Tropical Cyclone Landfalls: HighResMIP vs. Statistical Dynamical Downscaling

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HYPERFACETS

A Framework for Improving Analysis and Modeling of Earth System and Intersectoral Dynamics at Regional Scales

Image: Katia, Irma, and Jose (2017, NOAA)

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Opinions are mixed on future Tropical Cyclone (TC) impacts

High Confidence

↑ Precipitation rates
↑ Storm surge
↑Average intensity
↑ Relative frequency of extreme events

Low Confidence

? **Overall frequency**
? Storm genesis/landfall distributions
? Changes in certain ocean basins

- Two popular techniques: **high-resolution global climate models (GCMs)** and **statistical-dynamical downscaling (SDD) models**
- How different are the results from using these techniques? Is there an unequivocally “better” option?
- **Objective:** Compare landfalling TCs objectively-tracked storms in HighResMIP GCMs and synthetic storms using the SDD TC model described in Lin et al. (2023) against observations and reanalysis

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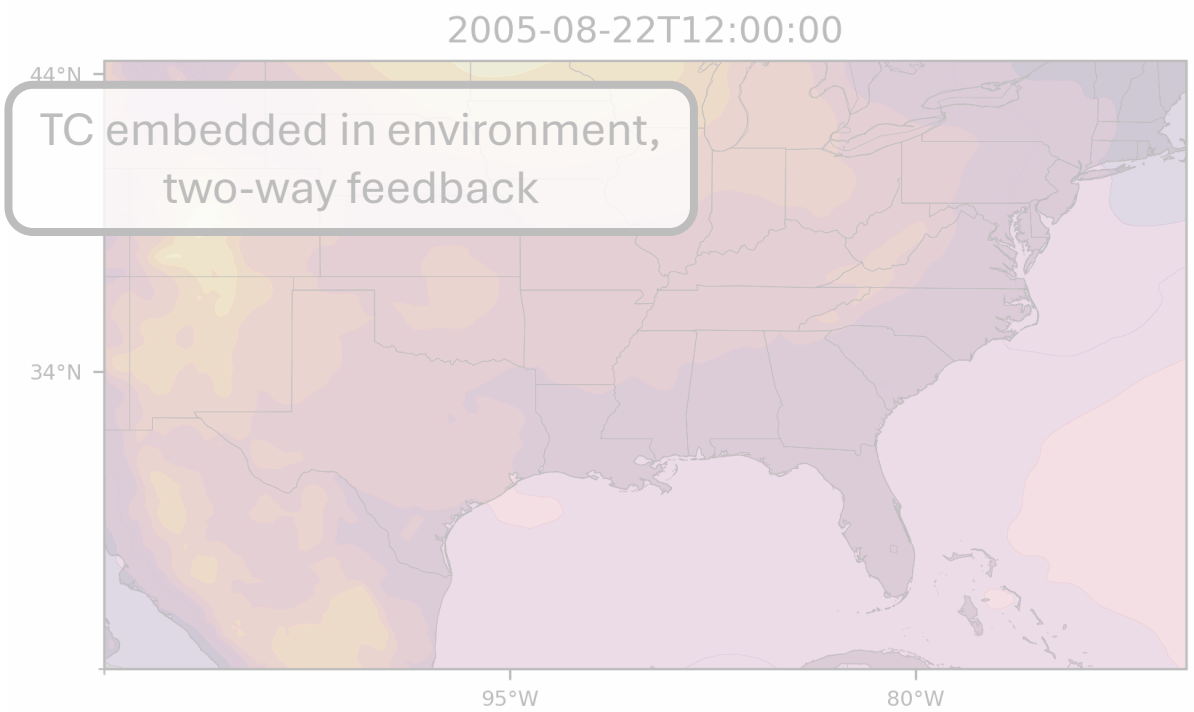
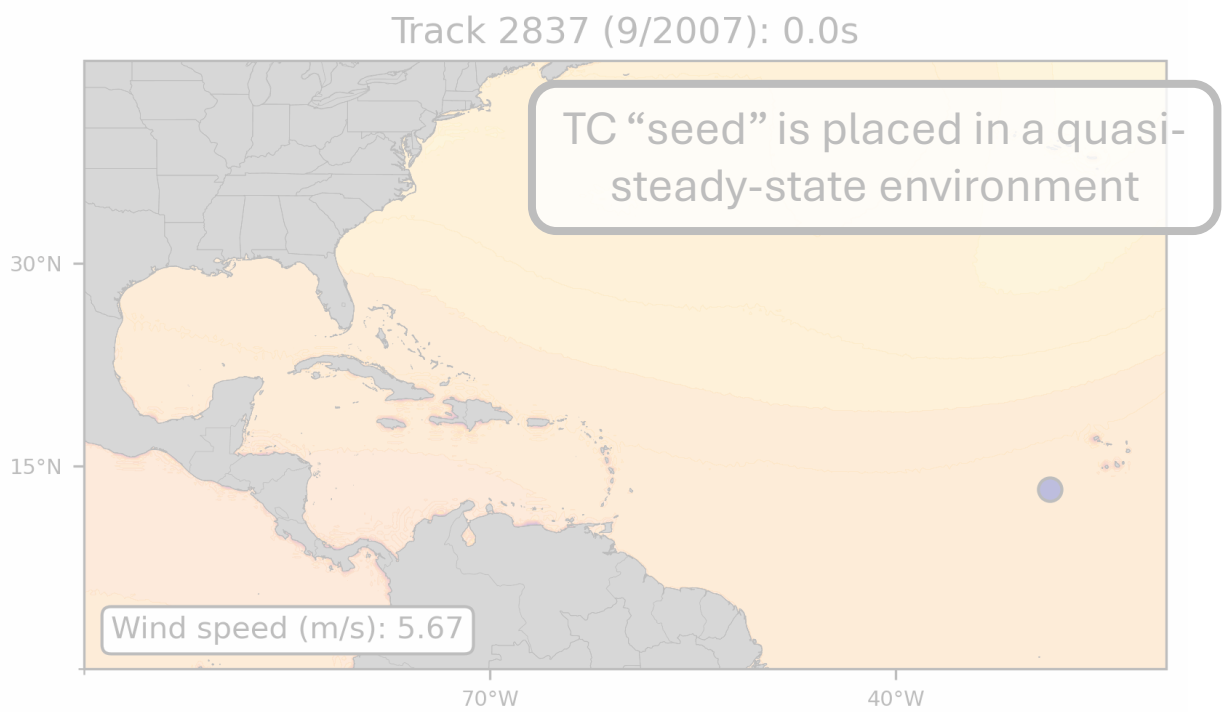
GCM vs SDD TC Example Using ERA5

GCM



SDD



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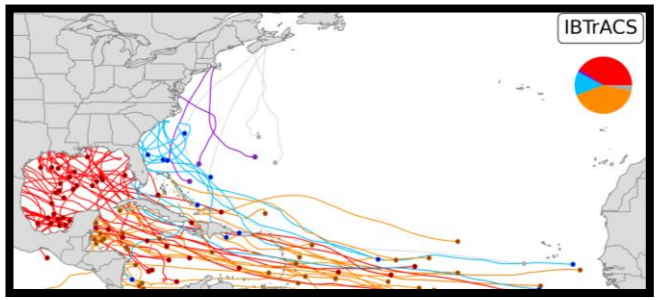
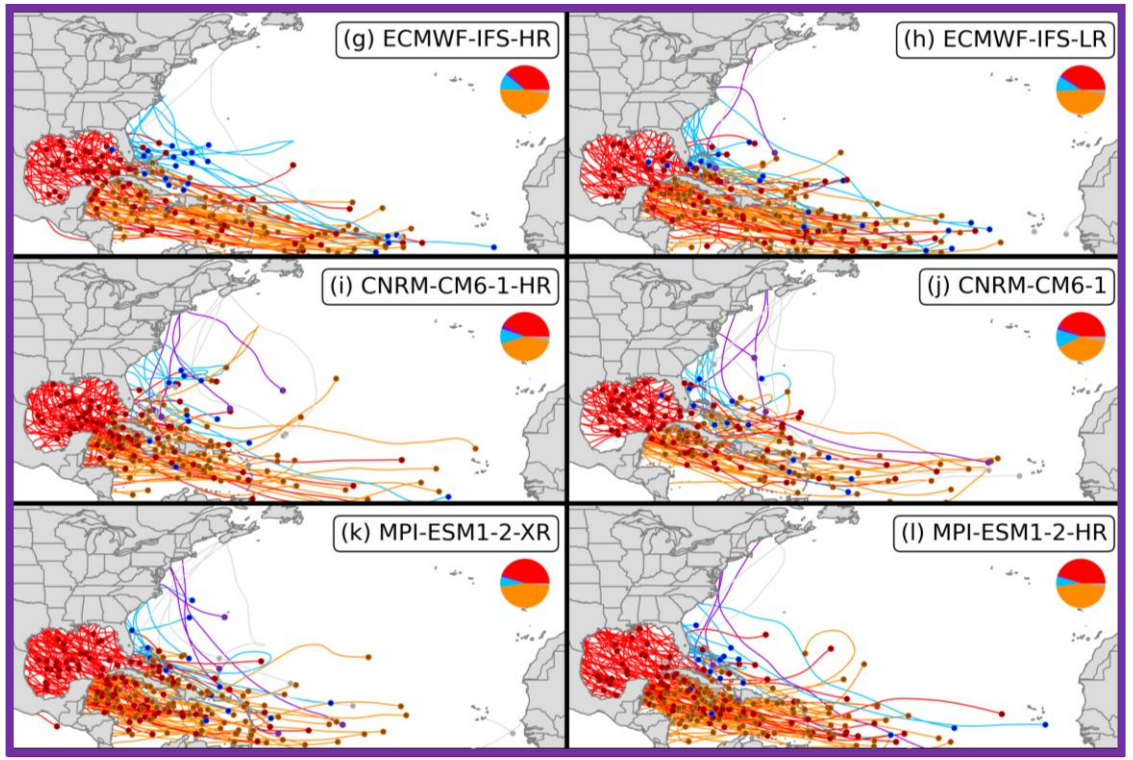
What we found

- GCMs:
  - TC counts, intensity, proportions generally underestimated
  - Struggles with long-track storms
  - Unrealistic relationships between genesis/landfall
- SDD:
  - Landfalls overrepresented
  - Latitude of maximum intensity, pressure accumulated cyclone energy, and intensity all improved
  - More convergence in solutions, but produces unphysical behaviors
- Other tidbits:
  - Resolution does not improve integrity of SDD solutions





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Climatological Statistics

GCM

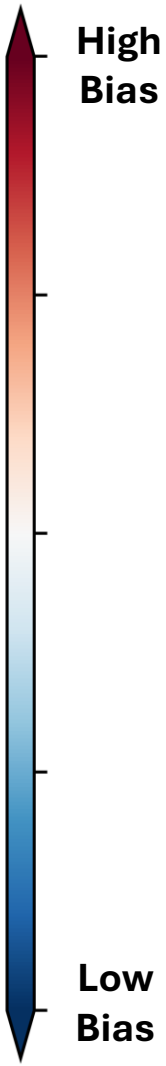
SDD

	LFP	NLFP	Mean LMI	PACE/yr	LF SLP	Min SLP
IBTrACS	42.8	57.2	26.1	110.9	989.8	982.9
ERA5	43.6	56.4	30.9	69.3	992.7	985.2
HadGEM3-GC31-HM	42.3	57.7	31.4	154.0	997.4	987.3
HadGEM3-GC31-LM	44.9	55.1	32.9	7.3	998.0	993.8
ECMWF-IFS-HR	35.2	64.8	31.8	12.0	993.5	989.2
ECMWF-IFS-LR	43.2	56.8	31.8	20.4	996.5	989.2
EC-Earth3P-HR	33.8	66.2	33.3	16.3	995.0	990.1
EC-Earth3P	25.0	75.0	29.0	2.8	1000.3	996.7
CNRM-CM6-1-HR	35.4	64.6	34.3	111.1	994.2	982.2
CNRM-CM6-1	26.6	73.4	28.7	9.4	998.9	996.9
MPI-ESM1-2-XR	34.6	65.4	23.4	3.0	1000.4	997.4
MPI-ESM1-2-HR	31.6	68.4	22.3	1.9	999.3	1000.8

PACE, LMI, SLP improved by SDD

LFP worsened by SDD

	LFP	NLFP	Mean LMI	PACE/yr	LF SLP	Min SLP
IBTrACS	42.8	57.2	26.1	110.9	989.8	982.9
ERA5	66.7	33.3	25.0	109.5	990.0	980.5
HadGEM3-GC31-HM	64.7	35.3	27.0	85.8	992.7	985.6
HadGEM3-GC31-LM	63.1	36.9	27.5	87.0	992.5	985.4
ECMWF-IFS-HR	66.3	33.7	24.9	81.7	994.3	988.7
ECMWF-IFS-LR	68.4	31.6	25.1	78.9	994.8	989.5
EC-Earth3P-HR	66.8	33.2	26.2	75.9	995.0	989.5
EC-Earth3P	67.5	32.5	25.6	75.2	995.6	990.3
CNRM-CM6-1-HR	67.1	32.9	26.8	87.2	992.4	985.0
CNRM-CM6-1	61.7	38.3	27.5	84.1	994.2	987.3
MPI-ESM1-2-XR	82.3	17.7	25.2	90.9	989.1	982.0
MPI-ESM1-2-HR	80.9	19.1	25.0	86.7	990.1	983.5



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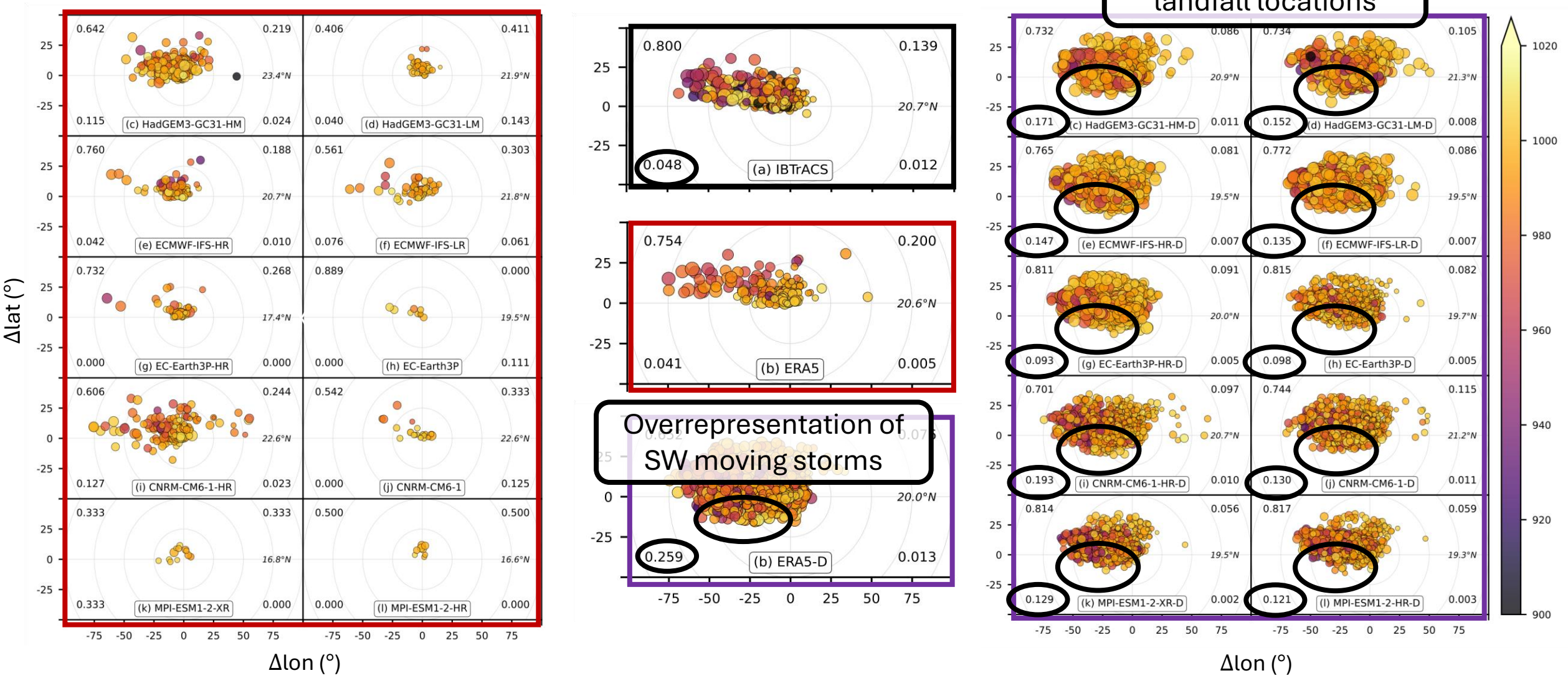
From Genesis to Landfall

GCM

SDD

Higher variance in landfall locations

Overrepresentation of SW moving storms



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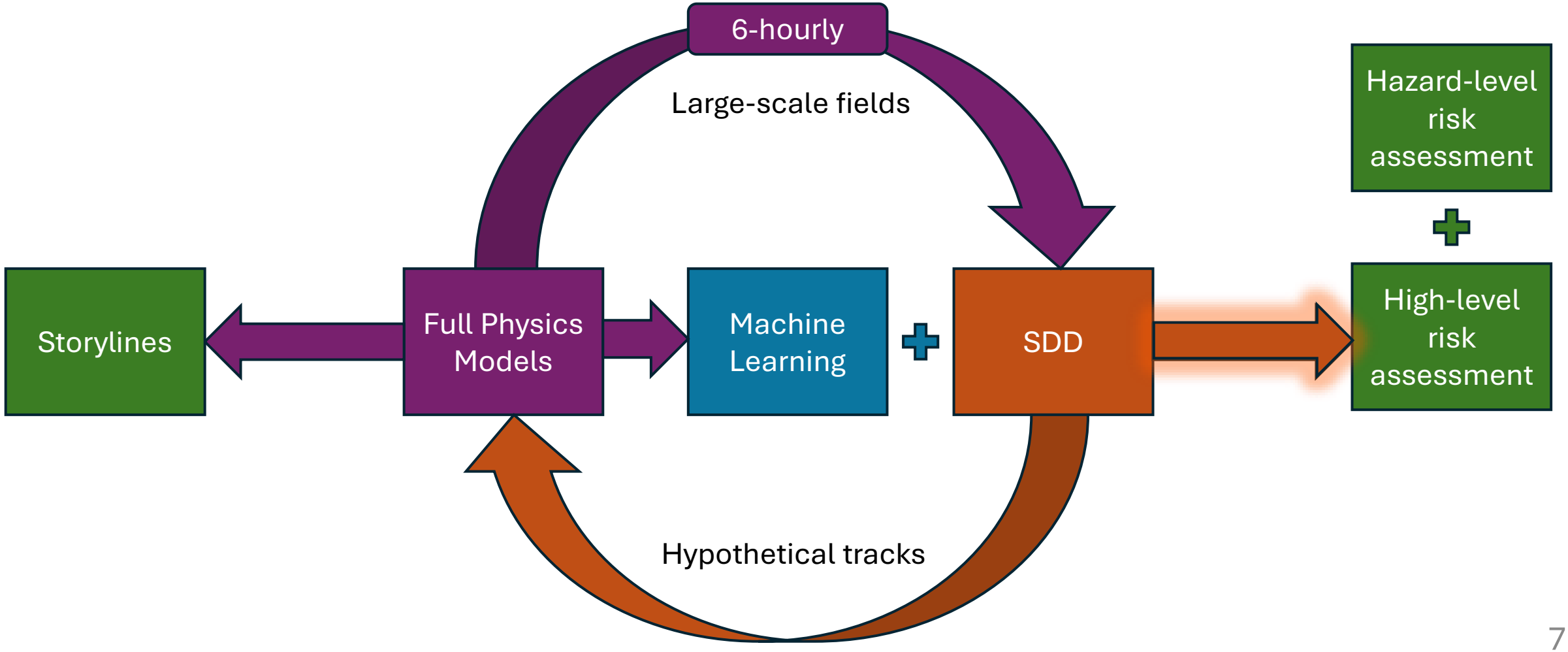
“Reversing the pipeline”

How can GCMs benefit SDD and how can SDD benefit GCMs?



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Model comparison, evaluation and validation

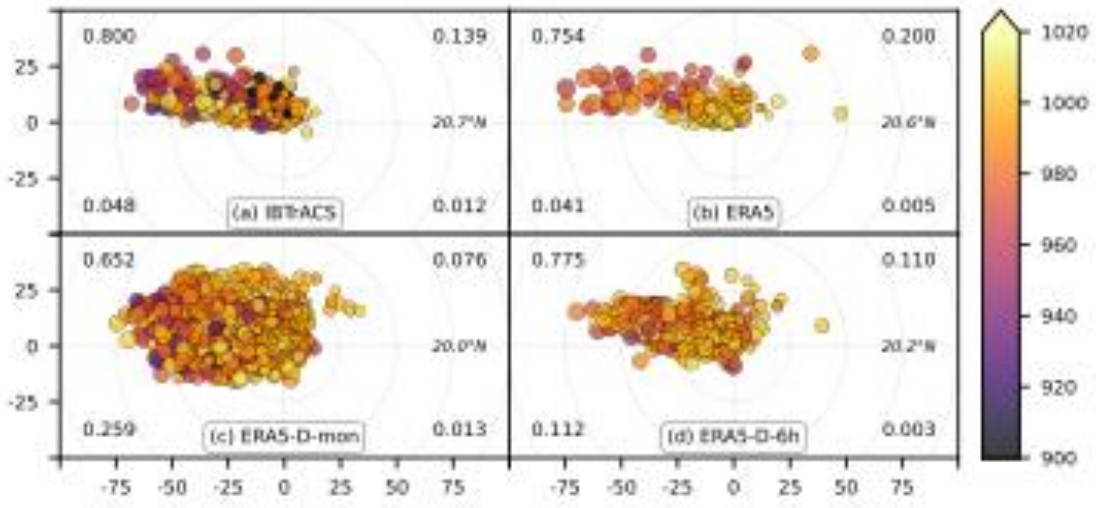
Transparency, robustness, and detailed documentation is key!

1. Standardized metrics

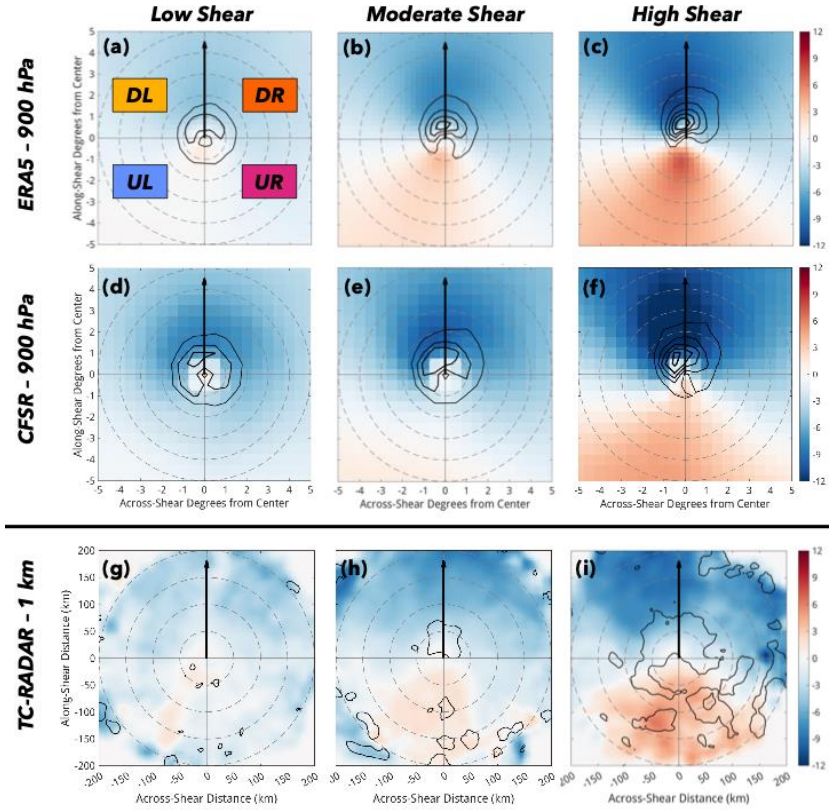
- Ability to compare models + modeling techniques to compare strengths and weaknesses
- Provide insights into model improvement

2. Process-oriented diagnostics

- Are we getting the right answer for the right reasons?



Bolivar and Zarzycki genesis/landfall scatter show SDD improvement with high-frequency wind data



Carstens et al., shear-relative benchmarking of reanalysis hurricanes against TC-RADAR data

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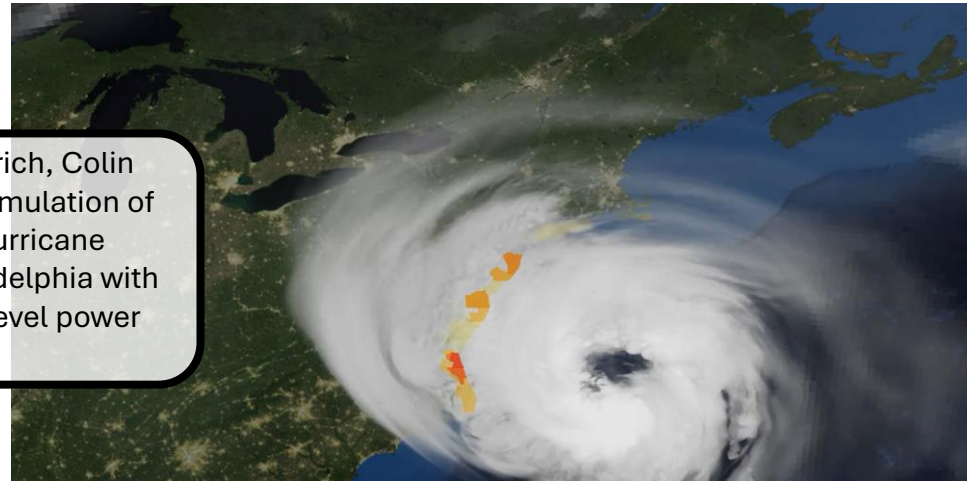
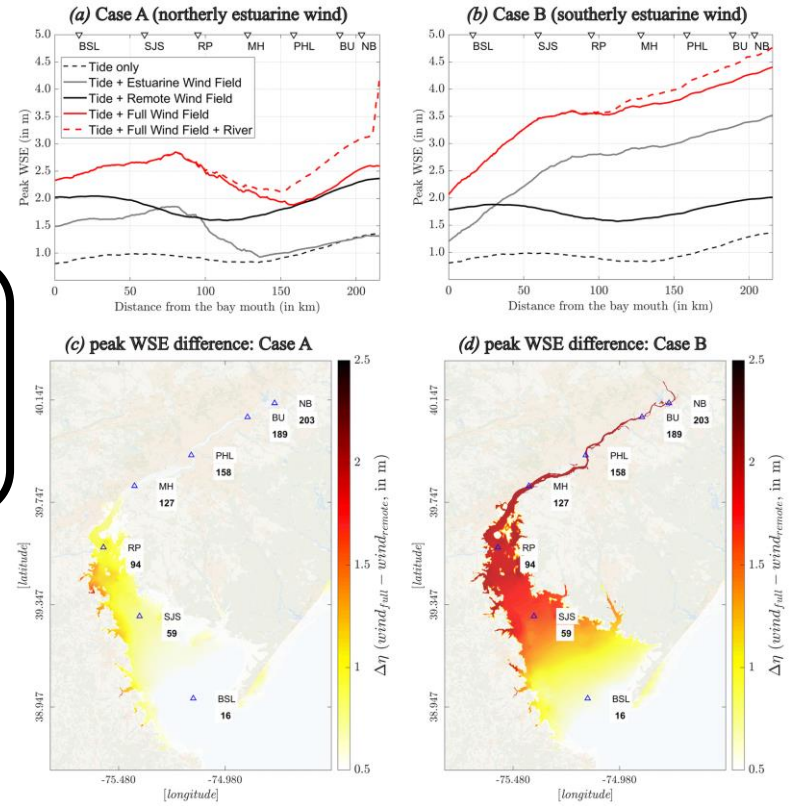
High-resolution storylines

- Leverage state-of-the-art DOE modeling capabilities to provide km-scale hazards
- Example: E3SM/SCREAM simulations -> coastal inundation -> impact models
- Tool development needed:
  - Improved mesh generation
  - Robust model initialization configuration routines
  - Improve model "connectivity" within DOE portfolio (e.g., tools for easily configuring/forcing DHSVM using E3SM storylines)

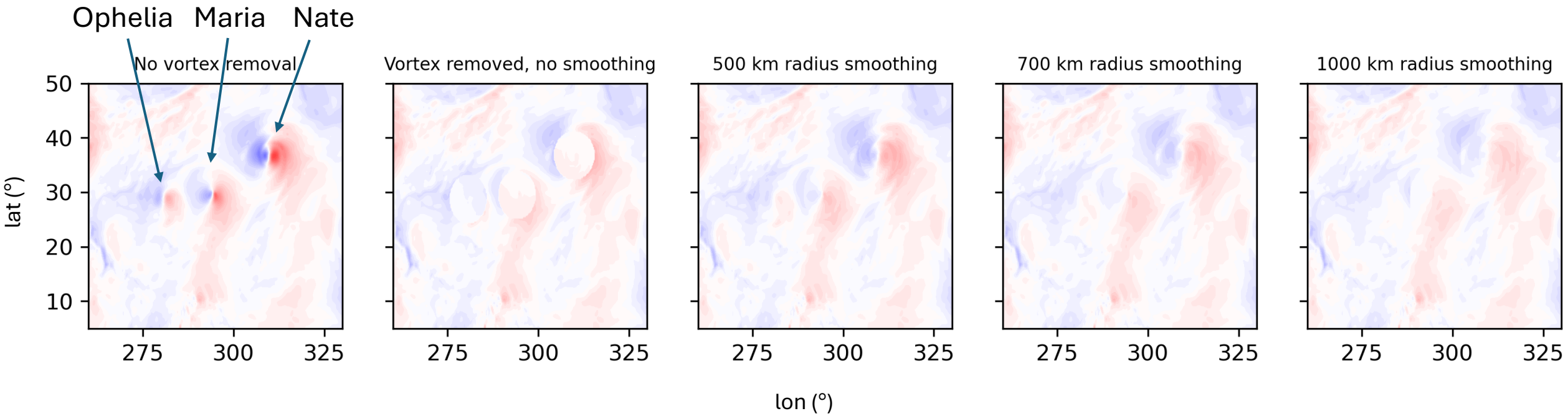


Julian Rice, Paul Ullrich, Colin Zarzycki – SCREAM simulation of synthetic E3SM hurricane landfalling near Philadelphia with associated county-level power outages



Deb et al., 2024 – FVCOM driven by 25km E3SM highlights hurricane track impacts on Delaware Bay/River flooding

Vortex removal example using ERA5 (V850): 00Z 8 September 2009



Manual seeding

- In lieu of random seeding, plant seeds at precise points in space and time