Probabilistic Prediction of Tropical Cyclone Track, Intensity, and Structure with an Analog Ensemble

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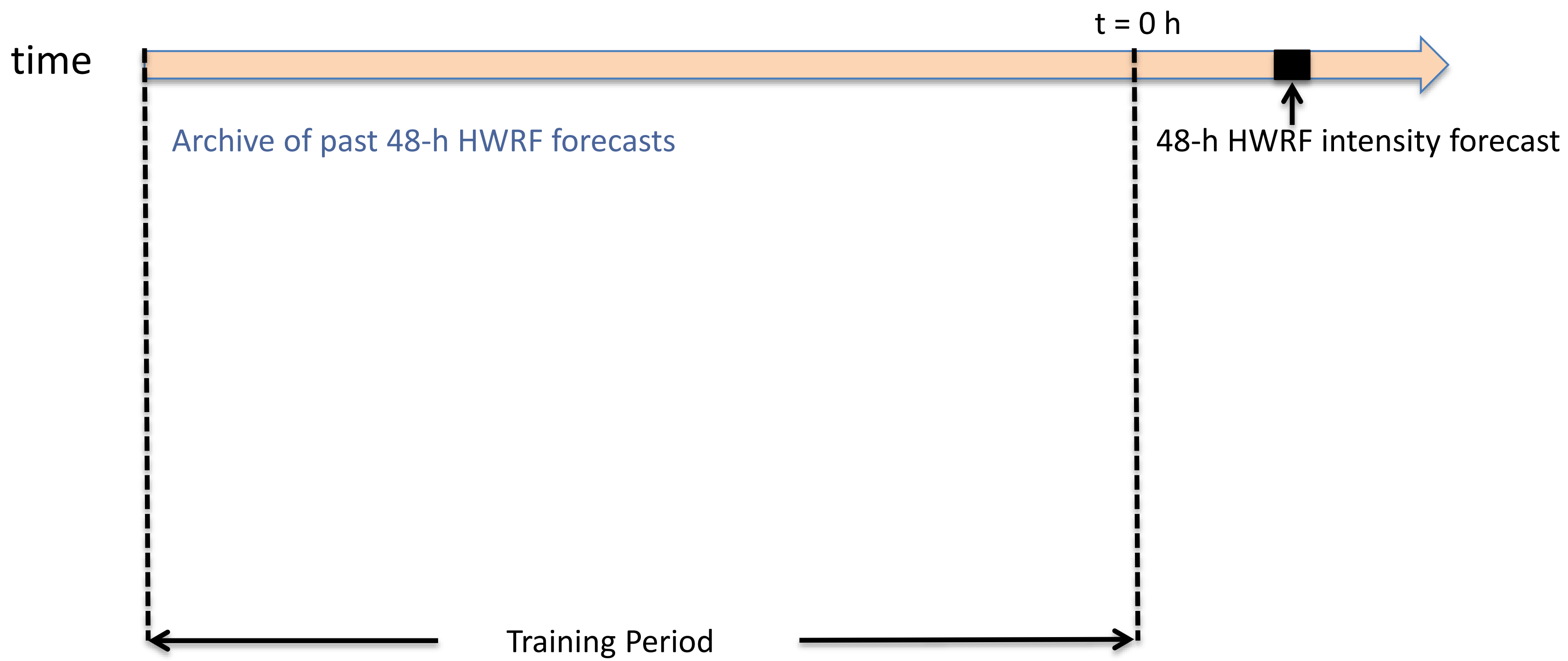
The Analog Ensemble (AnEn)

Adapted from Delle Monache et al. (2013)



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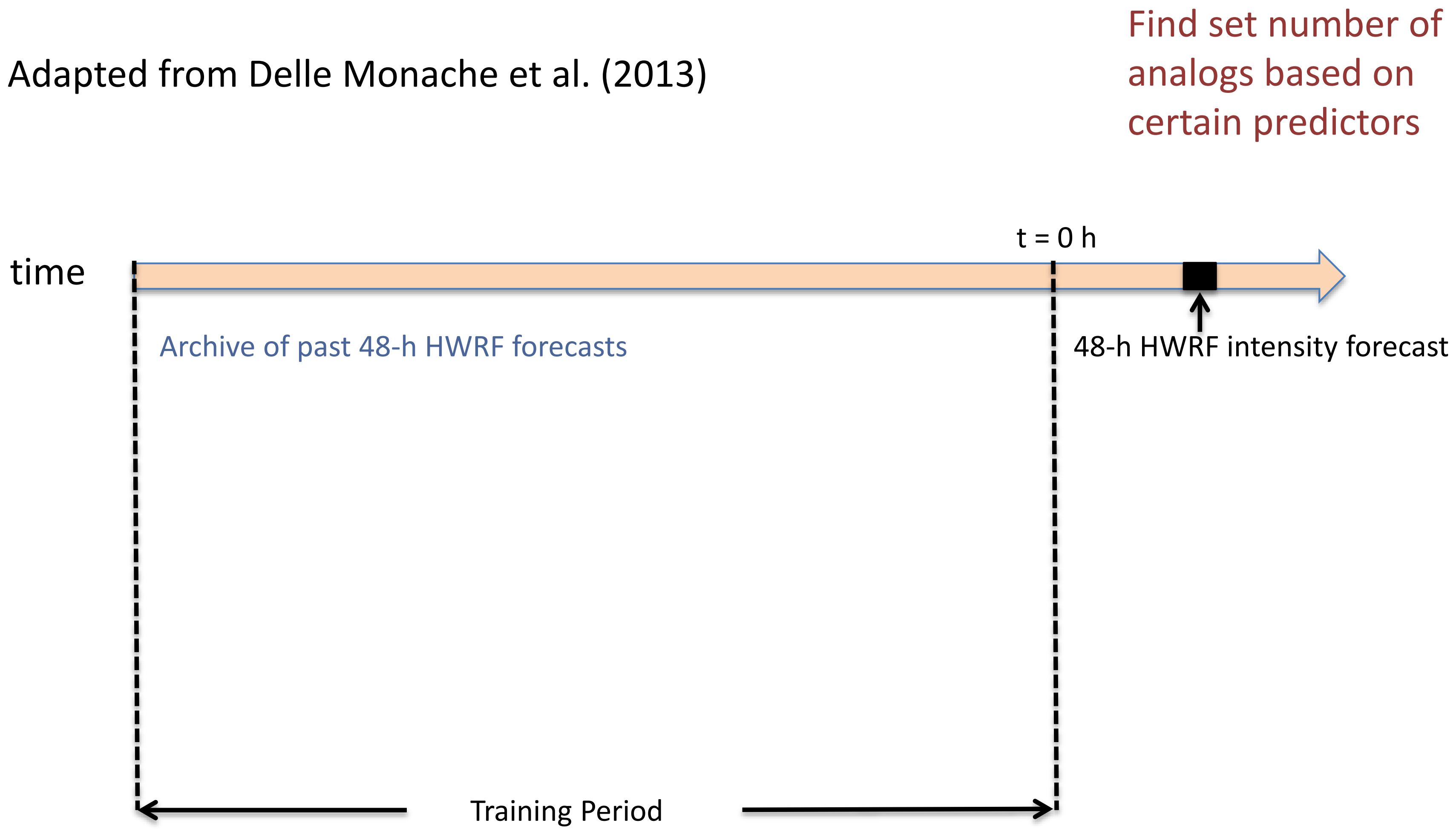

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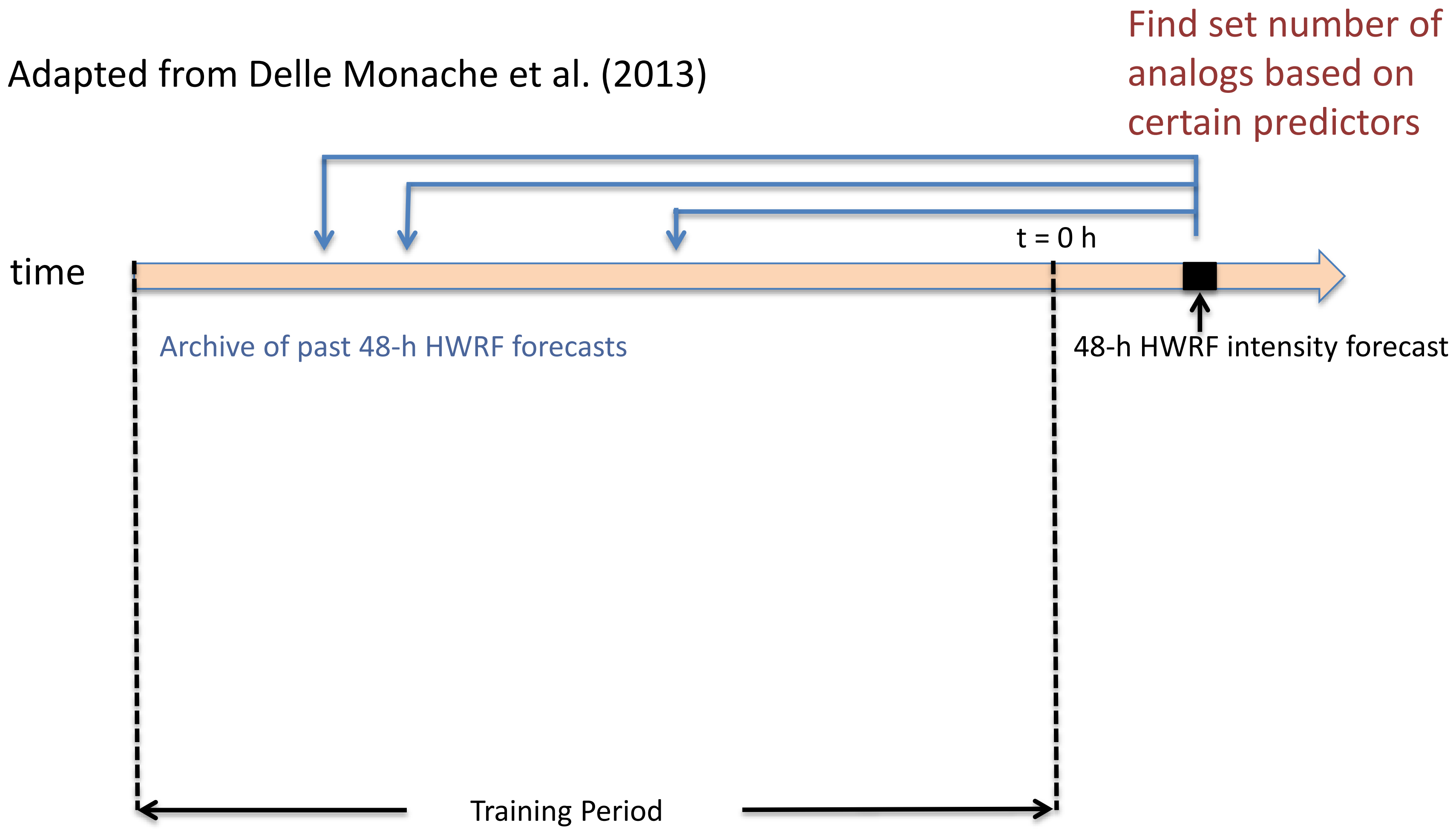

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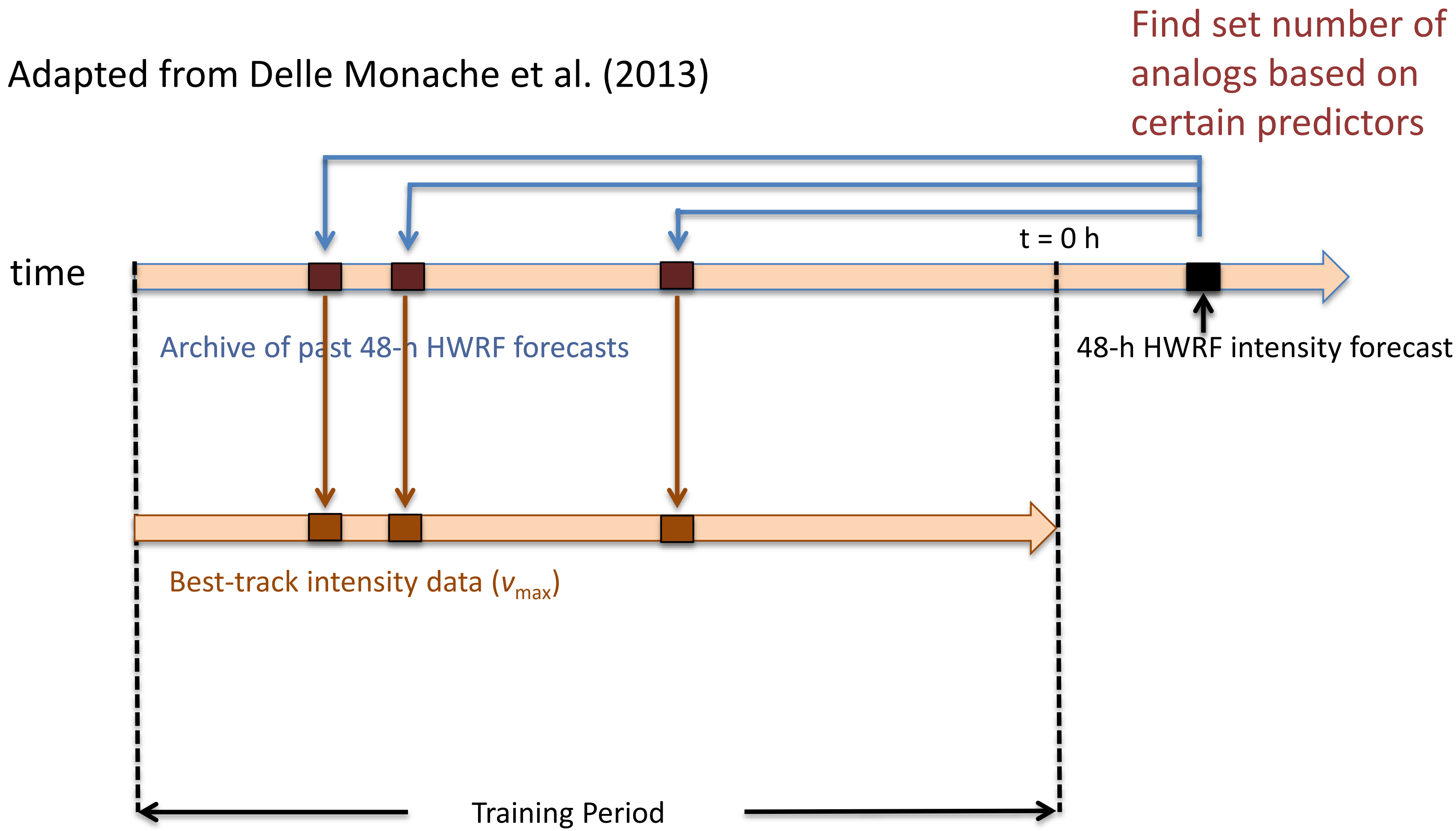

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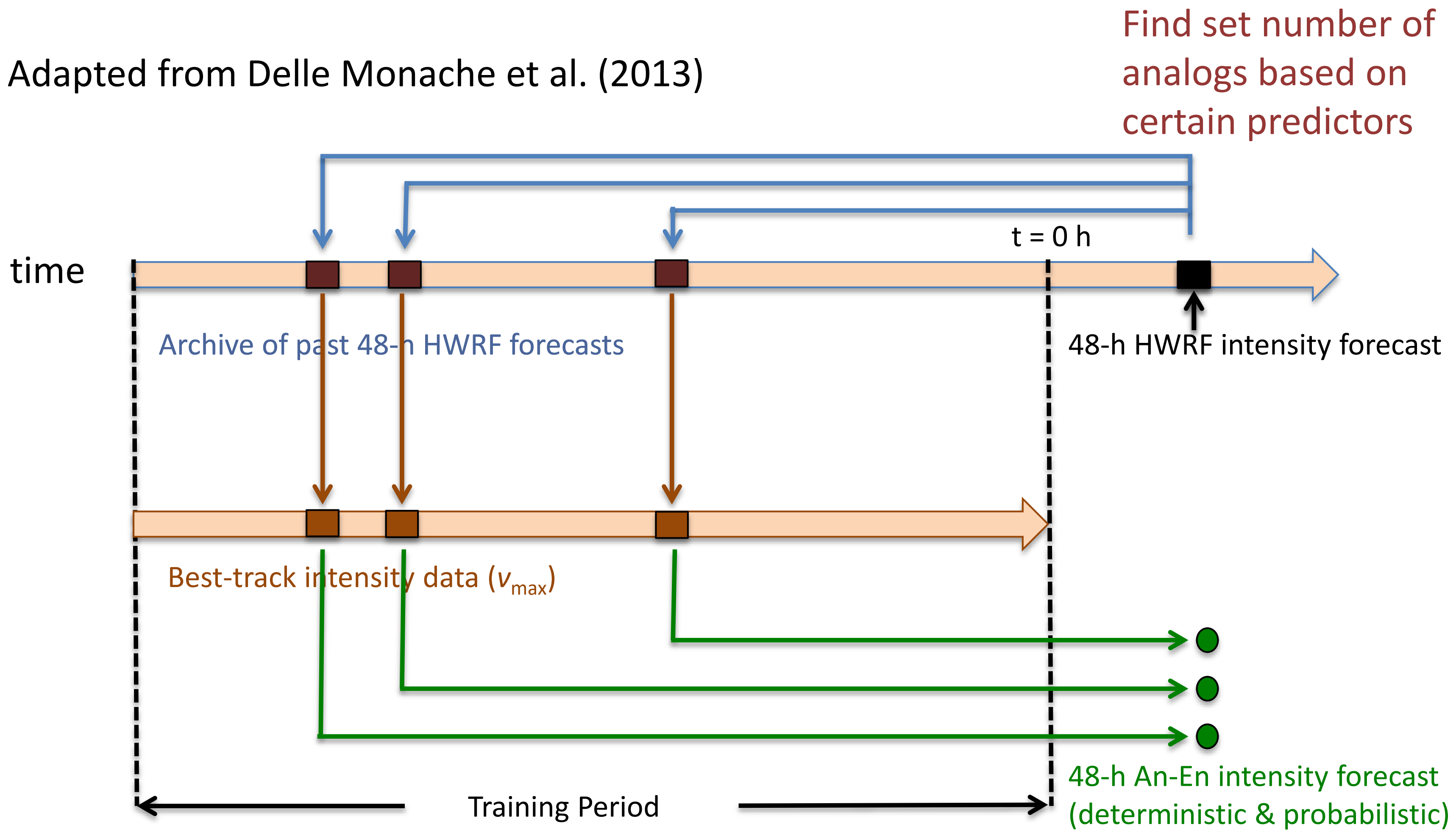

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- No need for initial conditions and model perturbation strategies to generate an ensemble
- Flow-dependent error characteristics are captured
- The AnEn is well-suited for improving the prediction of rare events since it searches for a small set of best analogs

Overarching goals

Develop AnEn systems for a variety of TC applications

- Intensity and intensity change
- Track
- Structure of wind field

AnEn Intensity Model

- First version of intensity ("vmax") AnEn developed in a previous HFIP-funded project
  - Alessandrini, S., L. Delle Monache, C. M. Rozoff, and W. E. Lewis, 2017: Probabilistic prediction of tropical cyclone intensity with an analog ensemble. To be submitted soon.

AnEn Intensity Model

- Based on 2015 version of HWRF
  - Currently working with 2016 data to upgrade AnEn intensity forecast, and will use 2017 HWRF reforecast data as soon as they become available.
- Includes predictors developed from the outer grid (18-km grid spacing) and inner grid (2-km grid spacing)
- 1110 and 1316 reforecasts (covering 43 and 57 TCs) for the Atlantic and Eastern Pacific Ocean basins
- 60 predictors describing thermodynamic and kinematic properties of a TC's environment and inner core were tested.

AnEn Intensity Model

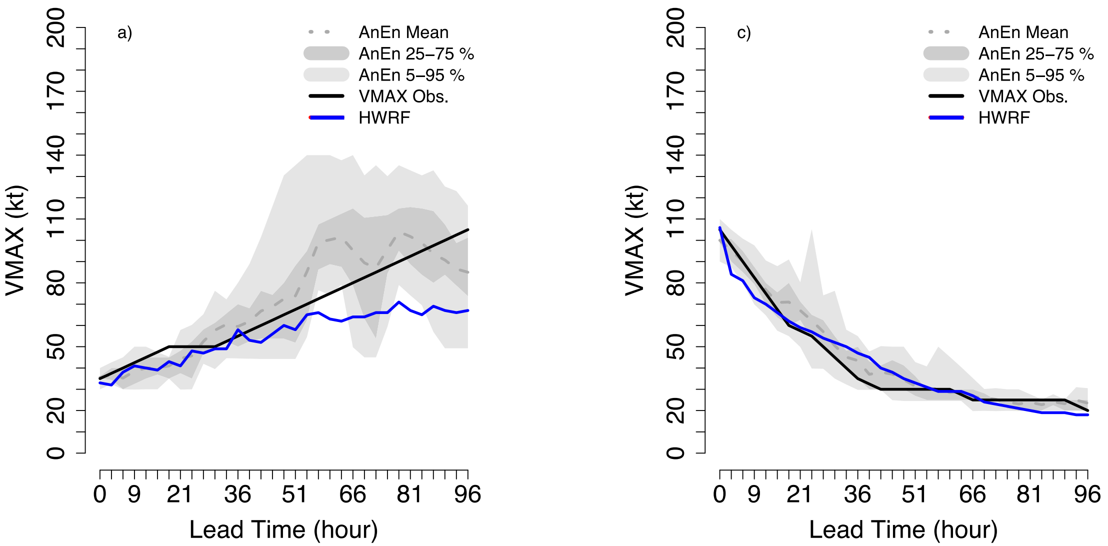
Predictors

Predictor	Basins	Definition
H215 VMAX	ATL, EP	The predicted intensity from HWRF
NHC VMAX	ATL, EP	The predicted intensity from the NHC
USFCSYM	ATL	The degree of axisymmetry of low-level radial flow in the radial region of $r = 100 – 250$ km
IKE	ATL	The 850-hPa integrated tangential wind kinetic energy over the radial region of $r = 0 – 100$ km
INRT	EP	The 850-500-hPa layer average of inertial stability in the radial region of $r = 100 – 250$ km
SHRD	EP	The 850-200-hPa vertical wind shear magnitude in the radial region of $r = 0 – 500$ km
COND	EP	The total condensate at the 700-hPa level averaged over the radial region of $r = 100 – 250$ km
CAPE	EP	The convective available potential energy (CAPE) in the radial region of $r = 100 – 250$ km
TPW	EP	Total precipitable water in the radial region of $r = 0 – 200$ km
RHMD	EP	The 700-500-hPa layer average of relative humidity in the radial region of $r = 200 – 800$ km
RHHI	ATL	The 500-300-hPa layer average of relative humidity in the radial region of $r = 200 – 800$ km
TGRD	ATL	The 850-700-hPa layer average of the temperature gradient in the radial region of $r = 200 – 800$ km
LAT	EP	The latitude of the TC

*EPAC + ATL models created for 0-24 h leadtimes, and 27-96 h leadtimes, versions with and without NHC VMAX. Only 1-4 predictors used per model

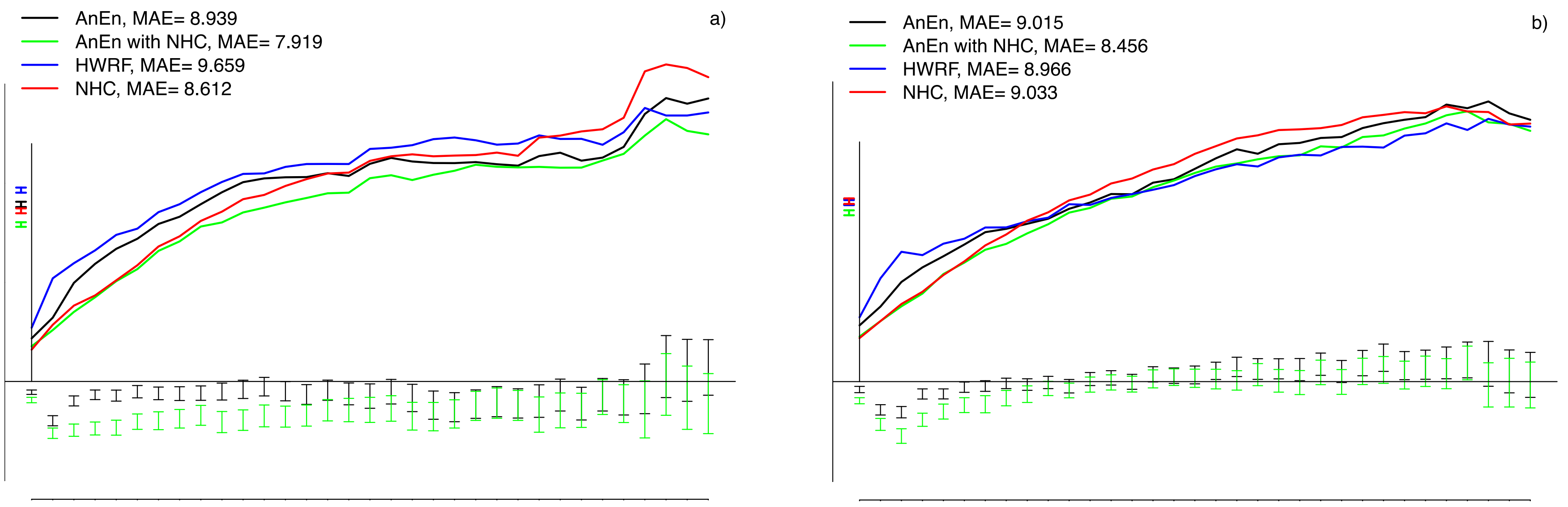
AnEn Intensity Model

Example output



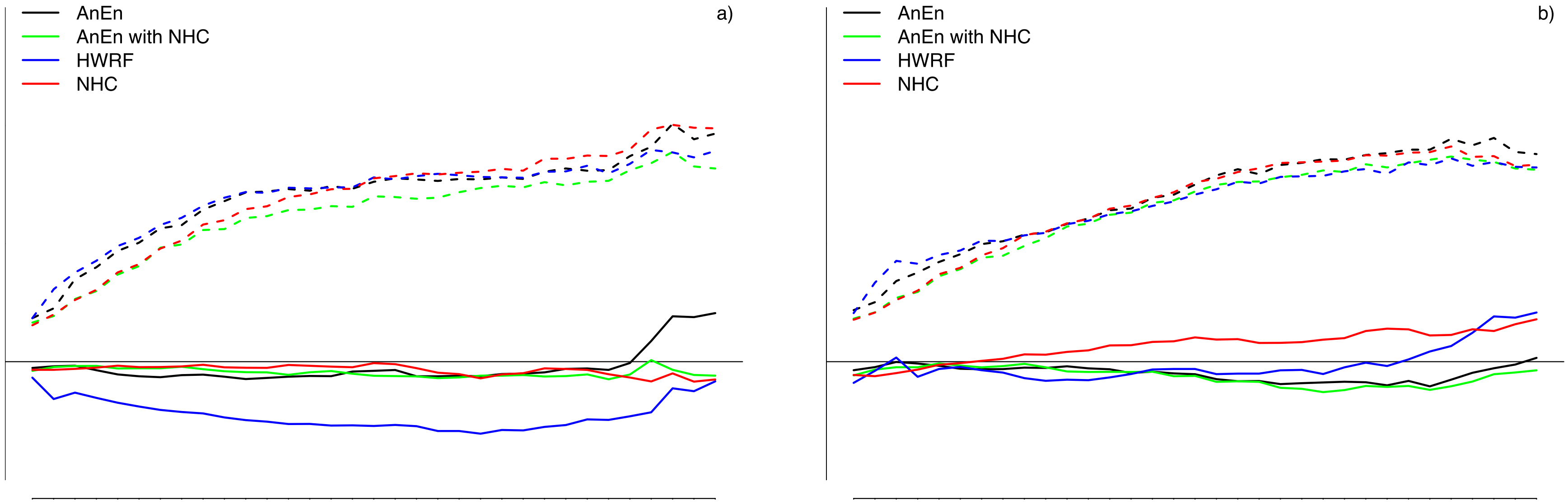
AnEn Intensity Model

Mean Absolute Error (MAE)



AnEn Intensity Model

Bias



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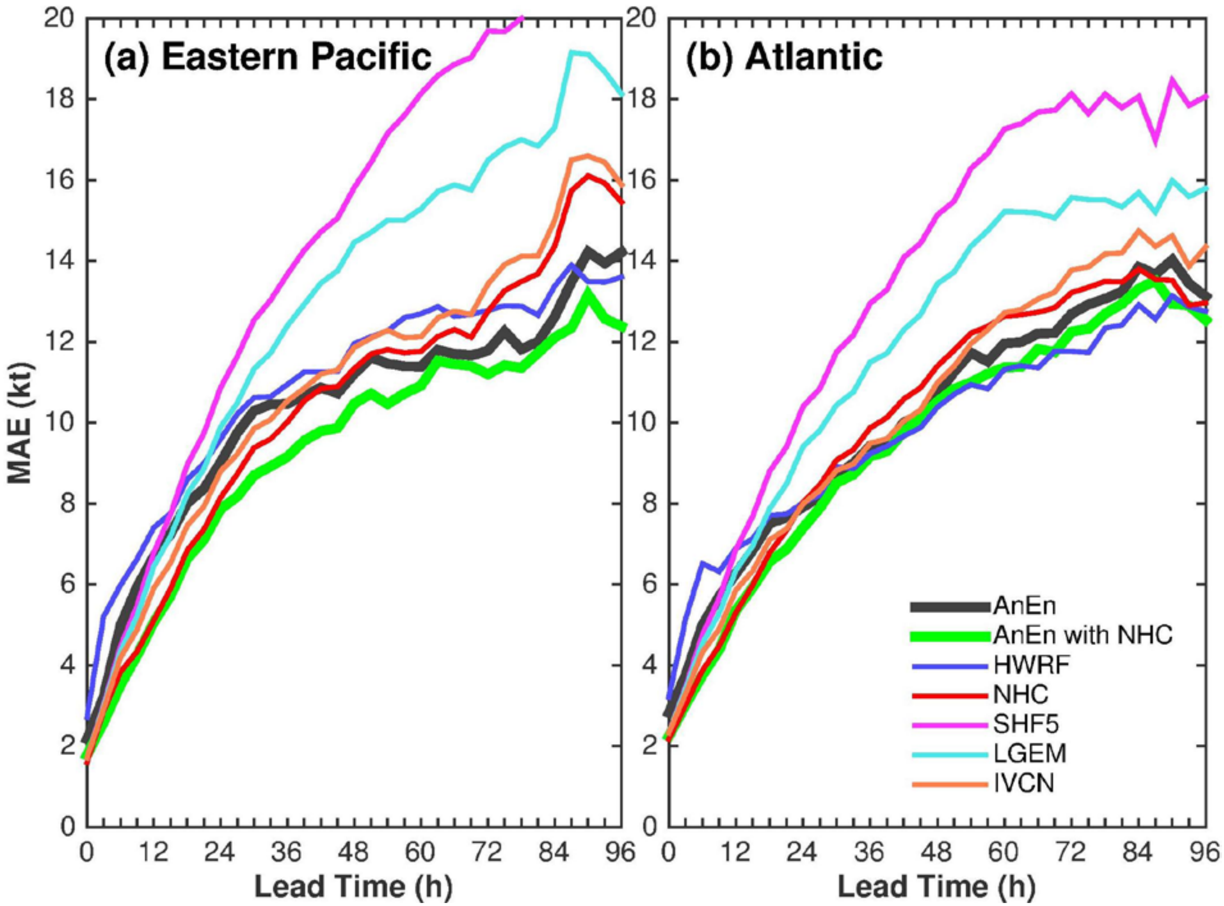

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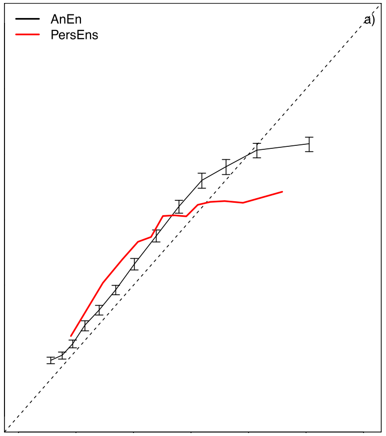
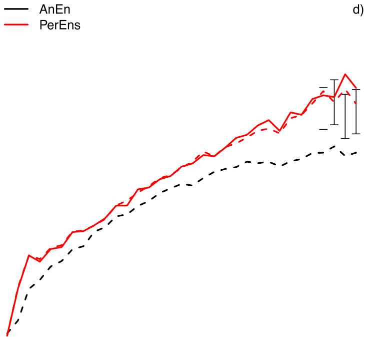




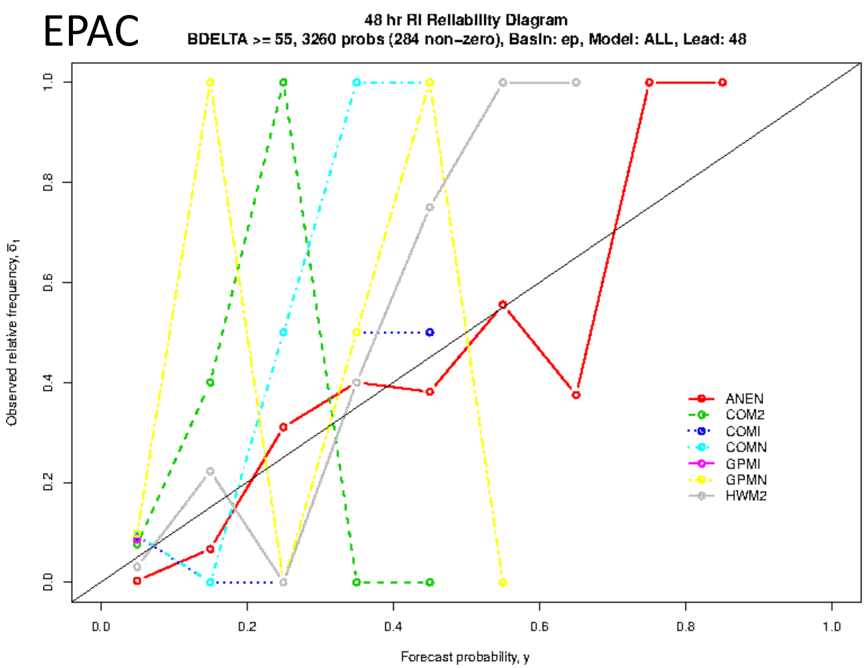
AnEn Intensity Model

- In 2015-version, the overall improvement of the AnEn over the HWRF was 7% with respect to MAE in the Eastern Pacific, while the improvement in the Atlantic is marginal overall, but with significant improvements at 0 – 30-h lead times.
- The 2016-version is being developed
  - We have 675 Atlantic reforecasts (2012 – 2015) and 1010 Eastern Pacific reforecasts (2014 – 2015)
  - We also have all of the real-time data 1060 Atlantic cases from 2016 but ran out of disk space for Eastern Pacific data, so we need to address our resources.

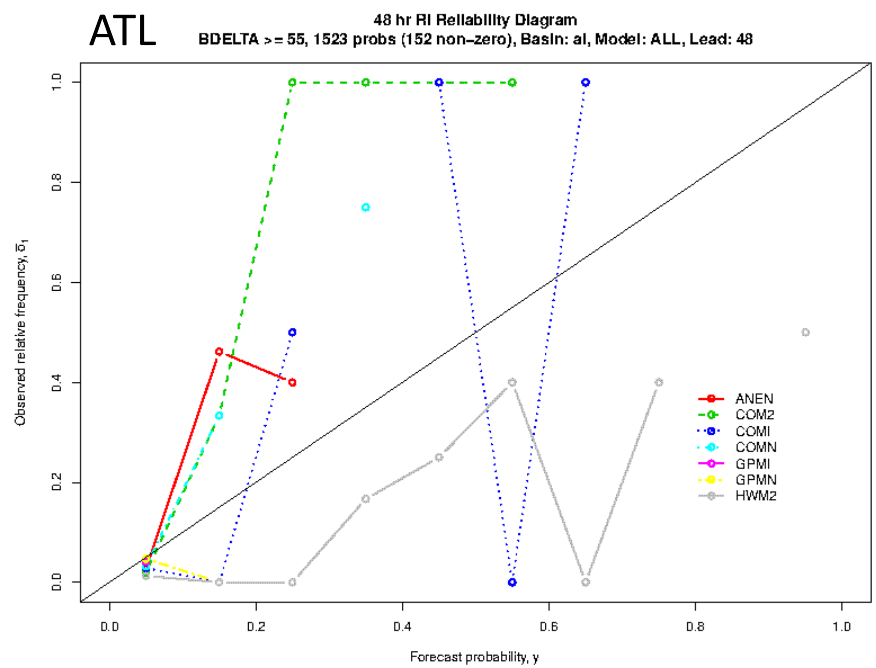
AnEn Intensity Change Model

- Here, we develop a model for Δv_{max} rather than v_{max}. Perhaps well suited for rapid intensification?
  - A preliminary version of the model trained with H215 reforecast data applied to 2013 – 2015 produced marginal results for the Atlantic, but had some reliability at various intensity change thresholds in the Eastern Pacific (plots from DTC and HFIP Ensemble Tiger Team) but suffered in the Atlantic, likely due to relatively lower number of RI analogs.

EPAC



ATL

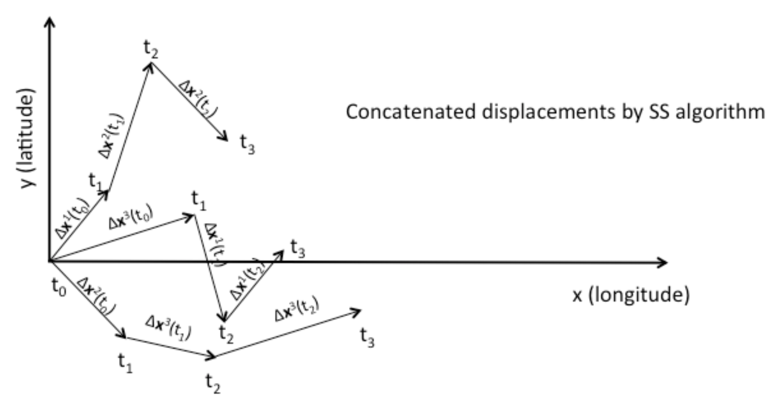


Current Status

- We are improving the AnEn intensity models with 2016 HWRF reforecast data, and will update to 2017 HWRF as that reforecast data become available.

AnEn Track Model

- Based in a Lagrangian framework following the TC trajectory
- Forecast relative displacements of TC center between 2 lead times.
- Two implementation strategies for the probabilistic prediction of total TC track
  1. Schaake Shuffle (SS) technique to concatenate a time series of analog-based observed displacements across all lead times. Here, the metric is observed track displacements for each forecast lead time.
  2. Similar to 1, but the metric we find is the difference between the analog position predicted and the observed position at a given lead time. The track corrections are applied to the current forecast of location, and added together into a total track via SS



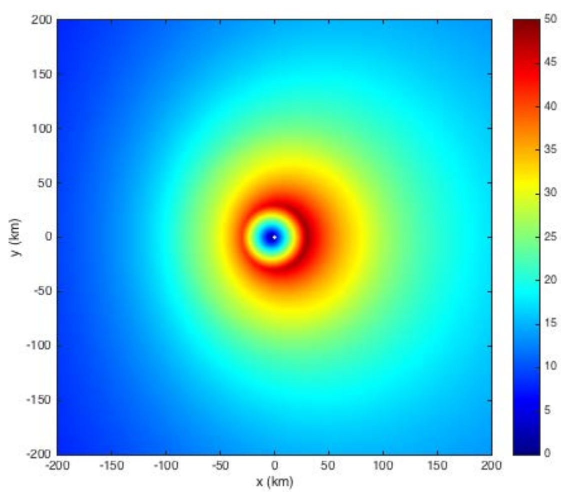
AnEn Track Model

- Currently creating AnEn predictors
  - Basic predictors
    - Storm lat/lon, storm translation speed, intensity, size, etc.
  - New predictors:
    - Structure based on two-dimensional EOF analysis of parent-domain grid 200-hPa and 500-hPa height fields.

AnEn Structure Model

- Goal: Predict 4 parameters: RMW, R34, R50, and R64 by quadrant
- Two implementation strategies
  1. Direct AnEn models for structure parameters
  2. Parameterized wind curves using the modified Rankine vortex

$$v(r,\theta) = a\cos(\theta-\theta_a) + b\cos[2(\theta-\theta_b)] + (v_{max} - a - b)\begin{cases} \left(\dfrac{r}{r_{max}}\right) & \text{for } r < r_1, \\ \left(\dfrac{r_{max}}{r}\right)^{\alpha} & \text{for } r \geq r_1. \end{cases}$$



  3. Predictors follow similarly to AnEn intensity model

Current Status

- Developing new predictors with the 2016-HWRF reforecast data
  - Will likely upgrade as soon as 2017 HWRF reforecast data become available
- 2016-2017 Progress and Plans
  - Developing Intensity and Intensity-change AnEn Systems, along with the Track Forecast system
  - Coordinate with HFIP Ensemble Tiger Team to evaluate AnEn with respect to other models
  - Real-time testing
- 2017-2018 Plans
  - Develop Structure based AnEn system
  - Real-time testing

Extra Slides

AnEn Intensity Model

			0-24 hours	27-96 hours
Atlantic	**First cycle**	**NHC VMAX (no)**	H215 VMAX (1.0)	H215 VMAX (0.4), RHHI (0.4), IKE2 (0.2)
		NHC VMAX (yes)	H215 VMAX (0.3), NHC VMAX (0.7)	H215 VMAX (0.6), NHC VMAX (0.4)
	Second cycle	**NHC VMAX (no)**	H215 VMAX (1.0)	H215 VMAX
		NHC VMAX (yes)	H215 VMAX (0.3), NHC VMAX (0.7)	H215 VMAX
	Third cycle	**NHC VMAX (no)**	H215 VMAX (0.8), USFCSYM3 (0.2)	H215 VMAX
		NHC VMAX (yes)	H215 VMAX (0.4), NHC VMAX (0.6)	H215 VMAX (0.4), NHC VMAX (0.4), TGRD (0.2)
East Pacific			0-24 hours	27-96 hours
	First cycle	**NHC VMAX (no)**	H215 VMAX (1.0)	H215 VMAX (0.8), SHR_MAG (0.2)
		NHC VMAX (yes)	H215 VMAX (0.2), NHC VMAX (0.8)	H215 VMAX (0.4), NHC VMAX (0.4), CAPE3 (0.2)
	Second cycle	**NHC VMAX (no)**	H215 VMAX (1.0)	H215 VMAX (0.5), TCOND7002 (0.5)
		NHC VMAX (yes)	H215 VMAX (0.2), NHC VMAX (0.7), TPW (0.1)	H215 VMAX (0.3), NHC VMAX (0.3), CAPE3 (0.2), TPW (0.2)
	Third cycle	**NHC VMAX (no)**	H215 VMAX (1.0)	H215 VMAX(0.3), LAT (0.3), INST3 (0.4)
		NHC VMAX (yes)	H215 VMAX (0.3), NHC VMAX (0.7)	H215 VMAX (0.4), NHC VMAX (0.4), RHMD (0.2)