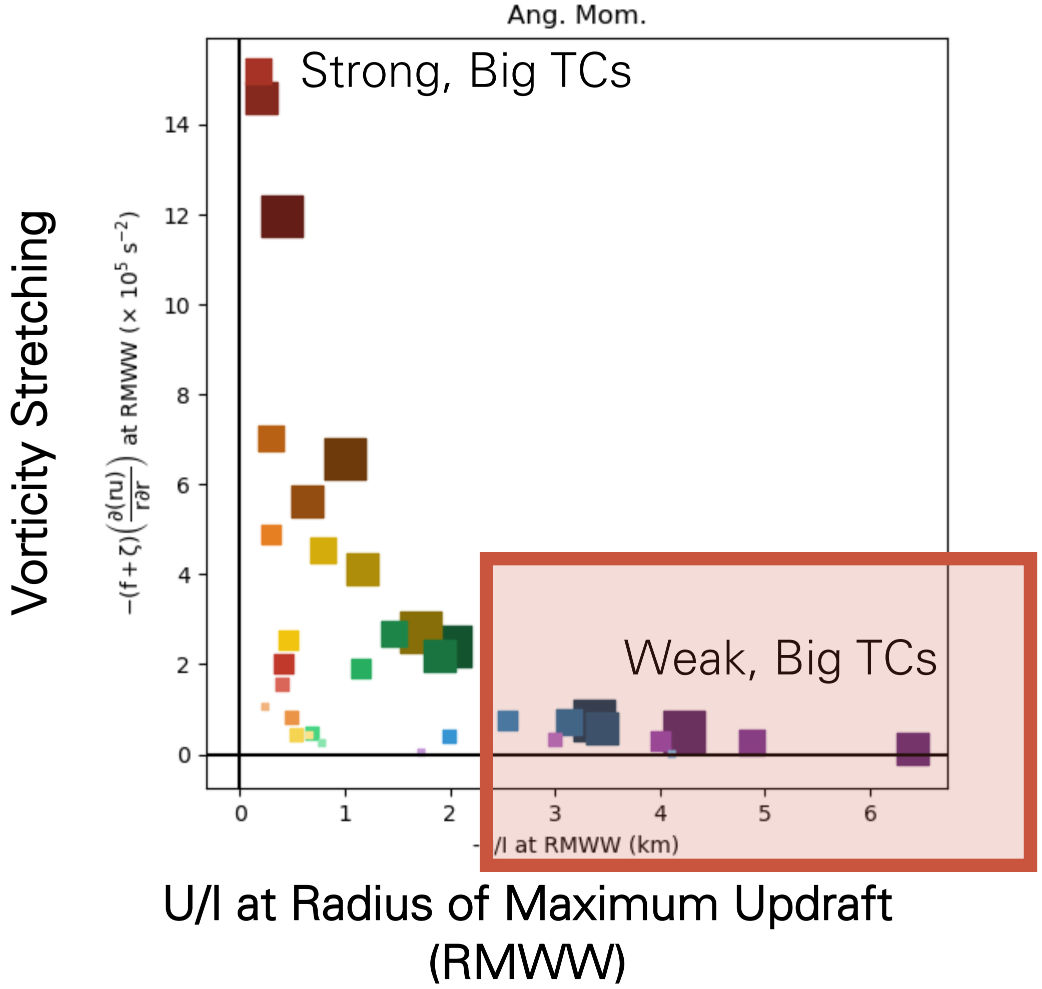


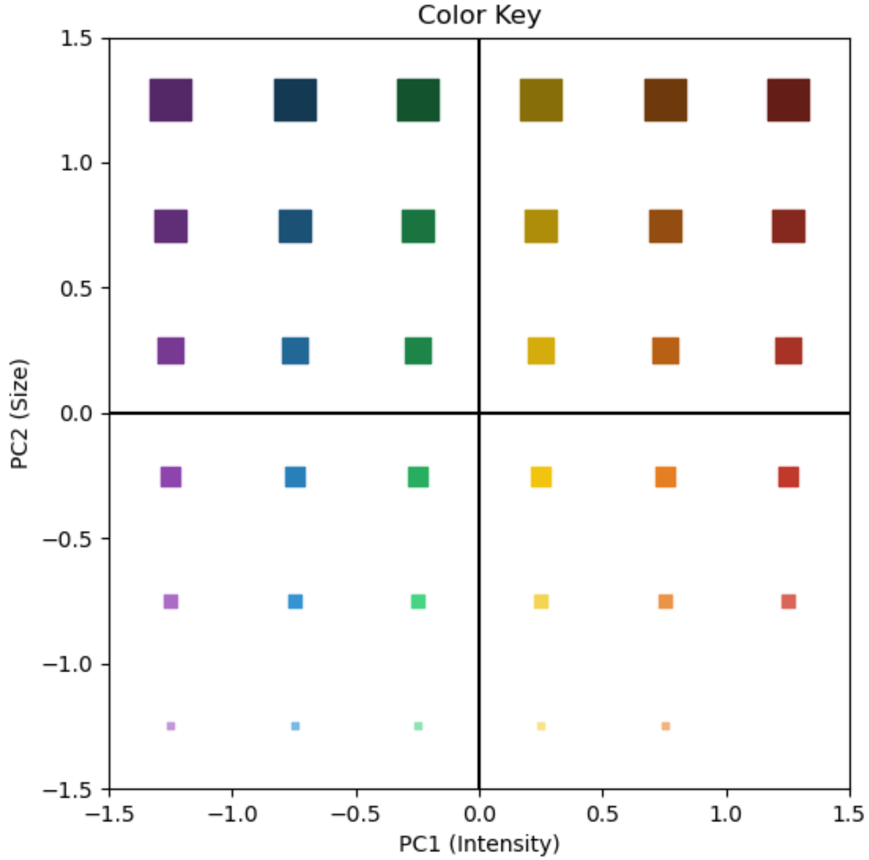
Intensification Rates 0-24 hr after RI Onset

Strong, Big TCs "amplified" the most

Consistent with TCBL model results

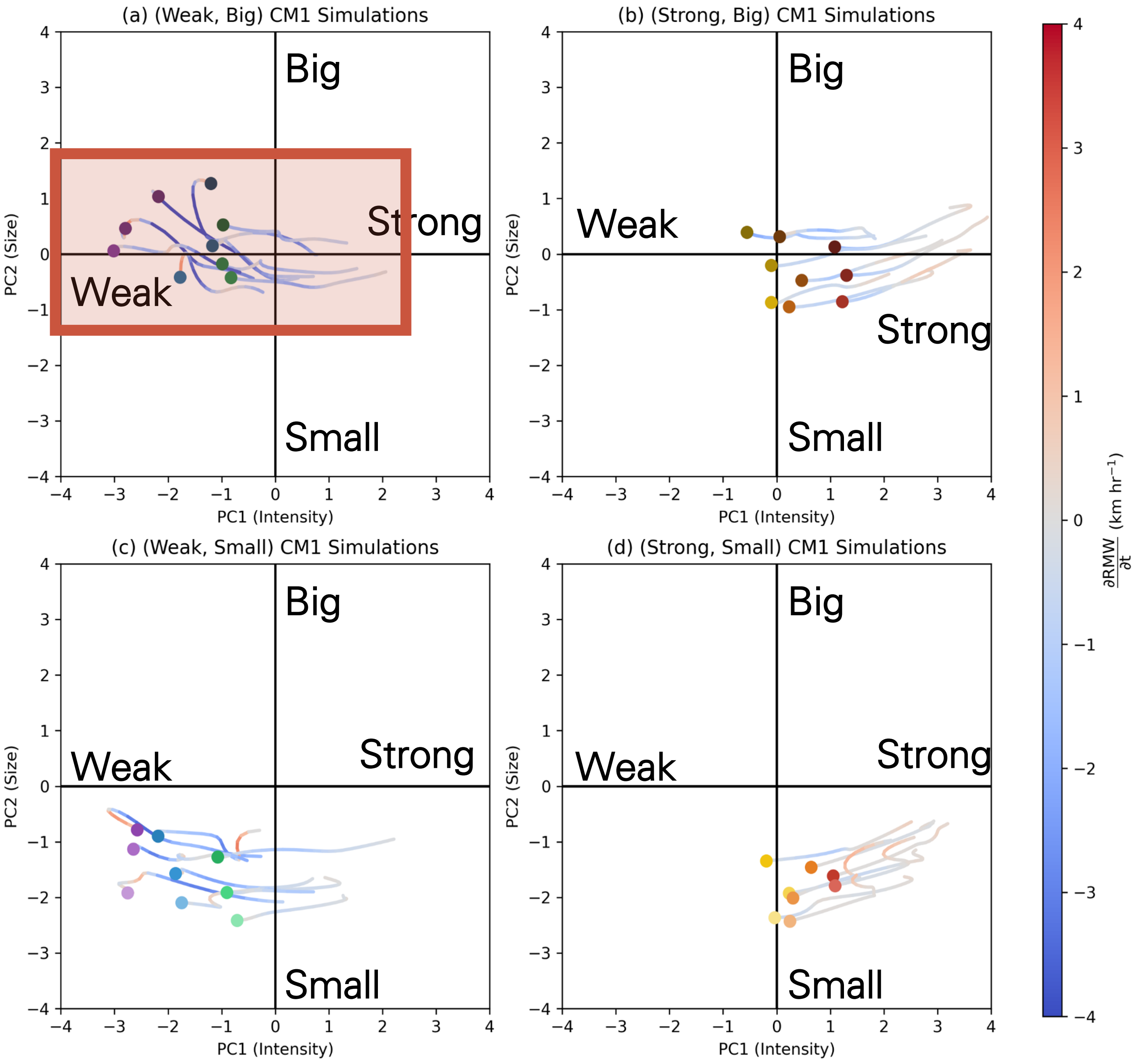
Small U/I is associated with more vorticity stretching in strong, big TCs

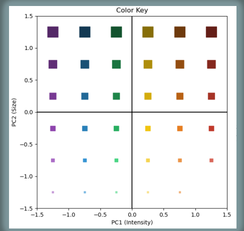




Slab TCBL

Color Key



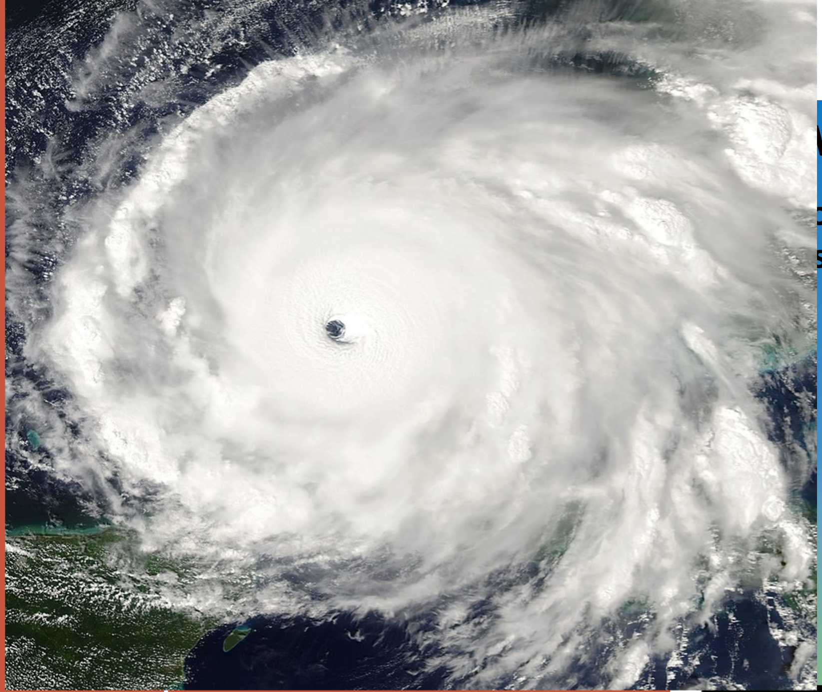


RMW Contraction Rates 0-24 hr after RI Onset

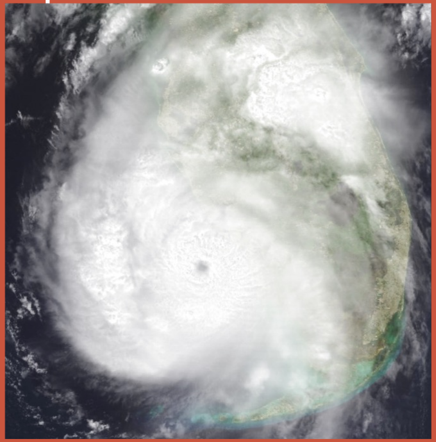
Weak, Big TCs contracted the most

Consistent with TCBL model results

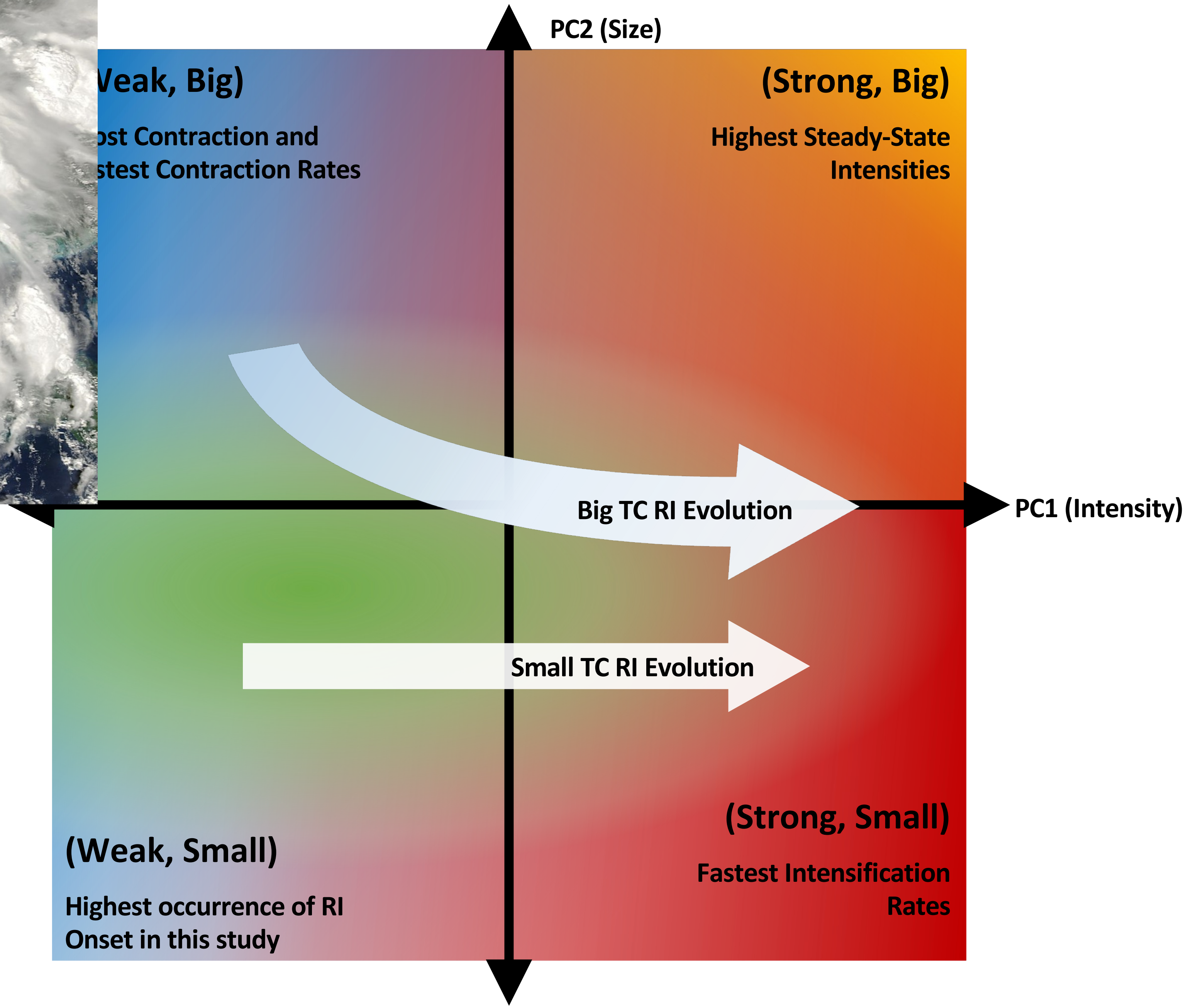
Rita



Charley



Final



Future work

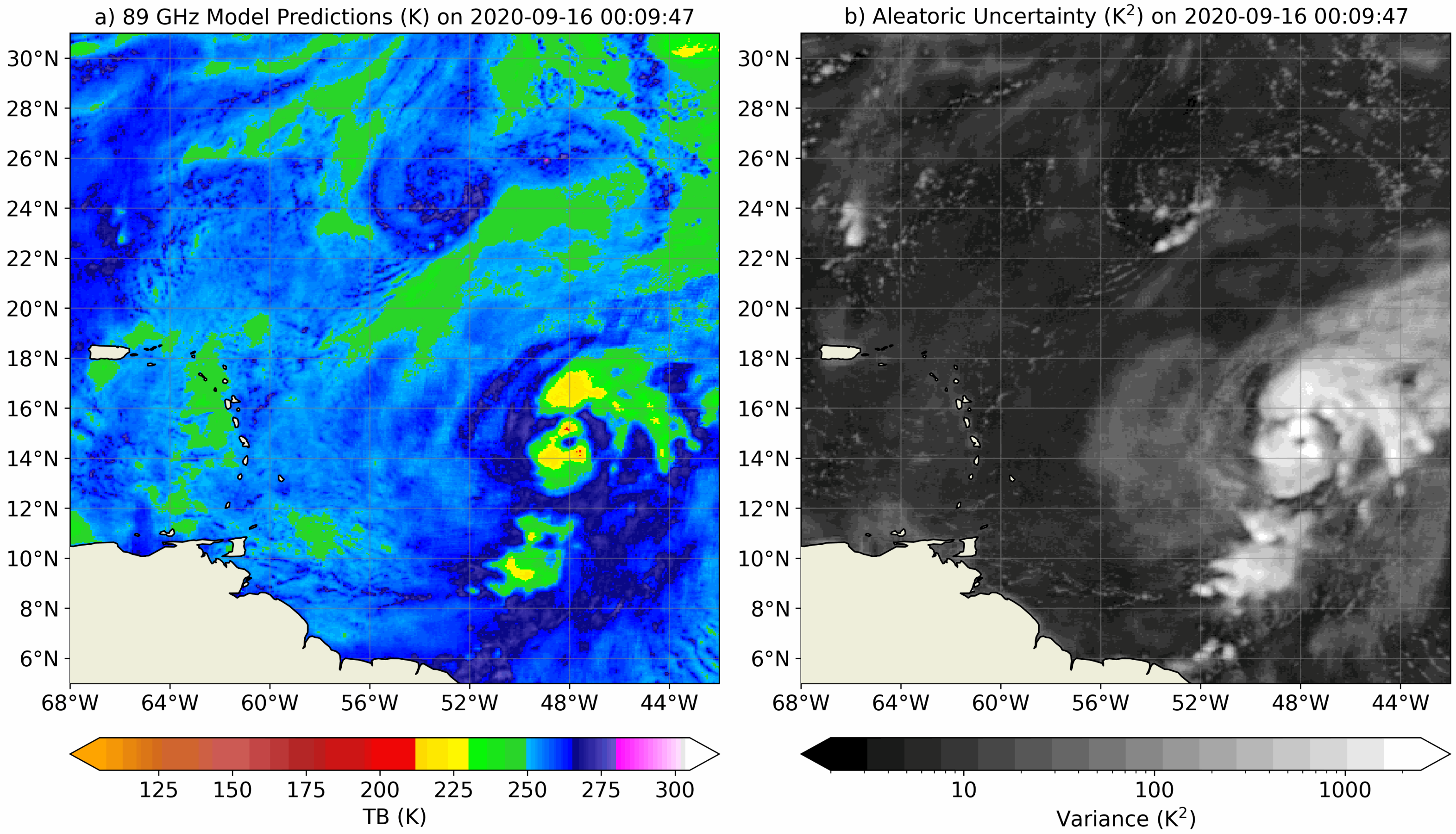
Continue investigating relationships between TC structure and intensification

Test results in 3D simulations, in both sheared and unsheared environments

Test results in observations…

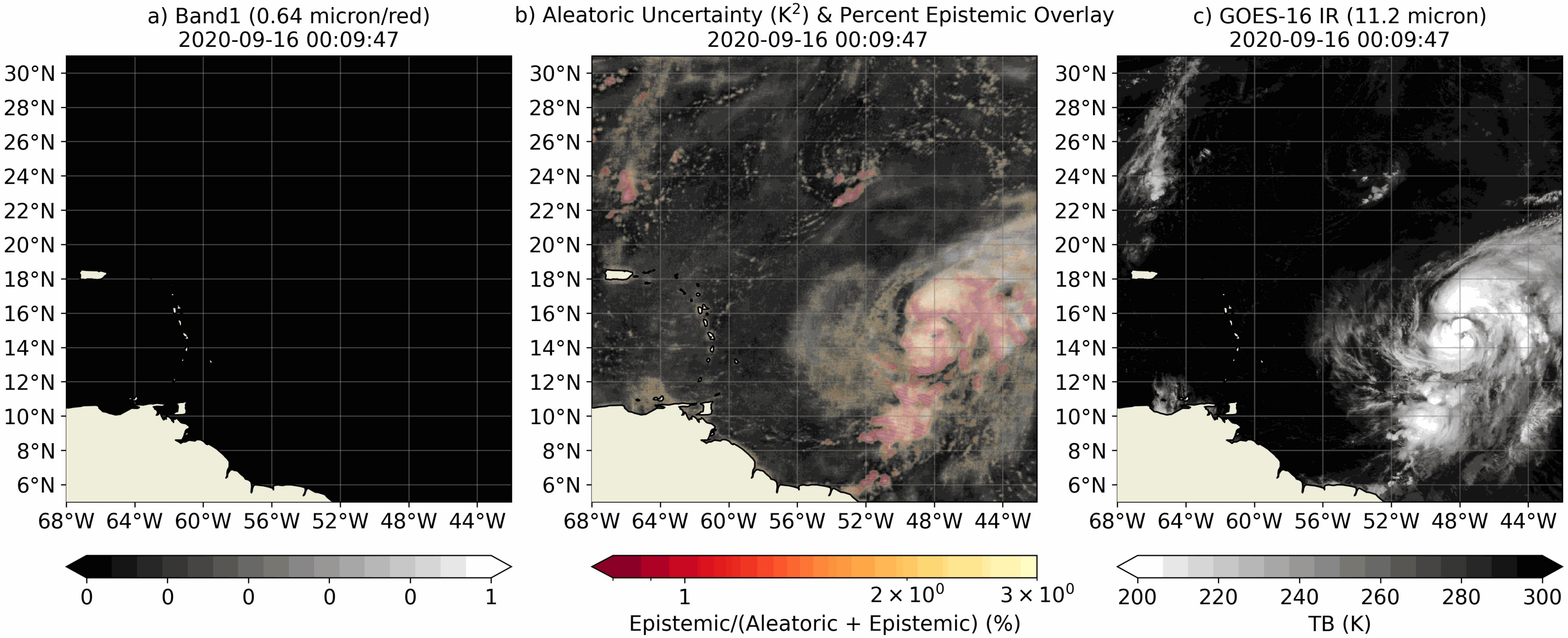
Future work

Current postdoctoral research project progress



Future Work

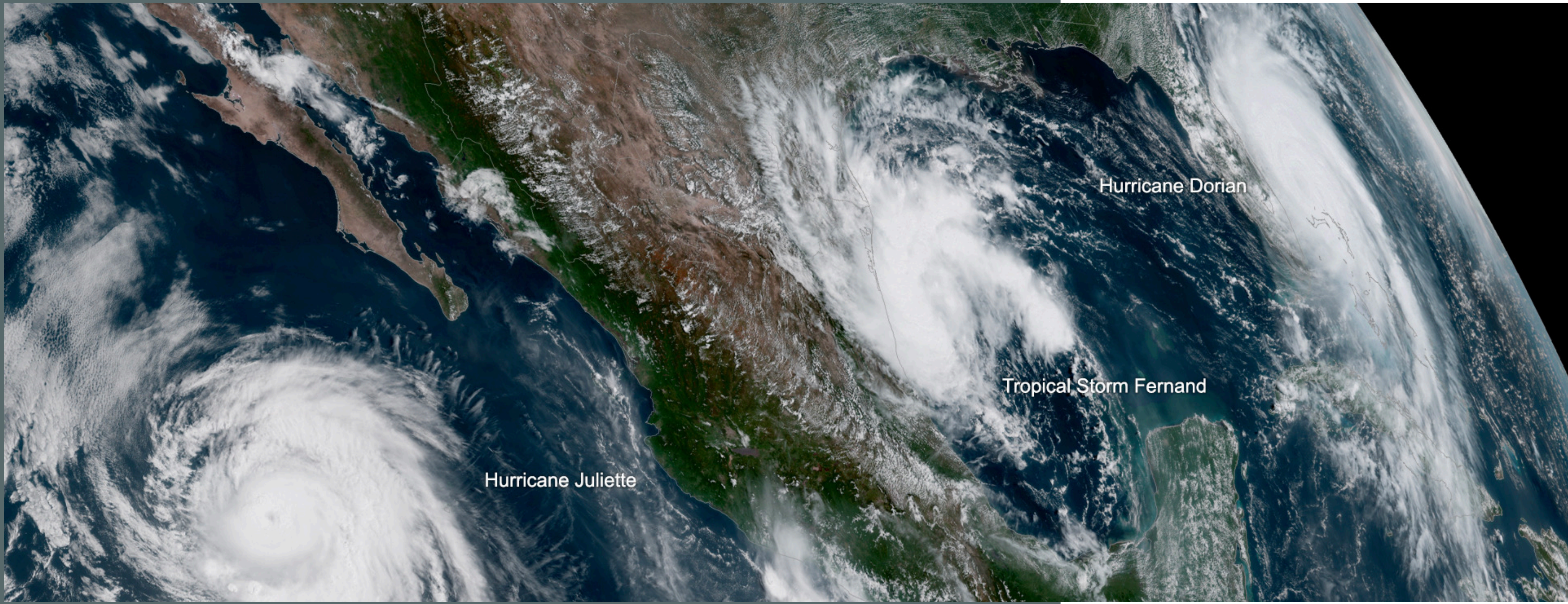
Current postdoctoral research project progress



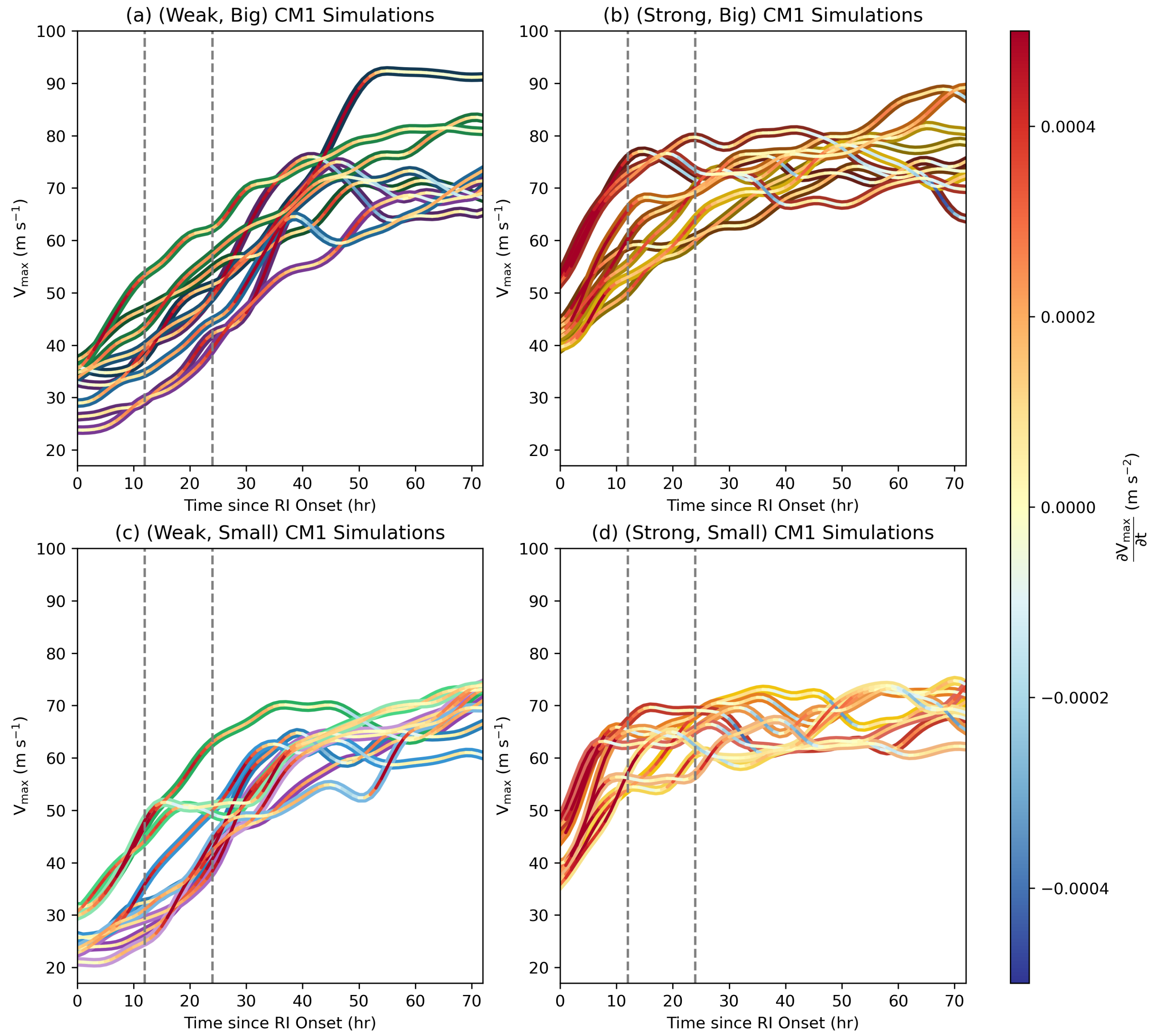
Questions?

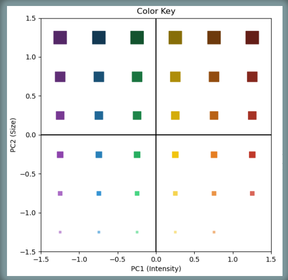
Comments? Questions?

Email: Eleanor.Casas@Millersville.edu



Extra slides

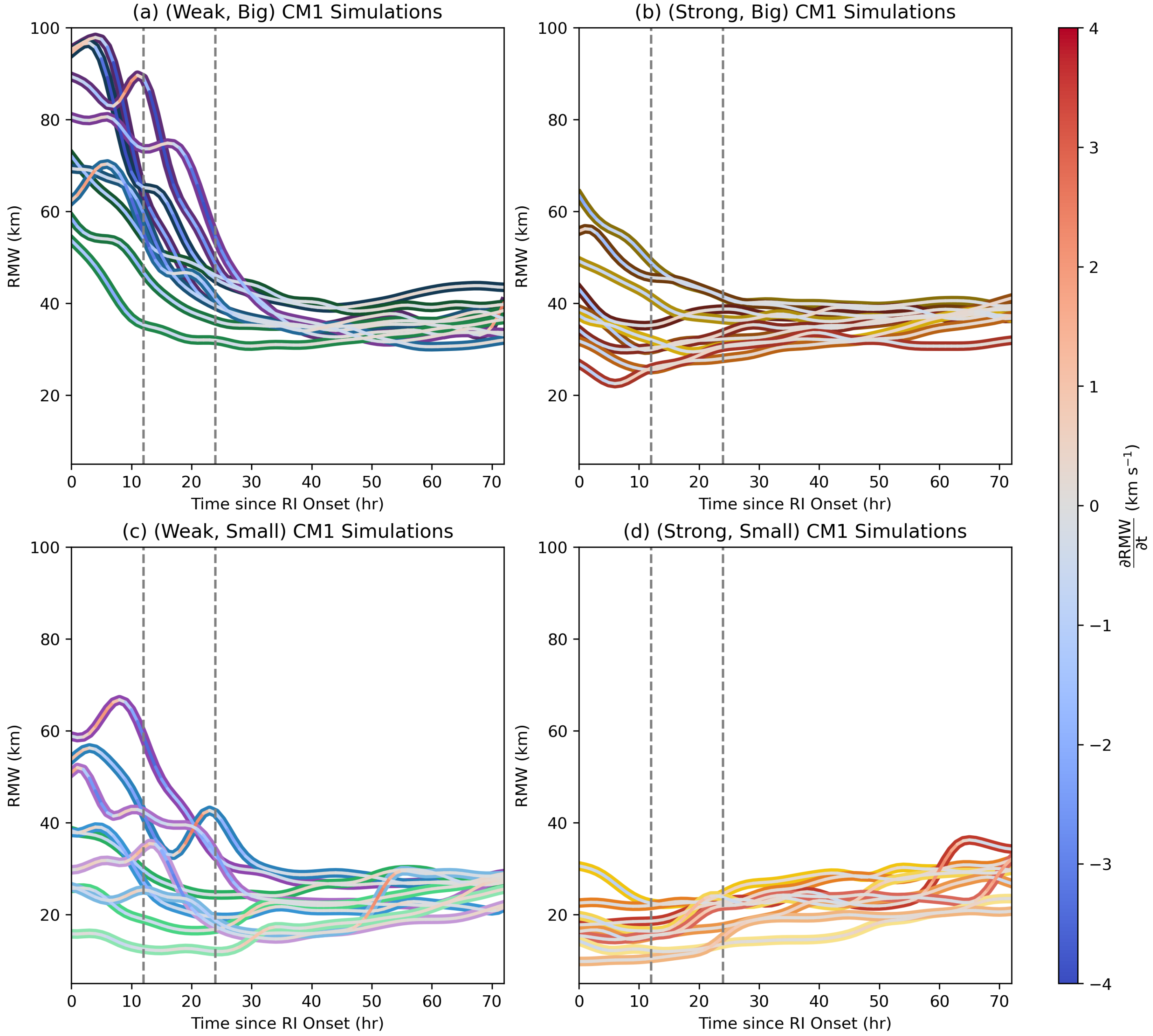


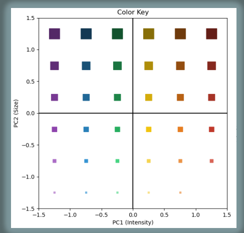


Vmax after RI Onset

Larger TCs reach higher intensities

Strong, small TCs may have the fastest intensification rates





RMW after RI Onset

Like the TCBL simulations, the initially weak, big TCs have the largest RMW contraction

Unlike the "ice-skater analogy," RI is **not** tied to the rate at which the RMW contracts