A Convolutional Neural Network Approach for Estimating Tropical Cyclone Intensity Using Satellite-based Infrared Images

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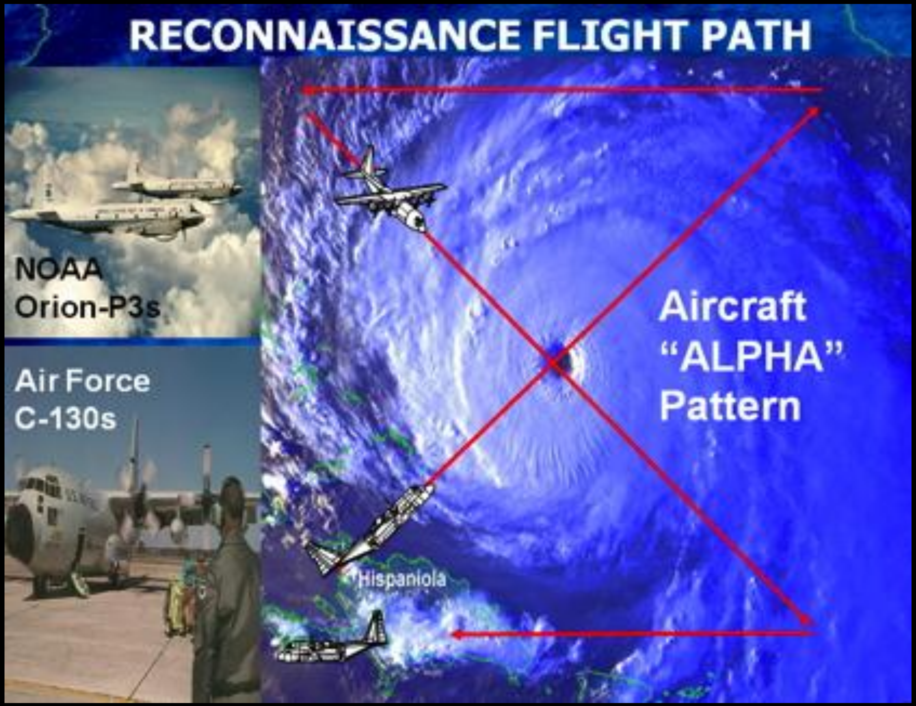
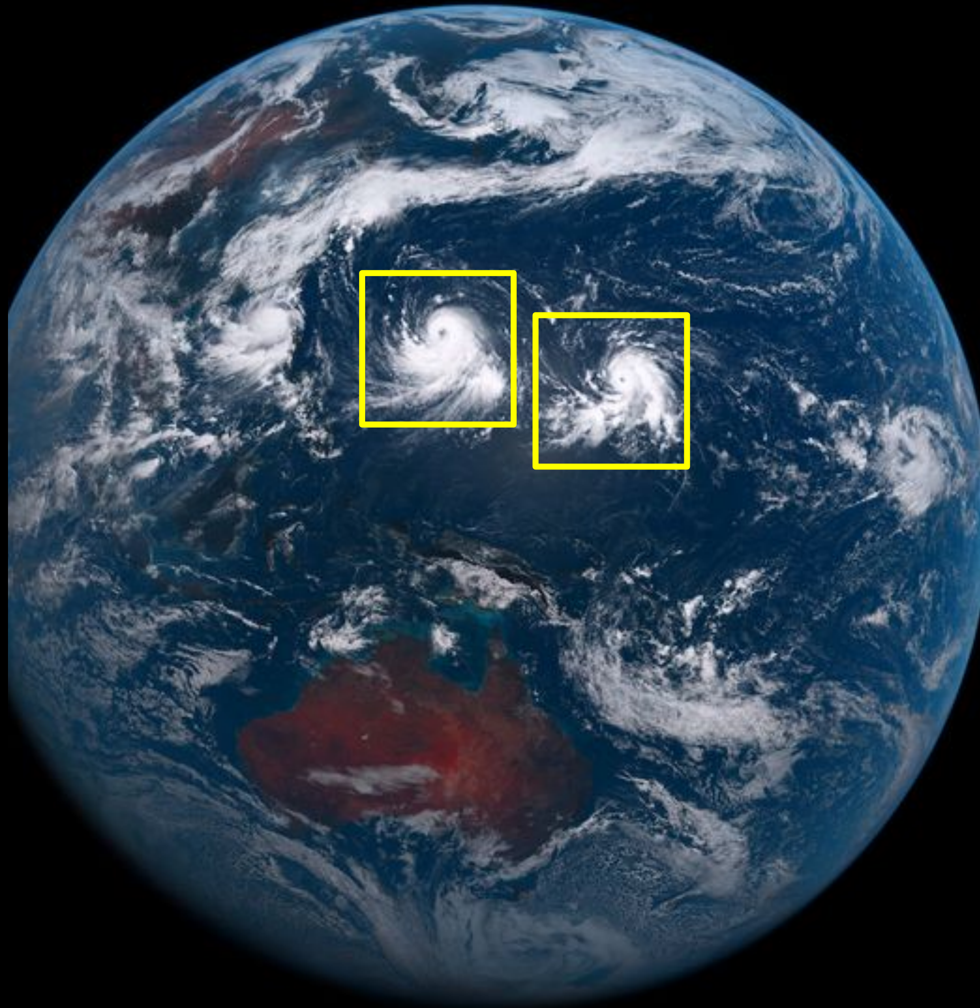
Aircraft reconnaissance

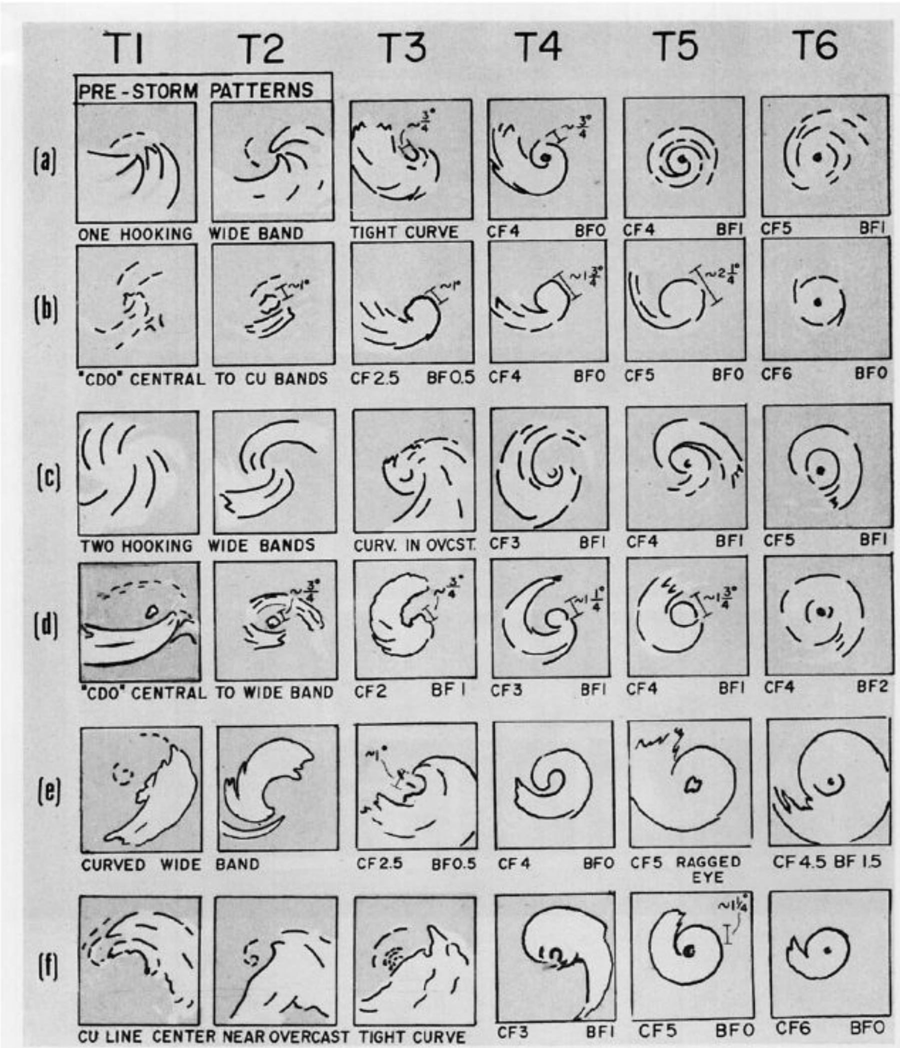


http://www.aoml.noaa.gov/hrd/Landsea/gw_hurricanes/fig17.jpg

Geostationary satellite imagery



https://himawari8.nict.go.jp/



V. F. Dvorak, "Tropical cyclone intensity analysis and forecasting from satellite imagery," Mon. Wea. Rev., vol. 103, no. 5, pp. 420–430, 1975.

Central dense overcasts (CDO) + outer banding features (Dvorak 1975)

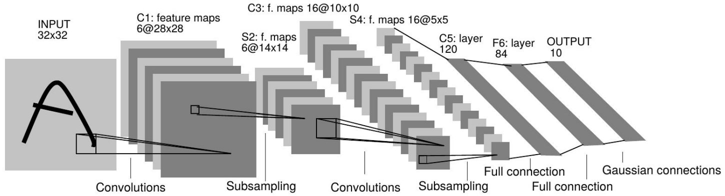
Cloud organization properties
Inner core characteristics
Radius of curvature
Rain rate

→ Objective techniques [1-6]

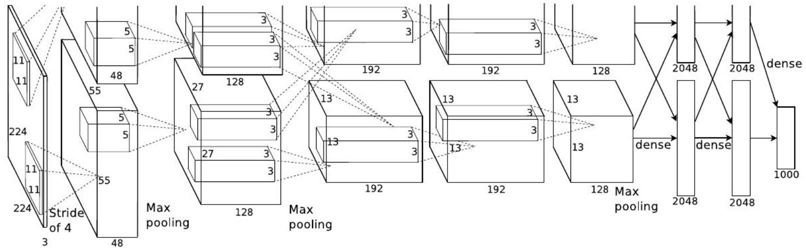
Commonality: feature extraction in a image classification problem

1. C. S. Velden, T. L. Olander, and R. M. Zehr, "Development of an objective scheme to estimate tropical cyclone intensity from digital geostationary satellite infrared imagery," Weather and Forecasting, vol. 13, pp. 172–186, 1998.
2. M. F. Piñeros, E. A. Ritchie, and J. S. Tyo, "Objective measures of tropical cyclone structure and intensity change from remotely-sensed infrared image data," Geoscience and Remote Sensing IEEE Transactions on, vol. 46, no. 11, pp. 3574–3580, 2008, doi:10.1175/WAF-D-10-05062.1.
3. ——, "Estimating tropical cyclone intensity from infrared image data," Weather and Forecasting, vol. 26, pp. 690–698, 2011, doi:10.1109/TGRS.2008.2000819.
4. A. Kulkarni, R. Bankert, and M. Hadjimichael, "Tropical cyclone intensity estimation using neural networks," in ASPRS Annual Conference, San Diego, California, 2010.
5. N. Jaiswal, C. M. Kishtawal, and P. K. Pal, "Cyclone intensity estimation using similarity of satellite IR images based on histogram matching approach," Atmos. Res., vol. 118, pp. 215–221, 2012, doi:10.1016/j.atmosres.2012.07.006.
6. Y. Zhao, C. Zhao, R. Sun, and Z. Wang, "A multiple linear regression model for tropical cyclone intensity estimation from satellite infrared images," Atmosphere, vol. 7, no. 40, 2016, doi:10.3390/atmos7030040.

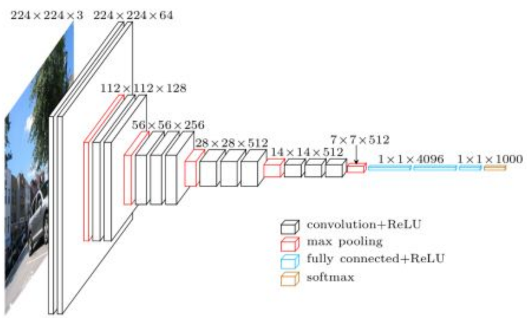
Convolutional neural networks



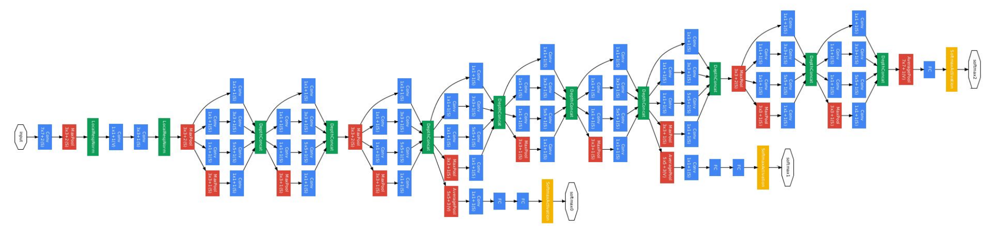
LeCun, et al. (1998)



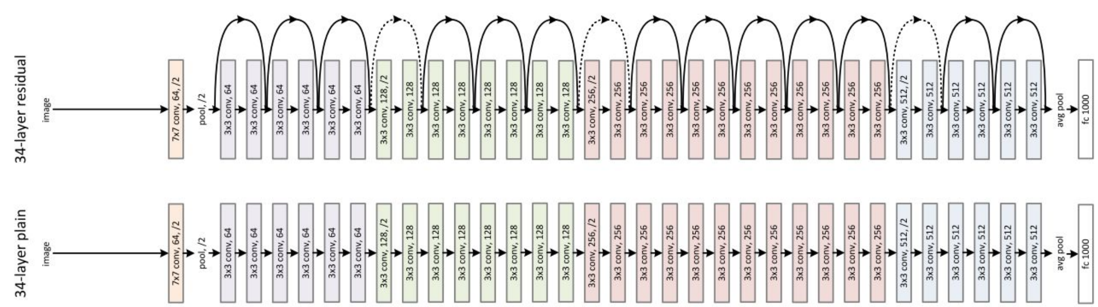
Krizhevsky, et al. (2012)



Simonyan and Zisserman (2014)



Szegedy, et al. (2015)



He, et al. (2016)

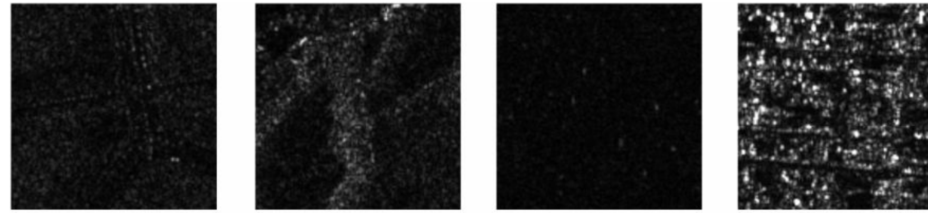
Needed: image-label pairs

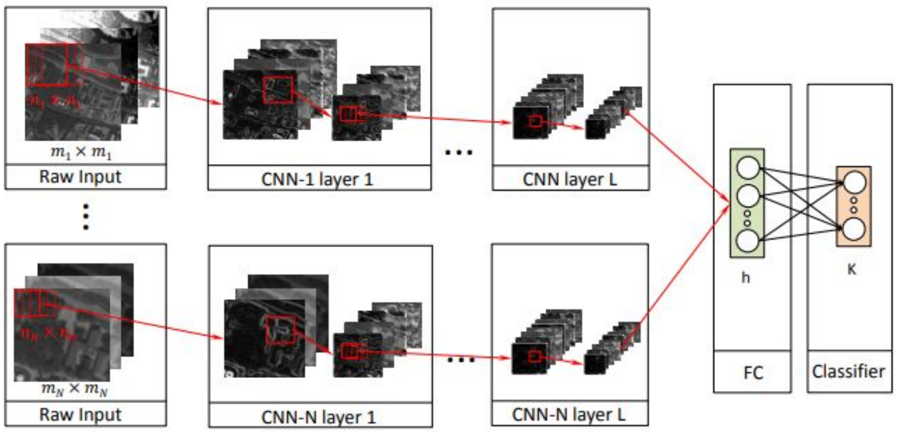
MNIST (grayscale)

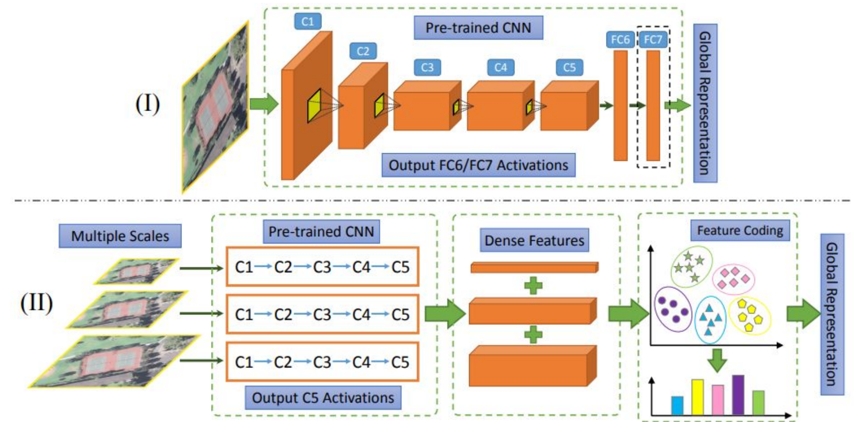
CIFAR10 (grayscale)

IMAGENET (RGB images)

Applications to remote sensing







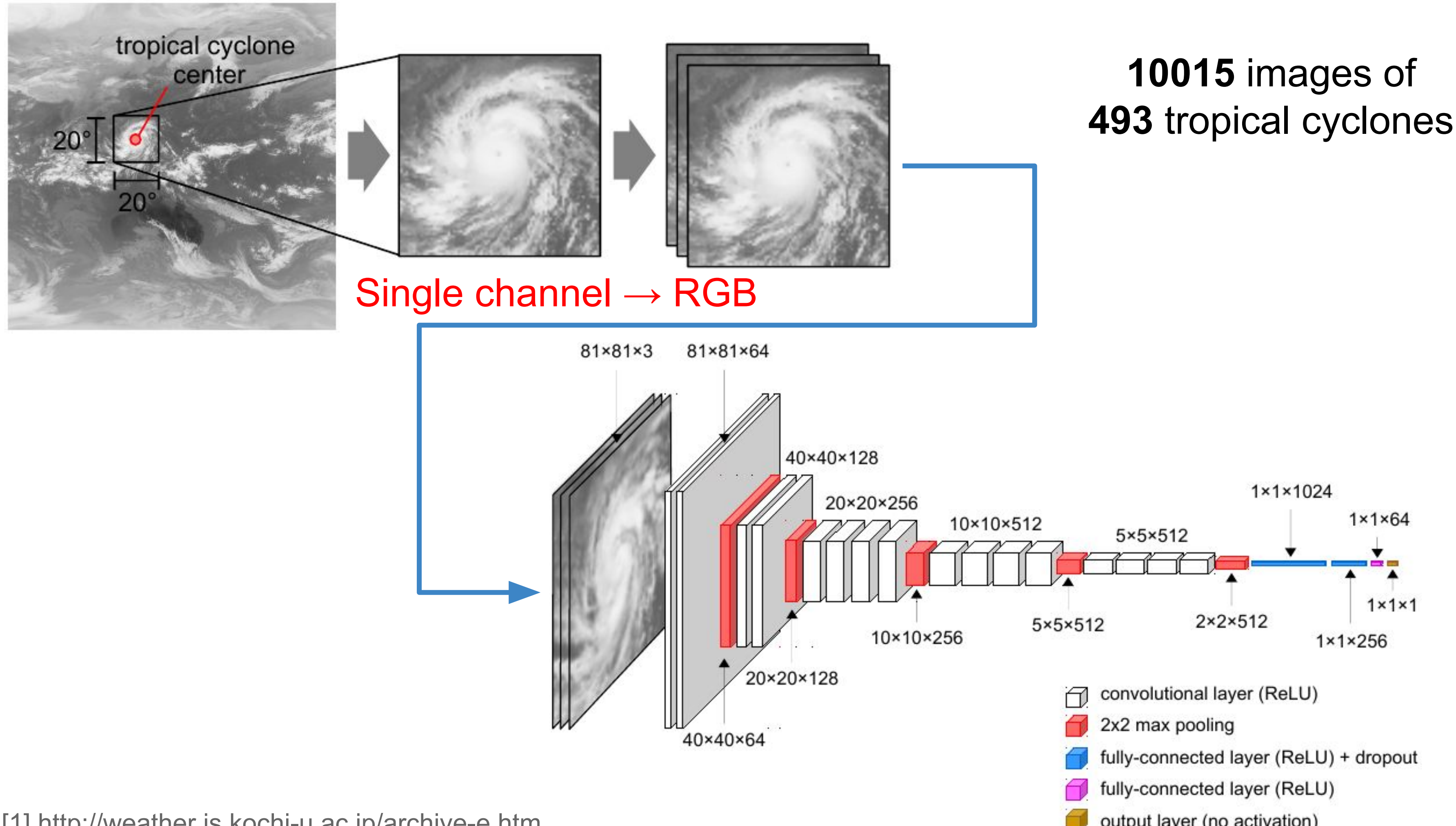
1. M. Castelluccio, G. Poggi, C. Sansone, and L. Verdoliva, “Land use classification in remote sensing images by convolutional neural networks,” arXiv:1508.00092, 2015.
2. M. Längkvist, A. Kiselev, M. Alirezaie, and A. Loutfi, “Classification and segmentation of satellite orthoimagery using convolutional neural network,” Remote Sens., vol. 8, no. 4, p. 329, 2016, doi:10.3390/rs8040329.
3. F. Hu, G. Xia, J. Hu, and L. Zhang, “Transferring deep convolutional neural networks for the scene classification of high-resolution remote sensing imagery,” Remote Sens., vol. 7, no. 11, pp. 14 680–14 707, 2015, doi:10.1016/j.atmosres.2012.07.006.
4. Z. Huang, Z. Pan, and B. Lei, “Transfer learning with deep convolutional neural network for SAR target classification with limited labeled data,” Remote Sens., vol. 9, p. 907, 2017, doi:10.3390/rs9090907.

Training process

Images → Tropical cyclone IR images from Kochi (2015)[1]

Labels → Intensity values from JMA best track data[2]

10015 images of
493 tropical cyclones



[1] http://weather.is.kochi-u.ac.jp/archive-e.htm

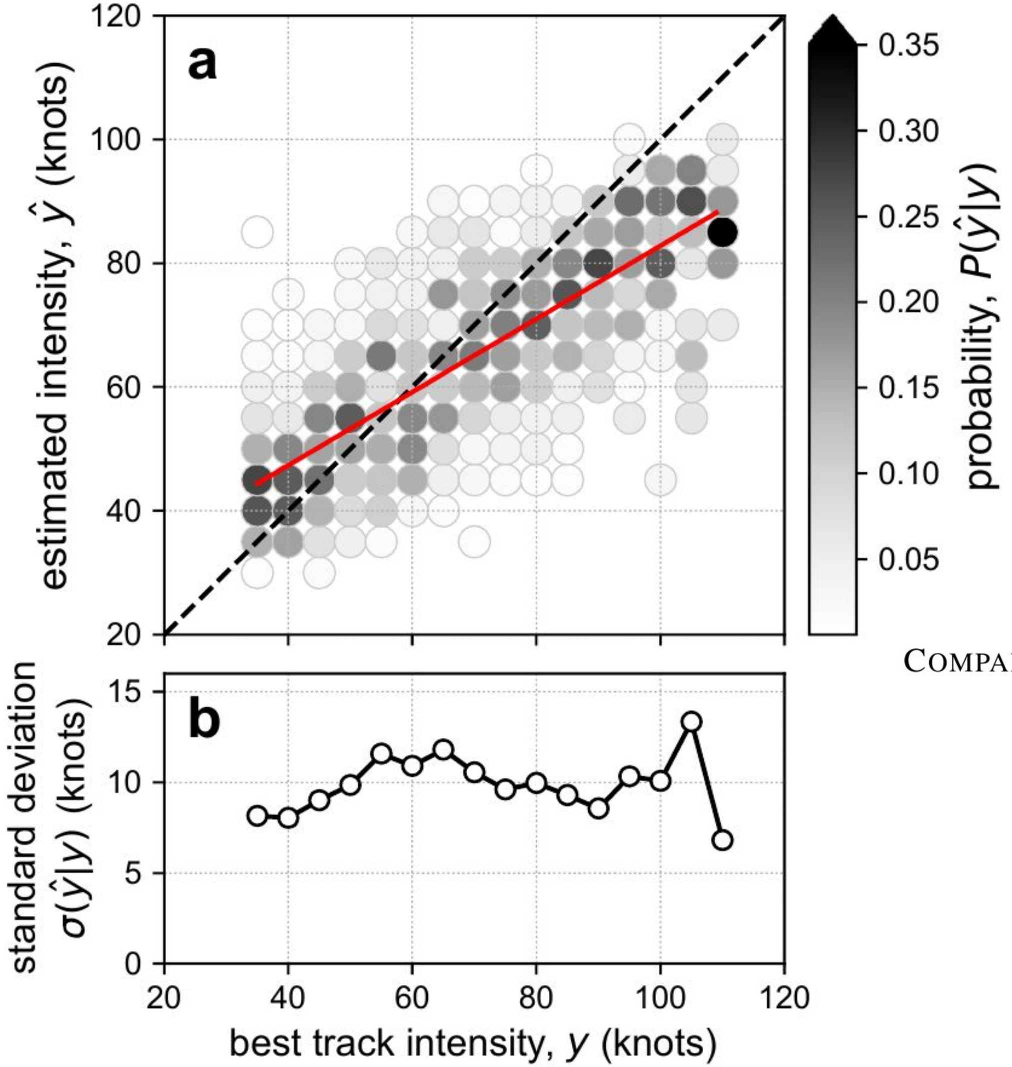
[2] http://www.jma.go.jp/jma/jma-eng/jma-center/rsmc-hp-pub-eg/besttrack.html

Training process

normalization coefficient

Loss function: $$H(y,\hat{y}) = \frac{1}{N}\sum_{i=1}^{N}\left[P(y_i)\,|y|\right]^{-1}(\hat{y}_i - y_i)^2$$

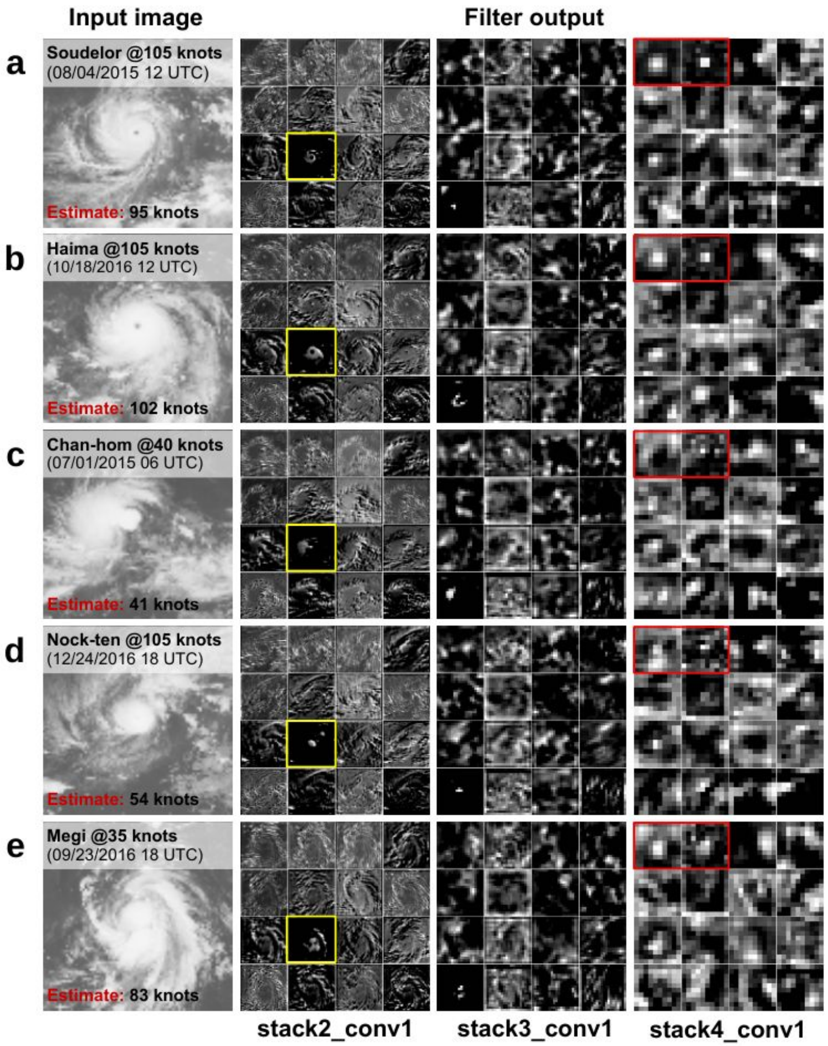
squared error



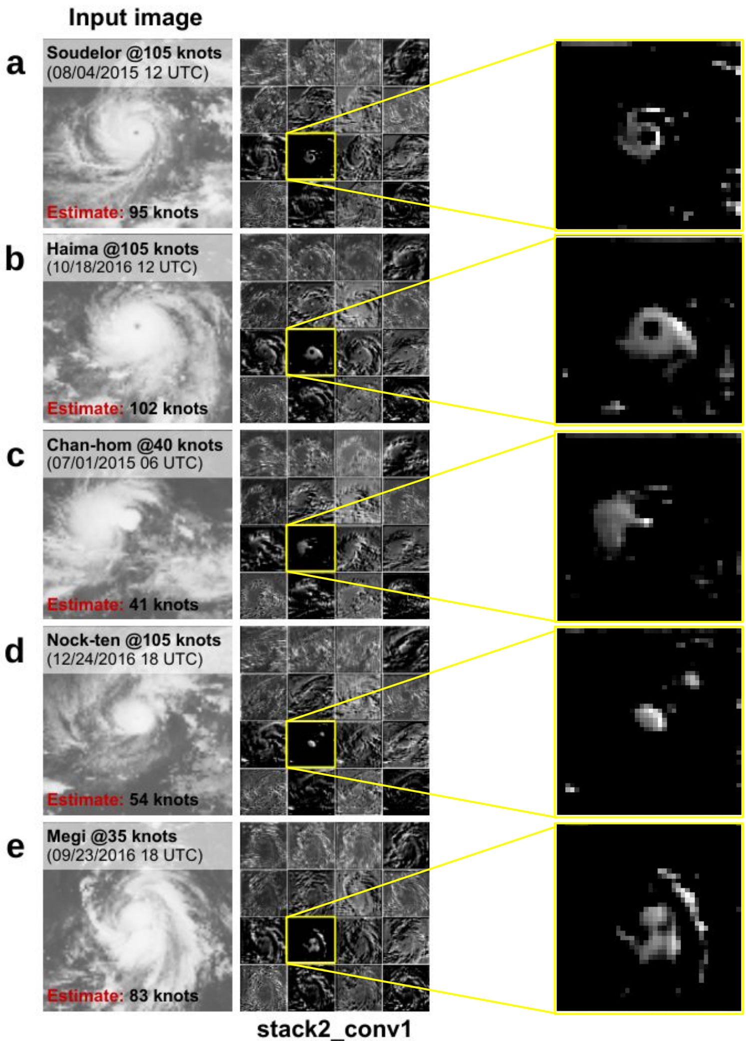
Model is robust and comparable to previous feature-based approach.

COMPARISON OF THE MODEL PERFORMANCE WITH EXISTING FEATURE-BASED TECHNIQUES.

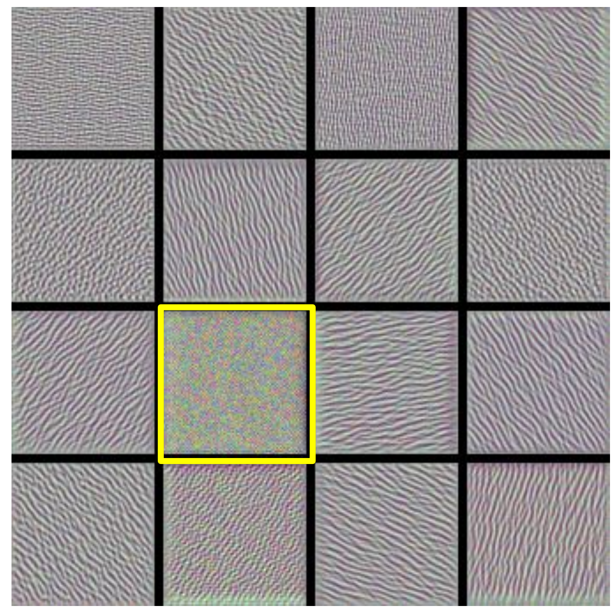
Technique	**RMSE (knots)**
Piñeros et al. [7]	13 – 15
Zhao et al. [10]	12.01
Bankert et al. [5]	19.80
Kulkarni et al. [8]	22.93
Our model	13.23



Estimated intensity	Best track intensity
95	105
102	105
41	40
54	105
83	35



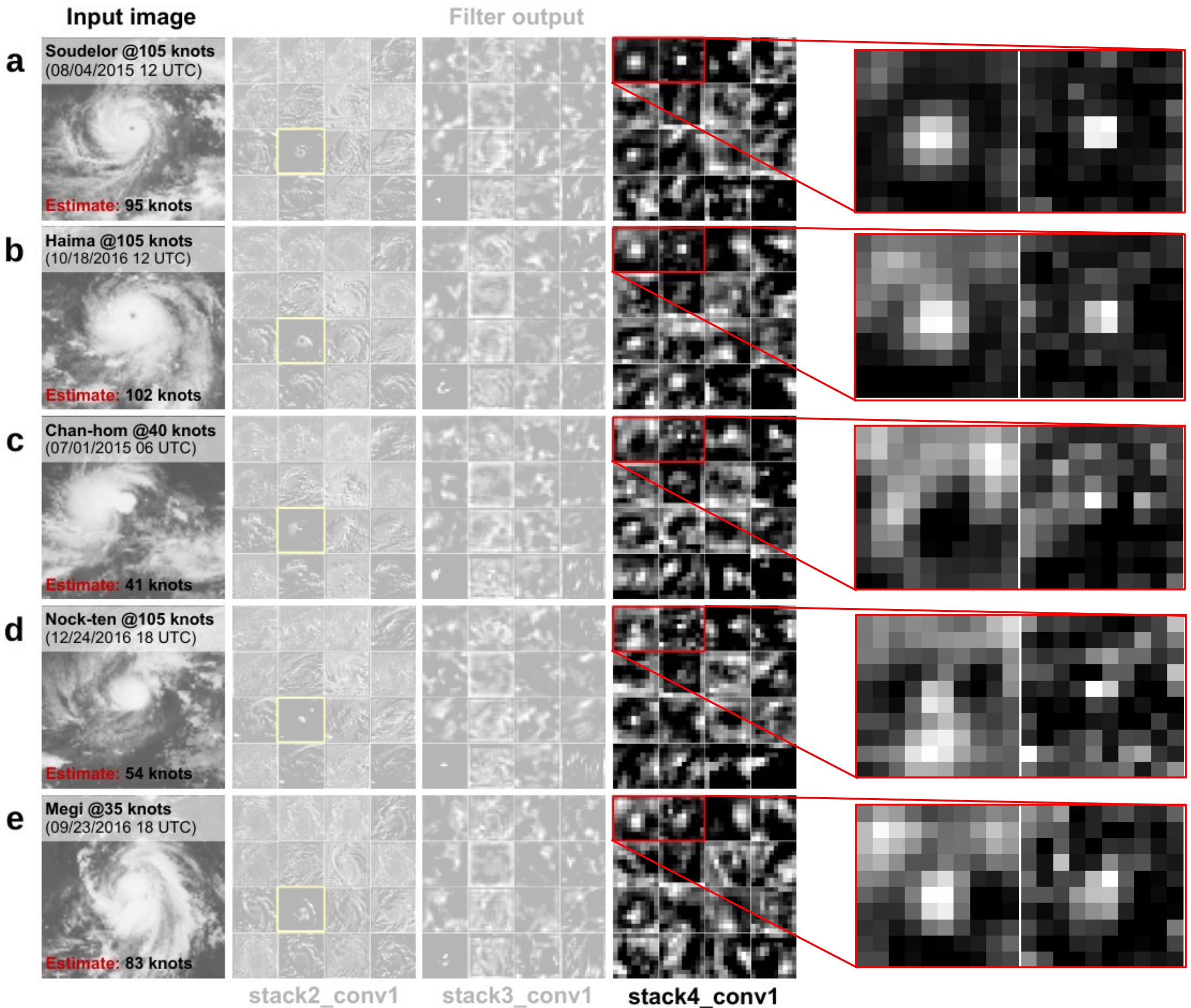
Images that maximize **stack2_conv1**



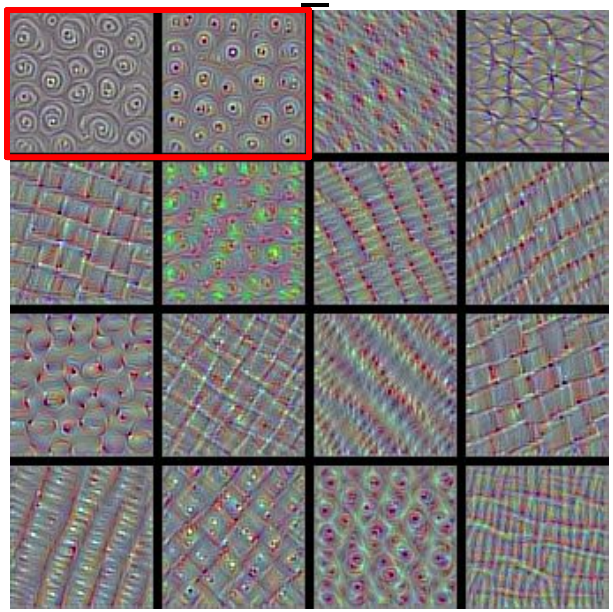
Estimated intensity	Best track intensity
95	105
102	105
41	40
54	105
83	35

Operation similar to Pineros (2010, 2011) and Zhao, et al. (2016)

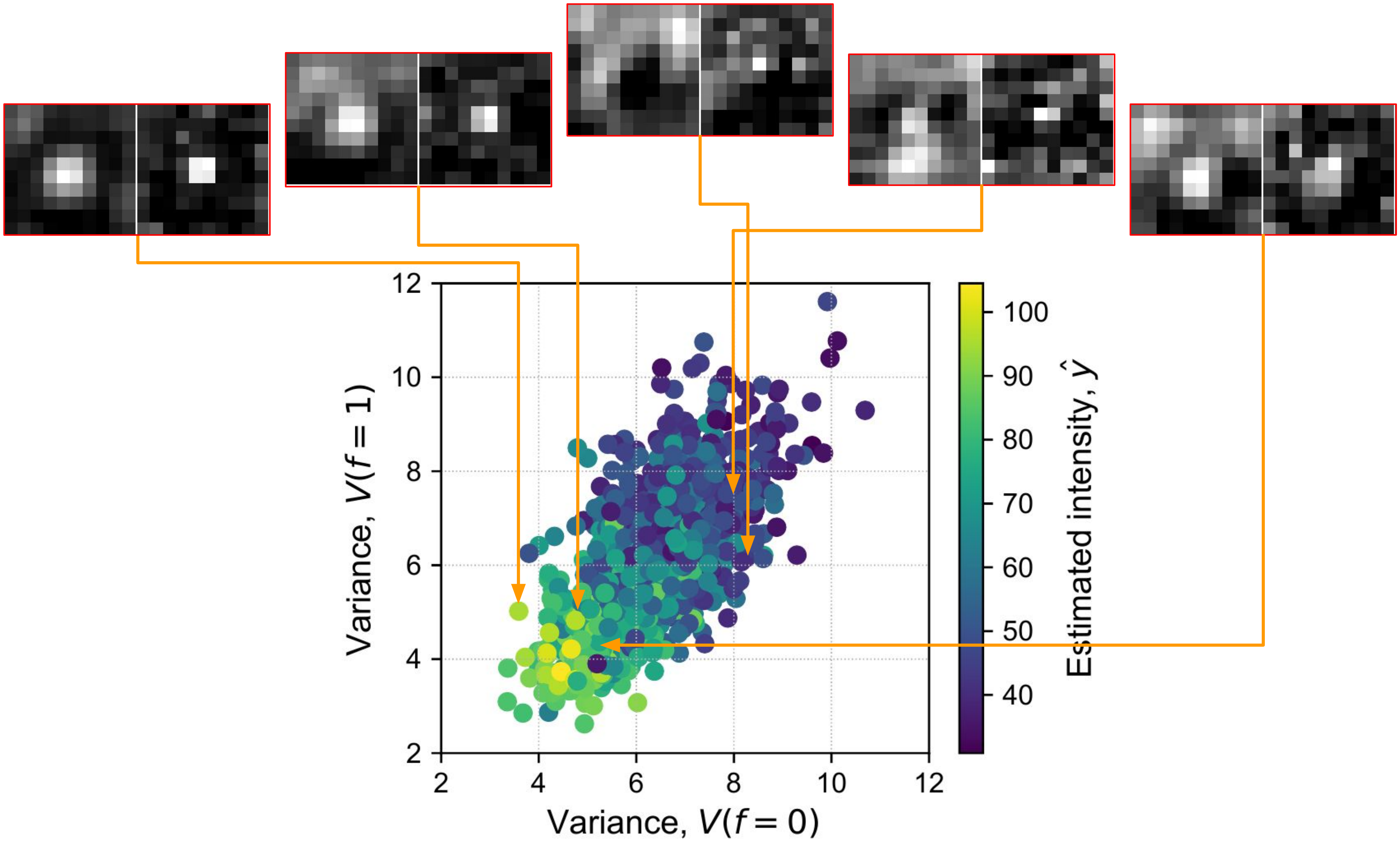
Consistent with Dvorak (1975)



Images that maximize
stack4_conv1

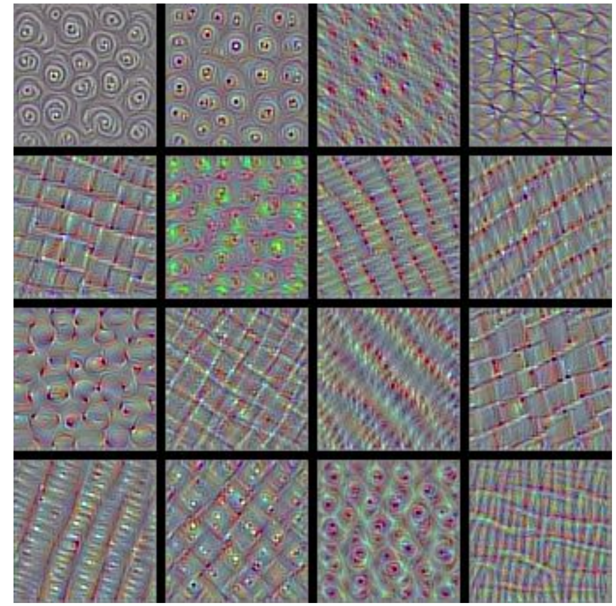


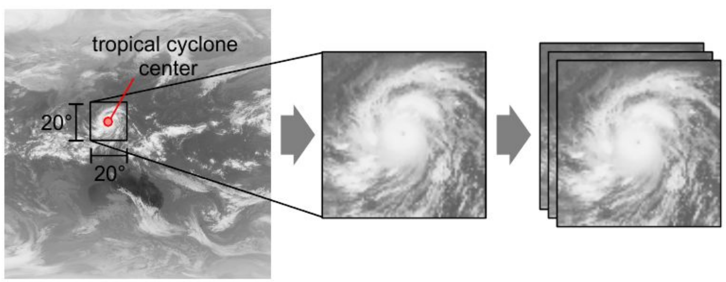
Model looks for an organized cloud circulation and a well-formed eye.

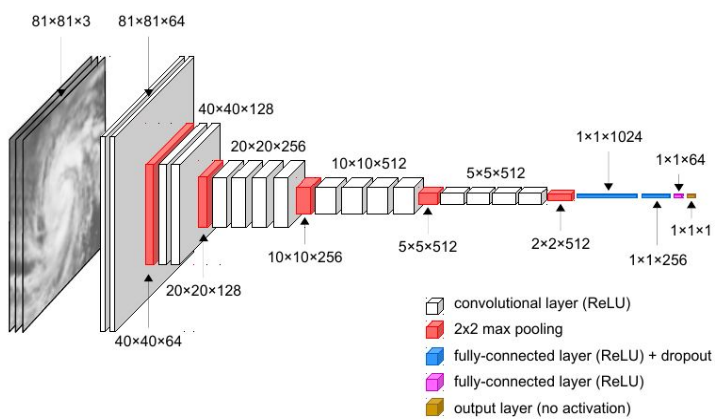

12
10
8
6
4
2
Variance, $V(f = 1)$
2
4
6
8
10
12
Variance, $V(f = 0)$
100
90
80
70
60
50
40
Estimated intensity, $\hat{y}$

Summary and recommendations

- Explored a CNN-based approach for estimating TC intensity based only on grayscale IR images
  No explicit feature extraction required
- Model looked for **organized cloud circulation** and the **presence/absence of an eye**
- IR + other sources (e.g. microwave)







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