Introduction to pacemaker experiments

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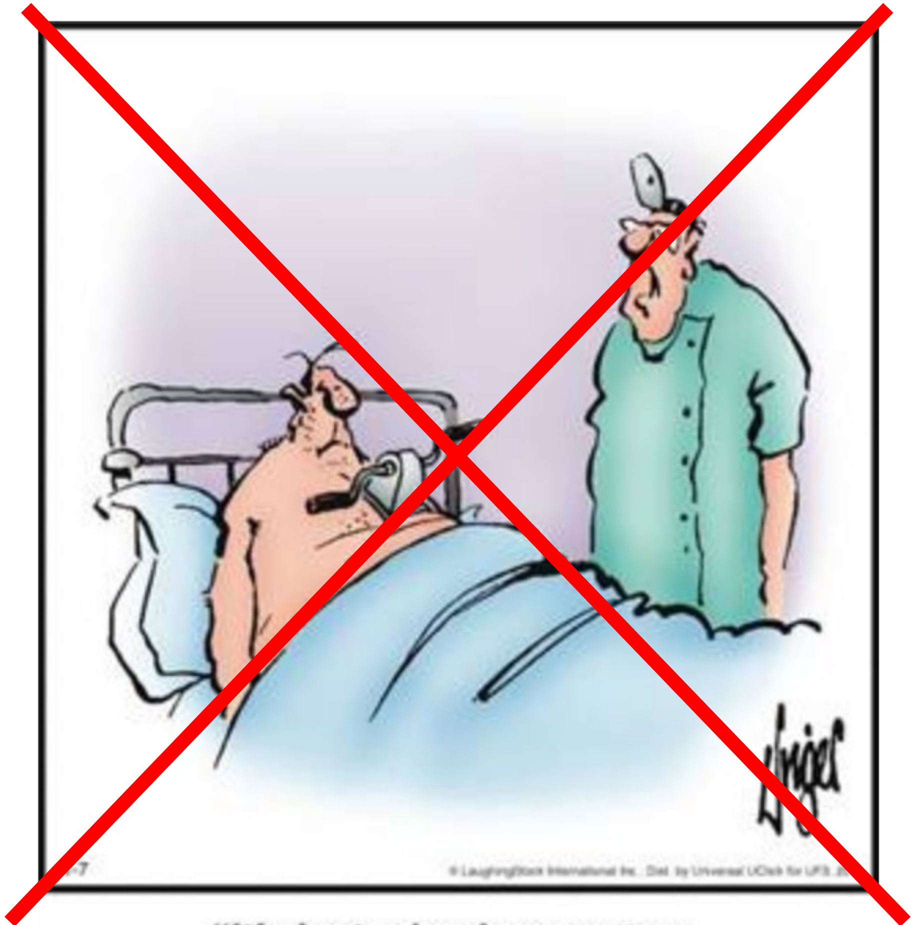
Outline

- motivation for pacemaker experiments
- methodology
- introduction to the TBI Coordinated Experiments
- drawbacks of pacemaker experiments
- alternative approaches

Motivation for pacemaker experiments

What is a pacemaker experiment?



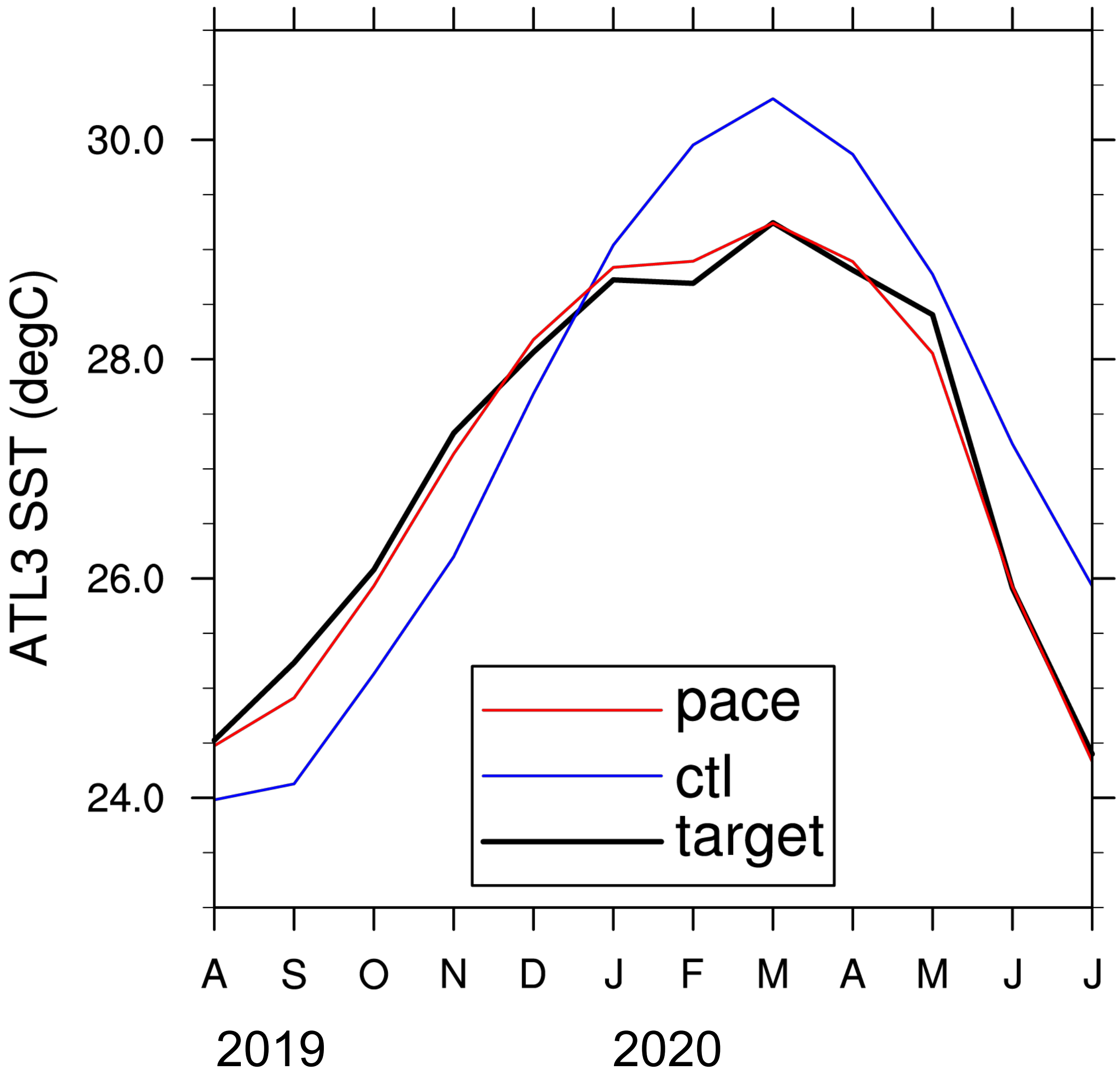
"It's just a backup system for your pacemaker."

What is a pacemaker experiment?

- type of climate model experiment
- modify a model variable by intervening in the physics
- most common variable to modified: sea-surface temperature (SST)
- most common modification: make the SST follow observations (“restore SSTs to observations”)
- typical restoring area: entire ocean basin (e.g. tropical Pacific)

Example of a pacemaker experiment

Restoring SST in the tropical Atlantic



What is this good for?

- understand how a variable influences the climate system <u>outside</u> the restoring region
- in the context of TBI: how do the SSTs in one basin influence another basin?
- e.g.: can the tropical Atlantic excite ENSO events?

Example 1: Influence of tropical Pacific on global surface temperatures

Kosaka and Xie (2013)

LETTER

doi:10.1038/nature12534

Recent global-warming hiatus tied to equatorial Pacific surface cooling

Yu Kosaka[1] & Shang-Ping Xie[1,2,3]

Example 1: Influence of tropical Pacific on global surface temperatures

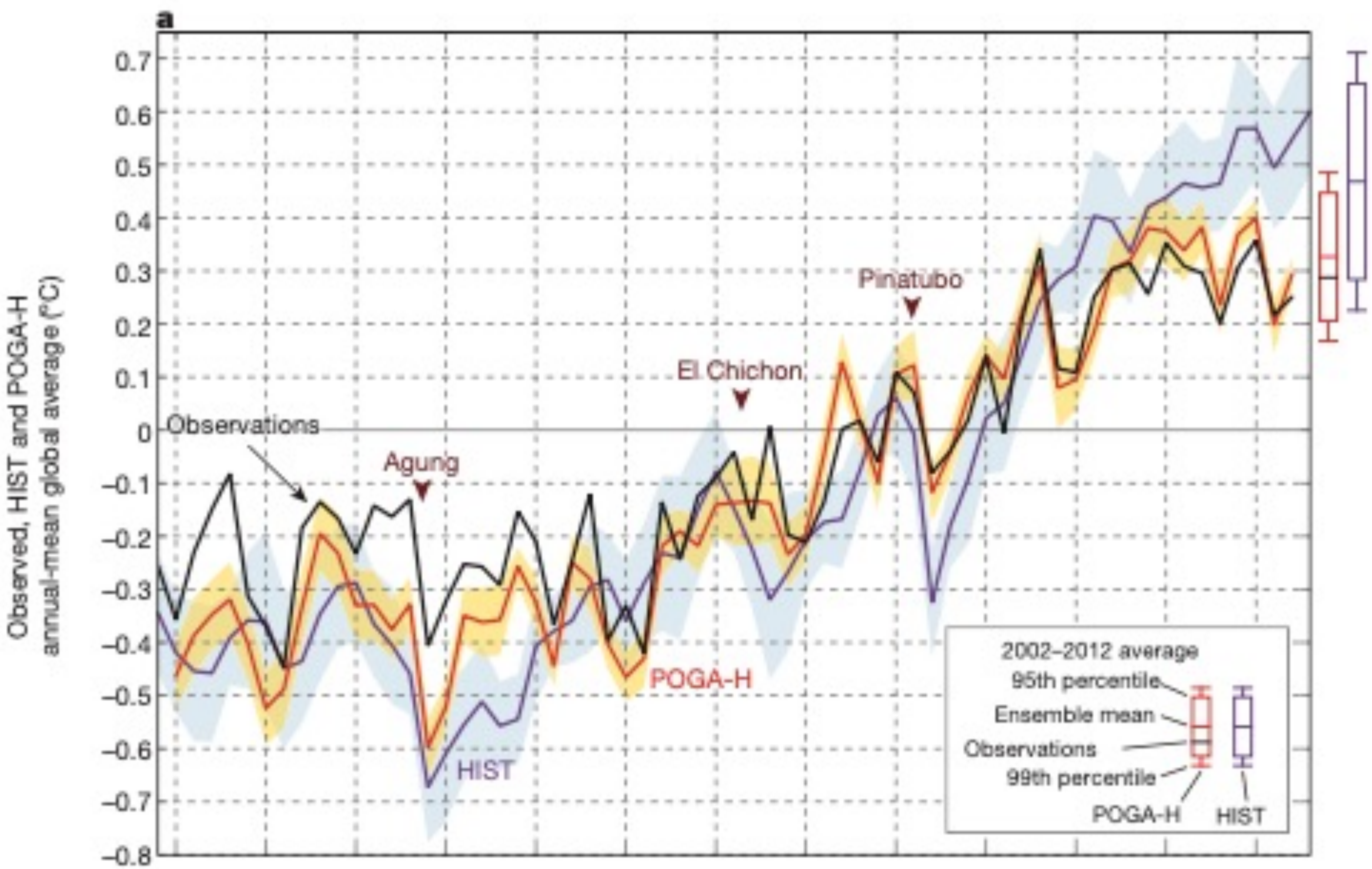
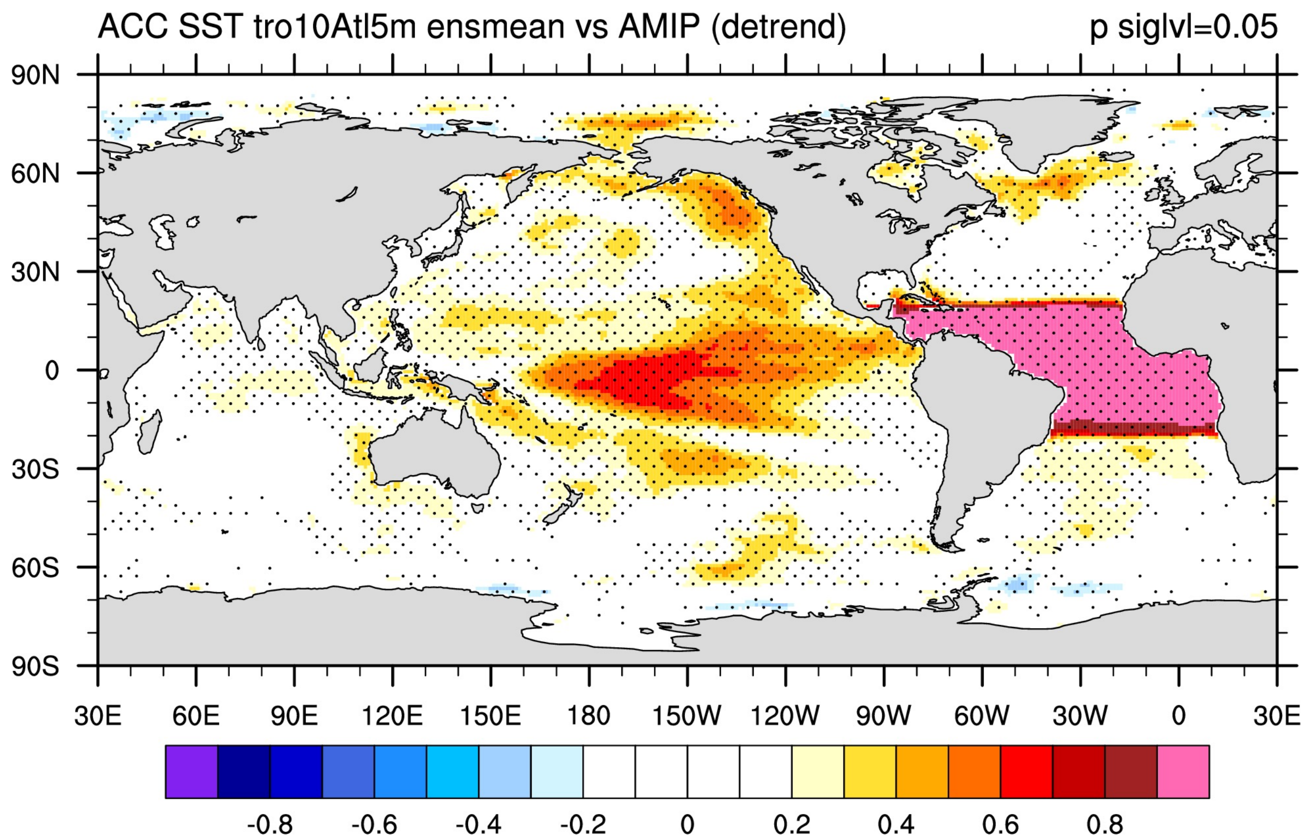


Figure 1 | Observed and simulated global temperature trends. Annual-mean time series based on observations, HIST and POGA-H (**a**) and on POGA-C (**b**). Anomalies are deviations from the 1980–1999 averages, except for HIST, for which the reference is the 1980–1999 average of POGA-H. SAT anomalies over the restoring region are plotted in **b**, with the axis on the right. Major volcanic eruptions are indicated in **a**. **c**, Trends of seasonal global temperature for 2002–2012 in observations and POGA-H. Shading represents 95% confidence interval of ensemble means. Bars on the right of **a** show the ranges of ensemble spreads of the 2002–2012 averages.

Example 2: Influence of Atlantic Ocean on ENSO (slides from Keenlyside et al.)

Tropical Atlantic SST restoring, 1980-2020

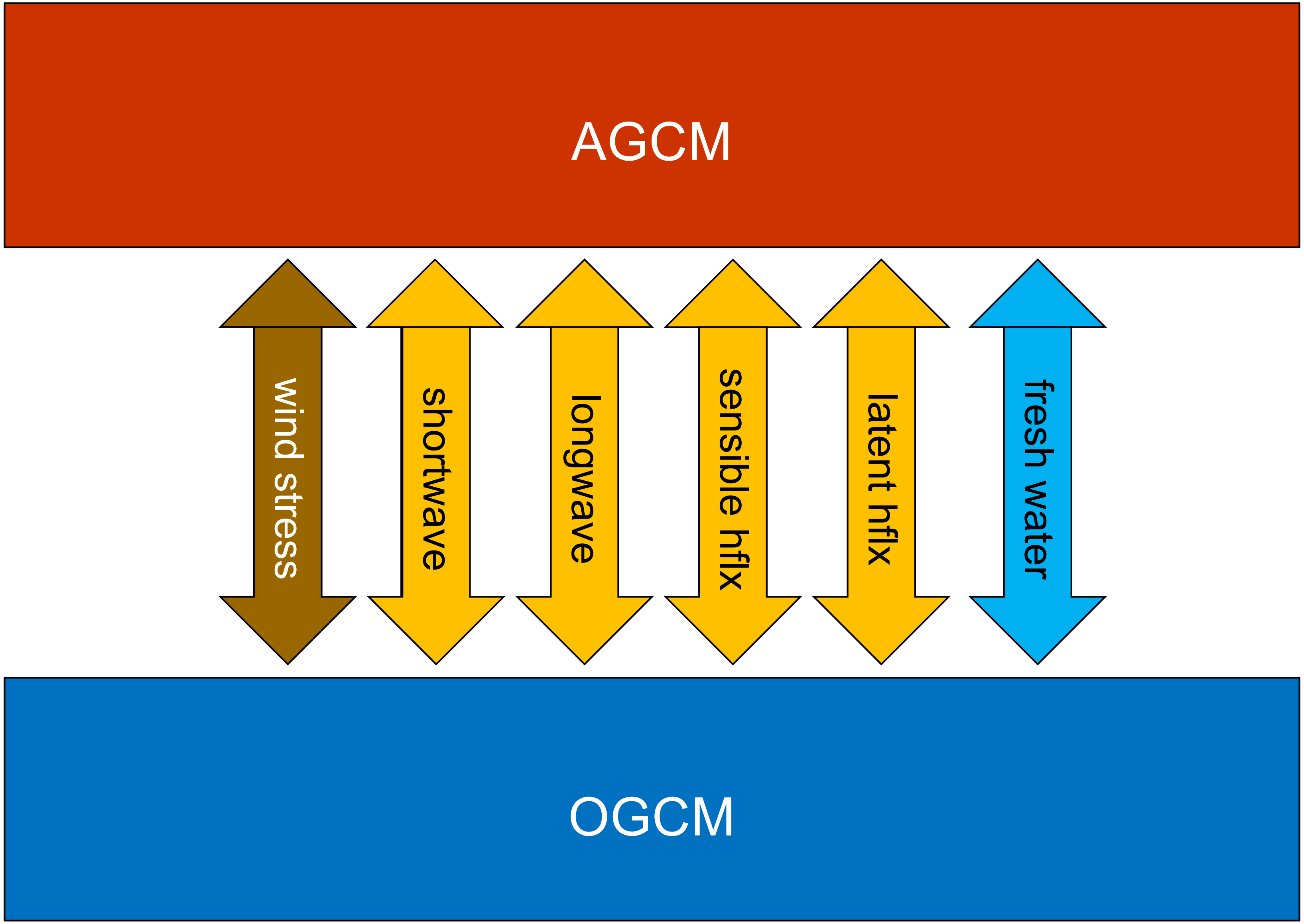
Anomaly correlation between 20 member ensemble mean and observations



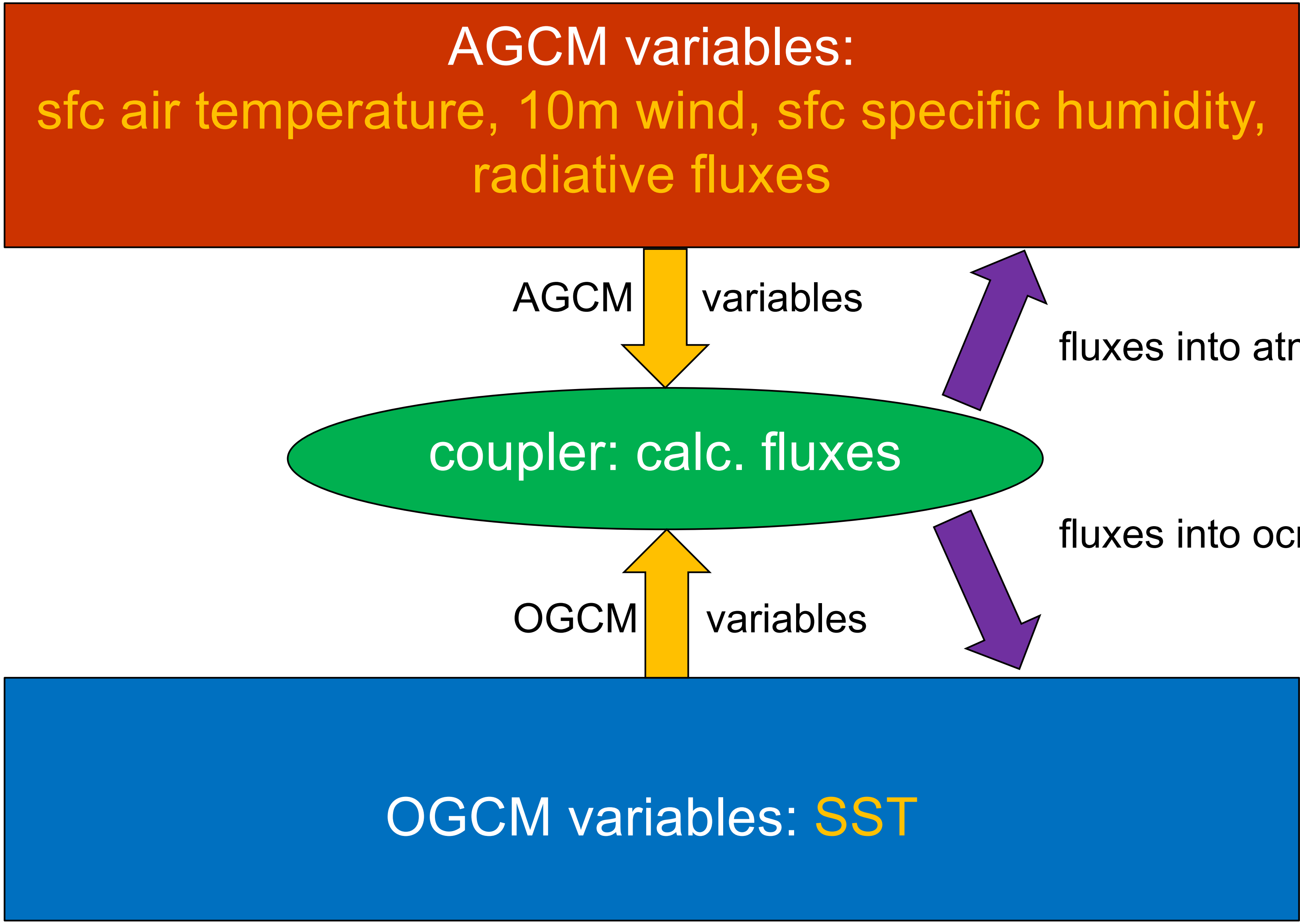
Ping-Gin Chiu

Methodology

Flux exchange between atmosphere and ocean



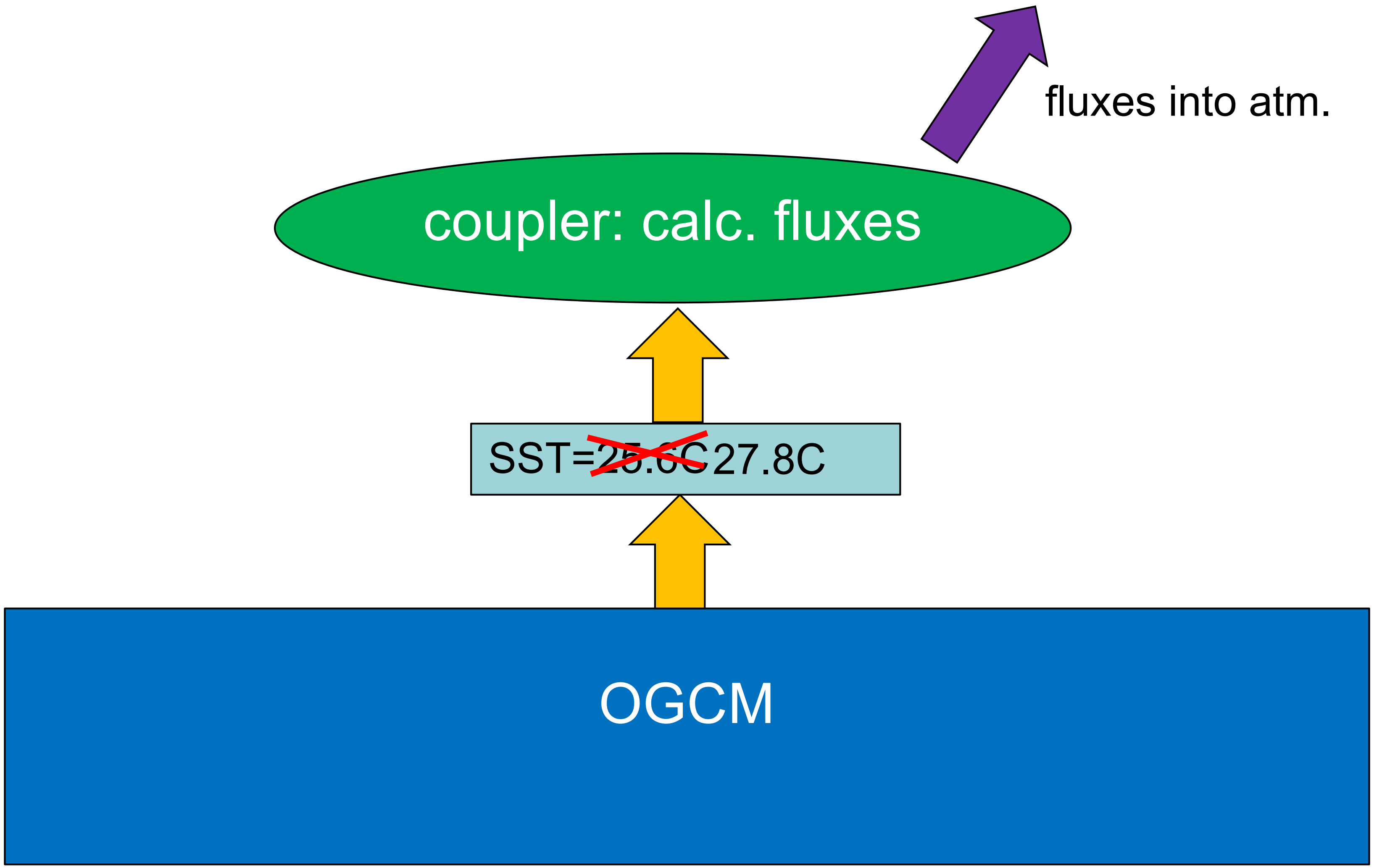
Flux exchange between atmosphere and ocean



How do we force SSTs to follow observations?

- simple method: override OGCM-generated SST before sending to coupler
- SST seen by AGCM will follow the observations exactly, but
  - may lead to very unrealistic surface fluxes
  - SSTs seen by the AGCM and SSTs generated by the OGCM may evolve on different trajectories

Flux exchange between atmosphere and ocean



More common method

- modify flux into the ocean, e.g. sensible heat flux
- formula: $F = c_p * H/\tau * (T_t - T_m)$

c_p = specific heat of sea-water

H = 50m; representative ocean mixed-layer depth in the tropics

τ = restoring time scale (e.g. 10 days)

T_t = target SST

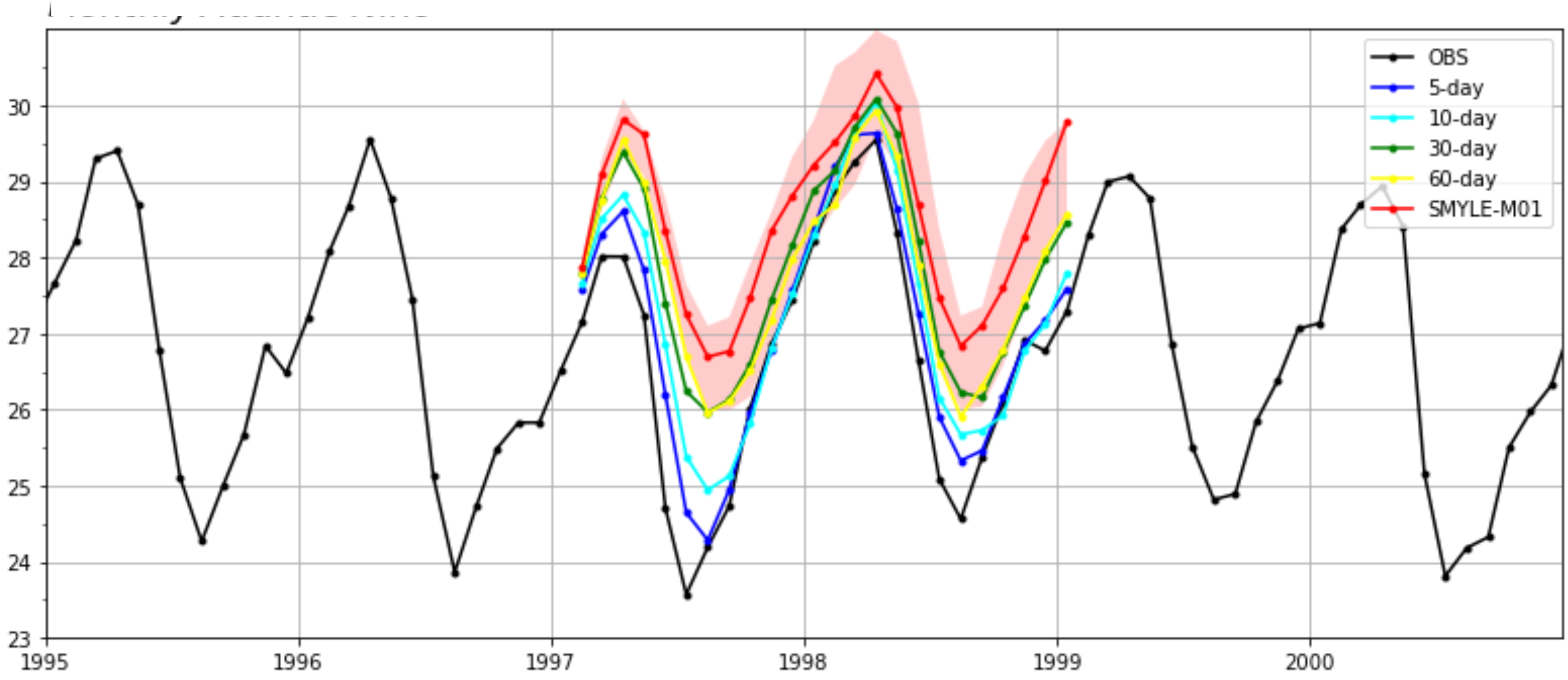
T_m = model-generated SST

Restoring time scale (τ)

- important consideration for pacemaker experiments
- small τ (e.g. 1d as in some SINTEX-F experiments): SSTs follow target very closely but
  - excessive restoring heat flux needed
  - “rigid” SST can lead to unrealistic atmospheric response
- large τ (e.g. 60d as in the DCPP Atlantic pacemakers): sfc fluxes are realistic but
  - SST may stray too far from the target
  - could invalidate reason for conducting pacemaker in the first place

Atlantic pacemaker experiment by Stephen Yeager (NCAR)

ATL3 SST



slide from Stephen Yeager

Historical pacemaker

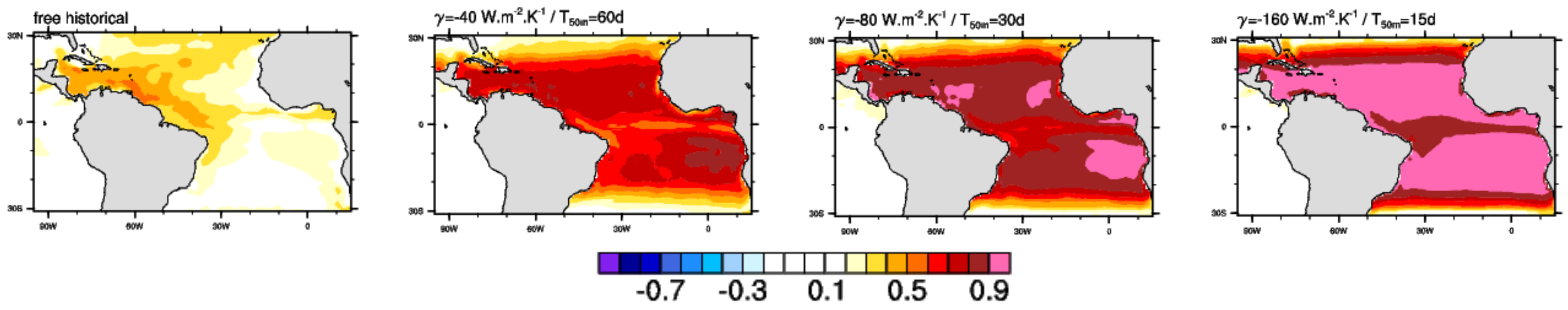
slide from Yohan Ruprich-Robert (BSC)

Historical pacemakers – tropical Atlantic

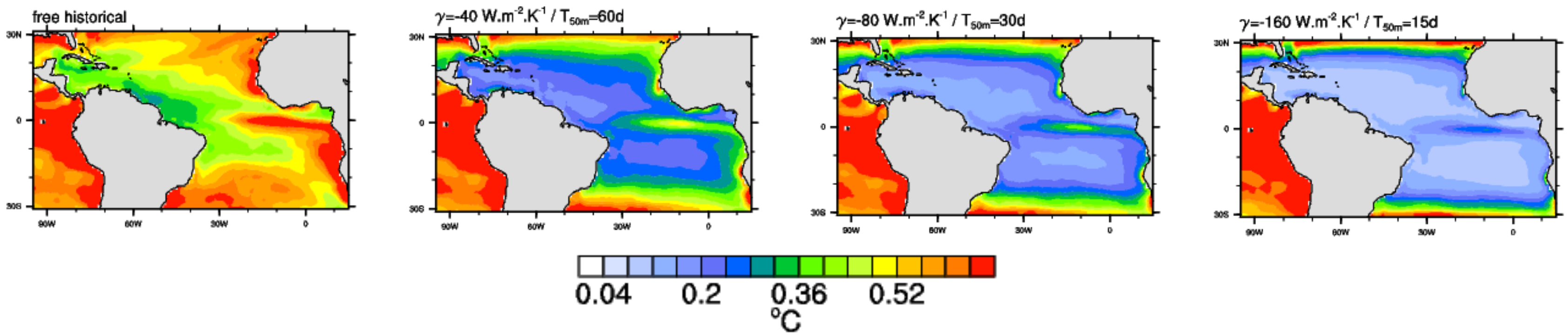
Comparison with SST target

Free historical	τ = 60 days	τ = 30 days	τ = 15 days
	Weak restoring	**Moderate restoring**	**Strong restoring**

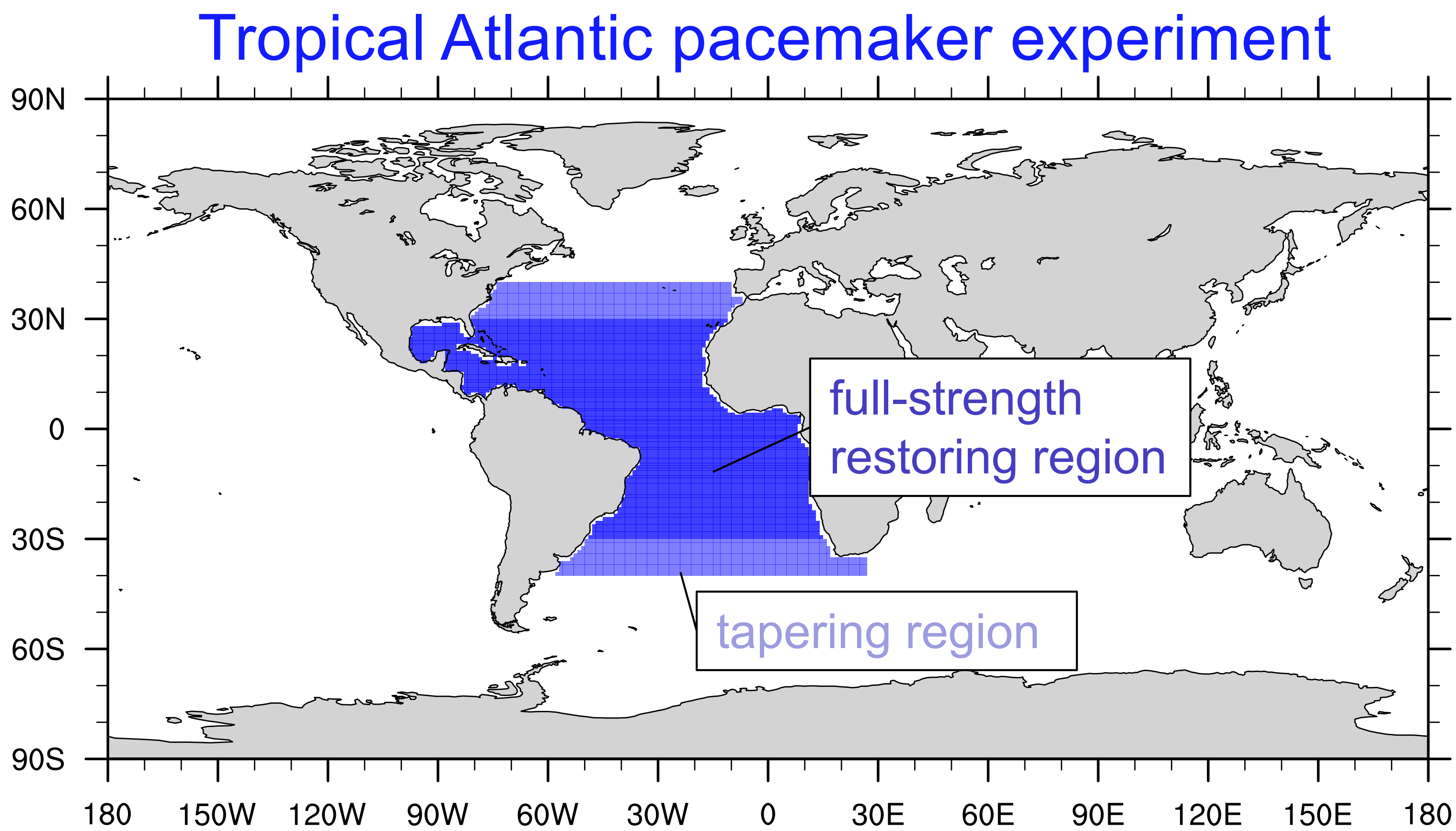
Correlation SST
with AMIP SST
Monthly data



RMSE SST
with AMIP SST
Monthly data



Would you like some tapering with that?



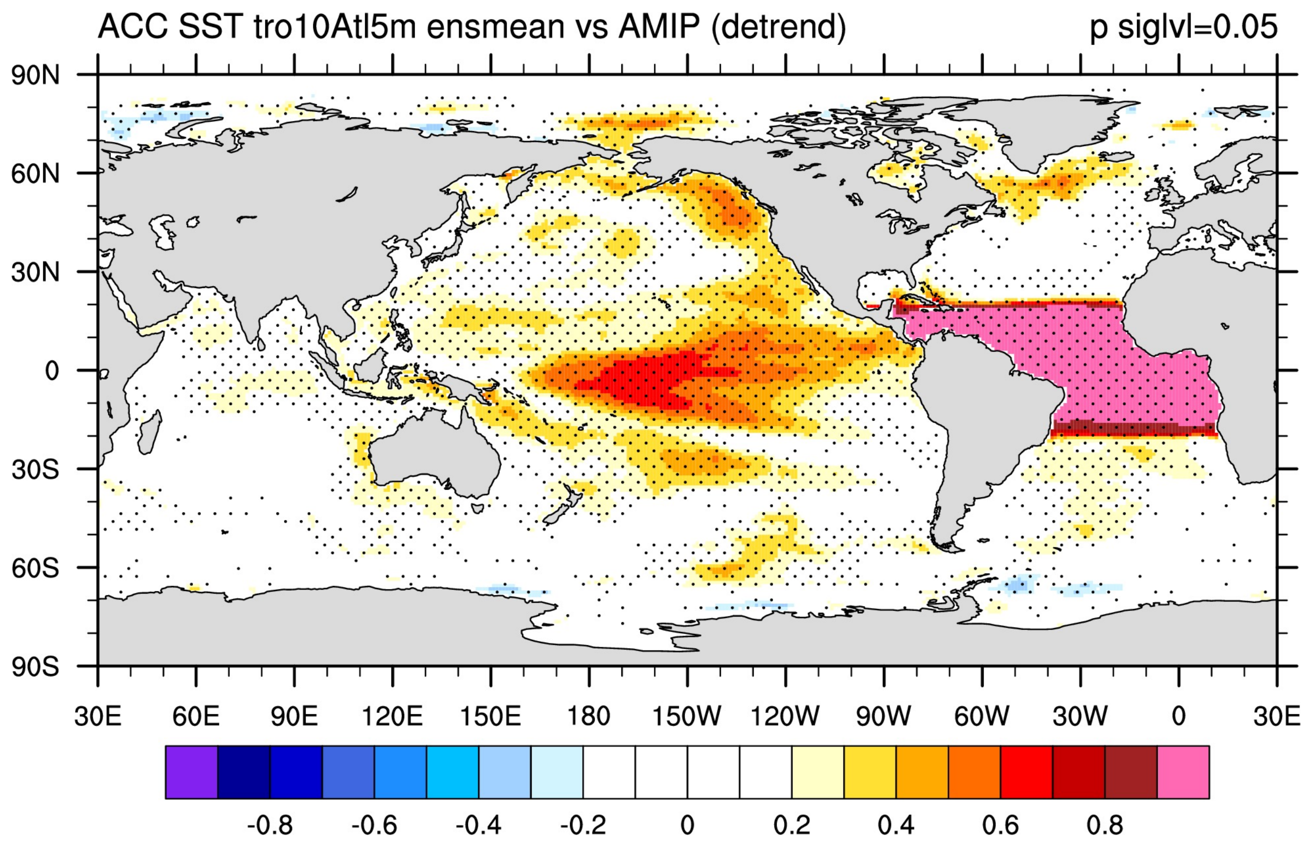
Would you like some tapering with that?

- edges of restoring regions are often subject to sharp SST gradients
- -> negative impacts on the experiments
- use tapering to avoid this problem
- α is the tapering coefficient
- $F = F_m * (1 - \alpha) + \alpha c_p H/\tau * (T_t - T_m)$

Example 2: Influence of Atlantic Ocean on ENSO (slides from Keenlyside et al.)

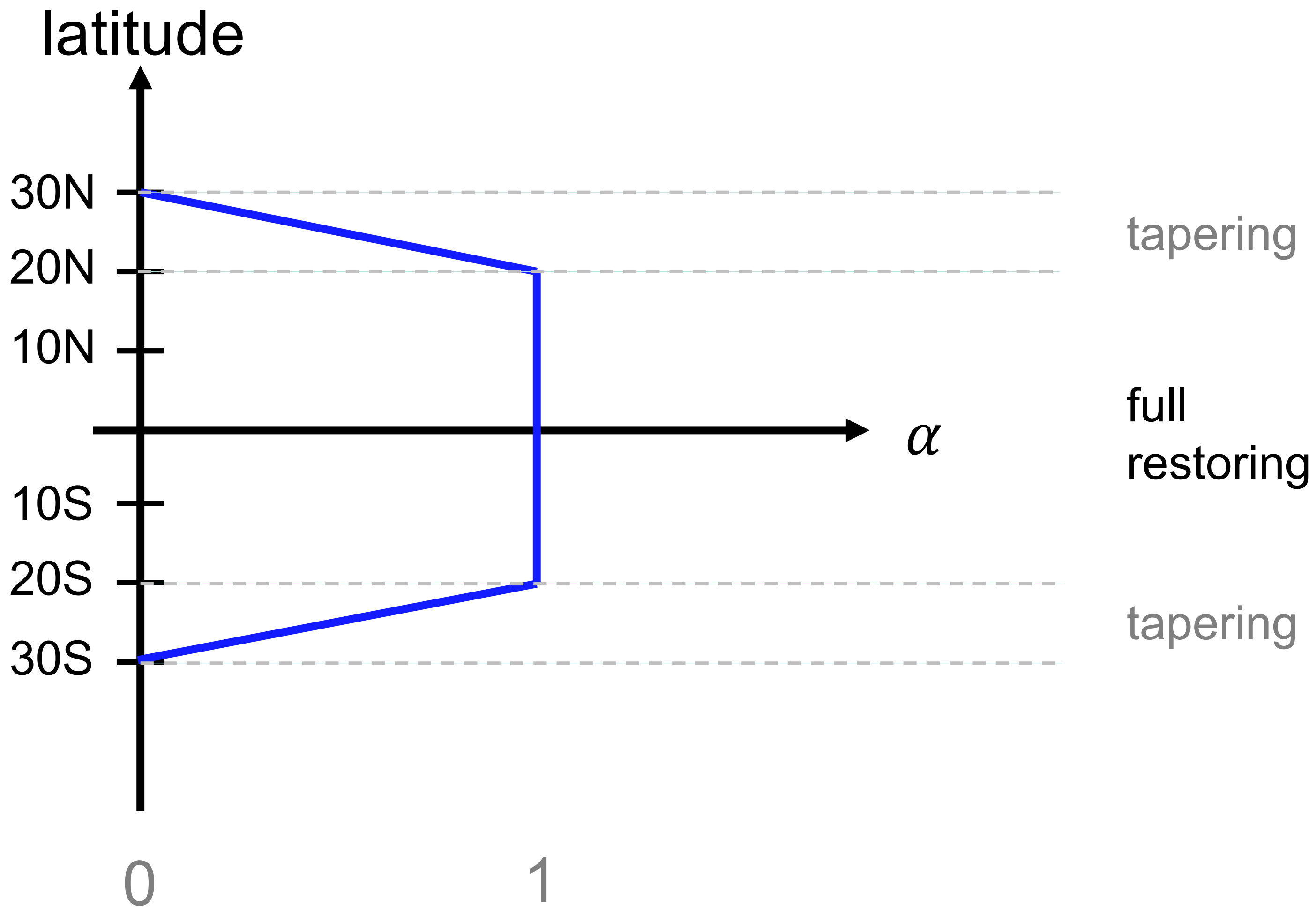
Experiments can constrain tropical Pacific SST

Anomaly correlation between 20 member ensemble mean and observations



Ping-Gin Chiu

Would you like some tapering with that?



At what latitude do we stop?

- influence of SST on atmospheric circulation is strongest in the deep tropics
  -> deep convection -> sfc wind anomalies…
- outside the deep tropics, it is often the atmosphere that forces the ocean
  -> latent heat flux anomalies, radiative flux

➢ restoring outside the deep tropics may lead to unrealistic results

Unrealistic fluxes outside deep tropics

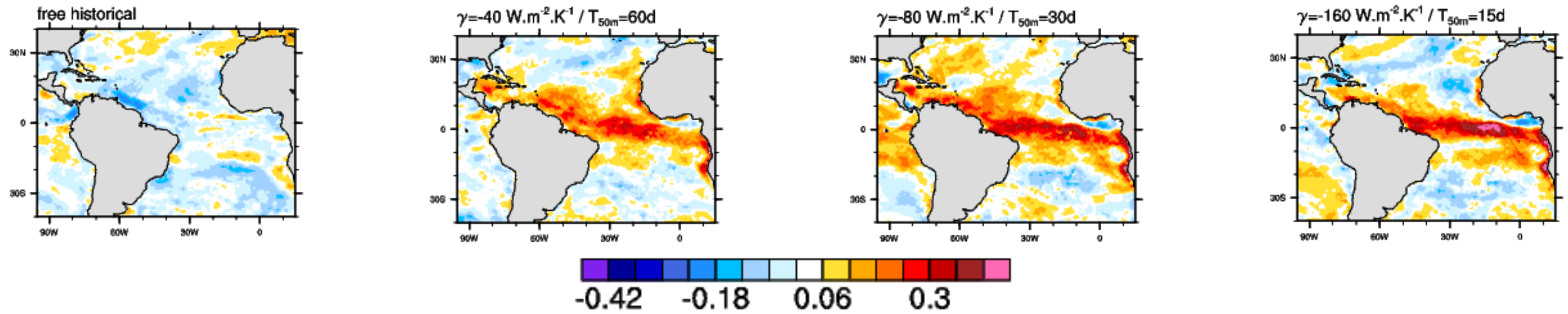
slide from Yohan Ruprich-Robert (BSC)

Historical pacemakers – tropical Atlantic

Comparison with "observed" surf. HF

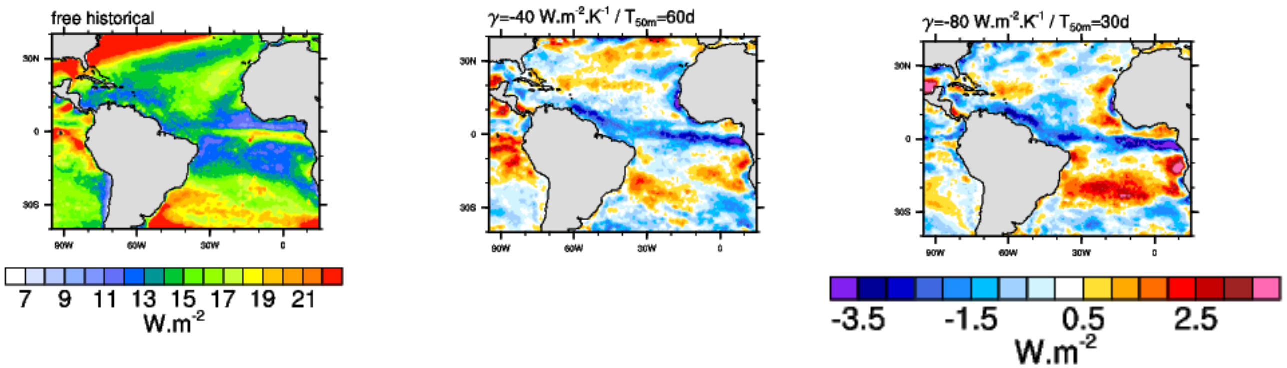
Free historical | **Weak restoring** | **Moderate restoring** | **Strong restoring**

Correlation SHF with **ERA5** SHF **3m Run.Mean**



Difference with historical RMSE

RMSE SHF with **ERA5** SHF **3m Run.Mean**



3 month Running Mean was applied

Unrealistic fluxes outside deep tropics

slide from Yohan Ruprich-Robert (BSC)

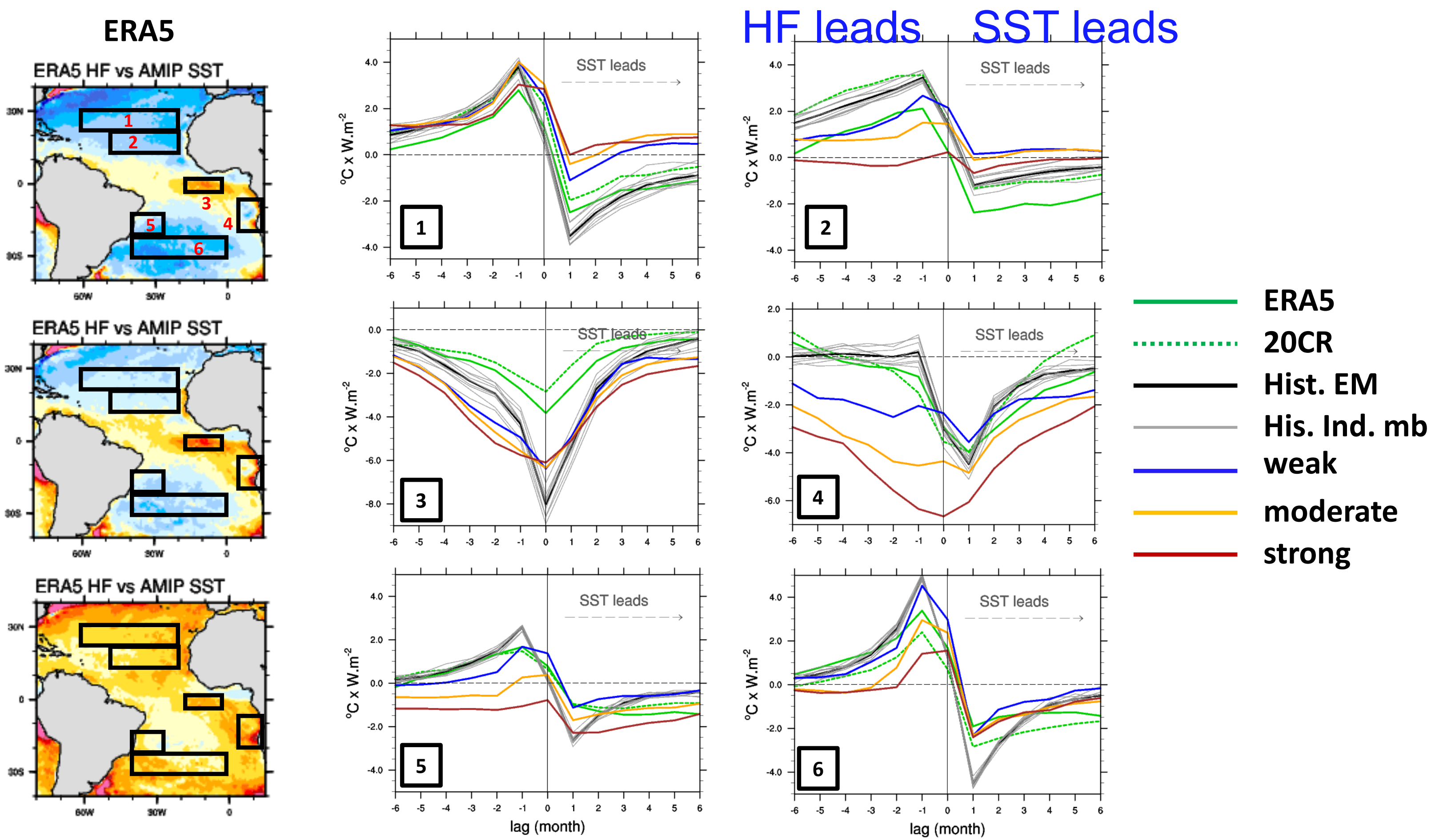
Historical pacemakers – tropical Atlantic

Covariance SST – surf. HF

HF leads by 1 month

In phase

SST leads by 1 month



N.B.: Covariance computed from each month separately then averaged over all months

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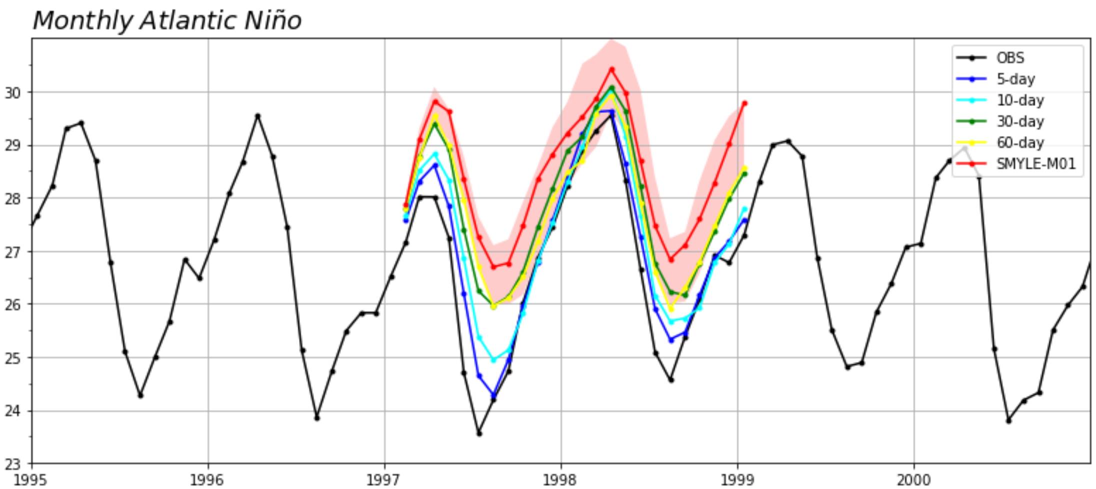
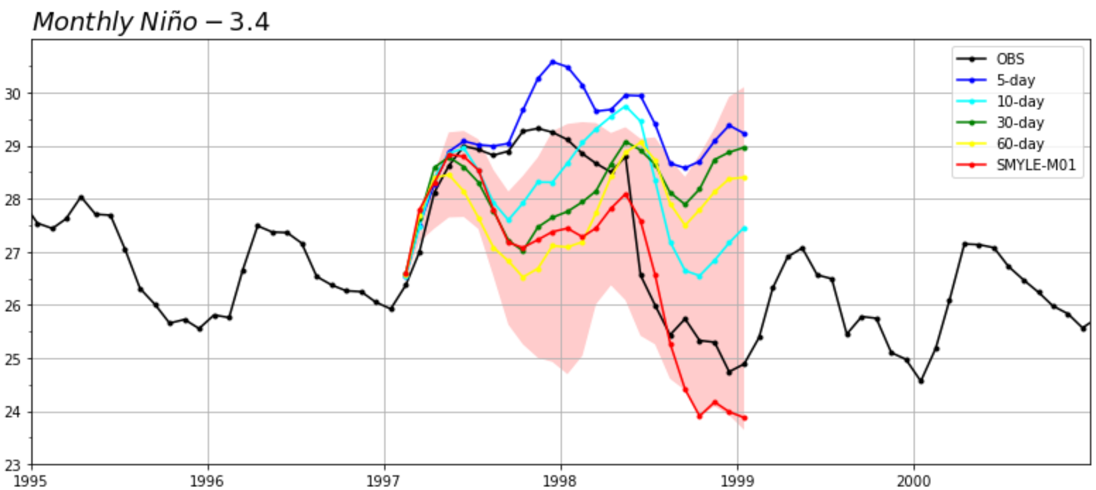


Niño 3.4 SST



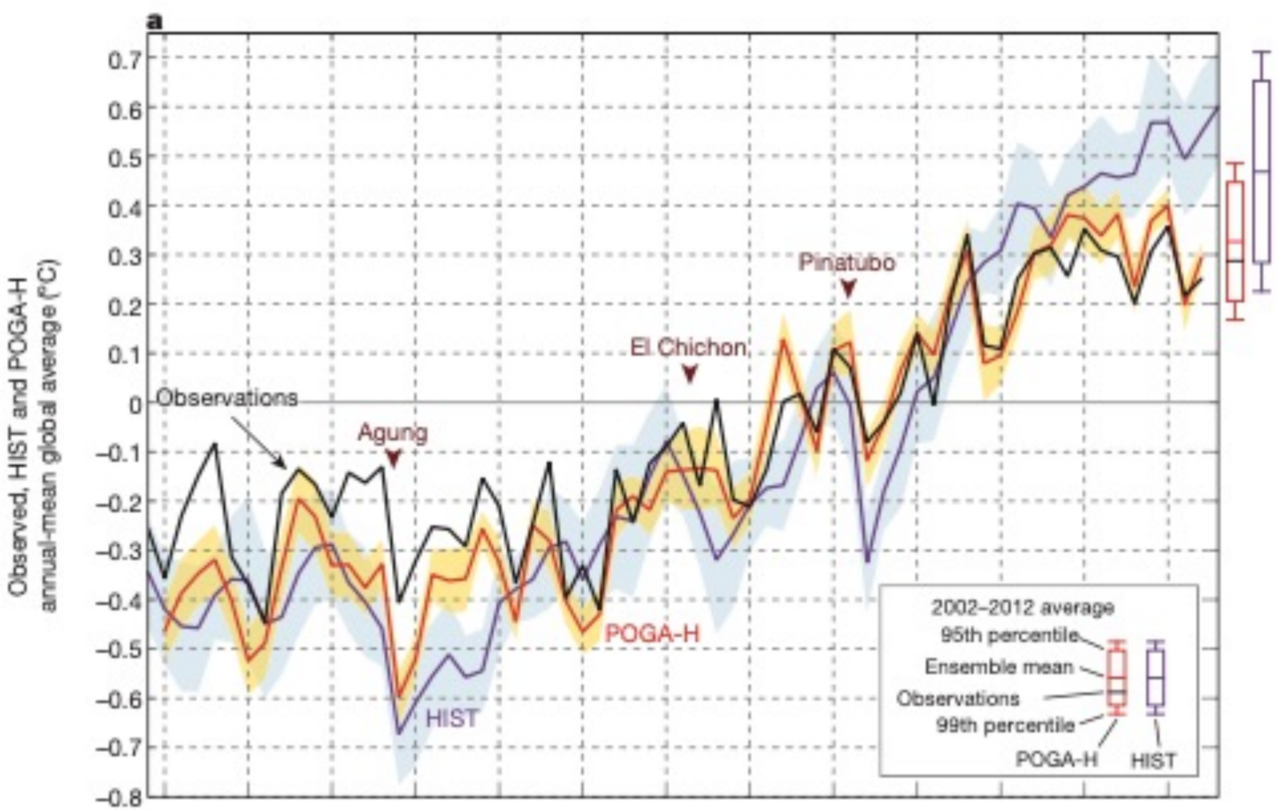
-> strong restoring substantially alters Pacific climatological SST

slide from Stephen Yeager

Standard pacemaker vs. pacemaker hindcast

- standard pacemaker
  - continuous long-term simulation with SST restoring (e.g. 1870-2019)
  - often with historical radiative forcing
  - question: How well do SSTs in other basins follow observations? Understanding the physical mechanisms of TBI.
- pacemaker hindcast
  - hindcast (aka reforecast) with regional SST restoring
  - series of short-term (e.g. 1 yr) simulations (predictions)
  - e.g. initialize in 1980/01, 1980/04, …, 2019/10
  - question: What implications does TBI have for predictability? Quantitative measure of TBI.

Standard pacemaker example



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Kosaka and Xie (2013)

Pacemaker hindcast example

Article | Open Access | Published: 12 March 2021

Impact of equatorial Atlantic variability on ENSO predictive skill

Eleftheria Exarchou, Pablo Ortega, Belén Rodríguez-Fonseca, Teresa Losada, Irene Polo & Chloé Prodhomme

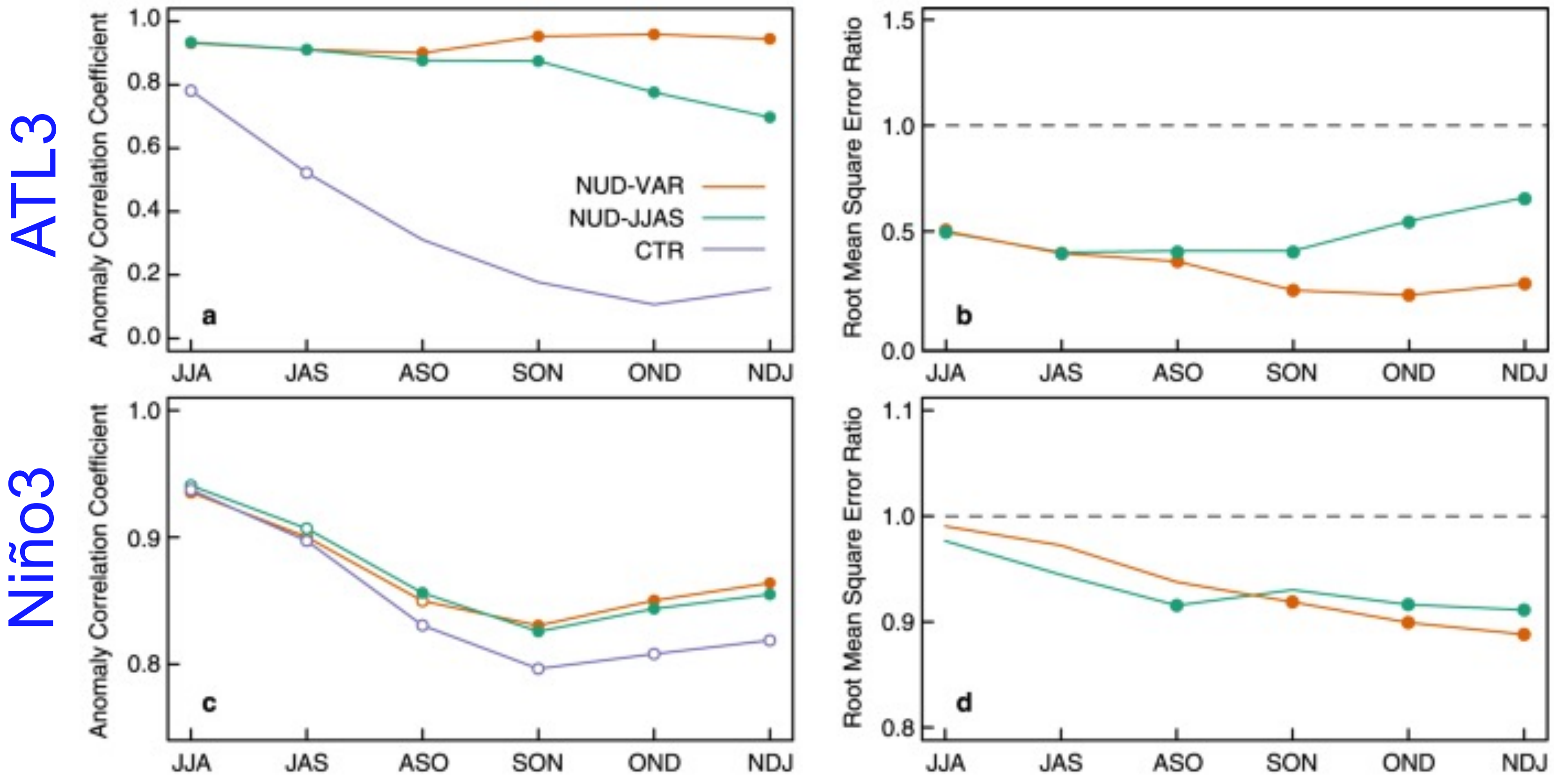
Nature Communications **12**, Article number: 1612 (2021) | Cite this article

Exarchou et al. (2021)

Pacemaker hindcast example

SST restored to observations in the tropical Atlantic

correlation skill in the equatorial Atlantic and Pacific



Exarchou et al. (2021)

The pacemaker experiments coordinated by the Research Focus on Tropical Basin Interaction

Motivation

- many pacemaker experiments exist but protocols differ (restoring width, restoring strength, tapering, target SST etc.)
- each model has its own systematic errors

→ conduct multi-model coordinated experiments with consistent protocol

→ examine influence of model errors

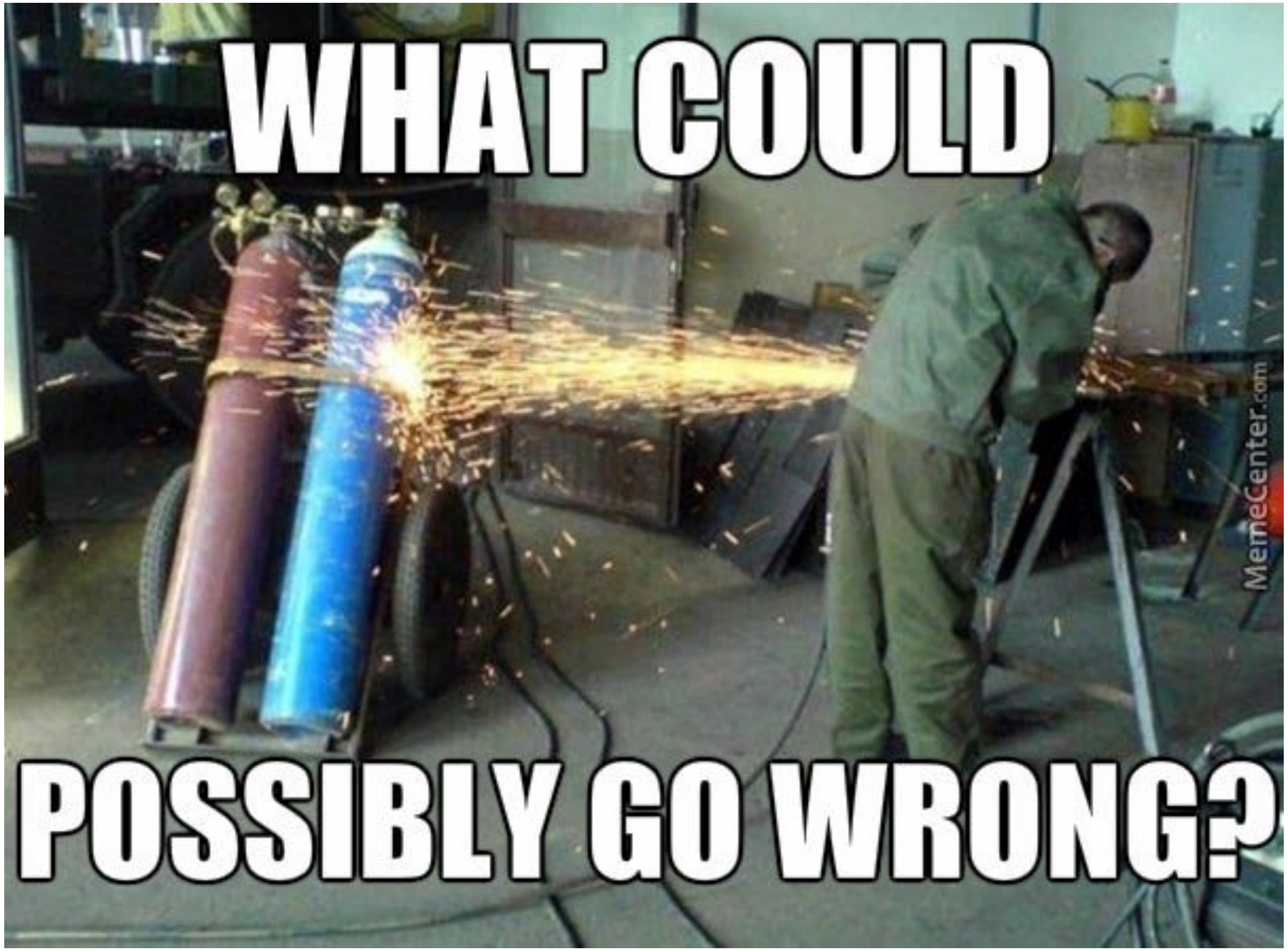
→ assess robustness of results

Current status

- test runs have been performed
- experiment design finalized (fingers crossed)
- production runs starting
- aim to store data on the Earth System Grid Federation (CMIP6Plus)
- data will be made available to the public

CoEx telecon on May 18, 2023

Drawbacks of pacemaker experiments


WHAT COULD
POSSIBLY GO WRONG?
MemeCenter.com

What could possibly go wrong?

1) SST restoring creates infinite heat source
2) intervention crucially disturbs model dynamics (e.g. mean state changes)
3) models do not represent TBI well enough to tell us anything
4) interpretation is difficult; e.g. the tropical Atlantic SST pattern we describe may itself have been generated by the tropical Pacific

Alternative approaches

Are there less invasive alternatives?

- given the inherent shortcomings of pacemaker experiments it is a good idea to supplement their results with alternative approaches
- some examples:
  - linear inverse models
  - composite analysis
  - other statistical tools

Final remarks

- pacemaker experiments aim to increase our understanding of how SSTs in one region can influence other regions
- these experiments are a useful tool but also have their shortcomings
- it is important to critically evaluate the results from such experiments, and to augment them with complimentary analysis (multiple lines of evidence)

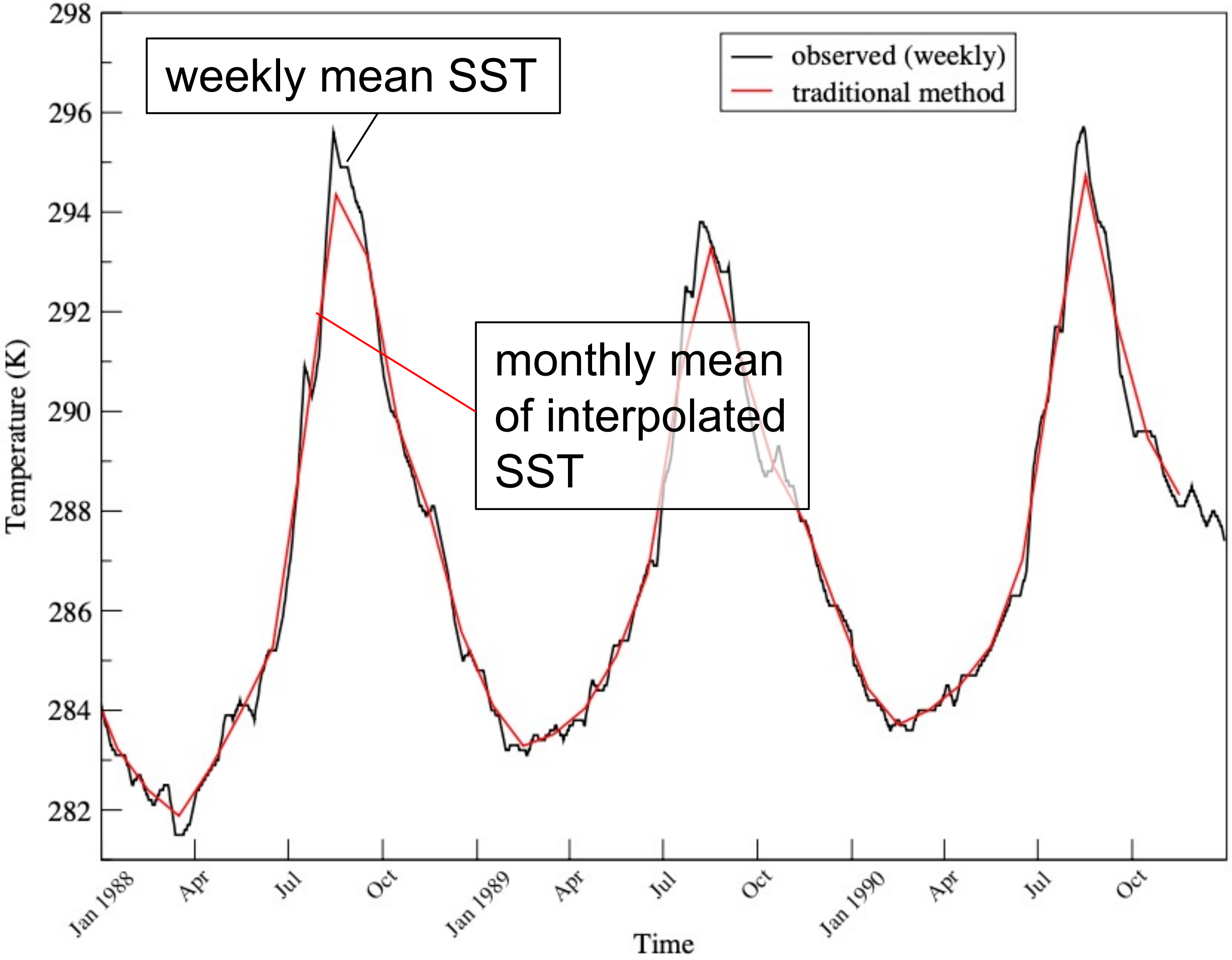
Additional topics

Time interpolation and damped variability issue

- target SST usually supplied as monthly means but model needs SST at each coupling time step (e.g. 1-hr intervals)
- -> interpolate from monthly values to coupling time step
- -> leads to loss of variability
- -> calculating monthly means over these boundary conditions does not reproduce the original montly mean SST
- this issue can be countered through “inflation” of the boundary condition SST

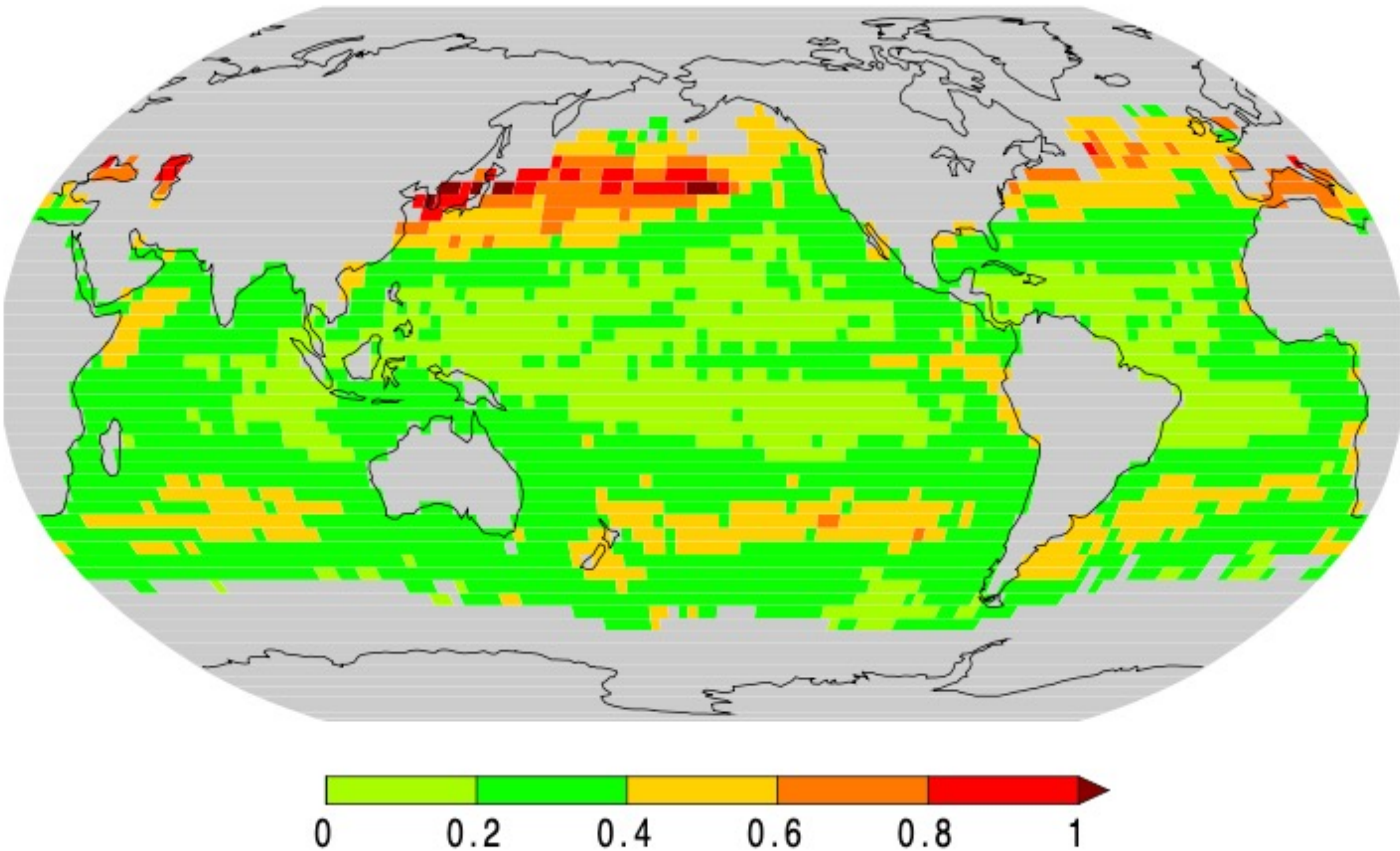
Damped variability

Observed weekly temperature near 180W 40N



from https://pcmdi.llnl.gov/report/pdf/60.pdf

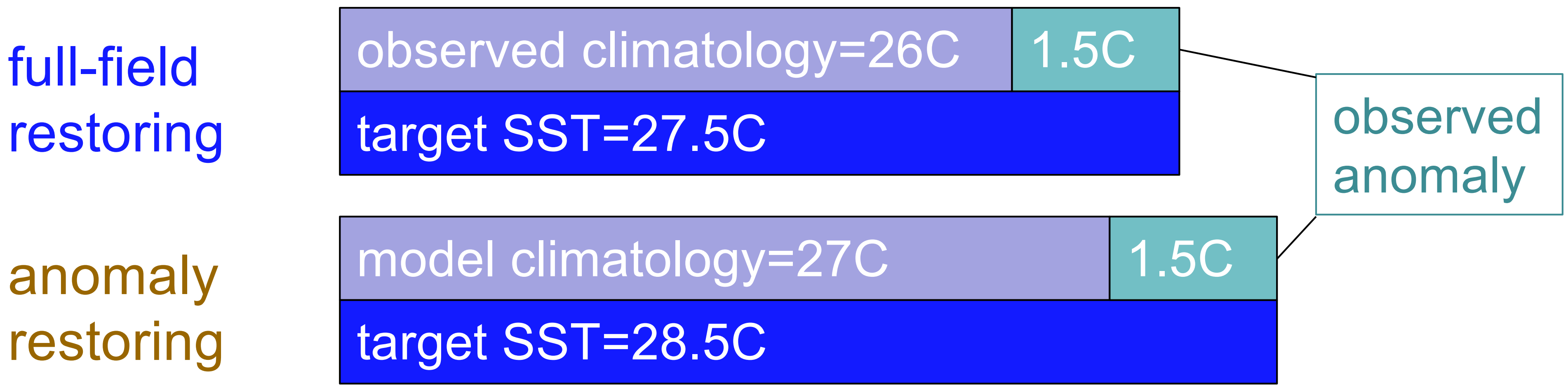
Maximum positive discrepancy (K)



from https://pcmdi.llnl.gov/report/pdf/60.pdf

Full-field or anomaly restoring?

- full-field restoring
  target SST are the observations
- anomaly restoring
  target SST is constructed as model climatology + observed anomalies



Pros and cons

full-field restoring

+ realistic SST
+ in multi-model experiments: comparability
- mismatch between climate in restoring basin and other basins
- model mean state may change

anomaly restoring

+ climatology remains unchanged
+ no drift
- model dependence of results
- mean state in restoring basin may be unrealistic