



Detected Climate Change in Global Distribution of Tropical Cyclones

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GFDL/UCAR

PNAS., published online

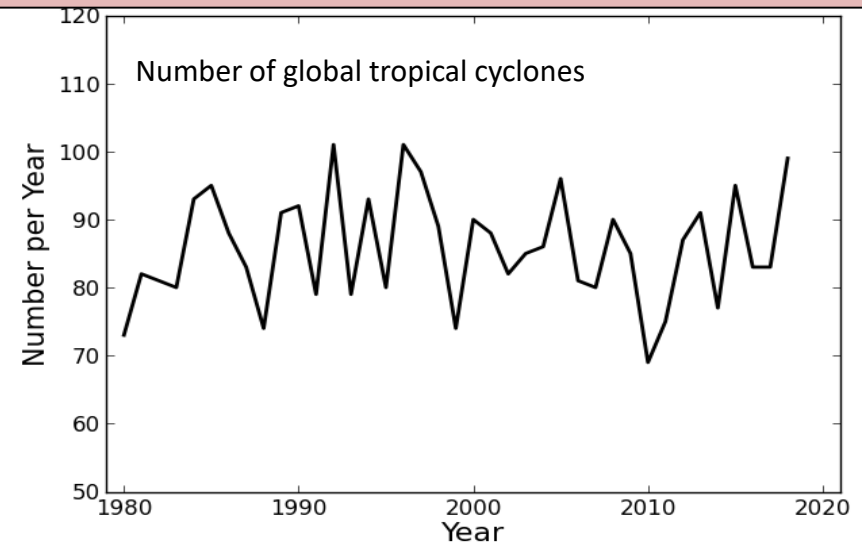
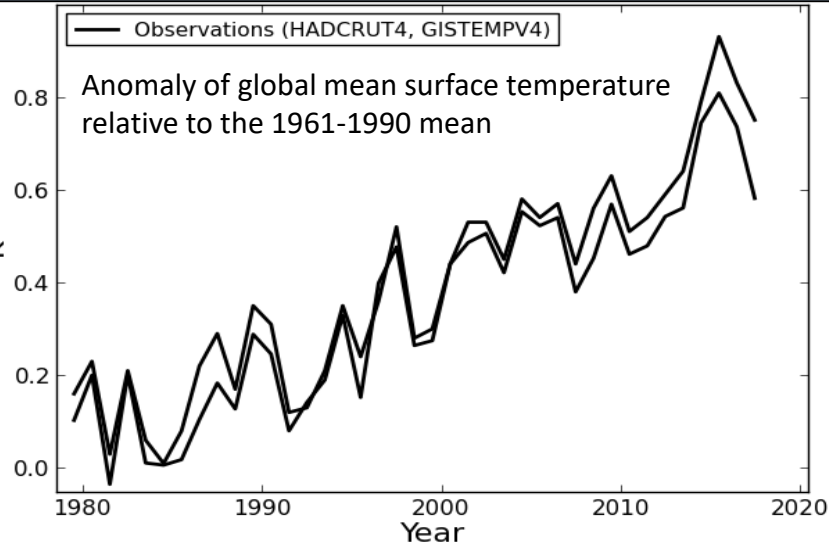
<https://www.pnas.org/content/early/2020/04/28/1922500117>

Observed Trends in Global Mean Surface Temperature and Number of Global Tropical Cyclones (1980-2018)



Observed global mean surface temperature shows an increase between 1980 and 2018.

There is no significant trend in global TC number, indicating no impact of global warming on global TC.

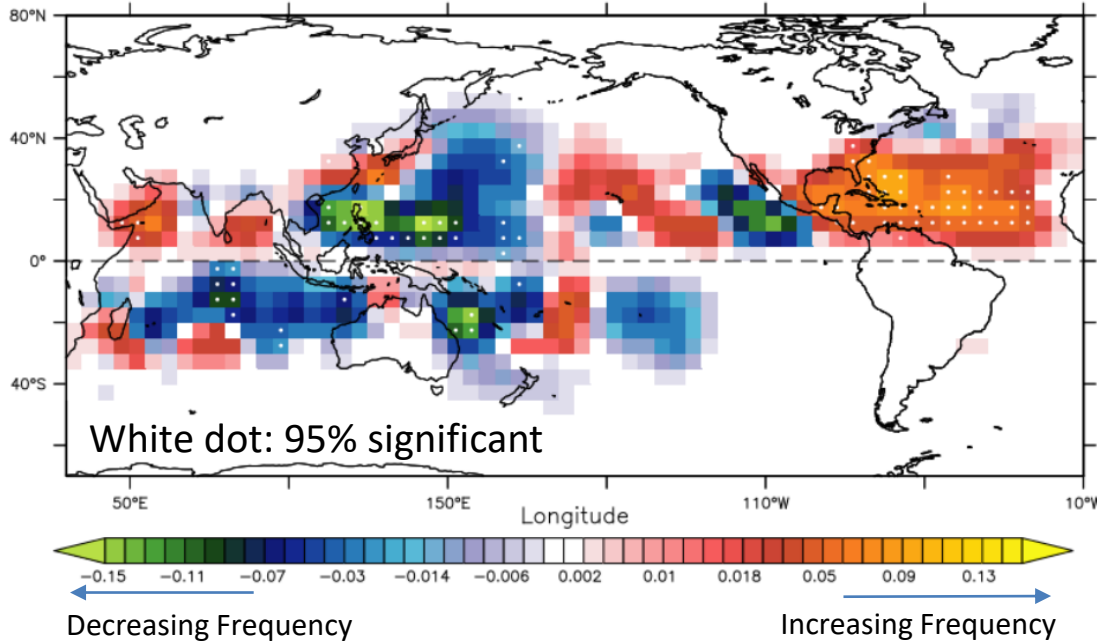


Are there any climatic change emerged in the global tropical cyclone activity?

Observed Trend in Global TC Activity (1980-2018)

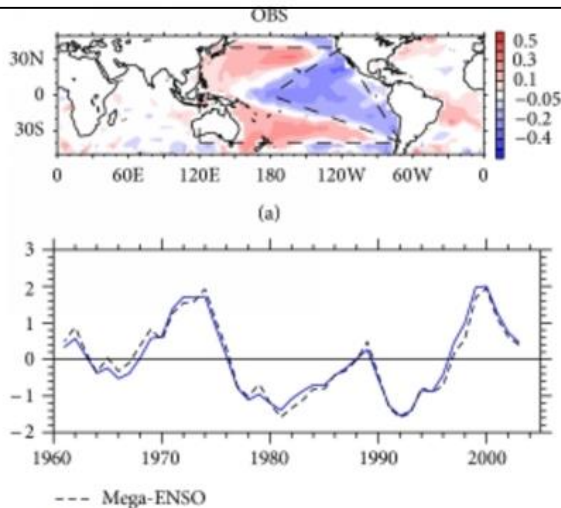


Observed Trend in TCF (1980–2018)

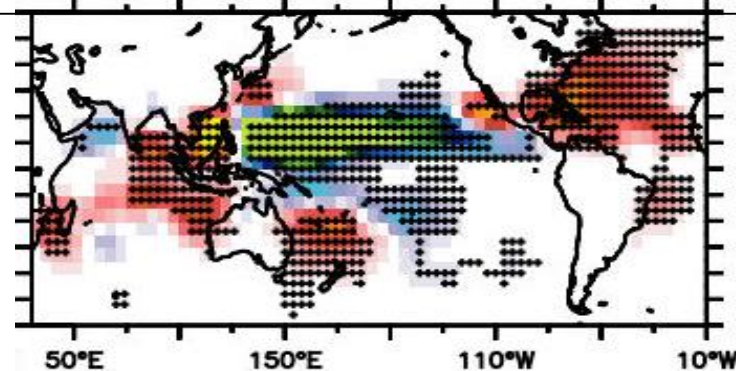


- TCF (or TC density) is defined as total TC frequency of occurrence for every 5x5 degree grid cell.
- TCF shows significant negative and positive trends depending on region over 1980-2018.
- **Is this spatial pattern of the trends due to the external forcing or internal variability?**

Inter-decadal Pacific Oscillation (IPO)



Expected pattern of the TCF change by IPO



We hypothesized that the observed TCF trend is **not only due to the multidecadal internal variability** like IPO.

Large-Ensemble Simulations by SPEAR, FLOR, and FLOR-FA



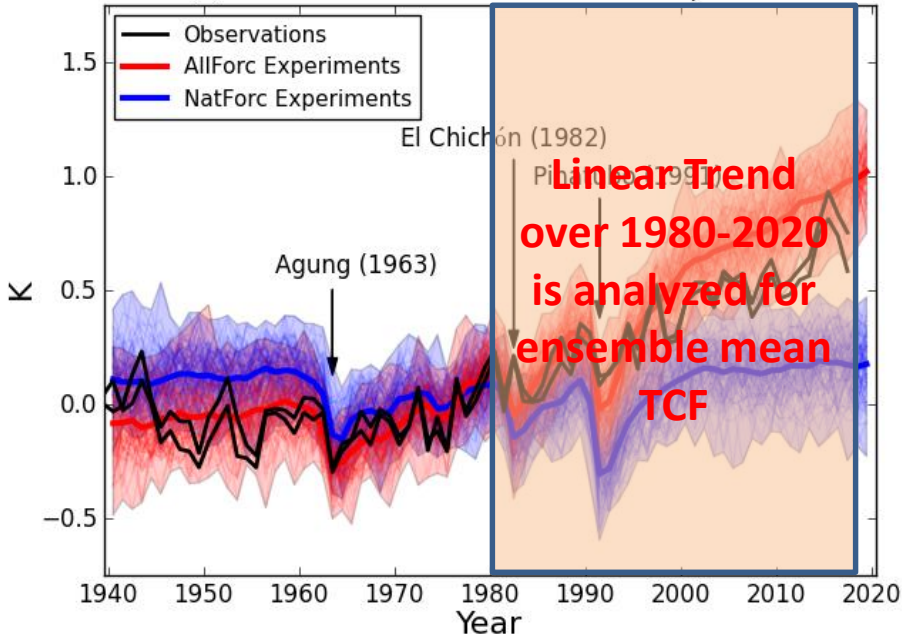
AllForc: Historical simulations by prescribing time-varying external forcing (green-house gasses, aerosols, volcanic forcing, and solar constant)

95 ensemble members: SPEAR_MED (30 members), FLOR (30 members), and FLOR-FA (35 members)

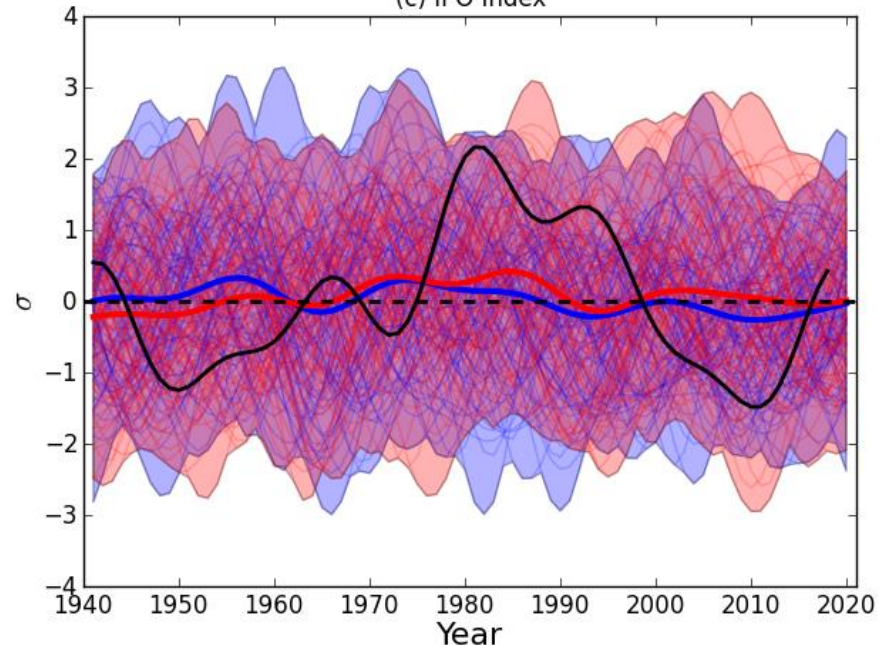
NatForc: As in AllForc, but only with time-varying volcanic forcing and solar constant.

90 ensemble members = SPEAR_MED (30 members), FLOR (30 members), and FLOR-FA (30 members)

(a) Anomalies of Global Mean Surface Temperature



(c) IPO Index

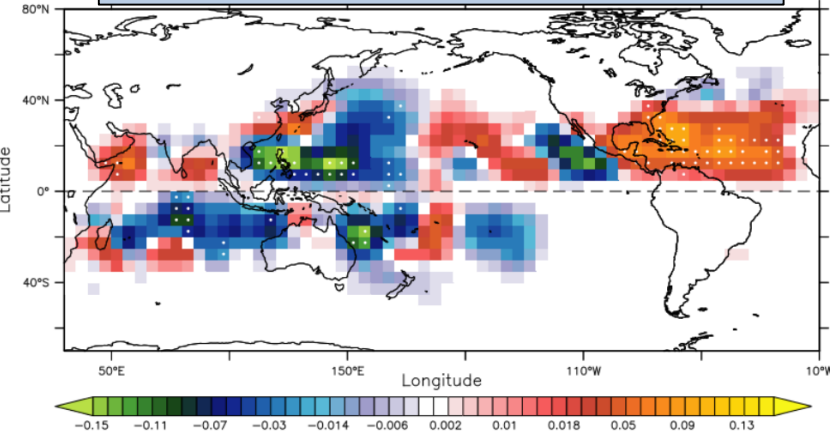


Each ensemble member shows different phase of internal variability.
Internal variability can be canceled out by averaging the members.

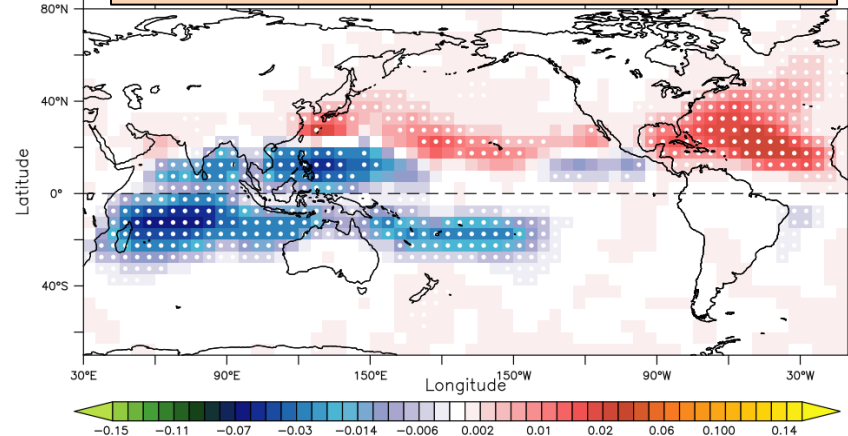
Effect of External Forcing on the TCF Trend



Observed Trend in TCF (1980-2018)

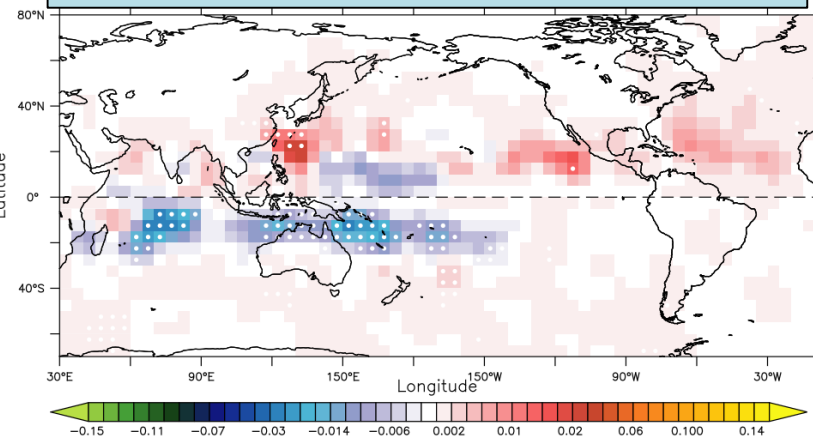


AllForc (95-member mean, 1980-2018)



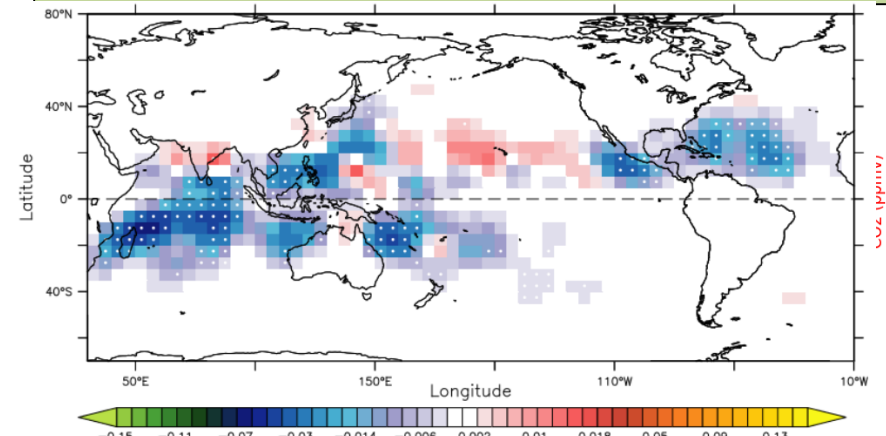
A similar spatial pattern with observations indicates marked influence of external forcing on global TCF.

NatForc (90-member mean, 1980-2018)



Volcanic forcing causes a northward shift in TCF, which is also similar to the observed TCF trend.

Transient 2xCO₂ (3-member mean, 70 yrs)



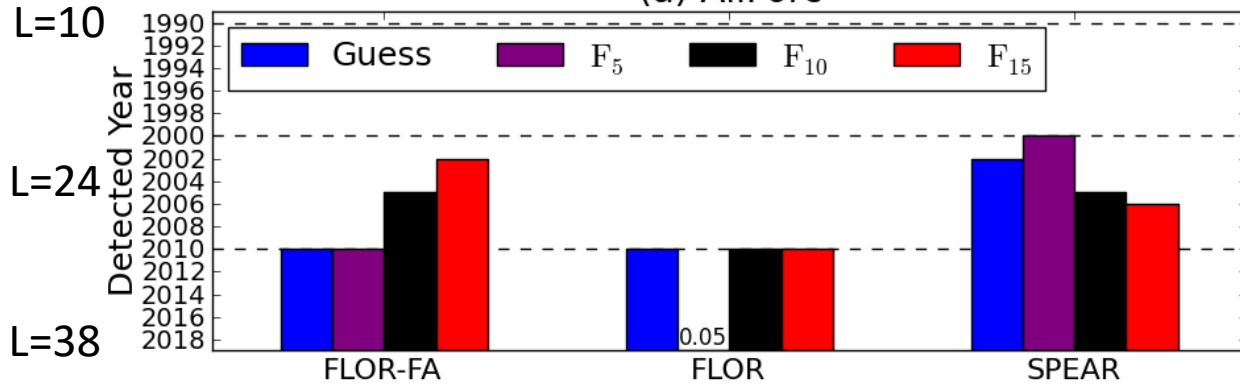
transient +1%/yr CO₂ experiment

- Fully Coupled
- +1% CO₂ increase up to 2xCO₂ (at year 171) then fixed

Optimal Fingerprint Analysis

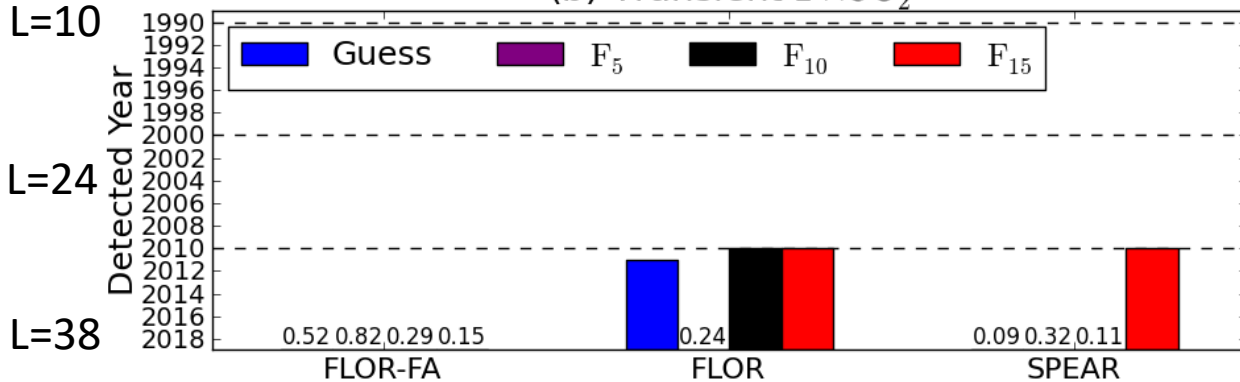


(a) AllForc



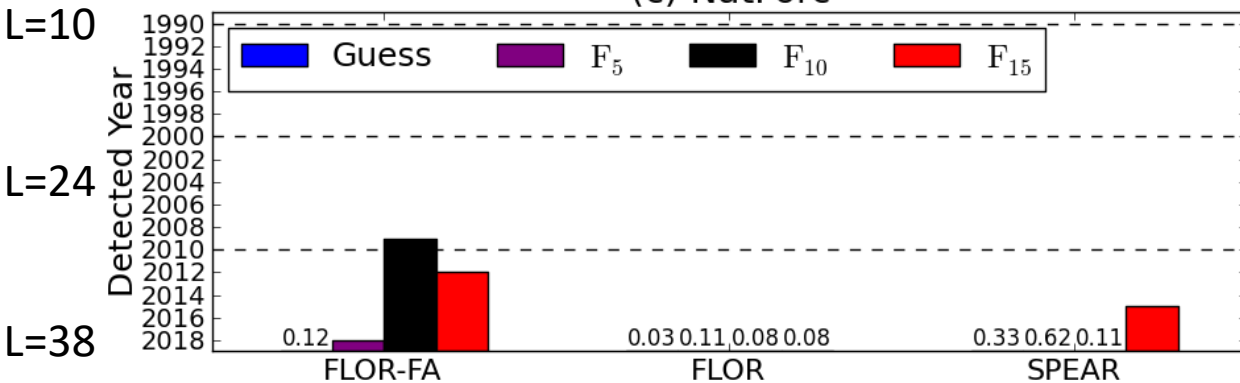
Detected around 2010
 ⇒ External forcing play an Important role for the observed trend.

(b) Transient 2 × CO₂



Detected around 2010
 ⇒ Increase in green-house gasses (CO₂) partially contributes to the observed trend.

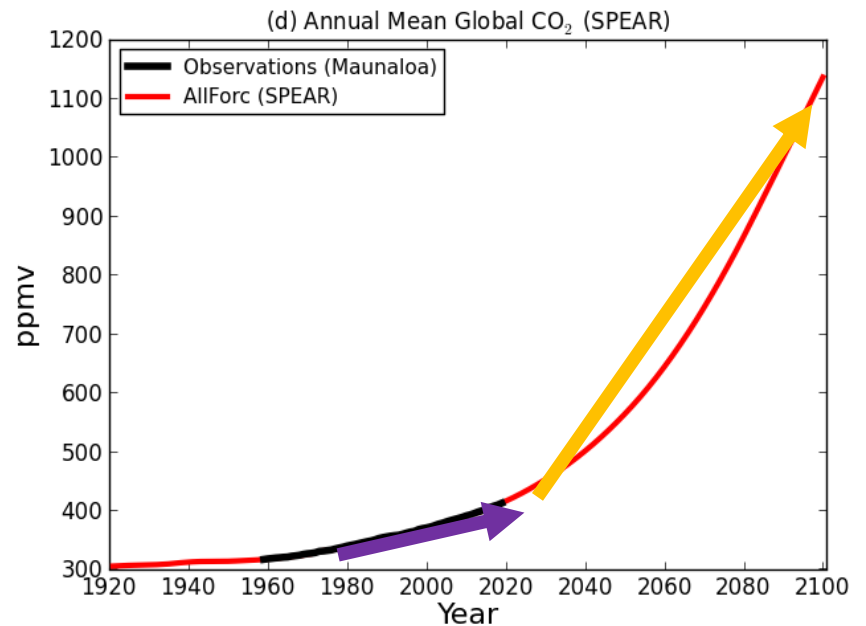
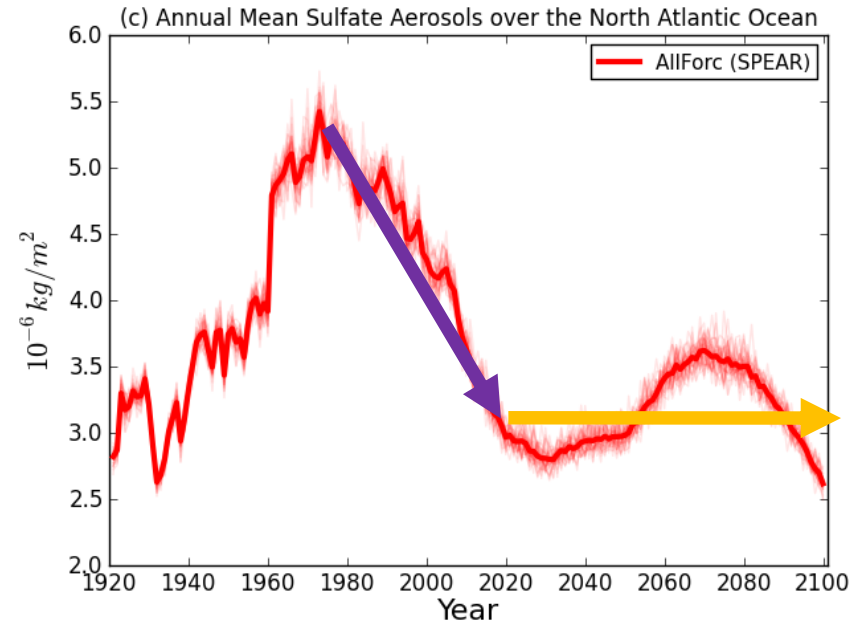
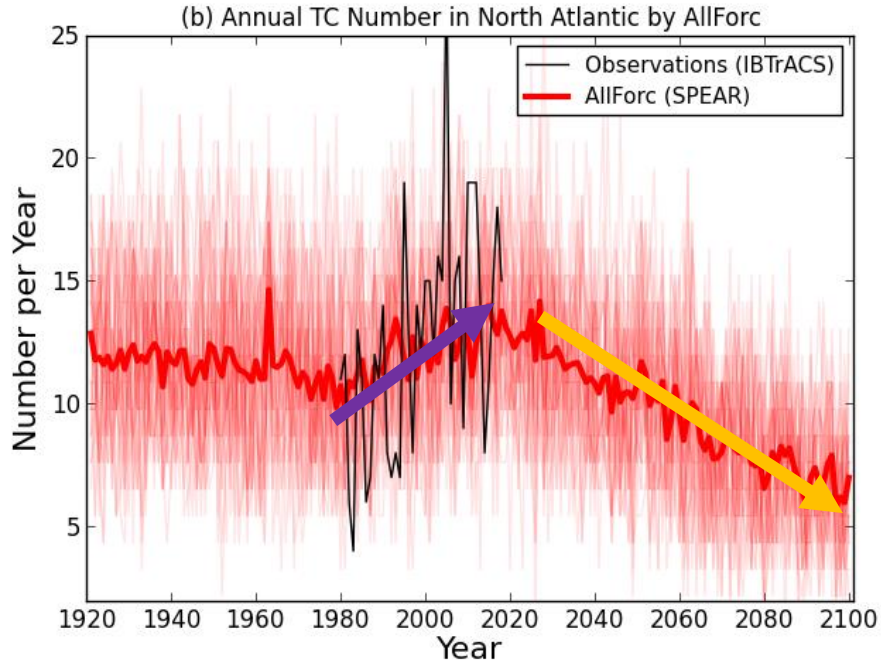
(c) NatForc



Volcanic forcing also plays a minor role.

- A climate change in global TC activity over 1980–2018 has been more evident in the spatial pattern of TC occurrence, rather than the overall number of global TCs.
- The observed spatial pattern of trends is very unlikely to be explained entirely by underlying multi-decadal internal variability; rather, external forcing such as greenhouse gases, aerosols, and volcanic eruptions likely played an important role.

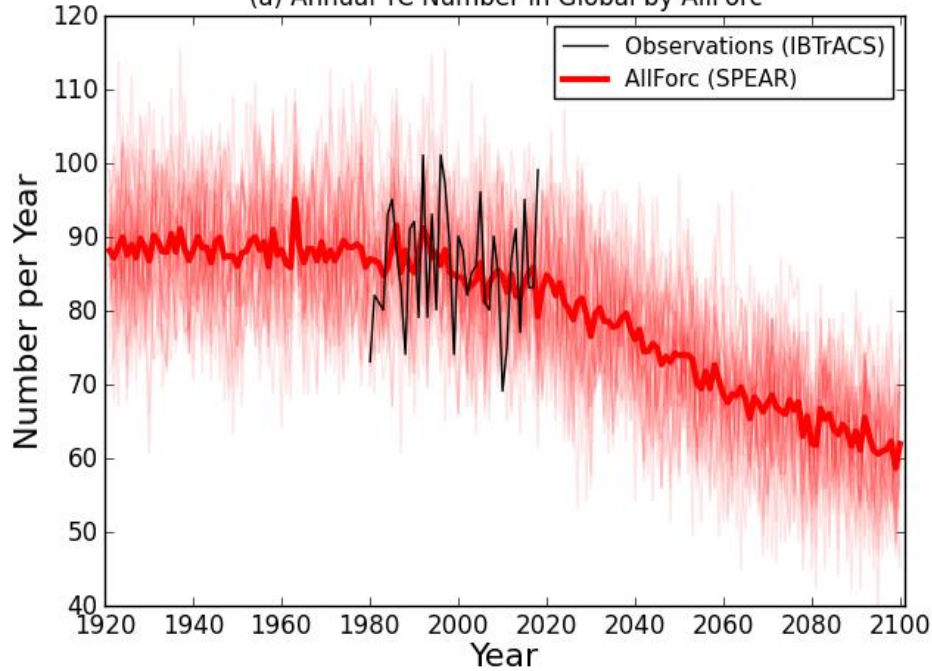
Projected Number of Atlantic Storms, Aerosols, and CO₂



Projected Number of Global Storms and CO₂



(a) Annual TC Number in Global by AllForc



(d) Annual Mean Global CO₂ (SPEAR)

