Deep Learning-based Tropical Cyclone Intensity Estimation Portal

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What can we say about this picture?
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- Hurricane
What can we say about this picture?

- Hurricane
- Well-defined inner core
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- Convective outer rainbands
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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
Can we leverage deep learning to estimate the maximum wind speed of a tropical cyclone using satellite imagery?
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.”
"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

```
  20 - 150
```

Linear Activation
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)

<table>
<thead>
<tr>
<th>Storm Category</th>
<th>RMSE (kts)</th>
<th>Total Observations</th>
</tr>
</thead>
<tbody>
<tr>
<td>TD</td>
<td>5.78</td>
<td>1541</td>
</tr>
<tr>
<td>TS</td>
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<td>2316</td>
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<td>3645</td>
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<tr>
<td>All Storms</td>
<td>10.68</td>
<td>5406</td>
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</tbody>
</table>

- 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)

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<tr>
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<th>Total Observations</th>
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</thead>
<tbody>
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<td>East Pacific Basin</td>
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<tr>
<td>All Storms</td>
<td>13.98</td>
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</tbody>
</table>

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

Feature maps from conv2

feature map 113

feature map 39

Input image
Uncovering the Black Box - CAMs

Category 1
105 images
Category 2
64 images
Uncovering the Black Box - CAMs

Category 3
54 images
Uncovering the Black Box - CAMs

Category 5
4 images
Hurricane Maria

DL predicted wind speed: 138 kts

Actual wind speed:
Deep Learning-based Hurricane Intensity Estimator

Applying machine learning to objectively estimate tropical cyclone intensity.

Explore or Read more
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
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?

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Explore and leave feedback
hurricane.dsig.net