Attribution Methodologies Applied to Tropical Cyclones

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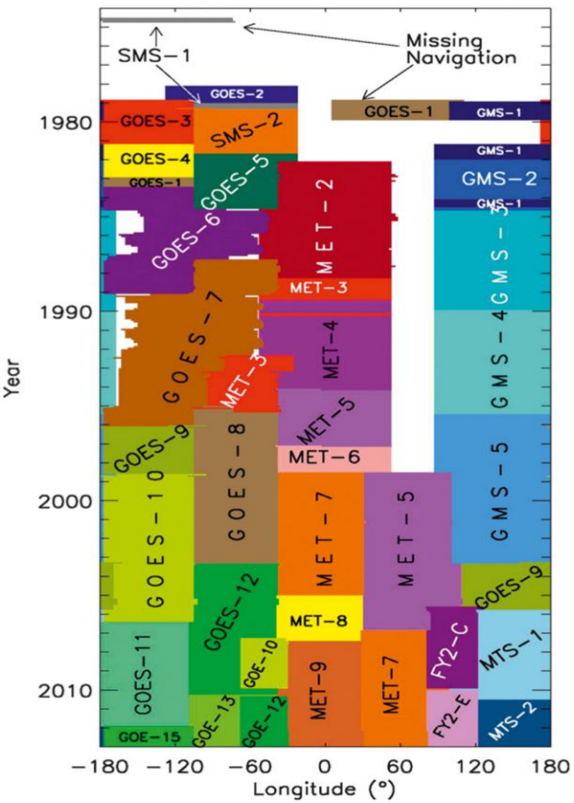
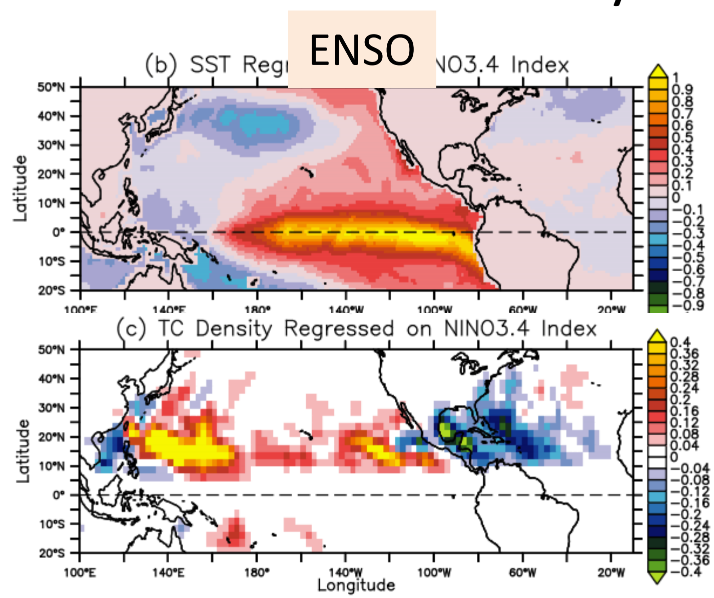
Blackboard Lecture at the 2022 Princeton AOS workshop

It is very difficult to attribute extreme tropical cyclone (TC) events to any climate changes. Why?

(1) Limited availability of long-term TC observations

(2) Significant influence of intrinsic internal variability on TC activity





(3) Expensive computational cost for conducting high-resolution climate model simulations

Introduction

Despite the challenges, there are some new studies that addressed the attribution of extreme TC events to climate changes.

1. Extreme single TC event (e.g., Cat 5 hurricane; Katrina, Florence)

   Weather Forecast Model, Pseudo-warming experiment

2. Extreme TC seasons (e.g., the 2015 active hurricane season in the Eastern North Pacific)

   Seasonal Forecast Model, SST nudging experiment

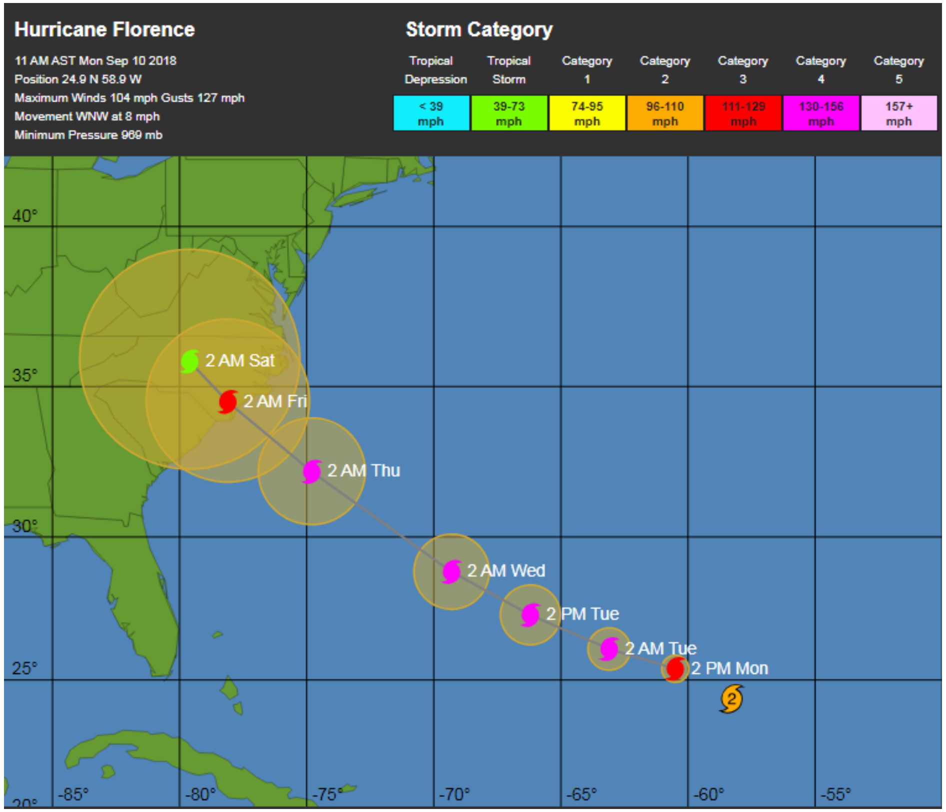
3. An unusual decade or trend (e.g., Increased North Atlantic hurricanes during the 2010s)

   Large ensemble experiment

4. Statistical-dynamical downscaling methodology

   Synthetic tropical cyclone climate model

1. Extreme single TC event (e.g., Cat 5 hurricane; Katrina, Florence)

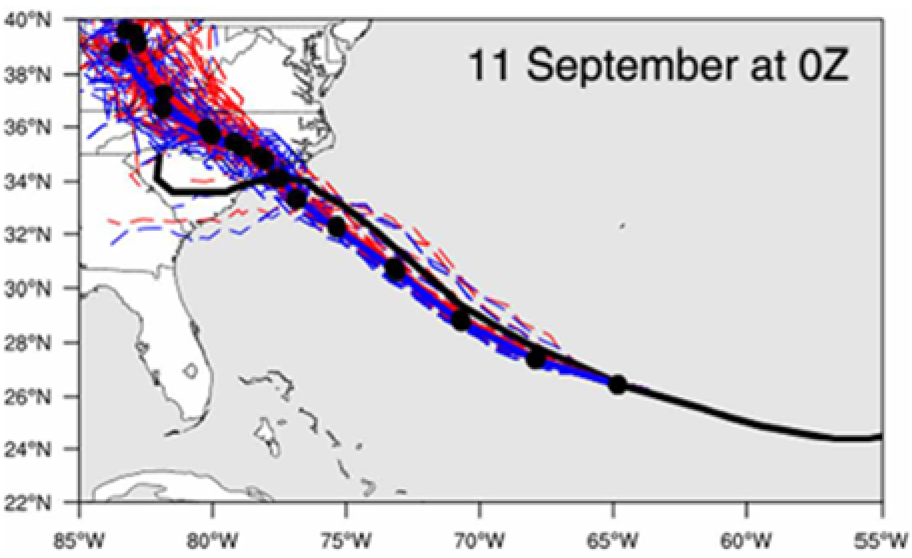


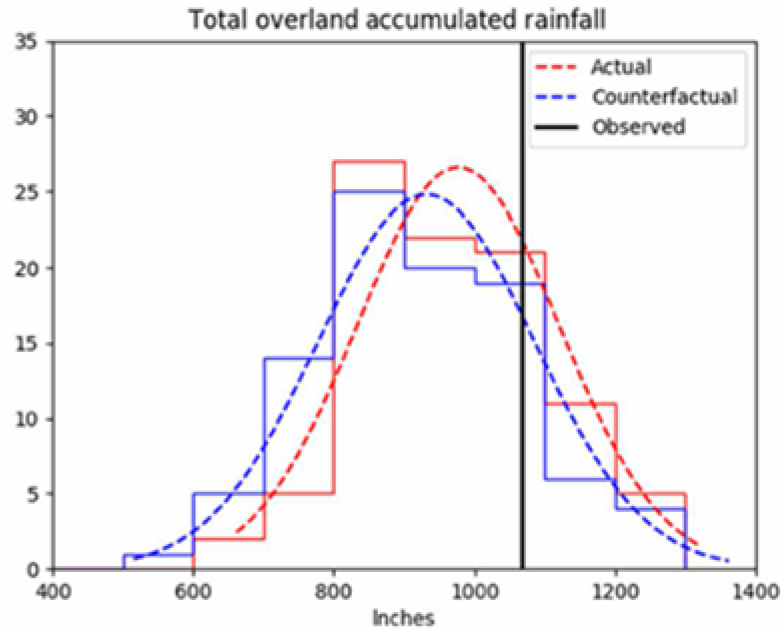
Hurricane Florence (2018)

How much did anthropogenic warming affect the heavy precipitation of Hurricane Florence?

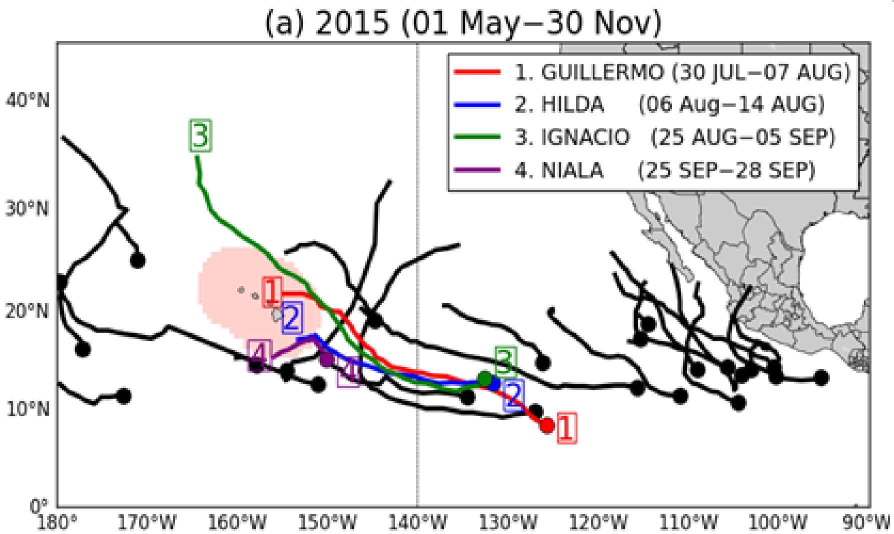
1. Extreme single TC event (e.g., Cat 5 hurricane; Katrina, Florence)

Wehner et al. (2019), Patricola and Wehner (2020), and Reed et al. (2020, 2022) applied so-called "***pseudo global warming sensitivity experiments***".

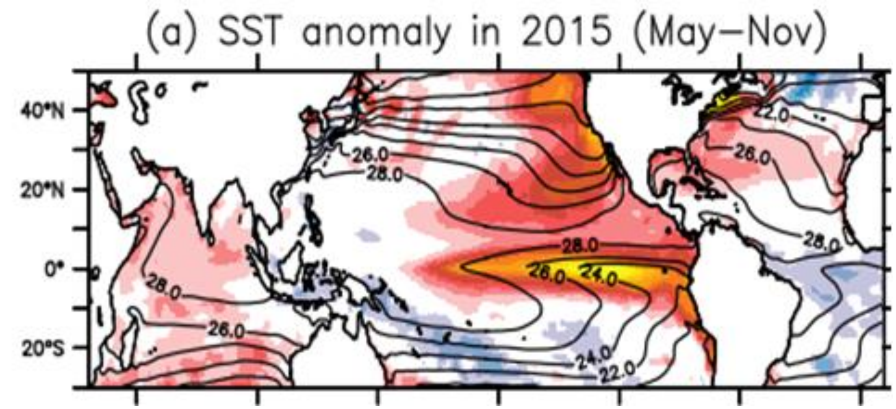




2.Extreme TC season



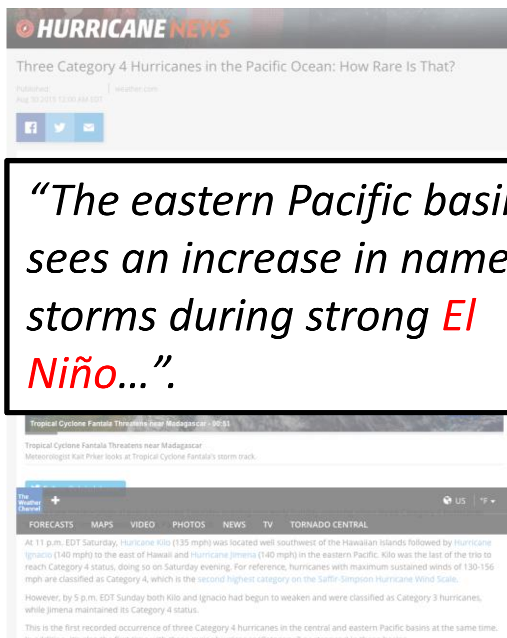
27 TCs in 2015 in the Eastern North Pacific



Observed SST anomaly in 2015 showing strong El Nino.

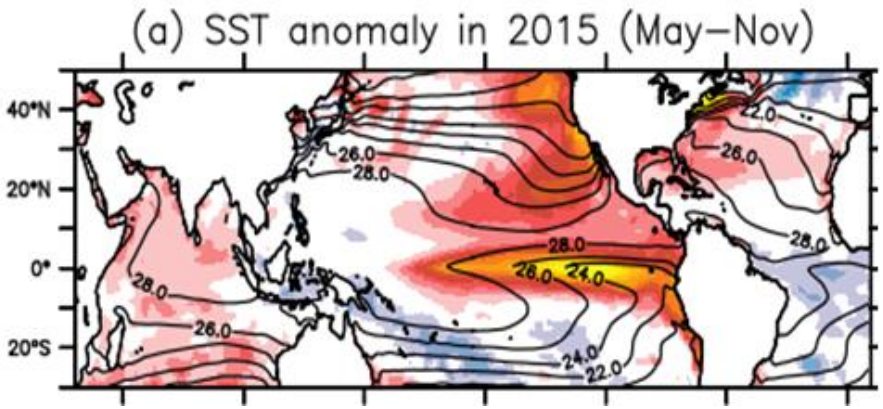
"The spike in cyclone activity is tied to well a still developing, significant El Niño".

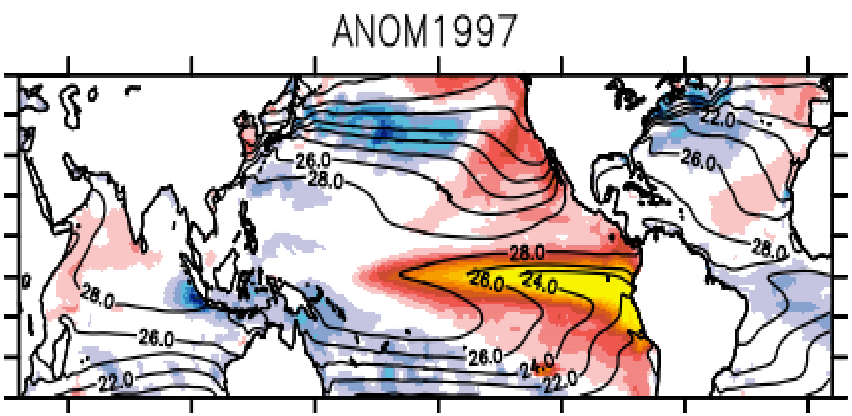
"El Niño helps boost Pacific storm season".



"The eastern Pacific basin sees an increase in named storms during strong El Niño…".

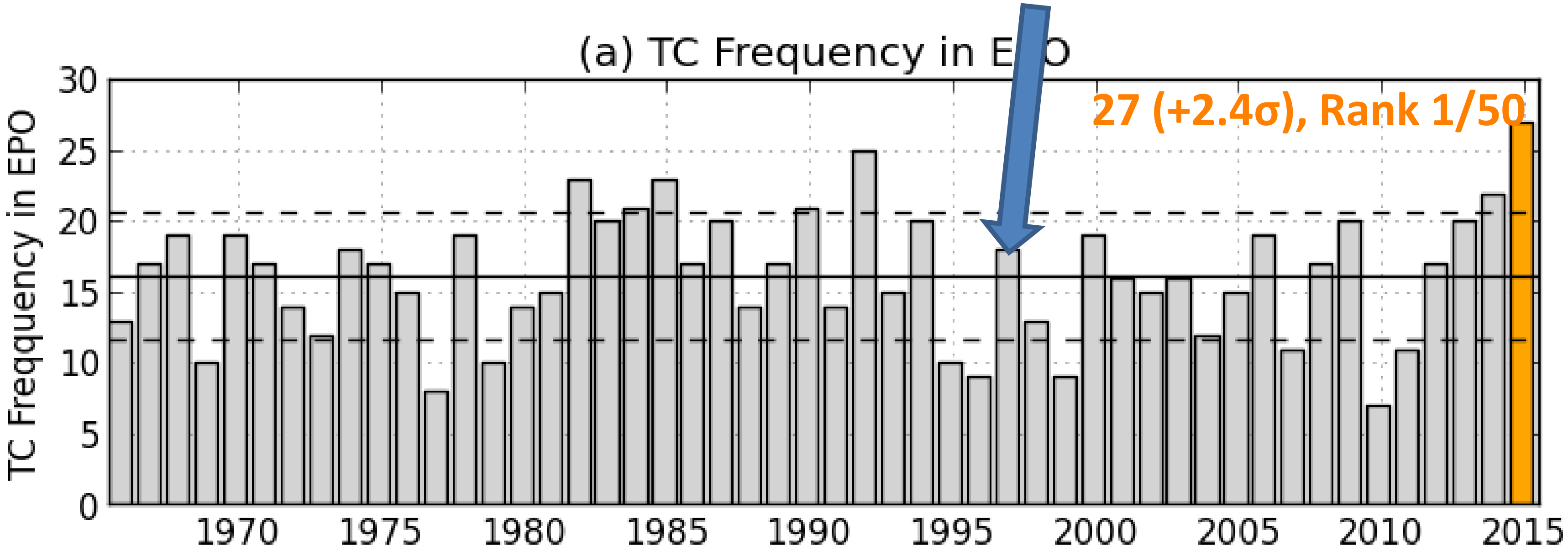
2.Extreme TC season





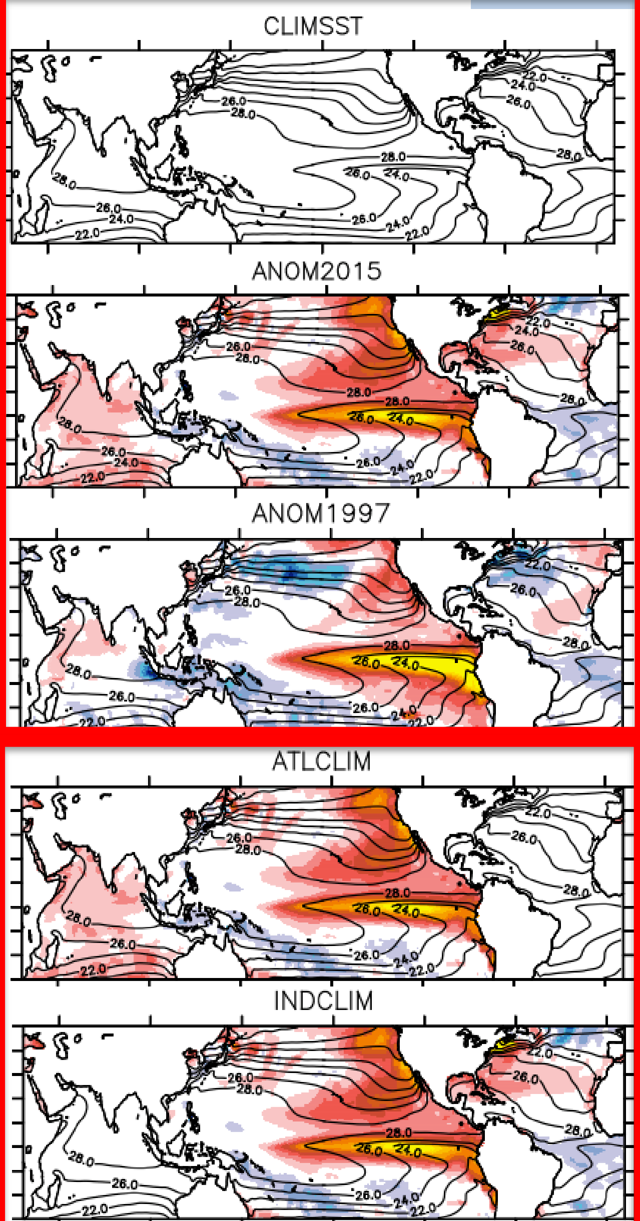
Observed SST anomaly in 2015 showing strong El Nino.

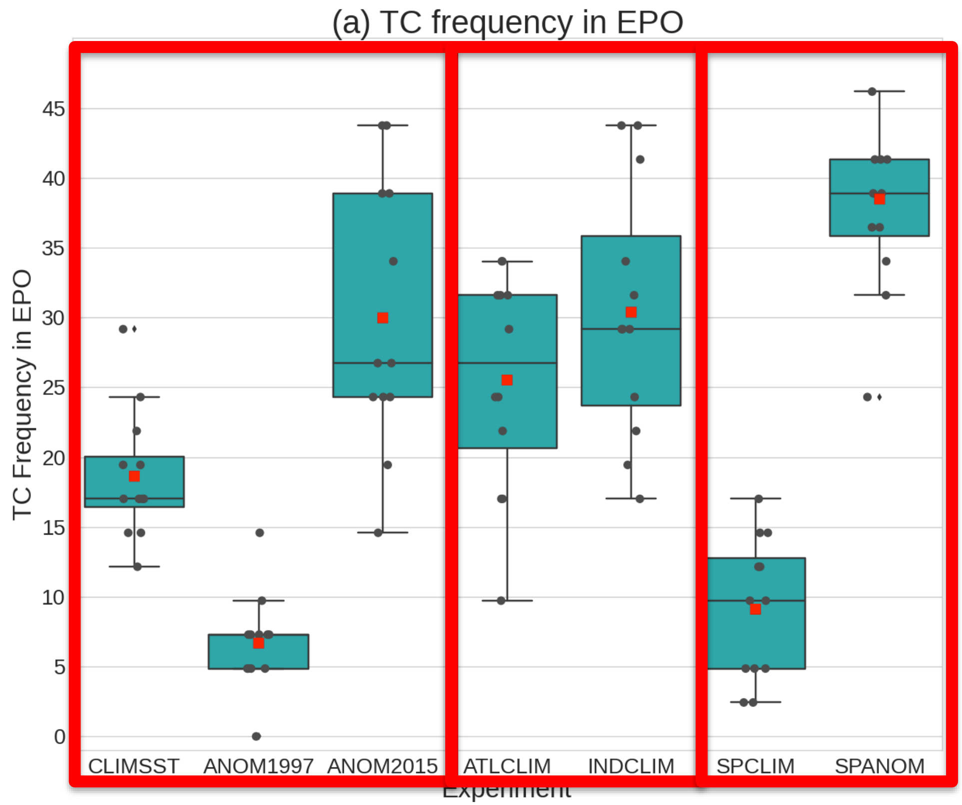
1997 was also a strong El Nino. But TC was not active.



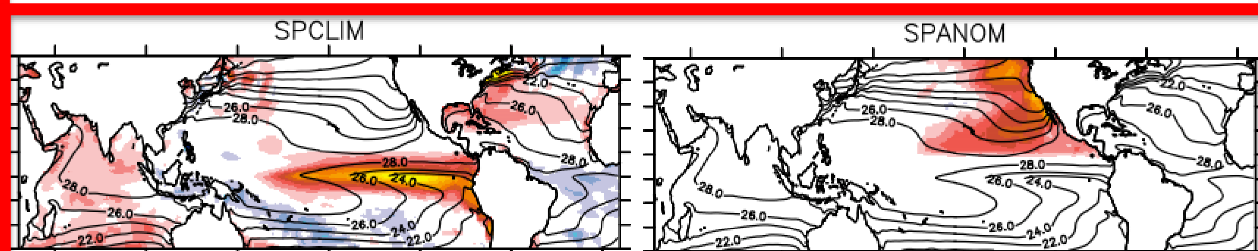
Murakami et al. (2016, J. Climate)

2.Extreme TC season





Subtropical SST anomaly is critical for the extreme TC year of 2015.



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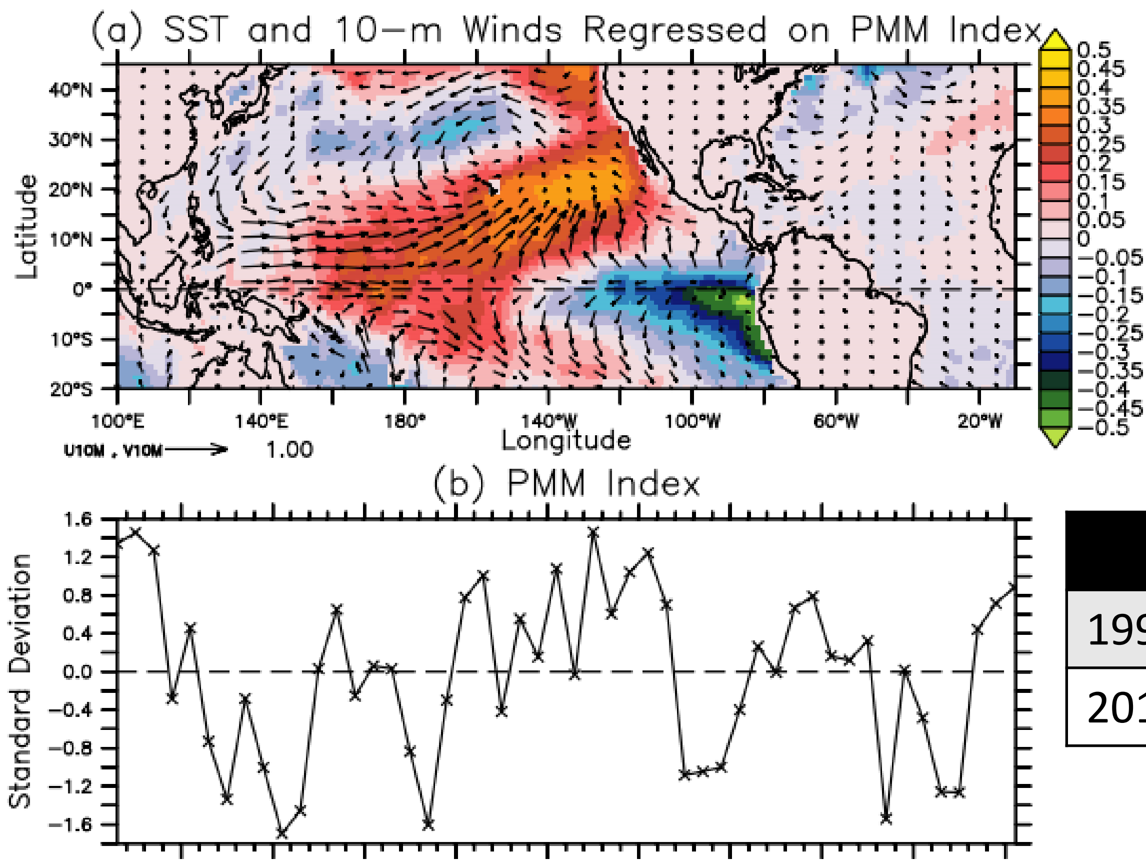
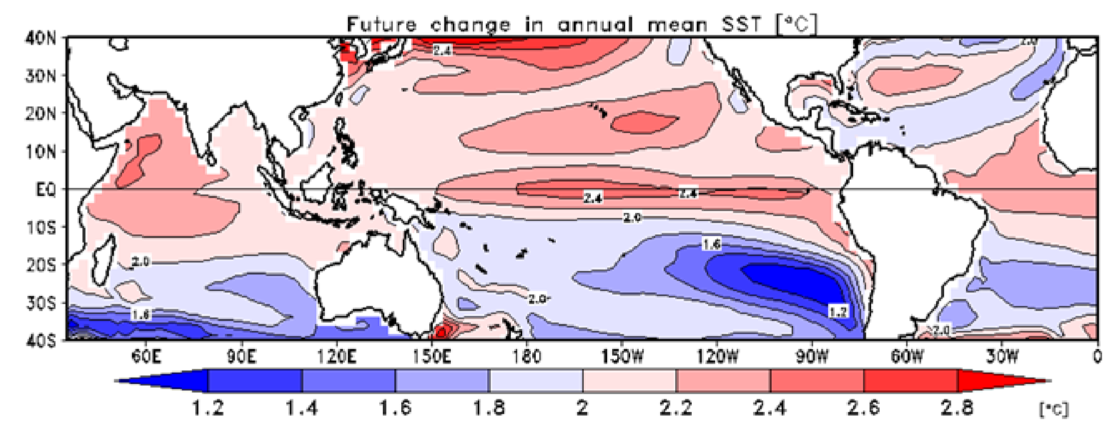
2.Extreme TC season



The PMM is the 1st singular decomposition (SVD) mode for the SST and zonal and meridional components of the 10-m wind field (*Chiang and Vimont* 2004).

	Niño-3.4	PMM
1997 (May–Nov)	+2.4σ	−1.0σ
2015 (May–Nov)	+2.4σ	+0.9σ

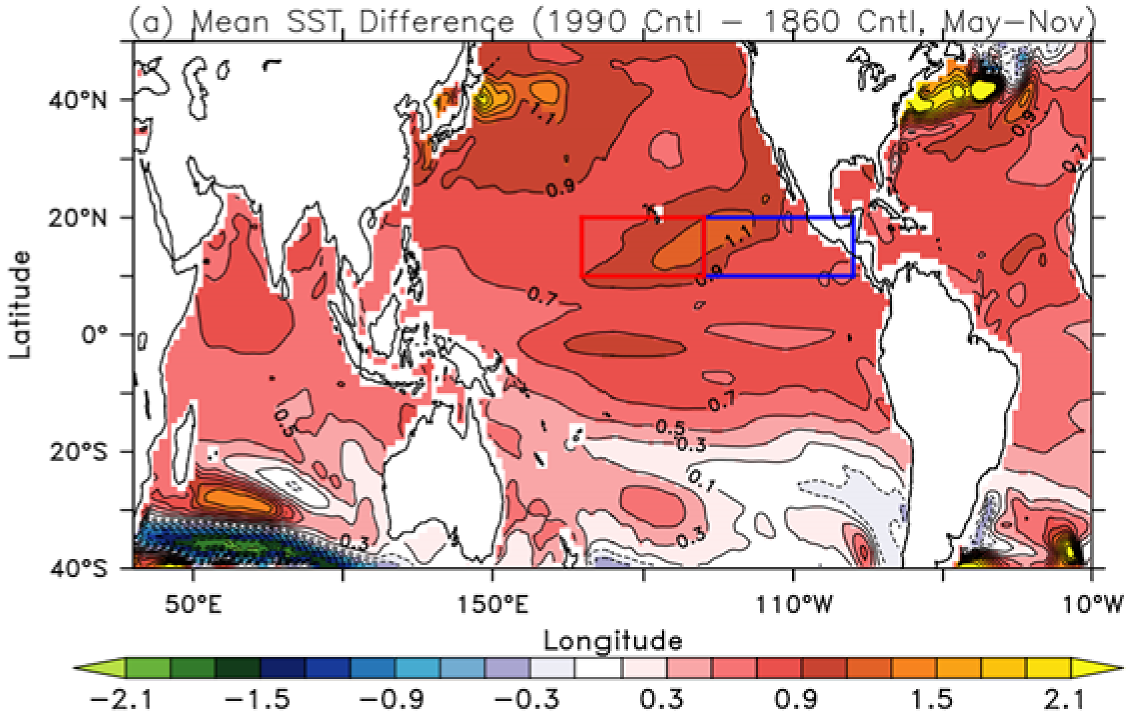


Projected future changes in SST by CMIP5 models.

Murakami et al. (2016, J. Climate)

2.Extreme TC season

Experiment	Radiative Forcing	Simulation Years
1860 Control	1860 Level	3500
1990 Control	1990 Level	500



Murakami et al. (2016, J. Climate)

2.Extreme TC season

Probability of Exceedance

$$P(x) \equiv \frac{\text{Number of years with TC number } \geq x}{\text{Total number of years}}$$

x : TC frequency in a year

Fraction of Attributable Risk (FAR)

$$FAR(x) \equiv \frac{P(x|E_1) - P(x|E_0)}{P(x|E_1)}$$

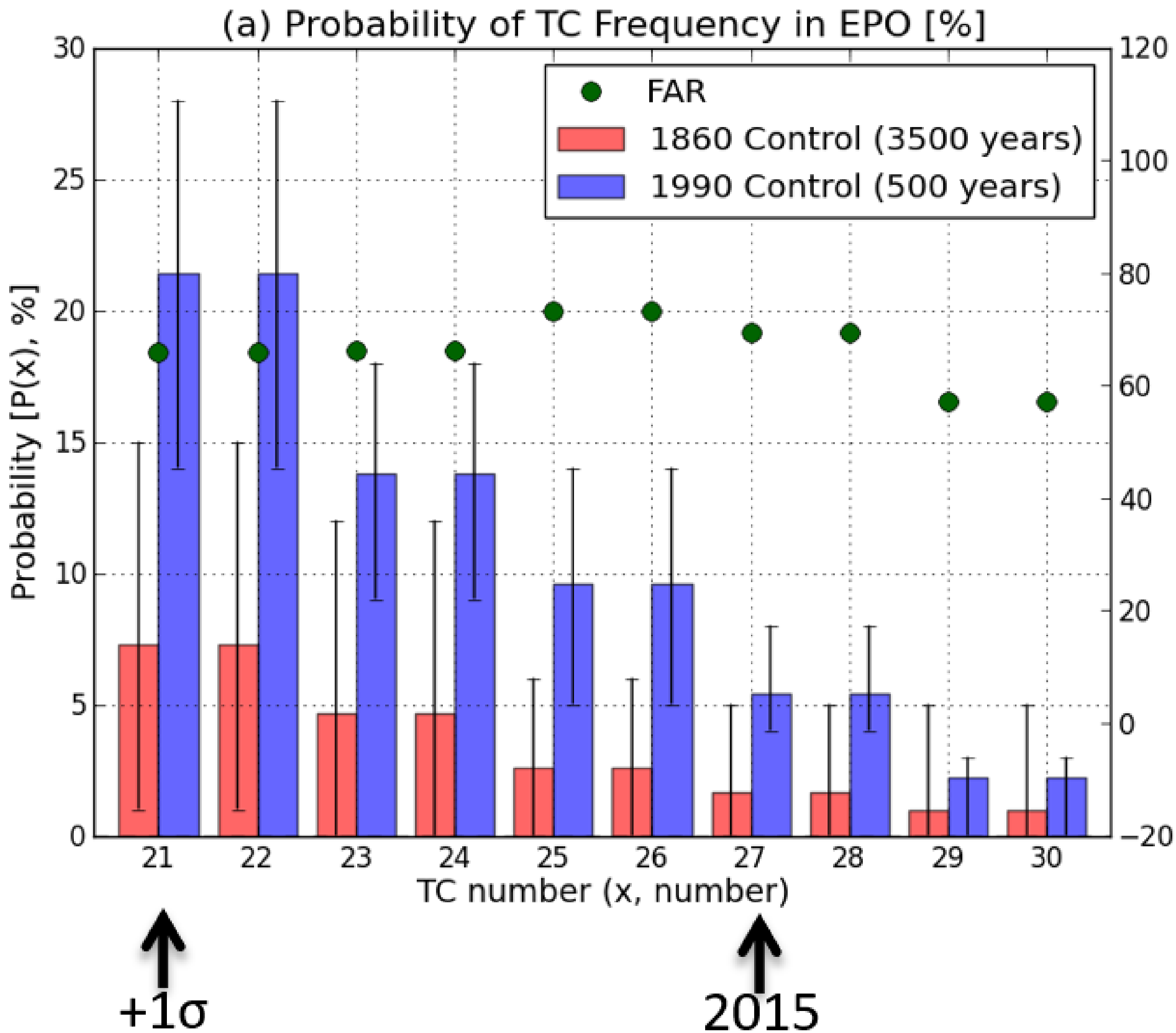
E_1: Anthropogenic Forcing (1990 Contl)

E_0: Non-anthropogenic Forcing (1860 Contl)

$-\infty$ (not attributable) < FAR ≤ +1.0 (attributable)

Murakami et al. (2016, J. Climate)

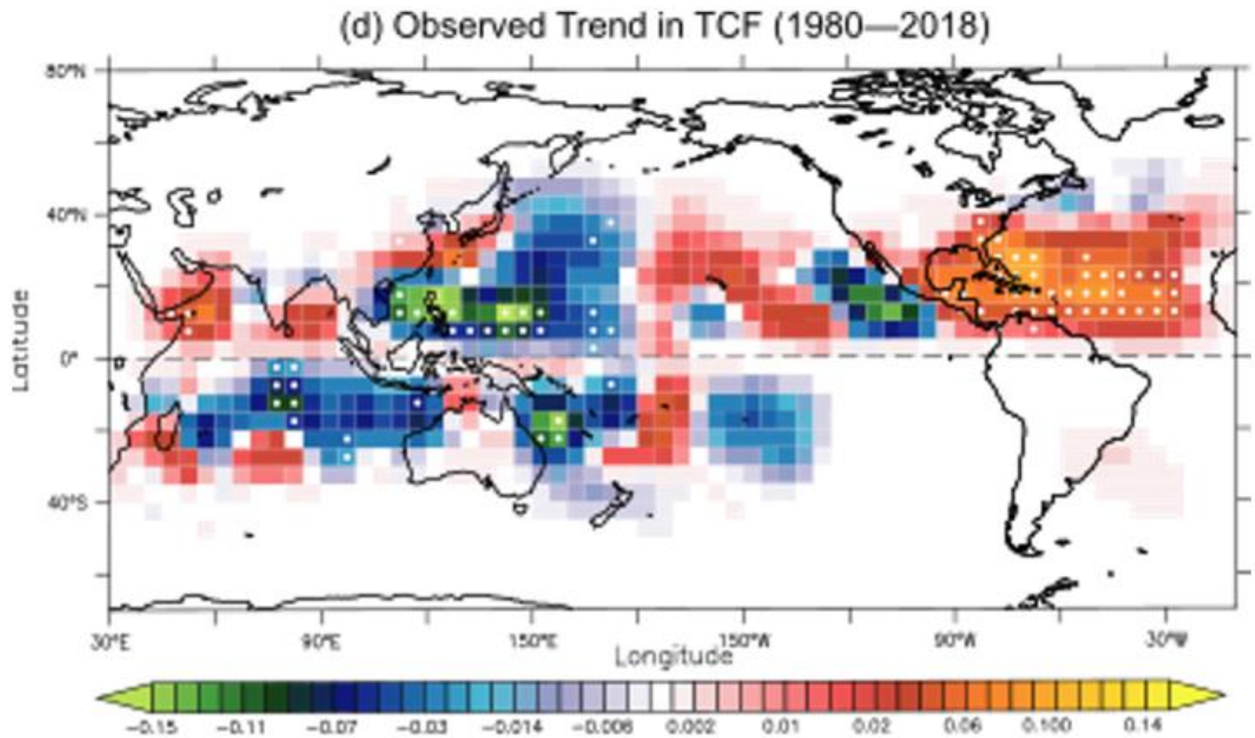
2.Extreme TC season



P(x) for 1860 Control (red) and 1990 Control (blue). FAR is shown in green dots.

Murakami et al. (2016, J. Climate)

3. An unusual decade or trend



Observed TC density trend over the period 1980-2018.

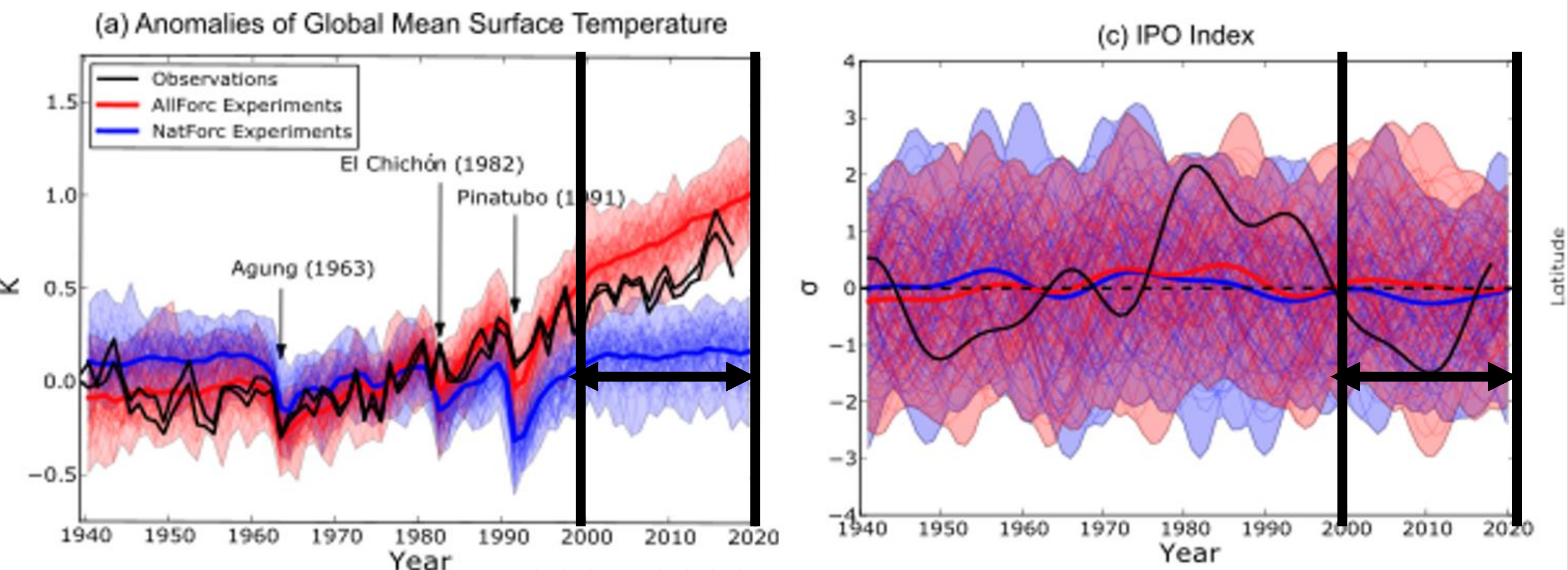
An open question:

Is the spatial pattern of the trends caused by anthropogenic forcing or internal variability?

The results will be shown in the plenary talk this afternoon.

Keywords: SVD, Fingerprint Analysis, **<u>Large Ensemble Simulations</u>**

3. Large ensemble simulations



2001-2020

20 years x 35 members = 700 samples

2.Extreme TC season

Effect of natural variability on the occurrence of extreme TC season

$$FAR(x|E_i) \equiv \frac{P(x|E_i) - P(x|E_5)}{P(x|E_i)}$$

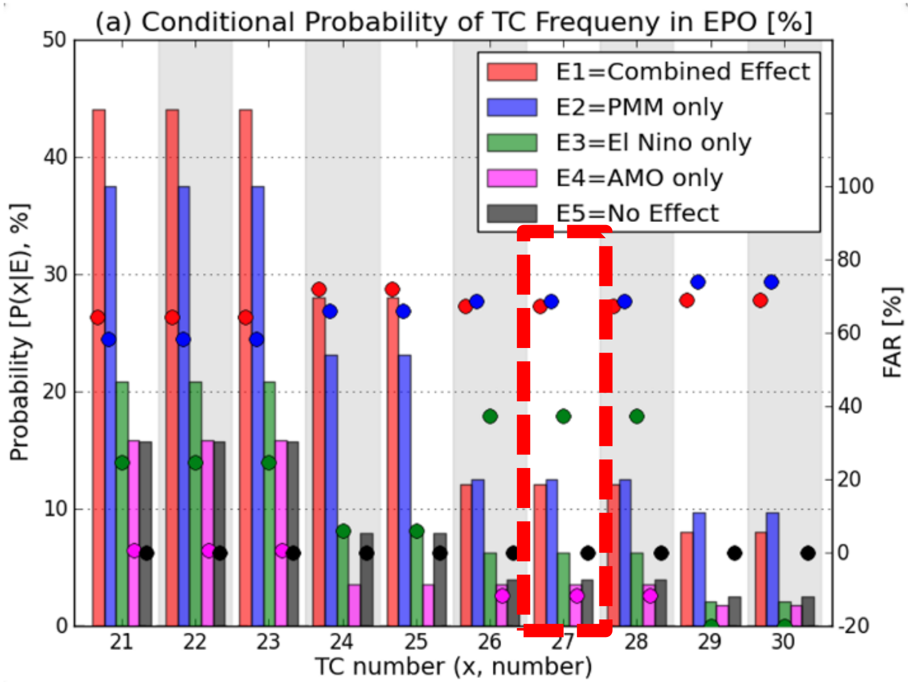
$$i = 1, \ldots, 4$$

E_i: A group of members showing a specific phase of natural variability

E_5: A group of members under neutral conditions

$-\infty$ (not attributable) < FAR ≤ 1.0 (attributable)

2.Extreme TC season



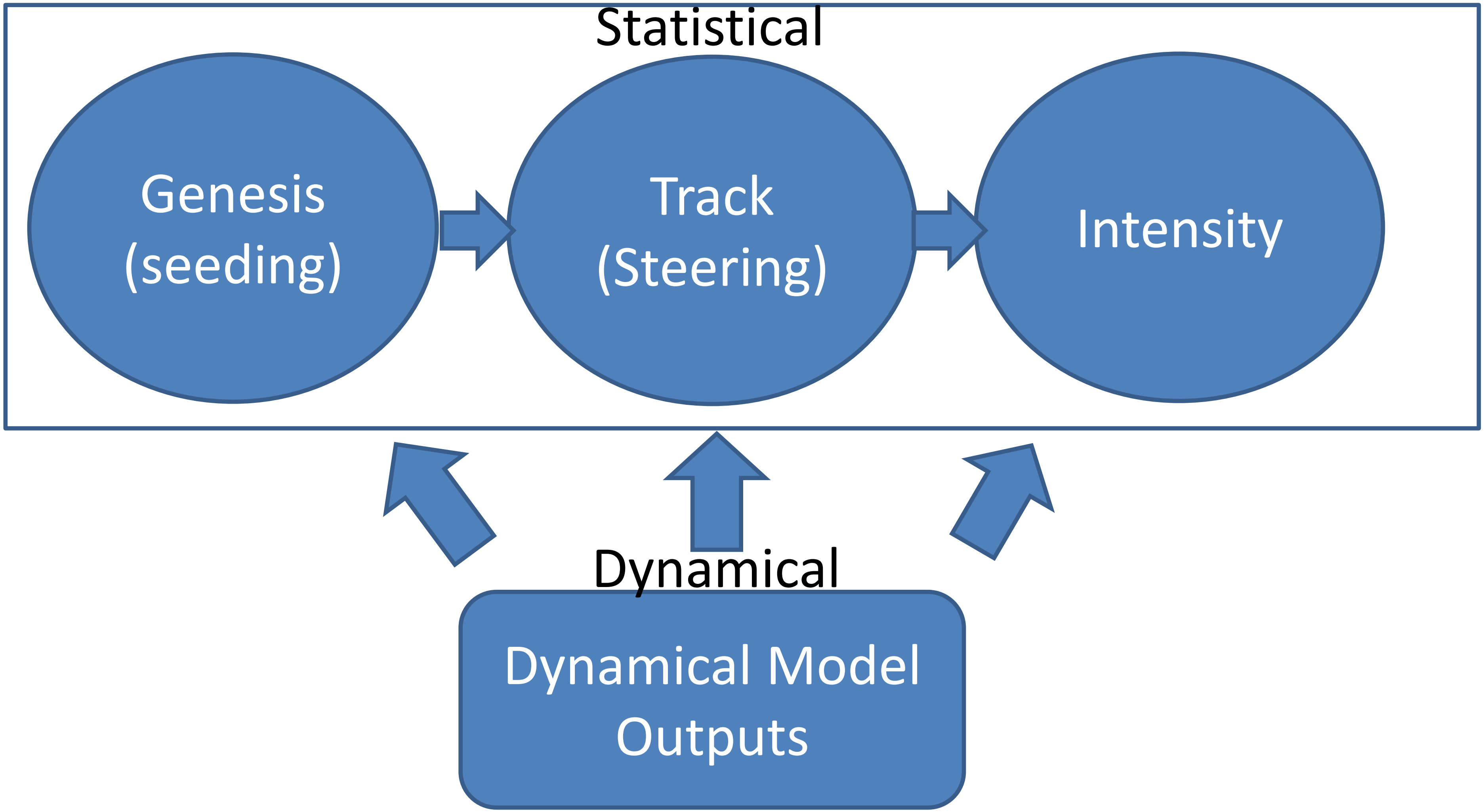
Using the 700 samples during 2001–2020 period in the AllForc, additional five conditional provability $P(x|E_n)$ are computed.

x: Number of TCs in the Eastern North Pacific

PMM(+) >> Nino-3.4 (+) > AMO (–)

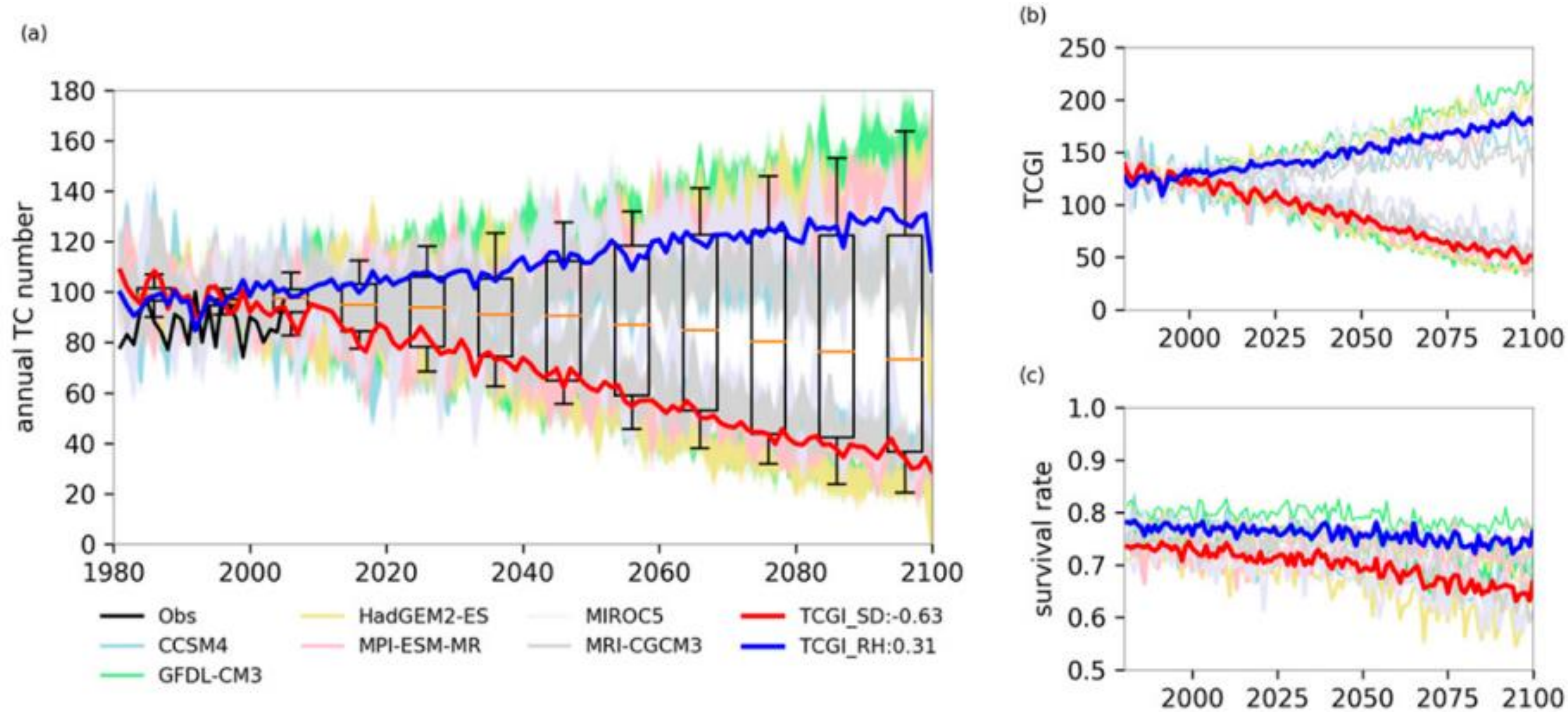
E_n	PMM ≥ +1σ	Niño-3.4 ≥ +1σ	AMO ≤ –1σ	Sample size	Effect
E1	✓	✓	✓	44/700	Combined Effect
E2	✓			94/700	Positive PMM only
E3		✓		83/700	Positive Niño-3.4 only
E4			✓	55/700	Negative AMO only
E5				282/700	No Effect

4. Statistical-dynamical downscaling



Emanuel (2006, 2008, 2013, 2021), Lee et al. (2018, 2020)

4. Statistical-dynamical downscaling



CRH case: $$\mu = \exp(b + b_{\eta}\eta_{850,c} + b_{\mathrm{CRH}}\mathrm{CRH} + b_{\mathrm{PI}}\mathrm{PI} + b_{\mathrm{SHR}}\mathrm{SHR}),$$

SD case: $$\mu = \exp(b + b_{\eta}\eta_{850,c} + b_{\mathrm{SD}}\mathrm{SD} + b_{\mathrm{PI}}\mathrm{PI} + b_{\mathrm{SHR}}\mathrm{SHR}).$$

Discussion

Let's discuss the pros and cons of each methodology.

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Synthetic tropical cyclone climate model