Climate Models, Climate Projections, and Uncertainty: A Primer for Southeast Alaska

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Climate models and climate scenarios

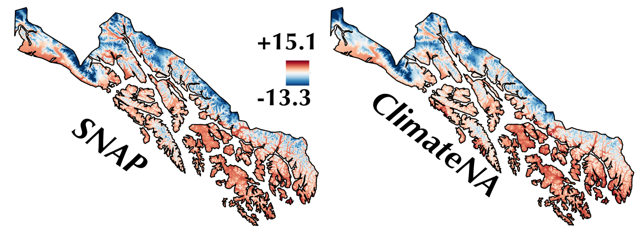
The future climate of a place is a product of the natural seasonal and annual climate, the natural climatic variability from year to year and decade to decade, and the factors that force changes in the long-term climate trends. Developing scenarios of plausible future climate at regional to local scales requires the use of global climate models (GCMs) because the processes that drive local climate range in scale from planetary to local. Climate models use inputs (initial climate conditions; "forcings" like atmospheric greenhouse gas concentrations, solar and volcanic variability, etc.) and dynamics (ocean and atmosphere variability, land surface conditions, feedbacks like the carbon cycle, etc.) to calculate the way that global climate varies and changes. Climate models keep track of many parameters in a gridded model of the planet at scales averaging about a degree of latitude and longitude (60-100+ miles on a side) and on finer than daily time scales. The climate they simulate is therefore actually the statistics of coarsely simulated weather, e.g., the average of 30 years of winter precipitation for a grid cell.

Strengths and limitations of climate models

Climate models attempt to sufficiently explain climatic processes with just the most necessary parts of the system – they are simplified versions of reality. Their skill is evident when comparing observed and simulated historical climate – the models capture most of the main features of the climate known to have happened. The consequences of this simplification are smallest at planetary scales and largest at local scales, where other factors are simplified enough that there is uncertainty. As such, the way most models are run, the resulting climate is a ***projection*** given the factors included in the model, not a forecast with probabilities. Global climate models often agree on signs (increases or decreases) of changes in temperature and precipitation that eventually happen as a result of forcing, but often disagree on sizes of changes and if they happen sooner or later. They often agree on the general changes in seasonal cycles, but not necessarily on the size of those changes or the extreme daily highs and lows that may occur with future dynamics. Model projections tend to agree more on temperature than on precipitation, and more on magnitude of changes at the equator and high latitudes than at mid-latitudes. The range of future conditions from a single GCM driven by a wide range of initial conditions can be a large fraction of the range of conditions across all GCMs.

This draft primer is based on published literature on climate models and climate impacts assessment as well as recent projections and interpretation. For more information, contact jlittell@usgs.gov.

IPSL5 2080s RCP8.5 Annual T (C°)



RCP 4.5 (low – mid emissions)

	2020s		2040s		2080s	
	C°	(F°)	C°	(F°)	C°	(F°)
ANN	1.0	(1.8)	1.9	(3.4)	2.7	(4.9)
DJF	1.0	(1.8)	2.1	(3.8)	3.0	(5.4)
MAM	0.5	(0.9)	1.3	(2.3)	2.0	(3.6)
JJA	0.9	(1.6)	1.6	(2.9)	2.4	(4.3)
SON	1.6	(2.9)	2.5	(4.5)	3.4	(6.1)
			Precipitation			
ANN	6.5%		10%		13.4%	
DJF	10.6%		14.5%		17.5%	
MAM	9.8%		14.7%		19.6%	
JJA	5.1%		7.9%		10.3%	
SON	4.4%		7.5%		11.6%	

RCP 8.5 (higher emissions)

	2020s		2040s		2080s	
	C°	(F°)	C°	(F°)	C°	(F°)
ANN	1.2	(2.2)	2.4	(4.3)	4.9	(8.8)
DJF	1.5	(2.7)	2.7	(4.9)	5.7	(10.3)
MAM	0.6	(1.1)	1.6	(2.9)	3.8	(6.8)
JJA	1.0	(1.8)	2.1	(3.8)	4.5	(8.1)
SON	1.8	(3.2)	3.0	(5.4)	5.7	(10.3)
			Precipitation			
ANN	7.6%		11.4%		20.6%	
DJF	11.1%		14.1%		26.5%	
MAM	10.2%		15.8%		29.4%	
JJA	5.6%		8.9%		14.1%	
SON	6.5%		10.2%		19.9%	

Table 1. Projected annual and seasonal deltas (1970-99 baseline) for temperature and precipitation in the Tongass region of southeast AK derived from SNAP projections. Values are five-model means (CCSM4, GFDL3, CGCM3, GISS2, IPSL5). 2020s – 2010-2039; 2040s – 2030-2059; 2080s – 2070-2099.

What is downscaling?

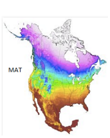
Downscaling refers to techniques for bridging the difference in scale from GCMs to more local processes. These techniques range in complexity from simple methods that add future average changes in temperature and/or precipitation from GCMs to local historical climate to complicated methods that simulate local climate using weather models constrained by GCM output. There are tradeoffs along this gradient of downscaling, but generally it is sufficient to say that the simpler methods are computationally efficient but sacrifice the ability to simulate extremes and local dynamics while the complex methods are computationally expensive and trade ease of interpretation for dynamical realism. Both methods are only as good as what they are ***downscaling from*** (they inherit the GCMs' uncertainties) and what they are ***downscaling to*** (from statistical representations of historical climate to parameterized regional weather models). The goal is to create a more locally-relevant set of scenarios, usually for specific impact quantification.

Sources of AK climate projections and downscaling

The following are sources of gridded historical and projected climate. Note that both sites provide tools for extracting projections for points on a map, but considerable GIS capacity is needed to extract data for areal averages or other non-standard purposes.

SNAP **https://www.snap.uaf.edu/**

- 771m (AK) and 2km (US and Canadian Arctic) statistically downscaled (delta) historical and projections from five CMIP3/ AR4 and CMIP5/AR5 climate models, RCP 4.5, 6.0, 8.5. Temporal scale varies – monthly time series and decadal averages are available.
- Temperature, precipitation, and 5+ derived variables
- Downscaled community projections for AK and western Canada
- GCM-gridscale extremes (statistical, quantile mapped) for AK communities
- Coming soon...dynamical downscaling for AK



https://adaptwest.databasin.org/pages/ adaptwest-climatena/

- 1km North American statistically downscaled (delta) historical and projections from eight CMIP5/AR5 climate models. Multi-decadal averages of monthly variables are available: 2020s, 2050s, 2080s.
- Temperature, precipitation, and 20+ derived bioclimatic variables

Where does uncertainty in future climate scenarios come from?

Uncertainty in future climate scenarios is the range of plausible climatic conditions that might reasonably occur at some time and place in the future. For climate scenarios, there are three main categories of uncertainty:

1. **Natural annual to decadal climate variability**
2. **GCM construction and initial conditions**
3. **Change in forcings, e.g., greenhouse gasses**

Climate variability: The interannual and decadal variation in regional climate is a product of persistent ocean-atmosphere interactions. The variability observed over the 20th century indicates that 30-year climate averages are affected by these variations, yet climate models do not simulate them as well as they capture forcings. So natural climate variations occurring on top of long-term forcing trends create uncertainty in projections. As we approach the mid 21st century, the change in mean climate is comparable to or exceeds late 20th century variation in temperature, and less clearly, precipitation, and for Alaska, is the largest source of uncertainty between now and the mid-21st century.

Model uncertainty: There are dozens of GCMs developed around the world by different research groups, and each is constructed from scientifically solid relationships and parameters, but each is also at least partially unique in its sensitivity to forcings, how it handles interactions between the parameters, and its representation of the ocean, land surface, atmosphere, and feedbacks. Climate model projections of future climate therefore vary some, particularly at finer scales and in places (such as the mid-latitudes) where the geographic location and timing of climatic changes are sensitive to the model's construction and sensitivity to forcings. These differences become most apparent in the middle-21st century.

Forcing uncertainty (greenhouse gas concentrations): While other factors force global climate, their variations are either periodic and relatively predictable (solar output) or most often do not persist longer than interannual time scales (volcanic eruptions). Trends in greenhouse gas concentrations, on the other hand, respond on seasonal to centennial time scales, and after the mid-21st century, global trends in emissions, technology, development, and policy affect the forcing most responsible for climate change. Whether emissions continue unabated (a high emissions scenario like A2 or RCP 8.5) or are moderated (a lower emissions scenario like A1B. RCP 6.0, or RCP 4.6) has a large effect on the rate of change in the climate.