Building Resilience to a Changing Climate:

A Technical Training in Water Sector Utility Decision Support

WUCA
Water Utility Climate Alliance

Climate Science for Water Professionals

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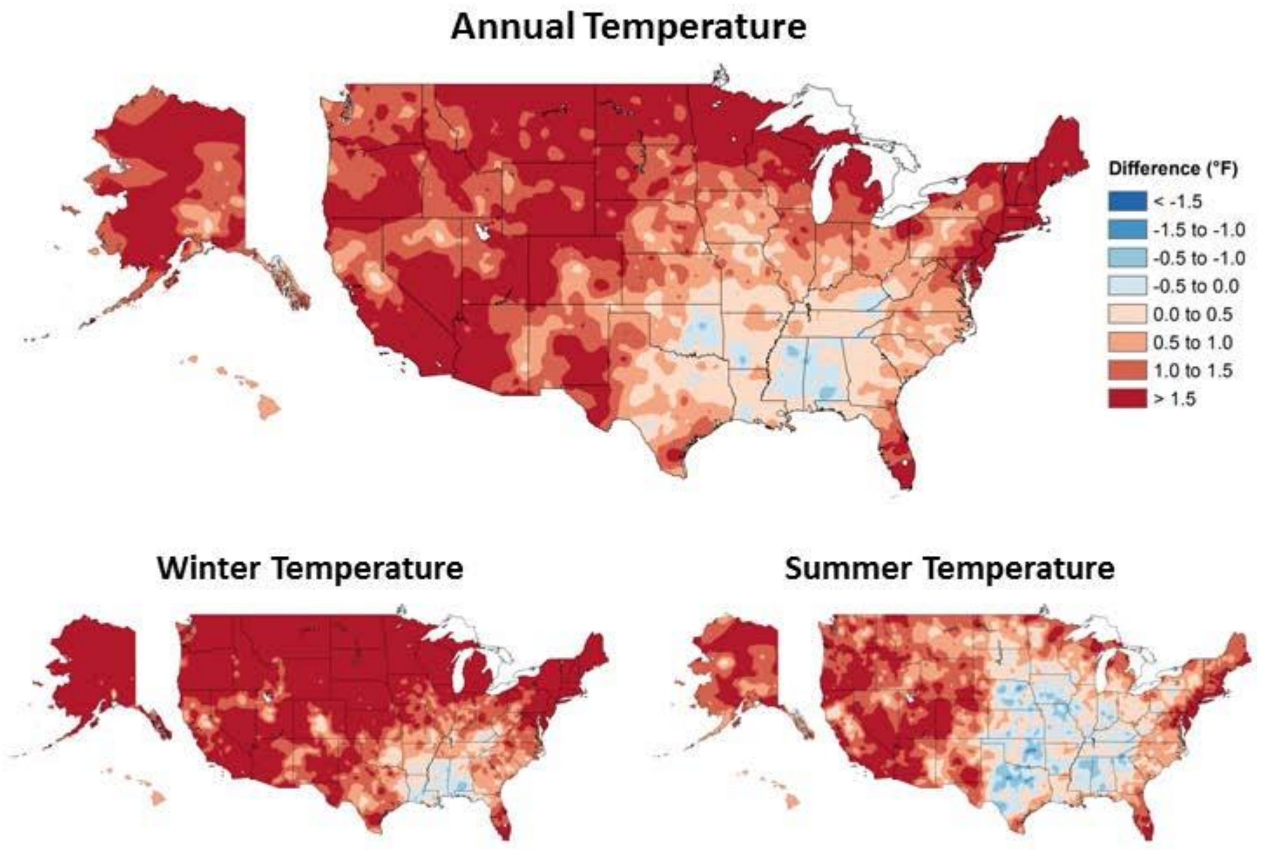
This Session and the Next Session

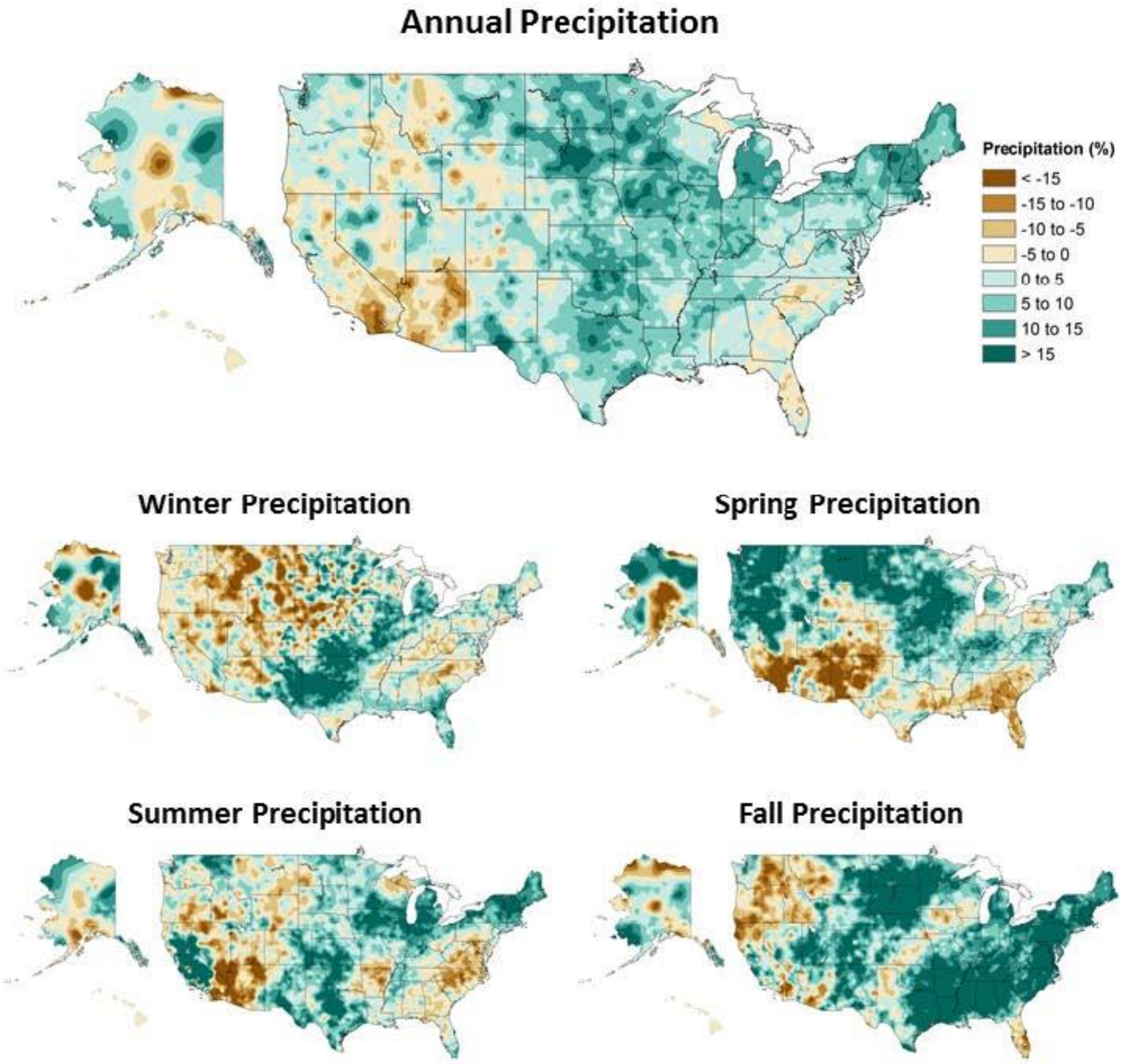
- This session will cover:
  - Overview of climate science and hydrologic cycle
  - Brief review of climate science
  - Discuss observed changes in climate of the West
  - Key sources of uncertainty about projections of change in climate
  - Introduction to climate modeling
    - Focus will be on the models of the world – Global Climate Models

Observed Temperature Changes 1901-1960 to 1986-2015



Data Provided by Dr. Ken Kunkel, NOAA

Observed Precipitation Changes
1901-1960 to 1986-2015



Data Provided by Dr. Ken Kunkel, NOAA

What Do We Expect to See in the Future?

- What we’re highly confident about increases in:

- What we’re not so sure about:

Climate Change Terminology

- A *Projection*
  - A plausible future condition
  - May be conditional, for example, based on a specific 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: Continuum of Certainty

More Confidence

- Expect to see increases in:
  - Temperature
  - Sea level
  - Intense precipitation
  - Earlier snowmelt

Less Confidence

- The magnitude of change (for example, temperature and sea level increase)
- Changes in precipitation patterns
- Changes in climate variability
- Change in peak snowpack

Future: Continuum of Certainty

More Confidence

- Global and continental scale projections
- Averages

Less Confidence

- Regional and local projections
- Extremes

Key Sources of Uncertainty in Predicting Future Climate

1. Human activity – Future emissions

2. The response of the climate system (climate sensitivity)

3. Regional pattern of change

4. Climate variability

5. An additional source of uncertainty is the climate models
    - More on that later….

1. Human Activity

- Key aspects of human contribution to climate
  - 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 stand for “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

Source: Moss, R. H., J. A. Edmonds, K. A. Hibbard, M. R. Manning, S. K. Rose, D. P. van Vuuren, T. R. Carter, S. Emori, M. Kainuma, T. Kram, G. A. Meehl, J. F. B. Mitchell, N. Nakicenovic, K. Riahi, S. J. Smith, R. J. Stouffer, A. M. Thomson, J. P. Weyant, and T. J. Wilbanks. 2010. “The next generation of scenarios for climate change research and assessment.” *Nature* 463: 747-756.

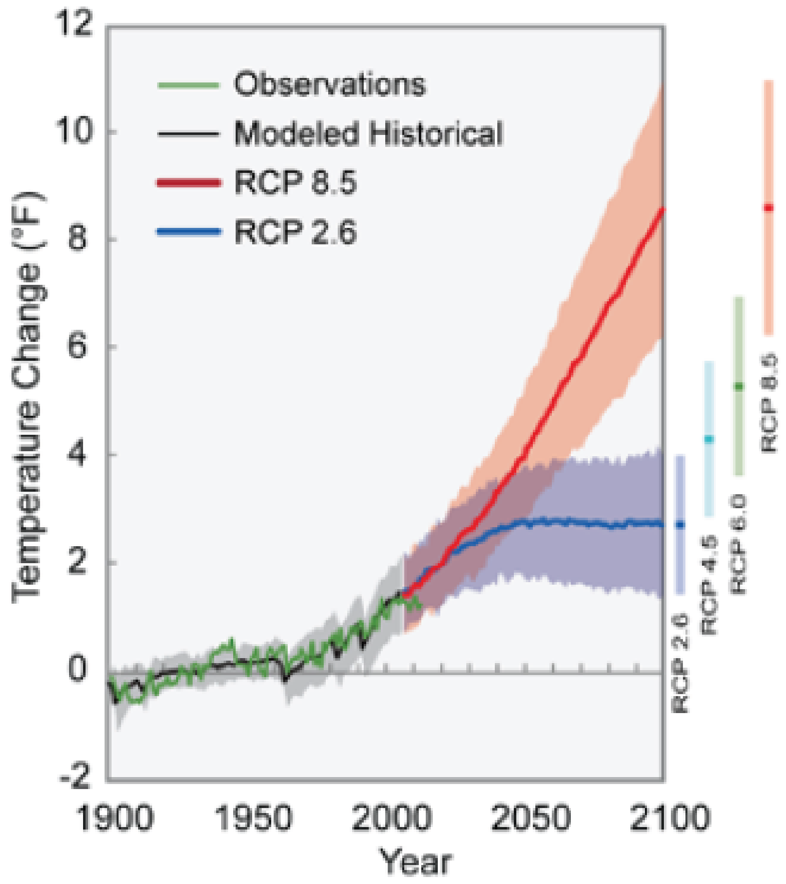
Source for current RCP is IPCC, 2013. Science Assessment.

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



Source: U.S. National Climate Assessment, 2014.

2. Climate Sensitivity

- How much does the Earth's atmosphere eventually warm with a CO_2 doubling
- What is the magnitude of warming
  - Best estimate is around 3^oC (5.4^oF)
  - Most likely between 2 (3.6^oF) and 4.5^oC (8^oF)
  - Very unlikely below 1 (1.8^oF) or above 6^oC (11^oF)

Image courtesy of UCAR

3. Regional Pattern of Change

Projected T and P for Western US

- Temperatures are expected to warm 2^{o}F to 5.5^{o}F
- Precipitation change uncertain, range -5% to +6%
- Colorado between areas expected to get drier (SW) and wetter
- RCP 4.5 at 2050

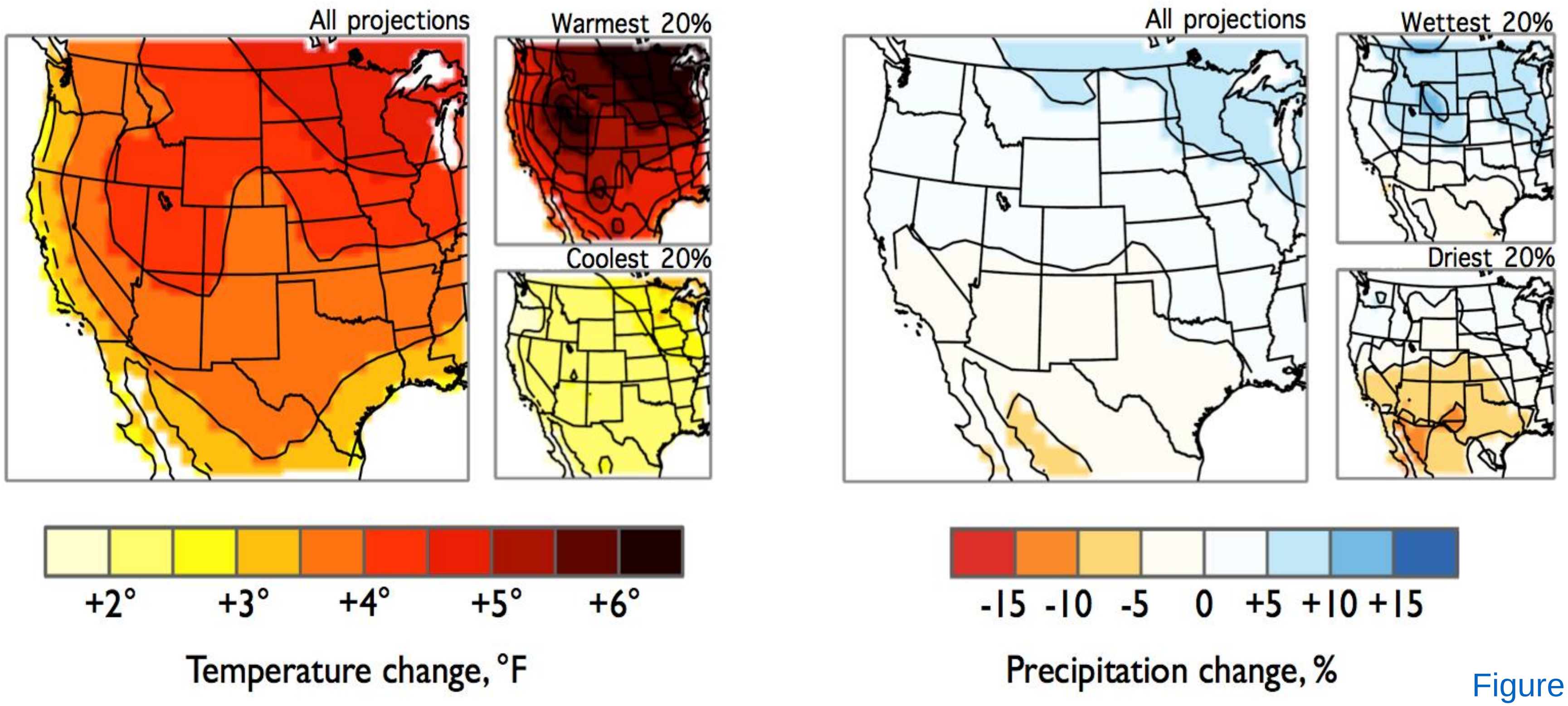


Figure ES-1

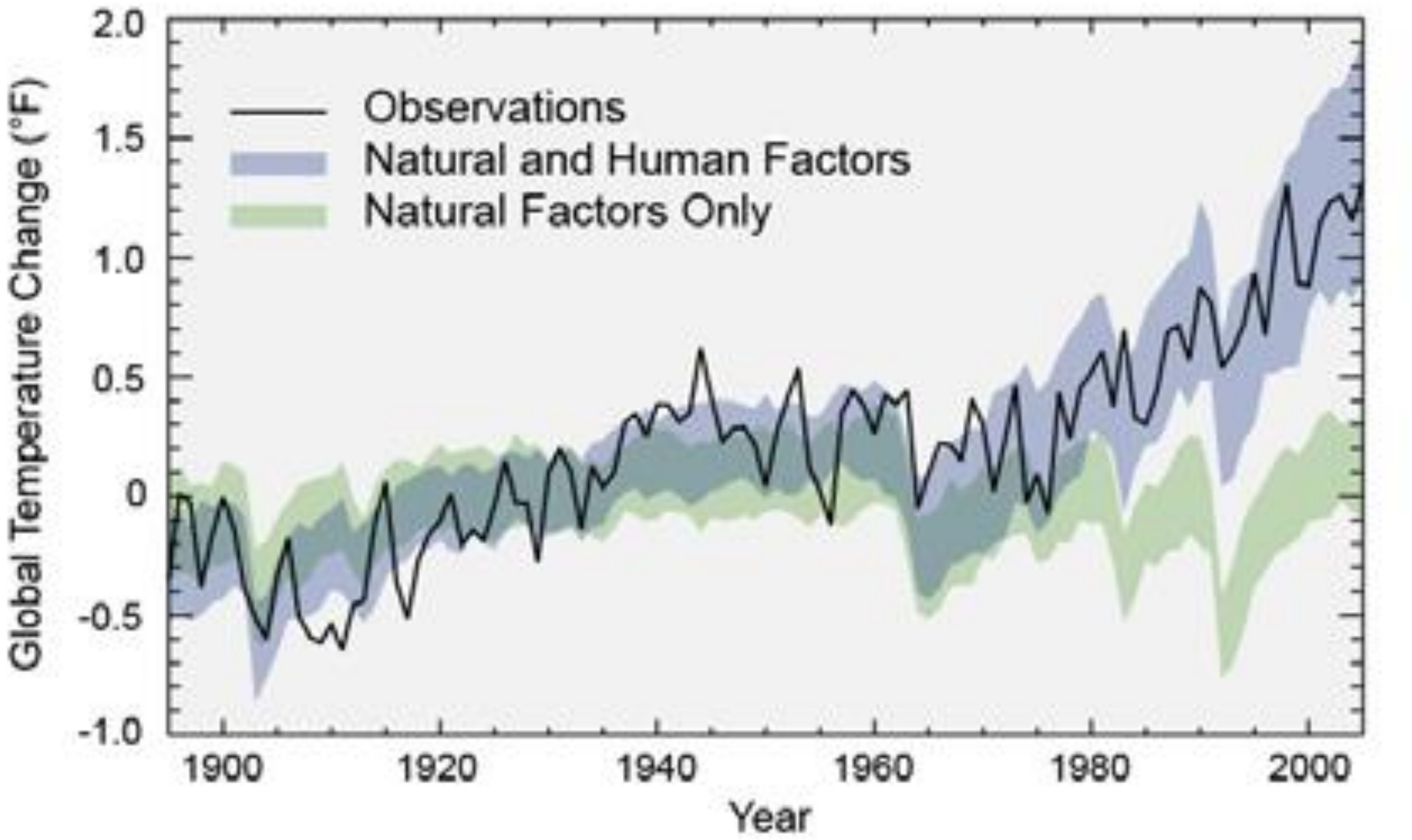
4. Climate Variability

- Multi-year events
  - El Nino Southern Oscillation (ENSO)

- Multi-decadal events
  - Pacific Decadal Oscillation (PDO)

- Not clear if and how these are affected by human induced climate change, for example, will ENSO become more intense?

Role of Natural Variability vs. Human Forcing of Climate



Source: U.S. National Climate Assessment, 2014

5. Climate Models

Why do We Use Climate Models?

- Models are the only way to project change in climate resulting from human activities
  - The system is very complex
  - There is no analogue for human induced warming

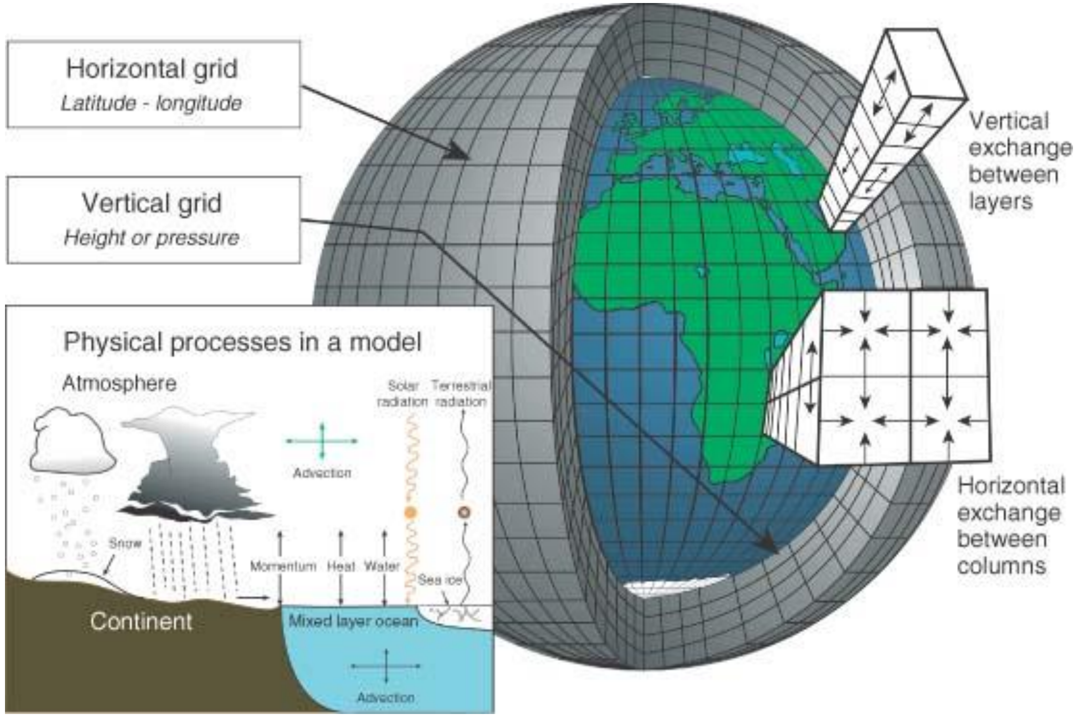
A Dose of Humility: Models Are Not Crystal Balls

- Models are simplifications of reality
- They can be wrong – even if they all or mostly agree
- But,
  - 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

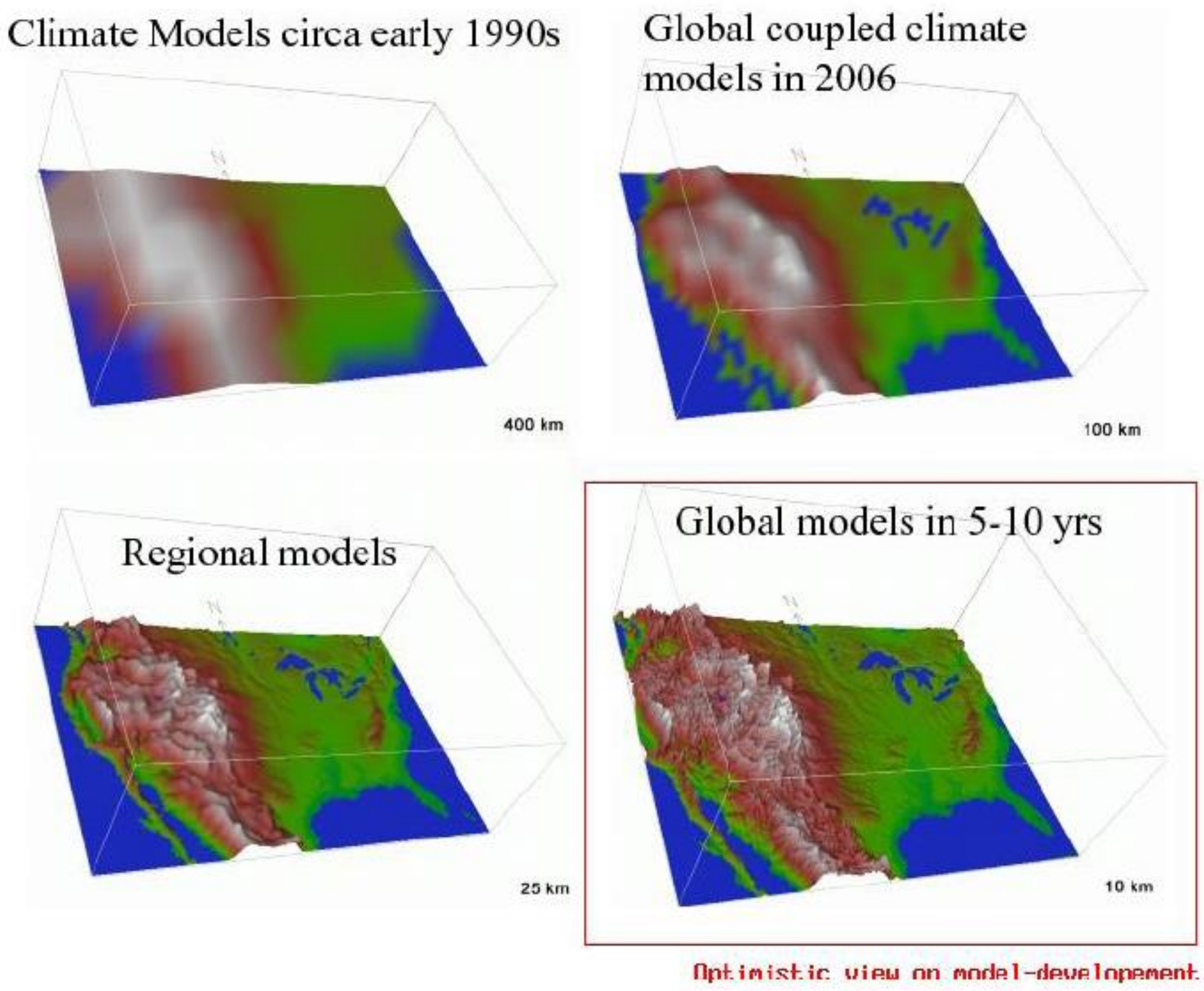
Global Climate Models

- Global Climate Models (GCMs), aka
  - 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)
  - Some models have 1 degree or less
- How models handle climate and biophysical processes may be more important than grid size.



More on GCMs

- 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



Source for image: https://www.e-education.psu.edu/meteo469/sites/www.e-education.psu.edu.meteo469/files/lesson05/GCMSchematicDP.jpg

This Leads to a Desire for Downscaling

- We downscale because we want information at higher resolution
- The next session will address downscaling techniques
- Higher resolution is not necessarily more accurate
- The key question should be how does downscaling improve the results?
  - 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 are:
  - Averages of many models
  - Also multiple runs from the same model under different conditions

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

Model Averages vs. Individual Models (con’t)

- 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
- Can use all models available
- If going to select, best to consult experts

Key Takeaways

- Temperatures are rising and precipitation patterns have changed
- 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.