The Impact of the El Niño-Southern Oscillation and Atlantic Meridional Mode on Seasonal Atlantic Tropical Cyclone Activity

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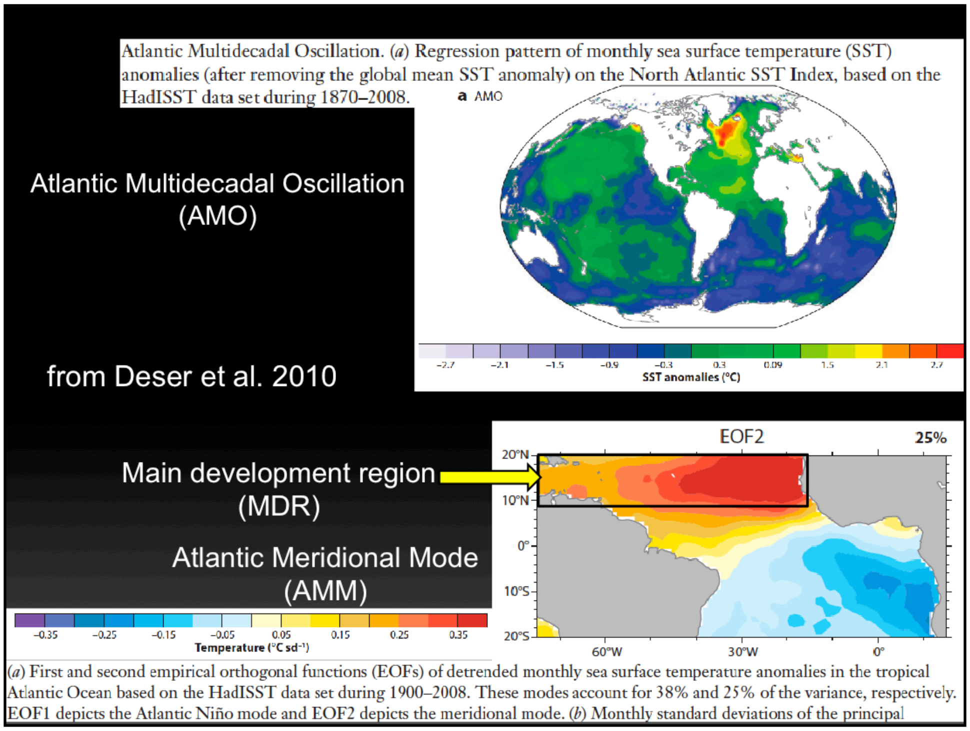
Questions:

- What is the impact of strong *concurrent* phases of the El Niño Southern Oscillation (ENSO) and Atlantic Meridional Mode (AMM) on seasonal Atlantic tropical cyclone (TC) activity?
- How do various phases of ENSO and AMM together shape the atmospheric environment for Atlantic TC development?

Bell and Chelliah (2006) – Atlantic Multidecadal SST can dampen or amplify ENSO's influence during hurricane seasons, suggesting that both modes together offer a more complete understanding of seasonal Atlantic TC variability compared to considering only ENSO.

Outline:

- Overview of ENSO and AMM, and their individual influences on Atlantic TCs
- Observational analysis: composites of TC activity
- Modeling experiments: force regional model with combinations of extreme ENSO and AMM phases
  - TC activity
  - Genesis potential index


Atlantic Multidecadal Oscillation. (a) Regression pattern of monthly sea surface temperature (SST) anomalies (after removing the global mean SST anomaly) on the North Atlantic SST Index, based on the HadISST data set during 1870–2008.
a AMO
Atlantic Multidecadal Oscillation (AMO)
from Deser et al. 2010
SST anomalies (°C)
EOF2
25%
Main development region (MDR)
Atlantic Meridional Mode (AMM)
20°N
10°N
0°
10°S
20°S
60°W
30°W
0°
Temperature (°C sd⁻¹)
(a) First and second empirical orthogonal functions (EOFs) of detrended monthly sea surface temperature anomalies in the tropical Atlantic Ocean based on the HadISST data set during 1900–2008. These modes account for 38% and 25% of the variance, respectively. EOF1 depicts the Atlantic Niño mode and EOF2 depicts the meridional mode. (b) Monthly standard deviations of the principal

Observed relationships between Atlantic TCs and ENSO and AMM

ENSO

phase	eastern Equatorial Pacific SST anomaly	Tropical Atlantic vertical wind shear	Tropical Atlantic static stability	Atlantic TC season
El Niño	warm	increase	increase	inactive
La Niña	cool	decrease	decrease	active

(Gray 1984; Shapiro 1987; Gray and Sheaffer 1991; Gray et al. 1993; Goldenberg and Shapiro 1996; Richards and O'Brien 1996; Knaff 1997; Tang and Neelin 2004; Camargo et al. 2007; many others)

AMM

phase	northern/southern tropical Atlantic SST anomaly	Tropical Atlantic vertical wind shear	Tropical Atlantic static stability	Atlantic TC season
positive	warm/cool	decrease	decrease	active
negative	cool/warm	increase	increase	inactive

(Kossin and Vimont, 2007; Vimont and Kossin, 2007)

TCs and Atlantic SST: Landsea et al. 1999; Goldenberg et al. 2001; Vitart and Anderson (2001); Emanuel (2005); Trenberth (2005); Webster (2005); Holland and Webster (2007); Knutson et al (2007); others

Why not focus on the AMO or MDR SST?

From Vimont and Kossin, 2007

Table 1. Correlations Between Hurricane Activity and Large-Scale Climatic Indices[a]

	Large-Scale Local Conditions						Climatic Indices			
	SST	SLP	VOR	SHR	CON	$\Delta\theta_e$	ACE	AMM	AMO	N34
					Correlations Between Unfiltered Time Series					
ACE							1	0.64	0.44	−0.31
AMM							0.64	1	0.60	(−0.14)
AMO							0.44	0.60	1	(−0.06)
					Correlations Between Lowpass-Filtered Time Series					
ACE							1	0.75	0.80	(−0.03)
AMM							0.75	1	0.82	(0.17)
AMO							0.80	0.82	1	(0.06)
					Correlations Between Highpass-Filtered Time Series					
ACE							1	0.49	(0.01)	−0.44
AMM							0.49	1	(0.23)	−0.39
AMO							(0.01)	(0.23)	1	−0.33

[a]Correlations that are expected, via physical arguments, to contribute to an increase in hurricane activity are listed in bold and underlined. Statistical significance is inferred when the correlation's T-statistic exceeds the one-tailed (for ACE) or two-tailed (for the AMM and AMO indices) 95% significance level, using the effective number of degrees of freedom [*Bretherton et al.*, 1999]. Correlations that are not statistically significant are listed in parentheses – all other correlations are statistically significant.

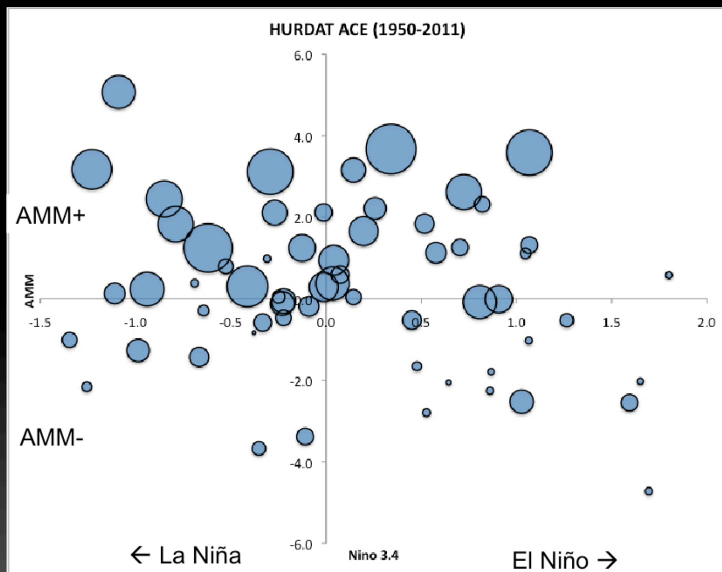
Quantifying TC activity

Accumulated cyclone energy (ACE) (Bell et al. 2000)
$ACE = 10^{-4} \Sigma v^2_{max}$

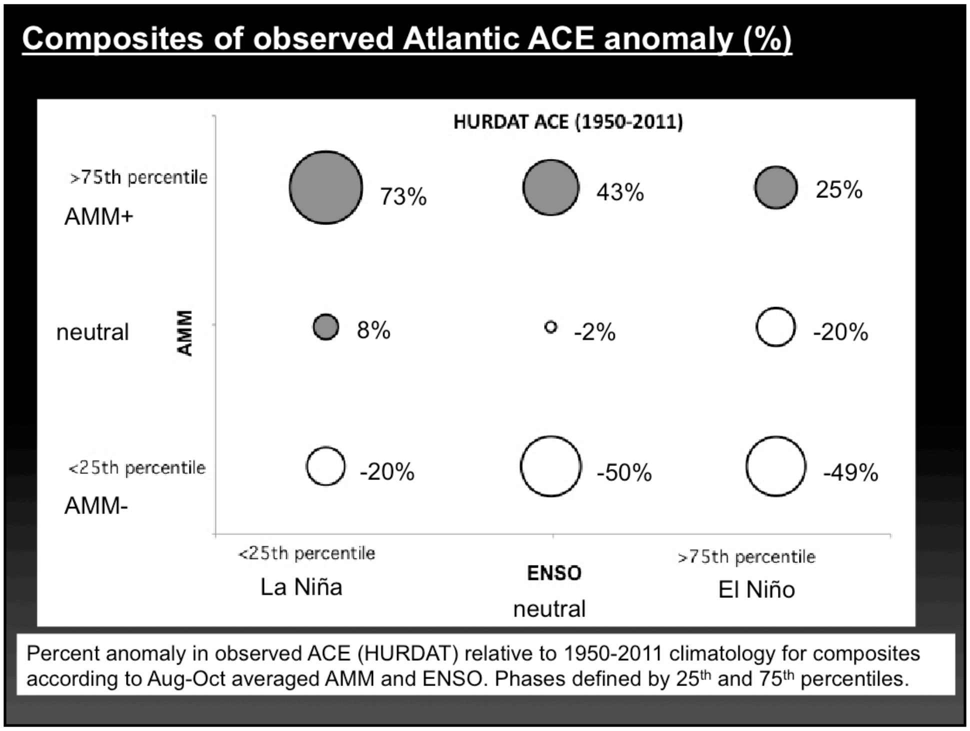
v_{max} = 6-hourly maximum sustained wind speed (knots)

- accounts for storm strength, number, and duration

ENSO, AMM, and observed Atlantic ACE (1950-2011)



Large part of Atlantic TC variability explained by AMM and ENSO



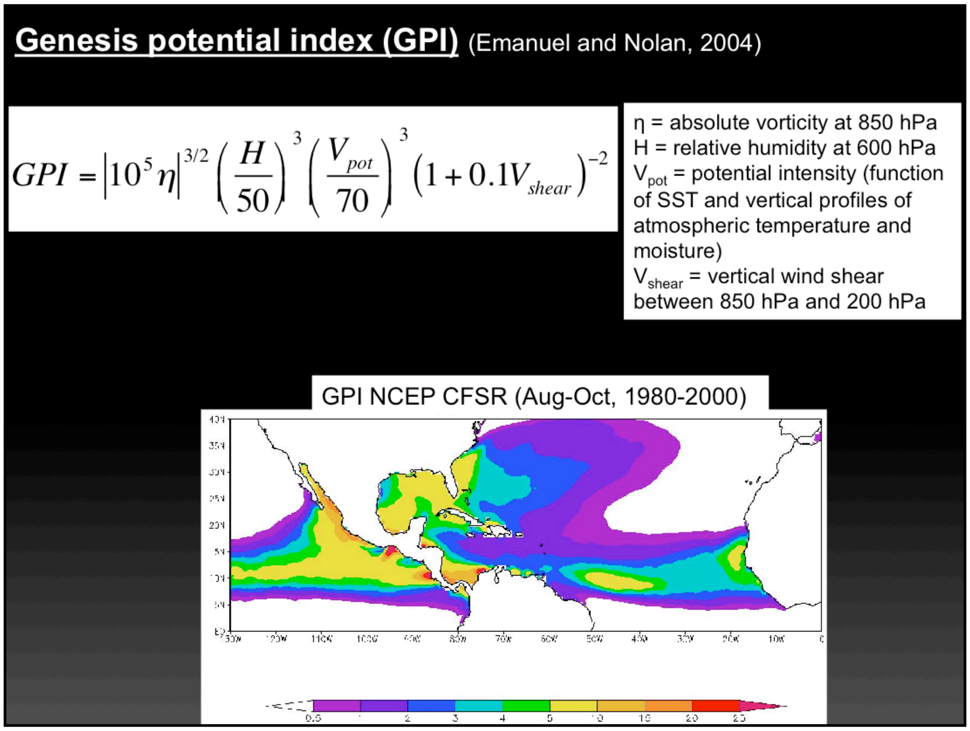
Here, we have composites of ACE anomalies, in percent, from 1950-2011 HURDAT observations, categorized by ENSO and AMM, with positive and negative phases defined by the 25th and 75th percentiles, respectively.

•Regardless of ENSO, ACE is above normal for positive AMM and below normal for negative AMM.

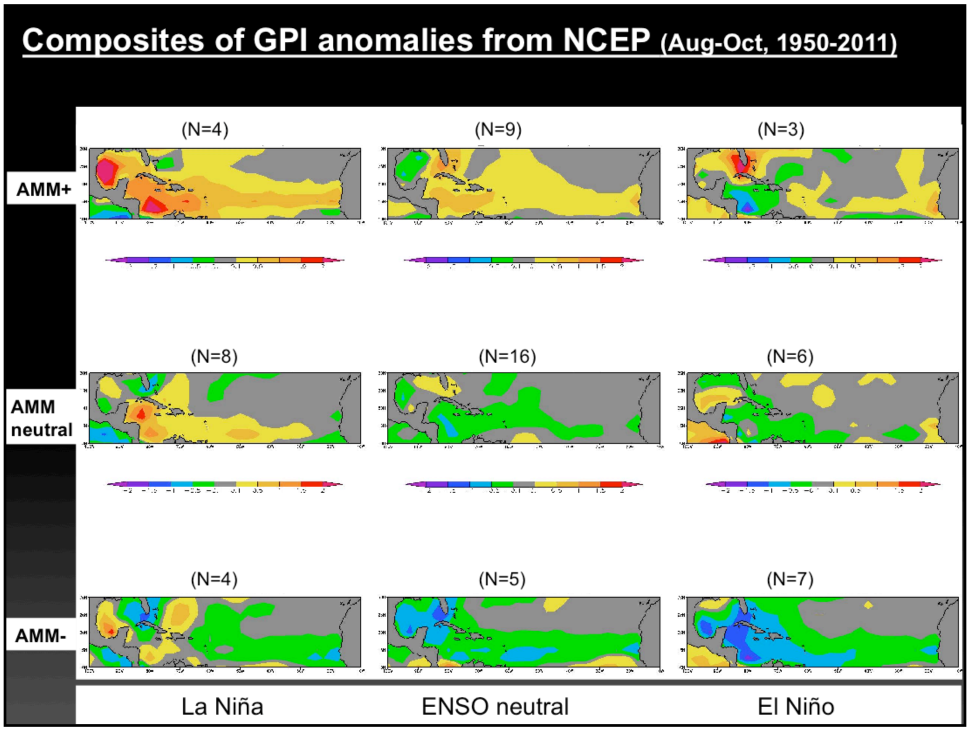
•Negative AMM and neutral ENSO is sufficient to largely suppress TC activity, with little change in going to negative AMM and El Nino.

• AMM and ENSO phases which individually oppose each other in their influence on Atlantic TC activity together support near-average TC activity.

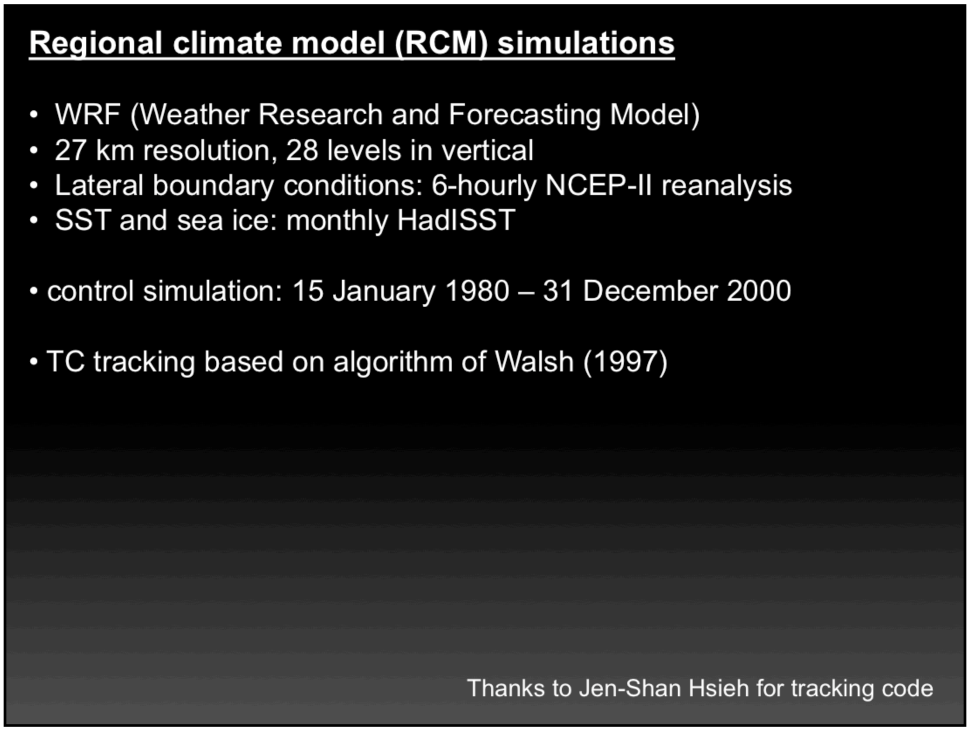
•Both positive AMM and La Nina together tend to support most active TC seasons



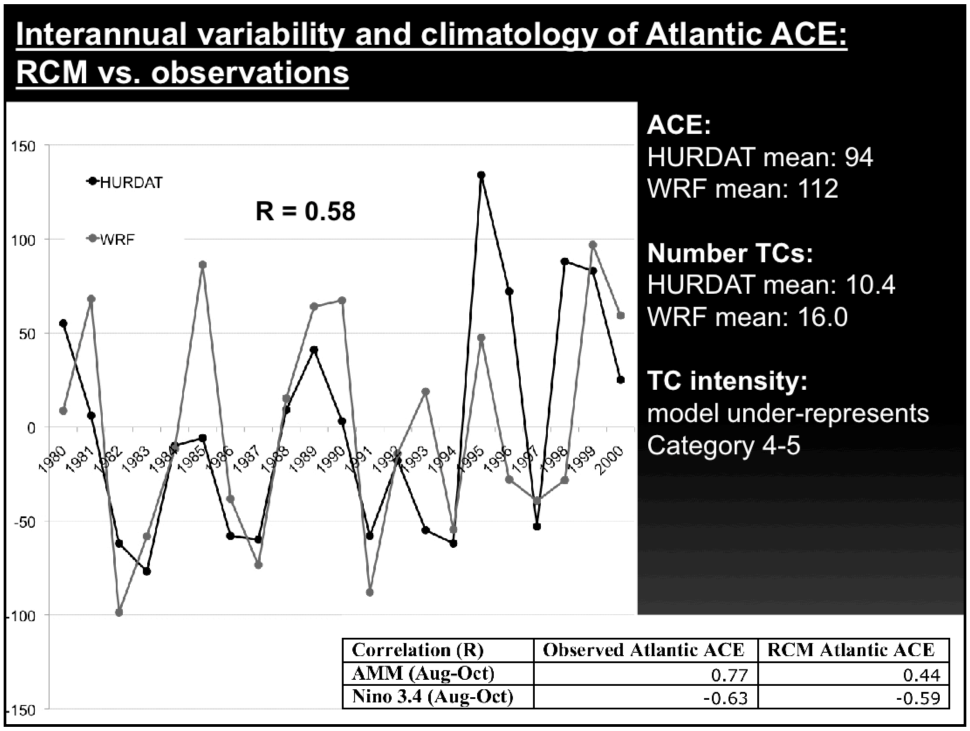
GPI used to evaluate atmospheric conditions relevant for TC formation



One issue in making composites from 6 decades of data is that we end up with some small sample sizes…



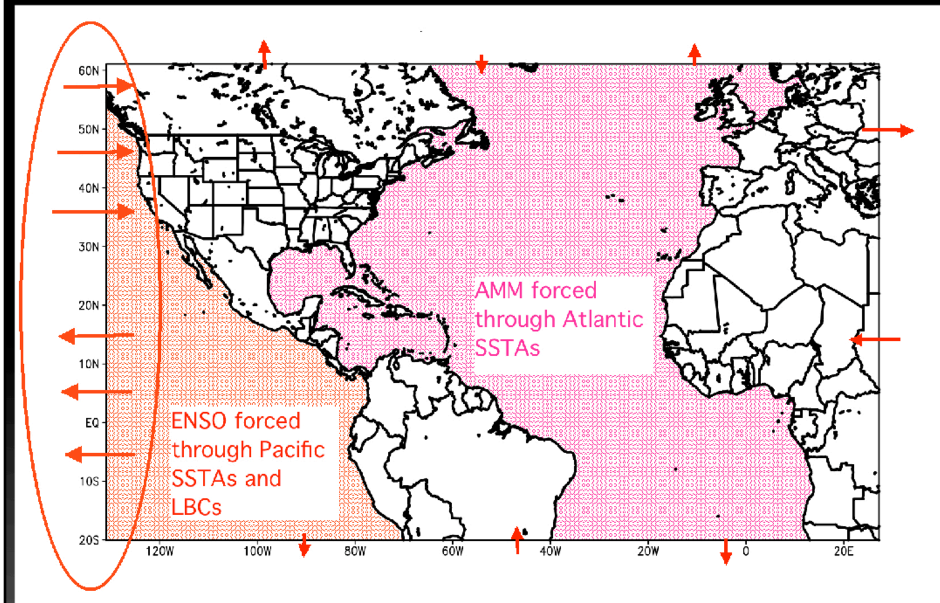
…so we supplement the relatively short data record with model simulations.



Correlation (R)	Observed Atlantic ACE	RCM Atlantic ACE
AMM (Aug-Oct)	0.77	0.44
Nino 3.4 (Aug-Oct)	-0.63	-0.59

To briefly demonstrate the model's capability, we show the timeseries of normalized seasonal ACE from the observations, in black, and the model, in grey. The model reproduces the interannual variability of ACE fairly well, with R of 0.58. Simulated mean ACE is close to observed, and WRF produces too many TCs and under-represents cats 4 and 5. The model also simulates a relationship between ACE and AMM that is slightly weaker than observed, and a relationship between ACE and ENSO that matches observations.

Regional model experiments



Regional model experiments

ENSO forcings (particular observed case of Pacific SST and LBCs)		
El Niño	1987	95th percentile Nino 3.4
La Niña	1999	15th percentile Nino 3.4
AMM forcings (particular observed case of Atlantic SST)		
Positive	2005	95th percentile AMM index
Negative	1984	5th percentile AMM index
Neutral	1987	60th percentile AMM index
Moderately positive	1999	80th percentile AMM index

Simulations (2- or 4-member ensembles):

- El Niño &
  - AMM-
  - AMM neutral
  - AMM+
- La Niña &
  - AMM-
  - AMM mod+
  - AMM+

La Niña & AMM+

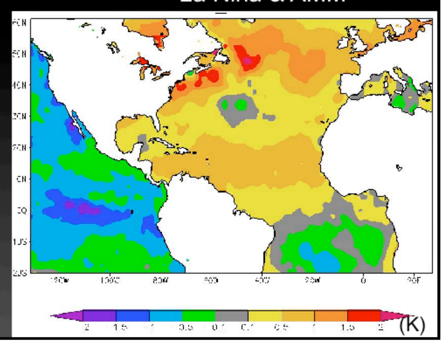


Fig: Prescribed SST forcing for La Nina and AMM+ case

ENSO and AMM combinations

Atlantic SST not entirely independent of Pacific and is strongly influenced by ENSO, particularly in the spring (Enfield and Mayer, 1997; Klein et al., 1999; Saravanan and Chang, 2000; Mo and Häkkinen, 2001)

Northern tropical Atlantic SST also modulated by:

- North Atlantic Oscillation (Mo and Häkkinen, 2001; Czaja et al. 2002)
- AMO (Vimont and Kossin 2007)
- anthropogenic warming

Therefore, while this may lead to some tendency for preferred ENSO/ AMM combinations, it does not preclude the occurrence of each combination.

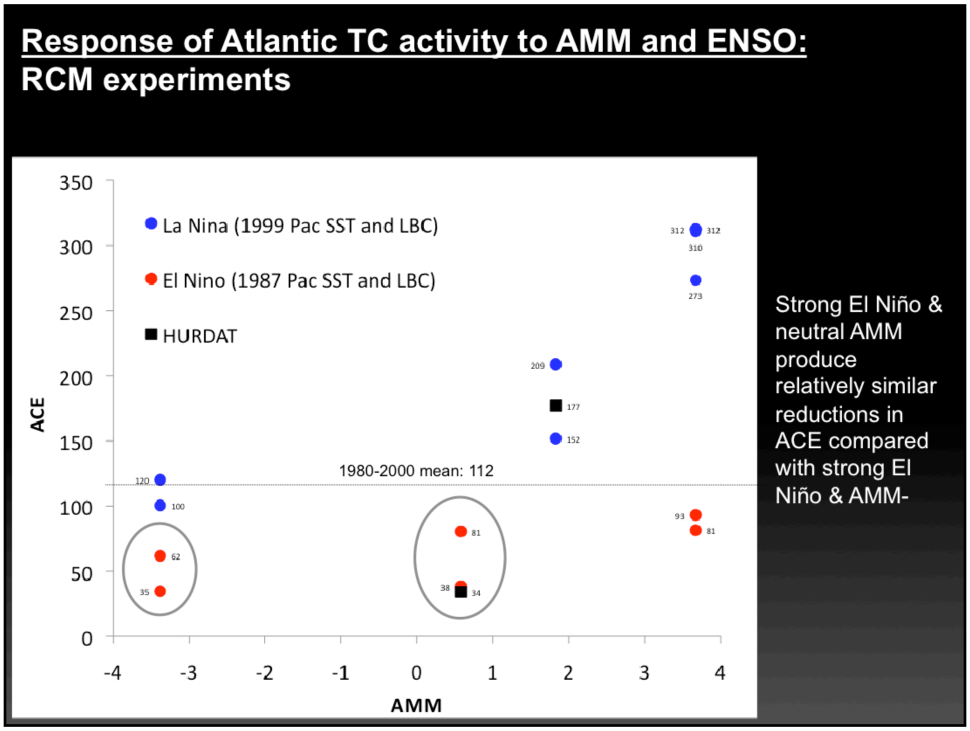
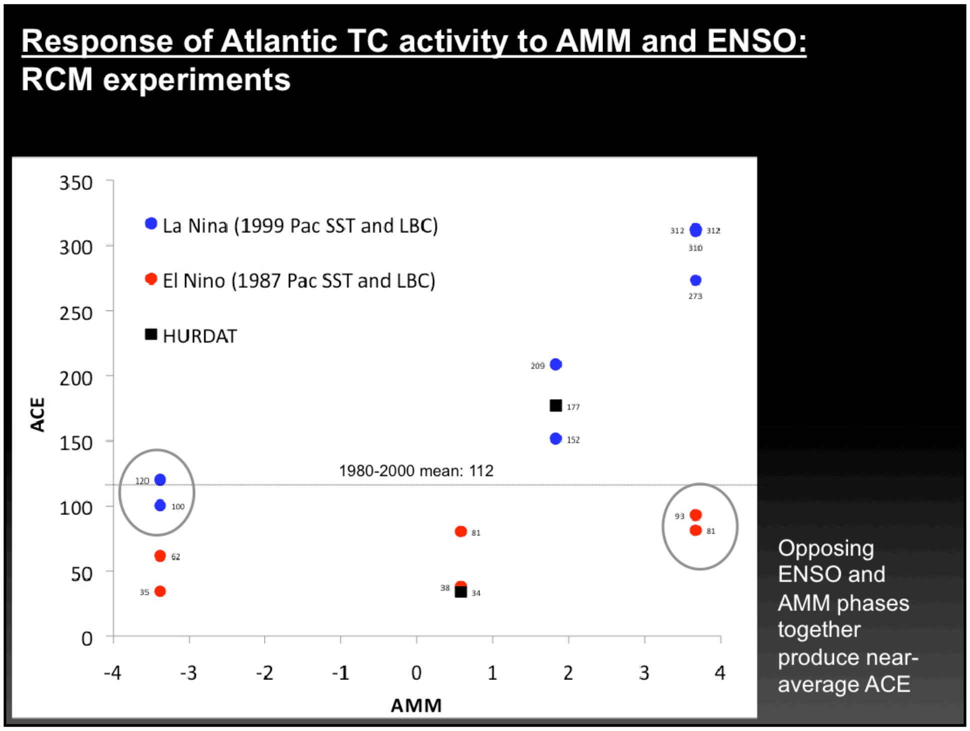


Fig: ACE for ENSO/AMM experiments. Prescribed AMM is on x-axis, prescribed ENSO denoted with color of mark. Model 1980-2000 mean dashed, for reference. Black dots for reference from HURDAT.



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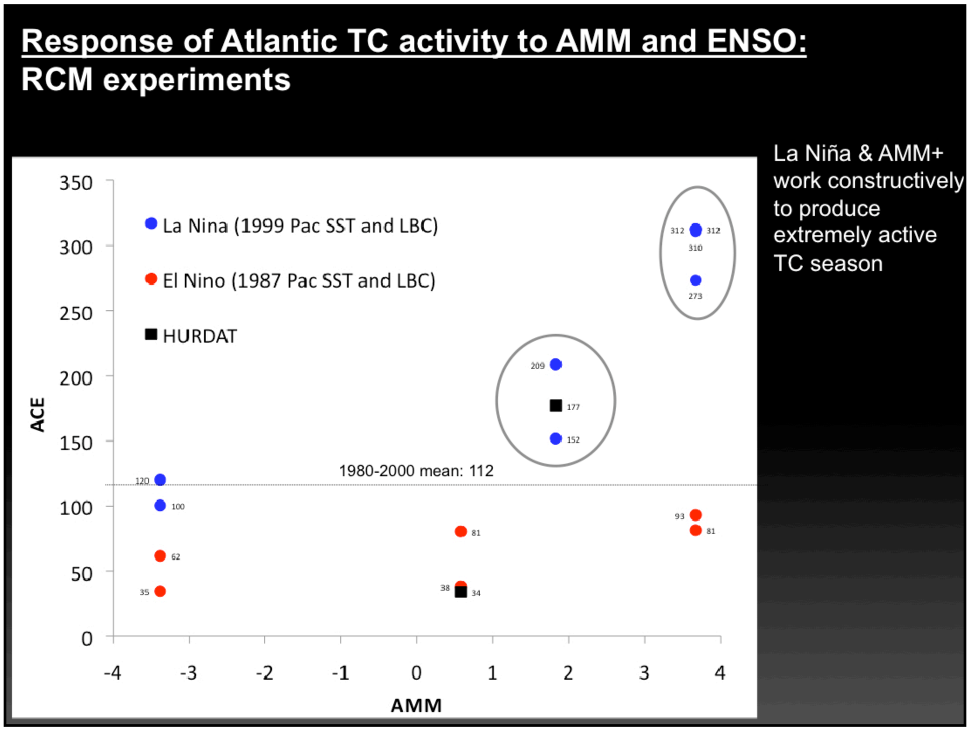

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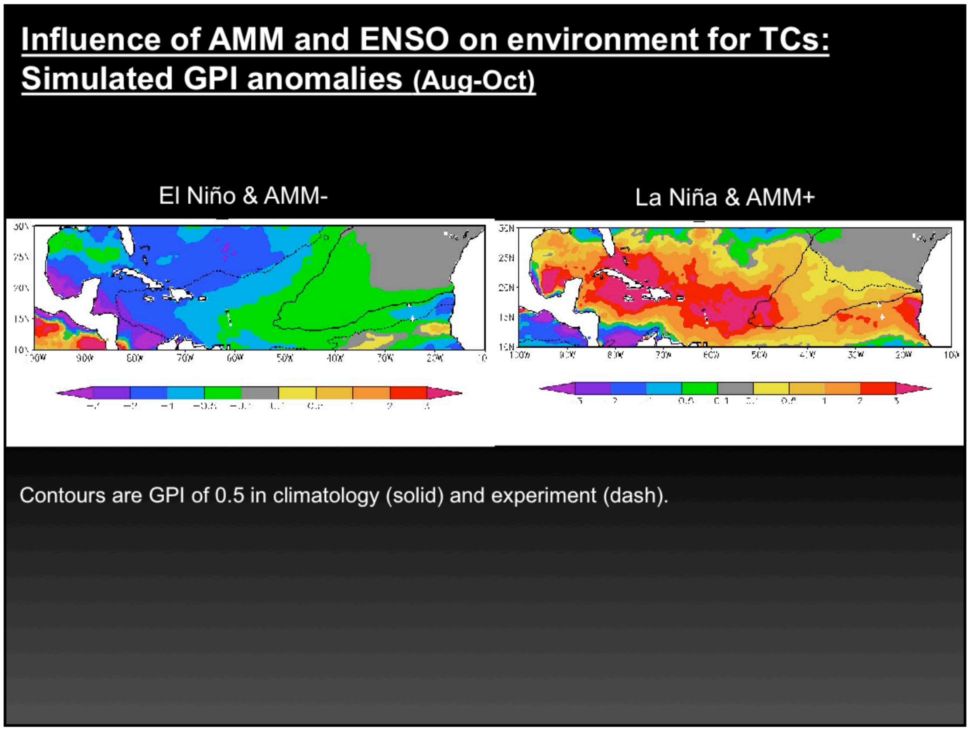
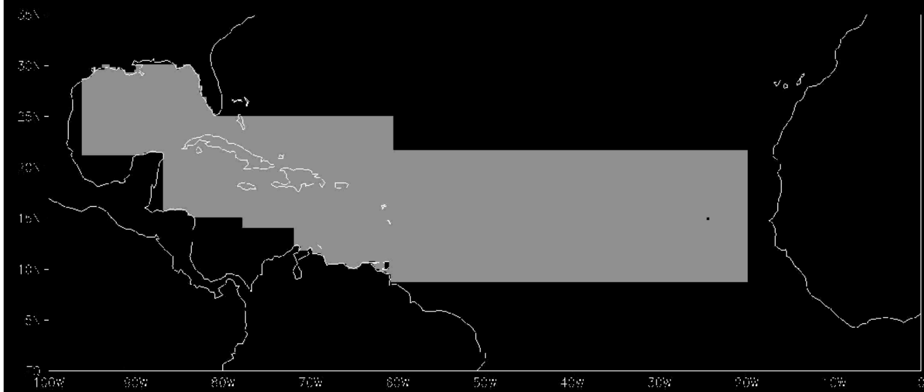


Reduced/increased GPI and area of supportive conditions for TCs. Fig: anomaly in GPI for experiments (shaded) with GPI=0.5 in climatology (solid) and experiment (dash)

Atlantic TC development region



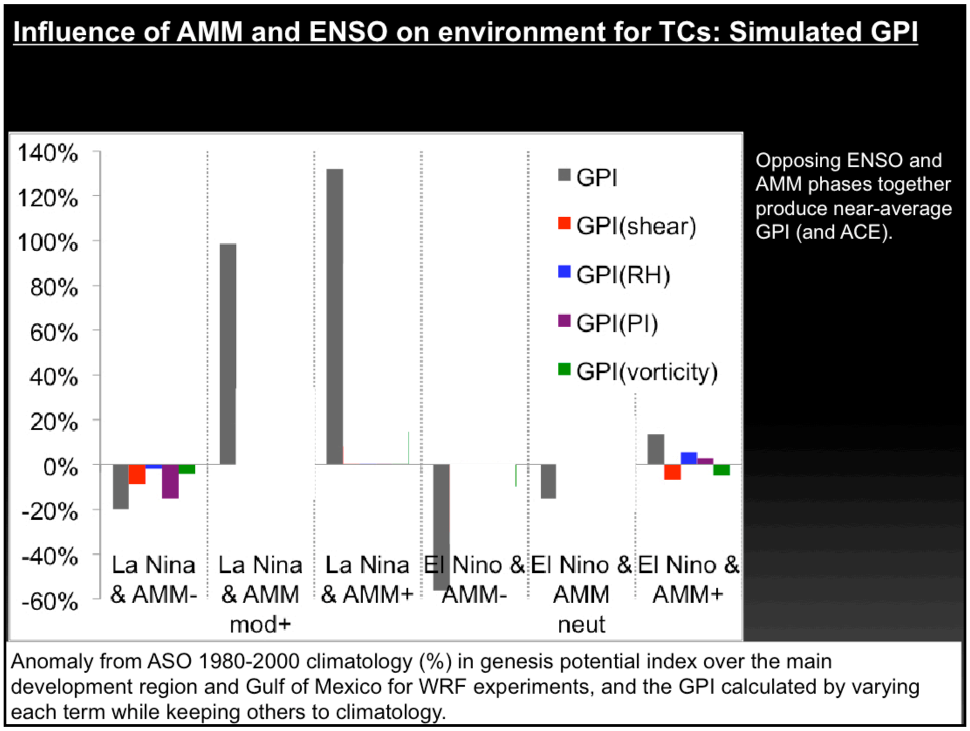
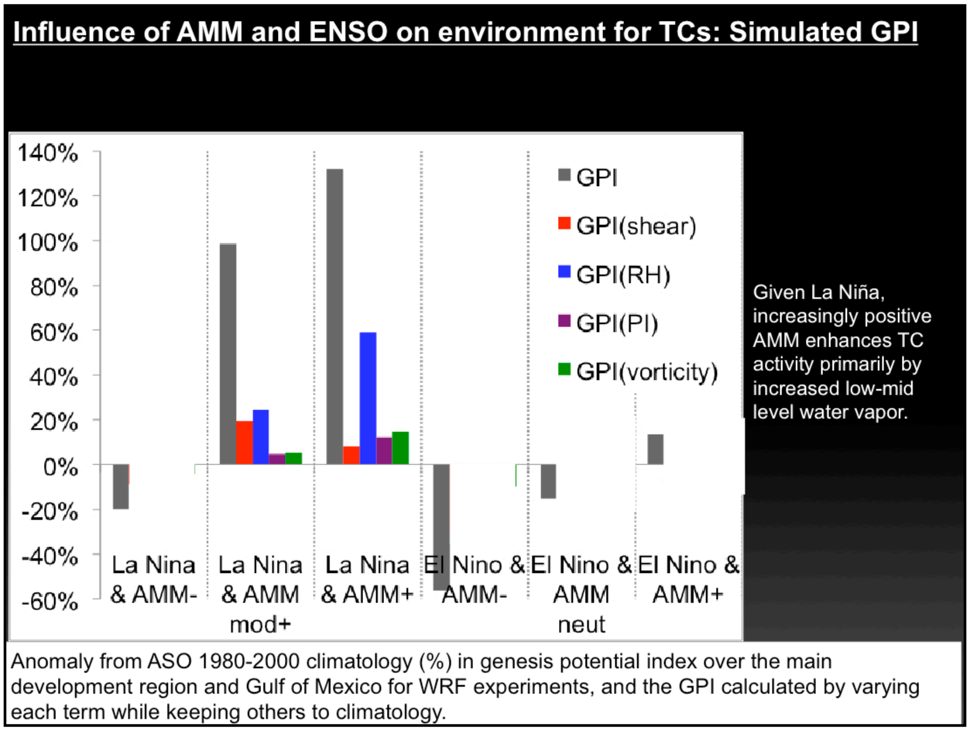


Fig: percent anomalies in MDR&GOM-averaged Aug-Oct GPI. Grey bars are GPI and colored bars are GPI calculated by varying only one term at a time, so we can evaluate role of each factor.

Point 3: this is related to 10m/s threshold in vertical wind shear, which is already reached over most of MDR and GOM in Niño&neutral AMM case.



Anomaly from ASO 1980-2000 climatology (%) in genesis potential index over the main development region and Gulf of Mexico for WRF experiments, and the GPI calculated by varying each term while keeping others to climatology.

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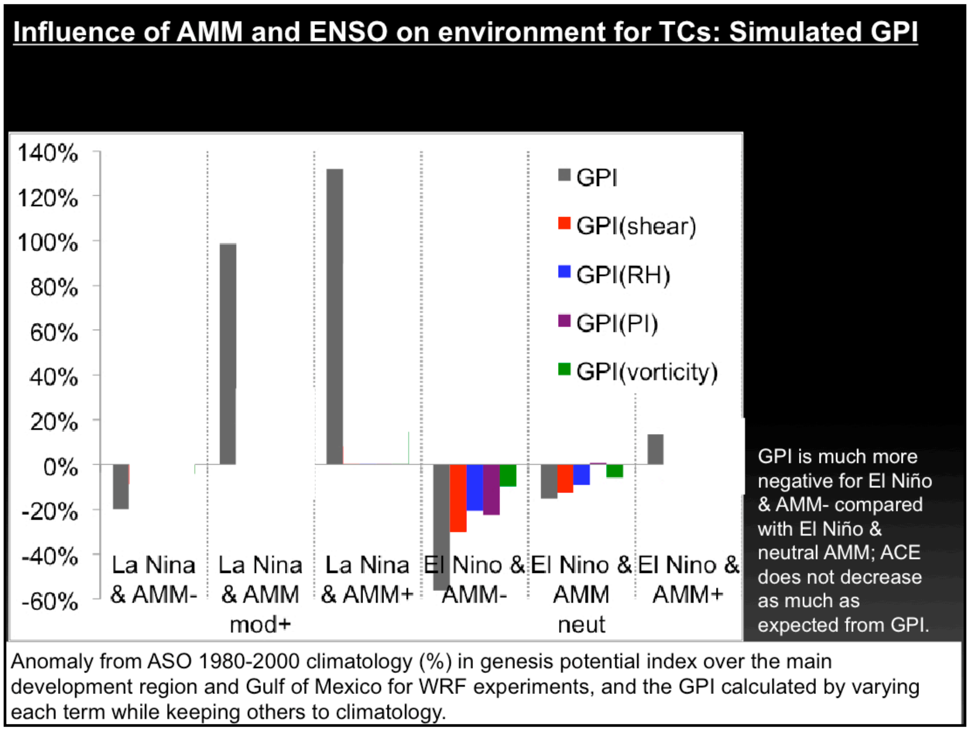

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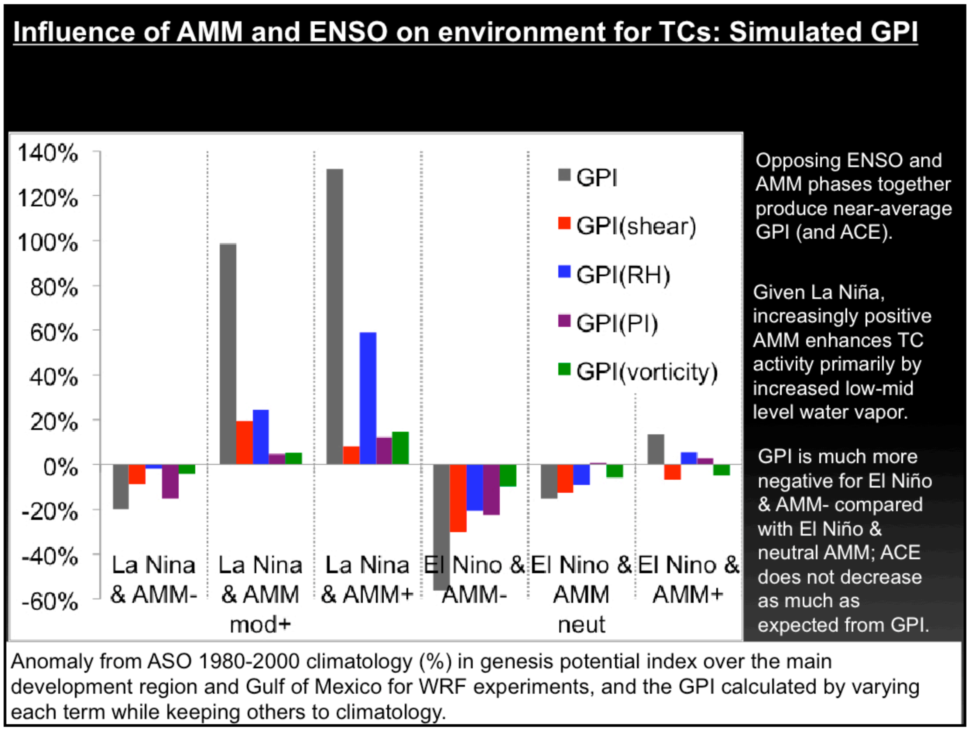

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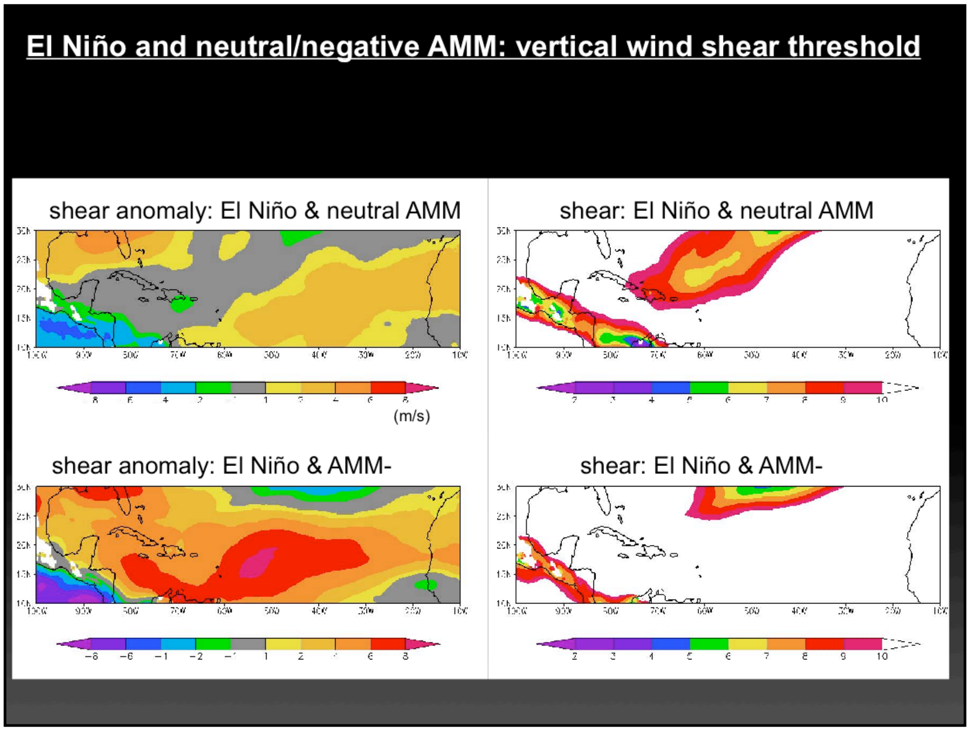

Shear over most of MDR and GOM already exceeds 10m/s threshold in Nino/neutral AMM case

Summary

- Observations and simulations demonstrate:
  - Importance of AMM and ENSO together in modulating seasonal Atlantic TC activity.
  - Concurrent strong ENSO and AMM phases that individually oppose each other in their influence on Atlantic TC activity produce near-average seasons.
  - La Niña and positive AMM <u>together</u> work constructively to produce prime conditions for Atlantic TCs and support extremely active TC season.
    - increasingly positive phase of AMM enhances TC activity primarily by increasing low- to mid-level atmospheric moisture.
  - Obs: negative AMM together with neutral ENSO is sufficient to largely suppress Atlantic TC activity.
  - Simulations: strong El Niño together with neutral AMM is sufficient to largely suppress TC activity.
    - related to the threshold of ~10m/s in vertical wind shear, which is already established over much of the MDR in the El Niño & neutral AMM case.

Important implications for climate change. We need to consider changes in frequency and magnitude of AMM and ENSO together – climatological ΔSST is not enough