Reconciling climate response estimates from climate models and Earth's energy budget

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Presentation at Department of Meteorology, University of Reading

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Climate response and global temperature

- Policy is to “prevent dangerous anthropogenic interference with the climate system”[1] which now means “to reduce global emissions so as to hold the increase in global temperature below 2 degrees Celsius.”[2]

- “Transient Climate Response” is a metric to relate emissions to global temperature change

1: Article 2 of the 1992 United Nations Framework Convention on Climate Change
2: Copenhagen Accord: FCCC/CP/2009/11/Add.1

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Transient climate response

- Transient climate response: temperature increase at moment of CO_2 doubling after 1% yr^{-1} increase

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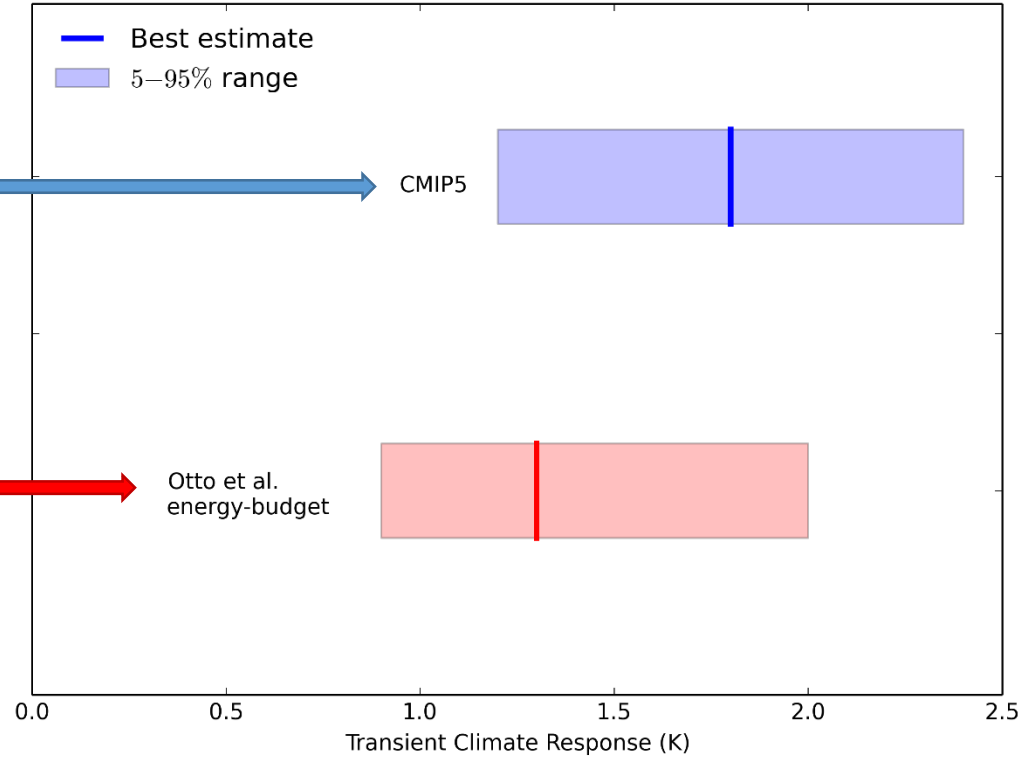
Transient climate response

- Transient climate response: temperature increase at moment of CO_2 doubling after 1% yr^{-1} increase

CMIP5 1pctCO2 simulations, best estimate = **1.8 K**

"Observed" energy budget, best estimate = **1.3 K**



IPCC WG1 AR5 Ch9, Otto et al. (2013)

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Transient climate response

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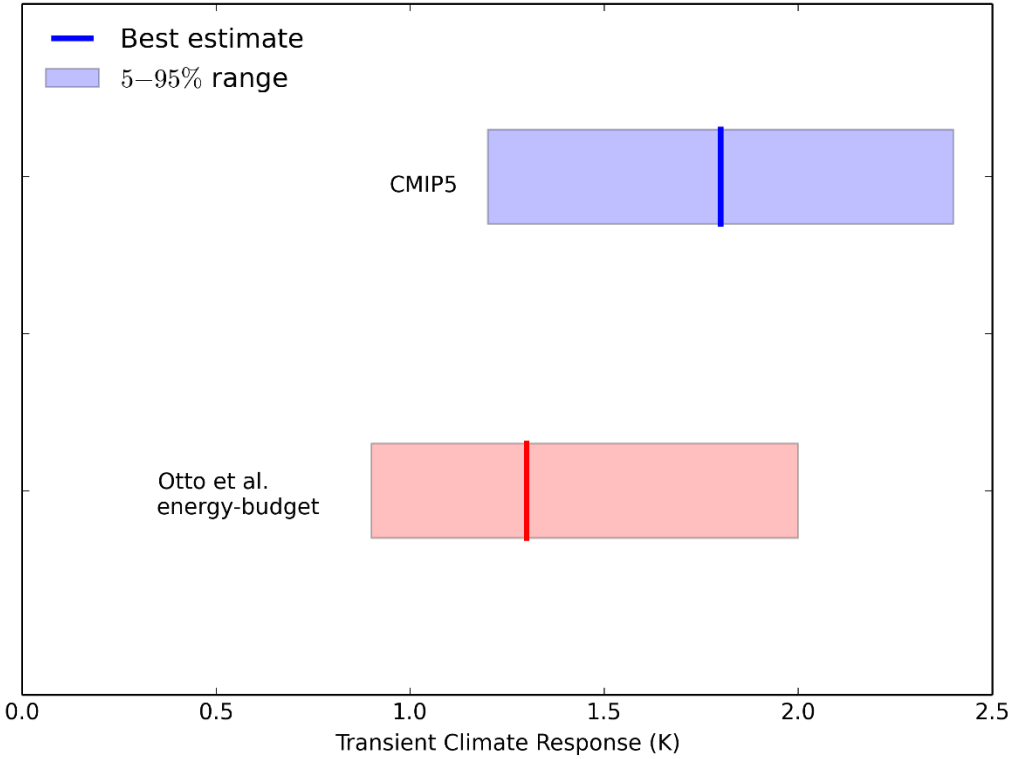

IPCC WG1 AR5 Ch9, Otto et al. (2013)

- Which global temperatures?

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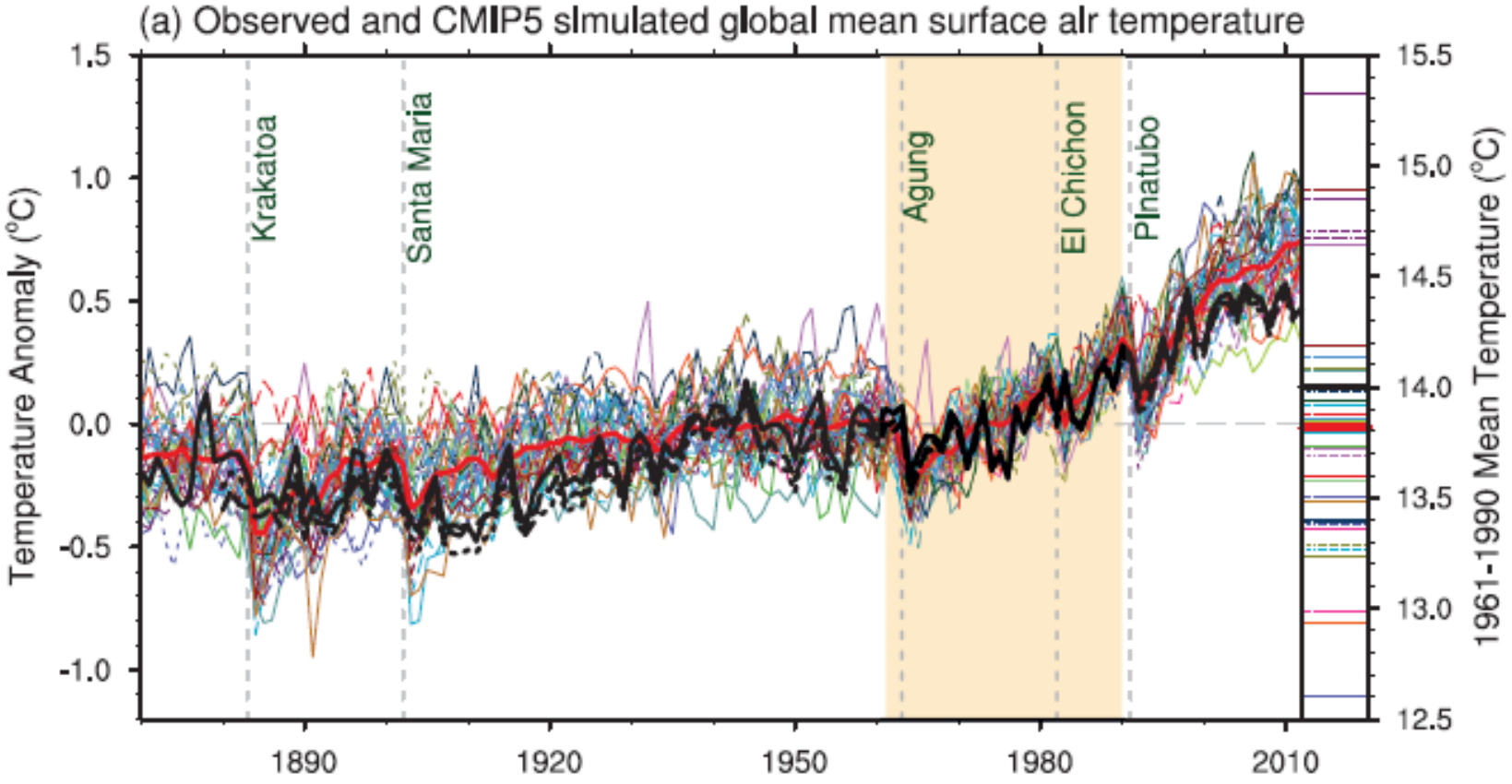
IPCC model v. observed temperatures



- IPCC 5th Assessment Report Figure 9-08, CMIP5 models versus observations. Focus here is on HadCRUT4 (thick black line)

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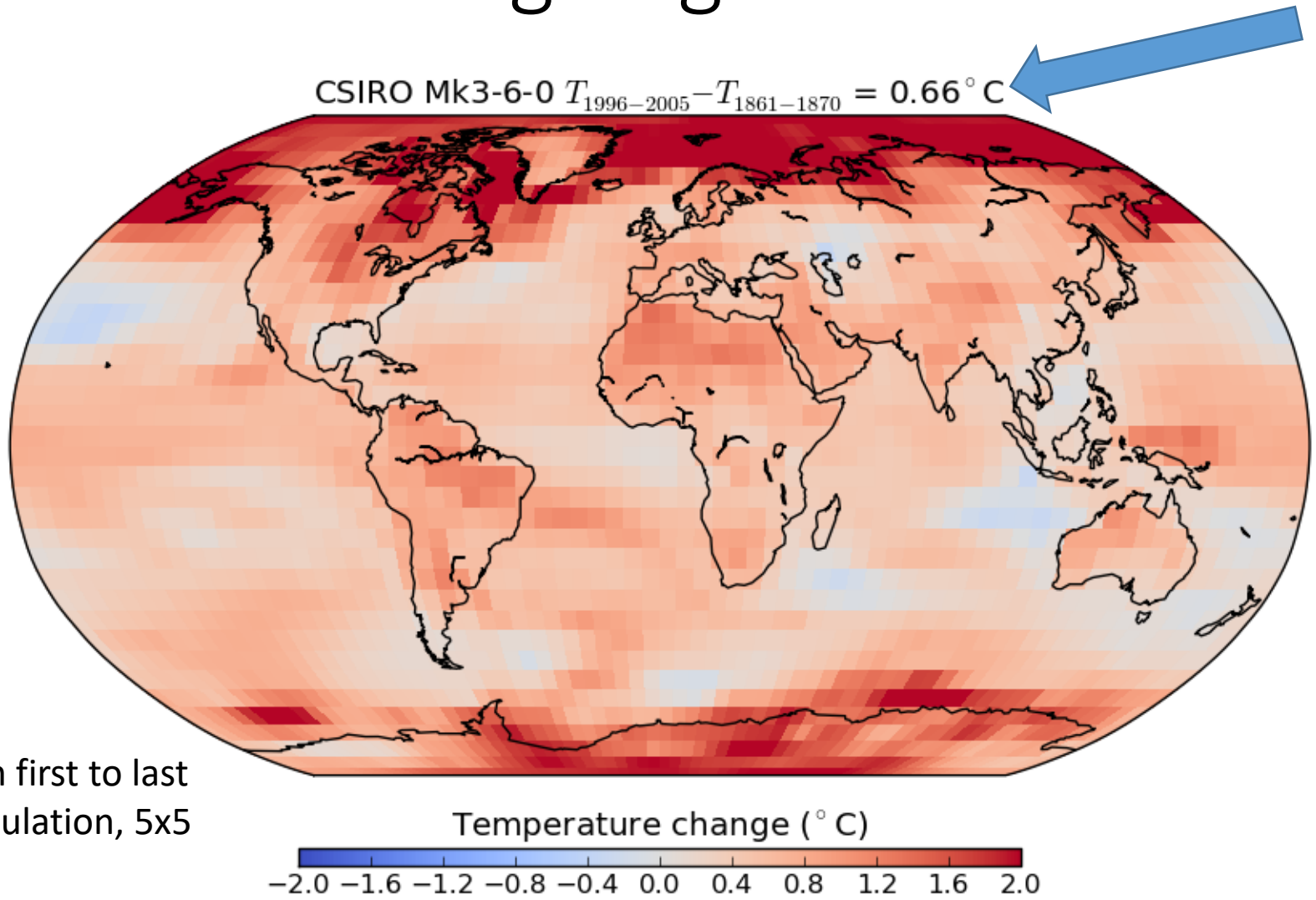
Observational coverage - global



Temperature change from first to last decade of “historical” simulation, 5x5 degree grid

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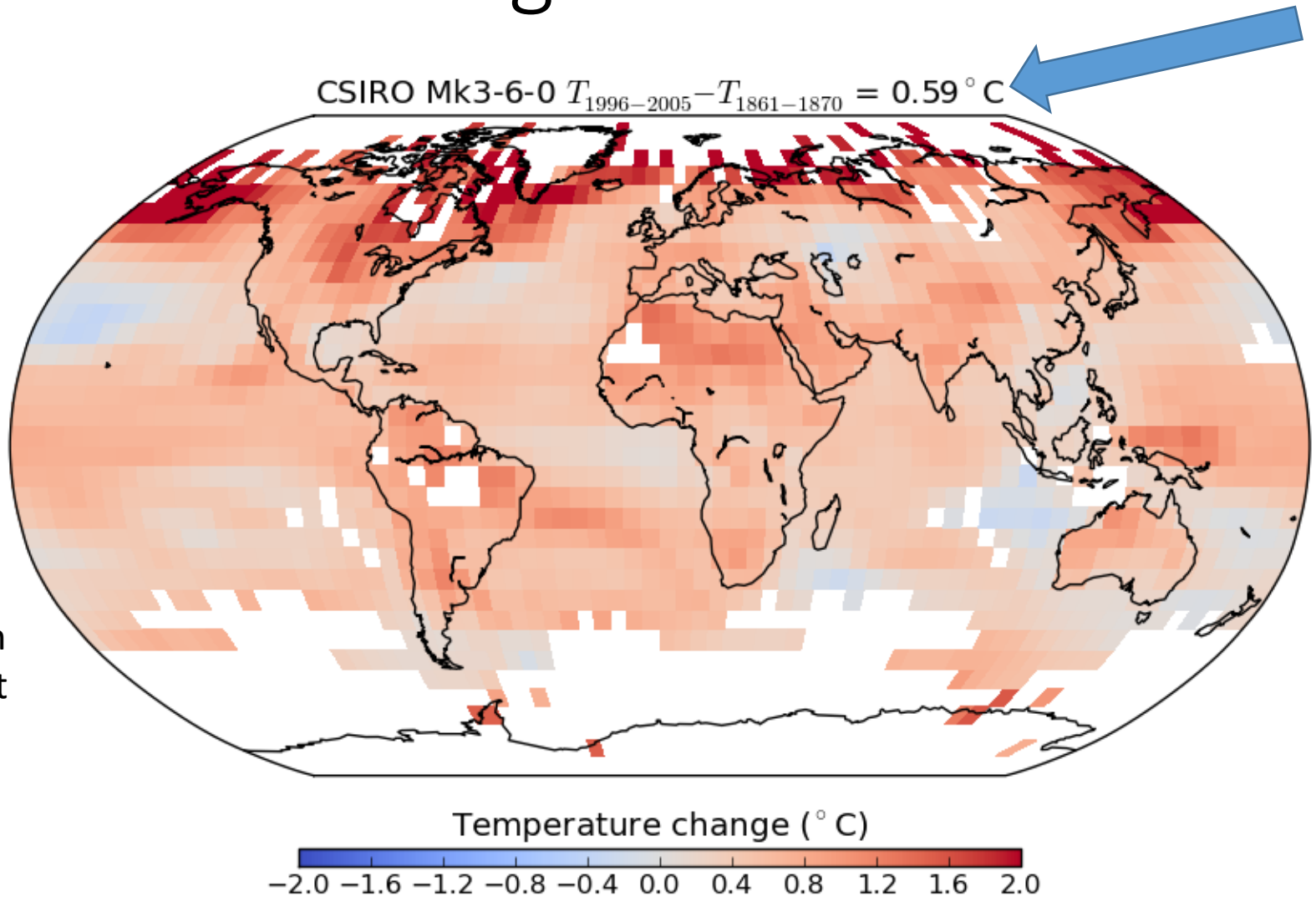
Observational coverage – 1996—2005

“Masking” model output to match observed geographical coverage

Shown where *any* month reported a measurement in this decade – true coverage is worse



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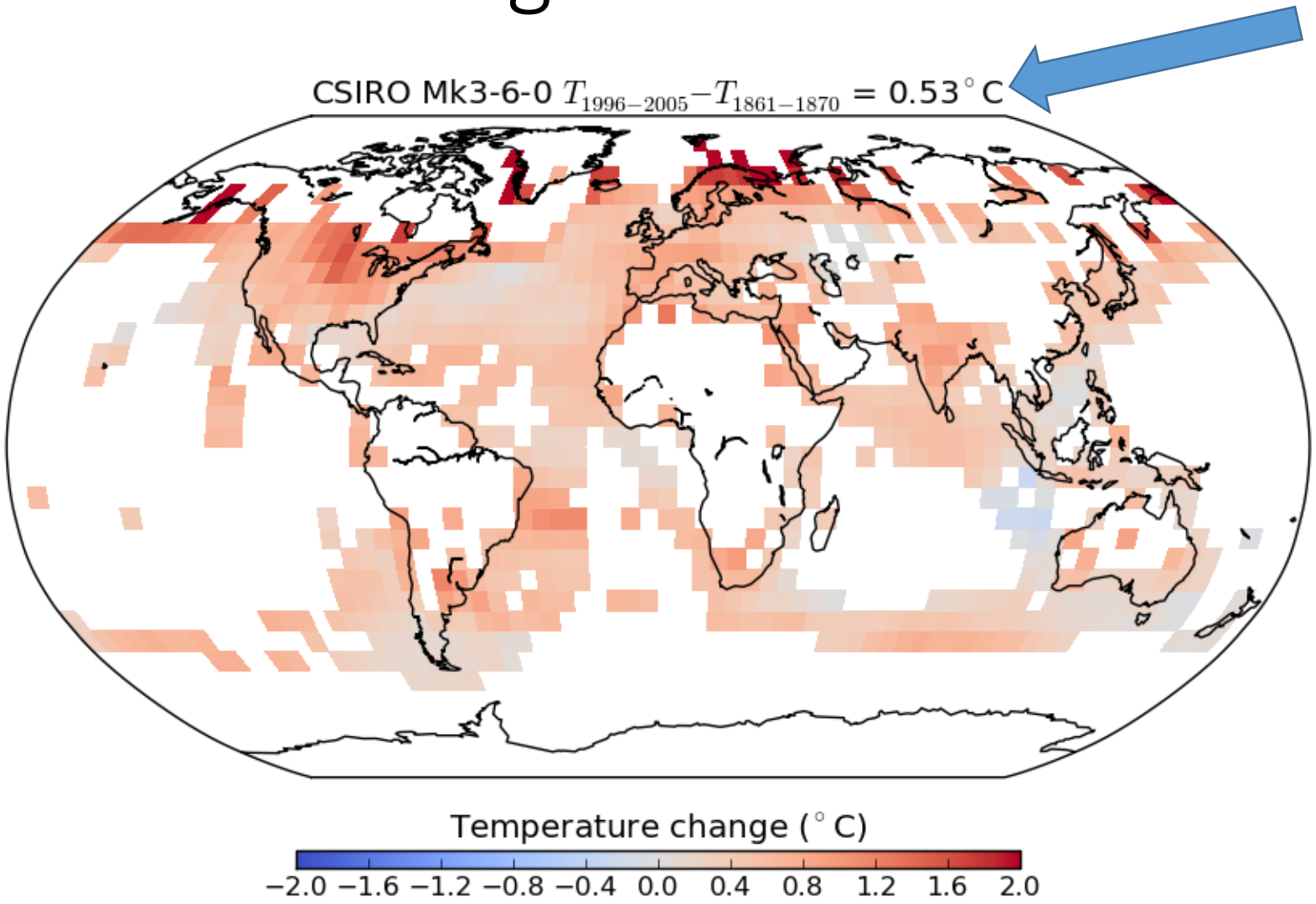
Observational coverage 1900—1909

“Masking” model output to match observed geographical coverage



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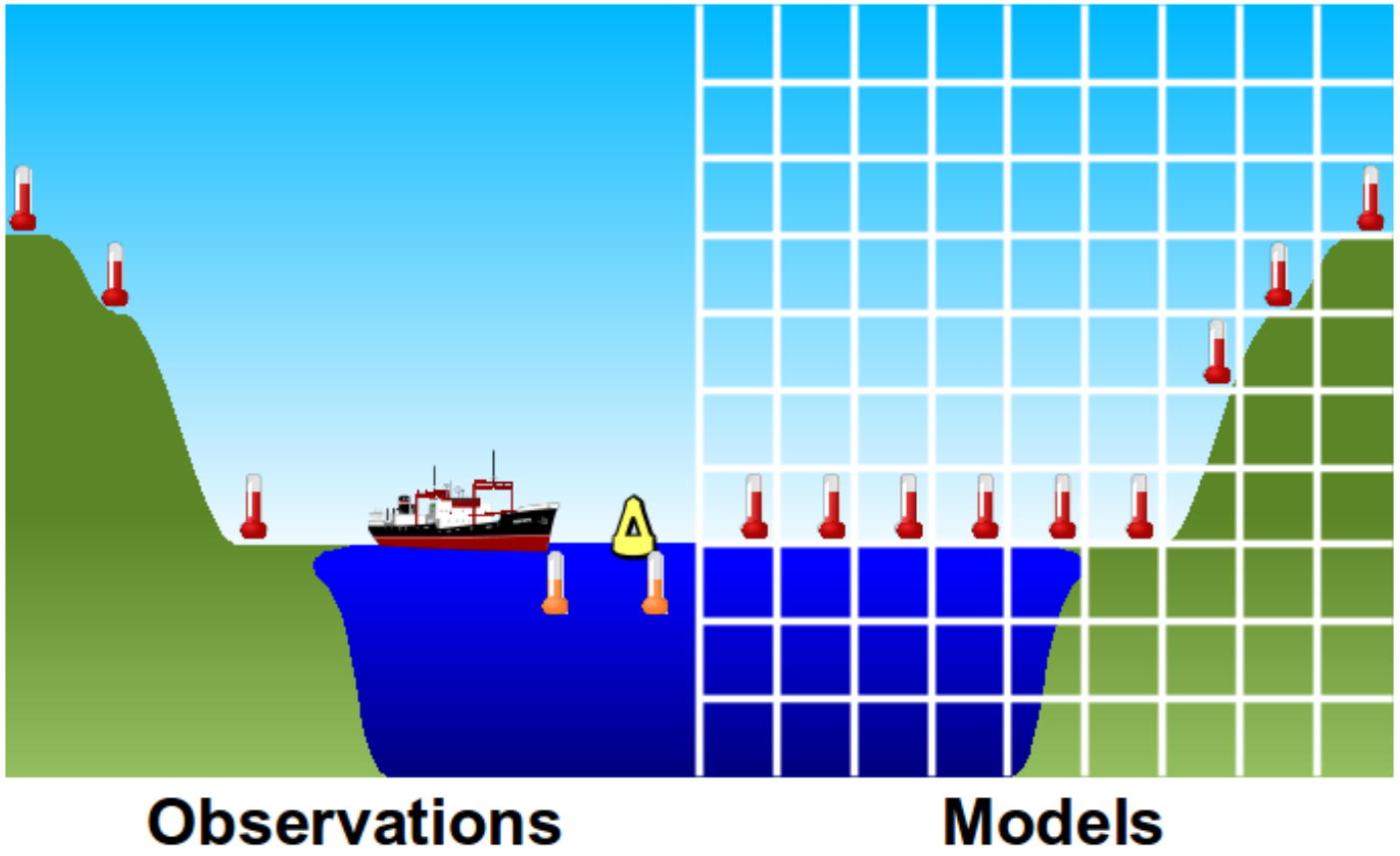
Global temperature estimates – land and ocean



Credit: Kevin Cowtan

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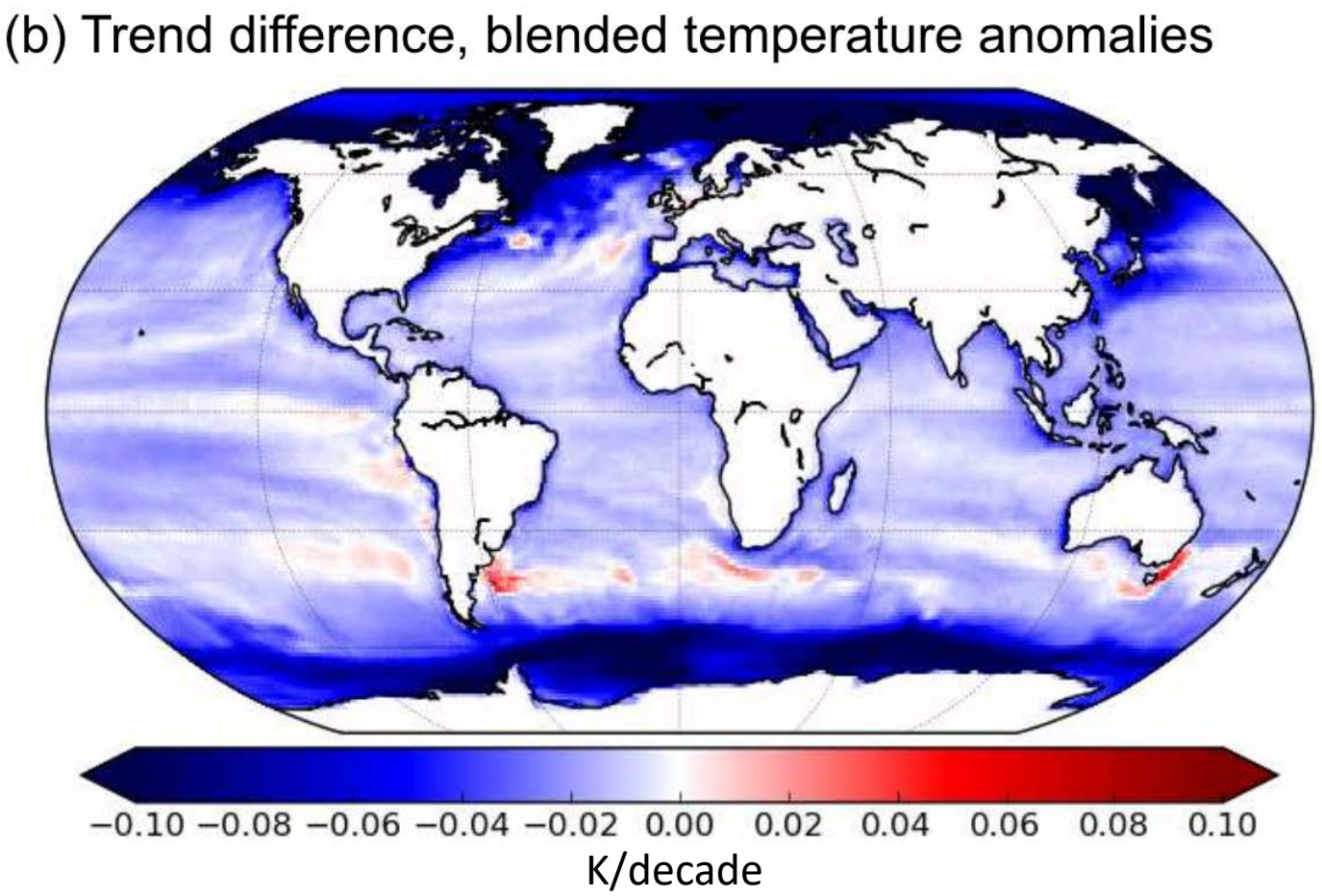
Global temperature estimates – land and ocean

- 1985—2014 CMIP5 mean trend
- Blue = less warming in blended air-water temperatures than air temperatures only
- Polar effects enhanced by loss of sea ice (switch from air over ice to open water)
- Otherwise: surface energy budget changes



Credit: Kevin Cowtan, Supplementary Information to Cowtan et al. (2015)

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Step 1 – a robust comparison

- Observations combine air temperatures over land with water temperatures over ocean (‘blending’)
- Observations are geographically incomplete (‘masking’)
- What if we blend and mask models in the same way as HadCRUT4 observations?

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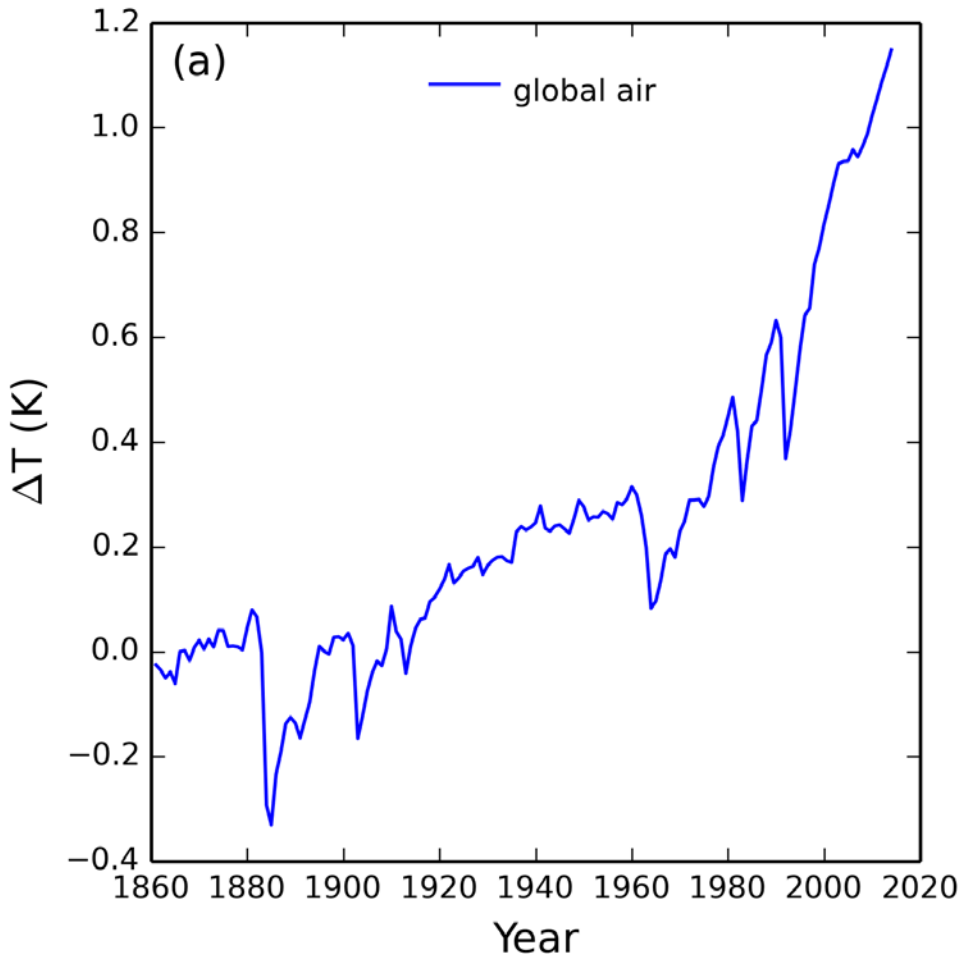

Ensemble median of 87 CMIP5 simulations, historical forcing to 2005, RCP8.5 from 2006.

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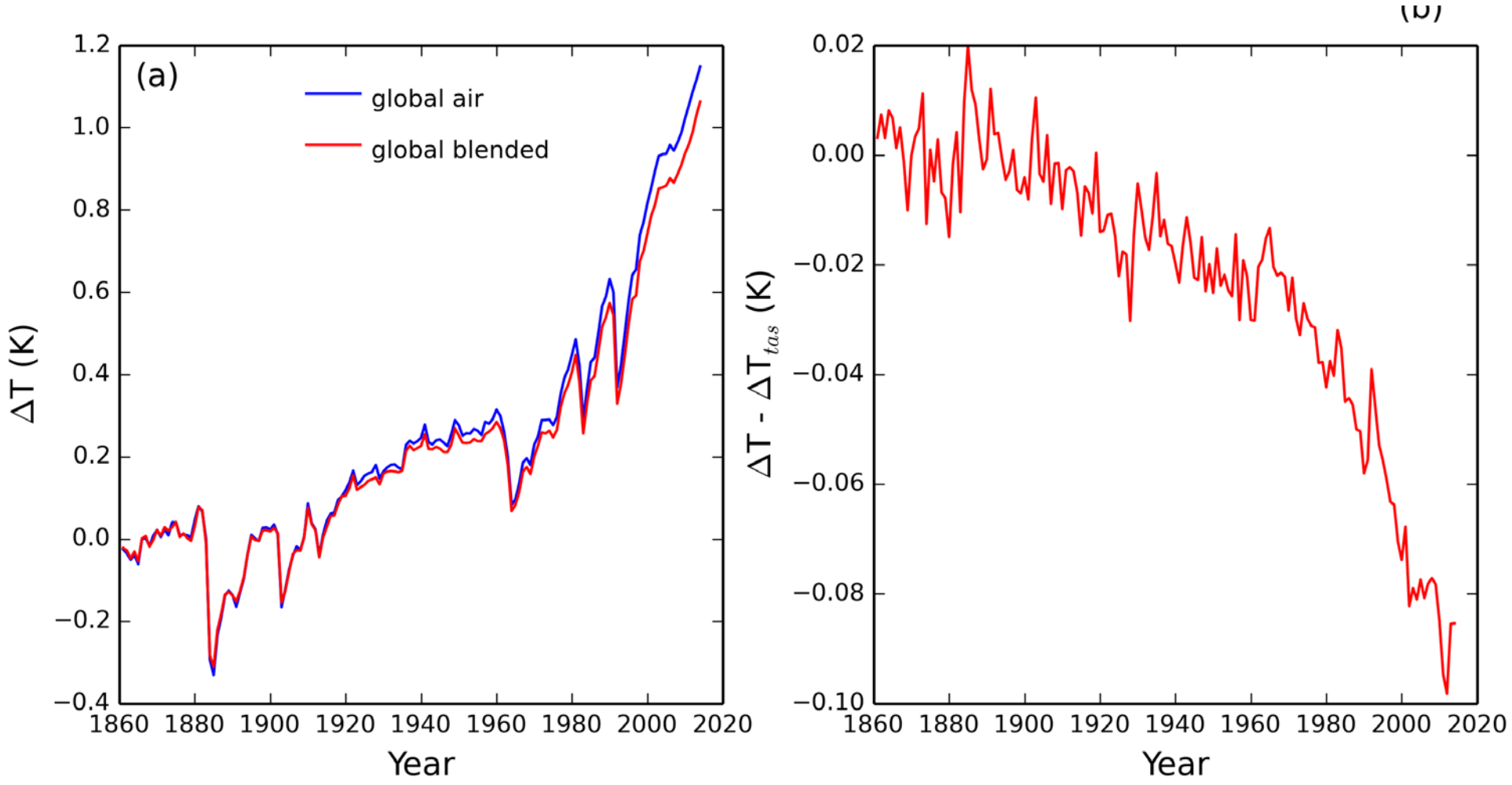

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Blended = combined air-water temperatures

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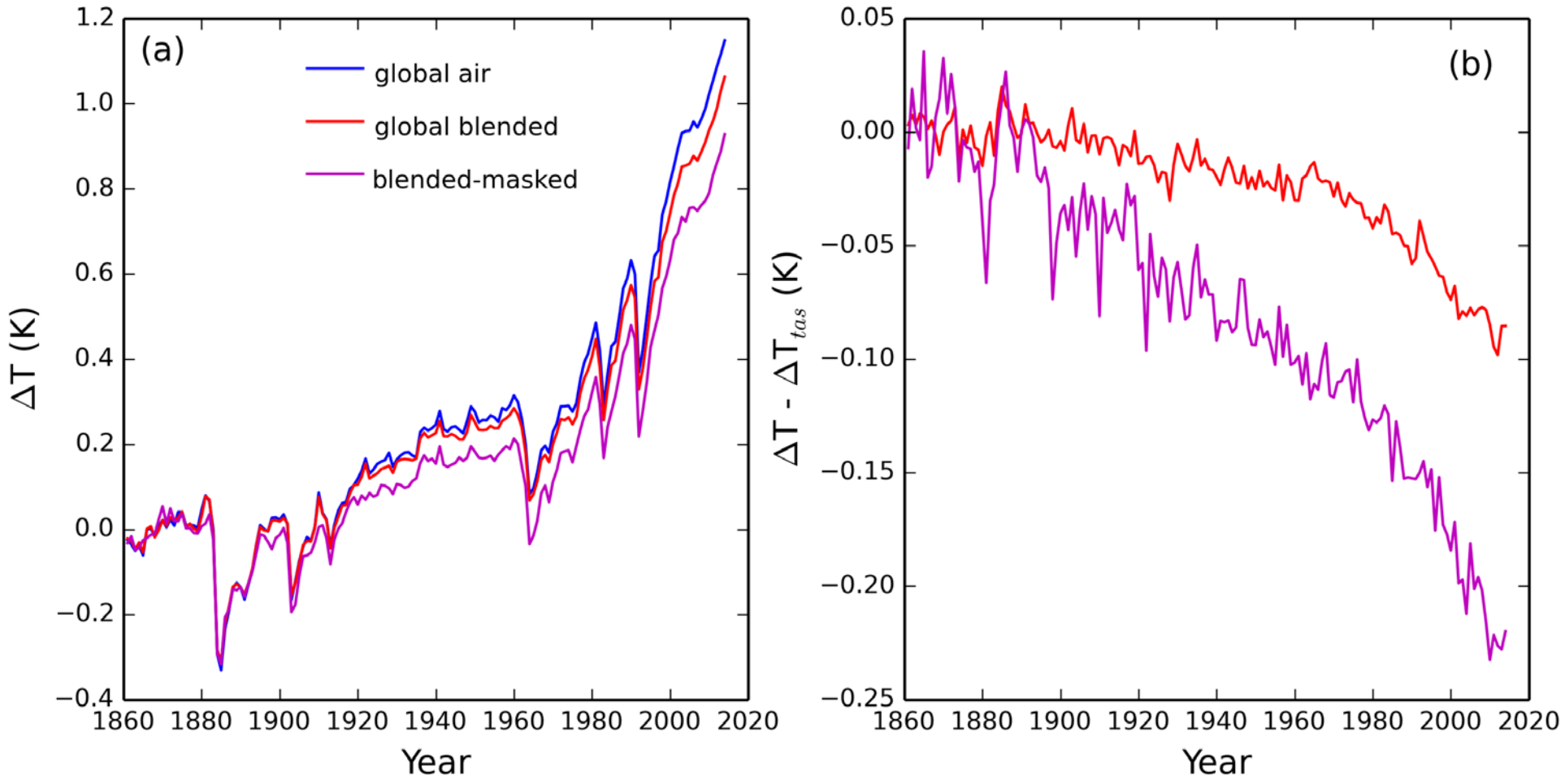

Ensemble median of 87 CMIP5 simulations, historical forcing to 2005, RCP8.5 from 2006.

Blended = combined air-water temperatures

Blended-masked = combined air-water temperatures, historical geographical measurement coverage

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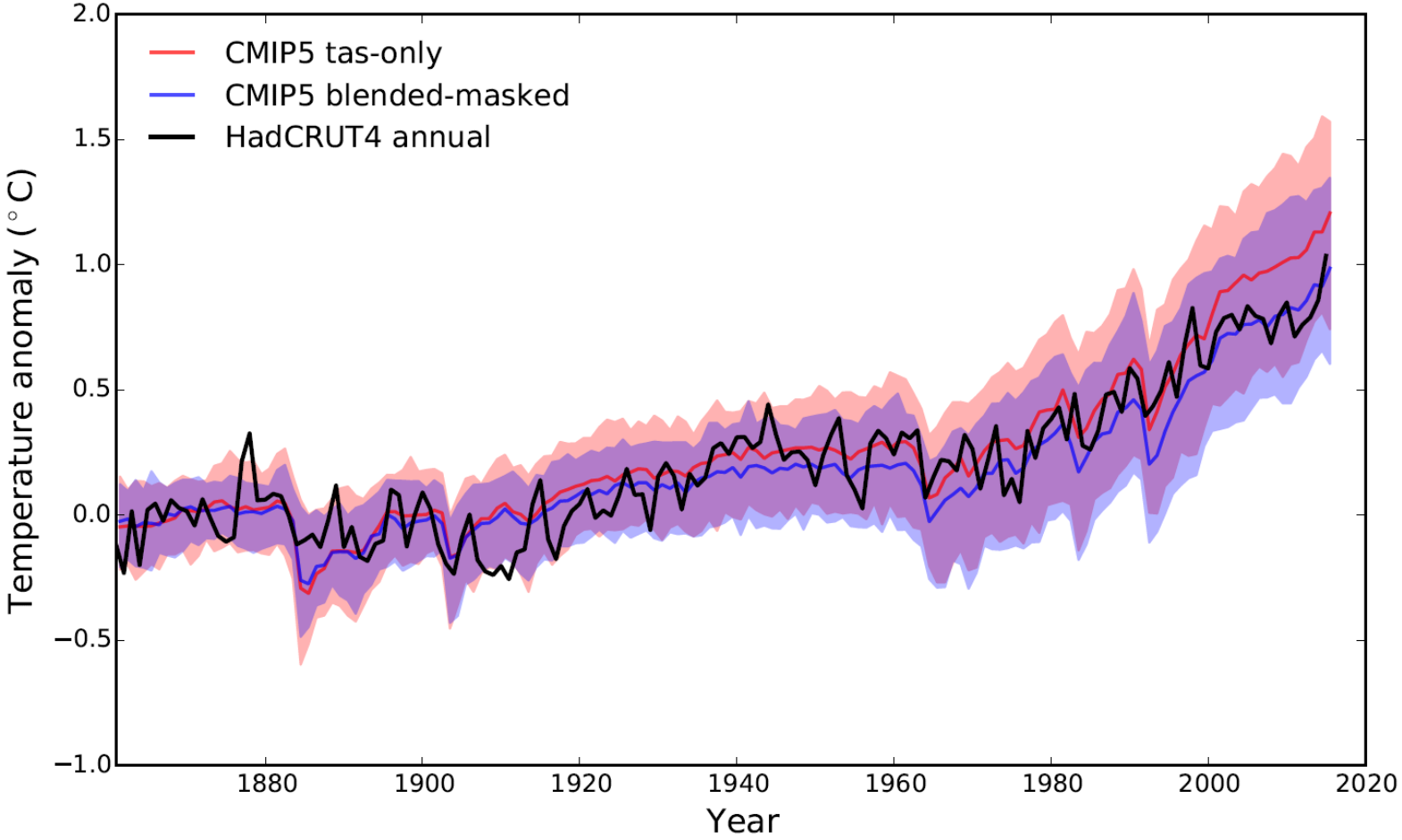
ΔT in models and observations from an 1861—1880 baseline



- Full period ΔT goes from 15th percentile of model distribution to 46th percentile (N = 87)
- ΔT over recent decades is lower in distribution, but similarly shifted

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Conclusions 1

- In CMIP5 T_{air} warms 7—9 % faster than global blended air/water, 24 % than blended-masked (depends on masking)
- **Global temperature records probably underestimate global ΔT_{air}**
- What does this mean for using the past to constrain the future?

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Transient Climate Response (TCR)

- Increase in mean global near-surface air temperature after a doubling of CO_2 in a scenario in which CO_2 increases at 1 % per year
- Should relate temperature change to radiative forcing change
- Theoretical: result depends on time scale, initial conditions, forcing…

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Transient Climate Response from Earth's energy budget

- Estimate from Earth's energy budget

$$TCR = \frac{\Delta T}{\Delta F} \Delta F_{2\times CO_2}$$

- Doubled CO_2 forcing $\cong 3.44$ W m^{-2}, so need ΔT and ΔF

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Transient Climate Response from Earth's energy budget

- Estimate from Earth's energy budget

$$TCR = \frac{\Delta T}{\Delta F} \Delta F_{2\times CO_2}$$

- Ocean heat content not explicit: manifests through making TCR lower than equilibrium response
- TCR can change with time due to OHC and changing warming pattern

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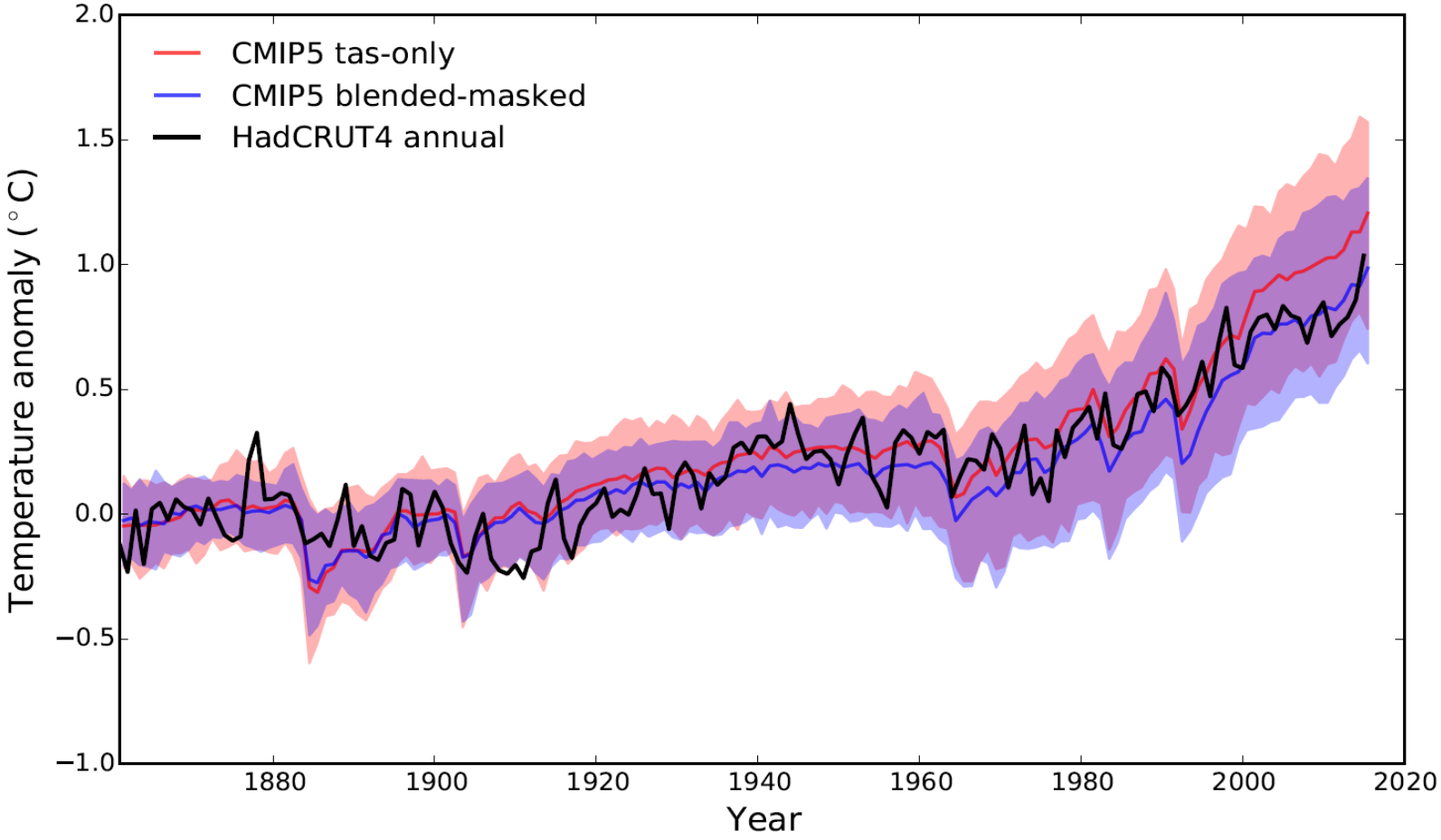
Temperature history

Global temperature record, HadCRUT4.

$$TCR = \frac{\Delta T}{\Delta F} \Delta F_{2\times CO_2}$$



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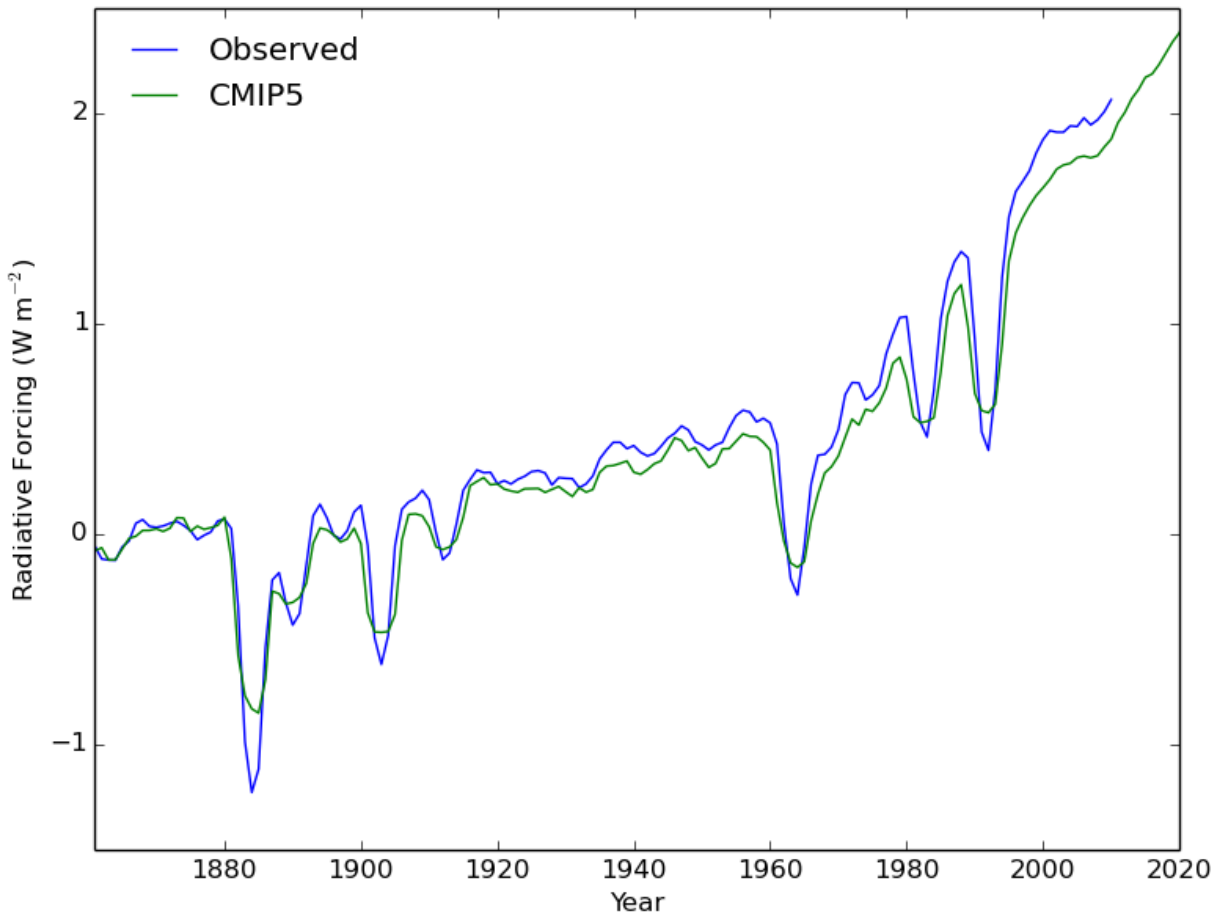
Radiative forcing history

Observed: from Otto et al. (2013) with uncertainties from Lewis & Curry (2015)

CMIP5: from Forster et al. (2013)

$$TCR = \frac{\Delta T}{\Delta F} \Delta F_{2\times CO_2}$$

ΔF



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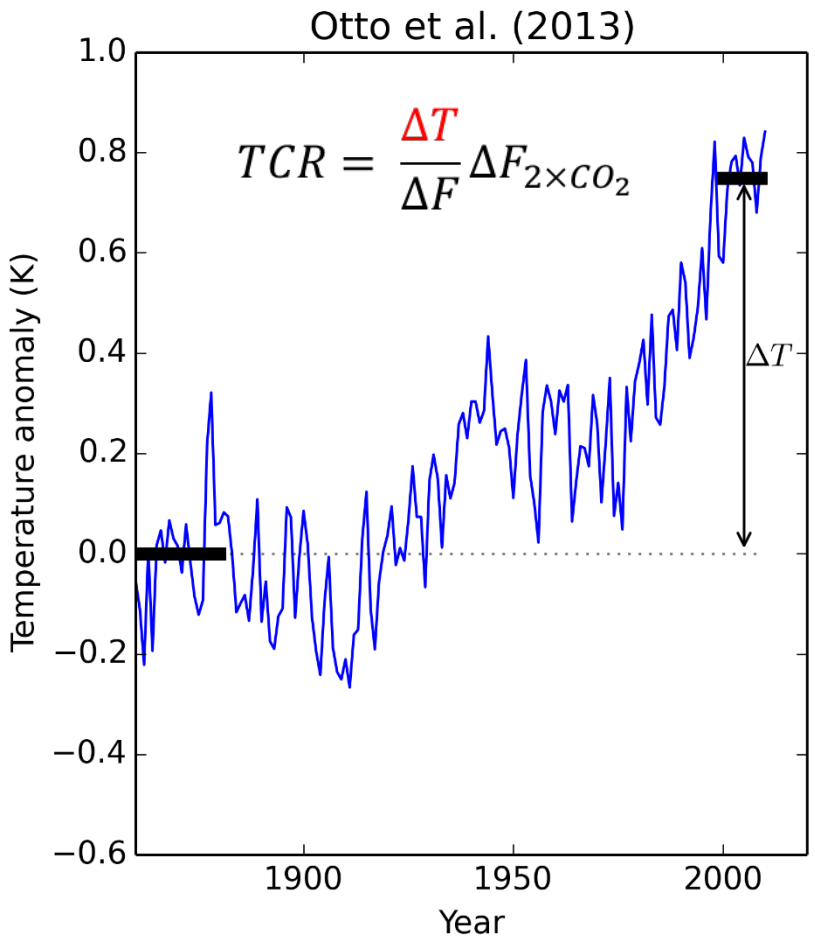
Selected method for presented results



Get ΔT, ΔF to calculate transient climate response for observations and CMIP5 historical-RCP8.5 runs

(we also tested the other methods)

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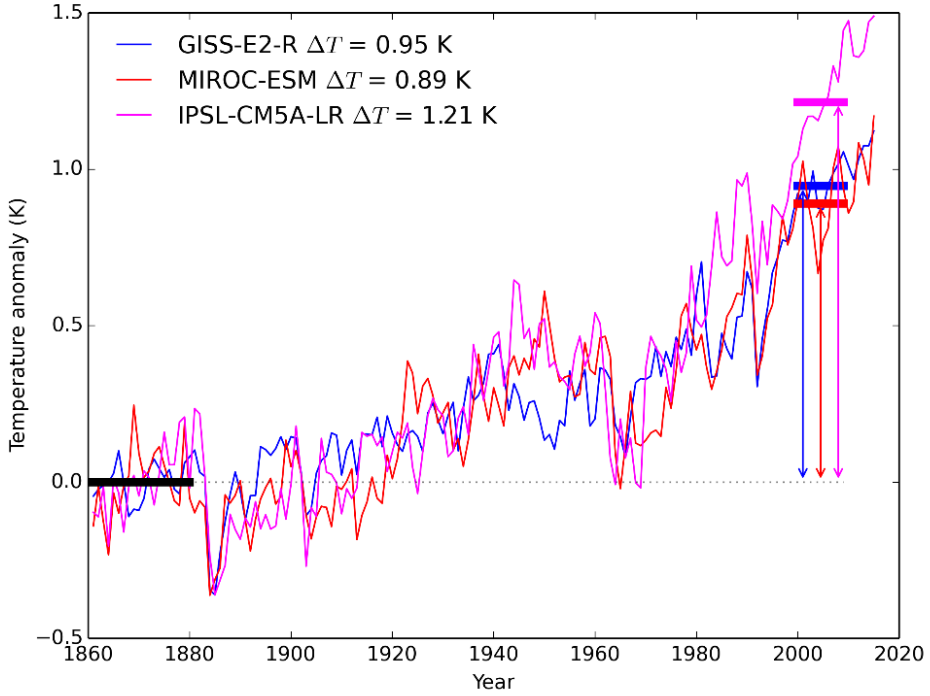
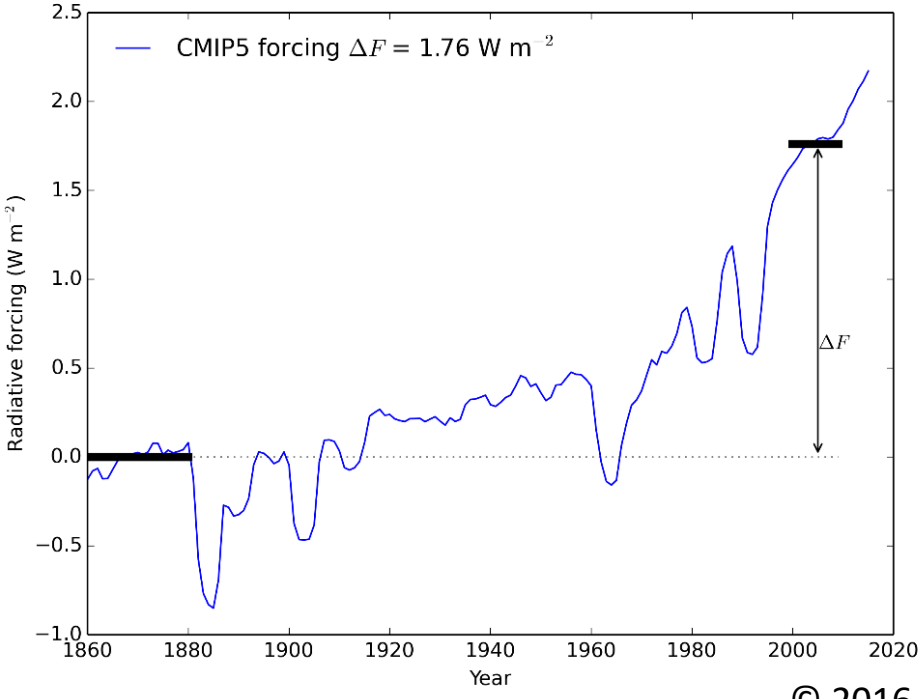
Test techniques against canonical values ("truth")

- Calculate TCR = $\frac{\Delta T}{\Delta F}\Delta F_{2\times CO_2}$ to 84 historical-RCP8.5 CMIP5 simulations, examples:





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Test techniques against canonical values (“truth”)

- Compare derived TCR for each simulation against canonical TCR (“truth”) from 1pctCO2 simulations
- **Median bias 4 %**

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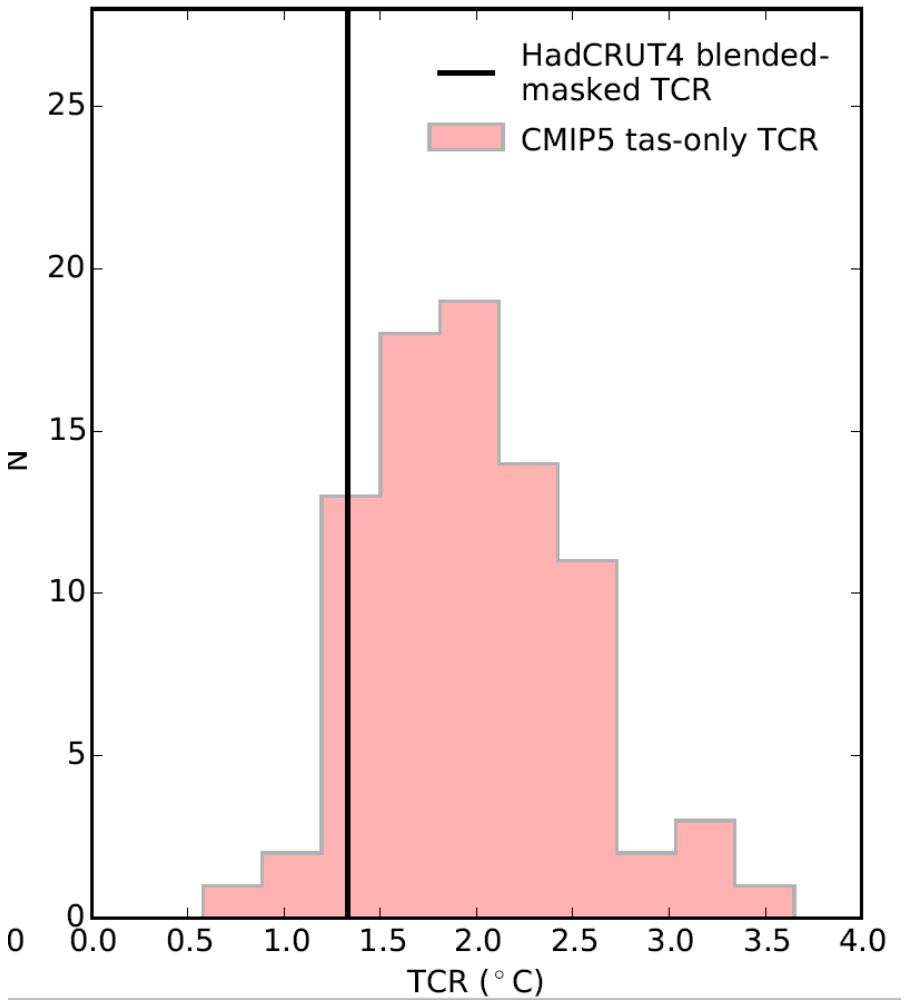
TCR observed vs. models



- TCR from observations vs. 84-member CMIP5 historical-RCP8.5 ensemble
- INCONSISTENT COMPARISON vs. modelled global air temperature
- Observations at 7th percentile

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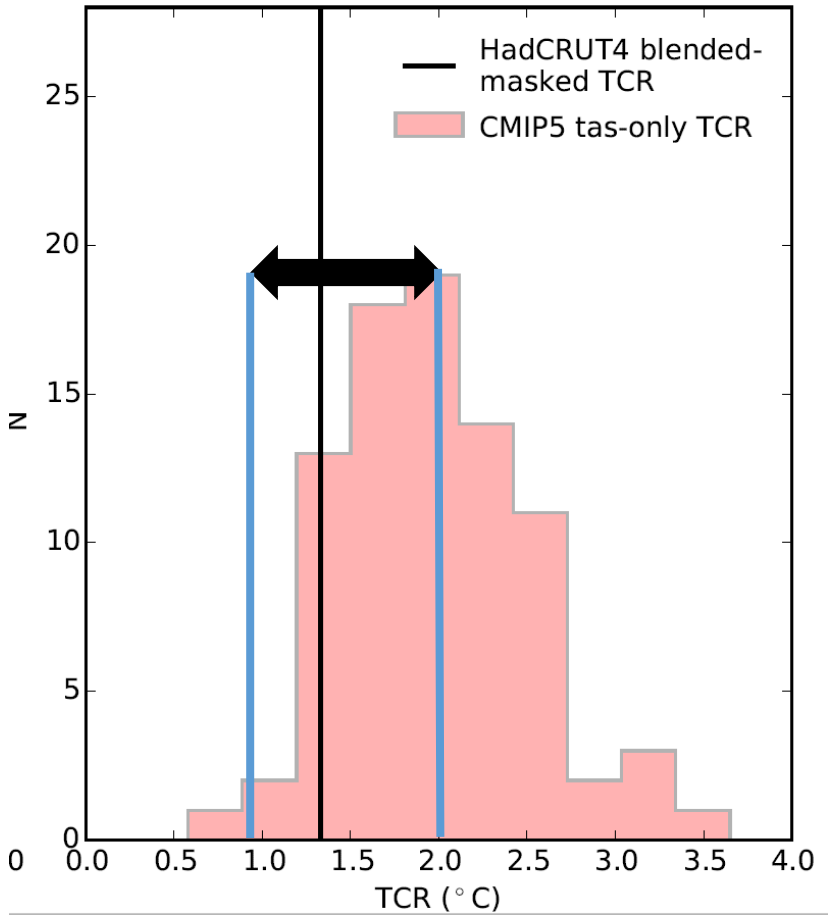
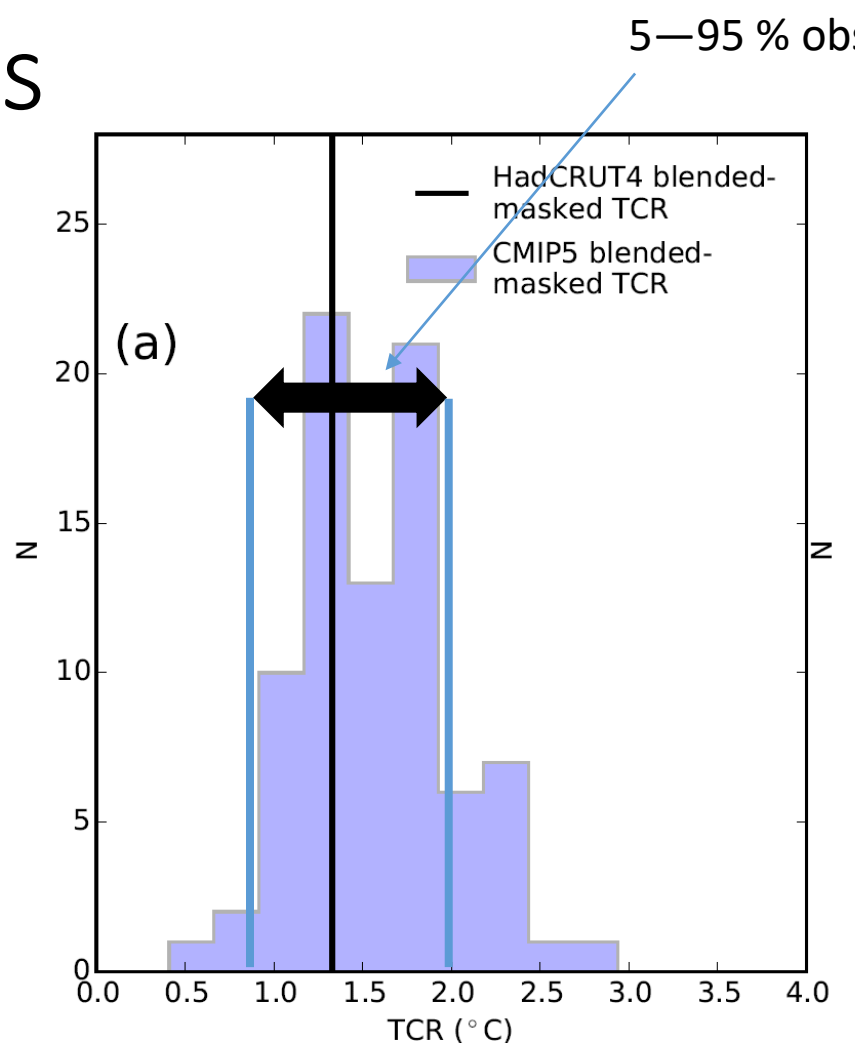
TCR observed vs. models



INCONSISTENT COMPARISON: vs. modelled global air temperature – **7th Percentile**



CONSISTENT COMPARISON: observations vs. blended-masked temperature to account for water temperatures and incomplete coverage – **33rd Percentile**

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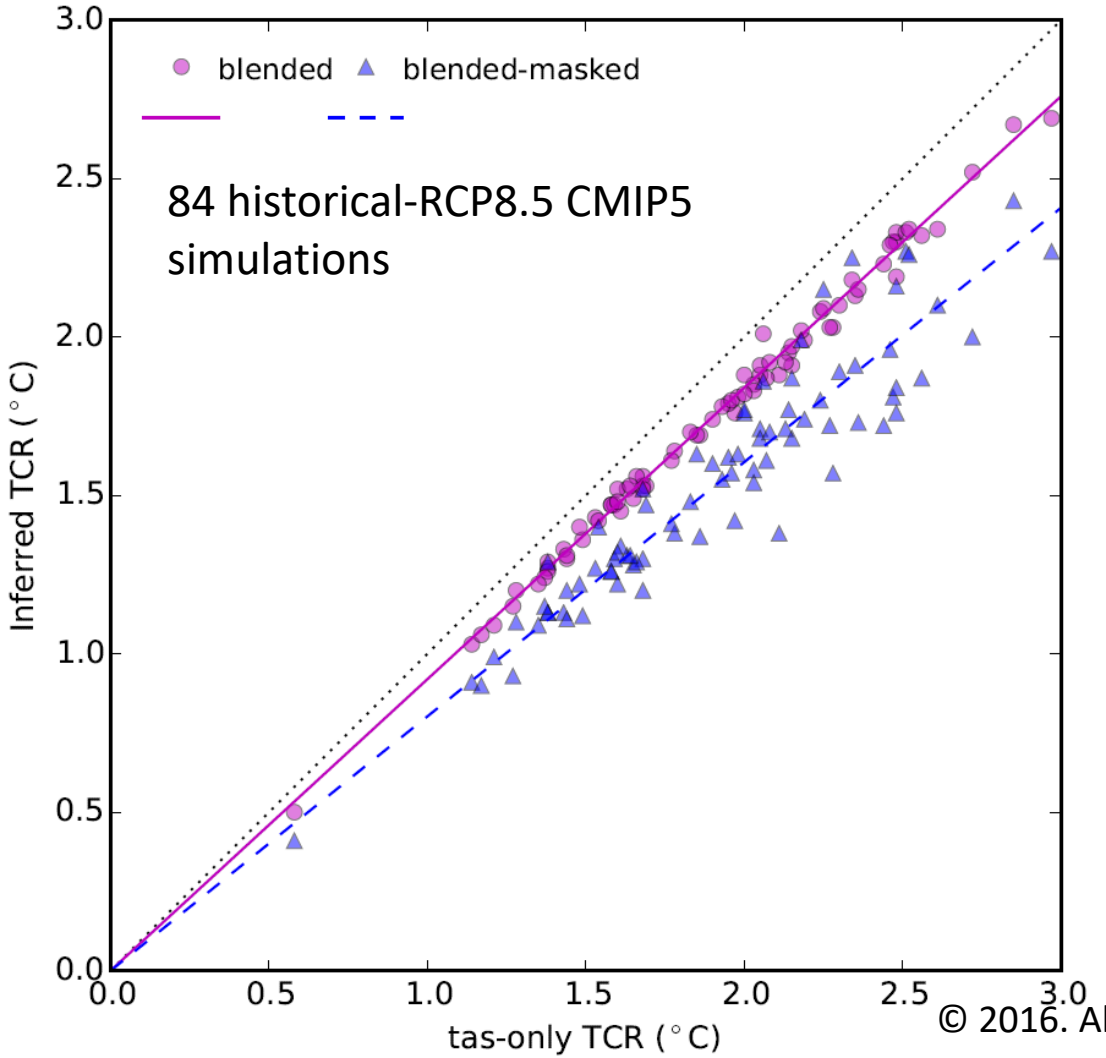
Blended-masking TCR bias in CMIP5 TCR

Historical estimates use HadCRUT4 which:

- “blends” air and water temperatures
- “masks” based on geographical coverage

Global air temperature TCR is ~24 % higher than determined from HadCRUT4 temperature reconstructions



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Correcting the bias

$$TCR = \alpha \, \Delta F_{2\times CO_2} \frac{\Delta T}{\Delta F}$$

α = bias correction, 1.24±0.02

$\Delta F_{2\times CO_2}$ = 3.44±0.34 W m^{-2}

ΔT= 0.73±0.20 K

ΔF=1.94 W m^{-2} (range 0.97—2.81 W m^{-2})

All uncertainties 5—95 % range

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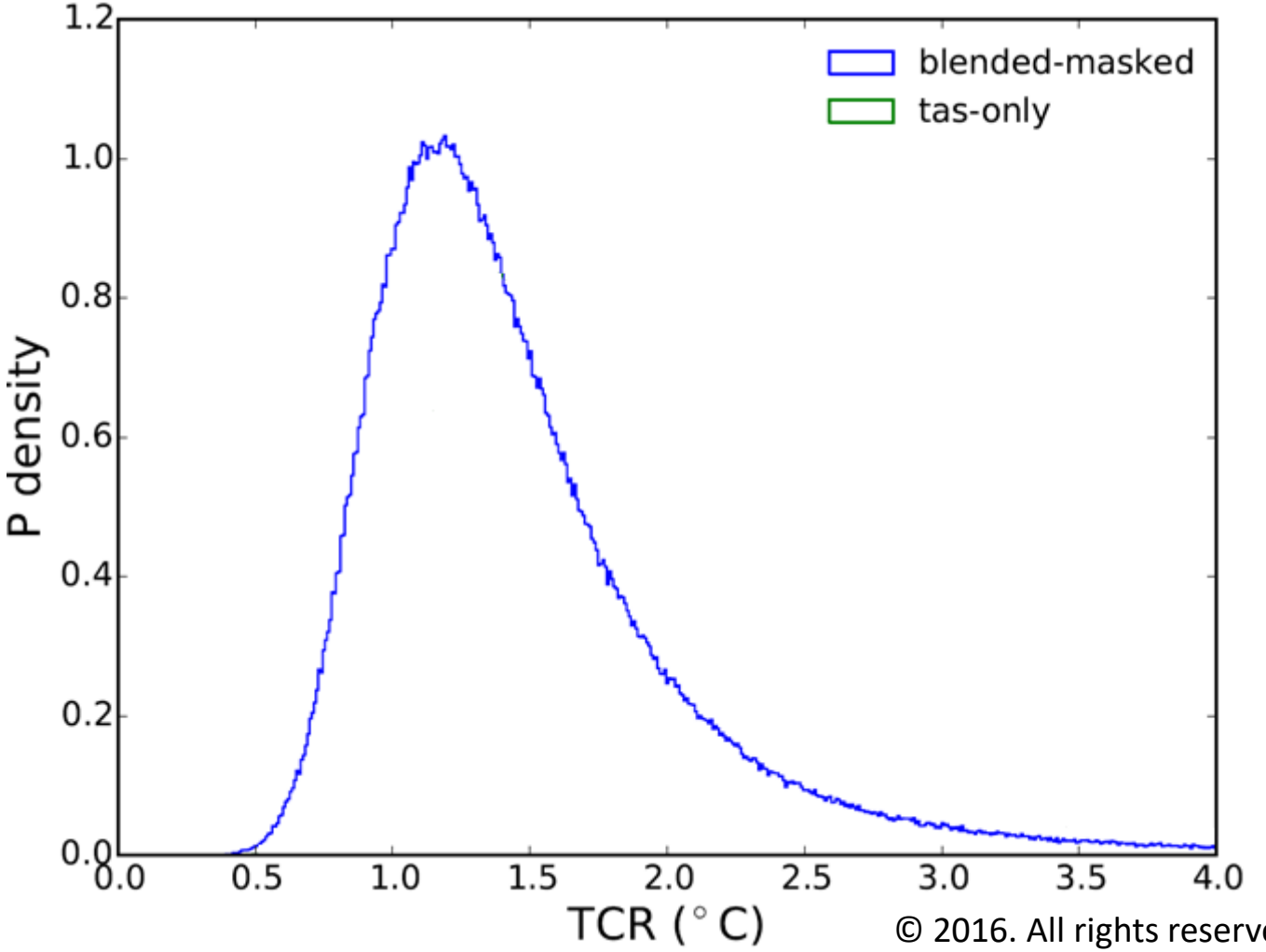

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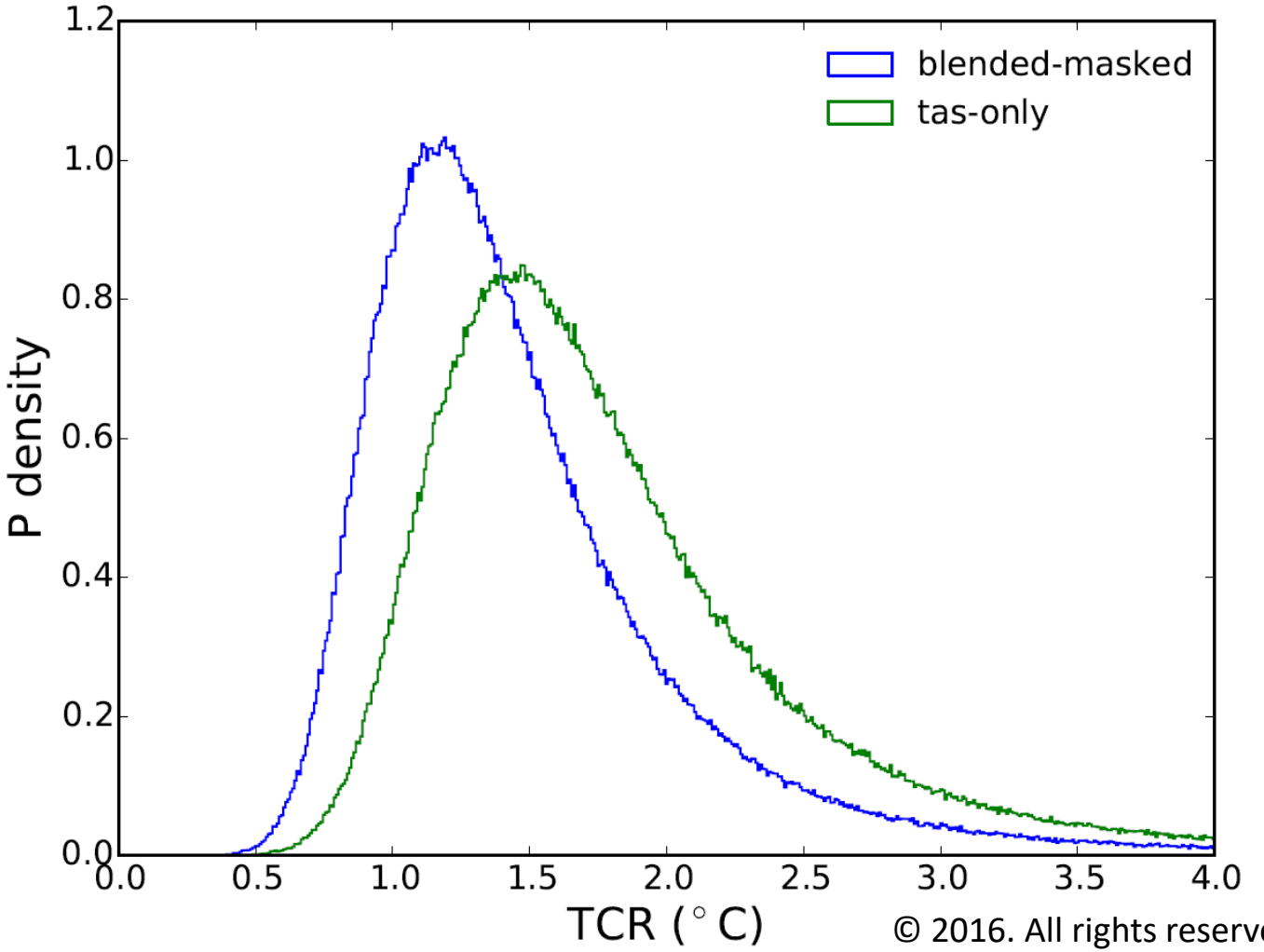

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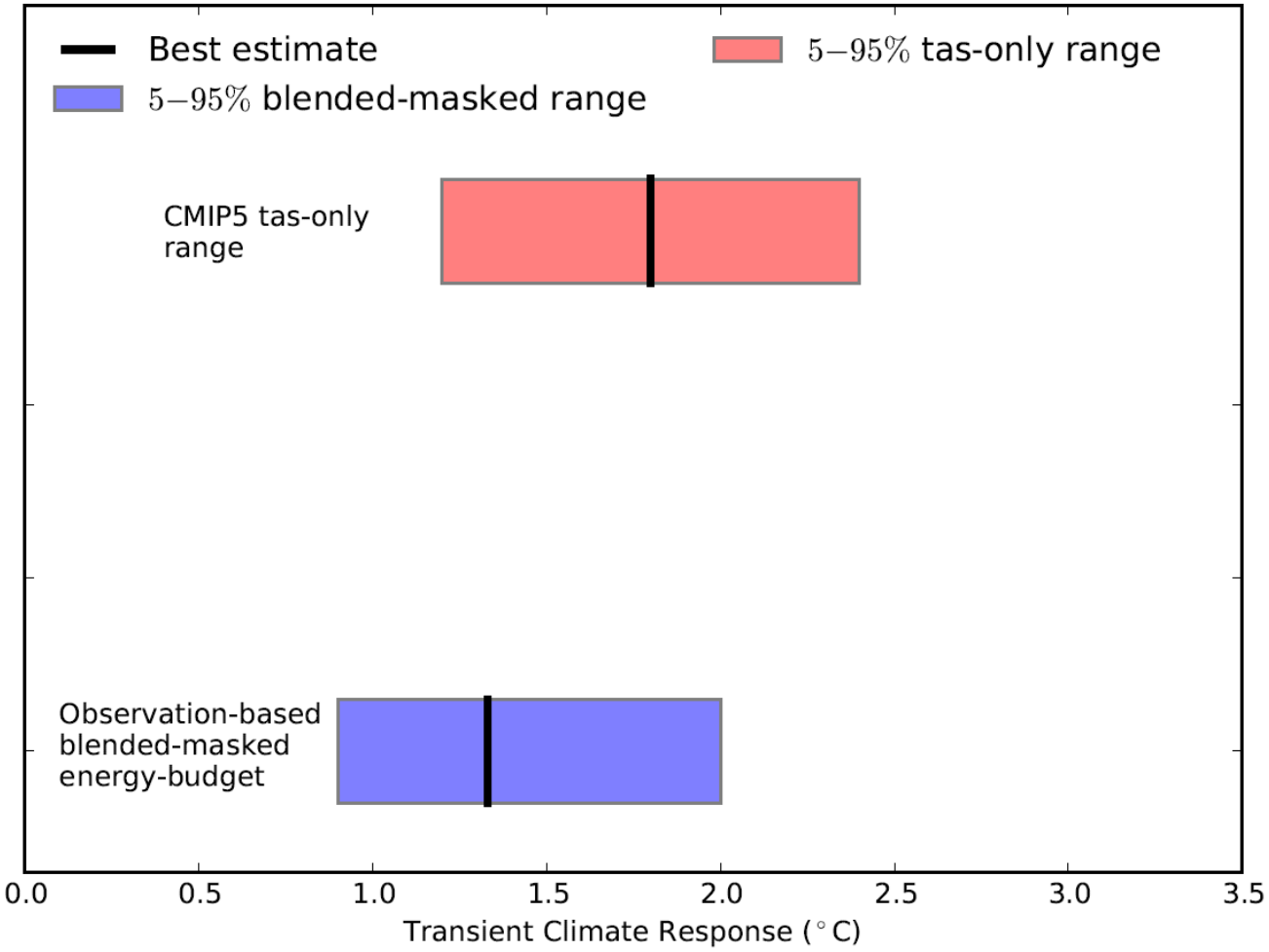
Updated TCR from Earth's energy budget



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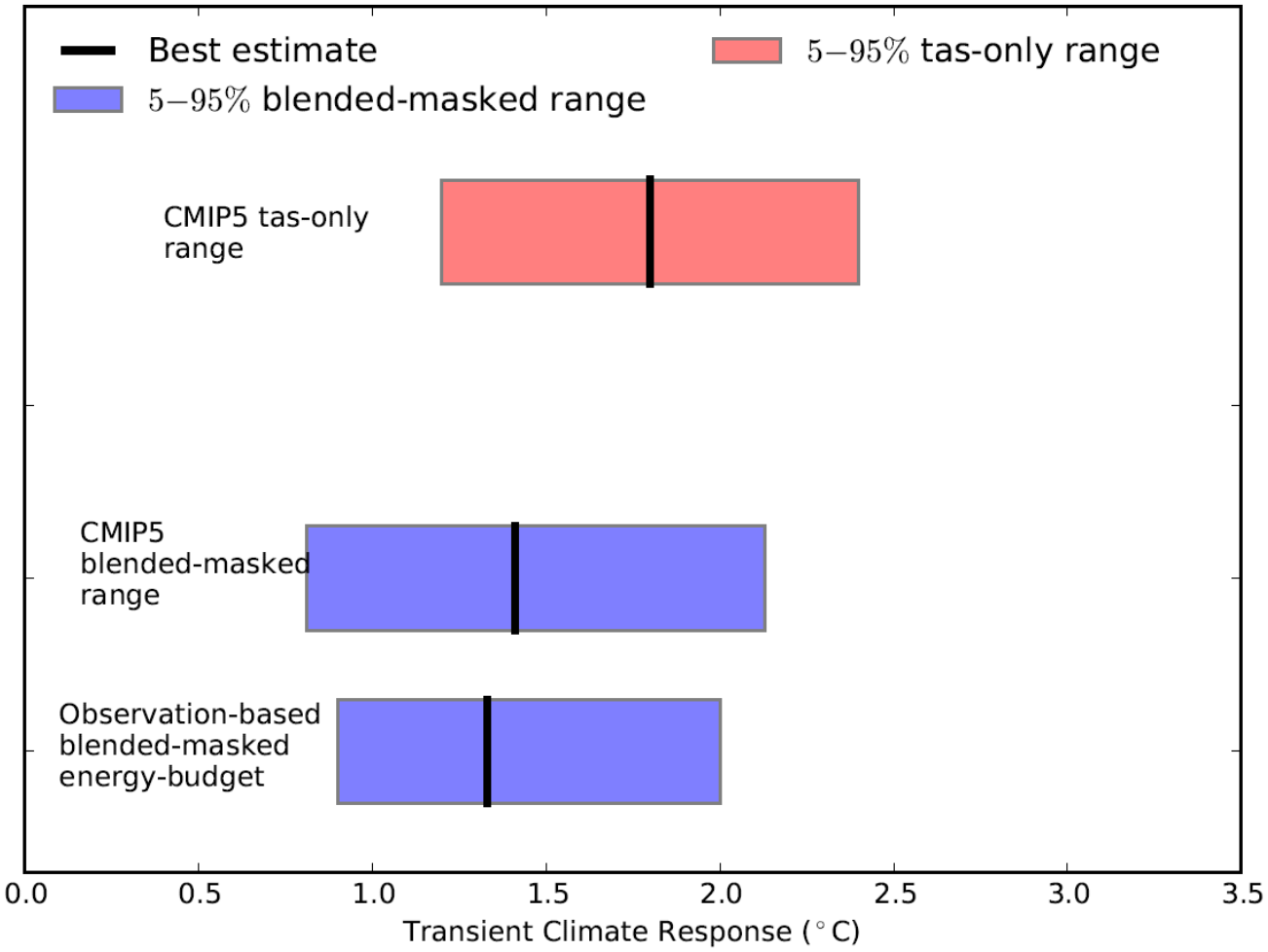

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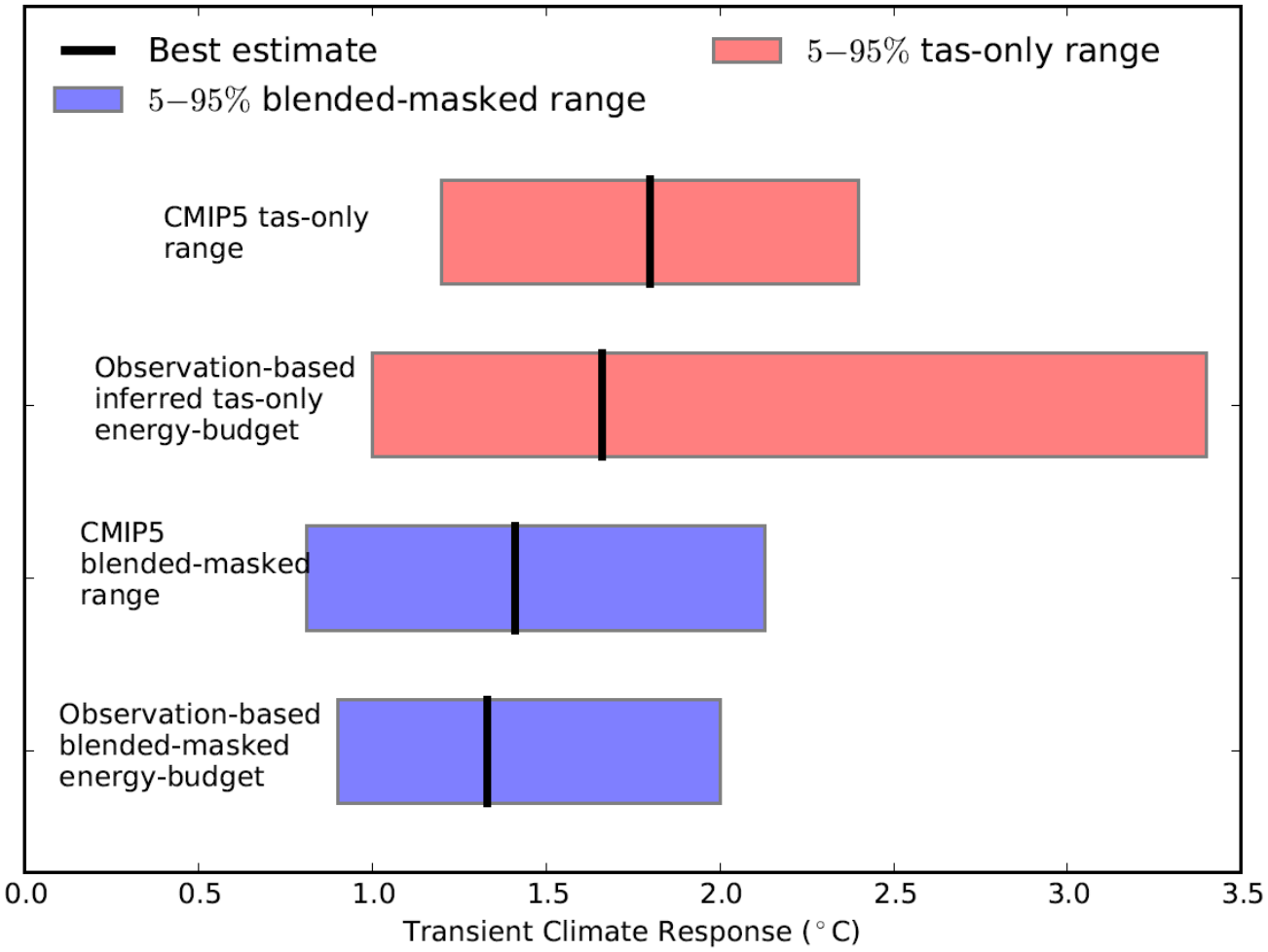

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Relevance

- In energy-budget framework, a 24 % adjustment in TCR also implies 24 % adjustment in equilibrium warming
- If policy is a 2 °C target, *which temperatures* are limited to 2 °C?
- Total “burnable carbon” budget is affected by this judgment

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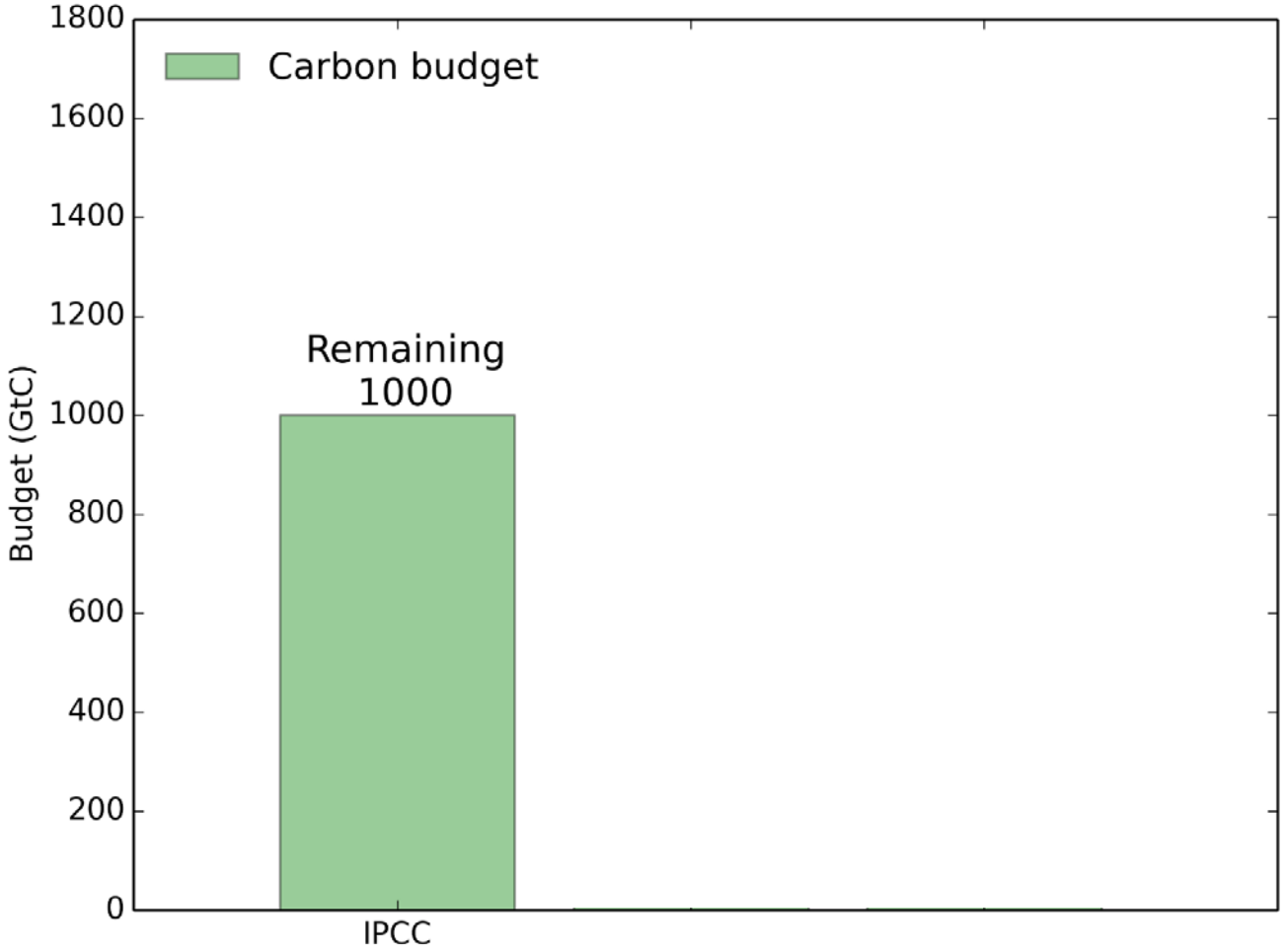
Carbon budgets

Very rough calculation – purely for illustration.
Budget for 66 % chance of achieving 2 C aim

Current emissions ~ 10 GtC/yr



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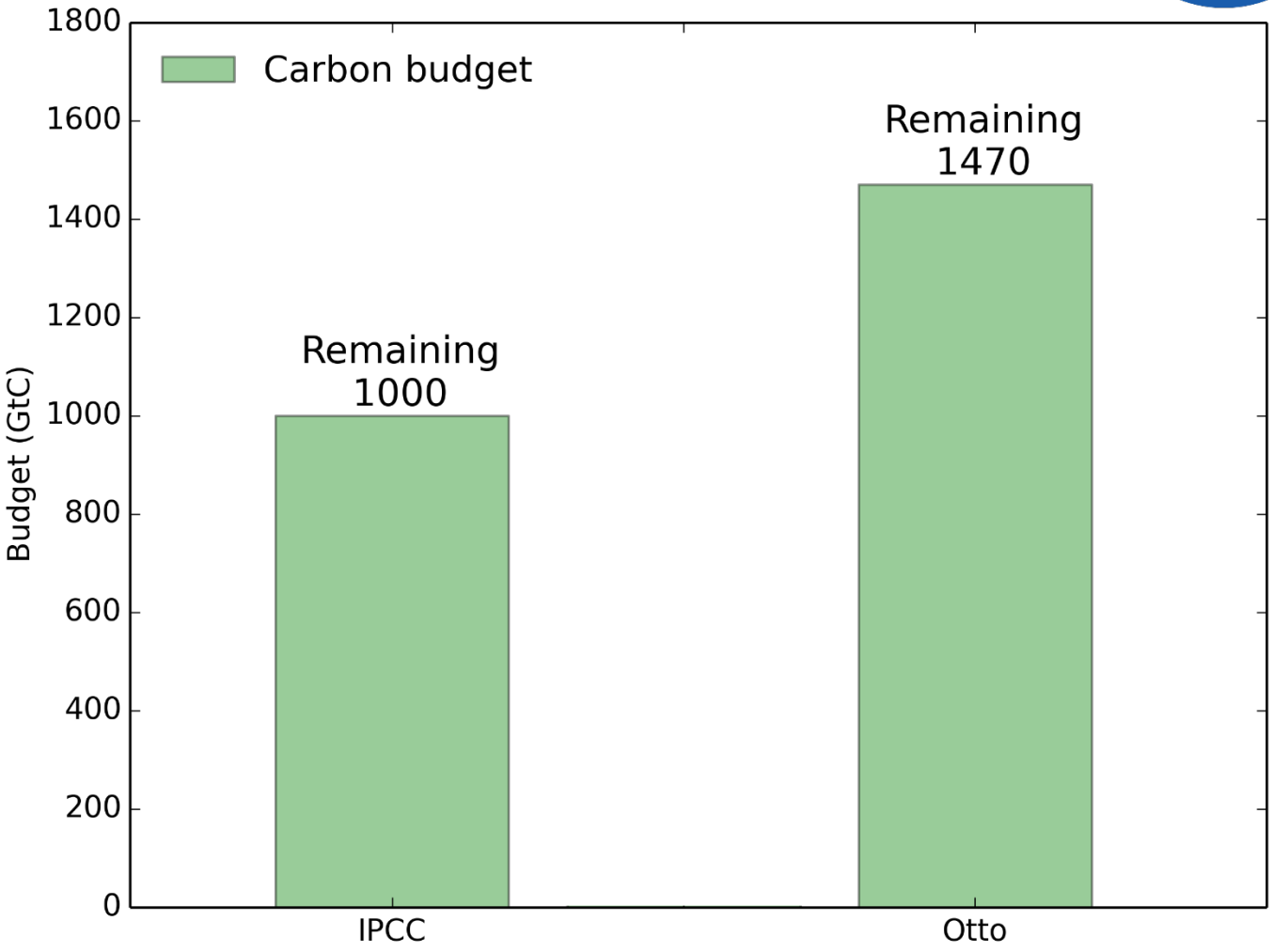

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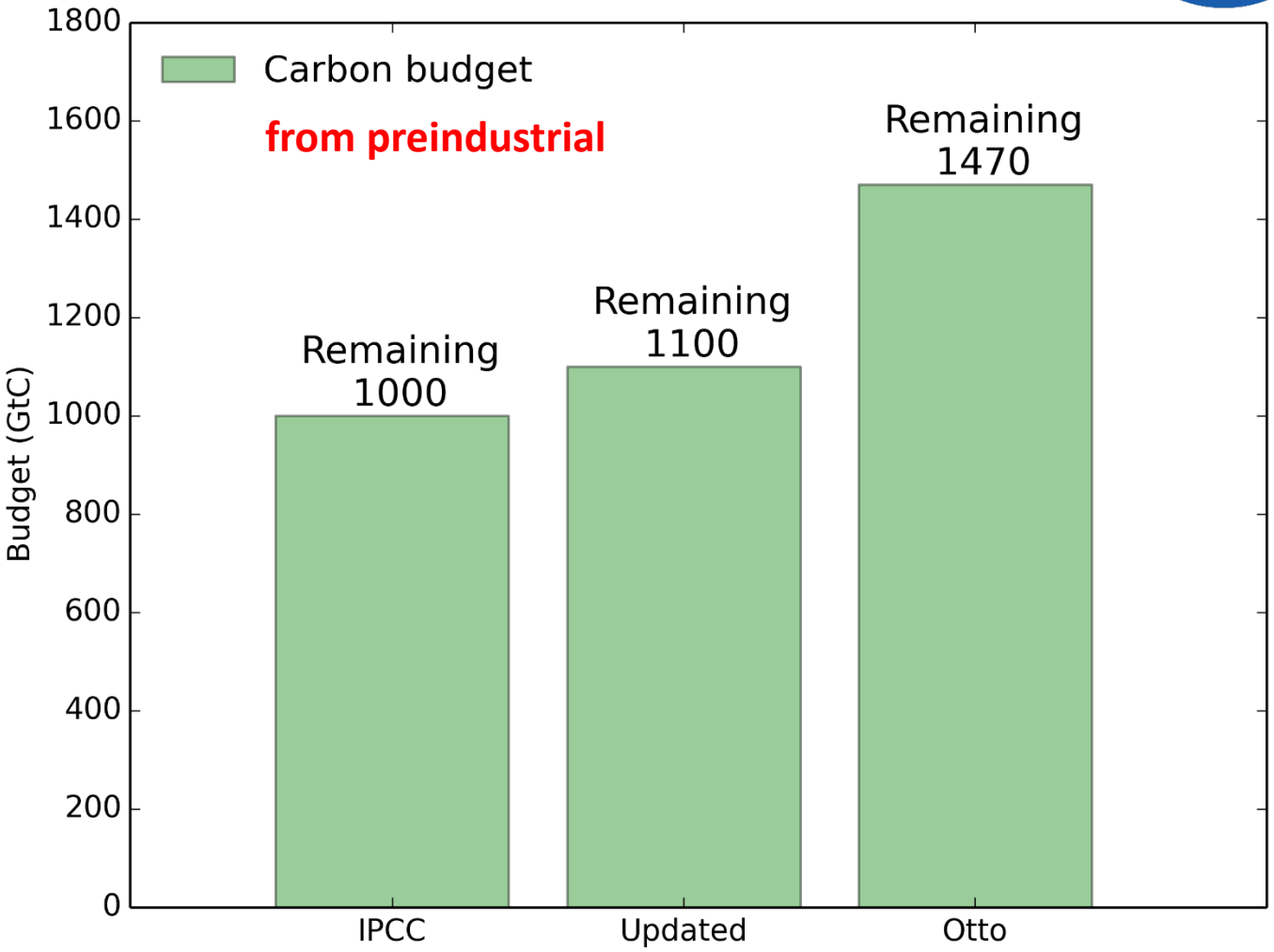

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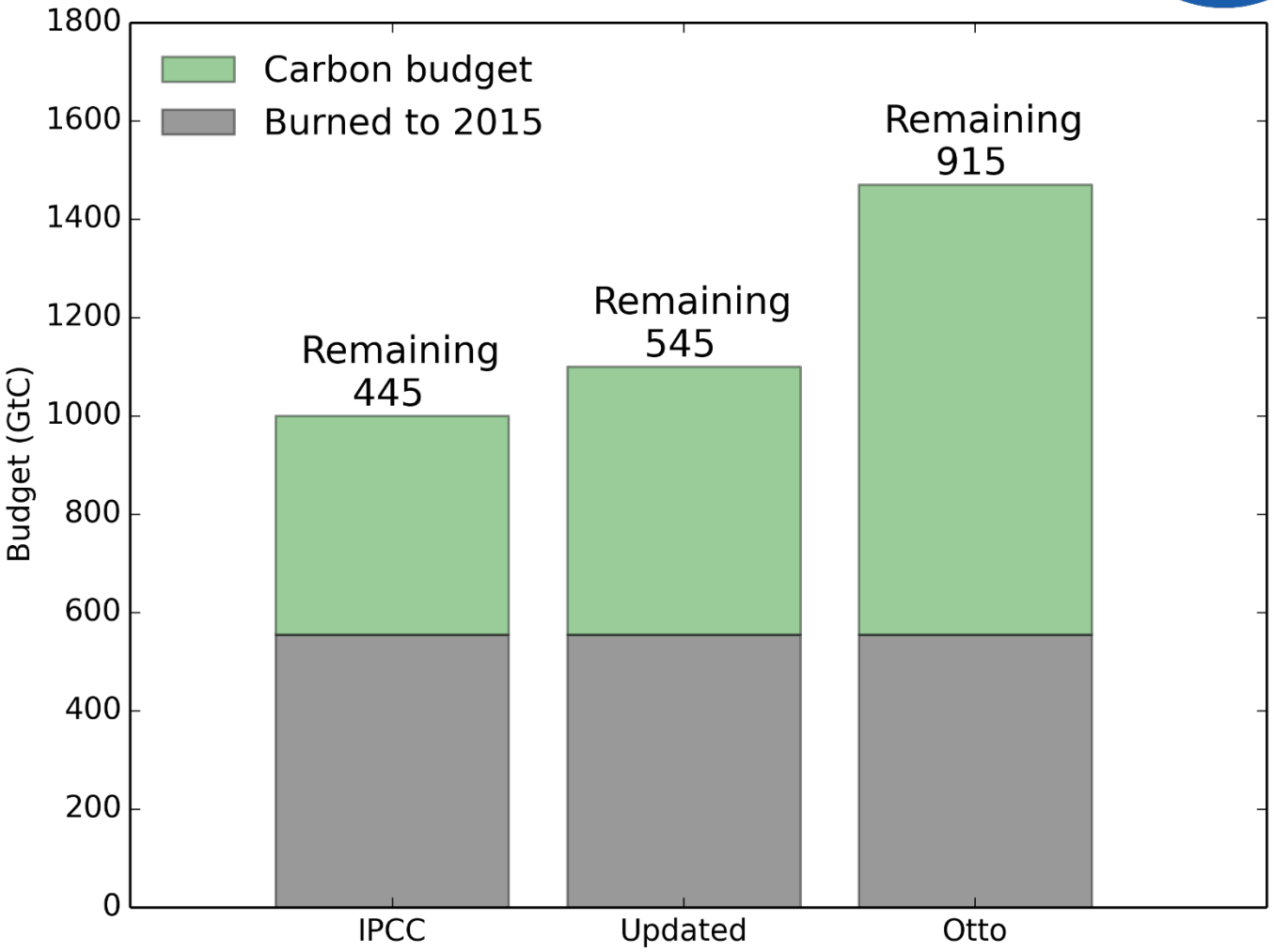
Carbon budgets



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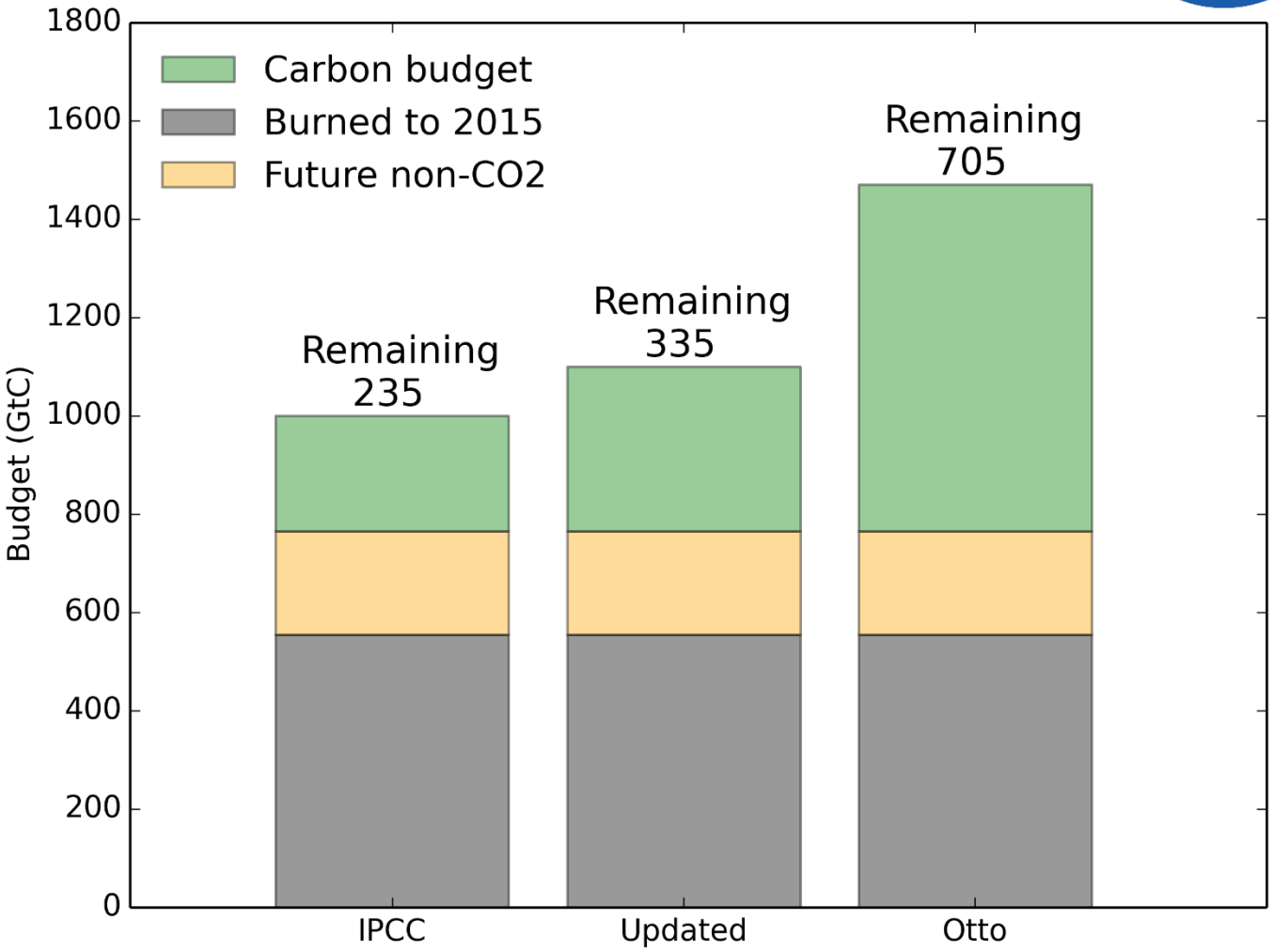
Carbon budgets

Very rough calculation – purely for illustration

Difference in implied carbon budget, in years of current emissions is:

IPCC = 23 years
Updated energy budget = 33 years
Otto et al. = 70 years

Could affect policy decisions despite very large uncertainty



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Conclusions 2

- **Global temperature records probably underestimate global air temperature change**

- This results in biased estimates of transient climate response (TCR) when techniques are applied to CMIP5 models
- Global air temperature response 24 % higher than estimated from energy-budget studies over historical period
- Largely resolves a disagreement in IPCC report (but could be right answer for wrong reason)

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