Climate models exaggerate the impact of greenhouse gases on recent interhemispheric temperature patterns and tropical climate

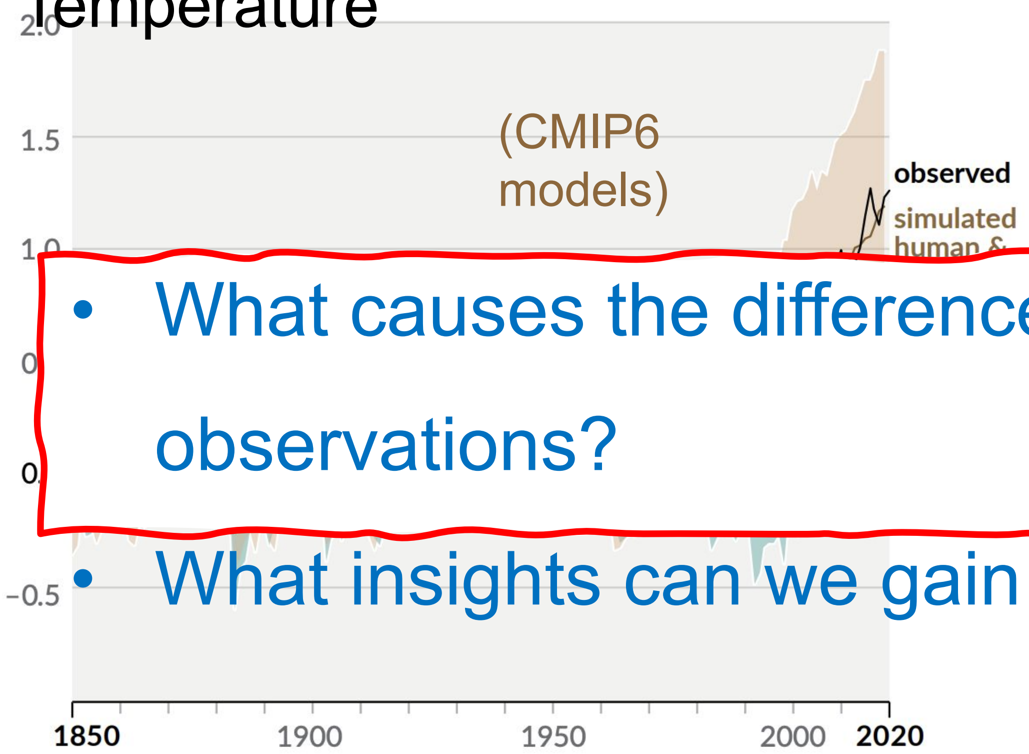
Chengfei He[1], Amy Clement[2], Mark Cane[3], Alex Gonzalez[4], Young-Oh Kwon[4], Jeremy Klavans[2], Lisa Murphy[2], and Jia-rui Shi[5]

[1]Northeastern; [2]U.Miami; [3]Lamont; [4]WHOI; [5]NYU

He, C. *et al.* Climate models exaggerate the impact of greenhouse gases on recent interhemispheric temperature contrast and tropical climate. (2026) accepted at Nat Communs.

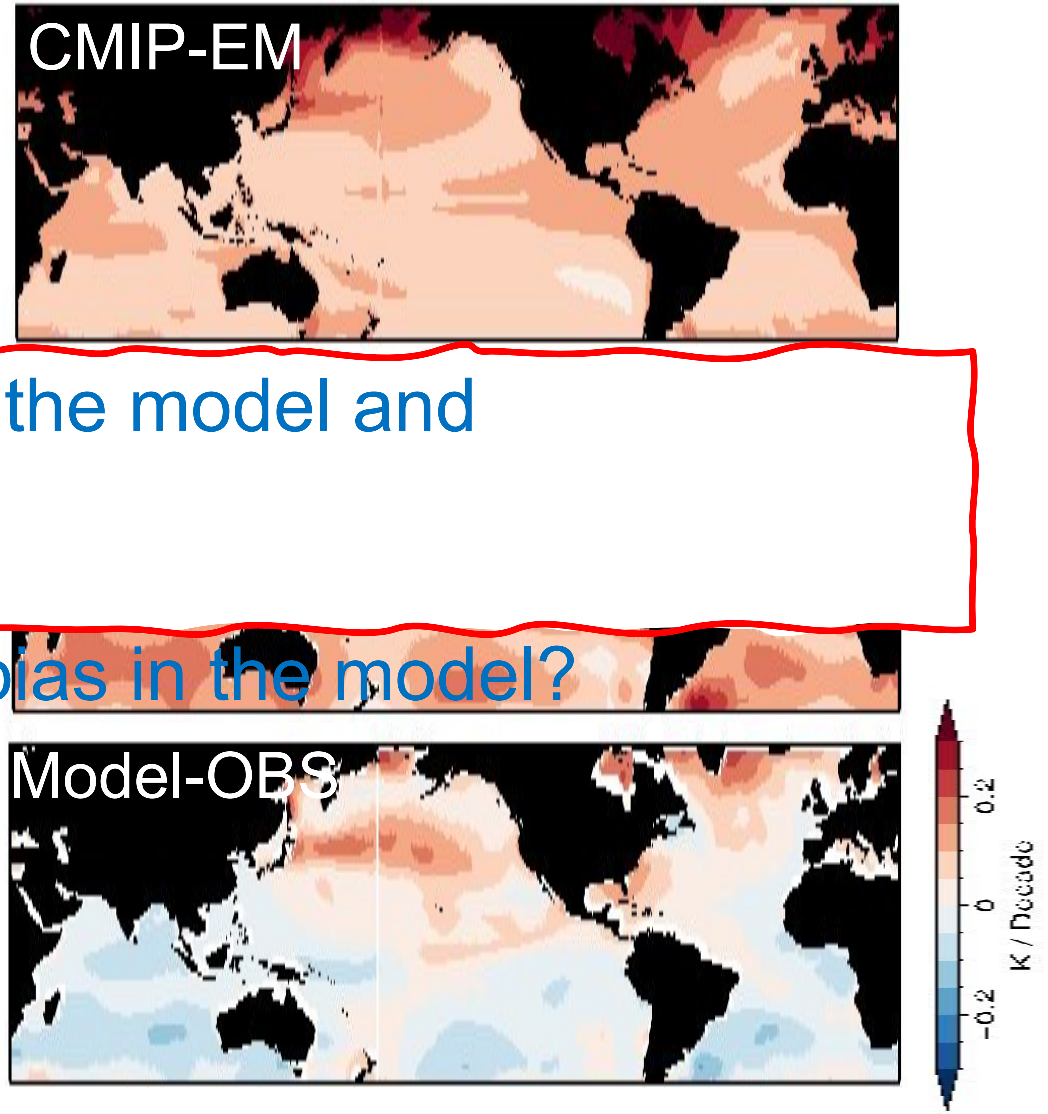
Compare surface temperature in ESMs and observations

Global Mean Surface Temperature



IPCC report, 2021

SST trend in 1950-2014



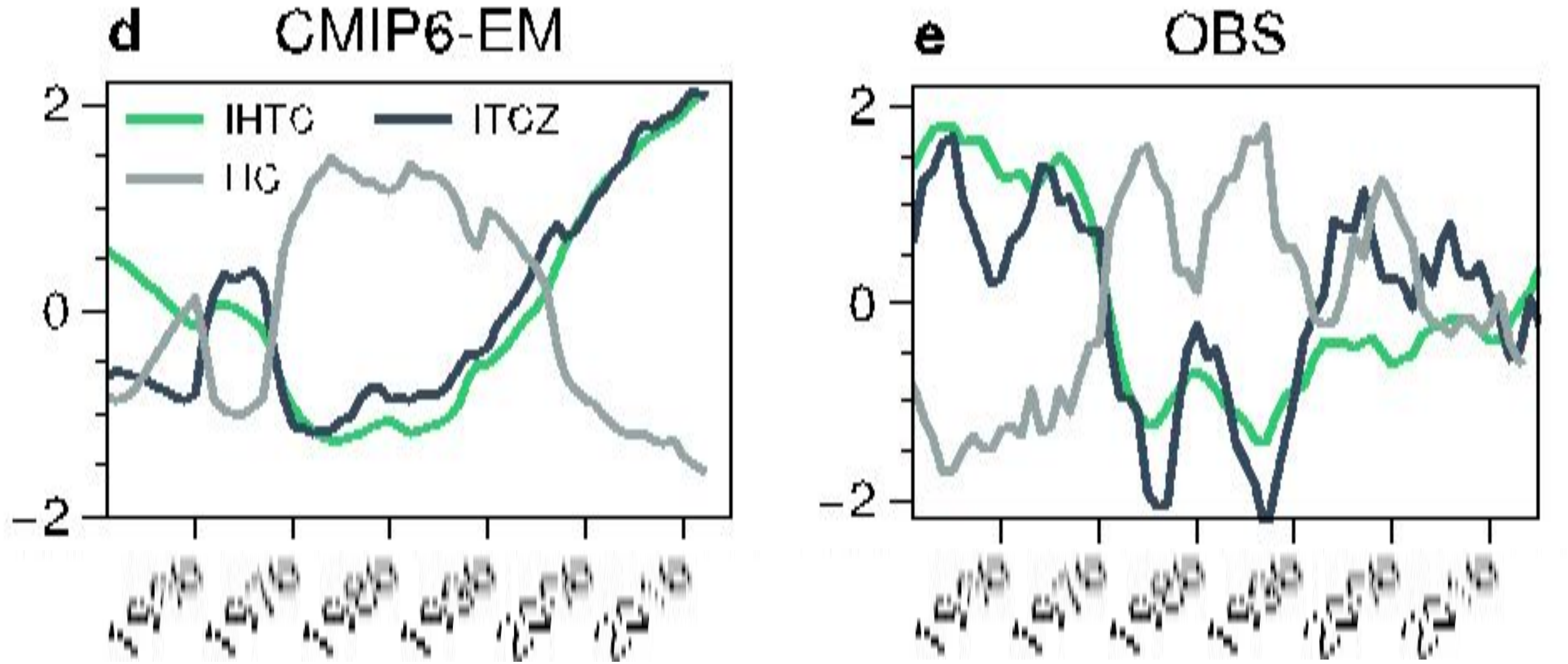
- What causes the difference between the model and observations?
- What insights can we gain from this bias in the model?

- (NH + SH) / 2

- (NH – SH)/2

He et al. 2023

IHTC has dramatic impacts on tropical circulation and rainfall



IHTC: InterHemispheric surface Temperature Contrast (NH-SH)
ITCZ: InterTropical Convergence Zone
HC: Hadley Circulation on the equator

He et al. 2026 (accepted)

- Observed IHTC has both internal variability and externally-forced responses.
- CMIP6-EM is forced response

H1: Observation dominated by internal variability, so model data difference is internal variability.

- AMOC (e.g., Friedman et al. 2020; Thompson et al. (2010); ….)
- Internal variability in CMIP6 PI control simulations cannot explain the model-data diff.

H2: Observation is dominated by external forcings, so the model-data difference is due to their sensitivity difference to forcings.

Real-world IHTC is largely driven by external forcings?

$$IHTC = \beta_{GHG} IHTC_{GHG} + \beta_{AER} IHTC_{AER} + \beta_{NAT} IHTC_{NAT} + \epsilon$$

$IHTC$ is a combined impact from

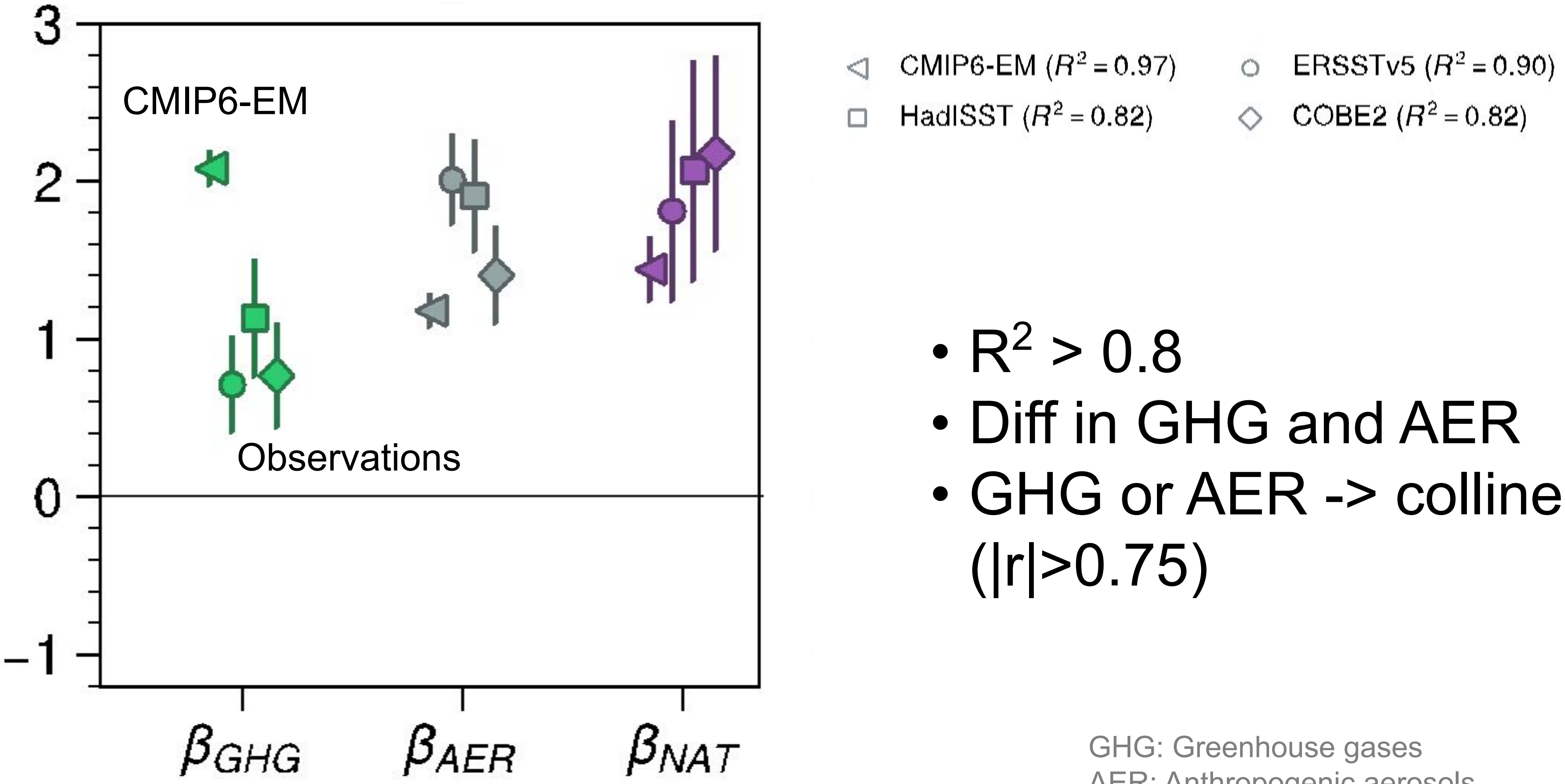
- Greenhouse gases ($IHTC_{GHG}$)
- Anthropogenic aerosols ($IHTC_{AER}$)
- Natural forcings ($IHTC_{NAT}$)
- Internal variability (ϵ)

- β: Scaling factors / Sensitivity to external forcings

GHG: Greenhouse gases
AER: Anthropogenic aerosols
NAT: natural forcings (volcanism, solar activity)

Real-world IHTC is largely driven by external forcings!

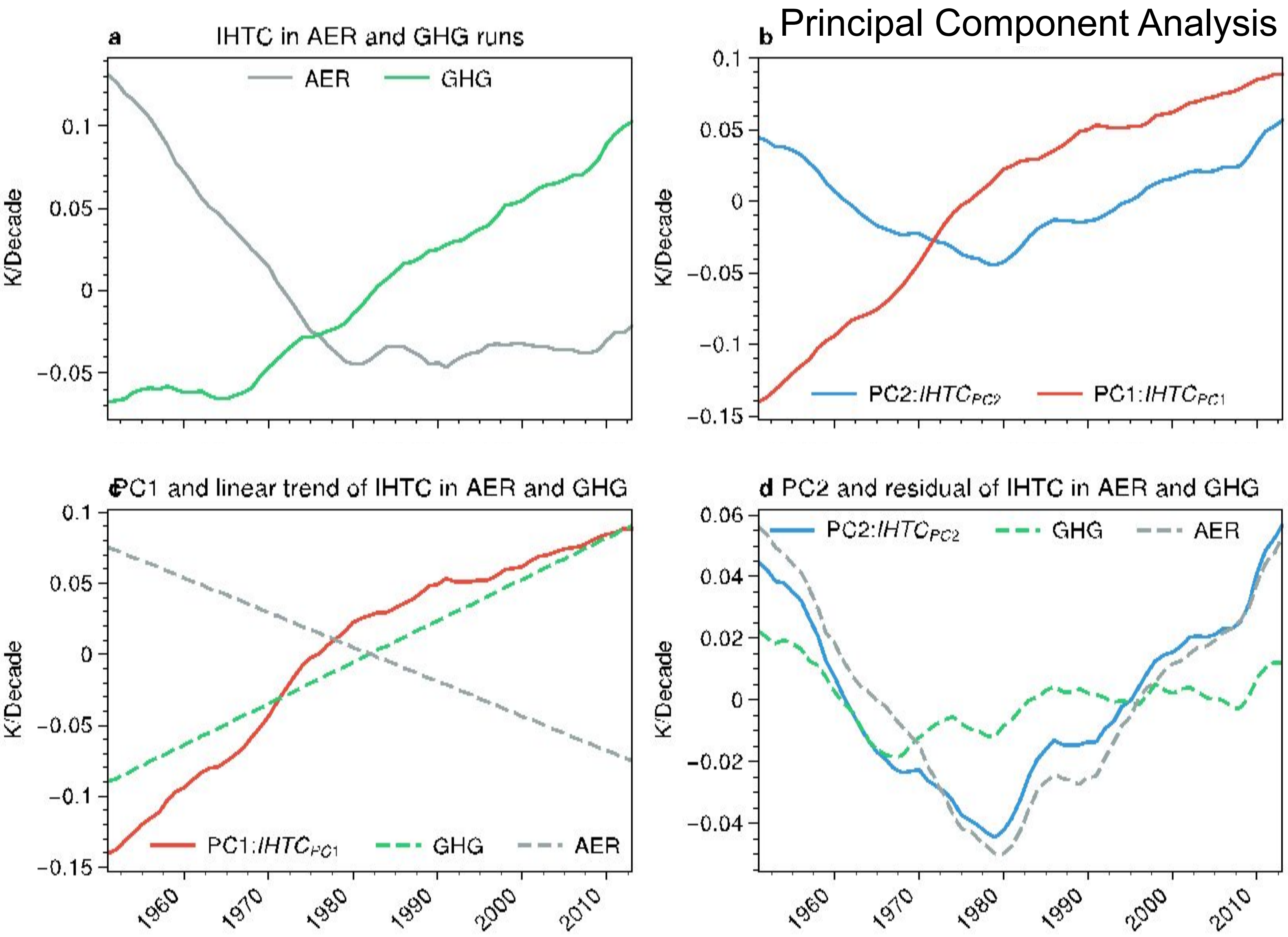
$$IHTC = \beta_{GHG} IHTC_{GHG} + \beta_{AER} IHTC_{AER} + \beta_{NAT} IHTC_{NAT} + \epsilon$$



- R^2 > 0.8
- Diff in GHG and AER
- GHG or AER -> collinearity (|r|>0.75)

GHG: Greenhouse gases
AER: Anthropogenic aerosols
NAT: natural forcings (volcanism, solar activity)

Disentangle collinearity in AER and GHG: Two modes



- PC1 is normal to PC2
- PC2 is multidecadal variability
- PC1 is long-term trend

GHG: Greenhouse gases
AER: Anthropogenic aerosols
NAT: natural forcings (volcanism, solar activity

Which forcing is responsible for the model-observation difference?

$$IHTC = \beta_{GHG} IHTC_{GHG} + \beta_{AER} IHTC_{AER} + \beta_{NAT} IHTC_{NAT} + \epsilon$$

⬇️

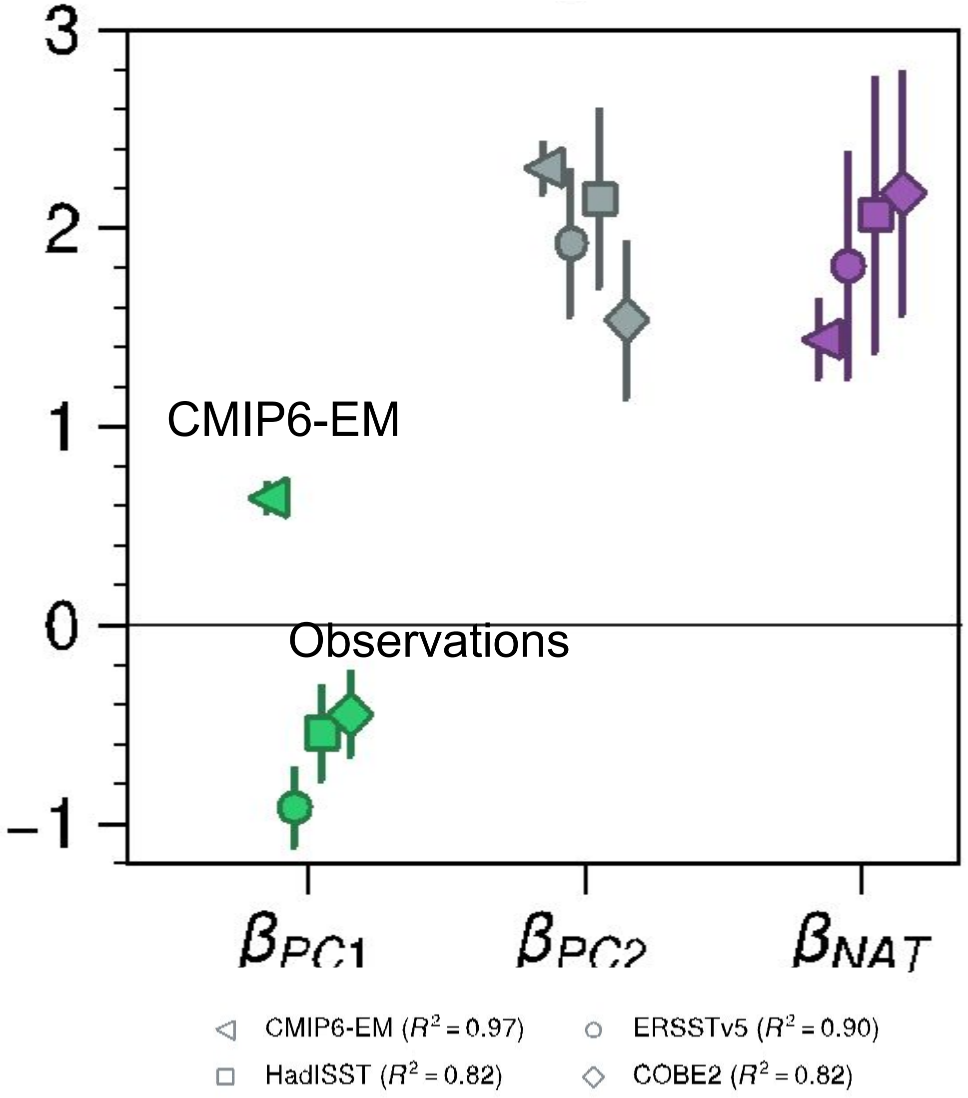
$$IHTC = \beta_{PC1} IHTC_{PC1} + \beta_{PC2} IHTC_{PC2} + \beta_{NAT} IHTC_{NAT} + \epsilon$$

$IHTC$ is combined by

- Long-term trend due to GHG and AER ($IHTC_{PC1}$)
- Multidecadal variability due to AER ($IHTC_{PC2}$)
- Natural forcings ($IHTC_{NAT}$)
- Internal variability (ϵ)

GHG: Greenhouse gases
AER: Anthropogenic aerosols
NAT: natural forcings (volcanism, solar activity)

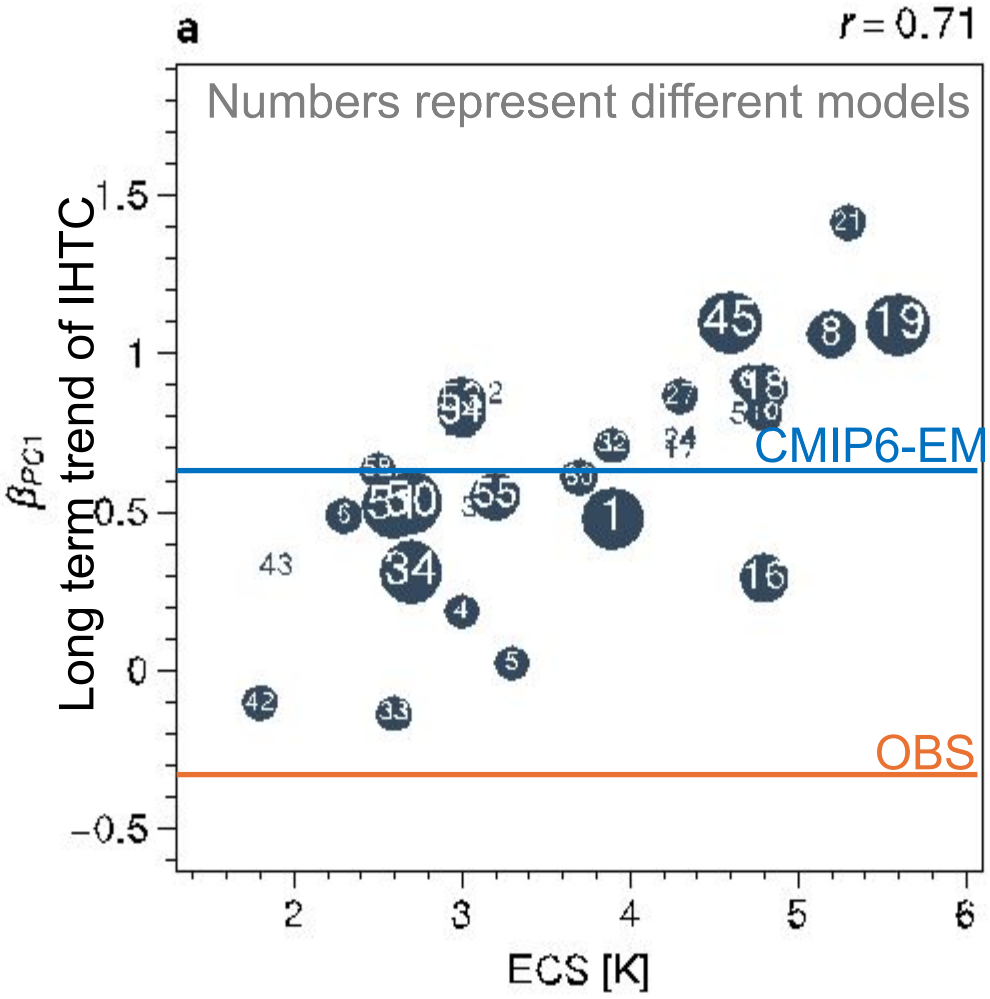
Model is dominated by GHG, but observation is dominated by AER



- PC2 (multidecadal variability) is consistent -> Sensitivity to AER in Model and OBS consistent
- PC1 (long-term trend) is opposite
  - $\beta_{PC1} > 0$: Greenhouse gases
  - $\beta_{PC1} < 0$: Anthropogenic aerosols

PC1: long-term trend (AER and GHG)
PC2: multidecadal variability (AER)
NAT: natural forcings (volcanism, solar activity)

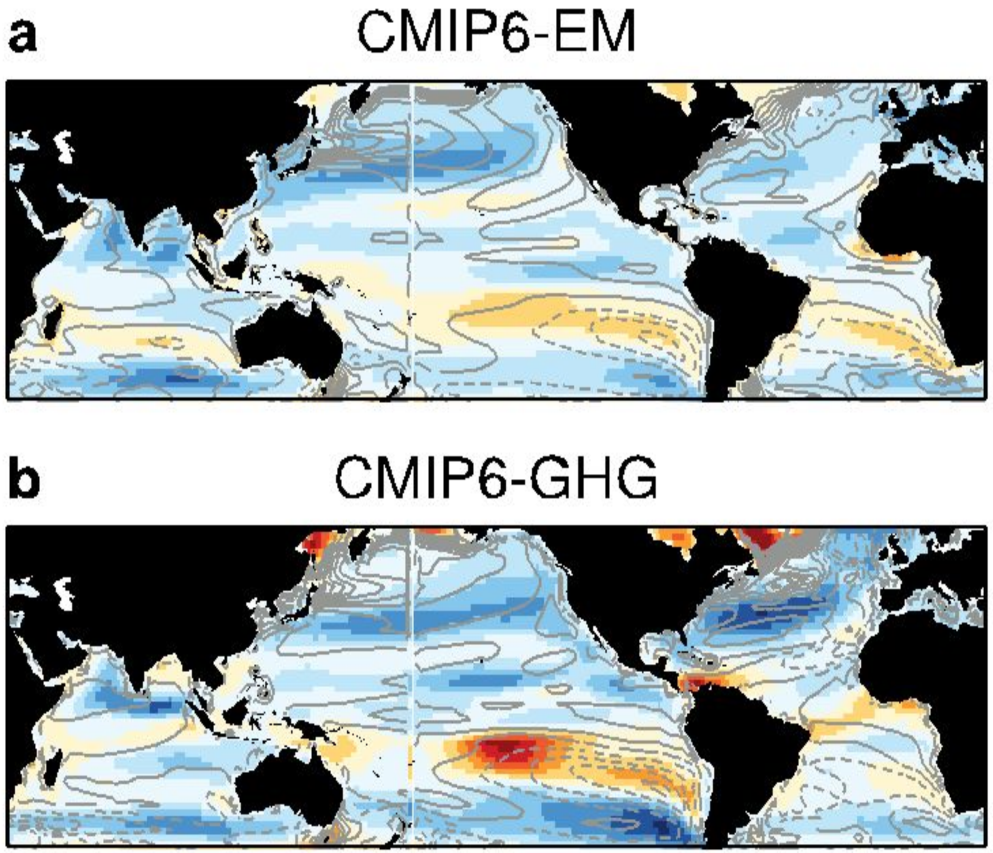
In addition to CMIP6-EM, model spread in long-term trend is also due to Greenhouse gases



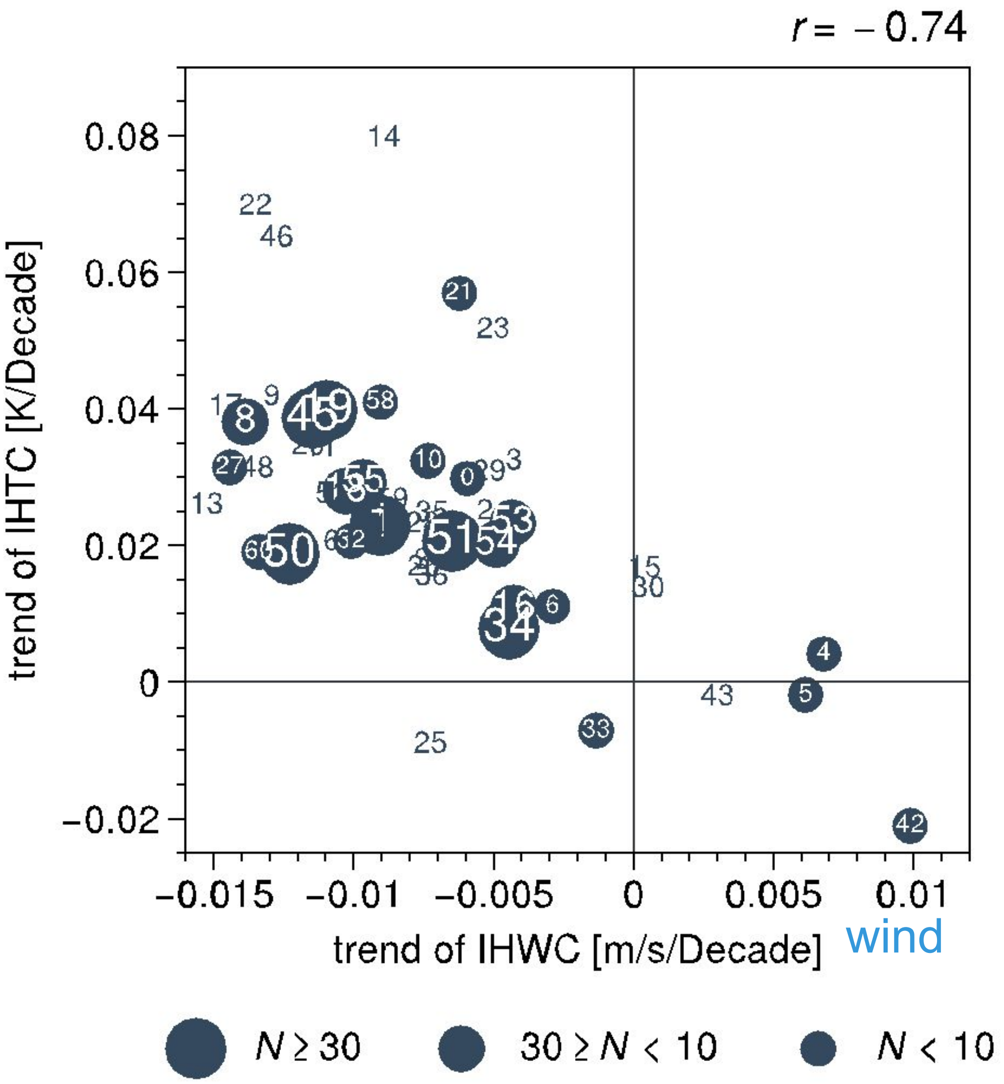
- ECS: Equilibrium Climate Sensitivity, sensitivity to GHG.
- Higher ECS, Higher IHTC Trend
- Real-world ECS is low

ECS taken from Wang et al. 2020 and Smith et al. 202

The physics of the model bias and model spread is because of wind in response to GHG.

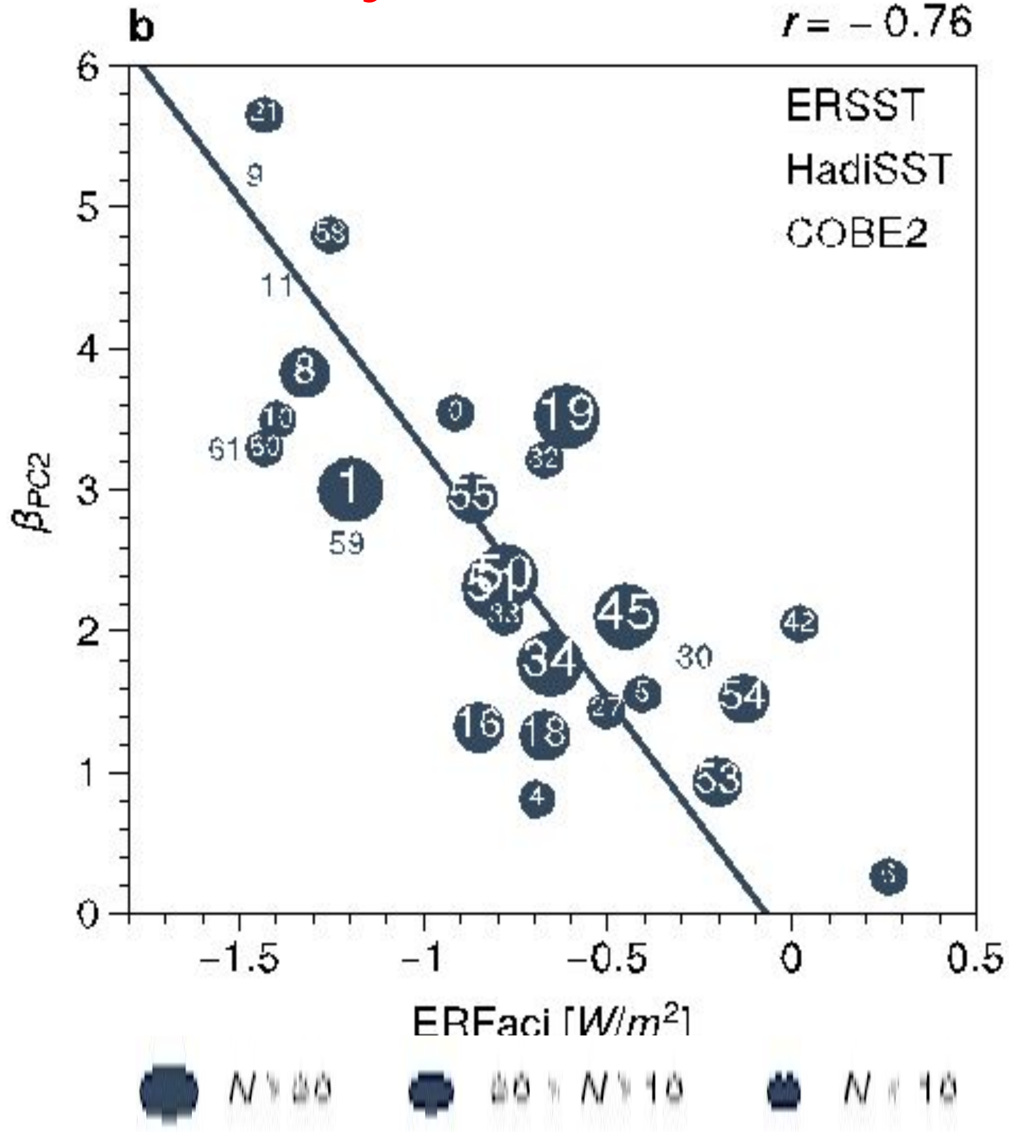


Shading: Trend of wind speed
Contours: SST trend



Xie et al. 2010; Lu et al. 2012

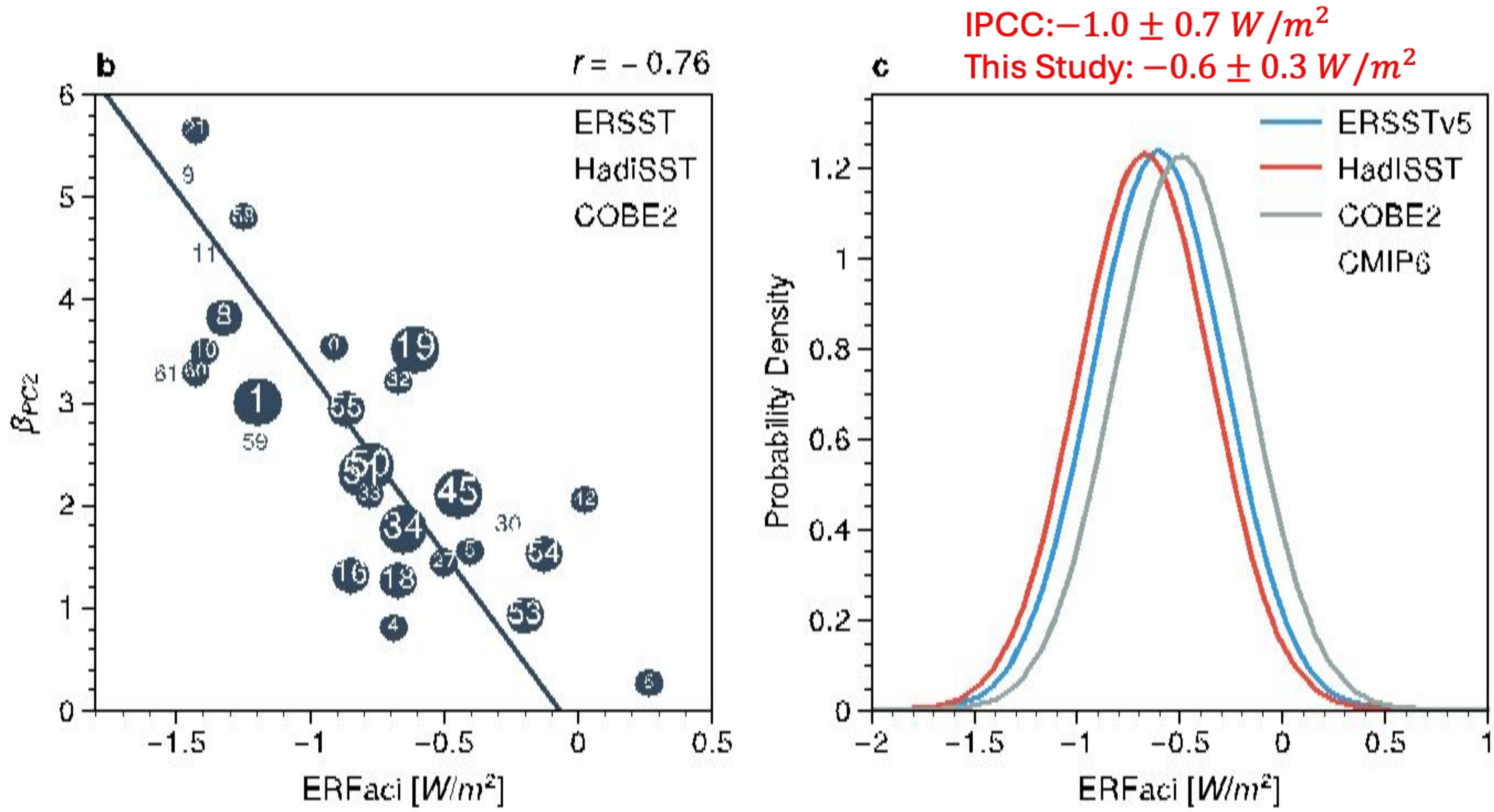
In addition to CMIP-EM, model spread in multidecadal variability is due to Aerosols



- ERFaci: Effective Radiative Forcing due to aerosol-cloud interaction, sensitivity to AER.
- Larger ERFaci, larger amplitude of multidecadal IHTC variability

ERFaci taken from Wang et al. 2020 and Smith et al. 20

Implication: Real-world ERFaci is $-0.60 \pm 0.30\ W/m^2$



ERFaci: Effective Radiative Forcing due to aerosol-cloud interaction, sensitivity to AER.

ECS and ERFaci taken from Wang et al. 2020 and Smith et al.

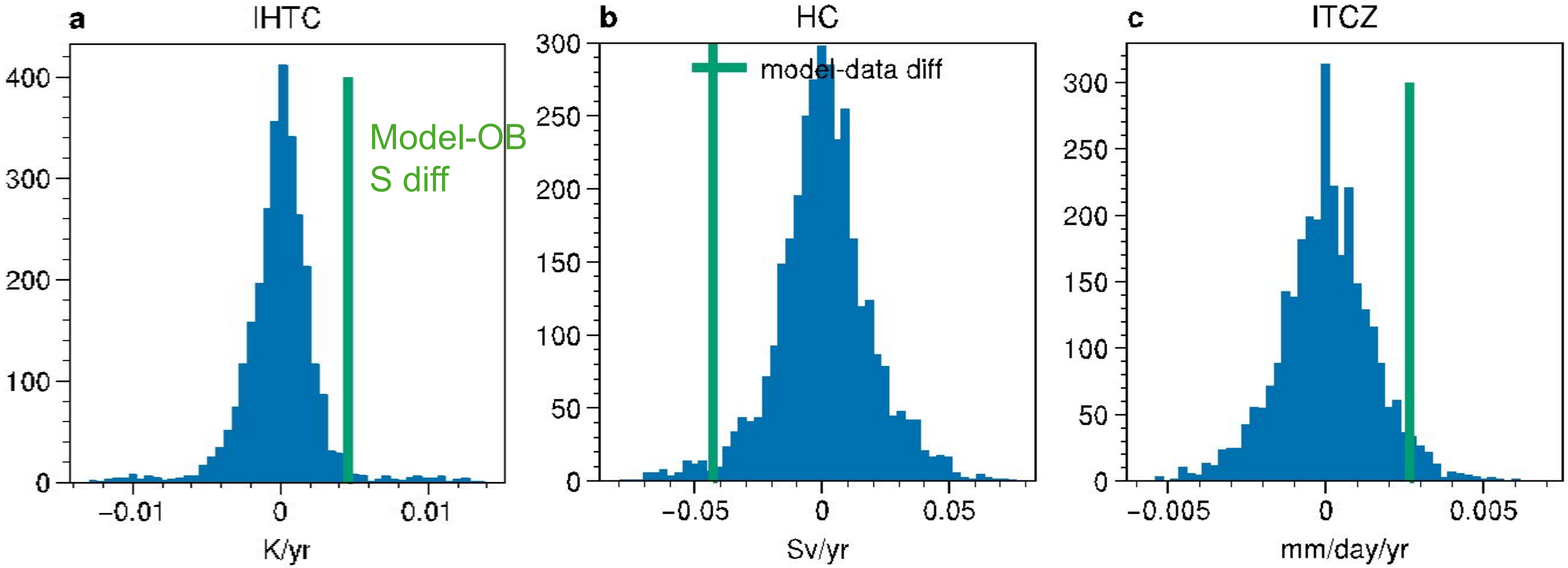
A Short Summary

- The systematic bias in IHTC is caused by the dominance of GHG in the model

- Model and OBS are consistent in multidecadal IHTC variability due to AER

- ERFaci = $-0.60 \pm 0.30\ W/m^2$
- ECS may be at the low end of current models' prediction

The model data difference is very unlikely to be explained by internal variability (~~H1~~)



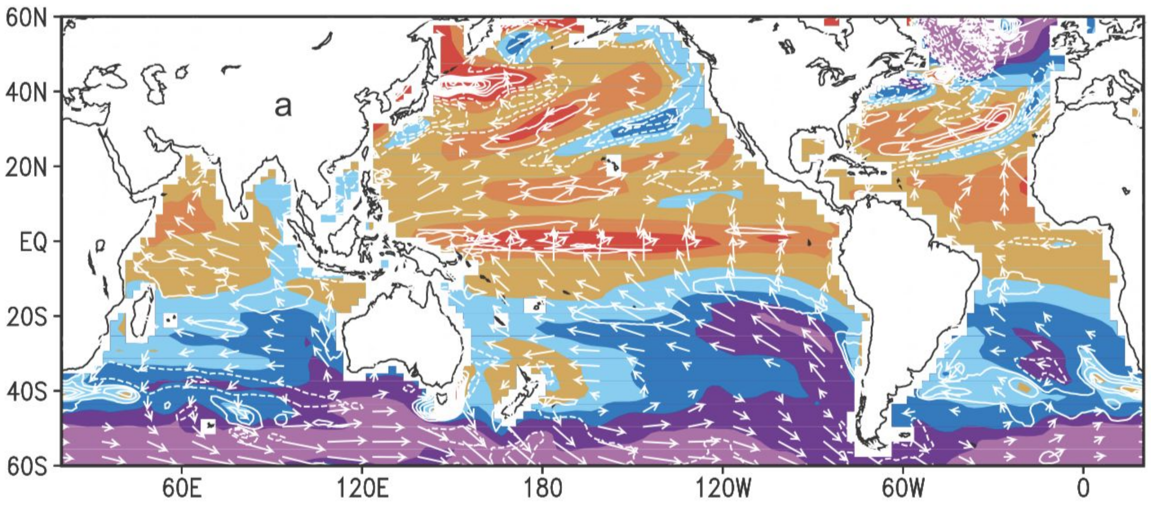
IHTC HC ITCZ

Trend of IHTC, HC, and ITCZ in 65 yrs (e.q. 1950-2014) in PI-Control simulations

IHTC: InterHemispheric surface Temperature Contrast
ITCZ: intertropical convergence zone (aka. tropical rainbelt)
HC: Hadley Circulation

Hypothesize the SST pattern under global warming is due to WES

a great paper shows the formation of sst pattern under global warming
Wind forms the warming pattern through latent heating
Ocean heat transport helps in mid latitudes



Global Warming Pattern Formation: Sea Surface Temperature and Rainfall*

SHANG-PING XIE,+ CLARA DESER,# GABRIEL A. VECCHI,@ JIAN MA,+ HAIYAN TENG,# AND ANDREW T. WITTENBERG@

+ *International Pacific Research Center, and Department of Meteorology, SOEST, University of Hawaii at Manoa, Honolulu, Hawaii*
# *Climate and Global Dynamics Division, National Center for Atmospheric Research, Boulder, Colorado*
@ *NOAA/Geophysical Fluid Dynamics Laboratory, Princeton, New Jersey*

(Manuscript received 1 July 2009, in final form 14 September 2009)

ABSTRACT

The trigger is wind, WES feedback

The Role of Oceanic Feedback in the Climate Response to Doubling CO_2

JIAN LU

Center for Ocean–Land–Atmosphere Studies, Institute of Global Environment and Society, Calverton, Maryland, and Department of Atmospheric, Oceanic and Earth Sciences, George Mason University, Fairfax, Virginia

BIN ZHAO

Global Modeling and Assimilation Office, NASA Goddard Space and Flight Center, Camp Greenbelt, Maryland, and Climate, Ocean and Sea-Ice Modeling (COSIM) Project, Group T-3, Los Alamos National Laboratory, Los Alamos, New Mexico

(Manuscript received 5 December 2011, in final form 7 May 2012)

ABSTRACT

Two suites of partial coupling experiments are devised with the upper-ocean dynamics version (UOM) of the CCSM3 to isolate the effects of the feedbacks from the change of the wind-driven ocean circulation and air–sea heat flux in the global climate response to the forcing of doubling CO_2. The partial coupling is achieved by implementing a so-called overriding technique, which helps quantitatively partition the total response in the fully coupled model to the feedback component in question and the response to external forcing in the absence of the former. By overriding the wind stress seen by the ocean and the wind speed through the bulk formula for evaporation, the experiments help to reveal that (i) the wind–evaporation–SST (WES) feedback is the main formation mechanism for the tropical SST pattern under the CO_2 forcing,

Novel experiment isolates WES feedback in climate models