Increasing Frequency of Extremely Severe Cyclonic Storms over the Arabian Sea

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GFDL/Princeton AOS

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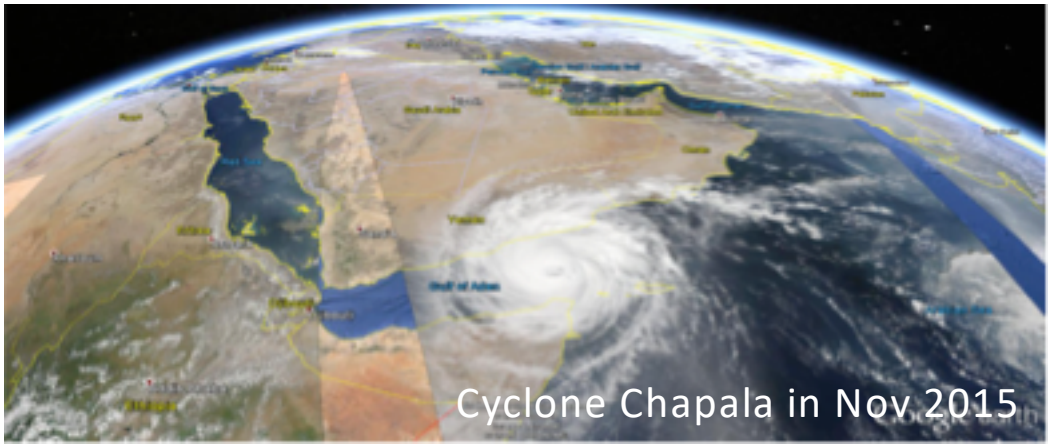
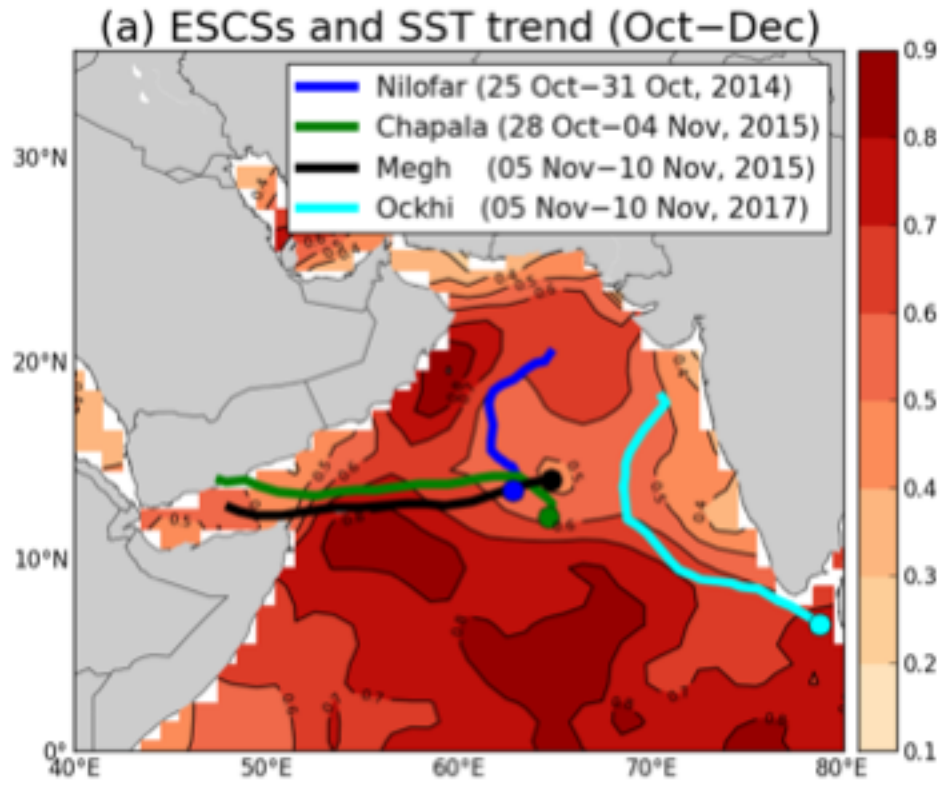
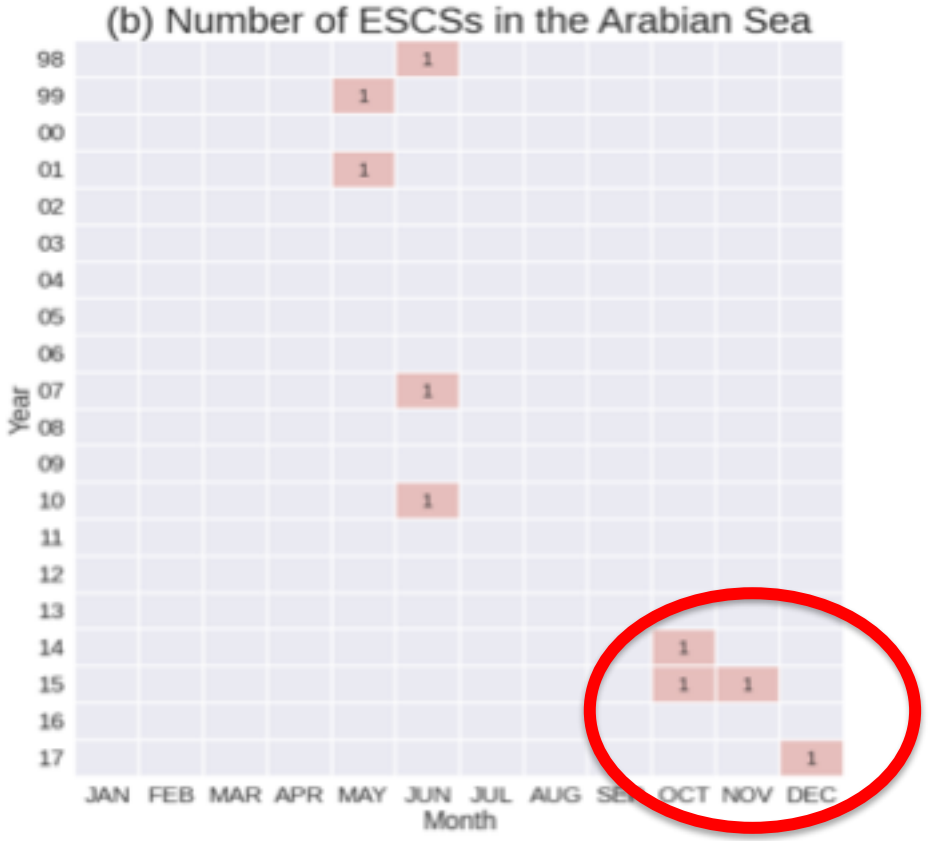
Extremely Severe Cyclonic Storm (≥ 46ms^{-1}; ESCS ≈ Major Hurricane)



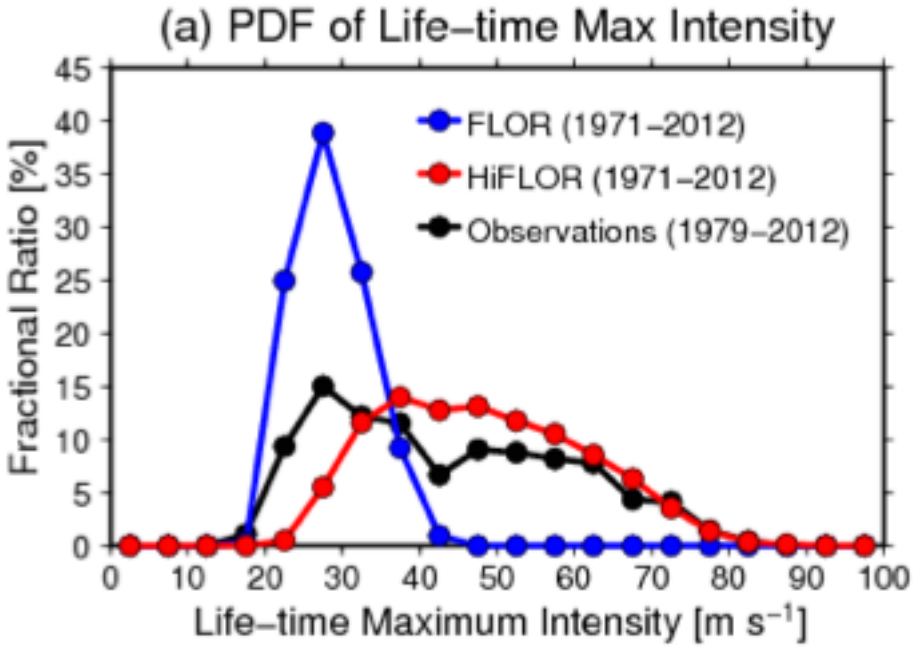
- Frequency of occurrence of ESCS has been abruptly **increasing only during post-monsoon season** since 2014.
- **What caused the increase?**
  - **anthropogenic forcing?**
  - **intrinsic natural variability?**





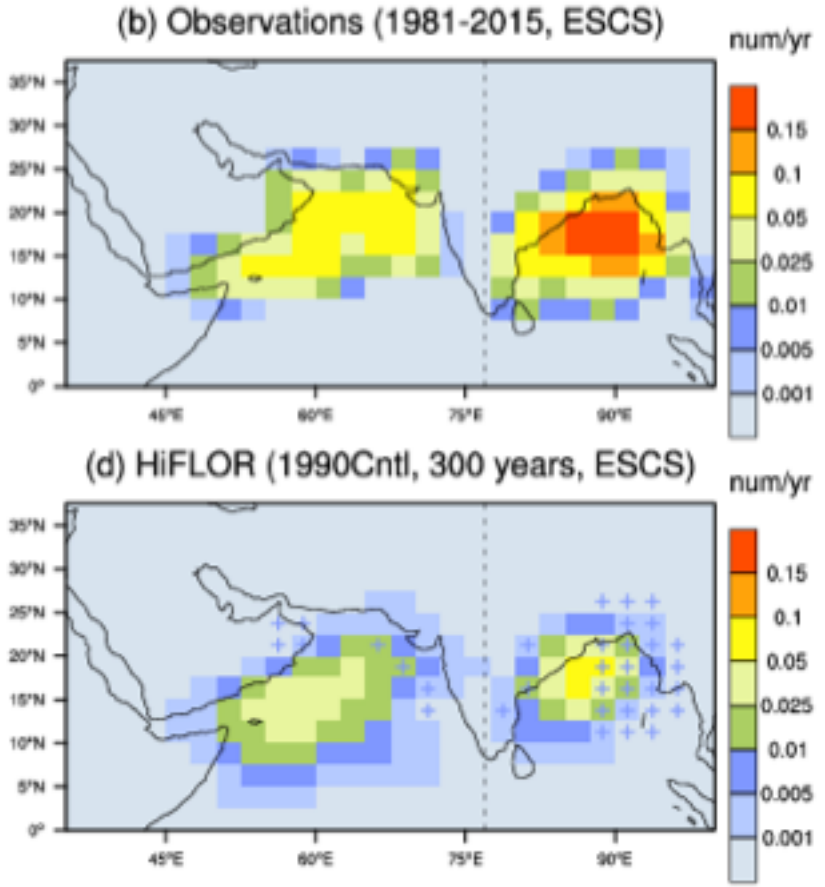
HiFLOR (**Hi**-resolution version of **F**orecast-oriented **L**ow **O**cean **R**esolution version of CM2.5)

- FLOR : Fully coupled model with 50km-mesh atmosphere and 1° ocean/sea ice
- HiFLOR: Fully coupled model with **25km**-mesh atmosphere and 1° ocean/sea ice



HiFLOR reproduce observed frequency of ESCS occurrence over the Arabian Sea

Climatological mean ESCS Density



Experimental Design using HiFLOR

Configuration

Free run prescribed by radiative forcing fixed at a specific year.

Simulation Length

Experiment Name	Year of Fixed Radiative Forcing	Length of Simulation
1860 Cntl	1860 (CO_2 = 286 ppm)	600 Years
1940 Cntl	1940 (CO_2 = 310 ppm)	200 Years
1990 Cntl	1990 (CO_2 = 353 ppm)	300 Years
2015 Cntl	2015 (CO_2 = 398 ppm)	200 Years

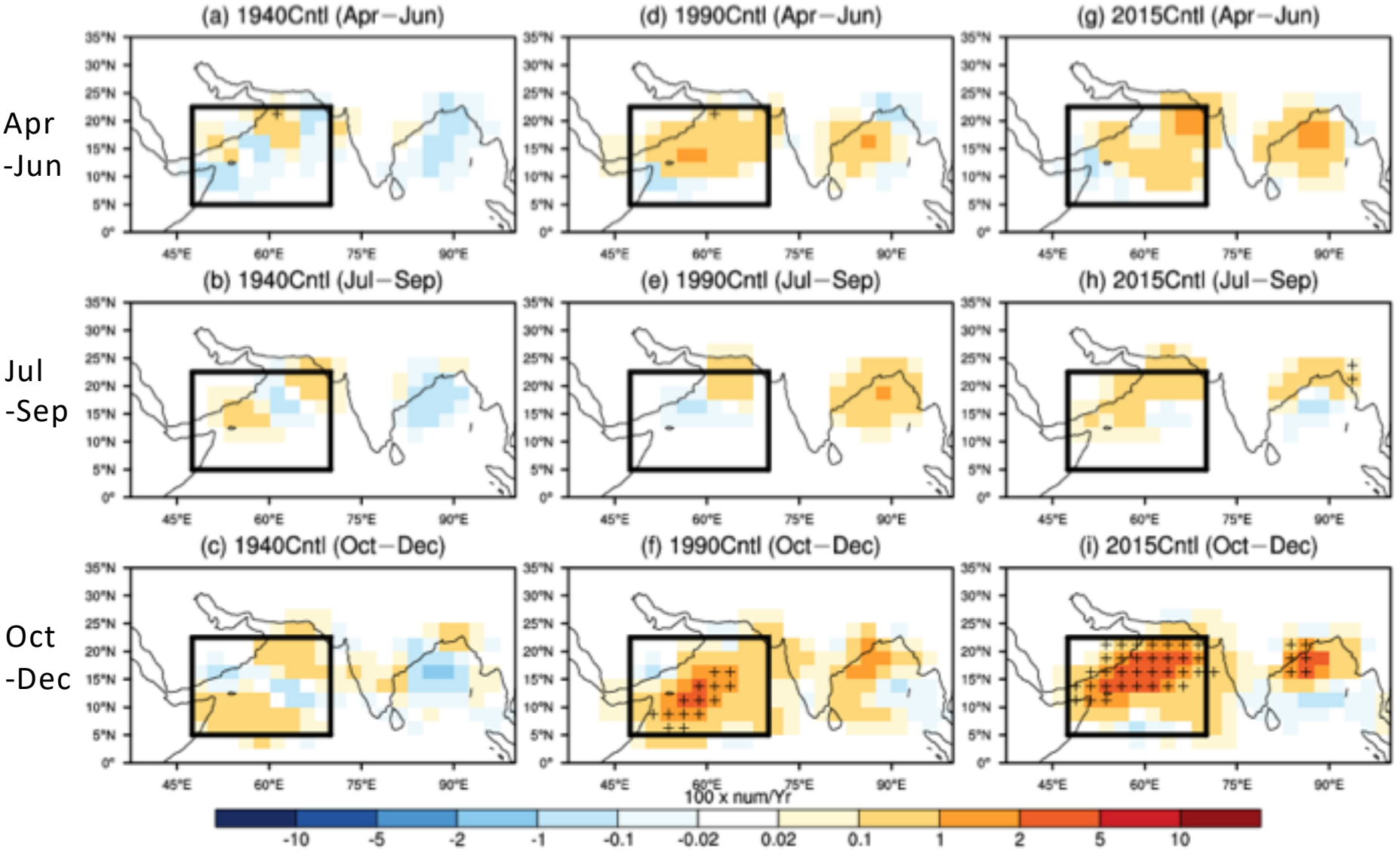
TC Detection Method

Based on Harris et al. (2016)

- Flood-Fill algorithm is applied to detect SLP minima.
- 2.0 K warm core
- 17.5m/s maximum wind speed
- Duration of satisfaction of the above criteria should be more than 36 hours

Projected Changes in the Seasonal Mean ESCS Density

Relative to 1860 Cntl



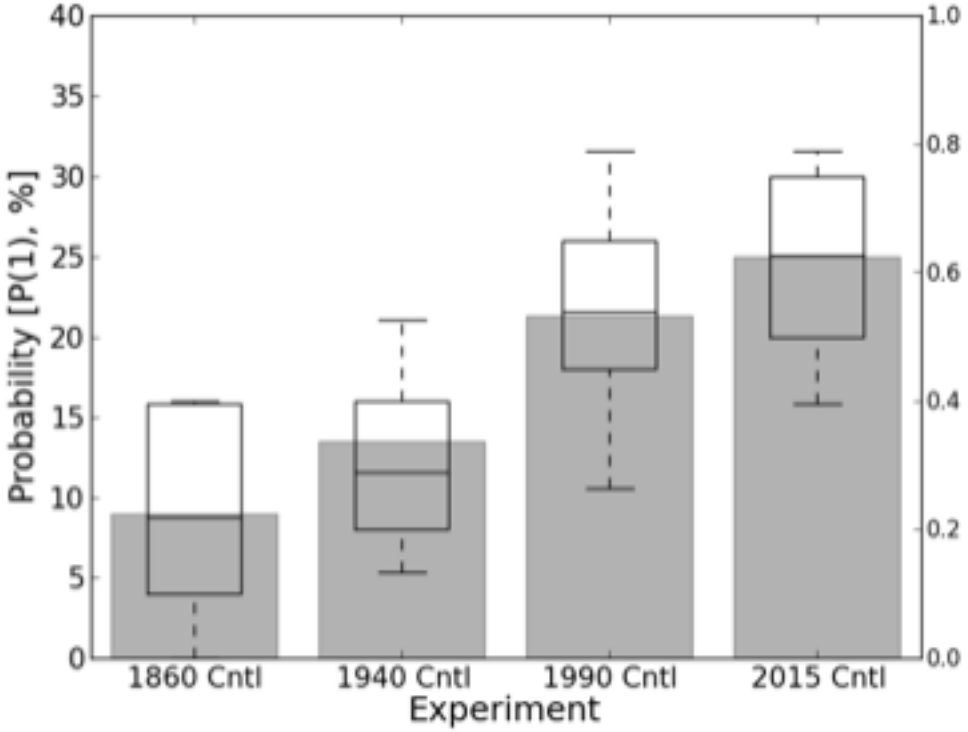
Only post-monsoon season shows significant increases in ESCSs over the Arabian Sea

Probability of Exceedance for ESCS Occurrence

$$P(1) \equiv \frac{\text{Number of years with ESCS number more than or equal to 1}}{\text{Total number of simulated years}}$$

Ex) If there are 50 years in which ESCS number ≥1 among the total 600 years,
P(1) = 50/600 = 8%

Post-Monsoon Season (October – December)



P(1) is more than **3** times larger in 2015 Cntl than 1860 Cntl.

$$FAR(1) = \frac{P(1 \mid E_1) - P(1 \mid E_0)}{P(1 \mid E_1)}$$

E_1: 2015 Cntl
E_0: 1860 Cntl

Far(1) is **64%**

Anthropogenic forcing has substantially changed the odds of active ESCS seasons relative to natural variability alone.

Probability of Exceedance for ESCS Occurrence

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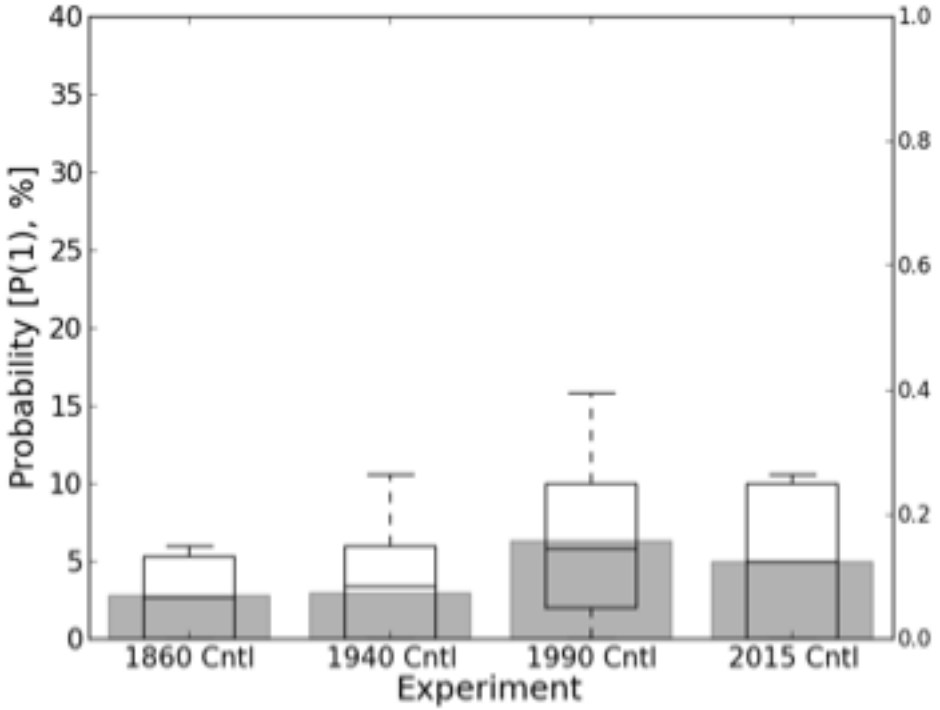
Ex) If there are 50 years in which ESCS number ≥1 among the total 600 years,
P(1) = 50/600 = 8%

Pre-Monsoon Season (April – June)



P(1) for 2017 Cntl is almost the same with that for 1860 Cntl.

$$FAR(1) = \frac{P(1 \mid E_1) - P(1 \mid E_0)}{P(1 \mid E_1)}$$

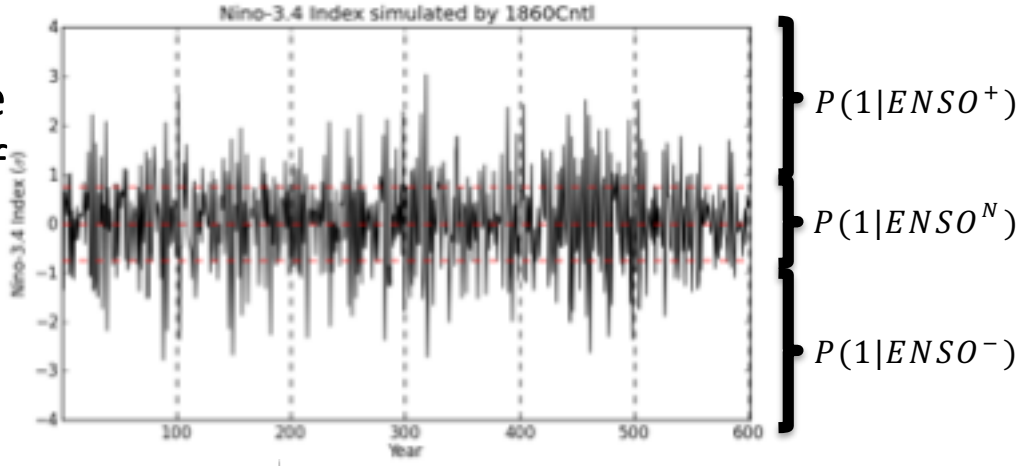
E_1: 2015 Cntl
E_0: 1860 Cntl

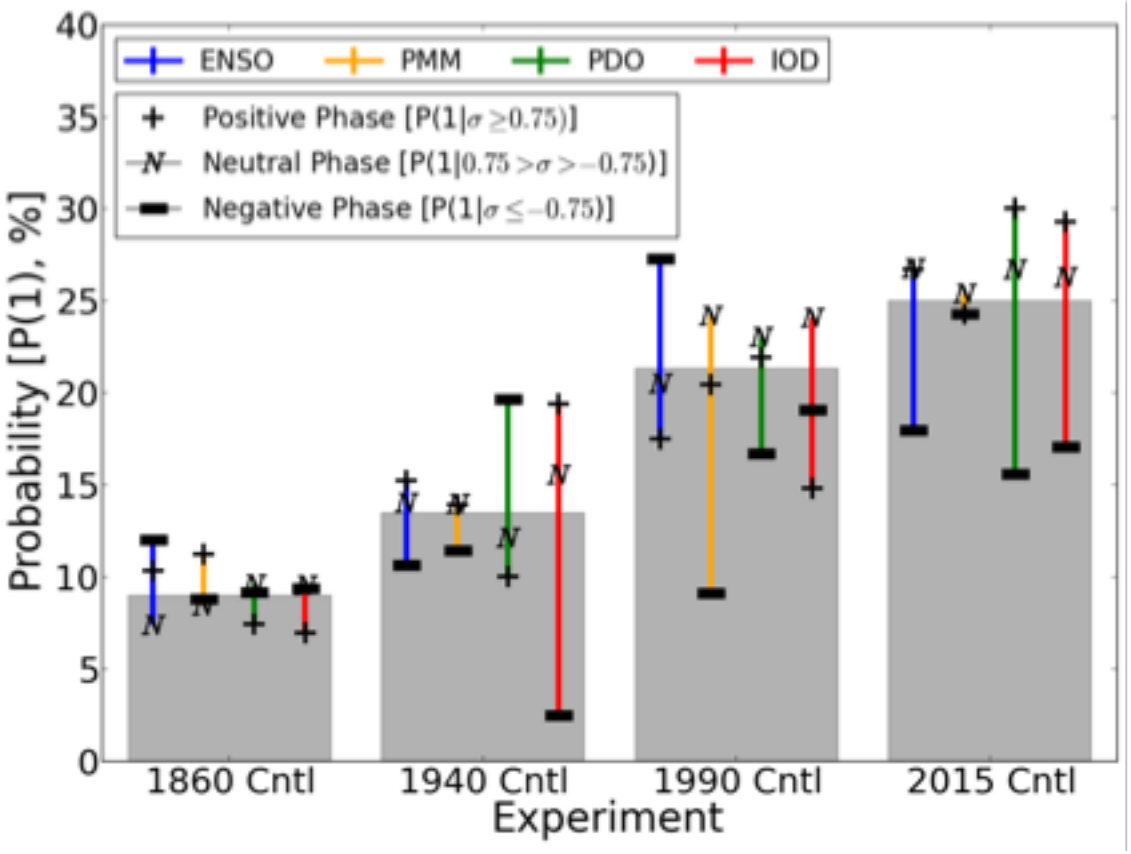
Far(1) is **29%**

There is no significant influence of anthropogenic forcing on ESCS during pre-monsoon season

Conditional Probability of Exceedance of ESCSs

Conditional provability of exceedance can be computed during any phase of natural variability.





Natural variability does not exert consistent variation of P(1),

suggesting that natural variability may not be a responsible factor for the recent active ESCSs.

Changes in Large-scale Parameter during Post-Monsoon Season

Post-Monsoon Season

SST

Vertical Wind Shear

HiFLOR

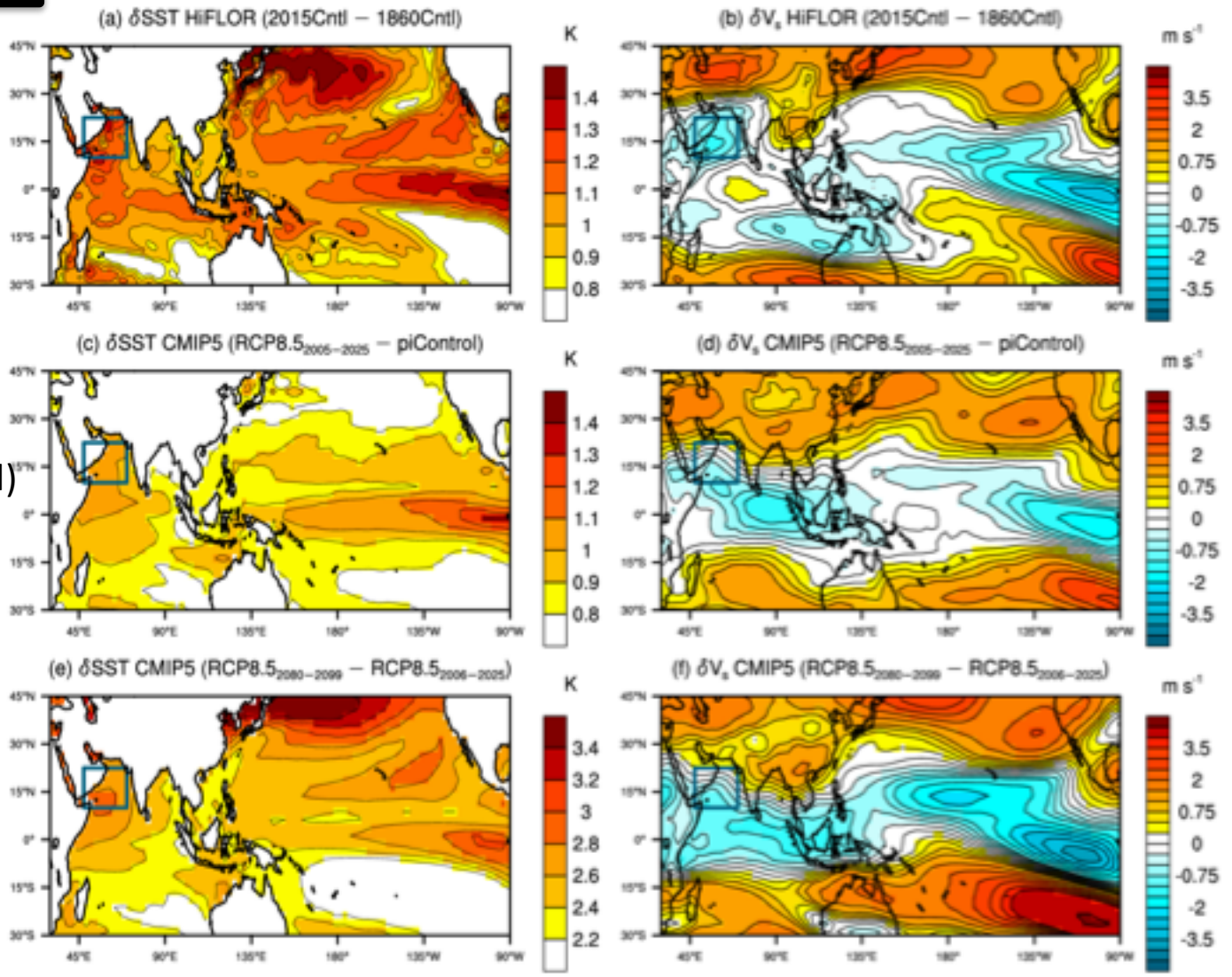
(2015Cntl – 1860Cntl)

CMIP5

(RCP8.5$_{2005\text{-}2025}$ – PiCntl)

CMIP5

(RCP8.5$_{2080\text{-}2099}$ – RCP8.5$_{2005\text{-}2025}$)



HiFLOR projects larger increase in SST as well as weaker vertical wind sear over the Arabian Sea. Similar changes are also projected by the CMIP5 models.

Changes in Large-scale Parameter during Pre-Monsoon Season

Pre-Monsoon Season

SST

Vertical Wind Shear

HiFLOR

(2015Cntl – 1860Cntl)

CMIP5

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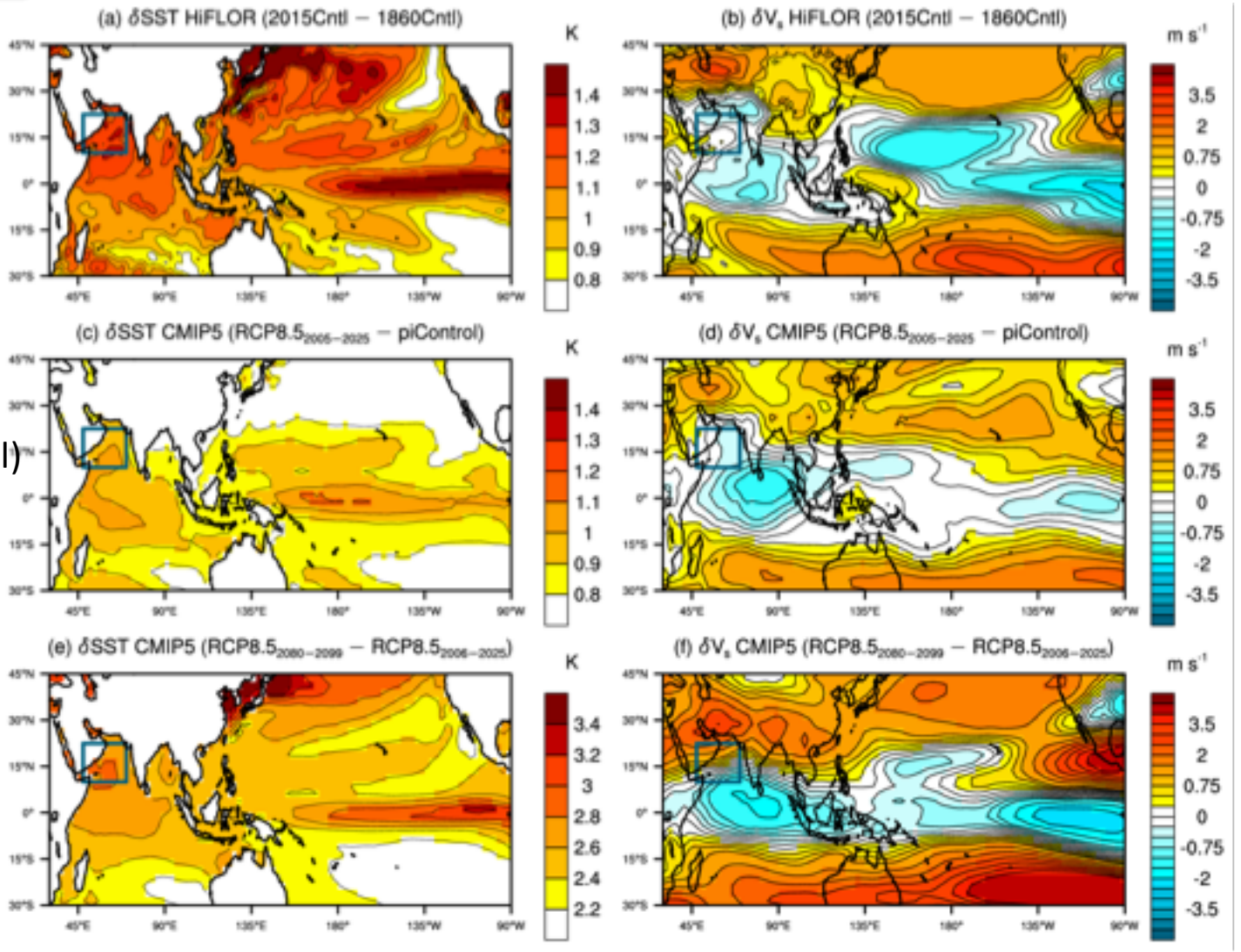
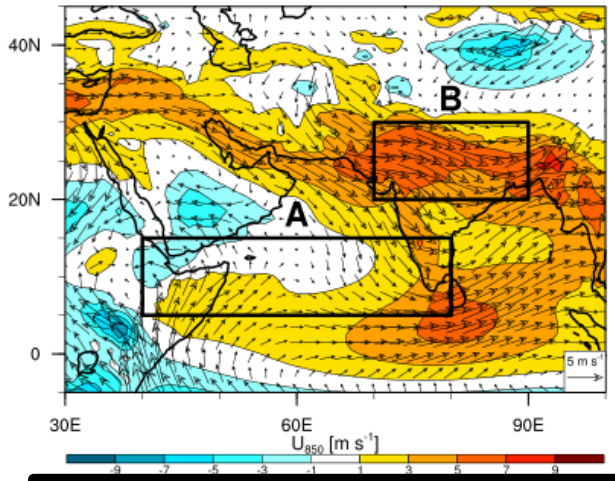


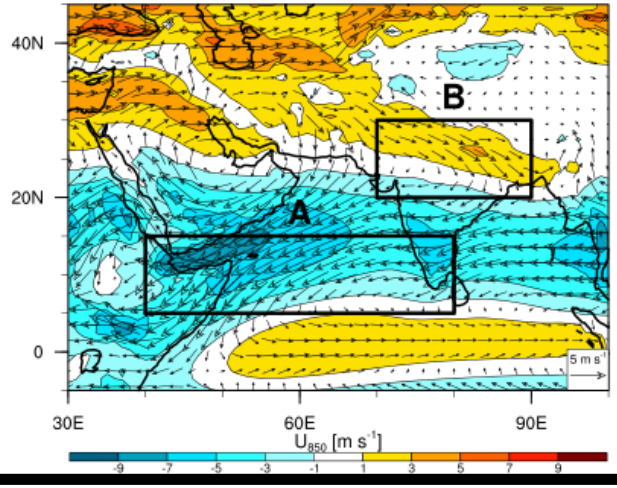
Although SST is projected to increase more than other open oceans over the Arabian Sea, vertical shear is not projected to decrease during the pre-monsoon season.

Weakening of Winter Monsoon Circulation

850hPa Winds (April–June)



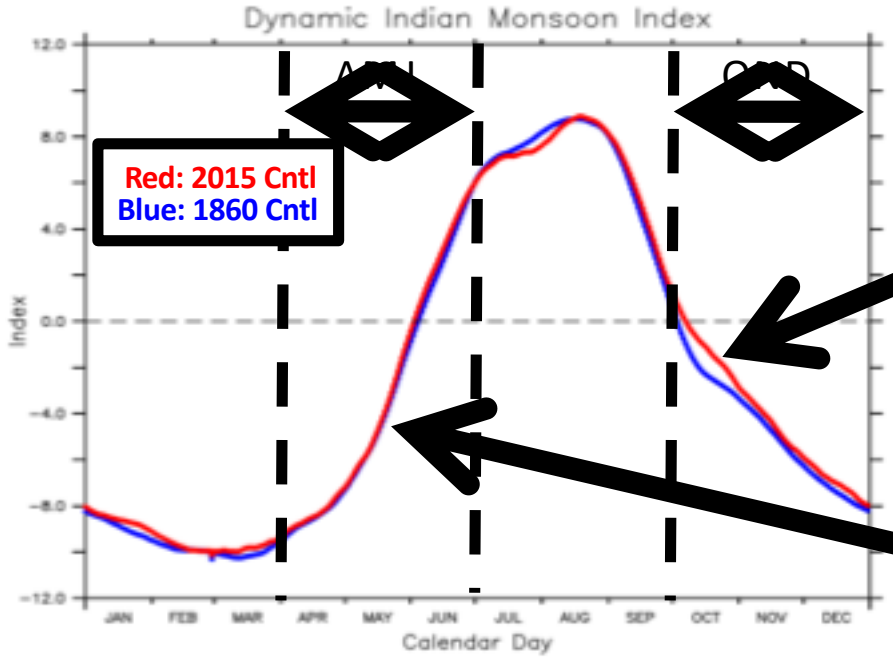
850hPa Winds (October–December)



Implication:
DIMI >0 : Summer Monsoon
DIMI <0 : Winter Monsoon

Dynamic Indian Monsoon Index (DIMI) = Zonal mean wind difference between A and B.

Wang and Fang (1999)



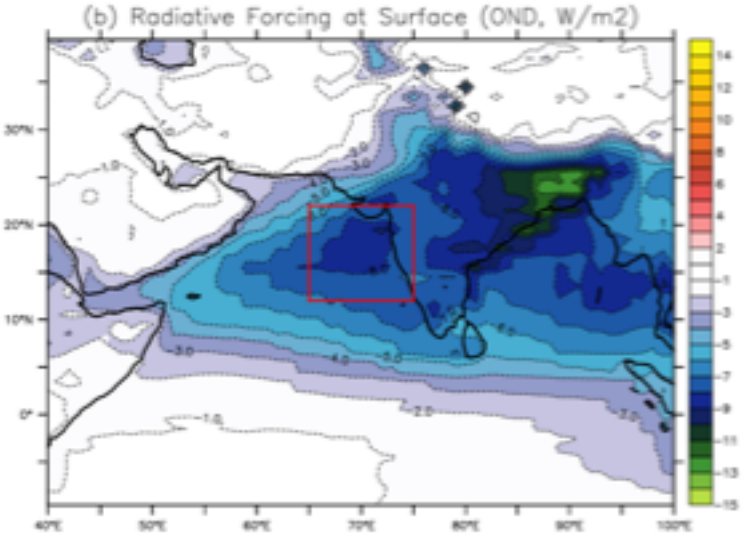
Significant decrease in DIMI in the post-monsoon season
=> Weakening of Winter Monsoon Circulation
=> Weakening of Vertical Wind Shear
=> Increase in ESCSs

No changes in DIMI in the pre-monsoon season

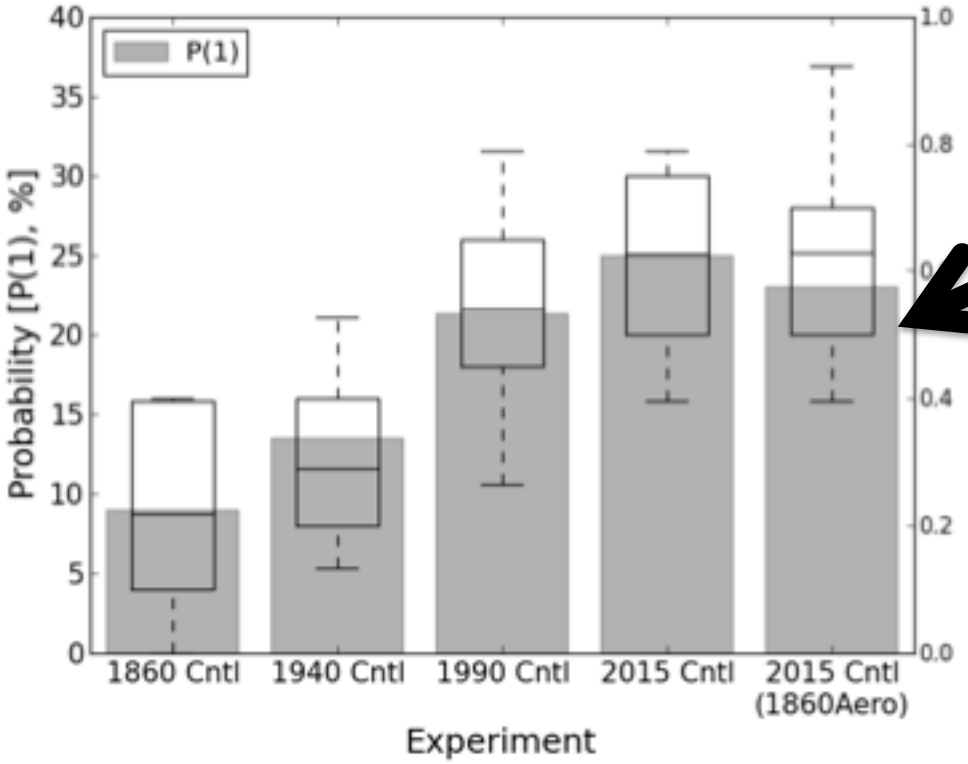
Summary

- Intense tropical cyclones (ESCSs) have been observed in the Arabian Sea during the post-monsoon season (October–December) since 2014.
- Experiments with high-resolution model suggest that the increase was made more likely by anthropogenic forcing, and not by effects of natural variability.
- Robust changes in SST and vertical wind shear are found in CMIP5 models.
- Weakening of winter Indian monsoon is a key for active ESCS season during the post-monsoon season.
- Increasing of aerosols may also play an important role for the active ESCSs, but refinement of model physics is necessary to estimate accurate impact of aerosols.

Impact of Aerosols



Radiative forcing of the aerosol–radiation interaction computed by the HiFLOR idealized experiment during the post-monsoon season (October–December) at the surface



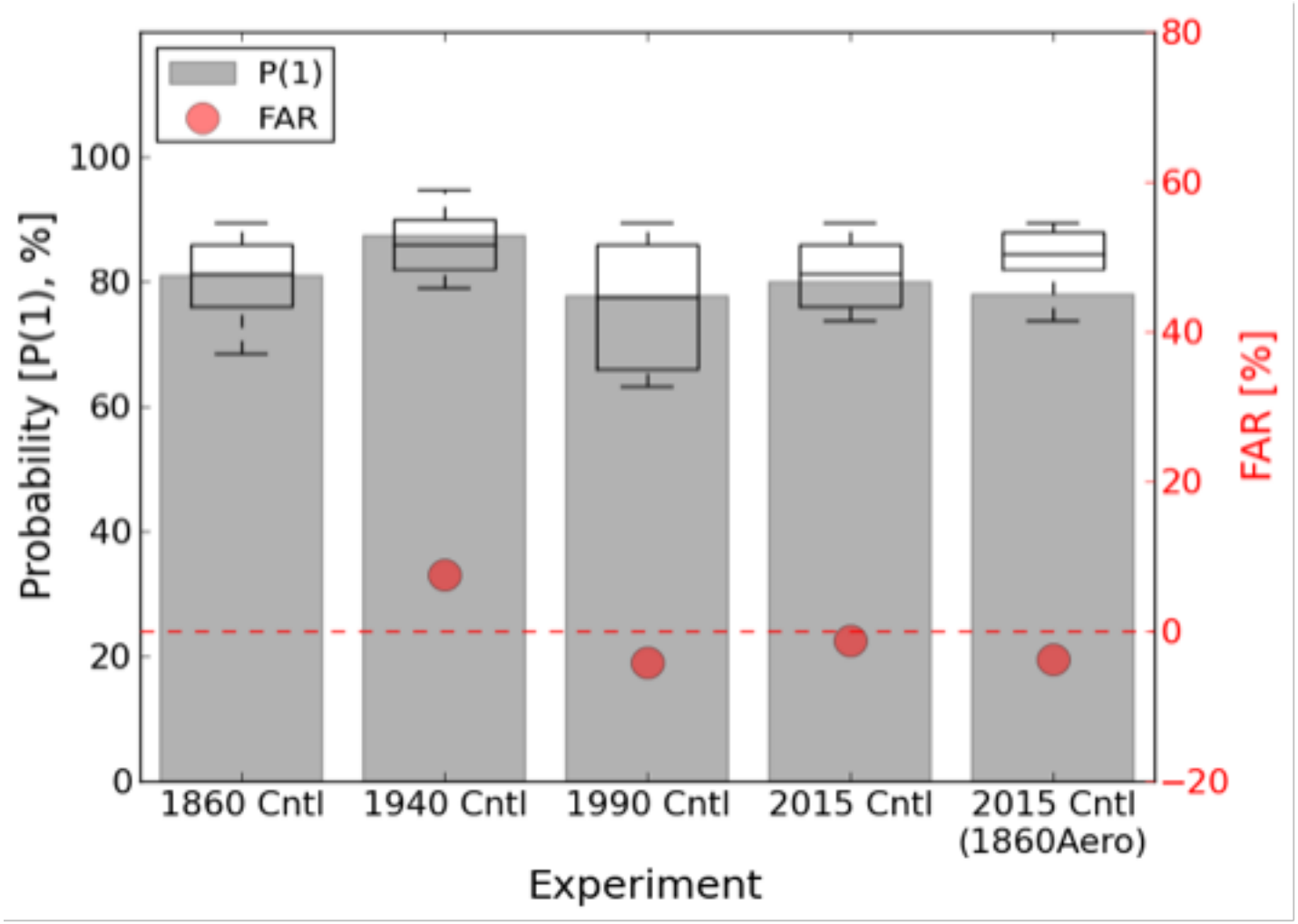
2015 Cntl, but with 1860 aerosol forcing.

Slight decrease in ESCSs.

⇒ Aerosols has a minor effect on increasing ESCSs.

Consistent with Evan et al. (2010, *Nature*)

Weaker Storms



There is no significant change for weaker storms during October–December.