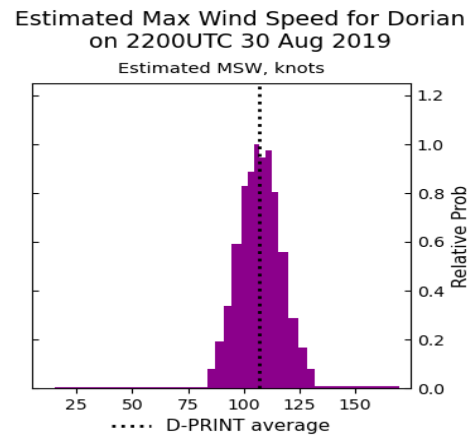
D-PRINT (DeeP learning - IR INtensity of TCs)

D-PRINT is neural network applied to GEO IR imagery, along with selected environmental variables to estimate TC intensity (max sustained 1-min. 10-m wind, MSW). D-PRINT is the same architecture as D-MINT, but it does not include any MW imagery. As a result, D-PRINT is slightly less skillful than D-MINT but provides continuous intensity estimates.

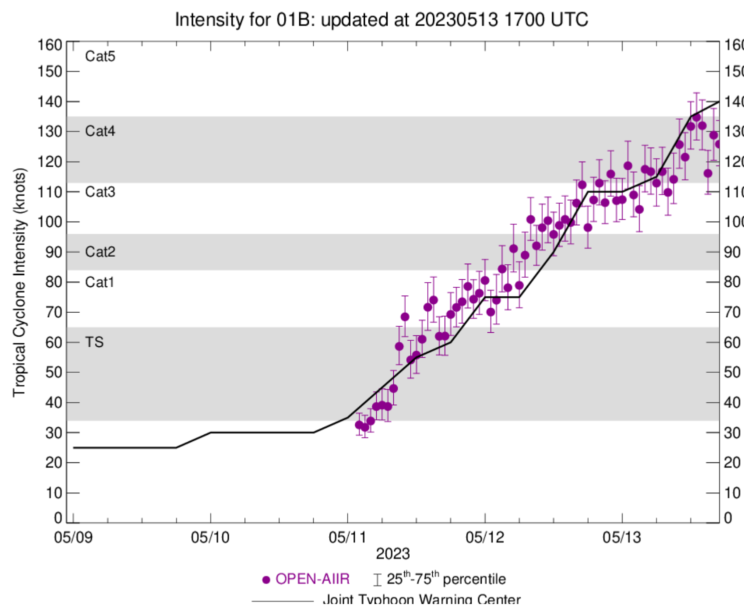
D-PRINT is operated in real-time and processed at the top of every hour, assuming at least 90% of the TC in the image is covered and environmental predictors are available. D-PRINT has a latency of about 30 minutes after the top of the hour.

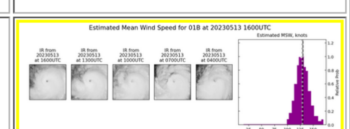
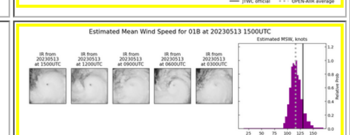
Output Graphics

The resulting model output is a histogram of TC intensity probabilities for 15 different percentiles: 1^{st}, 2^{nd}, 5^{th}, 10^{th}, 20^{th}, …, 90^{th}, 95^{th}, 98^{th}, and 99^{th}. The D-PRINT current intensity (MSW) is calculated from the inner average (30^{th} to 70^{th} percentile intensities), which has the best record for accuracy. An example for Hurricane Dorian (2019) is shown to the right.



In real-time output graphics (example for TC Mocha (2023) shown to the right), the estimated current D-PRINT intensity is plotted as a circle with whiskers out to the 25^{th} to 75^{th} percentile intensities. Wider whiskers mean D-PRINT is less certain of the intensity estimate. The working best track intensity from NHC or JTWC is depicted with a black line. A table of the average intensity and 25^{th} to 75^{th} percentile intensities is also available.



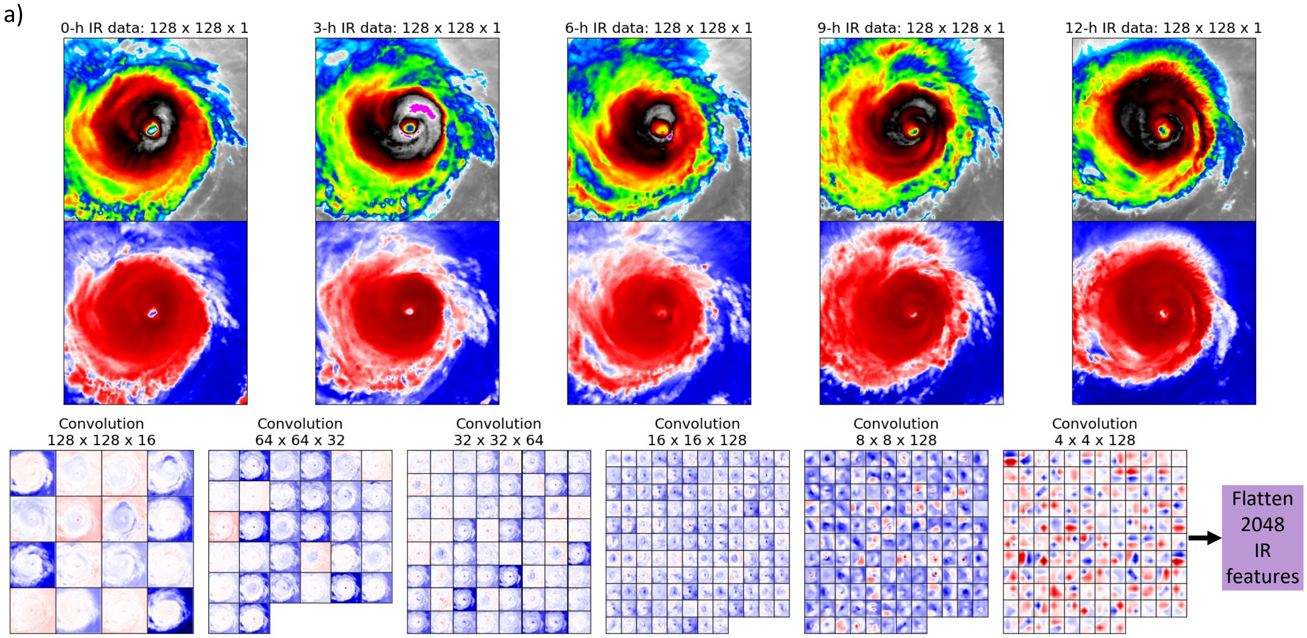
Date	Time	Average (30th-70th percentile)	25th percentile	75th percentile	Image
20230513	1600 UTC	**129 kts**	120 kts	138 kts	
20230513	1500 UTC	**116 kts**	109 kts	124 kts	

D-PRINT (DeeP learning - IR INtensity of TCs)

Model Configuration and Development

IR imagery:

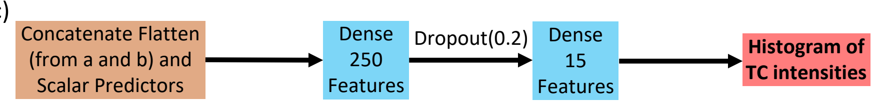
a)



D-PRINT uses 5 normalized IR window (10.3 μm) images over the previous 12 hours (or fewer if not all are available). While the above image displays each IR image as an individual 128x128x1 input for clarity, the actual IR image input into D-PRINT is 128x128x5. Thus, D-PRINT can identify differences between the IR images (see next page).

Scalar Predictors:

c)



The final inputs into D-PRINT are scalar predictors from the SHIPS lsdiag files.

D-PRINT is trained on global tropical cyclones.

North Atlantic	Eastern North Pacific	Western North Pacific	North Indian Ocean	Southern Hemisphere	Global
8578	9253	14,296	1190	7814	**41,131**

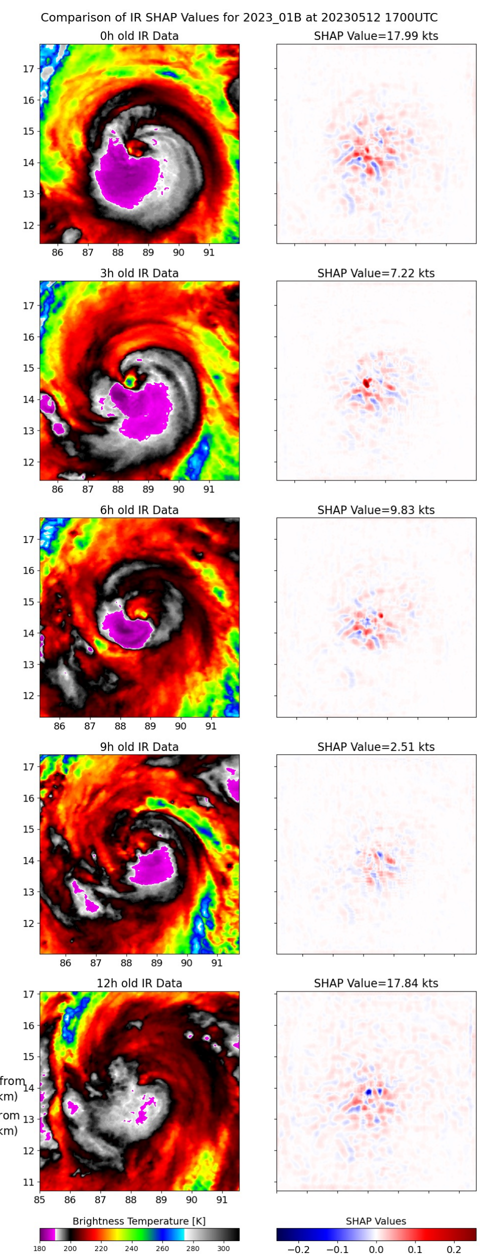
D-PRINT (DeeP learning - IR INtensity of TCs)

Diagnosing the D-PRINT intensity estimates: A Brief Guide to SHAP Values

The power of the deep learning model comes from the ability to form complex, nonlinear relationships between images and the environment in order to predict an unknown feature (TC intensity). However, this power also complicates our ability to interpret the reasoning used by the model. To address this, the SHapley Additive Explanation (SHAP) method *approximates* the nonlinear model as a linear model, in order to give a rough idea of the sensitivities of the model result to each input. We have organized a set of diagnostic graphics to show *a first-order approximation* of how the model arrives at its answer. In the next pages we'll break down the three elements of the SHAP diagnostic graphic.

1. Full input breakdown

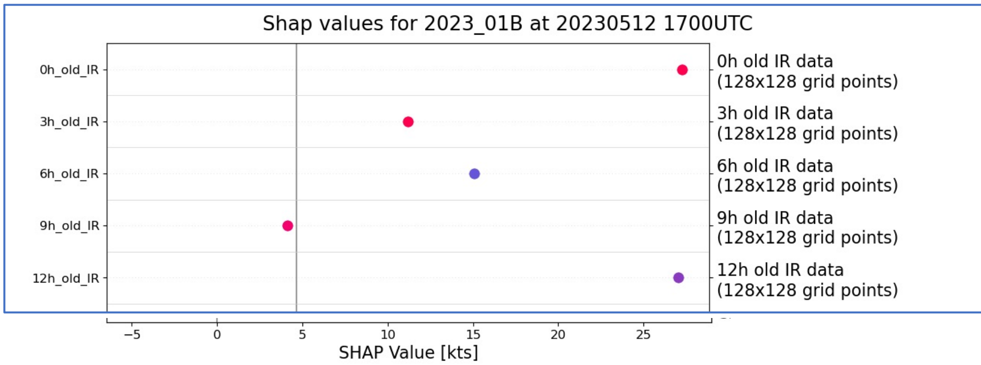
2. IR contribution

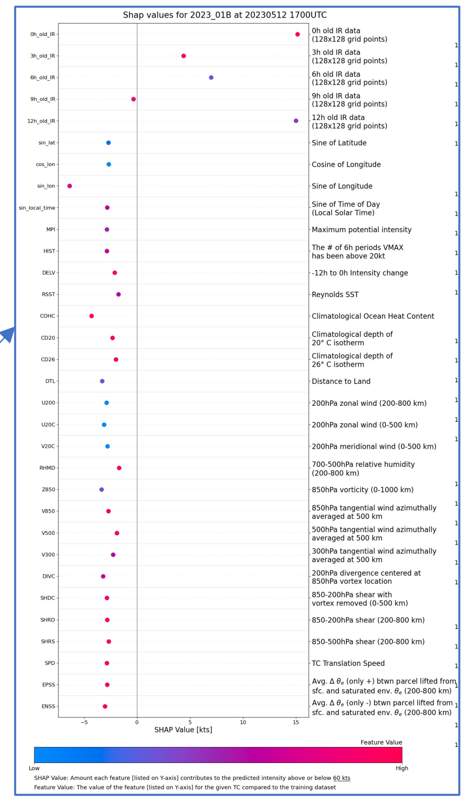


Why use IR imagery from 0 to 12 hrs old? We found this to be more accurate than models with any more or less IR imagery as their inputs. Adding this context of recent TC history seems to help prevent overfitting to the latest single image.

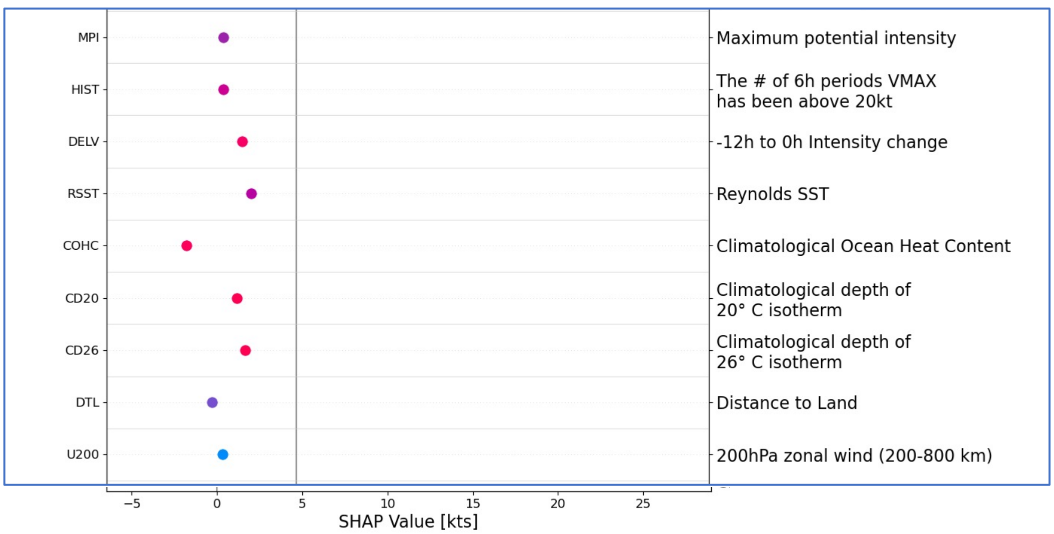
D-PRINT (DeeP learning - IR INtensity of TCs)

1. Full input breakdown



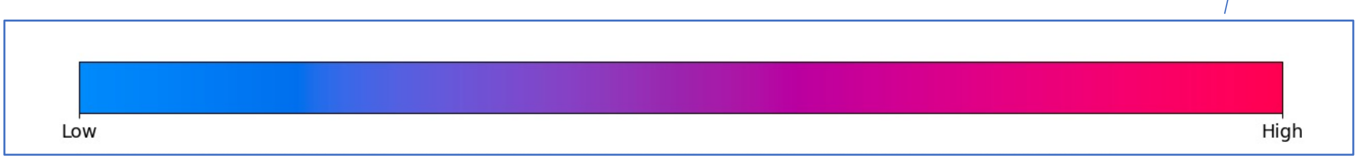


The top rows summarize the contributions of the satellite imagery to the final estimate. Each point on the chart stands for the amount that the image adds to the final estimate (**starting at a baseline 60 knots**).



The remaining rows summarize the contributions of the environmental/historical predictors to the final estimate. Refer to these to pick out

1) **Whether the environment/history is generally favorable or unfavorable**
2) **Whether it identifies any contributors that are uniquely influential**
3) **Whether any contributor may be in error**



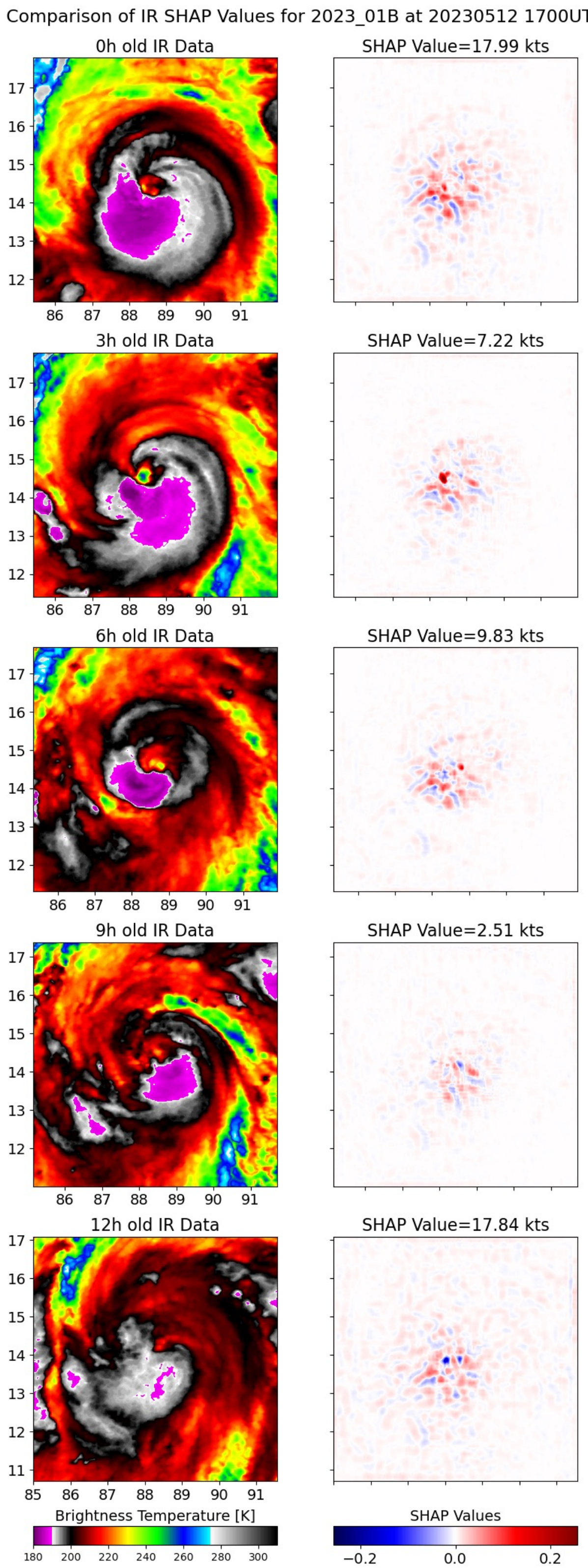
Finally, the color of each point indicates its value above or below the climatological average for TCs. For instance, the Distance to Land is blue, indicating a relatively short distance.

As for the image contribution coloring (top plot), we have simply set the colors to match our coloring of image brightness temperatures, where blue means warmer and red means colder.

D-PRINT (DeeP learning - IR INtensity of TCs)

2. IR contribution (spatial SHAP values)

Strong tropical cyclone
110 kt max. sustained winds (1 min.)

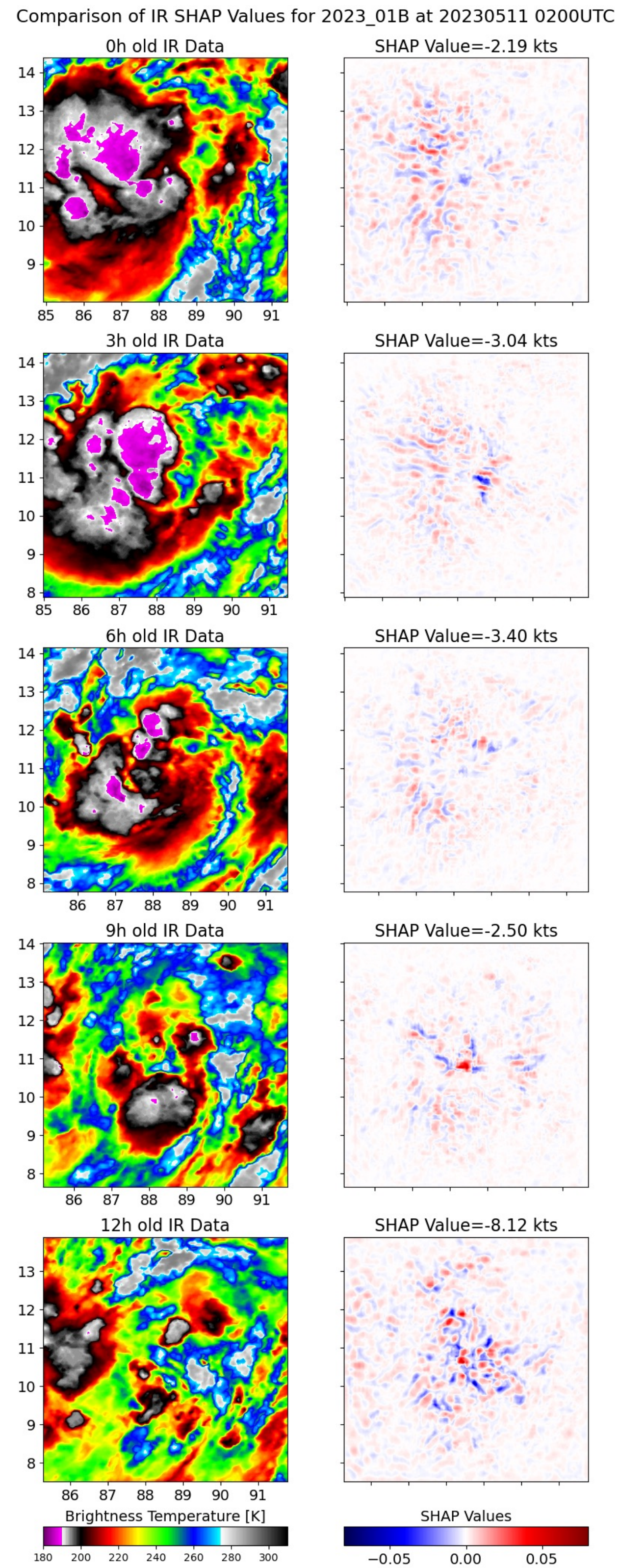


Most recent IR image

D-MINT inputs five IR imagery time frames together. *However, the images are always significantly autocorrelated*, so a high contribution from one time frame does not rule out the influence of other time frames. On the left case, the second strongest signal comes from the 12 hr old image. However, you can interpret this as a signal of the eyewall strength from all five images because the BTs are getting colder, and you can think of it as the SHAP algorithm choosing this signal to emphasize among several at the exact location.

Oldest IR image

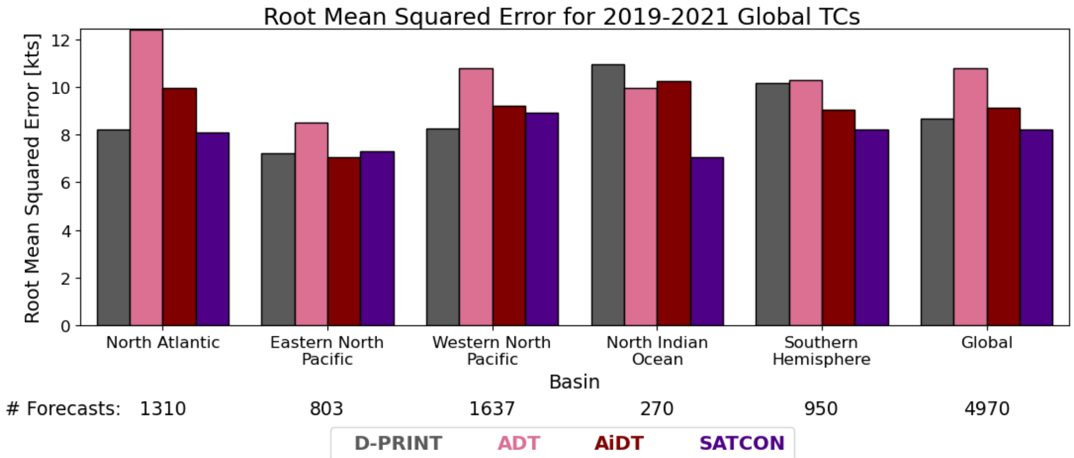
Weak tropical cyclone
30 kt max. sustained winds (1 min.)



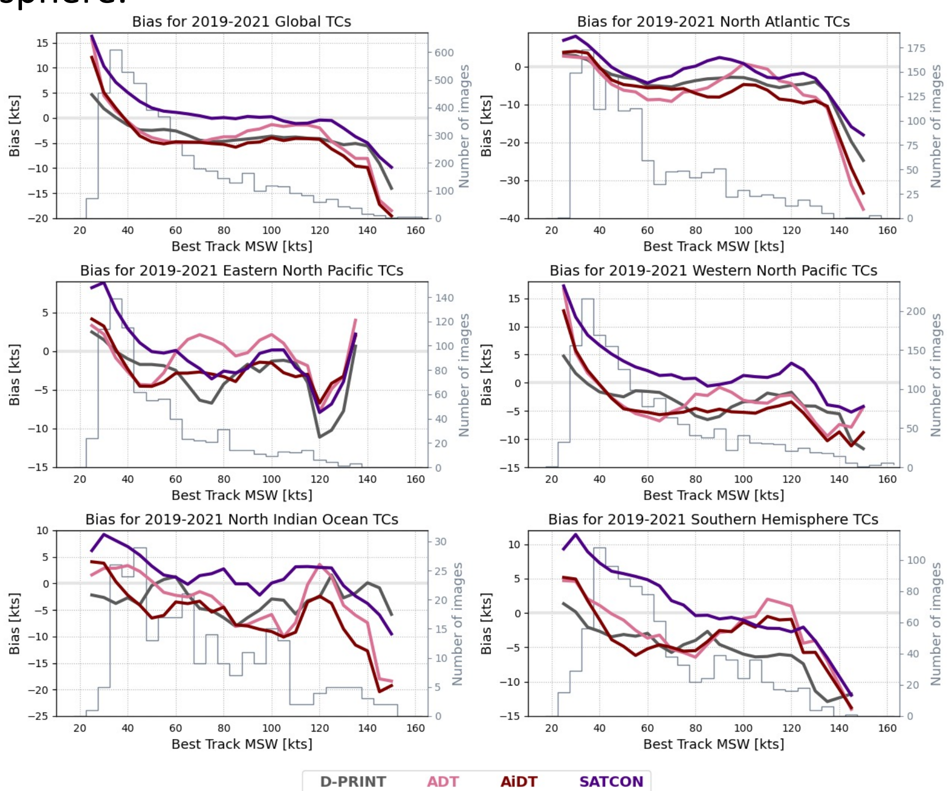
Unlike in the Full Input Breakdown, the blue-to-red colors are the pixelwise *SHAP values* for the IR images. These SHAP values sum up to the number listed above each image, which is plotted on the Full Input Breakdown.

D-PRINT (DeeP learning - IR INtensity of TCs)

Model Performance Statistics



D-PRINT has the lowest error in the Western North Pacific. In the North Atlantic and Eastern North Pacific, SATCON has a lower error but D-PRINT has less of a delay. For the North Indian Ocean, D-PRINT has the highest error. ADT has a higher error in the Southern Hemisphere.



D-PRINT has the lowest high bias for weak TCs (< 40 kts) and less of a low bias for strong TCs (> 100 or 120 kts depending on the basin), except for SATCON

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Reference: Griffin, S. M., A. Wimmers, and C. S. Velden, 2023: Predicting Short-term Intensity change in Tropical Cyclones using a Convolutional Neural Network. *In Review*