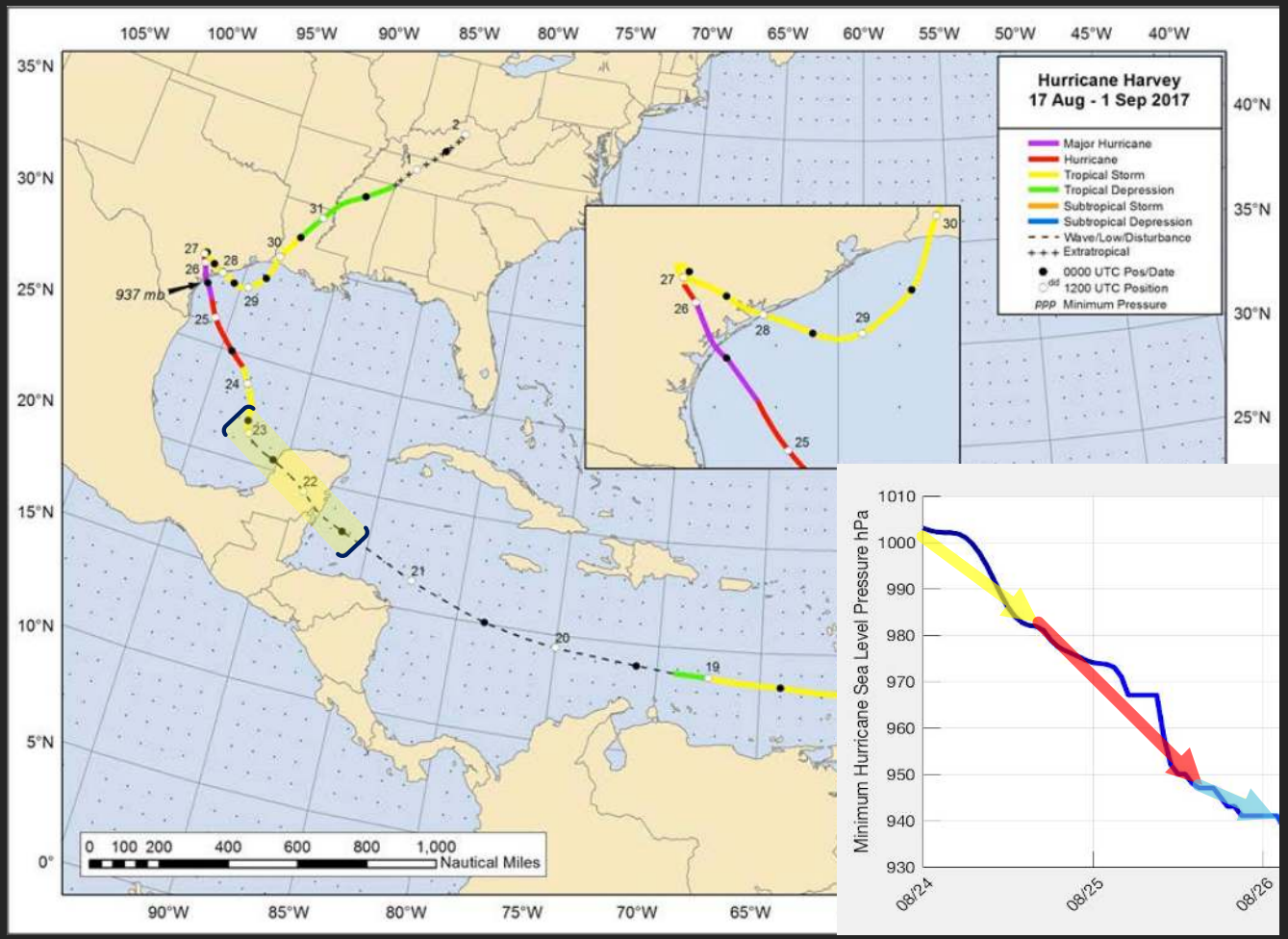
CASE STUDY HURRICANE HARVEY:

HOW NEURAL NETWORKS CAN HELP IN FORECASTING RAPID INTENSIFICATION IN TROPICAL CYCLONES

T.J. CORRIGAN

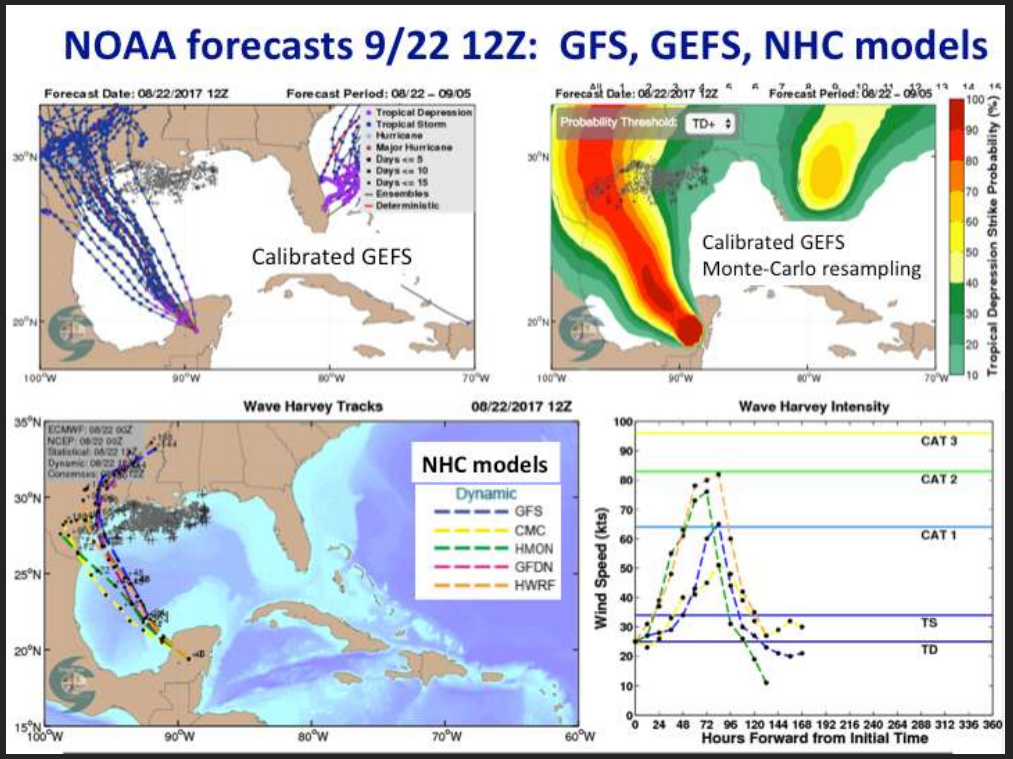
HURRICANE HARVEY 2017

- 8/22 TUE - 8/23 WED
  - LOW → TROPICAL STORM GENESIS
- 8/24 THU – 8/25 FRI
- 8/26 SAT - LANDFALL



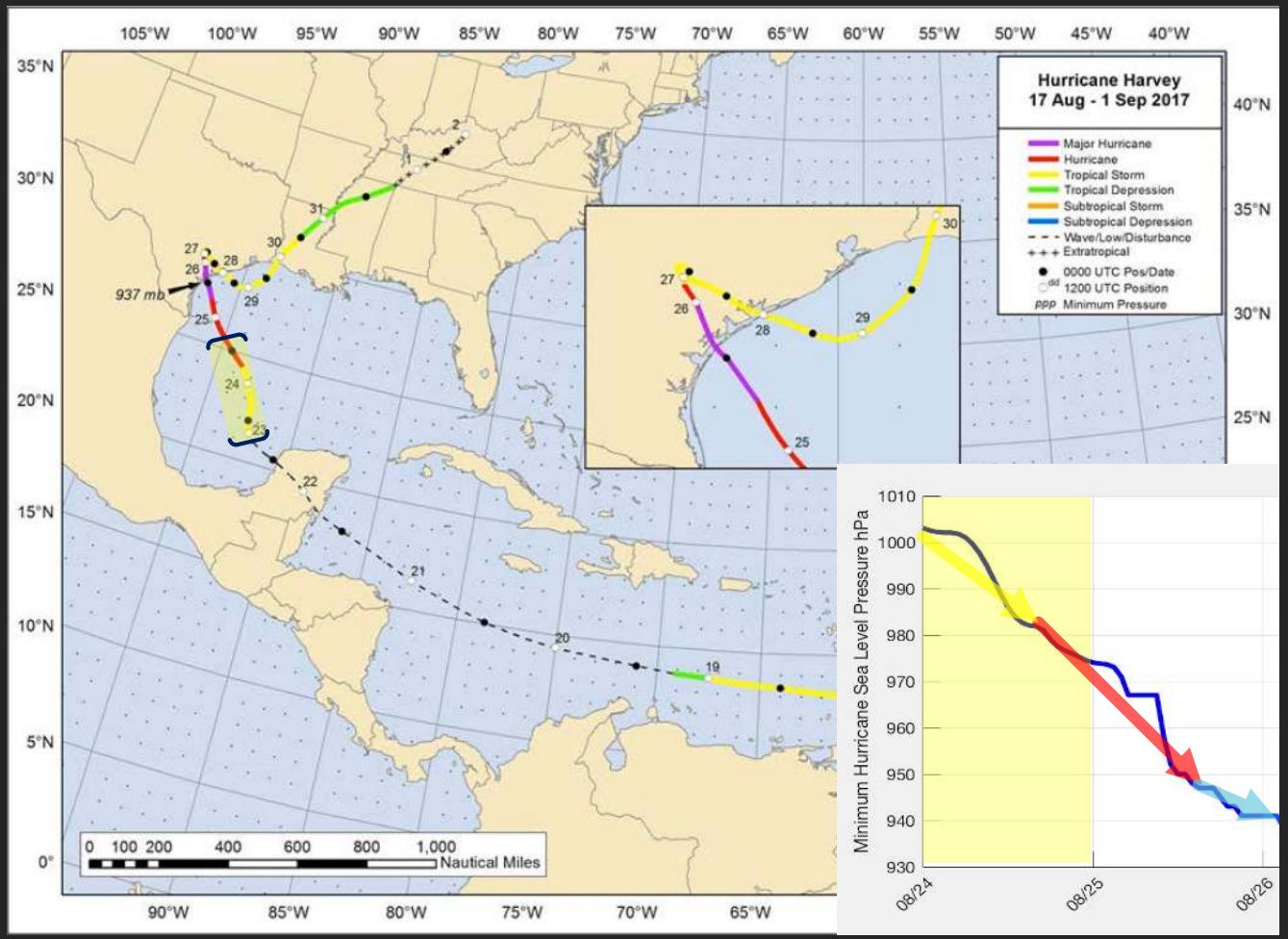
INITIAL MODEL PREDICTIONS

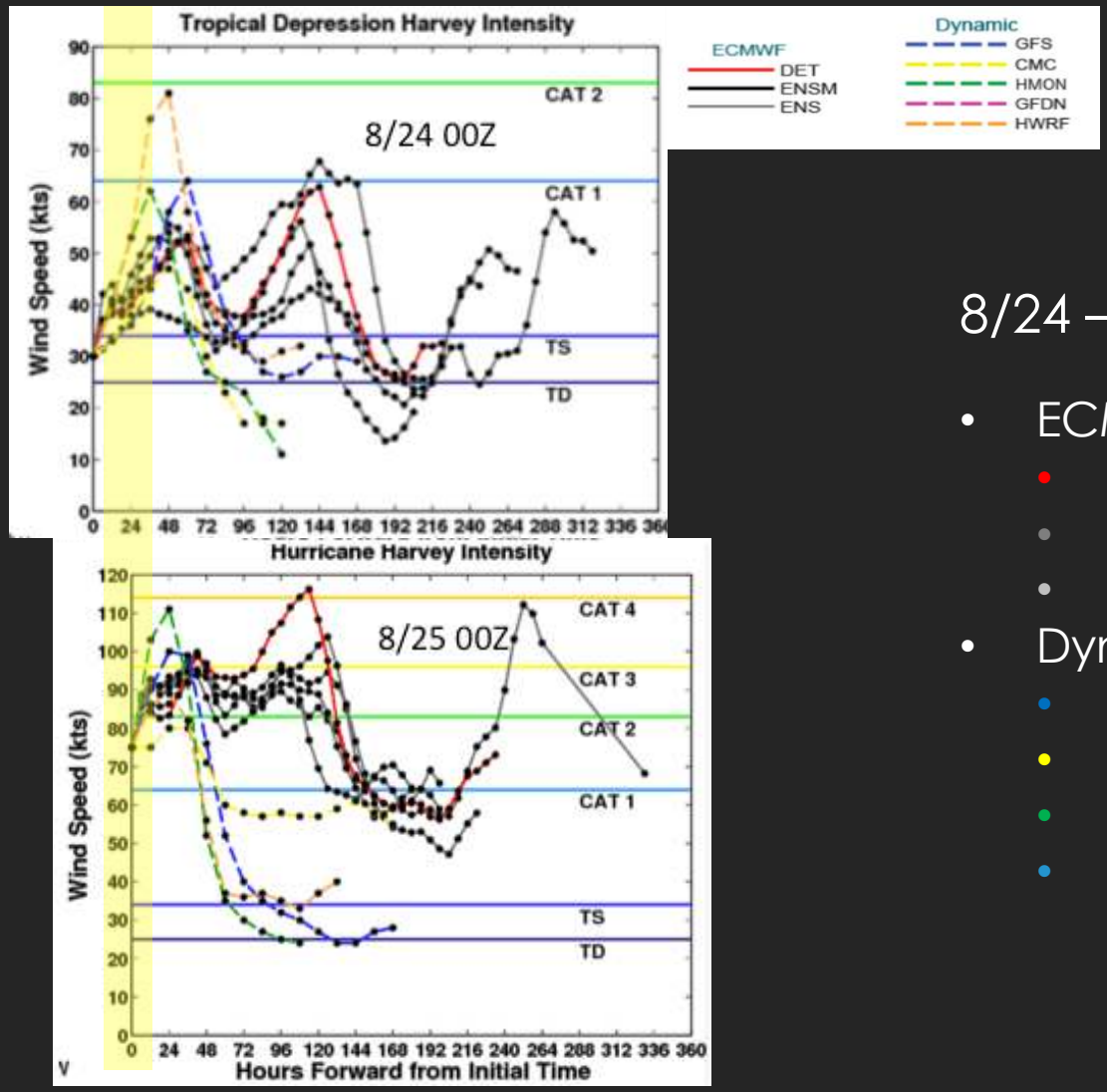
- GOOD HURRICANE TRACK AGREEMENT
- GOOD HURRICANE INTENSITY AGREEMENT
  - MAGNITUDE?



HURRICANE HARVEY 2017

- 8/22 TUE - 8/23 WED
  - LOW → TROPICAL STORM GENESIS
- 8/24 THU – 8/25 FRI
  - TROPICAL STORM → CAT1
  - RAPID INTENSIFICATION
    - 42MB IN 24HRS
    - 40MPH IN 24HRS
  - RAPID INTENSIFICATION BEGINS
    - 982MB AT ~16UTC
- 8/25 FRI – 8/26 SAT



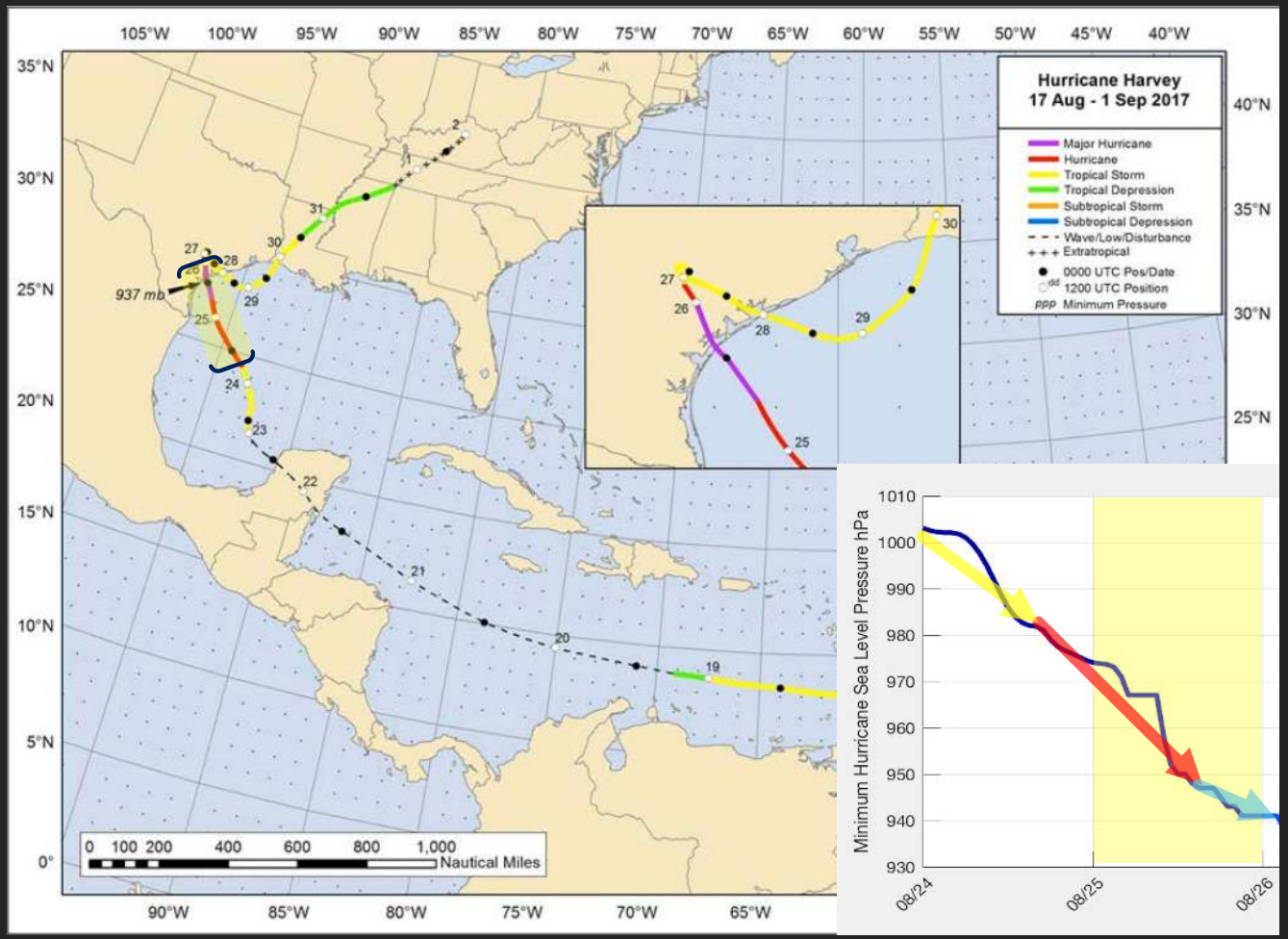


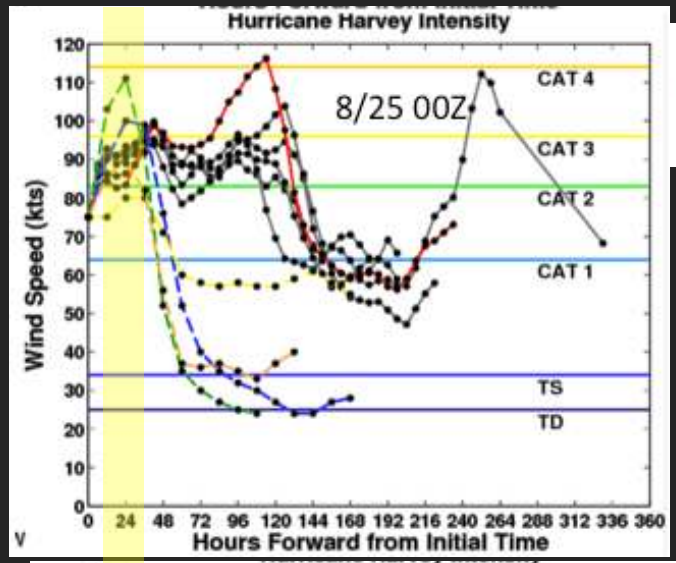
8/24 – 24hr Model Forecast Intensity Error

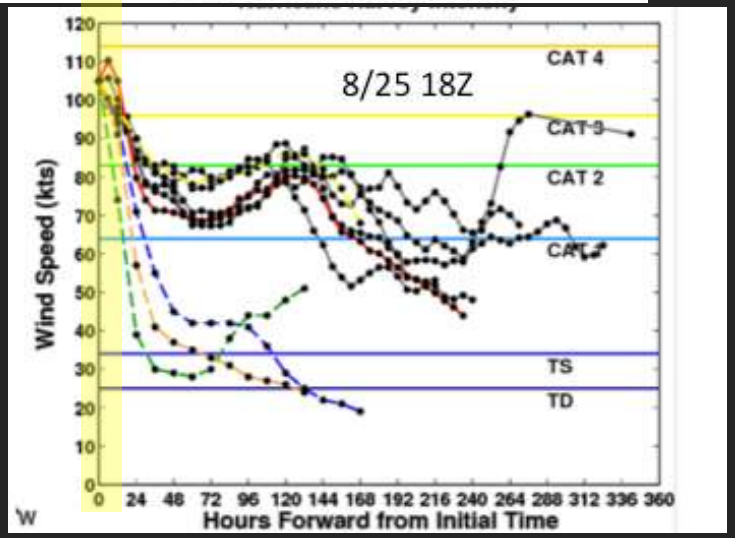
- ECMWF
  - ECMWF_DET ~ 48%
  - ECMWF_ENSM ~ 48%
  - ECMWF_ENS ~ 48%
- Dynamic
  - GFS ~ 45%
  - CMC ~ 52%
  - HMON ~ 33%
  - HWRF ~52%

HURRICANE HARVEY 2017

- 8/22 TUE - 8/23 WED
  - LOW → TROPICAL STORM GENESIS
- 8/24 THU – 8/25 FRI
  - TROPICAL STORM → CAT1
- 8/25 FRI – 8/26 SAT
  - RAPID INTENSIFICATION ENDS
    - 947MB AT 16UTC
  - CAT1 → CAT4
  - LANDFALL(939MB, 130MPH)





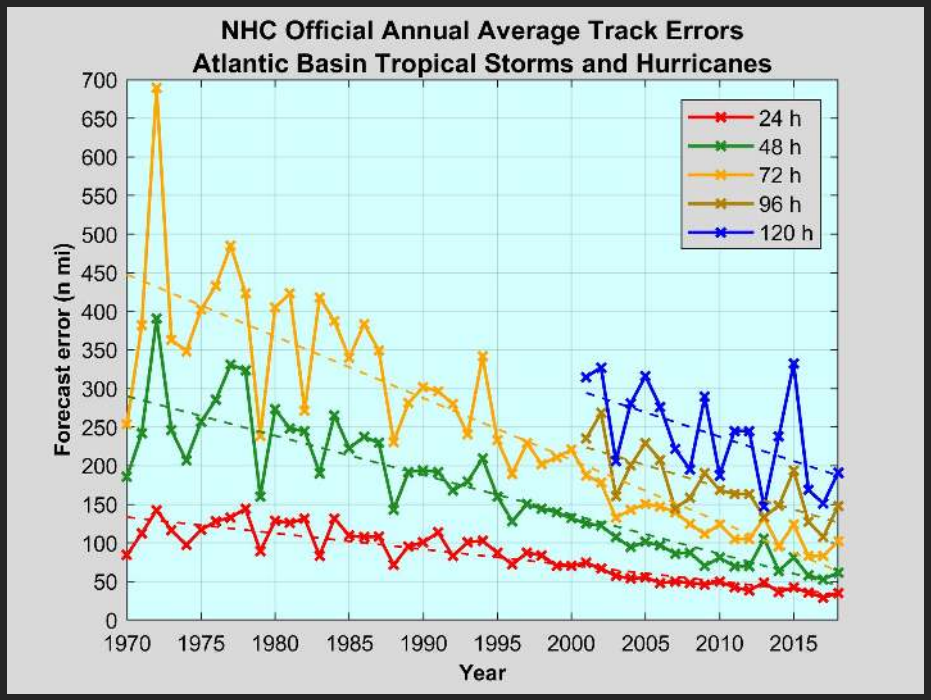


8/25 – 18hr Model Forecast Intensity Error

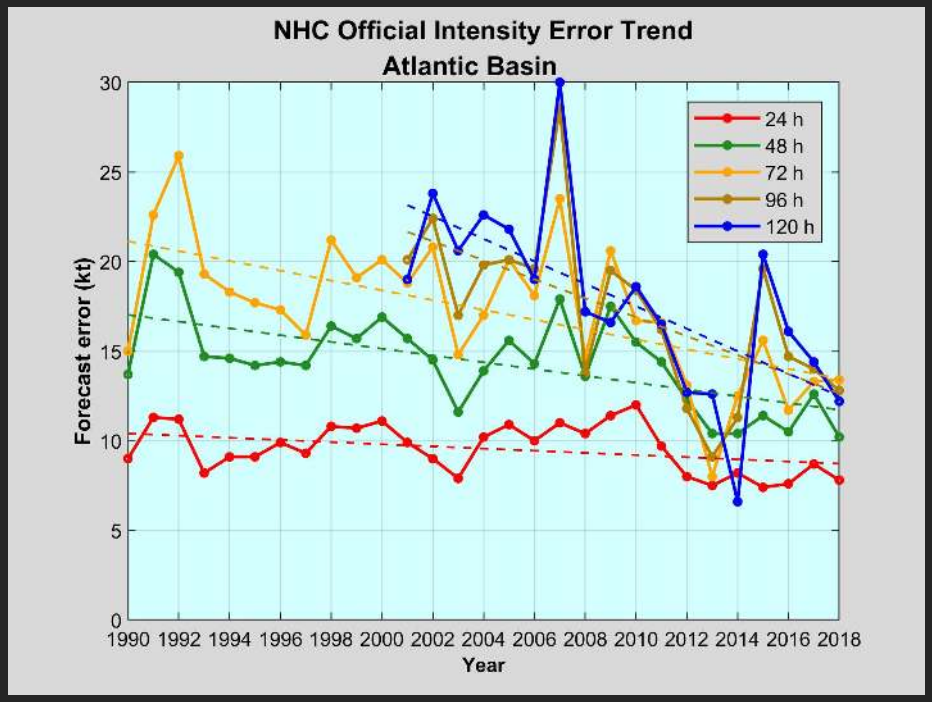
- ECMWF
  - ECMWF_DET ~ 20%
  - ECMWF_ENSM ~ 14%
  - ECMWF_ENS ~ 14%
- Dynamic
  - GFS ~ 5%
  - CMC ~ 23%
  - HMON ~ -6%
  - HWRF ~15%

MOTIVATION – HISTORICAL IMPROVEMENTS FORECAST ERRORS

- HURRICANE TRACK



- HURRICANE INTENSITY



SOURCES OF ERROR

- Storm Motion influenced by mean surrounding Flow and Coriolis Variation with latitude ➔ Large Scales (>100km)
  - Data frequent (spatial and temporal)
    - Geostationary Satellite
    - Reanalysis Models
- Storm Intensity and Rapid Intensification influences by inner core dynamics ➔ Small Scales (0-100km)
  - Data infrequent (spatial and temporal)
    - Buoy
    - Microwave Satellite Overpass
    - Dropsondes
    - Plane fly throughs

THEORY – KERRY EMMANUEL MAX POTENTIAL INTENSITY(MPI)

$$V_{MPI} = \sqrt{\epsilon \left(\frac{T_{SST}}{T_{out}}\right)\left(\frac{C_k}{C_D}\right)(k^*_{SST} - k_{ABL})}$$

$$\epsilon = \left(\frac{T_{SST} - T_{out}}{T_{SST}}\right)$$

$$T_{SST} = Sea\ Surface\ Temperature$$
$$T_{out} = Tropopause\ Temperature$$

$$\frac{C_k}{C_D} = Effective\ Energy\ Coefficent = \frac{Enthalpy\ Exchange\ Coefficient}{Drag\ Coefficient} = f(SST, V\ )$$

$$k^*_{SST} = Enthalpy\ of\ Sea\ Surface\ Air\ Temperature = f(q^*, SST)$$
$$k_{ABL} = \ Enthalpy\ of\ Top\ of\ Atmospheric\ \ Boundary\ Layer = f(P, T_{ABL}, q_{ABL}, RH)$$

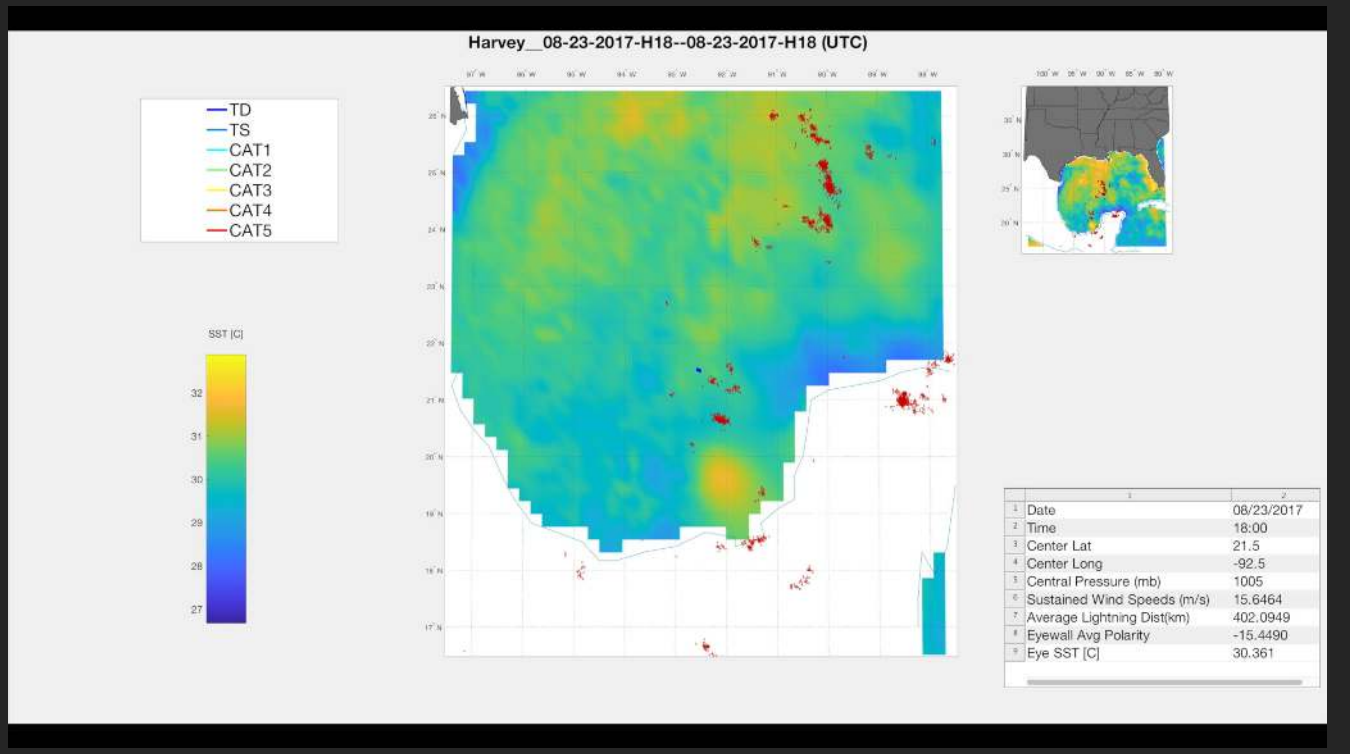
$$T_{ABL}, q_{ABL} = Temperature\ and\ Specific\ Humidity\ of\ Atmospheric\ Boundary\ Layer = f(RH)\ where\ RH = \sim.9 - .8$$

GOALS

- Develop A Deep Learning NN Model to Better Identify Cases of RI
  - Utilizing Real Time Data
  - Minimal Data Processing
  - Output prediction better or comparable than current forecast period

INPUT DATA

1. NOAA Hurricane Reanalysis Dataset - HURDAT(~6hr)
   1. Min. Pressure
   2. Velocity/Pressure Field(Rankine Vortex)
2. GLD360 Lightning Data(~milliseconds,90-95% accuracy, .3-.5km accuracy)
   1. Lightning Density
   2. Lightning Polarity(Pos/Neg)
3. Nasa Group High Resolution SST - GHRSST(~24hrs, .1km x 1km)
1. Miscellaneous
   1. Night/Day
   2. Land/Sea



1	Date	08/23/2017
2	Time	18:00
3	Center Lat	21.5
4	Center Long	-92.5
5	Central Pressure (mb)	1005
6	Sustained Wind Speeds (m/s)	15.6464
7	Average Lightning Dist(km)	402.0949
8	Eyewall Avg Polarity	-15.4490
9	Eye SST [C]	30.361

$$V_{MPI} = \sqrt{\epsilon \left(\frac{T_{SST}}{T_{out}}\right)\left(\frac{C_k}{C_D}\right)(k^*_{SST} - k_{ABL})}$$

MODEL PREPROCESS

- 40KM X 40KM GRID FOLLOWING CENTRAL PRESSURE OF HURRICANE
  - 1600 1KM X 1KM GRID ELEMENTS
- GRID ELEMENTS
  - SST TEMP
  - TOUT
  - LIGHTNING DENSITY
    - TOTAL
    - POSITIVE
    - NEGATIVE
  - VELOCITY/PRESSURE FIELD
  - DAY/NIGHT
  - LAND/SEA
- GRID IS INTERPOLATED FOR EVERY 5 MINUTES FROM 8/23@18UTC → 8/26@5UTC
  - 59HRS*12 (5MIN/HR) = 708-5MIN TIME INCREMENTS
- EACH GRID ELEMENT IS NORMALIZED

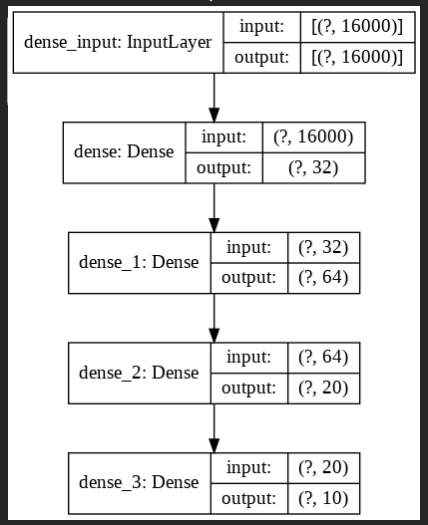
MODEL SETUP

- Each Grid Element is normalized
- Validation Data outputs in Rapid Intensification Scale (0-10) for 24 hours ahead
  - 0 = Storm Weakening (+5mb Pressure gain per hour or +.416mb per 5min)
  - 5 = Storm RI Threshold (-2mb Pressure drop per hour or -.16mb per 5min)
  - 10 = Strongest RI(-6mb Pressure drop per hour or -.5mb per 5min)
- Validation Data is randomized each run and account for 25% of initial data set
- 4 Runs = 2 DNN, 2CNN
  - DNN
  - DNN with additional 2hours of previous grid elements
  - CNN
  - CNN with additional 2hours of previous grid elements
- Machine Optimization parameters
  - Learning rate = .0005
  - Batch Size = 64
  - CNN filter size (8,7)
- Optimizer = ADAM – Adaptive learning rate optimization
- Model compile Loss = sparse categorical crossentropy (CAT 0-9)

ARCHITECTURE

DNN

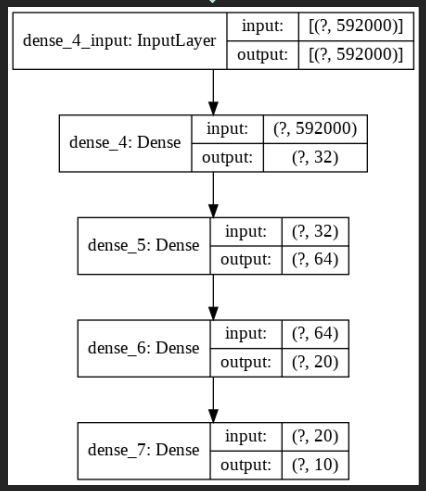
10 current gridded elements
10*(40x40grid) = 16000 elements



DNN with Time

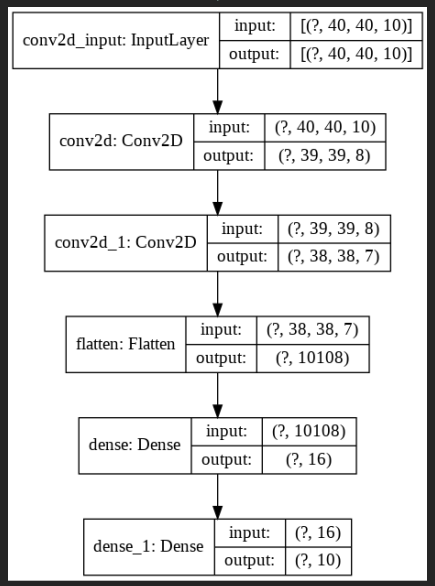
10 current gridded elements

3hrs previous gridded elements = (3*10*12) +10= 370*1600= 592000 elements



CNN

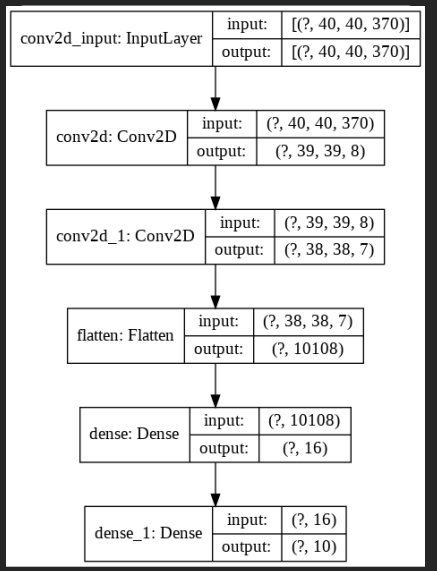
10 current gridded elements
10*(40x40grid) = 16000 elements



CNN with Time

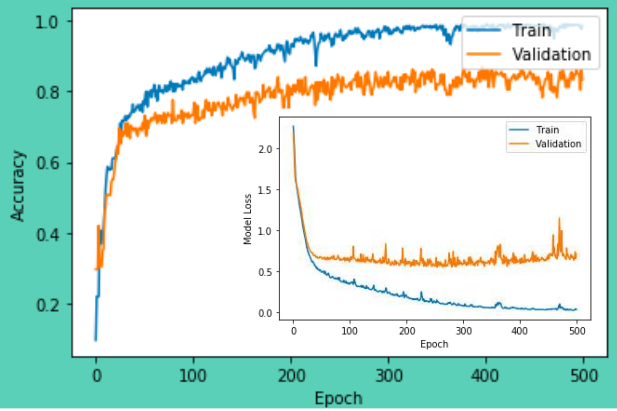
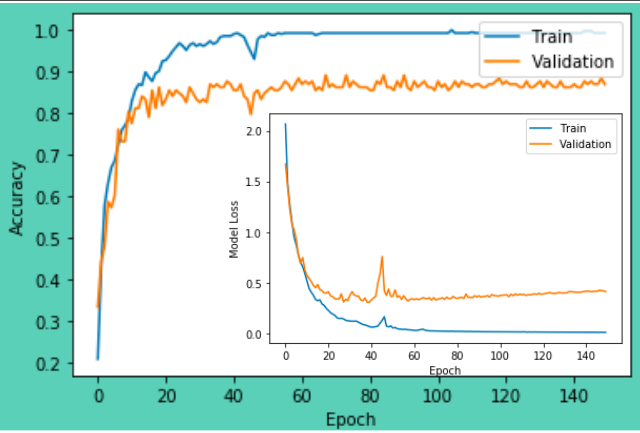
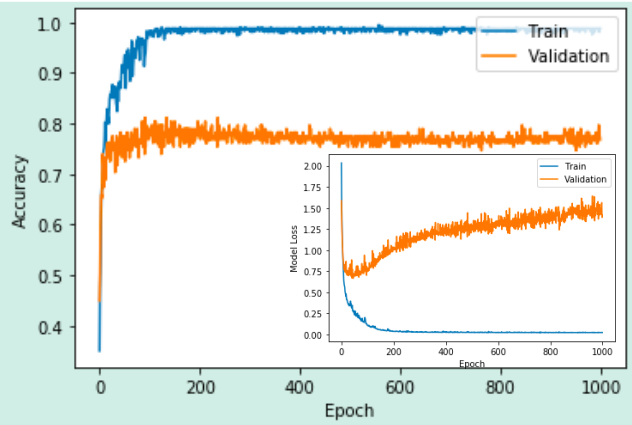
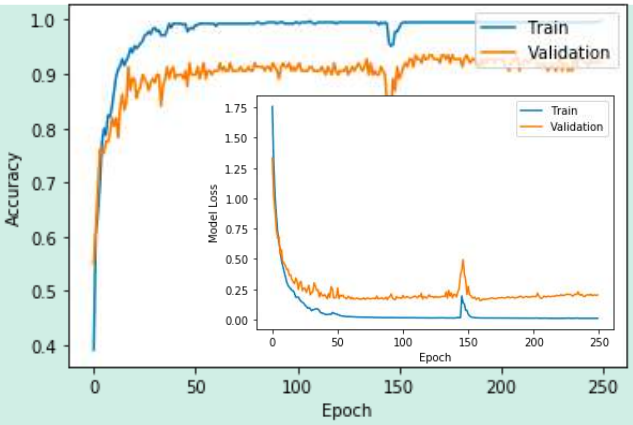
10 current gridded elements

3hrs previous gridded elements = (3*10*12)+10 = 370 gridded elements



RESULTS

- USING RANDOM VALIDATION ELEMENTS ACCOUNTING FOR 25% OF TOTAL DATA

	CURRENT	CURRENT + PREV. 2HOURS
DNN	83% 	87% 
CNN	77% 	92% 

FUTURE WORK

- Utilizing New and Available Variables
  - Heat content
  - Bathymetry
  - Satellite derived wind speeds aloft
  - Satellite imagery/microwave temperatures/moisture
  - Storm propagation speed
- Utilizing outside CNN and compare results
- Train model on other storms from same ocean basin and other storm basins

WORK CITED

1. https://judithcurry.com/2017/08/27/hurricane-harvey-long-range-forecasts/
2. https://www.nhc.noaa.gov/data/tcr/AL092017_Harvey.pdf
3. https://www.nhc.noaa.gov/verification/figs/AlInerrtrd.jpg
4. https://www.nhc.noaa.gov/verification/figs/AltkerrtrD_noTD.jpg
5. https://www.weather.gov/media/publications/assessments/harvey6-18.pdf
6. https://www.climate.gov/sites/default/files/Suomi_VIIRS_25Aug2017_large.png

QUESTIONS?