

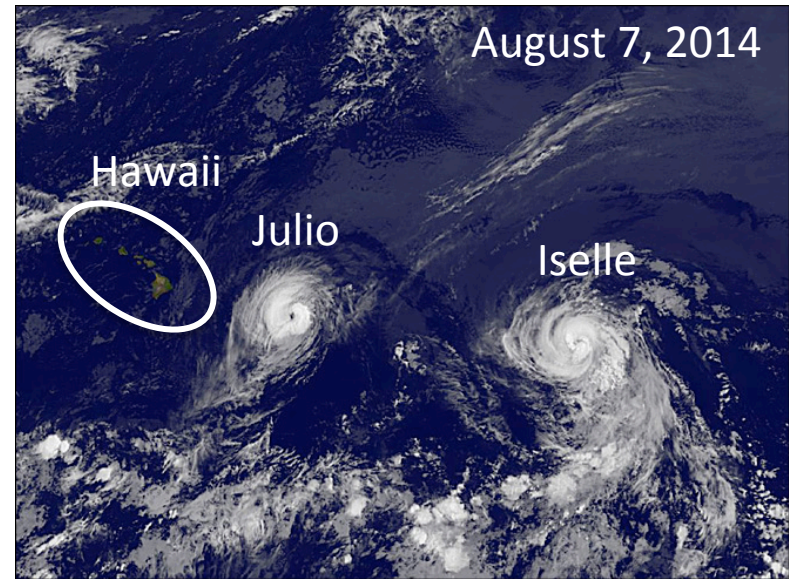
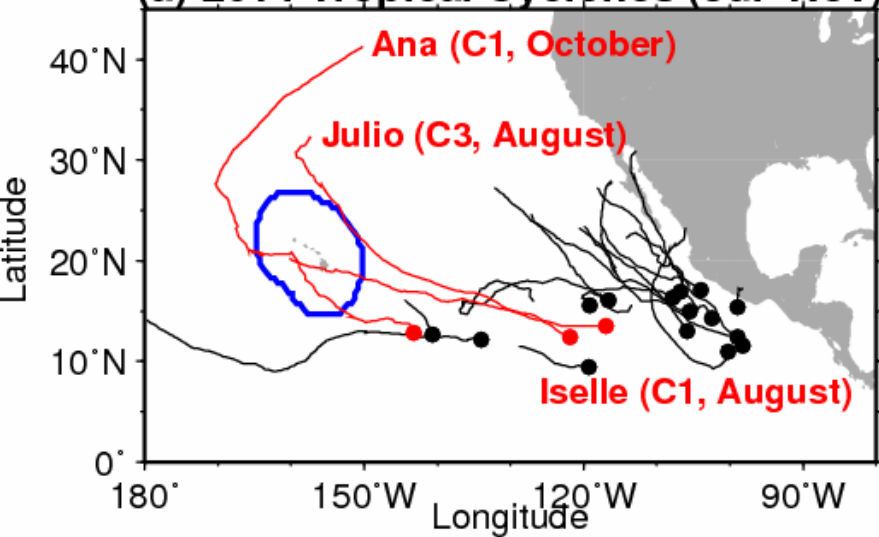
Investigating the Influence of Anthropogenic Forcing and Natural Variability on the 2014 Hawaiian Hurricane Season

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K. Paffendorf, R. Gudgel, L. Jia, and F. Zeng

Submitted to the 2014 BAMS Explaining Extreme
Events report

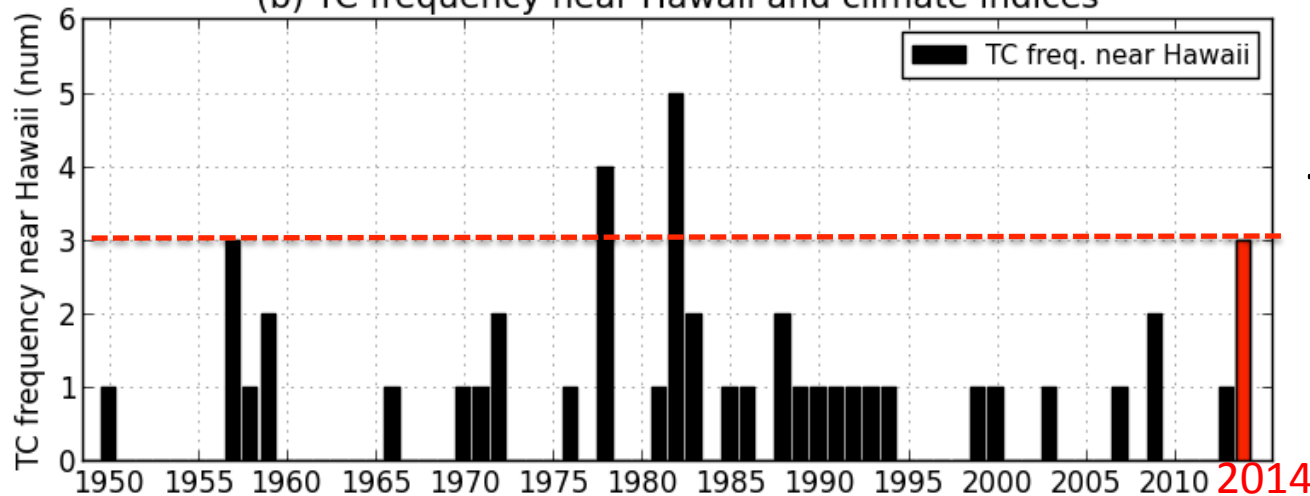
2014 Hurricane Season in the Eastern Pacific

(a) 2014 Tropical Cyclones (Jul–Nov)



Three hurricanes approached near Hawaii in 2014.

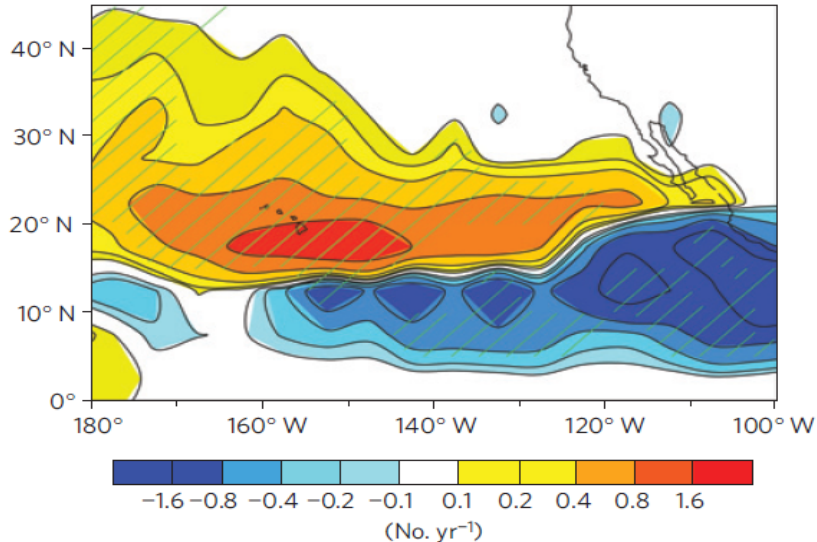
(b) TC frequency near Hawaii and climate indices



The third largest number since 1949.

Why? Global warming or Natural variability?

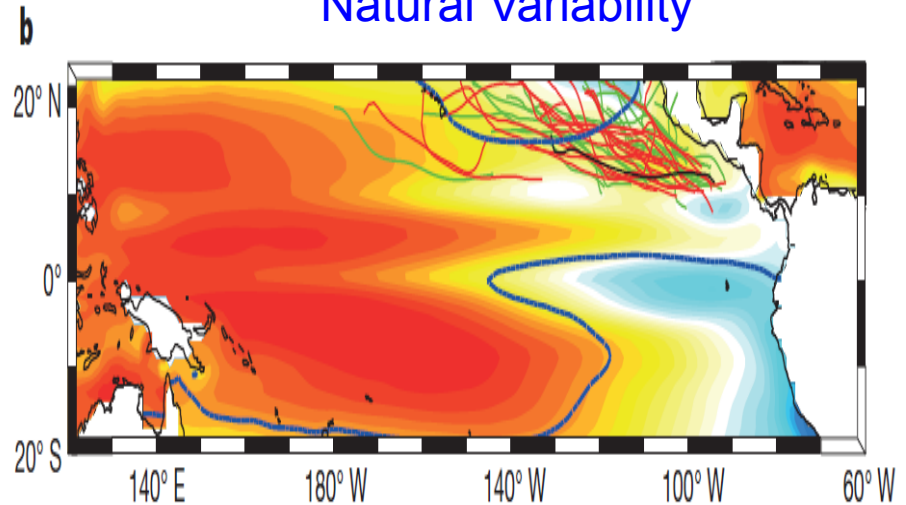
Global Warming



Projected future changes in TC density.

Murakami et al. (2013, *Nature Climate Change*)

Natural Variability



TCs are more active during
El Niño years

Jin et al. (2014, *Nature*)

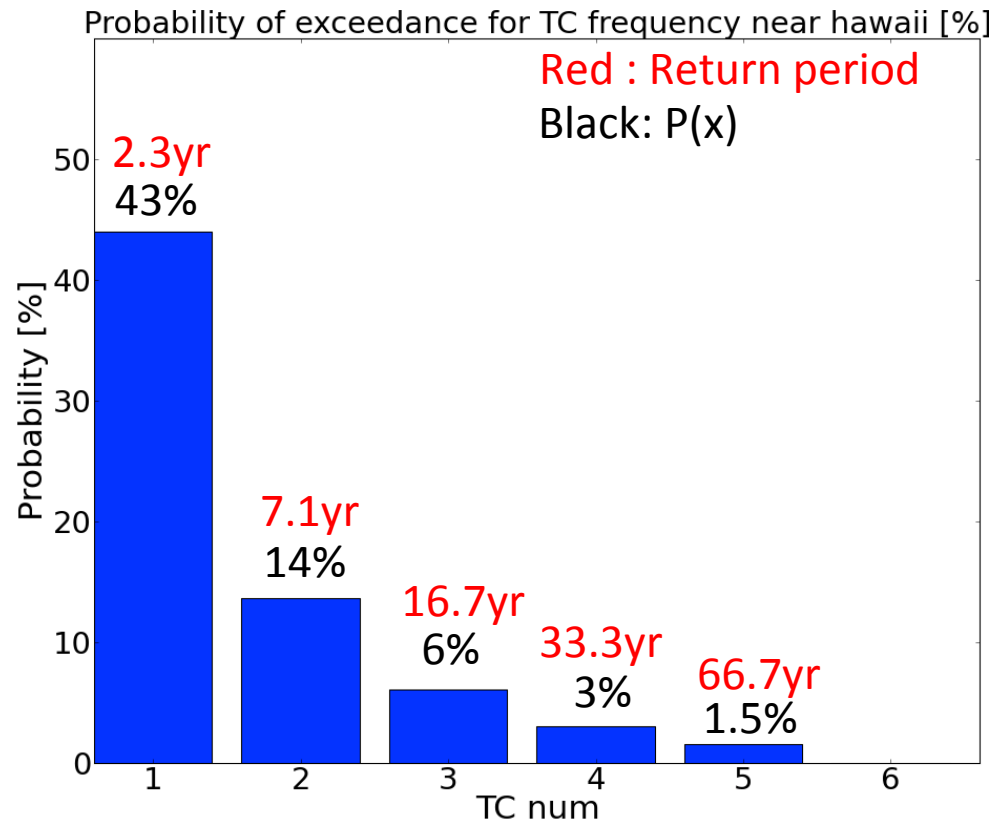
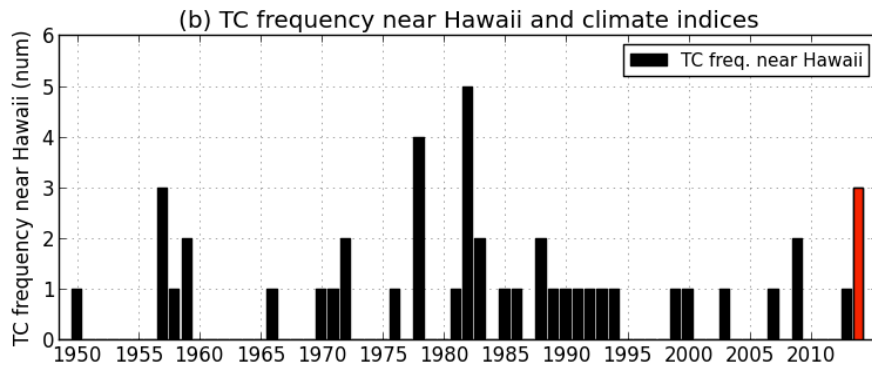
Main goal of this study

We explore whether the unusually large number of Hawaiian TCs in 2014 was made more likely by **anthropogenic forcing** or **natural variability** using a suite of climate simulations made using FLOR.

Probability of Exceedance

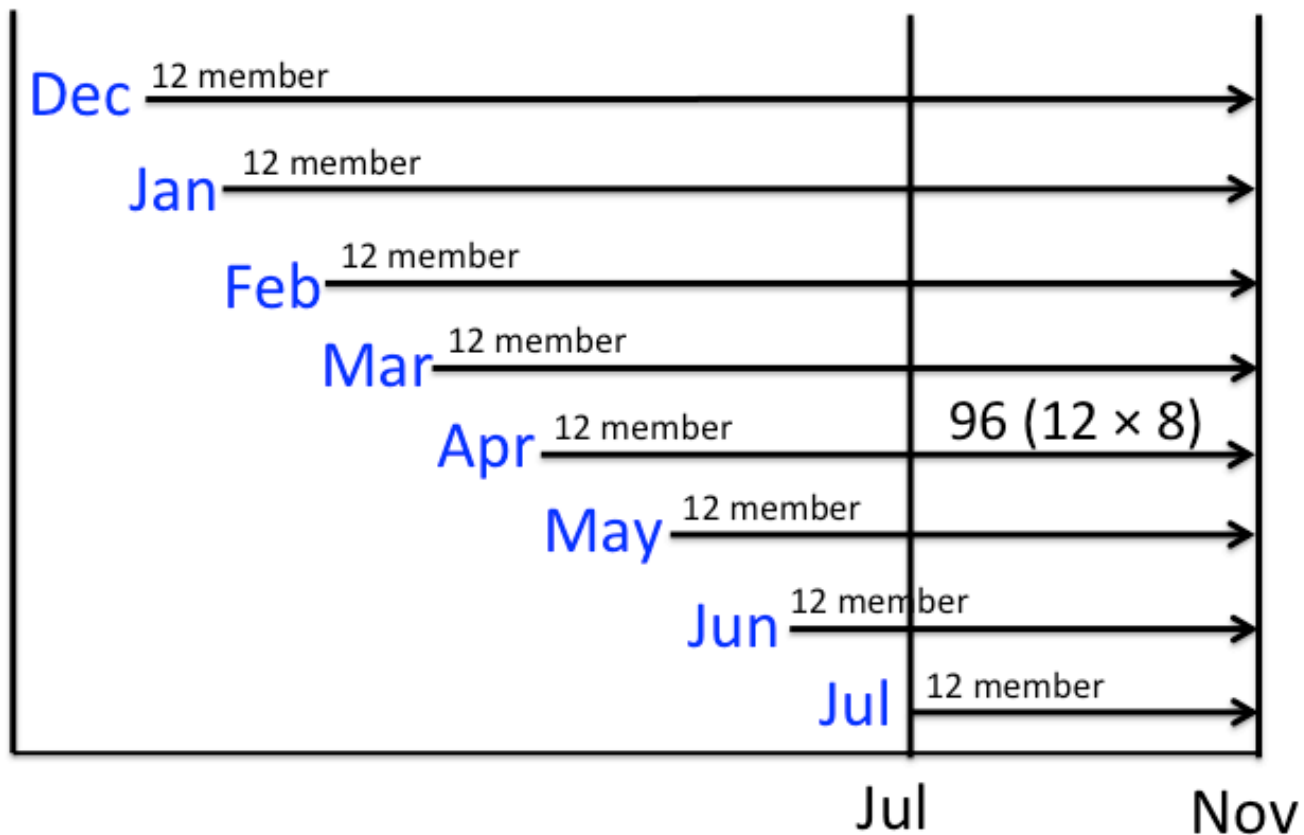
$$P(x) = \frac{\text{Number of years with TC number more than or equal to } x \text{ near Hawaii}}{\text{Total number of years}}$$

Observations (1949-2014, 66yr)



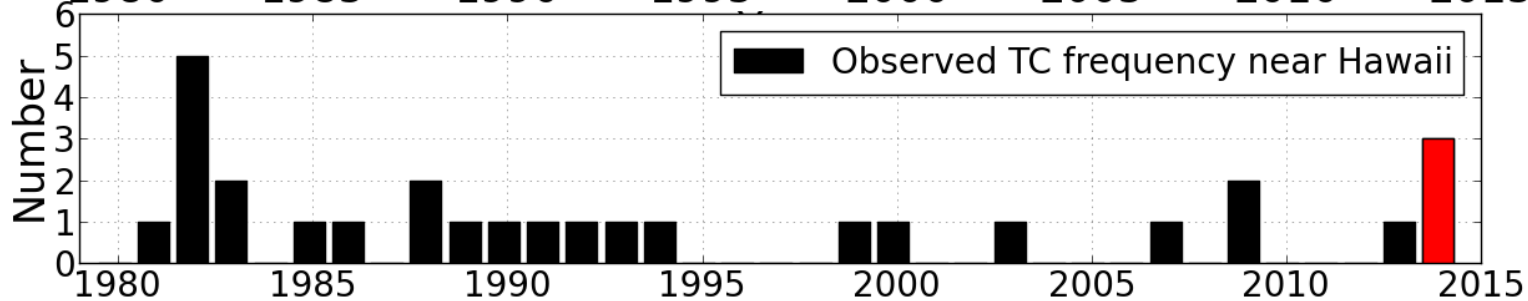
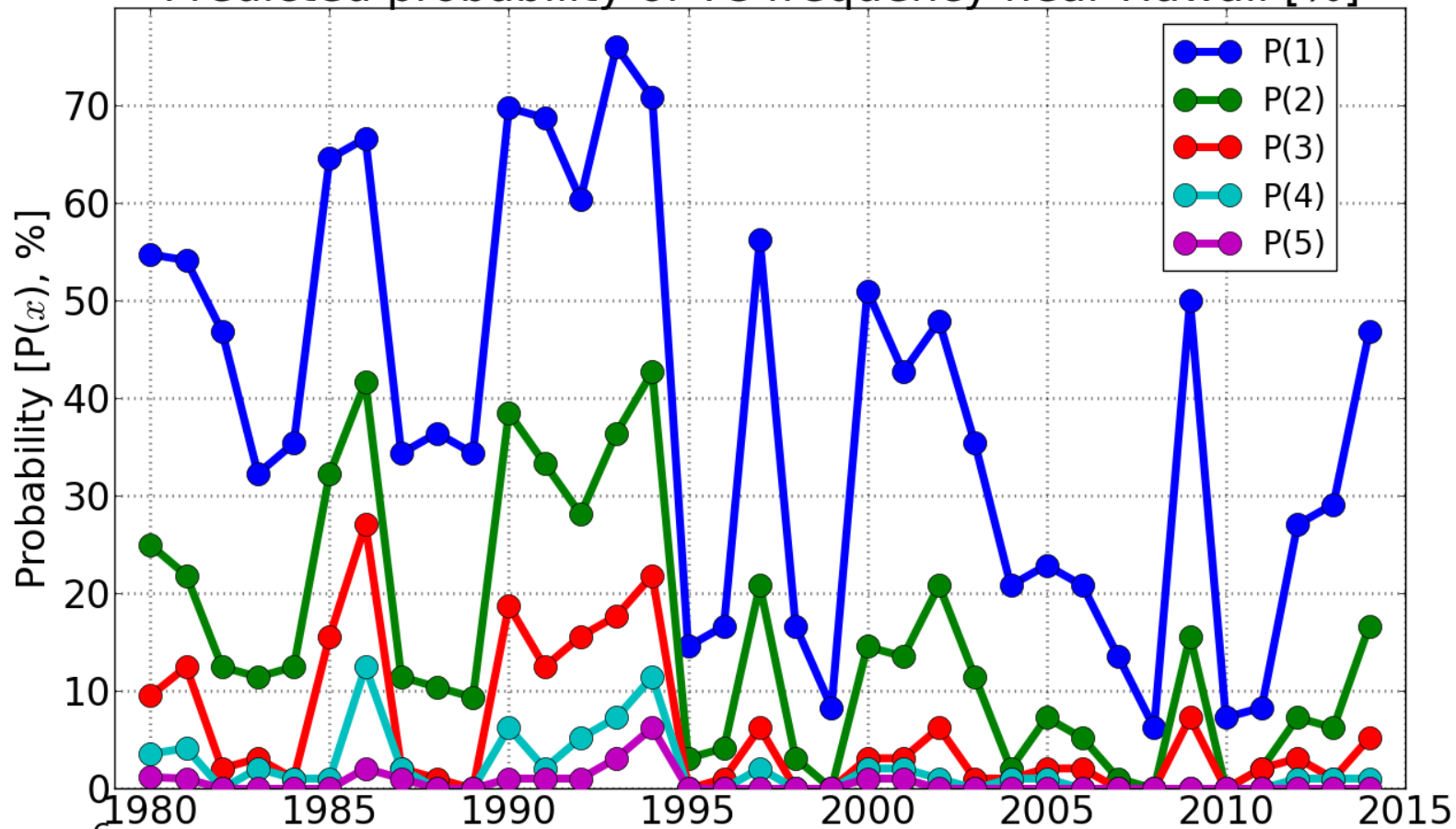
Retrospective Seasonal Forecast

- 12-member initialized retrospective seasonal forecast.
- For each year from 1980 to 2014, predictions from 8 lead months are used. 96 (= 12 member x 8 months) samples are available for computing $P(x)$.



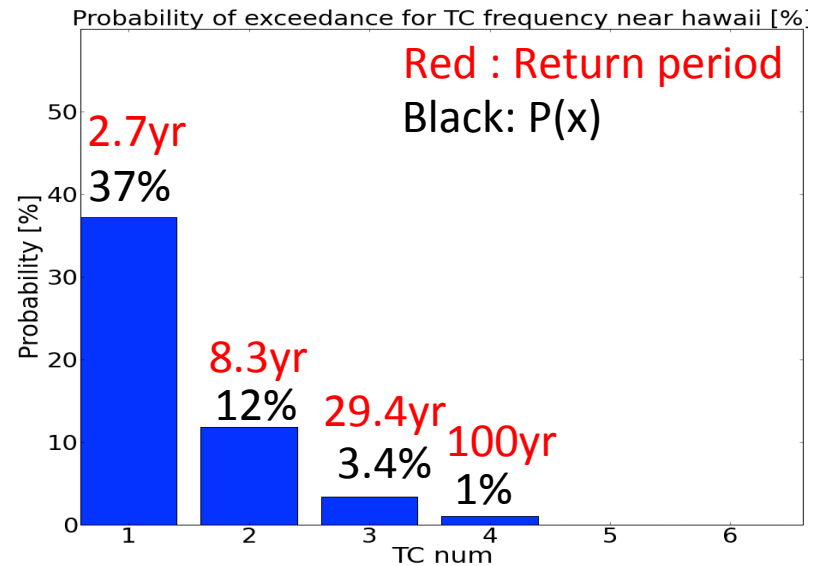
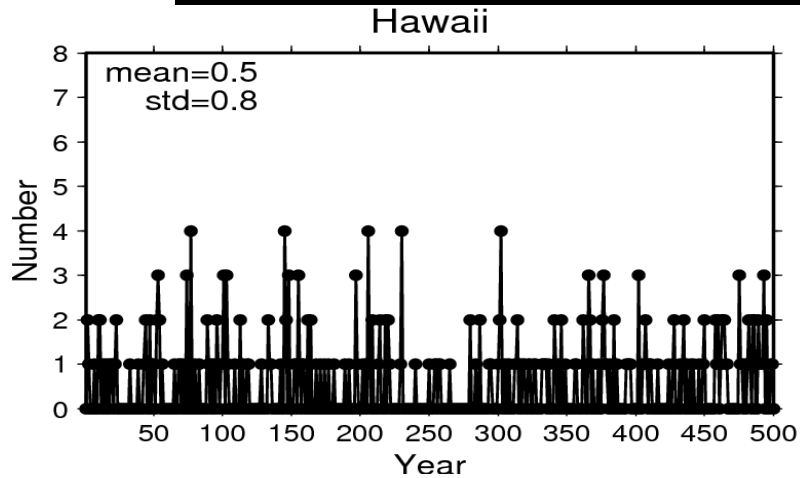
Retrospective Seasonal Forecast

Predicted probability of TC frequency near Hawaii [%]

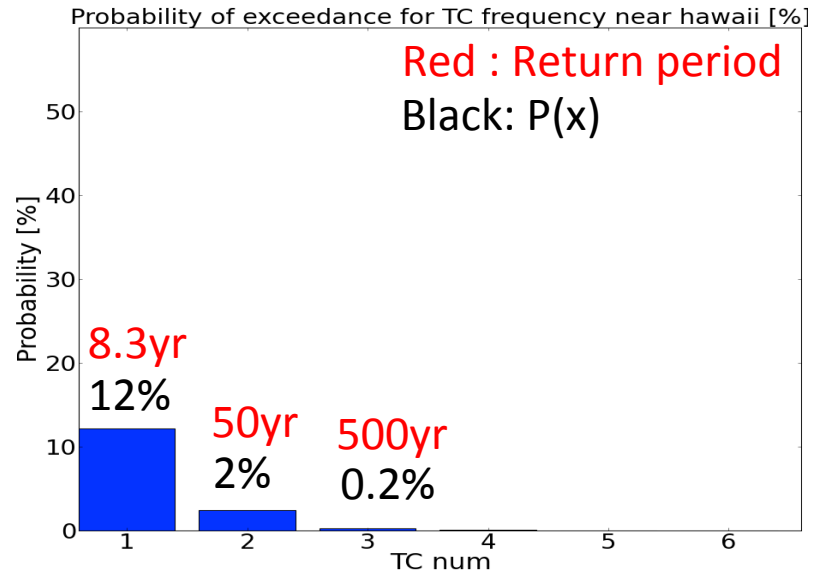
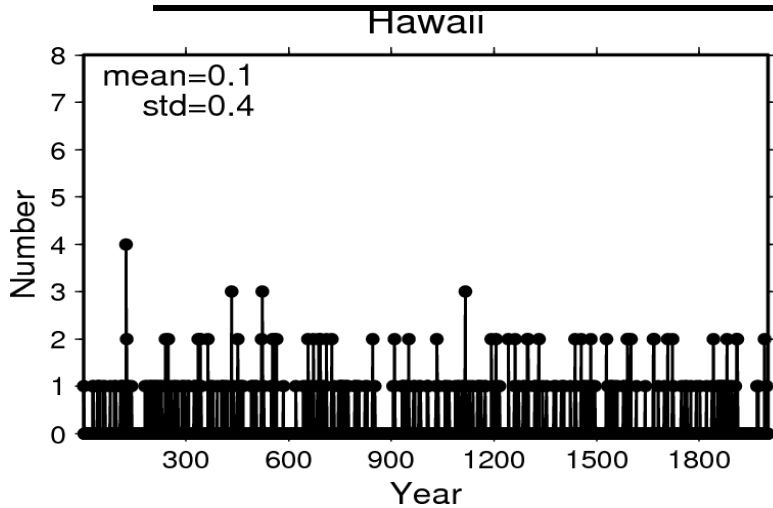


Control Experiments

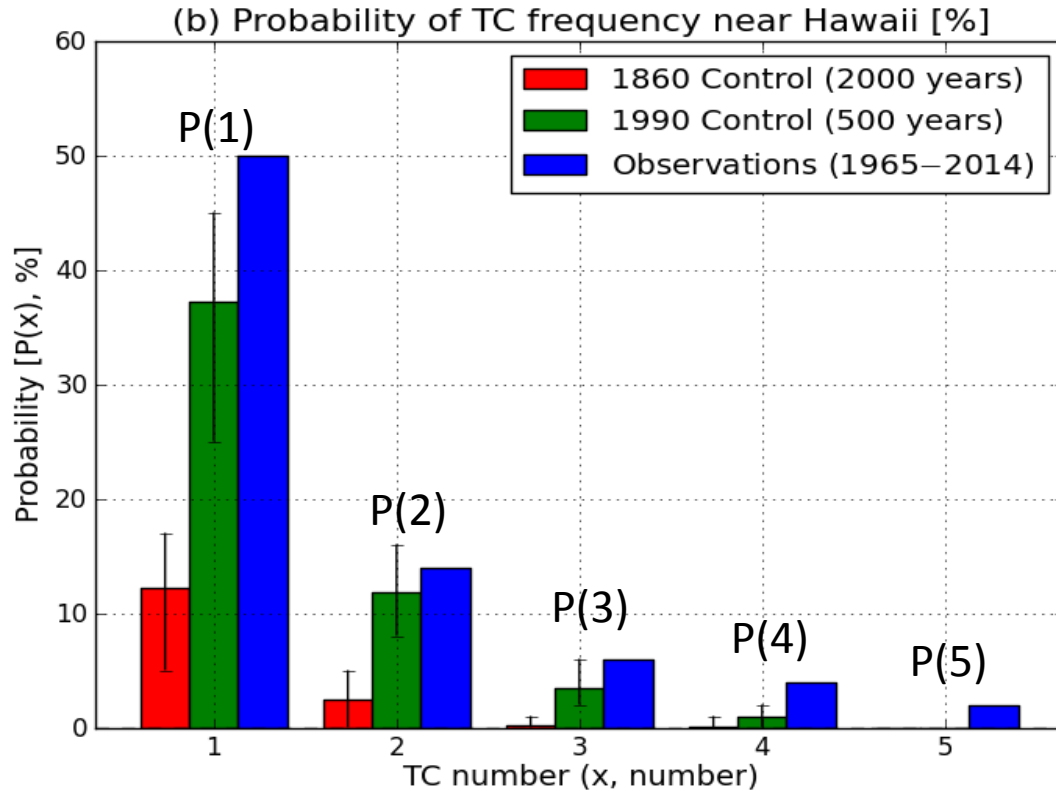
1990-level Radiative Forcing Control Experiment (500 yr)



1860-level Radiative Forcing Control Experiment (2000 yr)



Effect of Anthropogenic Forcing on TCs near Hawaii



P(2) and P(3) are about **5** and **17** times larger in 1990 control than 1860 control.

Fraction of Attributable Risk (FAR)

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

E_1 : Anthropogenic Forcing

E_0 : Non-anthropogenic Forcing

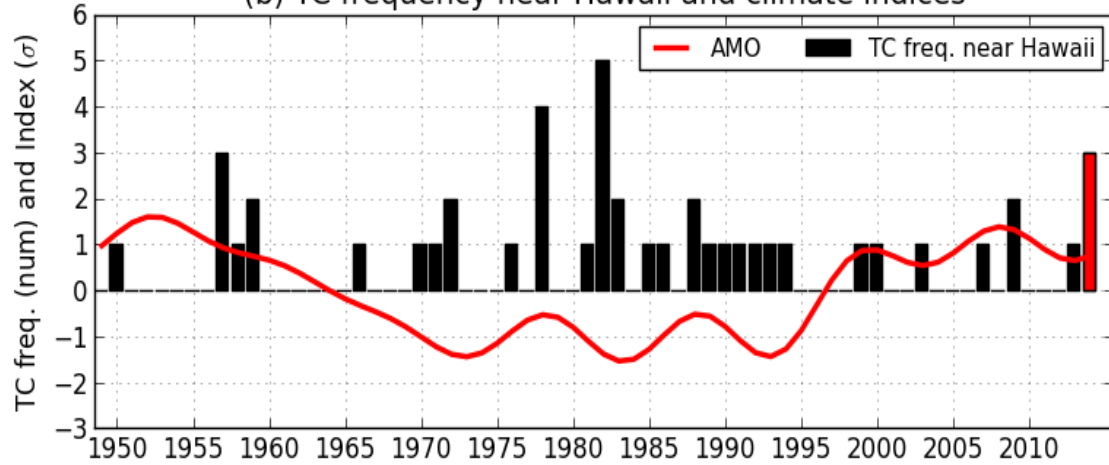
$$FAR(2) = 0.79$$

$$FAR(3) = 0.94$$

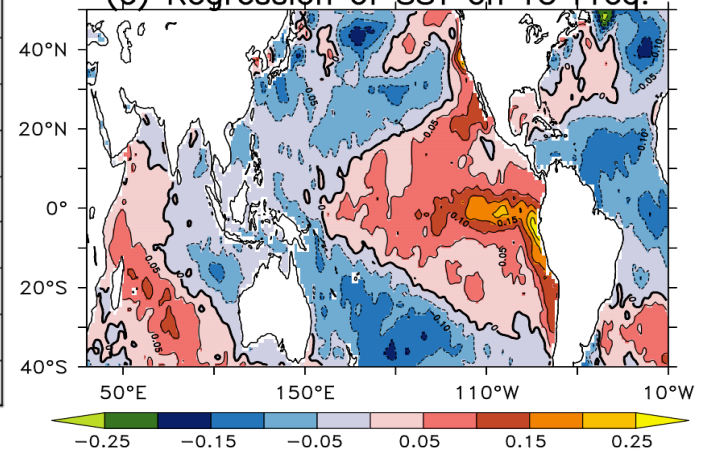
Anthropogenic forcing has substantially changed the odds of TC seasons like 2014 near Hawaii relative to natural variability alone.

Effect of Natural Variability on TCs near Hawaii

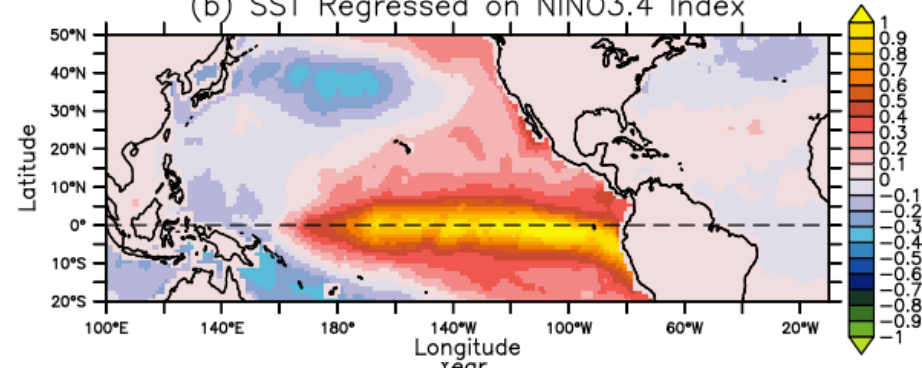
(b) TC frequency near Hawaii and climate indices



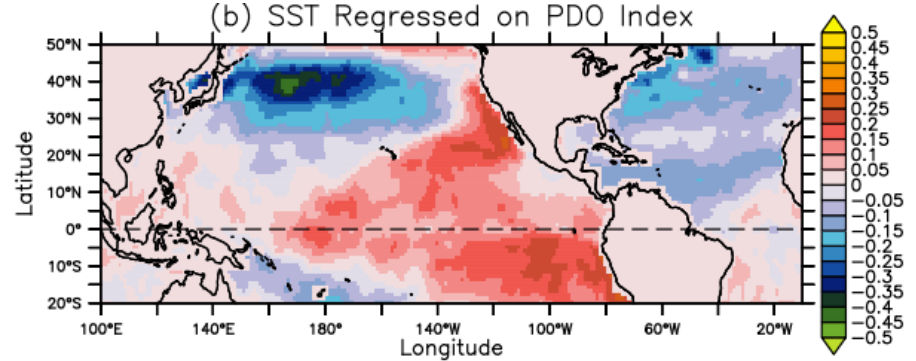
(c) Regression of SST on TC Freq.



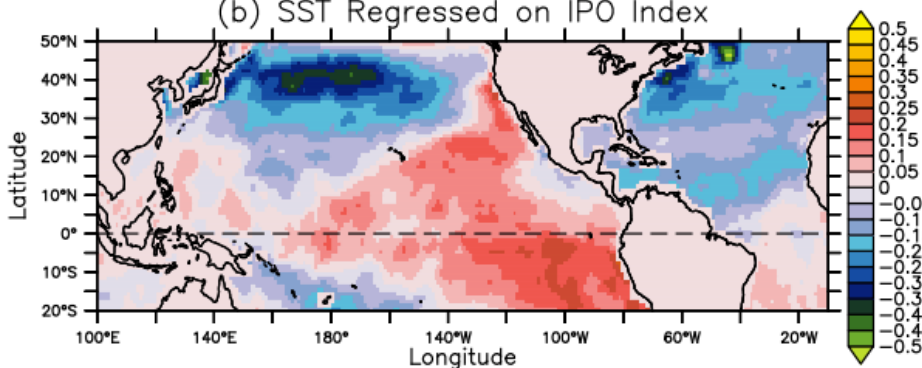
(b) SST Regressed on NINO3.4 Index



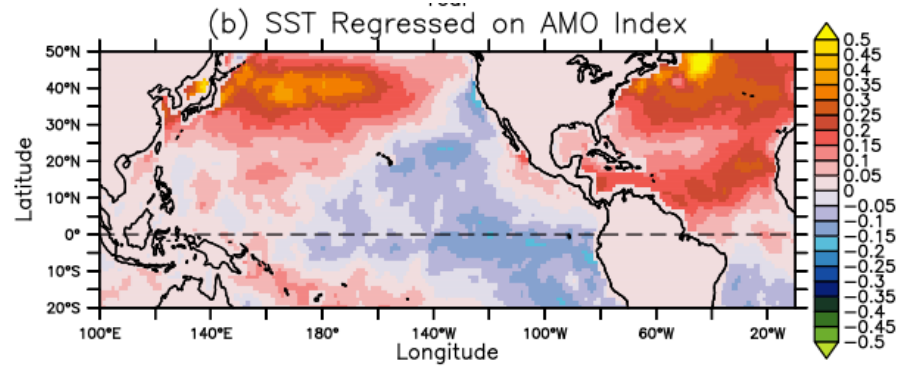
(b) SST Regressed on PDO Index



(b) SST Regressed on IPO Index

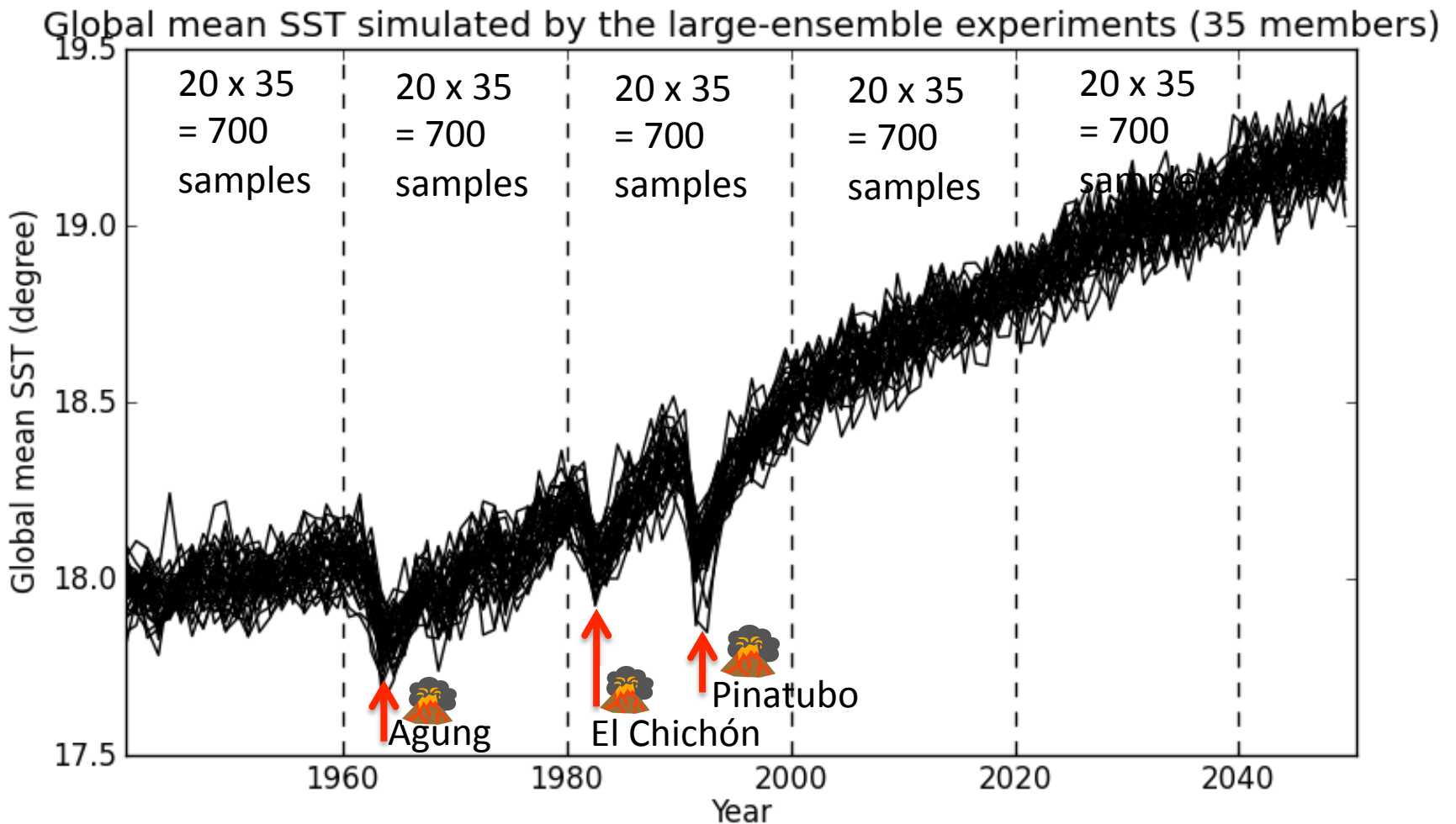


(b) SST Regressed on AMO Index



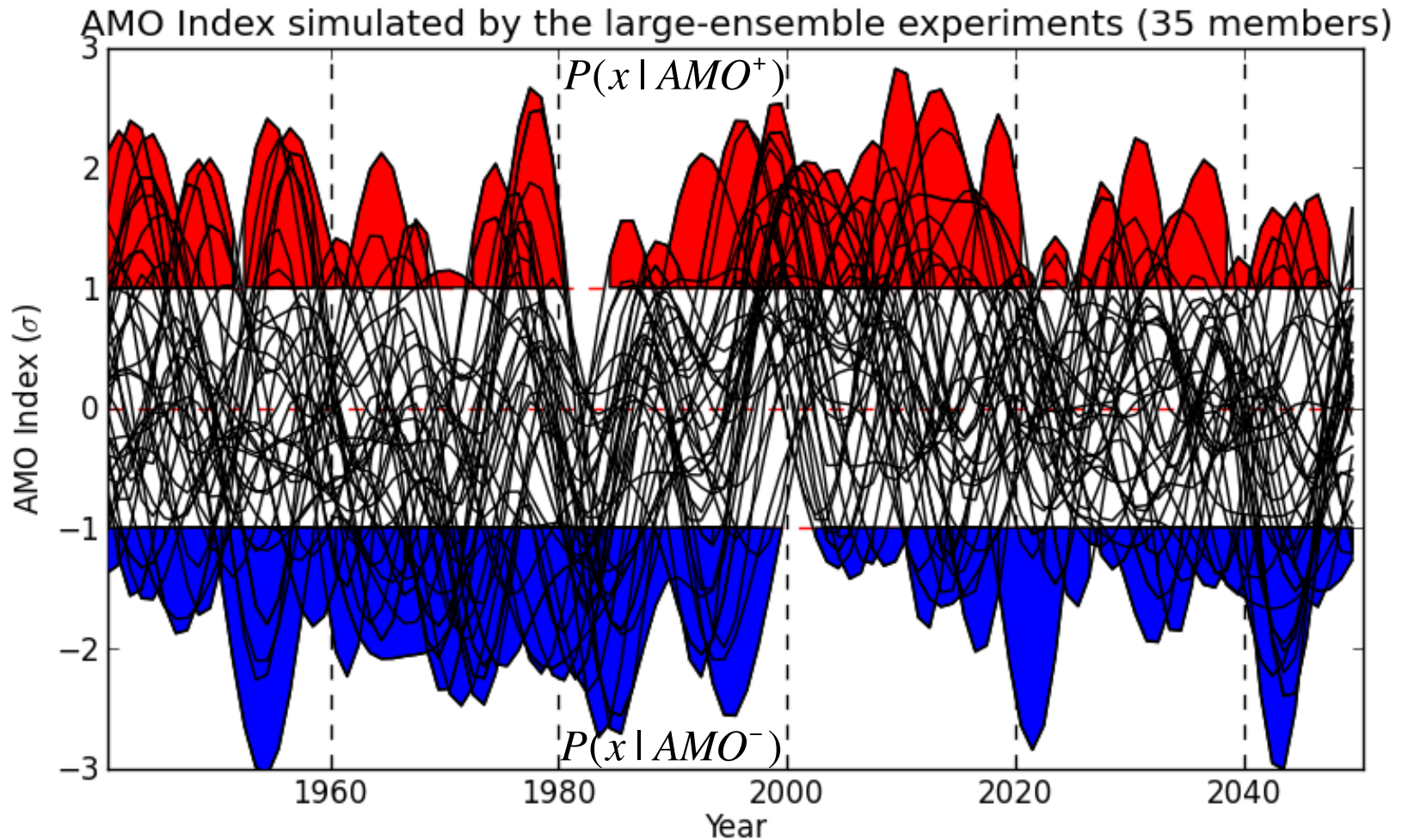
Large-ensemble Experiments

- 35-member large-ensemble simulations for the period 1941–2050.
- Historical volcanic forcing and aerosols are prescribed between 1941–2005. No volcanic event after 2005.
- After 2005, RCP4.5 scenario is assumed for the anthropogenic forcing.
- For each 20-yr chunk, there are 700 (20 yr x 35 member) samples to compute $P(x)$.



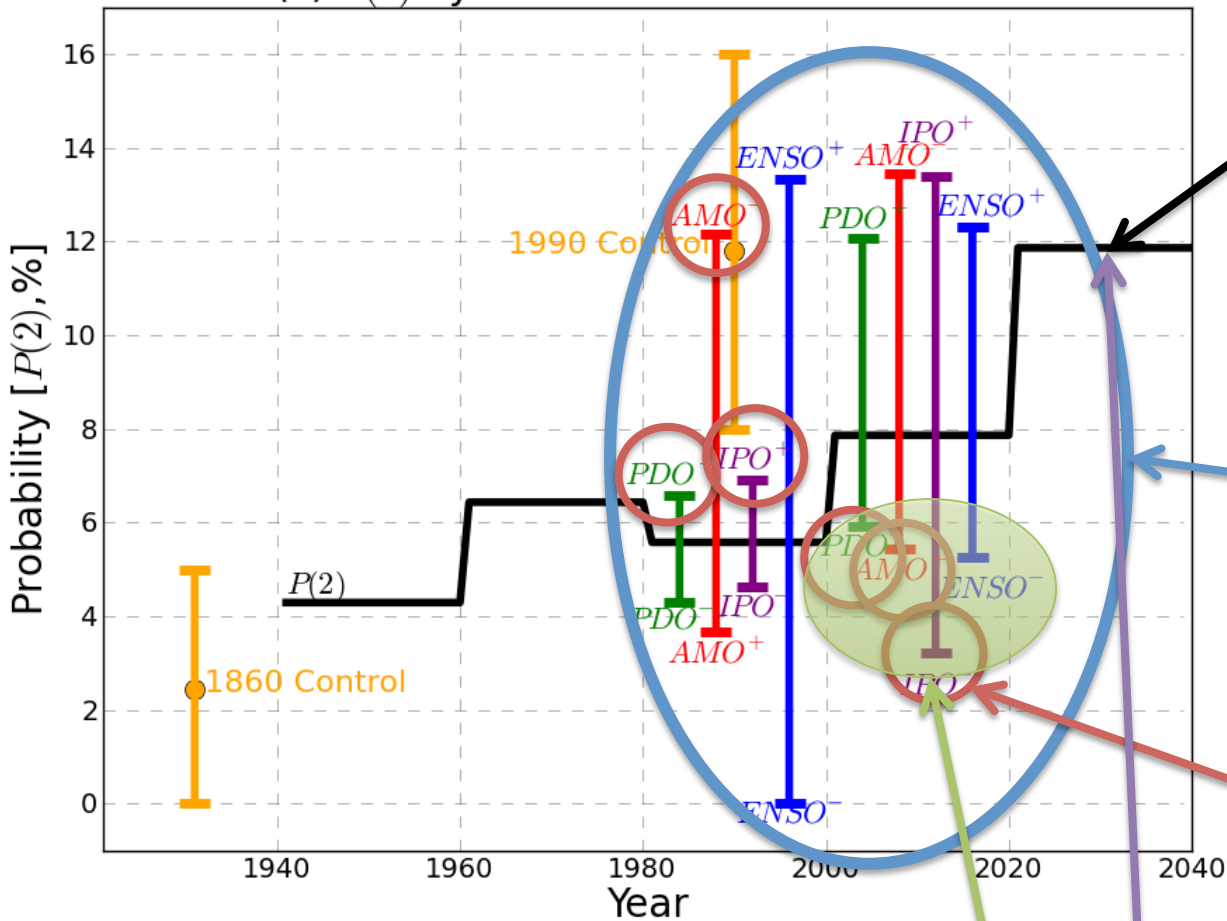
Large-ensemble Experiments

- Internal variability is independent among the ensembles.
- We can compute conditional probability under any phases of natural variability.



Large-ensemble Experiments

(c) $P(2)$ by the Multidecadal Simulations



• Black line reveals a gradual increase from 1940 to 2040, indicating global warming generates more TCs near Hawaii.

• Colors bars indicate that natural variability has marked potential to influence the probability.

• Observed multi-decade difference between 1980–2000 and 2000–2020 was mainly due to natural internal variability.

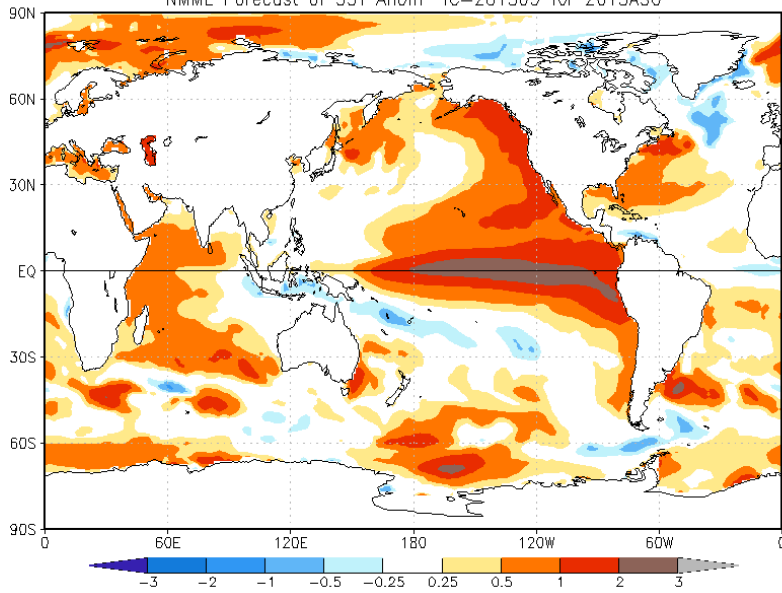
• The extremely large number of TCs during the 2014 summer season occurred despite the unfavourable IPO (−2.0), AMO (+0.6), and PDO (−0.7), and moderate El Niño (+0.6).

• Continued increase of probability is expected in the following decades.

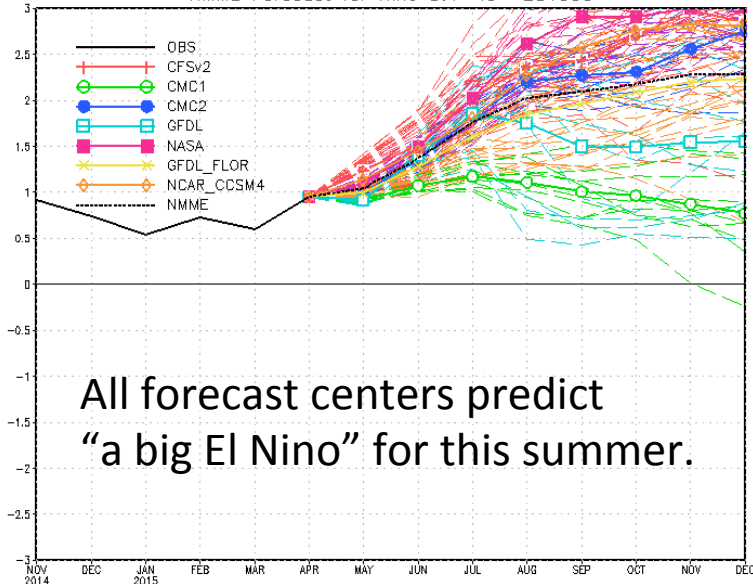
What about seasonal forecast for 2015?

2015 April initial to predict 2015 JAS.

NMME Forecast of SST Anom IC=201505 for 2015ASO

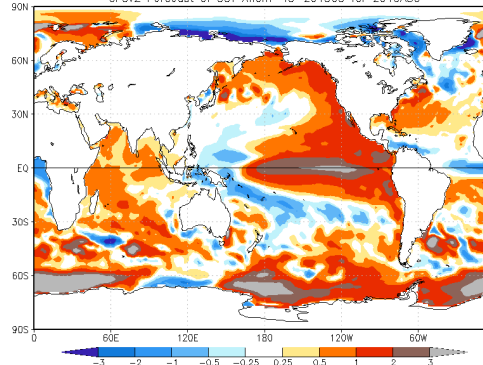


NMME Forecast for Nino 3.4 IC= 201505



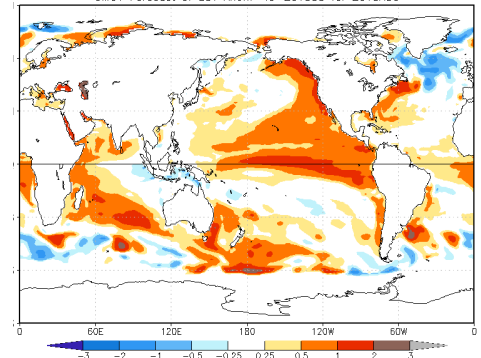
NCEP CFSv2

CFSv2 Forecast of SST Anom IC=201505 for 2015ASO



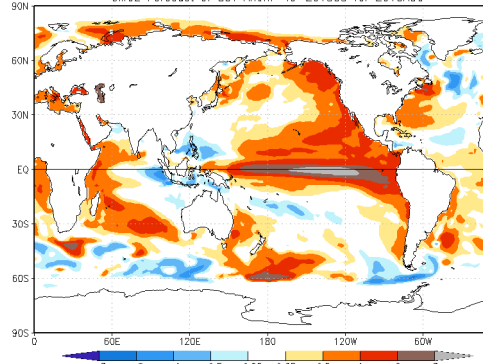
CMC1 CanCM3

CMC1 Forecast of SST Anom IC=201505 for 2015ASO



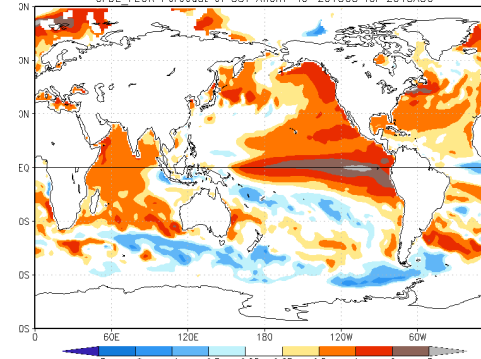
CMC2 CanCM4

CMC2 Forecast of SST Anom IC=201505 for 2015ASO



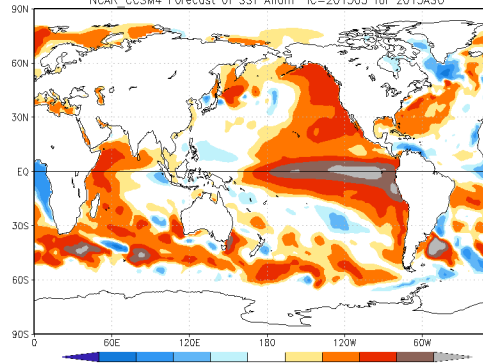
GFDL FLOR

GFDL FLOR Forecast of SST Anom IC=201505 for 2015ASO



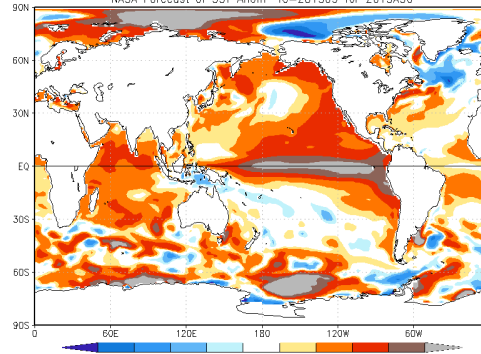
NCAR CCSM4

NCAR CCSM4 Forecast of SST Anom IC=201505 for 2015ASO

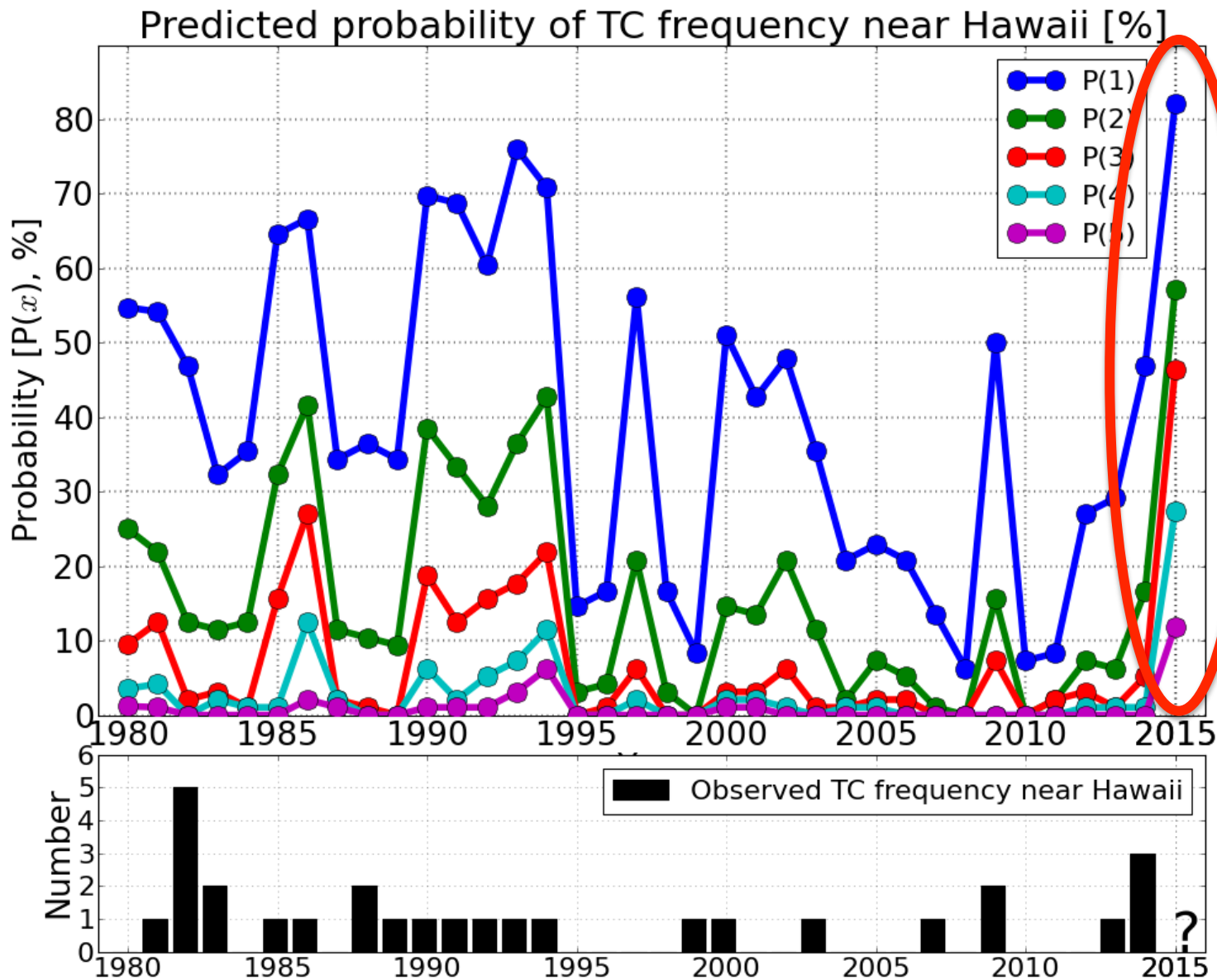


NASA GEOS5

NASA Forecast of SST Anom IC=201505 for 2015ASO



2015 Hawaiian TC Forecast using FLOR (2015 May Initial)



FLOR predicts historical record of Hawaiian TCs in 2015.

Summary

- The observed multi-decadal difference in TC frequency near Hawaii between 1980–1994 and 1995–2014 was mainly caused by **natural variability**.
- It is likely that **global warming** has increased the odds of the extremely large number of Hawaiian TCs in 2014, in combination with the moderately favorable condition of El Niño.
- The ensemble future experiments indicate **a continued increasing probability** of active seasons around Hawaii over the next few decades – though there will be substantial modulation on interannual and decadal timescales from internal variability.