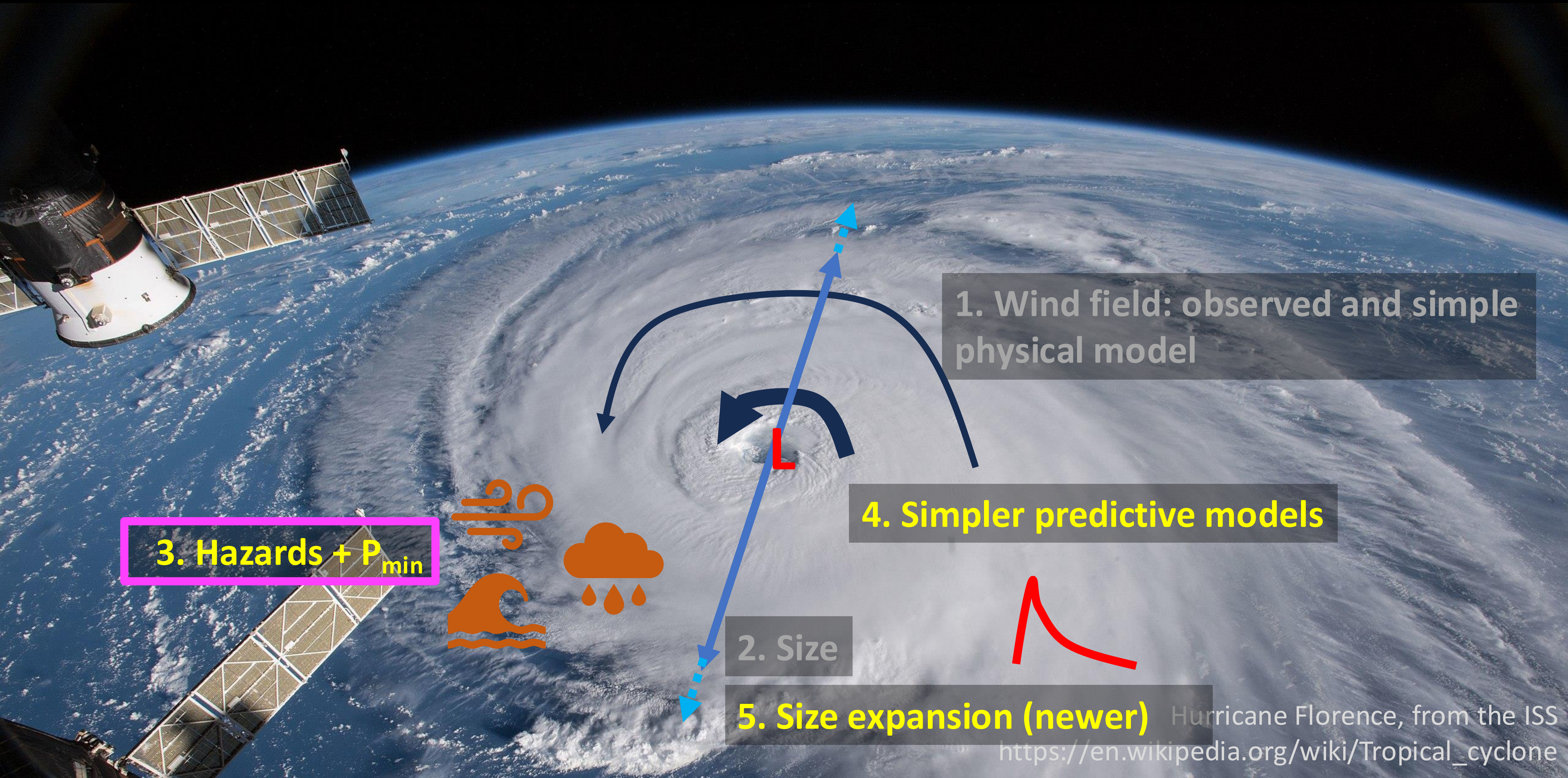
Roadmap

0. Intro: two recent events



Hurricane Florence, from the ISS
https://en.wikipedia.org/wiki/Tropical_cyclone

3. Hazards/damage

- Modeling hazards: wind, surge, rainfall
- Minimum pressure → damage/risk

Modeling hazards

Wind hazard exposure

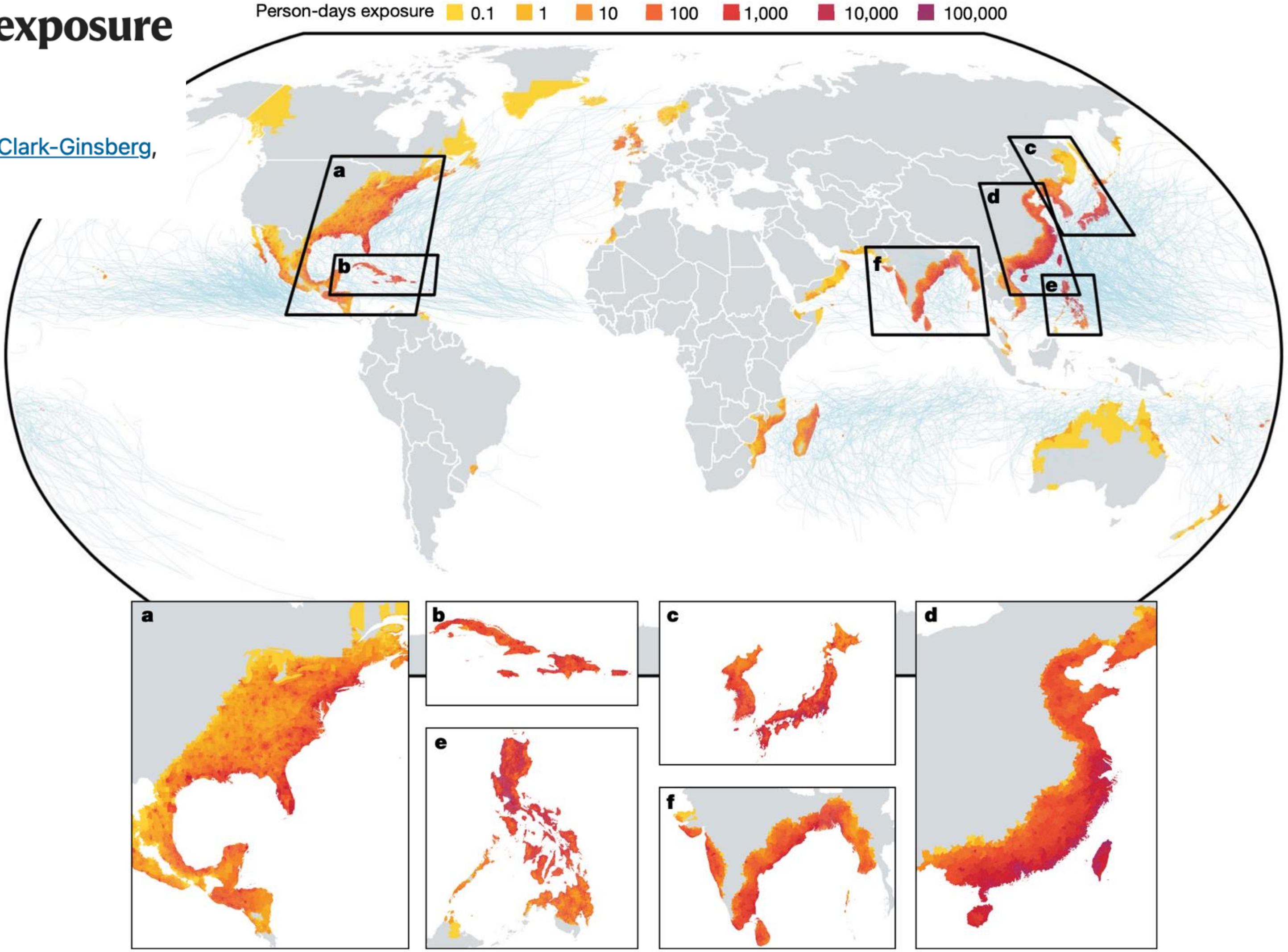
Jing et al. (2024, Nature)

nature > articles > article

Article | Published: 20 December 2023

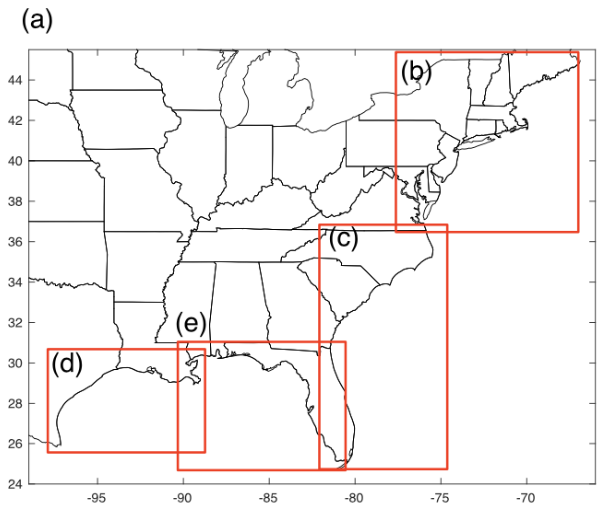
Global population profile of tropical cyclone exposure from 2002 to 2019

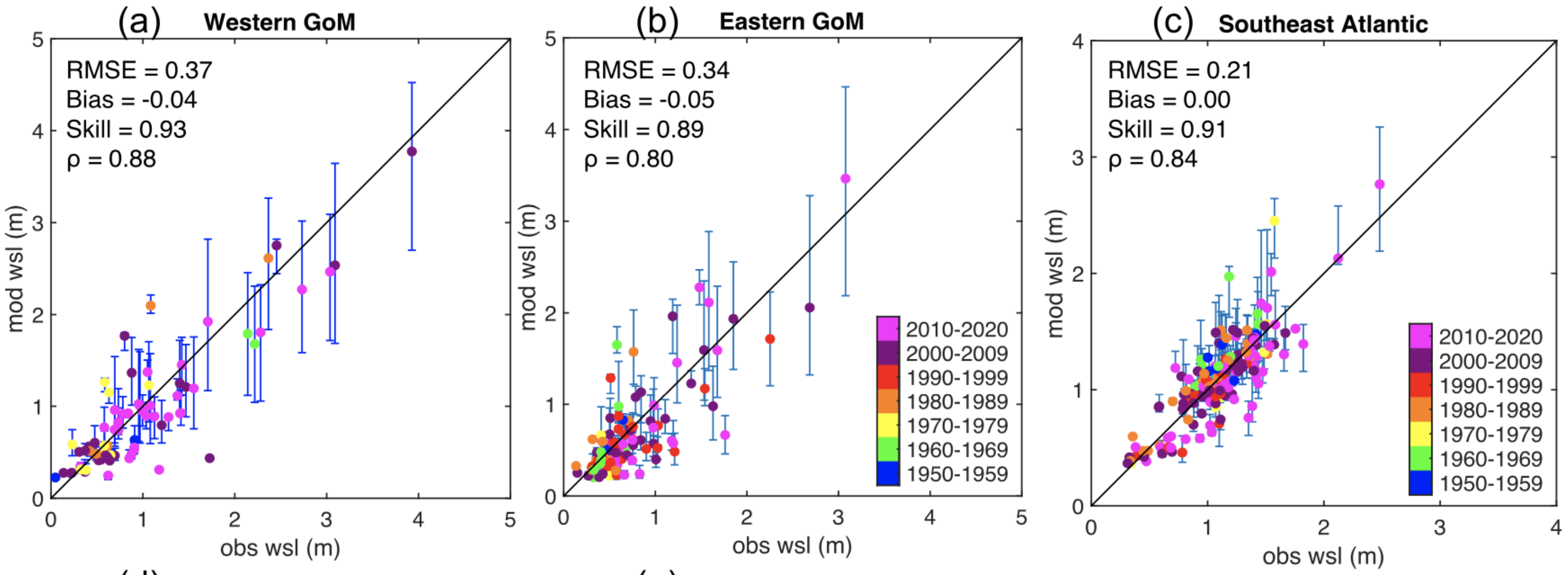
Renzhi Jing, Sam Heft-Neal, Daniel R. Chavas, Max Griswold, Zetianyu Wang, Aaron Clark-Ginsberg, Debarati Guha-Sapir, Eran Bendavid & Zachary Wagner

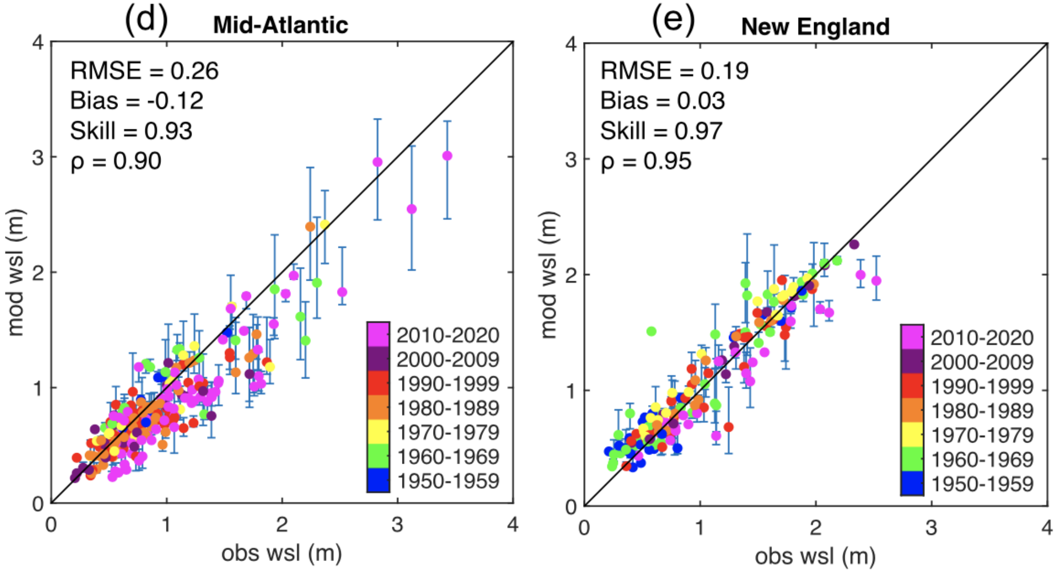


Storm surge: can simulate U.S. historical hurricane peak storm tide quite well

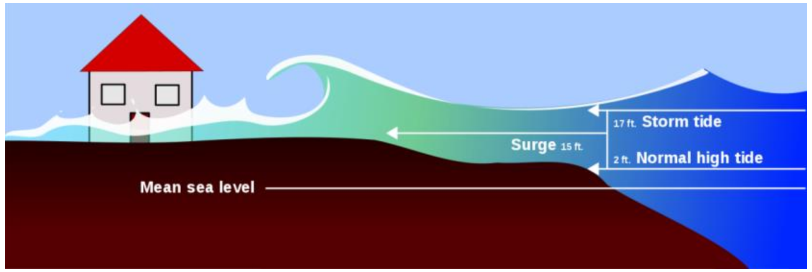
Gori et al. (2023, JGR-A)







forcing ADCIRC hydrodynamic model with our wind field model using intensity (Best Track) + outer size from ERA5 reanalysis



Our model works better than common empirical wind field model

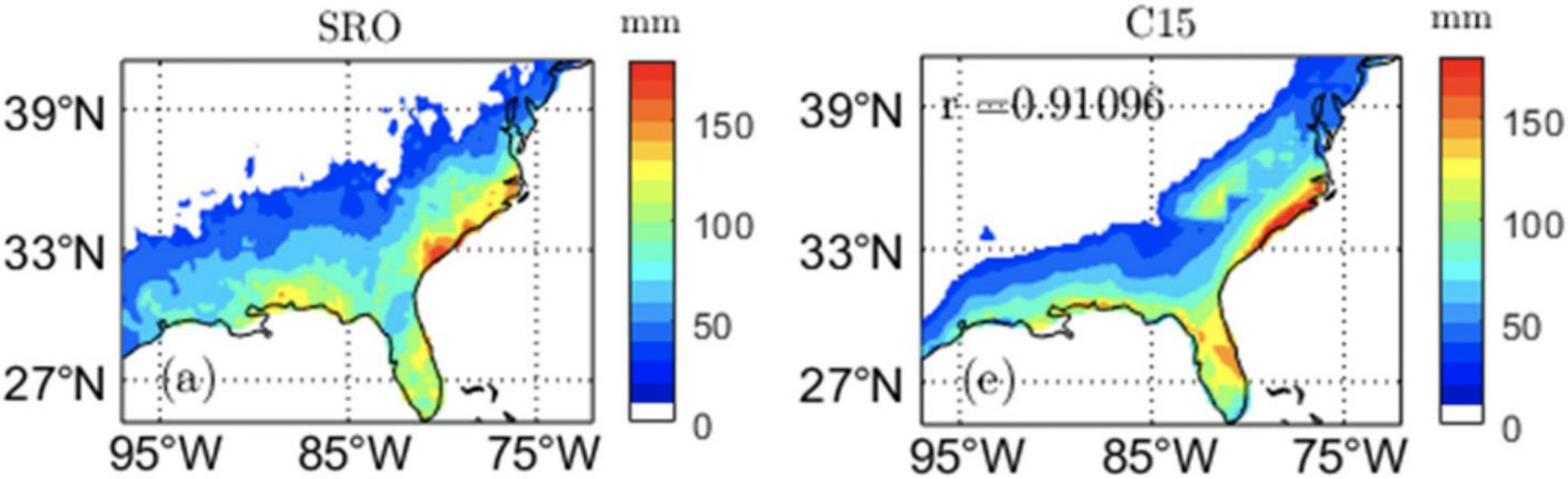
Wang, Lin, Gori (2022, JGR-A)

Rainfall: can simulate U.S. historical hurricane rainfall distribution

Xi et al. (2020, J. Hydromet.)

Satellite observed mean annual hurricane rainfall

Simulated by forcing a physics-based rainfall model with our wind field model



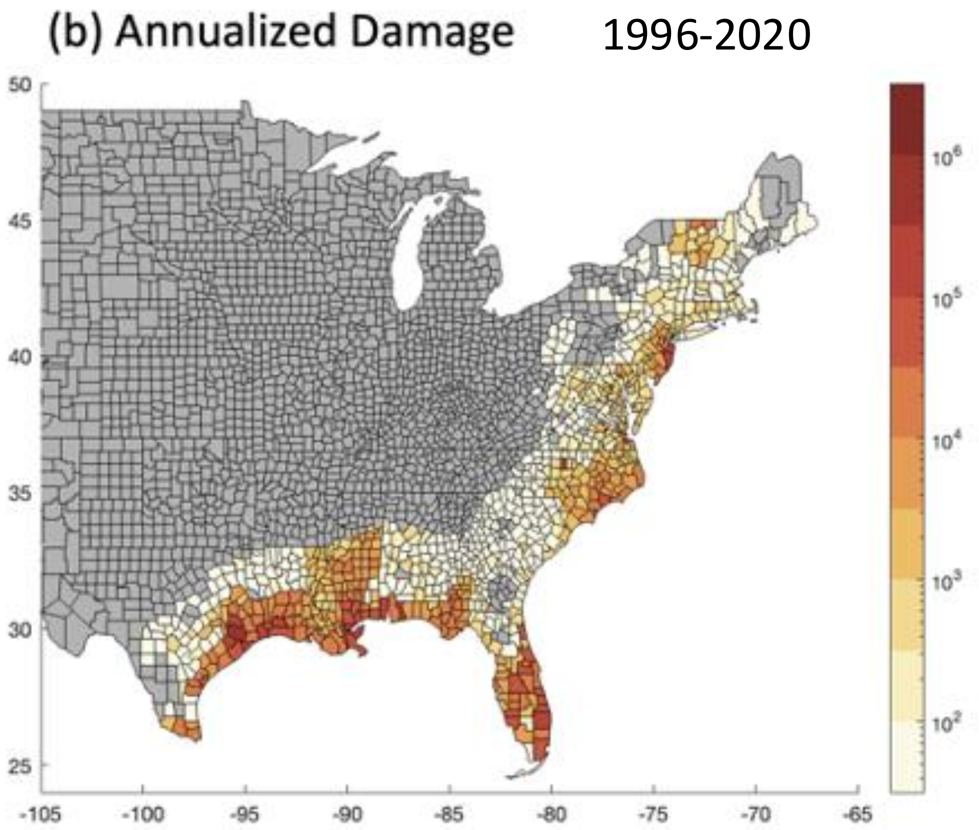
Works much better than multiple common empirical wind field models

Emanuel rainfall model details: Lu et al. (2018, JAS)

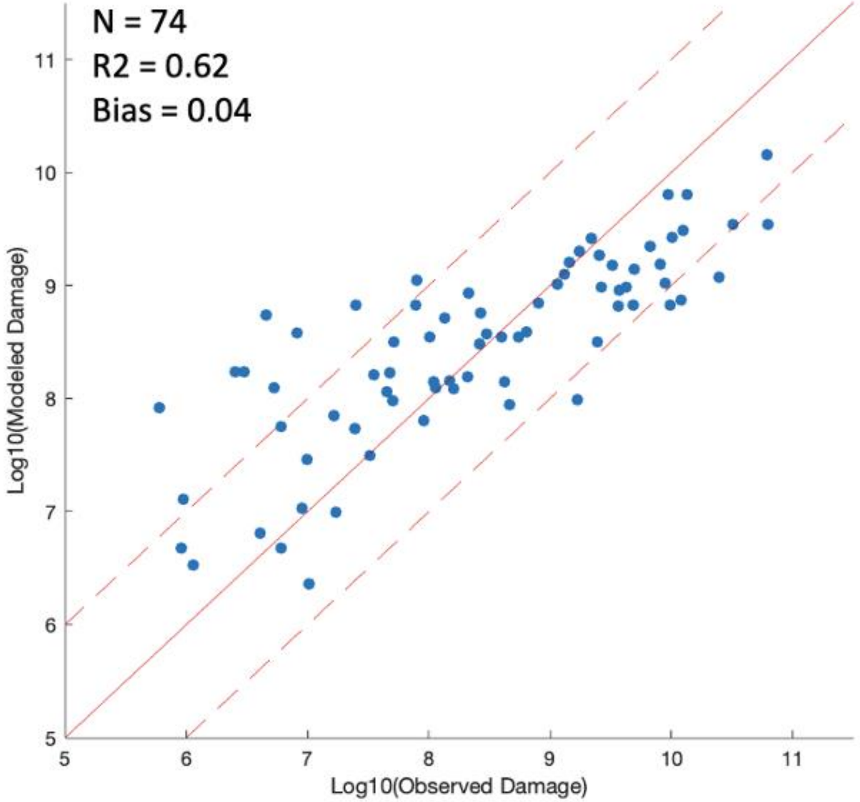
All together now! Simulate economic damage from wind/surge/rainfall

Gori et al. (2025, *Env. Res. Lett.*)

1996-2020



modeled vs. observed total TC damage



Simple log-link linear regression at the county level

$$Damage \sim f(wind\ speed, surge, rainfall)$$

all driven by Chavas et al. (2015) wind field model

Fills in the gaps: P_{min} → damage

Klotzbach et al. (2022, JGR-A)

Minimum pressure → damage/risk

”The **minimum central pressure** has remained around 913 mb... which is a very low pressure to have [a **maximum wind speed** of] only 125 knots.”

- Hurricane Rita NHC forecast discussion, 21 UTC on 22 September 2005

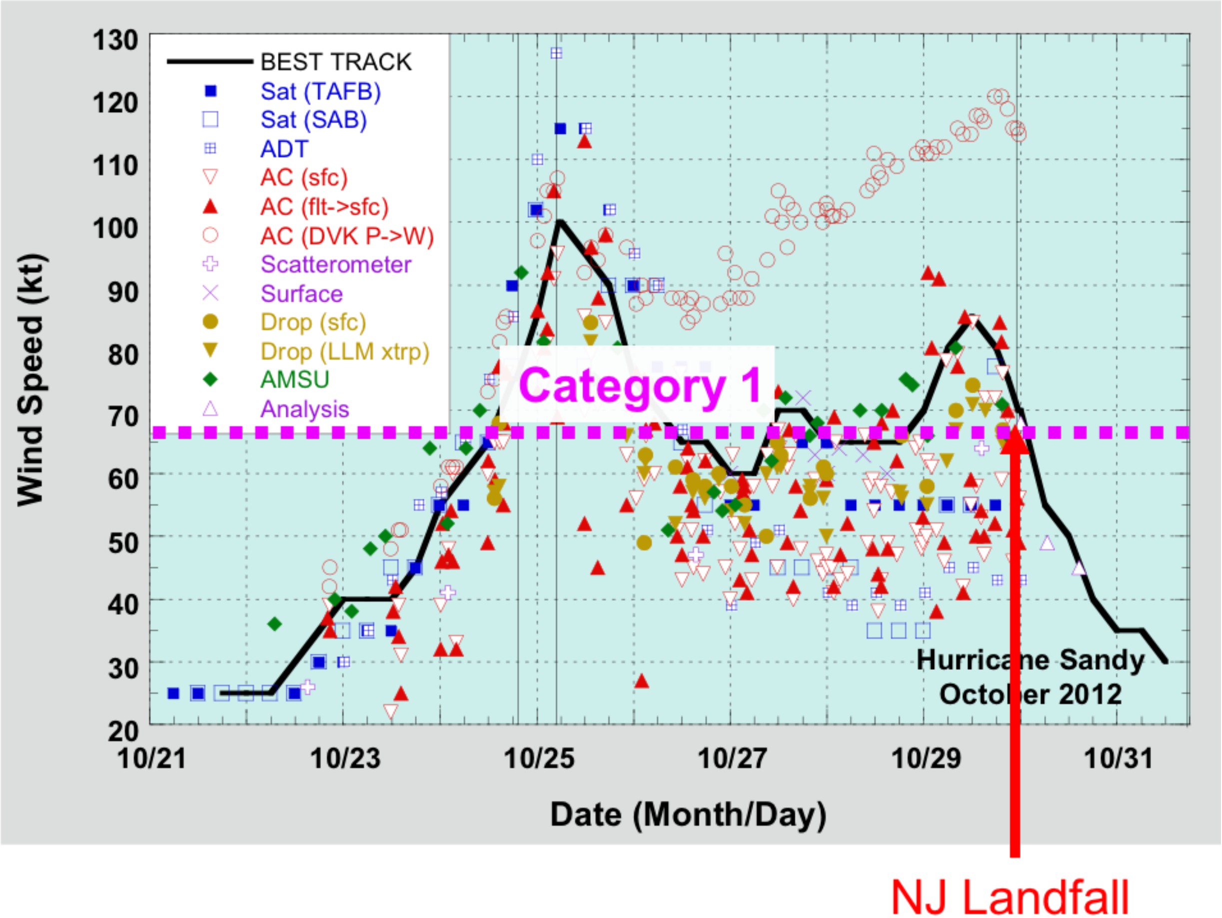
Having two measures of intensity is confusing.

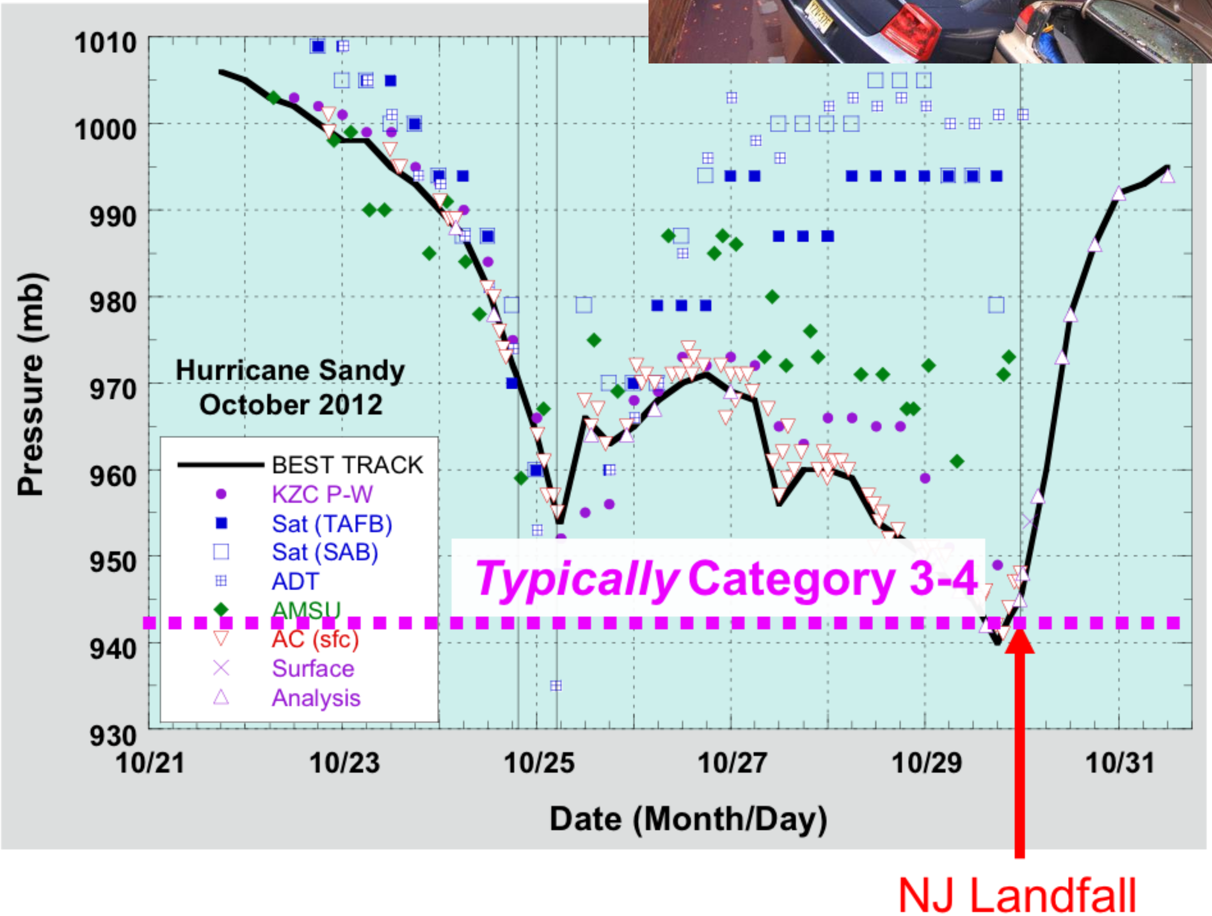
- Science: How strong is this storm?
- Risk: What impacts will it cause?

Risk: What impacts will it cause?

Hurricane Sandy (2012): $65 billion USD damage

A "weak" (V_{max}) but *very large* storm – evident in P_{min}

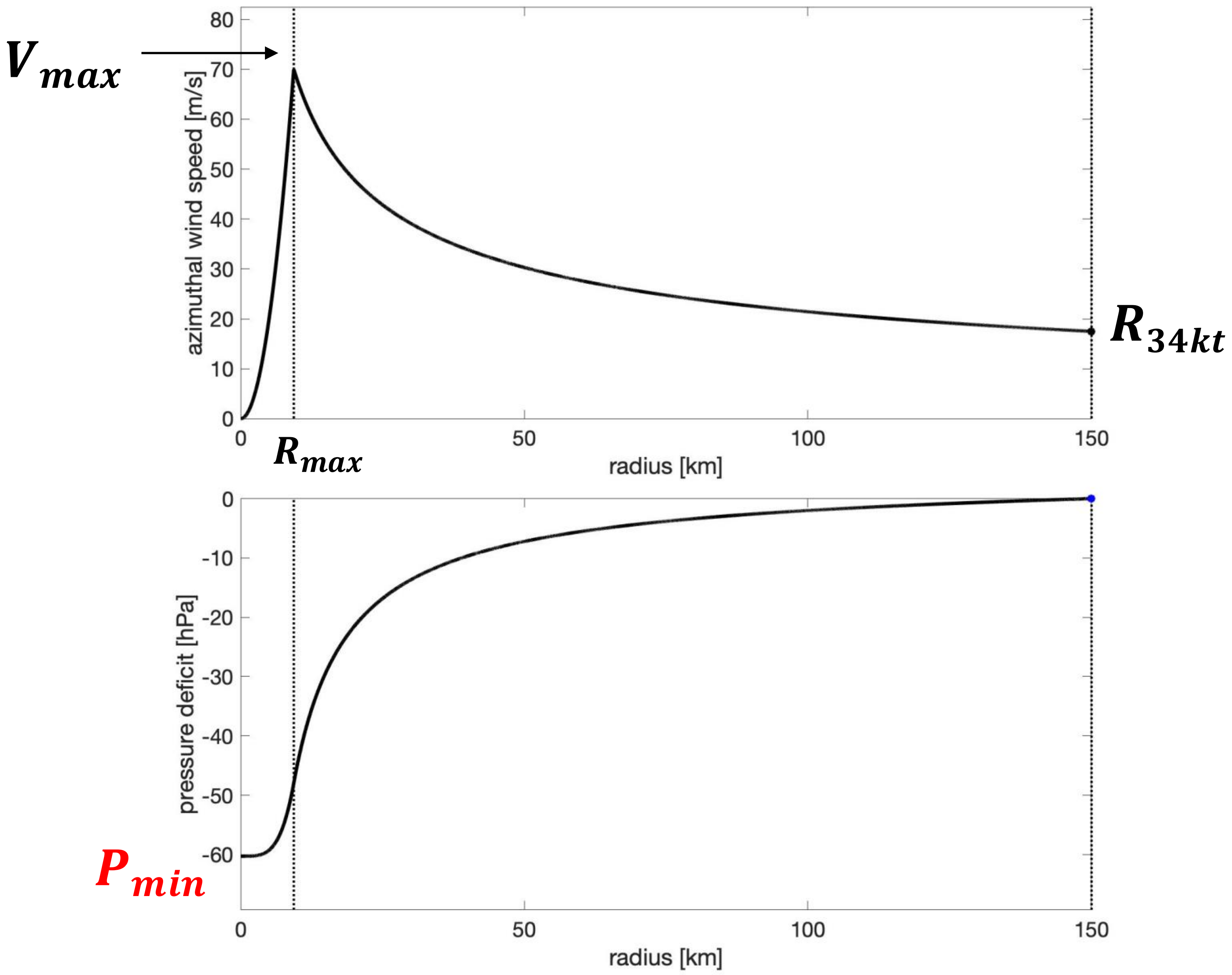




Maximum wind speed V_{max} **Minimum pressure P_{min}**

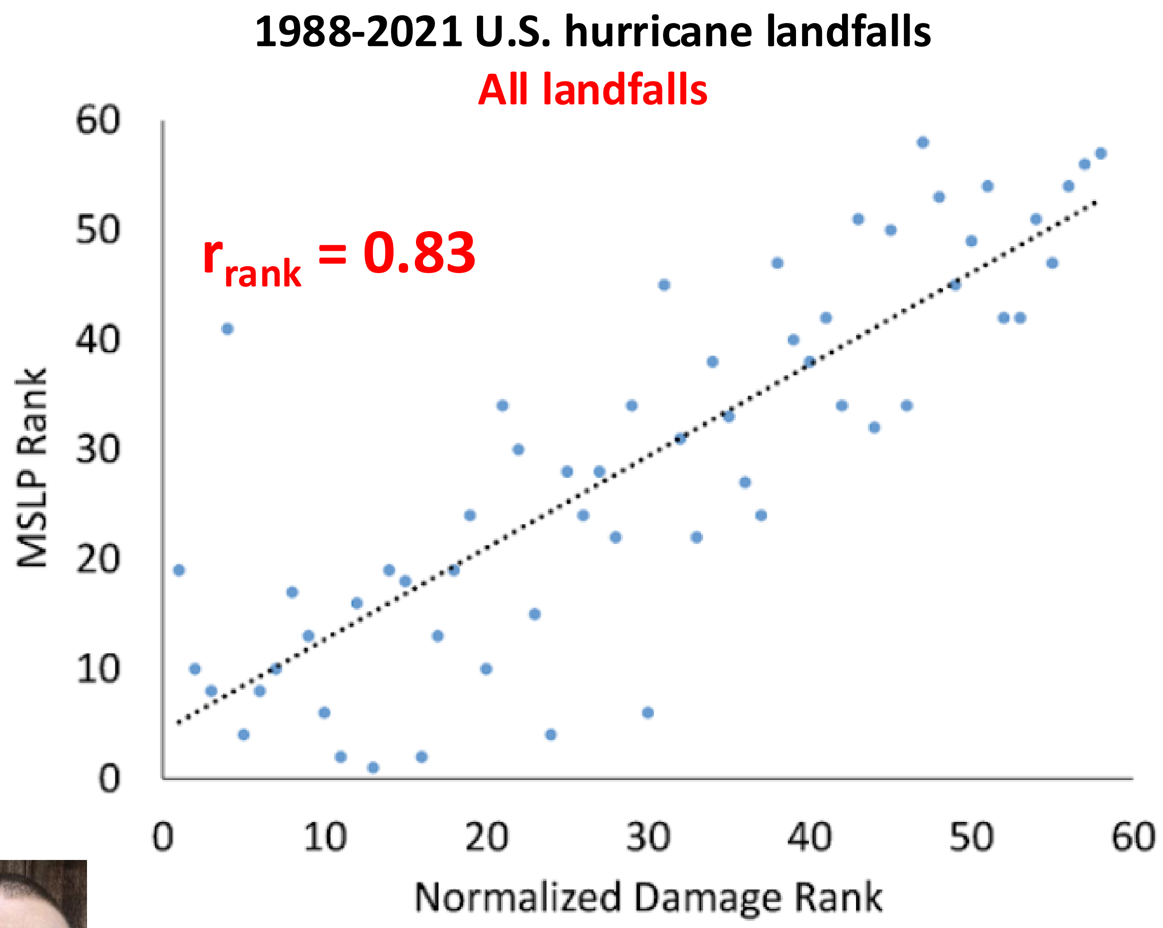
NHC Official Report

P_{min}: integrates intensity and size



Minimum pressure is an excellent predictor of historical U.S hurricane damages

Klotzbach+ (2022, *JGR-A)*



Better than…

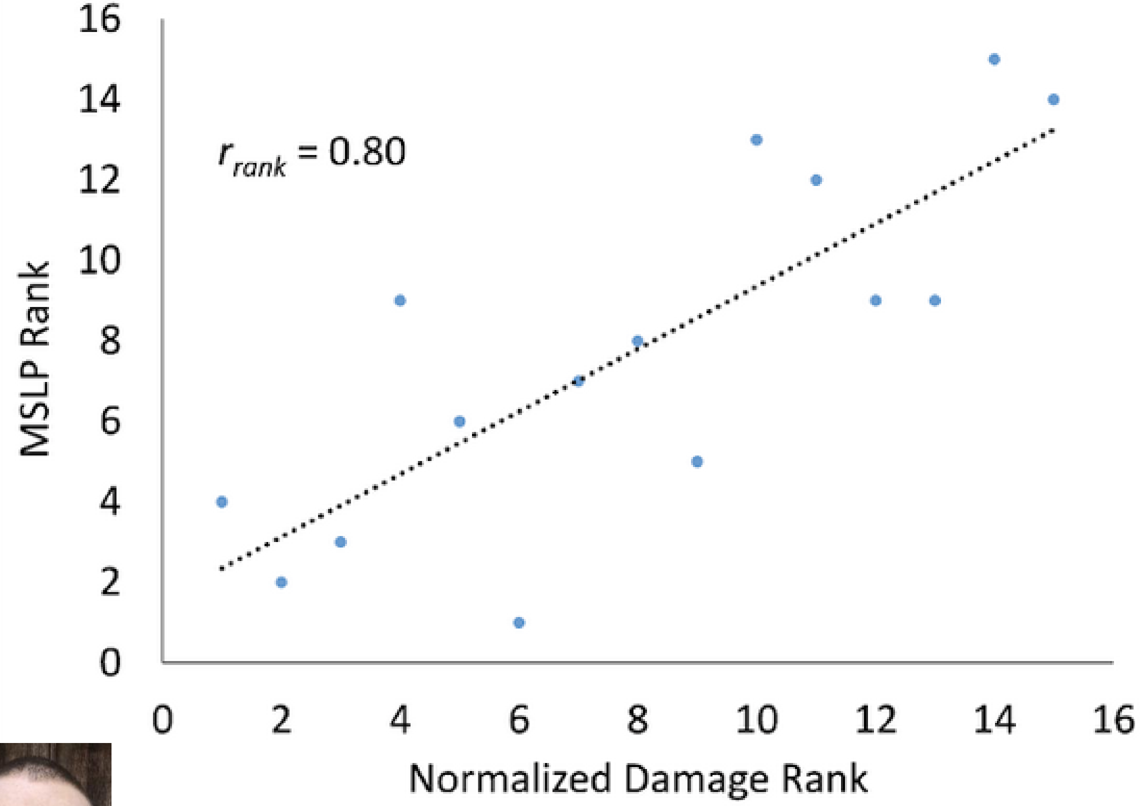
1) V_{max} (r_{rank} = 0.67)
2) Integrated Kinetic Energy (r_{rank} = 0.65)
   Misra et al (2013)

Minimum pressure is an excellent predictor of historical U.S hurricane damages

Klotzbach+ (2022, *JGR-A)*

1988-2021 U.S. hurricane landfalls

East coast: Georgia to Maine



East coast storms are often much larger.

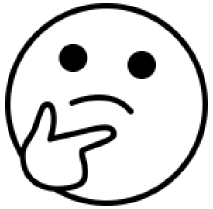
V_{max} is nearly **useless as a predictor!**

Better than...

1) V_{max} (r_{rank} = 0.08)
2) Integrated Kinetic Energy (r_{rank} = 0.67)

Misra et al (2013)

Recall!



Five	≥70 m/s, ≥137 knots ≥157 mph, ≥252 km/h
Four	58–70 m/s, 113–136 knots 130–156 mph, 209–251 km/h
Three	50–58 m/s, 96–112 knots 111–129 mph, 178–208 km/h
Two	43–49 m/s, 83–95 knots 96–110 mph, 154–177 km/h
One	33–42 m/s, 64–82 knots 74–95 mph, 119–153 km/h

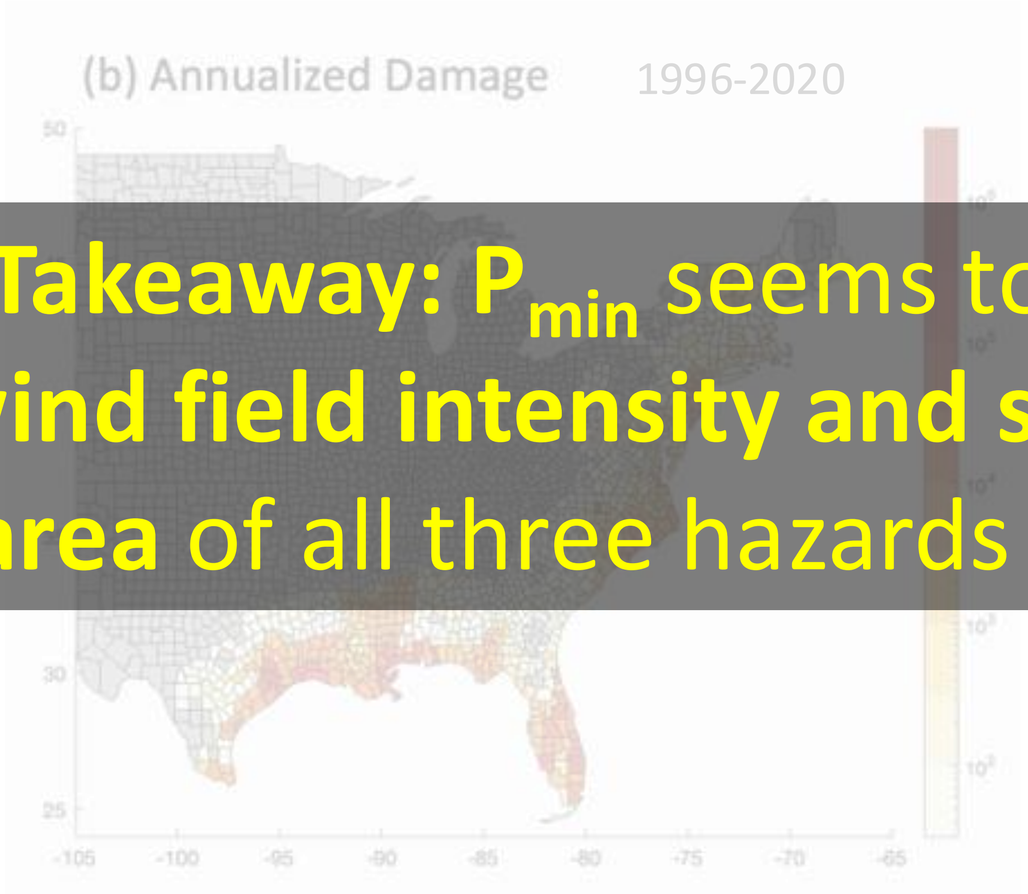
Related classifications

Tropical storm	18–32 m/s, 34–63 knots 39–73 mph, 63–118 km/h
Tropical depression	≤17 m/s, ≤33 knots ≤38 mph, ≤62 km/h

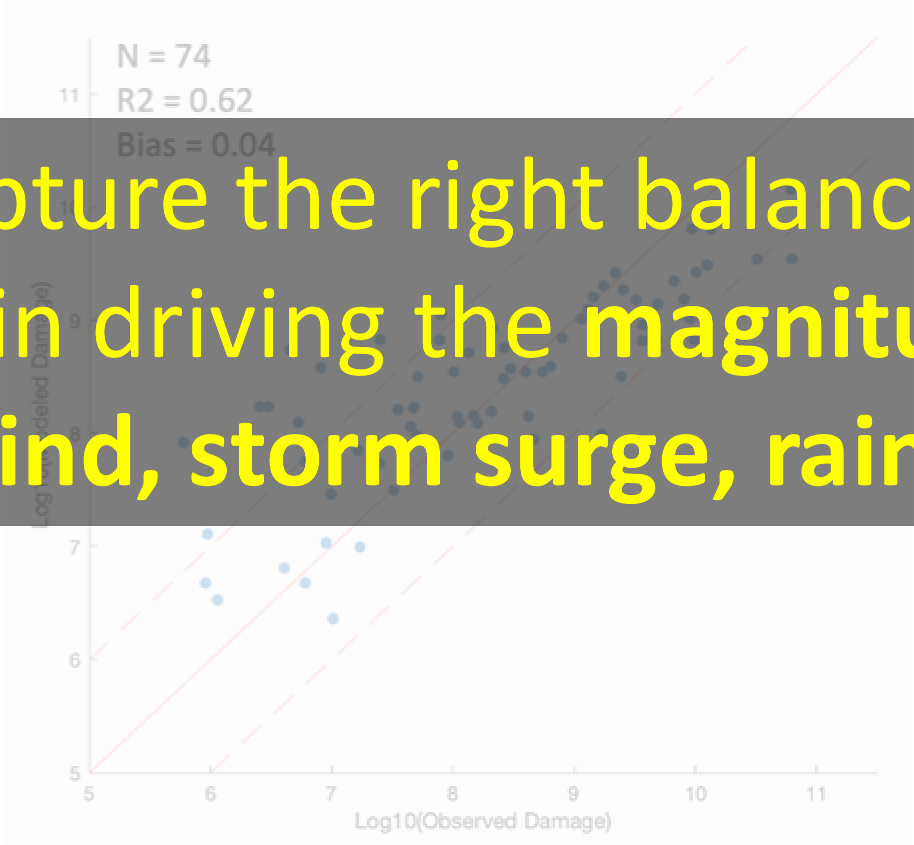
Minimum pressure captures effects of intensity <u>and</u> size – both of which drive damage

All together now! Simulate economic damage from wind/surge/rainfall

Gori et al. (2025, *Env. Res. Lett.*)



modeled vs. observed total TC damage



Takeaway: P_{min} seems to capture the right balance of wind field intensity and size in driving the magnitude + area of all three hazards – wind, storm surge, rainfall.

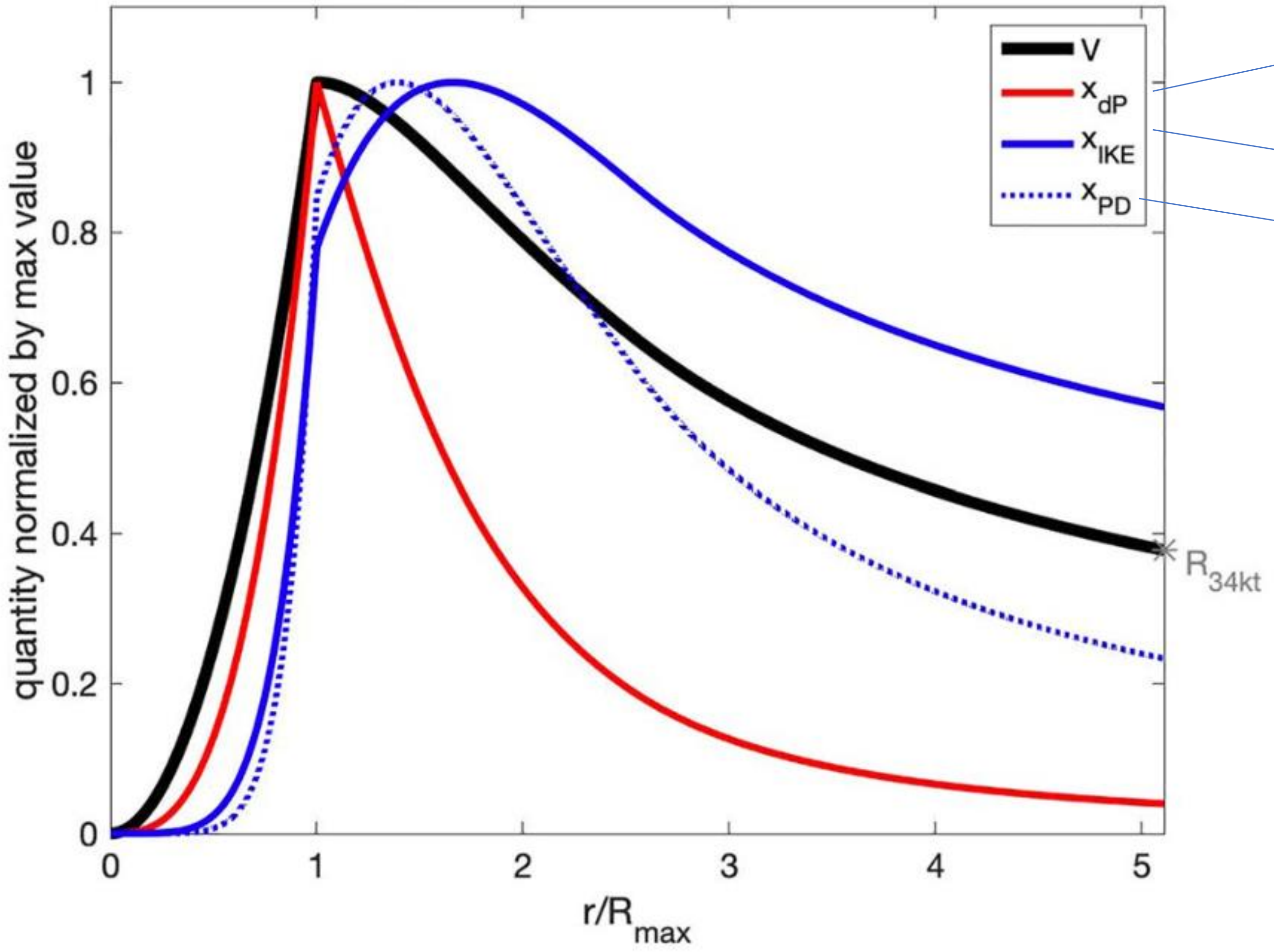
Simple log-link linear regression at the county level

$Damage \sim f(wind\ speed, surge, rainfall)$

all driven by Chavas et al. (2015) wind field model

Fills in the gaps: P_{min} → damage

Klotzbach et al. (2022, JGR-A)



$\frac{V^2}{r} + fV$

rV^2

rV^3

Weighting of wind profile across integrated metrics

Klotzbach et al. (2022), *JGR-Atmos.*

P_{min} is very practical and useful

	P_{min}	V_{max}	
Is it routinely estimated?	Yes	Yes	
What does it represent?	**Integrated measure of entire wind field (max wind and size)**	The max wind speed at a single point (averaged over 1 min? 10 min?)	Knaff and Zehr (2007) Chavas et al (2017)
How does it vary?	**Pretty smoothly**	Very noisy in space/time, embedded in turbulence	
Is it simple to estimate?	**Look near center** (ex: Josh Morgerman – a couple barometers)	Search entire 3D eyewall	Klotz and Nolan (2019)
Eyewall replacement cycle?	**Holds steady**	Decreases then increases	Sitkowski and Kossin (2011)
Climate models?	**Better represented**	Worse	Knutson et al 2015 Zarzycki et al. 2021
A measure of hazards (wind, surge, rainfall)?	Better -- hazards depend strongly on size	Worse – ignores size	Irish and Resio (2010) Gori et al (2023)
A measure of risk?	**Remarkably good predictor of historical U.S. economic damage** better than V_{max}/IKE/PDI	Very poor predictor along the U.S. East Coast	Klotzbach et al. 2022

P_{min} could unify tropical and extratropical cyclones

What if we used V_{max} to define the intensity of extratropical cyclones? *That would be silly*

Extratropical transition

European wind storms

(Source: Verisk)
https://www.insurancejournal.com/news/international/2022/02/25/655755.htm

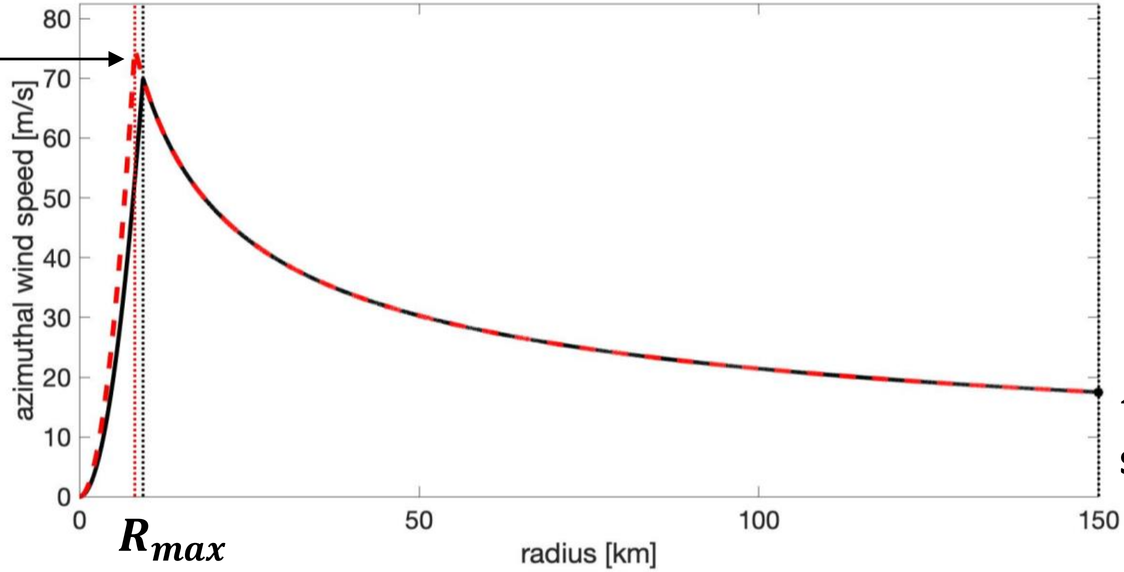
Response to warming

Lower minimum pressures with warming

V_{max}

increases slowly with global warming

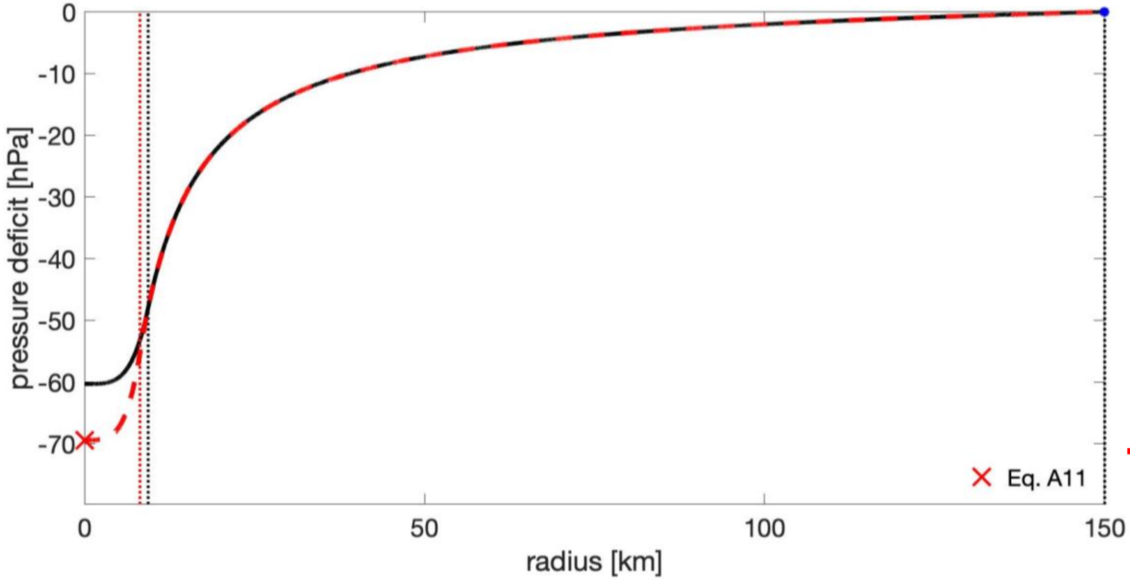
(many studies)



R_{max}

R_{34kt}

stays constant with warming



P_{min}

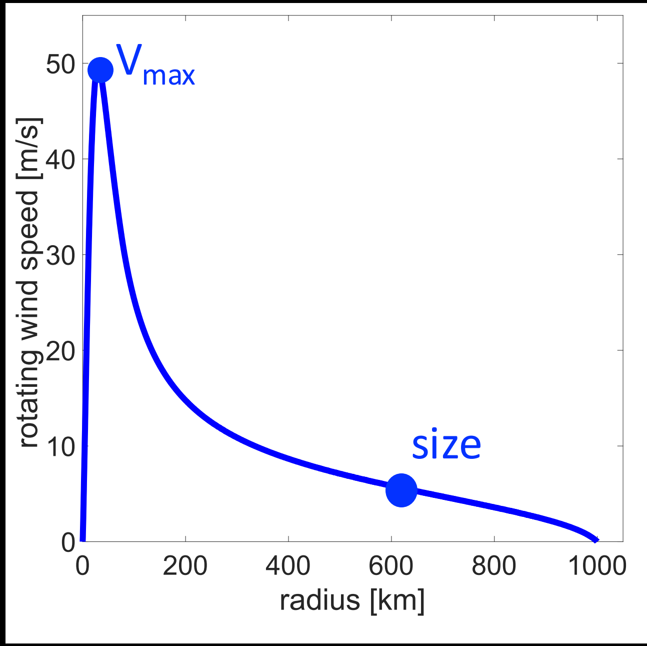
→ **lower pressures**

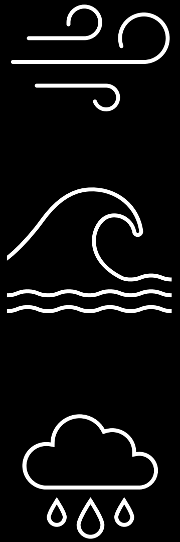
(many studies)

→ **more damaging?**

Klotzbach et al. (2022, JGR-Atmos)

Wind field physics can help us better understand and simulate tropical cyclone hazards+impacts today, and more confidently project how they will change in the future





Thanks! Questions?

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EXTRA

Kerry analytic rainfall model

$$P_{\text{rate}} = \epsilon_p \frac{\rho_{\text{air}}}{\rho_{\text{liquid}}} q_s (w_f + w_h + w_t + w_s + w_r)$$

$$w = w_f + w_h + w_t + w_s + w_r,$$

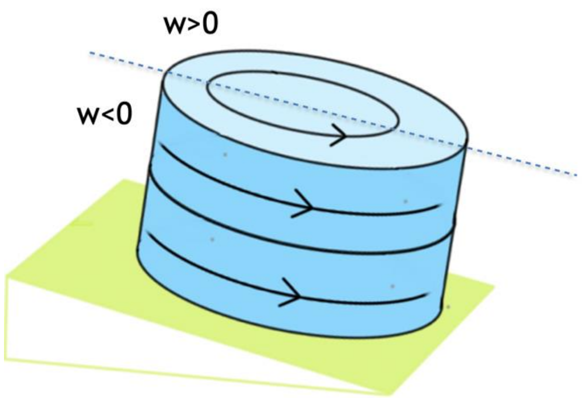
friction

topo

stretching

baroclinic

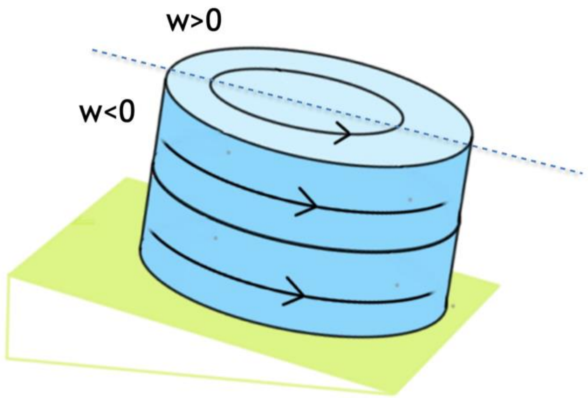
-0.005 m/s



$$w = \vec{V}_{total} \bullet \nabla h$$

$$\vec{V}_{total} = \vec{V}_{radial\ gradient} + \vec{V}_{environmental}$$

Surface of land



$$w = \vec{V}_{total} \bullet \nabla h$$

$$\vec{V}_{total} = \vec{V}_{radial\ gradient} + \vec{V}_{environmental}$$

Surface of constant potential temperature, i.e. isentropic surface

$$\nabla h = \nabla_\theta z$$

can be estimated by the thermal wind equation