

Projected changes in extreme windstorms and high-wind cyclone tracks across model resolutions

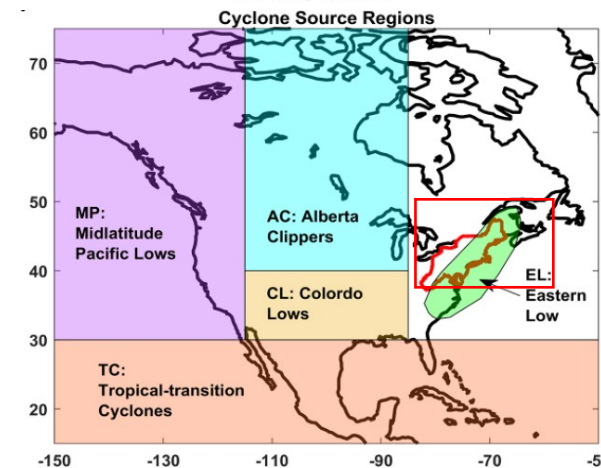
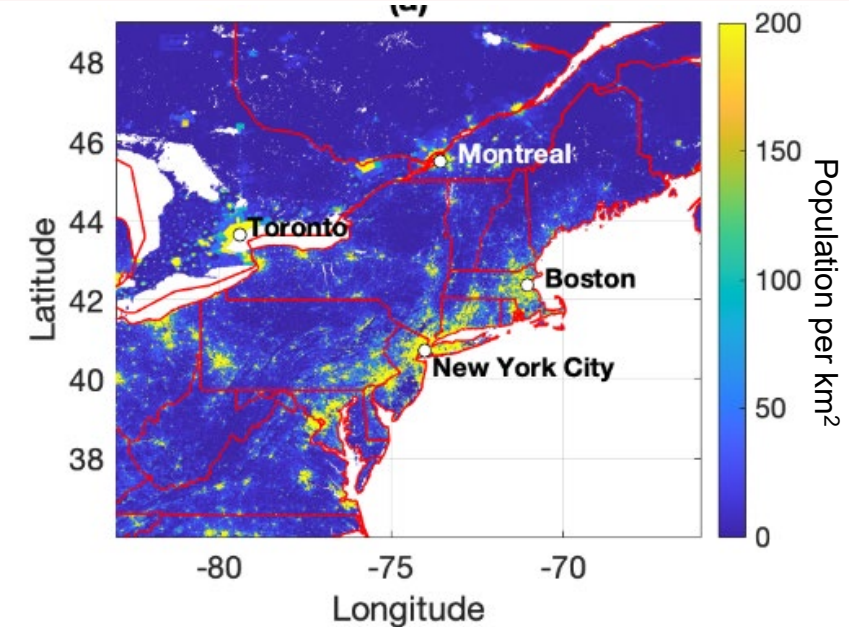


Rui Zhang¹, Rebecca J. Barthelmie¹, Olivier Asselin², Dominique Paquin², Sara C. Pryor¹



Introduction

- Windstorms (extended duration of spatially expansive damaging wind speeds) associated intense synoptic-scale cyclones
- Important natural hazard in NE US and SE Canada (NE)
- Population of 80 million - major cities & highly populated areas
- “very high exposure” value of capital to financial risks
- Previous: Events identified using wide-spread $U > U_{999}$
 - Top-10 (1979-2018): > \$34 billion adj. US\$2020 damage
 - Top-10: Alberta Clippers and Colorado Lows = 8, 2 = transitioning Tropical Cyclones.
 - Low serial correlation in current climate



Zhang, R. et al. 2026: Projected changes in extreme windstorms and high-wind cyclone tracks across model resolutions. *Npj climate and atmospheric sciences* (in review)

Coburn, J.J. Barthelmie, R.J. Pryor, S.C. 2024: Changing Windstorm Characteristics over the US Northeast in a Single Model Large Ensemble, *Env Res Let*, 19, 114045. <https://doi.org/10.1088/1748-9326/ad801b>

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Objectives, Definitions and Metrics

- Use multi-member ensemble of HighResMIP global models (low- to high-resolution, **coupled** & atmosphere-only) and regional dynamically downscaled simulations to investigate future changes of extreme windstorms and dynamical origins
- Historical 1950-1985. HighResMIP Future 2015-2050 RCP8.5 $\Delta T \sim 2.3^\circ\text{C}$, Regional SSP3-7.0 Dates vary $\Delta T \sim 2.3^\circ\text{C}$
- Windstorms 10 m wind speeds exceed local 99th percentile ($U > U_{99}$ 1950-1985) > 50% of NE land grid cells
- Mean area > $6.6 \times 10^5 \text{ km}^2$, most intense, ensemble mean average return period of ~ 2 yrs.
- Metrics: Max U, spatial extent, and spatial-mean kinetic energy (KE)

		Model Name	#	Atmos. Reso.	Ocean Reso.	Future Period
CMIP6 HighResMIP	Low	HadGEM3-GC3.1-LL	1	130 km	110 km	2015-2050
			2			
			3			
			4			
		HadGEM3-GC3.1-LM	5	130 km	N/A	
			6			
			7			
		CNRM-CM6-1*	8	110 km	N/A	
		EC-Earth3P*	9	80 km	N/A	
			10			
	Mid	HadGEM3-GC3.1-MM	11	60 km	25 km	
			12			
			13			
		HadGEM3-GC3.1-MM	14	60 km	N/A	
			15			
			16			
		CNRM-CM6-1-HR*	17	55 km	N/A	
		EC-Earth3P-HR*	18	40 km	N/A	
			19			
	High	HadGEM3-GC3.1-HH	20	25 km	8 km	
		HadGEM3-GC3.1-HM	21	25 km	25 km	
			22			
			23			
		HadGEM3-GC3.1-HM	24	25 km	N/A	
			25			
			26			
NA-CORDEX	Regional	CRCM5-CNRM-ESM2-1	27	12 km		2043-2078
		CRCM5-CanESM5	28			2015-2050
		CRCM5-MPI-ESM1-2-LR	29			2053-2088
			30			2057-2092
			31			2054-2089
			32			2055-2090
			33			2053-2088
			34			2058-2093
		CRCM5-NorESM2-MM	34			

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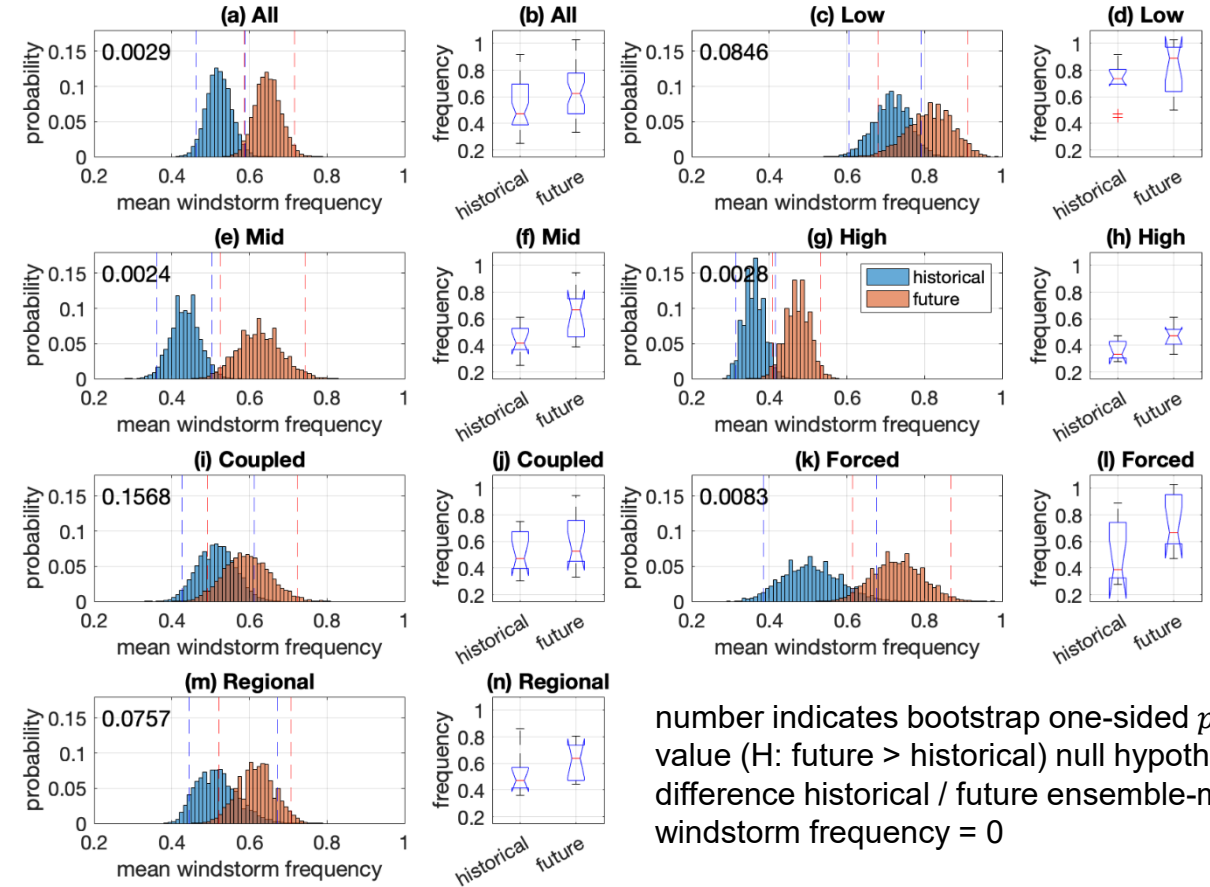
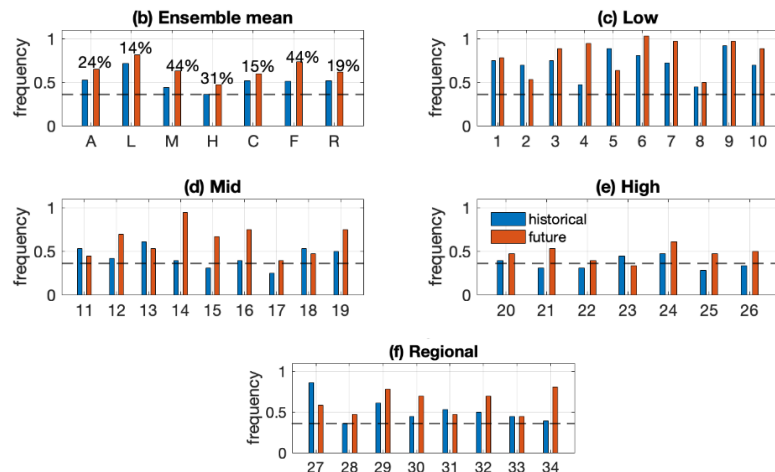
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Results: frequency

- 24% higher windstorm frequency in the future
- 20/26 HighResMIP, 5/8 CRCM5 (prob. 25/34 0.0003)
- +14% LR HighResMIP to +44% mid and forced HighResMIP
- Associated with reduced return periods
- **Very high certainty can be attributed to assertion that more windstorms are likely to occur over NE as climate warms**



number indicates bootstrap one-sided p -value (H: future > historical) null hypothesis difference historical / future ensemble-mean windstorm frequency = 0

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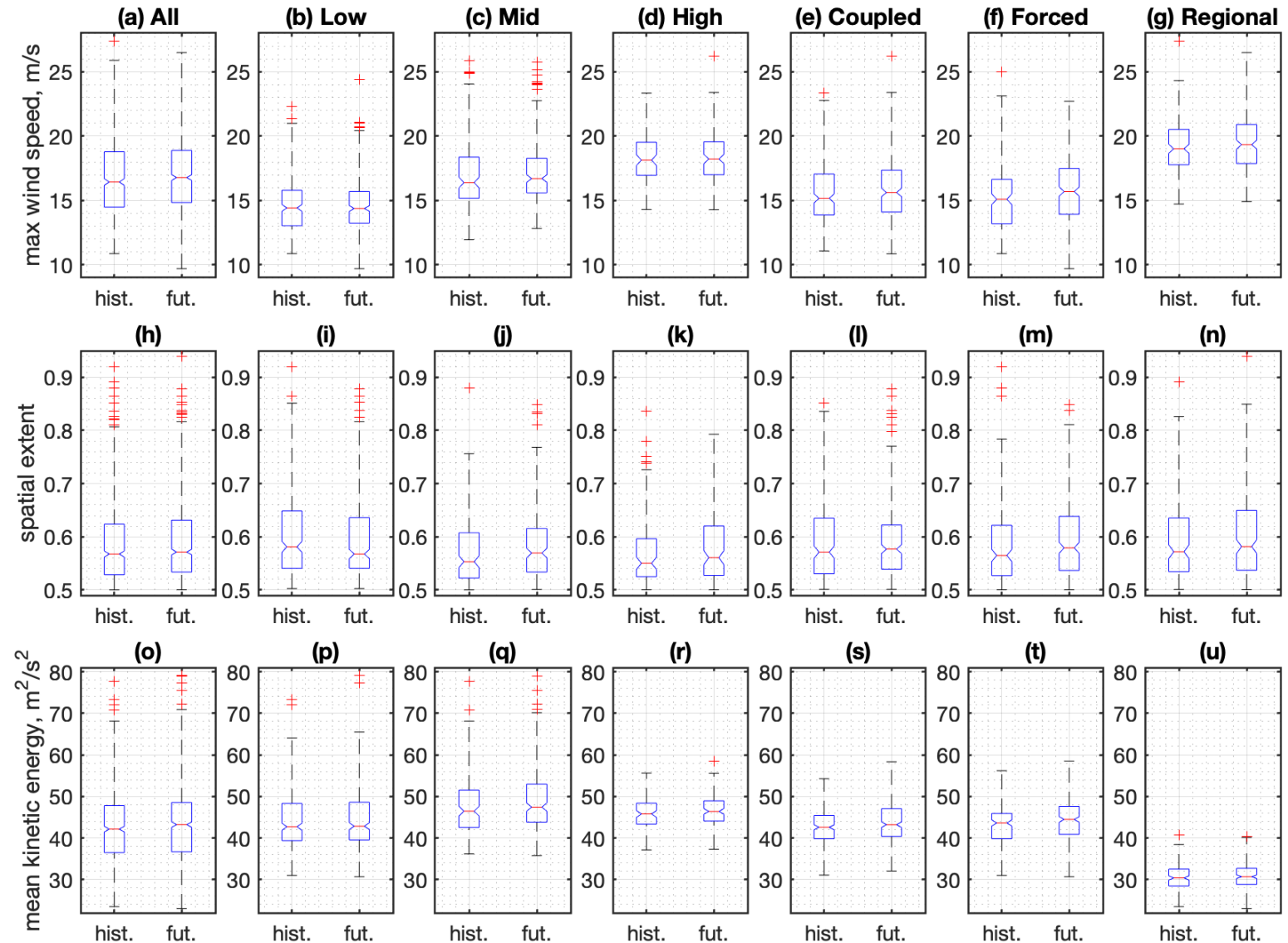
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Results: U, extent, KE

- Median windstorm max U and spatial extent higher in future period (ex. Low Res)
- Most also show increased KE



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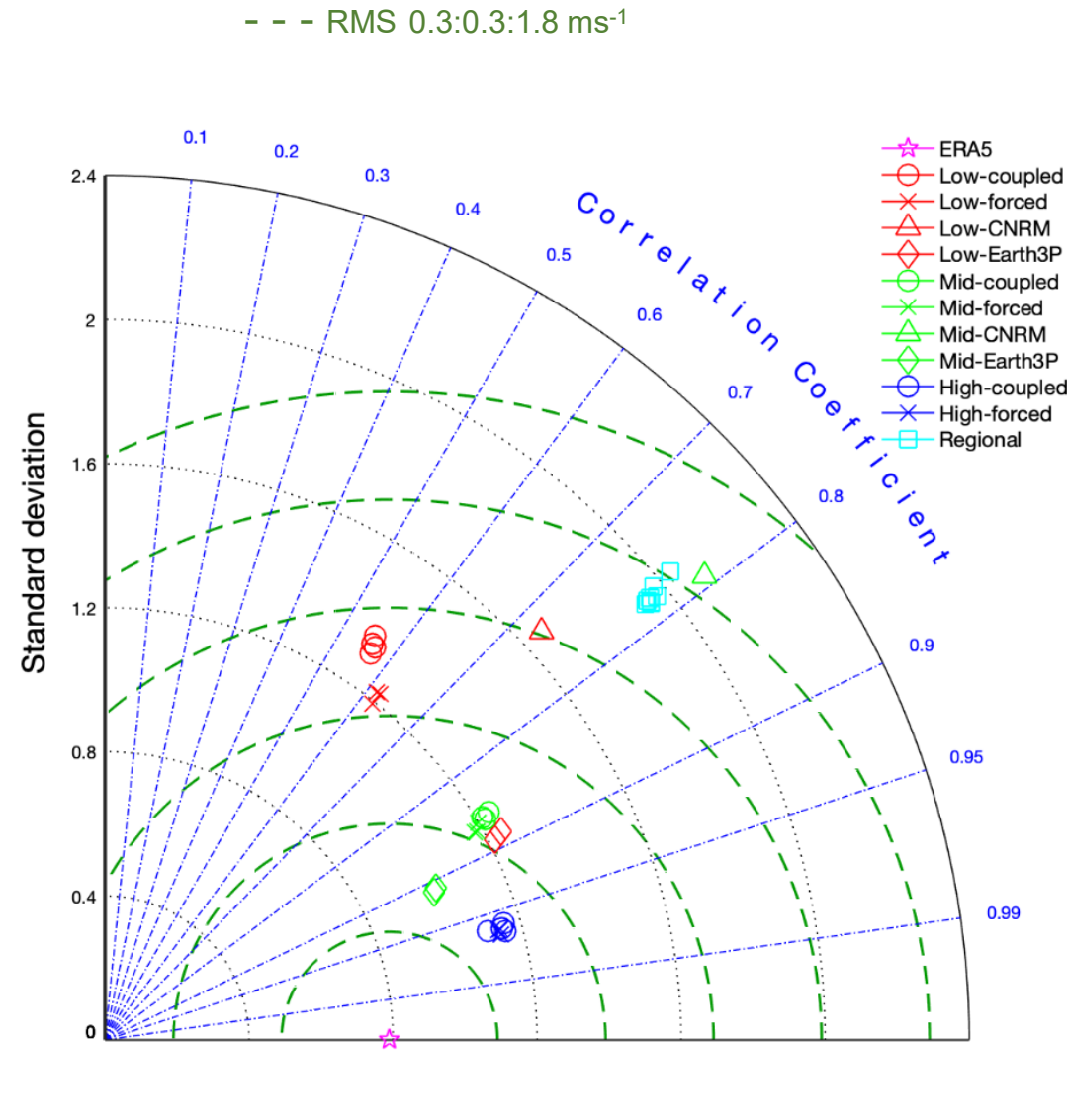
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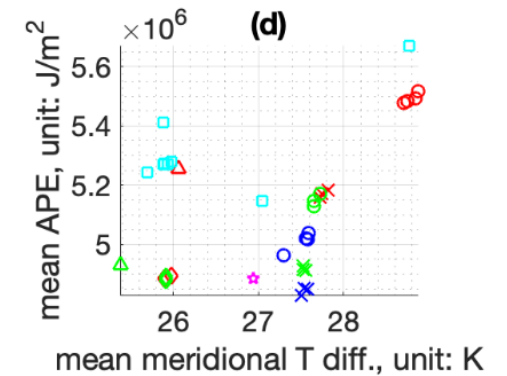
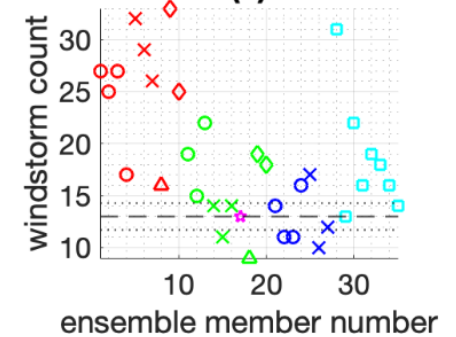
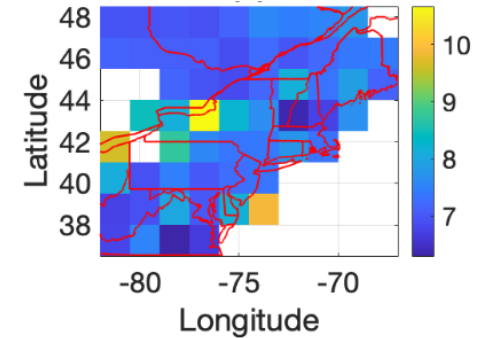


Results: Credibility vs ERA5

- 13 storms meet windstorm criteria in ERA5 36 yrs cf ~21 in models
- HighResMIP greatest accord with ERA5 (spatial variability, correlation and rms U_{99} fields)
- Most model groups higher U_{99} spatial extent and mean KE than ERA5
- Also hemispheric mean available potential energy (APE) is higher in model groups



U_{99} (ms⁻¹) field from ERA5 (1950-1985)



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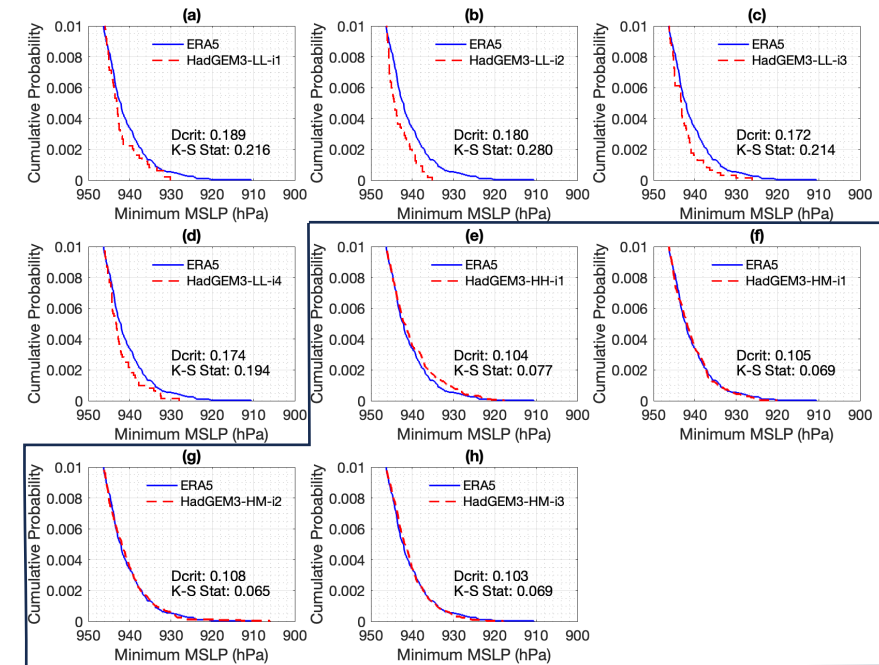
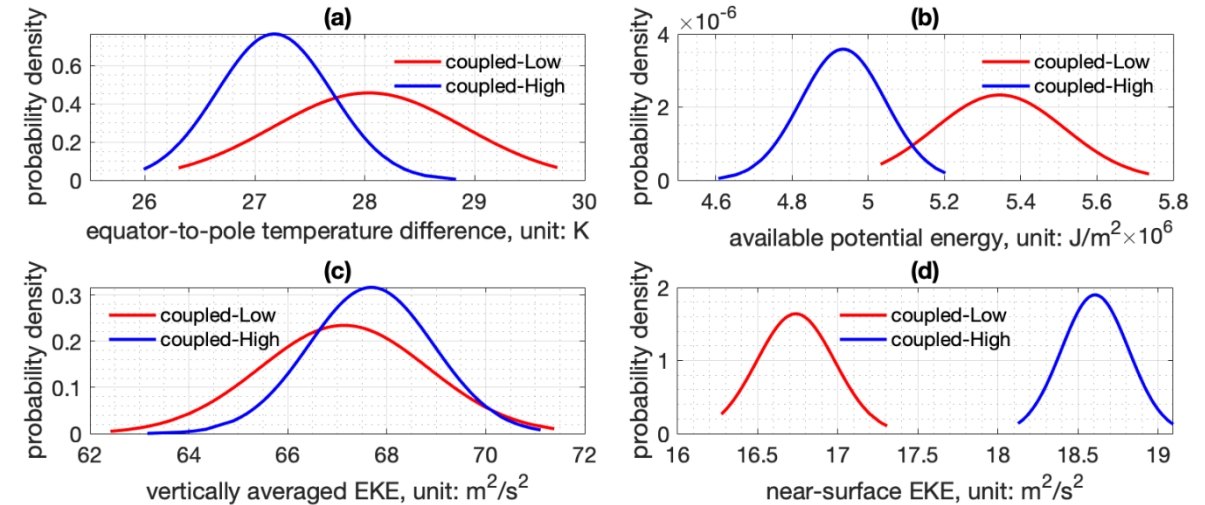


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Results: Dynamical

- HighResMIP lower baroclinicity (mean meridional temperature difference) but higher Eddy Kinetic Energy (EKE)
- Possible Low Res models cannot trigger cyclones at proper Rossby Deformation radius
- Threshold min MSLP ≤ 945 mb (99th perct. ERA5: 271 cyclones).
- 4 coupled low-res HadGEM3-GC31 simulations 49, 55, 62 and 60 cyclones. Cum. Prob. Dist. differ significantly from ERA5 ($D_{crit} < \text{Kolmogorov-Smirnov test}$)
- High-res simulations: 275, 272, 239 and 286 cyclones and have Cum. Prob. Dist. that overlap with ERA5
- All high-resolution models produce $K-S < D_{crit}$ i.e. do not reject the null hypothesis that same population as ERA5



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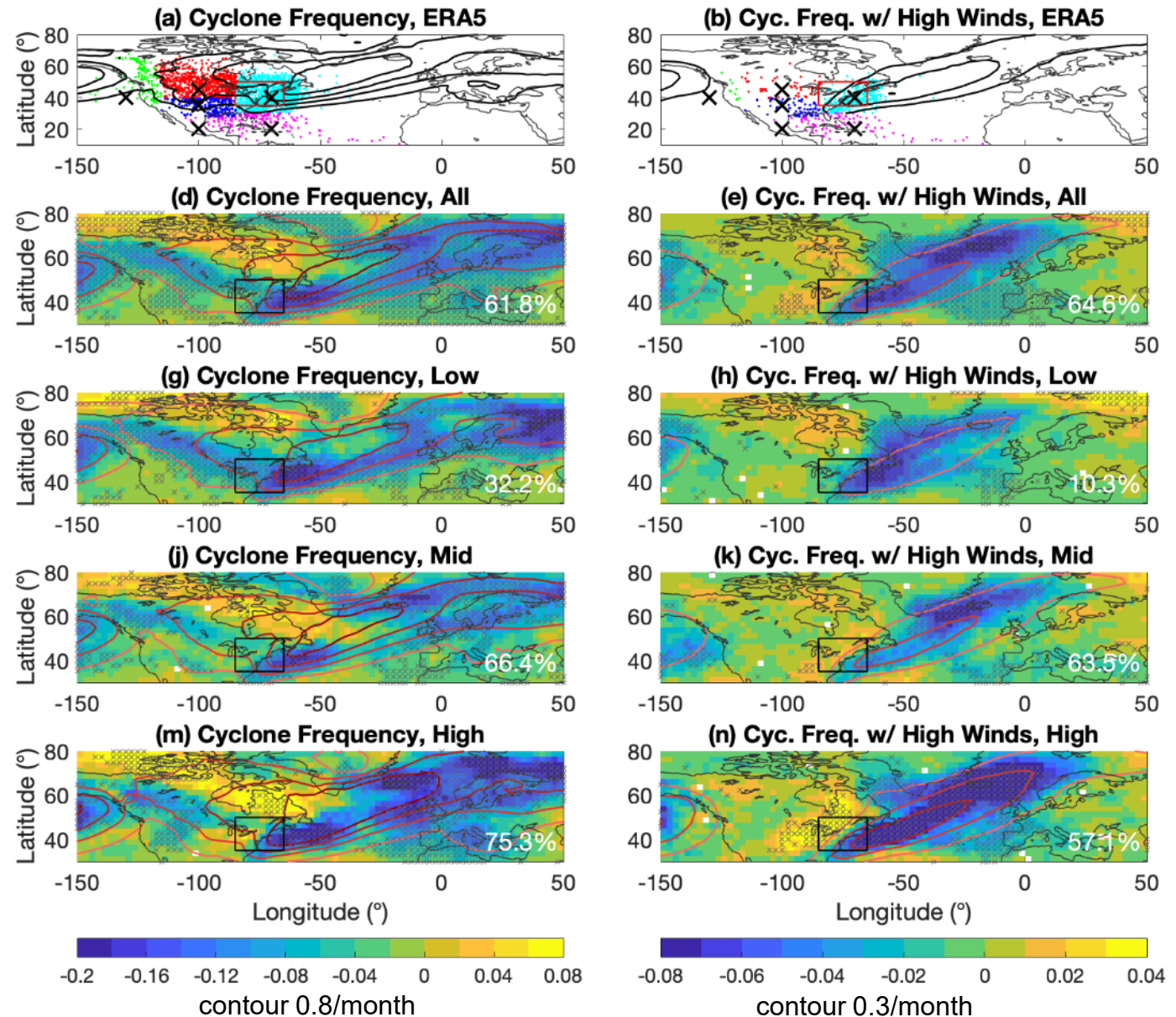
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Results: Cyclone climatology from tracking

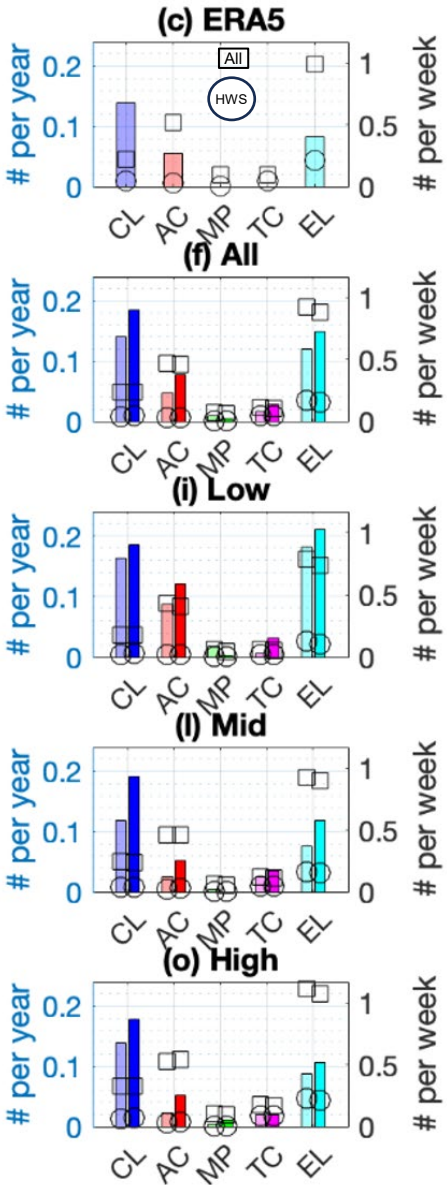
- Cyclone climatology from ERA5 & high winds upper 1% of most intense cyclone min. SLP
- Projected changes in track frequency & genesis regions of NE windstorms
- Diff in total cyclone track frequency (future minus historical, count/month)
- Overall decline in number of cyclones, irrespective of model resolution
- But Mid&High Res shows increase in NE and better agreement in areal overlap (White text %)



Conclusions

- Use 26 multi-member ensemble of HighResMIP global models
- Very high certainty more windstorms over the NE as climate warms
- Max U_{99} , spatial ext., KE higher in future period (ex. Low Res)
- Tracking decline in # cyclones & high U cyclones irrespective of model resolution BUT High and Med Res increases in NE
- Most windstorms extratropical origins historical & future periods
- Questions/comments: Please email Rui Zhang <rz479@cornell.edu>

	Skill vs ERA5
dx↓	Most similar to ERA5
dx↓	#windstorms↑ (+44%)
dx↓	APE & mean ΔT ↑
dx↓	Max U_{99} & U_{99} spatial field↑
dx↓	Cyclone count↑
dx↓	Windstorm # NE↑



Source regions; Colorado Lows (CL), Alberta Clippers (AC), Midlatitude Pacific Lows (MP), Tropical Cyclones (TC), Eastern Lows (EL)