WPO Letter of Intent to Submit a Proposal to the Joint Hurricane Testbed, September 2021
Cover Page

Project Title: A Machine Learning Model for Estimating Tropical Cyclone Track and Intensity Forecast Uncertainty

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Project Summary: The National Hurricane Center (NHC) and Central Pacific Hurricane Center (CPHC) provide several widely used probabilistic tropical cyclone (TC) products, including wind speed probabilities and probabilistic storm surge exceedances. However, the underlying forecast uncertainty used to create these products is primarily derived from historical error distributions. This project adapts a new Machine Learning method described in 2014 and 2021 publications in the *J. of Advances in Modeling Earth Systems* by E. Barnes and co-authors to estimate tropical cyclone (TC) track and intensity error uncertainty using the "abstention neural network (ANN)" technique. A fundamental difference between this approach and existing operational techniques is that the uncertainty estimates are obtained as part of the network training of the prediction model, rather than from post-analysis of forecast errors. Since the network training includes the uncertainty estimate, it provides an option to learn less from cases with large uncertainty to develop a prediction model that is better at learning the predictable signals. In real-time if a case is identified as having higher certainty, the prediction can be performed with the abstention network. The version of the neural network framework without the "abstention" option still outputs uncertainties with each prediction and can be run in parallel for comparison. The situationally dependent forecast uncertainty estimates can be used directly or as input to improve current probabilistic TC products.

Methodology: The TC-ANN model is a generalization of the Neural Network Intensity Consensus (NNIC) model that has been run experimentally at NHC since 2020 for the NHC and CPHC areas of responsibility. NNIC was designed to crudely mimic the procedures used by operational forecasters, where the starting point is a consensus of several models, and then the forecast is weighted more towards the models that forecasters consider more reliable, based on the current situation. NNIC provides an intensity forecast with input from four deterministic intensity models (DSHP, LGEM, HWFI, and GFSI) and several TC parameters, including intensity tendency, vertical wind shear, sea surface temperature (SST), and distance to land. The 2020 real-time NNIC runs had skill comparable to other intensity consensus models, especially for the shorter-range forecasts. The prototype TC-ANN model that includes the uncertainty estimates was developed at CSU based on NNIC. The intensity TC-ANN was trained on 2013-2020 cases, and the preliminary 2021 season testing show a strong correlation between the predicted intensity uncertainty and the intensity error. The track TC-ANN will be tested at CSU during the latter part of the 2021 season. The track uncertainty can be used as input to the intensity uncertainty estimation, since the two are related, especially near land or strong SST gradients. The prototype TC-ANN is the starting point for this JHT project.

Forecasters also use uncertainty information from dynamical model ensemble systems such as the GEFS, but the ensemble TC intensities typically have a large low bias for strong TCs. The TC-ANN model can also be trained on output from ensemble systems to distill a large amount of information into a simpler form and correct for ensemble biases. The inclusion of parameters from single model ensemble systems will be evaluated in the 2^{nd} and 3^{rd} years of the project.

An important consideration in any algorithm that estimates forecast uncertainty from model forecasts is the non-stationarity of the underlying modeling systems, making routine retraining essential. To facilitate the training, the TC-ANN model uses standard inputs already available at NHC, including model forecasts from the ATCF (Automated Tropical Cyclone Forecast), and environmental diagnostics used by NHC's statistical model guidance suite. The neural network development uses the standard Python 3 language with the TensorFlow toolkit, which are open-source and would be available in NHC's operational environment. Once the input has been processed, the prototype TC-ANN model takes less than one minute to train, and less than a second to run on hundreds of forecasts. The use of standard inputs and efficient processing software will facilitate adding inputs as new modeling systems are introduced or removing old modeling systems. This will also make it straightforward to train a version of TC-ANN for the Joint Typhoon Warning Center (JTWC), which will be demonstrated in the 3rd year of the project.

Project Outcomes: The primary project outcomes will be an integrated measure of situationally dependent TC track and intensity forecast uncertainty, or "guidance on guidance", and improved consensus forecasts. The final project result will be an integrated measure of track and intensity error uncertainty that combines input from multiple deterministic and ensemble models, which can be used as guidance by forecasters and as input to public-facing probabilistic products.

Timelines: Project Duration: 1 August 2022 – 31 July 2025

Year 1 – Finalize transition plan, add data from 2021 and 2022 seasons to training/testing sample, finalize track/intensity TC-ANN for the Atlantic/East Pacific, prepare for 2023 real-time demo.

Year 2 – Evaluate 2023 demonstrations, refine algorithm, compare the TC-ANN track/intensity forecasts for cases with high forecast certainty with the baseline version, test global model ensemble input (GEFS, ECMWF), perform real time demonstration in 2024.

Year 3 – Evaluate 2024 demonstrations, refine algorithm, adapt to JTWC areas of responsibility, evaluate the relationships of objective uncertainty estimates with NHC/CPHC forecast errors for possible downstream applications, set up real-time demos for all basins, publish results.

Relevance to WPO priorities: The project directly addresses priority JHT-3 by providing guidance on guidance for track and intensity forecasts that consolidates input from multi-model and single-model ensemble systems. It also applies to priority JHT-5 because the results have the potential to provide an integrated measure of forecast uncertainty that can be conveyed to users.

Operational Recipients: If successful, the uncertainty estimates would become part of the operational guidance suite used by NHC, CPHC, and JTWC forecasters, and could be used as input to other operational products such as the wind speed probabilities.

Readiness Level: The 4-model prototype version of the NNIC that includes forecast uncertainty (TC-ANN) is running in an experimental mode at CSU, and so the project is starting at RL5. All demonstrations will leverage resources at the JHT but no high performance computing resources will be needed.

Budget Table:

	Year 1	Year 2	Year 3	Total
Salaries/Fringe benefits	$107,000	$111,000	$115,000	$333,000
Equipment	$10,000	$0	$0	$10,000
Travel	$1,500	$3,000	$3,000	$7,500
Publications	$0	$0	$3,000	$3,000
Infrastructure support	$2,000	$4,000	$4,000	$10,000
Indirect Costs	$38,675	$41,300	$43,750	$123,725
Total	**$159,175**	**$159,300**	**$168,750**	**$487,225**