Building Resilience to a Changing Climate:

A Technical Training in Water Sector
Utility Decision Support

WUCA
Water Utility Climate Alliance
10 YEARS · 2008-2018

Climate Science for Water Professionals: What Do We Know About How the Climate of the Northwest Will Change?

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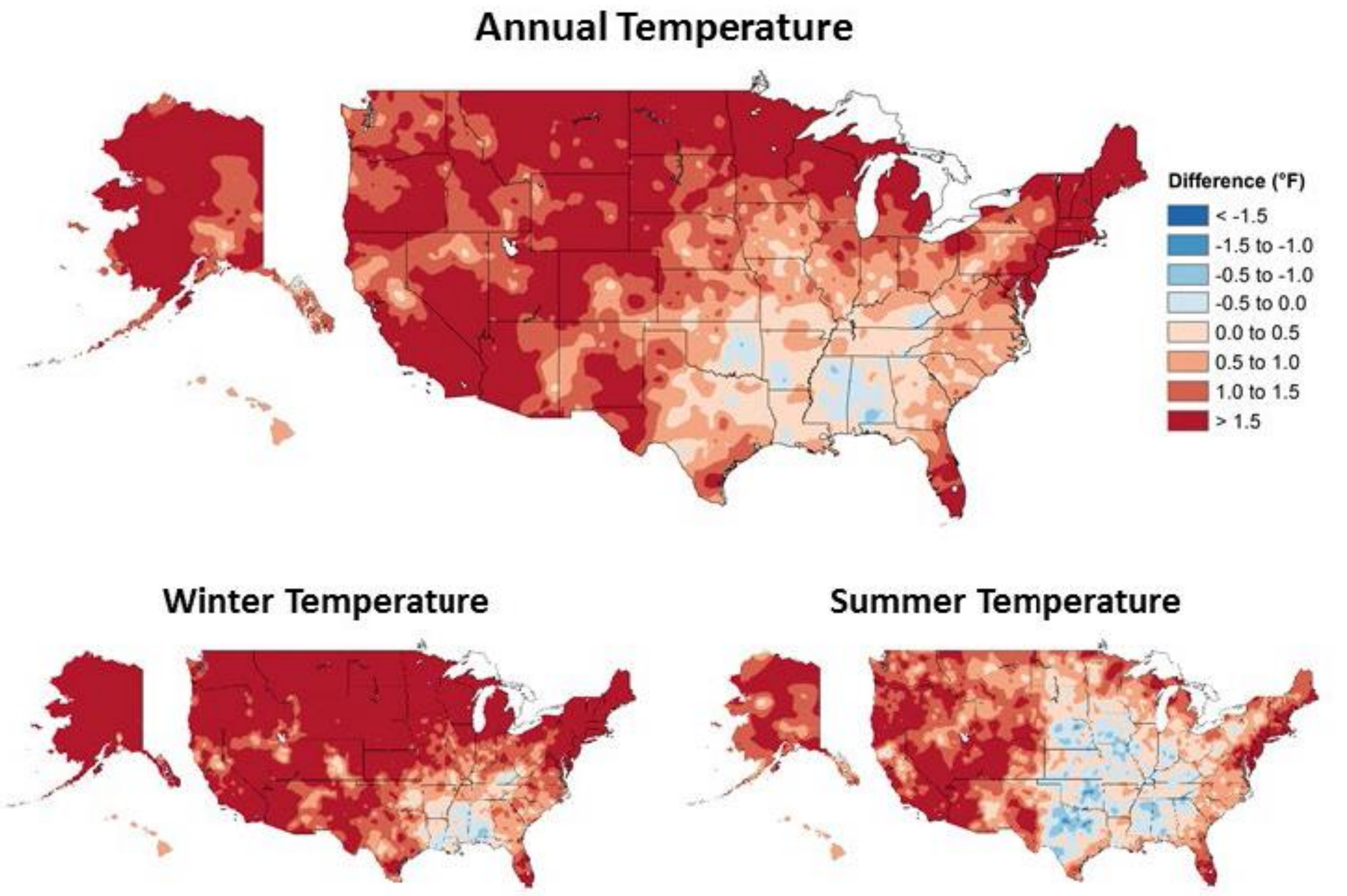
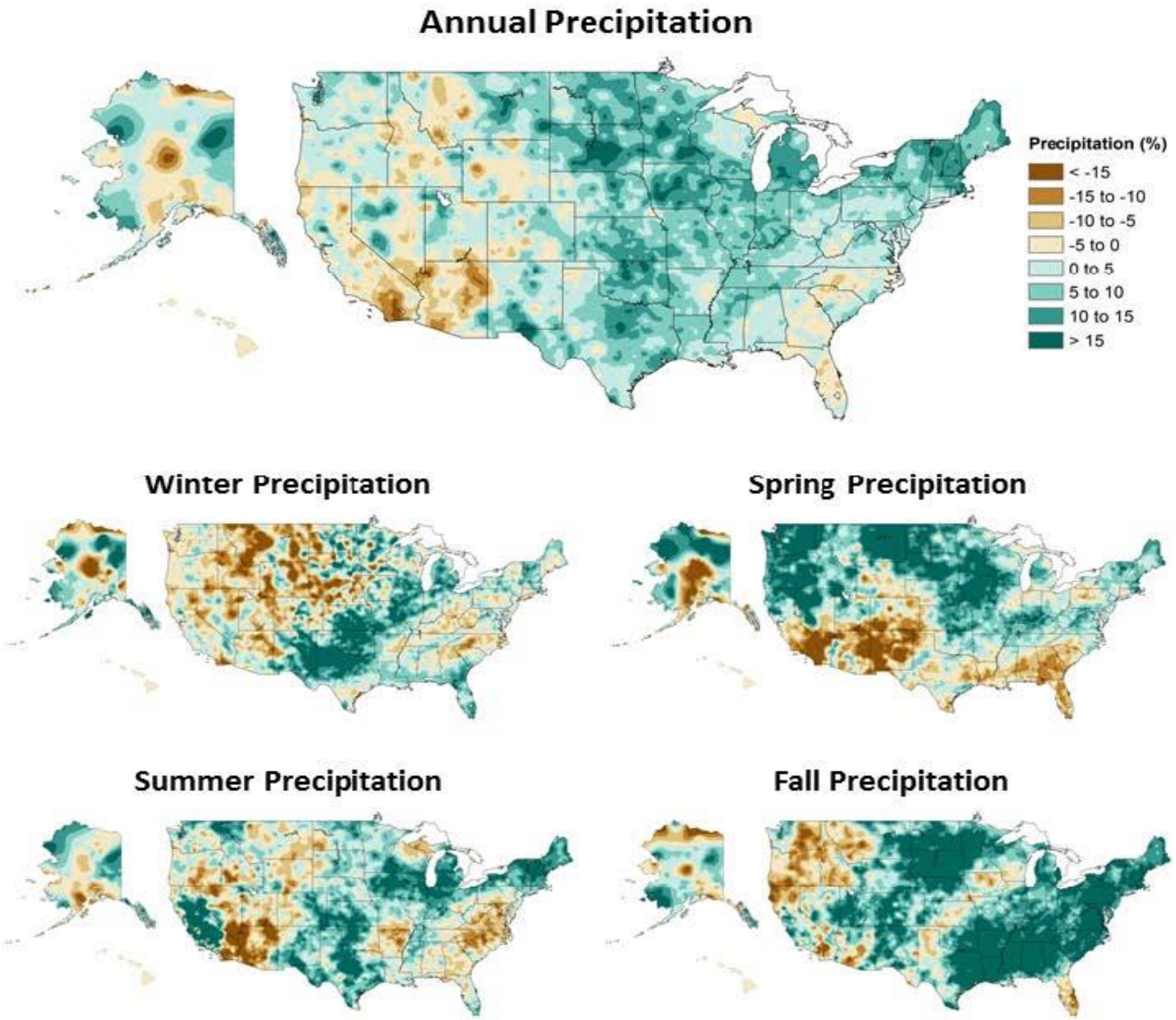
This Session and the Next Session

- This session will cover:
  - Discuss observed changes in climate of the Northwest
  - Projections about the future
    - Key sources of uncertainty about projections of change in climate
  - Introduction to climate modeling
    - Focus will be on the models of the world – Global Climate Models

Observed Temperature Changes: 1901-1960 to 1986-2015



Observed Precipitation Changes: 1901-1960 to 1986-2015



Data Provided by Dr. Ken Kunkel, NOAA

Climate Change Terminology

- A *Projection*
  - A plausible future condition
  - May be conditional, for example, based on a specific Representative Concentration Pathway (RCP)
  - Individual model estimates of future climate conditions are considered “projections”
  - Do not have probabilities assigned to projections
- A *Prediction* or *Forecast*
  - A “most likely” outcome
  - A precise statement about the future, for example:
    - “There is a 70% chance of rain tomorrow.”
    - “Global mean temperatures will rise 4 to 11ºF by 2100 over 1990.”

Future: More vs. Less Confidence

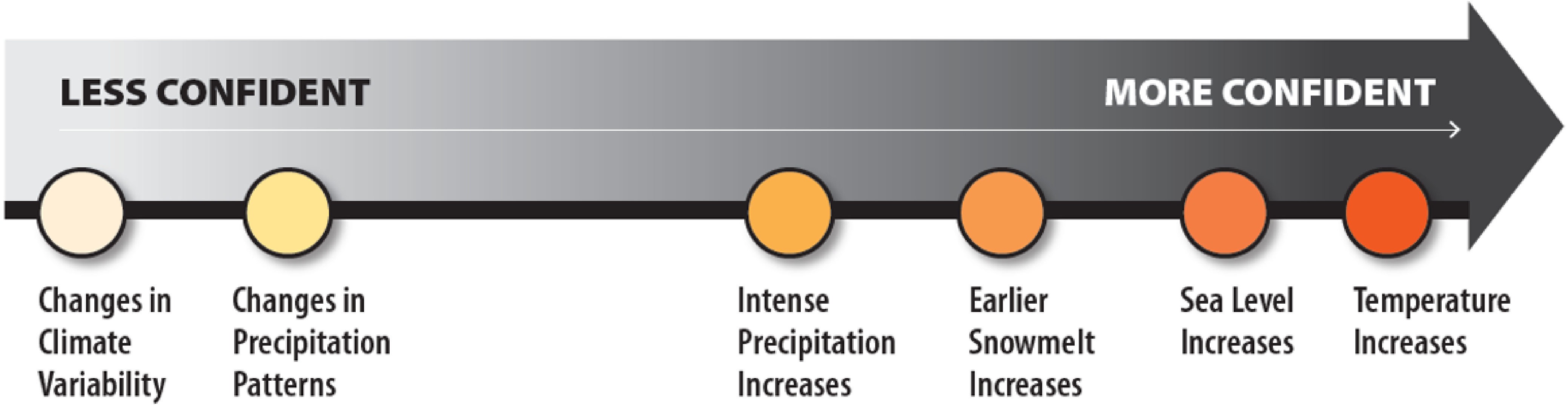
More Confidence

- Global and continental scale projections
- Averages
- Direction of change
- Temperature is dominant process

Less Confidence

- Regional and local projections
- Extremes
- Magnitude of change
- Other physical processes govern

Future: Continuum of Certainty in Direction of Change



Key Sources of Uncertainty in Predicting Future Climate

1. Human activity – Future emissions

2. The physical response of the climate system
    - Climate sensitivity
    - Regional patterns and timing of change

3. Natural climate variability

4. An additional source of uncertainty are climate models
    - Translation through downscaling, hydrologic modeling, etc.
    - More on that later….

1. Human Activity: Future Emissions

Uncertainty in amounts of:

- GHG emissions
  - Carbon dioxide (CO_2)
  - Methane (CH_4)
  - Others
- Aerosols
  - Soot
  - Dust
- Land use

Estimating Future Emissions

- IPCC is using "RCPs"
  - IPCC is Intergovernmental Panel on Climate Change
  - RCPs are "Representative Concentration Pathways"
    - We measure how much additional energy is being trapped by GHGs
    - Expressed in units of radiative forcing watts/square meter (w/m^2)
  - We get about 300 w/m^2 from the sun
  - Doubling of CO_2 concentrations will trap another 4.5 w/m^2
  - We are currently about 2.8 w/m^2 above preindustrial levels

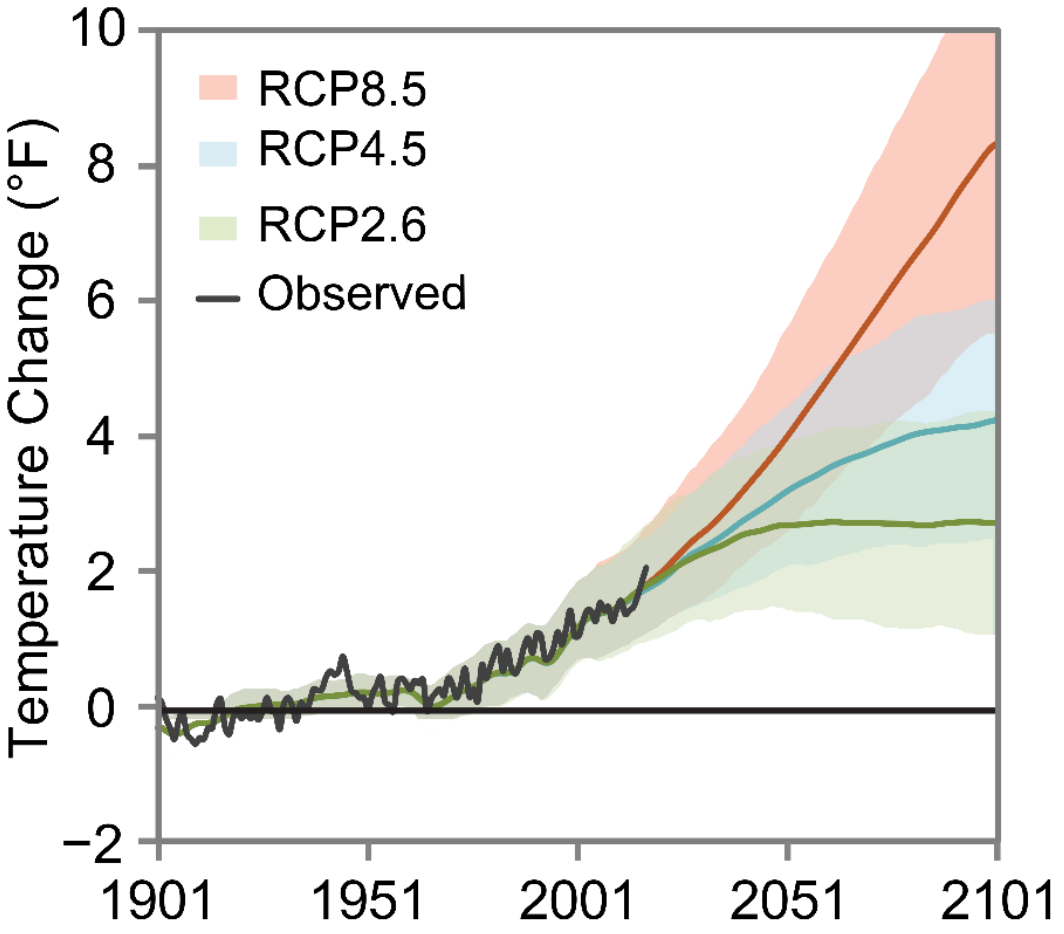
The Main RCPs

- These are scenarios
  - No likelihoods assigned
- Baseline scenarios
  - RCP 8.5
    - ~ 1000 ppm of CO_2 by 2100
    - Global population 12 billion
    - CO_2 emissions triple
      - Large increase in coal use
  - RCP 6.0
    - 600-700 ppm of CO_2 Carbon emissions peak in mid-century
- Stabilization scenarios
  - RCP 4.5
    - CO_2 doubling scenario – around 500-600 ppm of CO_2
  - RCP 2.6
    - Might limit warming to 2^oC (3.6^oF) above pre-industrial

Which RCP should be used as "Baseline?"

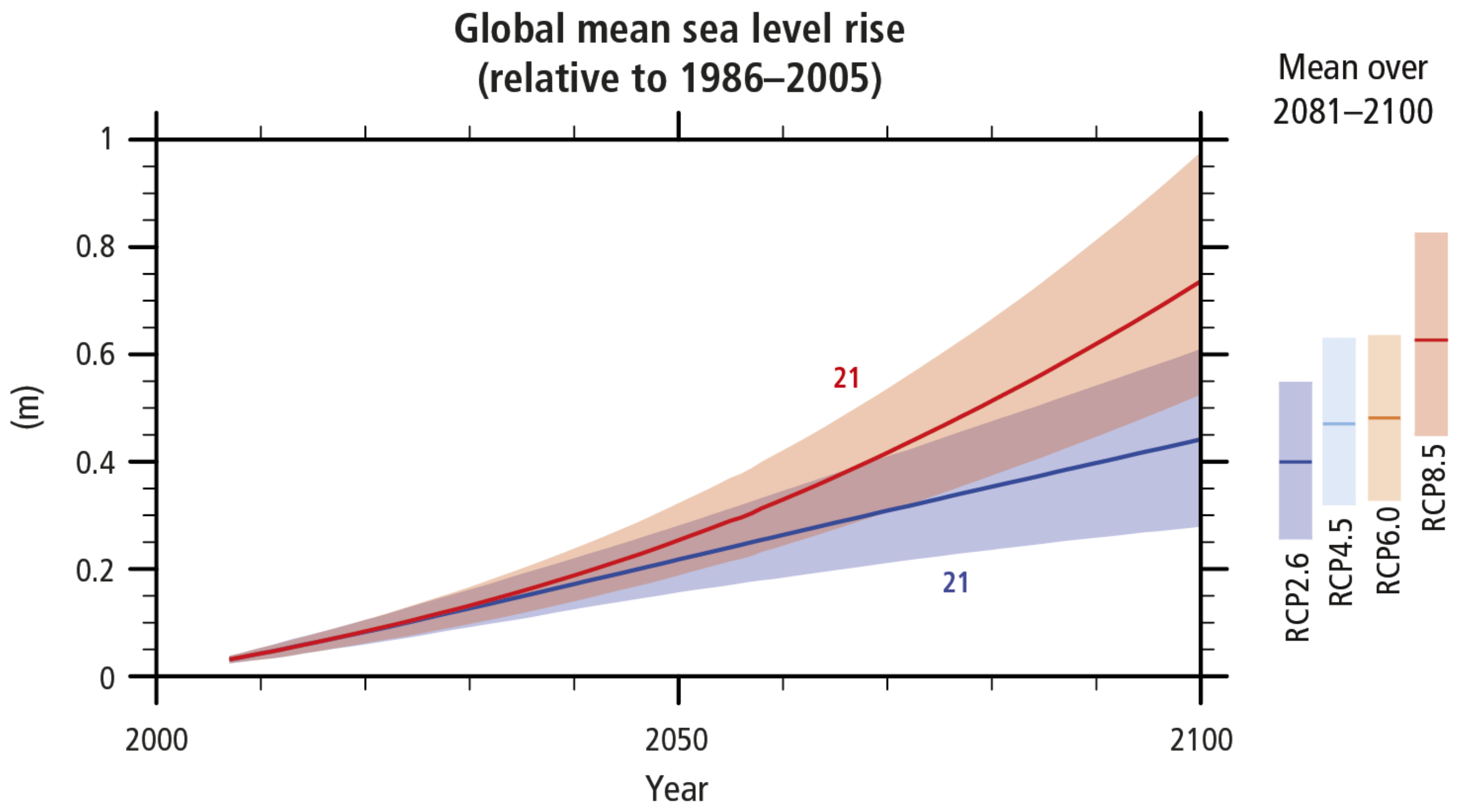
- Baseline Scenarios:
  - 8.5 and 6.0
- Credible estimates of likelihoods of RCPs do not exist
- Many assessments, for example, NCA, use 8.5 as high or BAU

Projected Global Temperatures



Source: U.S. National Climate Assessment, 2017

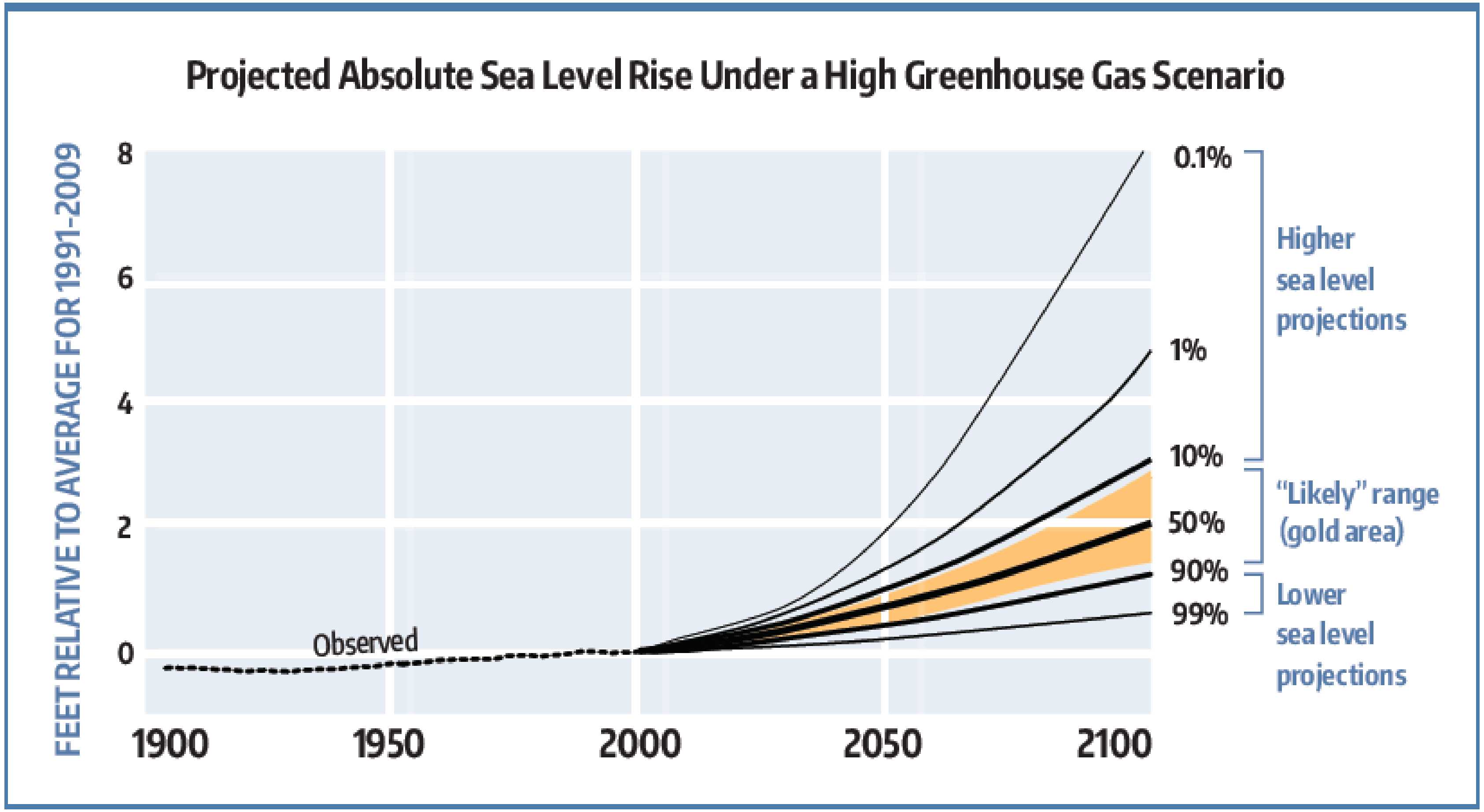
Sea Level Rise



Source: IPCC Summary for Policy Makers, 2014

New Science on Sea Level Rise

- DeConto and Pollard, 2016. Nature
- Kopp et al., 2016. Proceedings of the National Academy of Sciences



Source: Projected Sea Level Rise for Washington State, Miller et al., 2018

2a. Physical Response: Climate Sensitivity

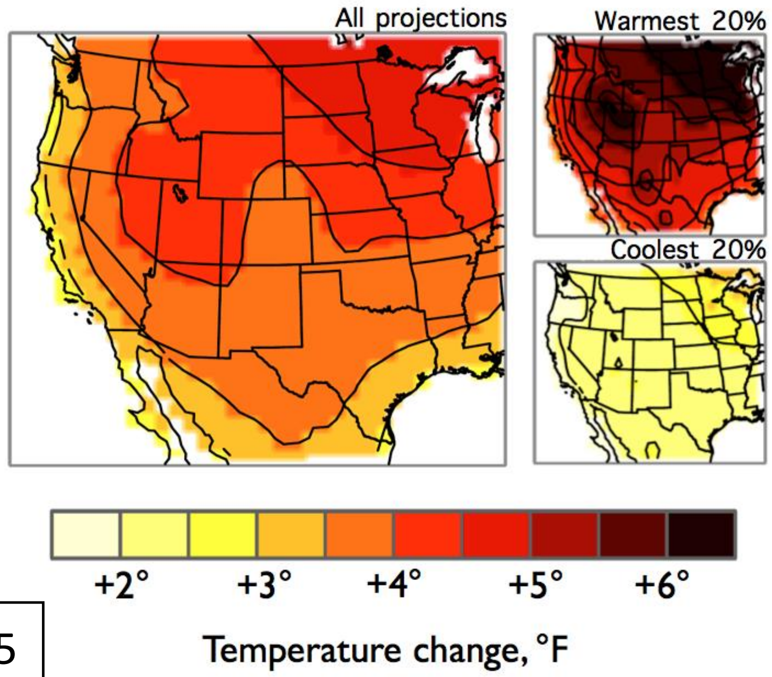
- How much does the Earth's atmosphere eventually warm with a CO_2 doubling?

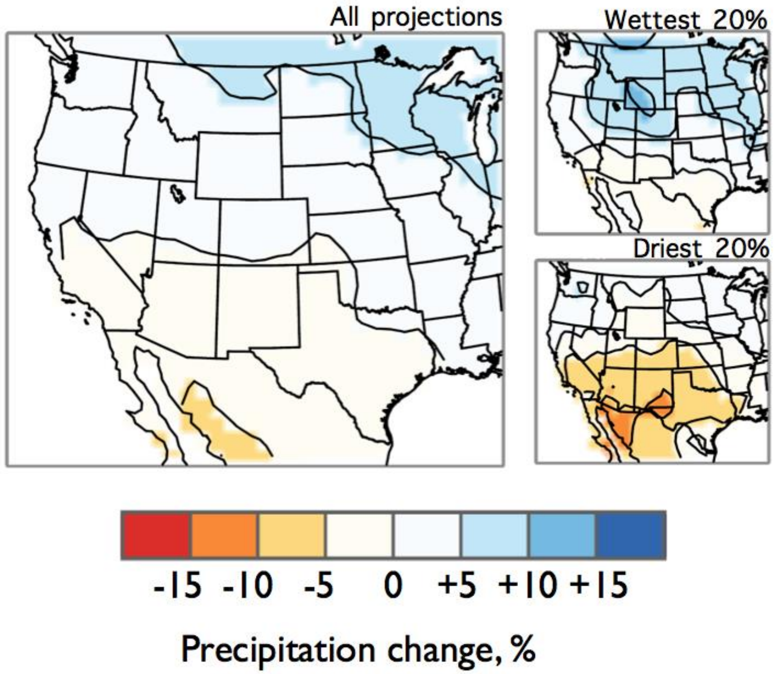
- What is the magnitude of warming
  - Most likely between 2 (3.6^{o}F) and 4.5^{o}C (8^{o}F)
  - Very unlikely below 1 (1.8^{o}F) or above 6^{o}C (11^{o}F)

2b. Physical Response: Regional Pattern and Timing of Change

Projected Annual T and P for Northwestern US at 2050

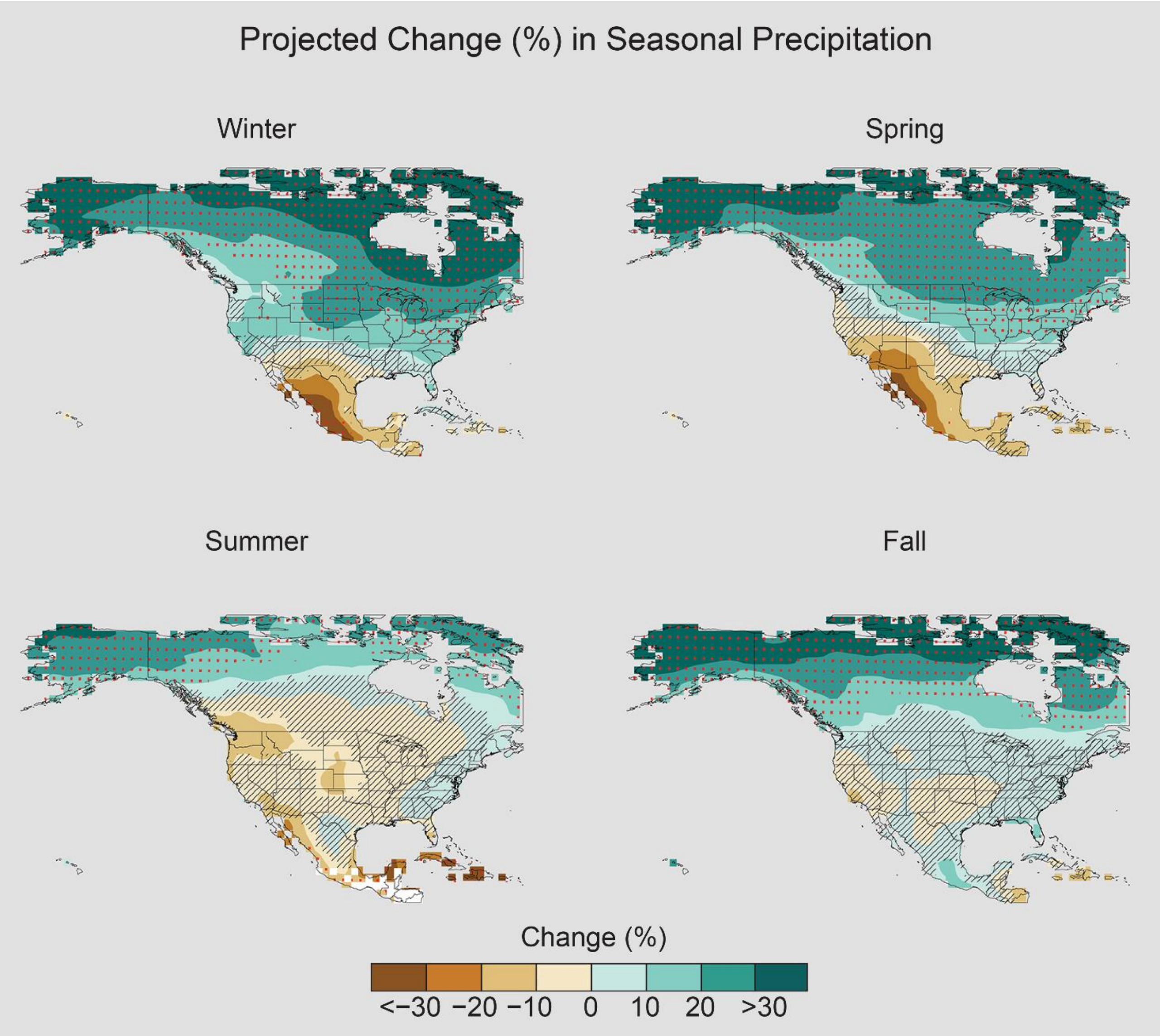
- PNW temperatures projected to warm ~2ºF to 8.5ºF (depending on RCP)
- PNW precipitation change range from ~-5 to ~+14% (depending on RCP)
- Will result in reduced soil moisture and runoff on *average*





Graphs Show RCP 4.5

Seasonal Precipitation Patterns Can Change



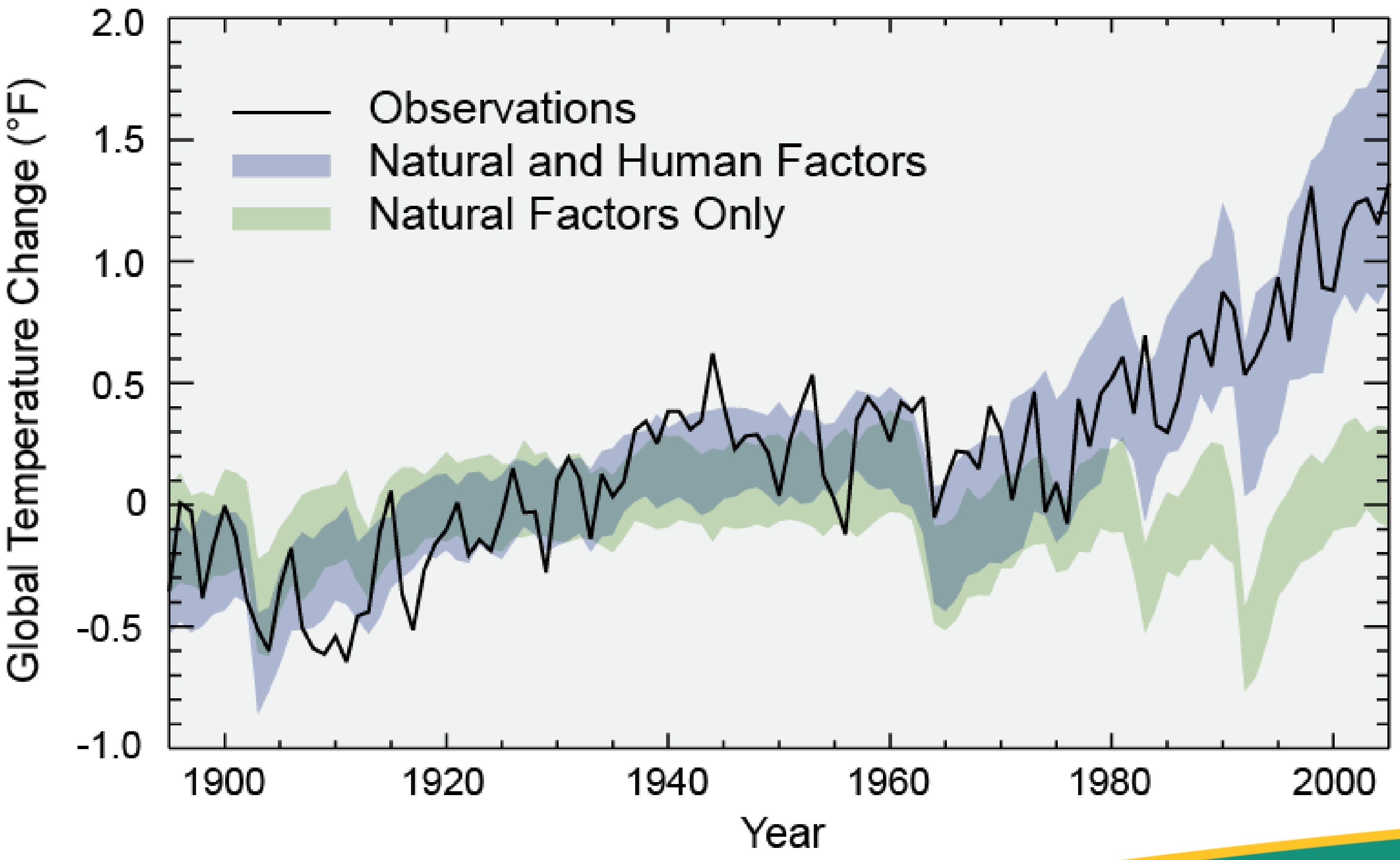
Graphs Show RCP 8.5

Source: U.S. National Climate Assessment, 2017

3. Natural Climate Variability

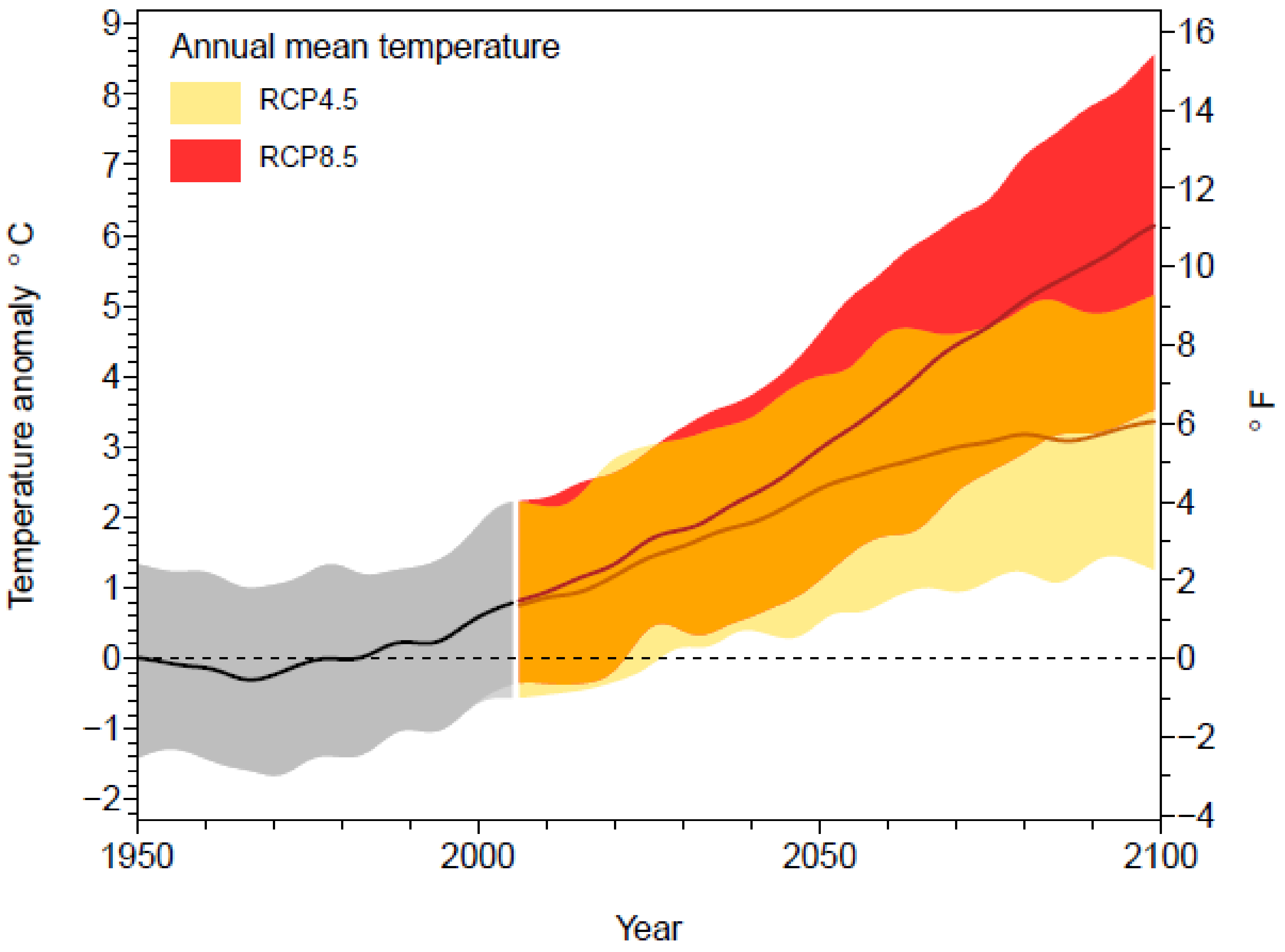
- Noise from year-to-year natural variability
  - Often greater than the climate change signal
- Multi-year and multi-decadal events
  - El Nino Southern Oscillation (ENSO)
  - Pacific Decadal Oscillation (PDO)
- How these will be affected by and will affect climate change is not clear
- Emerging literature that variability and extreme wet and dry events could increase (Swain et al., 2018)

Role of Natural Variability vs. Human Forcing of Climate



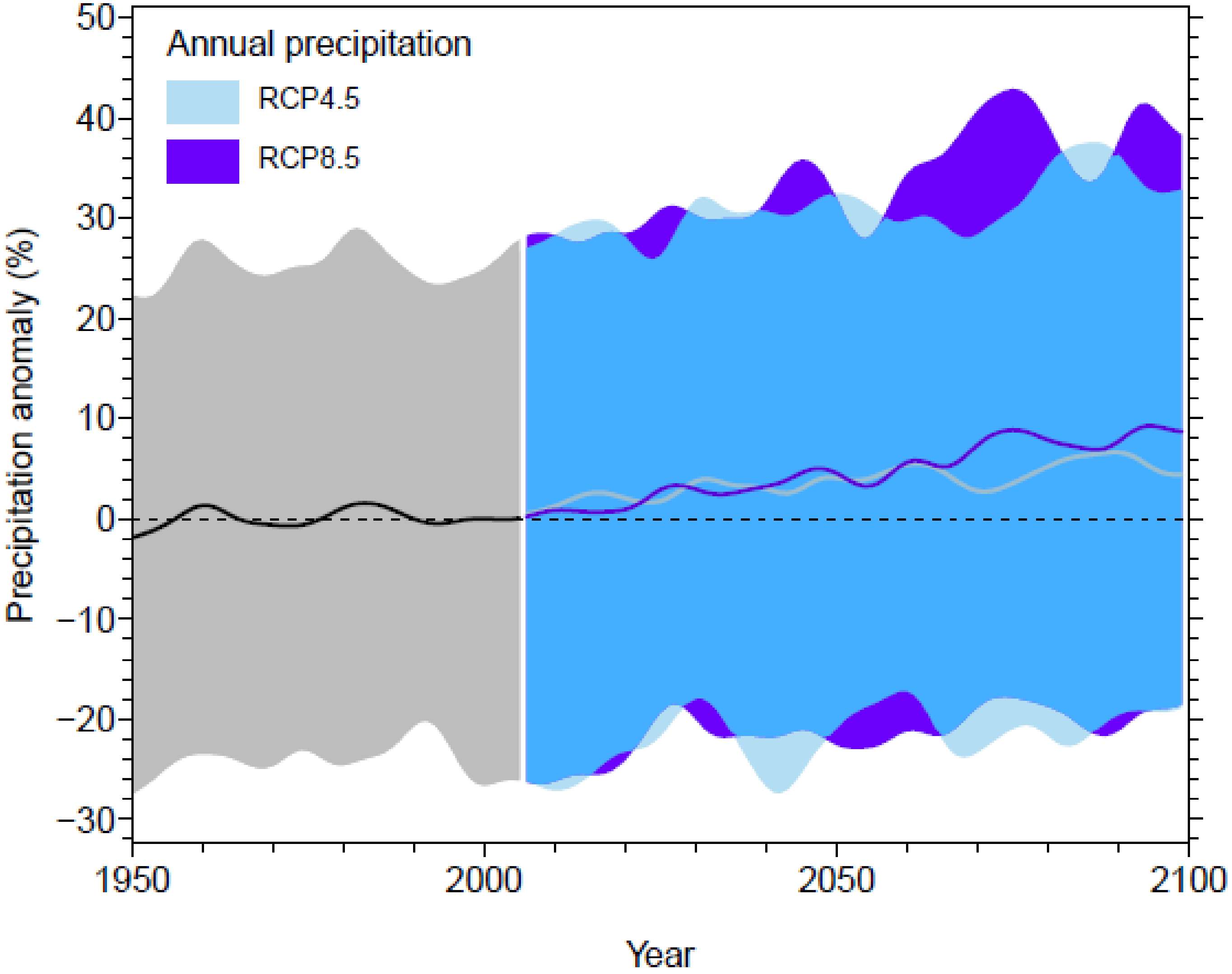
Source: U.S. National Climate Assessment, 2014

Projected Transient Changes in Temperature for PNW



Source: D. Rupp, CIRC, 2018

Projected Transient Changes in Precipitation for PNW



Source: D. Rupp, CIRC, 2018

4. Why Do We Use Climate Models?

- Models are the only way to project change in climate resulting from human activities
  - System is very complex, climate models represent best understand
  - There is no analogue for human induced warming
  - Unable to carry out deliberate controlled experiments

“If we had observations of the future, we obviously would trust them more than models, but unfortunately….

…. Observations of the future are not available at this time.

Tom Knutson and Robert Tuleya

A Dose of Humility: Models Are Not Crystal Balls

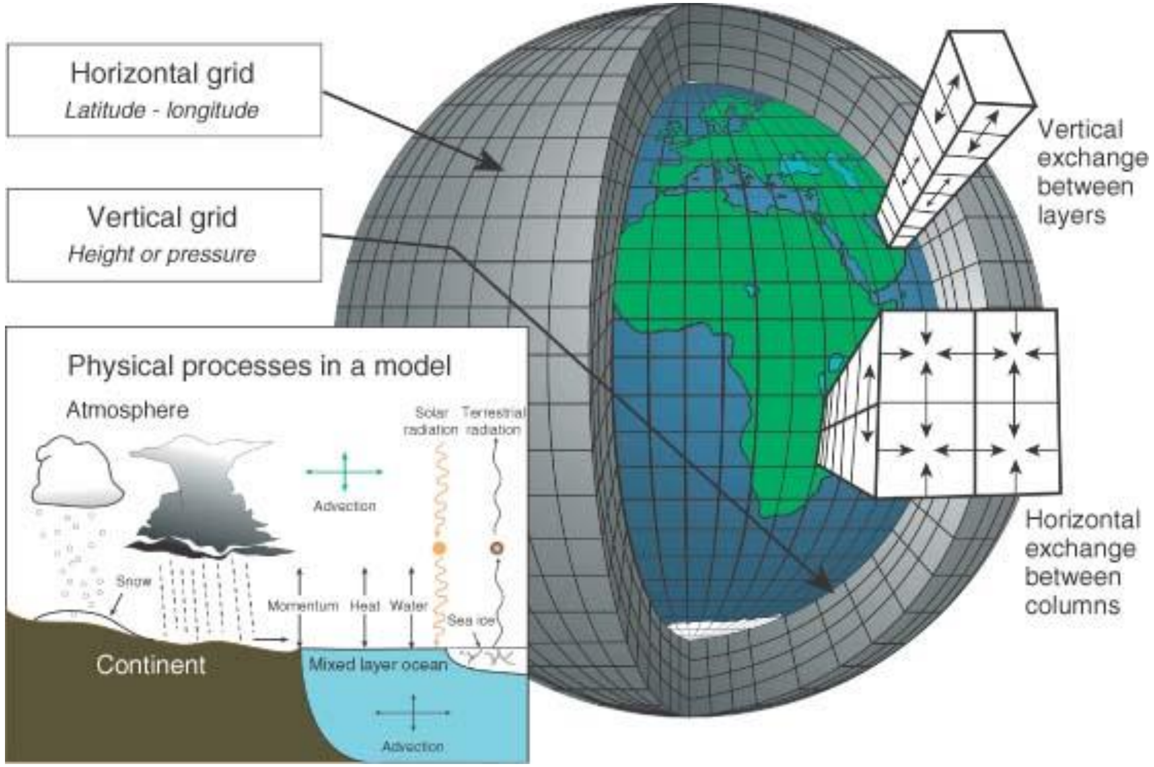
- Models are simplifications of reality
- They can be wrong – even if they all or mostly agree
- They are the best source of information we have on climate change
- They are improving
  - Resolution
  - Processes they simulate

Model Agreement is Not a Forecast

DENVER WATER

Global Climate Models

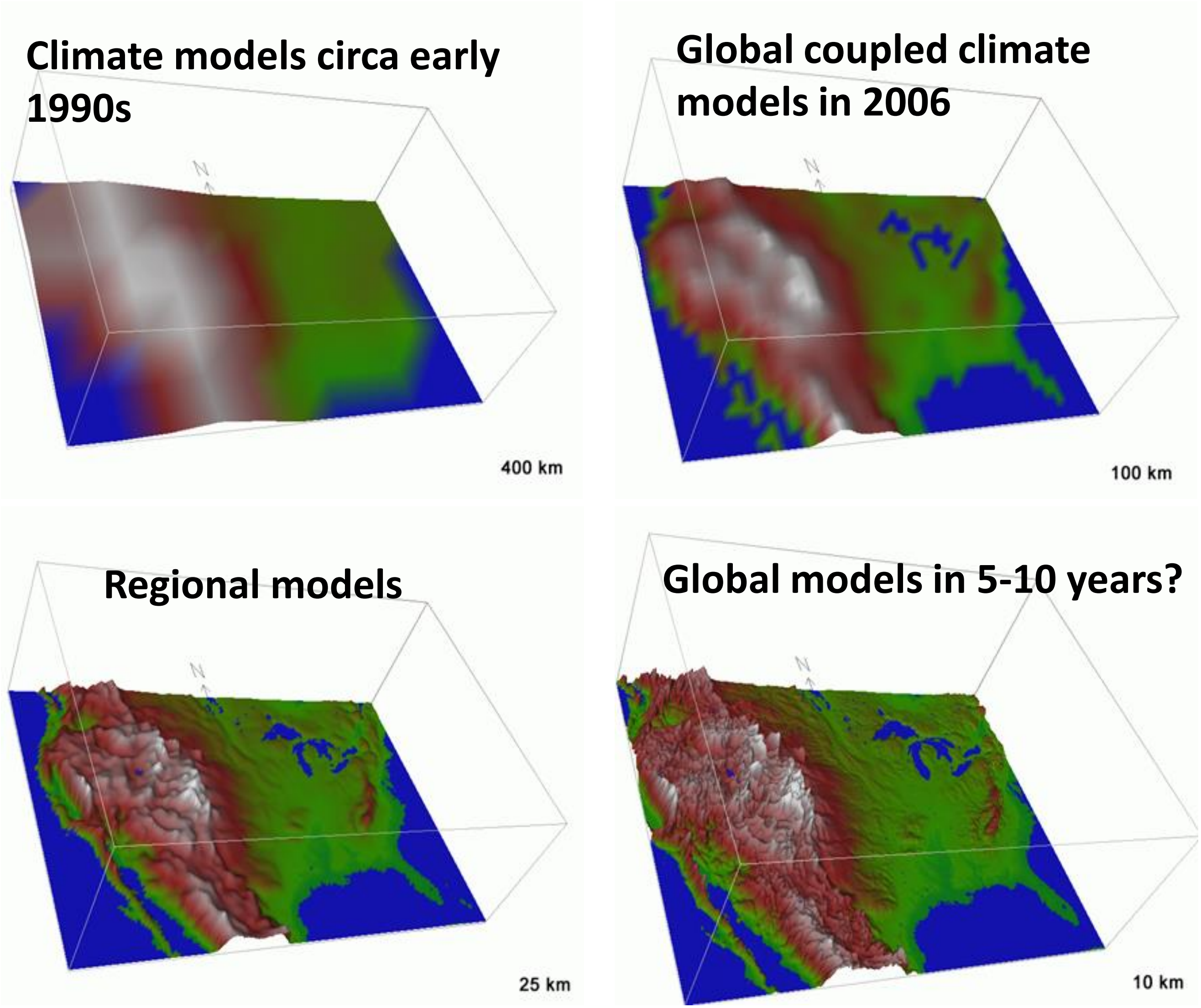
- Global Climate Models (GCMs), a.k.a.
  - General Circulation Models
  - Earth System Models
- Model the entire earth system
  - Atmosphere
  - Oceans
  - Land (including vegetation)
  - Cryosphere
- Divide the system into grid boxes
  - Typical grid boxes in GCMs are about 2 x 3 degrees
    - (~ 120 to 180 miles across)



How models handle climate and biophysical processes may be more important than grid size!

Global Climate Models

- They underlie all the projections we use for climate change
- Relatively low resolution
  - Give a uniform projection for each grid box
  - Cannot account for sub-grid scale processes
    - For example, convective thunderstorms
  - Particularly problematic along coasts and in mountains
- Resolution is improving because of computing power



Global Climate Models

Improving capabilities:

- More elements of earth system added
- More and improved observations
- More observations inform climate models

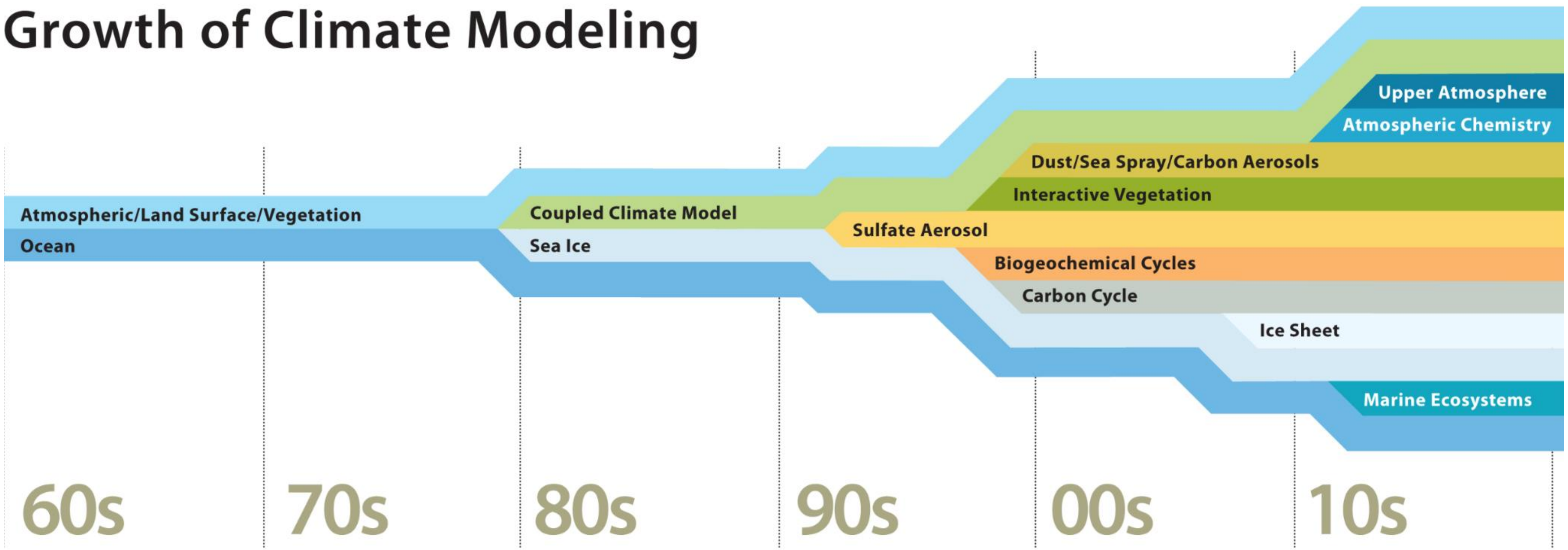


Figure courtesy of UCAR

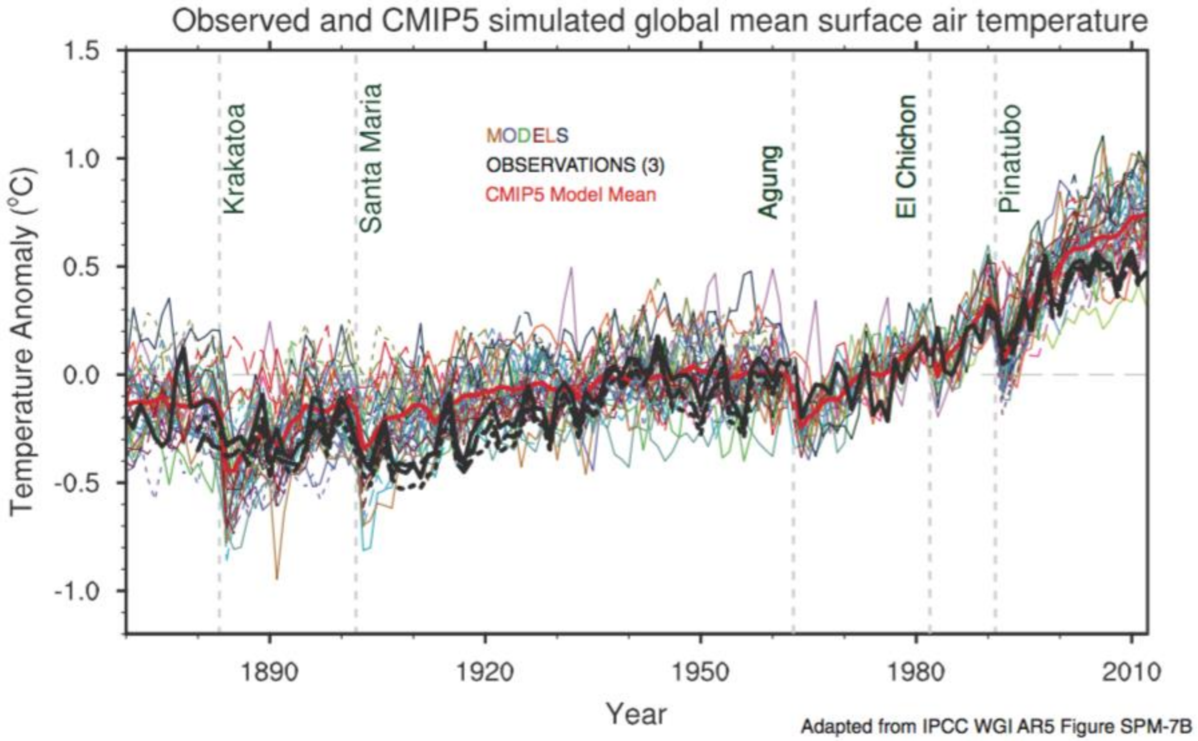
This Leads to a Desire for Downscaling

- We downscale because we want information at higher resolution
- Higher resolution is not necessarily more accurate
- The key question should be how does downscaling improve the results?
  - Do the results make physical sense?
  - Do we better understand direction of change at high resolution?
  - Do they project how change varies within the GCM grid box?
  - Does downscaling provide more accuracy or just precision?
  - Does it give us insight into sub-grid scale processes?

Model Averages vs. Individual Models

- Ensembles of multiple simulations that could include:
  - Many different global models
  - Multiple runs from the same model under different initial conditions

- The average of climate models' simulations of current climate is generally closer to observed climate than any individual model



Model Initialization Makes a Difference!

15 March 2014 DESER ET AL. 2275

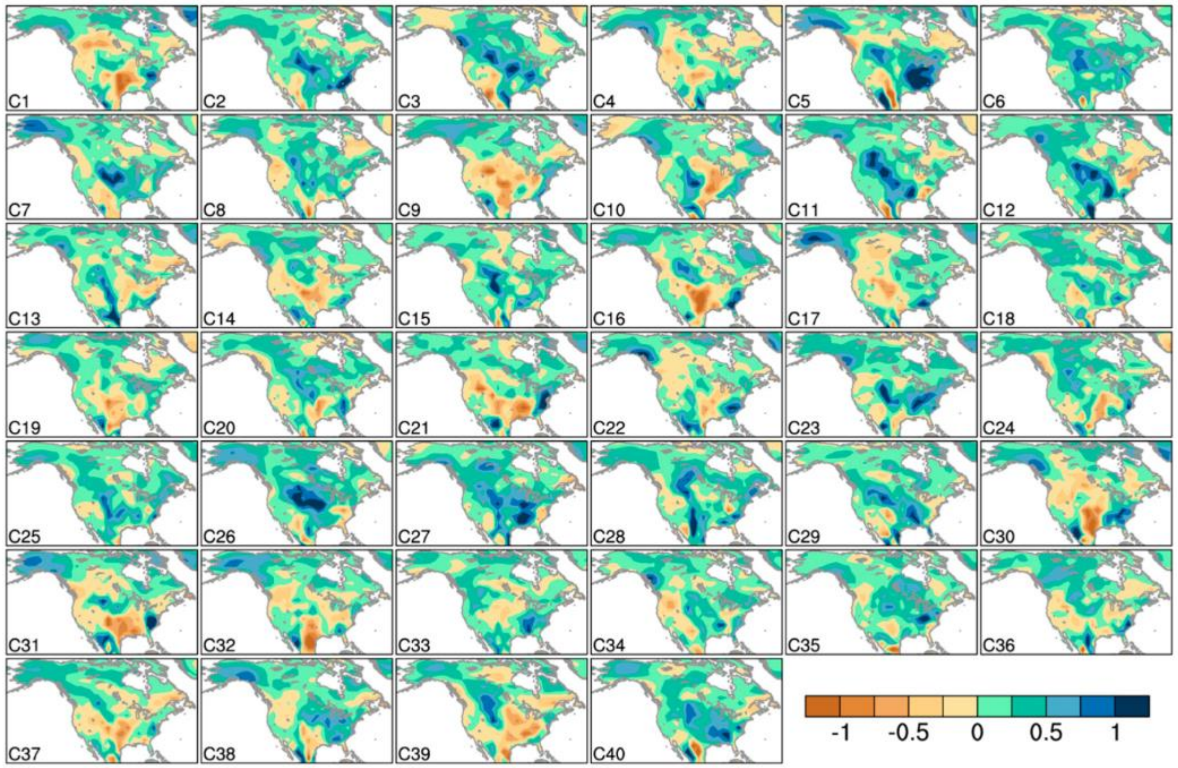


FIG. 2. Summer precipitation trends [2010–60; mm day^{-1} (51 yr)$^{-1}$] from each of the 40 CCSM3 ensemble members.

Model Averages vs. Individual Models

- Does that mean we should **only use** the average model projection of the future?
  - NO!!
  - The average is useful to show all the models combined
  - The average does not show the range of projections - It is hard to say which model(s) is (are) right or wrong
  - Ok to use the average as **a** scenario
    - Note it can smooth some things out such as year to year variability
  - Should also use ranges across the models to capture uncertainty across key variables
- Note, the range of model output DOES NOT define the true range of possibilities.

Are Some Climate Models Better than Others?

- Sometimes certain models are selected based on:
  - How well they simulate climate processes
  - Vintage (newer *tends* to be better)
  - How well they simulate observed climate
    - This is no guarantee projections of future are better than other models

- If going to select models, best to consult experts

Key Takeaways

- Temperatures are rising – the climate is changing
- We expect more warming in the future
  - Timing and magnitude are uncertain
- We can *project* potential changes in climate, but can’t *predict* them
- There are many sources of uncertainty including uncertainty about future emissions and exactly how the climate will change
- We expect some sources of uncertainty to not go away
- Climate models are the best source of information on future climate
  - They have important limitations
  - Their outputs are projections, not predictions

A Final Thought

We probably all know the saying:

“God grant us the serenity to **accept** the things we cannot **change**, the courage to **change** the things we **can**, and the **wisdom** to **know** the difference.”

An Update for We Who Wrestle With a Changing Climate

Grant us the serenity to accept the uncertainties that cannot be reduced; the will, patience, and resources to reduce those that can; and the wisdom to know the difference.