Historical and Future Extreme Windstorms in the Northeastern United States

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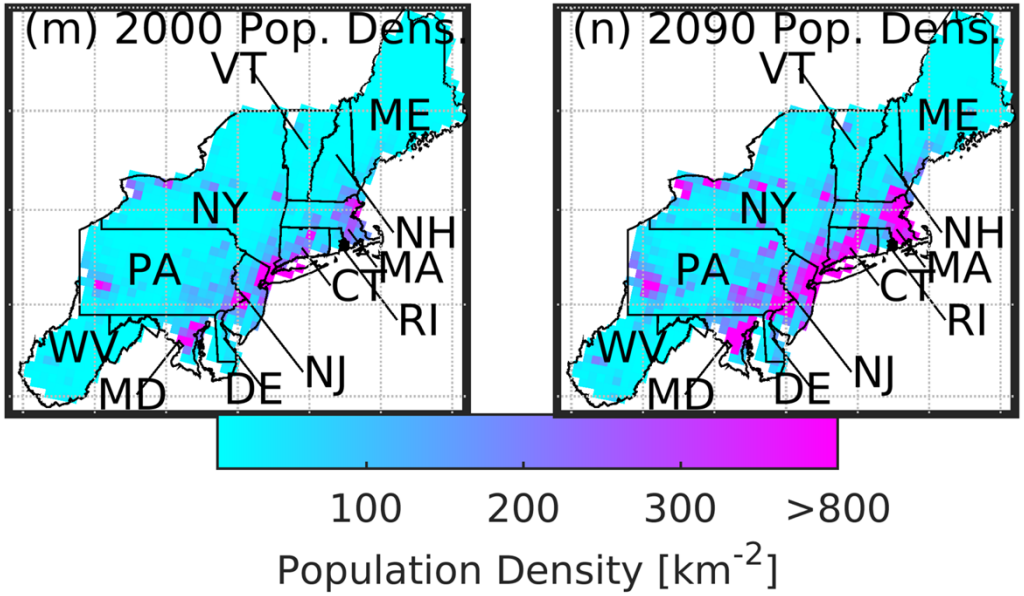
Why focus on Northeastern USA?

- High population density & asset exposure (6% US land, 20% of pop)
- Many multi-billion $ historical events
- Under SSP5-8.5 population doubles & urban coverage > 8* by 2100.

Past research has indicated some evidence for increased NE windstorm frequency/intensity….



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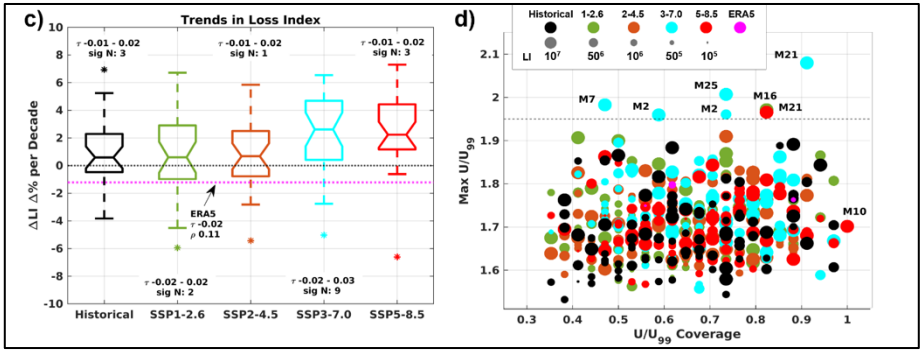
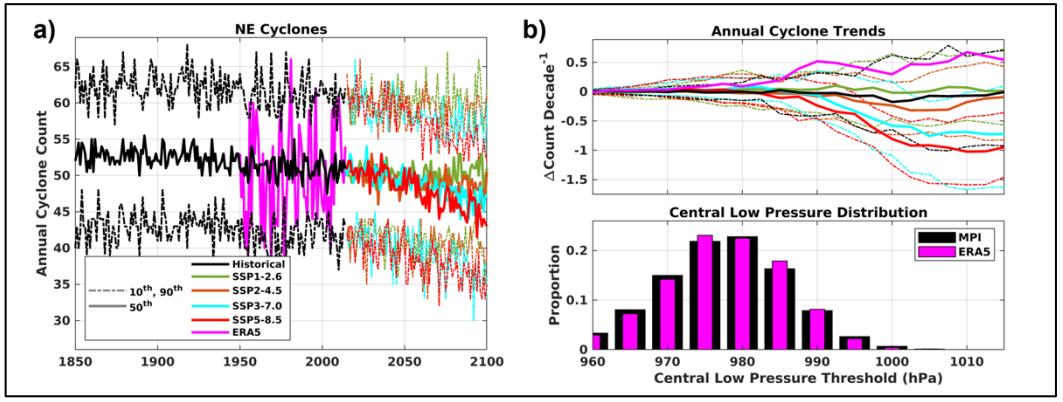
Coburn, Barthelmie & Pryor (2024):
***Environ Res Lett* 19 114045 doi:**
10.1088/1748-9326/ad801b

- MPI-LR SMILE: T63 (∽1.875°): 30 hist, 30 each SSP (1-2.6, 2-4.5, 3-7.0 & 5-8.5)
- Member-to-member variability but generally positive trends in LI (even for fixed pop) irrespective of SSP
- Even as cyclone frequency decreases

$$LI = \sum_{NE_{Land}} pop(cell)\left(\frac{U_{max}(cell)}{U_{\text{nth perc}}(cell)} - 1\right)^3$$





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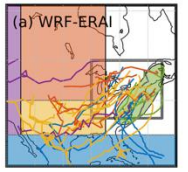
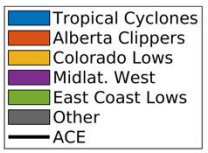
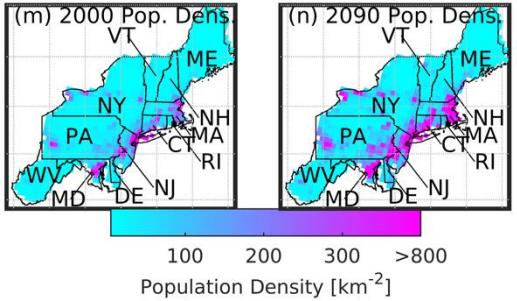
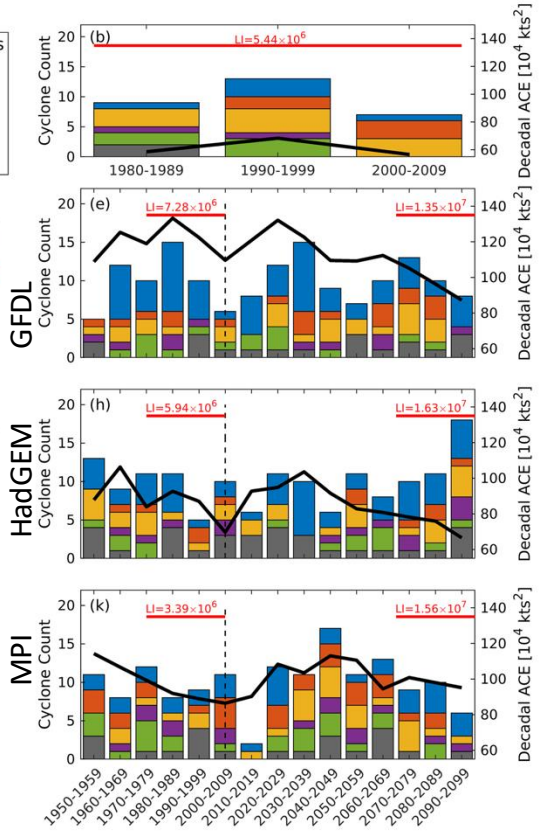
Pryor et al. (2025) *Climate* 13 105
doi:10.3390/cli13050105

- WRF: CMIP5 GFDL, HadGEM, MPI (RCP8.5).
- All show large decadal variability in windstorm occur & future LI ≥ 2* (Pop)
- WRF-MPI:
  - Best reproduces WRF-ERAI:
    - Spatial U_{999} field
    - Windstorm scale/frequency
    - Cyclone type responsible for windstorms
    - Internal climate modes
  - Biggest inc. in LI (**windstorms more intense along coast –i.e. transitioning tropical cyclones**)









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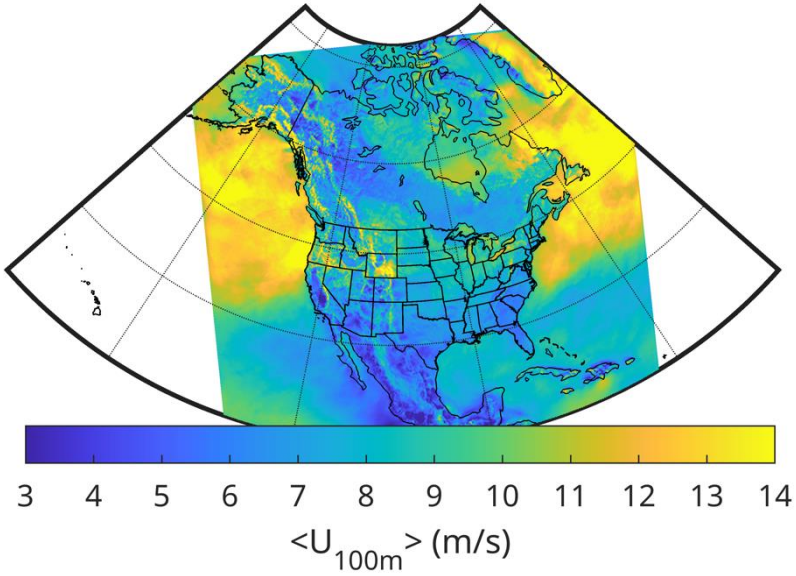
New simulations: WRF in CMIP6 MPI-LR (R1): 1960-1999 & 2040-2079 (SSP5-8.5)

- dx = 12km (662 × 629 .. >400,000 grid cells!)
  - Milbrandt-Yau microphysics (double-moment)
  - MYNN PBL with EDMF (shallow convection)
  - RRTMG LW/SW
  - Noah-MP
  - Time varying SST & AOD & LULC
  - Nudging above PBL



ZOOM back out, employ WS @ 100-m height

Main Objective

- Evaluate if/where 50-yr RP WS projected to ↑/↓

Technical Objectives

- Evaluate sensitivity to calculation method
- Explore new objective method to determine optimal threshold for GPD
- Explore use of supersite approaches

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Methods to derive U_{50}: Mann, Kristensen, & Jensen (1998) *Bridge Aerodynamics*, 49-56.

1) Gumbel distribution applied to annual maximum. MLE for parameters

$$P(Umax) = exp(-exp\left[\frac{Umax-\beta}{\alpha}\right])$$

$$U_T = \beta - \alpha ln\left[ln\left(\frac{T}{T-1}\right)\right]$$

$$\sigma(U_T) = \frac{\pi}{\alpha}\sqrt{\frac{1+1.14k_T+1.10k_T^2}{6n}},$$

$$k_T = -\frac{\sqrt{6}}{\pi}\left[lnln\left(\frac{T}{T-1}\right)-\gamma\right],$$

$$\gamma = Euler\ constant\ (0.577216)$$

95% confidence intervals = $\pm 1.96 \times \sigma(U_T)$

2) Generalized Pareto distribution (POT). MLE for parameters $\lambda = \frac{n_e}{n}\left(\frac{\#ev}{\#yr}\right), u_0 = threshold$

$$P(U,u_0) = 1 - \left(1 - \frac{k(U-u_0)}{\alpha}\right)^{\frac{1}{k}}, k \neq 0$$

$$P(U,u_0) = 1 - exp\left(\frac{U-u_0}{\alpha}\right), k$$

$$= 0\ (perfect\ exponential)$$

$$U_T = u_0 + \frac{\alpha}{k}\left[1-(\lambda T)^{-k}\right], k \neq 0$$

$$U_T = u_0 + \alpha ln(\lambda T), k = 0$$

$$\sigma(U_T) = \frac{\alpha}{\sqrt{\lambda n}}\sqrt{1+ln^2(\lambda T)}$$

95% confidence intervals = $\pm 1.96 \times \sigma(U_T)$

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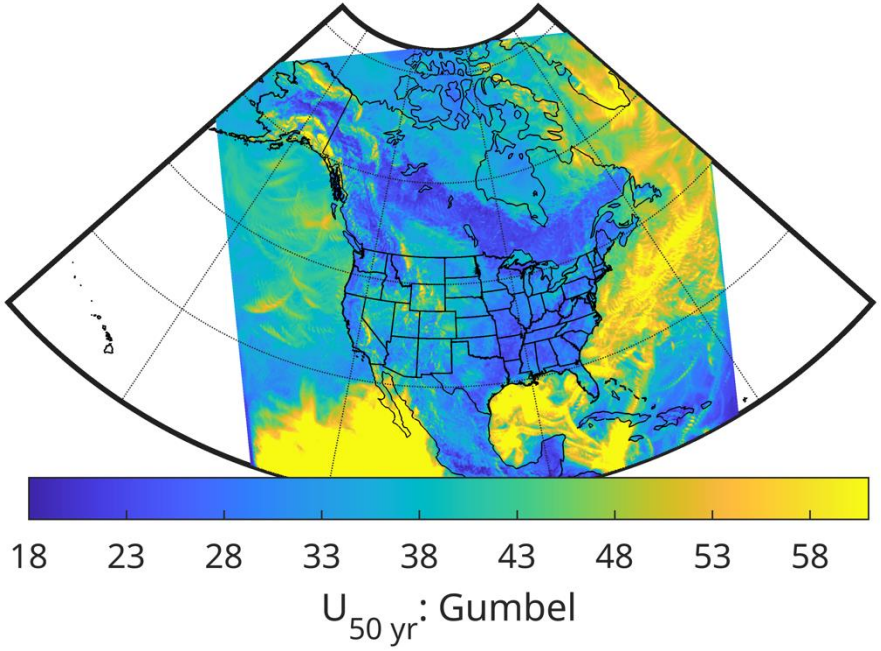
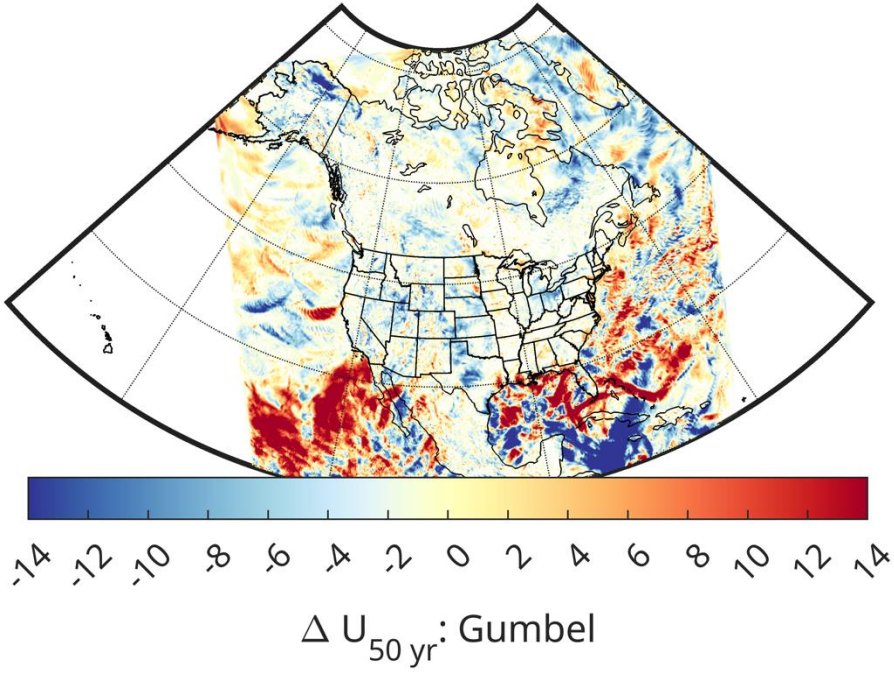
U_{50yr} & ΔU_{50} Gumbel (37 yr of hourly output hist & future)





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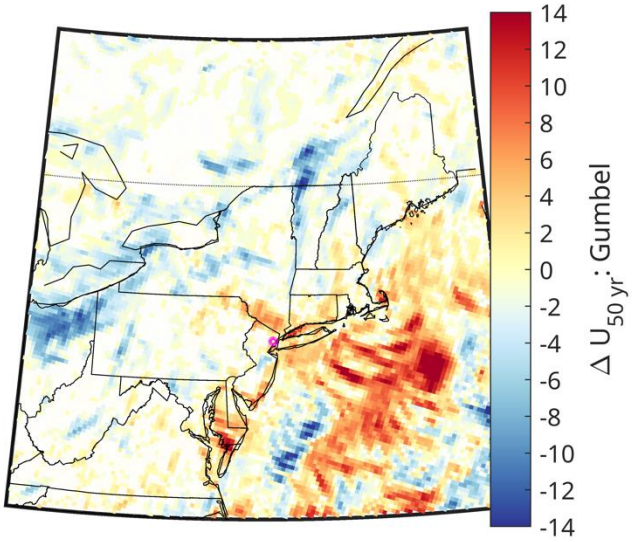

Zoom in on Northeast & Answer:

Qu#1: If invoke supersite concept how much does ΔU_{50} (future-historical) change?

Postulate: Cyclone tracks accurate only within ± 50 km

Results for New York City & NYC ± 50 km for Gumbel U_{max}

	Historical U_{50} (m/s)	ΔU_{50} (m/s)
NYC	26.4	+4.1
NYC±50km	44.1	+6.8

Differences exceed 95% CI.

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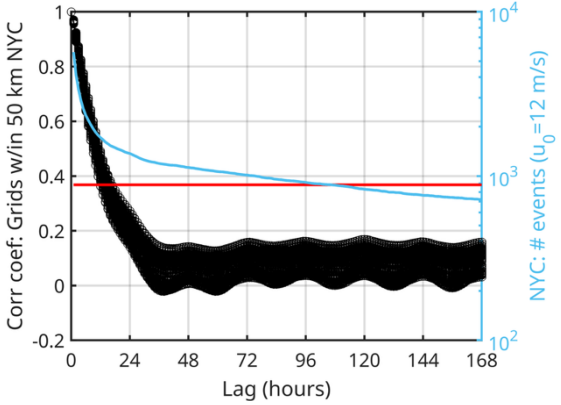

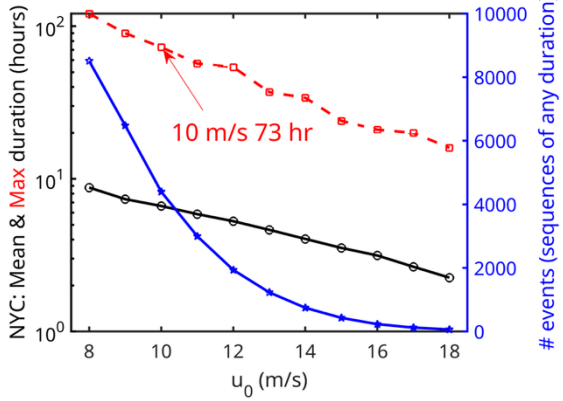

Qu#2: If use GPD (POT) do U_{50yr} and ΔU_{50} differ?

- **First need to decide: Δt for Independent events?**
  - Palutikof et al. (1999) *Meteorol Appl* **6** 119–132 suggest ≥ 48-60 hr.
  - Larsen et al. (2015) *Wind Energ*. **18** 59–74 used 7 days
- **E-folding time scale:**
  - Δt < 24 hr: for all grid cells w/in 50 km of NYC
  - *Note: Δt < 72 hr: ALL 100 randomly chosen grid cells in N.A. domain*
- **Mean & max duration of U>u_0:**
  - NYC: Δt <72 hr, if $u_0 \geq 10$ m/s

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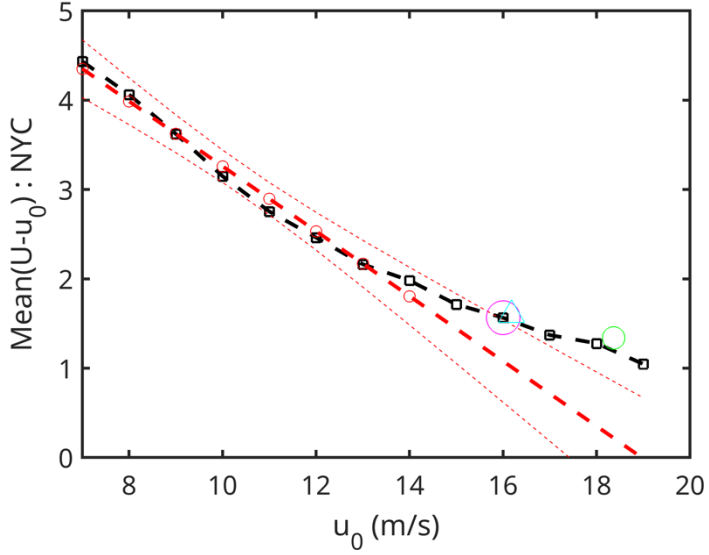
u_0? Avoid: large n_e << λ << 1

- $\overline{U - u_0}\ v\ u_0$ shows repeatable form… Proposal: Use deviation from linear fit: $\overline{U - u_0}\ v\ u_0$ to select u_0



Approach	U_{50yr} (# ev hist)
u_0=min(U_{max})	26.4 (156)
u_0 for λ=1	30.3 (37)
u_0 from fit to mean dev.	26.1 (178)
Gumbel U_{max}	26.4

- **Not massively different for THIS grid cell but for many u_0=min(U_{max}) and u_0 for λ=1 occur after plateau of gradient in mean deviation v u_0 relationship**

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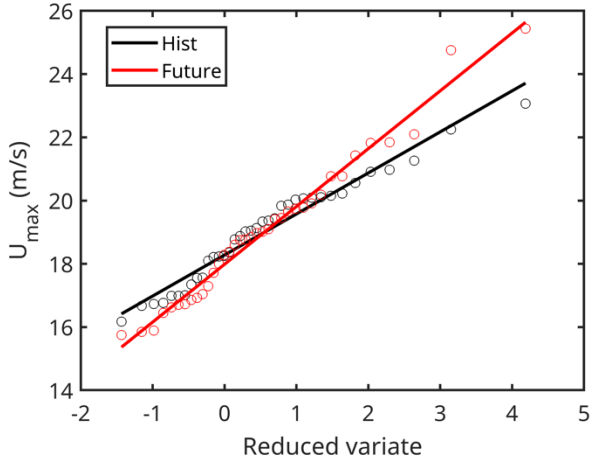
- **If use FIXED Δt & u_0 from historical period POT: BOTH $\lambda\downarrow$ & $\alpha\downarrow$ so $U_{50}\downarrow$**
  - $U_T = u_0 + \alpha ln(\lambda T), k = 0$
- **Conversely upper tail of U_{max} sample INCREASES so Gumbel $U_{50}\uparrow$**

Approach	U_{50yr} (m/s) (# ev hist)	ΔU_{50} (m/s) (# ev future)
u_0=min(U_{max})	26.4 (156)	-1.7 (95)
u_0 for λ=1	30.3 (37)	-6.2 (26)
u_0 from fit to mean dev.	26.1 (178)	-2.4 (112)
Gumbel U_{max}	26.4	+4.1



- **i.e. Declining # of intense (high WS) cyclones entering NE BUT U_{max} sample from increasingly mixed climate (transitioning TC $\uparrow$) differentially impacting two approaches.**
- **So how best to evaluate ΔU_{50}?**

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