Building Resilience to a Changing Climate:

A Technical Training in Water Sector Utility Decision Support

WUCA
Water Utility Climate Alliance

Climate Modeling and Projections for Water Sector Professionals

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10/17/23 - Day 1

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Climate & Energy | Climate Change

Climate change means New York City's flooding is 'new normal,' governor says

By **Kanishka Singh** and **Joseph Ax**

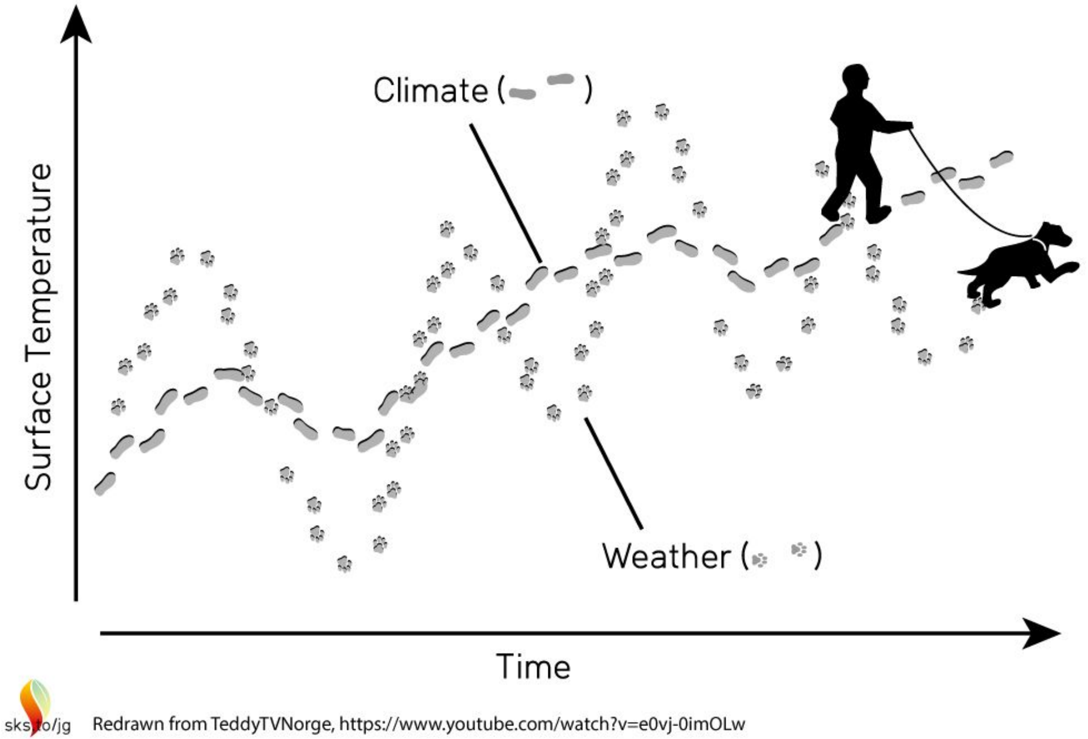
September 30, 2023 5:50 PM EDT · Updated 16 days ago

Aa

What is weather?

What is climate?

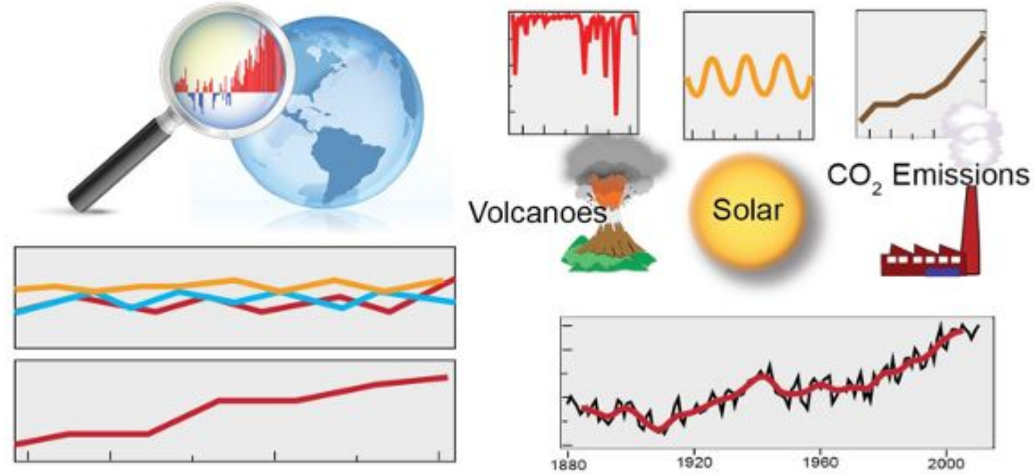
The Difference Between Weather and Climate



“Weather is what you get; climate is what you expect.”

Detection vs. Attribution

Detection and Attribution as Forensics



Detection: finding something out of the ordinary – a "signal" emerging from the noise

Attribution: determining the cause of the detected trend

Type of storm that drenched New York is up to 20% wetter due to climate crisis

Rapid attribution study finds storm 10-20% wetter after city experienced a month's worth of rain in just a few hours on Friday

A school bus drives in floodwaters at the FDR Drive in Manhattan on 29 September. Photograph: Andrew Kelly/Reuters

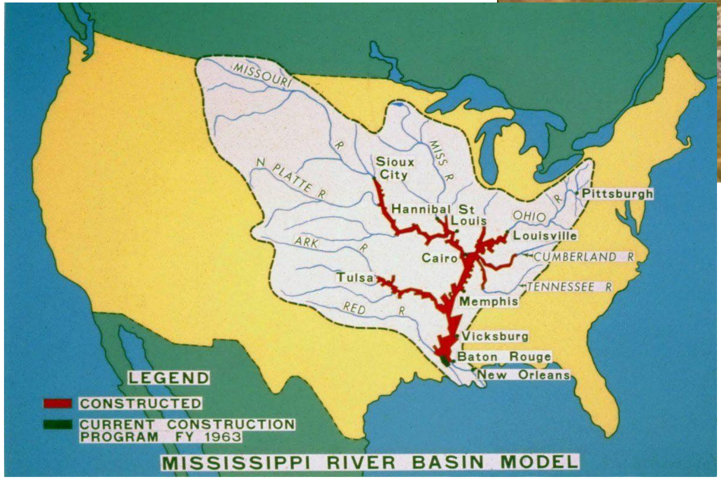
What is a model?

How are they used to understand climate change?

"A simplification of reality that is constructed to gain insights into select attributes of a… system. A formal representation of the behavior of system processes, often in mathematical or statistical terms…"

- US EPA

In the first half of the 20th century, when engineers needed to model a complex system, they would do just that, literally "model it," by building amazingly elaborate scale models.

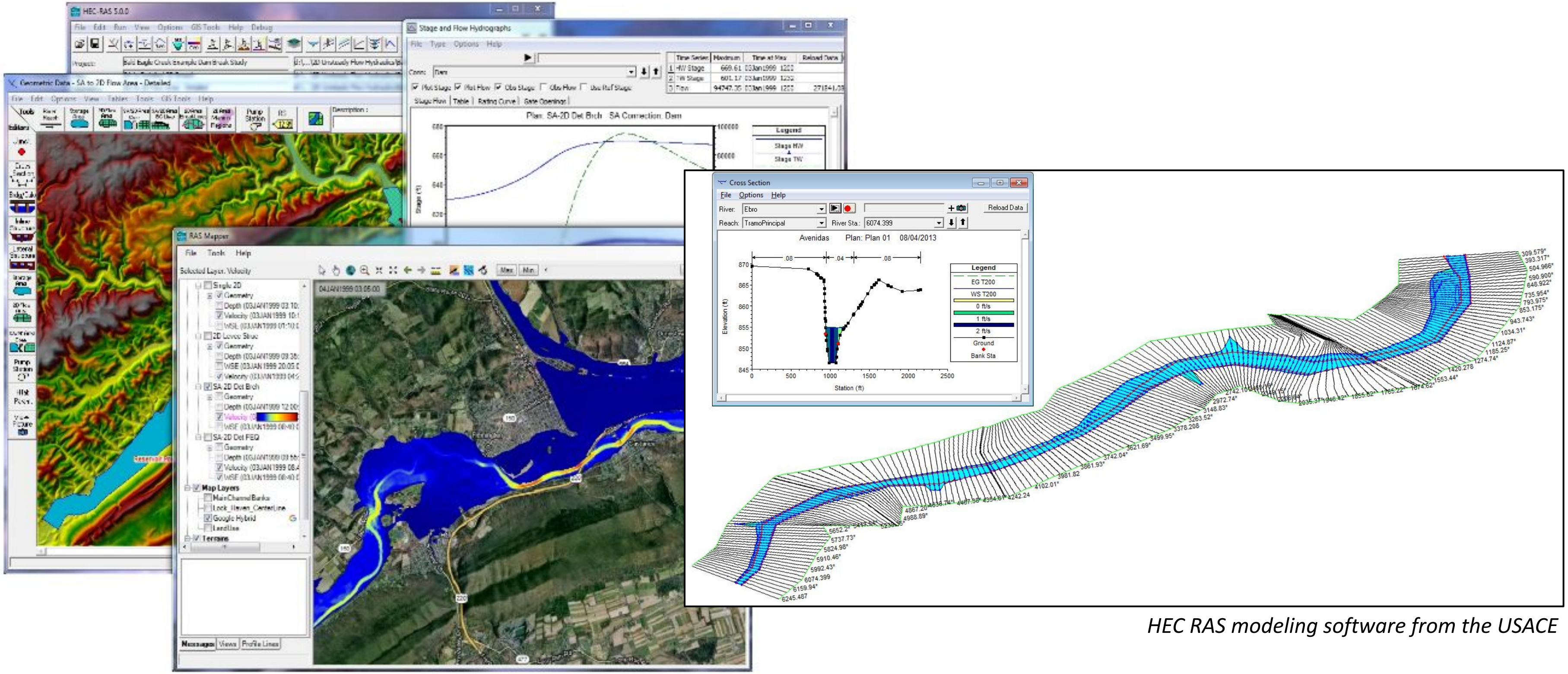


The US Army Corps of Engineers built many of these physical, scaled models. One of largest they ever built was a model of the Mississippi River watershed. It was a large-scale hydraulic model of the entire Mississippi River basin.

Image Source: Atlas Obscura

Image Source: US Army Corps of Engineers

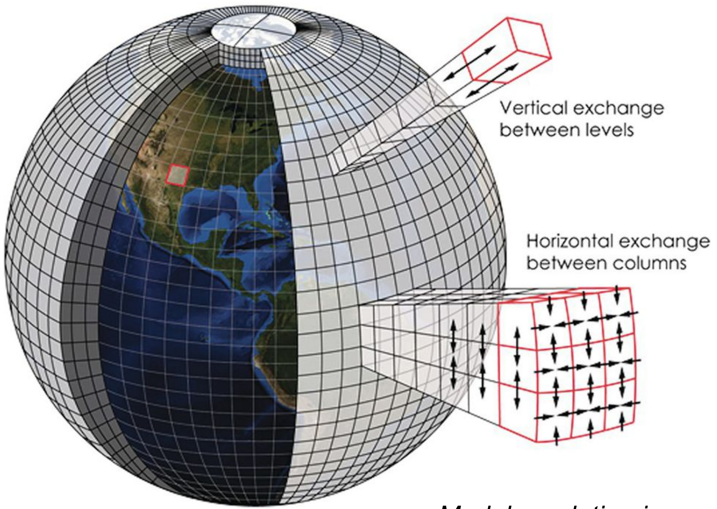
Today, physical models are not necessary -- computers are now used for the same purpose. Mathematical calculations and statistical formulas are used to represent physical principles and the real world is simulated with help of software and computer systems.



HEC RAS modeling software from the USACE

Global Climate Models

- GCMs attempt to describe the full three-dimensional geometry of the Earth's climate system.
- GCMs numerically solve the equations of physics (e.g., dynamics, thermodynamics, radiative transfer, etc.) and chemistry applied to the atmosphere and its components, including the greenhouse gases.
- Climate models have advanced and now typically include the ocean, hydrological cycle, ice sheets, biosphere, and carbon cycle.



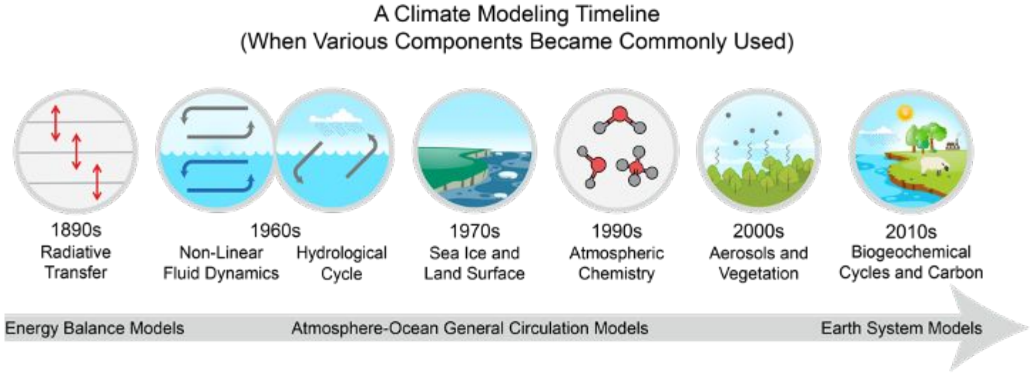
- Conservation of mass

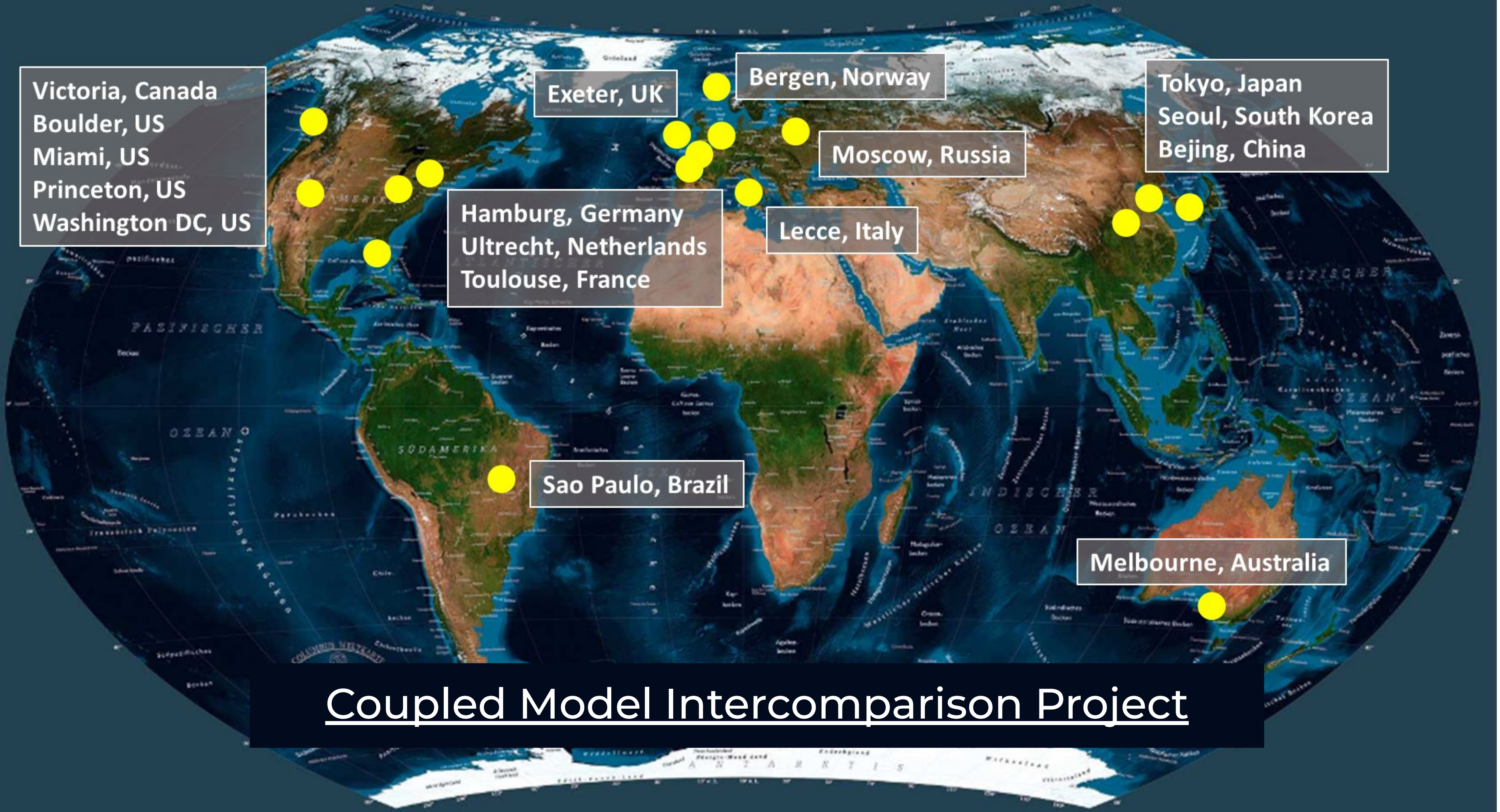
$$\frac{\partial \rho}{\partial t} = -(\vec{V} \cdot \nabla)\rho - \rho(\nabla \cdot V)$$

- Conservation of H_2O (vapor, liquid, solid)

$$\frac{\partial q}{\partial t} = -(\vec{V} \cdot \nabla)q + \nabla \cdot (k_q \nabla q) + S_q + E$$

Model resolution is approximately 75 x 75km





Coupled Model Intercomparison Project

How do we model future climate?

The Coupled Model Intercomparison Project (CMIP)

- The objective of the Coupled Model Intercomparison Project (CMIP) is to better understand past, present and future climate changes (Eyring et al., 2016)

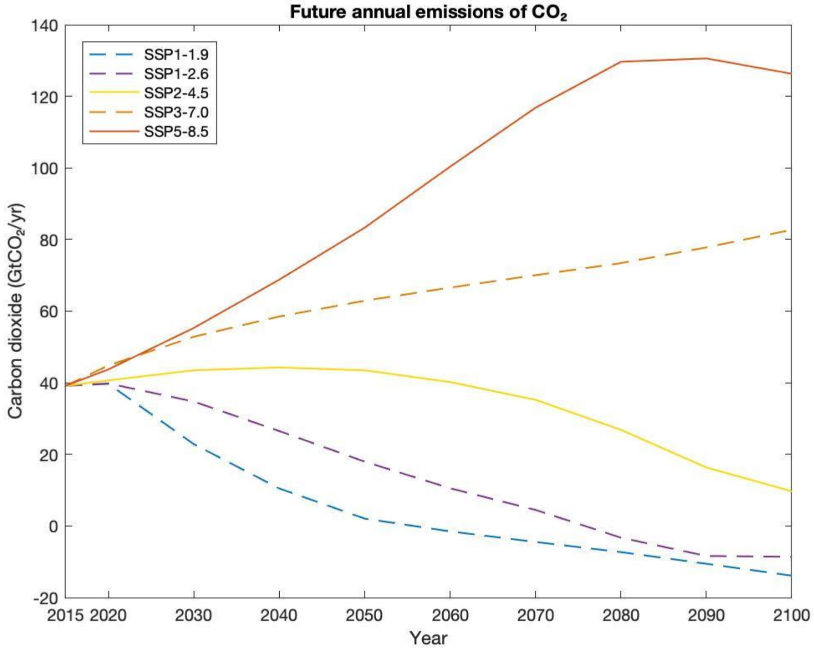
- The Scenario Model Intercomparison Project (ScenarioMIP) is the primary activity within CMIP6 that will provide multi-model climate projections
    - Based on alternative scenarios of future emissions and land use changes

- For CMIP6, there is a new framework that has been utilized to design scenarios that combine socio-economic and technological developments, known as the Shared Socio-economic Pathways (SSPs)

Shared Socioeconomic Pathways (SSPs)

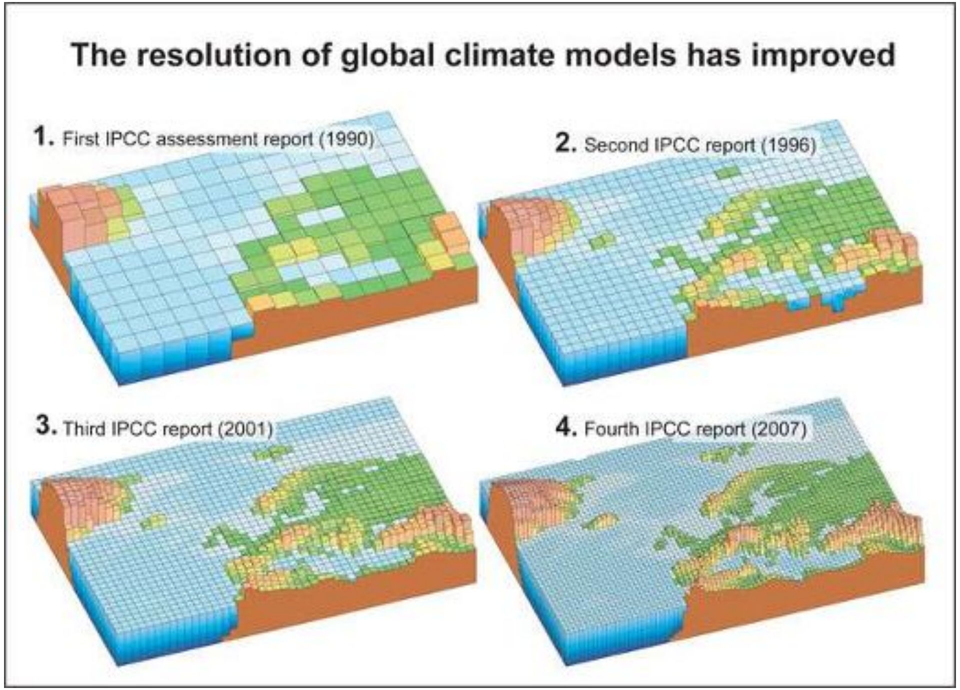
- The SSPs are based on five narratives describing alternative socio-economic developments, including sustainable development, regional rivalry, inequality, fossil-fueled development, and middle-of-the-road development.
  - For each SSP, a number of different radiative forcing targets can be met depending on policies implemented over the course of the century.

- The ScenarioMIP experiment developed a set of nine scenarios of future greenhouse gas emissions trajectories (Gidden et al., 2019) .
  - Four scenarios update the RCPs studied in CMIP5
  - Five scenarios fill gaps not previously studied in the RCPs

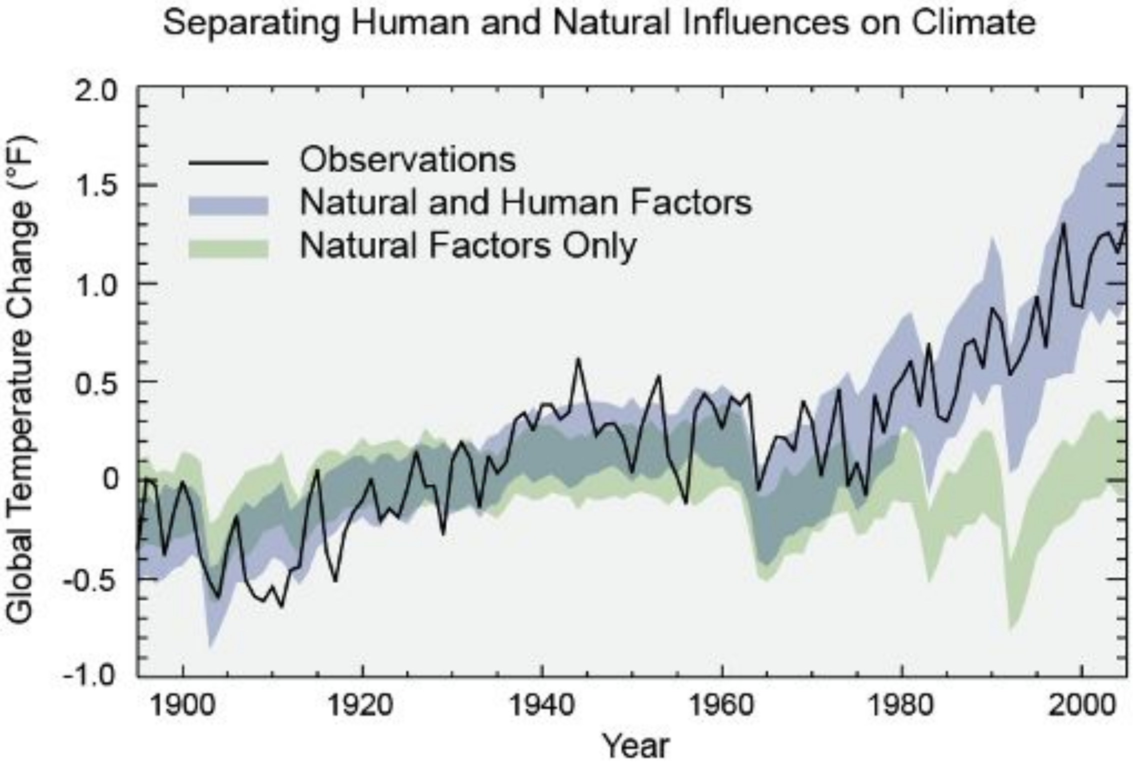


Comparing CMIP5 and CMIP6

- The CMIP6 models are higher spatial resolution than CMIP5
  - Gridbox sizes for many models are on the order of approximately 70 miles by 70 miles
- CMIP6 models also feature more advanced characterization of key climate system components
- Climate sensitivity—a measure of how sensitive global average temperatures are to changes in greenhouse gas concentrations—is higher in approximately one fourth of CMIP6 models than in CMIP5 and earlier CMIP generations
  - Some studies (e.g., Wang et al. 2021) have argued that projections from these high-sensitivity models are less reliable than other models.



Using Models for Data and Attribution

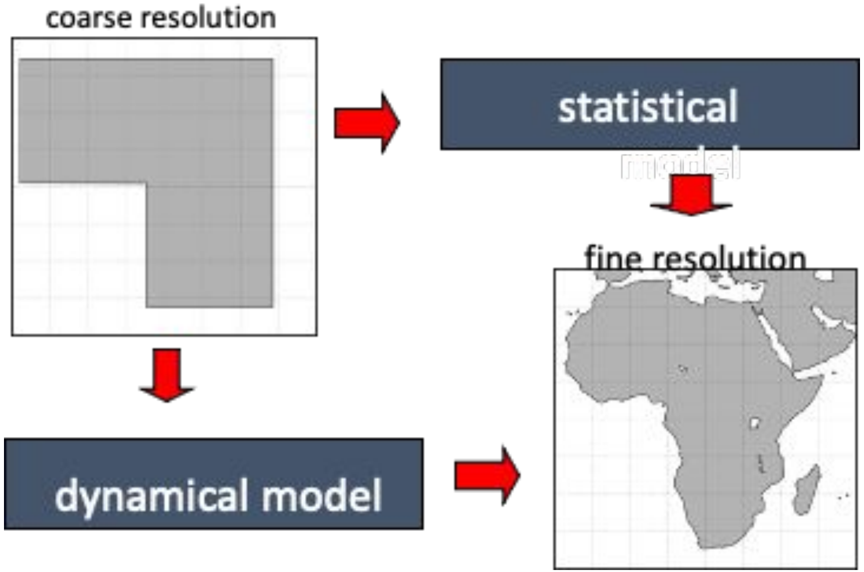


How can we use GCM projections locally?

Downscaling Methods

Statistical downscaling produces finer scale features than GCMs using historical relationships between the large and small scales

Dynamical downscaling (regional climate model) is achieved by running a global climate model at a high resolution over a small spatial domain.



Tradeoffs Between Dynamical and Statistical Downscaling

Dynamical

Pros

- Represents physical processes
- No stationarity assumptions
- Physically consistent across variables

Cons

- Computationally expensive
- Data set availability is limited
- Introduces need for additional ensembles
- Produces climate change signals that still must analyzed for credibility

Statistical

Pros

- Computationally tractable for large GCM ensembles
- Large high-resolution data sets publicly available
- Consistent with observations

Cons

- May not represent climate change signal correctly (often is effectively just interpolated GCM signal)
- Statistical nature often introduces artifacts

What do results look like and how are they used?

Where can I find climate projections?

In the Northeast United States (including work of the CCRUN)

- New York State Climate Impacts Assessment (NYSCIA)
- New York City Panel on Climate Change (NPCC)
- Philadelphia Climate Resilience Research
- City of Philadelphia Office of Sustainability

For the United States

- National Climate Assessment
- Interagency report for SLR

Presented here are the CCRUN methods, there are many different ways . . .

Climate Projections Methods – Mean Changes

- Projections for mean temperature and precipitation computed using the delta method (basic statistical downscaling).
  - Results for future time periods are compared to the model baseline period for each model gridbox.
- Annual, monthly, and seasonal changes are provided
- Presentation of results
  - Percentiles (10th, 25th, 75th, 90th) across the 2 SSPs and 35 GCMs
  - Ensemble average for each SSP

Climate Projections Methods – Extreme Events

- Projections for extreme temperature and precipitation events are computed using a method known as ‘quantile mapping’
  - Quantile mapping adjusts a model value by mapping percentiles of the model’s distribution onto percentiles of the observations
  - Produces a ‘synthetic’ daily timeseries for the future
- Presentation of results
  - Percentiles (10th, 25th, 75th, 90th) across the 2 SSPs and 16 GCMs
  - 3 future time periods, 2030s, 2050s, and 2080s
- Qualitative projections are provided for additional climate variables that aren’t well captured by global climate models (e.g., tropical cyclones, snowfall, extratropical storms)
  - Based on literature review and expert scientific judgement
  - ‘Descriptive scenarios’ also included

Sea Level Rise Projections

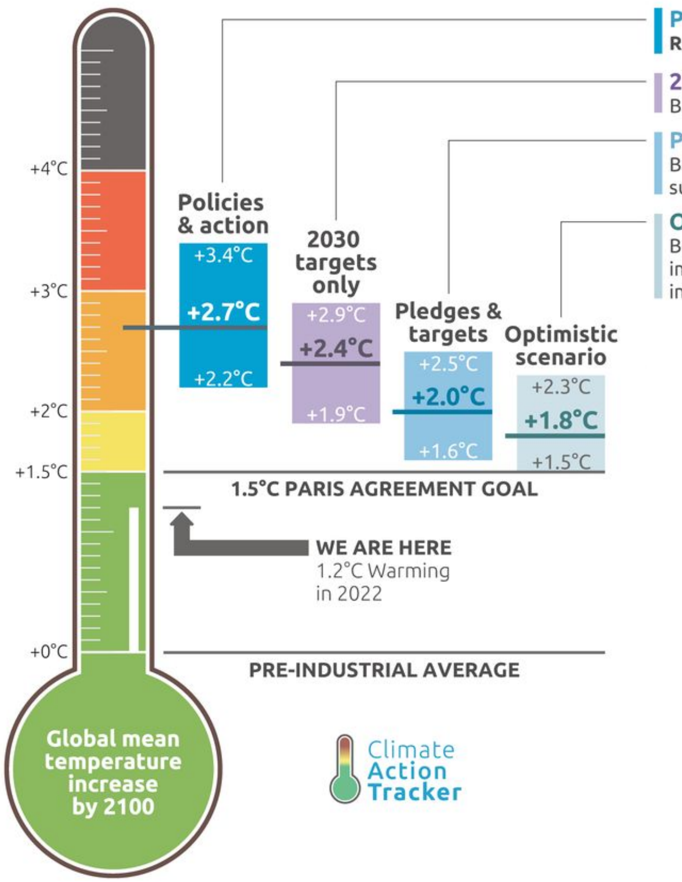
- Download IPCC AR6 sea level rise data files (for each scenario, a full set of percentiles in one percentile increments is available)
- Select 3 of the IPCC sea level rise scenarios (SSP2-4.5 medium confidence, SSP5-8.5 medium confidence, SSP5-8.5 low confidence)
- Interpolate the IPCC results to the middle year (e.g., 2055) of the decade to align with prior use of 10-year time slices for sea level rise projections
- Combine the 3 scenarios to form a 'distribution' of 297 values (3 scenarios X 99 quantiles)
- Present results (percentile values) across the combined 'distribution' to form updated sea level rise projections

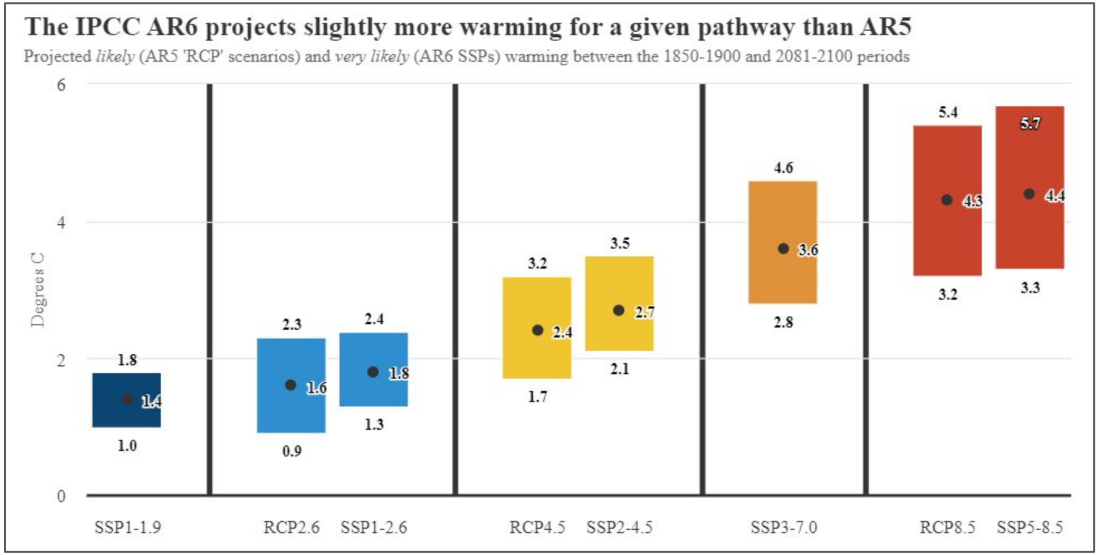
Key Considerations

- Continuity vs. the latest science
- There's a lot of data out there . . .
- Downscaling and displaying results . . .
- Comparison to prior results

How do you apply this information?

Climate Action Tracker - Global Temperature Increase by 2100





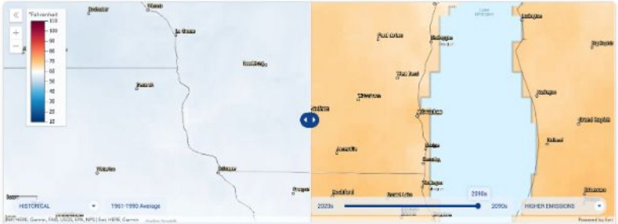
https://climateactiontracker.org/

The Climate Explorer https://crt-climate-explorer.nemac.org/

About the data

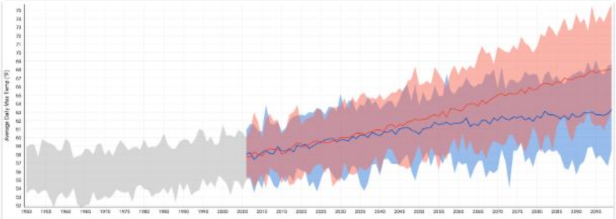
Philadelphia, PA

Select one of the following for **Philadelphia County**



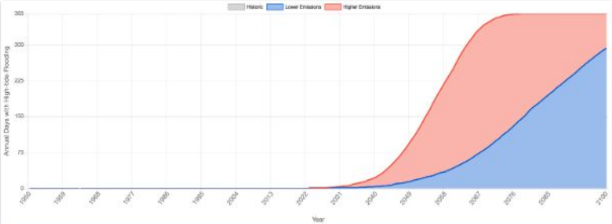
Climate Maps

Compare past and projected future conditions in your county.



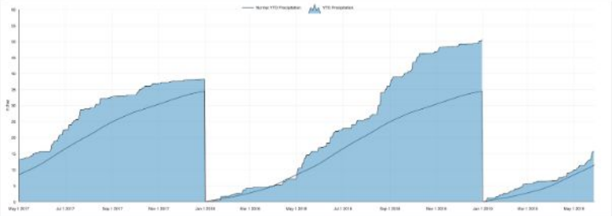
Climate Graphs

Check past and projected values for climate variables.



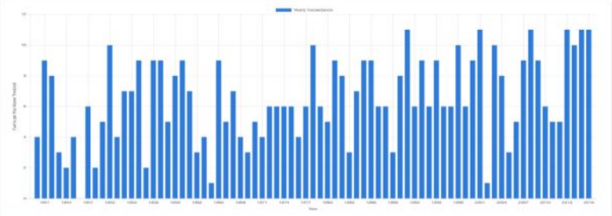
High-Tide Flooding

Explore the number of days per year with high-tide floods.



Historical Weather Data

Compare observed daily weather to long-term climate.



Historical Thresholds

Check how often temperature or precipitation has exceeded user-defined values.

Ready to plan for resilience?

Resources from our partners can help you identify what matters to your community and evaluate how climate change could affect it:

- Check your exposure to extreme events such as wildfires and flooding
- Identify social vulnerabilities across urban areas
- Get step-by-step guidance for completing a vulnerability assessment or crafting an action plan.

Explore planning tools →

Cards Home | Climate Maps | Climate Graphs | Historical Weather Data | Historical Thresholds | High-Tide Flooding | Take Action

SEA LEVEL CHANGE
Observations from Space

News & Features | Understanding Sea Level | Science Team | Climate Tools | Analysis Tools | Science to Action | Resources

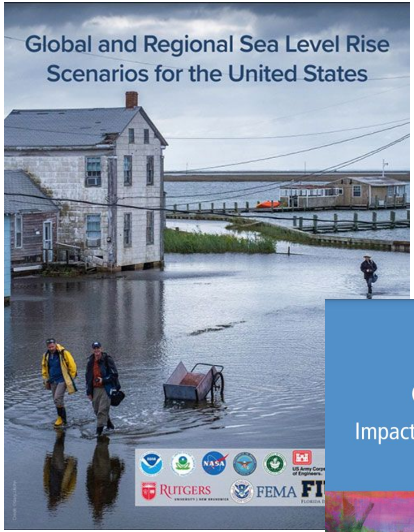
https://sealevel.nasa.gov/

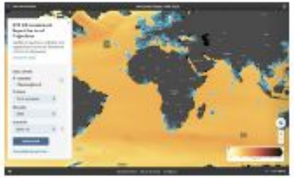
Climate Tools

Visualize and access information and data relevant to understanding and planning for sea level rise in response to ongoing climate change.

Interagency Sea Level Rise Scenario Tool

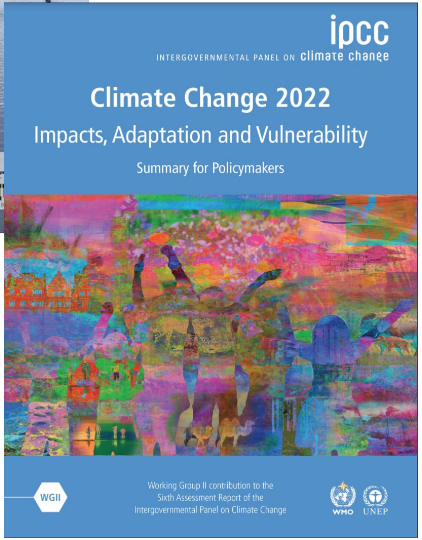
Visualize and download the sea level scenarios from the U.S. Sea Level Rise Interagency Task Force.

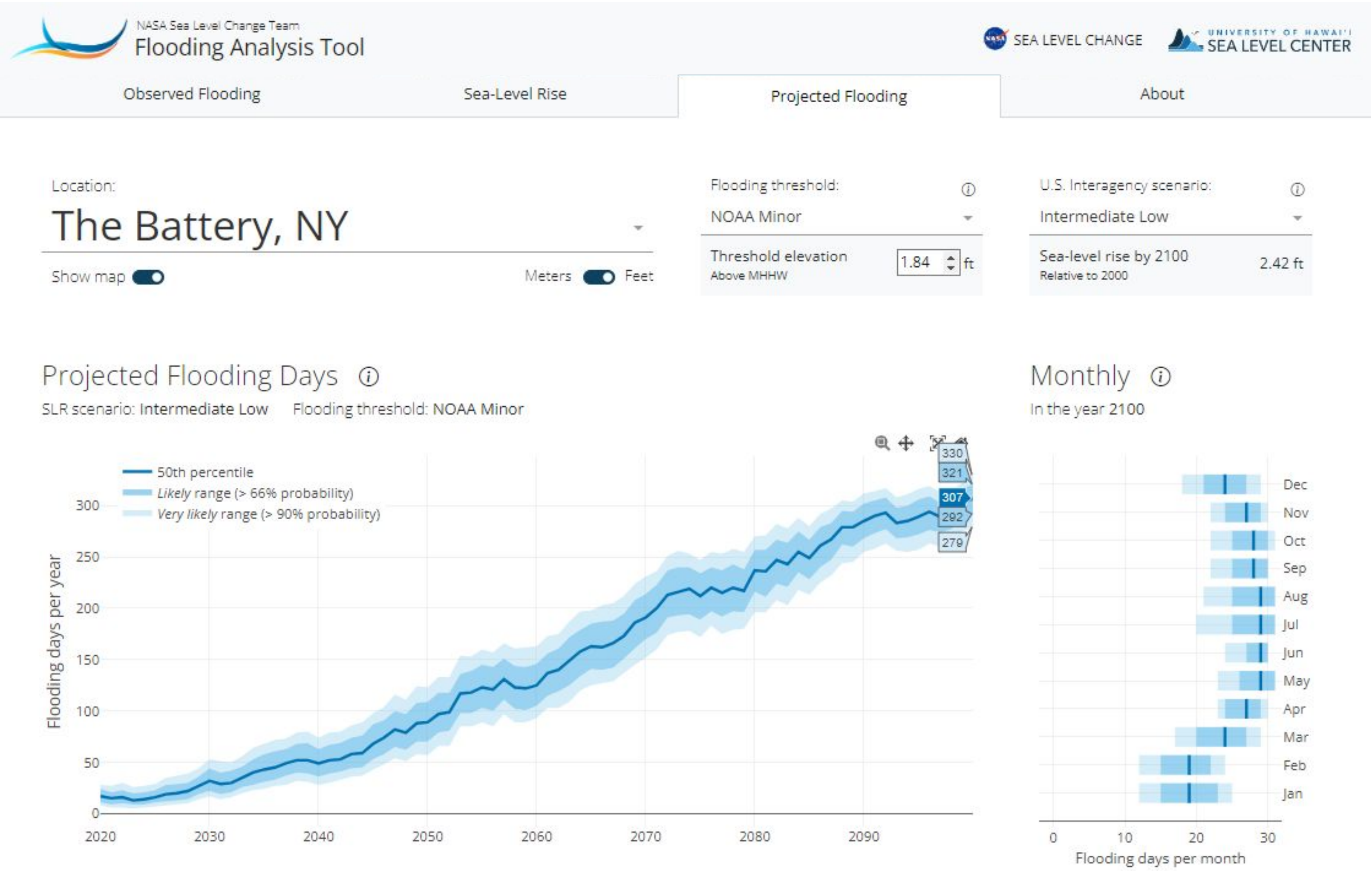




IPCC AR6 Sea Level Projection Tool

Visualize and download global and local sea level projections from the Intergovernmental Panel on Climate Change Sixth Assessment Report.





https://sealevel.nasa.gov/flooding-analysis-tool/projected-flooding?station-id=8518750&scenario=int-low

Practitioners developed and reviewed this document!

APPLICATION GUIDE
for the
2022 Sea Level Rise Technical Report

Increase in Average Global Air Temperature in 2100	Closest Emissions Scenario	Likelihood of Exceeding a SLR Scenario				
		Low	Intermediate-Low	Intermediate	Intermediate-High	High
2.7°F (1.5°C)	Low Emissions (SSP 1-2.6)	92%	37%	<1%	<1%	<1%
5.4°F (3.0°C)	Intermediate to High Emissions (SSP 2-4.5 – SSP 3-7.0)	>99%	82%	5%	<1%	<1%
9.0°F (5.0°C)	Very High Emissions (SSP 5-8.5)	>99%	>99%	23%	2%	<1%
*	Very High Emissions (SSP 5-8.5) with Low Confidence Processes	>99%	96%	49%	20%	8%

* Single temperature not listed because the exceedance probabilities were based on a framework of high emissions, high warming, and the occurrence of low confidence processes.

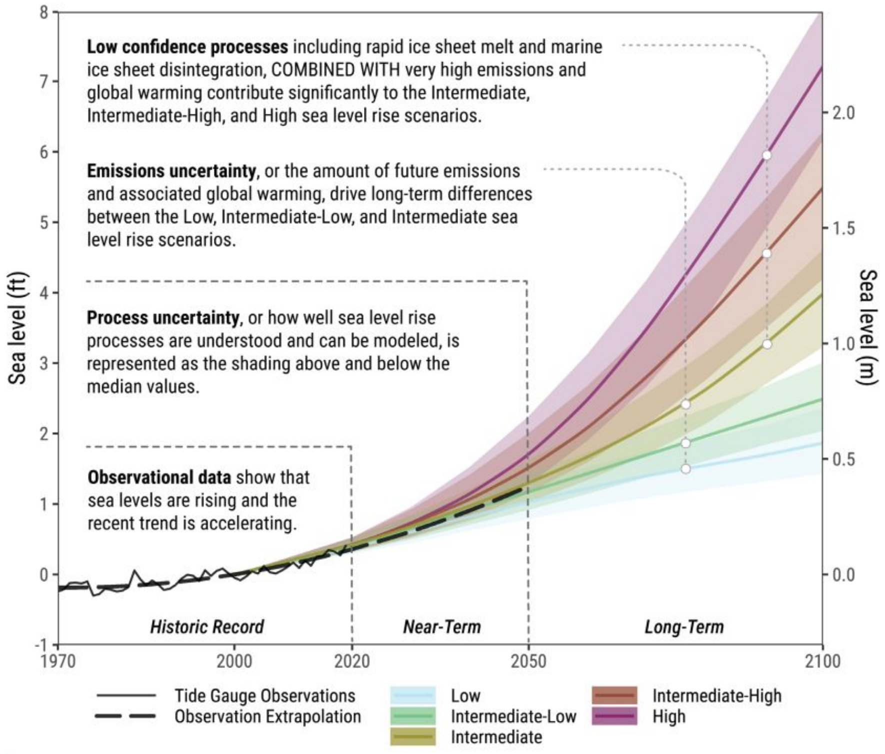
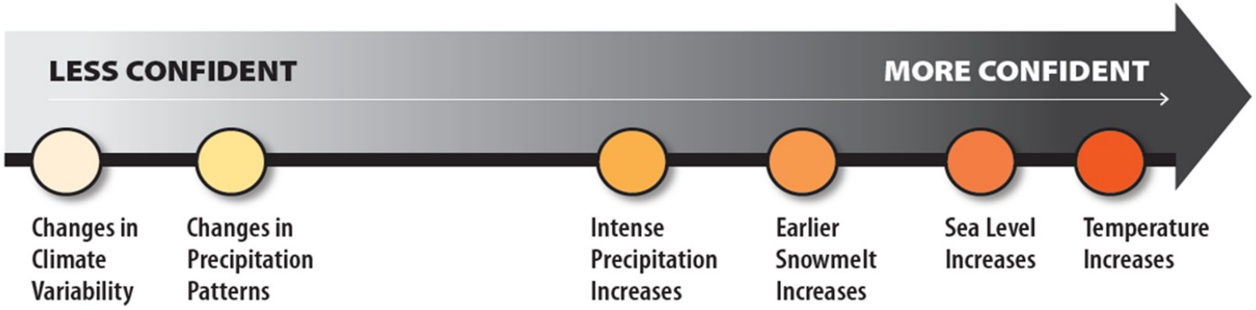


Figure 4. *Sea level rise scenarios for the contiguous United States relative to a year 2000 baseline. The ranges within and between the five scenarios represent different sources of uncertainty. Average annual*

https://aambpublicoceanservice.blob.core.windows.net/oceanserviceprod/hazards/sealevelrise/noaa-nos-techrpt02-global-regional-SLR-scenarios-US-application-guide.pdf

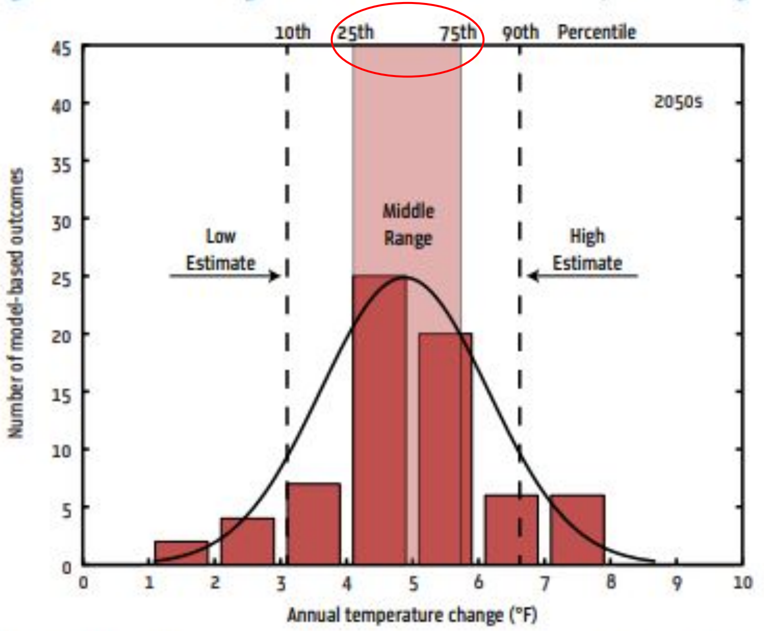
Considerations and Limitations



- We have the most confidence in temperature projections
- Extremes are not captured well, particularly for precipitation
- There are resolution challenges for precipitation projections
- CMIP 6 includes a new scenarios (SSP3-7.0)
- RCP8.5 is not “business as usual,” it is a worst-case scenario
- For Sea Level Rise
  - Confident in direction of change, but projections after 2050 still highly uncertain
  - CMIP6 now includes two “low confidence” scenarios
  - We have more confidence in mid-century projections and the range has decreased
  - For near-term applications (through 2050), best practice now recommends using the scenarios that most closely matches observed extrapolations.

Probabilities

Figure 1. Model-Based Range of Outcomes for 2050s Annual Temperature Change

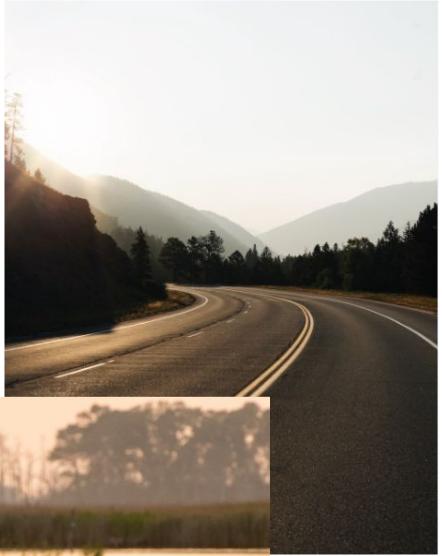


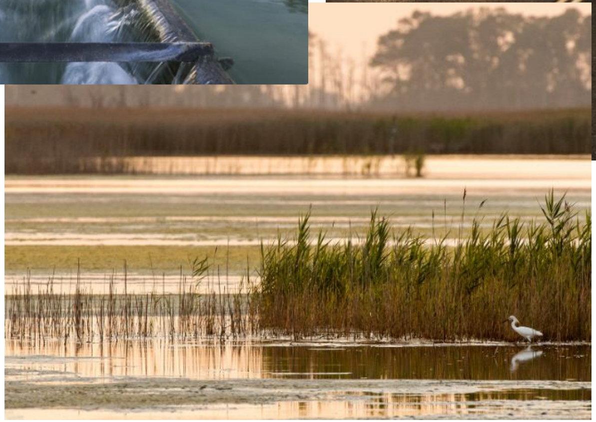
Model-based range of outcomes (distribution) for 2050s temperature change relative to the 1971 - 2000 base period. Based on 35 global climate models and 2 representative concentrations pathways. The 10th, 25th, 75th, and 90th percentiles of the distribution are presented.

- The range of outputs from the GCMs can be used to create a probability density function (or CDF) which helps us understand the spread of results
- IPCC shows results for the middle 17th to 83rd percentile (middle 66 percent) and does not attach probabilities
- Alternative approach is to show percentiles (supposed to help practitioners understand uncertainty) and show tail risk
- The middle of the distribution are where there is the most **model agreement**, hence, what is "likely" to happen.
- The tails of the distribution represent outliers in the results, yet those results may be correct. Hence, we say there is a "low probably" of it occurring but the consequences may be high.

Using a Risk-based framework can help you deal with uncertainty

- Criticality
- Risk tolerance
- Useful Life
- Adaptive capacity





GCM output is often used in further modeling or assessments. Using a risk-based framework will help you make decisions and move forward in the face of uncertainty.

The Question you ask will dictate what information you need, what statistics are needed, what assessments are necessary, What model and approach might you use?

What are the questions you are trying to answer?

How will flows in April-September change in the future?

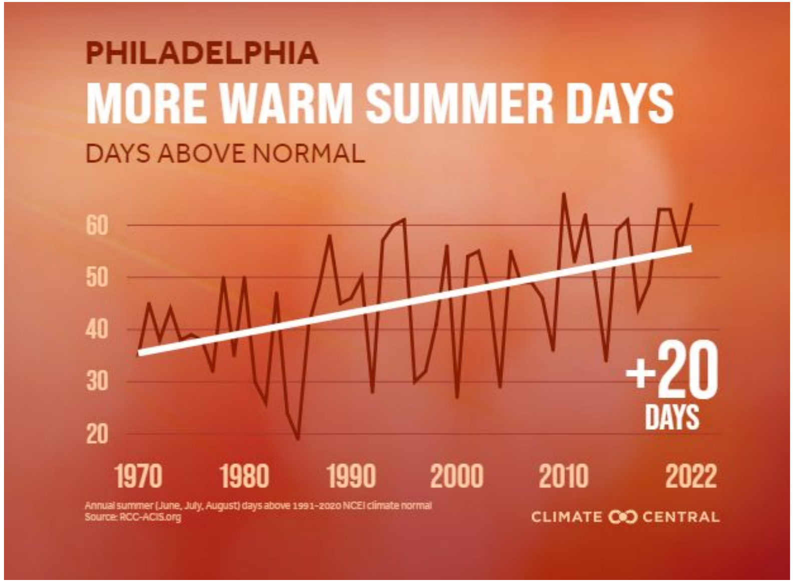
How should GSI be sized to prevent sewer overflows?

How will altered hydrology and rising temperatures impacts wetlands

How much warmer will streams be in 20 years?

Source: J. Vano, Dos and Don’ts https://ncar.github.io/dos_and_donts/v1.0/

Context and Application Matter



Meeting DBP regulations is hardest during the hot summer months like June, July and August.

In the future, will summer start earlier and end later?

Are there thresholds we want to assess under future climate scenarios?

What is the relationship between air temperature and source water temperature?

Table 1. US EPA disinfectant byproduct regulations

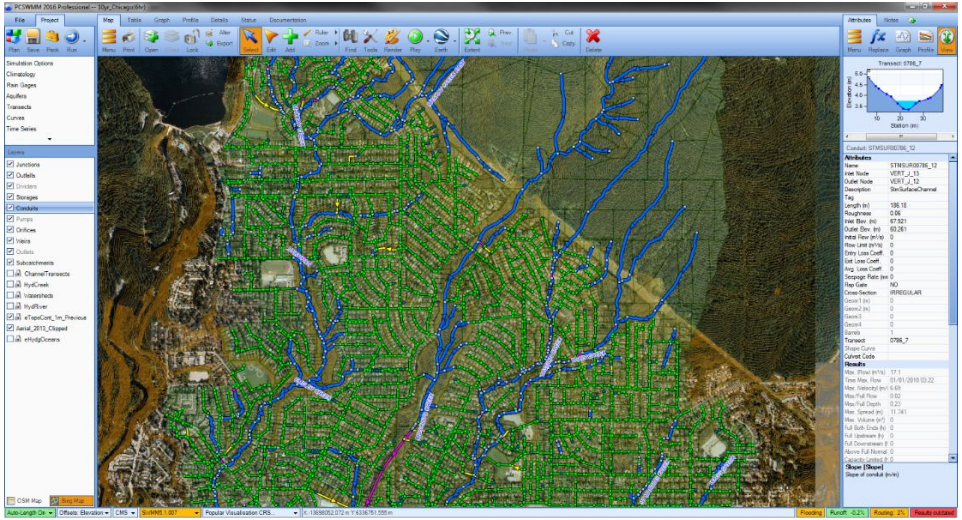
Contaminant	MCL (mg/L)	Potential health effects	Common sources	Public health goal (mg/L)
Total Trihalomethanes (TTHMs)	0.080	Liver, kidney or central nervous system problems; increased risk of cancer	DBP	N/A
Haloacetic acids (HAA5)	0.060	Increased risk of cancer	DBP	N/A
Bromate	0.010	Increased risk of cancer	DBP	0
Chlorite	1.0	Anemia, infants, young children and fetuses of	DBP	0.8

You may need additional statistics and assessments to answer your questions

Context and Application Matter

Limitations

- Temporal resolution - GCMs provide daily output when hourly or sub-hourly information is needed for many applications
- Spatial - GCM output has unrealistic rainfall patterns (drizzle effect)



Resources:
https://www.ccrun.org/workshops-and-events/stormwater-workshop/
PWD Method: https://www.youtube.com/watch?v=AcHOJ-7P0OU
https://ascelibrary.org/doi/abs/10.1061/%28ASCE%29WR.1943-5452.0001071

Context and Application Matter

Water quality modeling and policy assessments likely warrant different projections than flood assessments

- There is a lack of guidance on how to choose or apply SLR projections beyond flood assessments for built infrastructure
- Episodic water quality concerns vs. permanent water quality concerns vs. ecological limits (what is the risk tolerance? what is the adaptive capacity?)
- Water quality concerns could warrant a different risk tolerance and adaptive capacity than built infrastructure
- Policies may have a different “useful lifespan,” in this case the planning horizon, than built infrastructure.
- Given our confidence in near/mid term projections, a water-quality risk standard with a 50% exceedance probability (what is likely to occur), should be applied for near-term planning or extrapolation of observed SLR should be used to choose the SLR scenario.

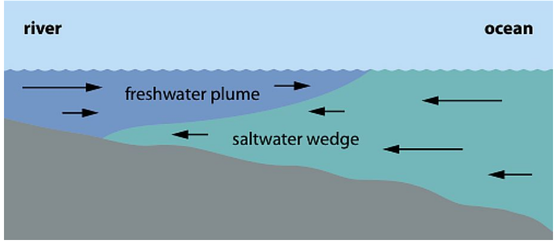


Image credit Yale Environment 360

Brook Trout - Image credit Jay Nichols

THANK YOU!

Co-production is key!

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