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Evaluation of Northern Hemisphere snow water equivalent in CMIP6 models during 1982-2014

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Introduction

- Global SWE shows negative trend, but seasonal and temporal variability is large
- Climate models have had difficulties in correctly reproducing the seasonal snow and its recent trends
- How the new CMIP6 climate models can describe the seasonal snow, and where the uncertainties and discrepancies arise?

The main goals of this study are:

1. to intercompare the CMIP6 and observation-based SWE estimates and
2. to analyze whether temperature and precipitation biases could explain the SWE biases

Model data

CMIP6

- **17** models (resolution 100 km)
- **Variables**: snw, pr and tas
- **Experiment ID**: historical and esm-hist

Institution	Model	Experiment ID
BCC	BCC-CSM2-MR	historical
		esm-hist
NCAR	CESM2	historical
	CESM2-WACCM	historical
LLNL	E3SM-1-0	historical
EC-Earth-Consortium	EC-Earth3	historical
	EC-Earth3-AerChem	historical
	EC-Earth3-CC	esm-hist
	EC-Earth3-Veg	historical
NOAA-GFDL	GFDL-CM4	historical
	GFDL-ESM4	historical
		esm-hist
MPI-M	MPI-ESM1-2-HR	historical
MRI	MRI-ESM2-0	historical
NCC	NorESM2-MM	historical
SNU	SAM0-UNICON	historical
AS-RCEC	TaiESM1	historical

Observation-based data

Snow water equivalent (SWE)

- **Non-mountainous regions:** Bias-corrected SnowCCI
  - Satellite passive microwave radiometer data, in situ snow depth data and snow course SWE measurements
  - The bias-correction method significantly reduces the uncertainty of NH SWE estimation
- **Mountainous regions**: mean of MERRA-2, Brown and Crocus v7 datasets

Temperature (T)

- MERRA-2 reanalysis
- 2 m air temperature

Precipitation (P)

- GPCC Version 2018 data
- Based on data from rain gauge stations

Methods

- **Study area**: snow-covered land areas (SWE > 10 kg m^{-2}) north of 40 °N
- **Study period**: 1982-2014
- Comparison grid cell by grid cell

SWE in winter:

- How the SWE bias in February depends on the P and T biases from November to January?

SWE in spring:

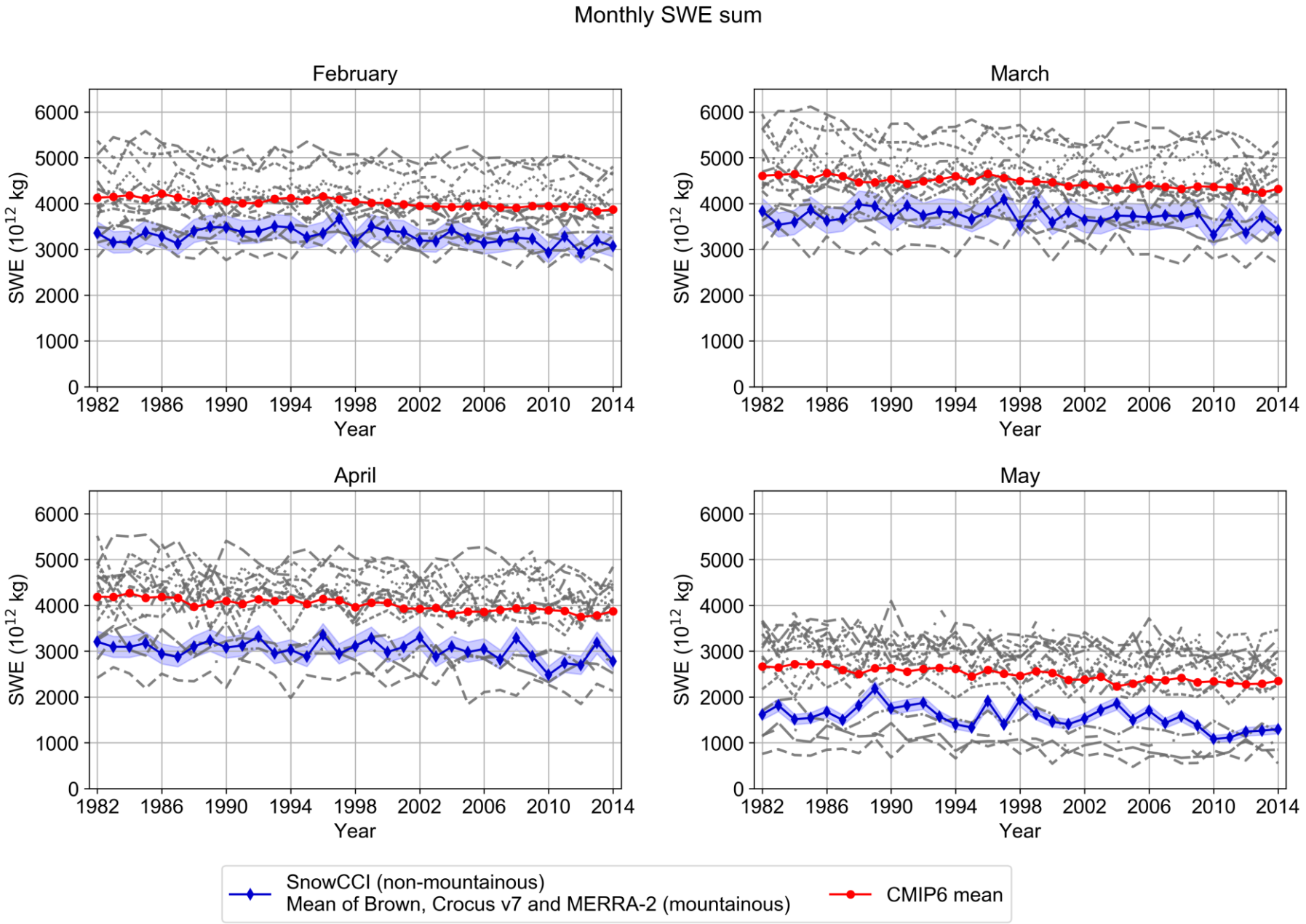
- How the bias in monthly SWE change depends on the P and T biases?

SWE biases was split into **three components** using **linear regression analysis** and the **mean model biases**:

1. the contribution of T ($\mathbf{T_C}$)
2. the contribution of P ($\mathbf{P_C}$)
3. the contribution of other factors (the residual term, **R**)

Results

Models on average overestimate SWE



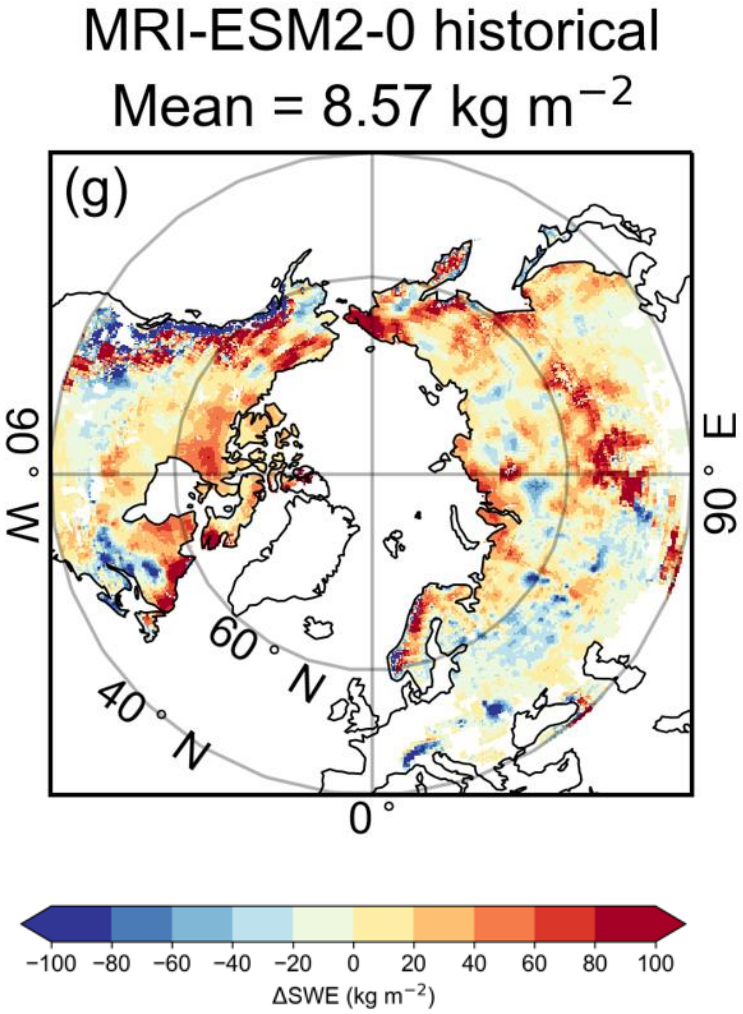
Grey dashed lines = individual CMIP6 models

Blue shaded area = the 7.4% uncertainty range of the SWE reference data

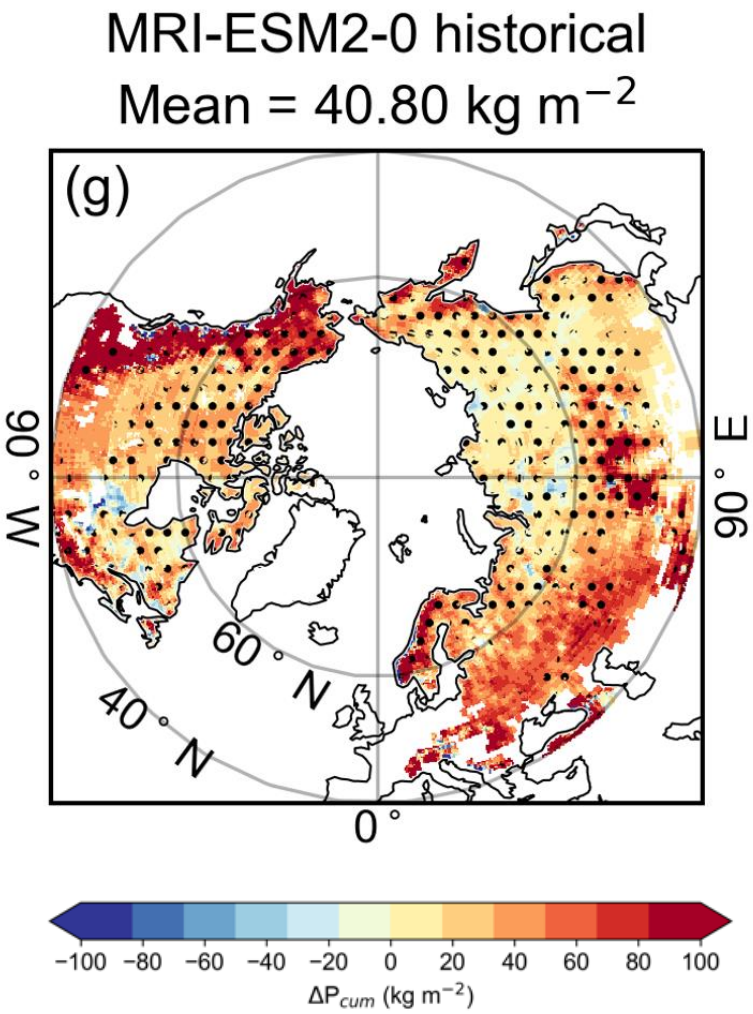
Results: winter

The models show on average positive bias in SWE, P and T

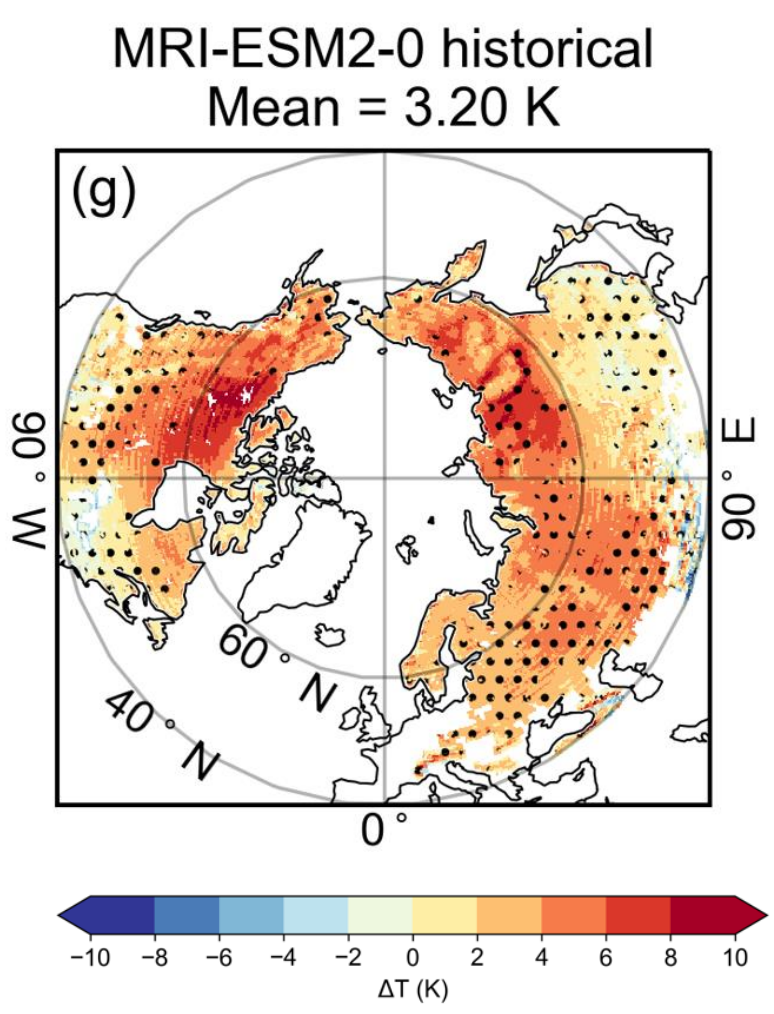
SWE bias



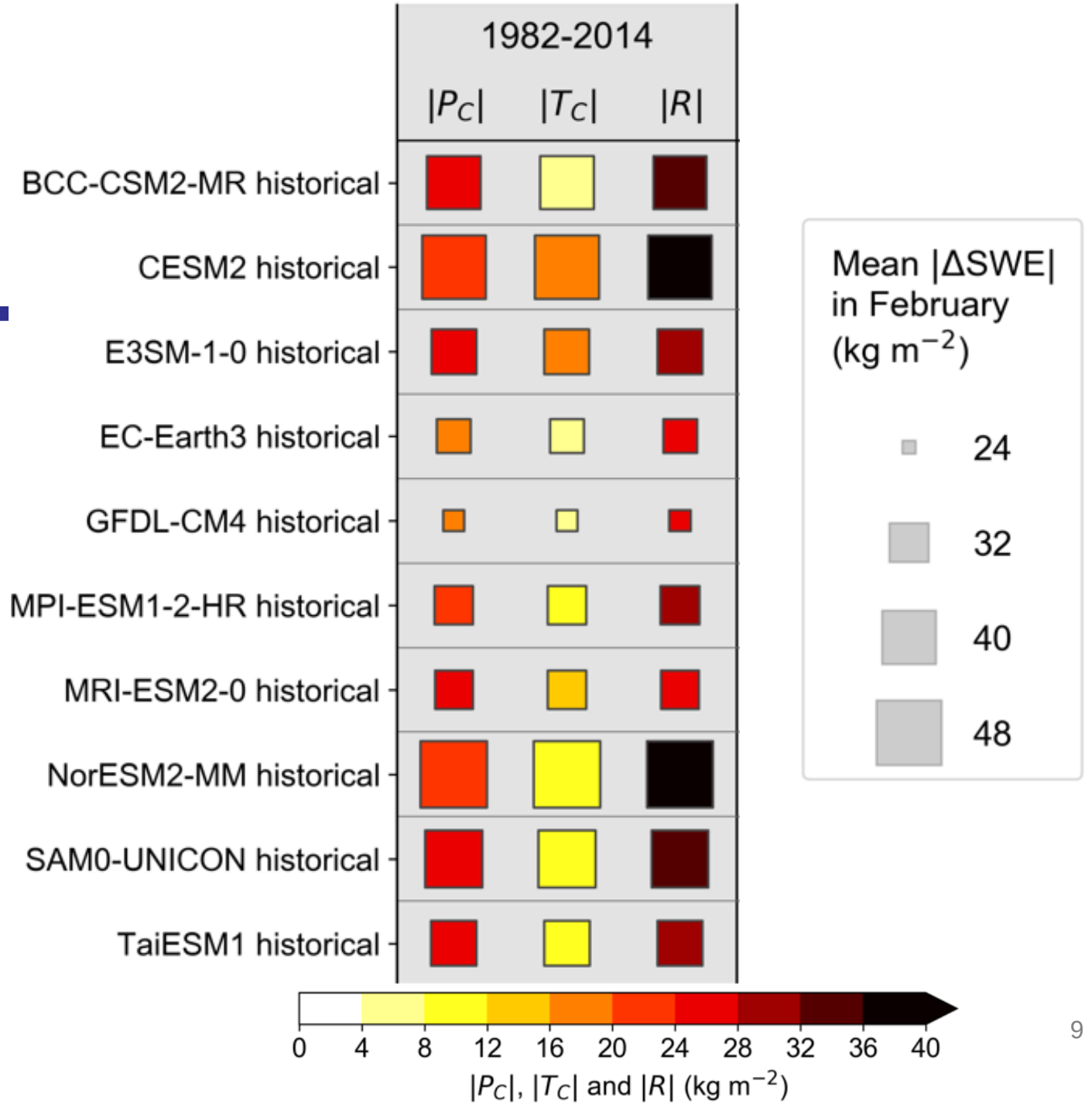
P bias



T bias



The contribution of P is larger than the contribution of T



T_C = the contribution of T
P_C = the contribution of P
R = the contribution of other factors
ΔSWE = SWE bias

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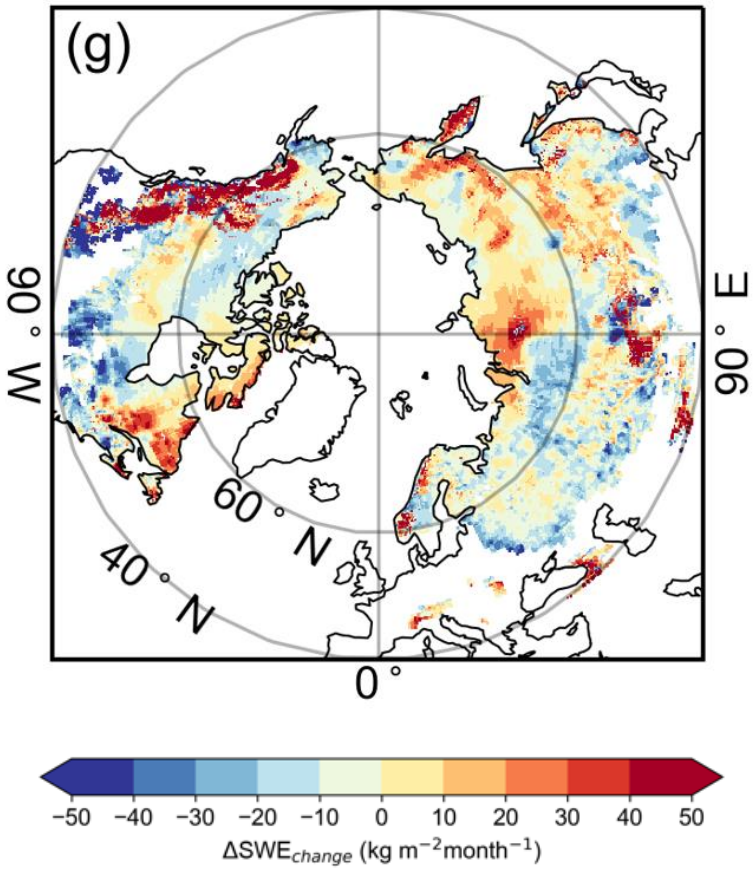
Results: spring

The model biases show large variability

SWE bias

MRI-ESM2-0 historical

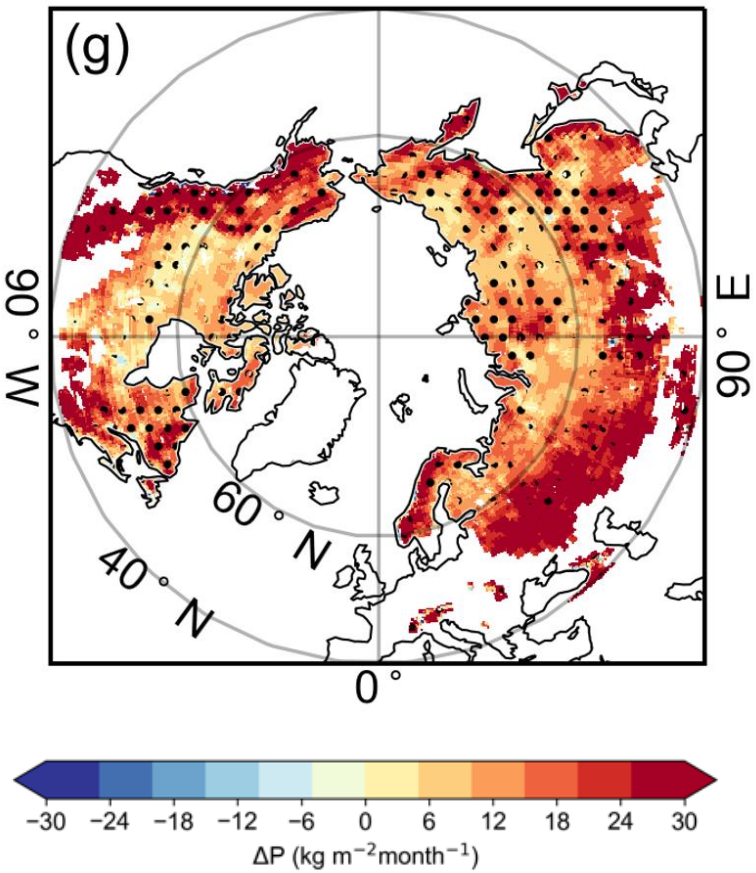
Mean = -0.15 kg m^{-2}month^{-1}



P bias

MRI-ESM2-0 historical

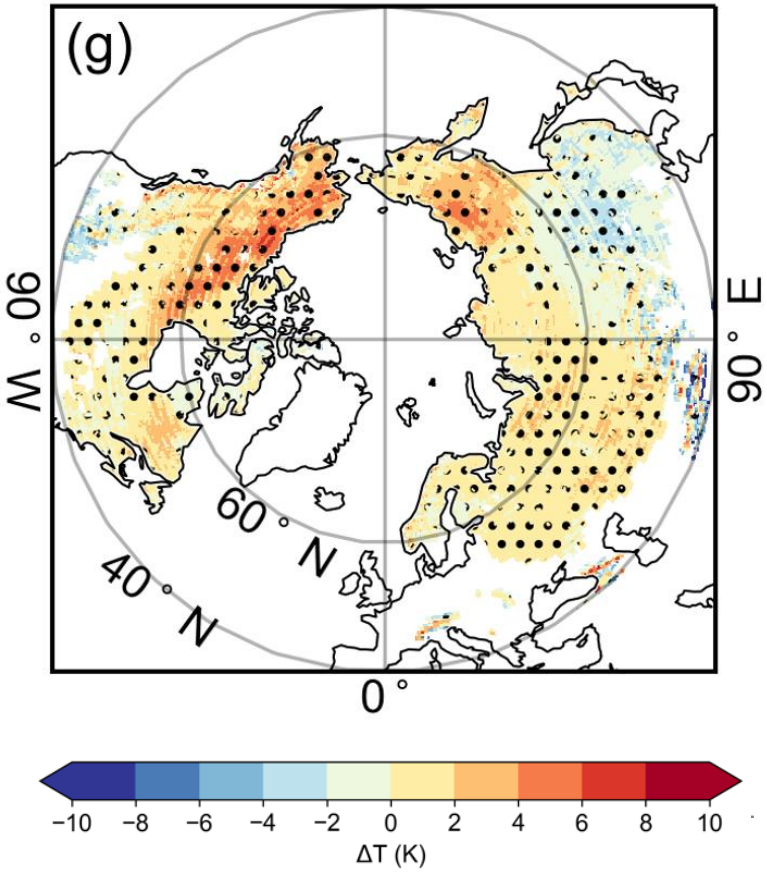
Mean = 19.12 kg m^{-2}month^{-1}



T bias

MRI-ESM2-0 historical

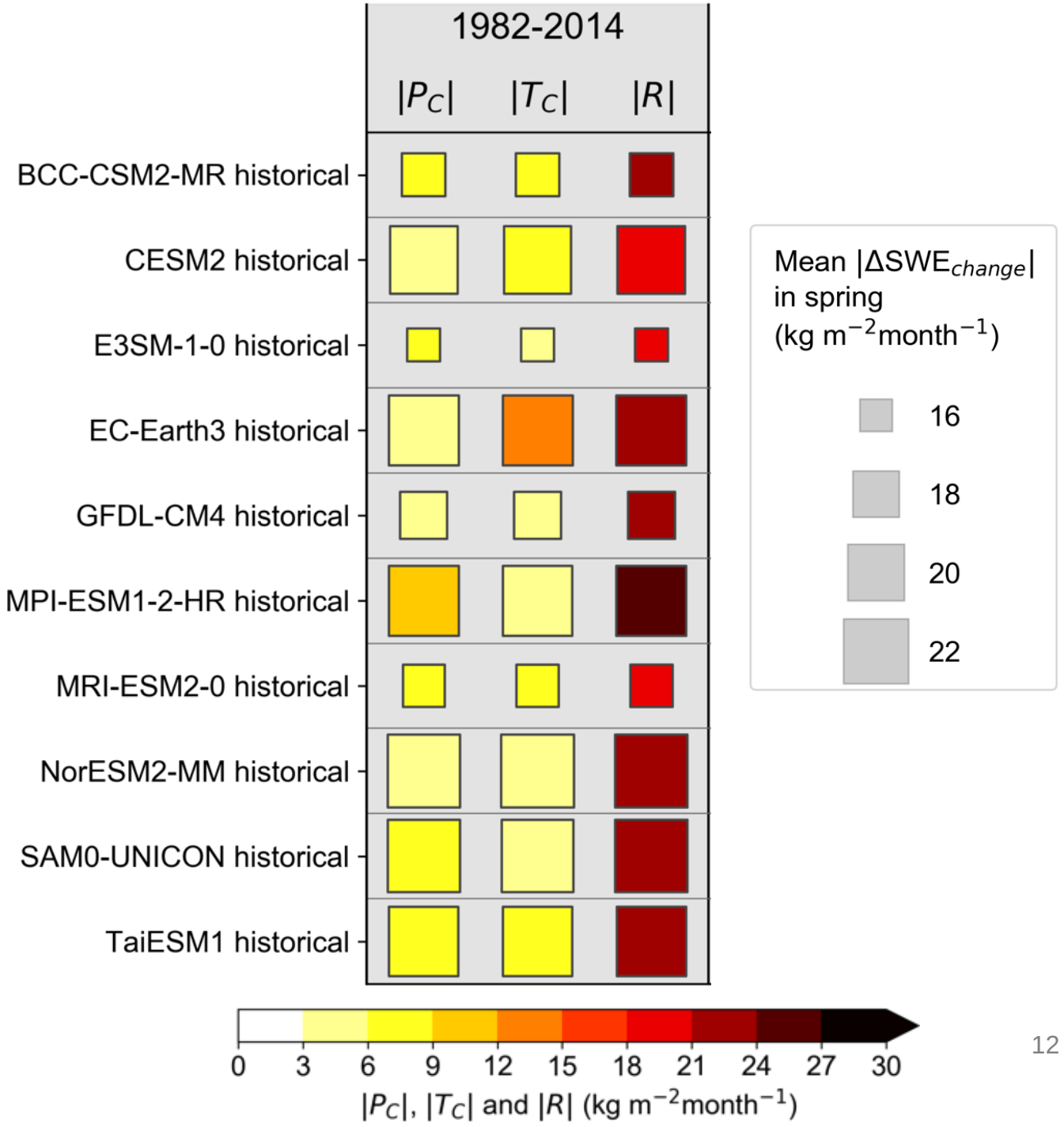
Mean = 0.72 K



The residual term is larger than the contributions of T or P

→ The biases in snow melt rate in spring are dominated by other factors than T or P

T_C = the contribution of T
P_C = the contribution of P
R = the contribution of other factors
ΔSWE_{change} = bias in monthly SWE change



Conclusions

- The models generally overestimate SWE, but large variability exists between models
- In winter, the contribution of P to SWE bias is larger than the contribution of T
  - The residual is also typically large, indicating that P and T cannot explain the SWE biases alone
- In spring, the large residual term indicates that the biases in snow melt rate in spring are dominated by other factors than T or P
- Further analysis would be required in the future to fully understand the factors behind the residual term.

Thank you!

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Kouki, K., Räisänen, P., Luojus, K., Luomaranta, A., & Riihelä, A. (2021). Evaluation of Northern Hemisphere snow water equivalent in CMIP6 models with satellite-based SnowCCI data during 1982–2014. *The Cryosphere Discussions*, 1-32.