A Markov Environment-dependent Hurricane Intensity Model and Its Application in Operational Forecasting

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Introduction

Motivation

- Improve statistical modeling of TC intensity climatology by considering TC intensity change as a temporally correlated sequence.

Research Objective

- Develop a new statistical model, the Markov Environment-dependent Hurricane Intensity Model (MeHiM), to simulate tropical cyclone intensity evolution.
- Evaluate MeHiM's performance.
- Evaluate MeHiM when appling to operational forecasting by introducing a rapid intensification indicator.

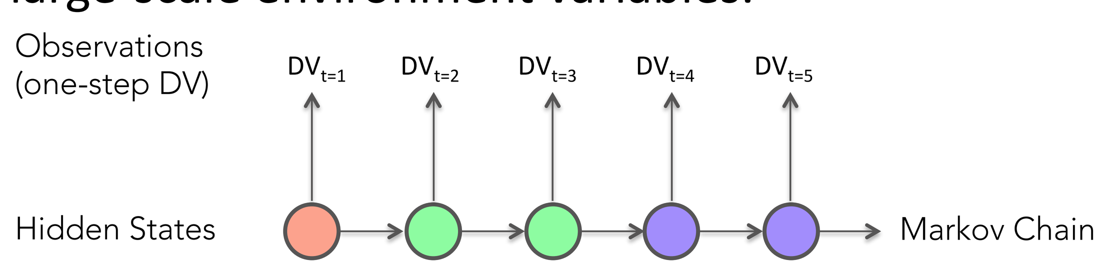
Data and Method

Data

- Best Track Data IBTrACS (1979-2014)
- ECMWF ERA-Interim climate reanalysis. Environmental variables: maximum potential intensity, wind shear and relative humidity.

Method

- **Three regression models**
  - **Ordinary Least Squares (OLS):** Linear regression model for whole data.
  - **Finite Mixture Regression (FMR):** Separates data into specified number of groups with unique statistical properties and performs linear regression for each group.
  - **Markov environment-dependent Hurricane Intensity Model (MeHiM):** storm's intensity change is assumed to be a Markov process with three unobserved discrete states. The three components in the MeHiM, namely the initial model, state transition model, and response model are all dependent on large-scale environment variables.



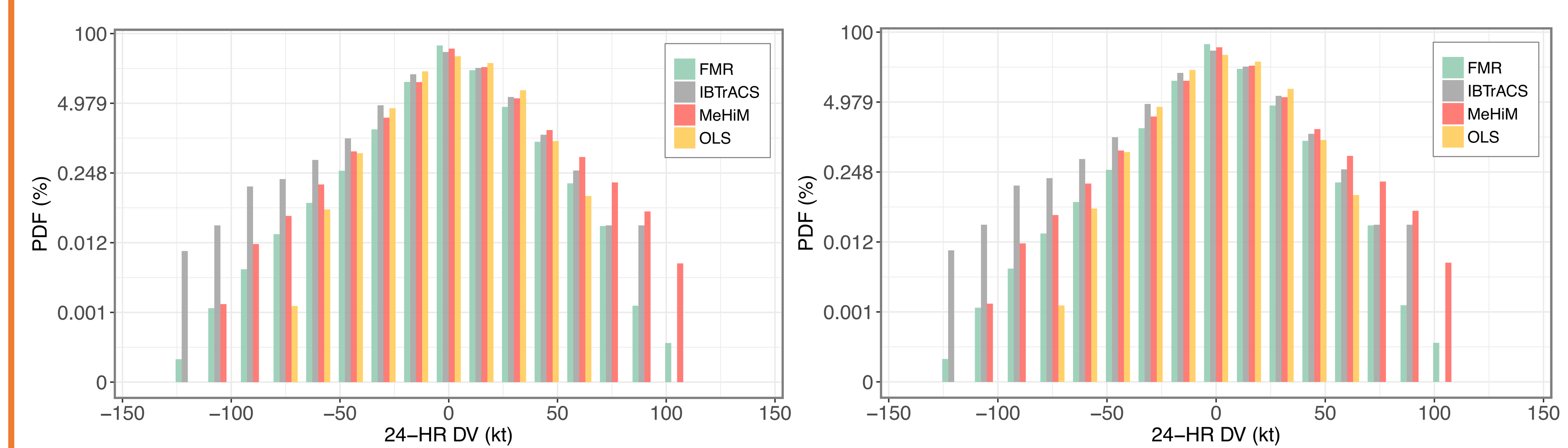
- **Simplified Land Model**

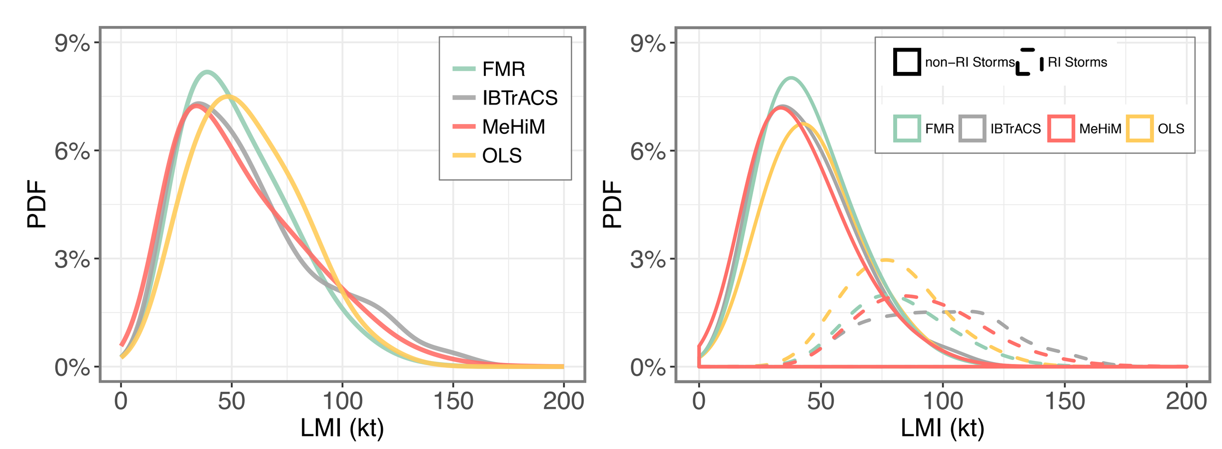
  A separate filling rate land model is added to simulate storm's behavior over land.
- **Model Evaluation**

  Monte Carlo simulations are performed , where MeHiM is run freely to simulate historical storms using historical tracks and environment taken from reanalysis datasets.

MeHiM Simulations

MeHiM Diagnostics

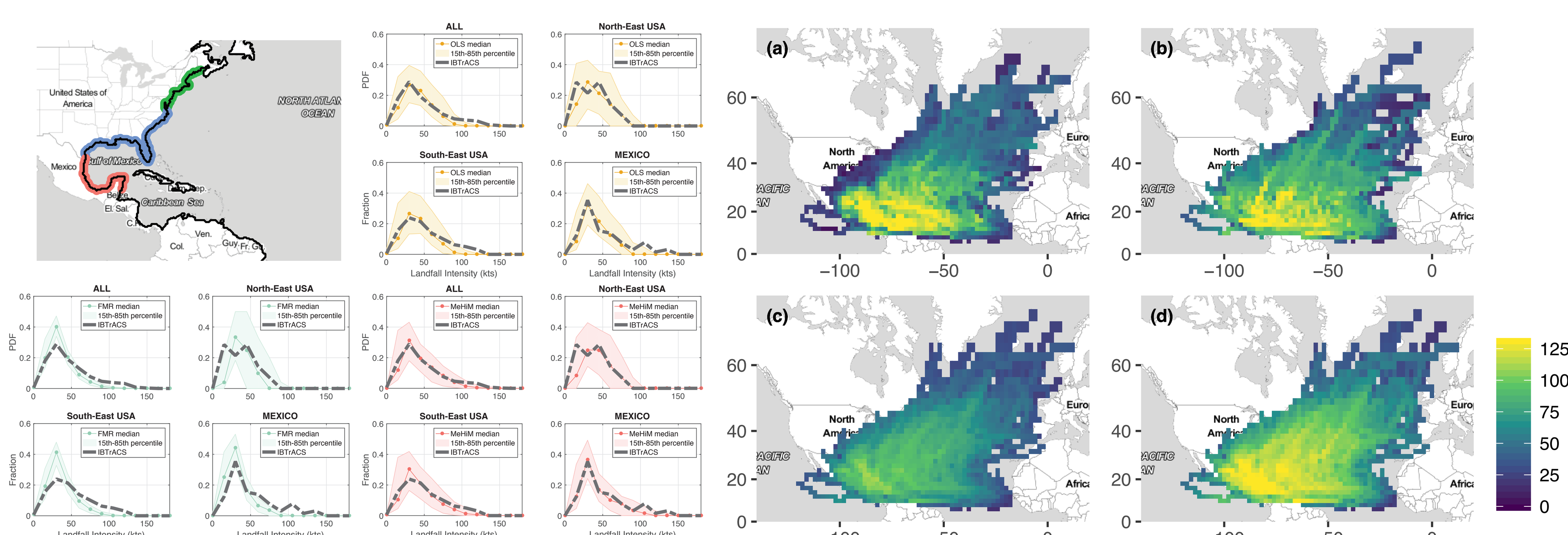




↑ Histograms of 6-h and 24-h intensity change probability distribution in logarithmic scale. Data are binned in 5-kt interval.

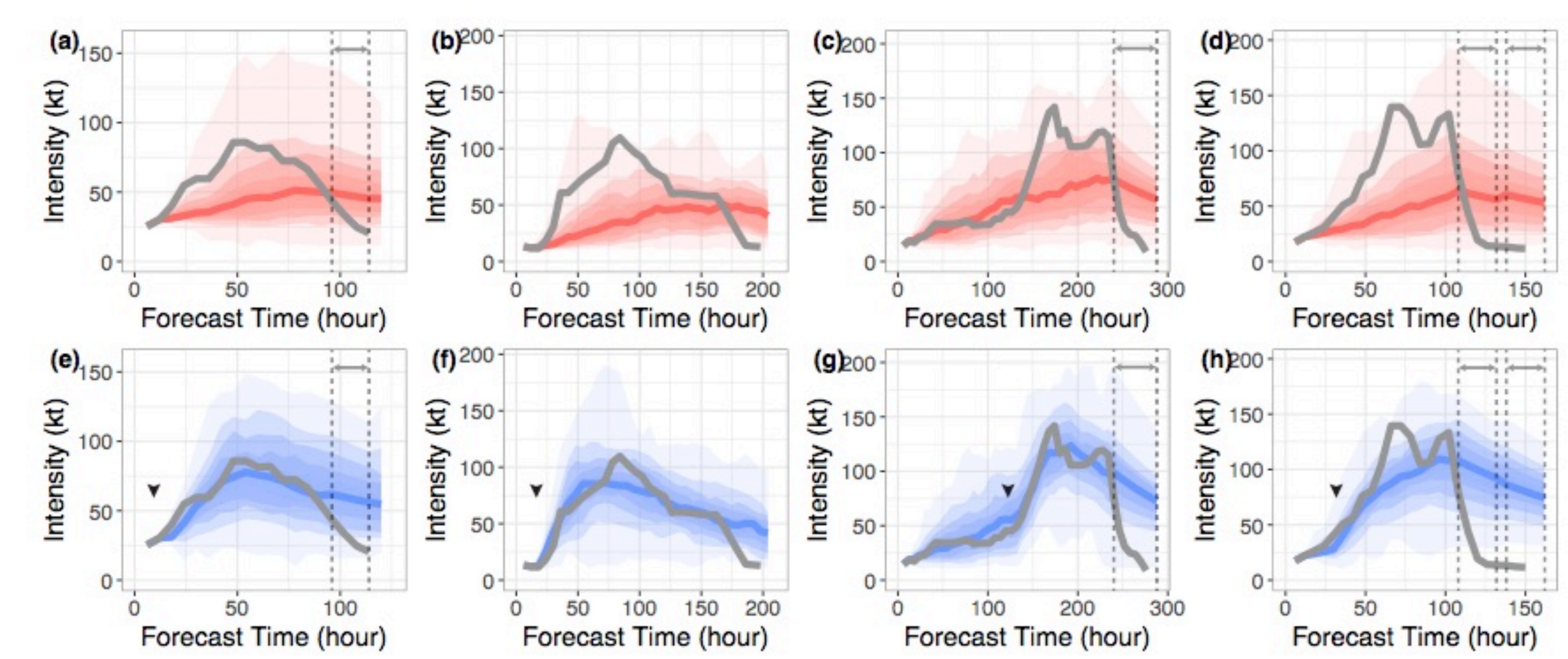
← PDFs of lifetime maximum intensity. Right: LMI distribution of RI storms (dashed lines) and non-RI storms (solid lines).

← TC intensity distributions at landfall over different segments of the North Atlantic coastline;
→ Spatial intensity distribution with color showing maximum intensity (kt) in each 2°×2° grid. The intensities plotted are from (a) observation, (b) one simulation randomly selected from 100 MeHiM realizations, (c) median of 100 MeHiM realizations, (d) 80th percentile of 100 MeHiM realizations.



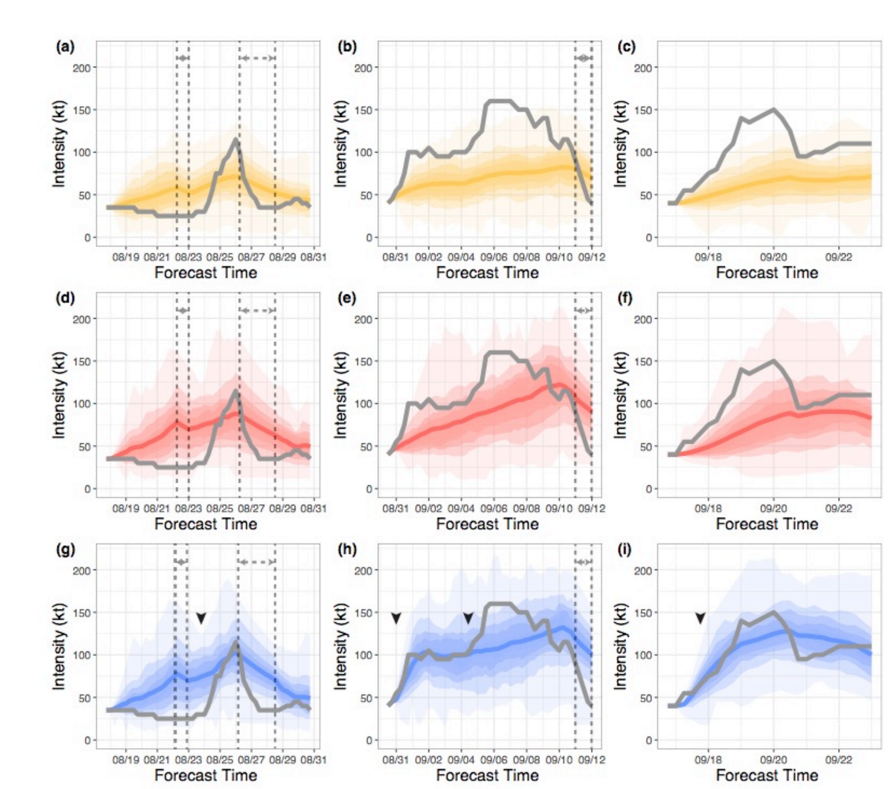
MeHiM + Rapid Intensification Indicator

MeHiM is improved by adding a process of state correction when applied in operational forecasting. At the time of RI (given by historical record), storm's underlying state is manually transitioned to the extreme state during next 24 hours.



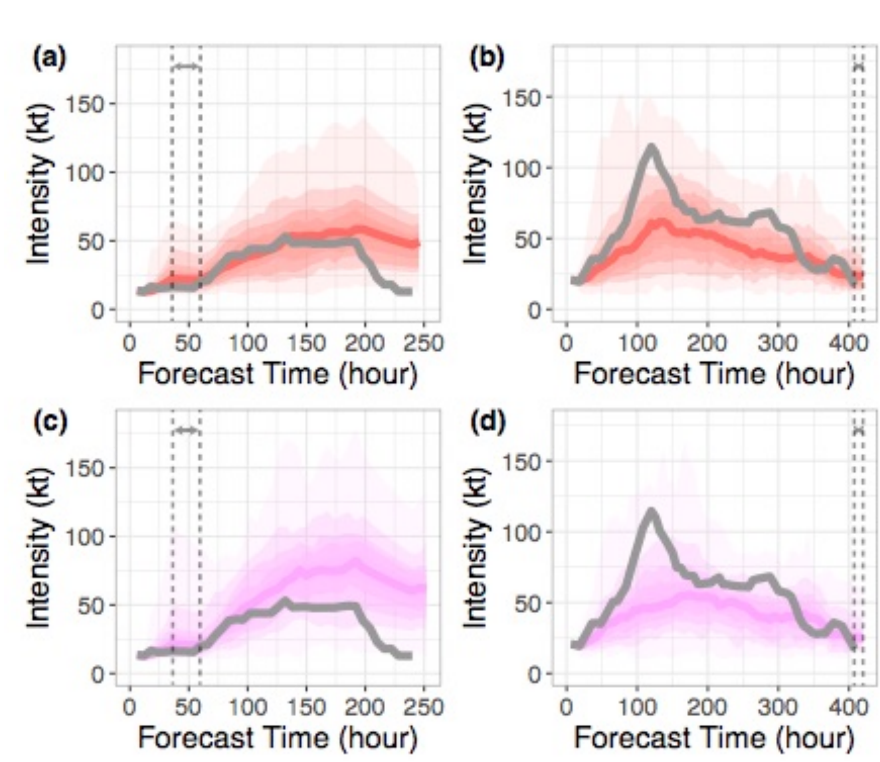
↑ MeHiM (upper) vs. MeHIM with RI state correction (lower). Selected four RI storms are (a, e) Paula (2010), (b, f) Harvey (1981), (c, g) Andrew (1992) and (d, h) Felix (2007). The black arrow indicates the occurrence of RI for each storm.

↓ Performance on three recent hurricanes (Hurricane Harvey, Hurricane Irma and Hurricane Maria) in the 2017 Atlantic hurricane.



- Simulated intensity evolutions from OLS (yellow), MeHiM (red), MeHiM-RI (blue) are shown.
- The colored shading boundaries represent the deciles of 100 realizations while the solid colored lines are the mean of ensemble average in each single storm simulation.
- The dashed lines indicate observations that are over land, during which the land model is applied.

Test of Ocean Feedback Parameter



$$\alpha = 1 - 0.87e^{-z},\ z \equiv 0.01\Gamma^{-0.4} h_m u_T V_p V^{-1}$$

Ocean feedback parameter depends on upper thermal stratification, mixed layer depth, storm's translation speed, storm's maximum potential intensity and storm's current wind speed.

← Comparisons of MeHiM simulated intensity with (upper) and without (lower) ocean parameter. Selected storms are (a, c) Tropical storm Larry (2003) and (b, d) Hurricane Felix (1995).

Conclusions

- A Markov environment-dependent hurricane intensity model (MeHiM) is developed to simulate the climatology of hurricane intensity given surrounding large-scale environment.
- MeHiM shows great improvement over previous statistical models (such as OLS and FMR) in simulating TC intensity climatology, such as DV distribution and LMI distribution.
- A ocean feedback parameter is tested and shown to be statistically significant in developing hurricane intensity model.
- MeHiM's shows great potential in operational real-time forecasting when combined with a RI indicator, which calls for an index that can accurately represent the occurrence of RI.

References

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