Evolution of US hurricane risk in a changing climate

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Quantifying the risk from Tropical Cyclones

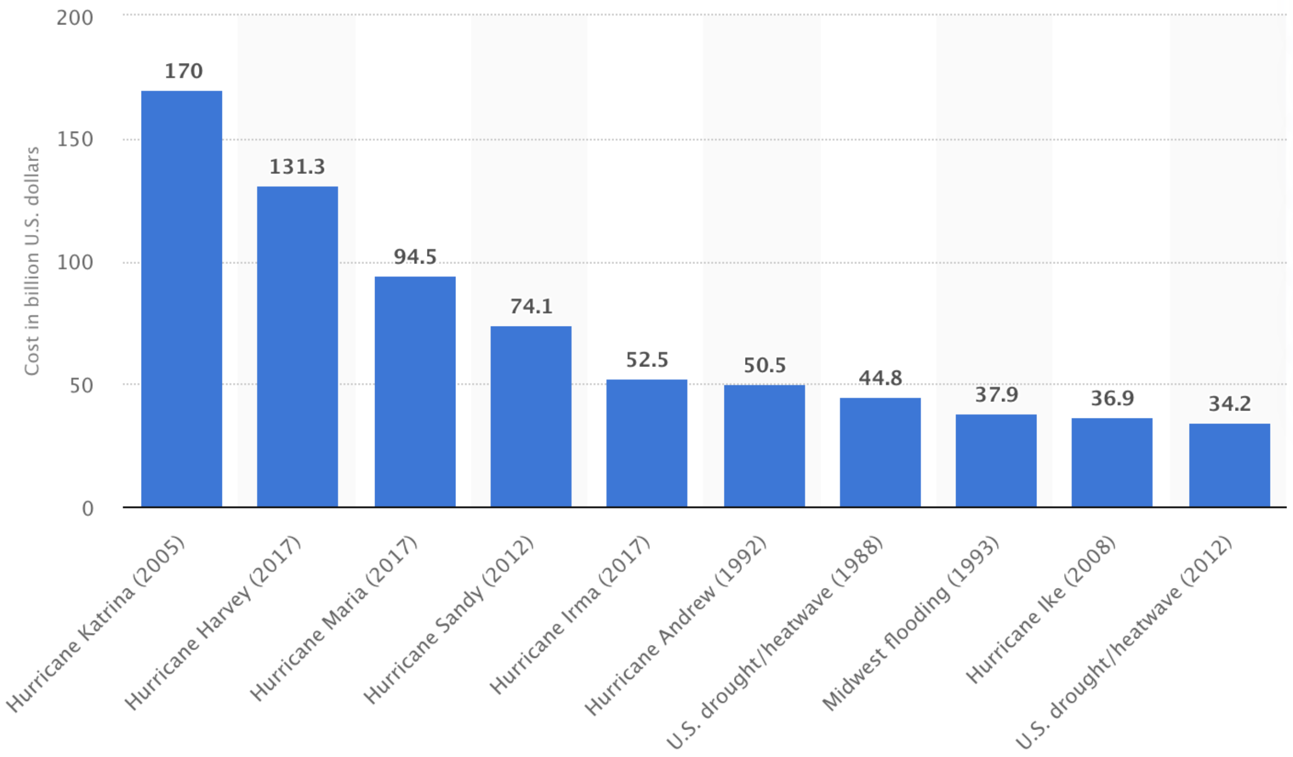
- Tropical Cyclones (TCs) or hurricanes are the deadliest and costliest natural disasters, including in the US.

- On average, 1-2 hurricanes make landfall over continental US each year, the number of historical landfall events during the satellite era is not sufficient to derive probabilistic hurricane risk.

- Using high-resolution dynamical models is computationally expensive, and they are associated with systematic model biases.

- To address this, we are developing the Risk Analysis Framework for Tropical Cyclones (RAFT)

Costliest natural disasters in the US



Source: statista

Top 5, 7 in top 10 are hurricanes

Why use RAFT for risk analysis ?

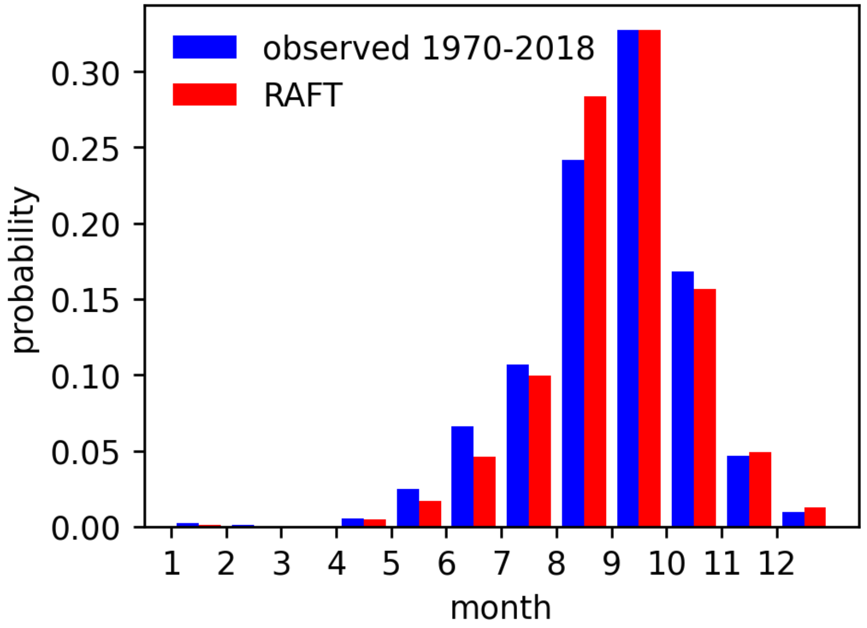
1) A hybrid model: RAFT combines Physics, Statistics and Machine Learning to generate synthetic TCs. It is trained based on observations and can accurately represent salient features of TCs.

2) Suitability for risk analysis:

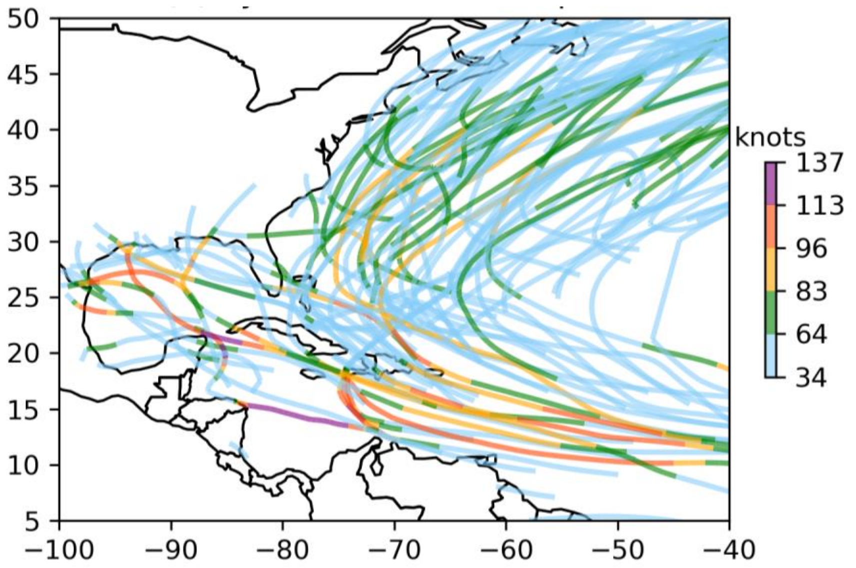
- ***a)*** ***Numbers*** - Simulate large number of TC events making uncertainty quantification and risk assessment feasible.
- ***b)*** ***Accuracy*** - Percentage of landfalling events (30%) is roughly consistent with observations (25%) and the simulated landfall risk for 51 selected cities is well-correlated with the observed (R-square 0.77)

3) Coupling with earth system models: RAFT can readily utilize output from models such as E3SM and address issues such as change in risk associated with a non-stationary climate.

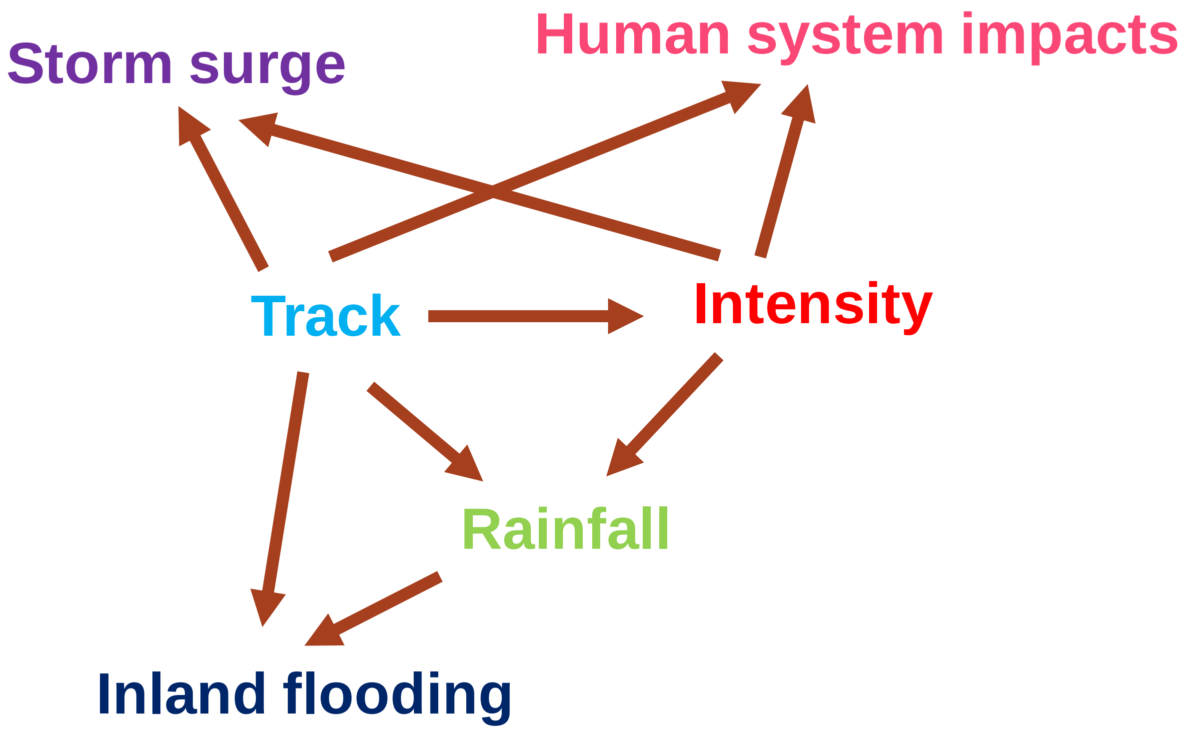
(a) Seasonal TC genesis distribution



(b) Sample synthetic TCs



RAFT: A Risk Analysis Framework for Tropical Cyclones



Storm surge

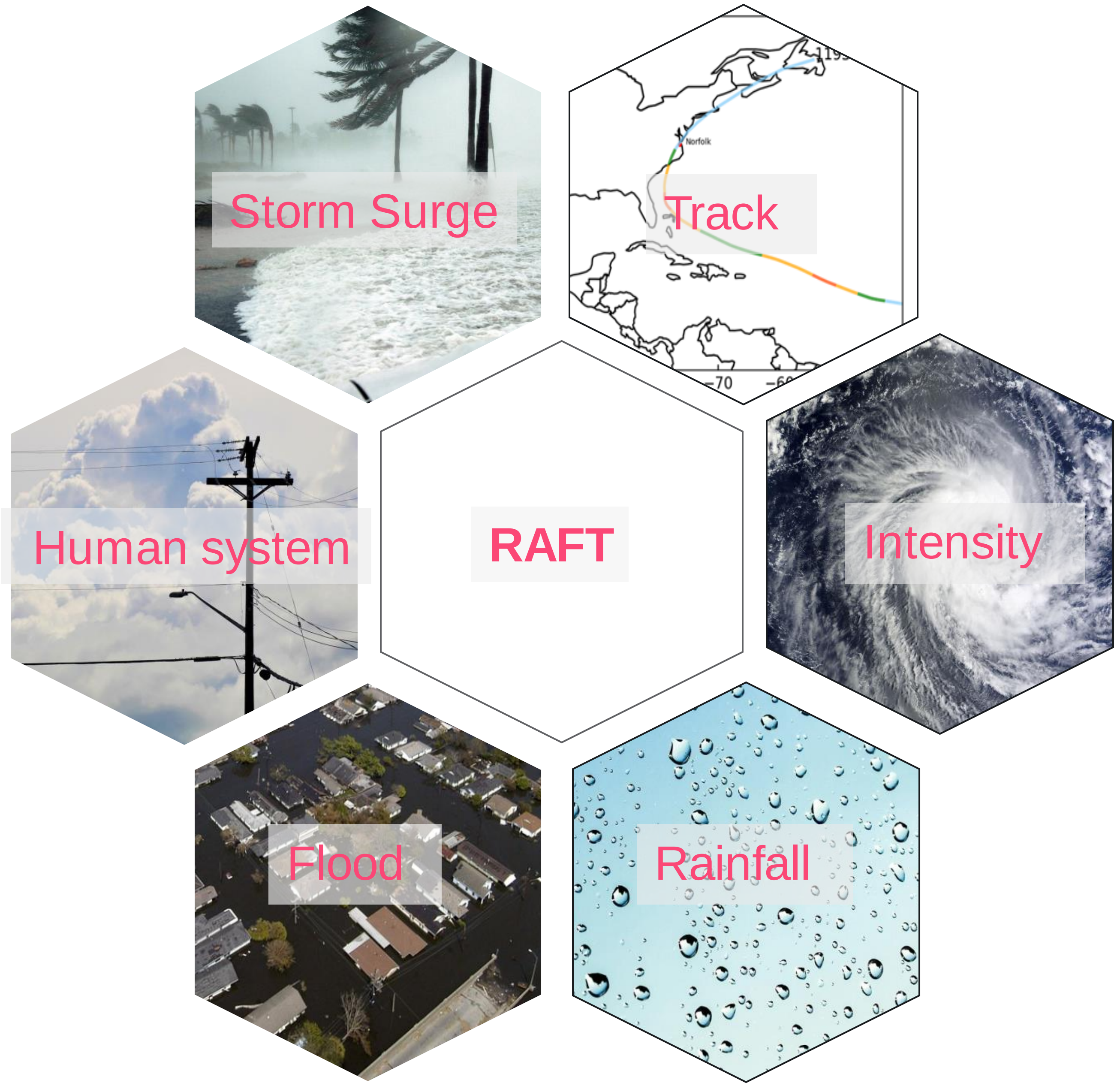
Human system impacts

Track

Intensity

Rainfall

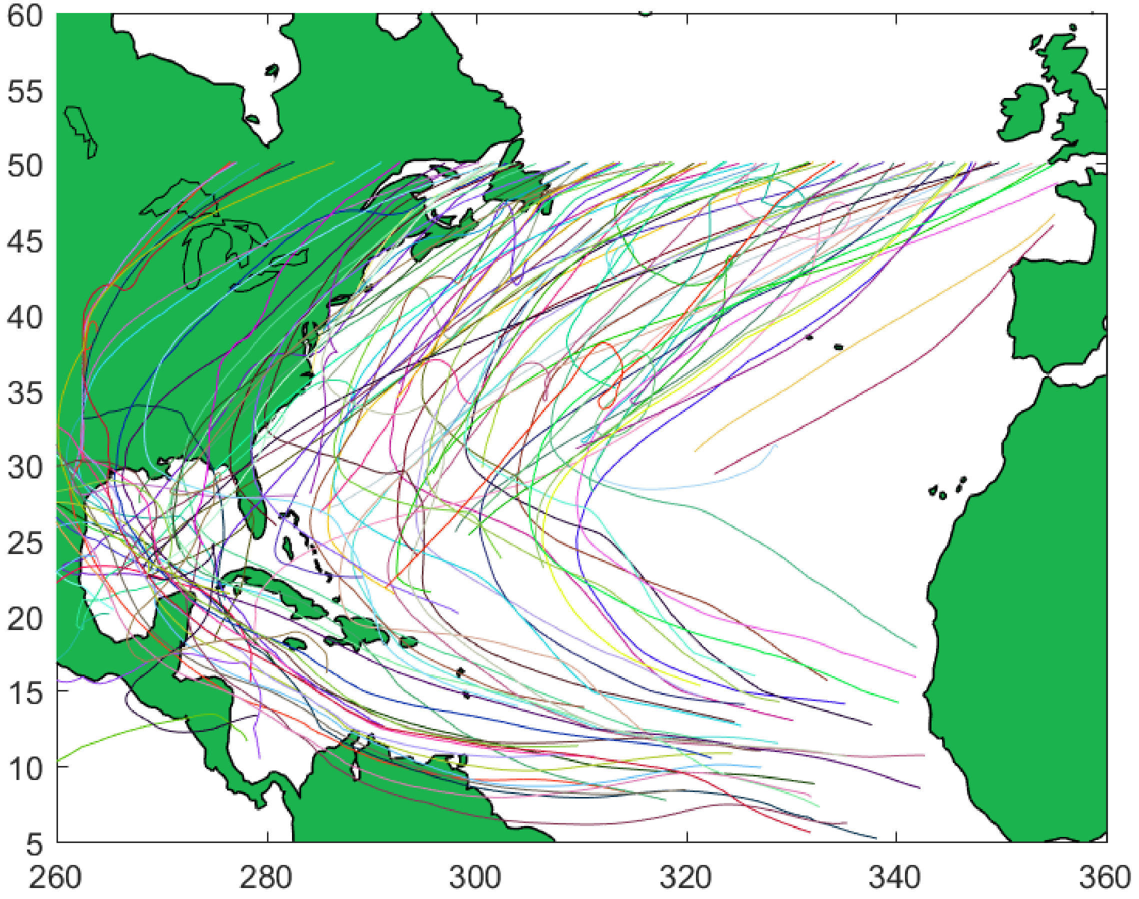
Inland flooding



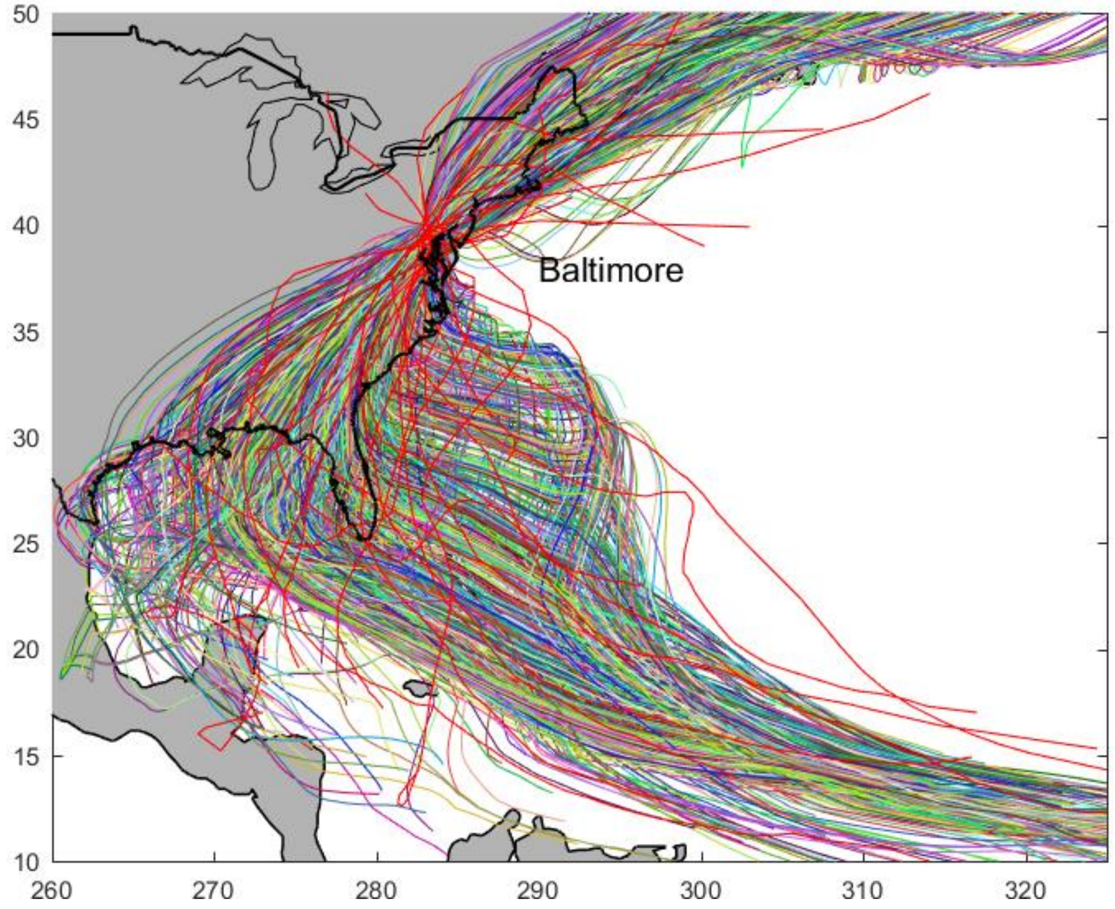
Physics-based synthetic TC Track Model

- Tracks propagate according to large scale wind and a beta-drift (Emanuel et al. 2006)
- Modified the method to use a spatially varying beta-drift, improved the model's ability to represent TC landfall (Kelly et al. 2018)

(a) Example 100 synthetic tracks



(b) Example 2000 synthetic tracks passing near Baltimore



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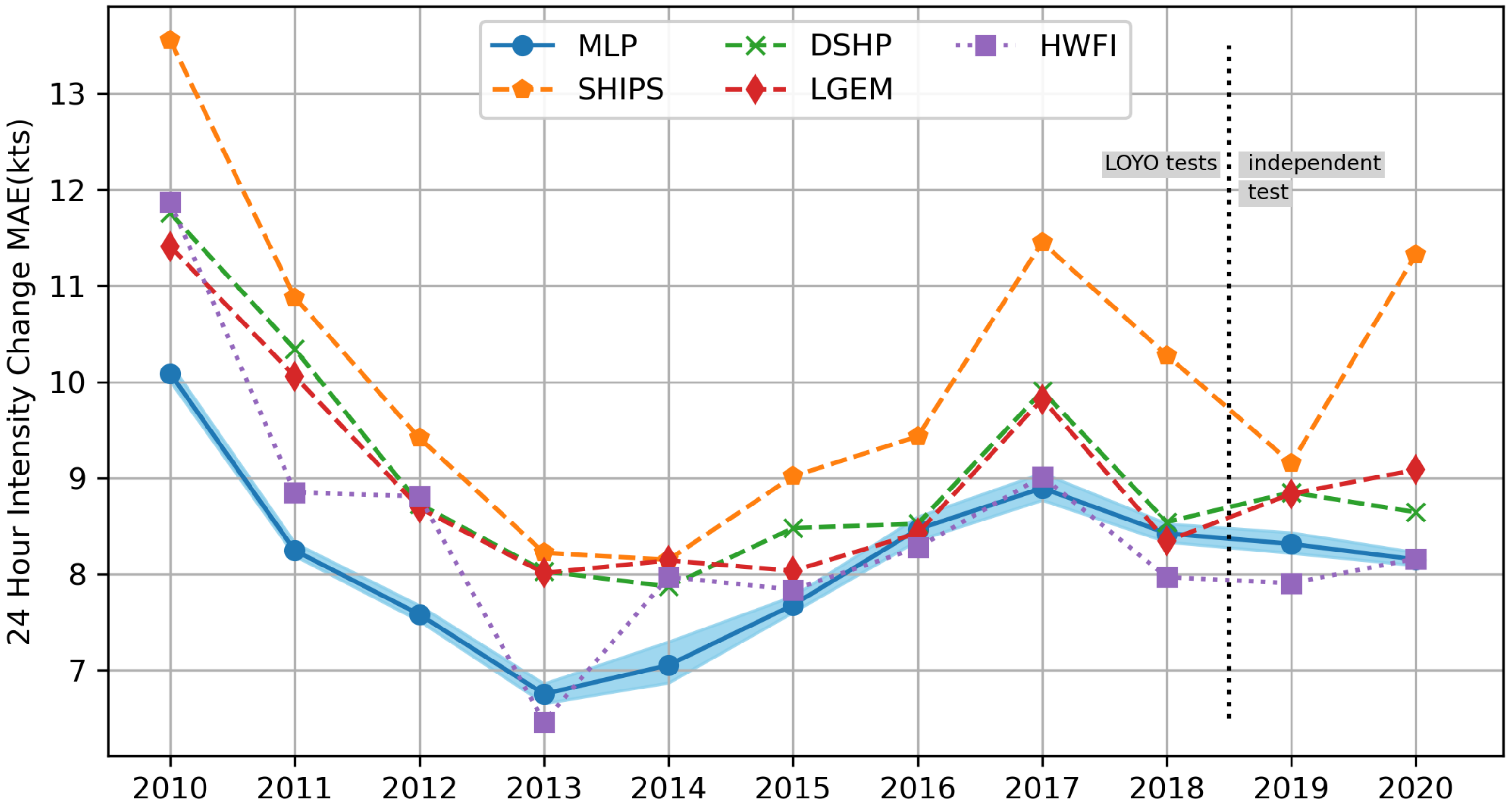
Neural Network based Intensity Model

- Multilayer Perceptron Model (MLP) with automated architecture and hyperparameter search
- Trained using global Statistical Hurricane Intensity Prediction Scheme (SHIPS) predictors from 1982–2018
- Two versions:
    - 24-hour model for operational forecast, which consistently outperforms SHIPS, DSHP, and LGEM (5-22%)
    - 6-hour model for climate studies (with 11 environmental variables as inputs)

24-hour MLP model evaluated in the North Atlantic basin



Xu et al. *WAF (2021)*

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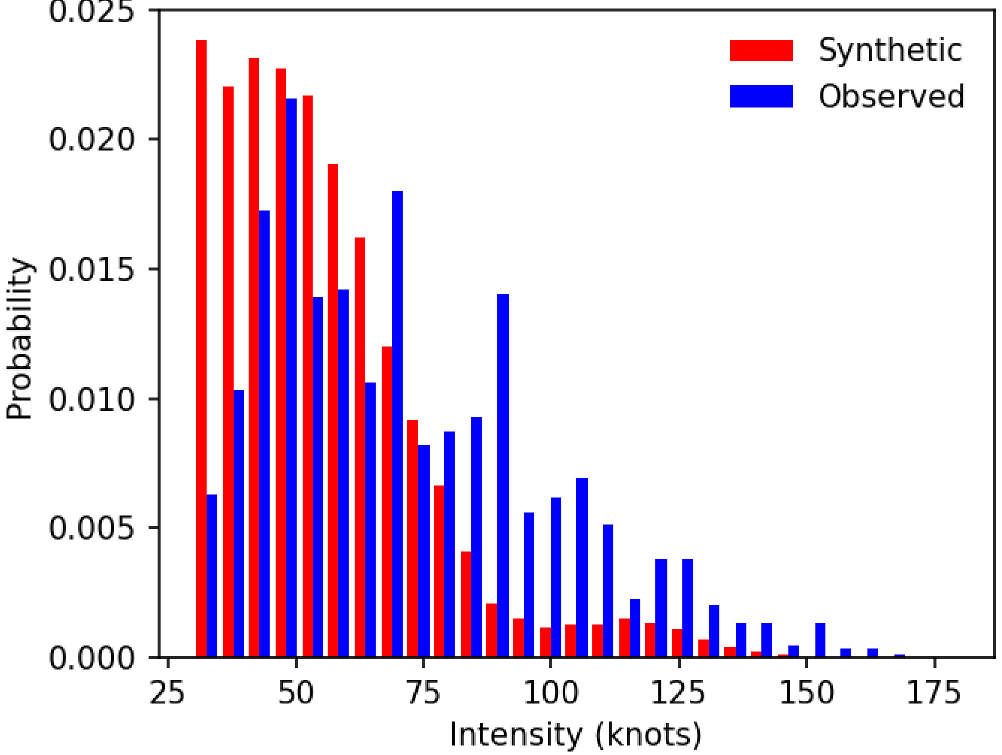
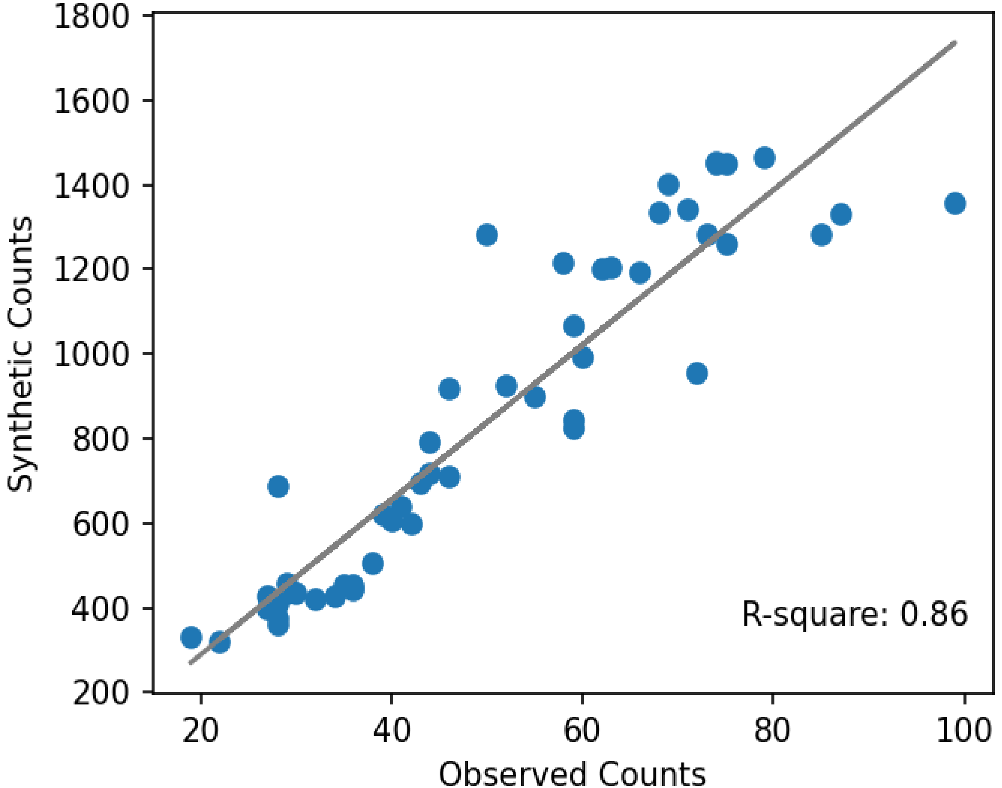
Coupling track model with 6-hourly intensity model

- Generated realistic intensities along synthetic tracks
- Reasonable TC lifetime maximum intensity distribution (a), the most intense synthetic event reaches Category 5 strength.
- The landfall probability based on synthetic TCs for 51 selected US coastal cities is well-correlated with the observed (b).



(a) TC lifetime maximum intensity



(b) TC counts at coastal cities

TC rainfall model

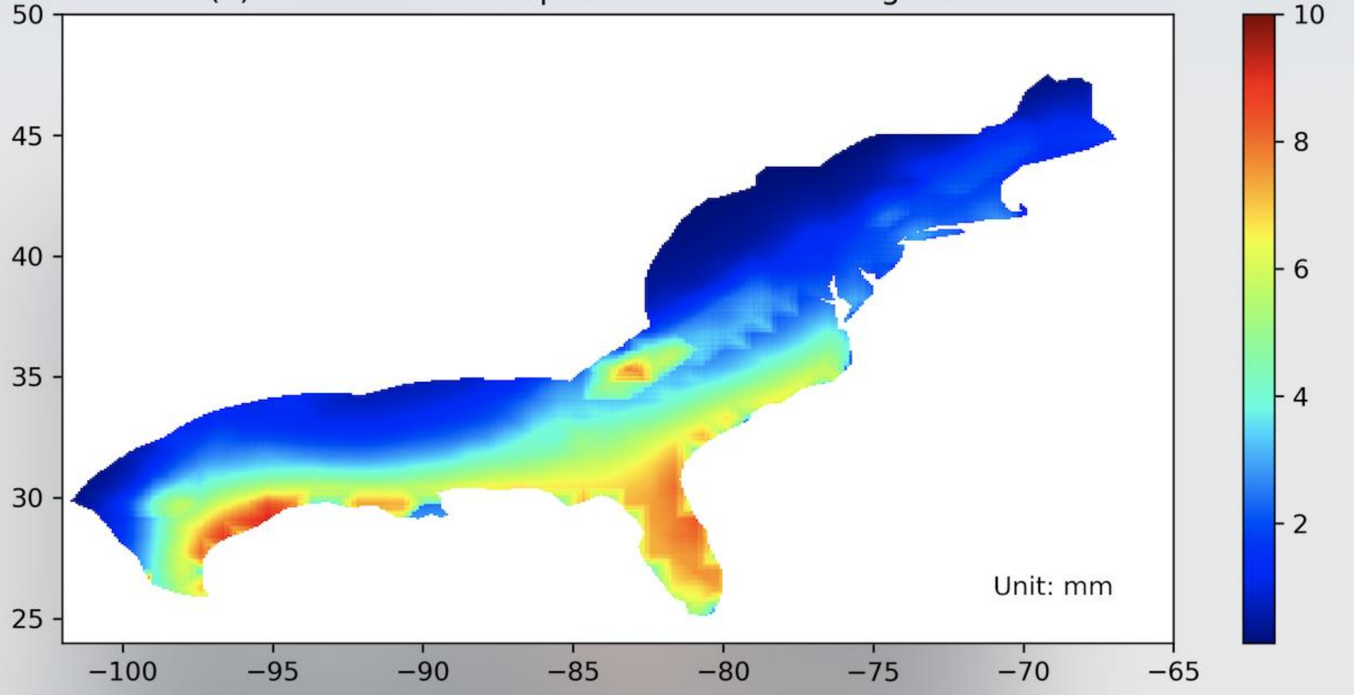
- Physics-based TC rainfall model (Zhu et al. GRL, 2013; Lu et al. JAS, 2018)
- TC rainfall is proportional to the upward vapor flux, estimated as the product of saturation specific humidity and the vertical velocity.
- The vertical velocity has 4 components to it

  a) Frictional effect

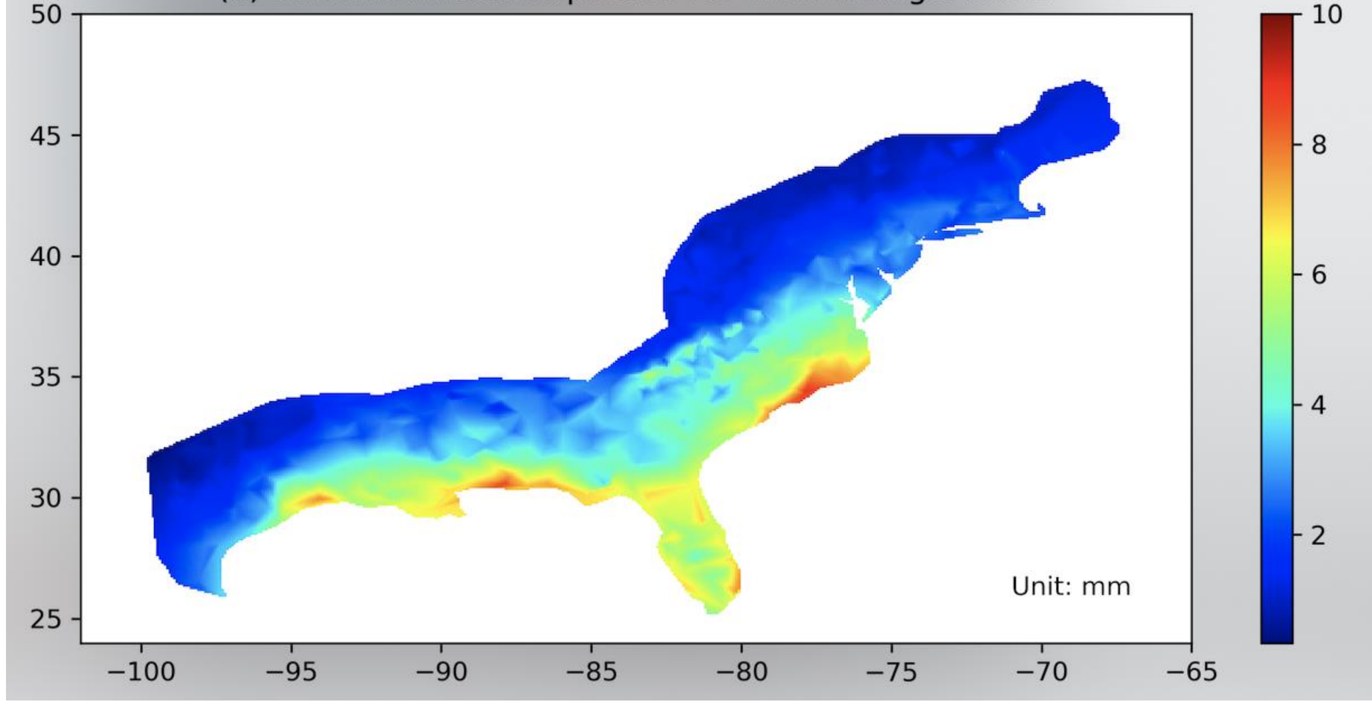
  b) Stretching effect

  c) Topographic effect

  d) Baroclinic effect



(a) Modeled mean expected TCP from a single storm



(b) Observed mean expected TCP from a single storm

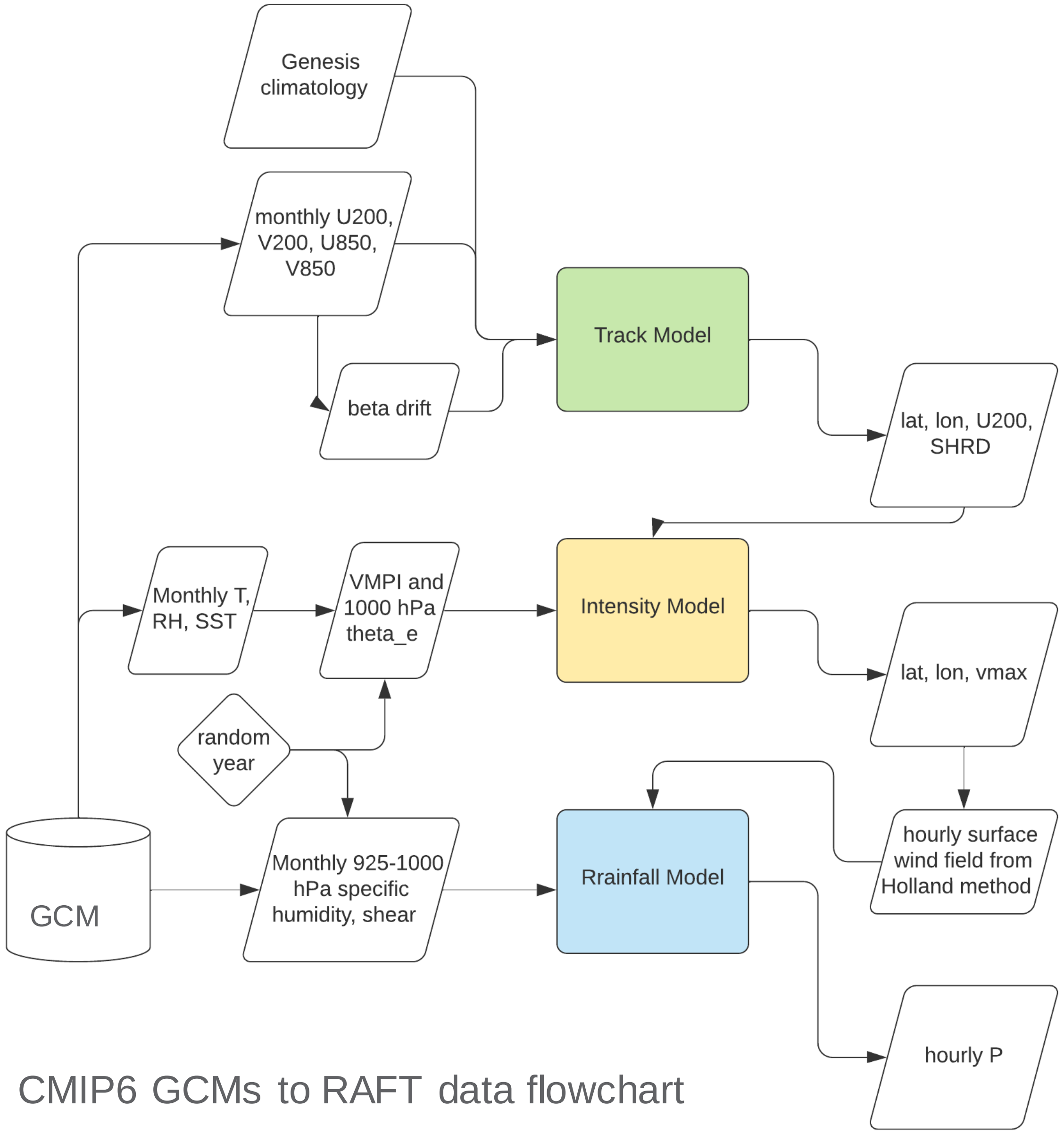
CMIP6 global climate projections

- Historical period (1980-2014) and future period (2066-2100)

- 8 CMIP6 models used:

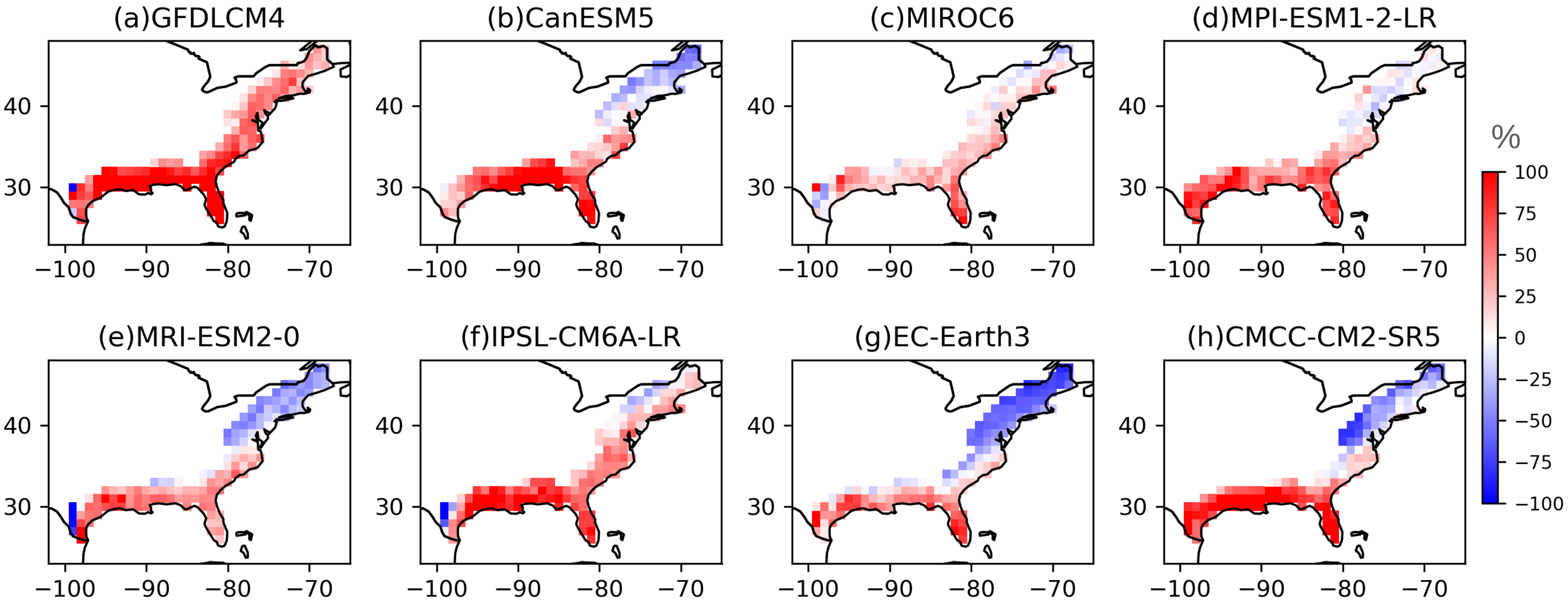
GFDLCM4, CanESM4, MIROC6, MPI-ESM1-2-LR, MRI-ESM2-0, IPSL-CM6A-LR, EC-Earth3, CMCC-CM2-SR5

- Scenario SSP585:
  - Storyline dominated with mitigation challenges
  - Radiative forcing increase of 8.5 Wm^{-2} by the year 2100

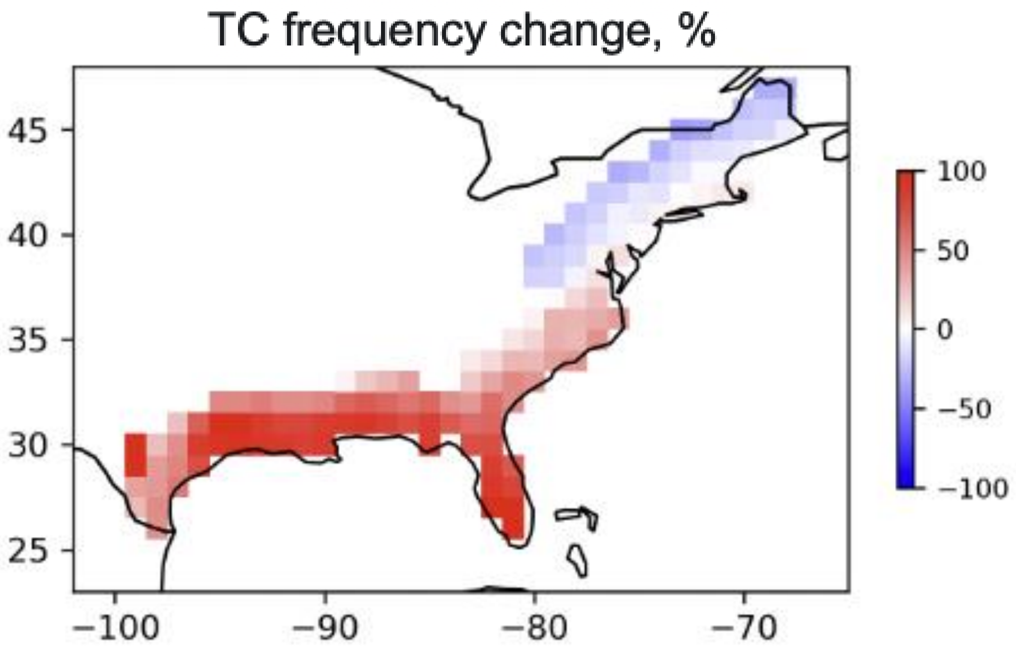


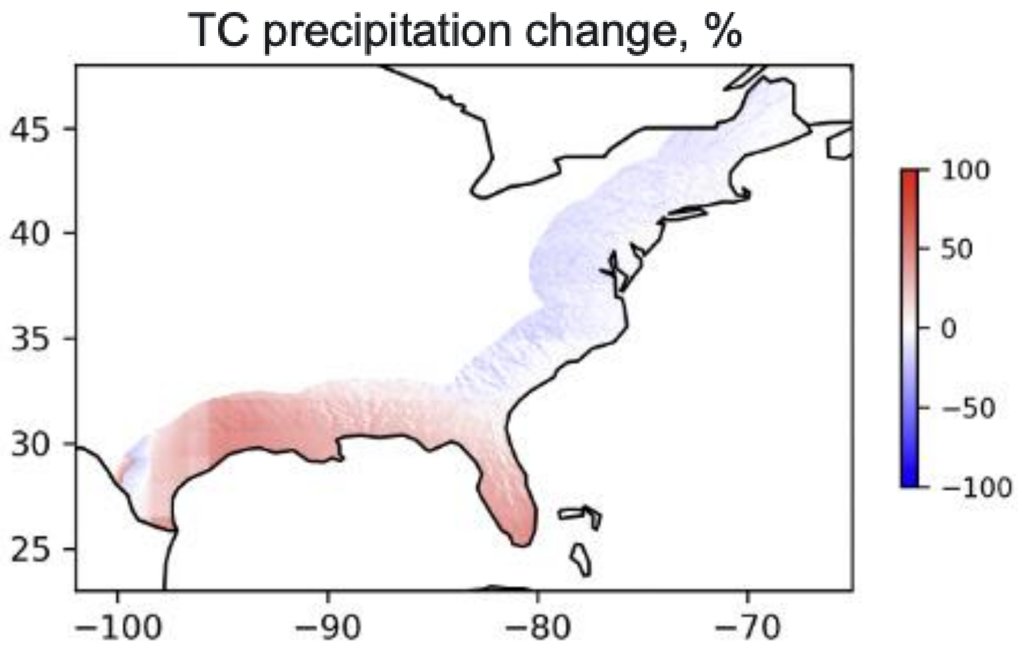
CMIP6 GCMs to RAFT data flowchart

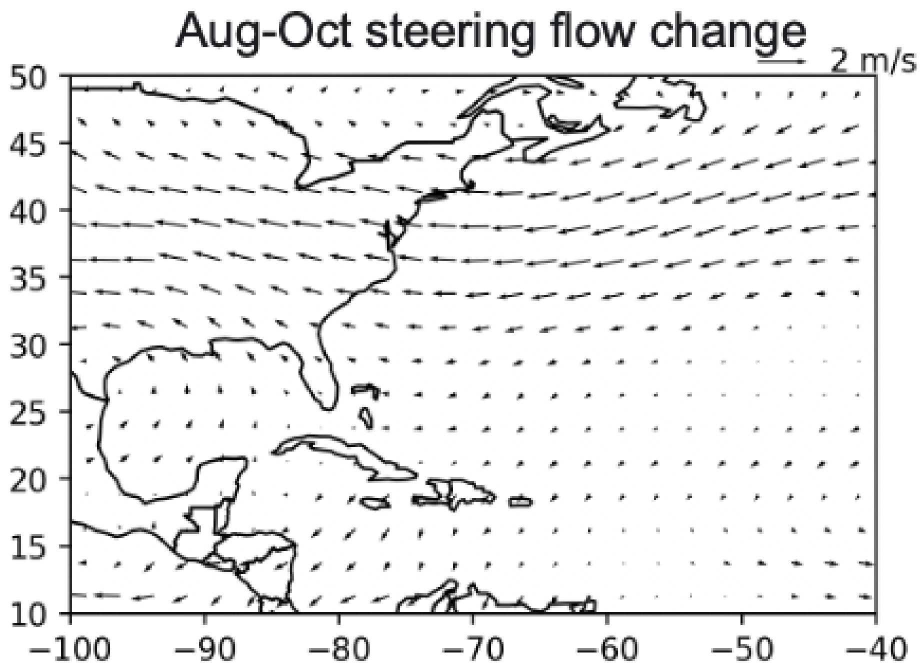
TC density change (%): future vs historical

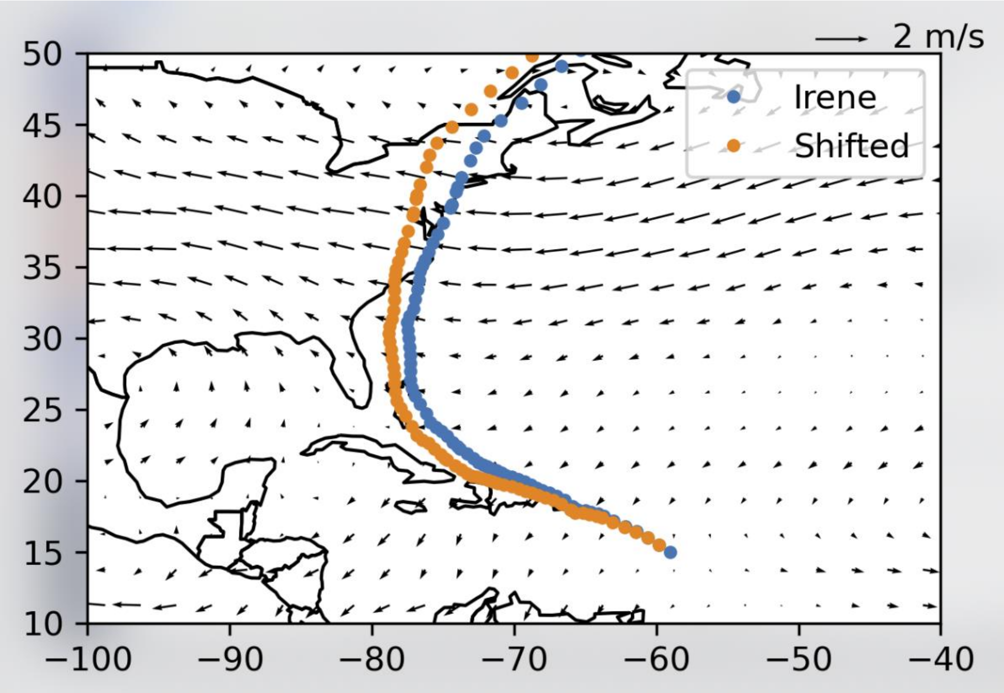


Ensemble mean changes in TC risk

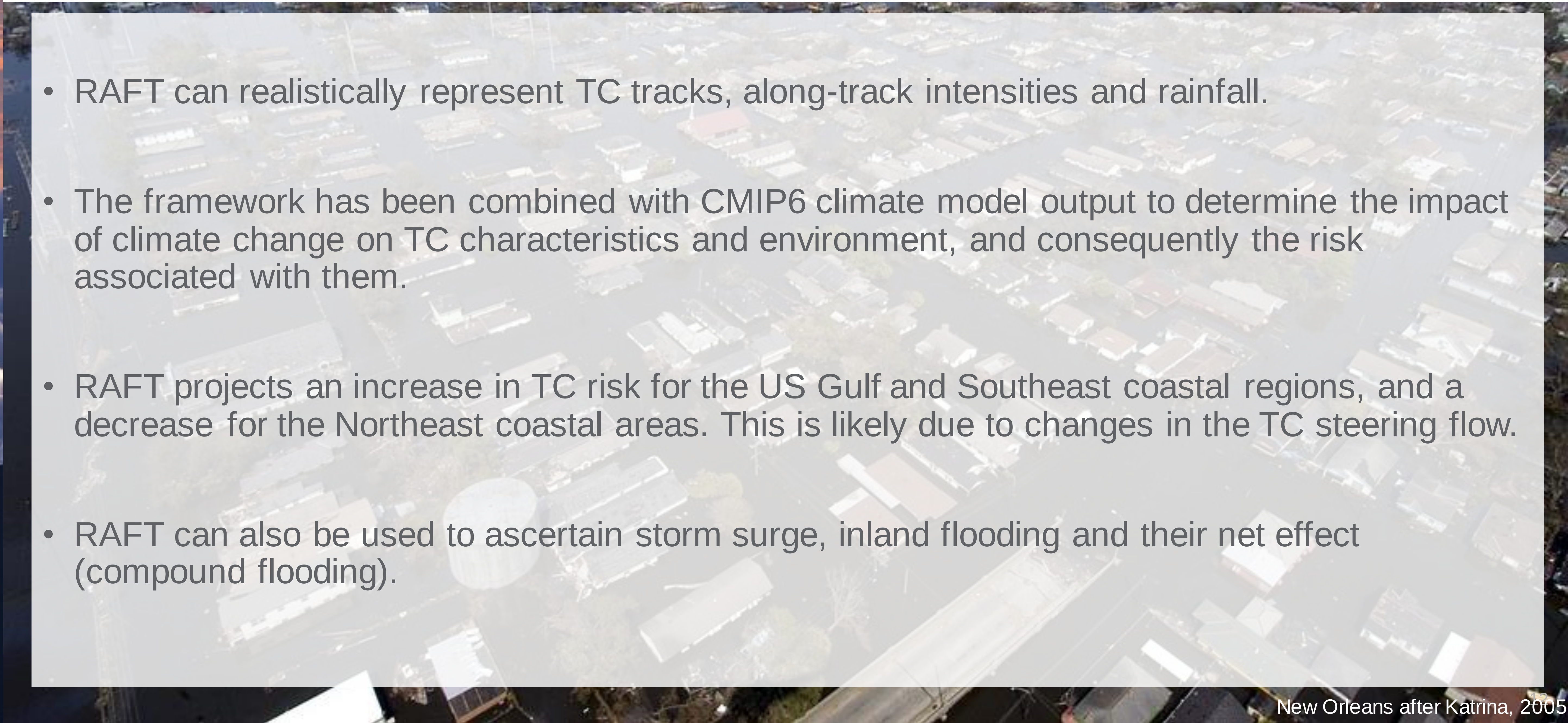

TC frequency change, %


TC precipitation change, %


Aug-Oct steering flow change



Summary



- RAFT can realistically represent TC tracks, along-track intensities and rainfall.
- The framework has been combined with CMIP6 climate model output to determine the impact of climate change on TC characteristics and environment, and consequently the risk associated with them.
- RAFT projects an increase in TC risk for the US Gulf and Southeast coastal regions, and a decrease for the Northeast coastal areas. This is likely due to changes in the TC steering flow.
- RAFT can also be used to ascertain storm surge, inland flooding and their net effect (compound flooding).

New Orleans after Katrina, 2005

Thank you!

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