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 ($\text{CO}_2$)
    - Methane ($\text{CH}_4$)
    - 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/m²)
  • We get about 300 w/m² from the sun
  • Doubling of CO₂ concentrations will trap another 4.5 w/m²
  • We are currently about 2.8 w/m² above preindustrial levels


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°C (3.6°F) 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

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°C (5.4°F)
  • Most likely between 2 (3.6°F) and 4.5°C (8°F)
  • Very unlikely below 1 (1.8°F) or above 6°C (11°F)
3. Regional Pattern of Change
Projected T and P for Western US
- Temperatures are expected to warm 2°F to 5.5°F
- Precipitation change uncertain, range -5% to +6%
- Colorado between areas expected to get drier (SW) and wetter
- RCP 4.5 at 2050
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
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.
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 \textbf{accept} the things we cannot \textbf{change}, the courage to \textbf{change} the things we \textbf{can}, and the \textbf{wisdom} to \textbf{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.