



A hybrid AI hurricane forecasting system: deep learning ensemble approach and Kalman filter

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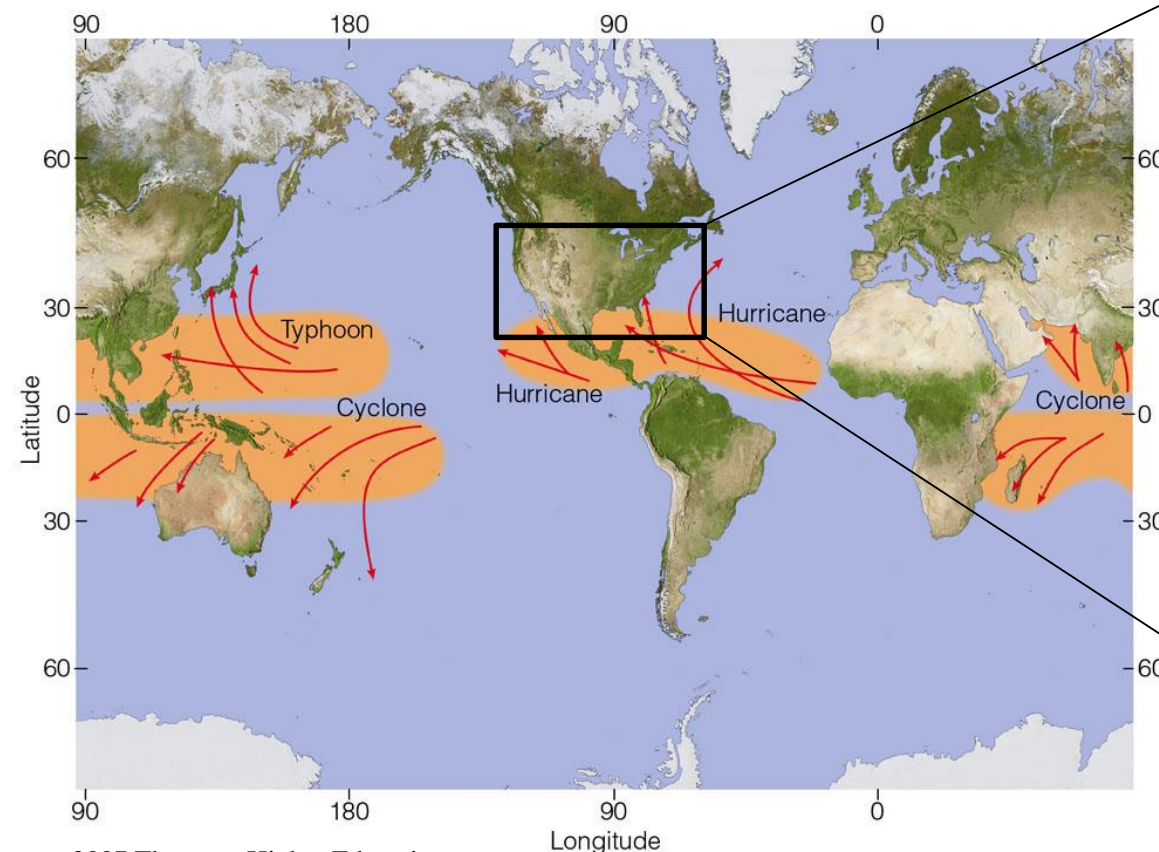


Overview

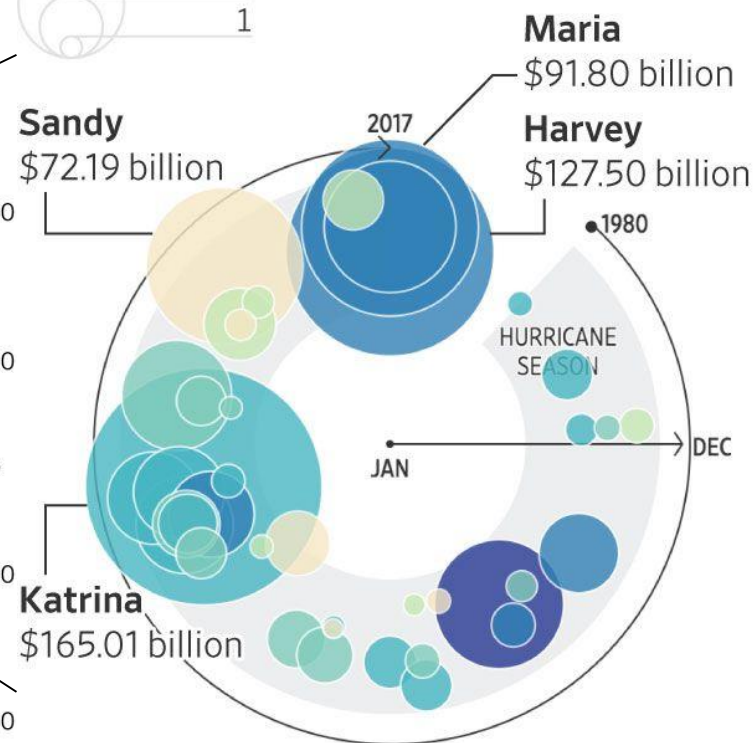
Damage by billion-dollar U.S. hurricanes

Strength at U.S. landfall

● Category 5 ● 4 ● 3 ● 2 ● 1 ● Other*



2007 Thomson Higher Education



*Includes tropical storms and Sandy

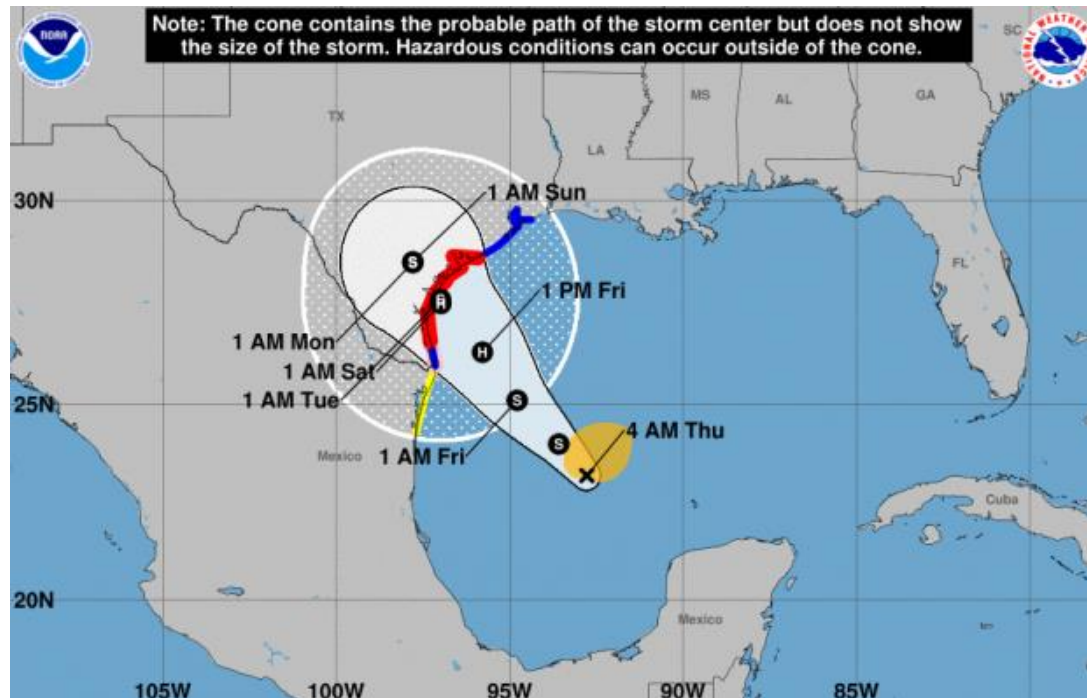
Notes: 2018 inflation-adjusted dollars; includes storms with less than \$1 billion in damage at the time of the event but exceed \$1 billion after adjusting for inflation

Source: NOAA National Centers for Environmental Information (NCEI) U.S. Billion-Dollar Weather and Climate Disasters (2018)

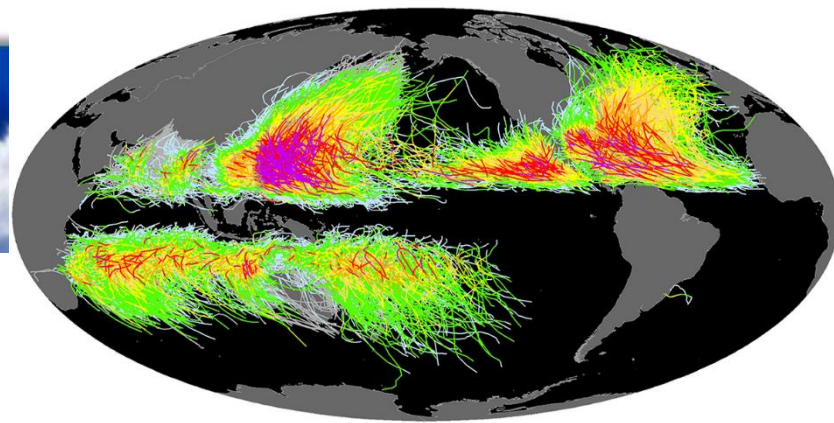
Overview

Tracking the path and forecasting the intensity of hurricanes are challenging:

- ✓ Dynamical models, like HWRF, produce a significant model-measurement error.
- ✓ Accurate forecasting is very difficult to achieve after landfall.
- ✓ Machine learning can be a supplementary approach to tune hurricane forecasting.



Overview



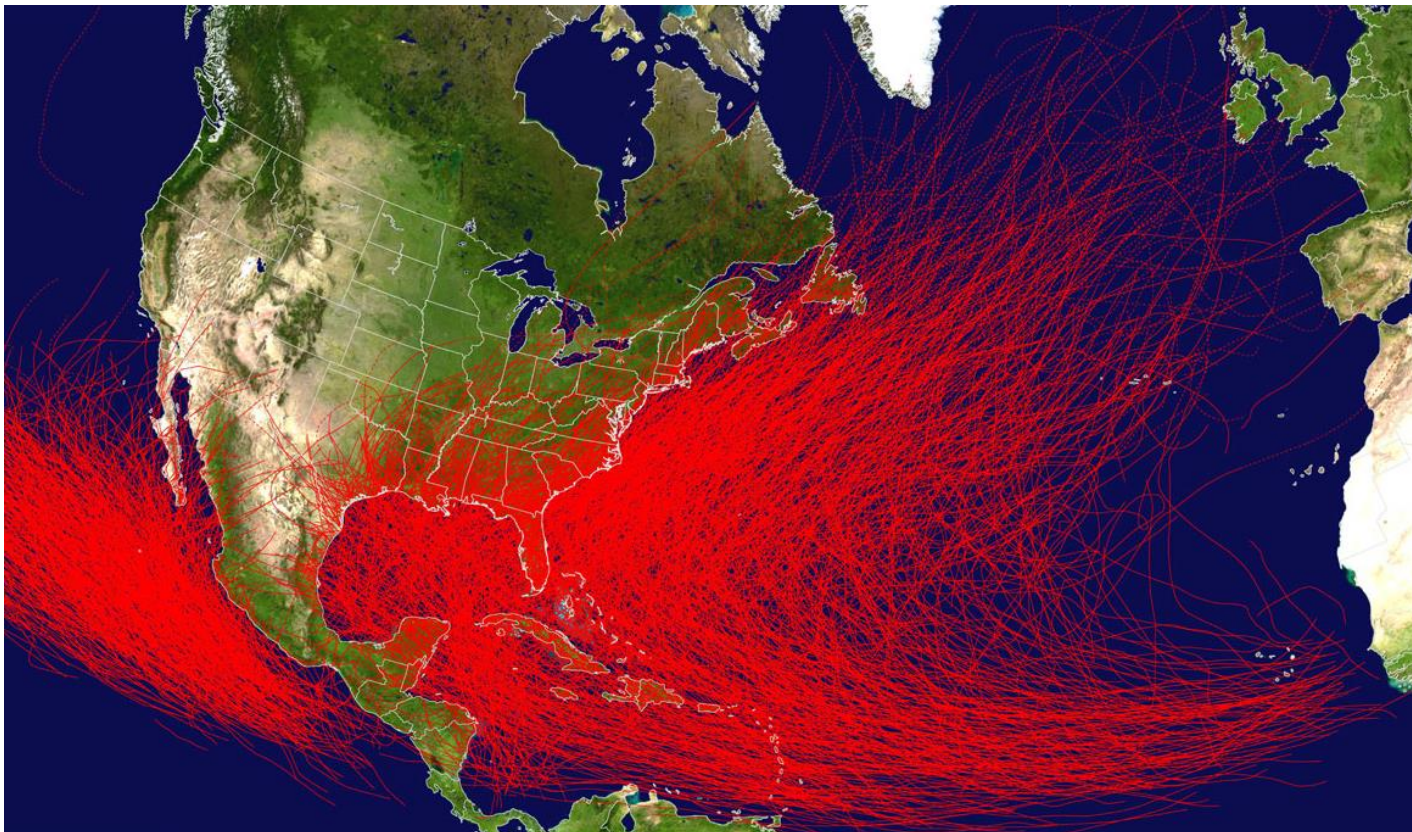
Tropical Cyclone History Pacific: since 1949 , Atlantic: since 1851



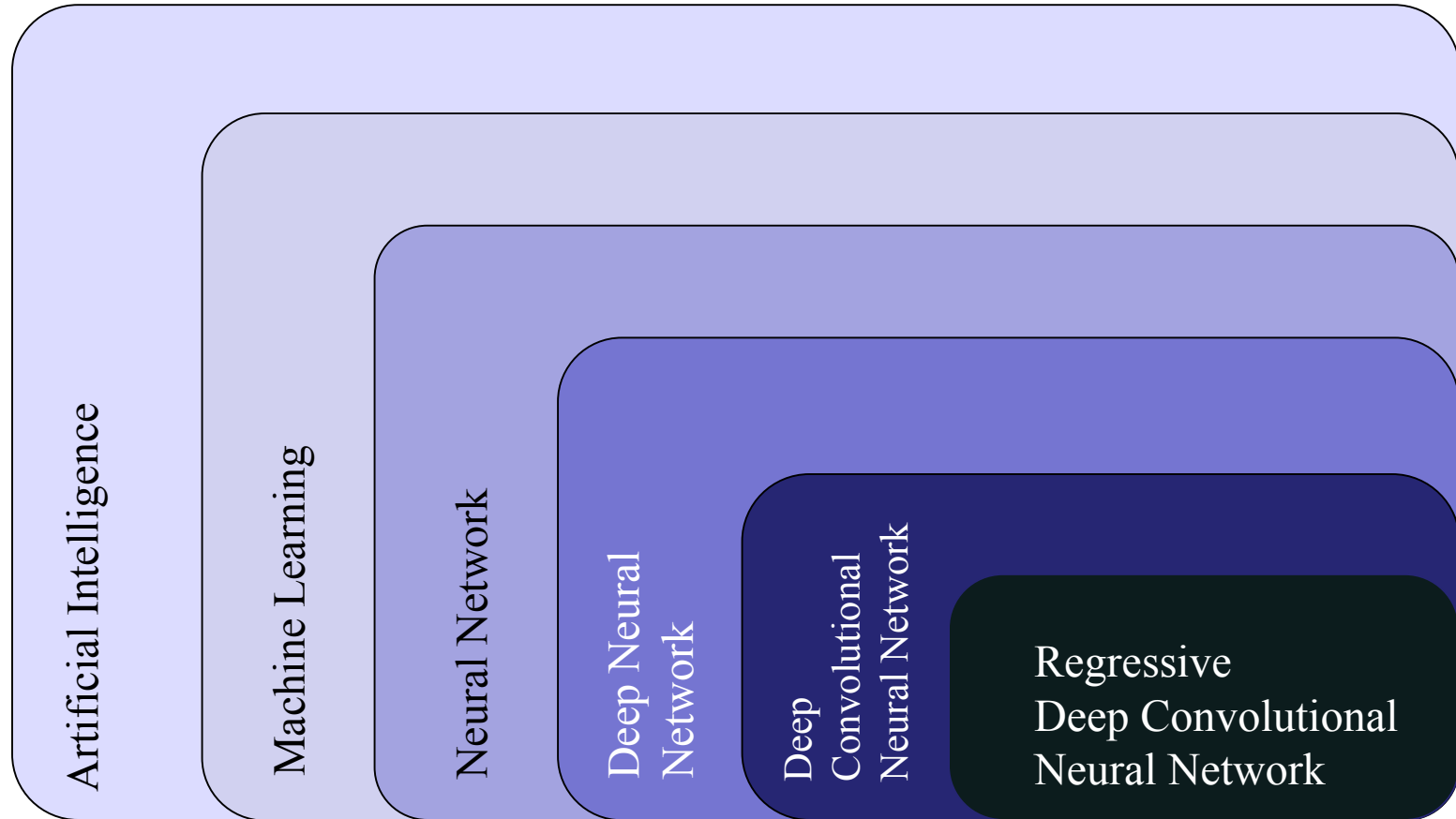
The International Best Track Archive for Climate Stewardship (IBTrACS) stores global tropical cyclone information.

Saffir-Simpson Hurricane Wind Scale

Intensity Missing	Category 1
Tropical Depression	Category 2
Tropical Storm	Category 3
	Category 4
	Category 5

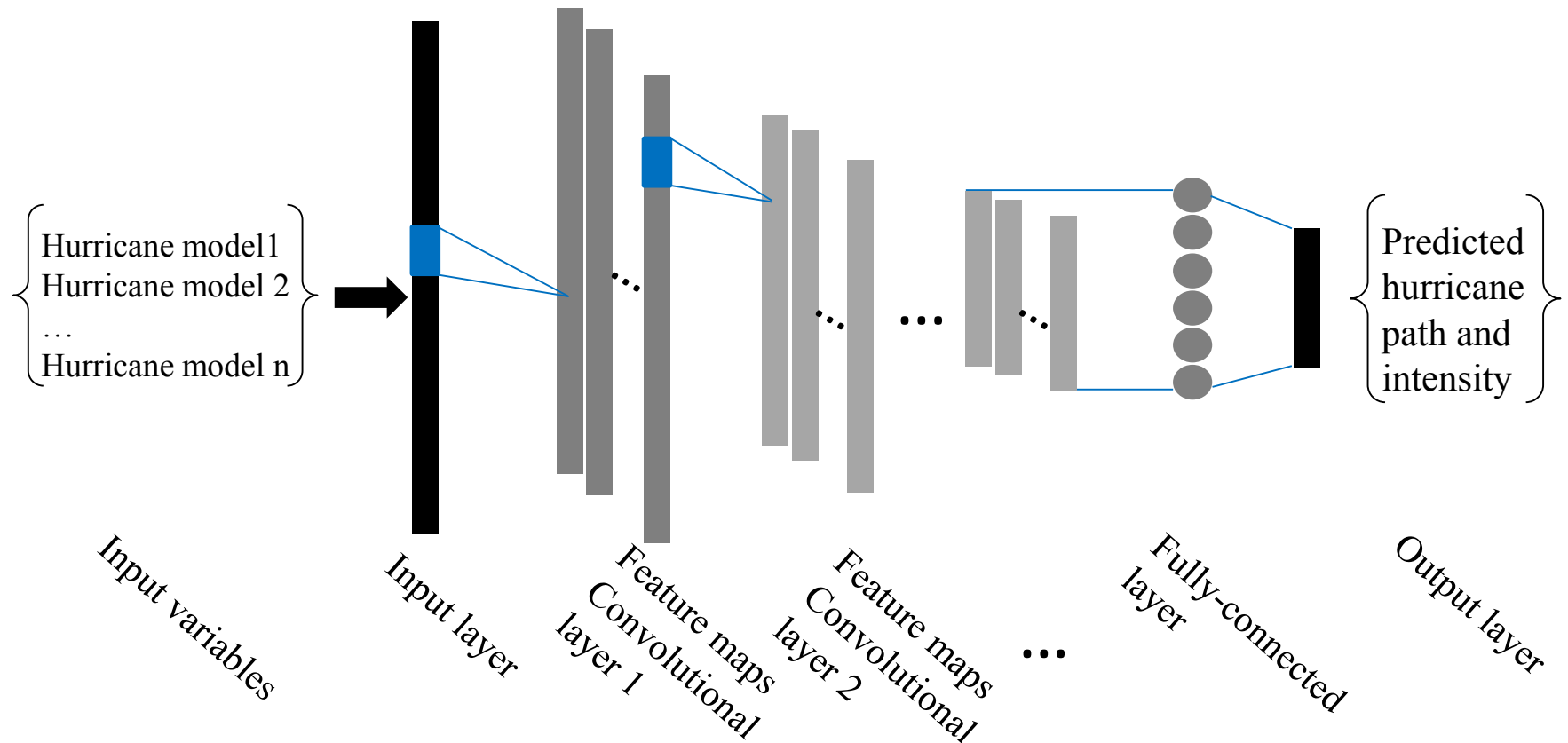


Deep Learning



Deep Learning

Regressive Deep Convolutional Neural Network:



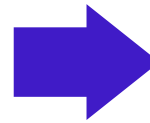
Hurricane Forecasting

- A tropical cyclone forecast involves the prediction of several interrelated features, including:
 - Track, intensity, rainfall, storm surge, areas threatened, etc.
- National Hurricane Center (NHC) normally issues a forecast every 6 hours and up to 72 hours.
- Official forecast is based on the guidance obtained from a variety of subjective and objective models.
- Ensemble model is a mainstream approach in hurricane forecasting.
- Machine learning (deep learning) is proven as a powerful ensemble technique.

Hurricane Forecasting

Best for hurricane
track forecasting

Dynamical
model



Best for hurricane
intensity forecasting

Statistical
model

ML
Ensemble
model

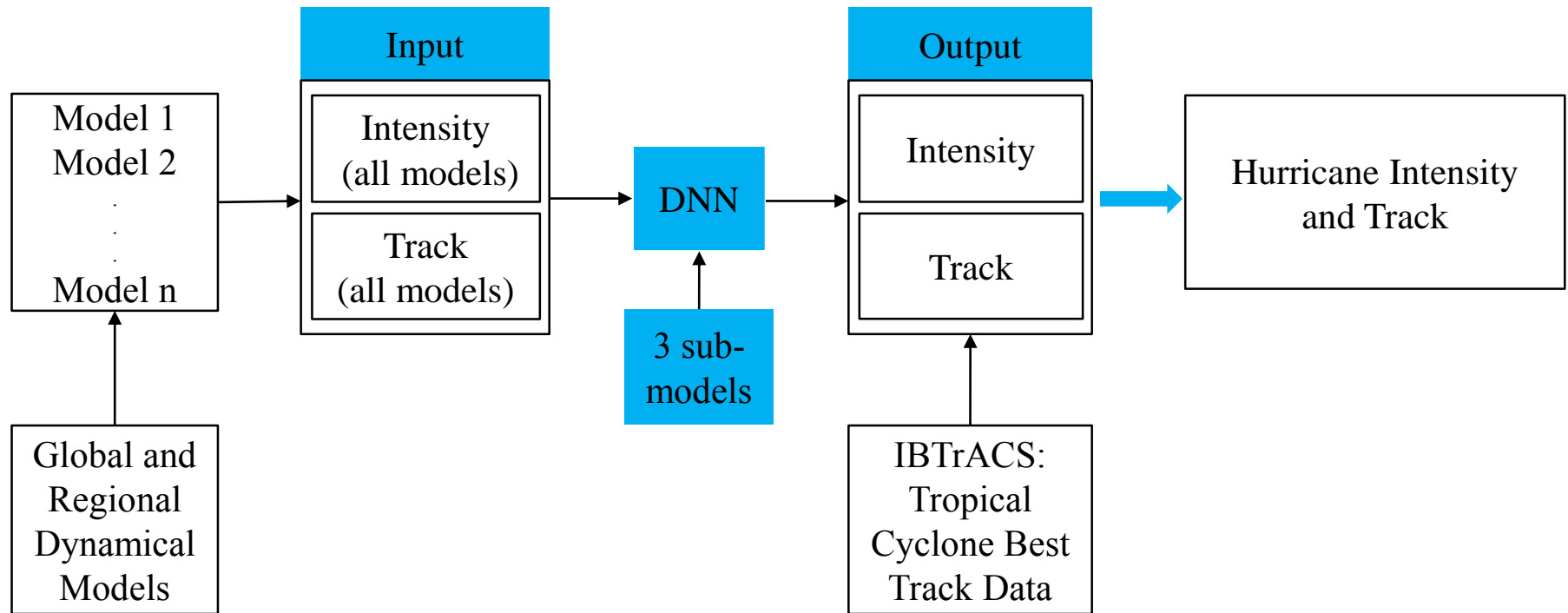
Input Models

Summary of global and regional dynamical models for track, intensity, and wind radii:

ATCF* ID	Model Name	Horizontal Resolution	Cycle/Run Period	NHC Forecast Parameters
NVGM/NVGI	Navy Global Environmental Model	Spectral (~31 km)	6 hr (144 hr)	Track and intensity
AVNO/AVNI GFSO/GFSI	Global Forecast System	Spectral (~13 km)	6 hr (180 hr)	Track and intensity
EMX/EMXI/EMX2	European Centre for Medium-Range Weather Forecasts	Spectral (~9 km)	12 hr (240 hr)	Track and intensity
EGRR/EGRI/EGR2	U.K. Met Office Global Model	Grid point (~10 km)	12 hr (144 hr)	Track and intensity
CMC/CMCI	Canadian Deterministic Prediction System	Grid point (~25 km)	12 hr (240 hr)	Track and intensity
HWRF/HWFI	Hurricane Weather Research and Forecast system	Nested Grid point (18-6-2 km)	6 hr (126 hr)	Track and intensity
CTCX/CTCI	NRL COAMPS-TC w/ GFS initial and boundary conditions	Nested Grid point (45-15-5 km)	6 hr (126 hr)	Track and intensity
HMON/HMNI	Hurricane Multi-scale Ocean-coupled Non-hydrostatic model	Nested Grid point (18-6-2 km)	6 hr (126 hr)	Track and intensity

Methodology

UH ML Ensemble Hurricane Forecasting System:

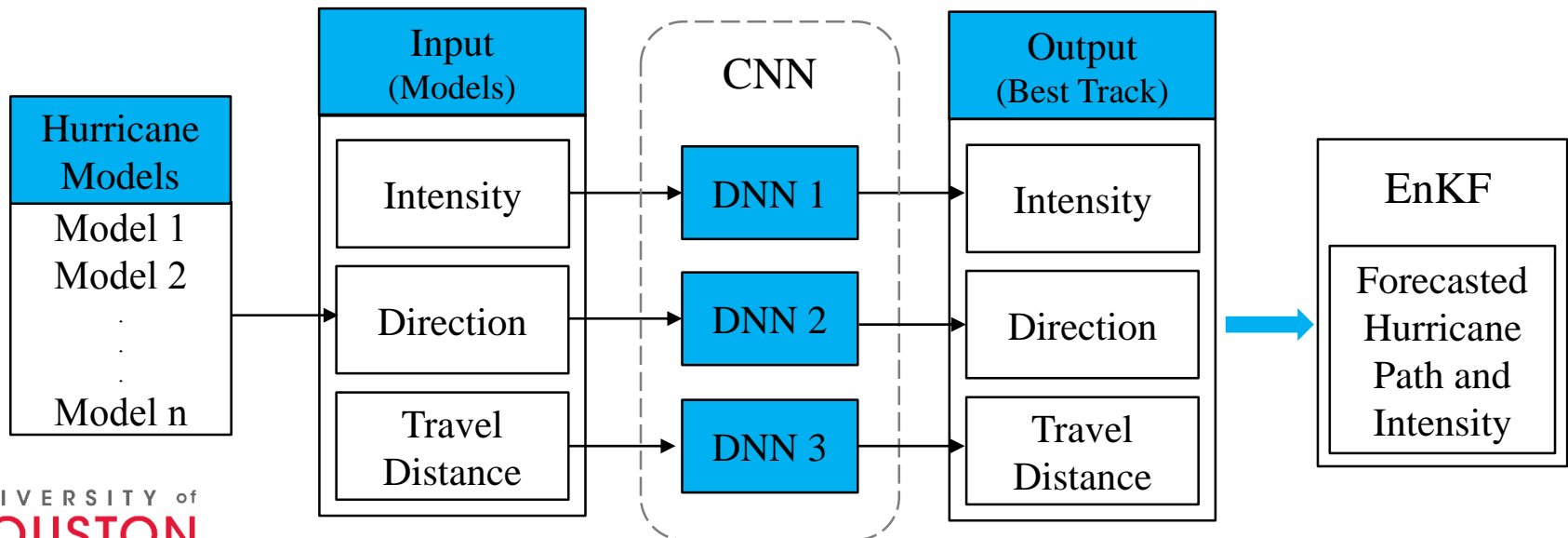


DNNs modeling time period:

- Training data: 2003 – 2016
- Next step prediction: 2017 (e.g. Hurricane Harvey)

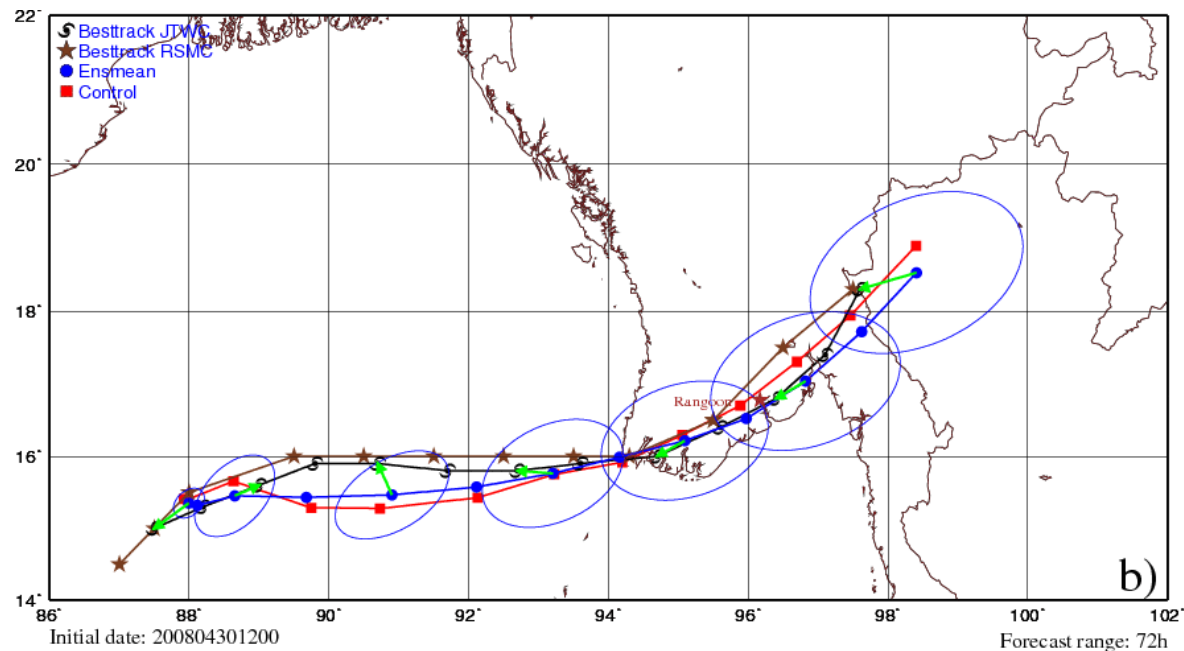
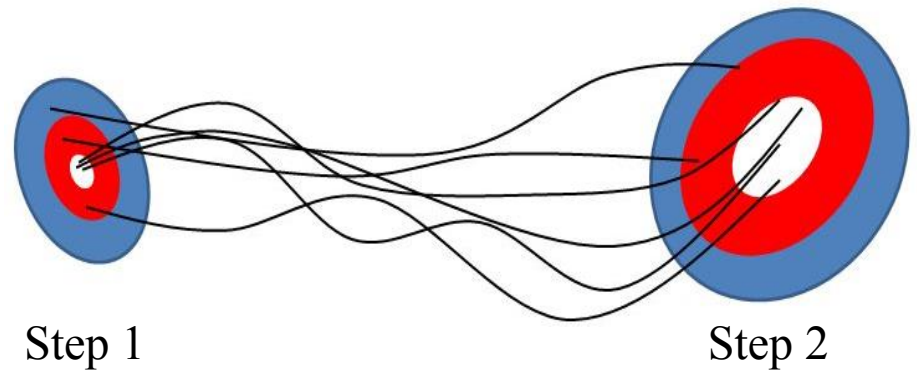
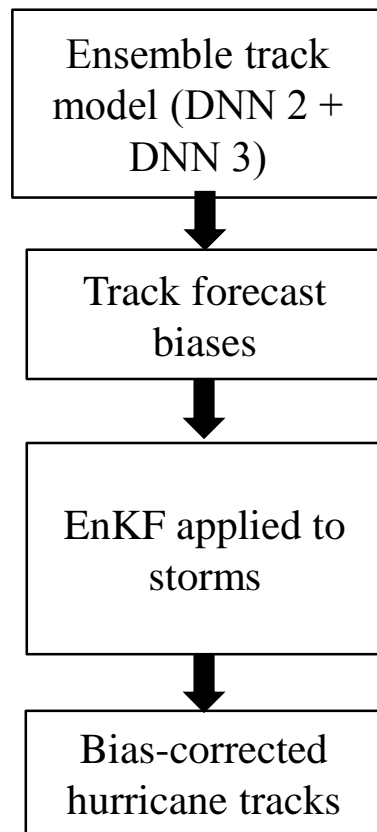
Methodology

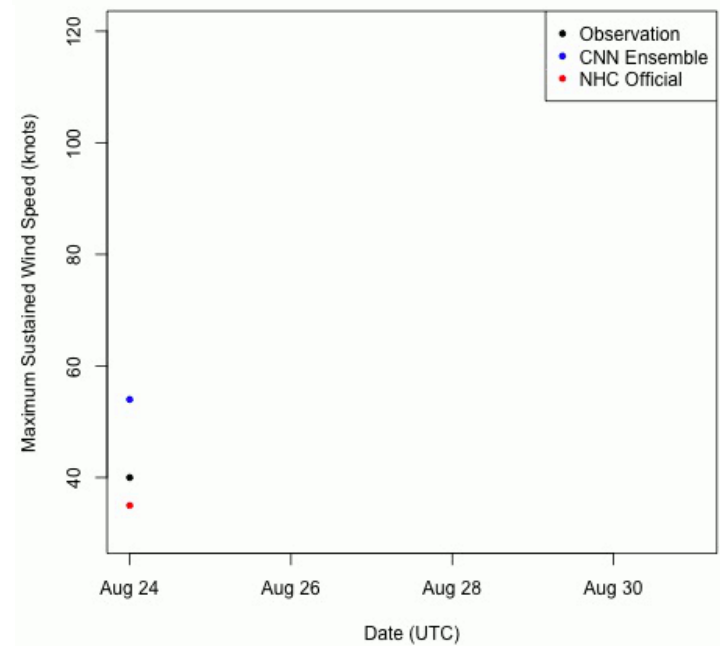
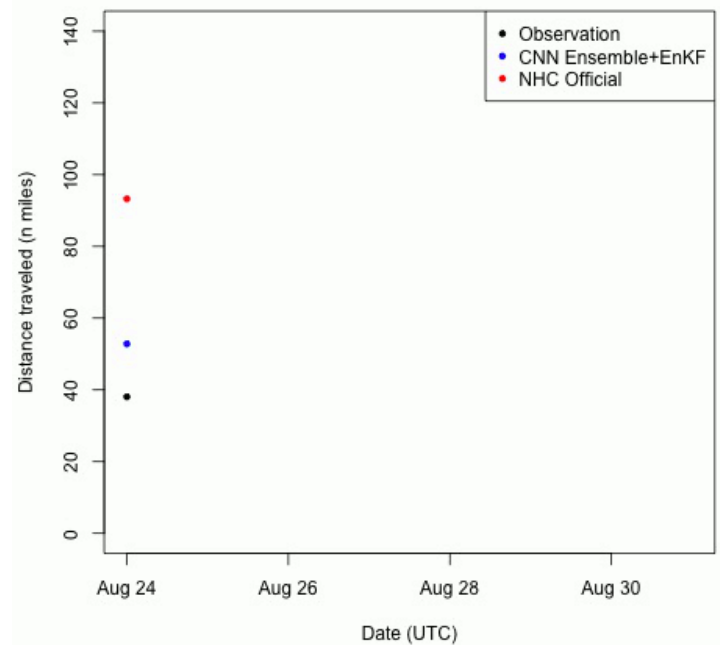
- We used three sub-models in our ensemble model:
 - I. Intensity predictor
 - II. Direction predictor
 - III. Travel distance predictor
- Regressive Deep Convolutional Neural Network was used for all DNN models.
- After ensemble track model, an Ensemble Kalman filter (EnKF) was used to bias-correct the hurricane's path.



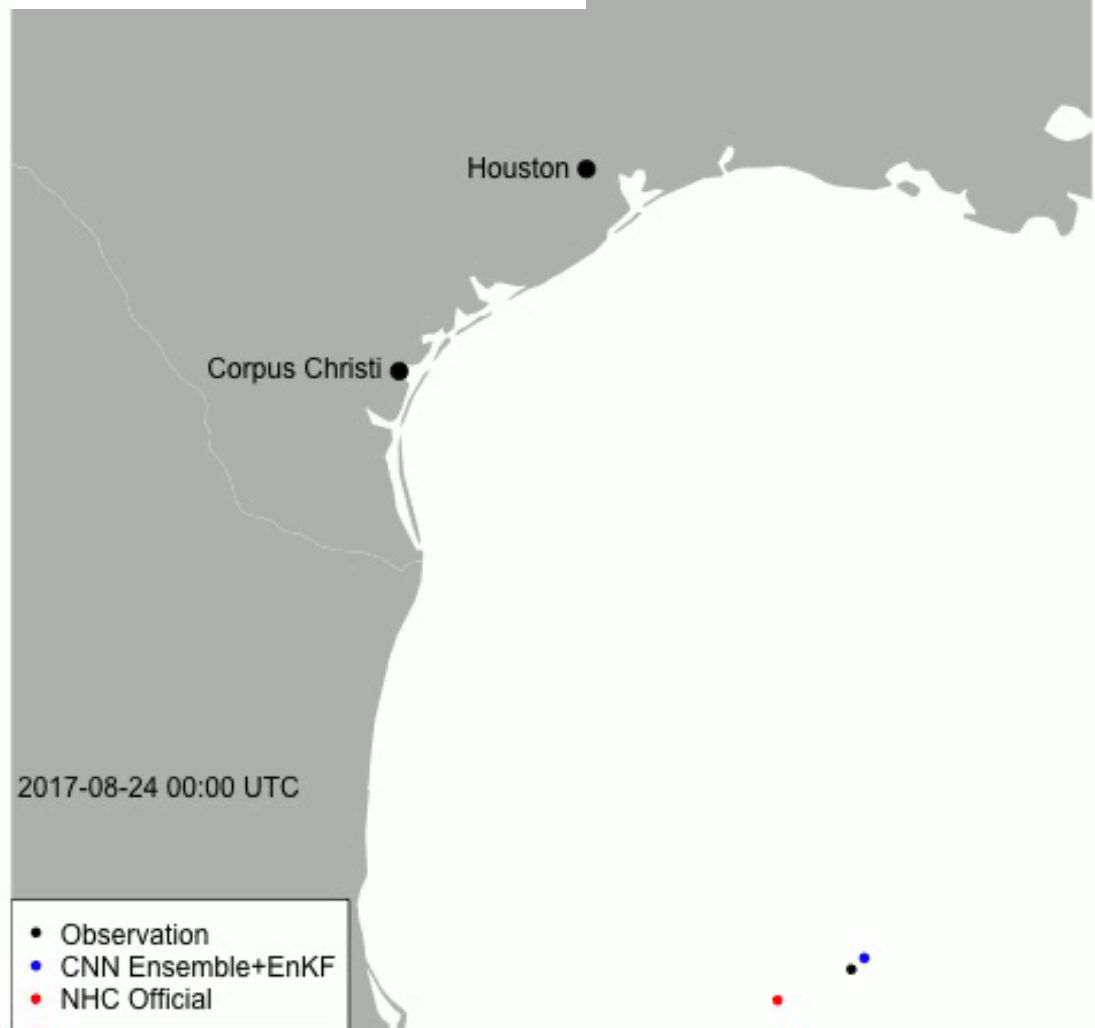
Methodology

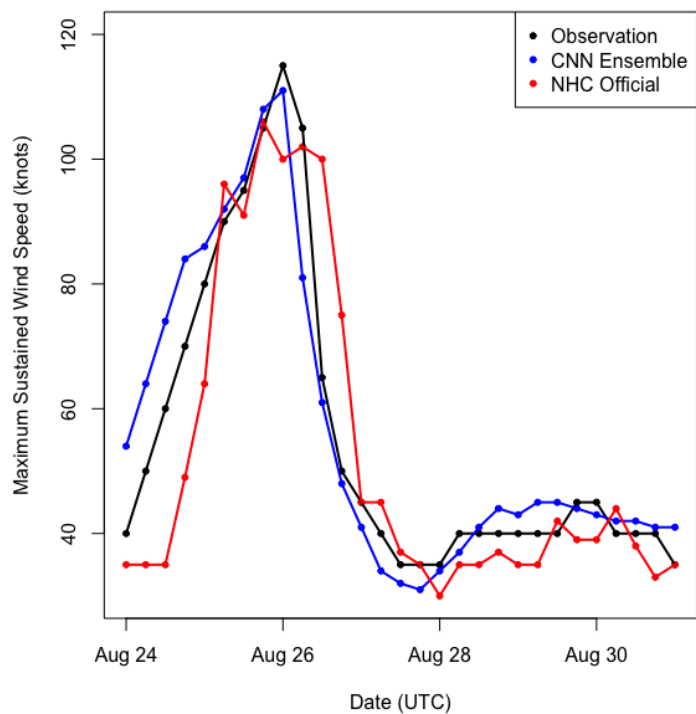
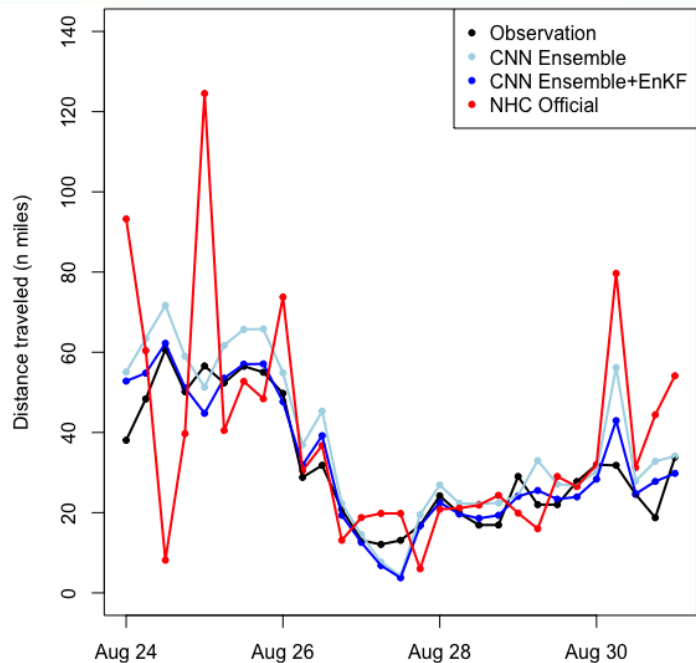
Ensemble Kalman Filter (EnKF)



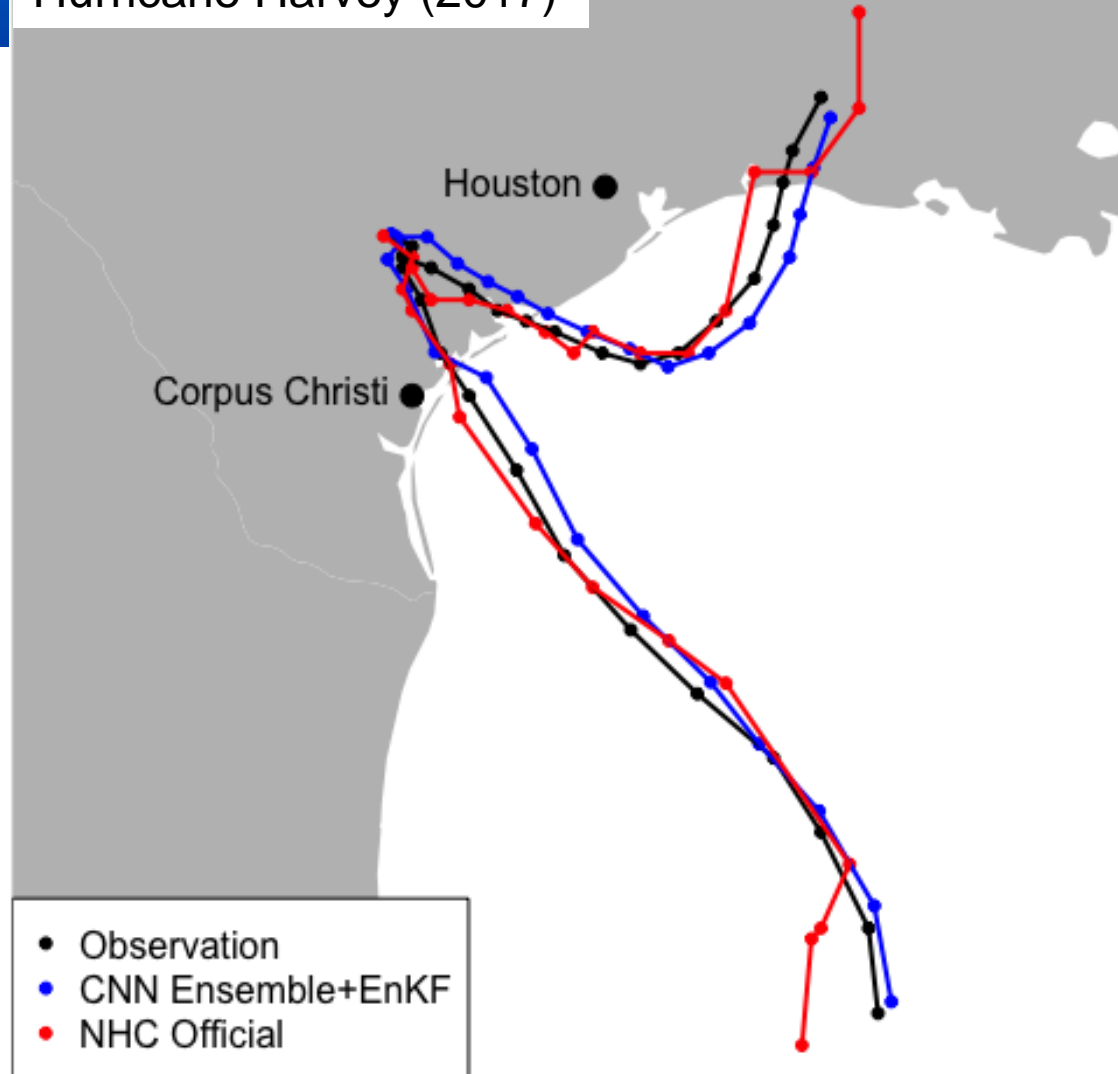


Hurricane Harvey (2017)





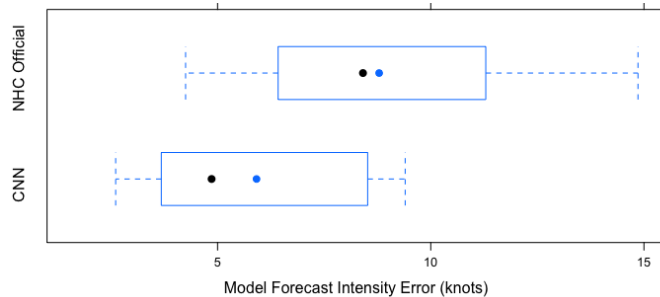
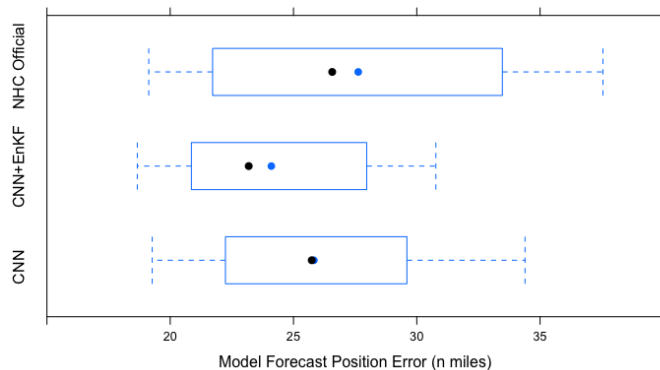
Hurricane Harvey (2017)



Results

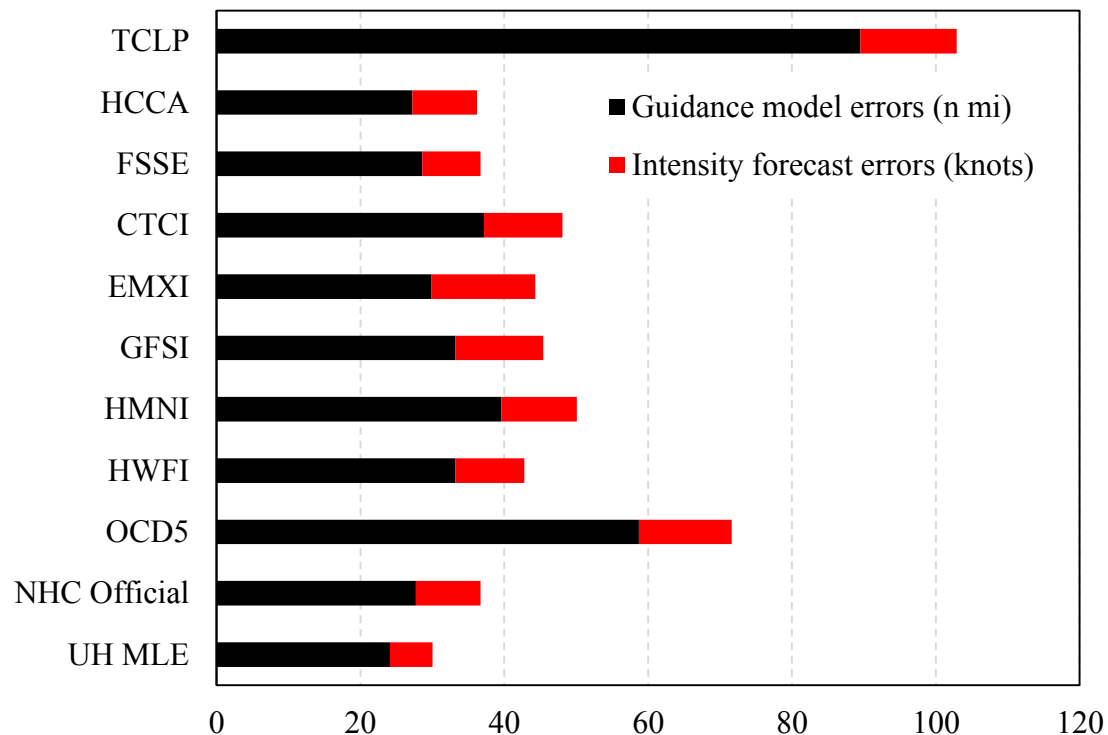
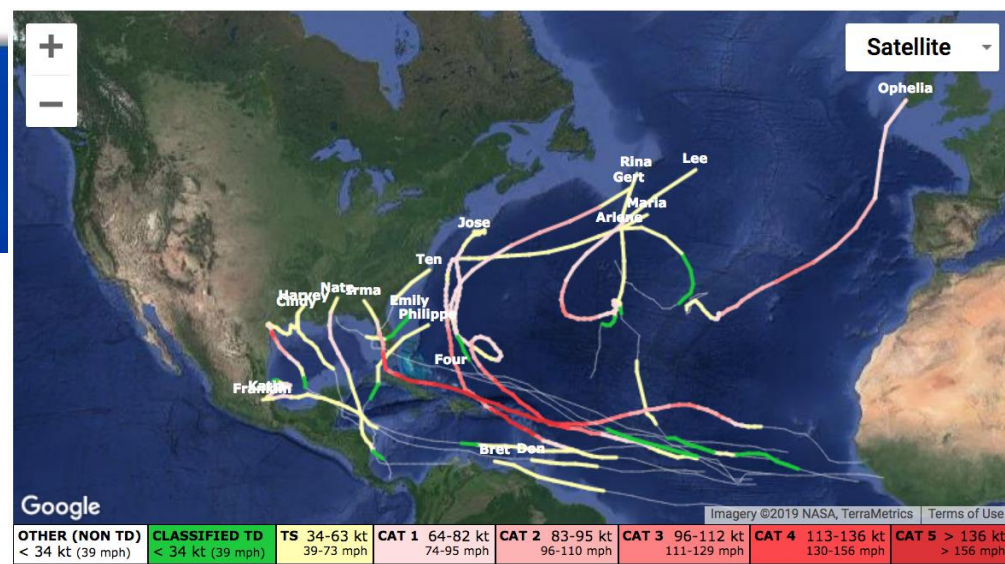
All Tropical cyclones (models & best track) for the North Atlantic in 2017:

RMSE for hurricane position and intensity:



UH Machine Learning Ensemble (UH MLE) Hurricane Modeling System vs. NHC official forecast (above) and other models (right).

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Summary

- ✓ We developed a hybrid three-step DNN-based ensemble hurricane forecasting model with Ensemble Kalman filter (EnKF) post-processing. The model used the output of eight dynamical hurricane models.
- ✓ We used all tropical cyclones in Atlantic Ocean from 2003-2016 and tested the model for those in 2017.
- ✓ EnKF further improved the hurricane track forecasting by reducing the bias.
- ✓ The preliminary results show statistical advantages over NHC official forecasts – ~13% improvement in track forecast biases and ~30% improvement in intensity forecast biases.

Challenges:

- ✓ Long-term forecasting and flooding prediction could be challenging due to uncertain training datasets.

Acknowledgements

- ✓ Thanks to Earth Science Information Partner (ESIP) for seed funding
- ✓ Thanks to Dr. Young-Joon Kim (NOAA AFS) for providing a useful suggestion on this study

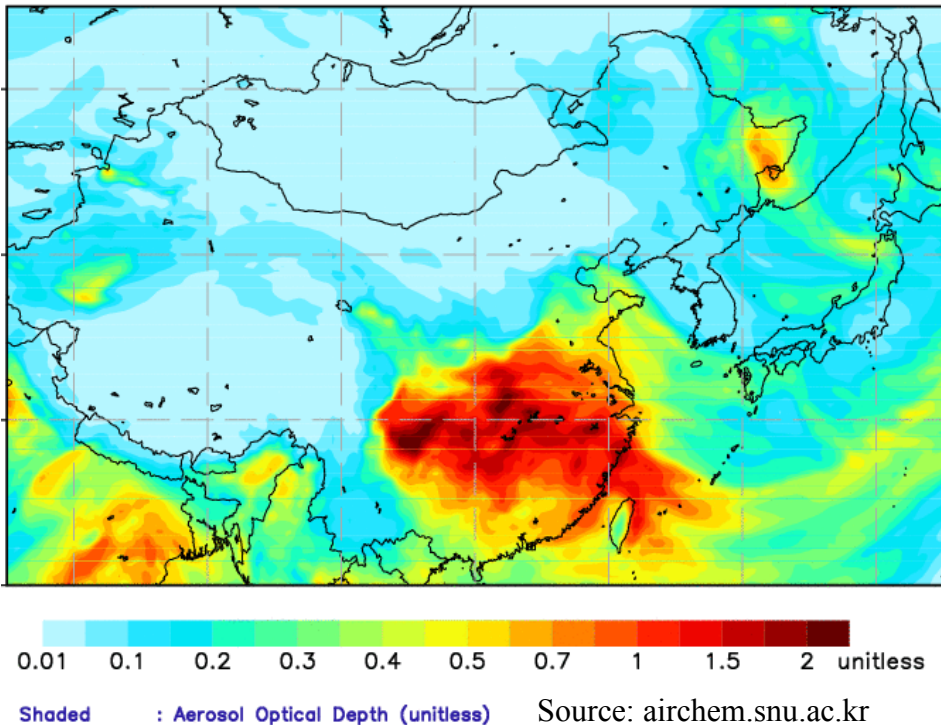
On-going Hurricane study

Image forecasting using advanced deep neural network:

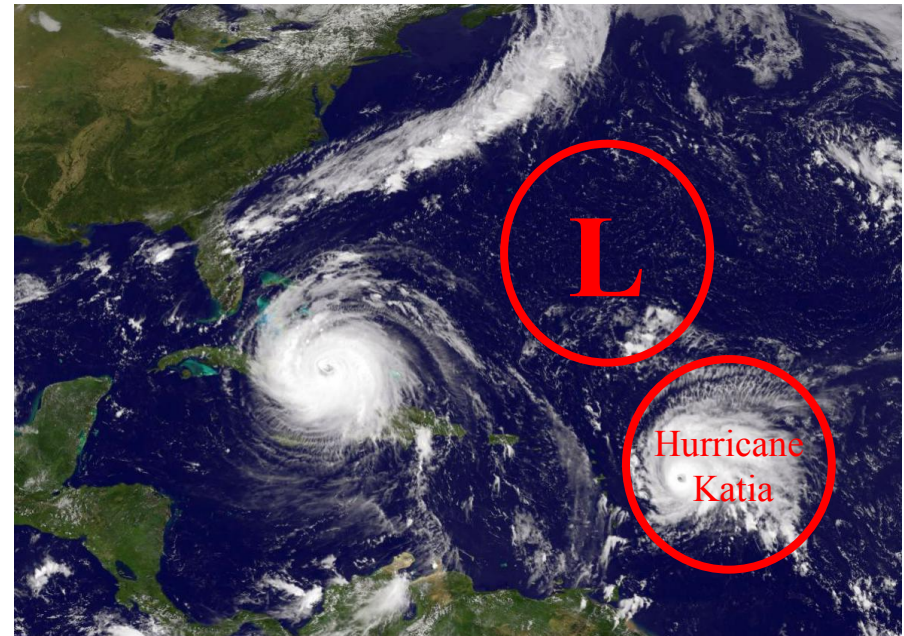
For AOD and Hurricane tracking

Motivation

AOD prediction (left) and hurricane tracking (right) are both image forecasting problems...



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Hurricane Irma, 2017 (source: GOES, NOAA)

Methodology

Testing Image Forecasting with AI:

Question: Can AI predict basic movements from just receiving previous states with just image as input?

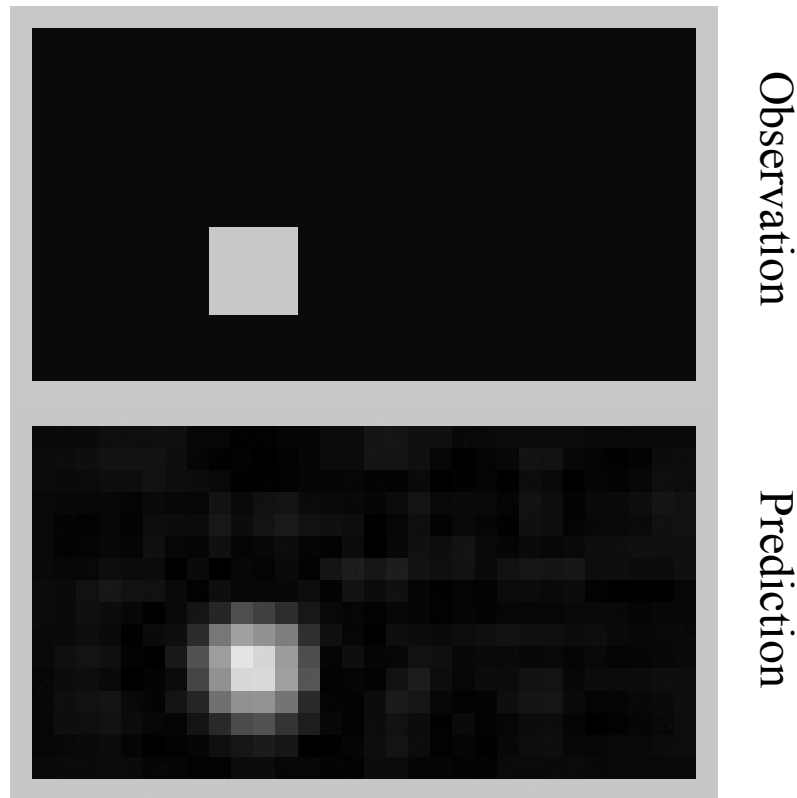


Methodology

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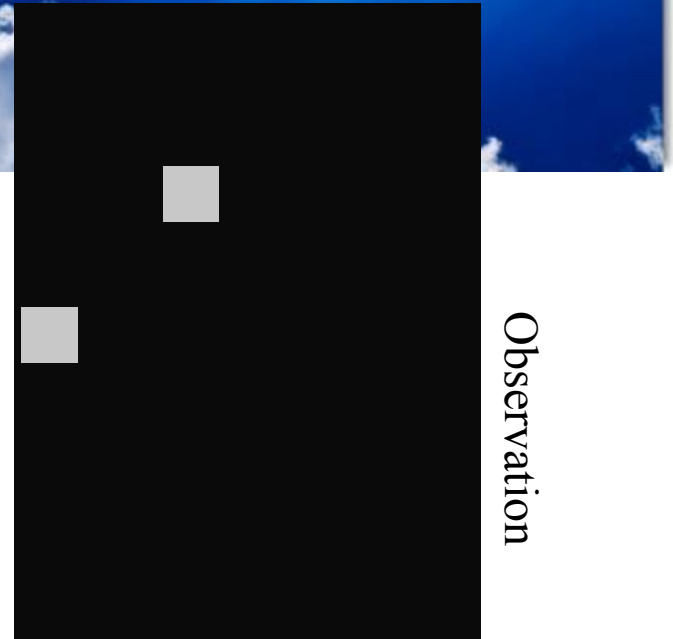
YES IT CAN!



Methodology

Testing Image Forecasting: Part 2

Can the AI follow two features traveling independently and understand collisions between them?

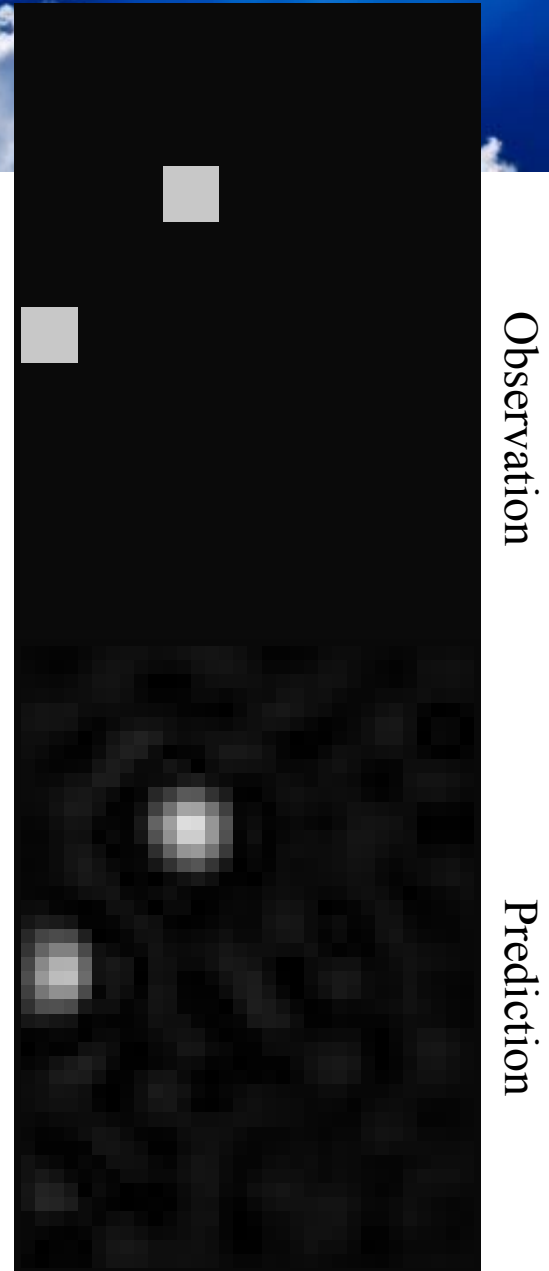


Methodology

Testing Image Forecasting: Part 2

Can the AI follow two features traveling independently and understand collisions between them?

YES IT CAN!



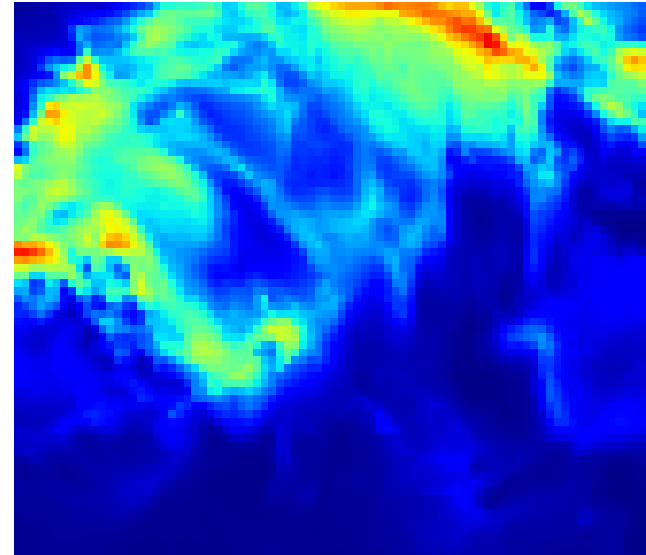
2D CNN Image Forecasting

Testing Image Forecasting:

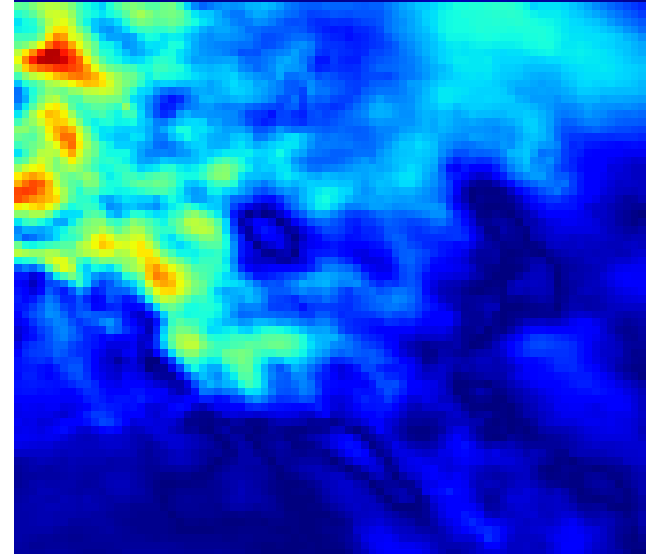
Applied 2D-CNN to forecast CMAQ AOD
3-hours ahead with just 3 images as input.

Model Accuracy:

✓ ≈ 0.8 IOA & COR



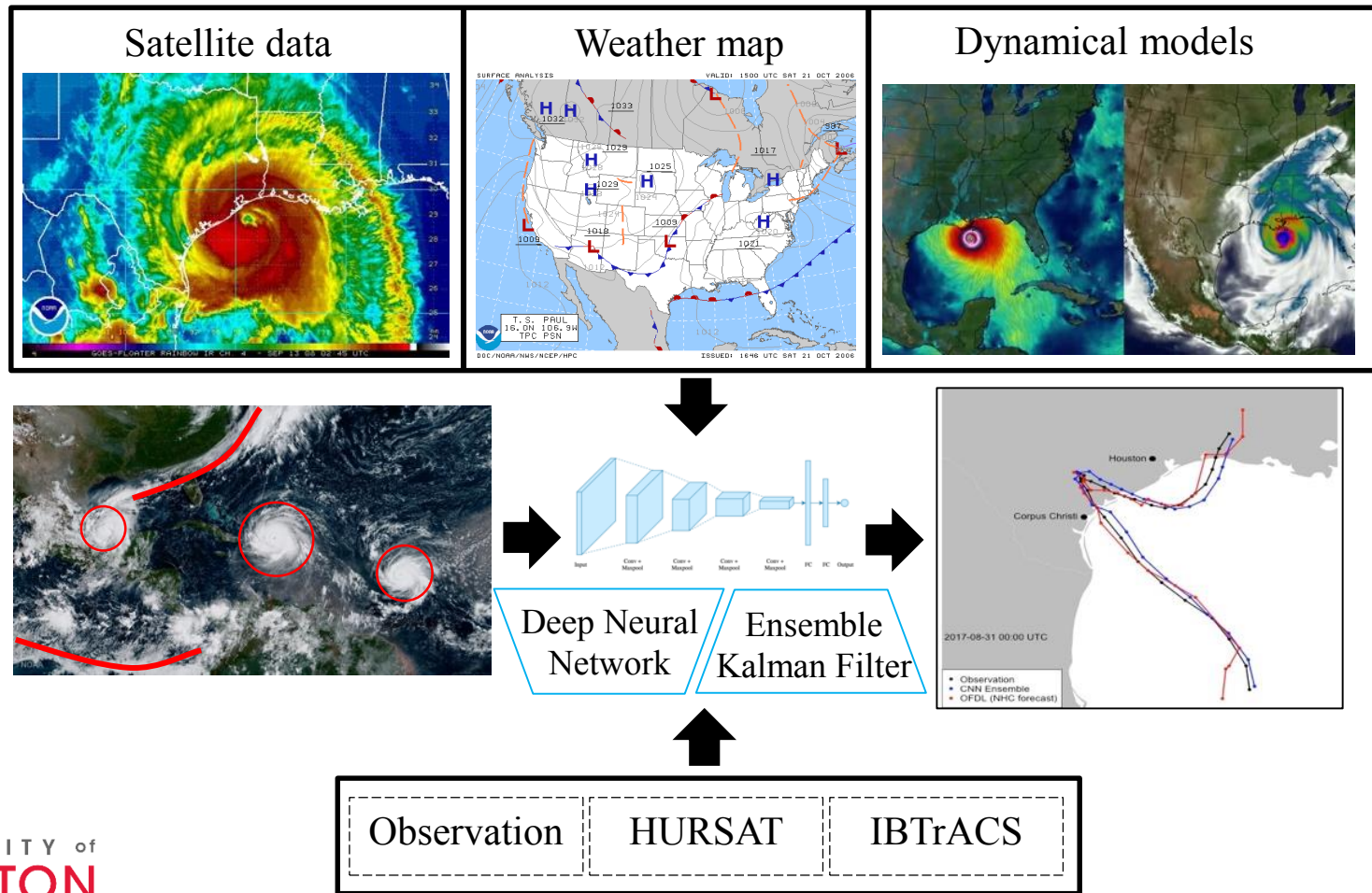
Observation



Prediction

Proposed study

- Hurricane-AI based on image forecasting:



"It only takes one storm to devastate a community"
– FEMA's Daniel Kaniewski



Thank
you
for
your
attention