The Response of Atlantic Tropical Cyclones to Suppression of African Easterly Waves

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Conditions for Atlantic tropical cyclones

1) warm upper-ocean temperature
2) unstable atmosphere
3) moist mid-troposphere
4) weak vertical wind shear
5) **"seedling" low-pressure disturbance – in Atlantic, usually AEWs**

African Easterly Waves (AEWs)

- trough of low pressure, 850 – 600 hPa
- generate over the Sahel with 2-10 day periodicity
- two preferred tracks: north and south of AEJ
- peak with the Atlantic hurricane season

(Gray 1968; Carlson 1969; Burpee 1974; Reed et al. 1977; Diedhiou et al. 1998; Chen et al. 2008)

Observed AEW – Atlantic TC relationships

<u>Synoptic</u>: strongly linked

- 85% of major Atlantic hurricanes originate from AEWs

<u>Interannual</u>: unknown

- Depends on reanalysis, time period, vertical level
- Covariability in TCs, AEWs, Atlantic SST, and West African monsoon → causality is difficult to unravel

(Dunn 1940; Frank 1970; Landsea 1993; Russell et al. 2017; Thorncroft and Hodges 2001; Hopsch et al. 2007; Belanger et al. 2012; Landsea and Gray 1992; Grist 2002; Martin and Thorncroft 2014; Frank 1970; Dunkerton et al. 2009; Agudelo et al. 2011; Satoh et al. 2013)

Other tropical cyclone genesis mechanisms

ITCZ wave instability

- observed in Atlantic and Pacific

Disturbances from monsoon trough

- observed in NW Pacific, where 10-25% of typhoons form from tropical waves

Self-aggregation of convection

- in rotating radiative-convective equilibrium simulations

(Agee 1972; Thompson and Miller 1976; Kieu and Zhang 2008; Cao et al. 2013; Yokota et al. 2012; Bretherton et al. 2005; Nolan et al. 2007; Held and Zhao 2008; Khairoutdino and Emanuel 2013; Zhou et al. 2014; Reed and Chavas 2015; Wing et al. 2016; Frank 1988; Ritchie 1995; Lander 1994; Chen et al. 2004; Chen et al. 2008; Yoshida and Ishikawa 2013)

Questions

- Lack of clear seasonal connection between AEWs and Atlantic TCs
- Several alternative TC genesis mechanisms

Are AEWs necessary to maintain climatological TC frequency, i.e., are Atlantic TCs limited by AEWs?

➢ Unclear whether changes in AEWs are a source of uncertainty in seasonal predictions and future projections of TC activity.

Regional climate model experiments

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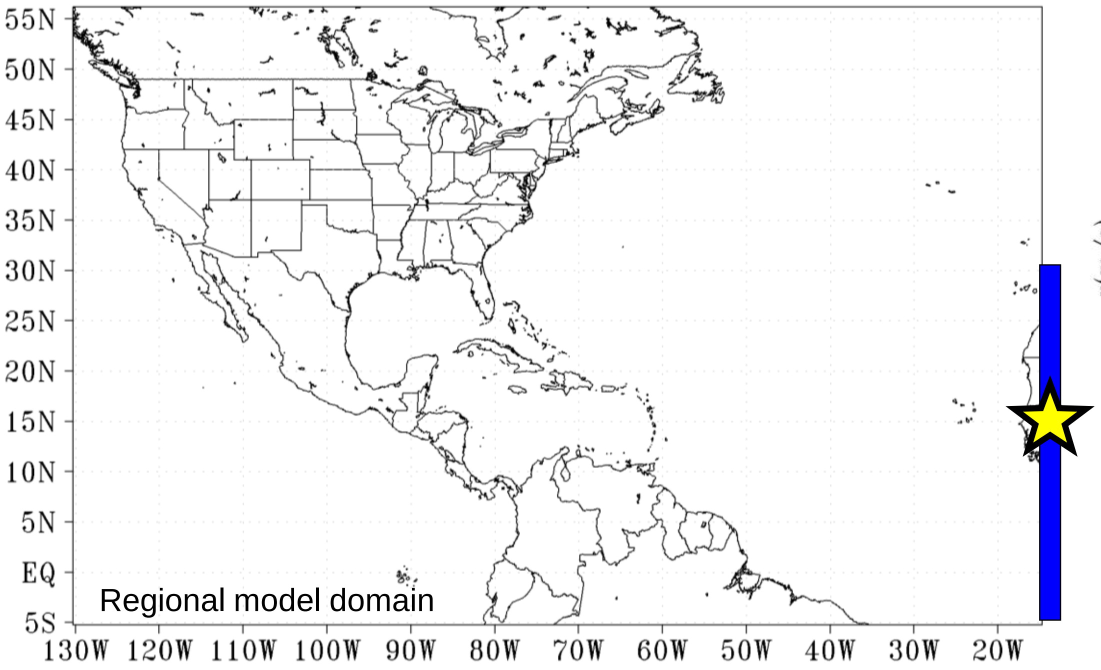
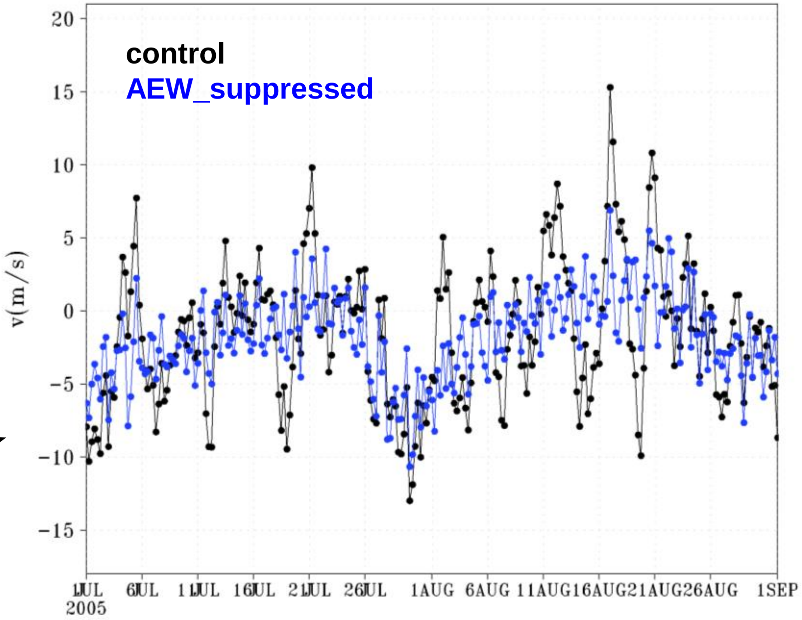
<u>Weather Research and Forecasting Model (WRF)</u>

- Eastern lateral edge location: include TC development, exclude AEW genesis over Sahel
- LBCs: 6-hourly NCEP CFSR; SST: daily NOAA-OI V2
- 27 km resolution
- 10 ensemble members (1 Jun -1 Dec 2005)

▪ **Control: 2005** AEWs contributed to 75% of Atlantic TC genesis (Beven et al. 2008)

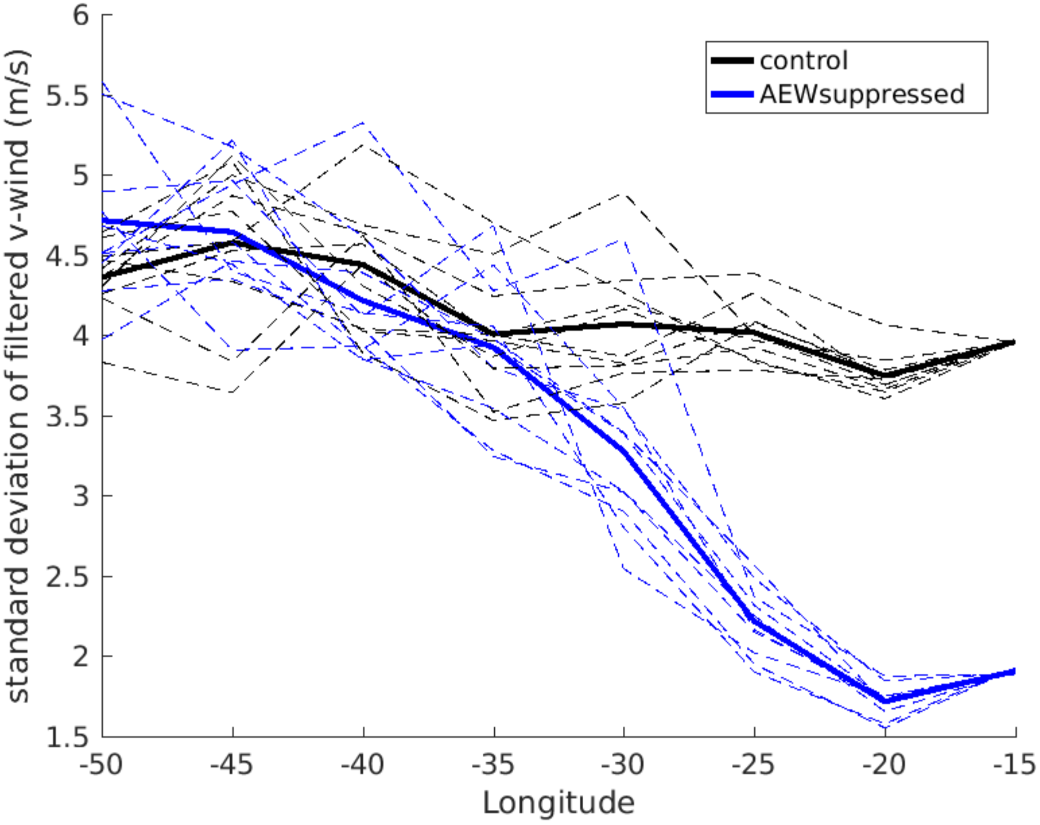
▪ **AEW_suppressed: 2-10 day variability removed from eastern LBC (5°S-30°N) w/ Lanczos filter**





Time series of meridional wind (m/s) at 700mb, 15N, and 15W from the eastern LBC of control (black) and AEW_suppressed (blue) simulations

Downstream impact of AEW filtering



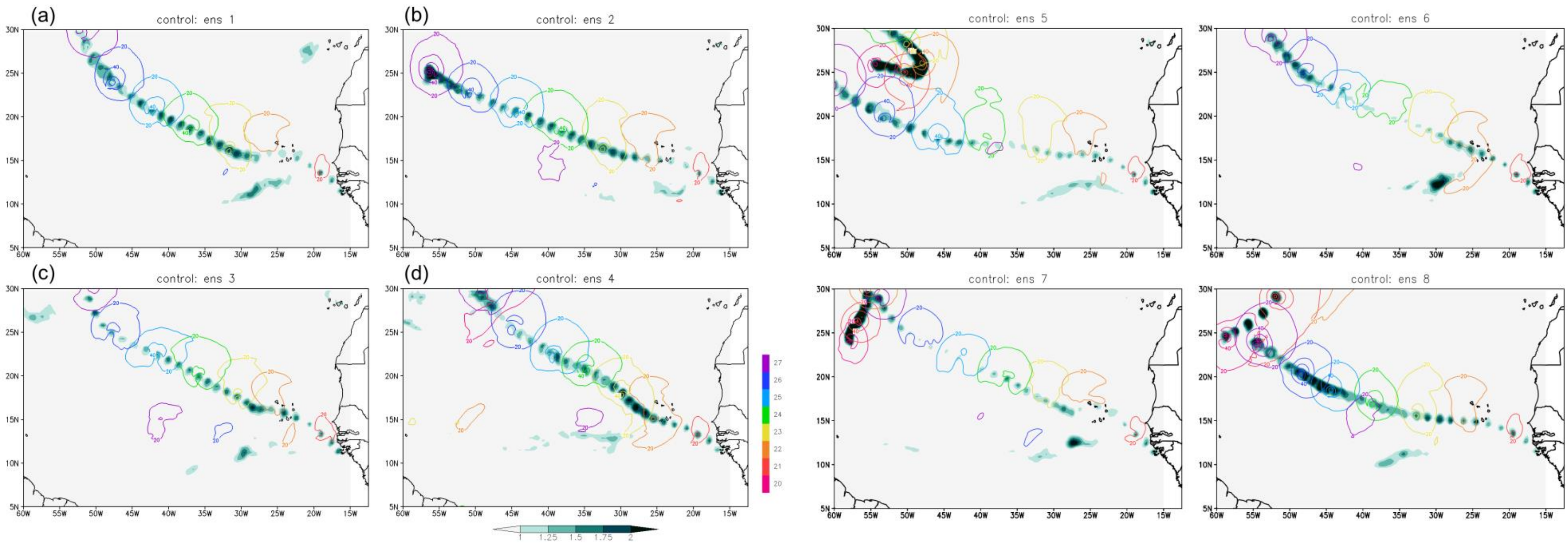
Standard deviation of the 10-day high-pass filtered meridional wind ($m\ s^{-1}$) at 15°N and 700 hPa. Wind data cover 1 Jul – 1 Oct, 2005.

- Filtering is largely effective at diminishing AEWs
- Model generates its own synoptic variability ~20° of longitude downstream from the lateral edge (no nudging applied within model domain)

Prescribing AEWs provides synoptic TC predictability

A vorticity maximum enters via the eastern lateral edge and develops into a TC in temporally and spatially coherent manner in all control ensemble members.

control (8 ensemble members)

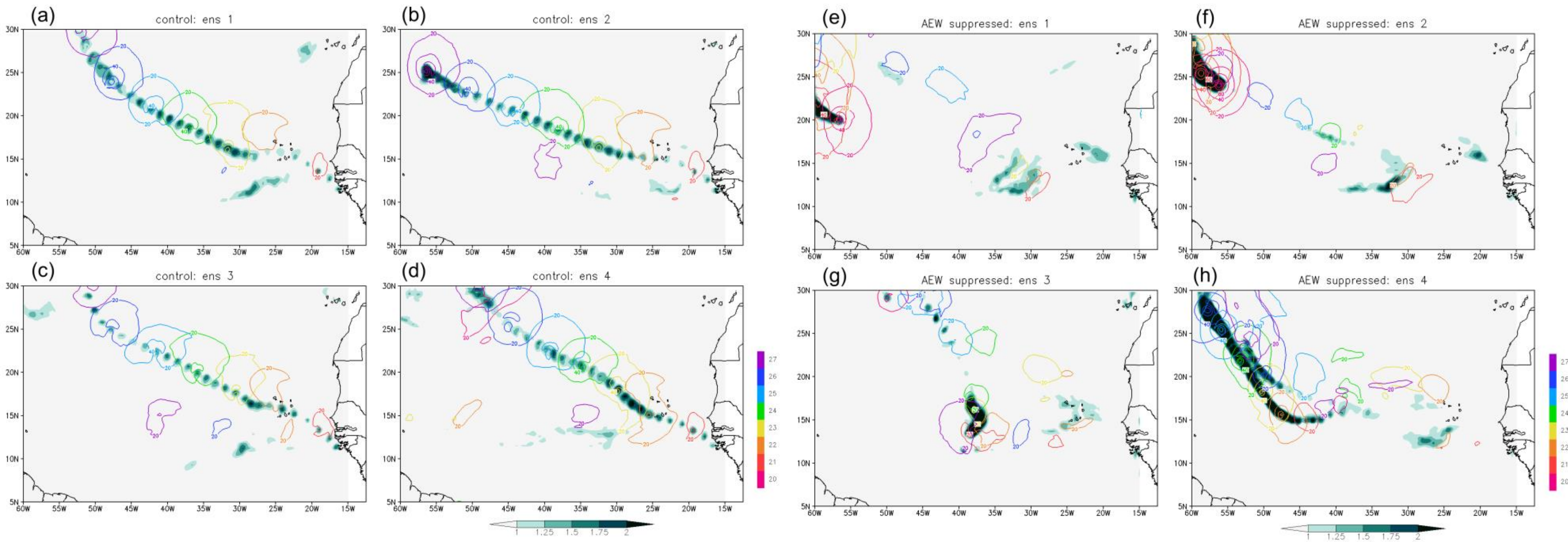


The sum of 6-hourly positive relative vorticity at 850 hPa (10^3 s^{-1}; shaded green) and daily snapshots of 10-m wind speed at 00z (m s^{-1}; contour; color denotes day of Aug) over Aug 20–27, 2005.

Filtering AEWs eliminates synoptic TC predictability

Filtering removes the vorticity maximum present in the control
→ TCs develop, but not in a temporally and spatially coherent manner.

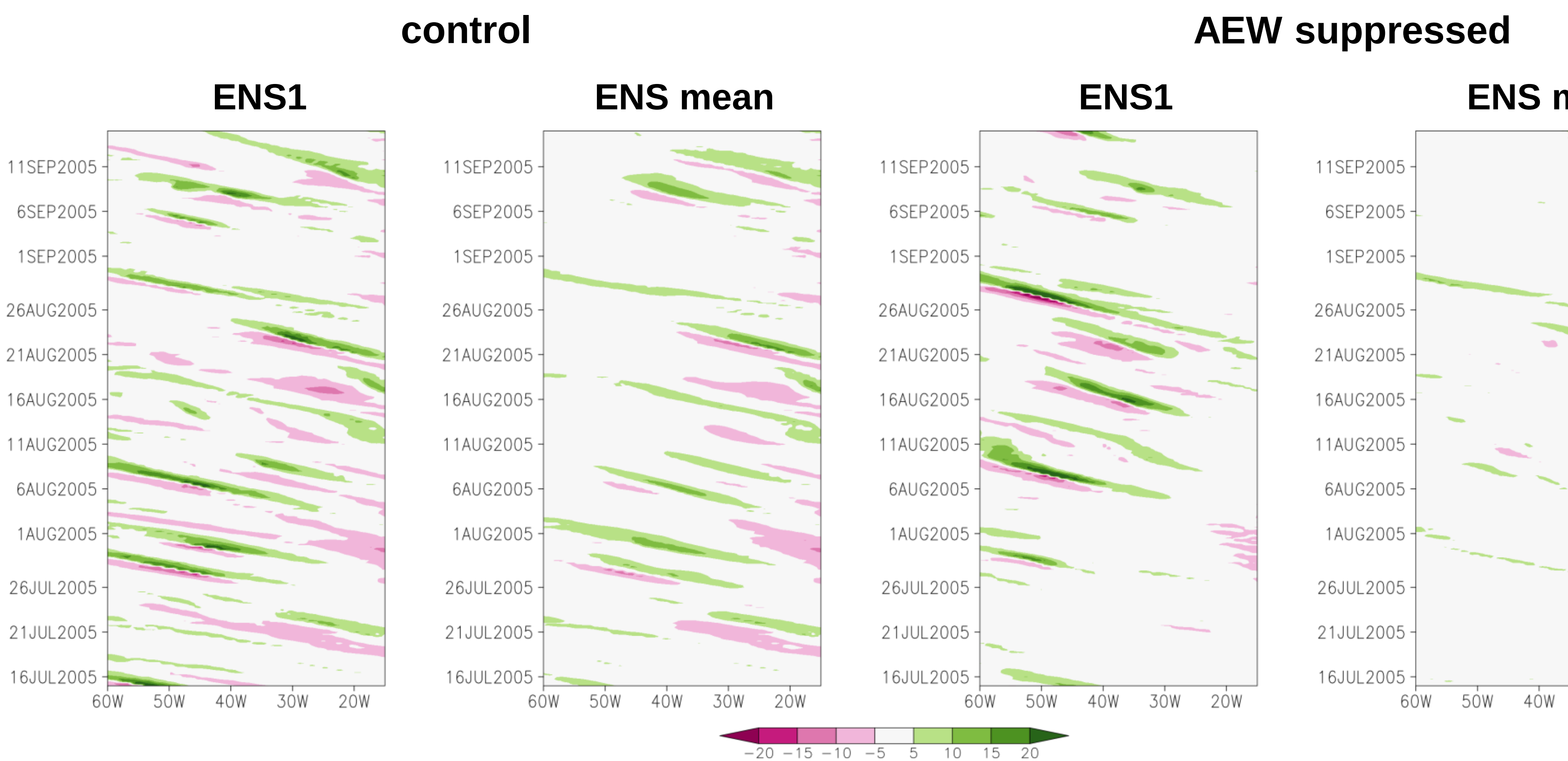
control **AEWs suppressed**



The sum of 6-hourly positive relative vorticity at 850 hPa (10^3 s^{-1}; shaded green) and daily snapshots of 10-m wind speed at 00z (m s^{-1}; contour; color denotes day of Aug) over Aug 20–27, 2005.

Seasonal impact of AEW filtering

- Prescribing AEWs: spatial and temporal patterns in ensemble members resemble ensemble mean → AEWs initiated TC genesis in a coherent way throughout the season
- Filtering AEWs: little spatial and temporal coherence among ensemble members



Hovmöller diagrams of meridional wind (m s^{-1}) at 700 hPa and averaged 14°N–16°N.

Seasonal Atlantic TC response to AEW suppression

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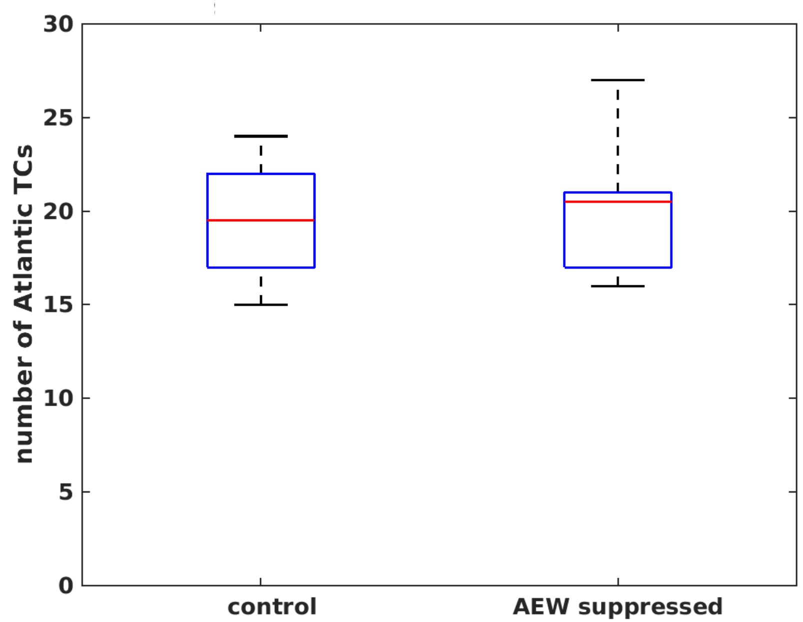
Suppression of AEWs produced no significant change in seasonal Atlantic TC number

Supported by results from synthetic track models and statistical models

- Input: atmospheric thermodynamic state, vertical wind shear, SST
- No information about AEW variability is given to the model.
- Largely reproduce interannual variability of Atlantic TC activity

(e.g., Emanuel et al. 2008; Emanuel 2010; Saunders et al. 2017)



	control	AEW suppressed	% change	p-value
Number of TCs/season	19.5	20.2	+4%	0.64
Number TC days/season	105	117	+11%	0.17
ACE (10^4 kt^2)	168	192	+15%	0.07

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Conclusions

Regional model experiments: delineate causality between AEWs and TCs

Seasonal basin-wide Atlantic TC numbers can be maintained in the absence of AEWs (for an active hurricane season), suggesting:

- ❖ Atlantic TCs are not limited by AEWs on *season* – *climate* timescales.
  - ❖ AEWs are important for TC genesis on synoptic scale.
  - ❖ Spatial pattern of TC tracks?
- ❖ Covariability in AEWs and TCs may be driven by ocean variability.
- ❖ Although TCs readily generate from AEWs, in the absence of AEWs TCs will generate by other mechanisms.
  - ❖ The *specific type* of disturbance is unimportant for determining basin-wide seasonal Atlantic TC number.
- ❖ AEWs are not a reliable predictor of variability and change in *basin-wide* Atlantic TC frequency
  - ❖ … So what are predictability sources?

Oceanic Sources of Tropical Cyclone Predictability

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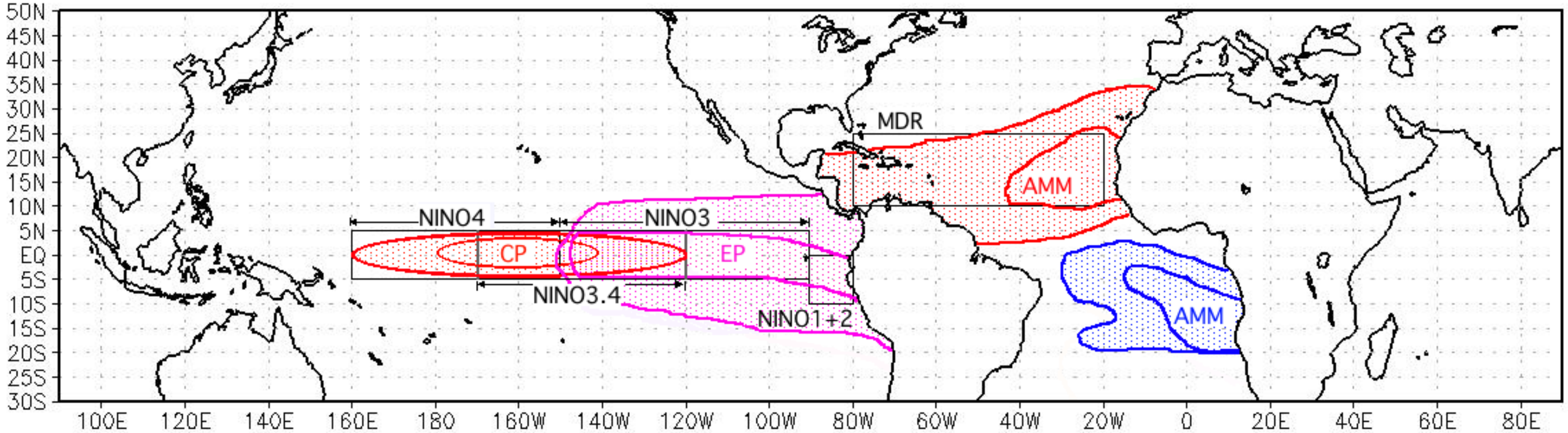
- **Atlantic and Pacific SST variability jointly**
  - Compensating and constructive influences on TCs
  - Extremely active/inactive hurricane seasons driven by ocean variability, not internal atmospheric variability.
- **El Niño's spatial patterns**
  - SST warming near warm pool is more effective than warming of cold tongue at suppressing Atlantic TCs.
- **Coupled model SST biases** substantially impact simulated TC activity → improvements needed for better prediction/projection. (Hsu et al. 2018)



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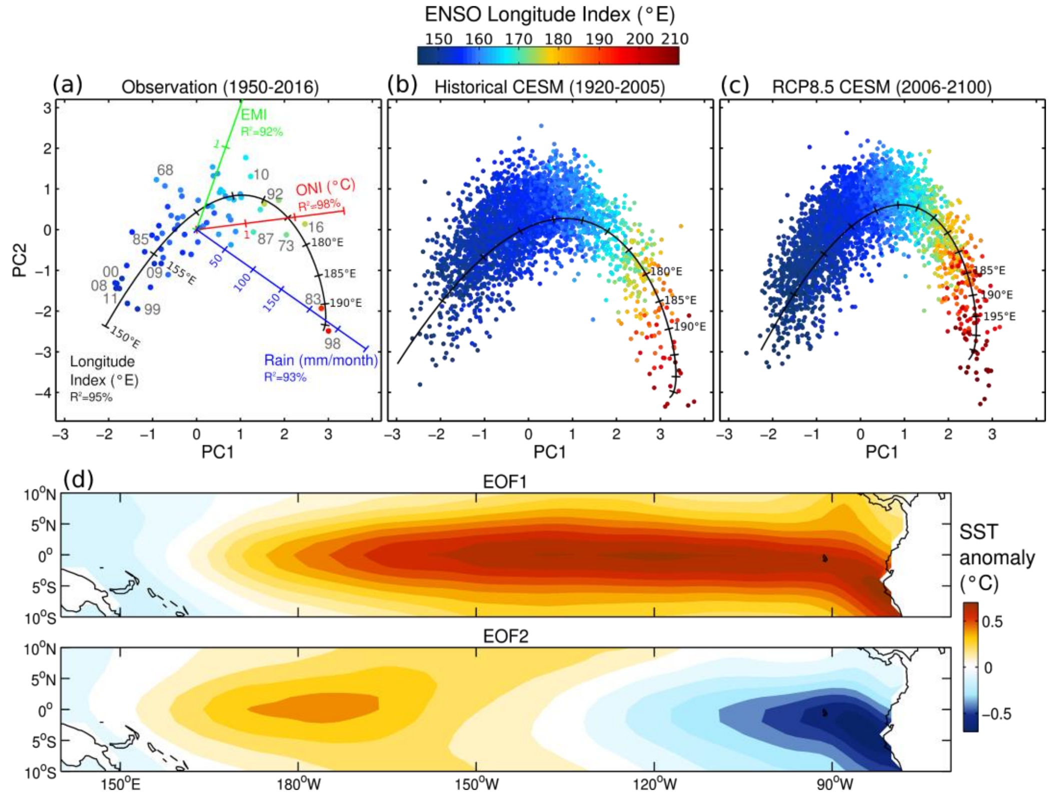
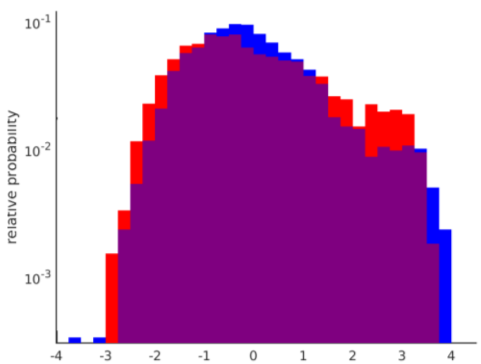
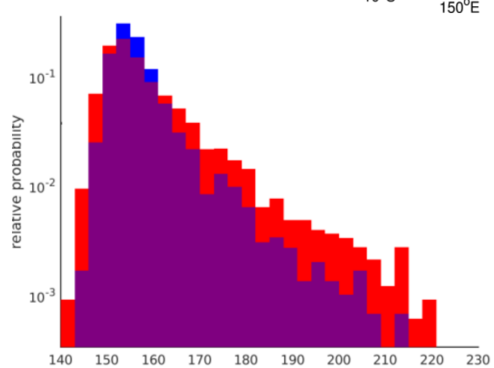
ENSO Longitude Index (ELI)

- Accounts for the nonlinear relationship between SST and deep convection.
- Calculation requires only monthly SST.
- Tracks the average longitude of tropical Pacific deep convection.
- **Characterizes the diversity and extremes of ENSO in a single index.**





Nino3.4



ELI

- ELI reveals increases in extreme El Niño, La Niña, and Modoki events at the expense of neutral ENSO in 21st century climate projections from CESM-LENS.

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