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Early-twentieth-century cold bias in ocean surface temperature observations and implications for global temperature projections

Sebastian Sippel

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WCRP EPESC – LEADER Science Meeting

Collaborators: E. Kent, N. Meinshausen, D. Chan, C. Kadow, R. Neukom, E. M. Fischer, V. Humphrey, R. Rohde, I. de Vries, and R. Knutti

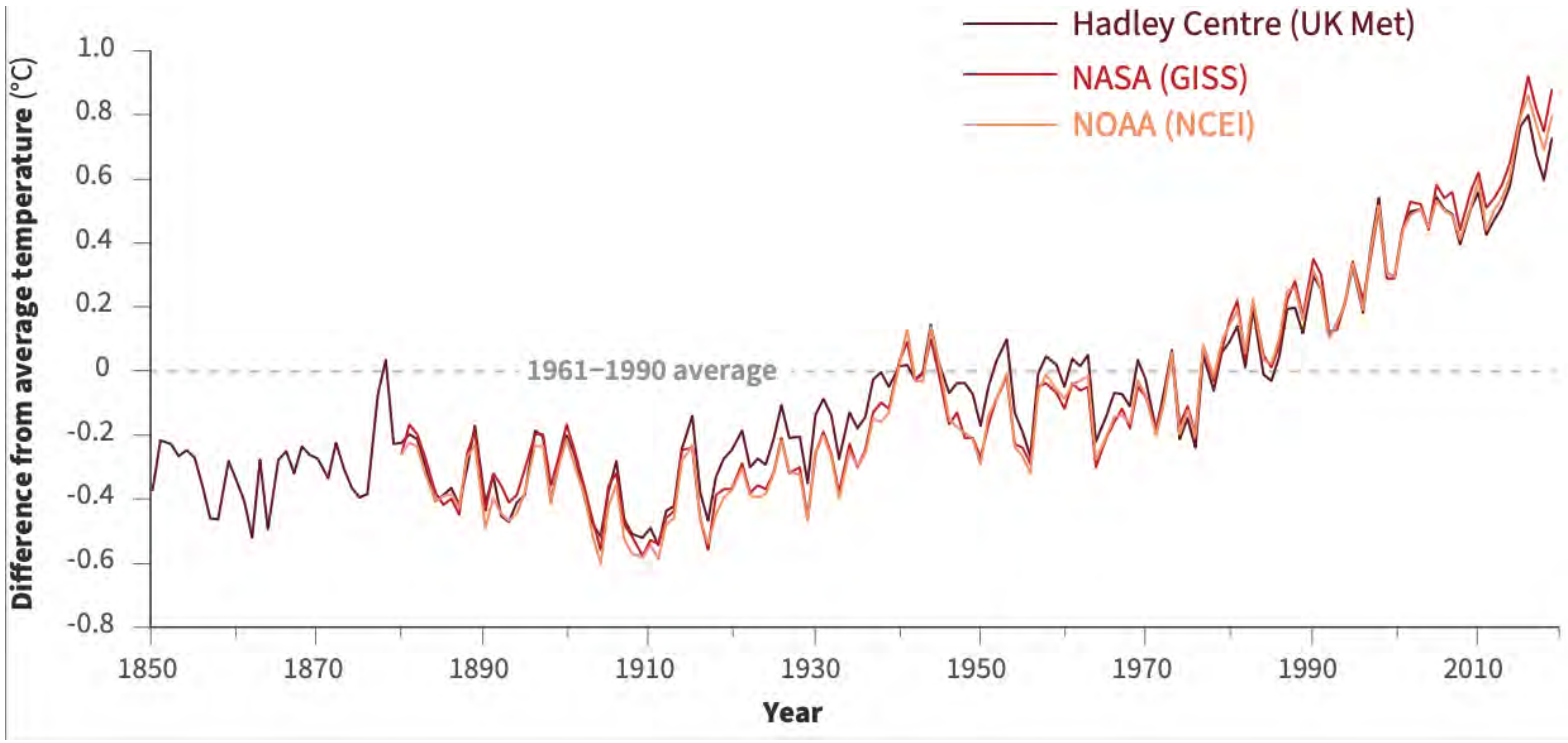
Agenda

1. **Early-twentieth-century cold bias in ocean surface temperature observations**[1]
2. Implications for global temperature projections

[1]Sippel et al., 2024, *Nature*, doi:s41586-024-08230-1

Global mean surface temperature (GMST)

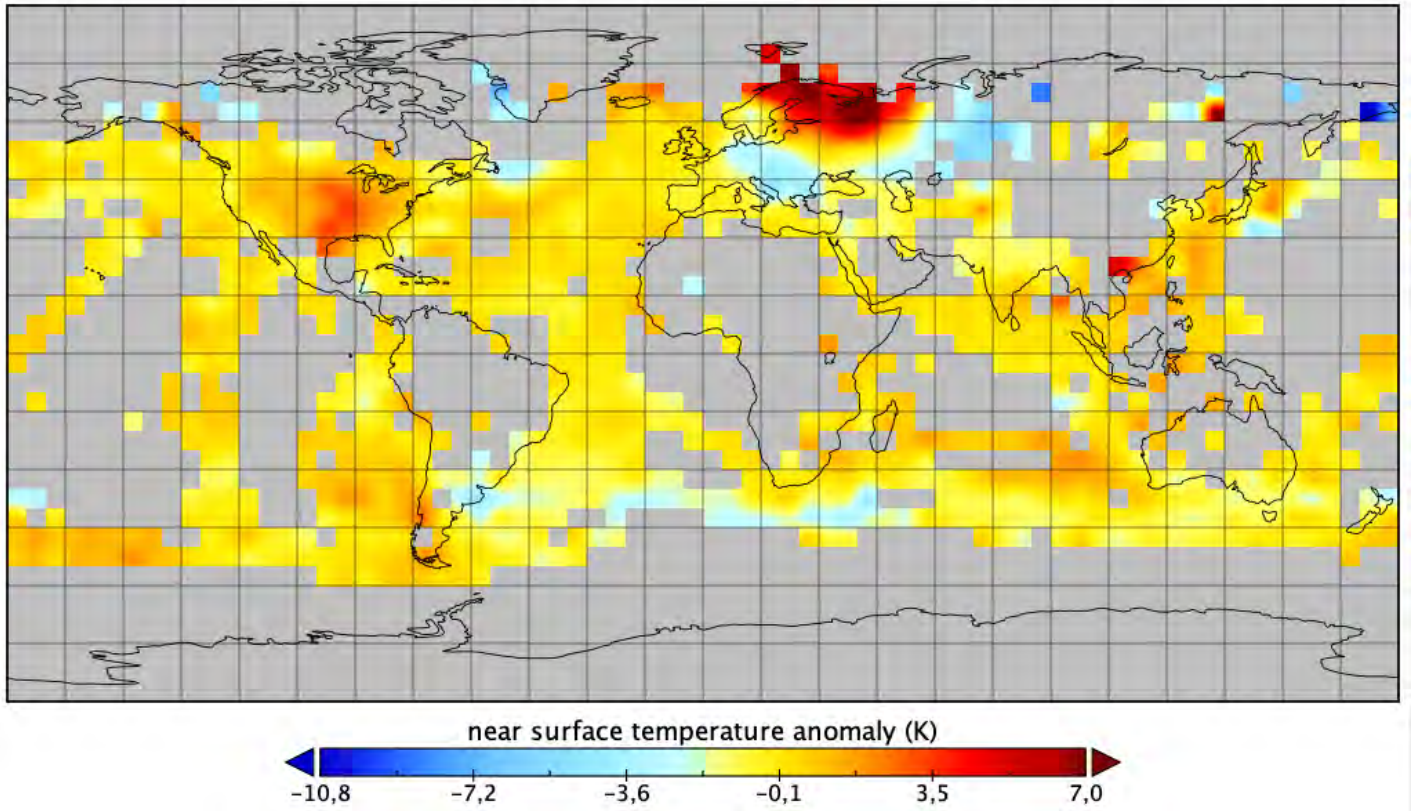
- GMST is a key policy metric
- Different reconstructions in reasonable agreement
- Observation-based estimates derived from blending sea surface temperatures (SSTs) with land surface air temperatures (LSATs)



US National Research Council, 2020. Climate Change: Evidence and Causes: Update 2020.

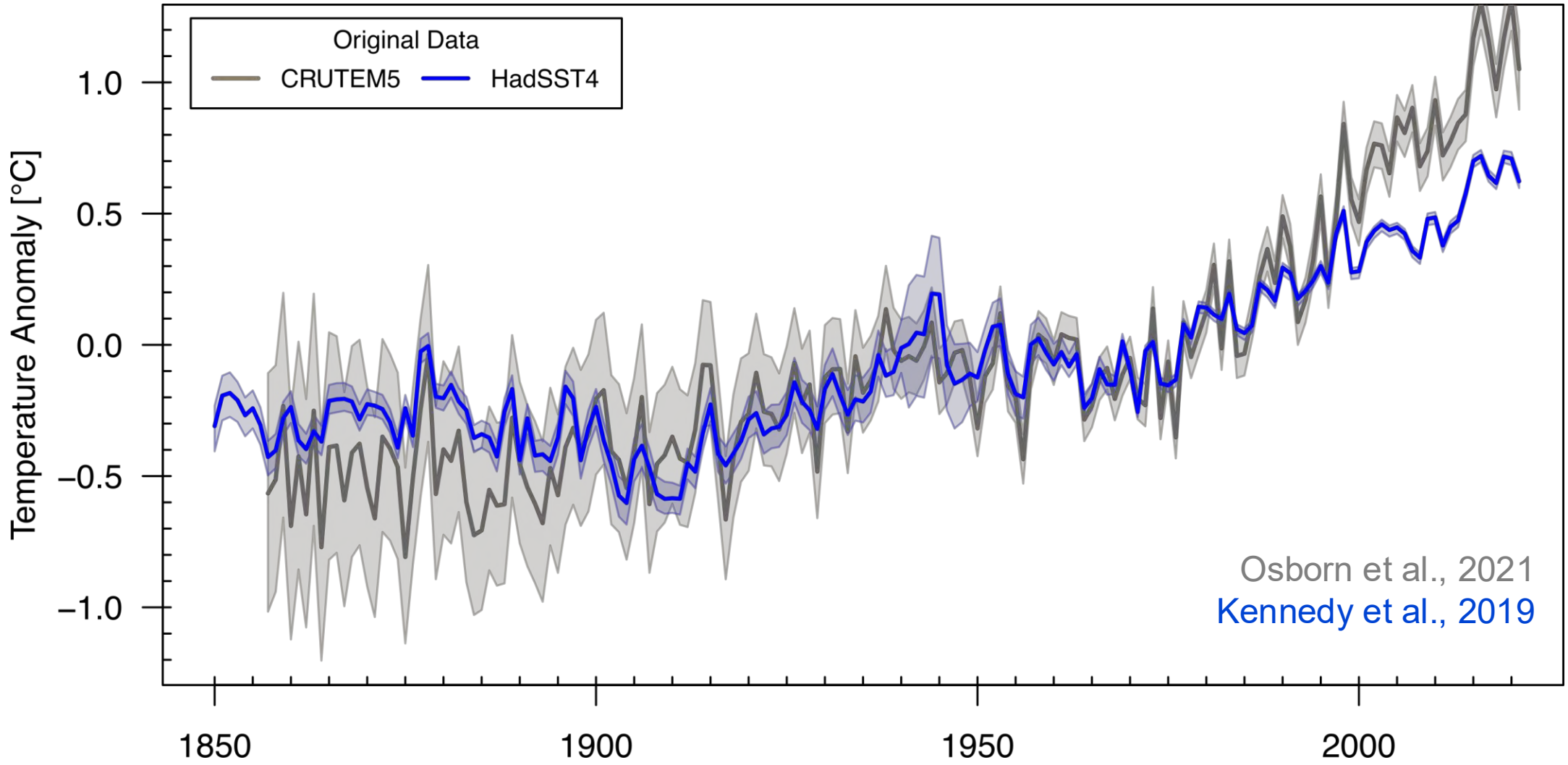
GMST reconstructions are challenging

- Coverage is limited, in particular in the early instrumental record
- Observing techniques vary over time
- LSAT and SST measurements contain **different** biases and uncertainties



January 1901 coverage in HadCRUT4, Kennedy et al., 2019

The land air vs. sea surface temperature record



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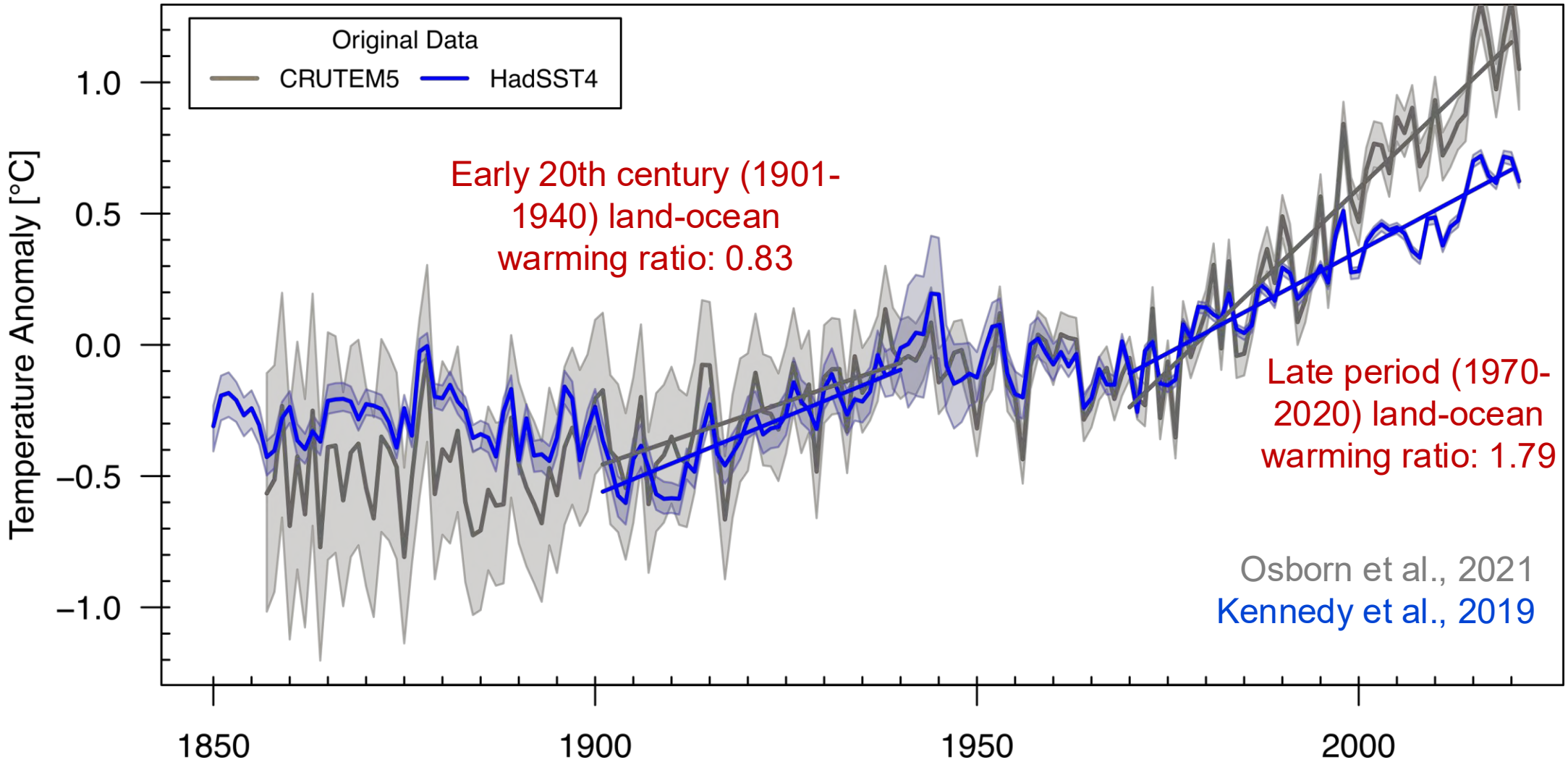
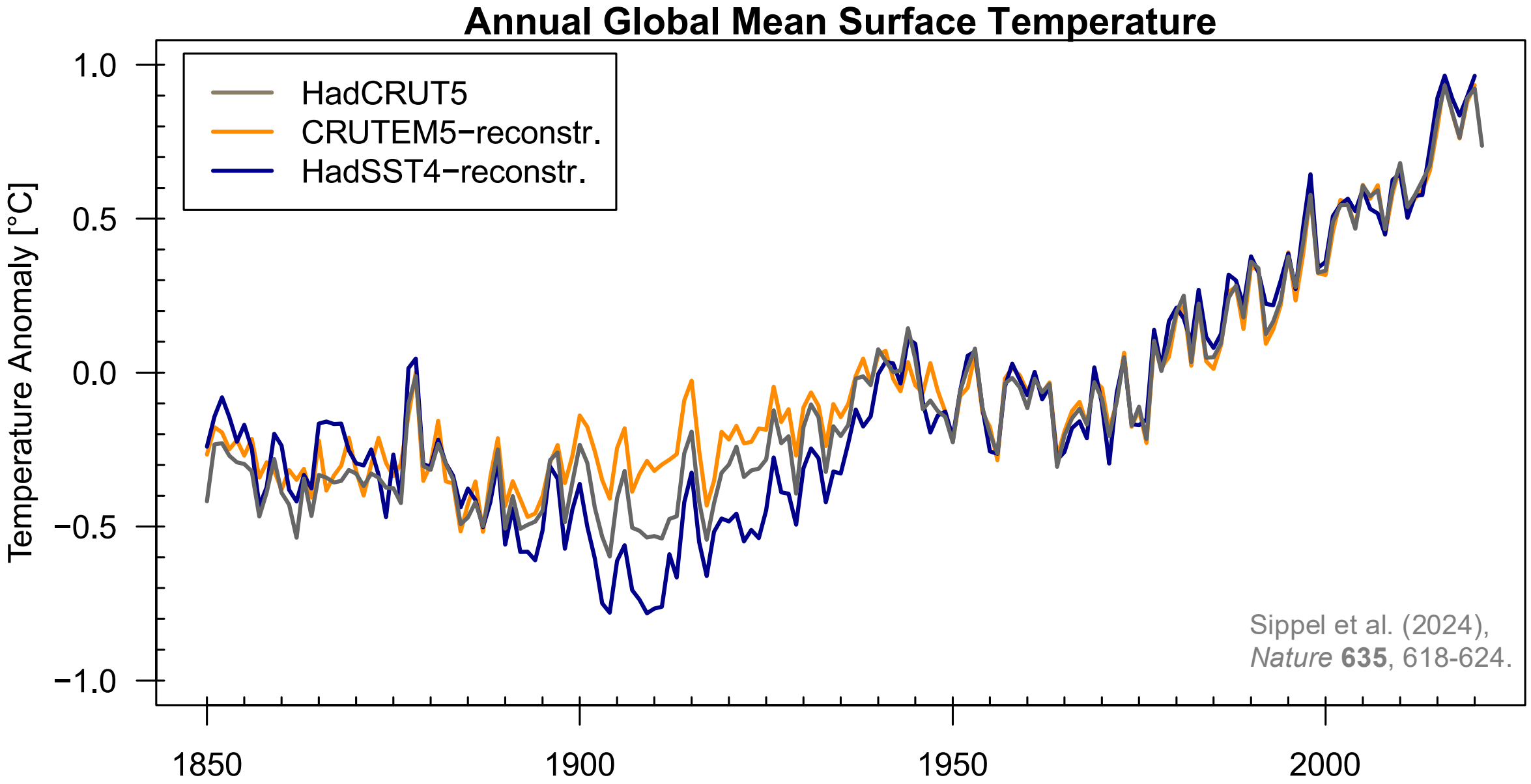


How consistent are global mean surface temperature estimates from land air- and sea surface temperatures, if reconstructed individually?

Reconstruction method

- A statistical learning method is trained on CMIP6 historical simulations (masked to observed historical fields) to predict GMST independently from land or ocean data
- Uncertainties and bias realizations from observations (HadSST4 / CRUTEMP) are added to CMIP6 fields before training
- Statistical model is then applied to land temperatures or SSTs to predict $GMST_{Land}$ or $GMST_{Ocean}$ from observations


Annual Global Mean Surface Temperature
HadCRUT5
CRUTEM5−reconstr.
HadSST4−reconstr.
Temperature Anomaly [°C]
1.0
0.5
0.0
−0.5
−1.0
1850
1900
1950
2000
Sippel et al. (2024),
Nature **635**, 618-624.

Results

High consistency between land- and SST-based reconstruction in long-term GMST warming

Period	IPCC AR6	$GMST_{Land}$	$GMST_{Ocean}$
1850-1900 to 2011-2020	**1.09** [0.95 – 1.20]	**1.07** [0.92 – 1.20]	**1.10** [1.05 – 1.16]

Sippel et al. (2024), *Nature* **635**, 618-624.

Results

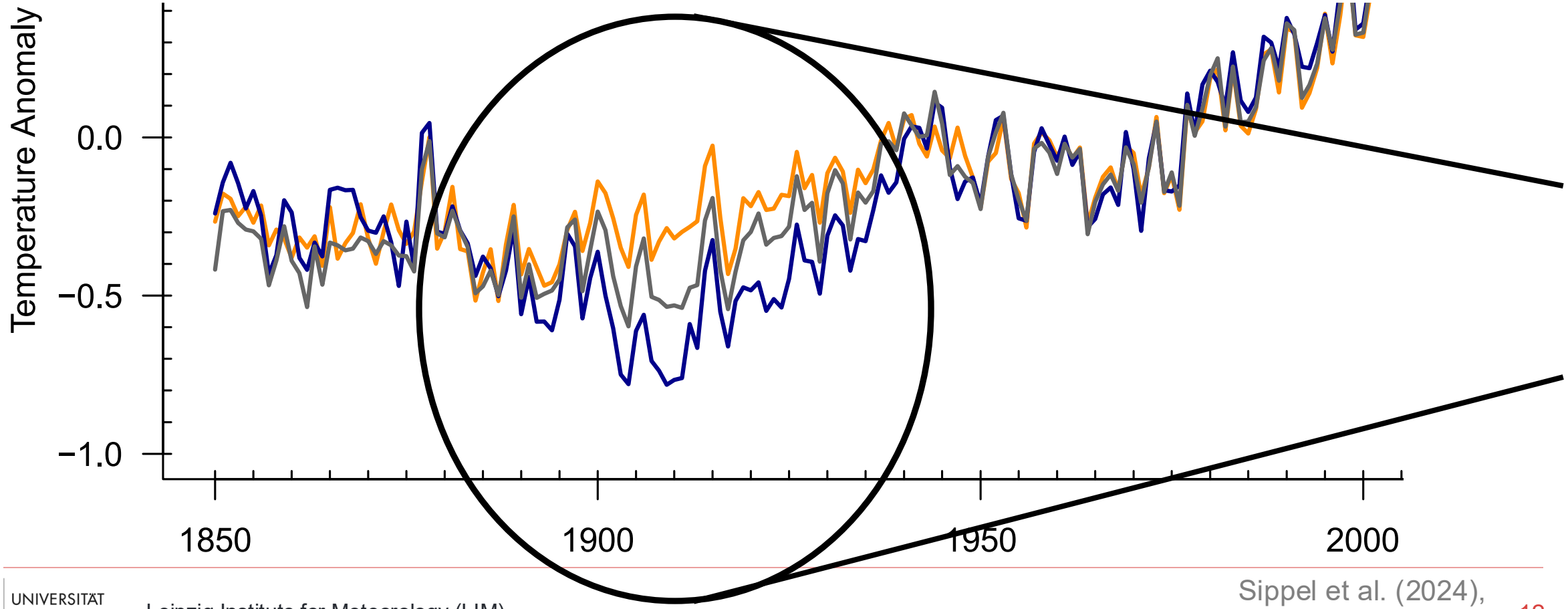
Increased Pearson correlation between $GMST_{Land}$ and $GMST_{Ocean}$

Period and metric	CRUTEM5 vs. HadSST4	New reconstr. (land vs. ocean)
1850-2020, monthly	0.77	0.87
1850-1900, annual	0.47	0.70

Sippel et al. (2024), *Nature* **635**, 618-624.

Results

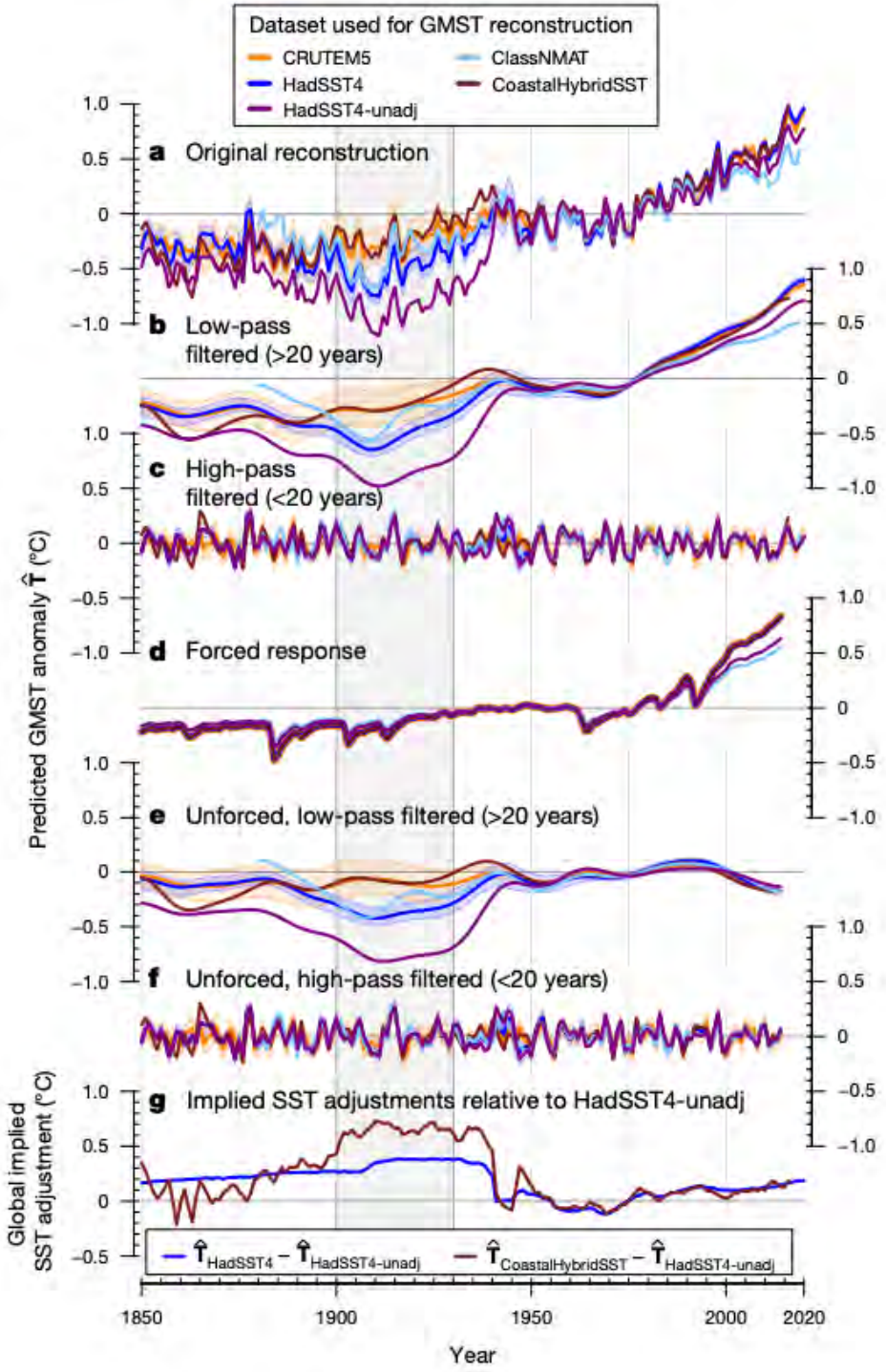
Discrepancy between ocean and land during ~1900 up to 1930, with $GMST_{Ocean}$ substantially colder than $GMST_{Land}$



Sippel et al. (2024), *Nature* **635**, 618-624.

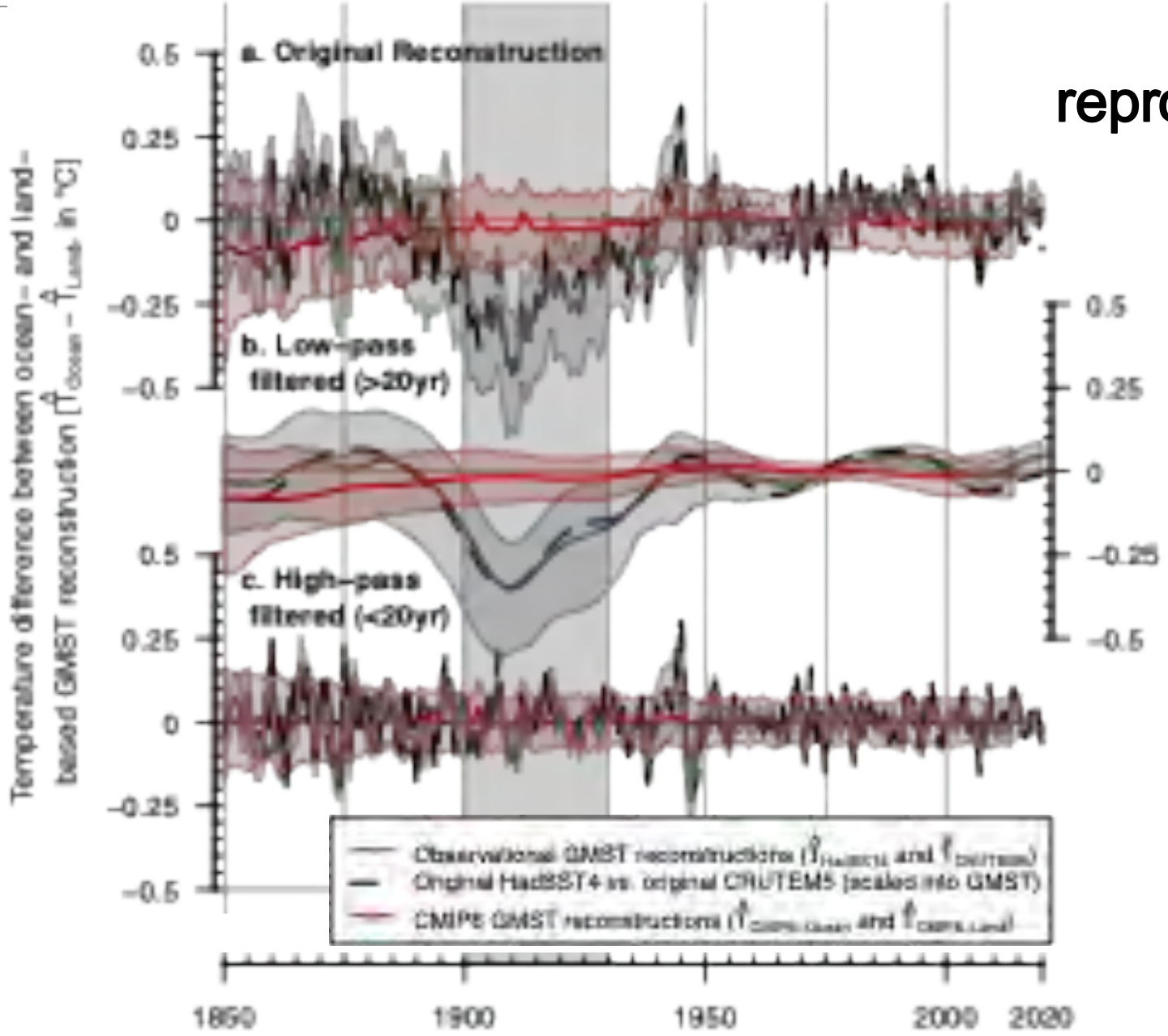
Is this multi-decadal ocean cold anomaly realistic?

Decadal ocean cold anomaly is unforced



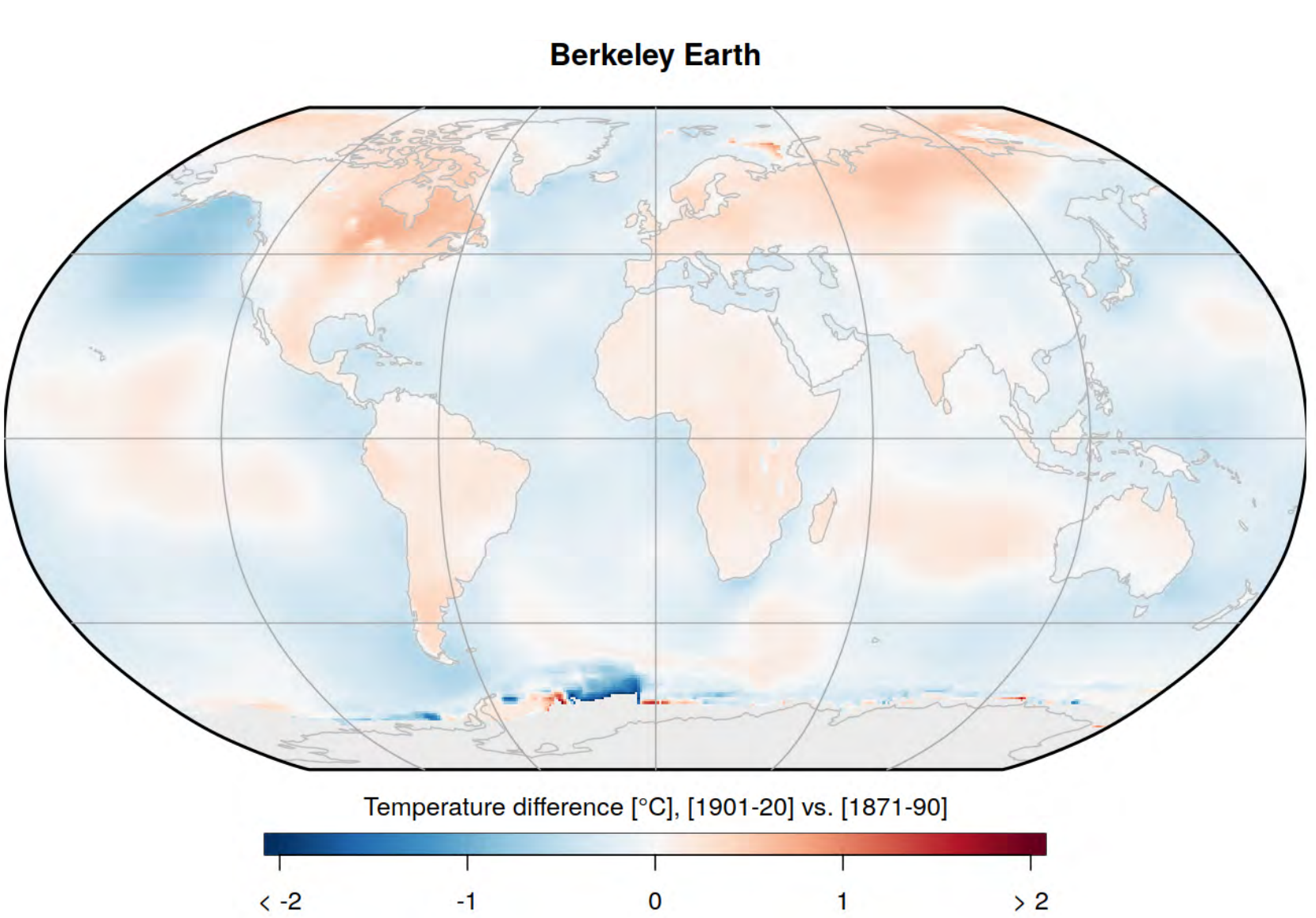
Sippel et al. (2024), *Nature* **635**, 618-624.

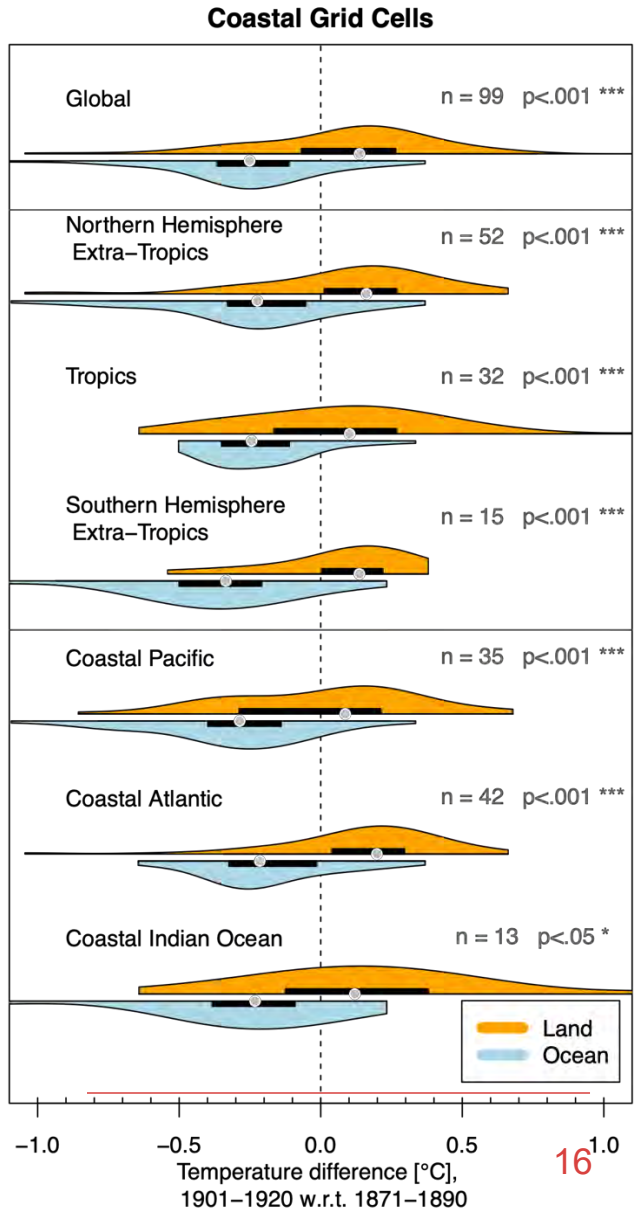
Ocean-land decoupling not reproduced by any CMIP6 model



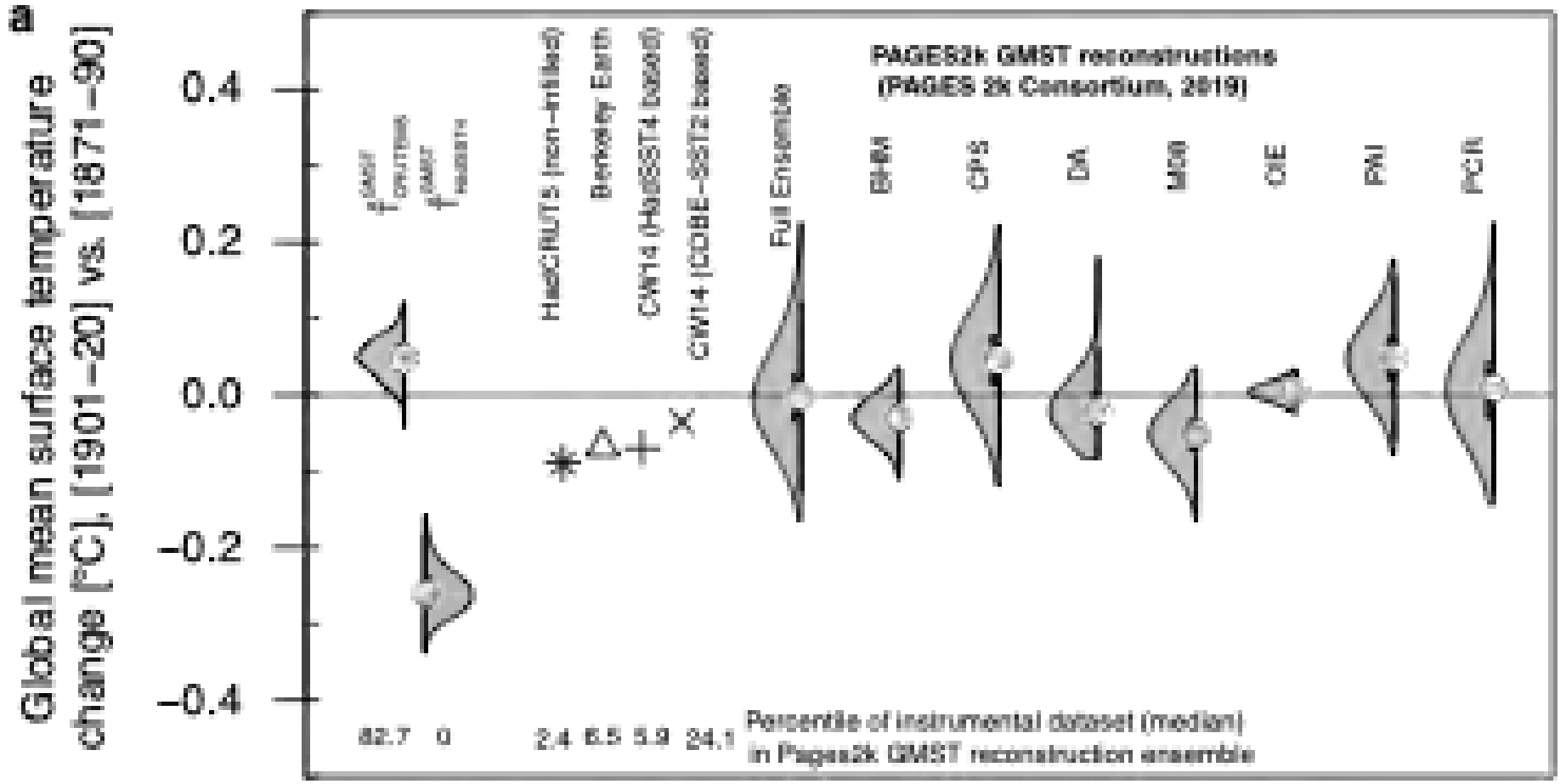
Sippel et al. (2024), *Nature* **635**, 618-624.

Odd coastal temperature patterns post- vs. pre 1900





No evidence for global cooling in paleoclimate reconstructions



Sippel et al. (2024), *Nature* **635**, 618-624.

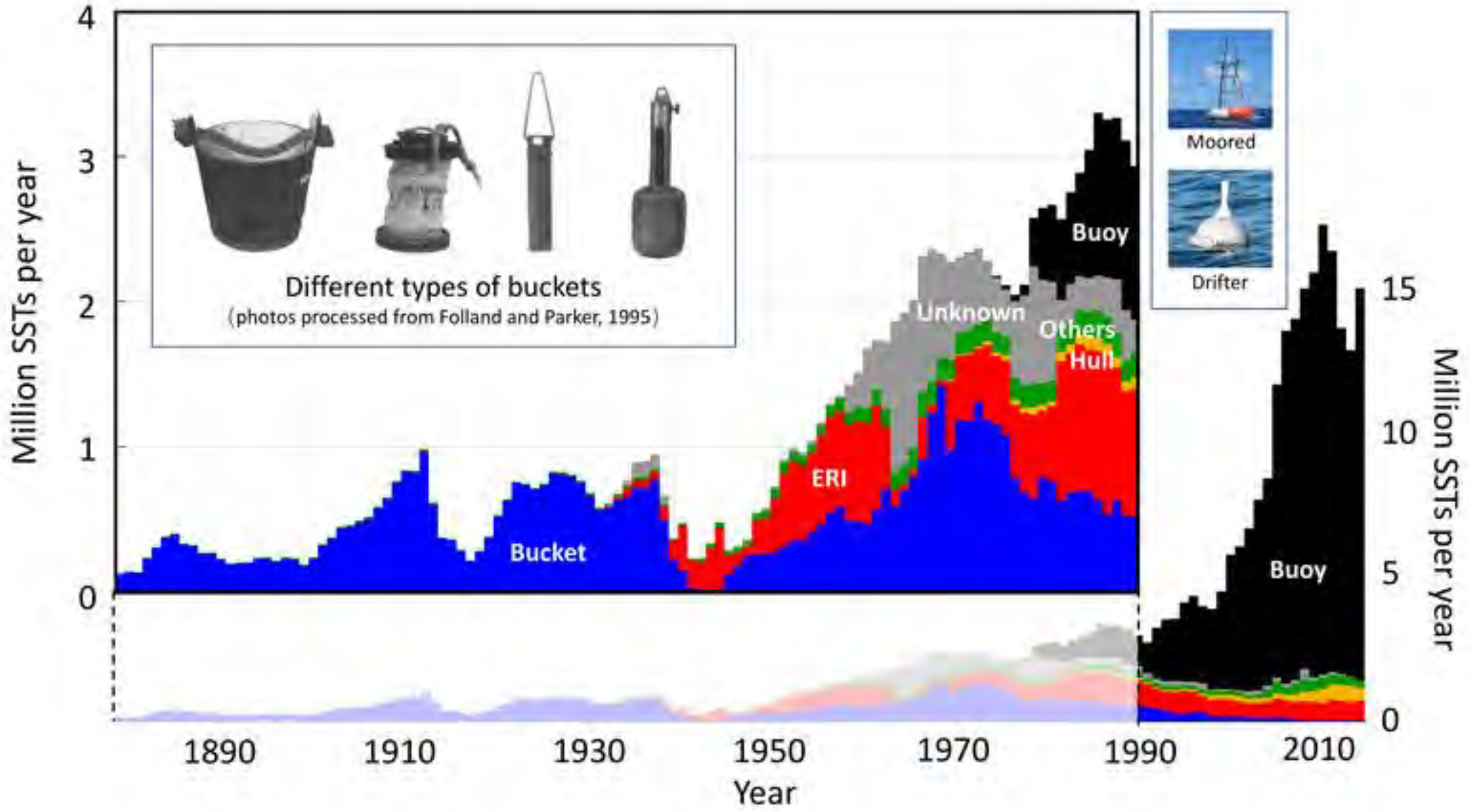
Conclusions Part 1

High consistency between $GMST_{Land}$ and $GMST_{Ocean}$ in large(st) part of instrumental period

Unexplained ocean cold anomaly identified during 1900-1930

Different lines of evidence (attribution, statistics, coastal patterns, paleoclimate data) suggest that the early 20th century ocean cold anomaly likely arises partly due to uncorrected SST biases

Cold Bias in early 20th century ocean surface temperature estimates?



Duo Chan (2021), *Harvard Data Science Review*

Conclusions Part 1 – independently supported by SST diurnal cycle analysis and coral proxy data

Geophysical Research Letters®

RESEARCH LETTER
10.1029/2025GL116615

Key Points:

- Changes in the diurnal cycle of ship-based sea surface temperature (SST) measurements indicate that a wooden-to-canvas bucket transition occurred by 1910
- Leading SST products apply corrections for a later transition, leading to the appearance of excess 19c cooling and early 20c warming
- An SST product capturing the early bucket transition is more consistent with coral proxies and expected responses from anthropogenic forcing

Re-Evaluating Historical Sea Surface Temperature Data Sets: Insights From the Diurnal Cycle, Coral Proxy Data, and Radiative Forcing

Duo Chan[1,2], Geoffrey Gebbie[2], and Peter Huybers[3]

[1]School of Ocean and Earth Science, University of Southampton, Southampton, UK, [2]Department of Physical Oceanography, Woods Hole Oceanographic Institution, Woods Hole, MA, USA, [3]Department of Earth and Planetary Sciences, Harvard University, Cambridge, MA, USA

Abstract Discrepancies in historical global mean surface temperature (GMST) estimates largely stem from differences in bias corrections applied to sea surface temperature (SST) records. Here, using the amplitude of the diurnal cycle in SST, we provide evidence that wooden-to-canvas bucket transitions were mostly complete by the early 1900s, earlier than commonly assumed by two decades, resulting in strong early 20th century cold

Agenda

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2. **Implications for global temperature projections**

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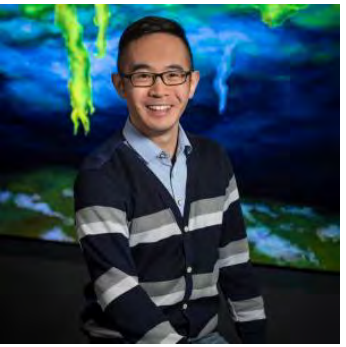
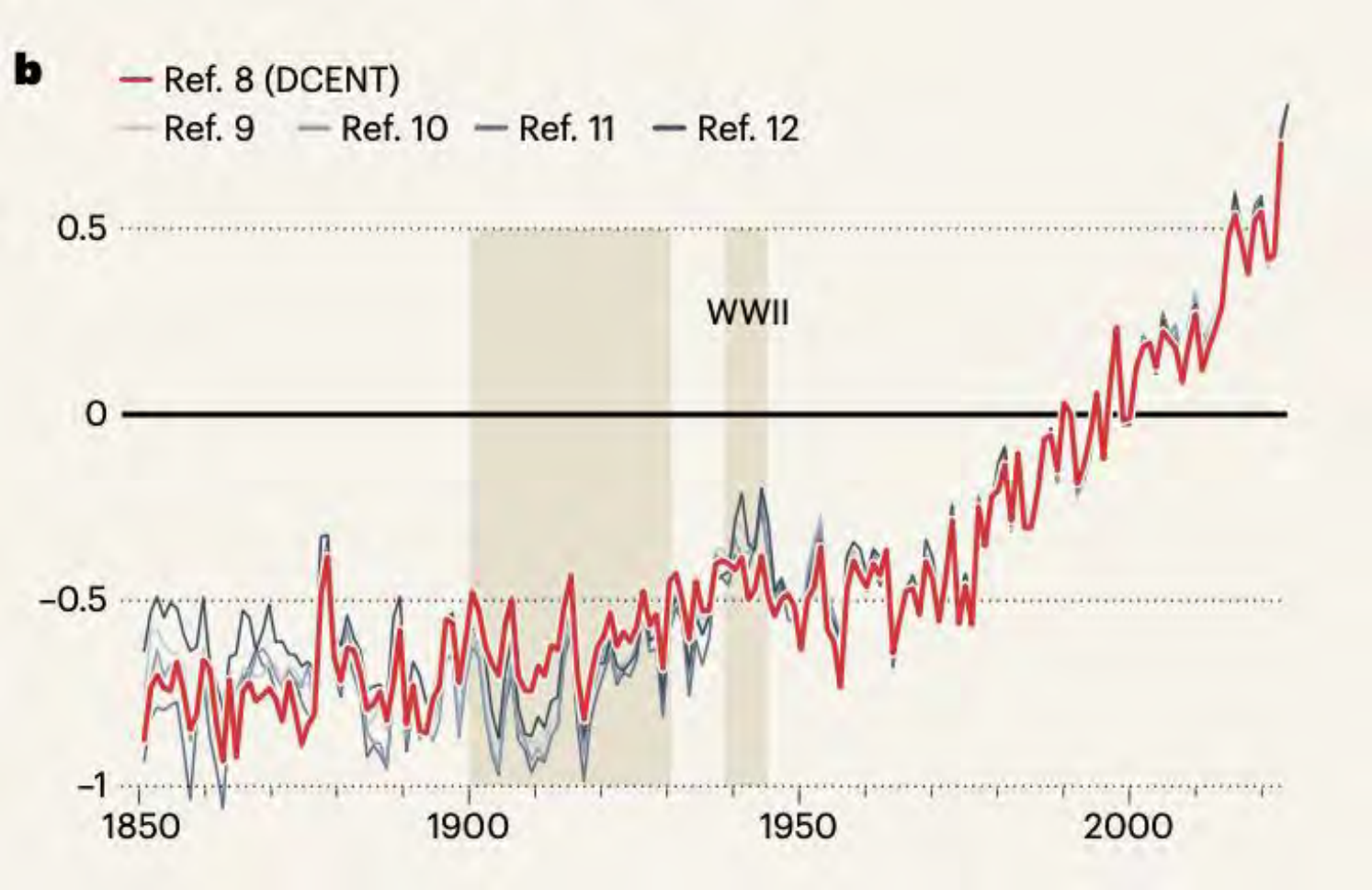


Duo
Chan

DCENT* – A new perspective on the global temperature record



- DCENT is less cold (dynamically consistent) in the early 20th century
- DCENT is less warm during WWII
- Slightly lower 1850-1900 baseline

What does DCENT imply for constraints on future warming?

*A Dynamically Consistent ENsemble of Temperature at the Earth surface since 1850 from the DCENT dataset

Chan et al. (2024), *Scientific Data*
Osborn & Kennedy (2024), *Nature*

High-end CMIP6 temperature projections were considered unlikely

SCIENCE ADVANCES | RESEARCH ARTICLE

CLIMATOLOGY

Making climate projections conditional on historical observations

Aurélien Ribes[1]*, Saïd Qasmi[1], Nathan P. Gillett[2]

CLIMATOLOGY

Past warming trend constrains future warming in CMIP6 models

Katarzyna B. Tokarska[1*†], Martin B. Stolpe[1*], Sebastian Sippel[1], Erich M. Fischer[1], Christopher J. Smith[2], Flavio Lehner[1], Reto Knutti[1]

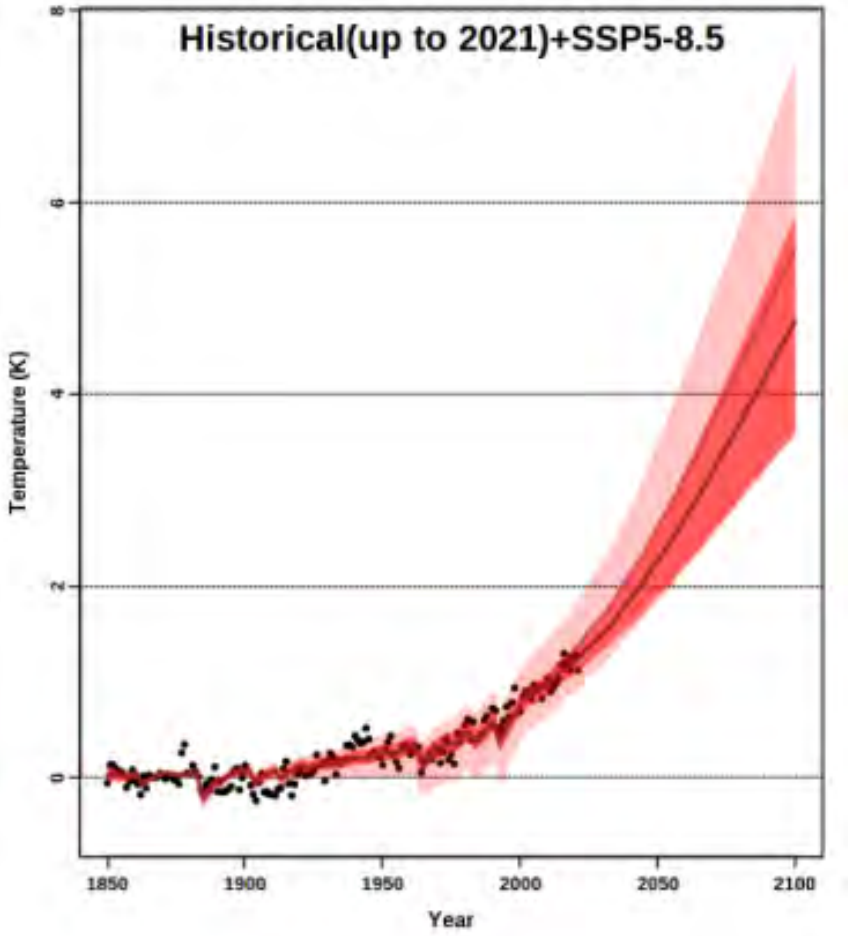
Climate simulations: recognize the 'hot model' problem

Zeke Hausfather, Kate Marvel, Gavin A. Schmidt, John W. Nielsen-Gammon & Mark Zelinka

Emergent constraints on transient climate response (TCR) and equilibrium climate sensitivity (ECS) from historical warming in CMIP5 and CMIP6 models

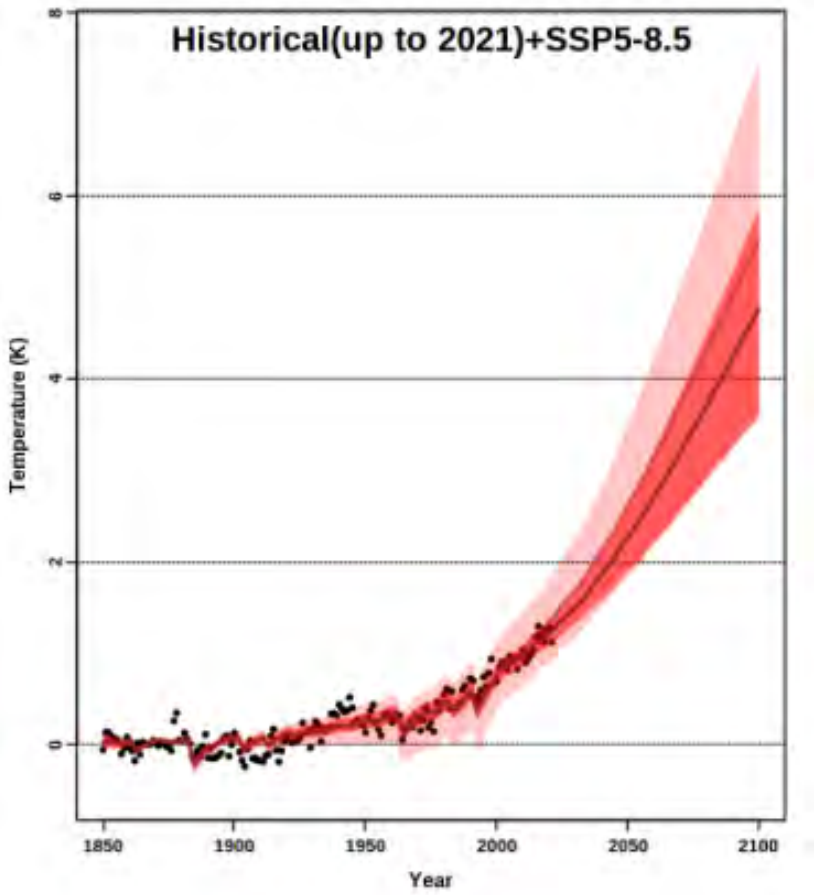
Femke J. M. M. Nijsse[1], Peter M. Cox[1], and Mark S. Williamson[1,2]
[1]College of Engineering, Mathematics and Physical Sciences, University of Exeter, Exeter, EX4 4QE, UK
[2]Global Systems Institute, University of Exeter, Exeter, EX4 4QE, UK
Correspondence: Femke J. M. M. Nijsse (f.j.m.m.nijsse@exeter.ac.uk)

Received: 19 December 2019 – Discussion started: 6 January 2020

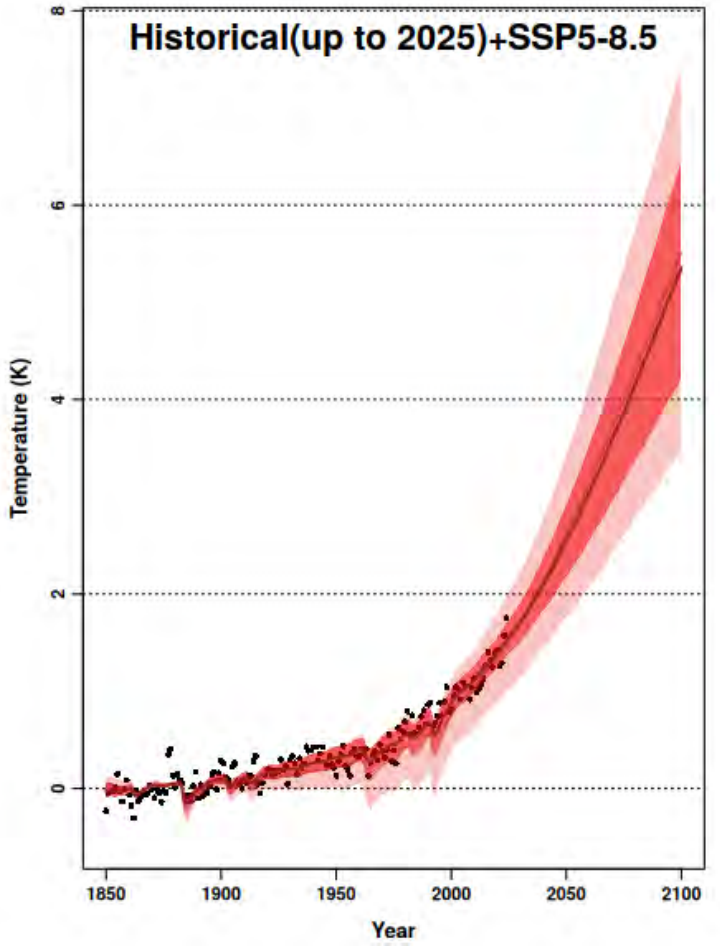


Sippel et al. Work in progress

Constraints on future warming may not fully rule out high climate sensitivity



} Old constraint (2020)



} New DCENT constraint

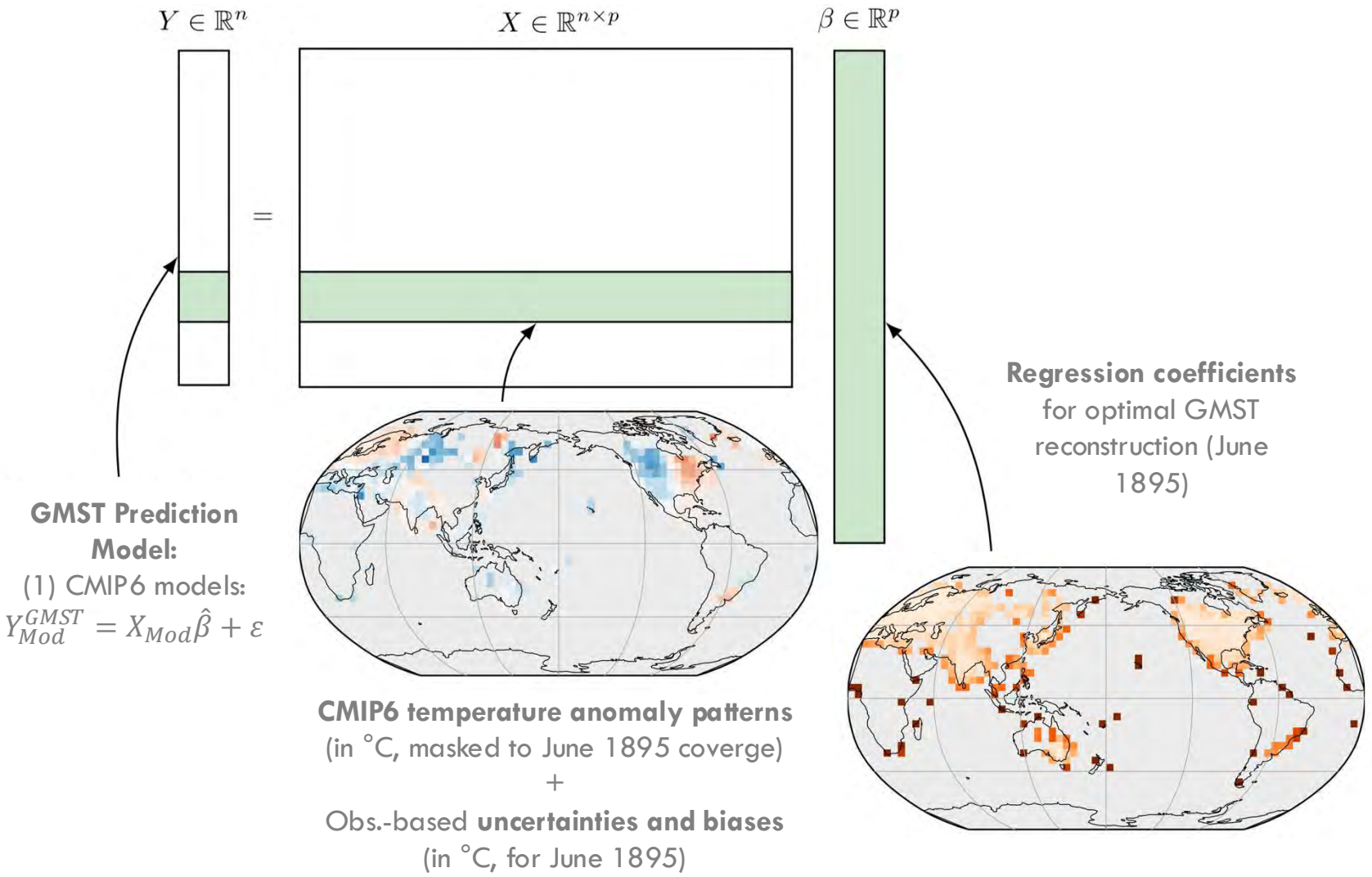
Sippel et al. Work in progress

Thank you for the attention!

Reconstruction method

Training setup

- CMIP6-hist. masked to observed coverage for each time step
- Uncertainties and bias realizations added to CMIP6 fields
- Statistical learning method to predict GMST from sparse reconstruction
- About 20% lower MSE compared to simple benchmark method before ~1950

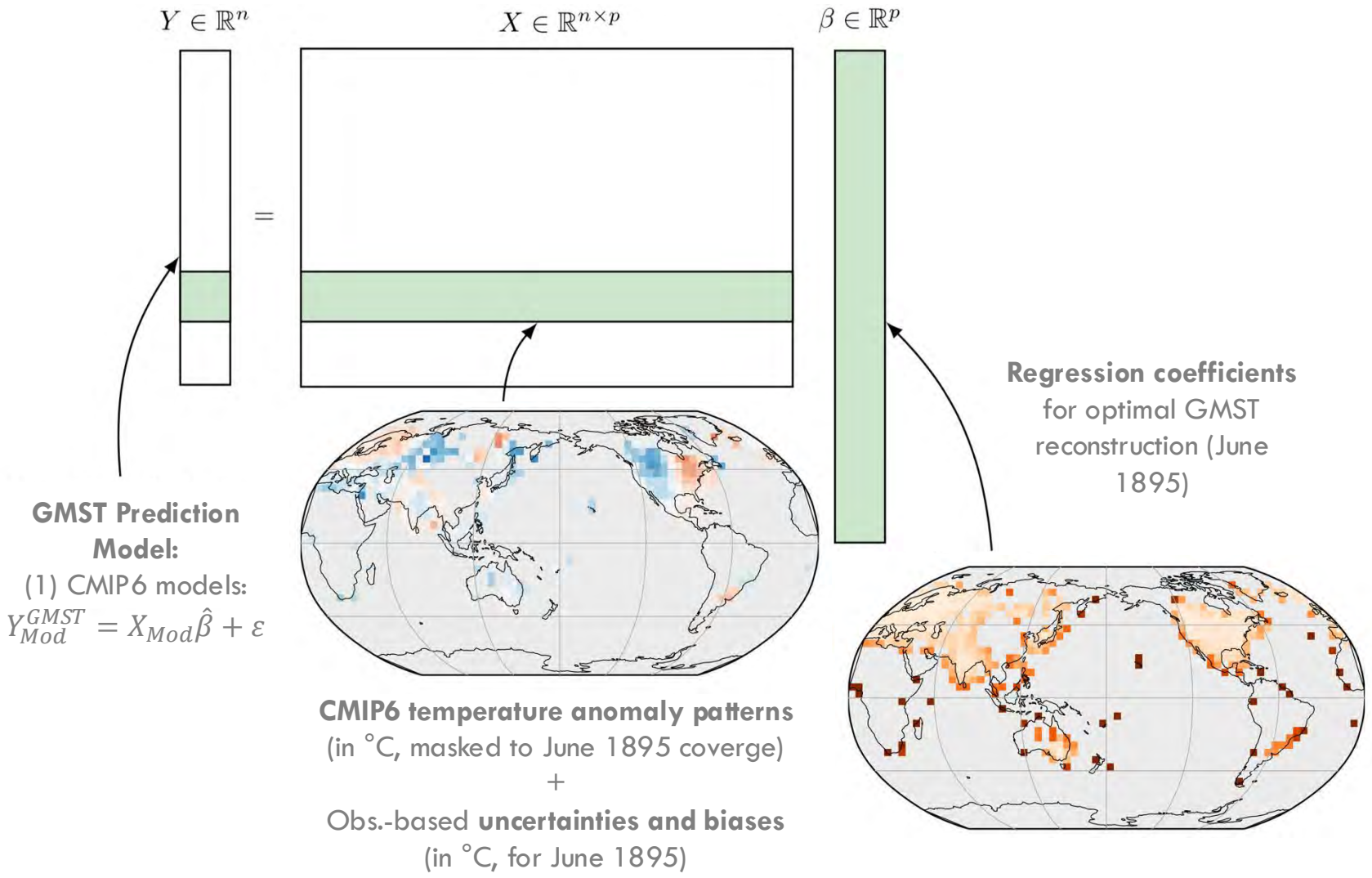


Reconstruction method

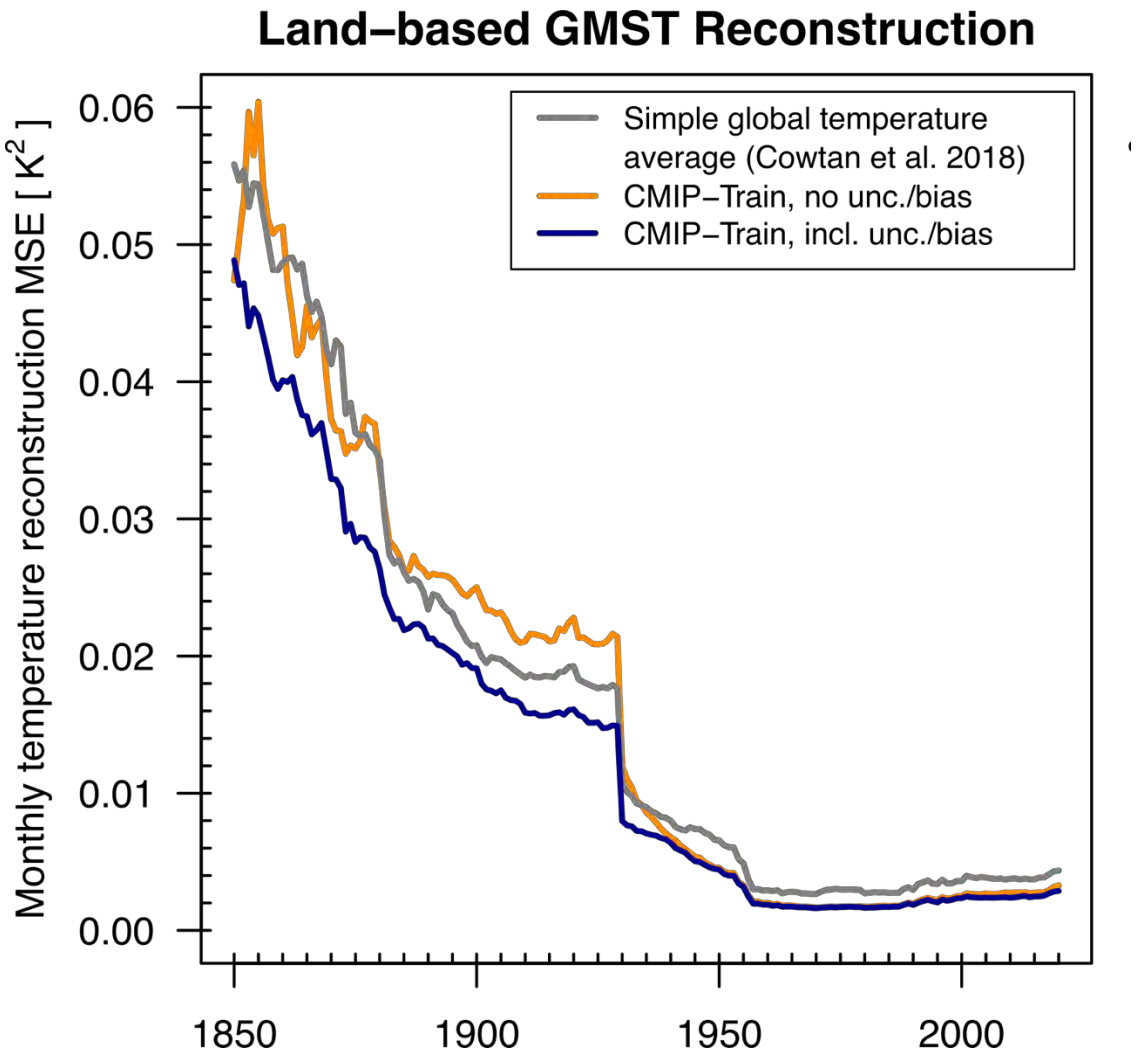
Observations-based reconstruction

Observations and statistical model to predict GMST

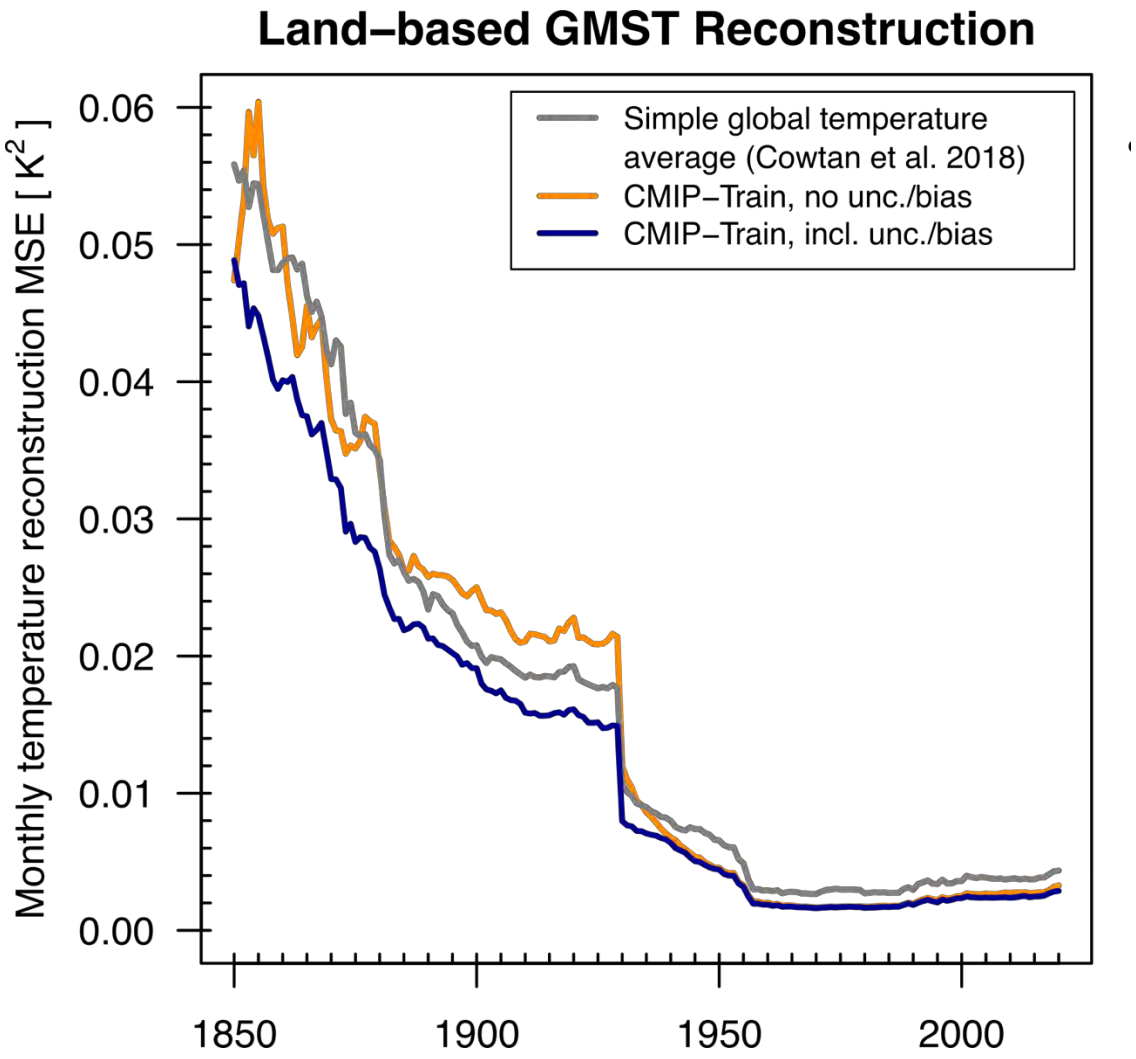
- $GMST_{Land}$: CRUTEM5-based
- $GMST_{Ocean}$: HadSST4-based



Evaluation


Land–based GMST Reconstruction
Monthly temperature reconstruction MSE [K^2]
0.06
0.05
0.04
0.03
0.02
0.01
0.00
1850
1900
1950
2000
Simple global temperature average (Cowtan et al. 2018)
CMIP–Train, no unc./bias
CMIP–Train, incl. unc./bias

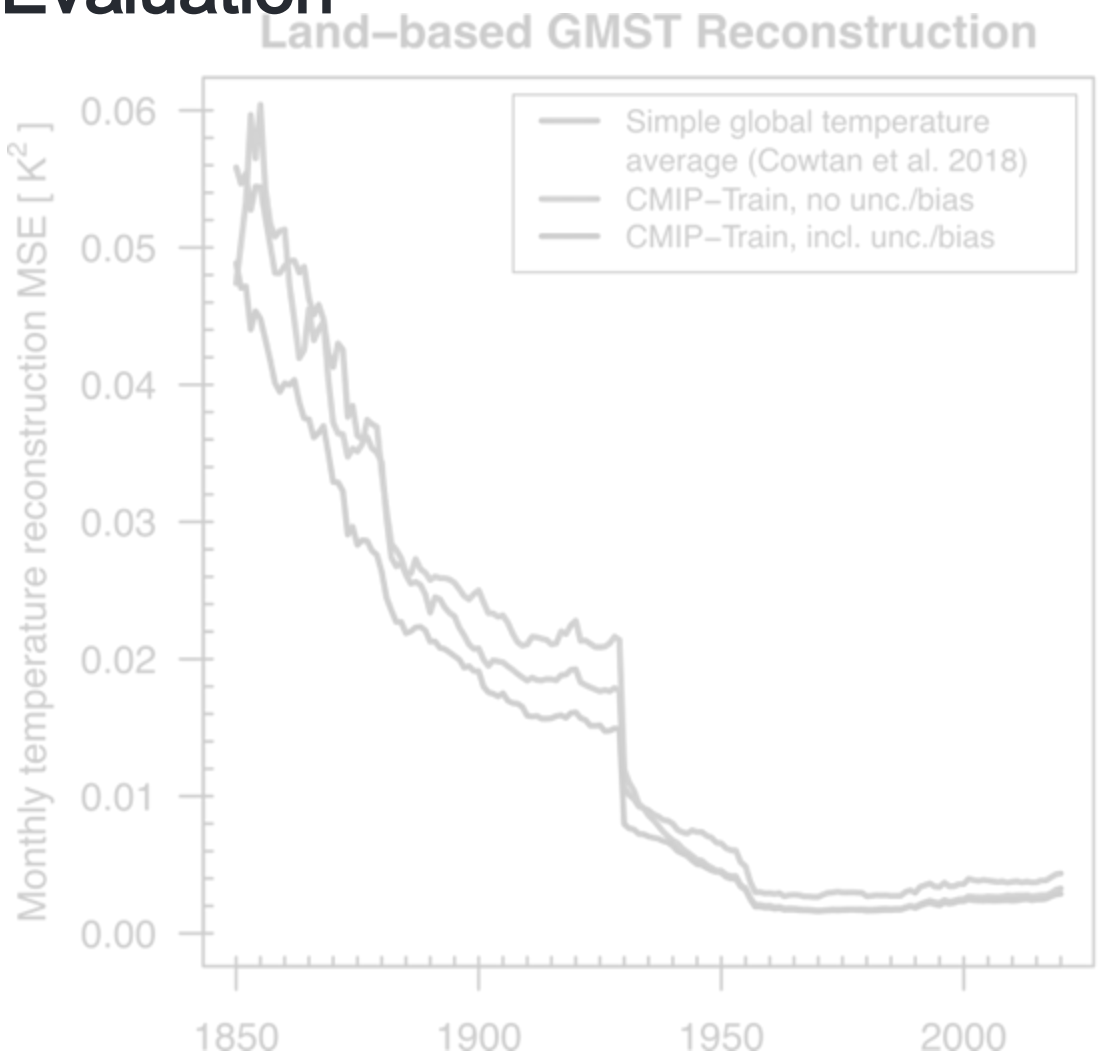
Evaluation



- Reconstruction MSE reduces substantially with increasing coverage over time

- 20% lower MSE before 1950 with statistical learning reconstruction as compared to reference setup

Evaluation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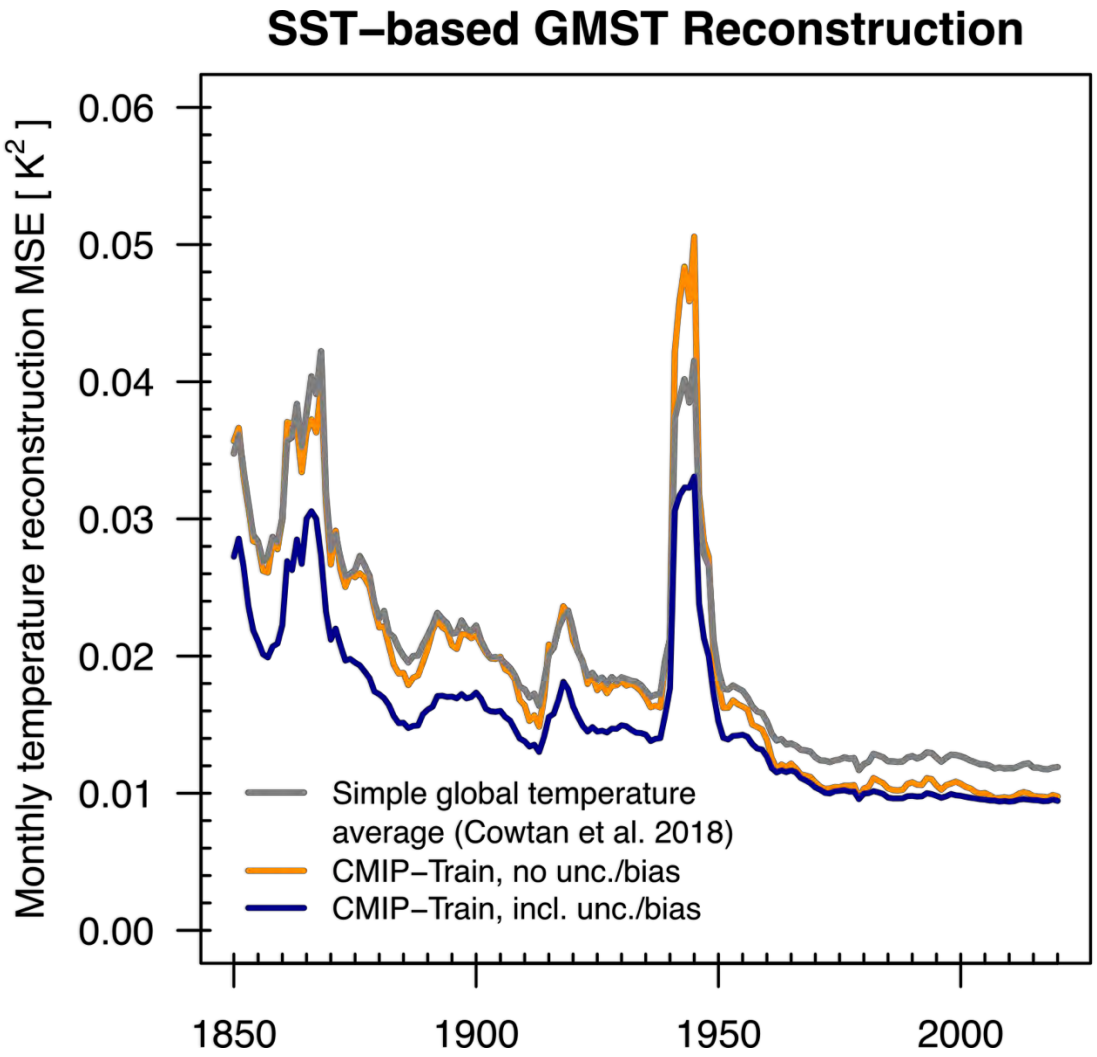
CMIP–Train, incl. unc./bias


SST–based GMST Reconstruction
Monthly temperature reconstruction MSE [K^2]
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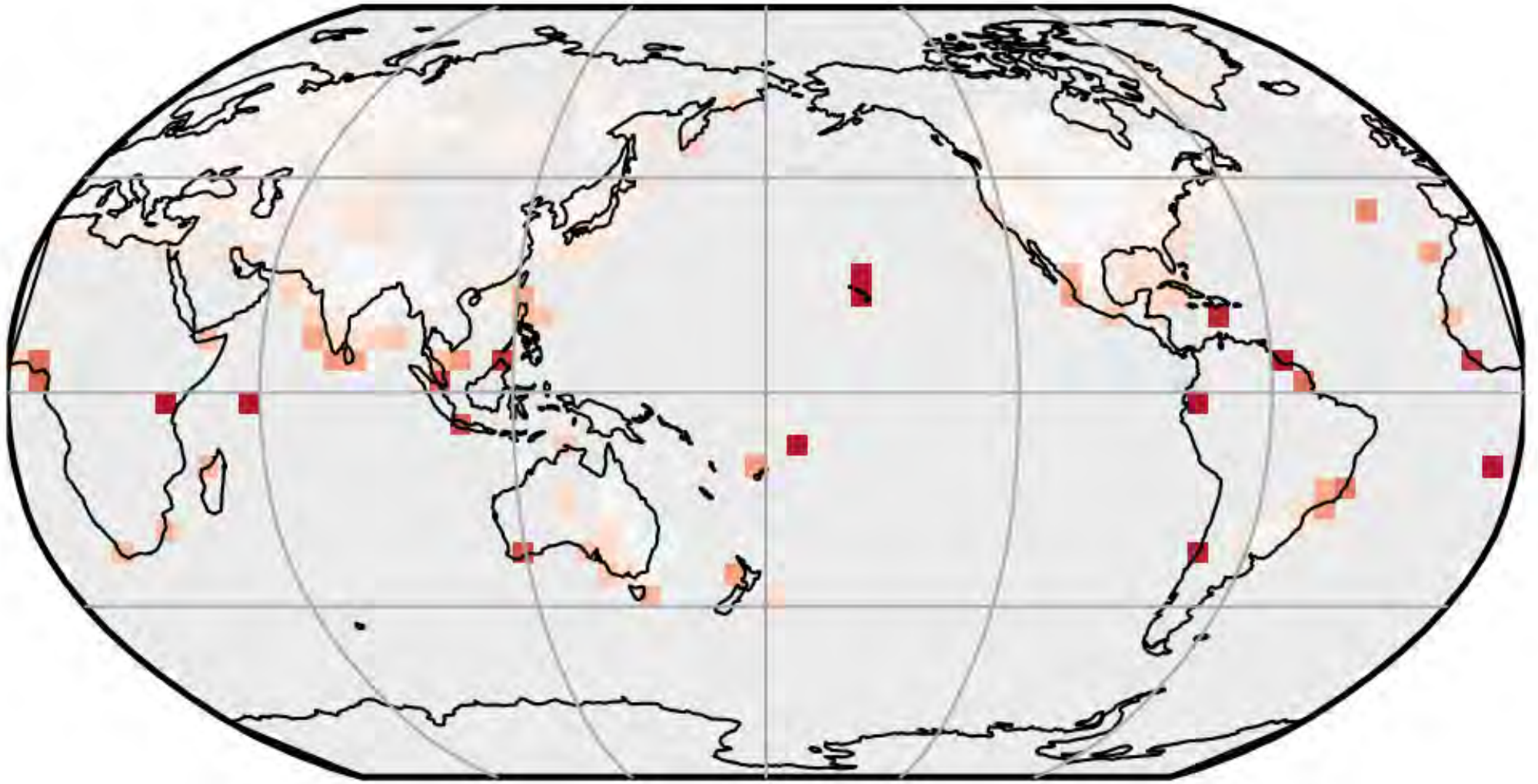
0.05
0.04
0.03
0.02
0.01
0.00
1850
1900
1950
2000
Simple global temperature average (Cowtan et al. 2018)
CMIP–Train, no unc./bias
CMIP–Train, incl. unc./bias

Why does including uncertainties/biases reduce reconstruction MSE?



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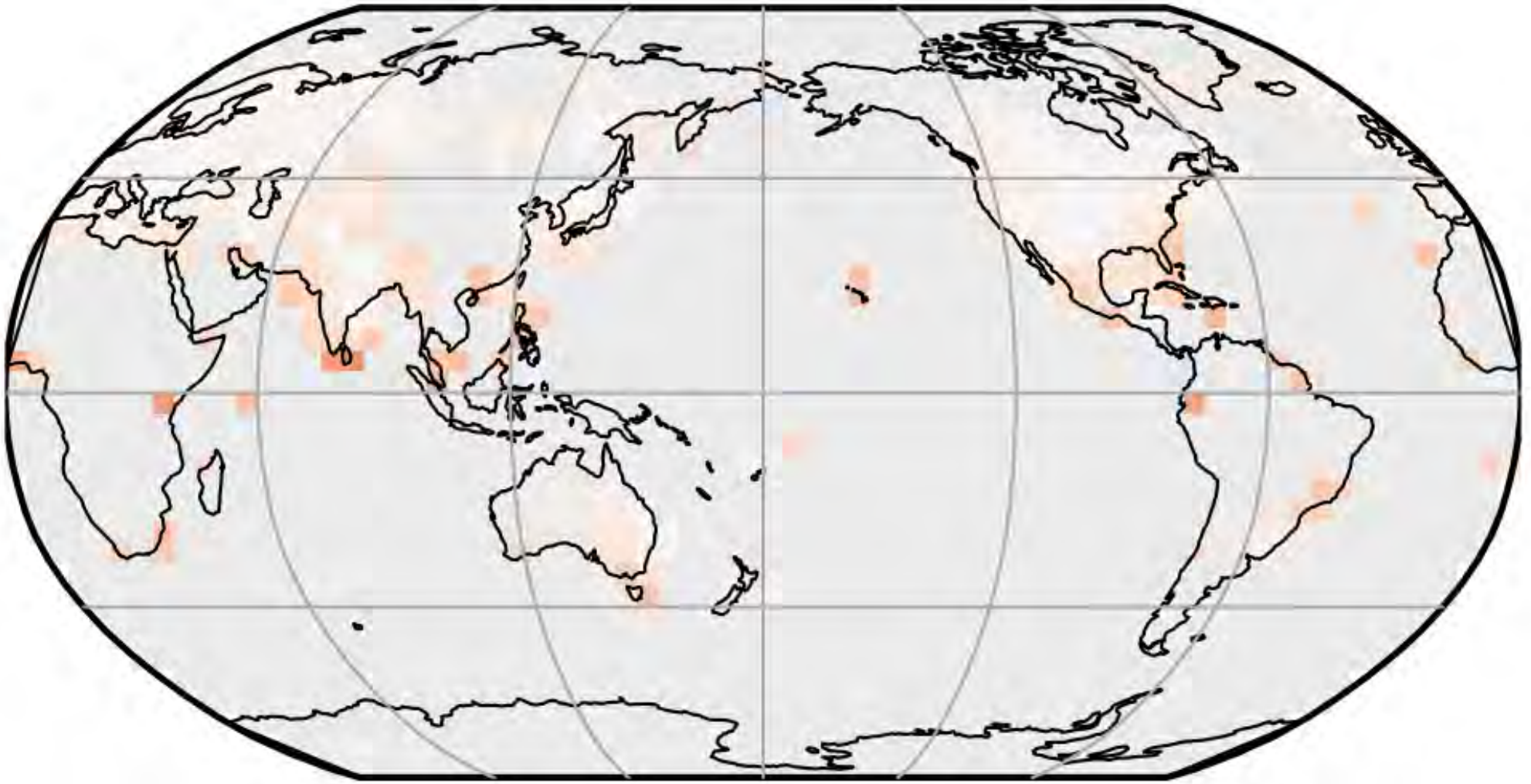
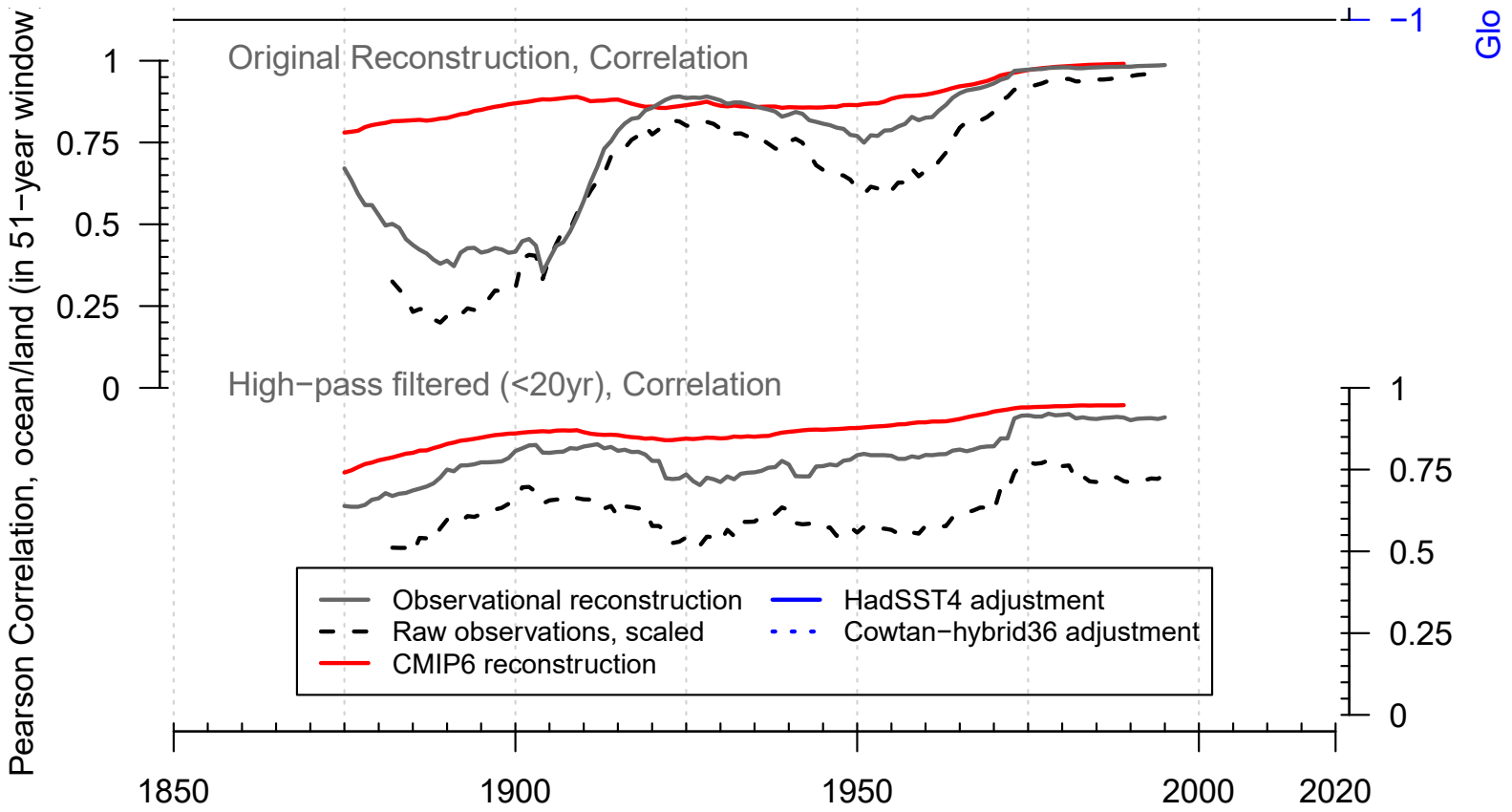
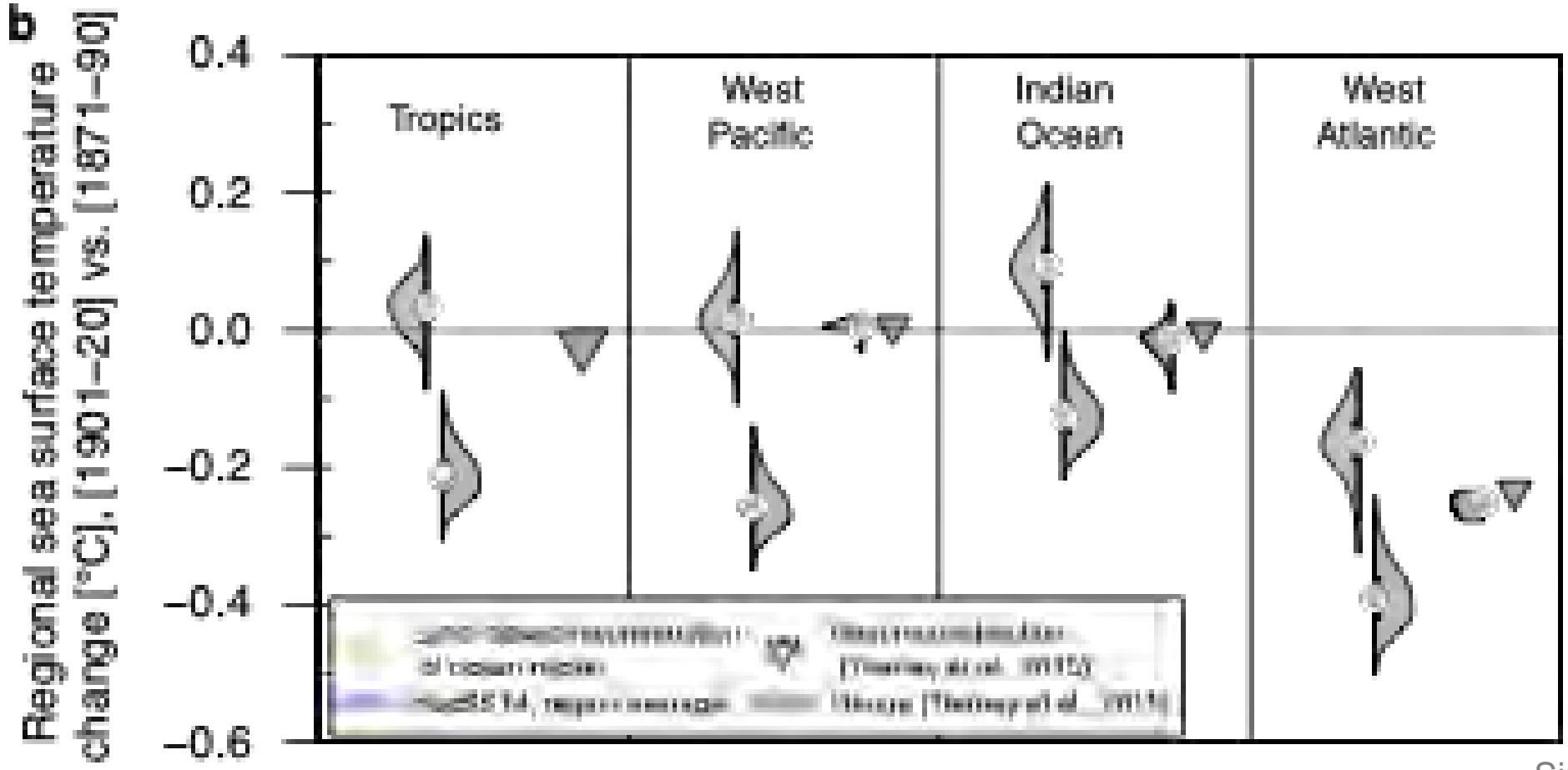


Ocean-land decoupling not reproduced by any CMIP6 model



No evidence for global cooling in paleoclimate reconstructions

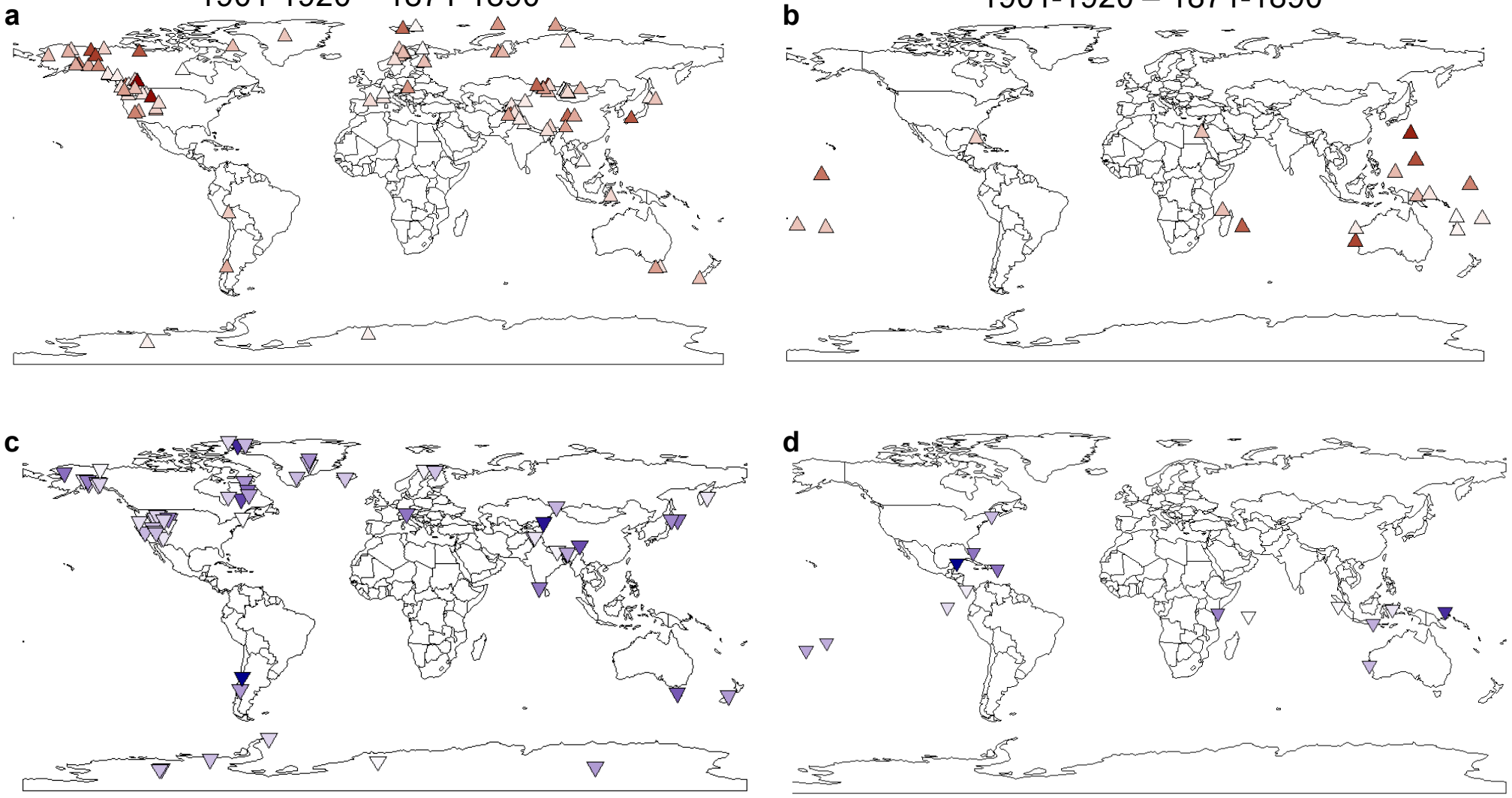


Sippel et al. (2024), *Nature* **635**, 618-624.

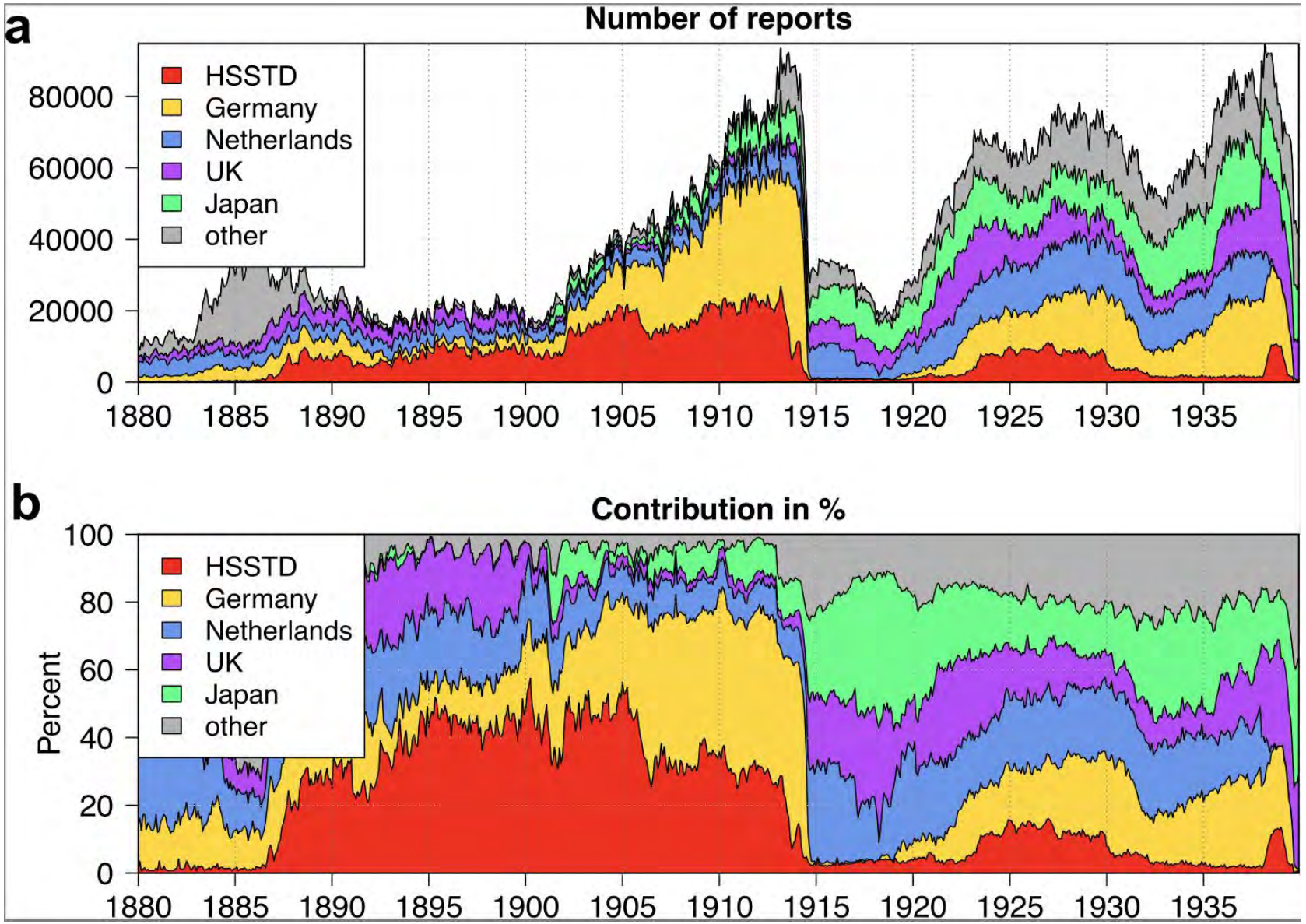
In-situ paleoclimate reconstructions

Terrestrial anomalies from proxies (z-scores), 1901-1920 – 1871-1890

Marine anomalies from proxies (z-scores), 1901-1920 – 1871-1890



Cold Bias in early 20th century ocean surface temperature estimates?



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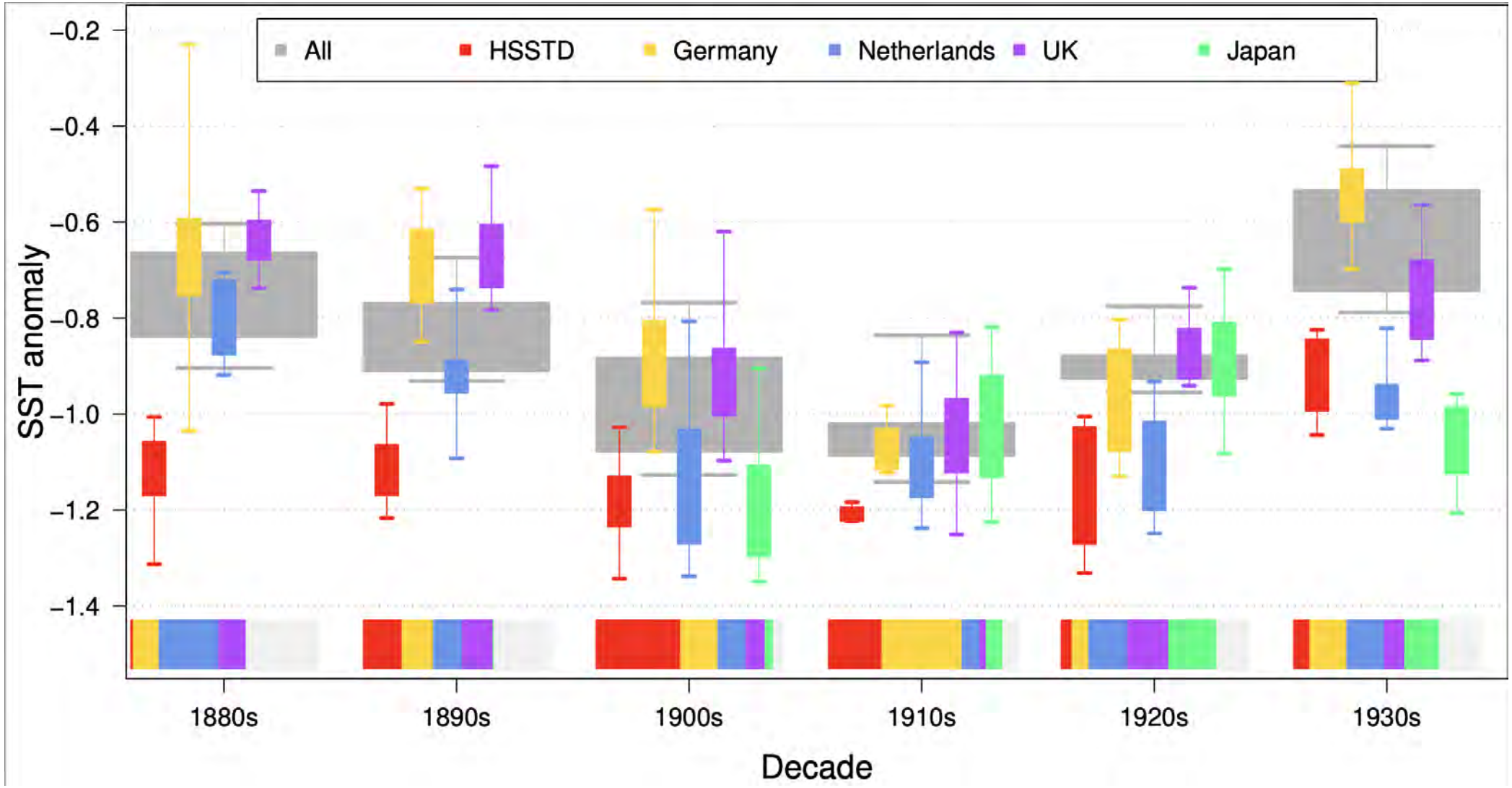

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Table title

Column heading	2021	2020	2019	2018
Lorem ipsum dolor	1,606	1,678	2,072	2,196
Excepteur sint occaecat	373	281	381	410
Ut enim ad minim veniam	537	607	733	786
Nostrud exercitation	365	425	506	559
Consectetur adipiscing elit	318	349	355	359
Nim ad minim veniam	13	16	97	82

Professor John Doe
Role of person giving presentation
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0000 Town, Country

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