Recent global temperature trends: What do they tell us about anthropogenic climate change?

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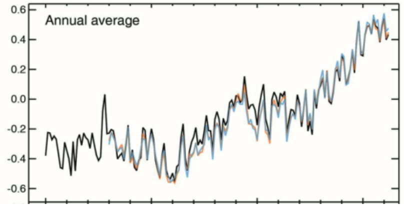
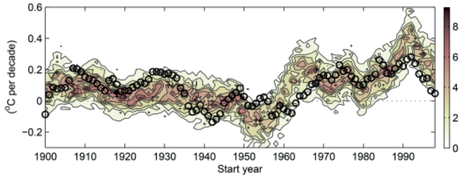
Outline

1. Observed global climate change



2. Climate variability and the surface-warming hiatus



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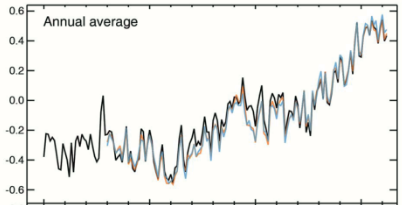
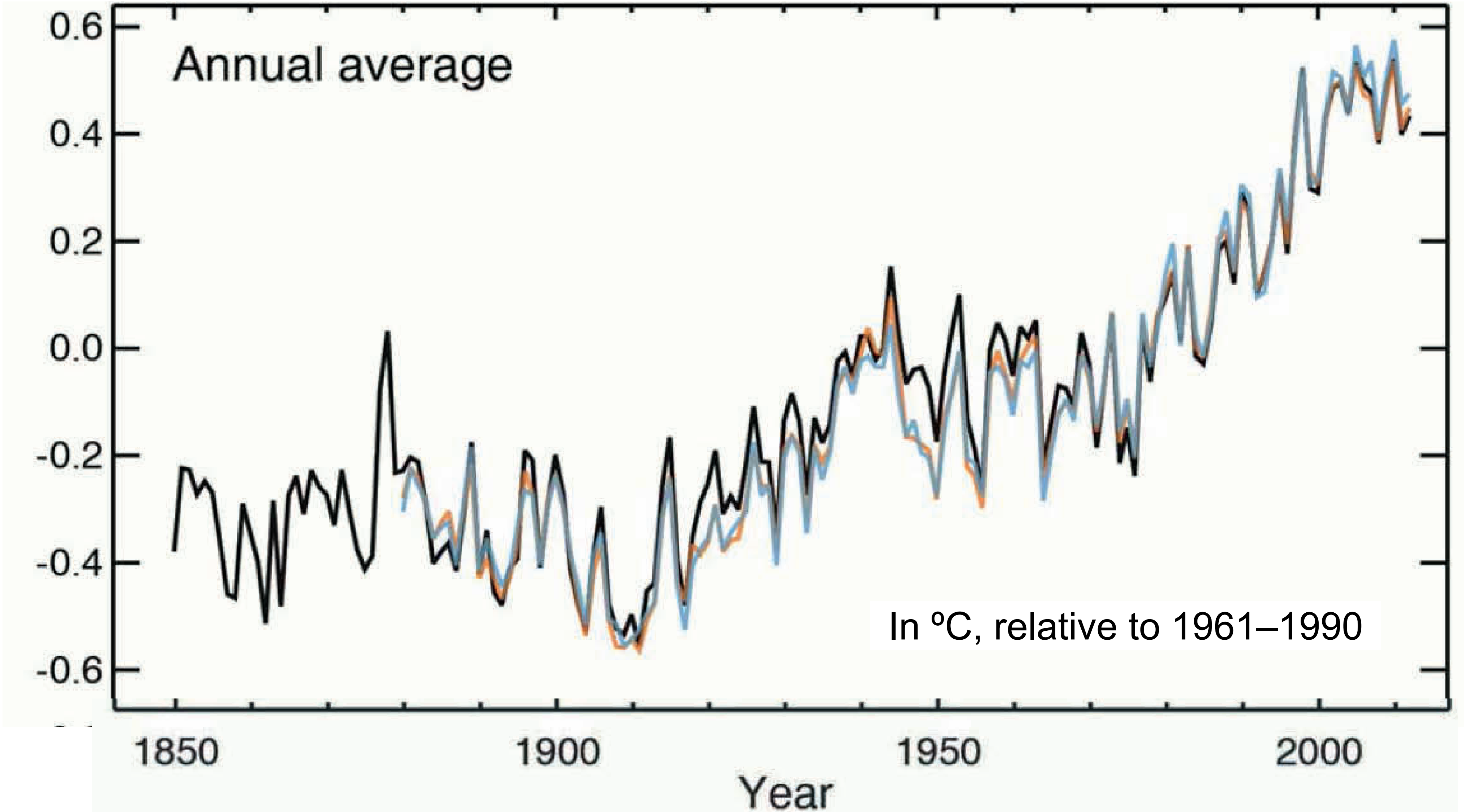
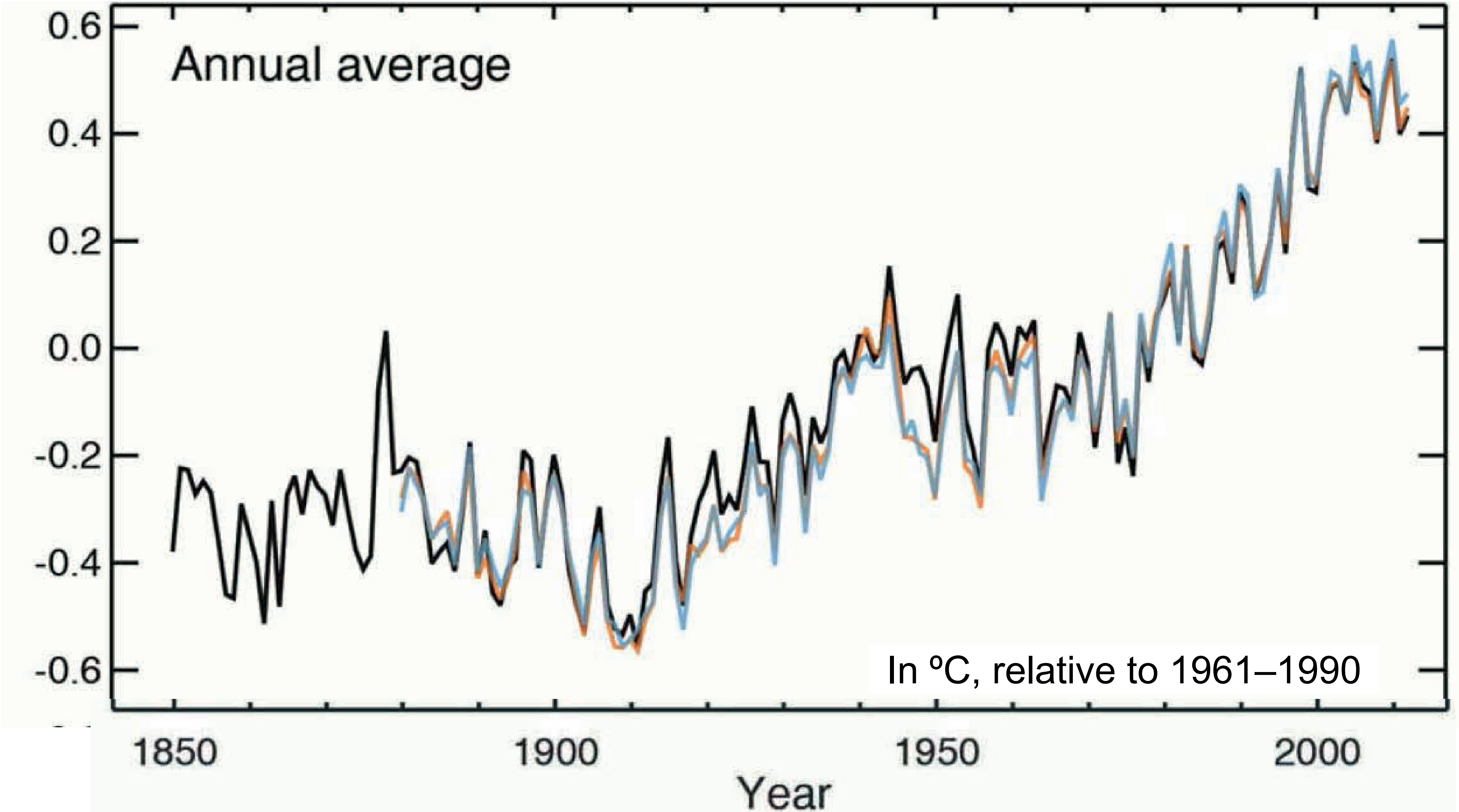


2. Climate variability and the surface-warming hiatus

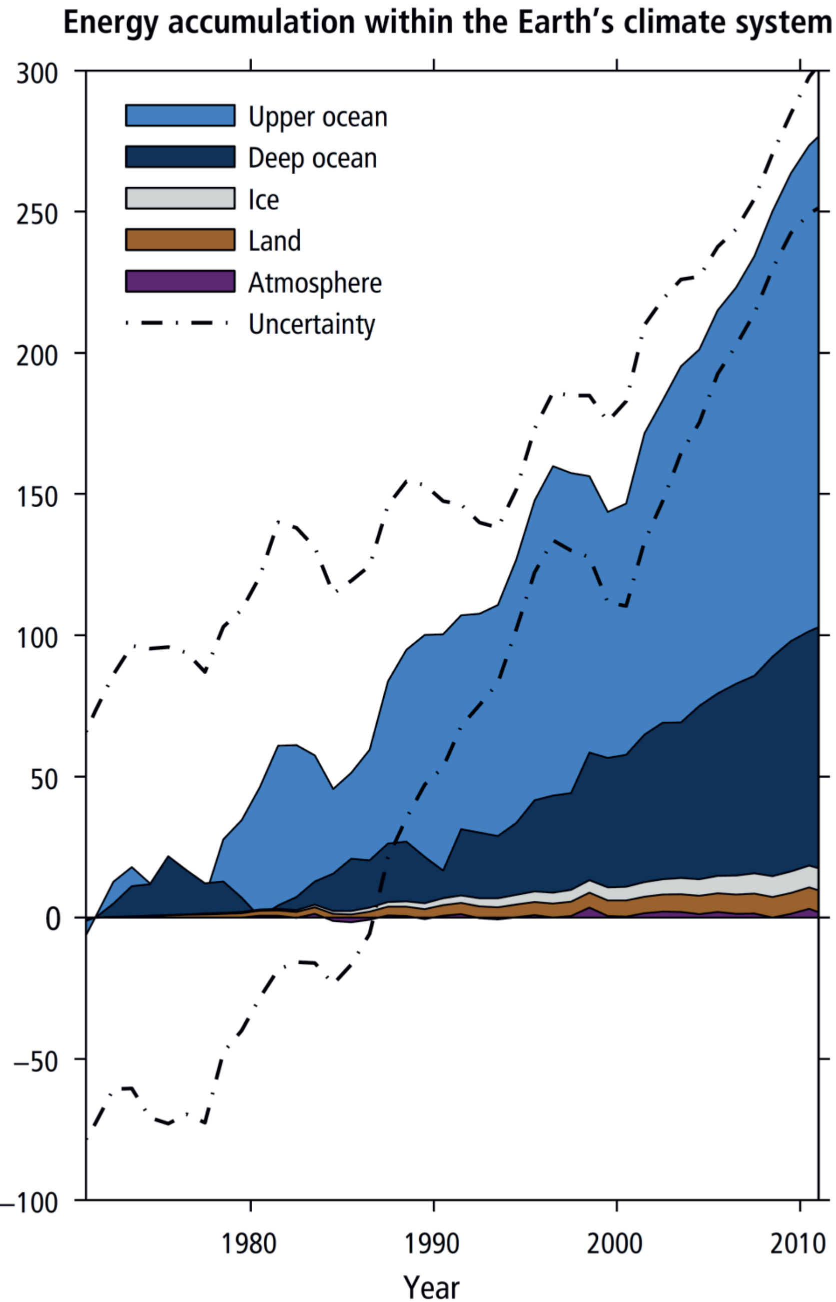
Observed global-mean surface temperature (GMST) since 1850 shows long-term warming trend, overlaid by fluctuations



IPCC 2013: Most of the warming since 1950 was caused by humans



How do we know? Many arguments; now the most fundamental



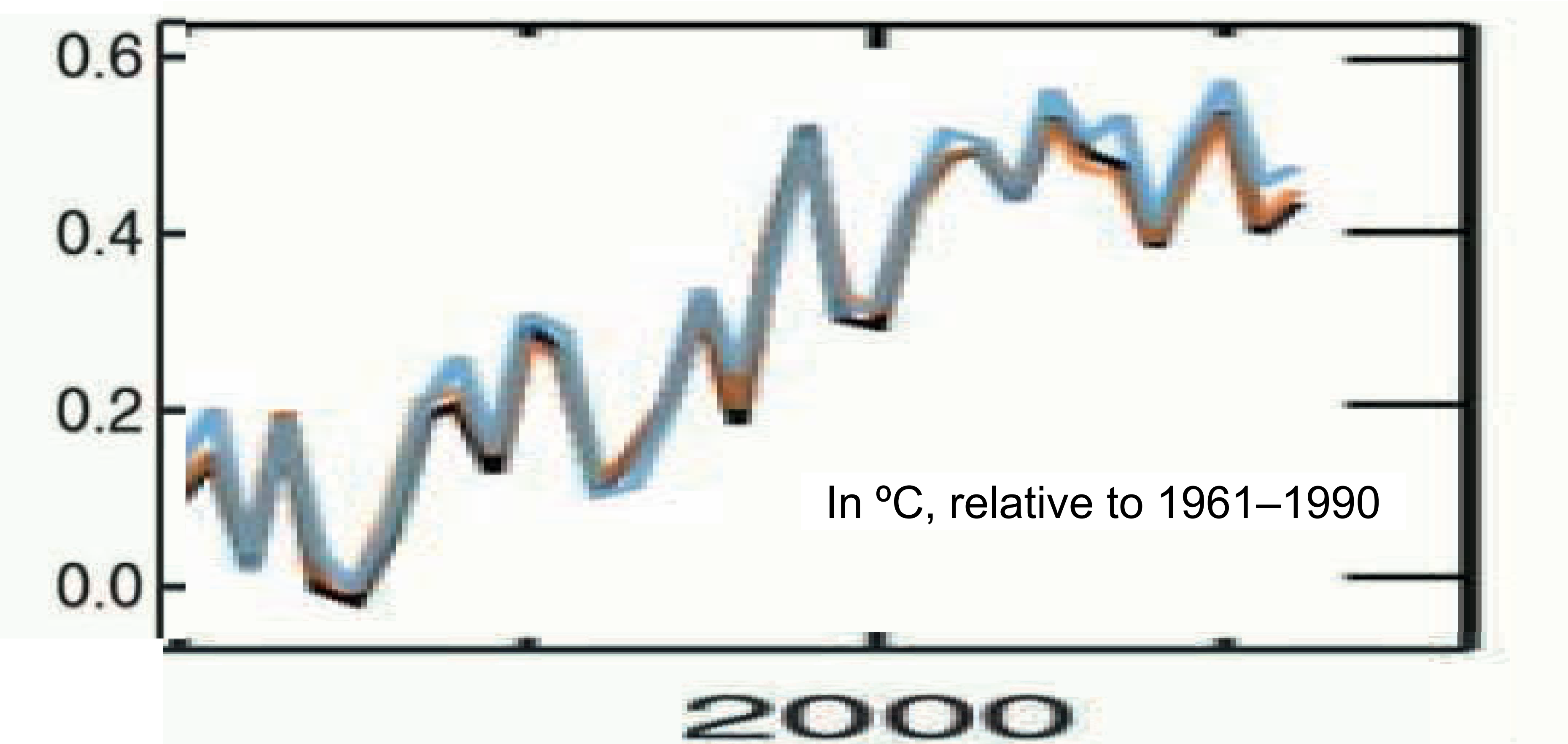
We find the energy imbalance that is caused by the anthropogenic increase in greenhouse-gas (minus aerosol) concentrations

We can observe the energy accumulation in the climate system, mostly in the increase of the ocean heat content!

Ocean accounts for 93% of the increase in heat content since 1970.

IPCC AR5 Synthesis Report, Figure 1.2; based on WG1 Box 3.1 Figure 1

Observed global-mean surface temperature appears to have reached a plateau over the past 10–15 years (“warming hiatus”)



Such hiatus periods are common in the record, and yet this last one has sparked enormous debate.

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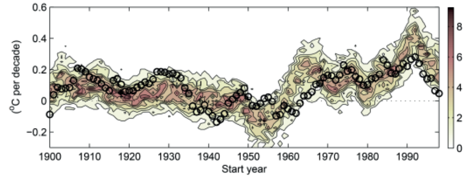
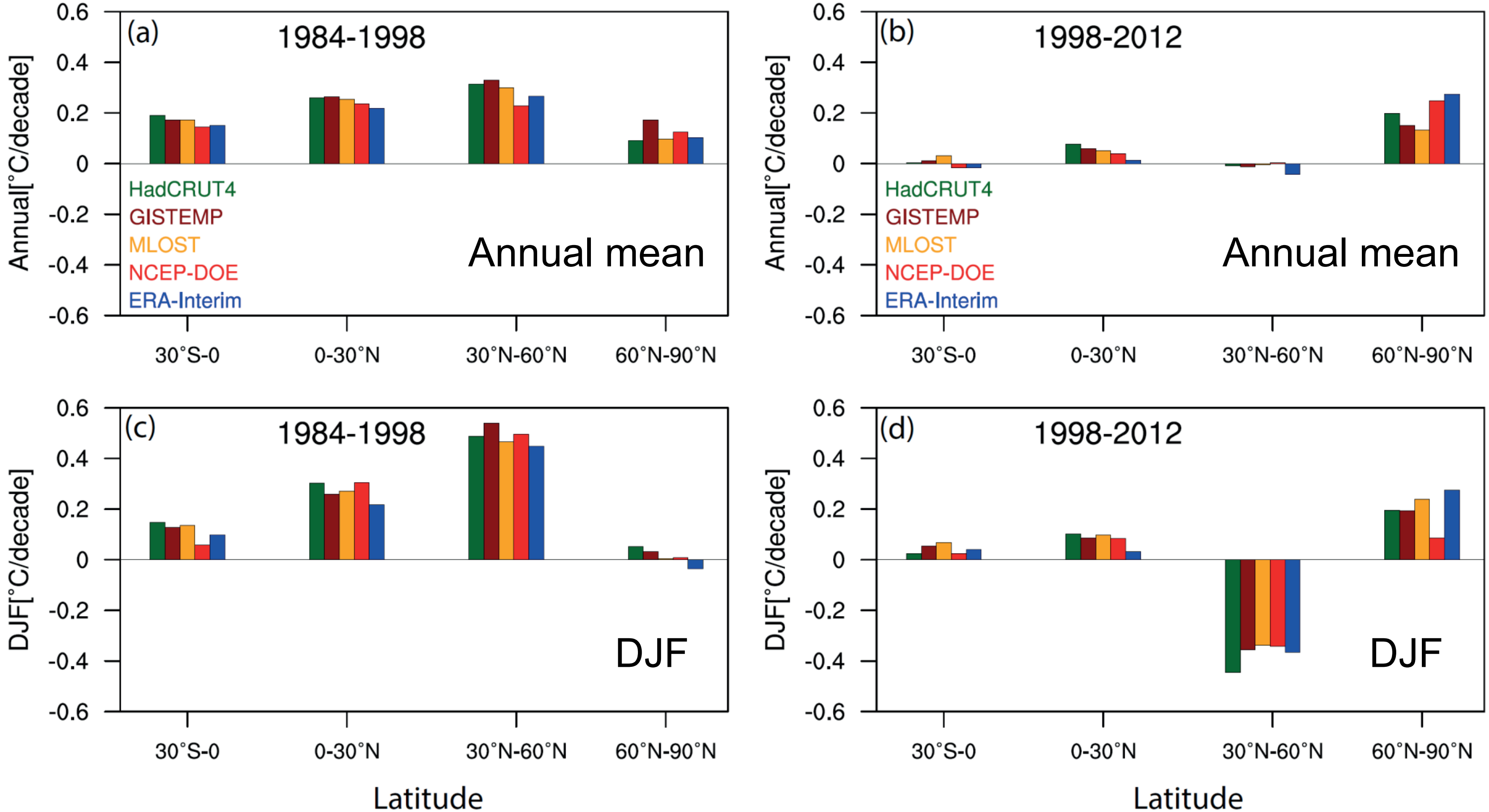
2. Climate variability and the surface-warming hiatus



Hiatus poses fascinating challenges to scientific community (1)

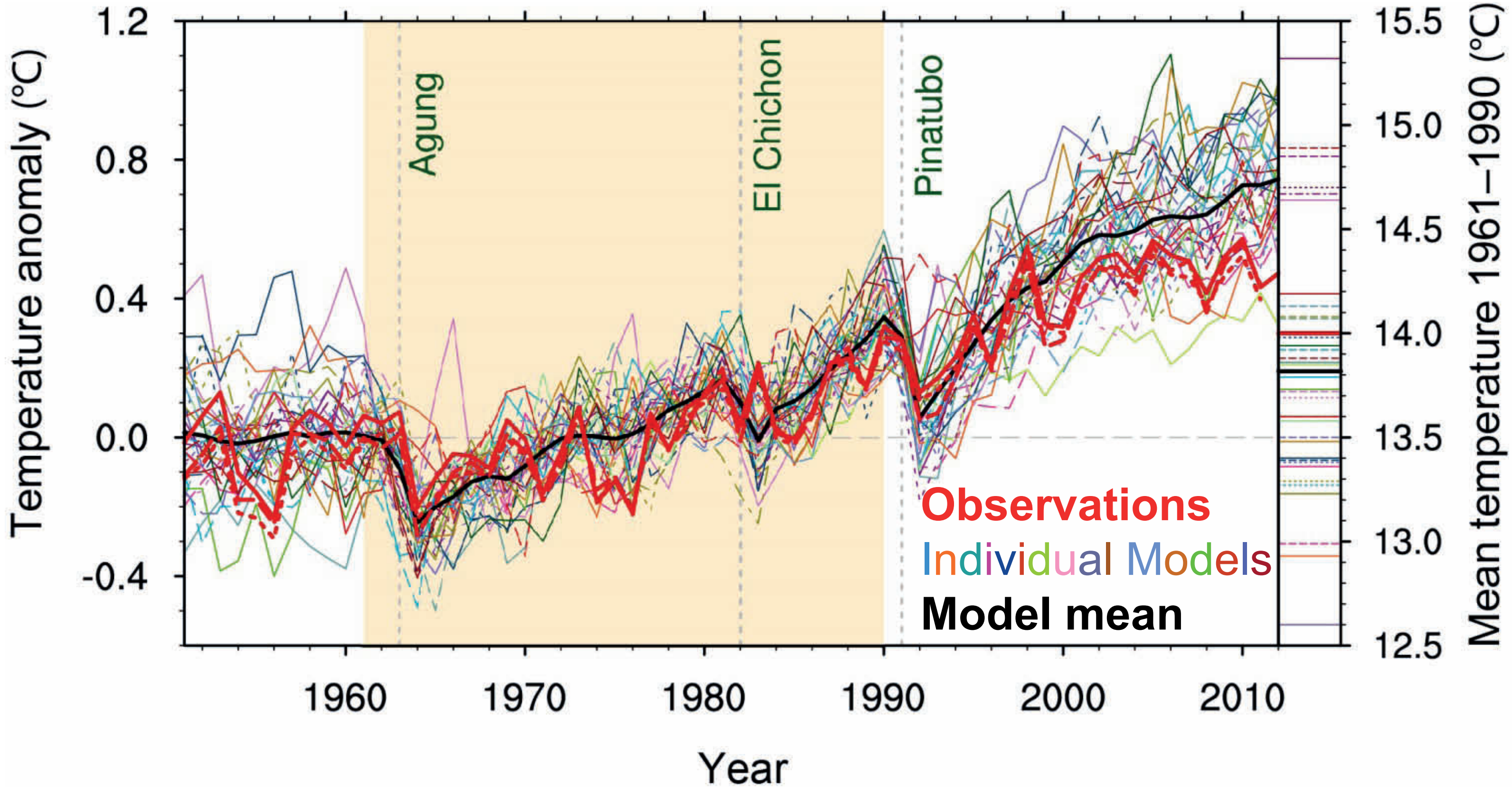
- Possible causes: forcing
  - Stratospheric/volcanic aerosol, Solomon et al. (2011), Santer et al. (2014)
  - Downward phase of solar cycle, Kaufmann et al. (2011)
- Possible causes: internal variability
  - Increased subsurface-ocean heat uptake in Pacific (e.g., Meehl et al. 2011, Guemas et al. 2013, Balmaseda et al. 2013, Watanabe et al. 2013, Trenberth and Fasullo 2013), or Atlantic (Chen and Tung 2014), or Indian (Lee et al. 2015)
  - Low sea surface temperature in tropical eastern Pacific, Kosaka and Xie (2013), England et al. (2014)
- Focus has been on the tropical Pacific, but during hiatus there was a strong winter cooling trend over Eurasia (Cohen et al. 2012) – not reproduced in simulations of Kosaka and Xie (2013)
- Moreover: suggestions that hiatus is an artifact of missing Arctic data (Cowtan and Way 2013) or ocean data biases (Karl et al. 2015)
- Here: Contributions to hiatus from different latitude bands?

GMST trend reduction over 1998–2012 compared to 1984–1998 in annual mean at all latitudes north of 30°S except Arctic, in all datasets. Most pronounced in DJF between 30°N and 60°N.



Trends scaled by area; directly comparable in influence on global mean

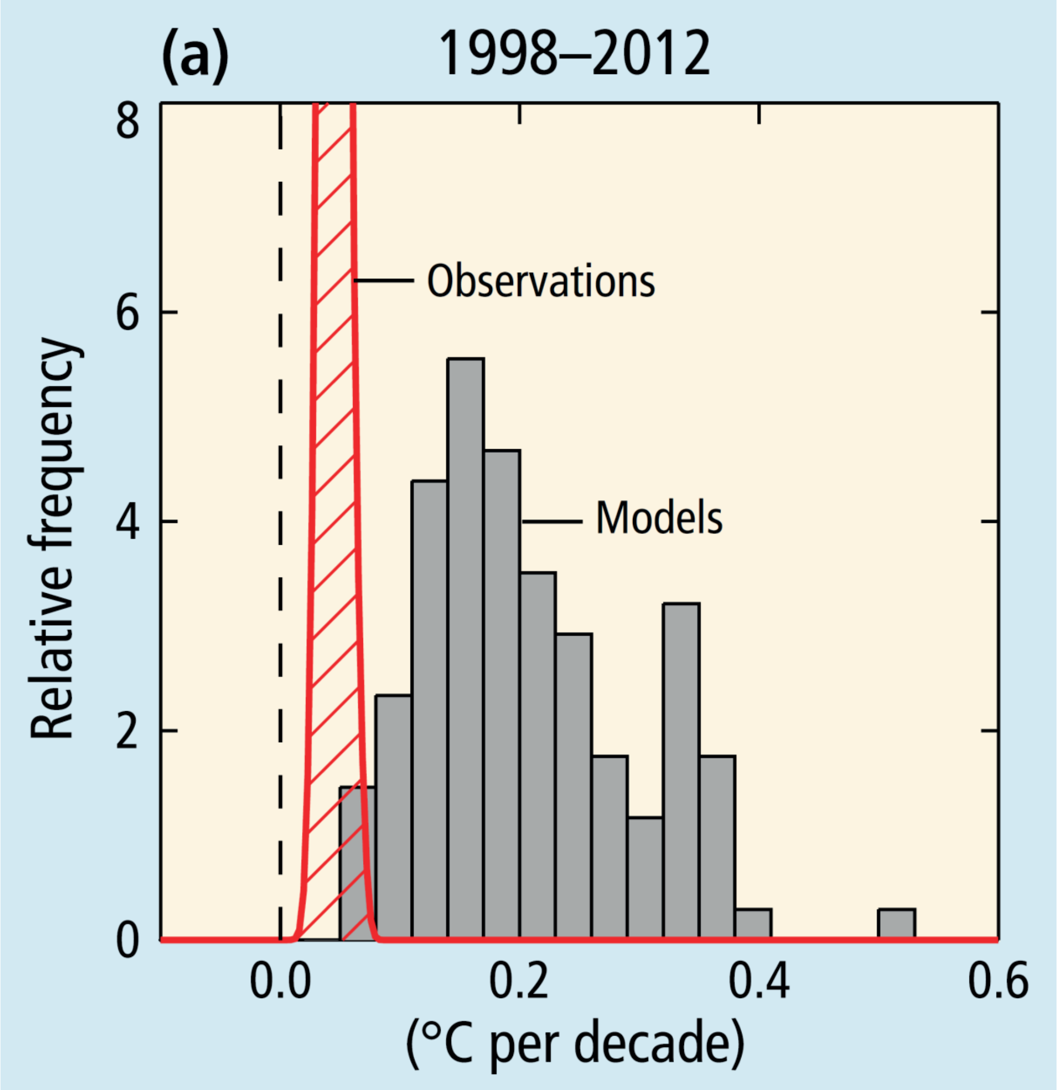
Challenge (2): Climate-model simulations reproduce the surface warming since 1951, but not the hiatus of the past 15 years



Should they? CMIP5 historical simulations, started around year 1850, are not expected to match the timing of internal-variability events

Here: Quantify roles of forcing, feedback, and internal variability (rudimentarily in IPCC WGI AR5 Box 9.2, comprehensively in Marotzke and Forster 2015)

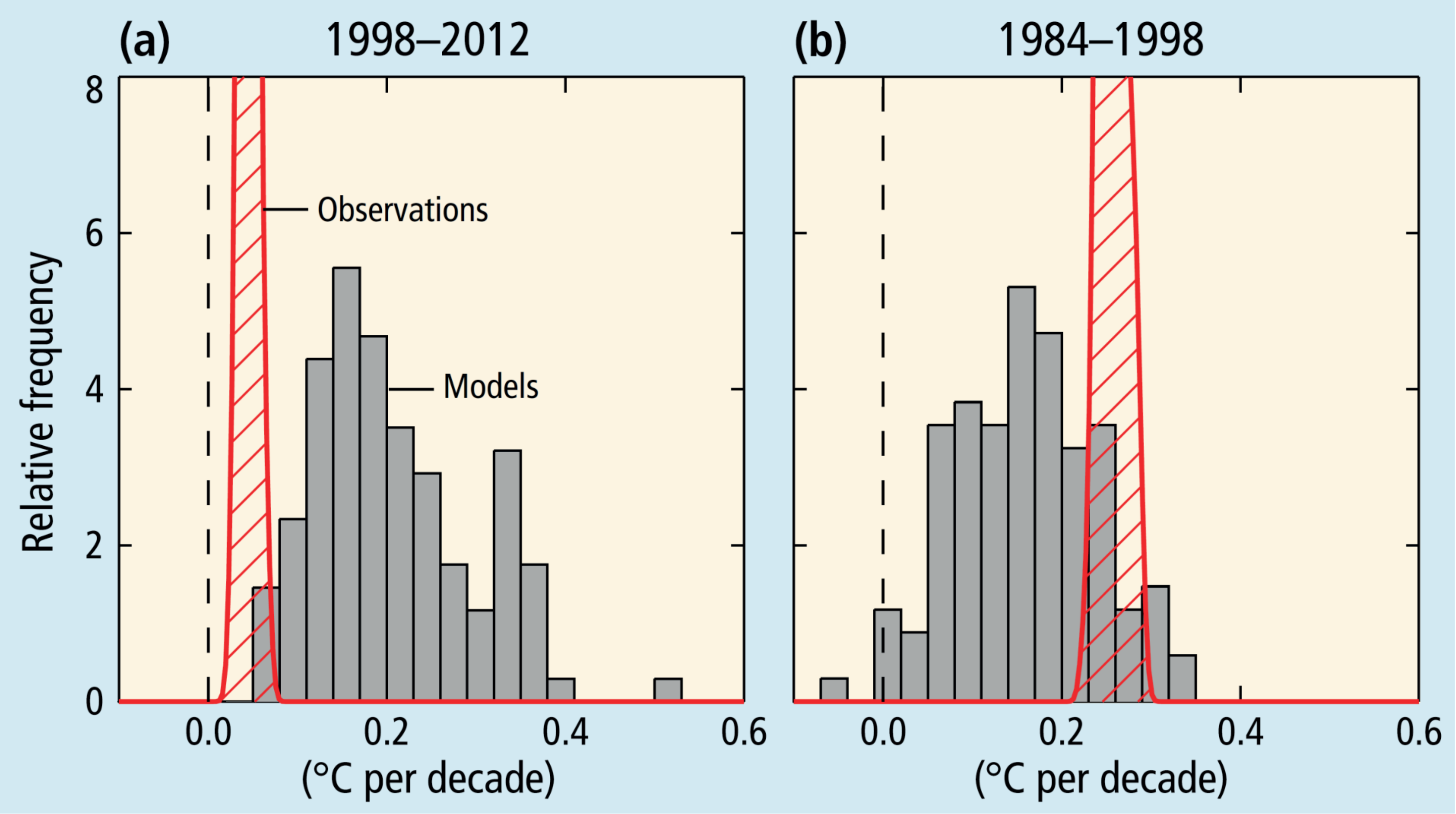
1998–2012: globally averaged surface temperature shows larger trend than observed in 111 of the 114 simulations



Length of bars: how many simulations show a trend in a certain interval (the latter given by width of bars)?

IPCC AR5 Synthesis Report, Box 1.1 Figure 1; based on WG1 Box 9.2 Figure 1

It matters when you compare – observations show larger trend than simulations over 1984–1998.



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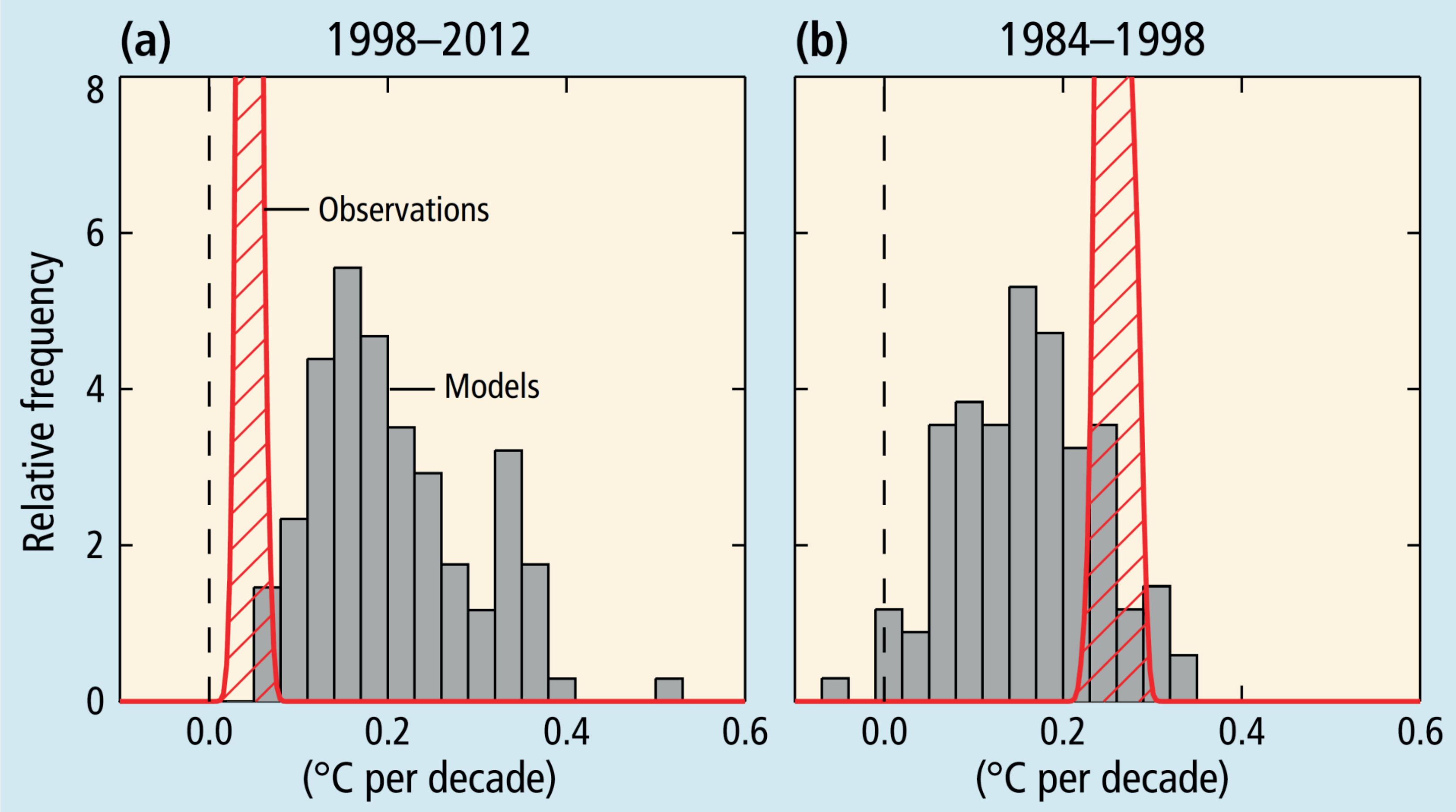
IPCC AR5 Synthesis Report, Box 1.1 Figure 1; based on WG1 Box 9.2 Figure 1

Why do simulations and observations compare so differently between different 15-year periods?



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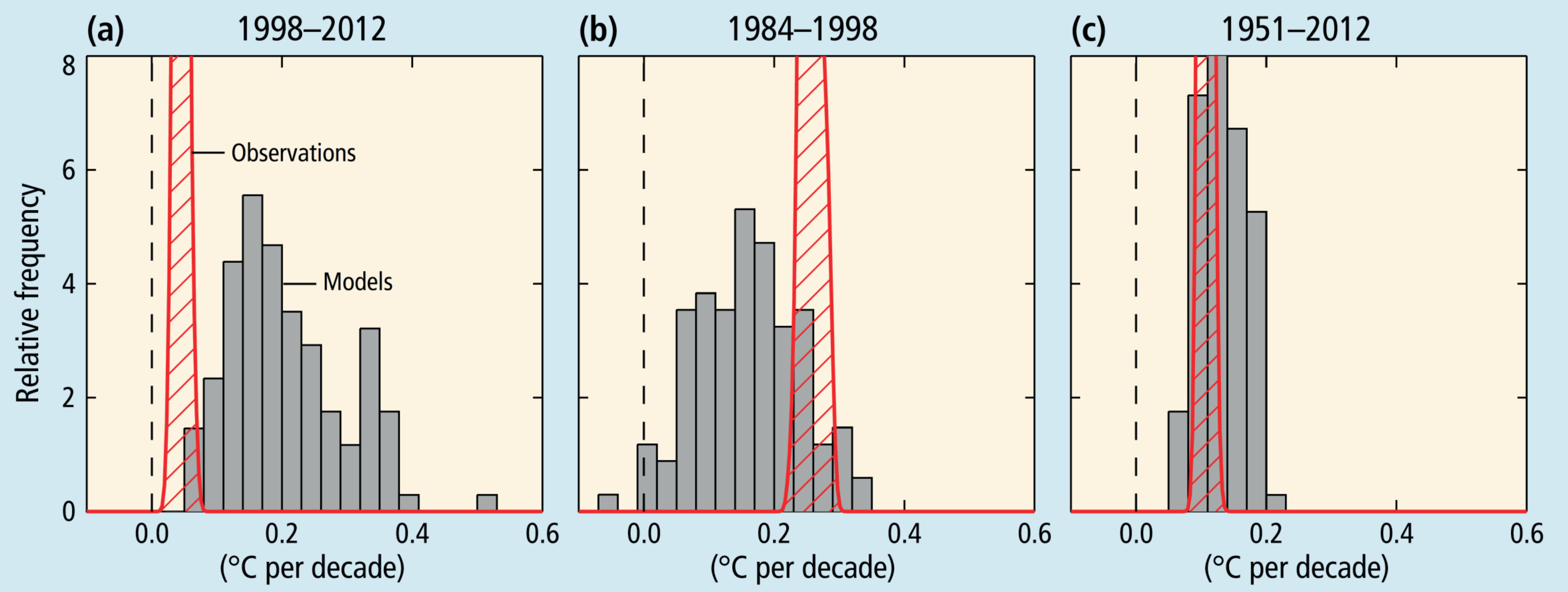
Model-mean long-term warming trend matches observations well



15-year trends have little relevance for long-term warming (IPCC AR5)

But: How representative is the comparison of simulated and observed trends over any 15-year period?

And: What causes model spread in trends over 1951–2012?

IPCC AR5 Synthesis Report, Box 1.1 Figure 1; based on WG1 Box 9.2 Figure 1

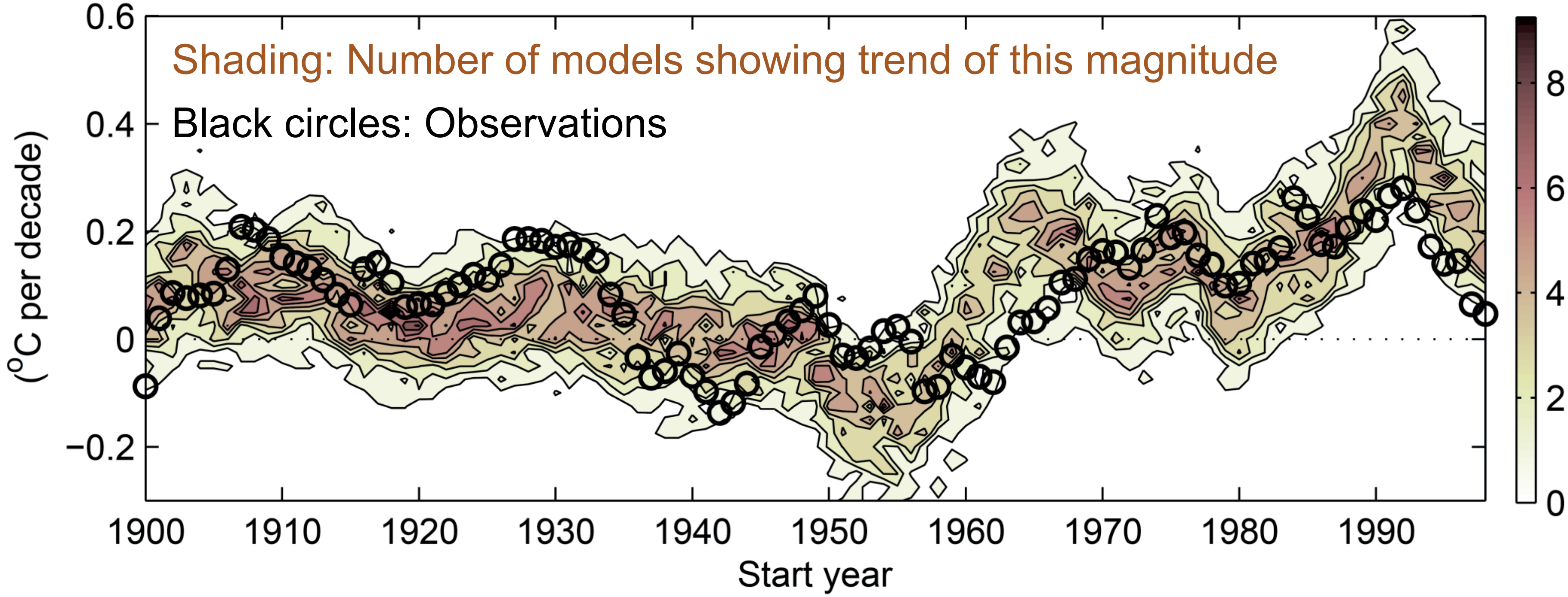
New, unified conceptual framework for investigating GMST trends (Marotzke and Forster 2015)

Three-pronged approach:

1. Owing to internal variability, difference between simulations and observations contains quasi-random elements. To avoid selection bias, consider all available trends of a certain length
2. Quantify contributions from radiative forcing, climate feedback, ocean heat uptake, and internal variability to simulated GMST trend
3. Consider 15-year and 62-year trends

Puts 15-year GMST trend over 1998–2012 into appropriate context

All 15-year GMST trends: Position of observations vis-à-vis simulation ensemble shows no systematic bias and is largely determined by (quasi-)random effects



- Assumes that multi-model ensemble spread arises from internal climate variability and not from “deterministic” physics (forcing, feedback, ocean heat uptake) that differs between models
- Now: Quantify contribution of deterministic physics to ensemble spread and thus to difference between simulations and observations

How much of model-ensemble spread arises from internal variability and how much from different deterministic model physics?

- Combine energy balance for surface layer with internal variability
- Theory & models: with generally increasing radiative forcing R_F, surface temperature responds quasi-instantaneously and linearly to change in R_F (e.g., Gregory and Forster 2008):

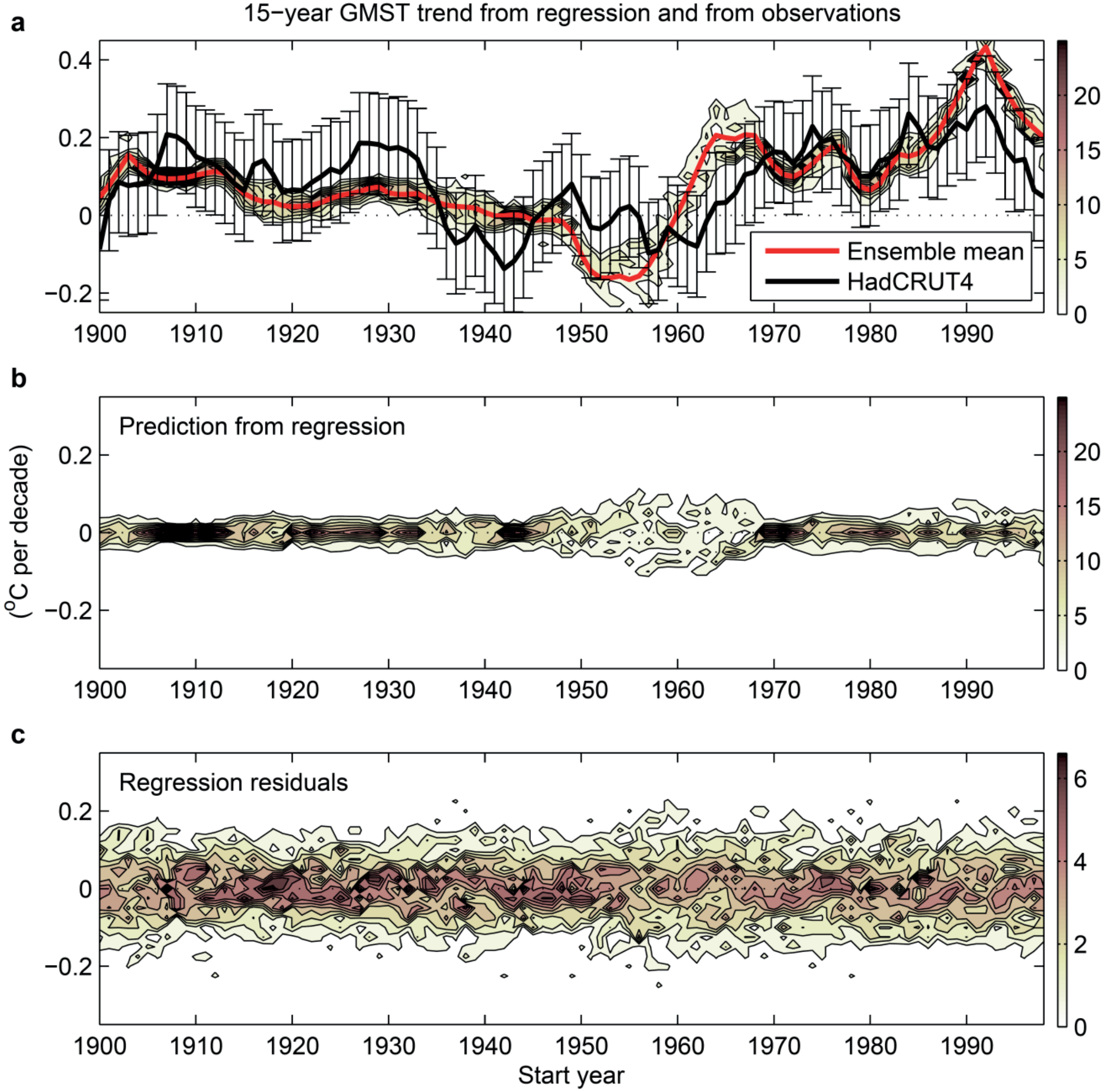
$$\Delta GMST = \frac{\Delta R_F}{\alpha + \kappa};$$

  α: climate feedback parameter; κ: efficiency of ocean heat uptake; each has units of W m^{-2} K^{-1} and varies three-fold among models.

  (Note: Equilibrium climate sensitivity is $R_{F,2xCO2} / \alpha$)

- We perform multiple linear regression of GMST trend against R_F trend, α, and κ (deterministic contribution to ensemble spread)
  - Because α and κ vary three-fold, we should see an effect if there is one!
- We interpret residual as contribution from internal variability

15-year GMST trends: deterministic (regression) part consistent with observations + internal variability; the latter is 2.5 times deterministic spread

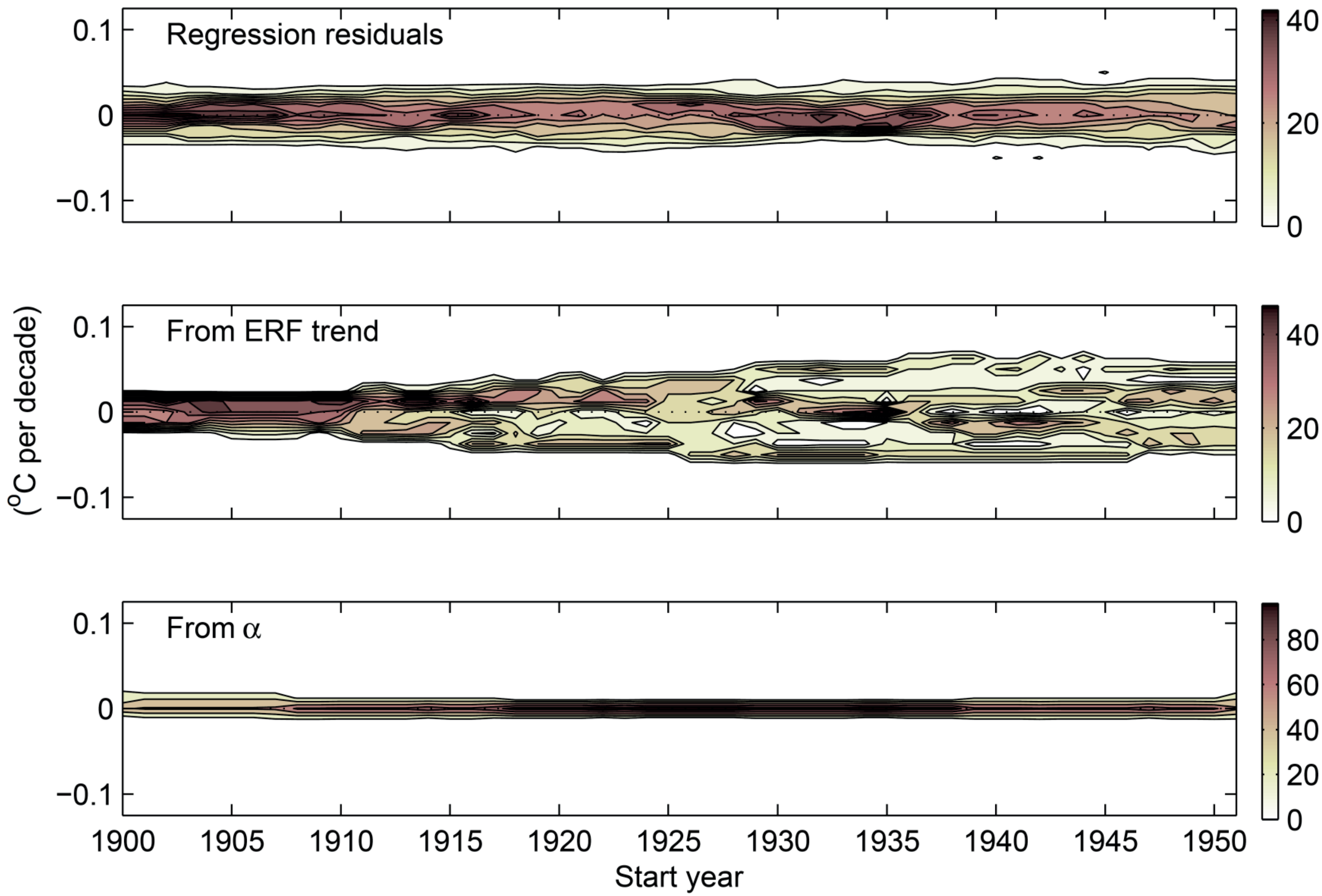


Whiskers: uncertainty from internal variability (average spread from c)

Deterministic spread (regression against forcing trend, climate feedback, ocean heat uptake efficiency)

Residual, interpreted as internal variability

62-year GMST trends: largest spread due to variations in radiative forcing; role of climate feedback negligible in explaining model–observation difference



Residual (internal variability)

GMST trend from radiative-forcing trend

GMST trend from climate feedback parameter

Marotzke and Forster (*Nature*, 2015)

Conclusions: the recent surface-warming hiatus and anthropogenic climate change

- Distribution of simulated 15-year trends in global-mean surface temperature (GMST) shows no systematic bias against observations and is largely determined by quasi-random internal variability
- Spread in simulated climate feedback leaves no traceable imprint on GMST trends – the claim that climate models systematically over-estimate response to greenhouse-gas increase seems unfounded
- The recent surface-warming hiatus masks anthropogenic warming and is scientifically fascinating: which mechanisms act?
  - Unprecedented Pacific trade-wind strengthening: more cold water to surface
  - Extreme Eurasian winter cooling
- However, hiatus is largely irrelevant for long-term anthropogenic climate change – this continues unabated, as witnessed by continued heat uptake of the climate system, especially the oceans

I thank you for your attention!