Deep Learning-based Tropical Cyclone Intensity Estimation Portal

National Weather Association 44th Annual Meeting
10 September, 2019

Brian Freitag[1], M. Maskey[2], R. Ramachandran[2], M. Ramasubramanian[1], I. Gurung[1], J. Miller[3]

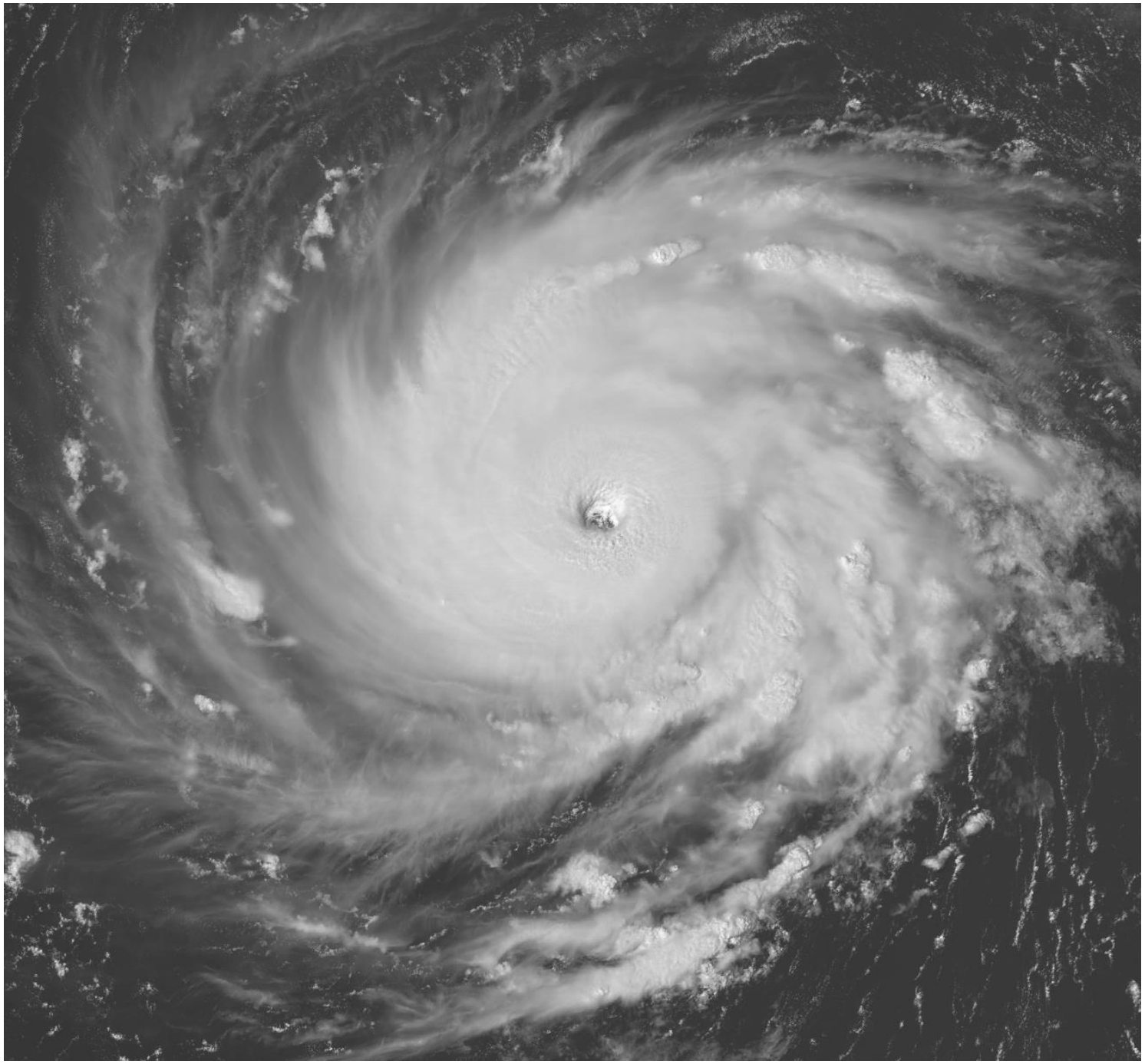
1 – Univ. Alabama in Huntsville, 2 – NASA/MSFC, 3 – Climate Forecast Applications Network

developmentSEED

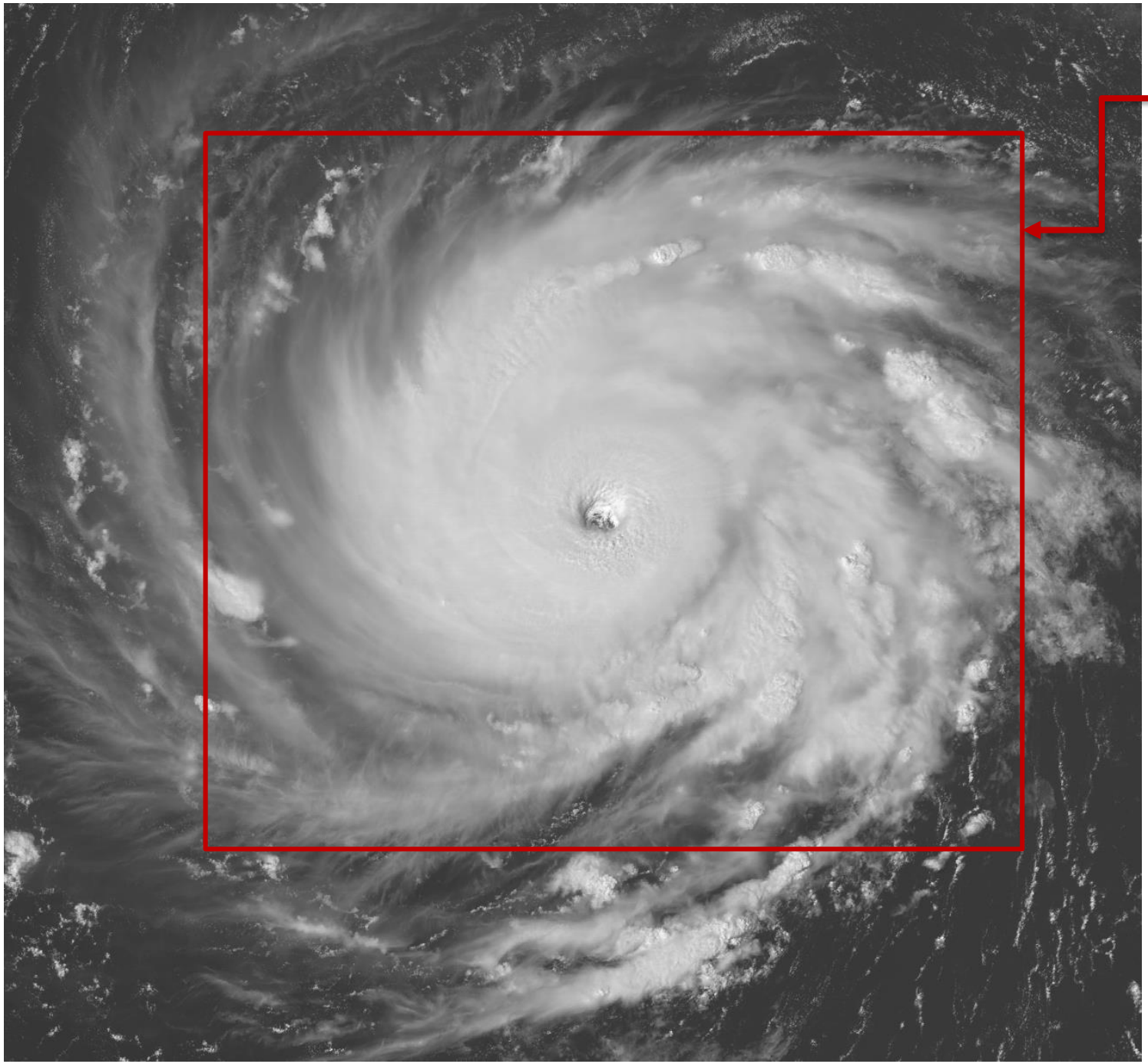
NASA

IMPACT
Interagency Implementation and Advanced Concepts Team

What can we say about this picture?

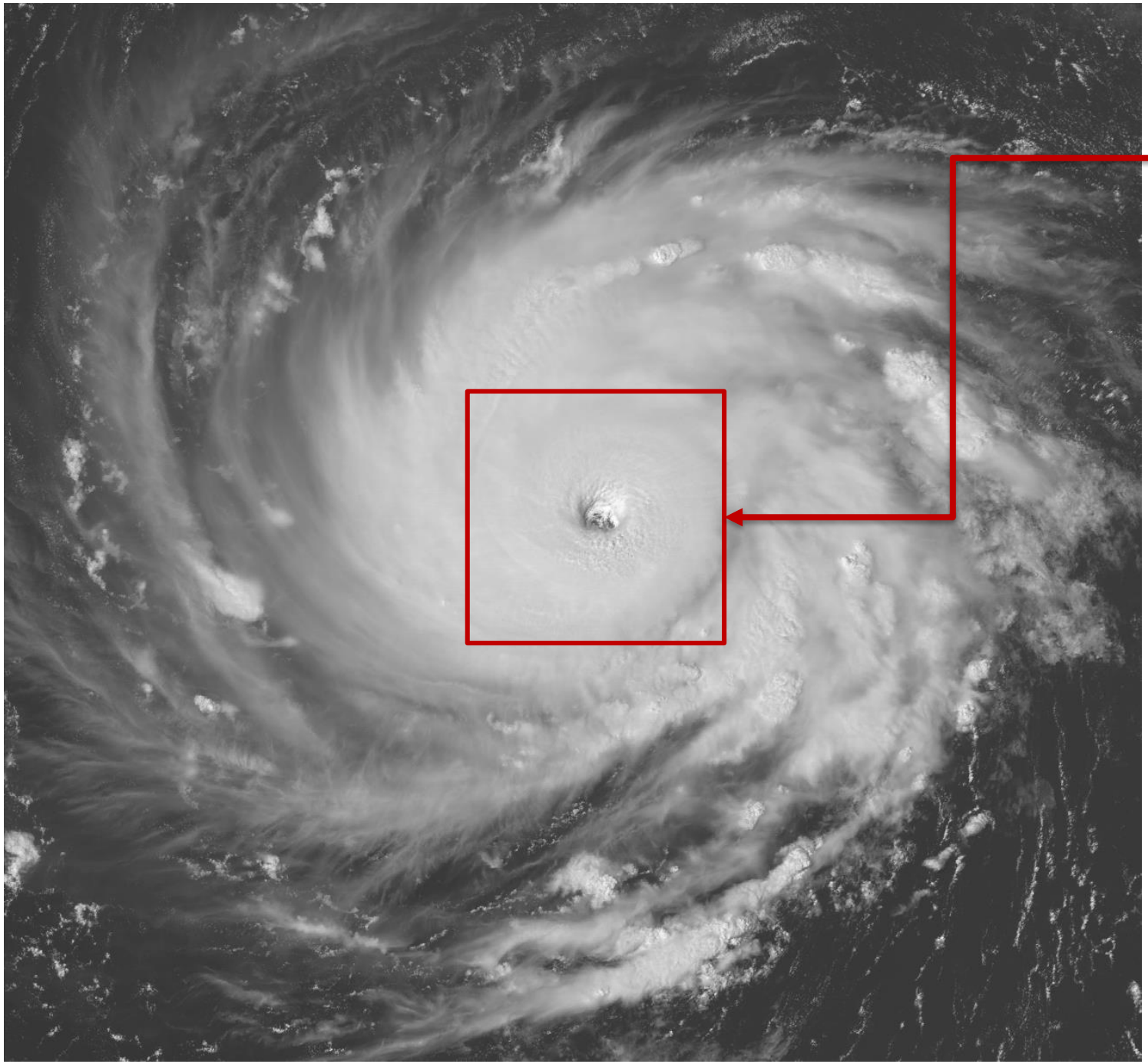


What can we say about this picture?



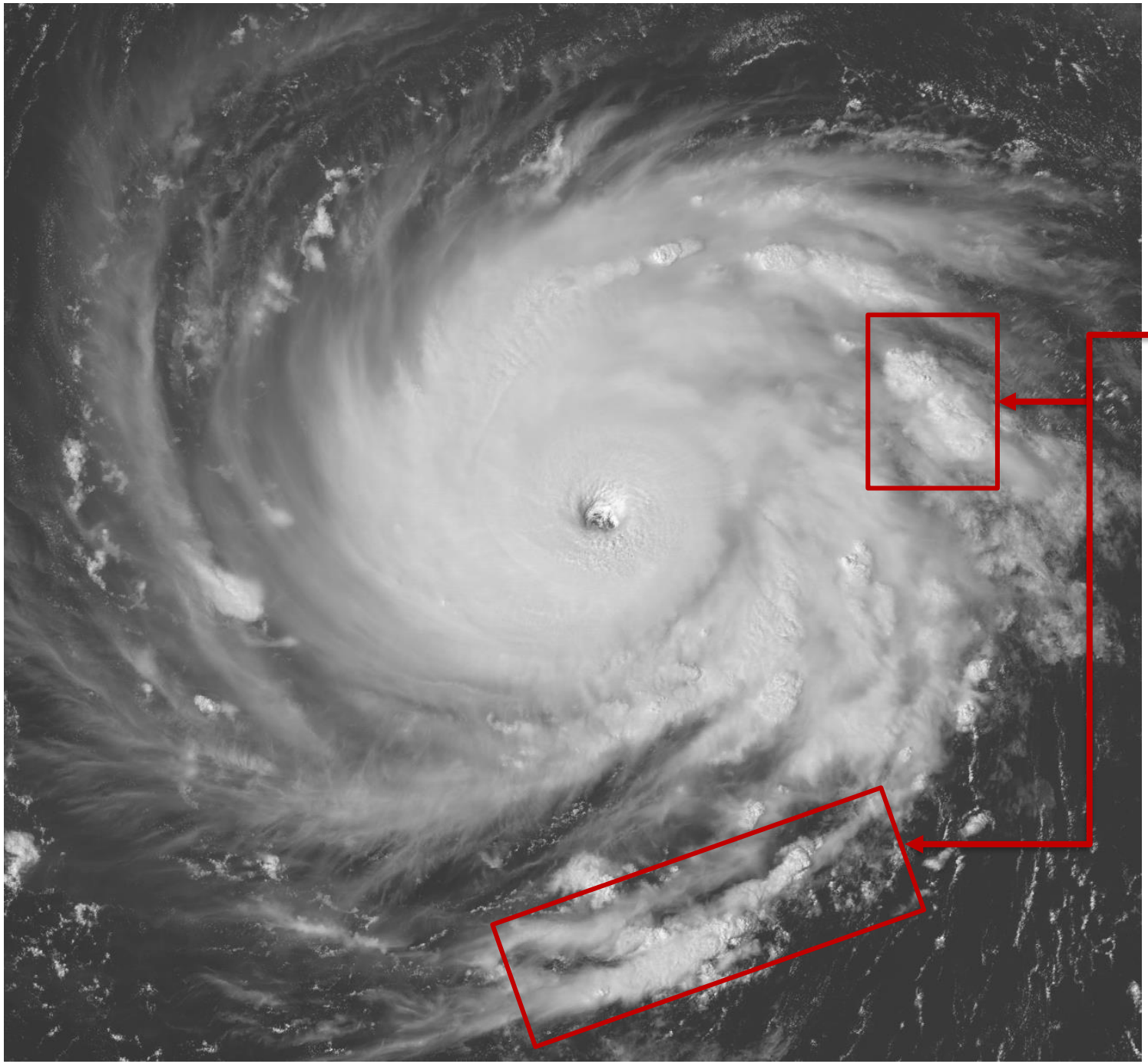
- Hurricane

What can we say about this picture?



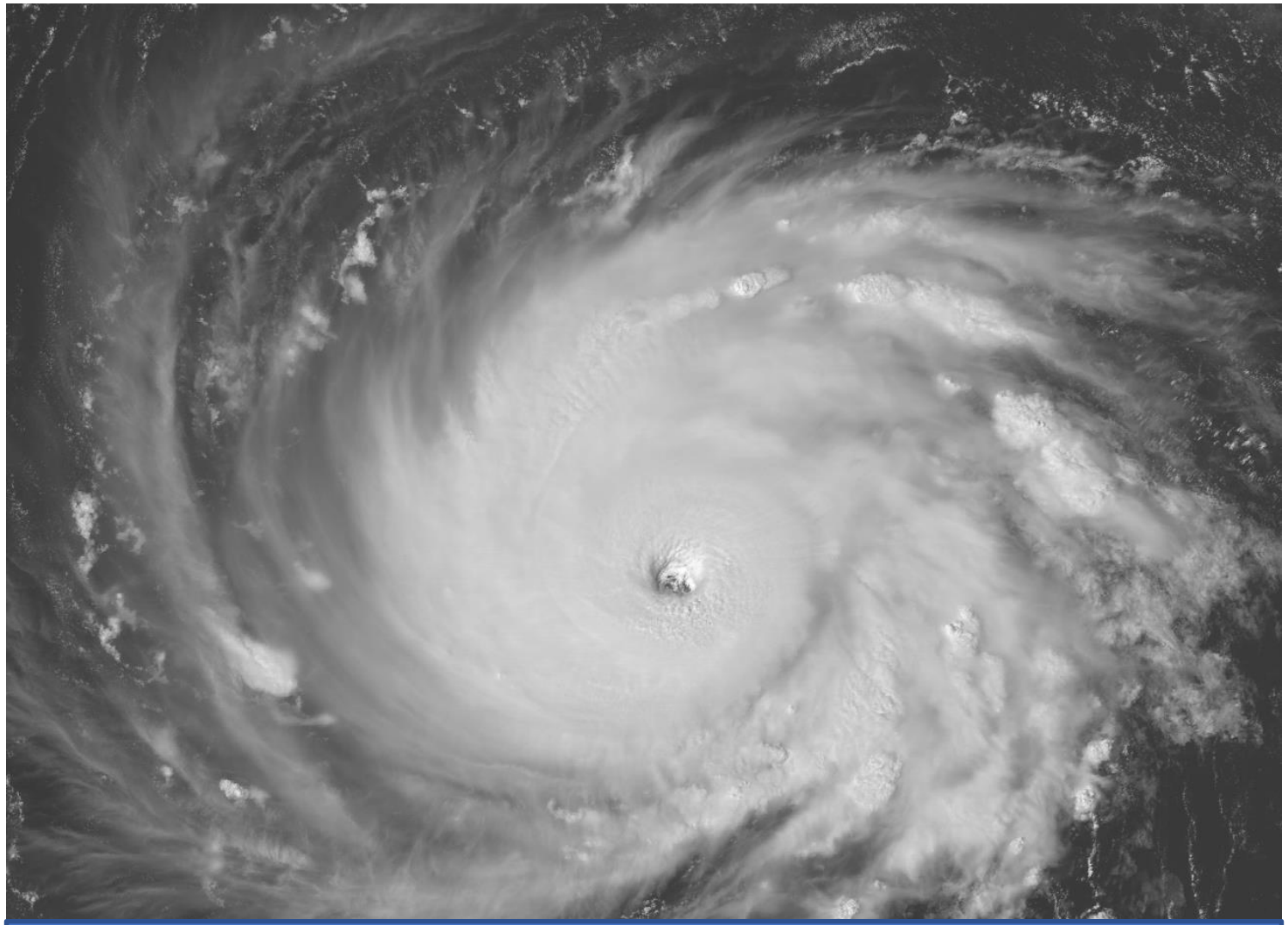
- Hurricane
- Well-defined inner core

What can we say about this picture?



- Hurricane
- Well-defined inner core
- Convective outer rainbands

What can we say about this picture?



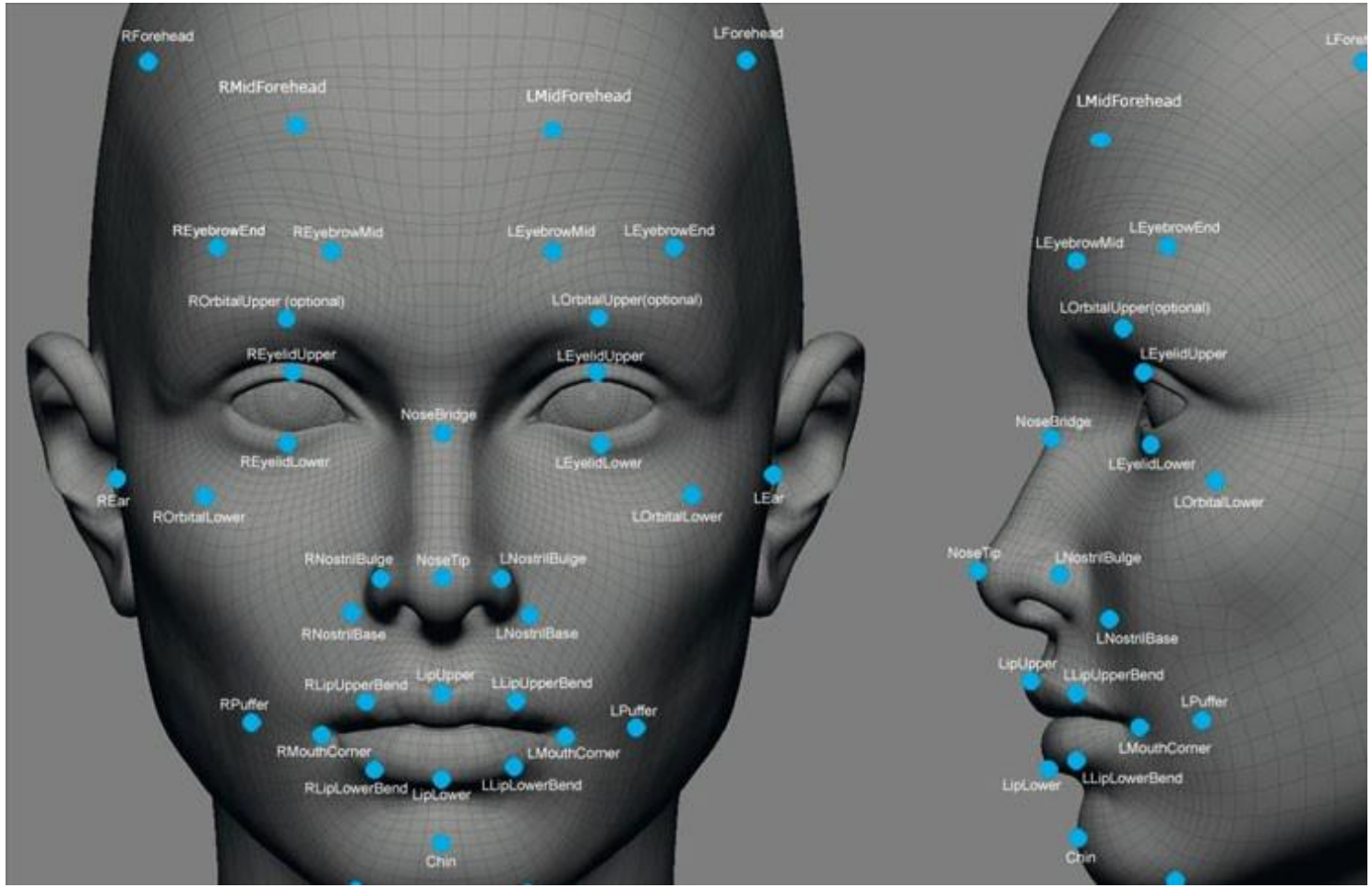
- Hurricane
- Well-defined inner core
- Convective outer rainbands

Given our background and expertise, we recognize this is an image of an intense tropical cyclone

Introduction

Similarly, computers recognize images of objects through a set of features
(e.g. facial recognition software)

1. mouth curvature
2. eyebrow shape
3. orbital structure
4. others



Research Question

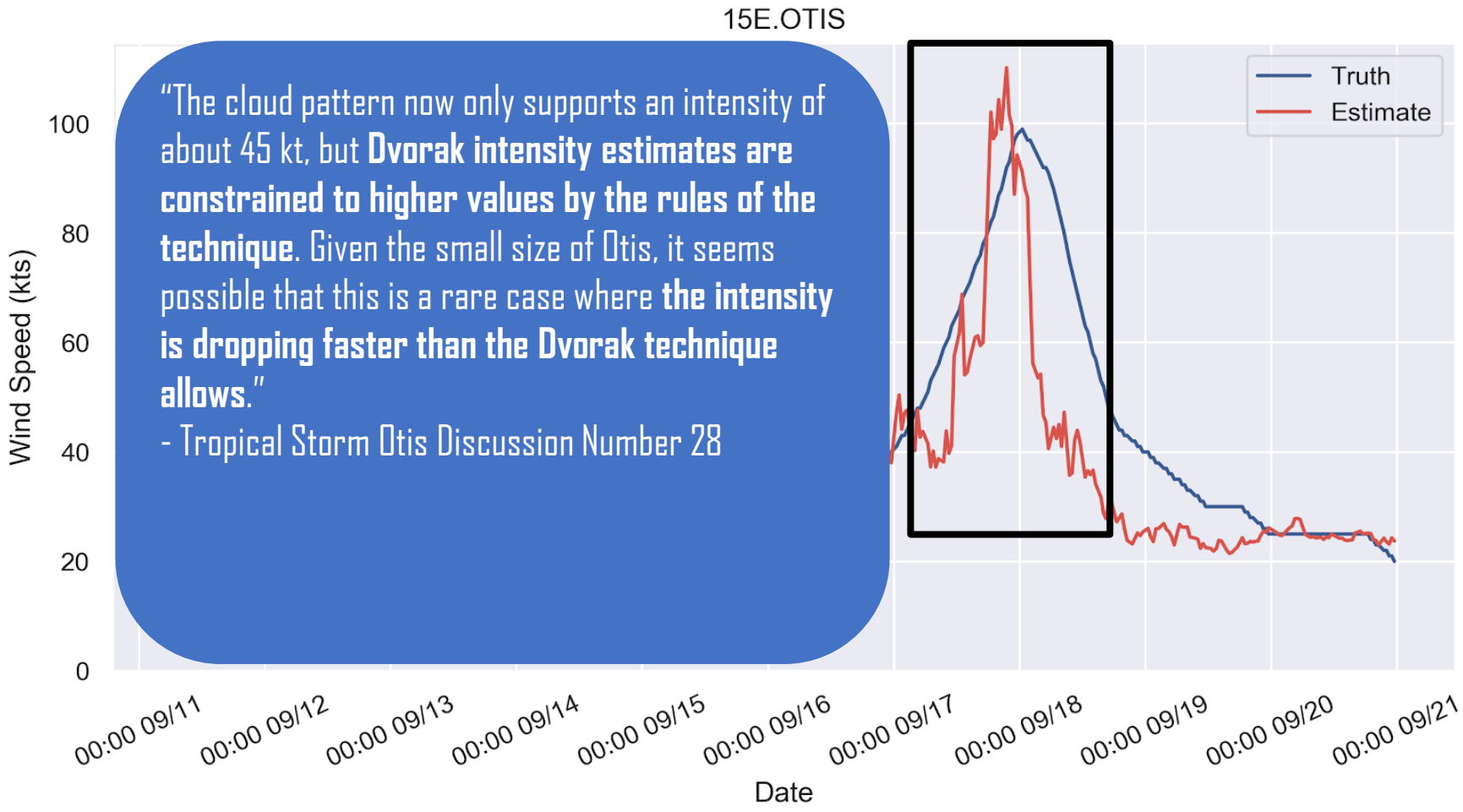
Can we leverage deep learning to estimate the maximum wind speed of a tropical cyclone using satellite imagery?

Motivation

15 UTC 10 Oct 17 NHC advisory on Tropical Storm Ophelia:

*"Dvorak intensity estimates range from T2.3/**33 kt** from UW-CIMSS to T3.0/**45 kt** from TAFB to T4.0/**65 kt** from SAB. For now, the initial intensity will remain at **45 kt**, which is an average of the scatterometer winds and all of the other available intensity estimates."*

Motivation



"The cloud pattern now only supports an intensity of about 45 kt, but **Dvorak intensity estimates are constrained to higher values by the rules of the technique**. Given the small size of Otis, it seems possible that this is a rare case where **the intensity is dropping faster than the Dvorak technique allows**."

- Tropical Storm Otis Discussion Number 28

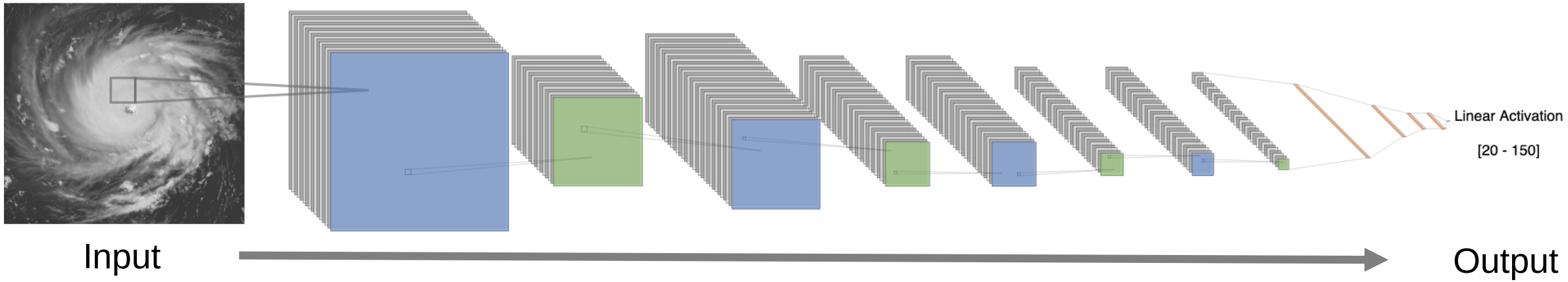
Motivation

Problems with current approach:

1) Subjective (varies between methods and forecasters)
2) Lacks generalizability
3) Requires domain expertise
4) Constrained to empirical thresholds

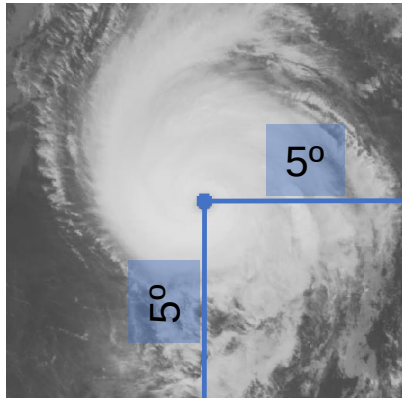
Methodology

- Use a custom network architecture that outputs wind speed (linear model)
  - 4 convolutional layers
  - 4 pooling layers
  - 4 dense layers
  - 1 output layer

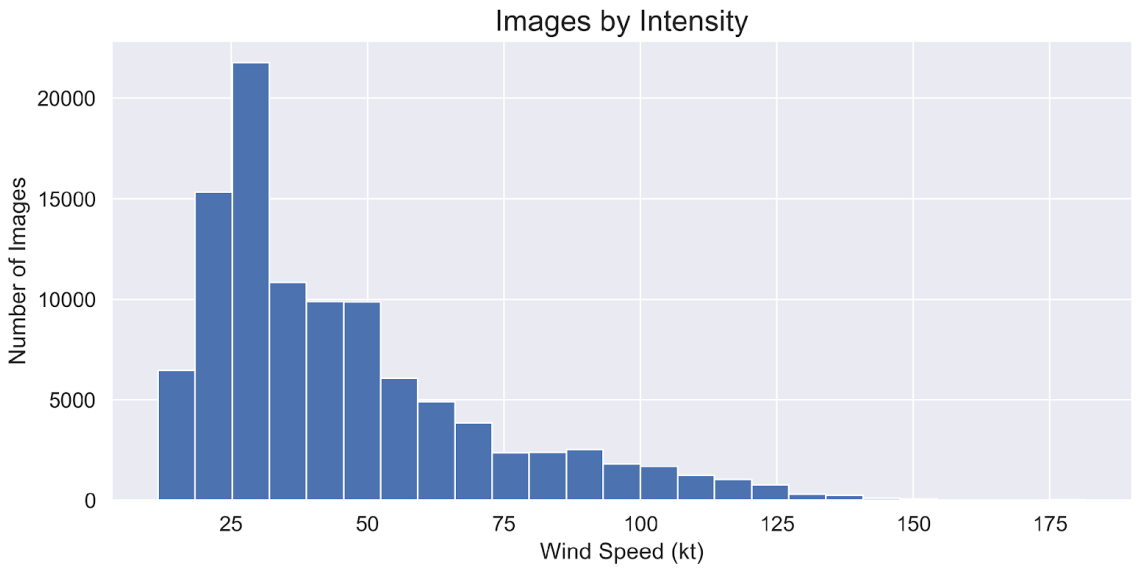


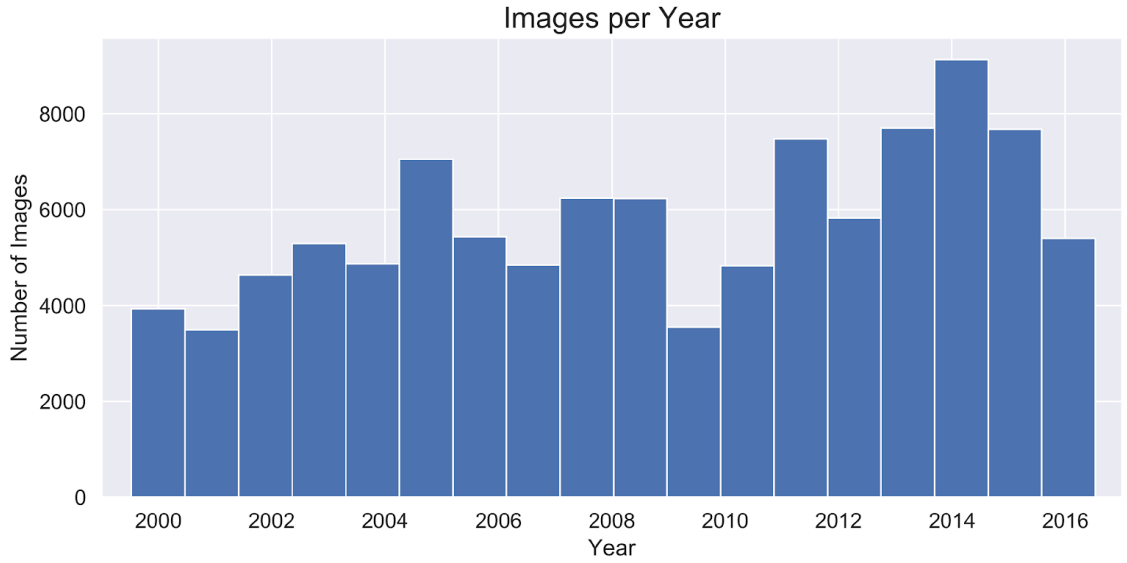
Data

- Use GOES IR imagery
  - Atlantic and Eastern Pacific Basins
    - 103,600 images from 2000 – 2017



- Wind speed information from HURDAT2 reanalysis





Model Performance (2017)

Storm Category	RMSE (kts)	Total Observations
TD	5.78	1541
TS	9.29	2316
H1	15.03	494
H2	16.85	354
H3	15.65	362
H4	12.63	242
H5	16.45	97
Atlantic Basin	13.02	1761
East Pacific Basin	9.35	3645
All Storms	10.68	5406

Pineros et al. (2011)
RMSE: 14.7 kts

Ritchie et al. (2012)
RMSE:12.9 kts

Ritchie et al. (2014)
14.3 kts

Olander and Velden (2007)
14.3 kts

Model Performance (2018)

Storm Category	RMSE (kts)	Total Observations
TD	15.57	127
TS	12.04	422
H1	13.20	105
H2	15.80	64
H3	17.81	54
H4	19.26	41
H5	16.69	4
Atlantic Basin	12.59	376
East Pacific Basin	15.07	441
All Storms	13.98	817

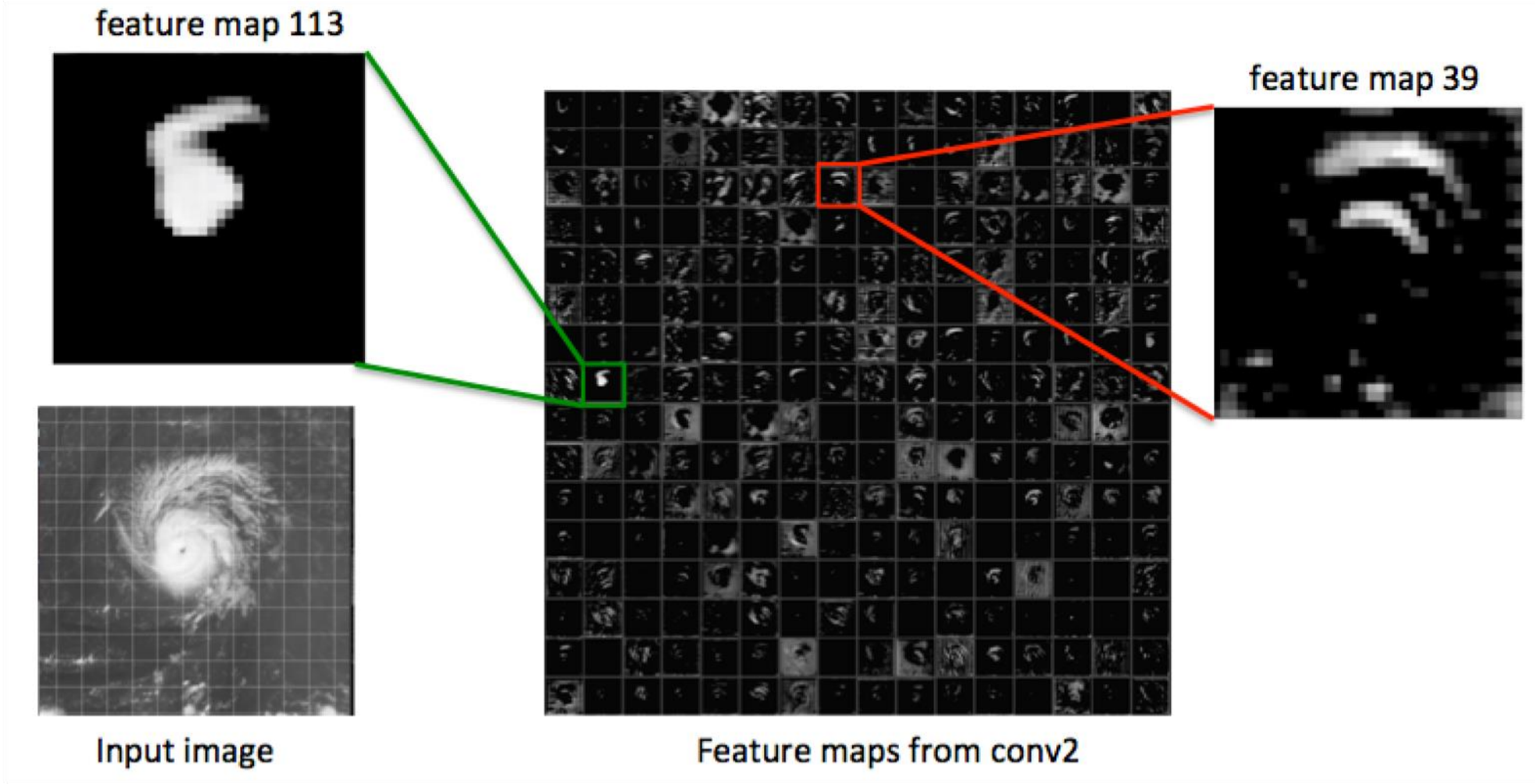
Pineros et al. (2011)
RMSE: 14.7 kts

Ritchie et al. (2012)
RMSE:12.9 kts

Ritchie et al. (2014)
14.3 kts

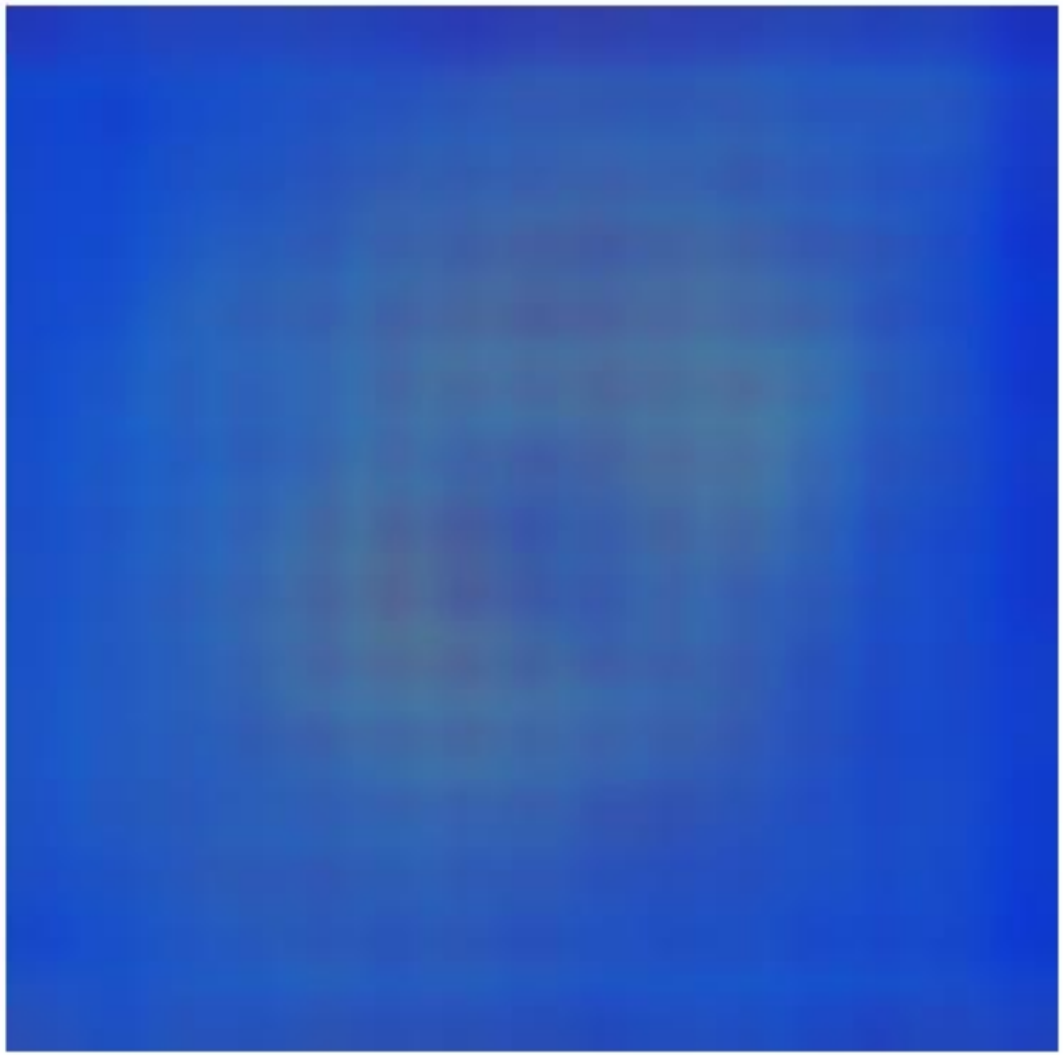
Olander and Velden (2007)
14.3 kts

Uncovering the Black Box



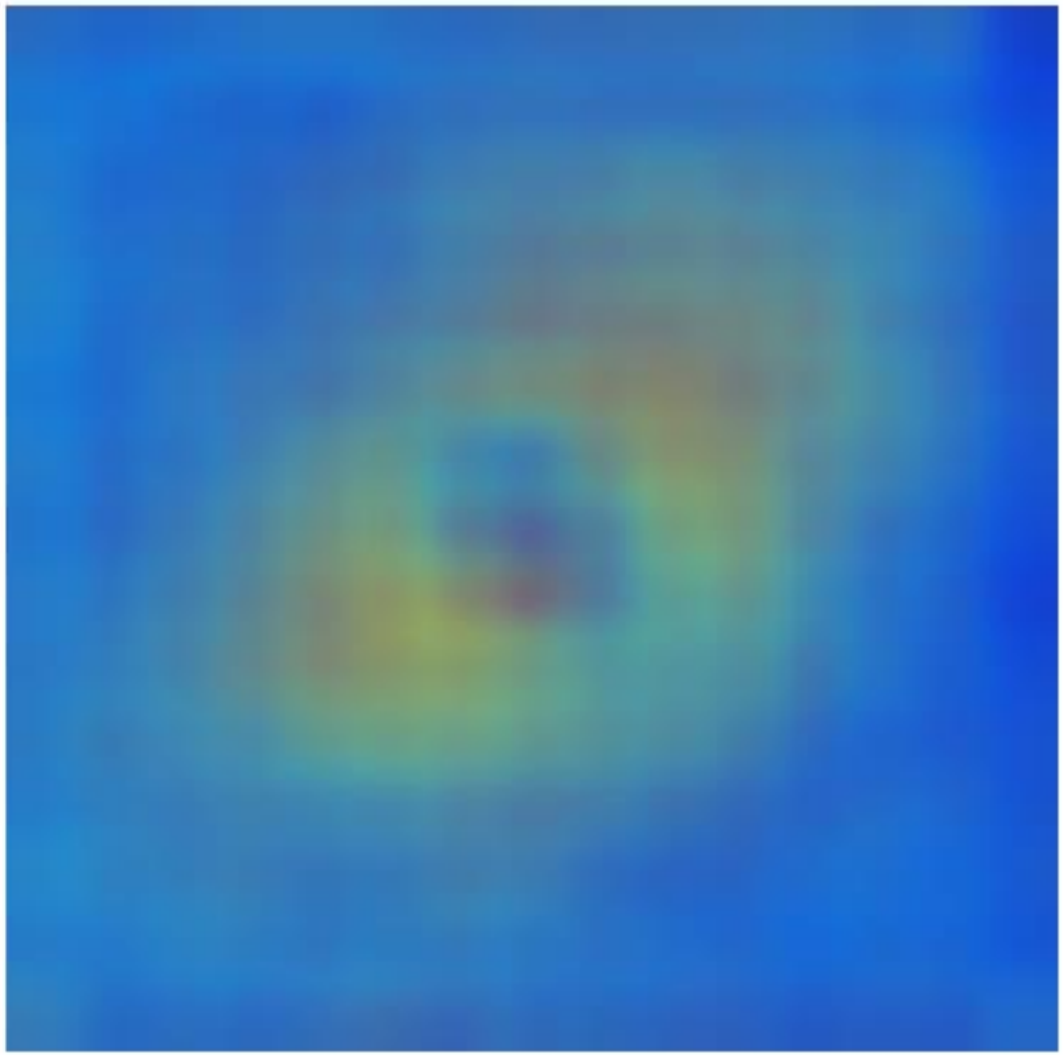
Uncovering the Black Box - CAMs

Category 1
105 images



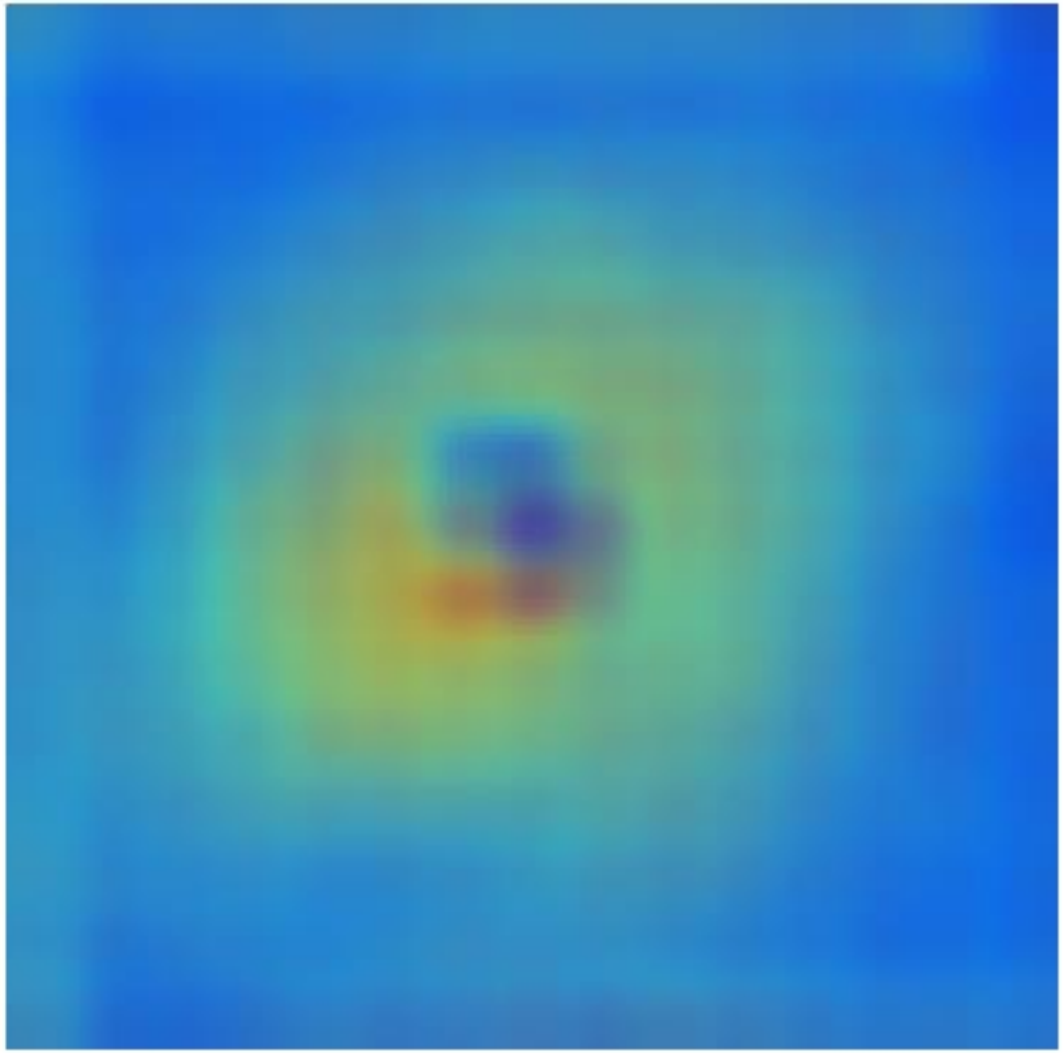
Uncovering the Black Box - CAMs

Category 2
64 images



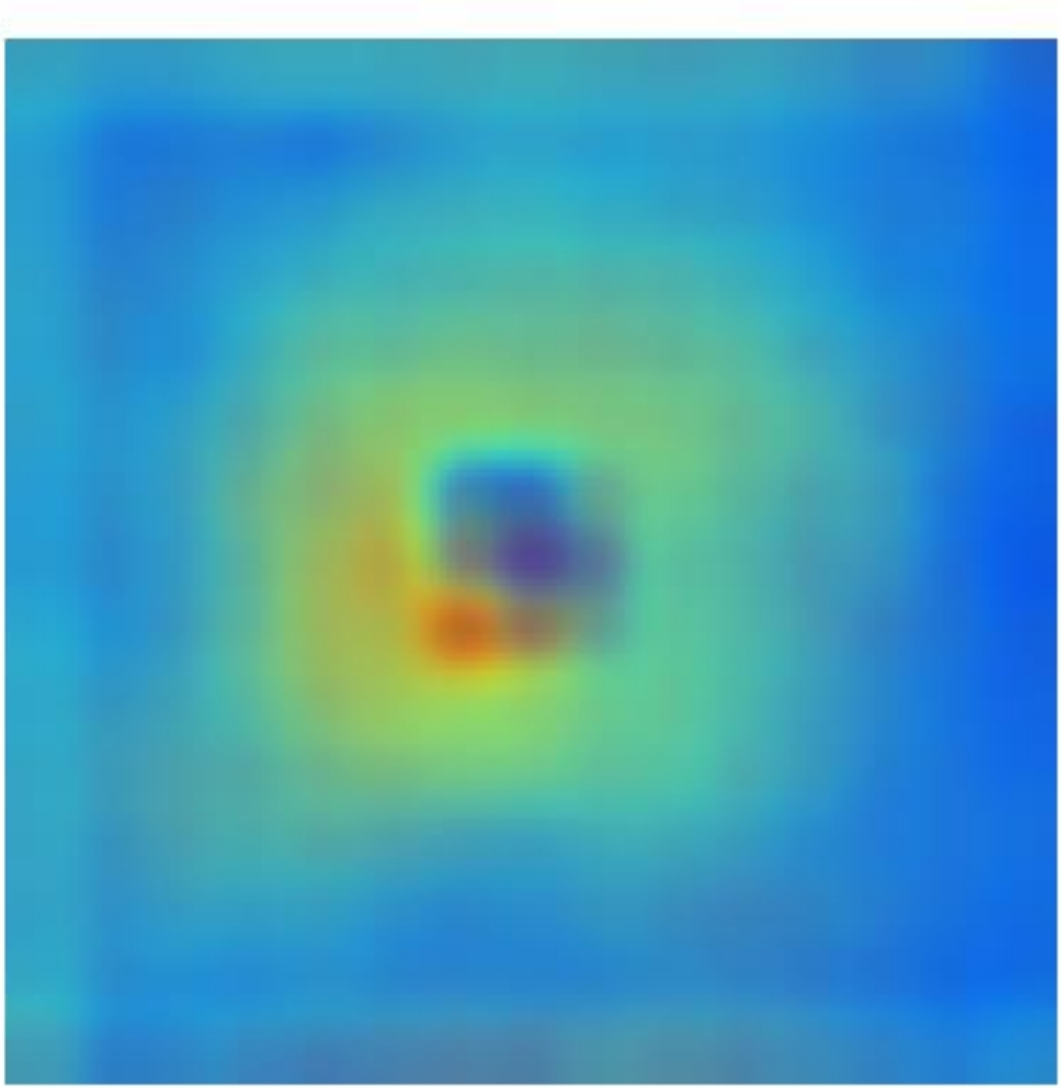
Uncovering the Black Box - CAMs

Category 3
54 images



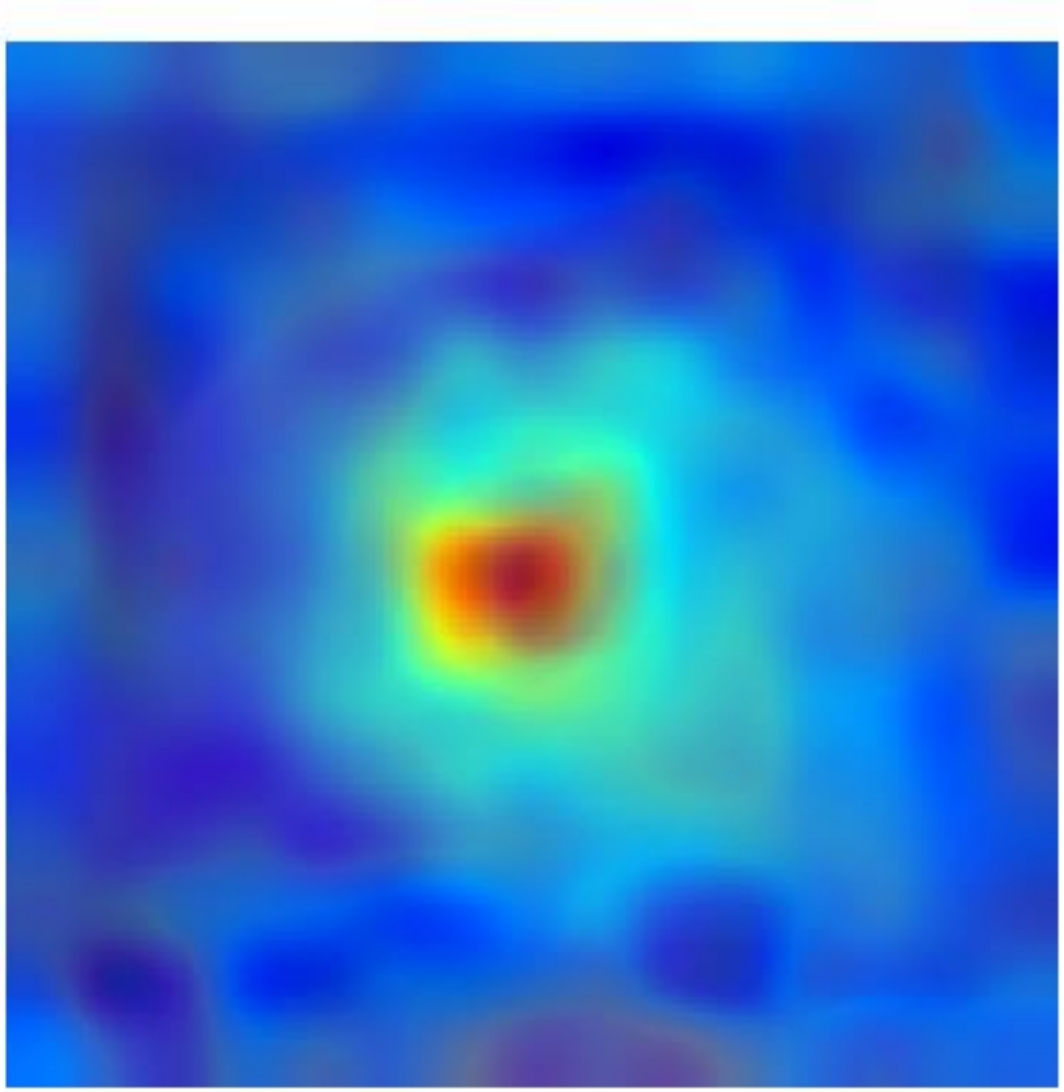
Uncovering the Black Box - CAMs

Category 4
41 images



Uncovering the Black Box - CAMs

Category 5
4 images

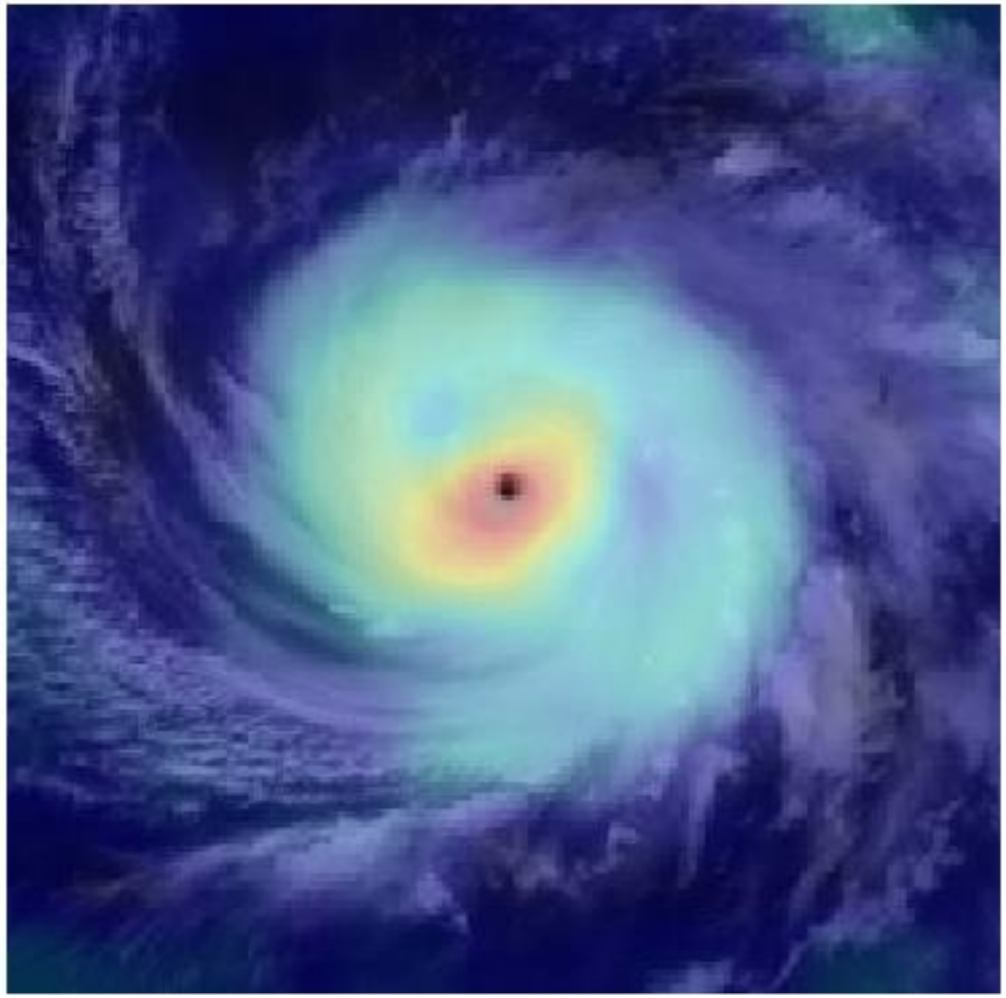


Uncovering the Black Box - CAMs

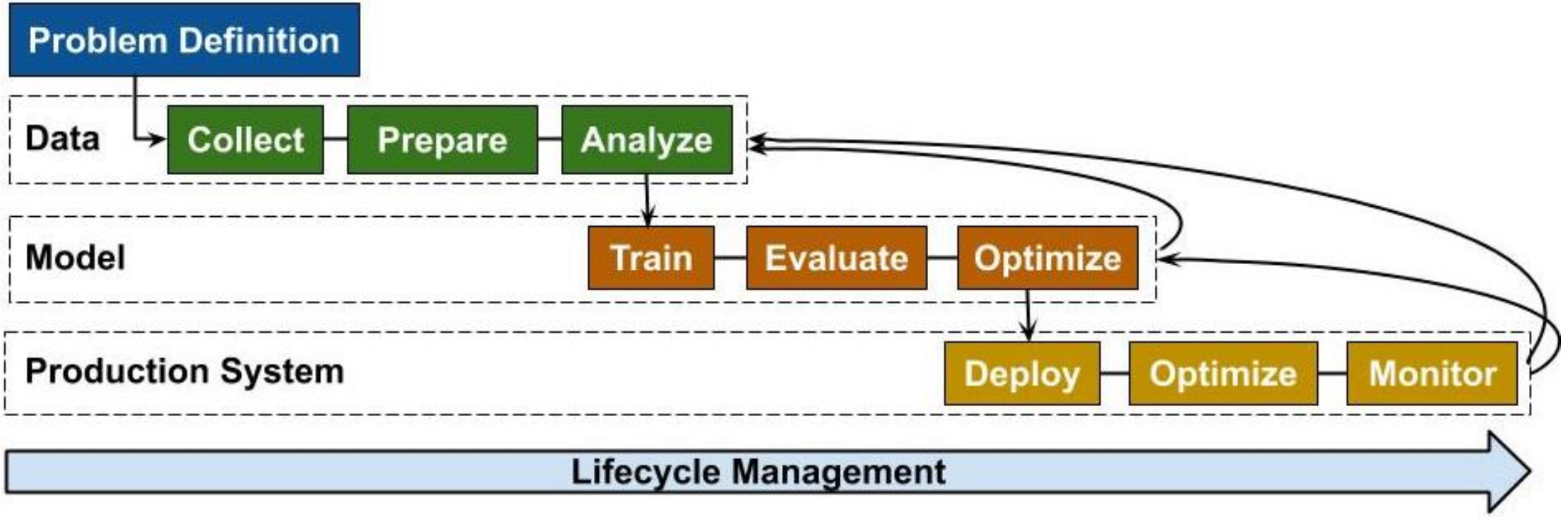
Hurricane Maria

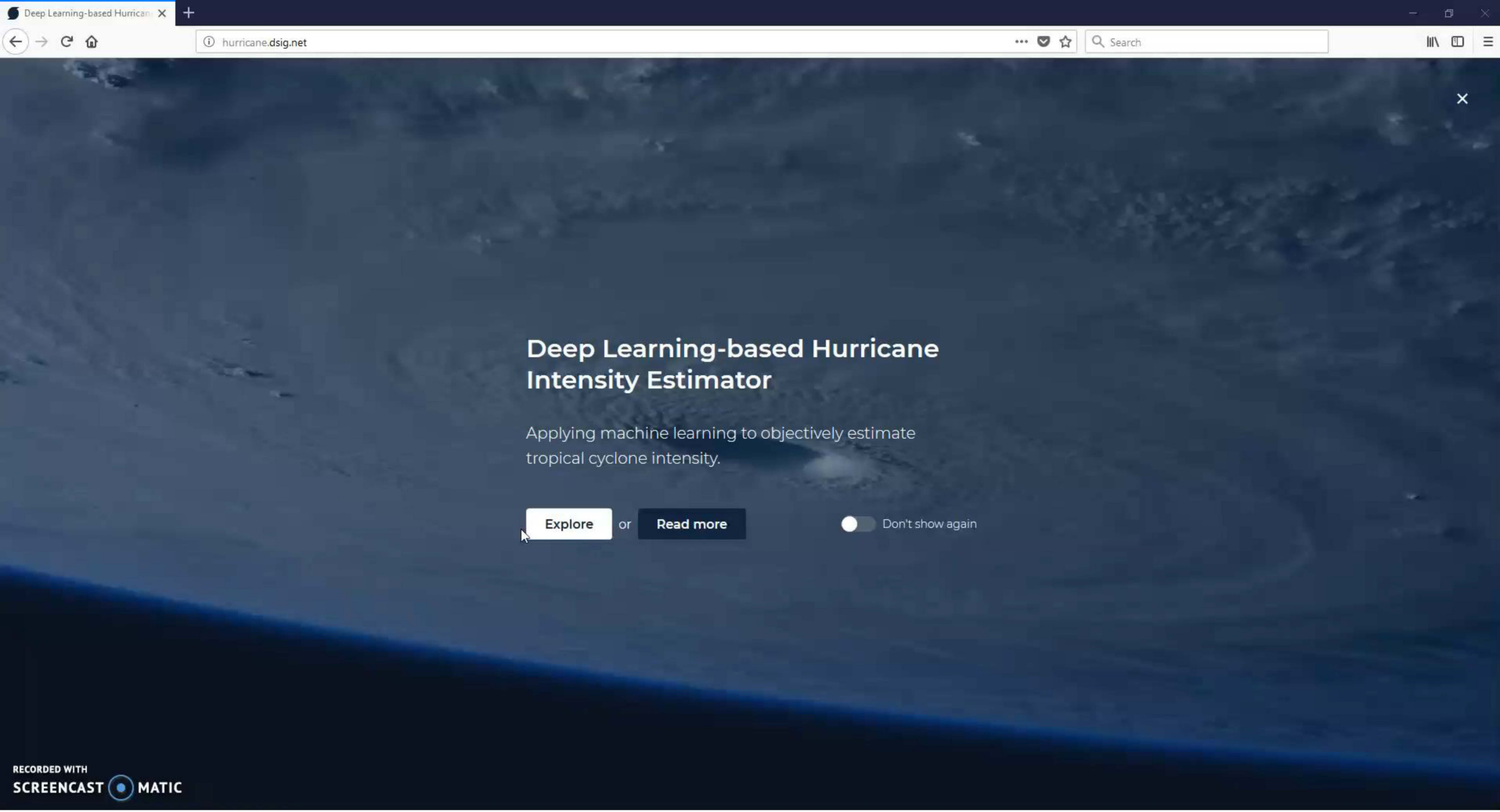
DL predicted wind speed: 138 kts

Actual wind speed:



Research to Operation




Deep Learning-based Hurrican
hurricane.dsig.net
Search
Deep Learning-based Hurricane Intensity Estimator
Applying machine learning to objectively estimate tropical cyclone intensity.
Explore
or
Read more
Don't show again
RECORDED WITH
SCREENCAST MATIC

Overview of portal features

- Estimate wind speed from GOES IR every hour
- Provide real-time data layers from NASA SPoRT team at MSFC for additional context on storm structure/environment
  - GLM Lightning
  - SST
  - GOES SWIR/LWIR channels
- Archive of storms from 2018 and 2019 including
  - Model estimate and NHC advisory
  - Images used for classification

Strengths/Weaknesses

Strengths

- Rapid intensification/ weakening cycles
- High temporal frequency
- Incorporate additional data layers in portal for added context
- Archived data for storms from 2018 - present

Weaknesses

- Compact cyclones
- Cyclones with symmetric structure over land
- Storms with unpredictable tracks
- Only operational on GOES-East
- Purely diagnostic model

Conclusions

- Deployed operational maximum wind speed estimation model for tropical cyclones
- Model performance consistent with existing automated techniques
  - 2018: 13.98 RMSE, 2017: 10.68 RMSE, Total: 11.1 RMSE
- Created a user interface for comparison between model estimates and official NHC wind speeds
  - Archive images used for classification
  - Publicly available for further scientific investigation
- Portal integrates relevant data layers to provide additional context to users

Expected Feature Updates

Model Improvements

- Improved centering algorithm
- Include microwave imagery as an input layer

Portal Improvements

- Incorporate GOES-West SWIR and LWIR layers
  - Expand coverage to CPHC domain
- Add GPM as a toggle layer
- Archive WMS layers when cyclones present
- Atmospheric motion vectors
- Integrate model activation maps to uncover black box
- Automated performance metrics in browser

Questions?

Email: brian.freitag@nsstc.uah.edu

Explore and leave feedback
hurricane.dsig.net