

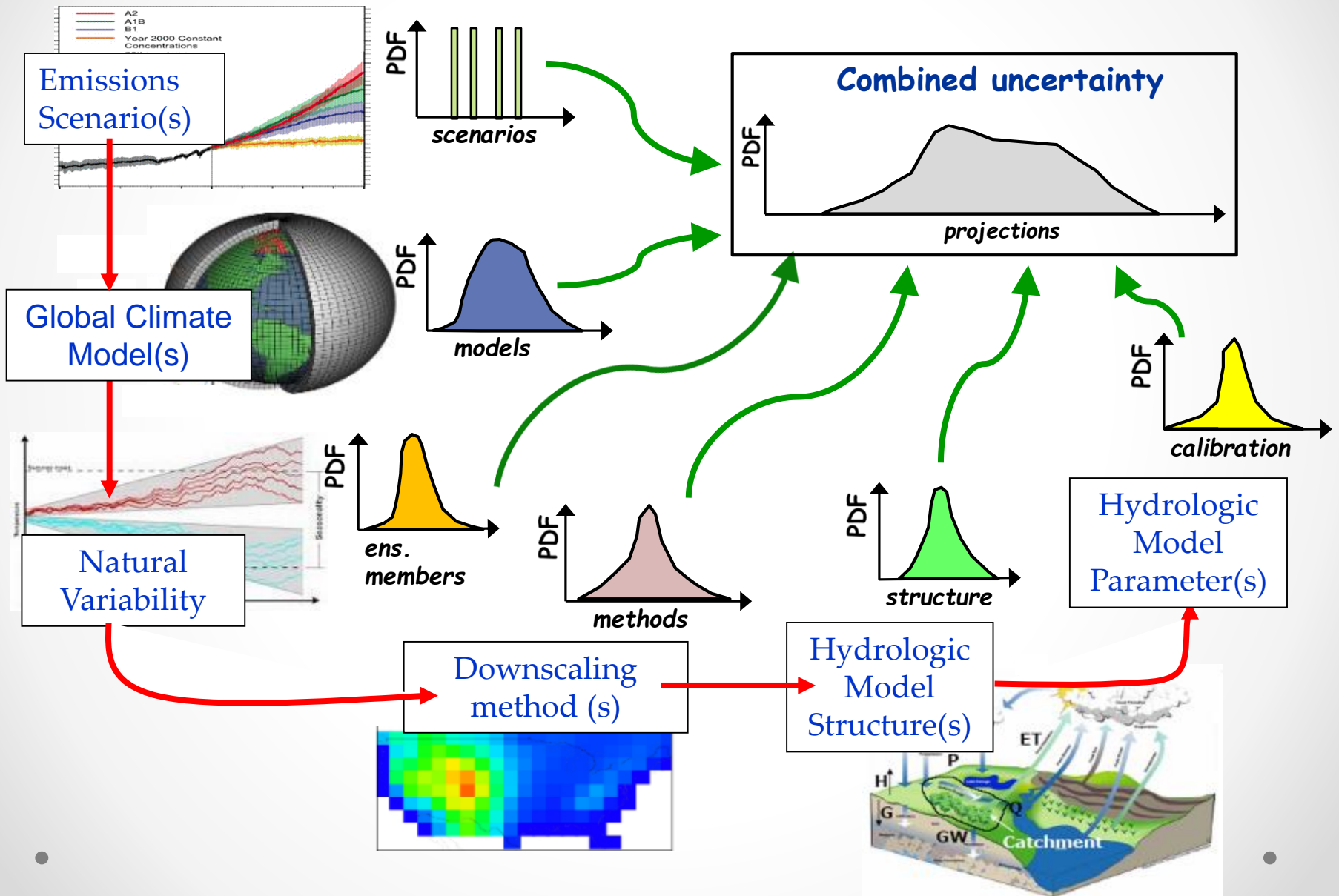
Uncertainties in the Climate Change Signal



Ethan Gutmann,
Kyoko Ikeda,
Clara Deser,
Roy Rasmussen,
Jeff Arnold,
Martyn Clark
2016

The
First
GEWEX
Convection
Permitting CM
Workshop

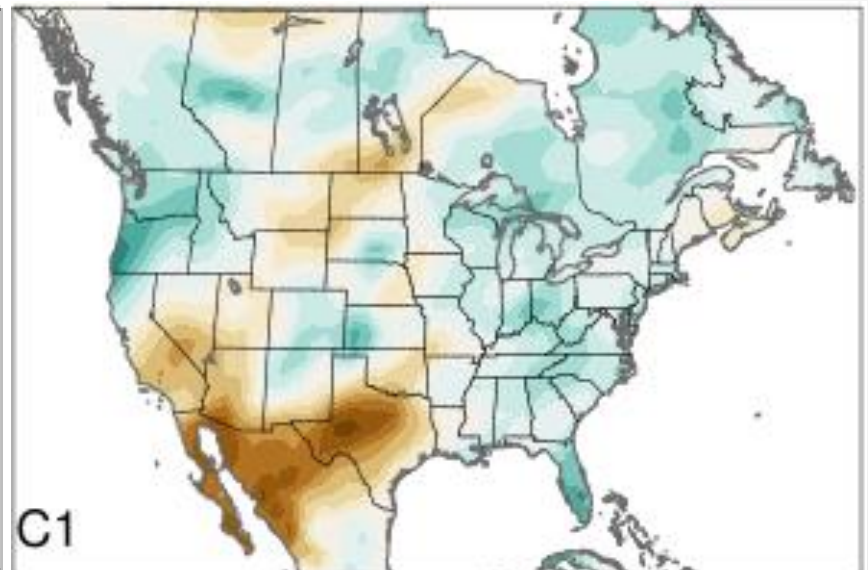
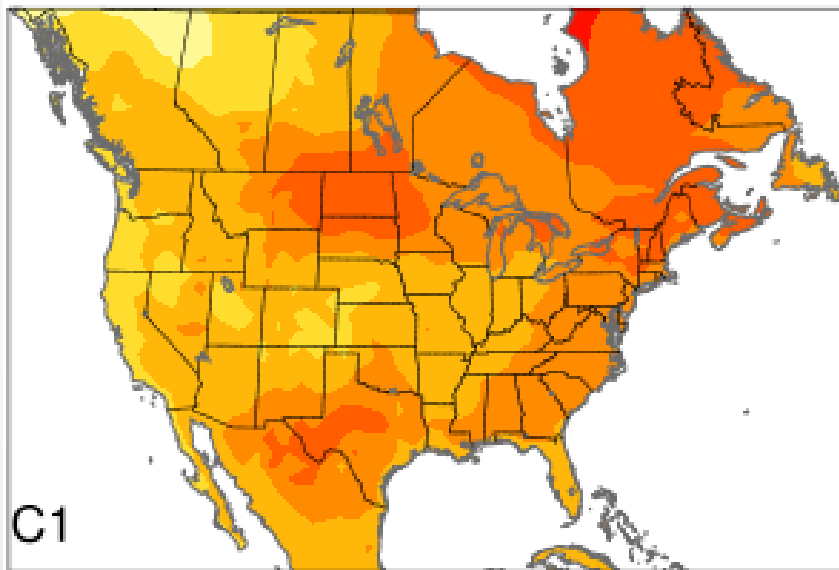
Revealing the uncertainties



What will the future look like?

Warmer
Air Temperature
(2030 – 1995)

Precipitation
Wetter and Drier...
(2030 – 1995)

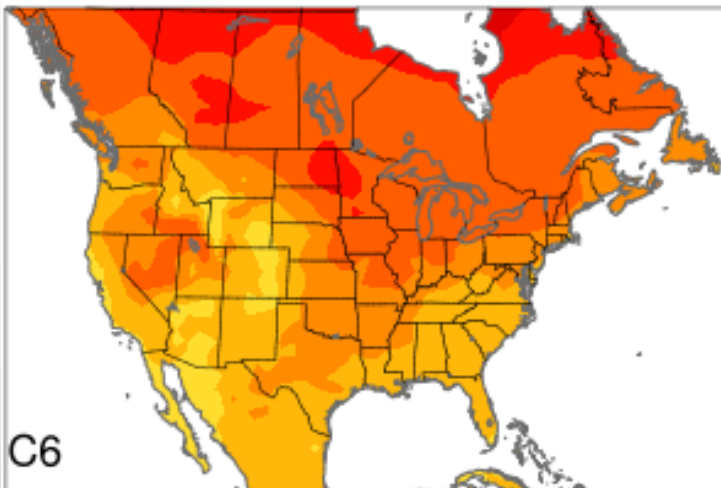
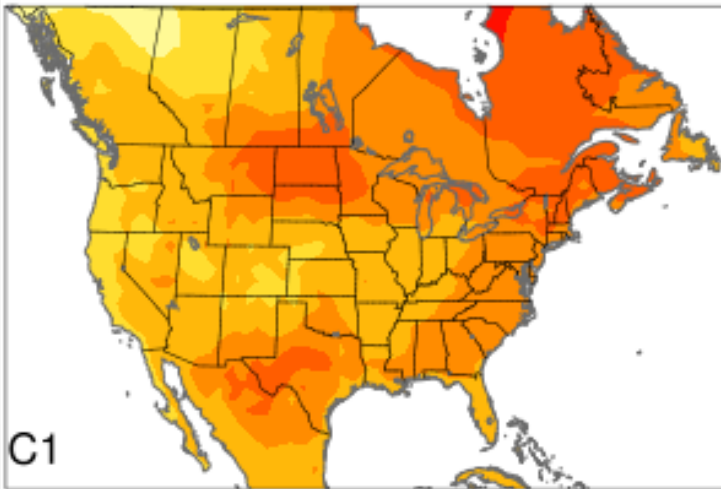


-6 -5 -4 -3 -2 -1.5 -1 -0.5 0 0.5 1 1.5 2 3 4 5 6

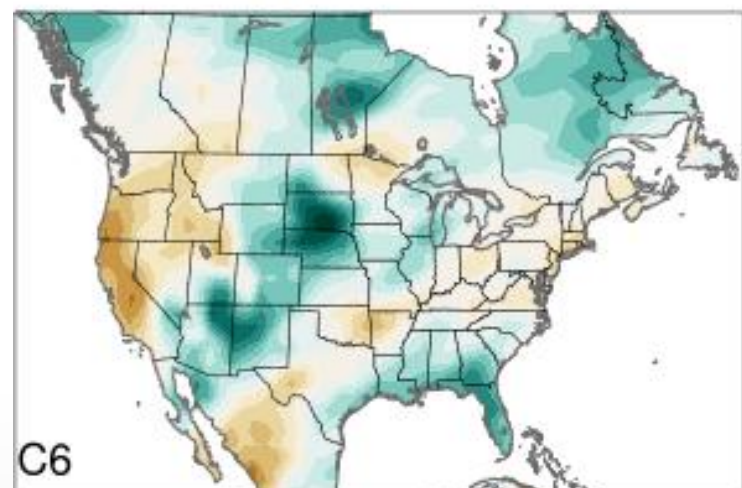
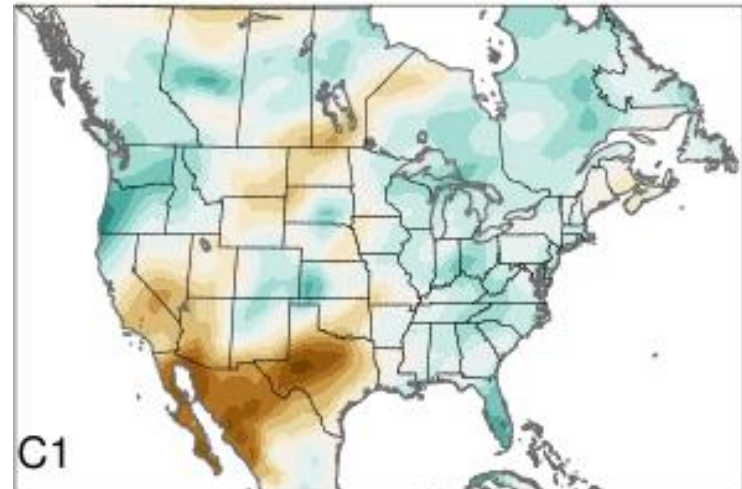
-40 -35 -30 -25 -20 -15 -10 -5 0 5 10 15 20 25 30 35 40

What will the future look like?

Warmer
Air Temperature
(2030 – 1995)



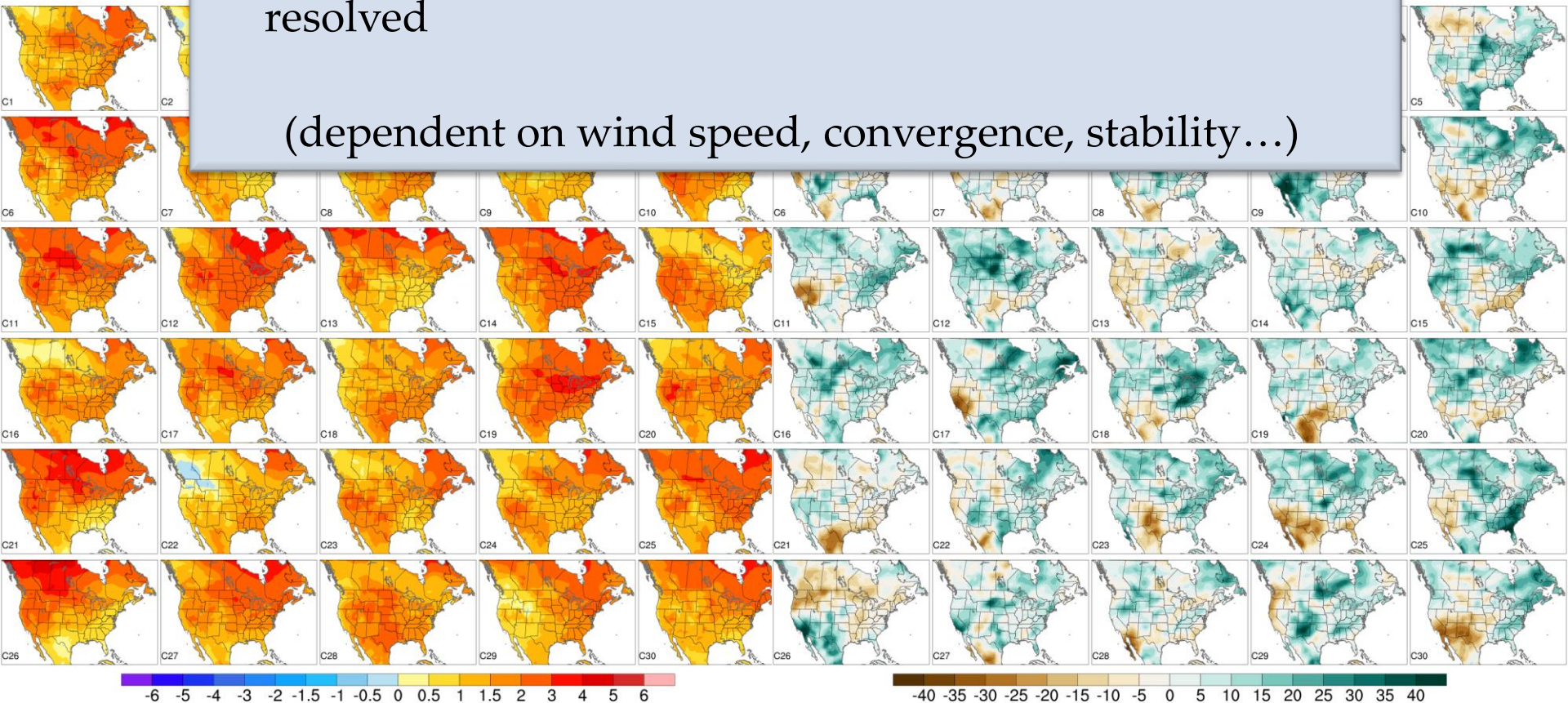
Wetter
And Drier...
(2030 – 1995)



What will the future look like?

- Warmer -> More Moisture -> More Precipitation?
- Especially if mountains and convection are properly resolved

(dependent on wind speed, convergence, stability...)

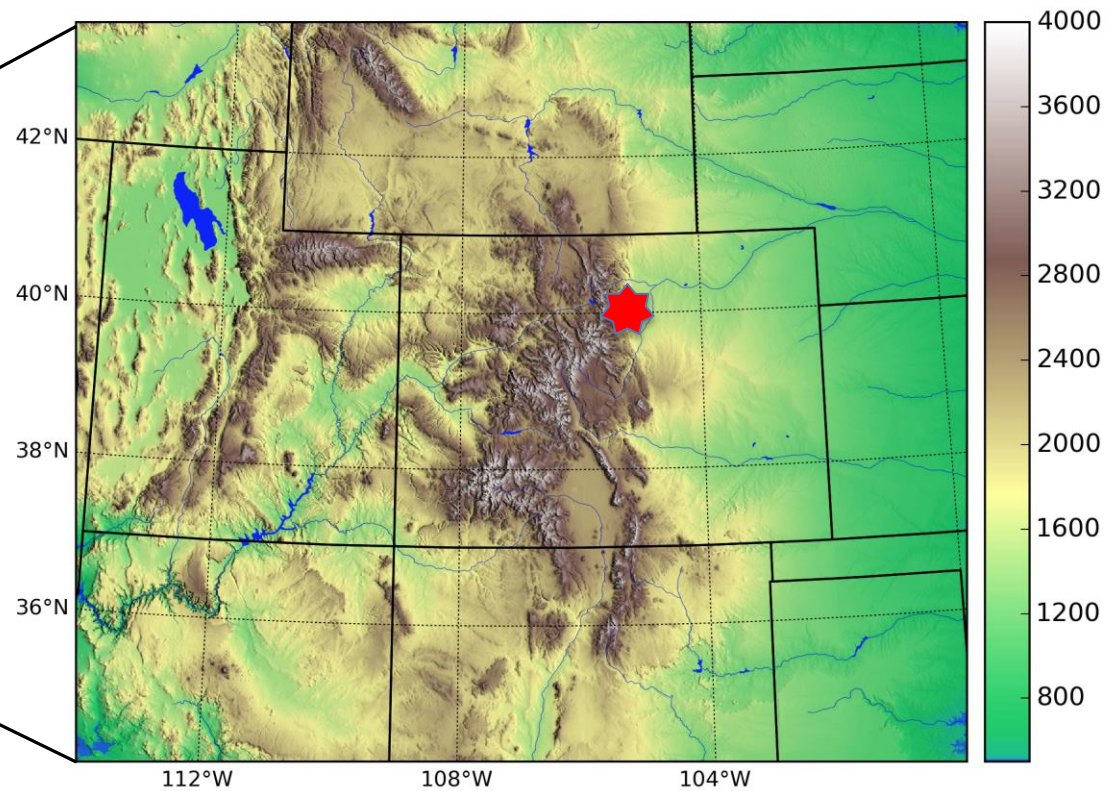
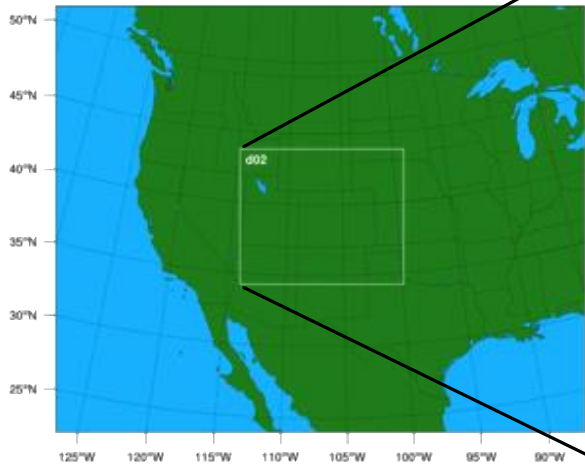


WRF Simulations

- **WRF v3.6.1**

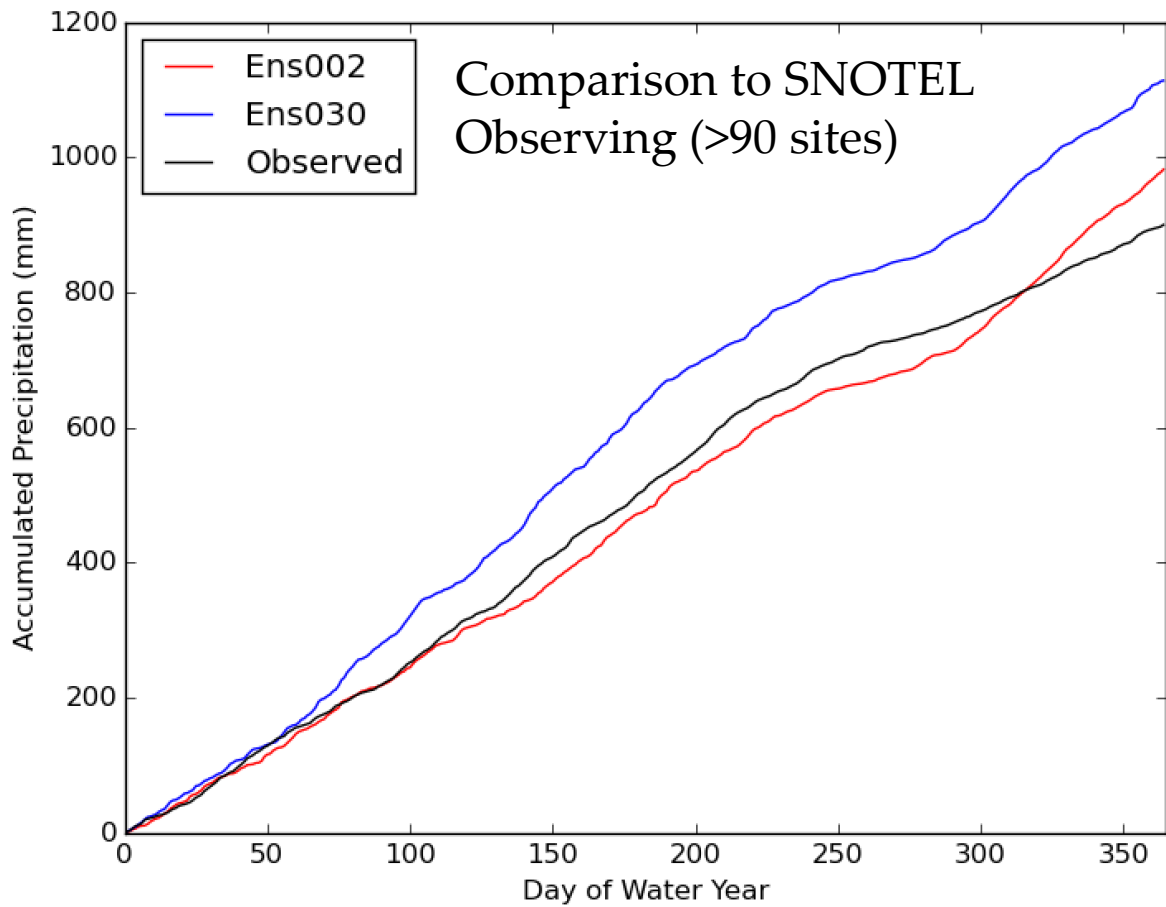
- Noah, Thompson, YSU, RRTMG

WPS Domain Configuration



○ 2010-2017

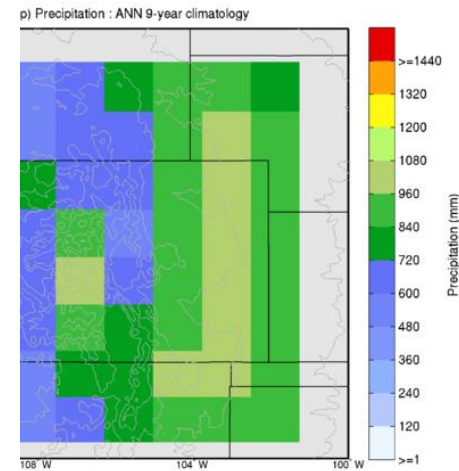
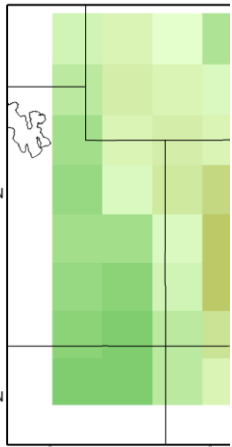
Cold



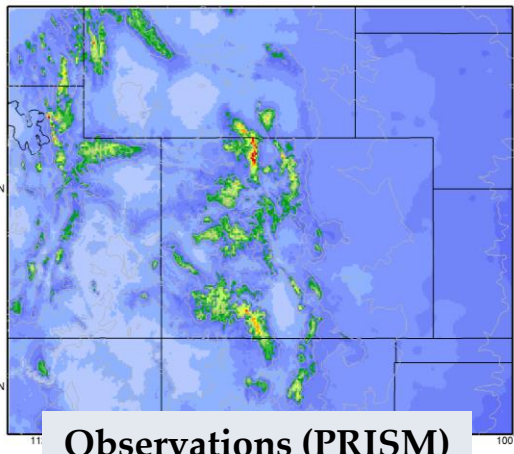
Precipitation

1)

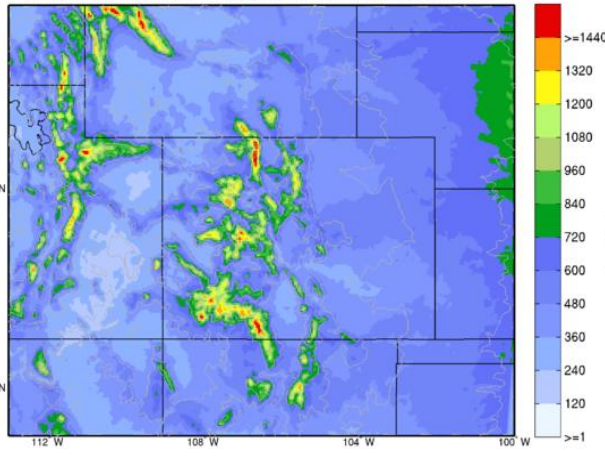
Ens. 030



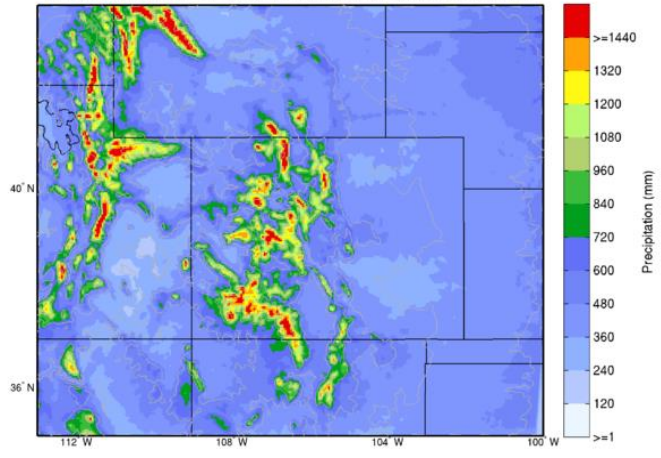
Annual PRISM Precipitation : 1990-1999



Annual Precipitation from WRF Ens002 (4km) : 9-yr climatology starting Oct 1990



Annual Precipitation from WRF Ens002RCP (4km) : 9-yr climatology starting Oct 2071

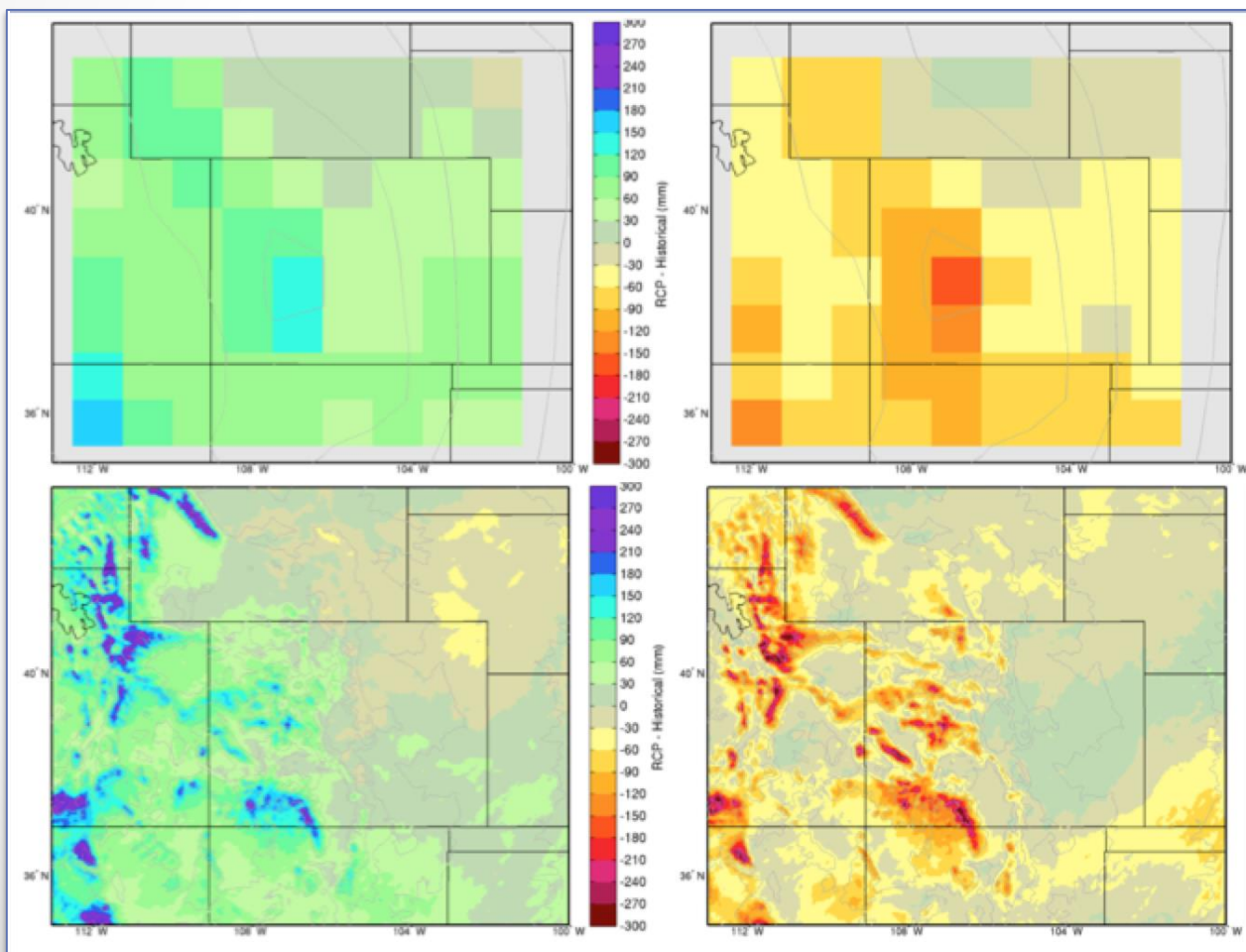


Observations (PRISM)

Change in Cool Season Precipitation

Increasing Precipitation
(Ens. 2)

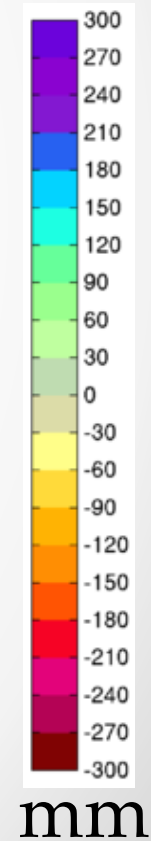
Decreasing Precipitation
(Ens. 30)



CESM
111km



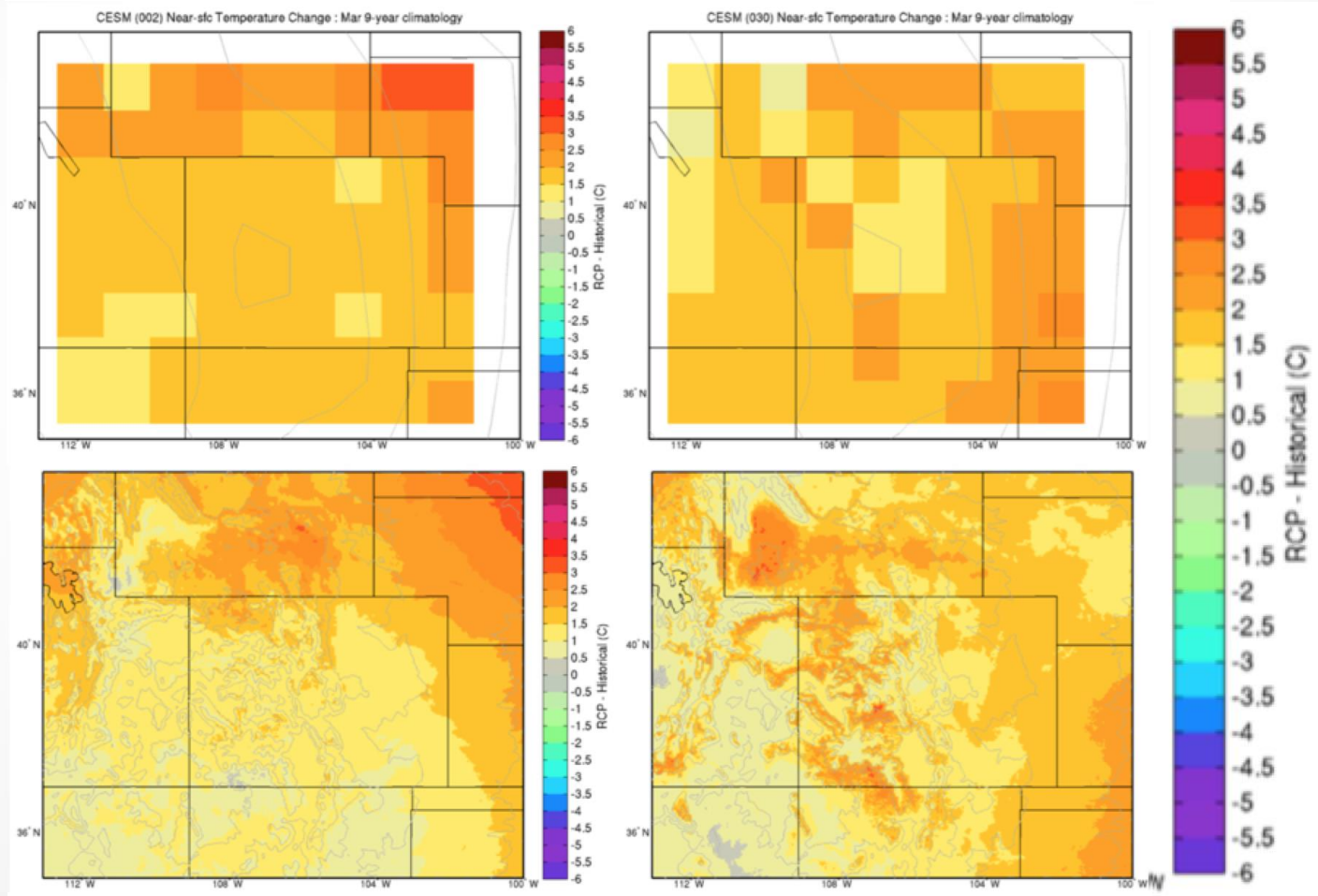
WRF
4km



Change in March Temperature

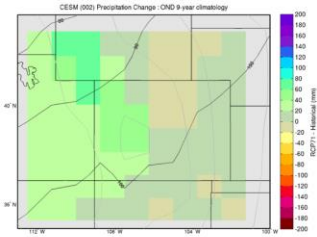
Increasing Precipitation
(Ens. 2)

Decreasing Precipitation
(Ens. 30)

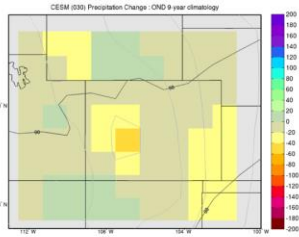


9-year Climatology of OND Precipitation Change in the inner domain

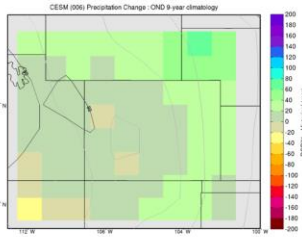
Ens 02



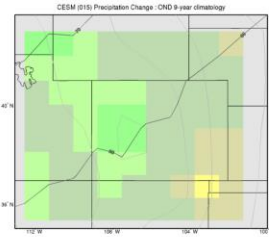
Ens 30



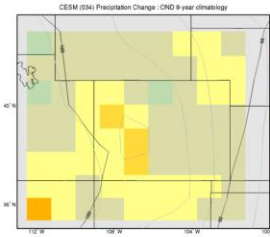
Ens 06



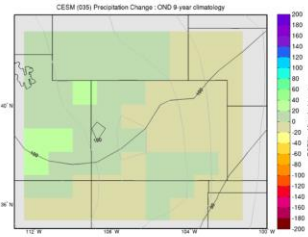
Ens 15



Ens 34

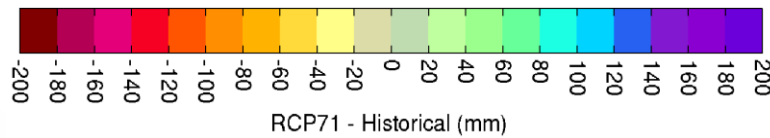
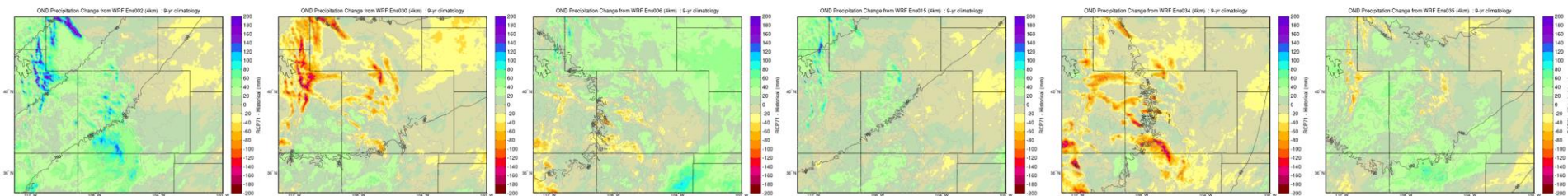


Ens 35



CESM ~100km

WRF 4km



9-year Climatology of JFM Precipitation Change in the inner domain

Ens 02

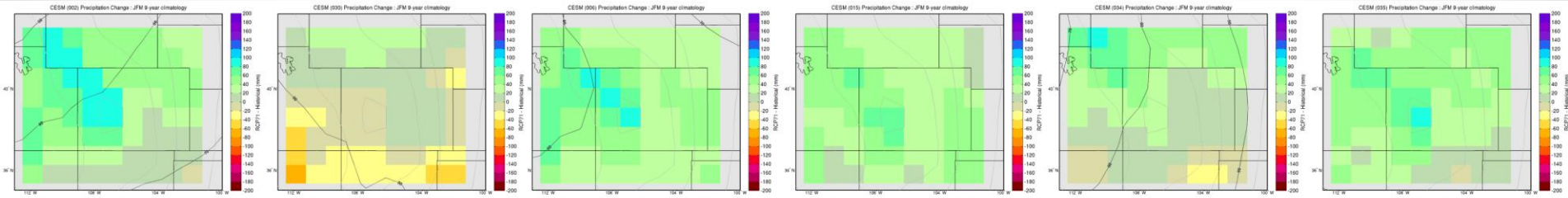
Ens 30

Ens 06

Ens 15

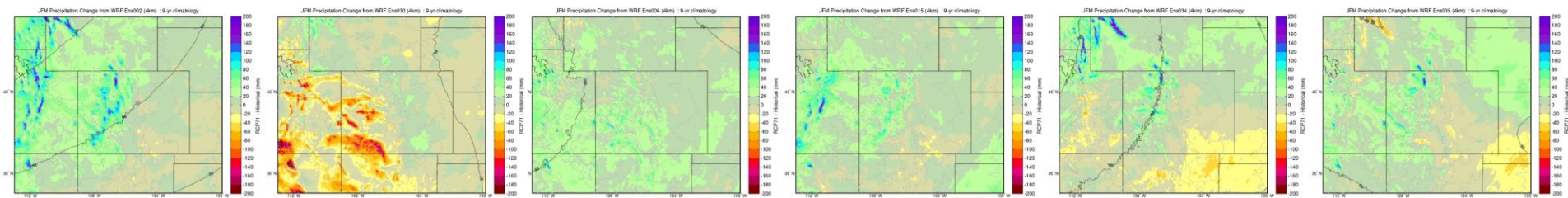
Ens 34

Ens 35



CESM ~100km

WRF 4km



9-year Climatology of AMJ Precipitation Change in the inner domain

Ens 02

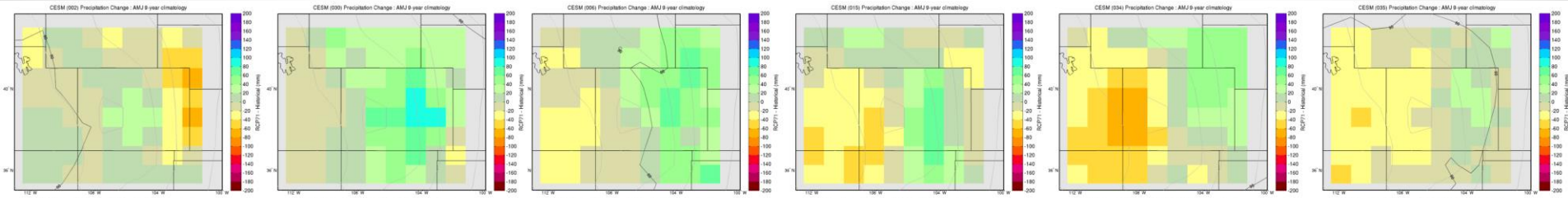
Ens 30

Ens 06

Ens 15

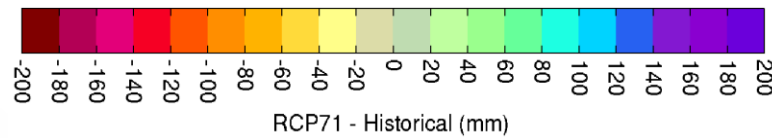
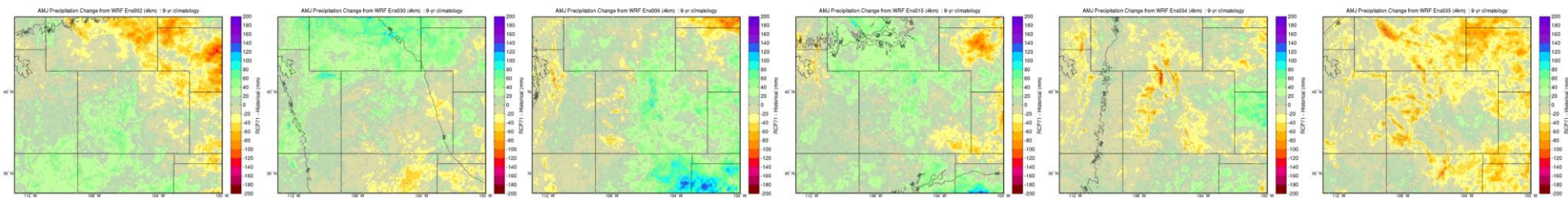
Ens 34

Ens 35



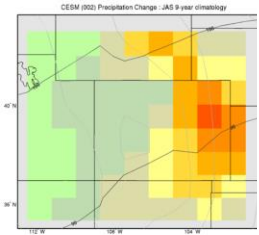
CESM ~100km

WRF 4km

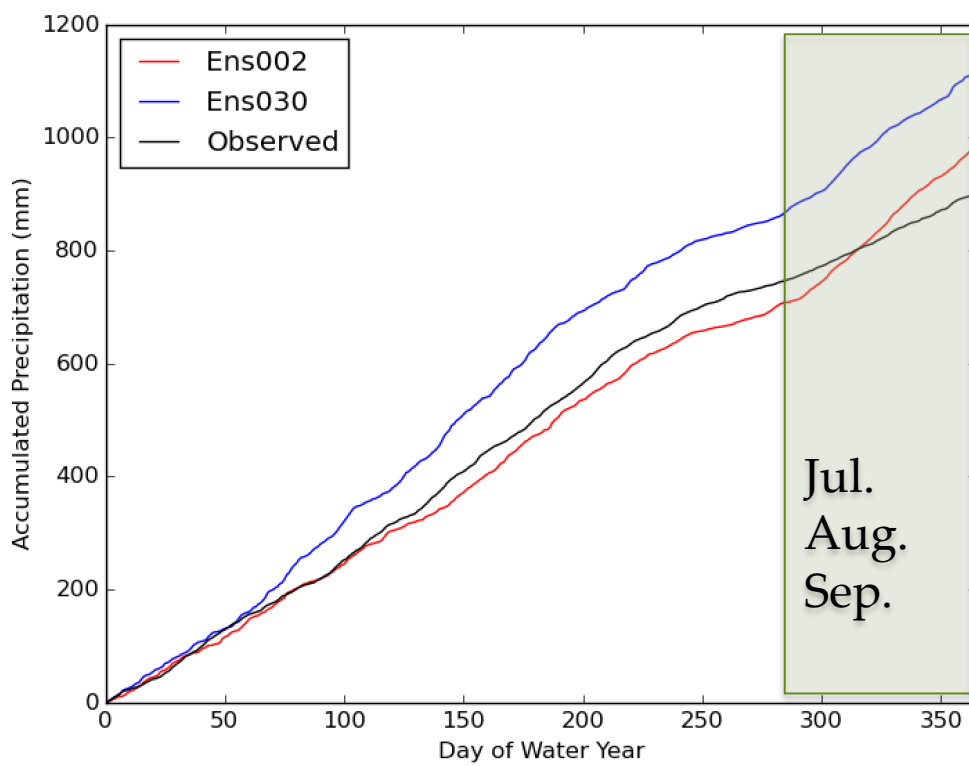


9-year

Ens 02

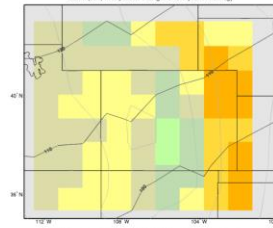


CESM ~100k

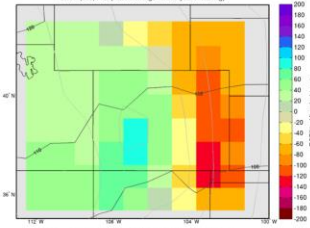


Change in the inner

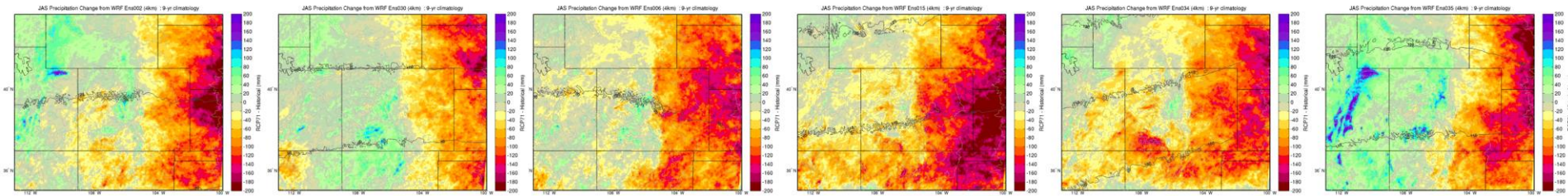
Ens 34



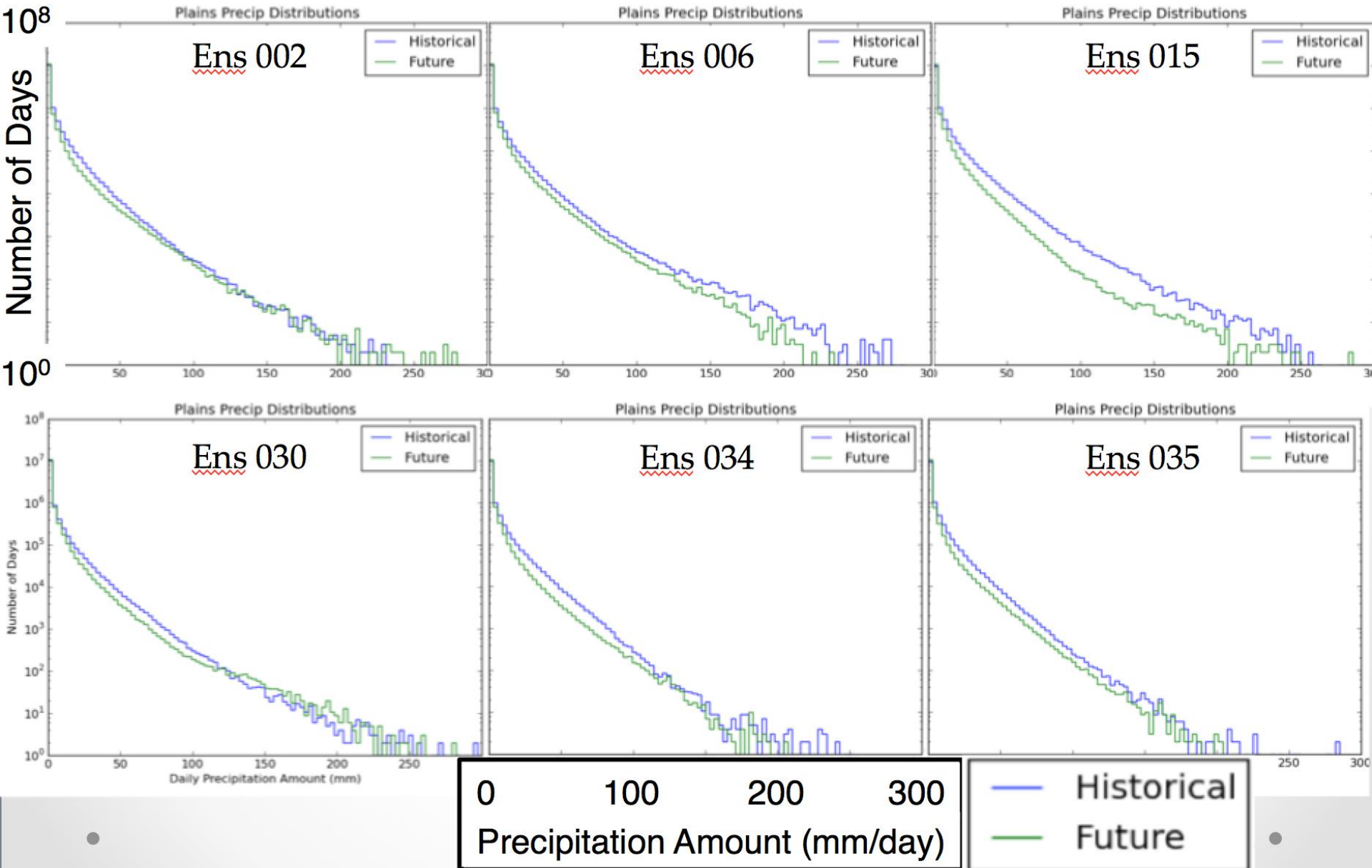
Ens 35



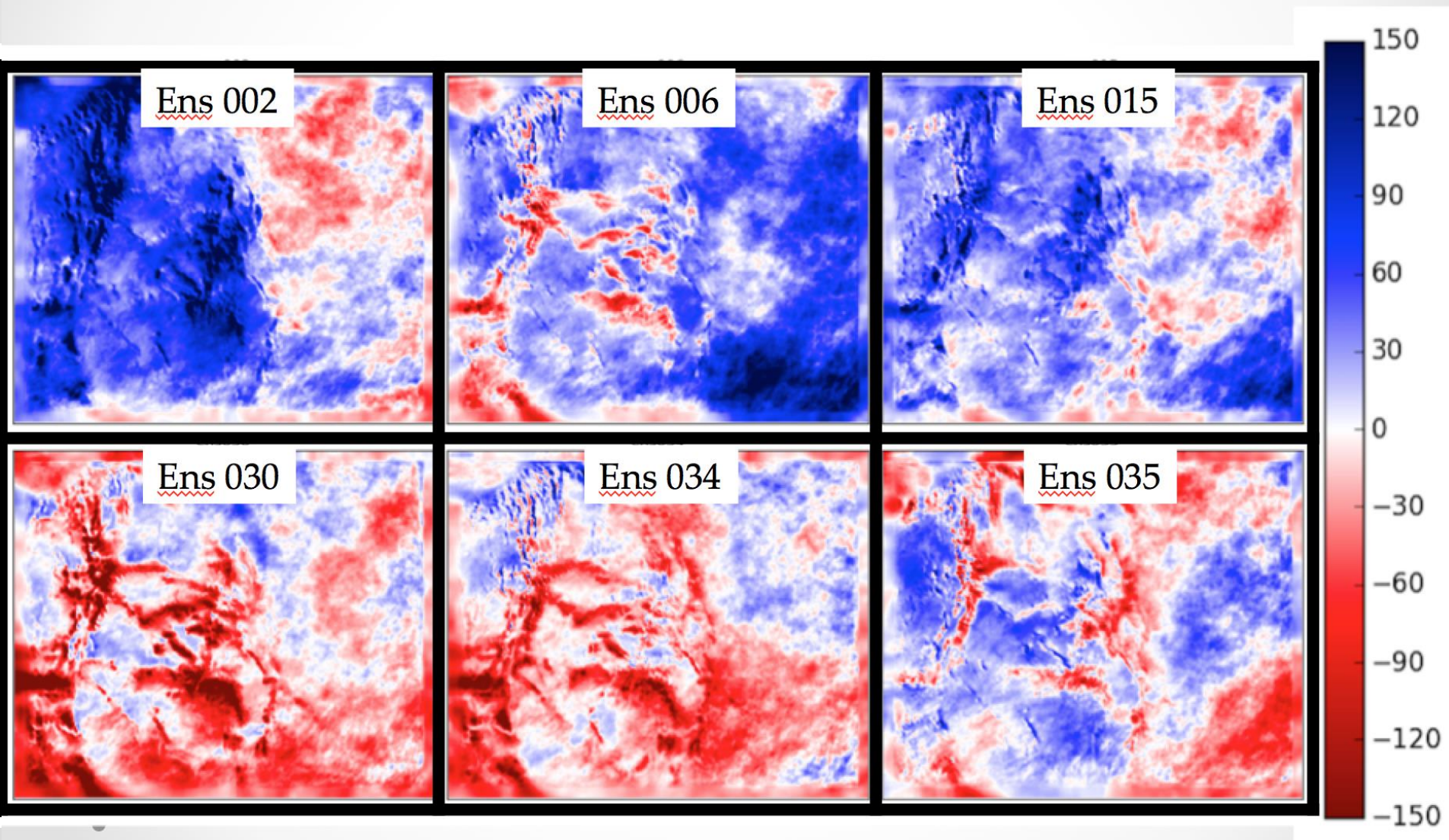
WRF 4km



Warm Season Extremes



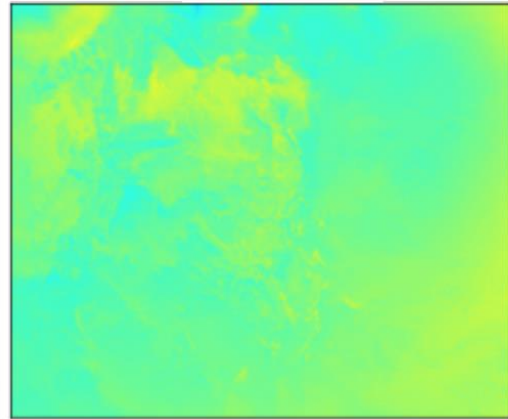
Cool Season Precipitation



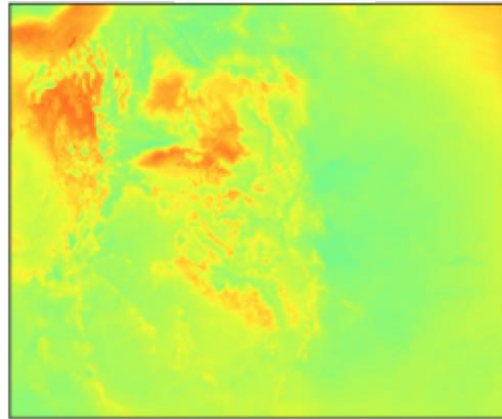
Snow Albedo Feedback

February Temperature Change

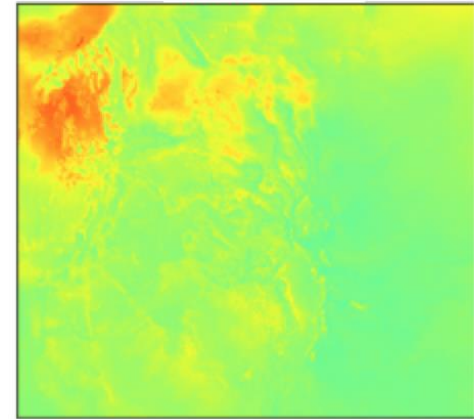
Ens 002



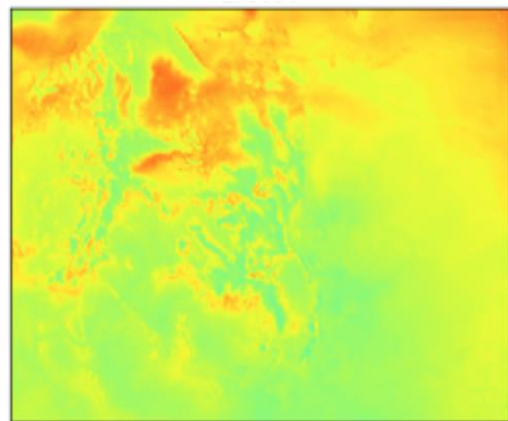
Ens 006



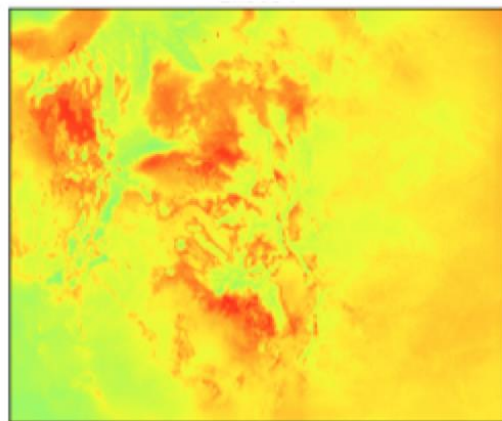
Ens 015



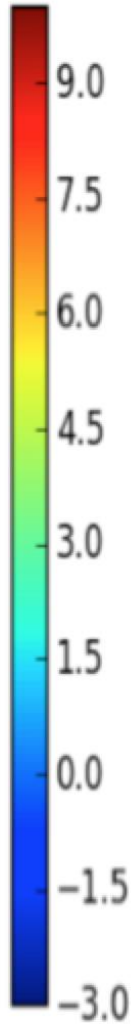
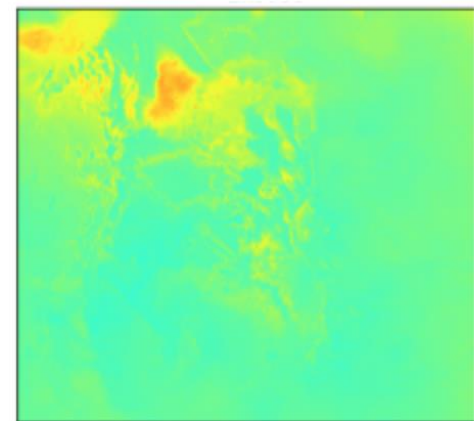
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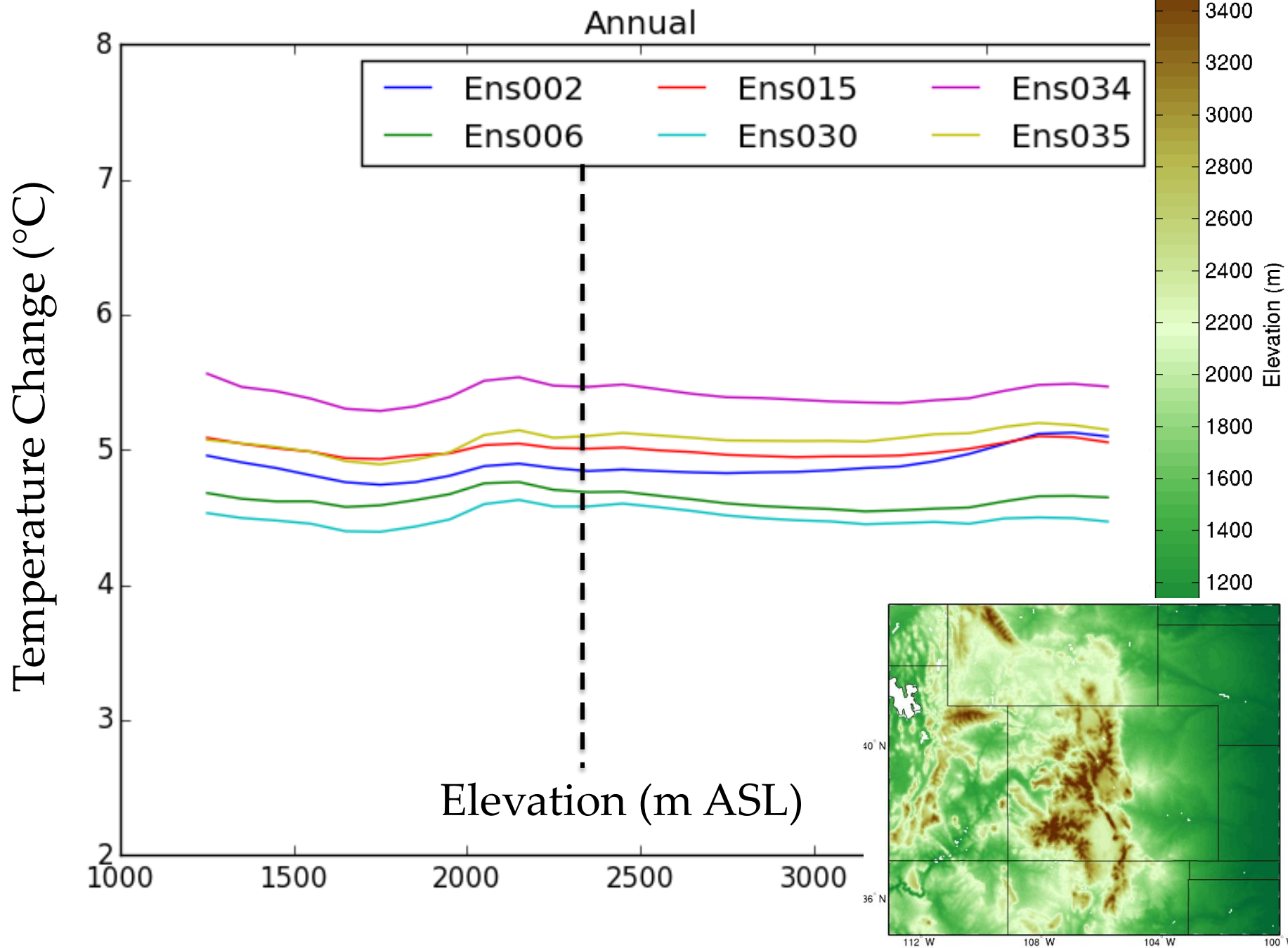
Ens 034



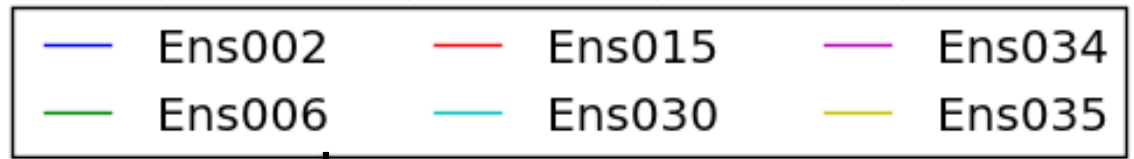
Ens 035



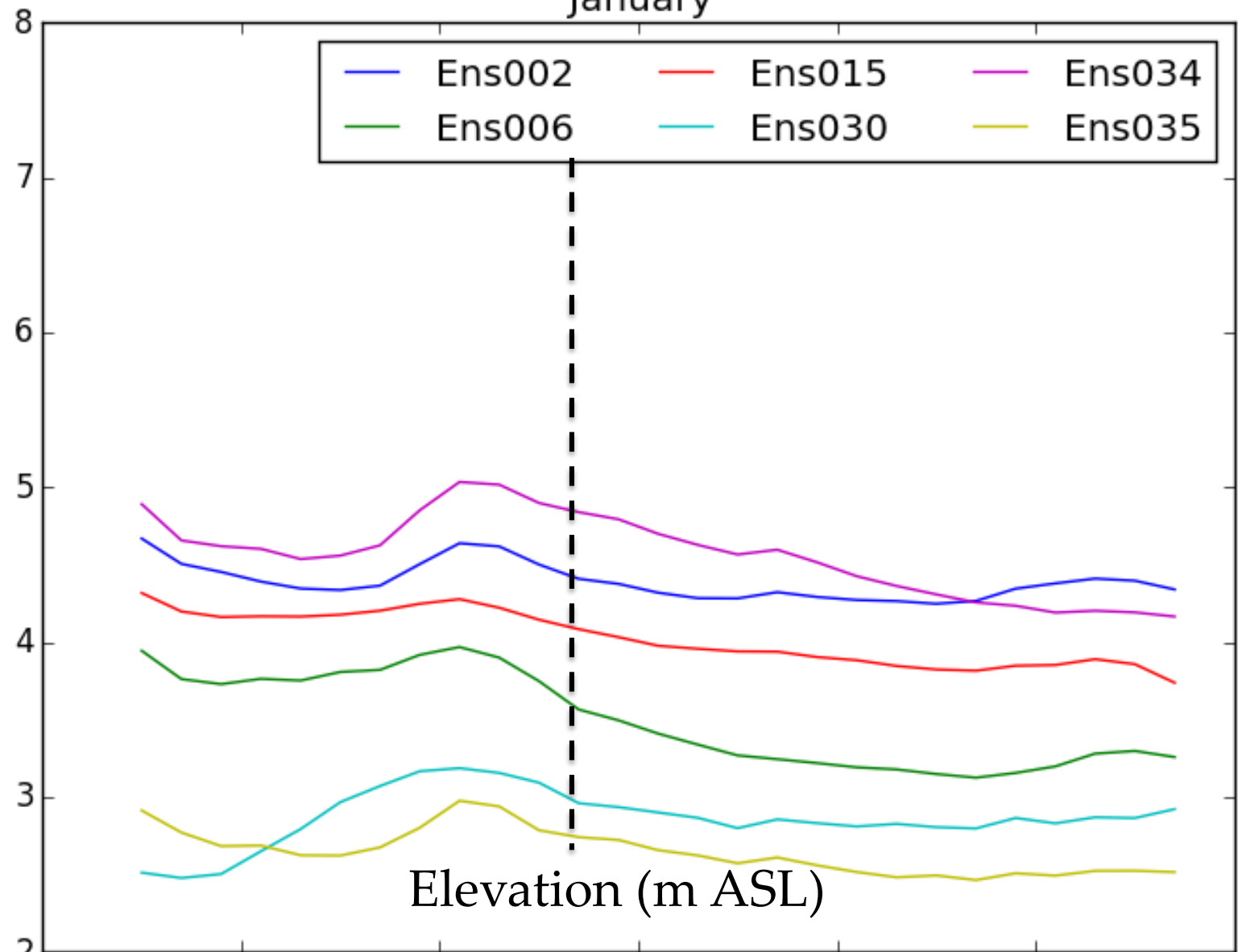
Elevation Dependent Warming



January

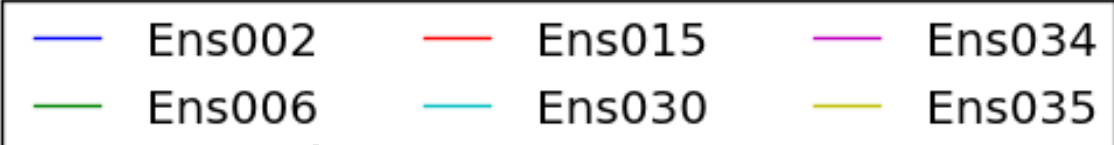


Temperature Change (°C)

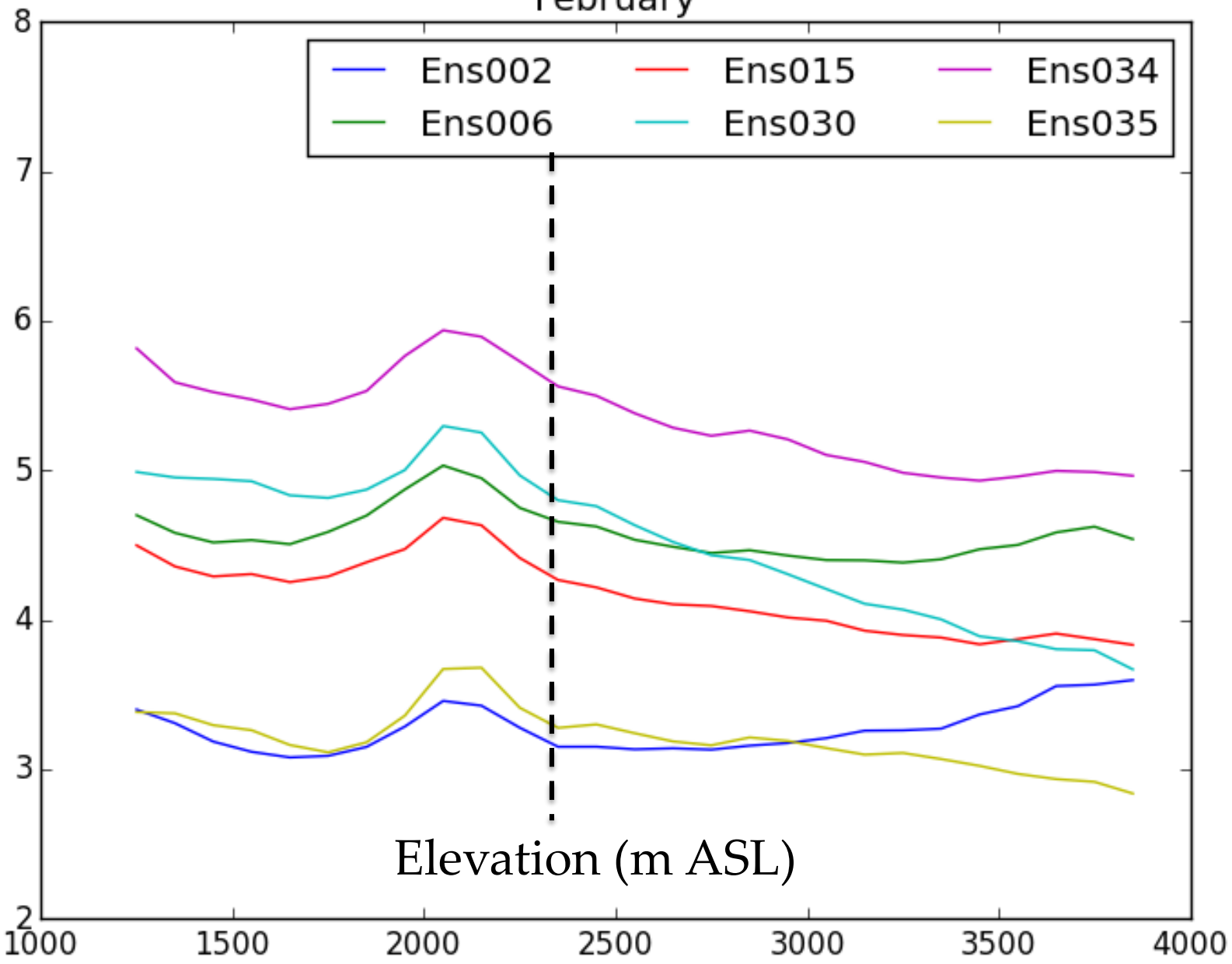


Elevation (m ASL)

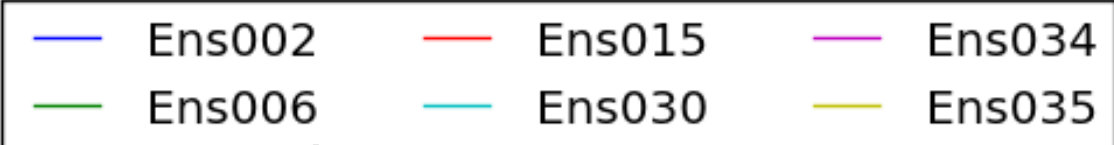
February



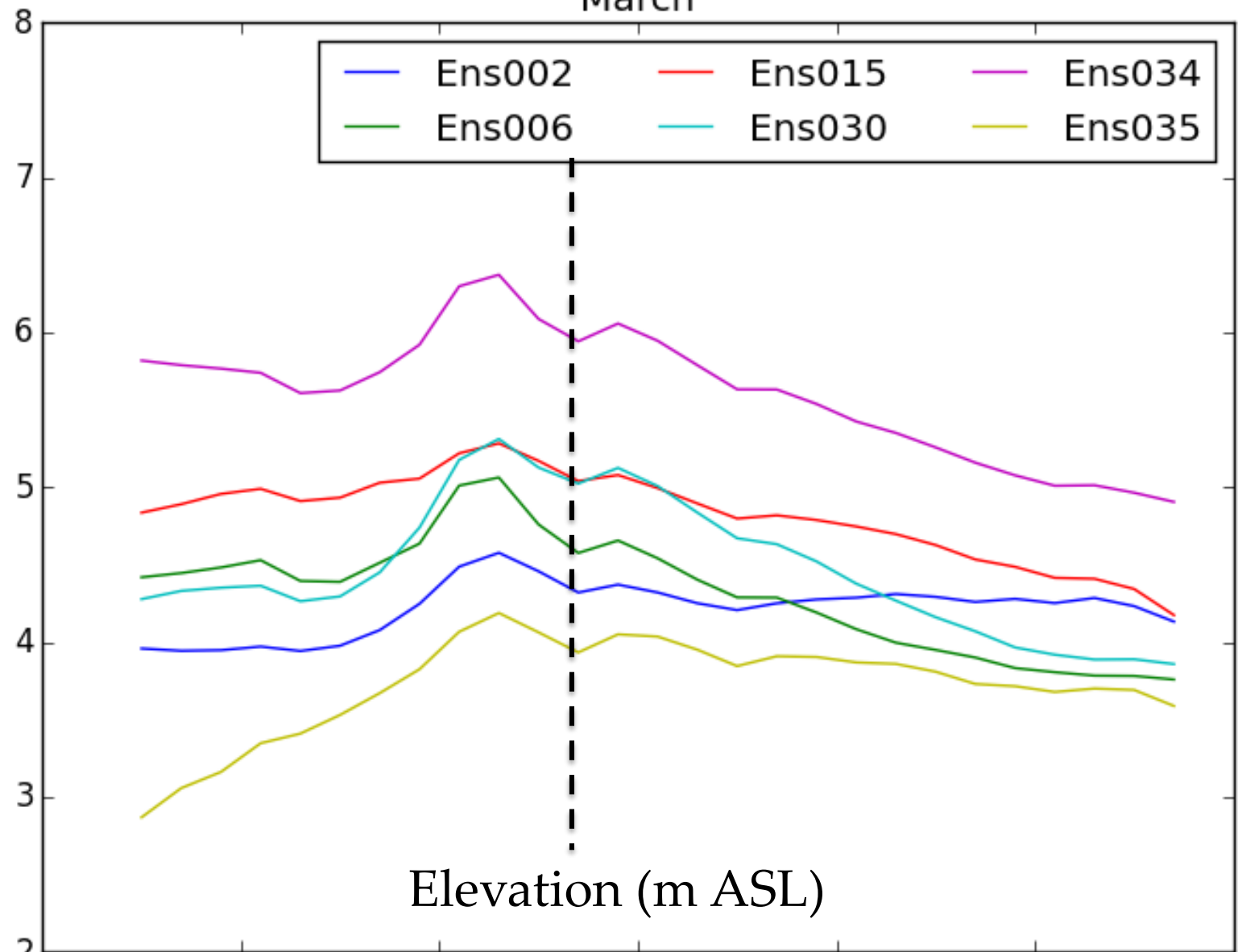
Temperature Change (°C)



March

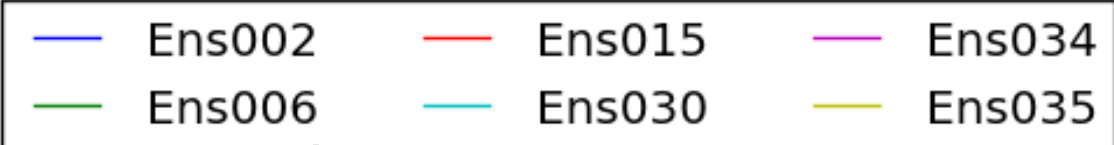


Temperature Change (°C)

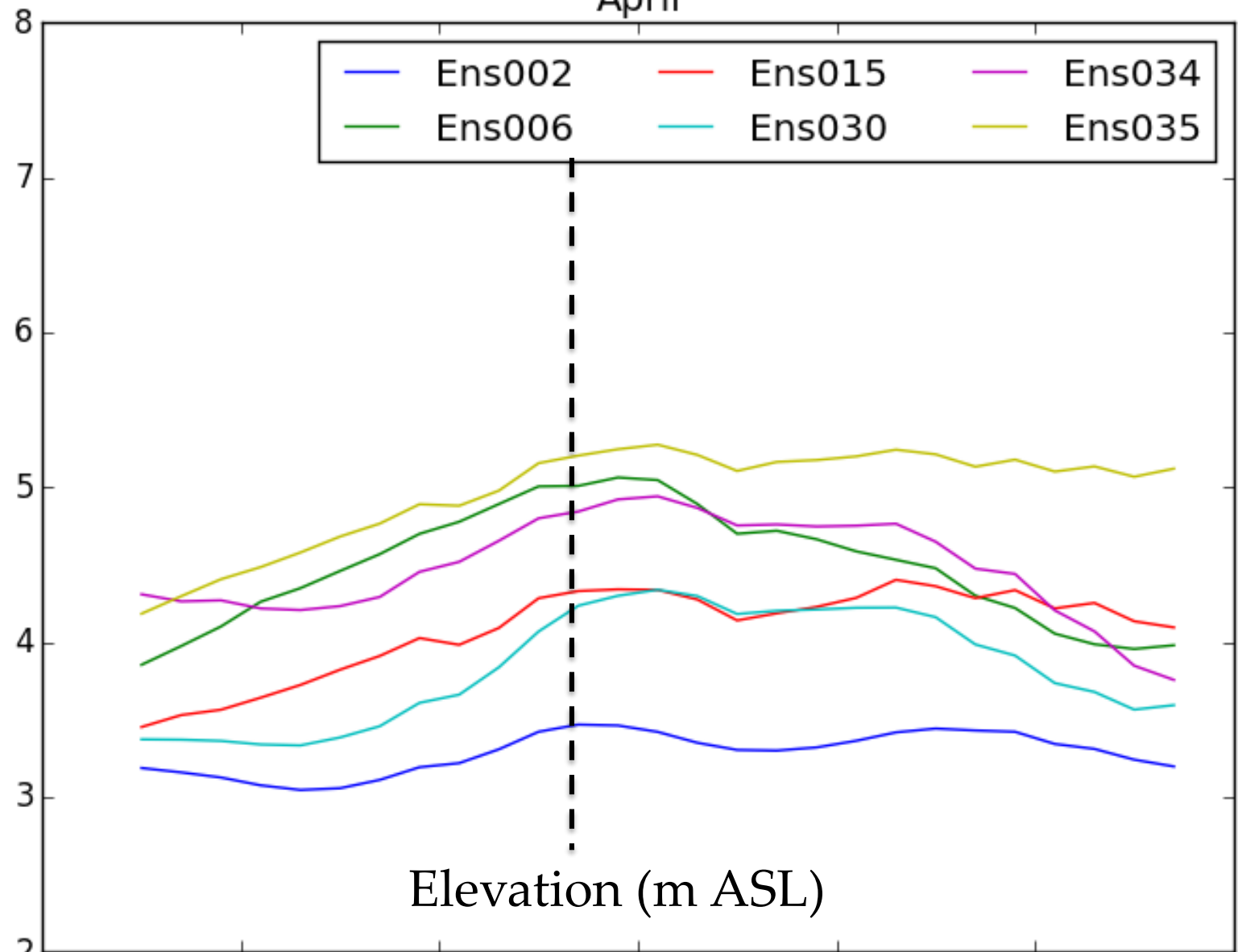


Elevation (m ASL)

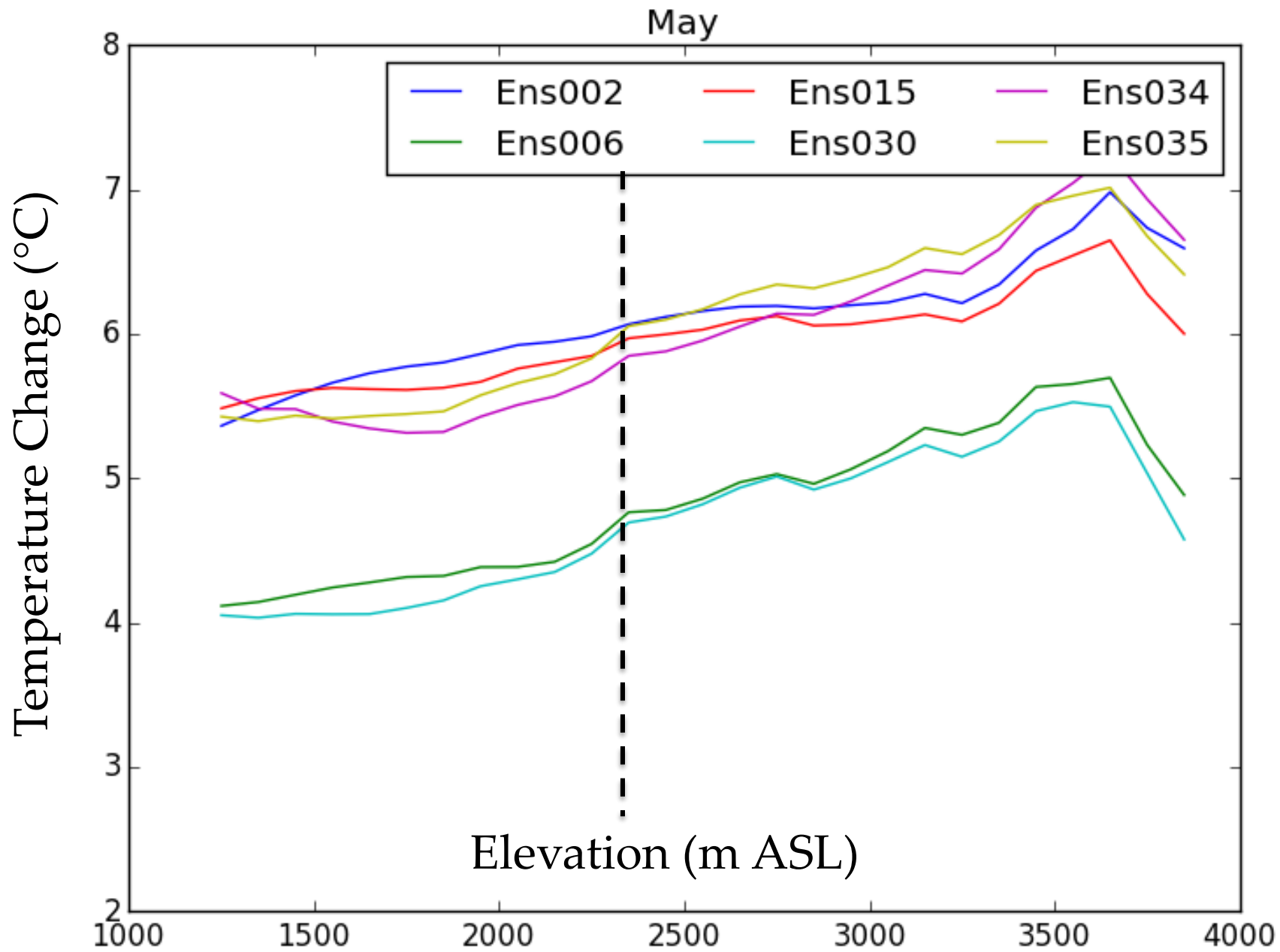
April



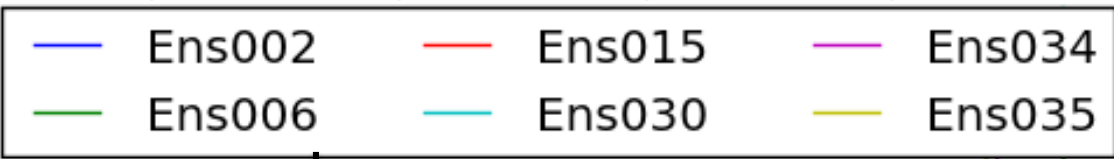
Temperature Change (°C)



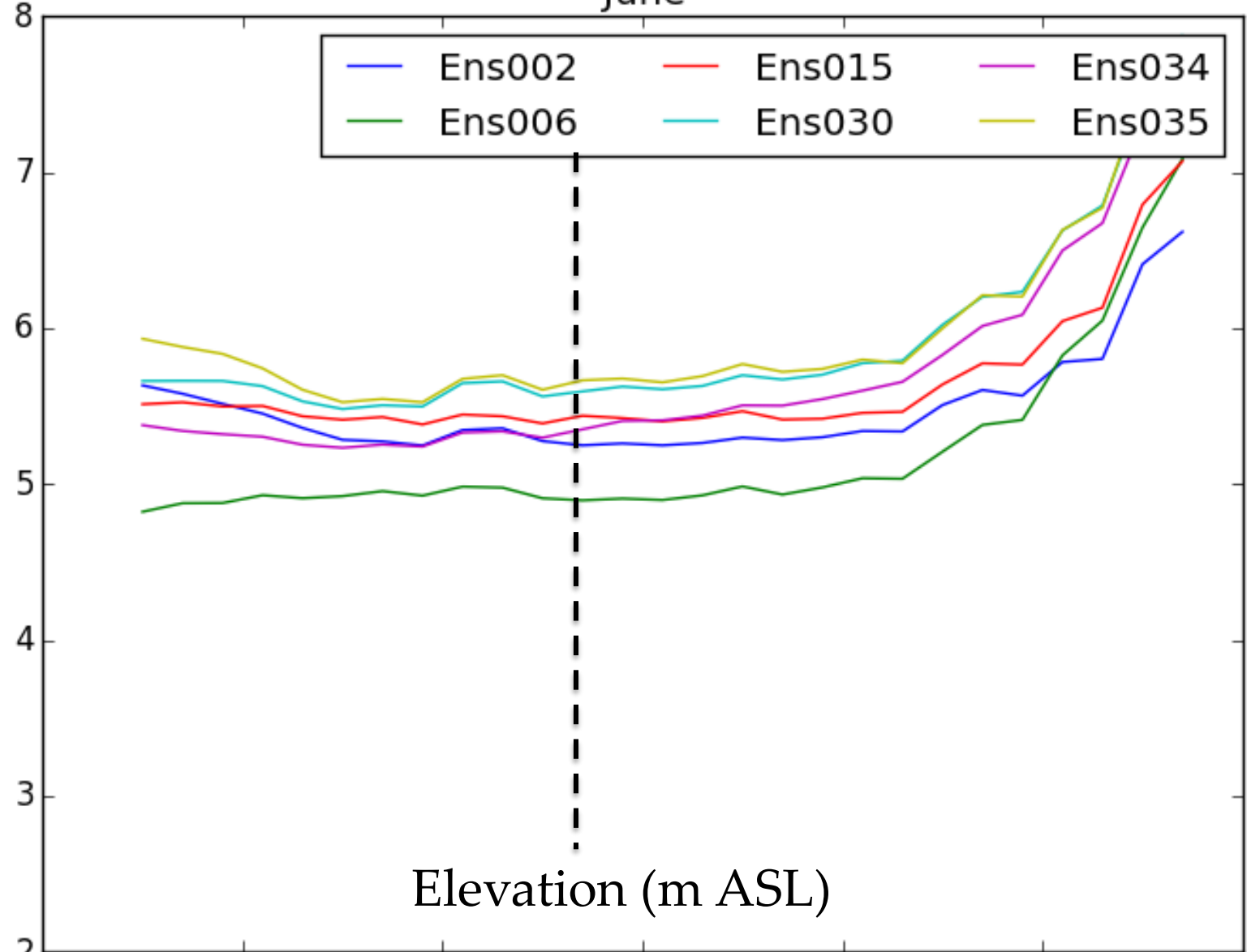
Elevation (m ASL)



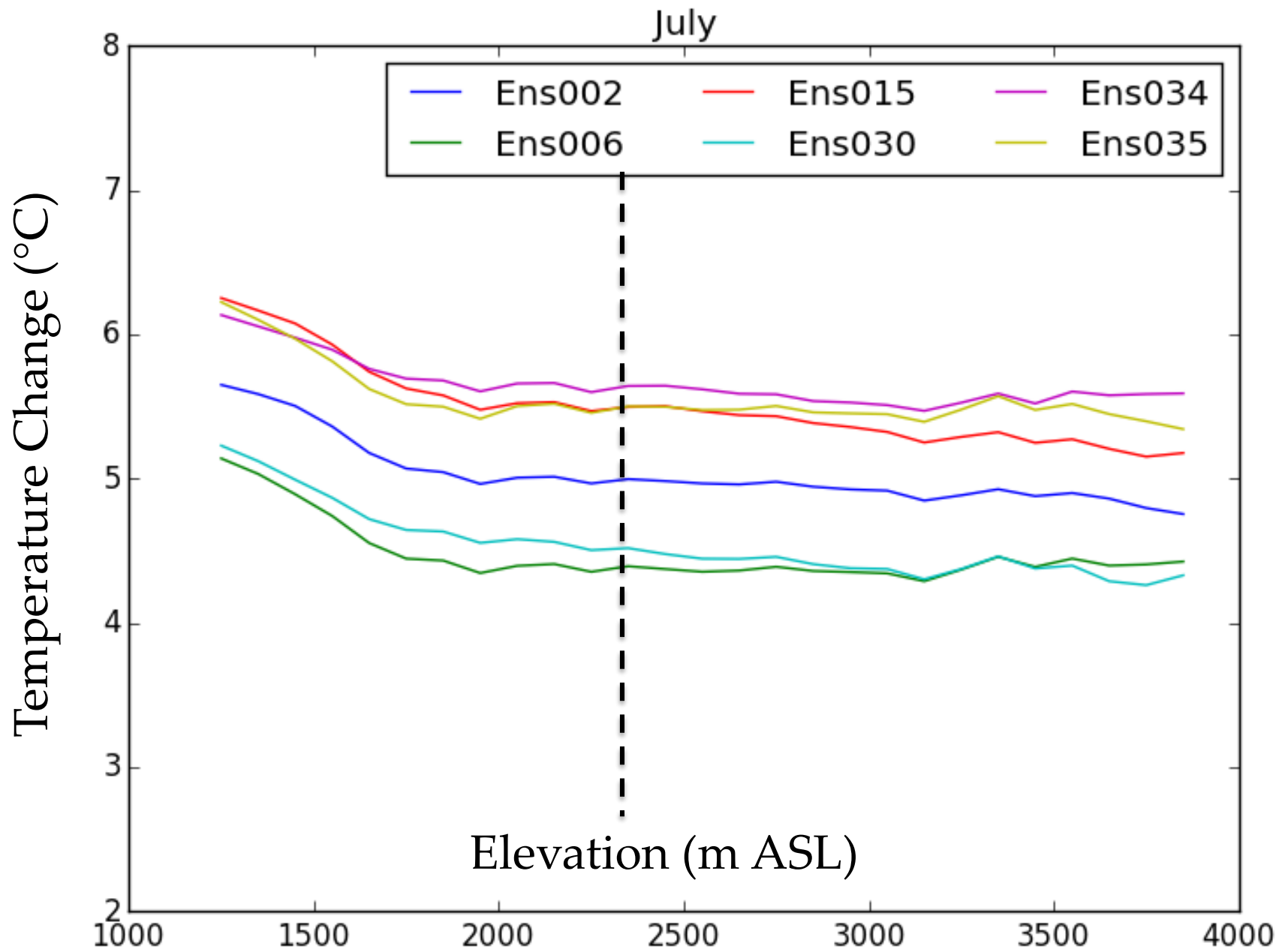
June



Temperature Change (°C)



Elevation (m ASL)



Summary

- **Climate projections must consider uncertainty**
- For cool-season precipitation, internal variability appears greater than the climate change signal.
- Changes in precipitation can alter more predictable signals such as the snow albedo effect
- Elevation dependent warming is seasonally dependent
- Consistent decreases in summer time convection does not lead to change in extreme events

