Antarctic ice-sheet meltwater drives lower effective climate sensitivity through the pattern effect

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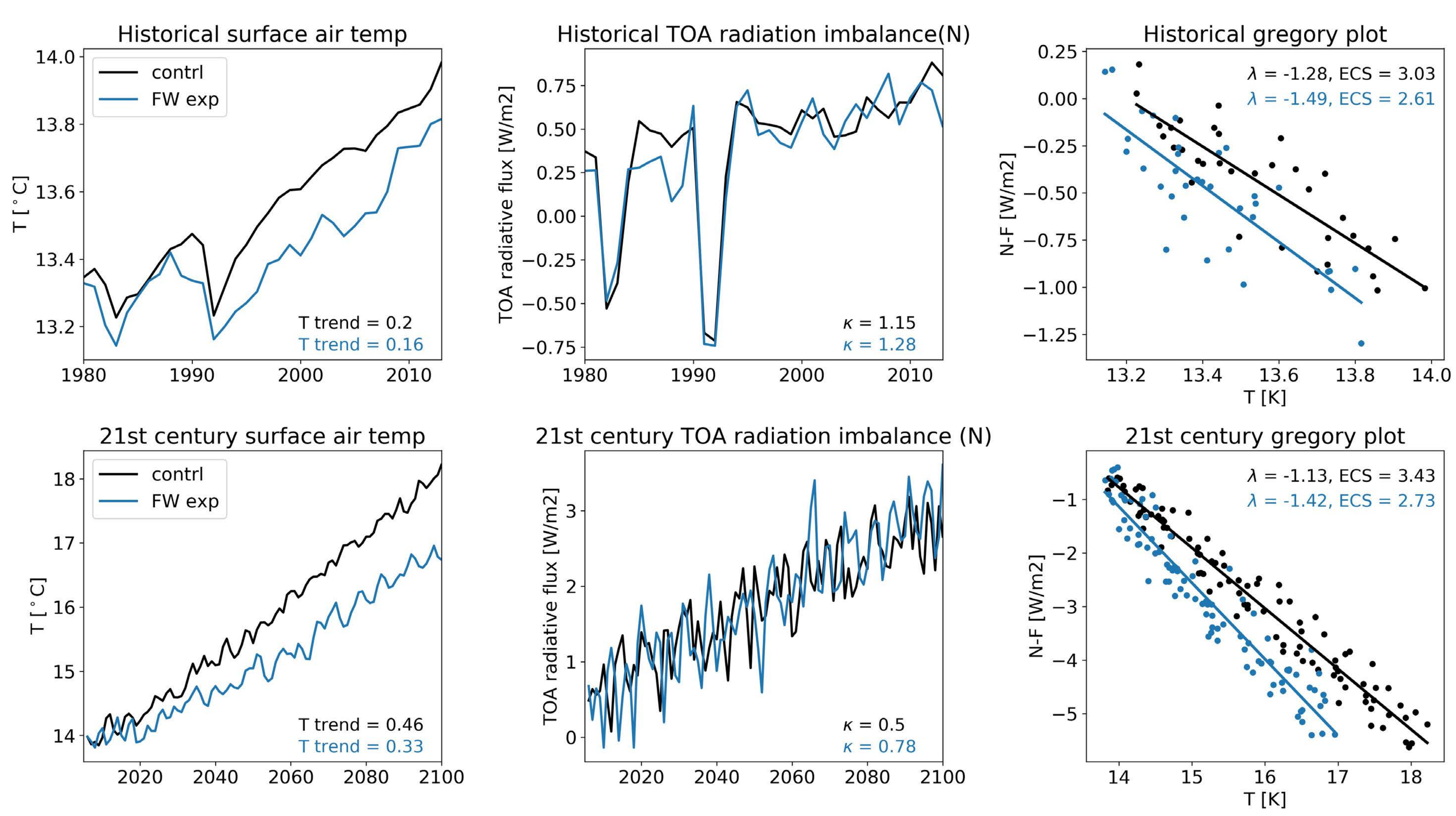
- **Background:**
  - Coupled GCMs generally fail to reproduce the observed SST trend pattern since the 1980s, leading to biased estimates of effective climate sensitivity
- **Simulations:**
  - We employ two sets of CESM1 simulations forced by Antarctic ice-sheet meltwater fluxes, over 1980-2013 with all historical forcing and over the 21st century with RCP8.5 forcing respectively
- **Results:**
  - Both show a reduced global warming rate and an SST trend pattern closer to observed, with cooling in the Southern Ocean and the southeast Pacific
  - The reduced global warming is found to arise from both increased ocean heat uptake efficiency (more heat being taken down to the deep ocean) due to changes in ocean mixing, and a more stabilizing radiative feedback (more heat being released out at TOA) due to changes in SST pattern
- **Implications:**
  - Accounting for Antarctic meltwater may change projections of transient global warming and EffCS through the pattern effect

Antarctic meltwater input results in reduced warming rate, together with increased OHU efficiency (κ) and strengthened radiative feedback (λ)



Question 2: Which (change in OHU efficiency or change in feedback) contributes more to the reduced global warming?

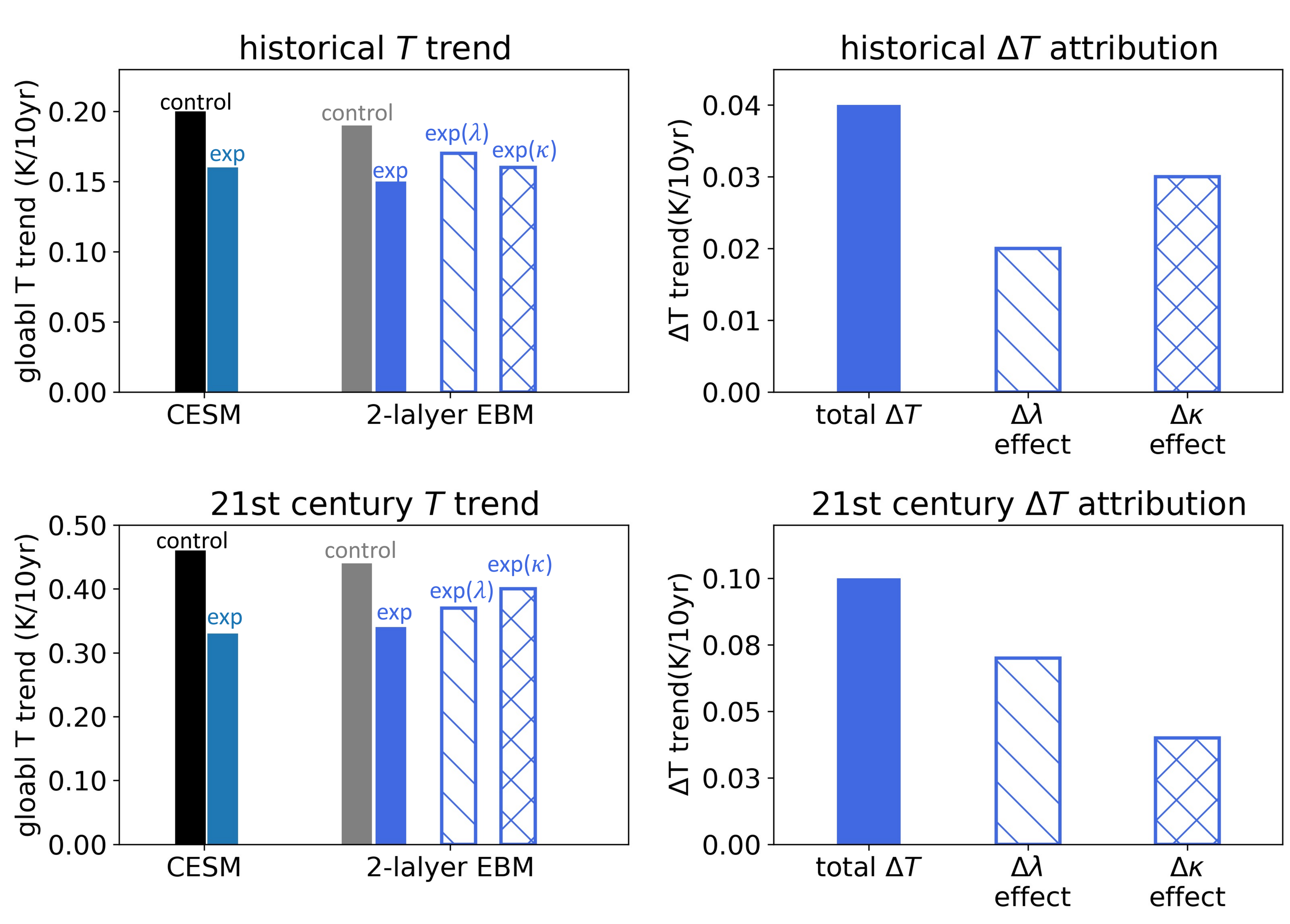
Energy budget constraints

$$T = \frac{F}{\kappa + |\lambda|}$$

OHU efficiency: $\kappa = \partial N / \partial T$
Radiative feedback: $\lambda = \partial (N - F) / \partial T$

We employ 2-layer energy balance model (EBM) as in (Geoffory et al. 2013), with λ and κ values from the CESM runs, which can reproduce the warming trends in CESM (c.f. color-filled bars on the left panel below)

Then we run EBM with λ or κ from the meltwater experiments respectively (keeping the other unchanged), to examine the contribution of λ and κ changes to the total decrease in the warming trend.



Both $\Delta\lambda$ and $\Delta\kappa$ cause the reduction of global T

Over historical period, $\Delta\kappa$ contributes more to the global cooling

Over 21st century, $\Delta\lambda$ contributes more to the global cooling

Two sets of Antarctic meltwater hosing simulations within CESM1-CAM5

1. Historical (1980-2013)
extended from (*Pauling et al. 2016 J. Climate)*
- 6 ensemble members with meltwater imposed at depth
- constant meltwater input of 2000Gt/yr for each run

2. RCP8.5 21st century (2005-2100)
from (*Sadai et al. 2021 Science Advance)*
- 1 ensemble member under RCP8.5
- spatially-temporally varying Meltwater estimated by an offline ice-sheet model

We have also performed RFMIP-type of fixed-SST runs with varying historical and RCP8.5 forcing agents, to get time-varying effective radiative forcing in order to diagnose the energy budget

Question 1: What causes the change in radiative feedback in response to Antarctic meltwater?

Meltwater input reduces deep-ocean mixing, leading to surface cooling and enhanced OHU over the Southern Ocean.

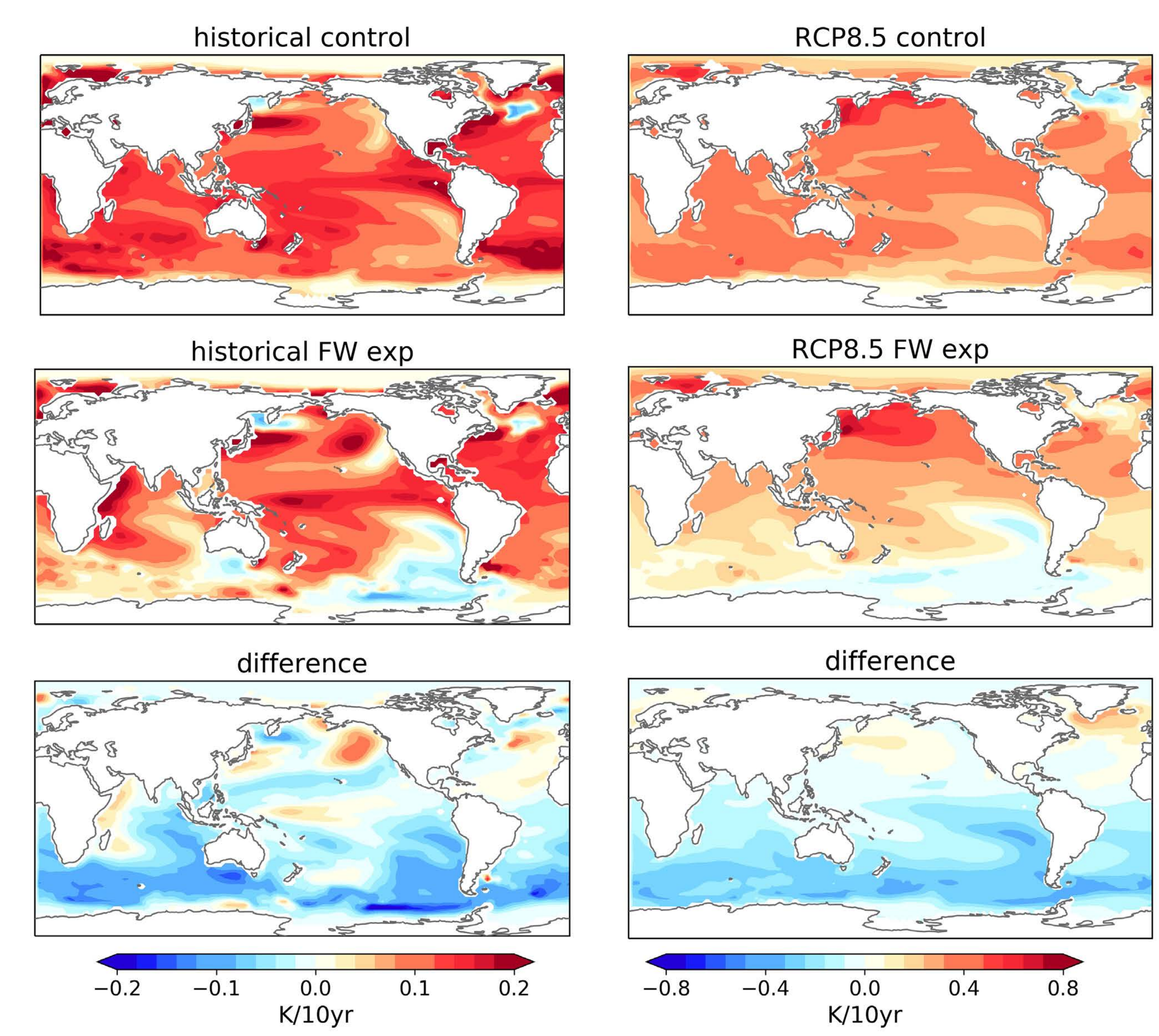


Fig. SST trend maps from CESM control and meltwater exp

The Southern Ocean surface cooling further propagates to the tropical southeast Pacific through teleconnections, promoting local negative cloud feedback.

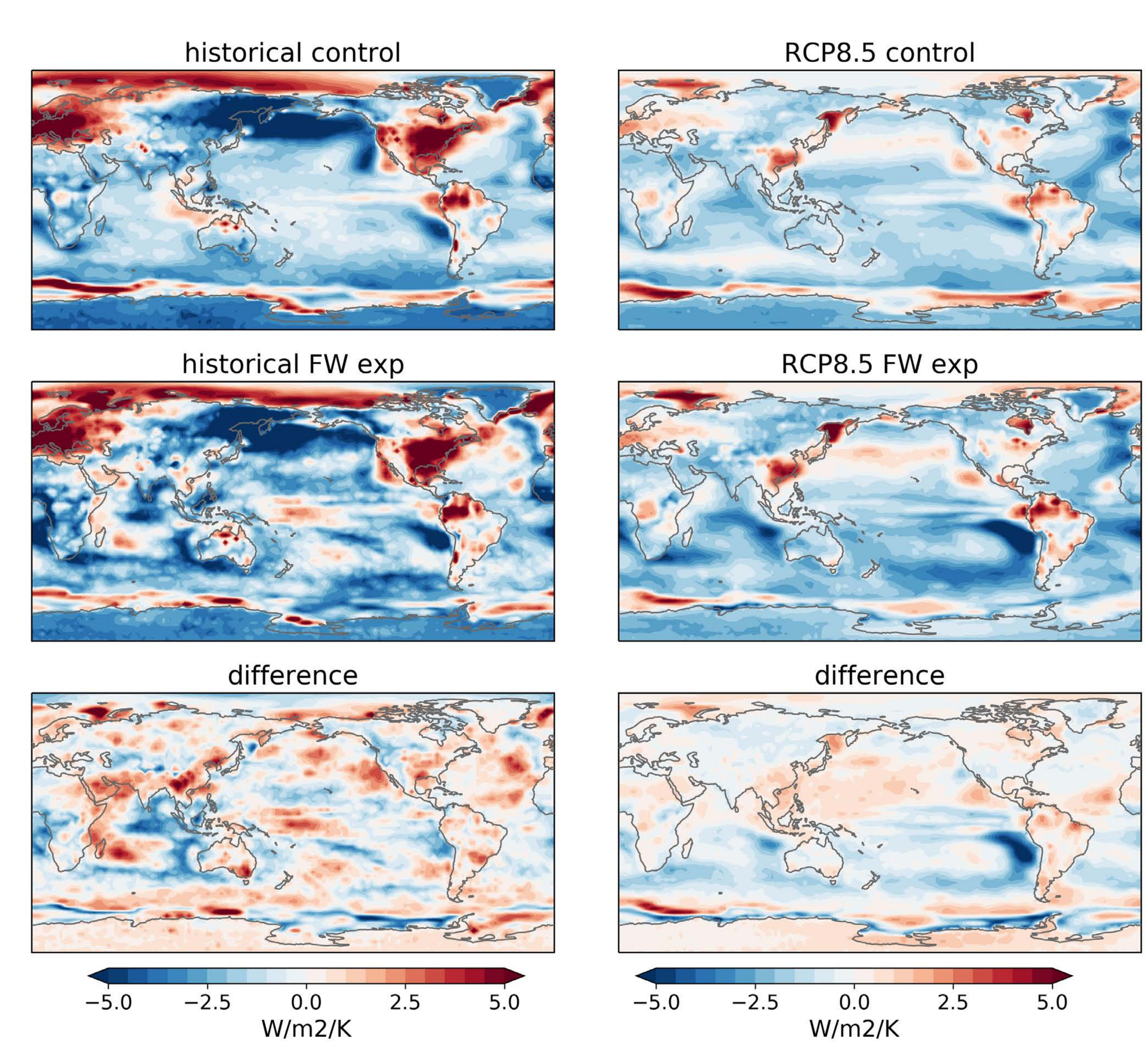


Fig. Local λ from CESM control and meltwater exp