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A NMME-based Hybrid Prediction System for Atlantic Hurricane Season Activity

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A North American Multi-Model Ensemble (NMME)-based hybrid statistical-dynamical prediction system for Atlantic hurricane season tropical storm activity has been developed at Climate Prediction Center to support the NOAA Hurricane Season Outlooks. Multiple-linear regression relationships have been previously established between combinations of observed and coupled general circulation model (GCM) forecast atmospheric and oceanic states and subsequent hurricane season activity (*e.g.* Wang *et al.* 2009) and have been used in operations at the Climate Prediction Center to support NOAA's Hurricane Seasonal Outlook. This work addresses whether aggregation of multiple GCM forecasts from the North American Multi-model Ensemble (NMME; Kirtman *et al.* 2014) can improve upon single GCM inputs with a similar hybrid approach.

Predictors are selected as the forecast August-October (ASO) zonal wind shear (difference between 850 and 200 hPa) over the Atlantic Main Development Region (MDR; 10-20°N, 20-80°W) and preseason sea surface temperature (SST) for the North Atlantic (55-65°N, 30-60°W) averaged over the preceding 3 months to the forecast being made. Predictands are seasonal total hurricane count, tropical storm count, major hurricane count, and accumulated cyclone energy (ACE) as a percentage of median. The prediction system was evaluated in cross-validation mode for the hindcast period of 1982-2010. Table 1 details the performance of the hybrid model predictions of seasonal hurricane count for each of the four member GCMs (CanCM3, CanCM4, CCSM4, and CFSv2) and the NMME multi-model mean in terms of correlation and root mean squared error. The NMME multi-model mean correlations exceed those of each individual member GCMs, while reducing RMSE by 19% and 25% relative to the best performing GCMs initialized in April and July respectively. Comparable relationships are also obtained for other predictands, with the NMME consistently displaying improved correlations with observed hurricane activity and reducing RMSE relative to the best

Table 1: Hindcast ensemble mean correlations and RMSE (in parentheses) for hybrid model cross-validation with April and July initial conditions. Columns indicate GCM used to force hybrid model and number of ensemble members, with NMME referring to the multi-model mean.

Init. Cond.	CanCM3 (10)	CanCM4 (10)	CCSM4 (10)	CFSv2 (12)	NMME (4)
April	0.42 (2.87)	0.47 (2.80)	0.46 (2.80)	0.46 (2.80)	0.49 (2.27)
July	0.67 (2.36)	0.66 (2.37)	0.62 (2.47)	0.67 (2.36)	0.71 (1.76)

Table 2: Hybrid model forecasts for April 2015 utilizing predictors of forecast ASO wind shear over the MDR and observed January-March mean North Atlantic SST. Columns indicate GCM used to force the hybrid model, with NMME referring to the multimodel mean. Last column denotes preliminary observed 2015 hurricane activity. Numbers in bold indicate the observations fell within the forecasted range.

Predictand	CanCM3	CanCM4	CCSM4	CFSv2	NMME	Observed
Hurricanes	**3 (1-5)**	2 (0-3)	**5 (4-6)**	6 (5-7)	**4 (3-5)**	4
Tropical Storms	6 (1-10)	4 (1-6)	9 (8-10)	**11 (9-13)**	7 (5-10)	11
Major Hurricanes	**1 (0-2)**	1 (0-1)	**2 (2-2)**	**2 (2-3)**	**1 (1-2)**	2
ACE (% Median)	**50 (5-94)**	21 (0-45)	**80 (64-96)**	102 (75-128)	**62 (35-91)**	64%

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GCM member.

The hindcast evaluation indicated that the hybrid prediction system provides skillful prediction of seasonal tropical storm activity and gave impetus to attempt a real-time test for the 2015 hurricane season. For the April 2015 NMME hybrid model forecast the ensemble mean anomalous wind shear for ASO across the Atlantic is shown in Figure 1. While all GCMs forecast above normal wind shear across the MDR associated with the developing El Niño, the two Canadian GCMs portrayed strong shear focused within the MDR while the CCSM4 and CFSv2 kept the strongest shear south of the MDR. The resulting NMME mean ASO forecast wind shear anomaly of 3.20 m/s lies between the four individual GCM projections, while also keeping the strongest shear south of the MDR. These shear values were then used to drive the hybrid forecast to generate an initial forecast of 2015 hurricane activity for each ensemble mean, with additional uncertainty conveyed by adding and subtracting one standard deviation of the ensemble member predictions. Table 2 provides the details of the April 2015 hybrid model forecast for each of the NMME members and the multi-model mean forecast. The four hurricanes observed in the Atlantic during 2015 matched the NMME prediction, while also falling within the forecast ranges of the CanCM3 and CCSM4. CFSv2 was the only model to accurately depict tropical storm activity in 2015, with the mean prediction matching the observed eleven tropical storms, while the NMME forecast predicted fewer storms due to the low forecast values from the CanCM3 and CanCM4. The two observed major hurricanes fell within the forecast ranges of all GCMs and the NMME mean with the exception of the CanCM4. ACE activity was correctly forecast by the CanCM3, CCSM4, and NMME ranges with the NMME mean prediction only 2% removed from the preliminary observed value. The 2015 season marked an early success for the NMME hybrid hurricane prediction model, with optimism for improved skill as additional GCMs have their hindcasts added to the NMME Phase 2 archive. Expectations are for the NMME hybrid prediction system to remain a critical component in developing the NOAA Hurricane Seasonal Outlooks for years to come.

For much more on this work please see a forthcoming manuscript of the same title in a special NMME edition of *Climate Dynamics*.

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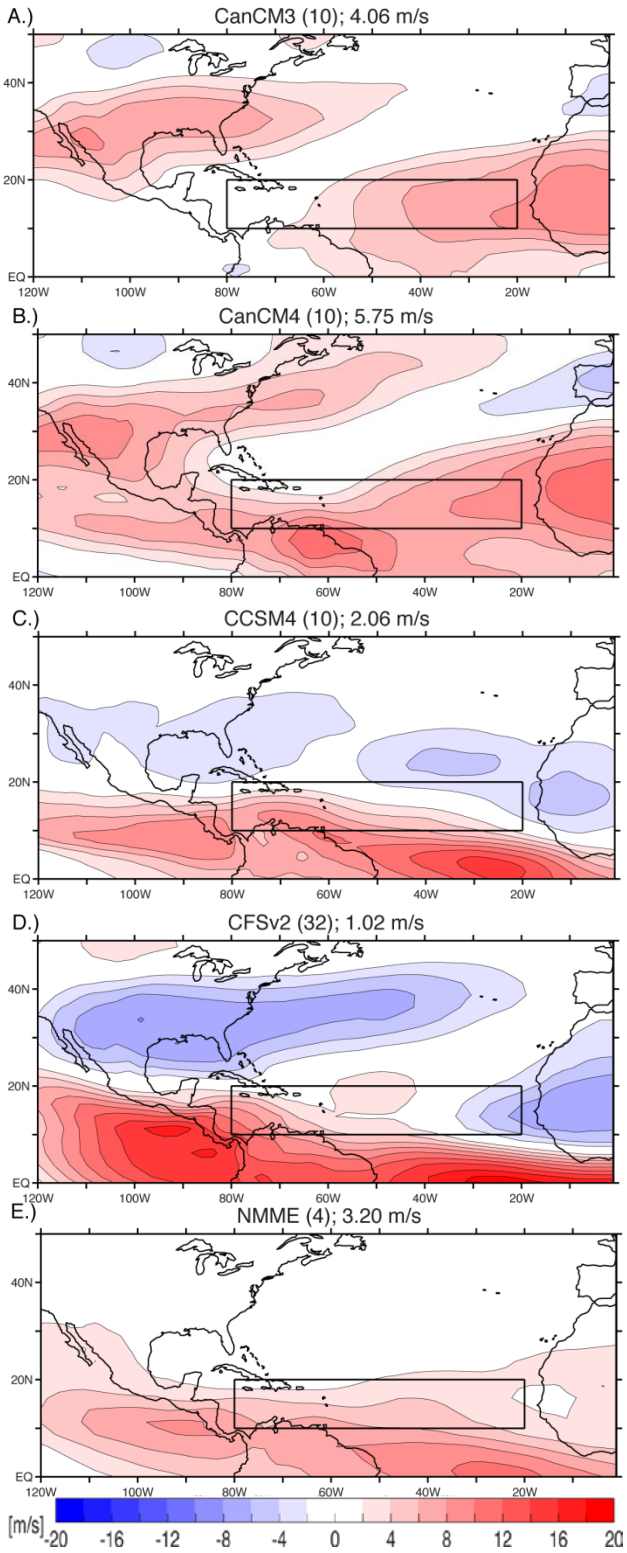

Fig. 1 Forecast anomalous ensemble mean vertical wind shear for ASO 2015 with April initial conditions relative to 1982-2010 for CanCM3 (A), CanCM4 (B), CCSM4 (C), CFSv2 (D), and NMME multi-model mean (E). MDR region is outlined in black box. Ensemble sizes and averaged MDR shear anomaly are listed in each panel's title. Contour interval is 2 m/s.

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