Can We Do Better at Predicting Regional Hydroclimate

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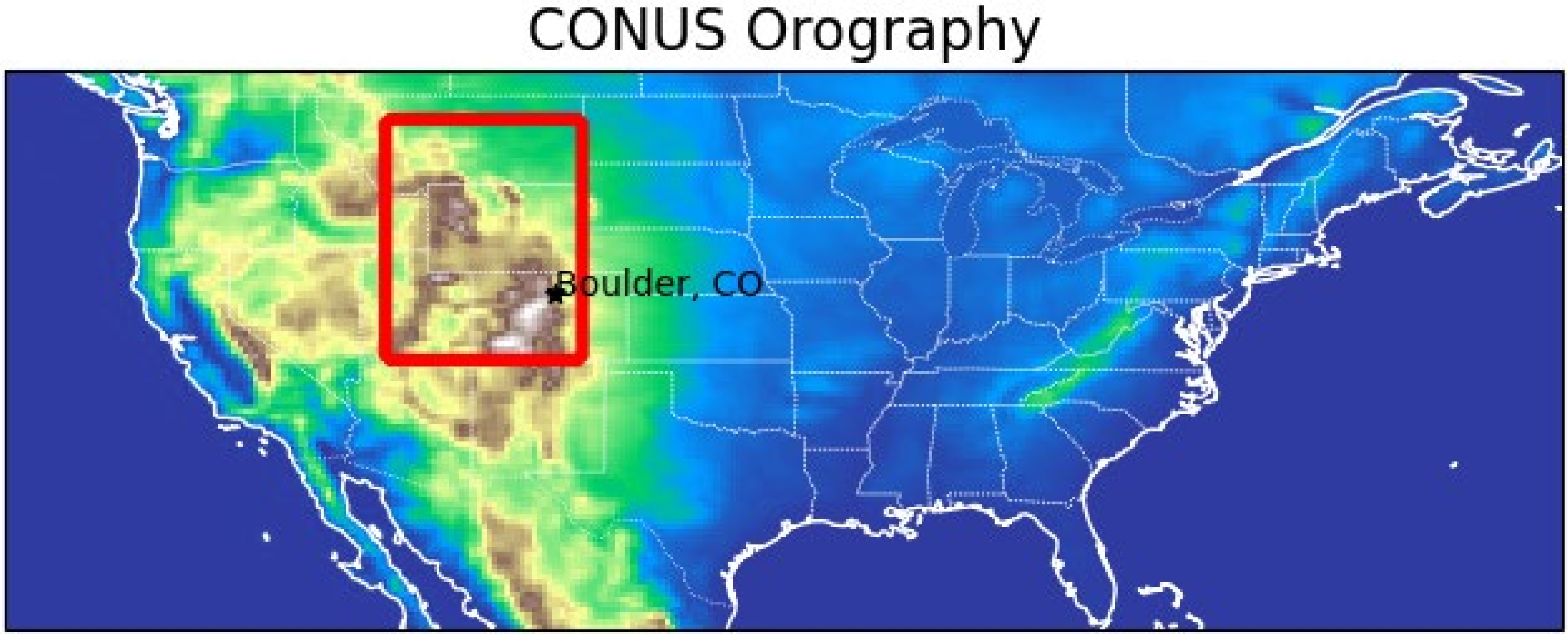
2024 CESM Workshop

Earth System Predictability Working Group

The American Mountain West



What causes precipitation in the Mountain West?

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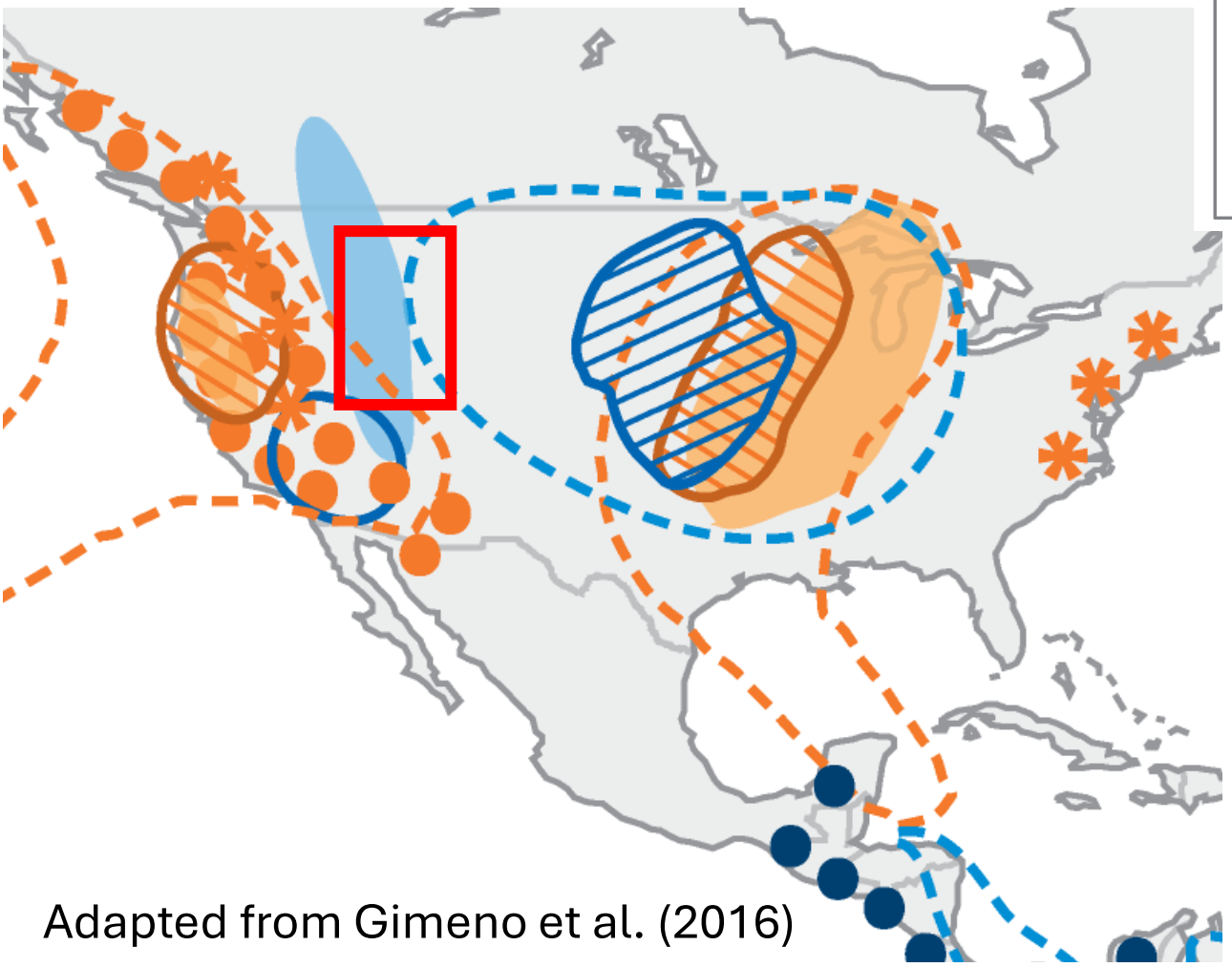
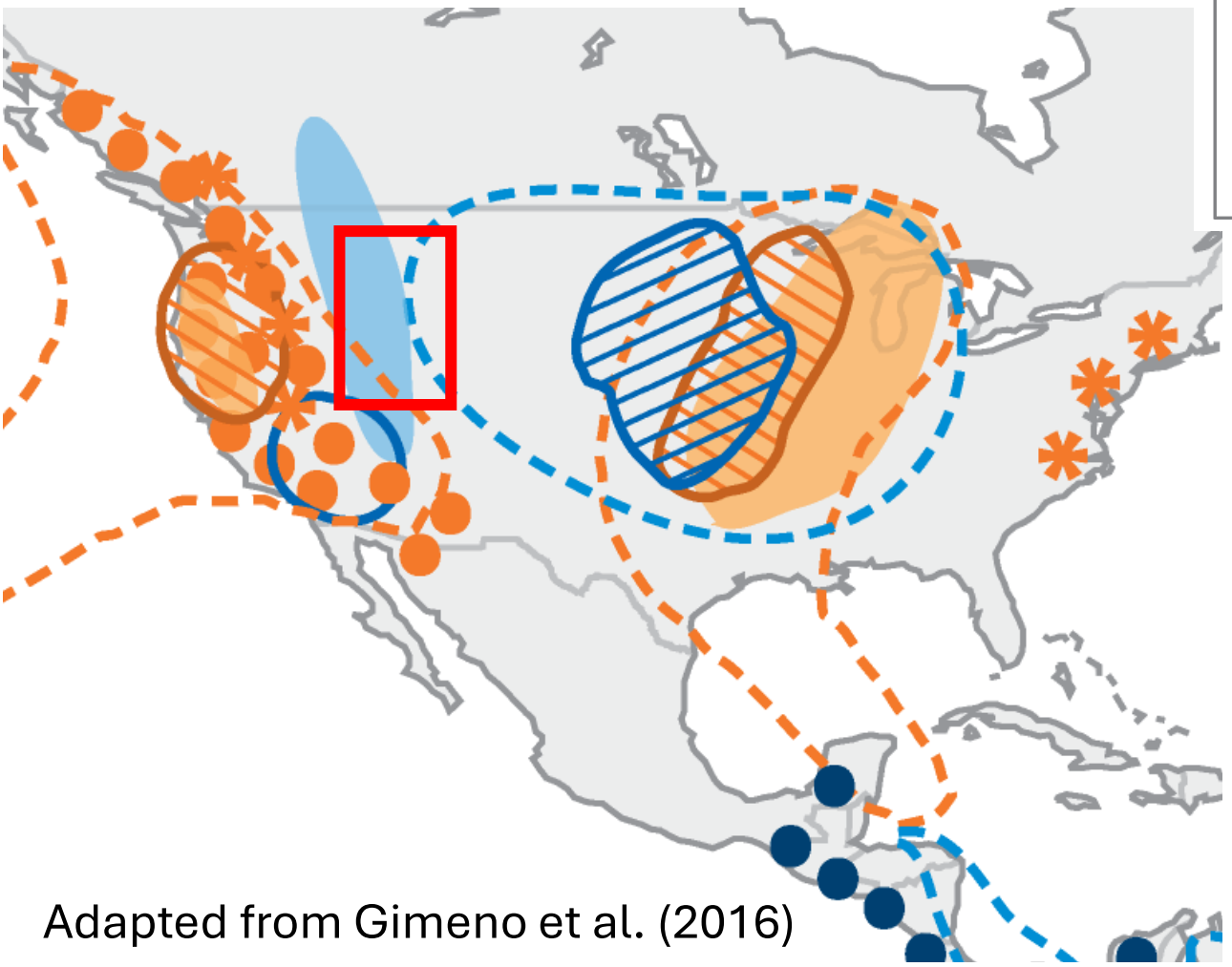


Adapted from Gimeno et al. (2016)

What causes precipitation in the Mountain West?



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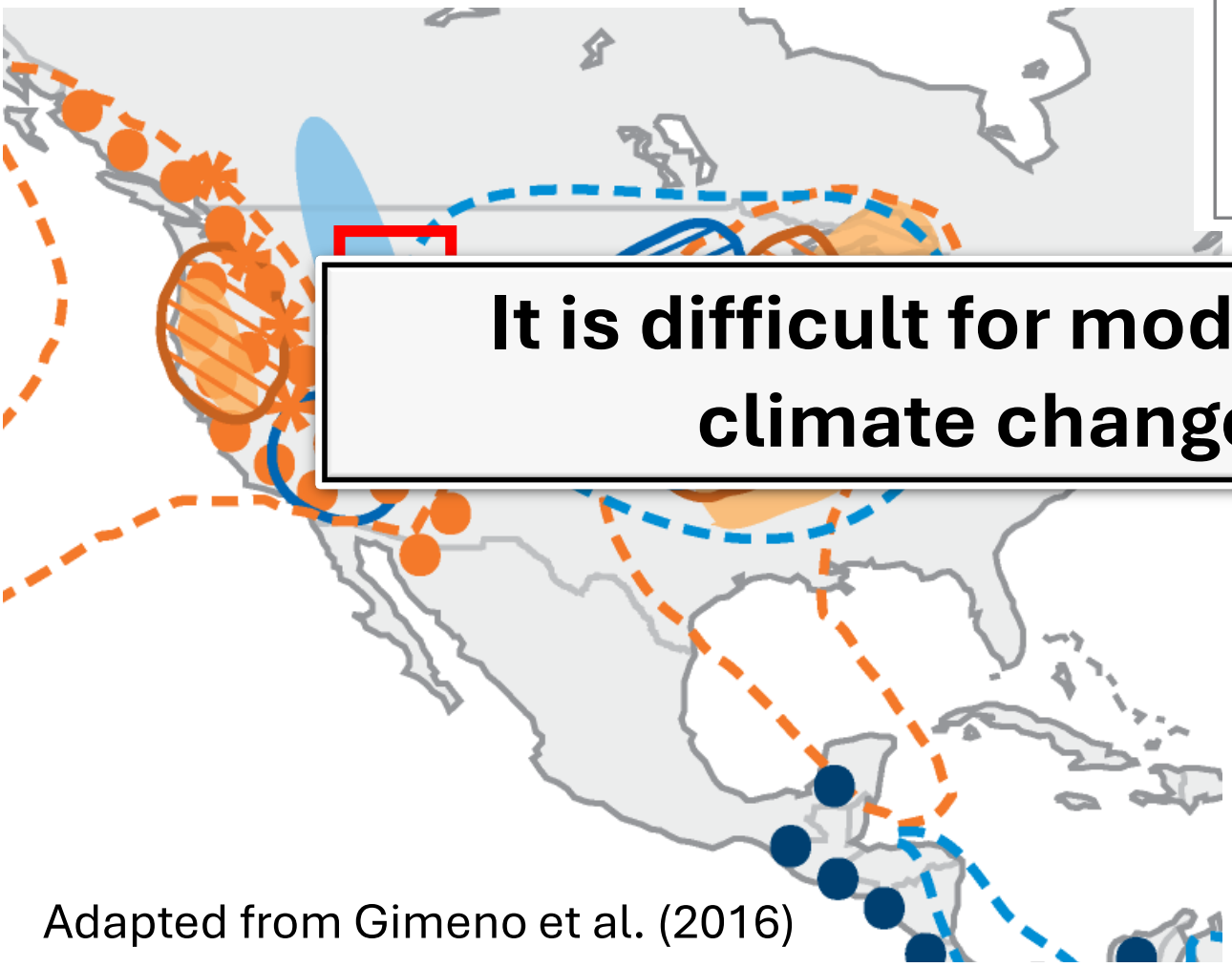
- Both the Low-Level Jet and Atmospheric Rivers can cause precipitation in the Mountain West.

What causes precipitation in the Mountain West?



Adapted from Gimeno et al. (2016)

It is difficult for models to predict future climate change in this region

- Both the Low-Level Jet and Atmospheric Rivers can cause precipitation in the Mountain West.

Mountain West Hydroclimate

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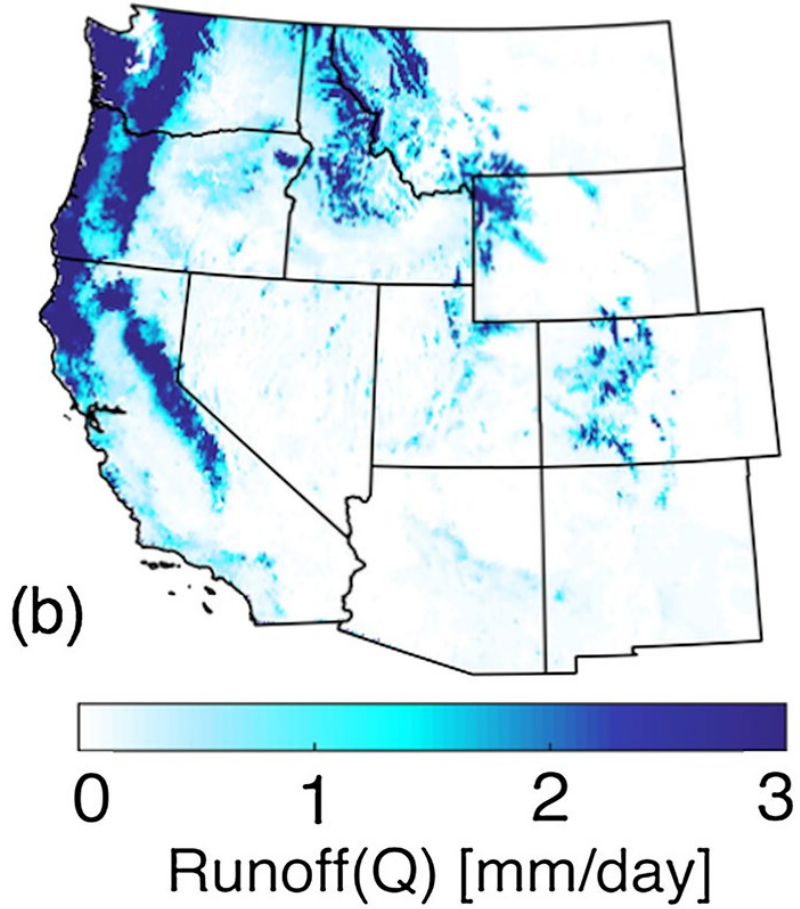
Li et al. (2017)



25% of the area produces
90% of the runoff.

Mountain West Hydroclimate

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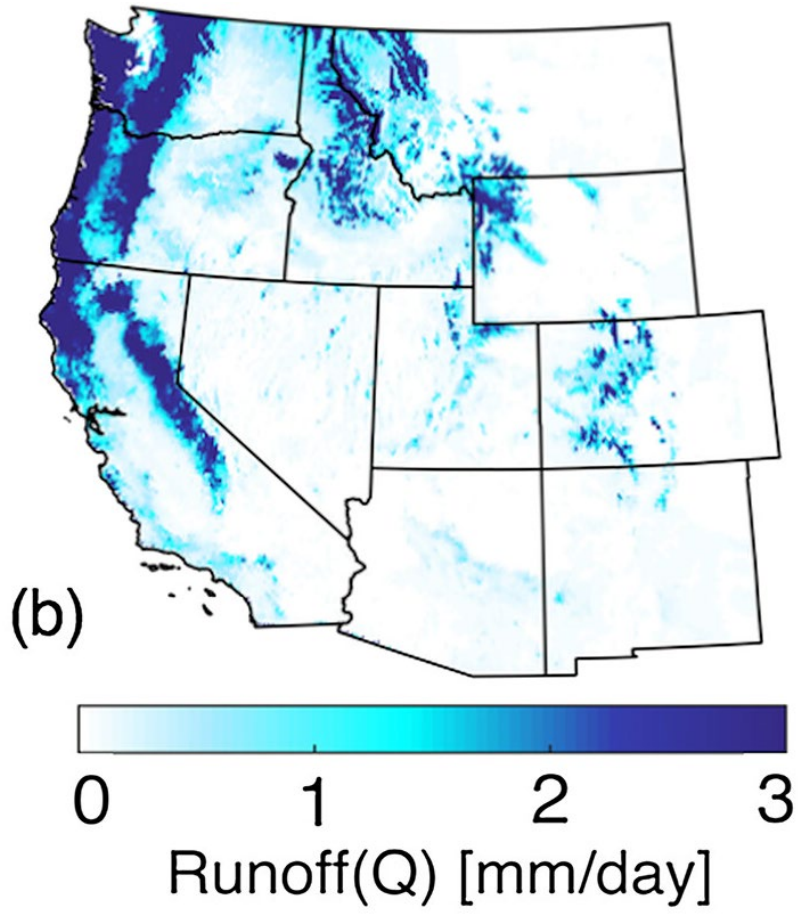

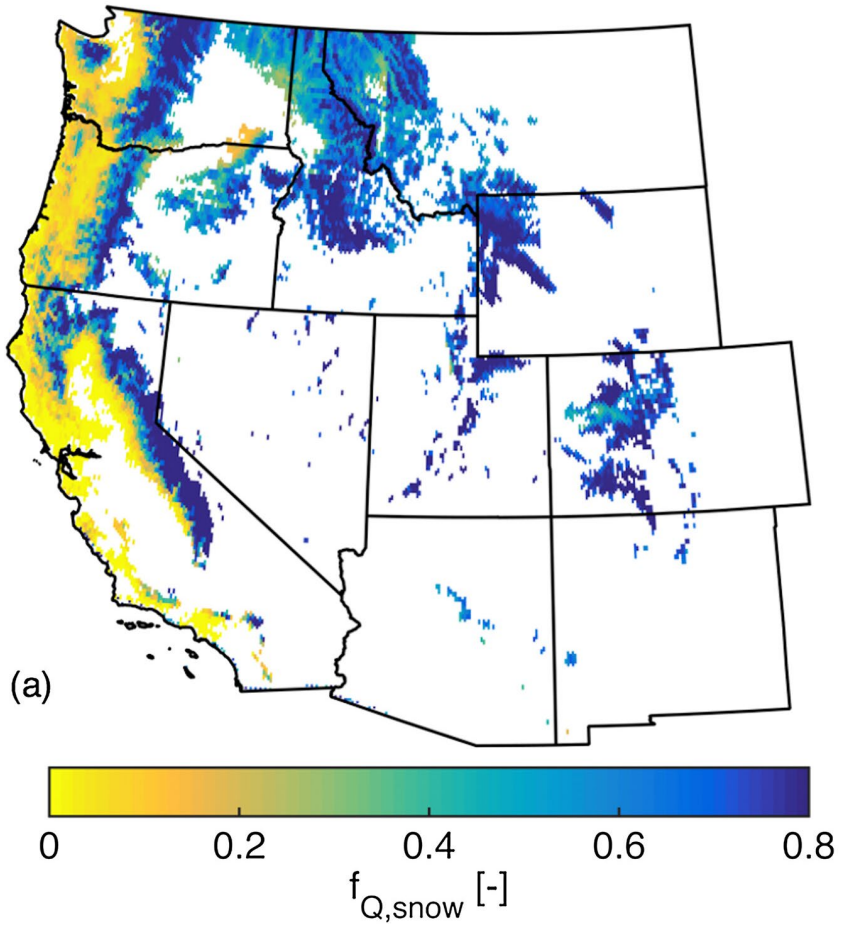

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- Majority of the runoff originates as snow.

Mountain West Hydroclimate

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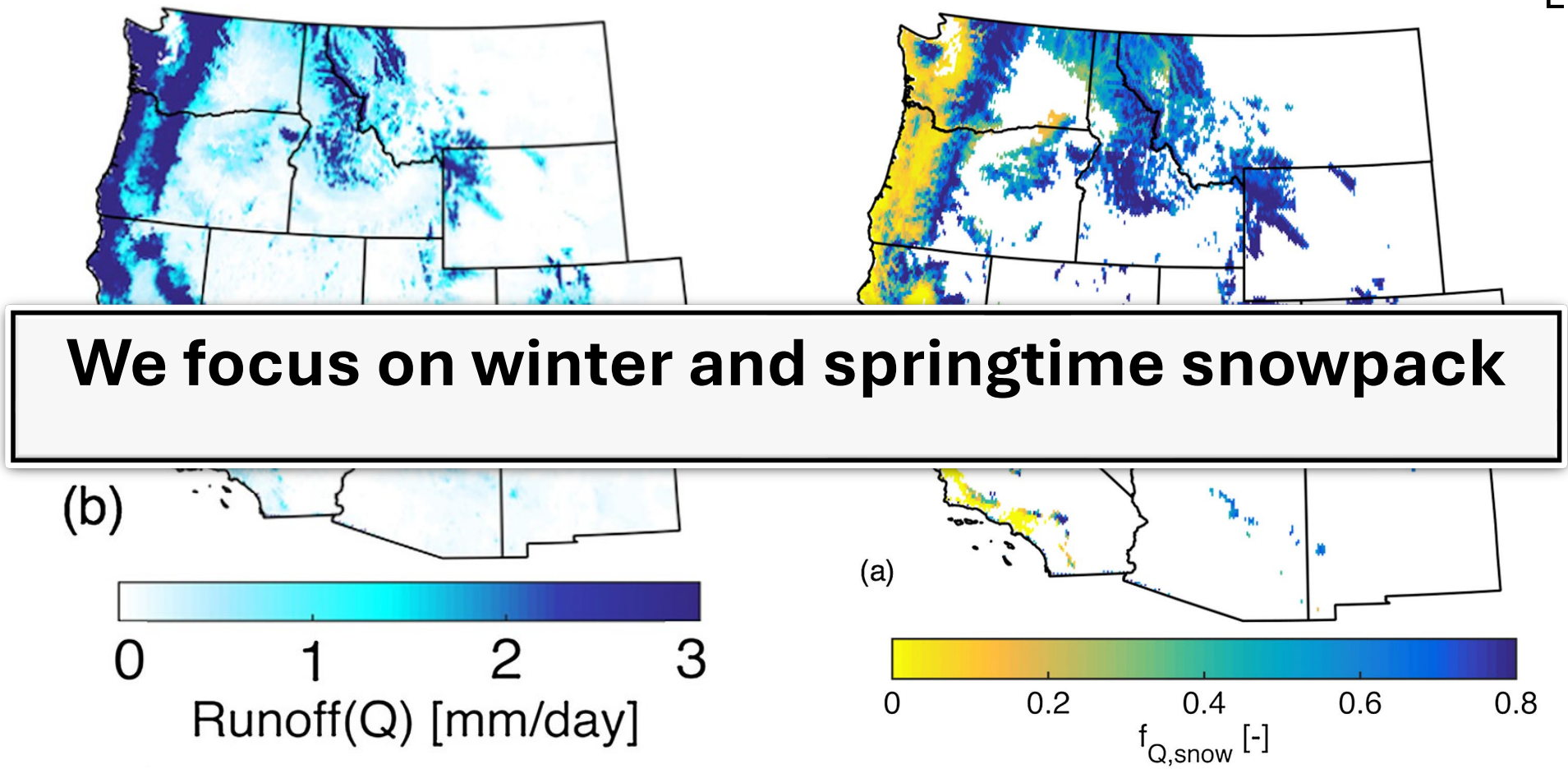

We focus on winter and springtime snowpack

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90% of the runoff.

- Majority of the runoff originates as snow.

Snow Water Equivalent (SWE)

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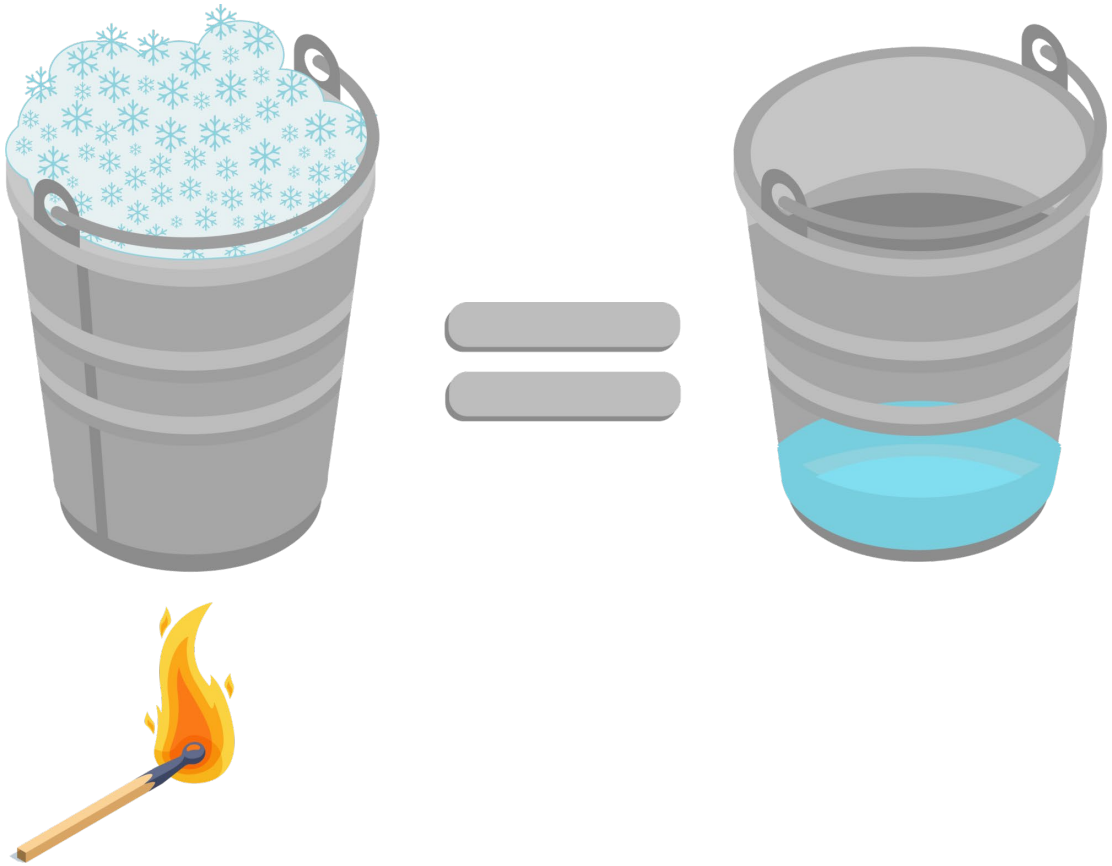


- The amount of liquid water from melting the snowpack.

Avalanche.org

Snow Water Equivalent (SWE)

- The amount of liquid water from melting the snowpack.
- We focus on SWE from ERA5 reanalysis and CMIP6 models.

Avalanche.org

Snow Water Equivalent (SWE)

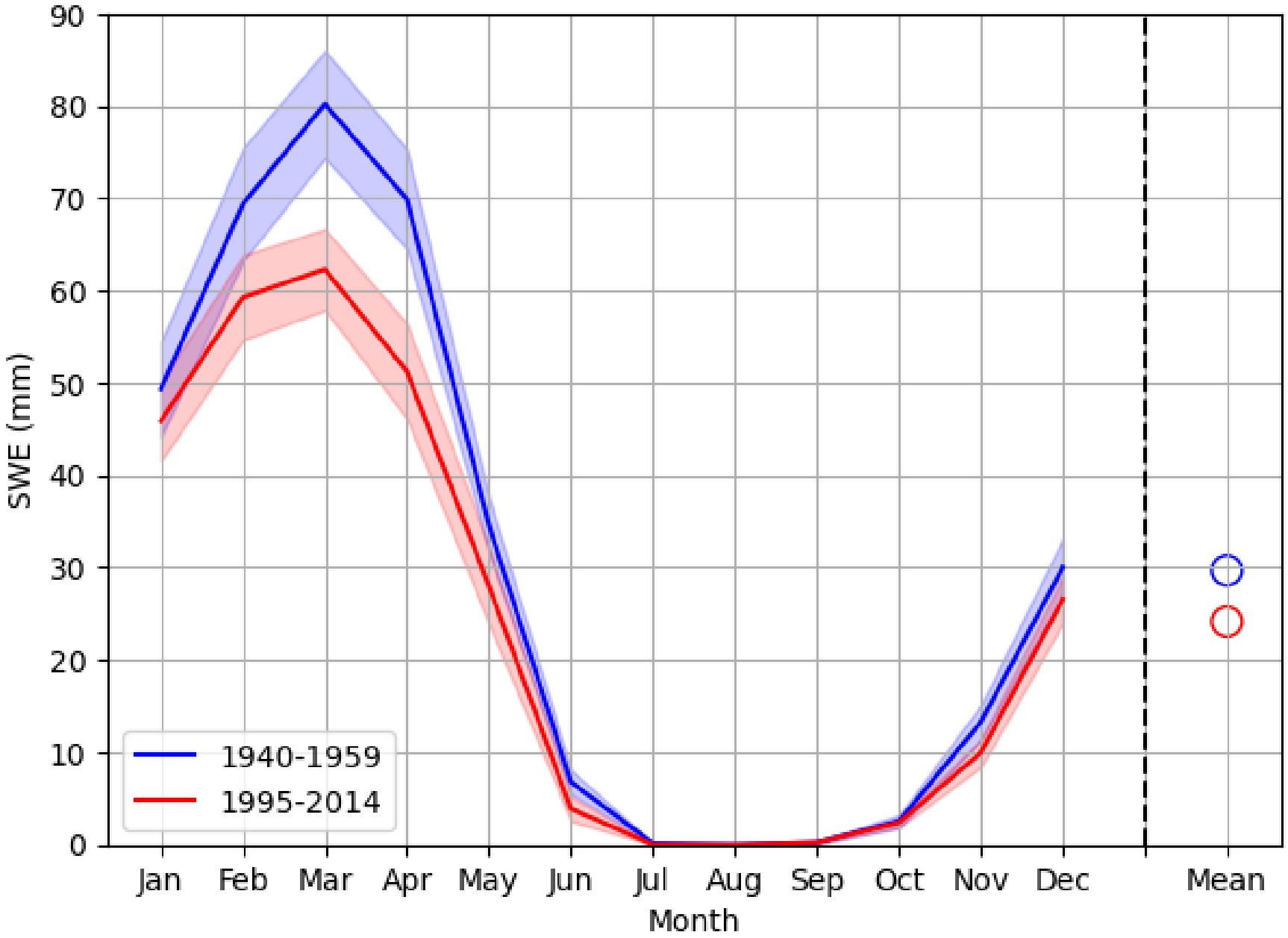
- The amount of liquid water from melting the snowpack.
- We focus on SWE from ERA5 reanalysis and CMIP6 models.
- Validated ERA5 SWE variability against SNOTEL (not shown).

Goals of this work

1. How is SWE in the mountain west impacted by climate change?

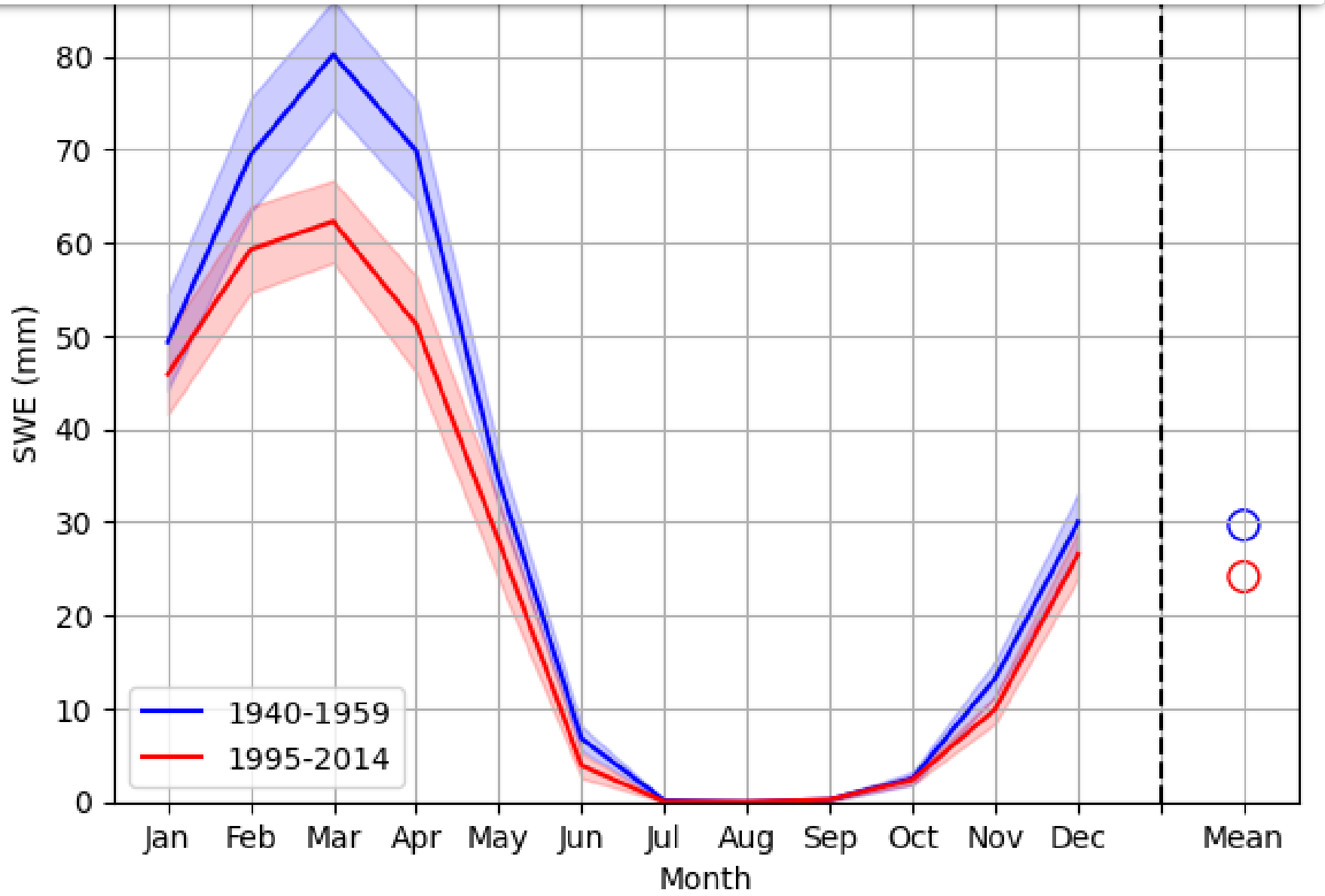
2. What part of the model physics is responsible for errors in SWE predictions?

ERA5 SWE in Mountain West



ERA5 SWE in Mountain West

SWE decreases during historical climate change.



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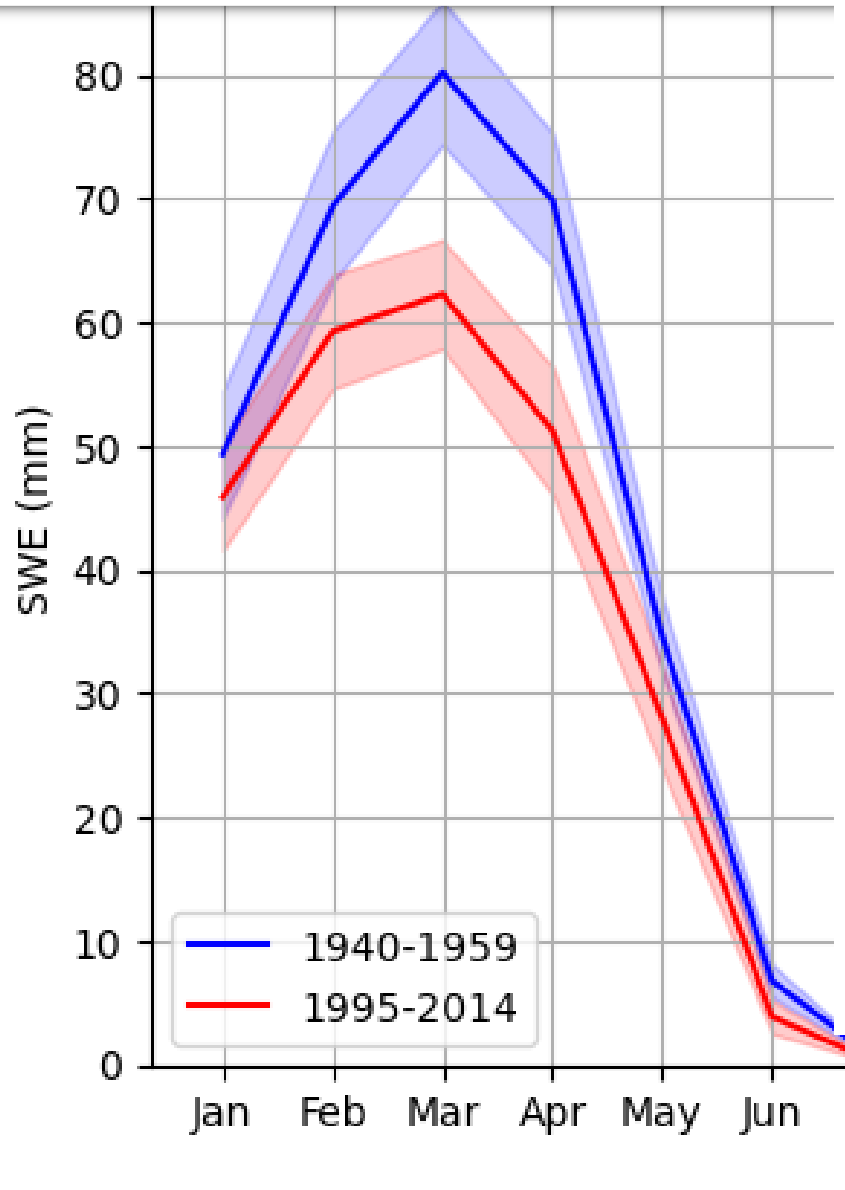

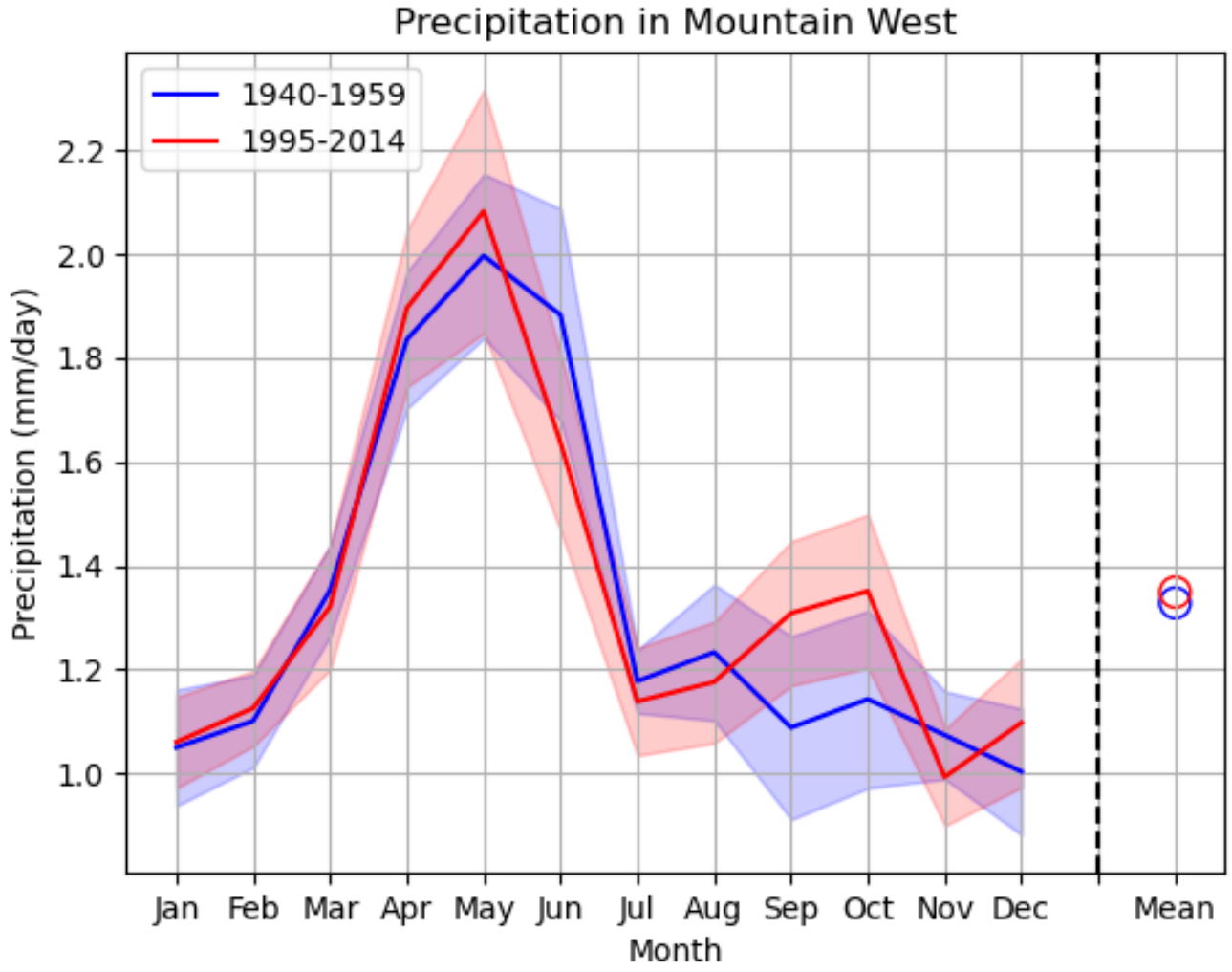

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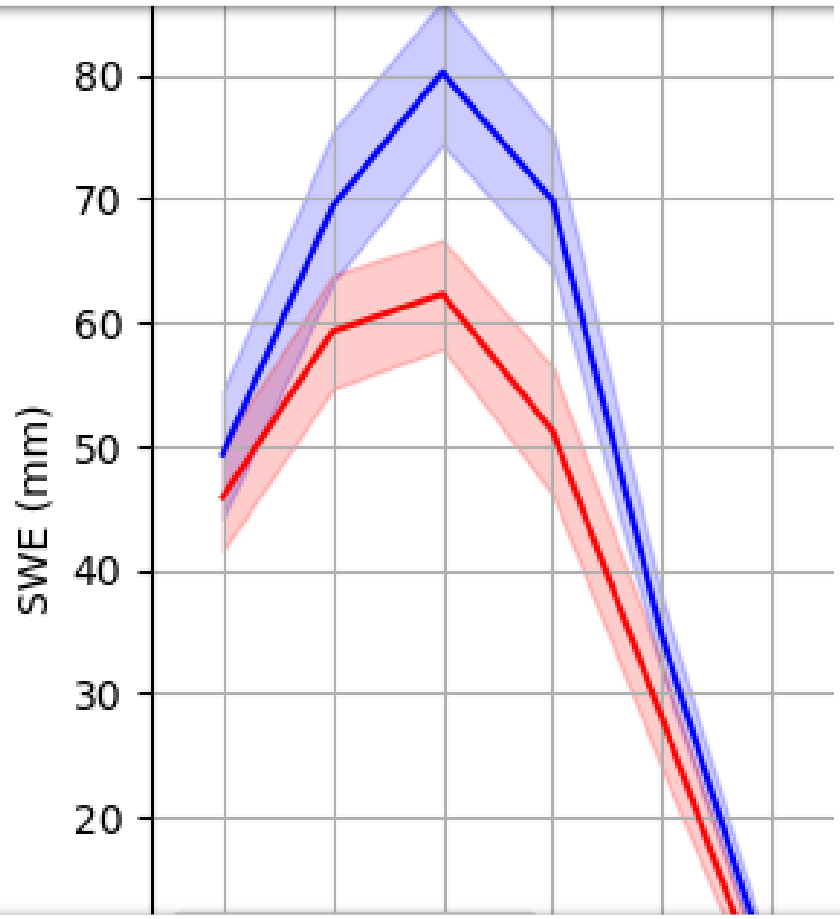
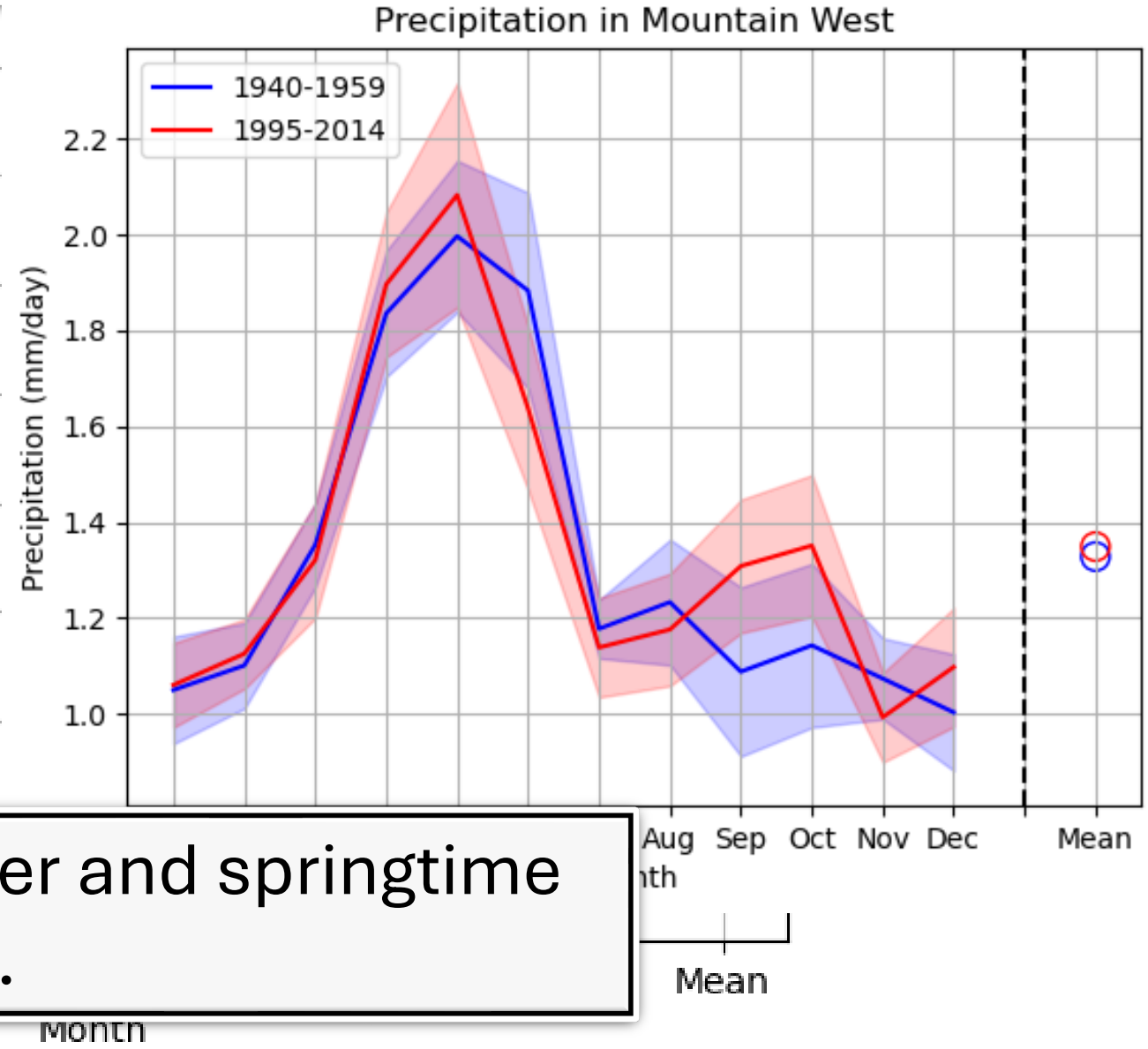
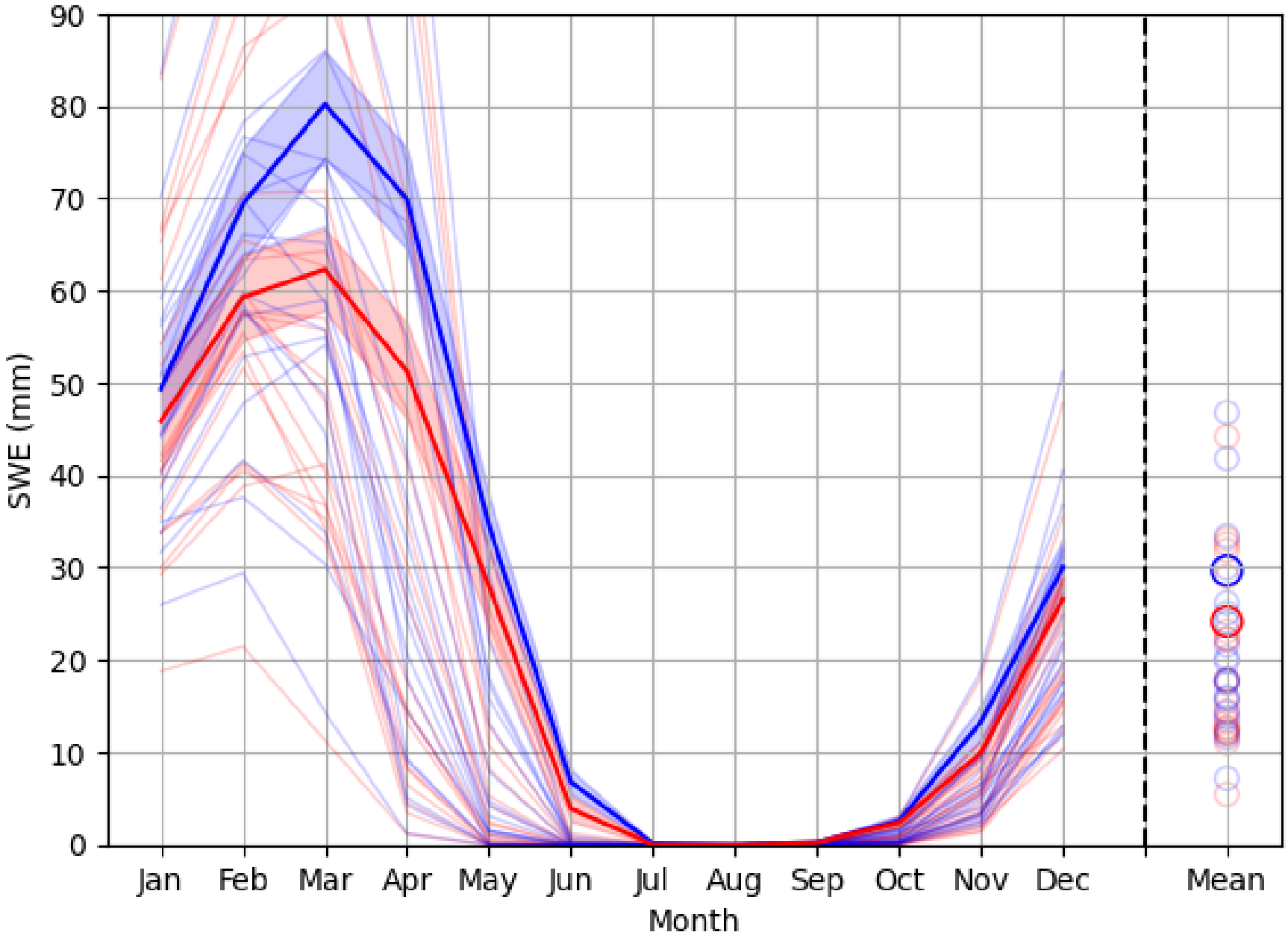




Even with little change to winter and springtime precipitation.

ERA5 and CMIP6 SWE in Mountain West



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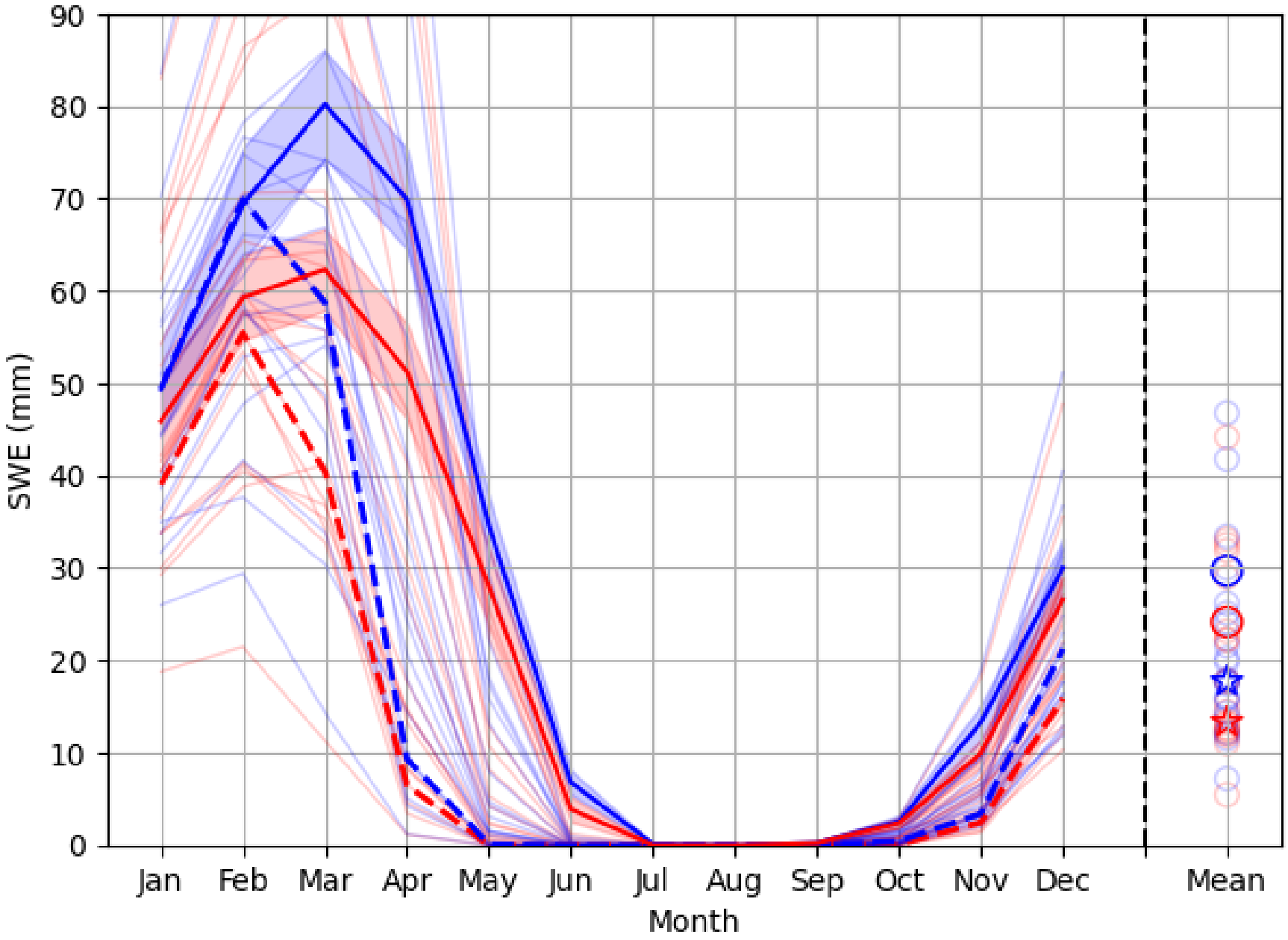

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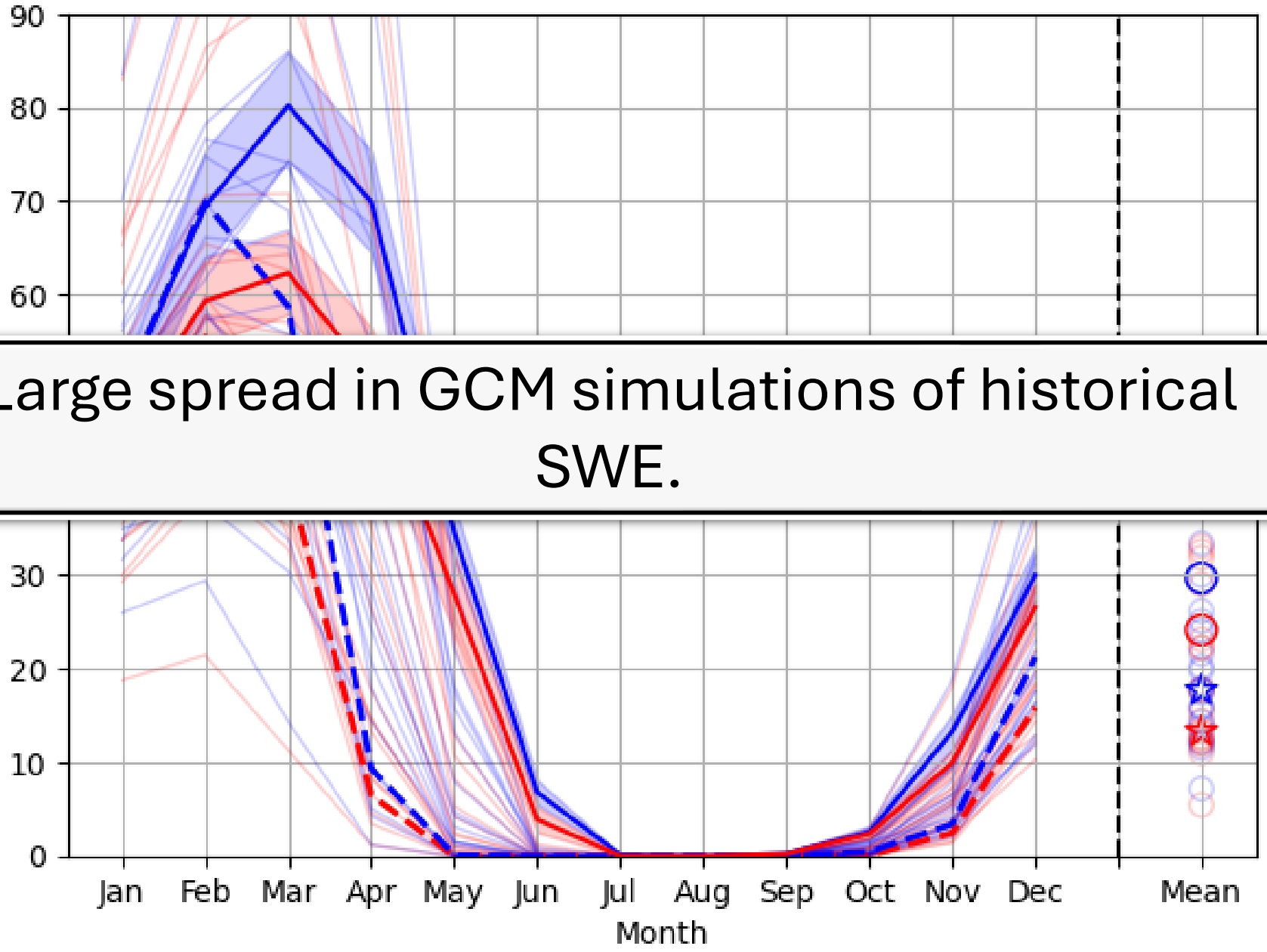
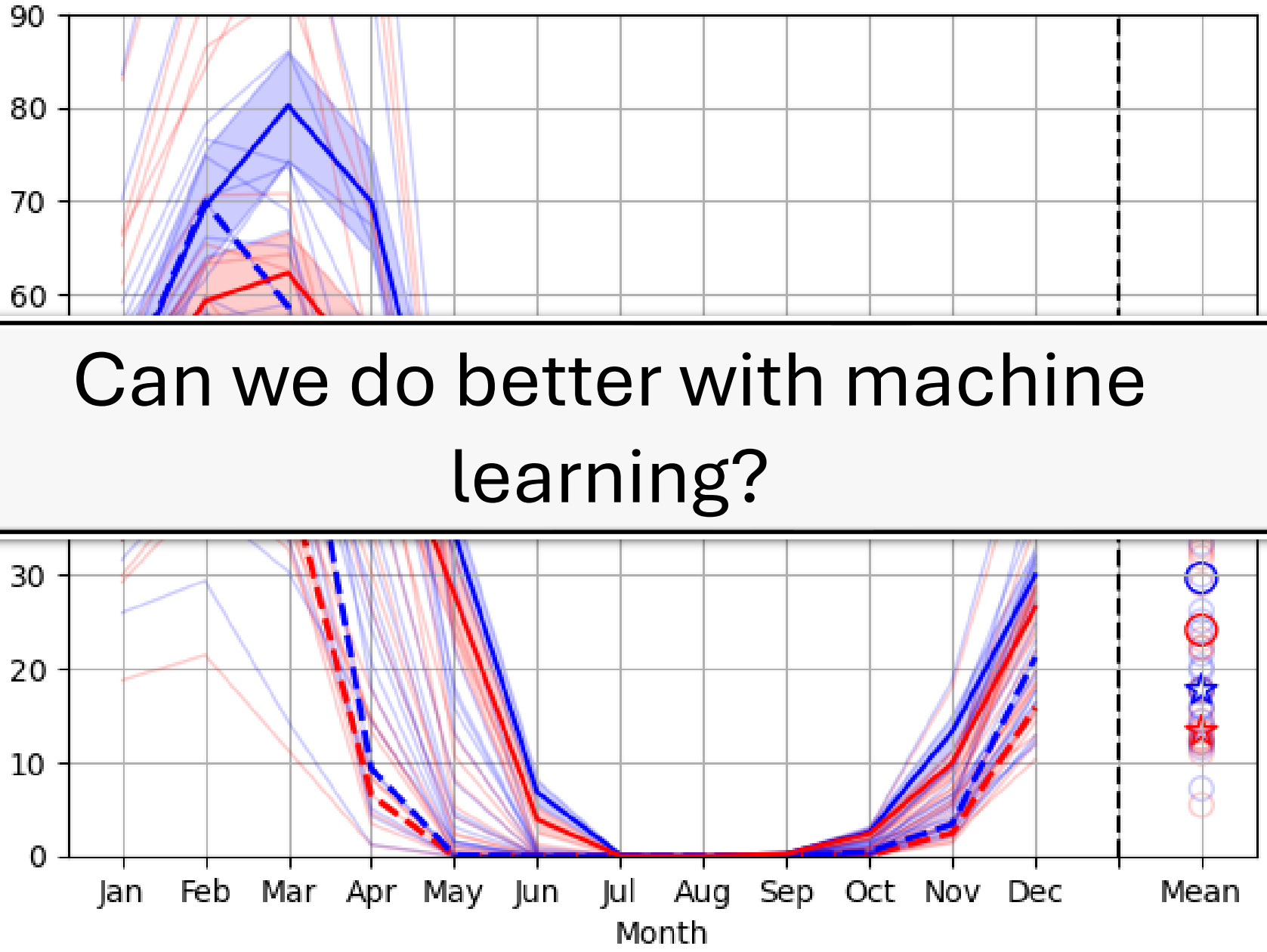


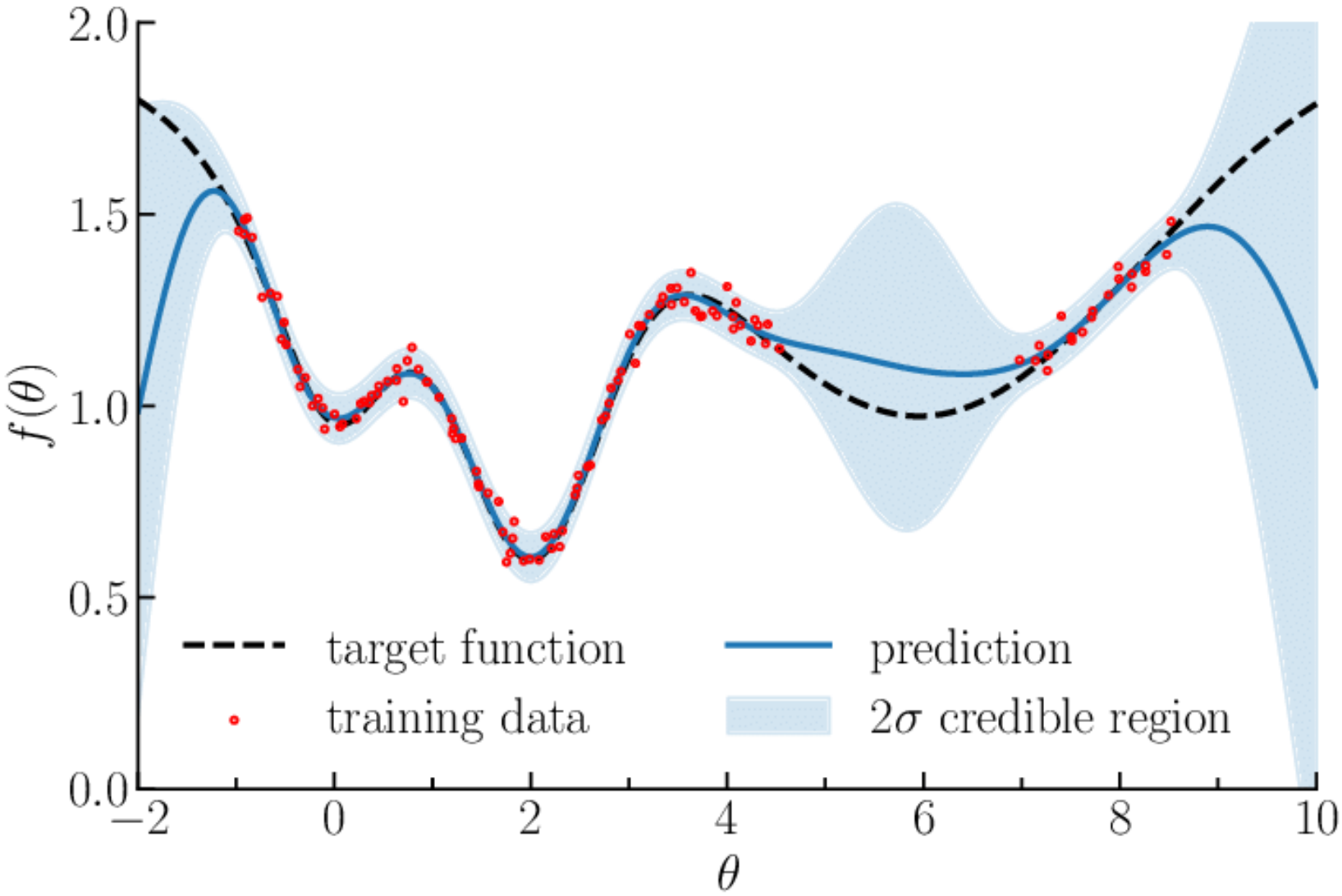
Large spread in GCM simulations of historical SWE.

ERA5 and CMIP6 SWE in Mountain West



Can we do better with machine learning?

Gaussian Process Emulation



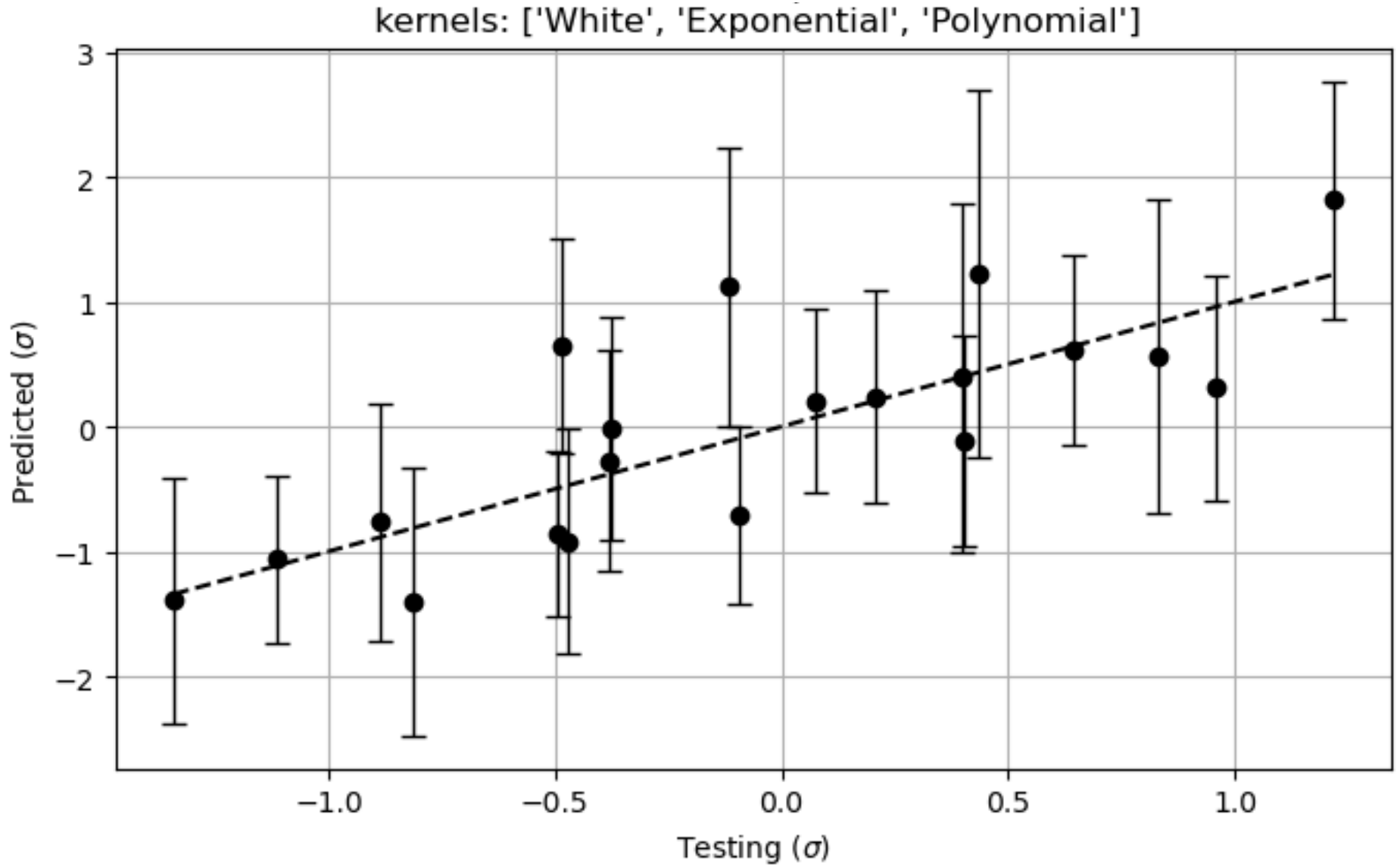
Leclerq (2018)

Emulating SWE

$$SWE_{Mar} = f(tas_{Oct-Mar}, P - E_{Oct-Mar})$$

Train the GP model (f) with ERA5 surface air temperature and moisture convergence.

March SWE prediction
From ONDJFM tas, P-E
R2 = 0.63, slope = 1.01



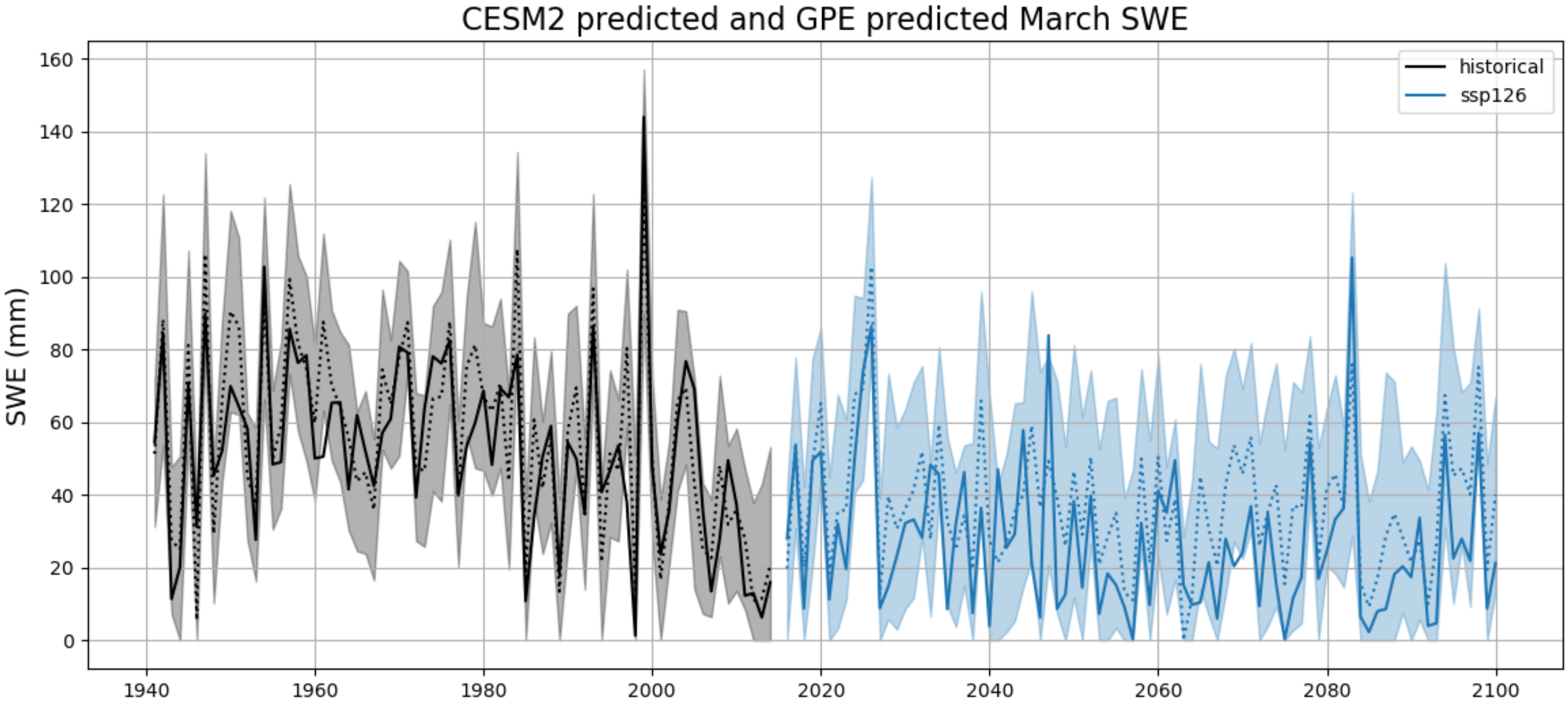
Use the GP model trained on reanalysis with CESM2

$$SWE_{Mar} = f(tas_{Oct-Mar}, P - E_{Oct-Mar})$$

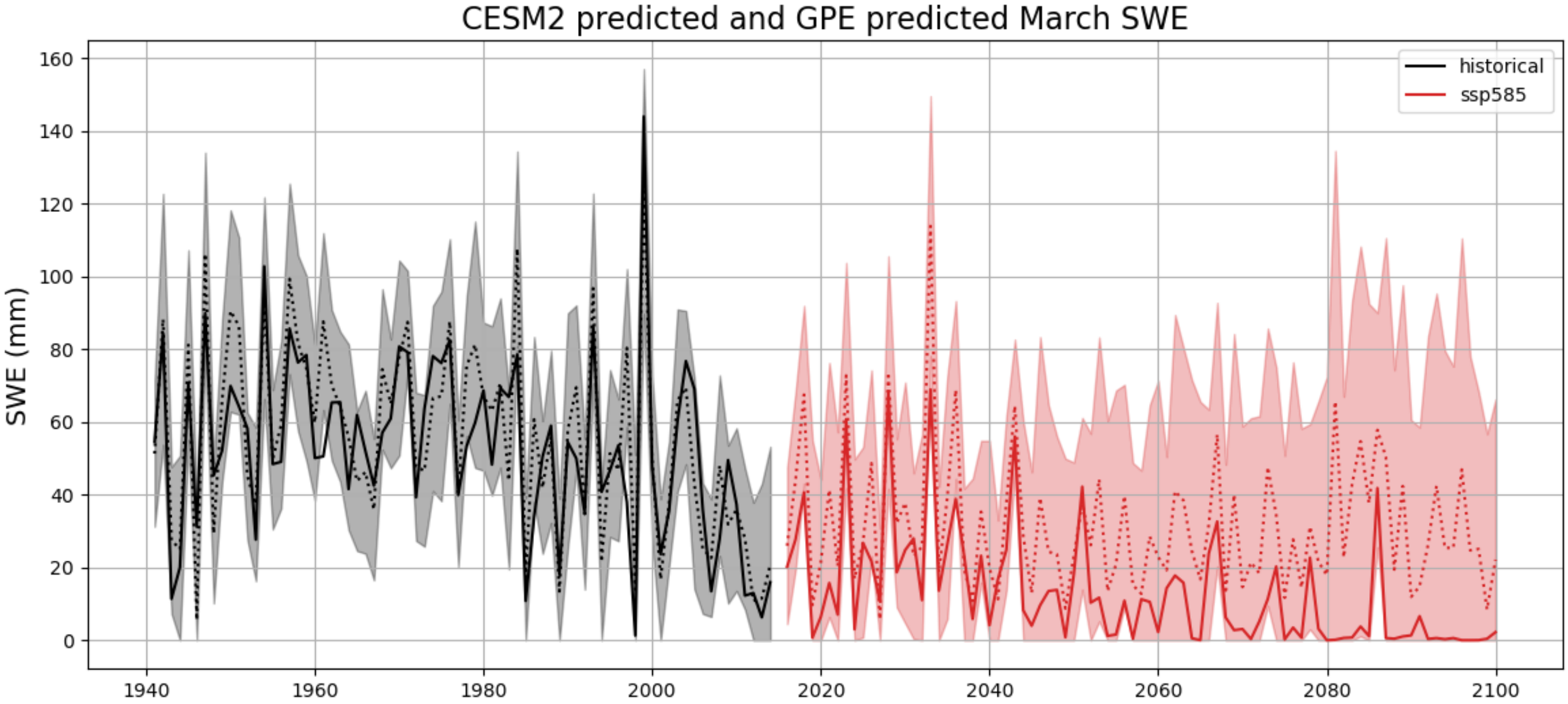
ERA5 CESM2

- Large scale (moisture convergence and temperature) from model.
- Small scale from GP model trained on ERA5.

During historical simulation and SSP126 CESM2 matches well with the GP model



Higher warming model simulations lead to a large uncertainty in the GP prediction.



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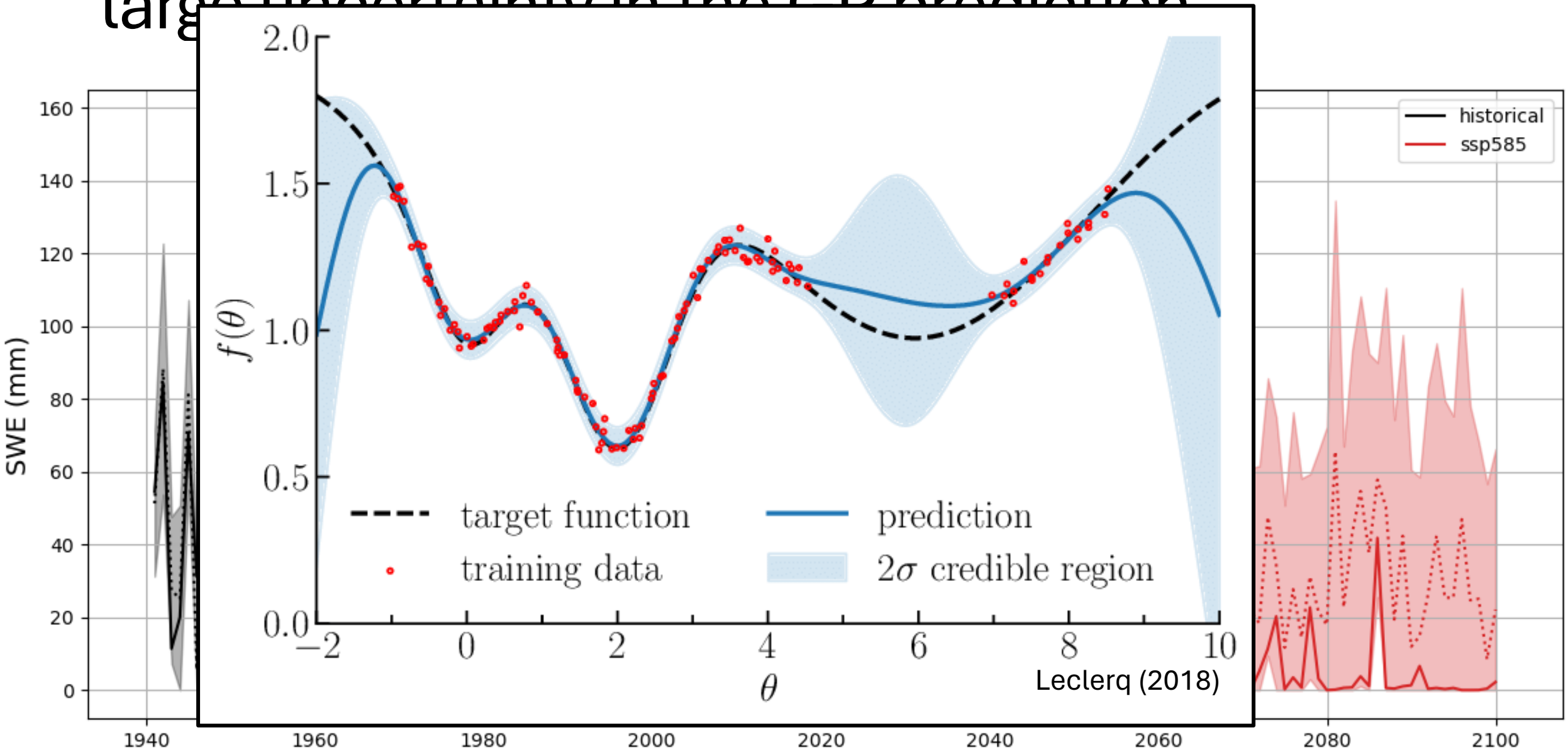

So what can we learn from this?

- GP model prediction of historical SWE with CESM input variables is very good!

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- GP model prediction of historical SWE with CESM input variables is very good!

- Errors in models' prediction of historical climate change is linked to their prediction of surface temperature and moisture convergence.

Conclusions

1. How is SWE in the mountain west impacted by climate change?

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Future work will include using a perturbed parameter ensemble to further understand what aspects of the model modulate SWE.

Thank you

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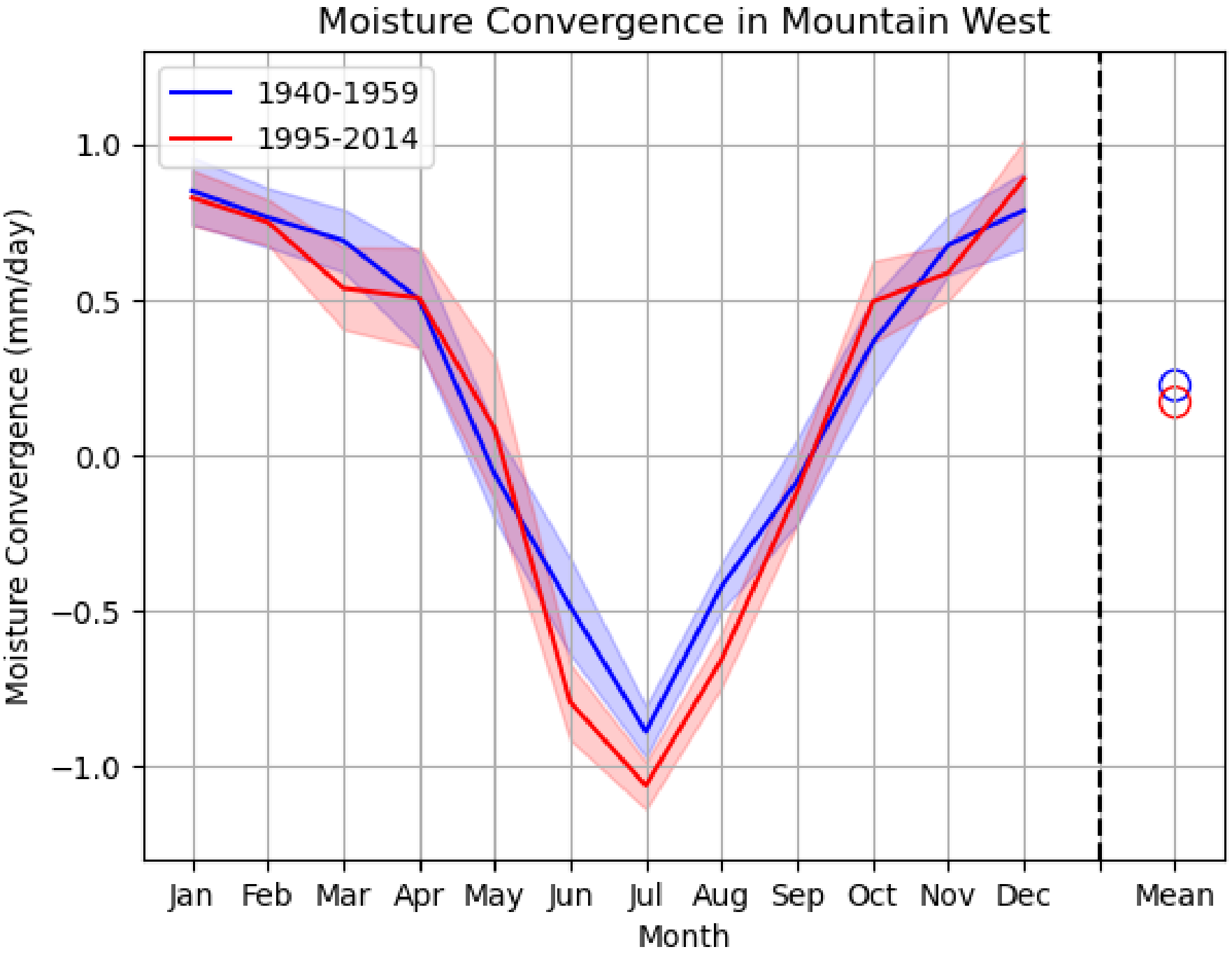
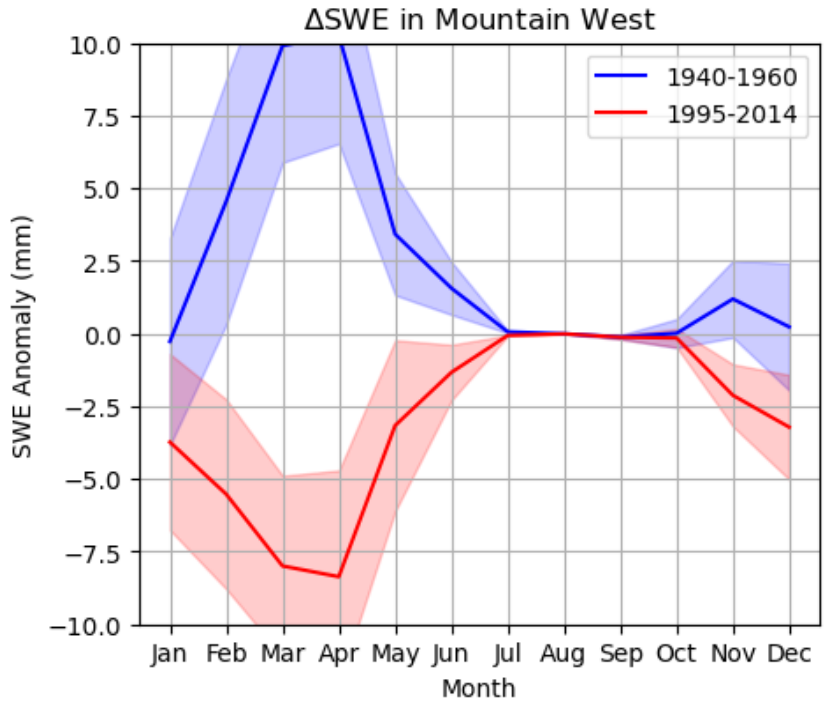
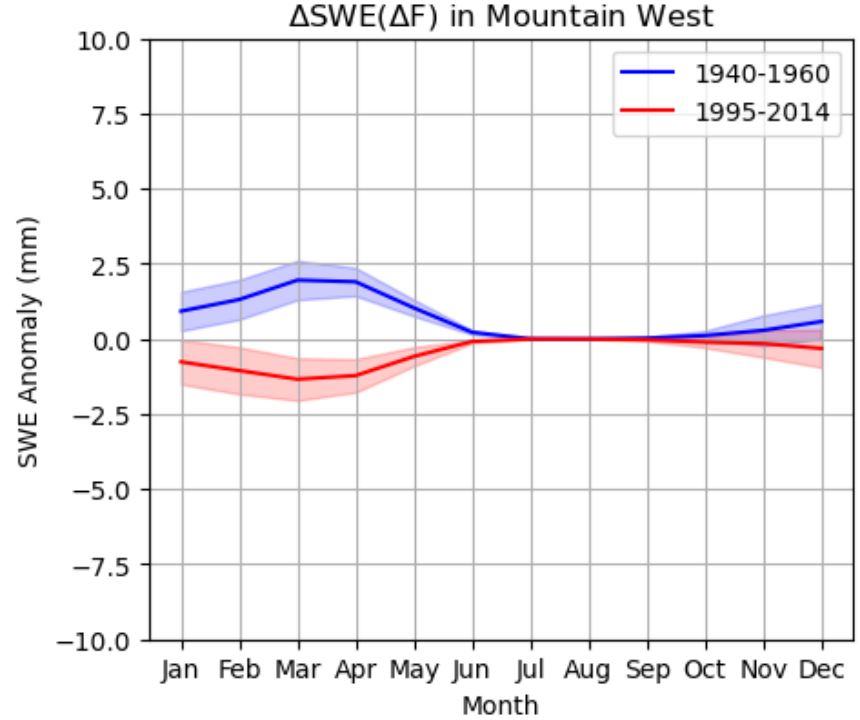
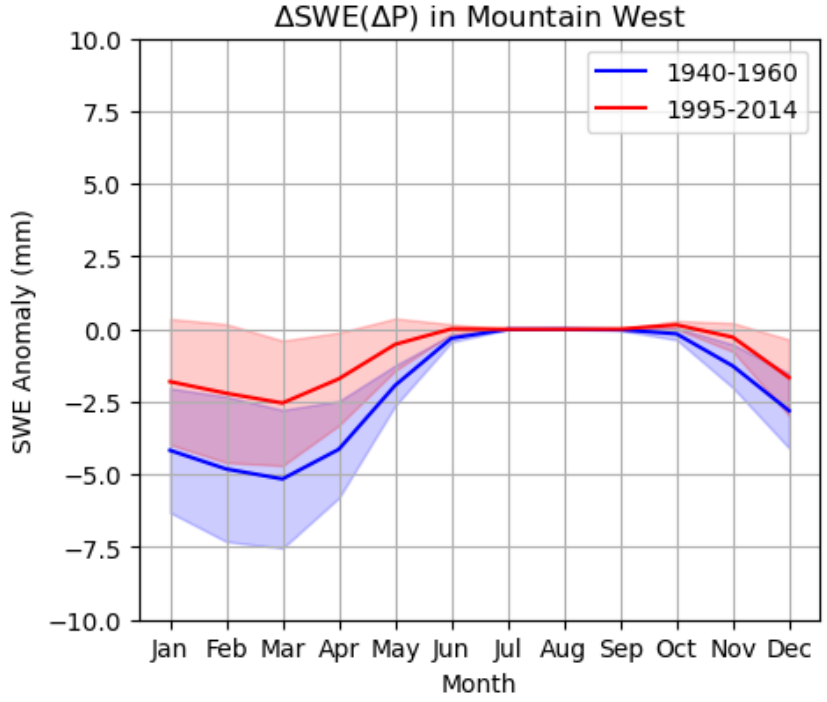
Extra slides


Moisture Convergence in Mountain West
1940-1959
1995-2014
1.0
0.5
0.0
−0.5
−1.0
Moisture Convergence (mm/day)
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Mean
Month


ΔSWE in Mountain West
1940-1960
1995-2014
SWE Anomaly (mm)
10.0
7.5
5.0
2.5
0.0
−2.5
−5.0
−7.5
−10.0
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Month


ΔSWE(ΔF) in Mountain West
1940-1960
1995-2014
SWE Anomaly (mm)
10.0
7.5
5.0
2.5
0.0
−2.5
−5.0
−7.5
−10.0
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Month


ΔSWE(ΔP) in Mountain West
1940-1960
1995-2014
SWE Anomaly (mm)
10.0
7.5
5.0
2.5
0.0
−2.5
−5.0
−7.5
−10.0
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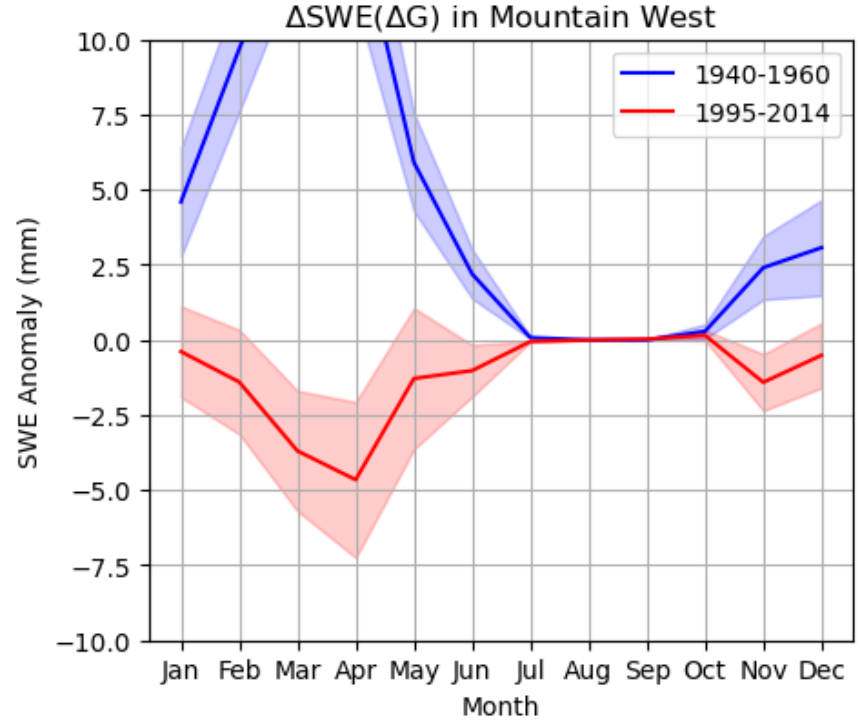
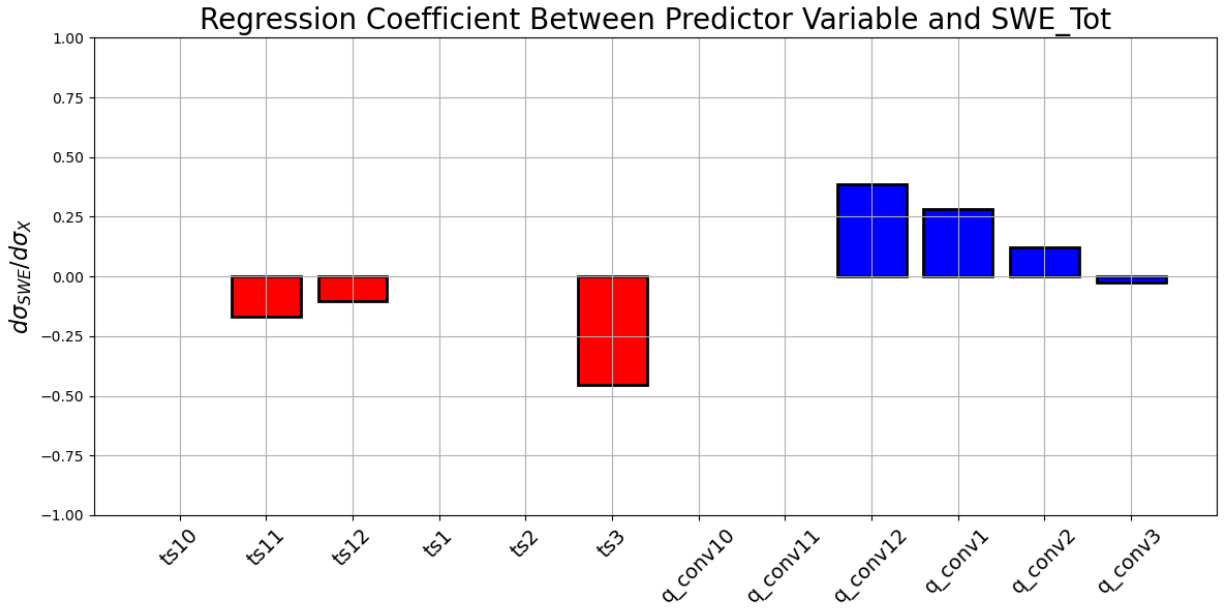
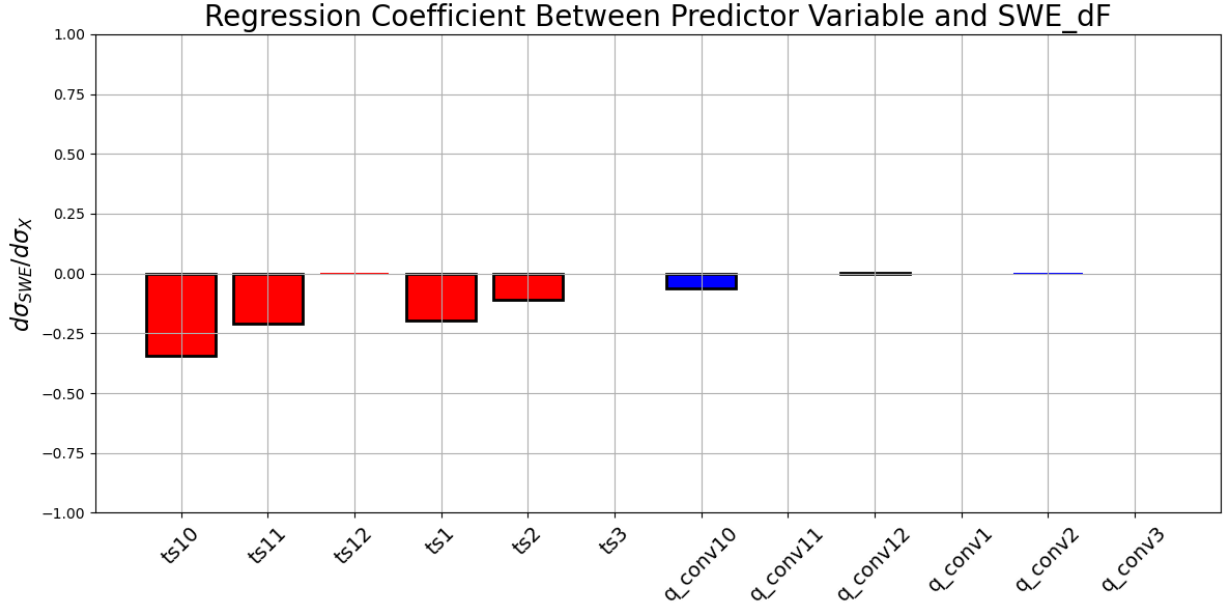
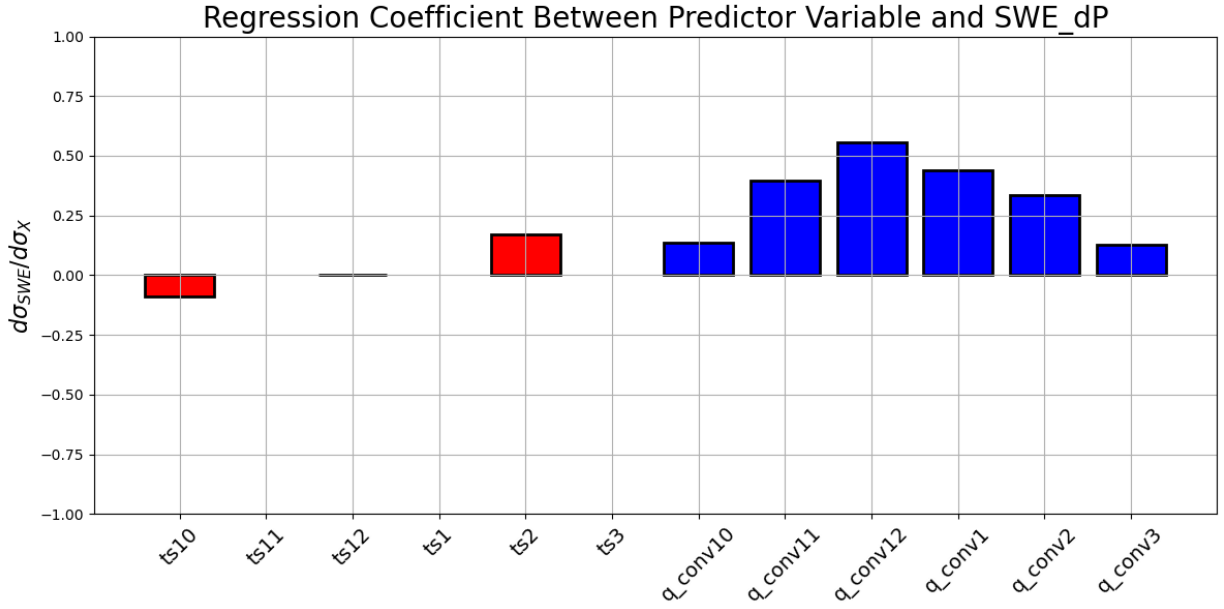
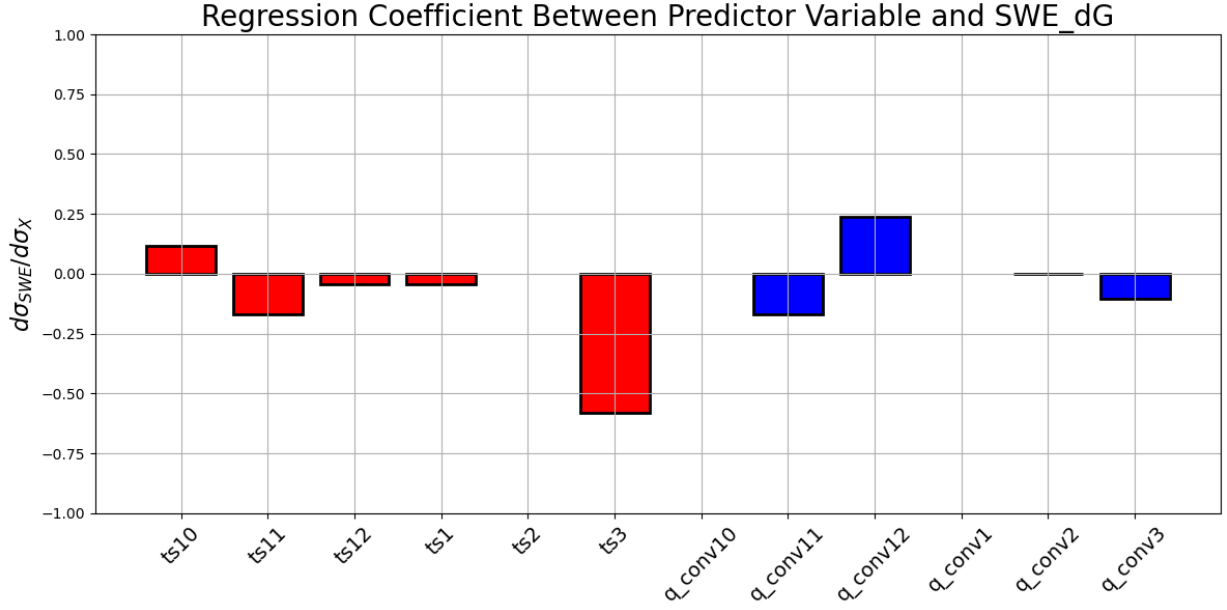
Month


ΔSWE(ΔG) in Mountain West
1940-1960
1995-2014
SWE Anomaly (mm)
10.0
7.5
5.0
2.5
0.0
−2.5
−5.0
−7.5
−10.0
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Month


Regression Coefficient Between Predictor Variable and SWE_Tot
$d\sigma_{SWE}/d\sigma_X$
1.00
0.75
0.50
0.25
0.00
−0.25
−0.50
−0.75
−1.00
ts10
ts11
ts12
ts1
ts2
ts3
q_conv10
q_conv11
q_conv12
q_conv1
q_conv2
q_conv3


Regression Coefficient Between Predictor Variable and SWE_dF
$d\sigma_{SWE}/d\sigma_X$
1.00
0.75
0.50
0.25
0.00
−0.25
−0.50
−0.75
−1.00
ts10
ts11
ts12
ts1
ts2
ts3
q_conv10
q_conv11
q_conv12
q_conv1
q_conv2
q_conv3


Regression Coefficient Between Predictor Variable and SWE_dP
$d\sigma_{SWE}/d\sigma_X$
1.00
0.75
0.50
0.25
0.00
−0.25
−0.50
−0.75
−1.00
ts10
ts11
ts12
ts1
ts2
ts3
q_conv10
q_conv11
q_conv12
q_conv1
q_conv2
q_conv3


Regression Coefficient Between Predictor Variable and SWE_dG
$d\sigma_{SWE}/d\sigma_X$
1.00
0.75
0.50
0.25
0.00
−0.25
−0.50
−0.75
−1.00
ts10
ts11
ts12
ts1
ts2
ts3
q_conv10
q_conv11
q_conv12
q_conv1
q_conv2
q_conv3