Fine-scale climate projections for Utah from statistical downscaling of global climate models

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Three questions

A. How do climate models work and what are the strengths and weaknesses of such models?

B. What are the methods to get regional climate information from global models?

C. How will climate change affect Utah?

A. How do climate models work?

Why modeling climate?

- Climate is too complex to
  - observe it consistently
  - reproduce it in a laboratory
  - understand it analytically
- Alternative
  - devise a mathematical model that simulates the key processes that govern climate
- Such a model can then be used to
  - understand what cannot be directly observed
  - perform experiments
  - gain quantitative understanding for change

What exactly is a “model”?

- Merriam-Webster:

Main Entry: **¹mod·el**
Pronunciation: \ˈmä-dᵊl\
Function: *noun*
Etymology: Middle French *modelle,* from Old Italian *modello,* from Vulgar Latin **modellus,* from Latin *modulus* small measure, from *modus*
Date: 1575

1 *obsolete* **:** a set of plans for a building
2 *dialect British* **:** COPY , IMAGE
3 : structural design <a home on the *model* of an old farmhouse>
4 : a usually miniature representation of something ; *also* **:** a pattern of something to be made
5 : an example for imitation or emulation
6 : a person or thing that serves as a pattern for an artist ; *especially* **:** one who poses for an artist

- Remember: A model is only a <u>representation</u> or <u>imitation</u> of reality

Three types of models

Statistical
- From statistical relationships amongst data
- Empirics based
- Limited usefulness

Dynamical
- From first principles
- Physics based
- More realistic

Combined
- Statistical/dynamical approaches

Climate models: strengths

Global climate models (GCMs)

- global coverage

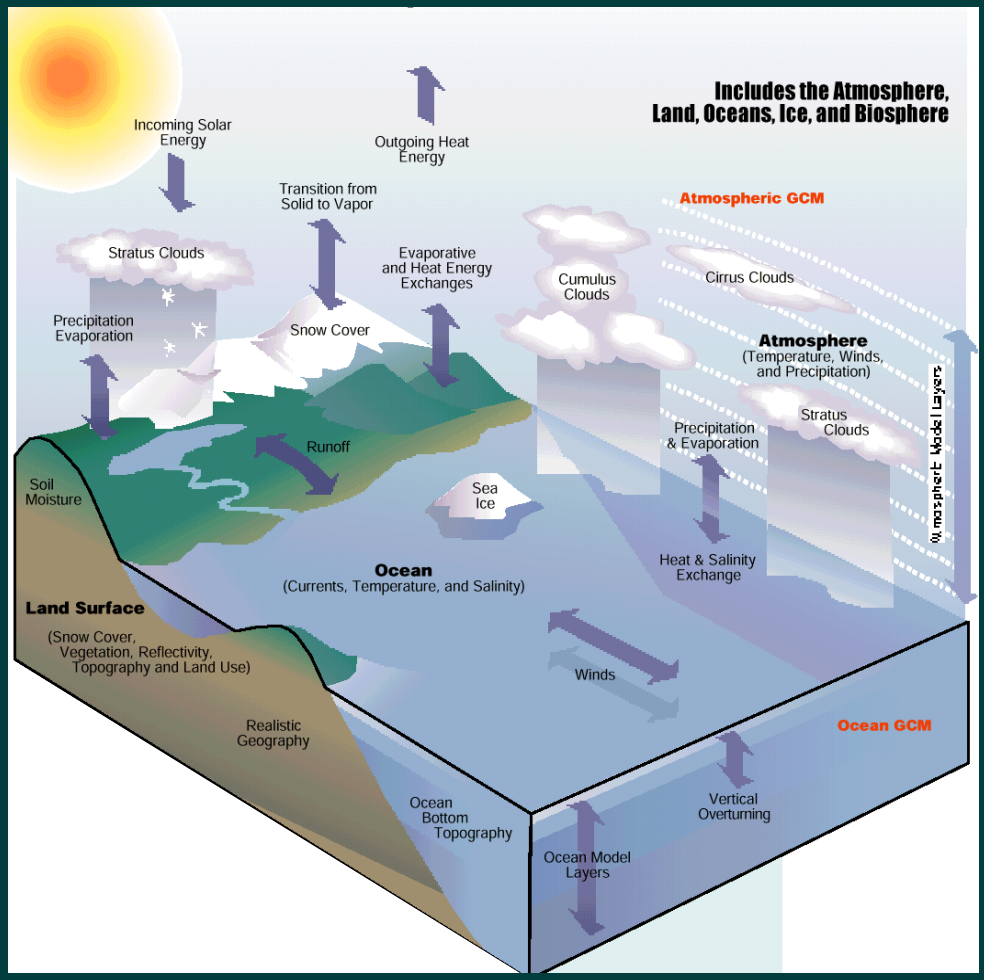
Explicitly simulate

- 3D evolution of atmosphere & ocean (dynamics)
- key physical processes (radiation, hydrological cycle, …)
- physical cause for relationships
- interactions and feedbacks

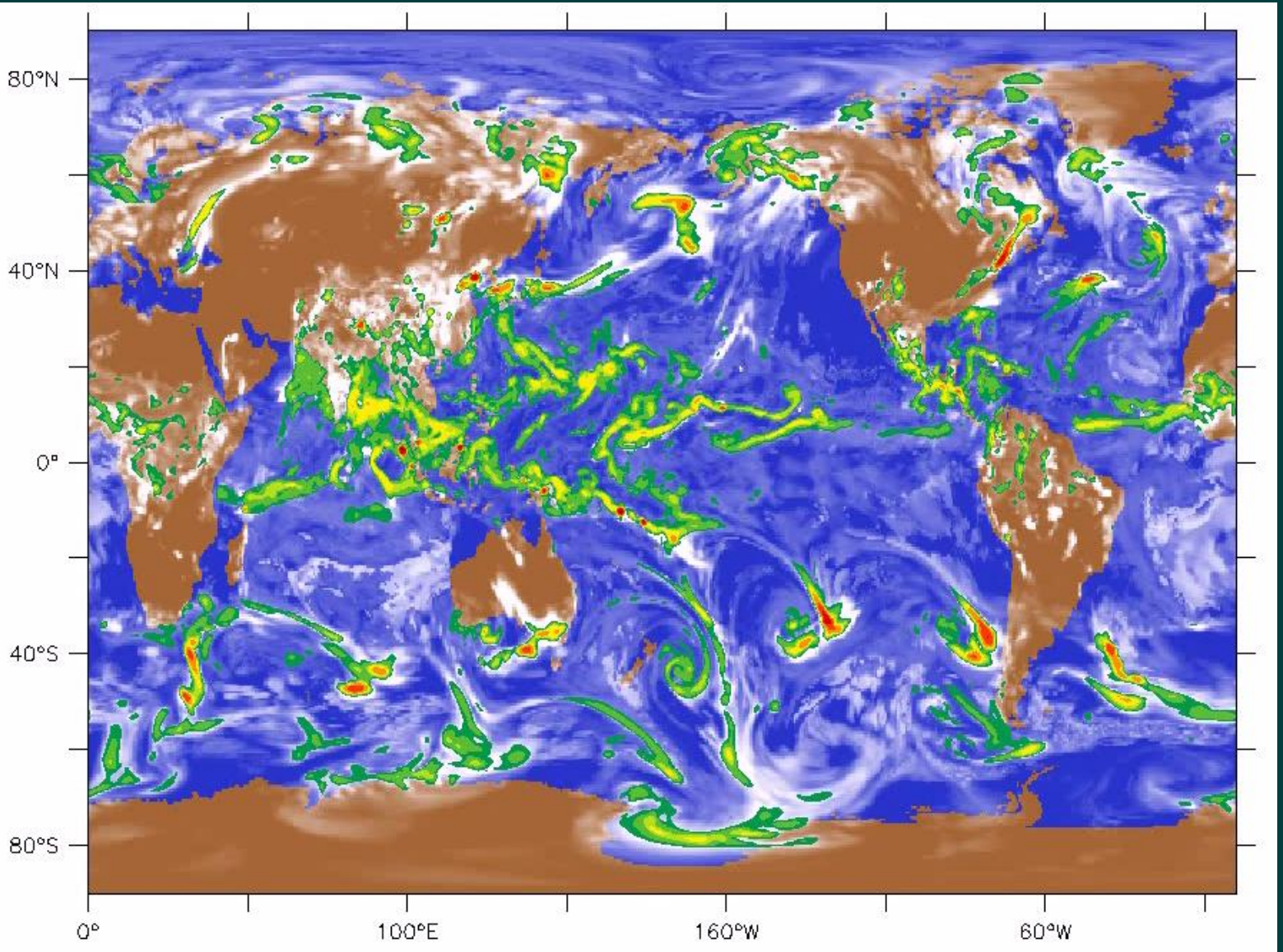
Examine statistics: wind, temperature, precipitation, …

Climate models: development

- Interacting components: Atmosphere, ocean, land, ice, vegetation, chemistry
- Development requires major resources
- Worldwide: ~24 models, ~12 centers
- 4 US centers: NSF (NCAR), NASA (GISS, GSFC), NOAA (GFDL)



Climate models: output

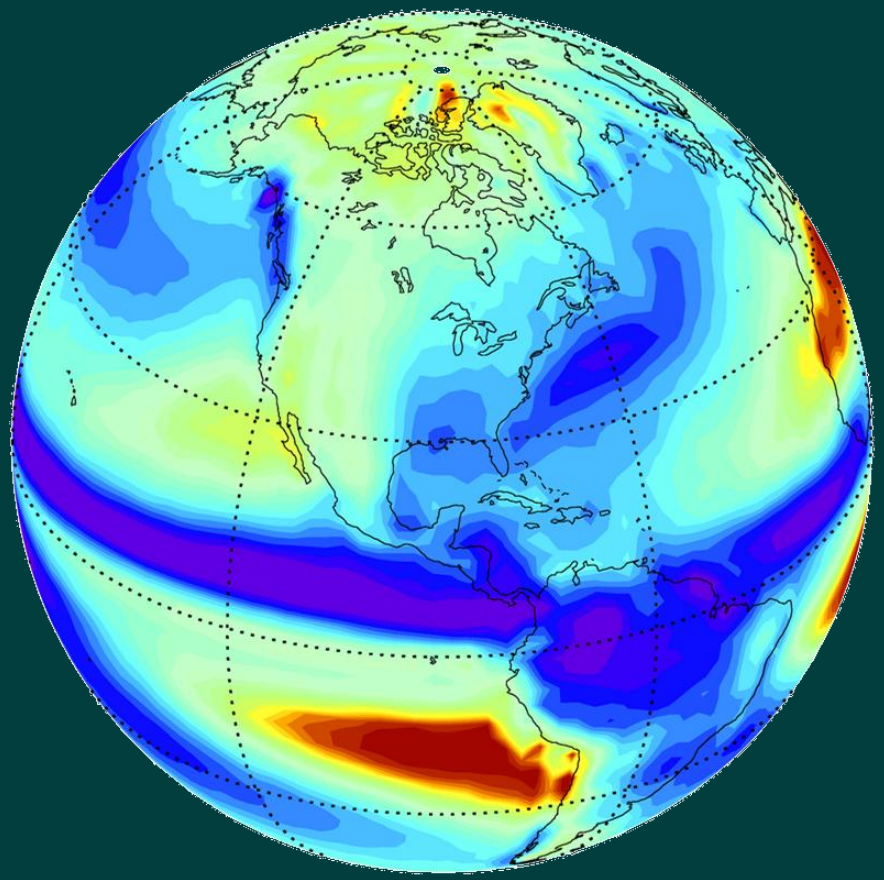


High-resolution (0.5° x 0.5°) atmosphere-only simulation with the NOAA-GFDL model AM2.1

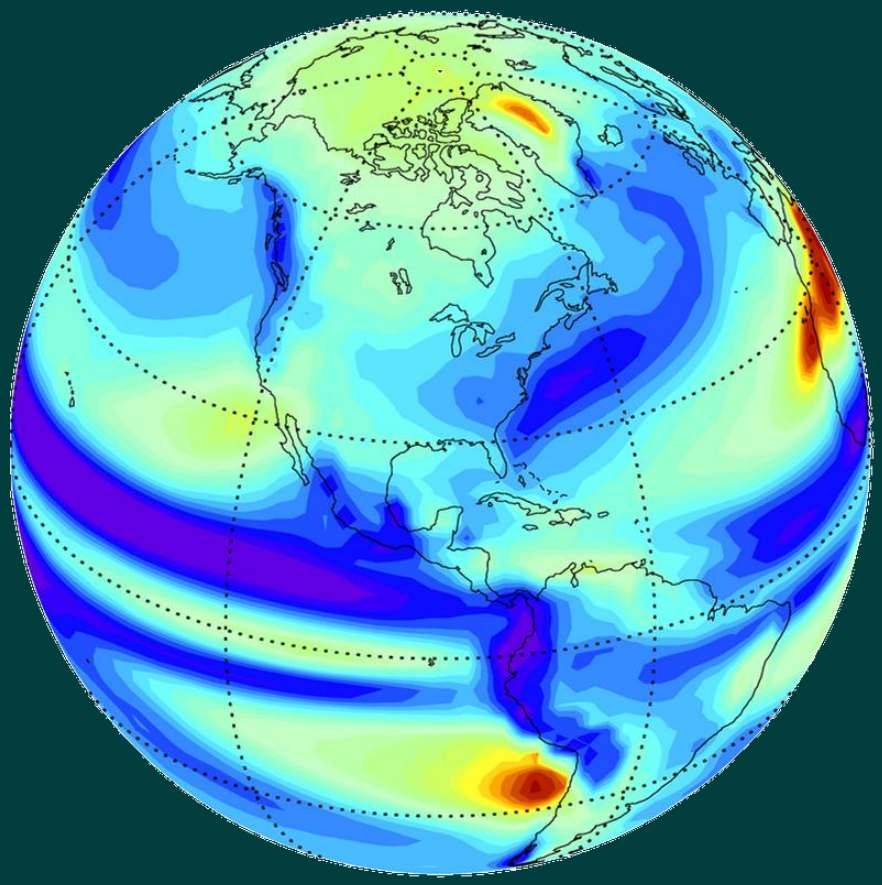
Observed vs. simulated climate

annual mean precipitation, 1979-1999

Observations (CMAP)

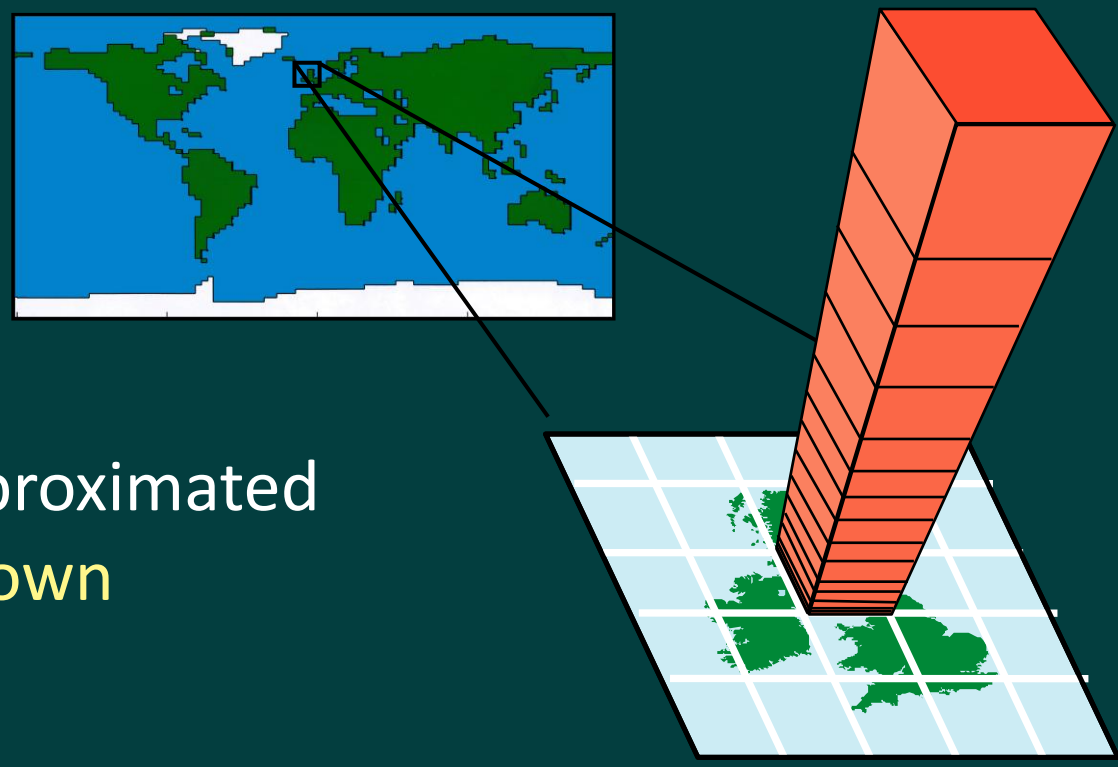


Simulation (CM2.1)



Climate models: limitations

- Models contain unavoidable simplifications

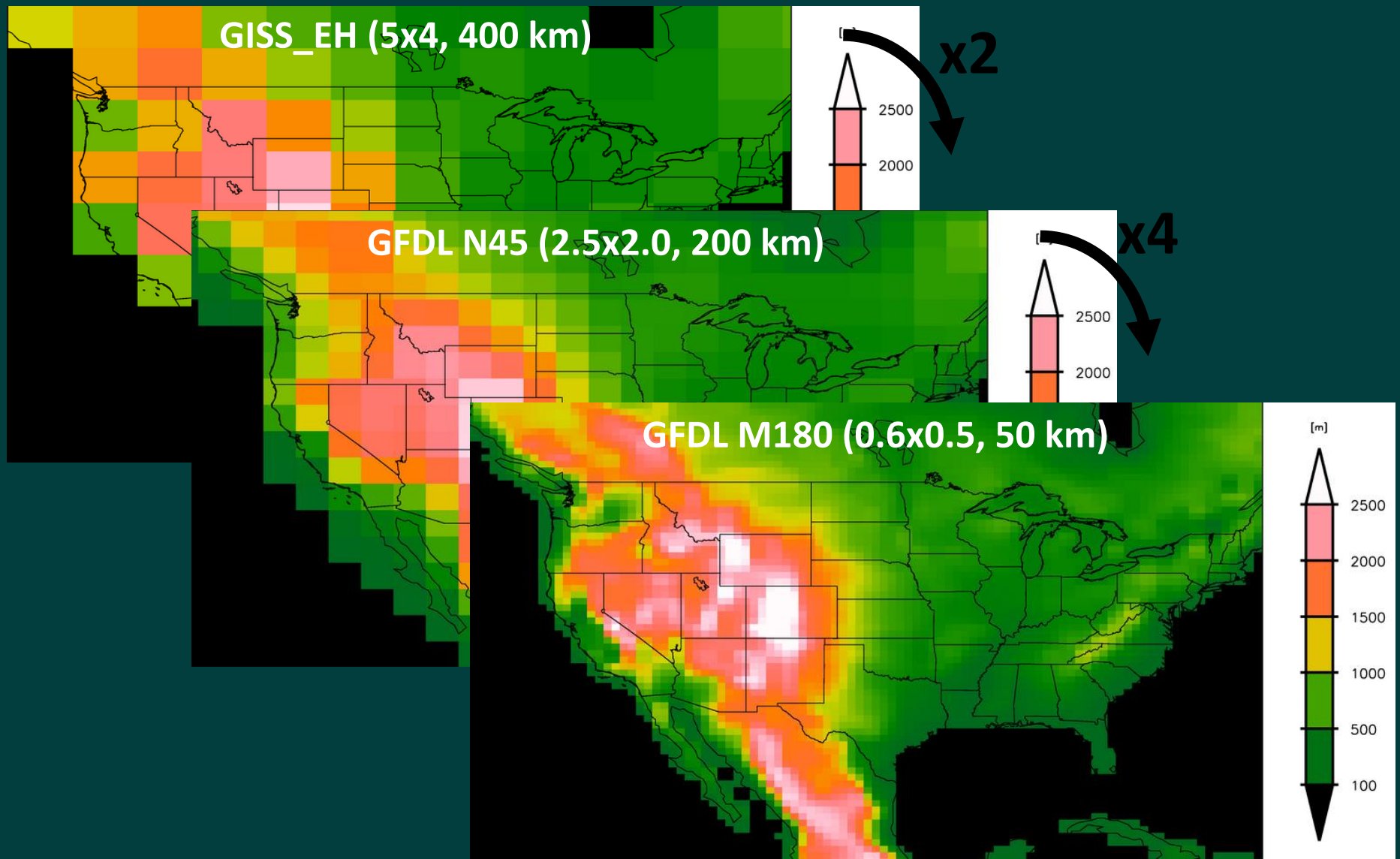


- Some processes are
  - well-known but approximated
  - only empirically-known
  - largely un-known
  - un-resolved

- The resulting simplifications create uncertainties, in particular for processes that occur on small scales (clouds, precipitation)

Spatial GCM resolution

model topography [m]



Emission scenarios

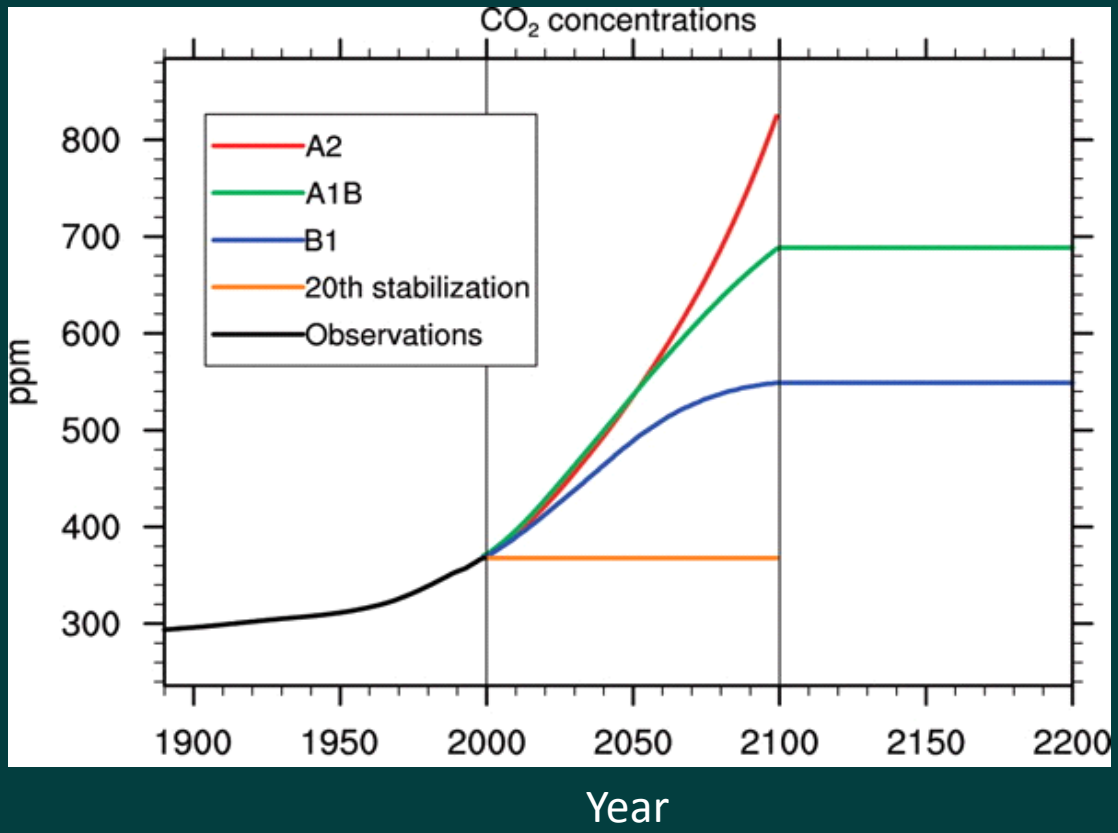
- Additional uncertainties from unknown GHG emissions
- Certain assumptions about societies and its economies
- Translated into greenhouse gas concentrations

A1B

- most common
- CO_2 stabilization at 700 ppm
- optimistic

A2

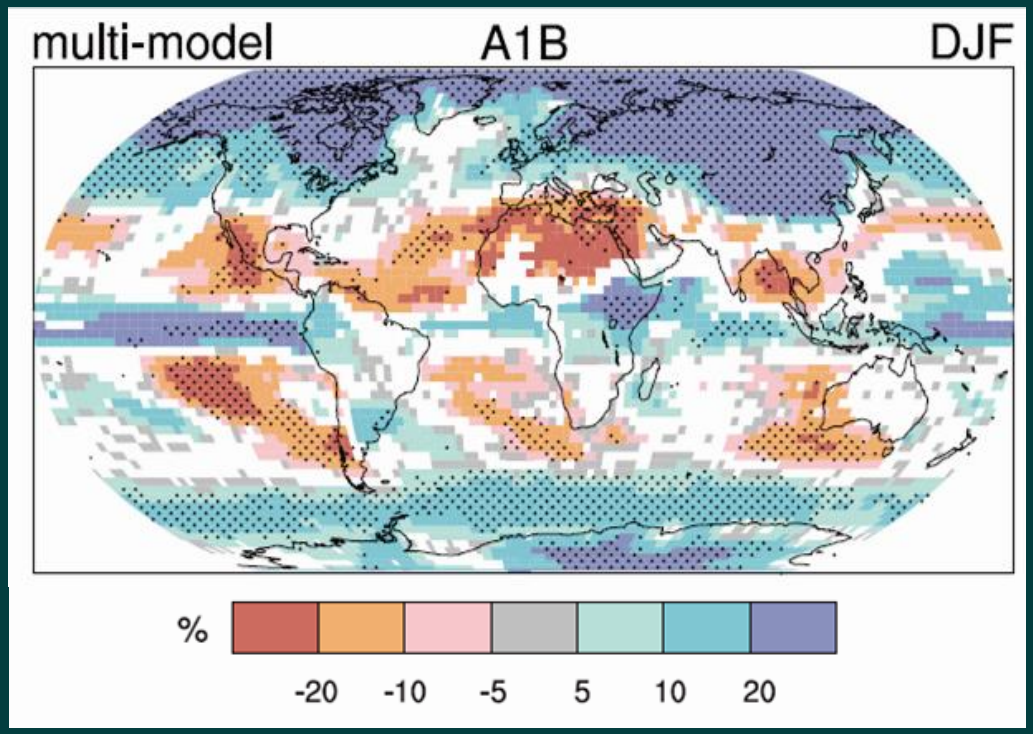
- no stabilization
- CO_2 exceeds 800 ppm
- realistic

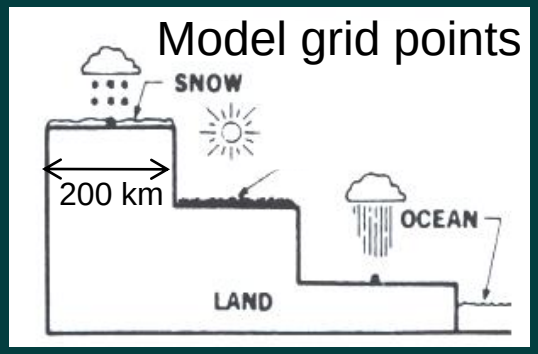


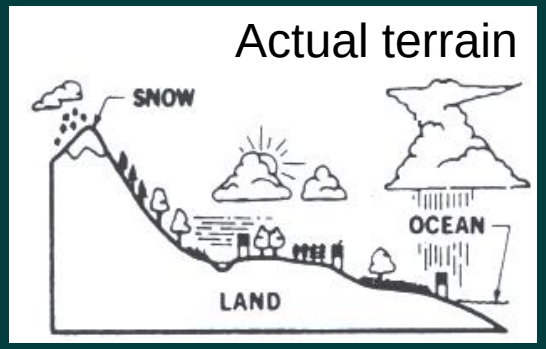
B. Regional climate change information

The GCM "resolution problem"

IPCC-AR4: projected precipitation change





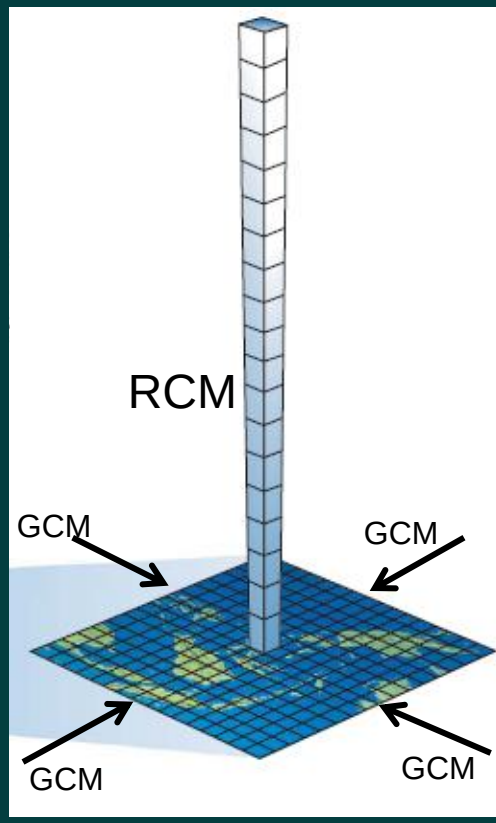


Figs. E. Maurer

- Current GCMs have grid sizes of 100-400 km
- This is too coarse for hydrological processes and meaningful regional predictions

Solution

A. Increase GCM resolution
- very expensive
- x2 resolution, x10 resources
- clean



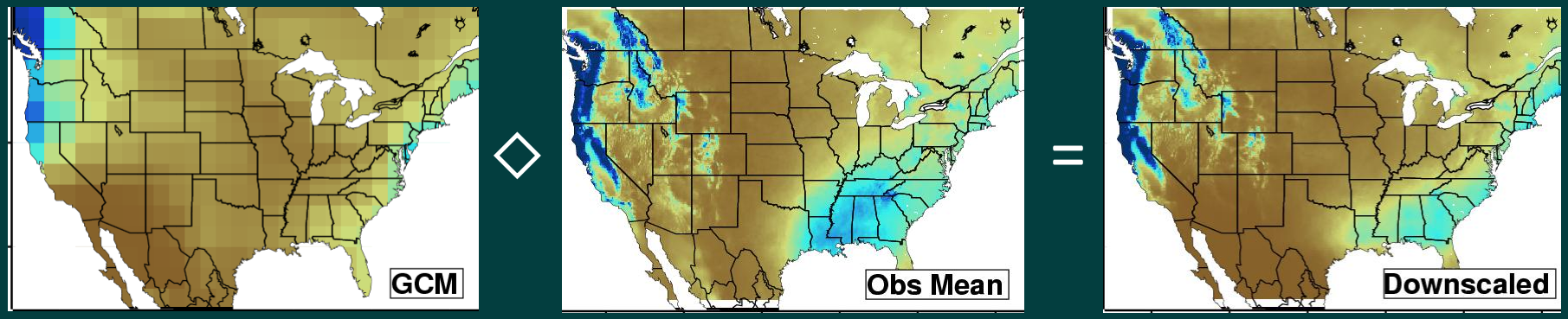
B. Downscaling techniques

1. Dynamical
- embed high resolution RCM into coarse resolution GCM
- computationally expensive
- not entirely consistent
- two model uncertainties

2. Statistical
- statistical correction of model prediction
- based on observations under current climate
- cheap
- remainder of this talk

Statistical downscaling

1. For present climate, derive a statistical relationship between GCM output and observations



2. Apply sane relationship to GCM predictions for future climate

Critical assumption of stationarity

- relationship between coarse- and fine-scale data do not change
- model biases do not change

High-resolution US downscaling

- Lawrence Livermore National Laboratory (LLNL), Bureau of Reclamation, and Santa Clara University (SCU)

- Monthly mean precipitation and temperature, 1950-2099
- US only: 1/8 degree (ca. 12x12 km)
- 16 GCMs (IPCC-AR4), 3 scenarios (A2, A1B, B1)
- Methodology: Wood et al. 2004, Maurer 2007
- gdo-dcp.ucllnl.org/downscaled_cmip3_projections/

C. Utah and climate change

Summary

- Precipitation
  - Northern Utah: ~10% increase in winter and ~10% decrease in summer
  - Southern Utah: Similar change but smaller magnitude
- Temperatures
  - uniform warming by ~3°F in winter and ~4°F in summer
- Summer
  - warming and drying will increase water demand
- Winter
  - warming and moistening have opposing effects; overall impact on water supply is uncertain

Conventions

20 year averages, centered at

- 1990 (reference),
- 2050 (A1B),
- 2090 (A2)

Multi-model means

16 models

Winter	Summer
Nov-Apr	May-Oct

Precipitation change

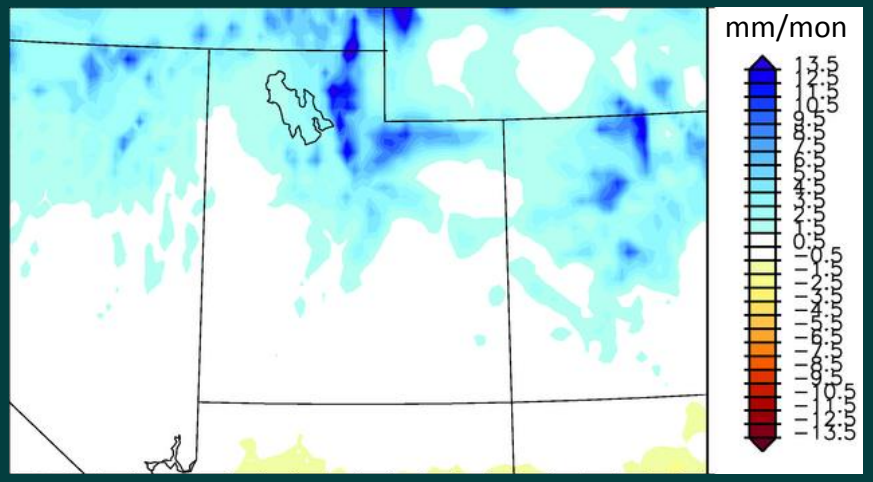
IPCC Scenario A1B (A2)

Precipitation change

A1B, 2050 minus 1990

Winter

Absolute



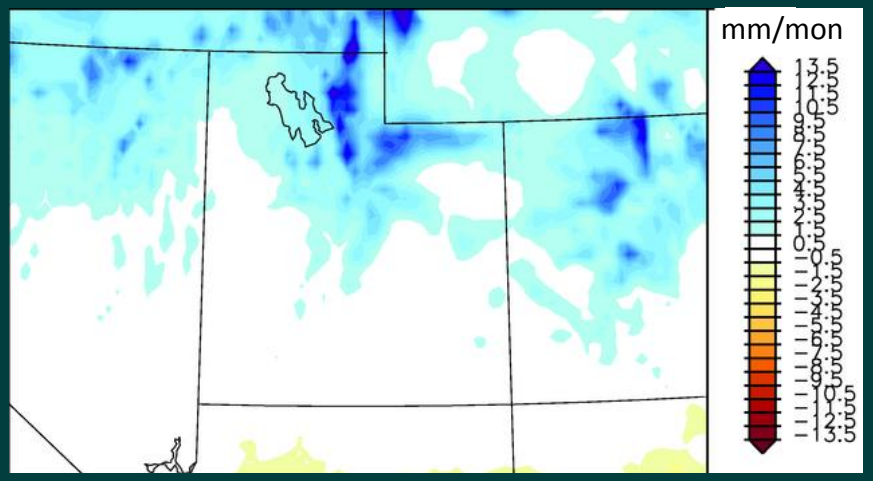
Precipitation change

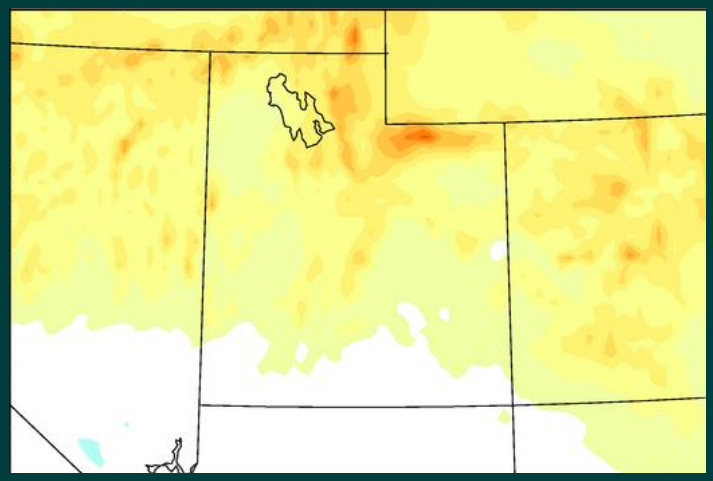
A1B, 2050 minus 1990

Winter

Summer

Absolute



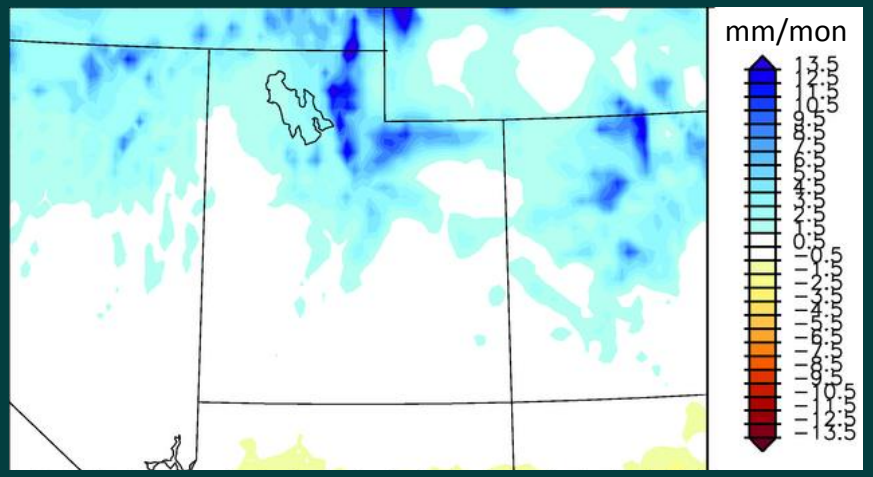


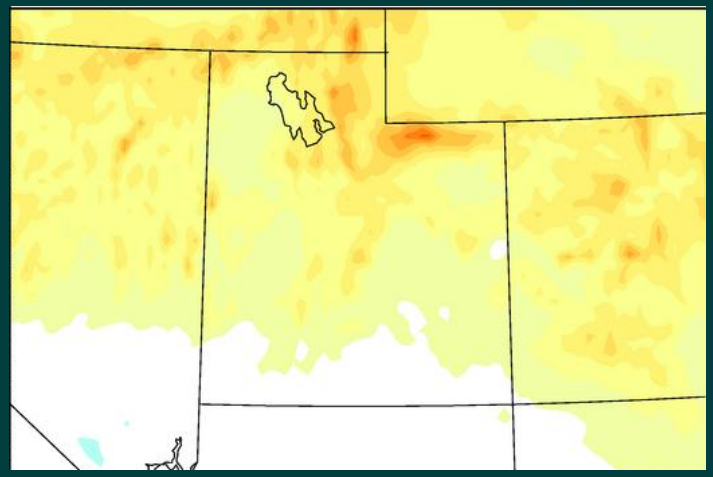
Precipitation change

A1B, 2050 minus 1990

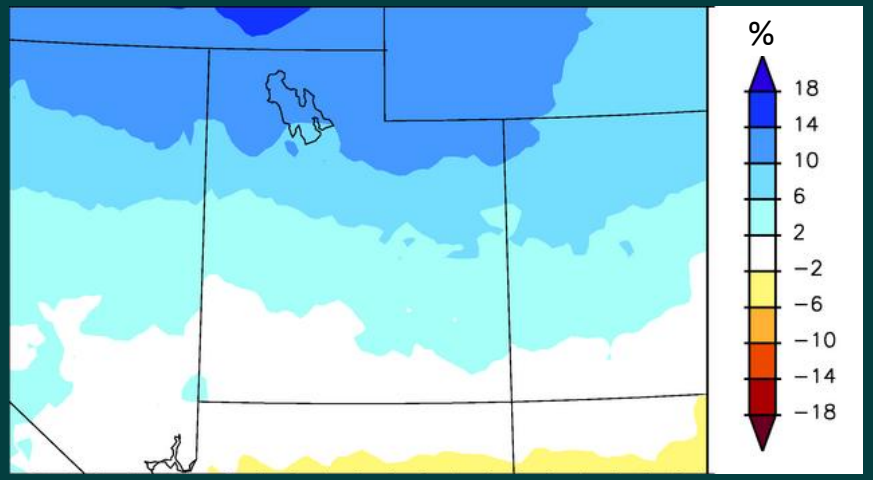
Winter **Summer**

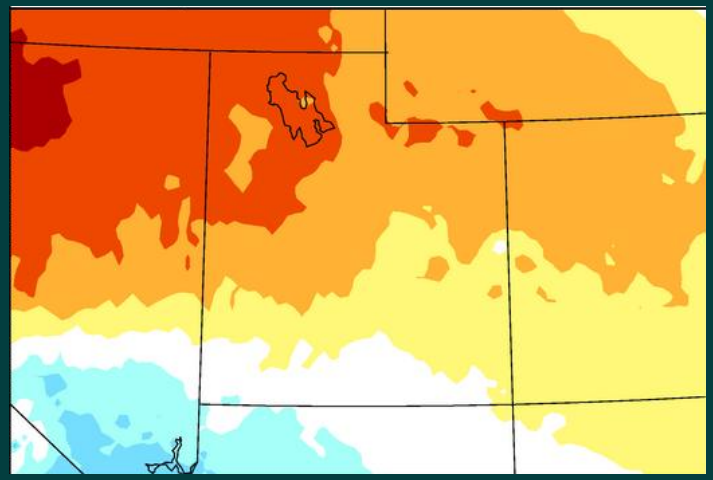
Absolute





Relative



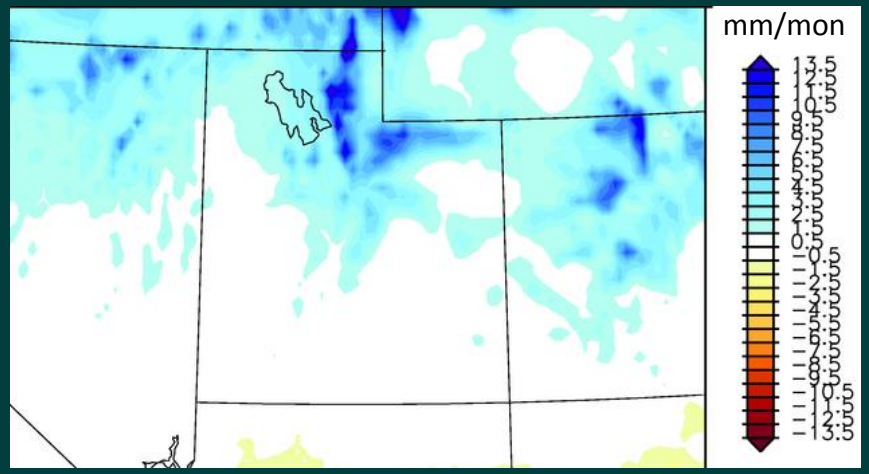


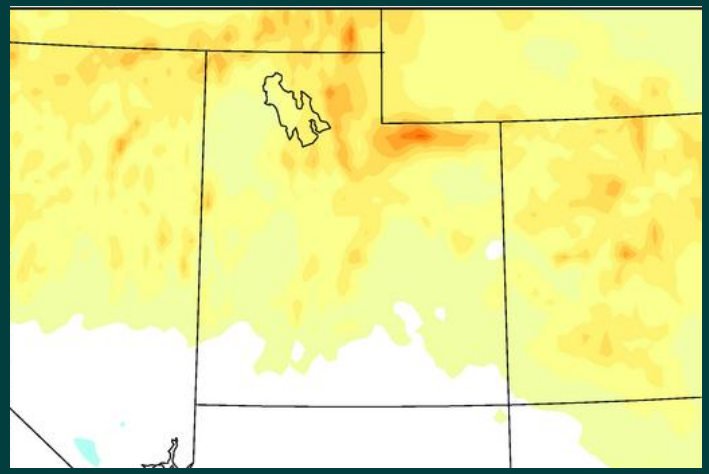
Precipitation change

A1B, 2050 minus 1990

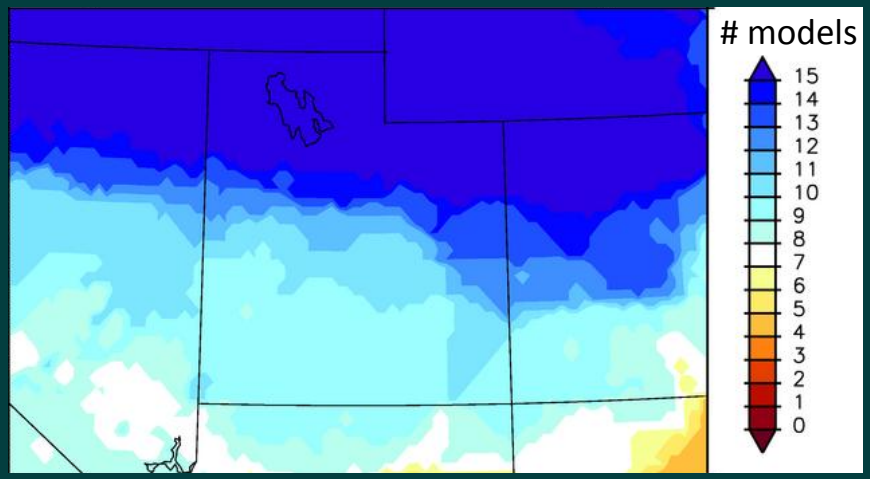
Winter | **Summer**

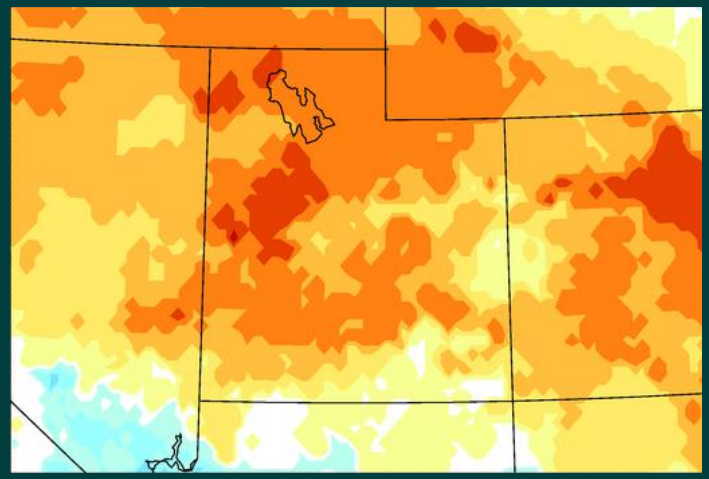
Absolute





# of models with positive change





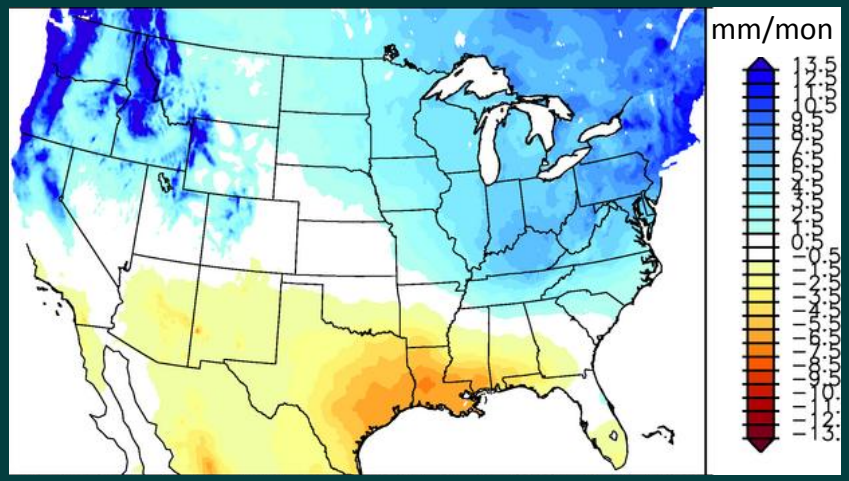
Precipitation change

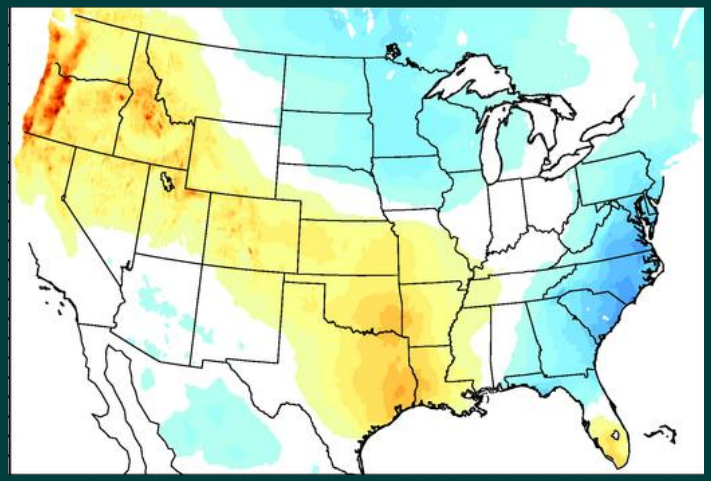
A1B, 2050 minus 1990

Winter

Summer

Absolute



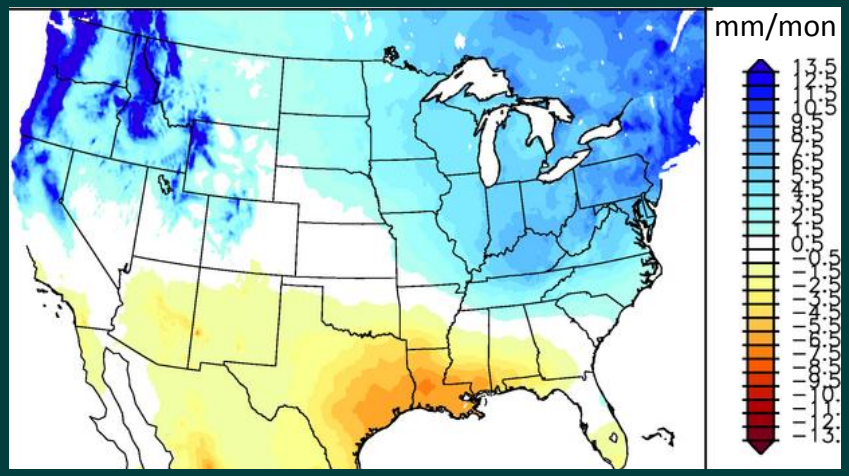


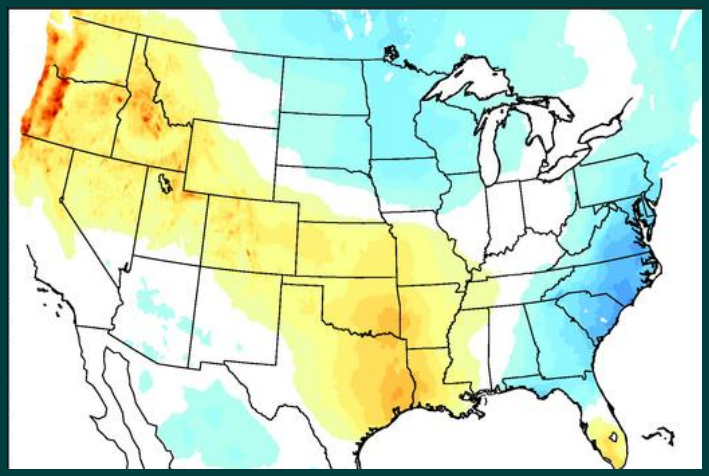
Precipitation change

A1B, 2050 minus 1990

Winter **Summer**

Absolute





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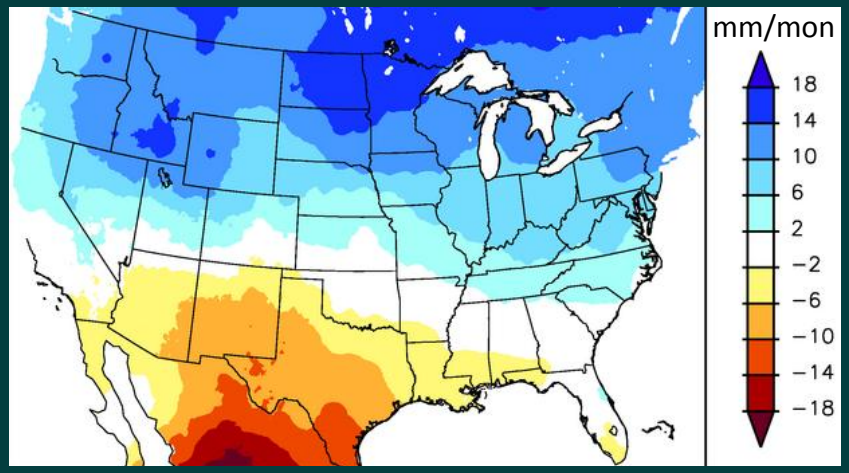
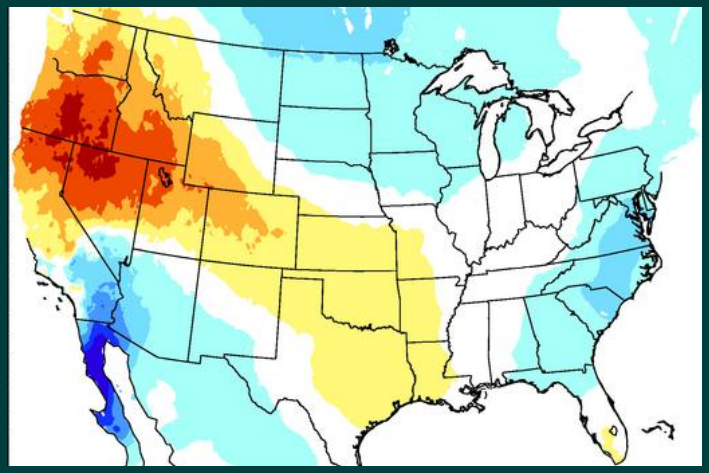


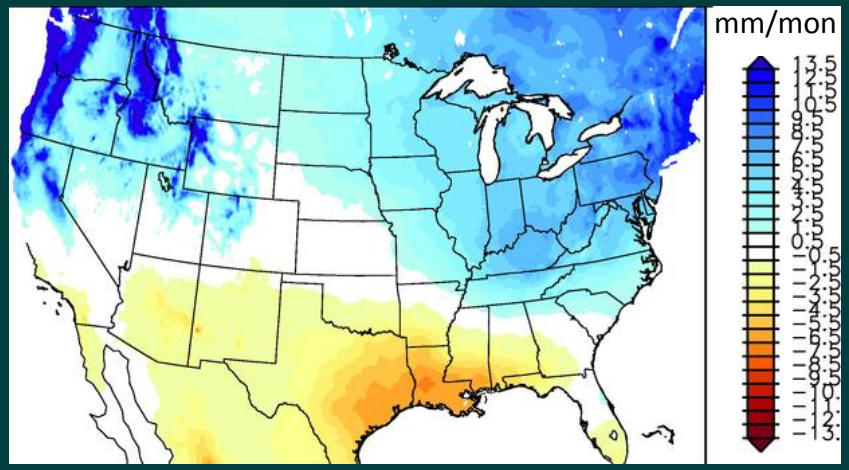


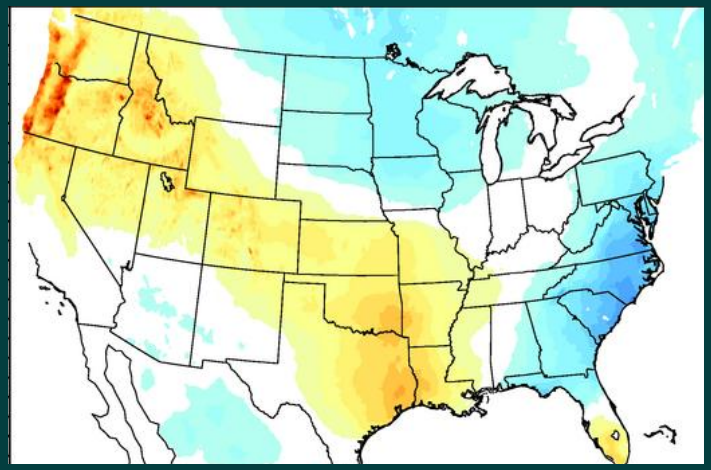
Precipitation change

A1B, 2050 minus 1990

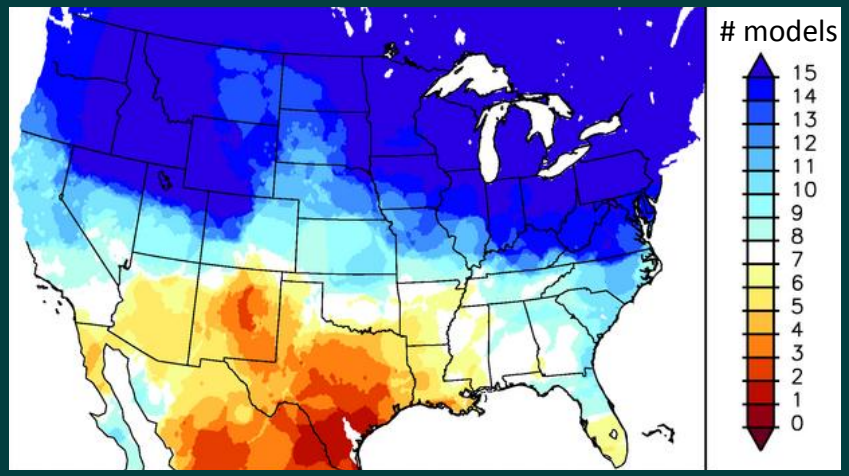
Winter **Summer**

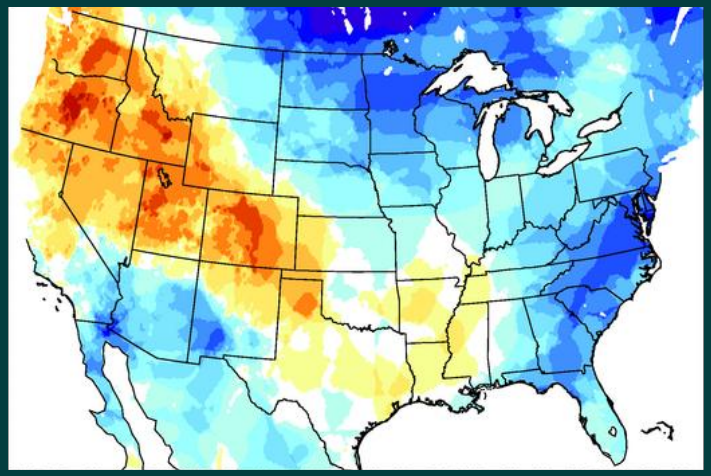
Absolute





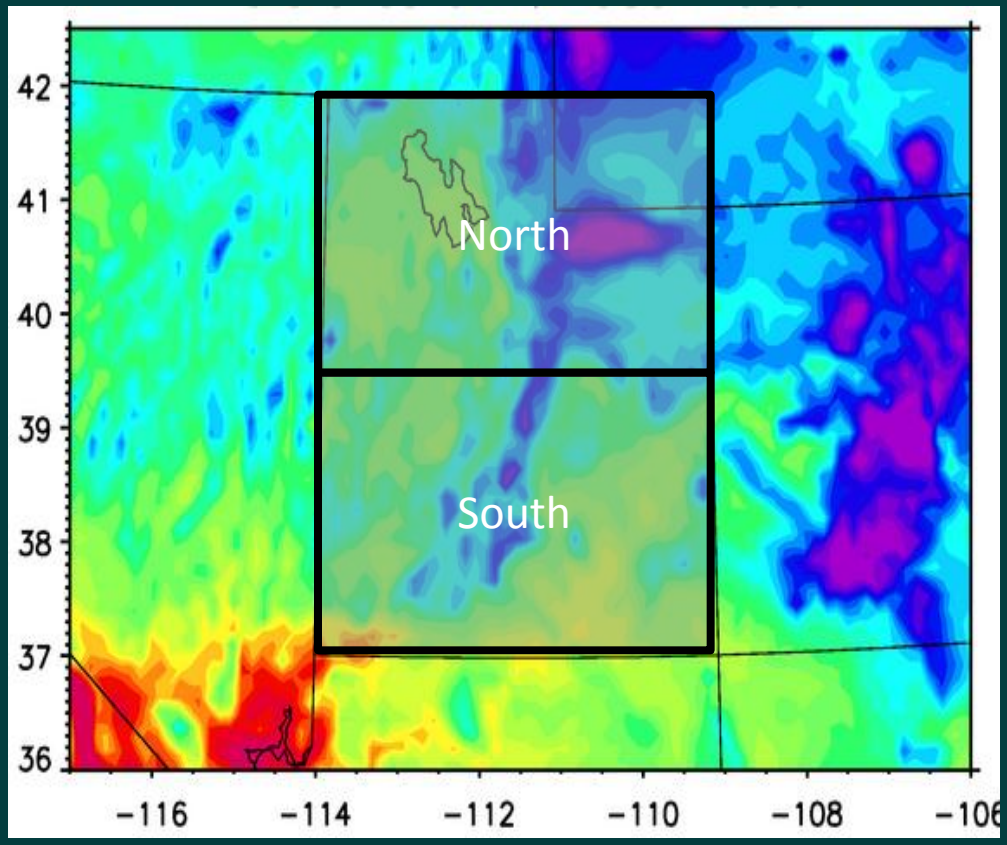
Models with positive change



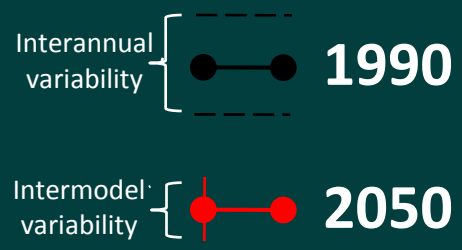


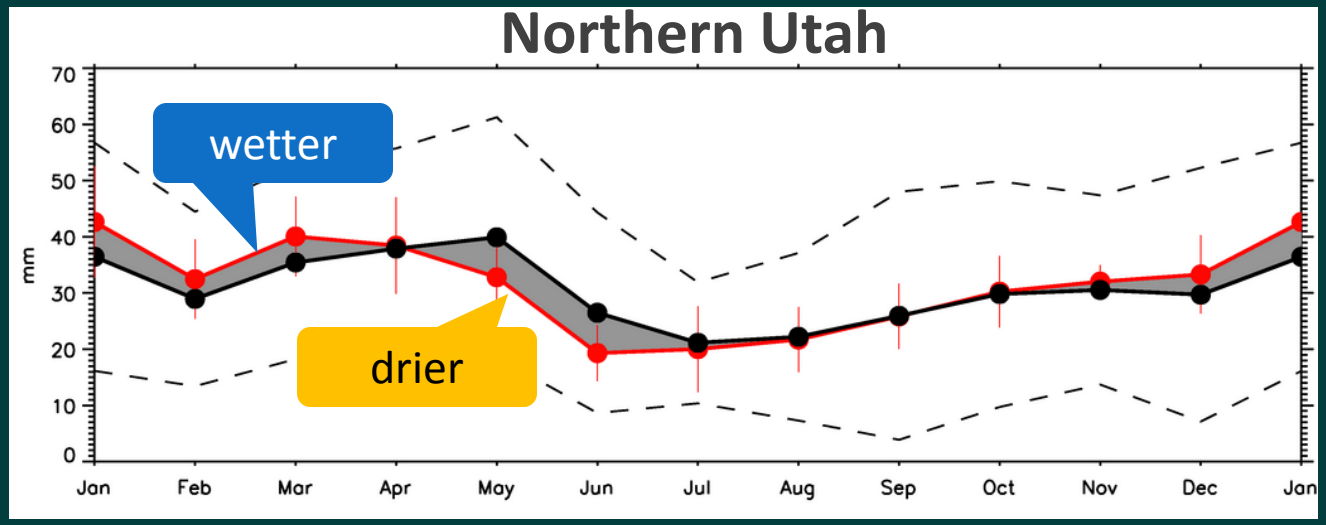
Seasonal cycle changes

Northern vs. Southern Utah



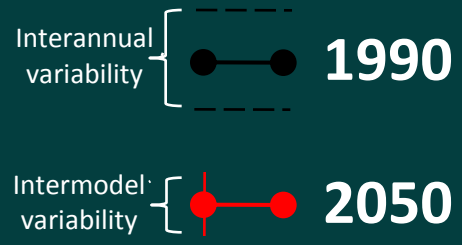
Precipitation change: A1B

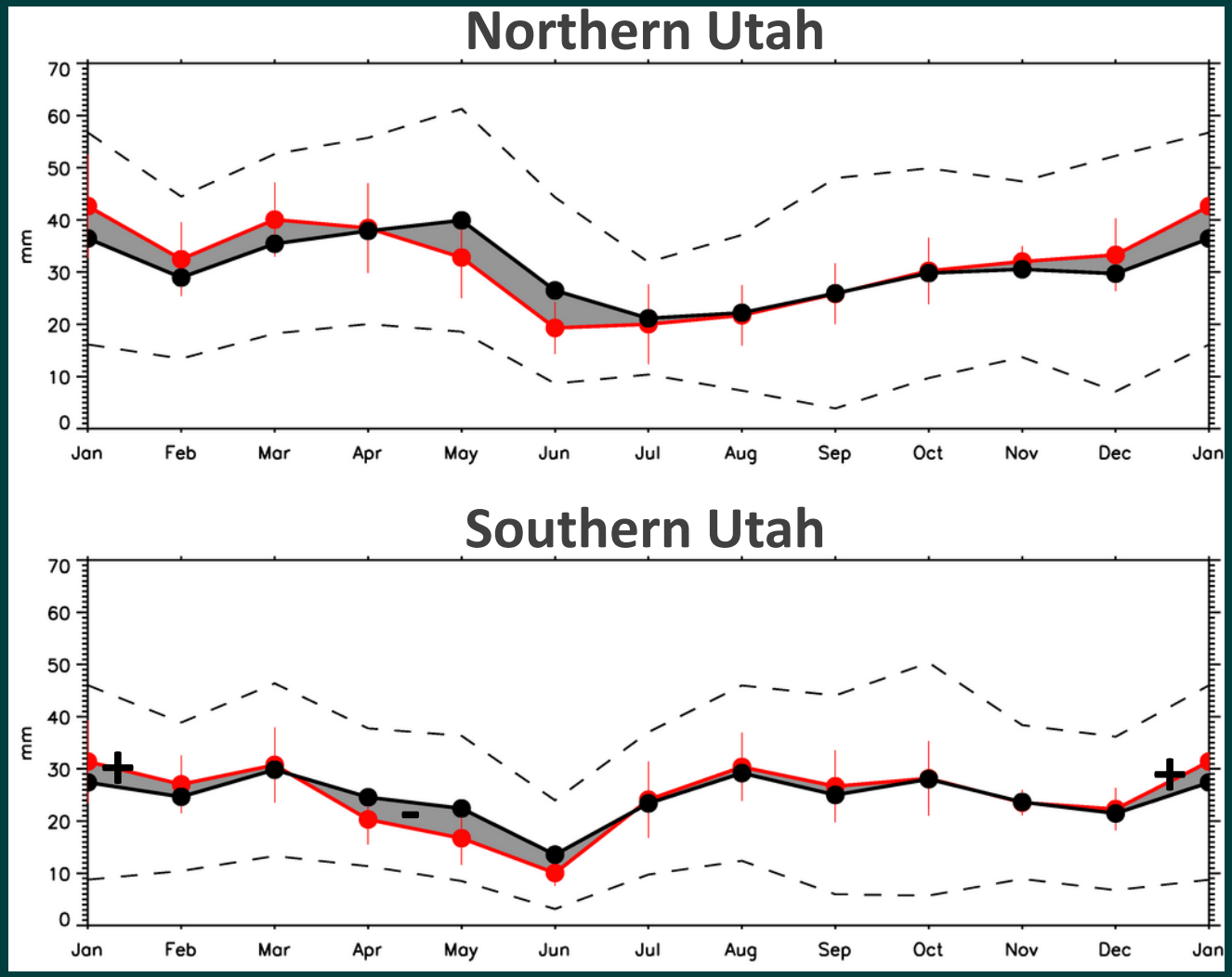




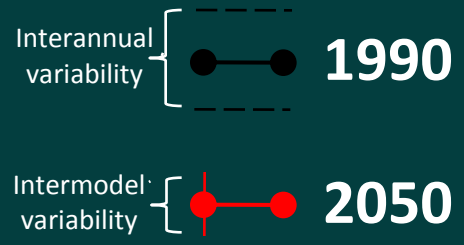
- Changes are much smaller than natural year-to-year variability (black dashed) and small compared to variability amongst models (red bars)

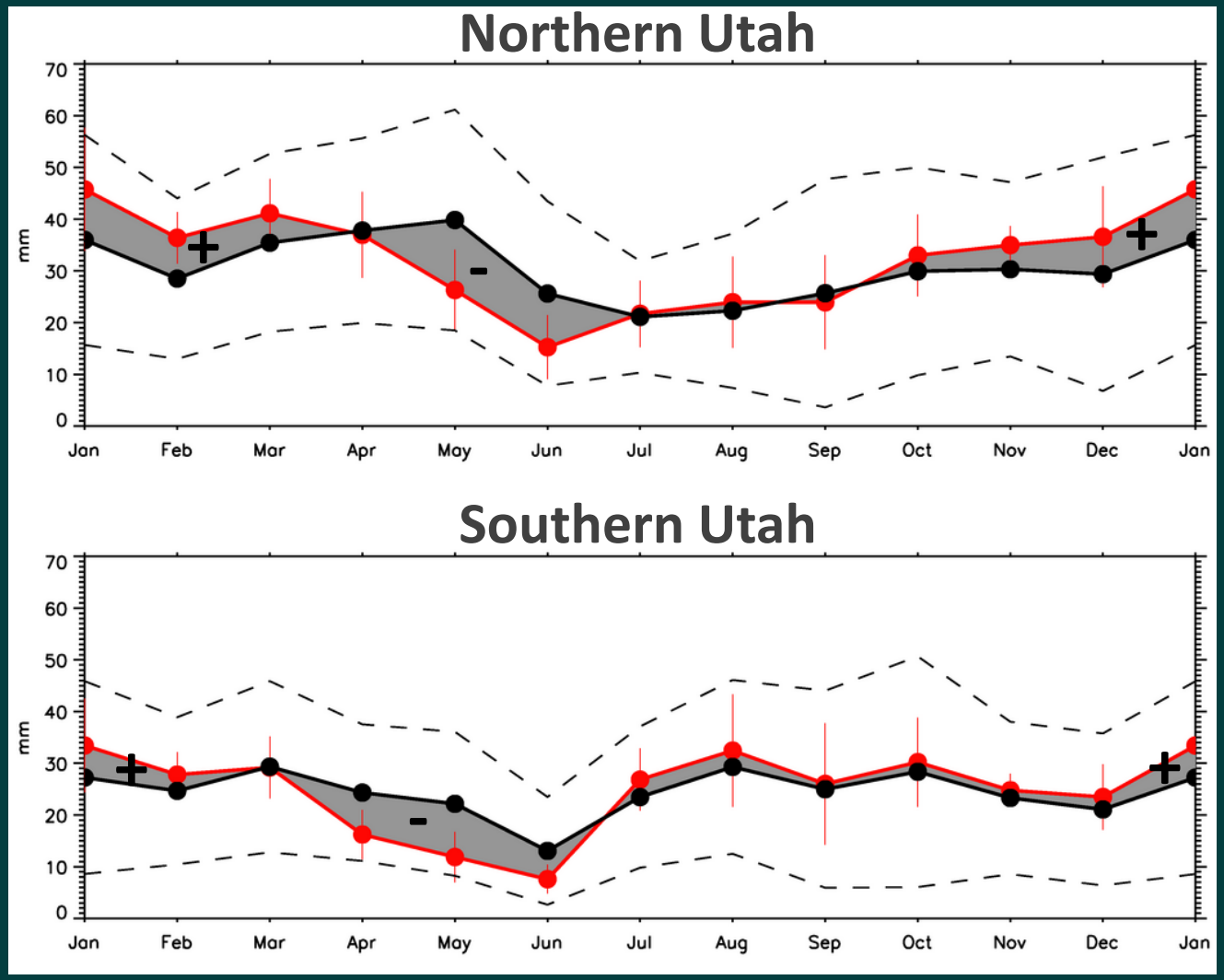
Precipitation change: A1B





Precipitation Change: A2





Temperature change

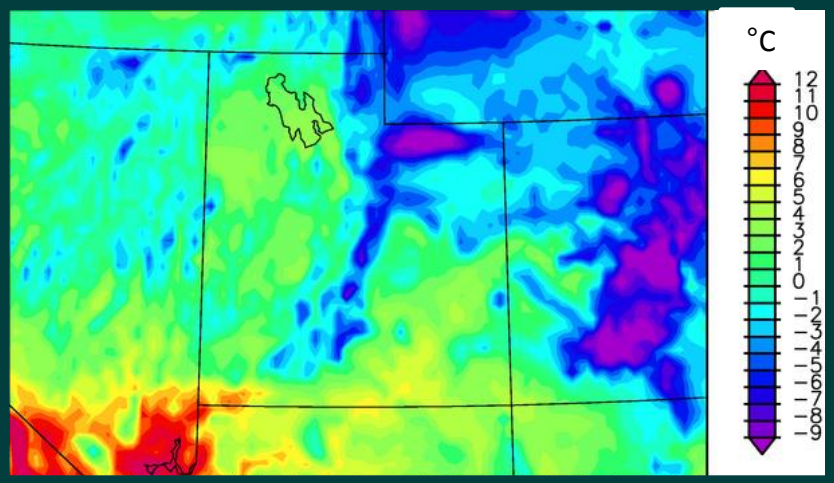
IPCC Scenario A1B (A2)

Temperature change

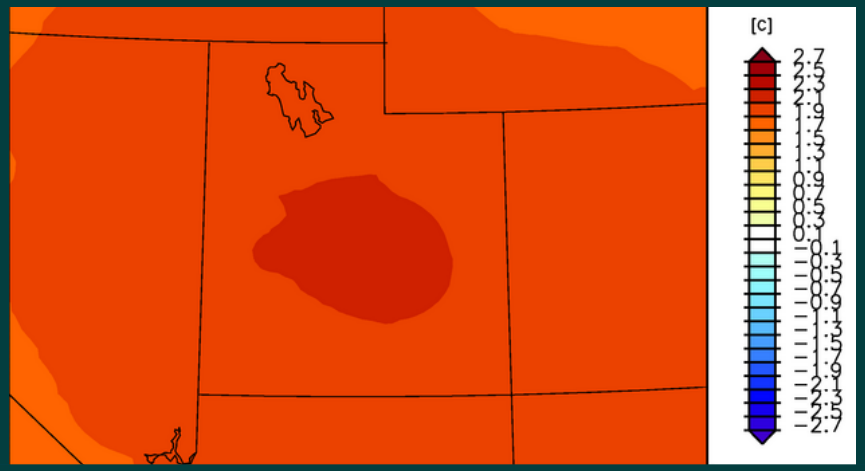
A1B, 1990 vs. 2050

Winter

1980-1999



Change

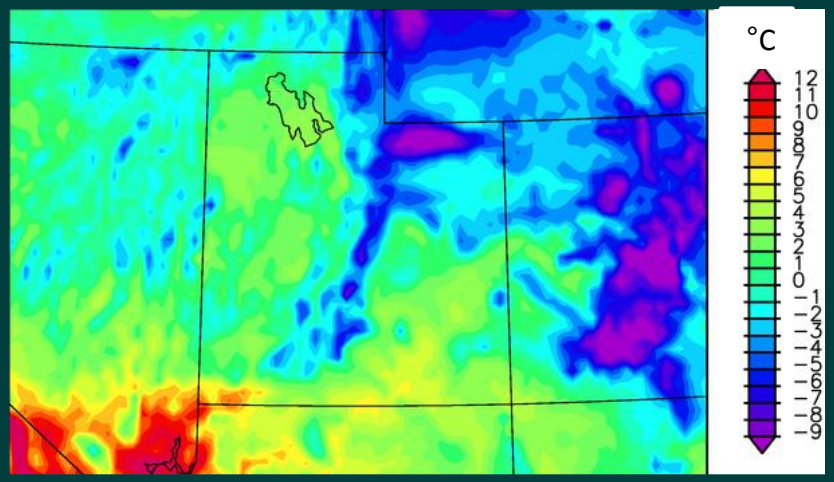


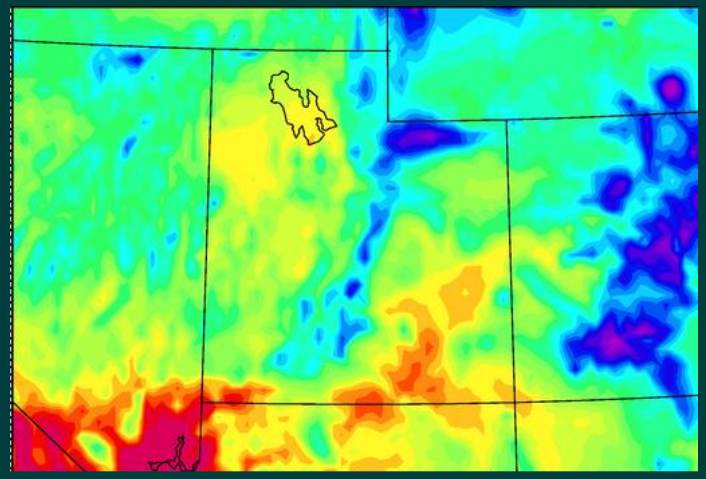
Temperature change

A1B, 1990 vs. 2050

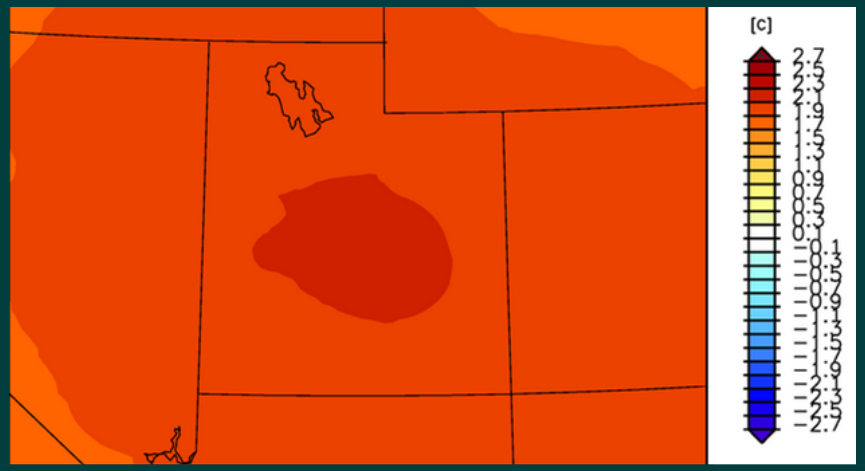
Winter **Summer**

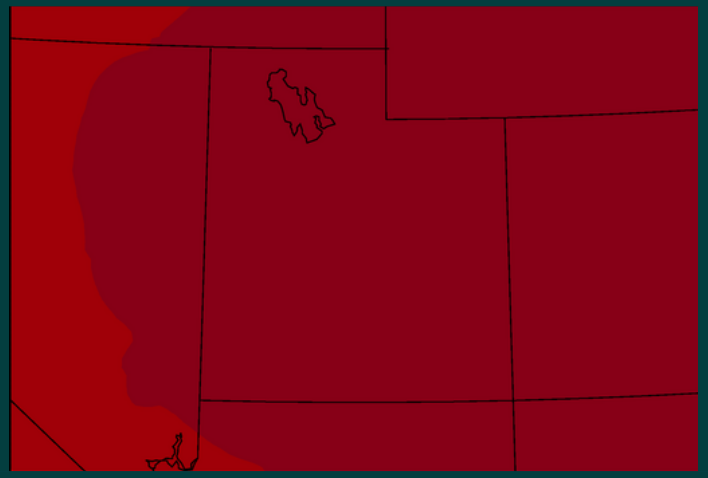
1980-1999



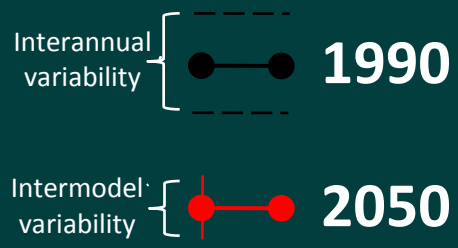


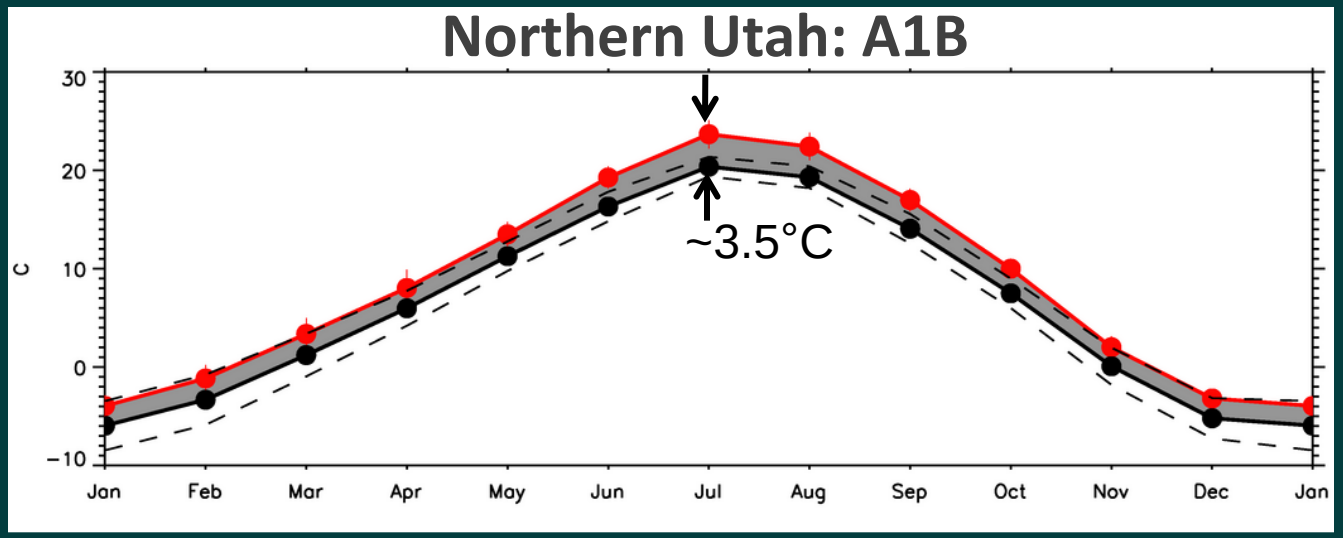
Change





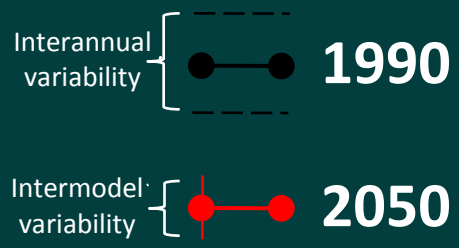
Temperature change: A1B/A2

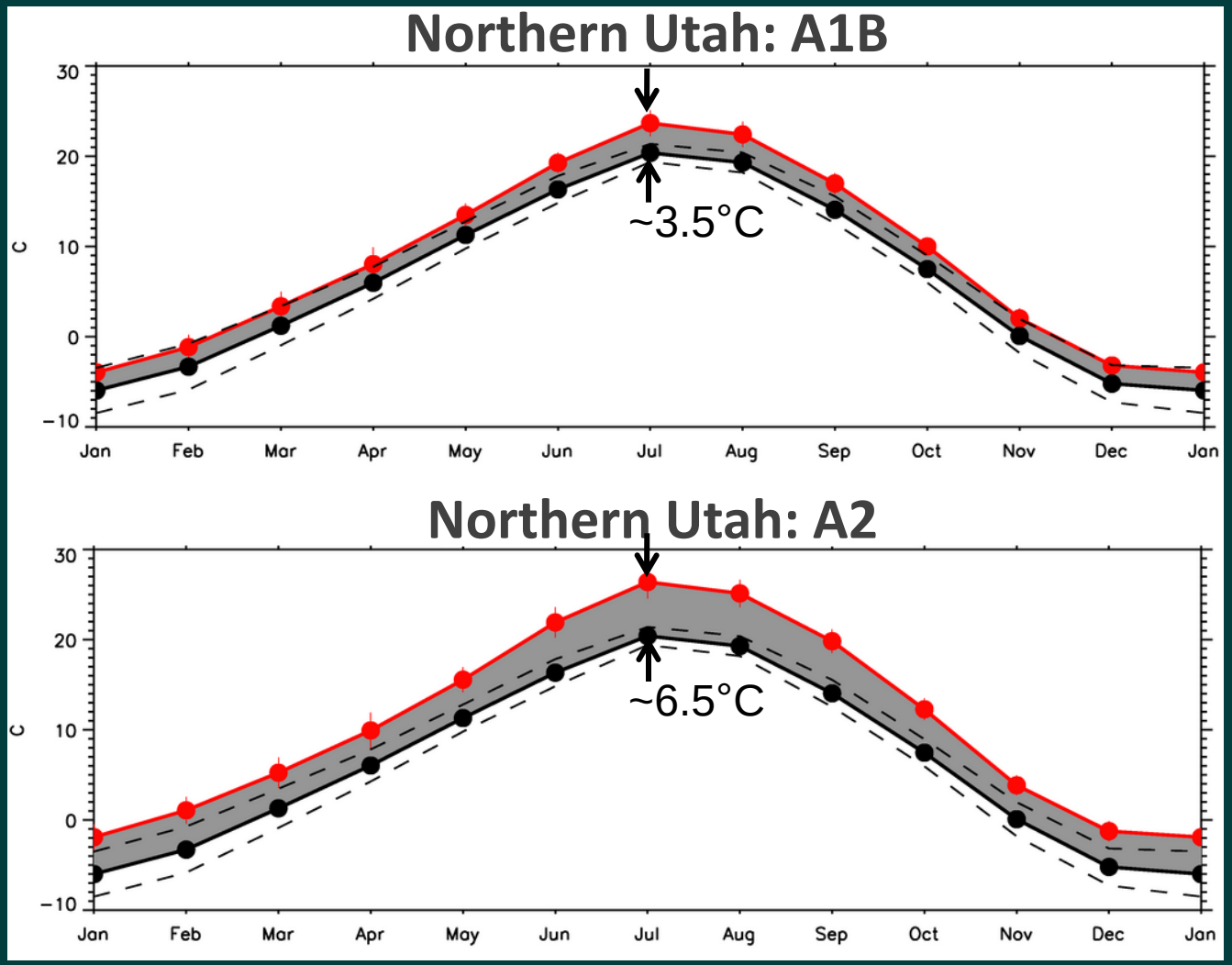




- Changes are highly significant

Temperature change: A1B/A2



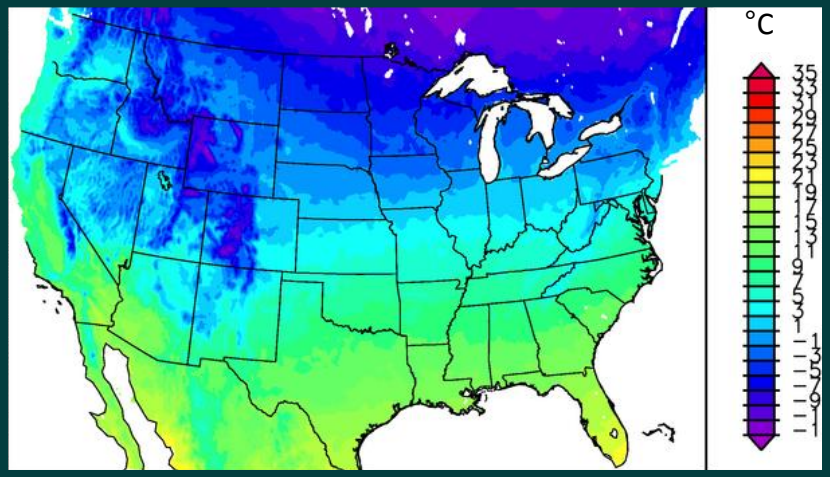


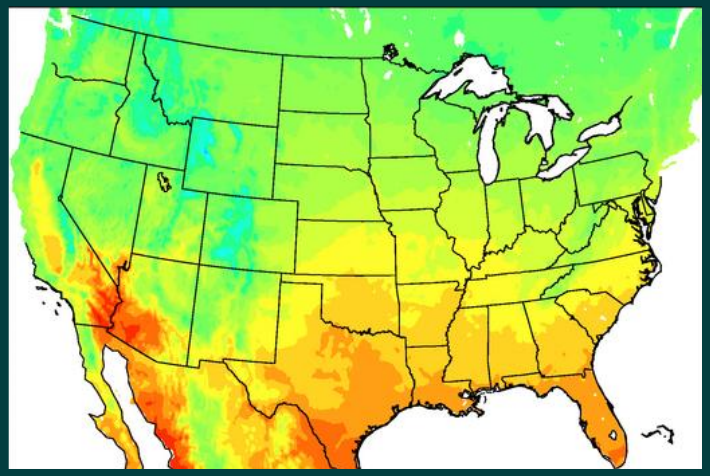
Temperature change

A1B, 1990 vs. 2050

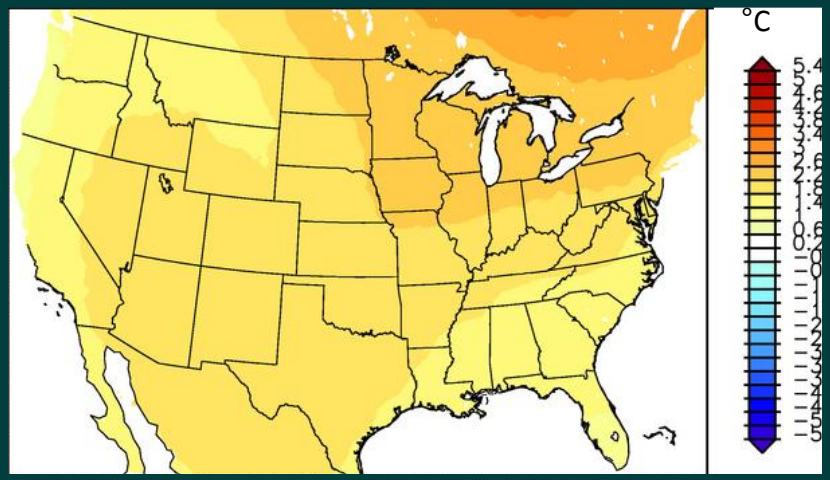
Nov-Apr | **May-Oct**

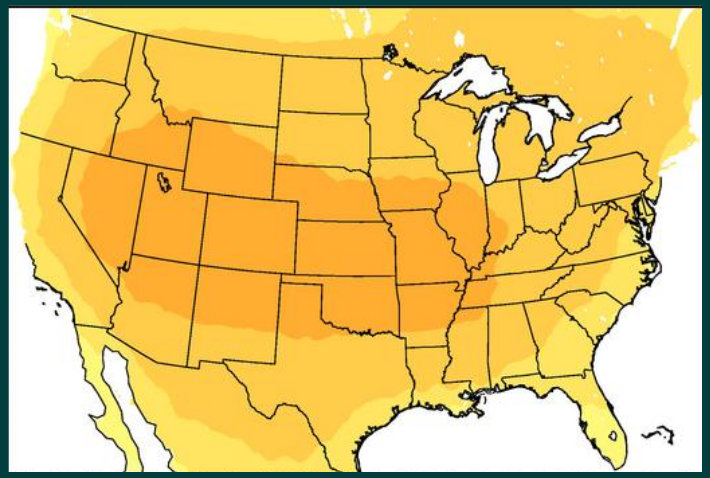
1980-1999





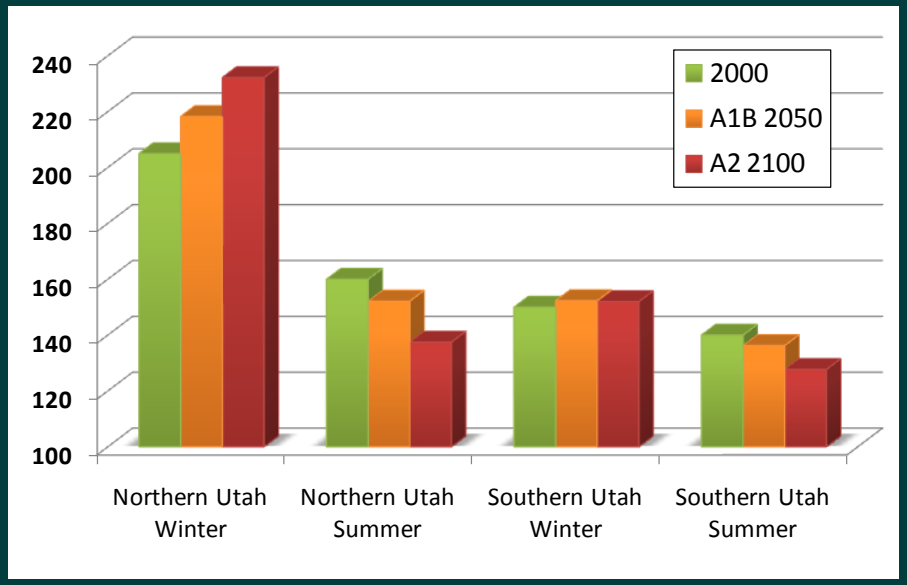
Change





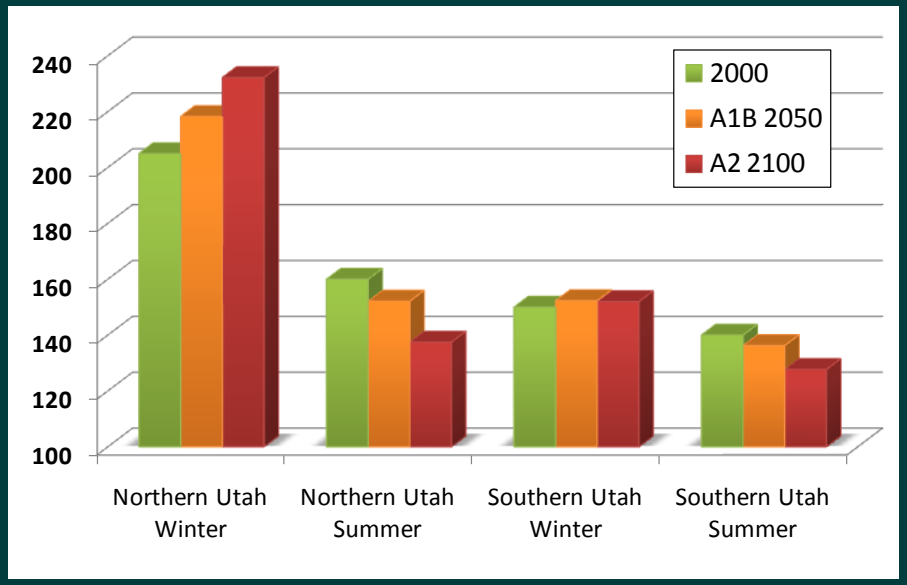
Summary: precipitation change

Absolute

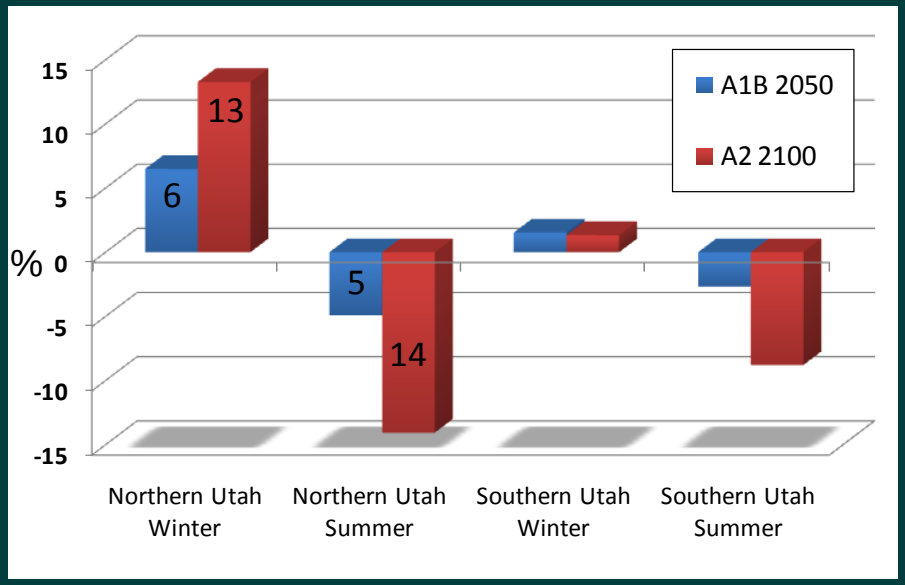


Summary: precipitation change

Absolute (mm/6 months)

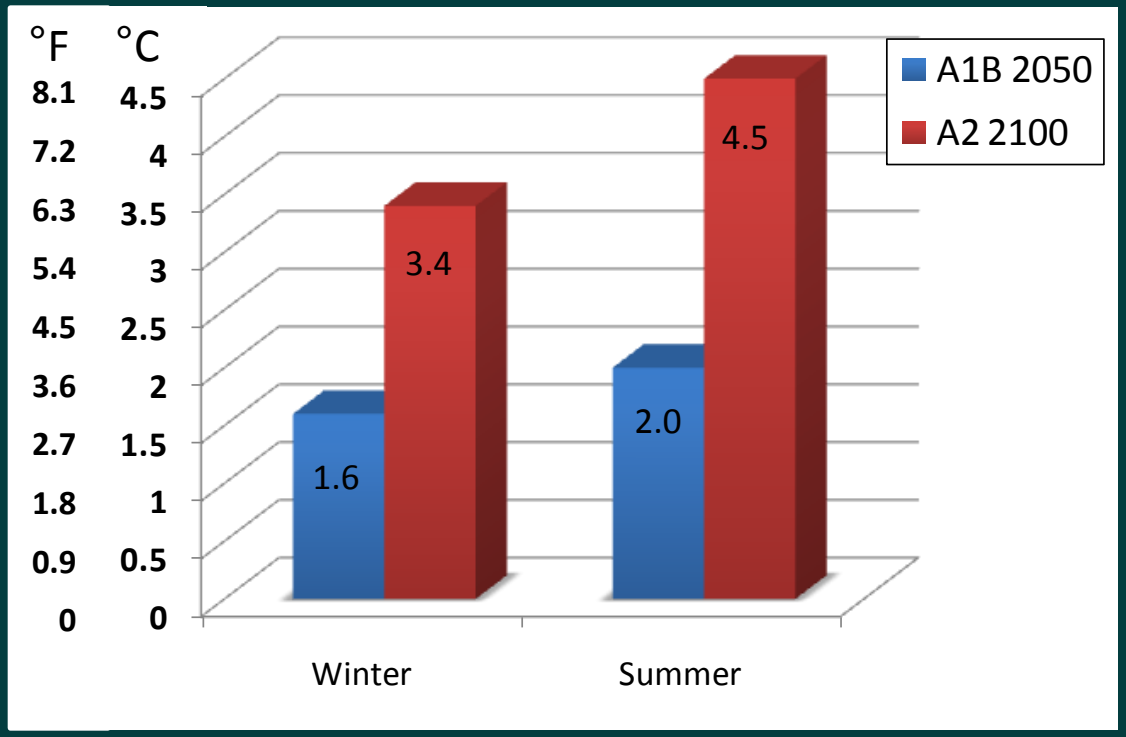


Relative (%)



Reference: year 2000

Summary: temperature change



Reference: year 2000

Can we trust these results?

No way!

- Climate models contain many uncertainties and are coarsely resolved
- Statistical downscaling is just a quick fix to the resolution problem
- Additional uncertainties arise from emission scenarios

Can we trust these results?

Yes, of course!

- Models are improving
- High degree of model agreement
- Results are from many models, improving predictions
- Errors are corrected by statistical downscaling
- Change is consistent with theoretical expectations
  1. General global warming
  2. Intensified hydrological cycle
  3. Widening of the tropical belt

Conclusion

- It will get year-round warmer in Utah by several degrees
- This will negatively impact Utah's water supply
  - winter: less snow pack
  - spring: earlier snow melt
  - summer: more water demand
- Precipitation results are less robust
- It is unclear whether in winter the predicted small precipitation increases can make up for the increase in temperatures

Thank you