National Aeronautics and
Space Administration

ARSET

Applied Remote Sensing Training

http://arset.gsfc.nasa.gov

@NASAARSET

Introduction to Remote Sensing for Scenario-Based Ecoforecasting

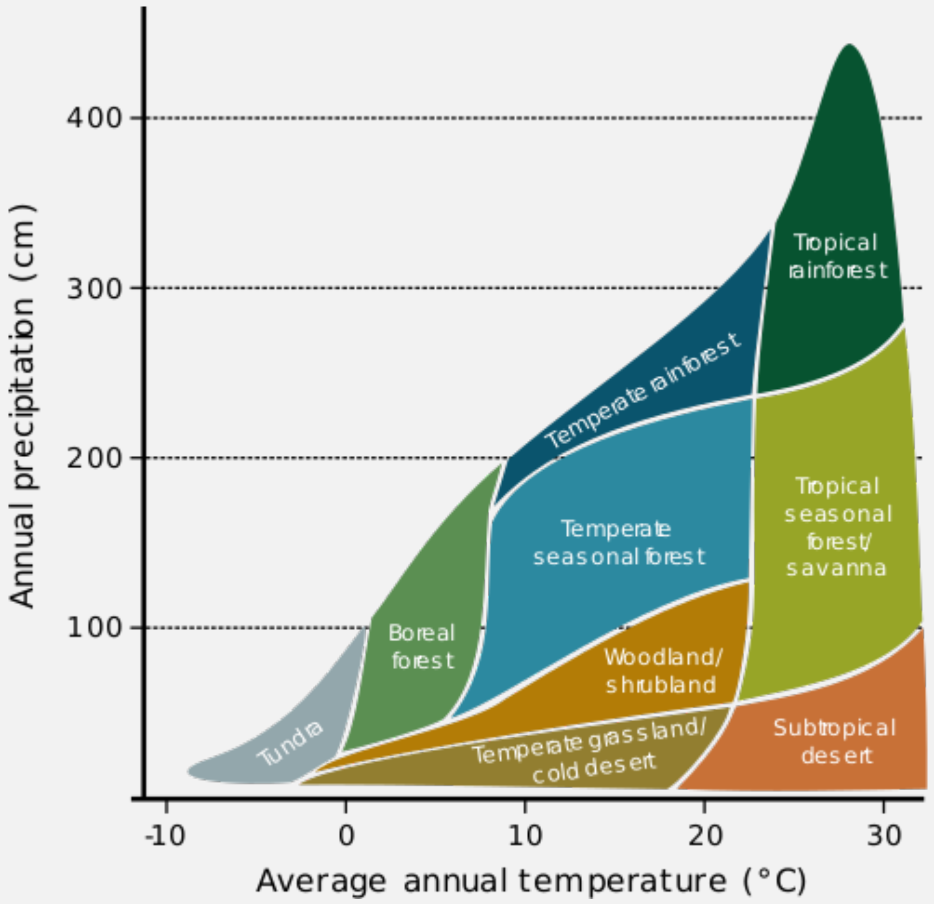
Week 2: Overview of Climate Science and Data

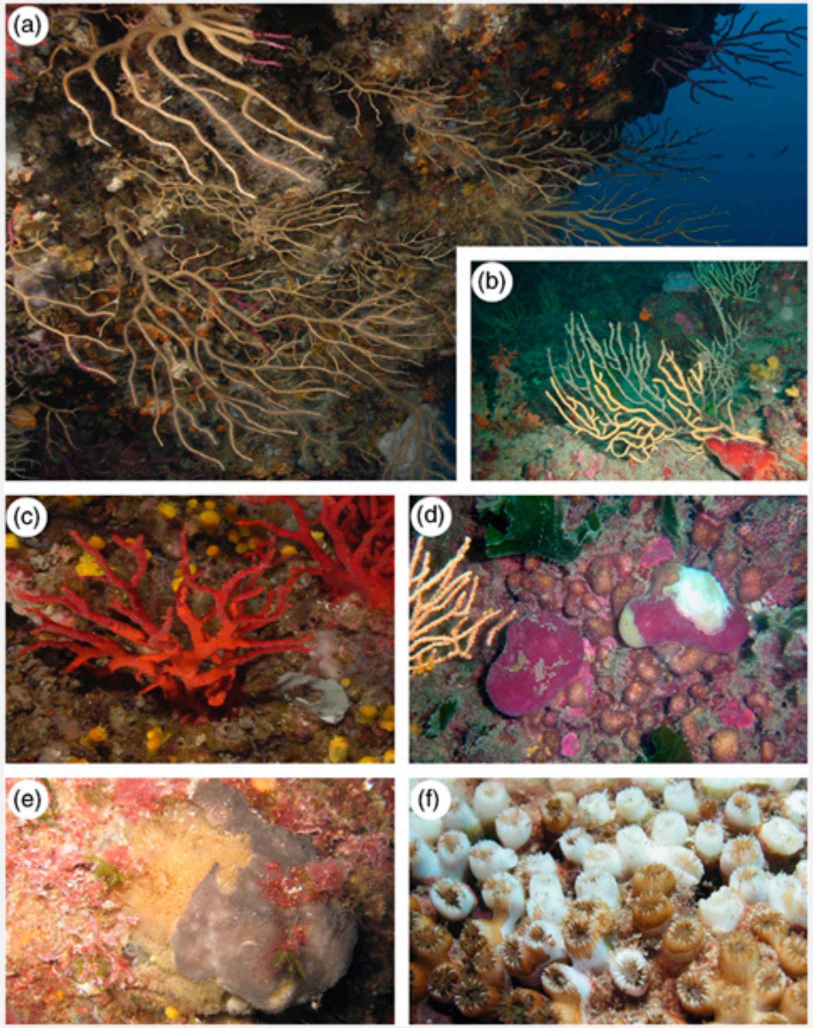
Helen Sofaer, U.S. Geological Survey, Fort Collins Science Center

USGS
science for a changing world

Gridded Historic Climate Data

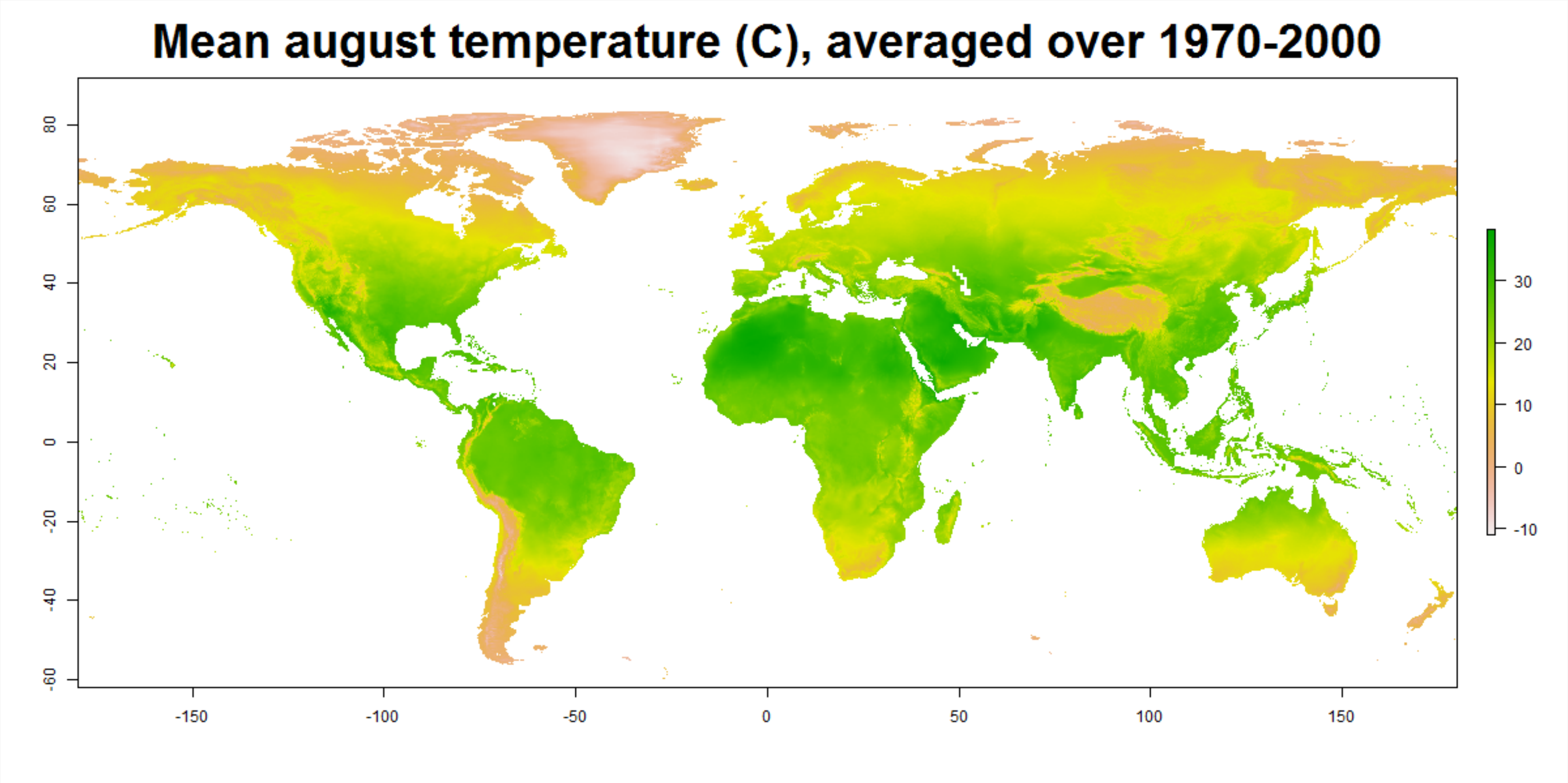
Climate and Weather Drive Key Ecological Processes





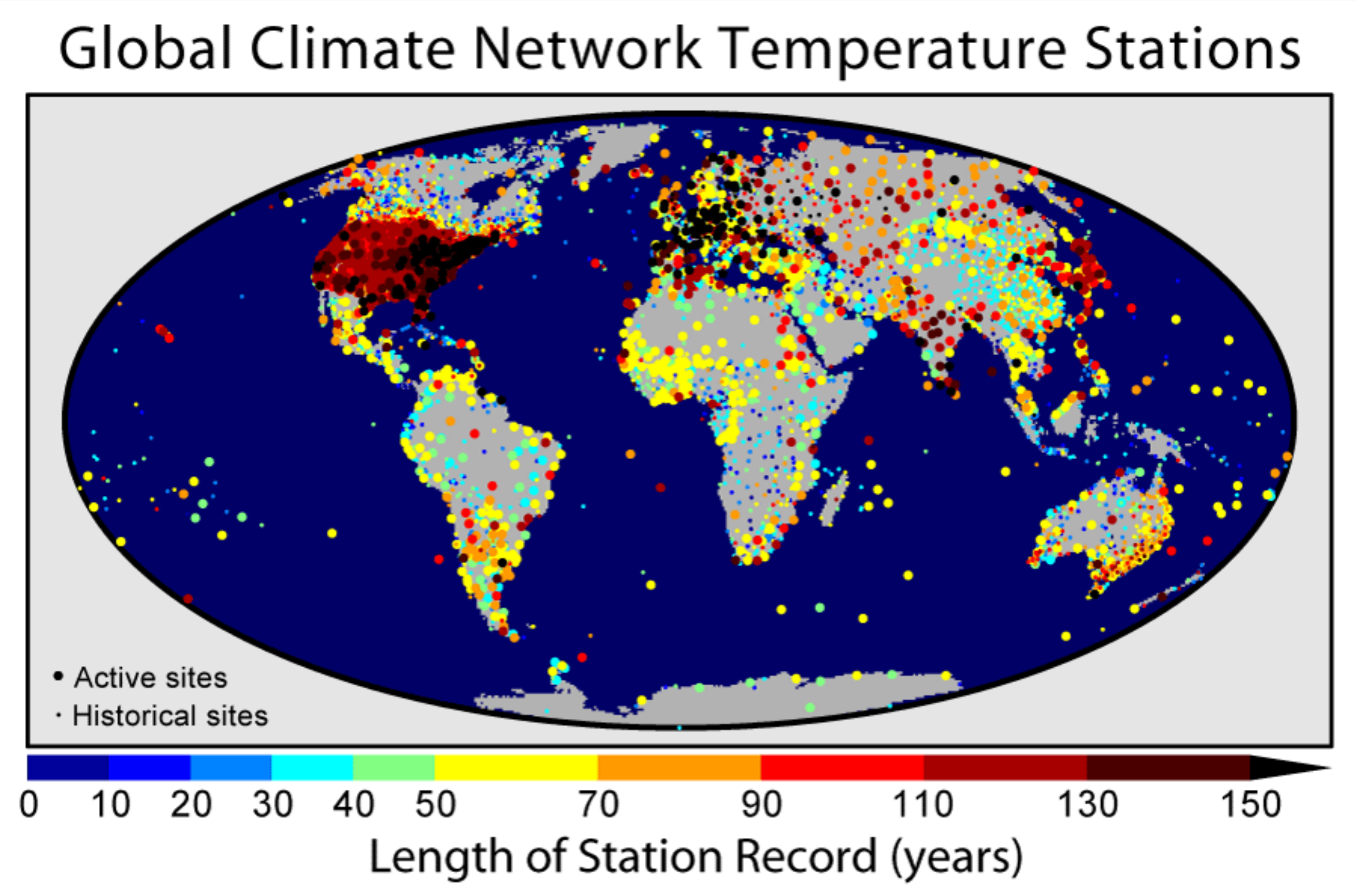
Whittaker's biome classification; image from Wikipedia, Garrabou et al. 2009 Global Change Biology

Broad Scale Studies Link Ecological Data to Gridded Climate Data



Fick, S.E. and R.J. Hijmans, 2017. Worldclim 2: New 1-km spatial resolution climate surfaces for global land areas. International Journal of Climatology

Gridded Data are Estimated from Climate Stations

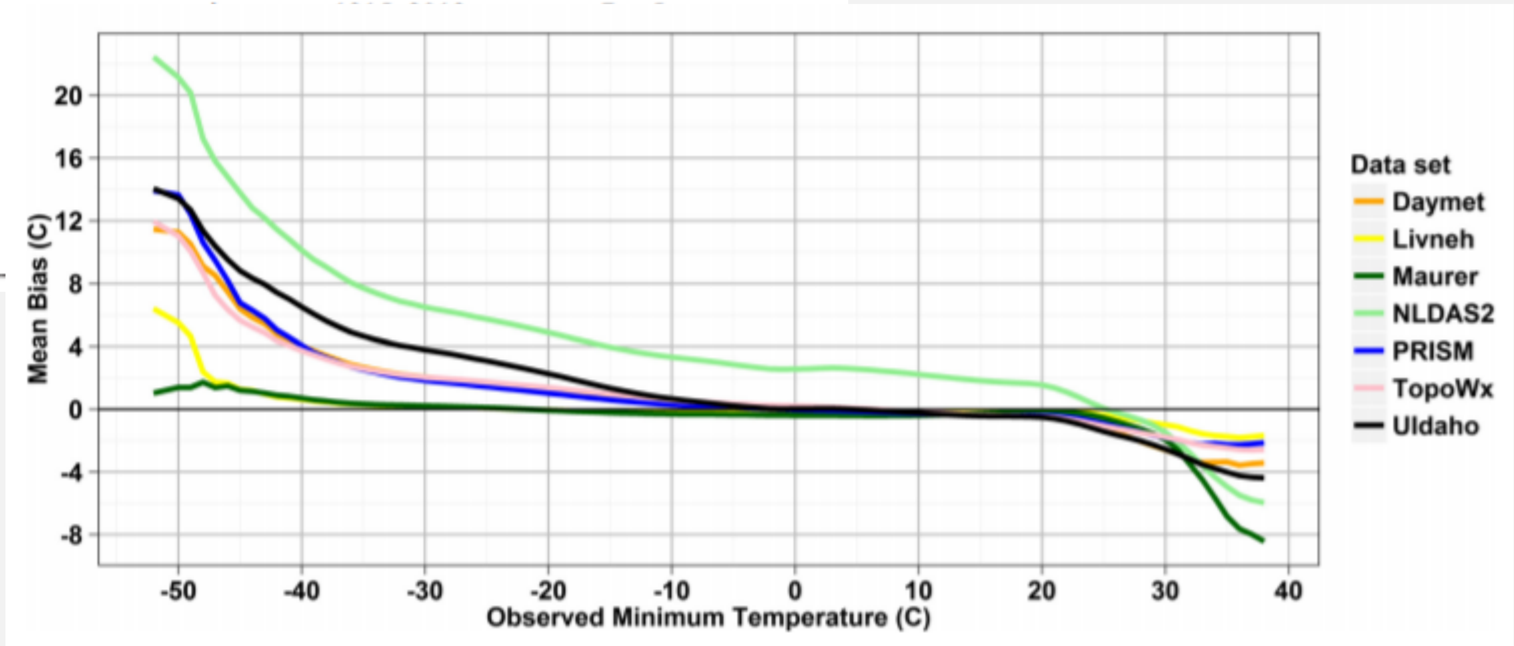


Credit: Robert Rohde/Global Warming Art

Gridded ‘Observations’ Are Still Estimates

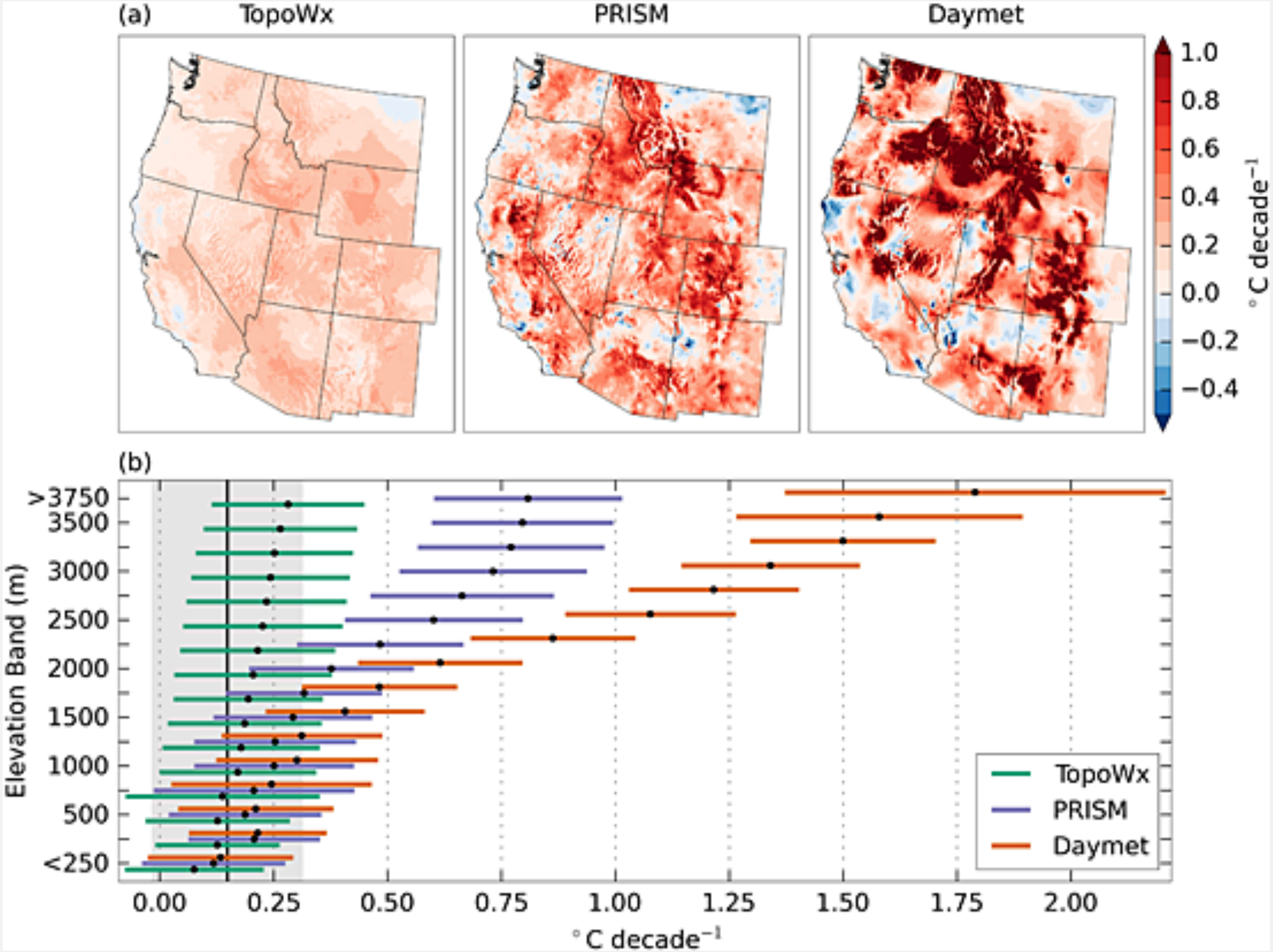
TABLE 1. Information on the eight gridded data products used in this study.

Data set	Variables used	Time span	Resolution (km)
Climate prediction center unified gauge-based analysis of daily precipitation (CPC)	prcp	1948–	28 × 21
Daymet	prcp, tmax, tmin	1980–2014	1 × 1
Livneh			
Maurer			
National land data assimilation system, version 2 (NLDAS2)			
Parameter-elevation regressions on independent slopes model (PRISM (AN81d))			
Topographical (TopoClimatic) weather (TopoWx)			
UIdaho			



Behnke et al. 2016 Ecological Applications

More Uncertainty in 'Observed' Climate in the Mountains



Oyler et al. 2015 Geophysical Research Letters

Datasets differ in spatial resolution, available years, and variables

WorldClim Version2

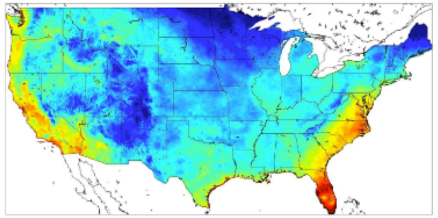
WorldClim version 2 has average monthly climate data for minimum, mean, and maximum temperature and for precipitation for 1970-2000.

You can download the variables for different spatial resolutions, from 30 seconds (~1 km^2) to 10 minutes (~340 km^2). Each download is a "zip" file containing 12 GeoTiff (.tif) files, one for each month of the year (January is 1; December is 12).

variable	10 minutes	5 minutes	2.5 minutes	30 seconds
minimum temperature (°C)	tmin 10m	tmin 5m	tmin 2.5m	tmin 30s
maximum temperature (°C)	tmax 10m	tmax 5m	tmax 2.5m	tmax 30s
average temperature (°C)	tavg 10m	tavg 5m	tavg 2.5m	tavg 30s
precipitation (mm)	prec 10m	prec 5m	prec 2.5m	prec 30s
solar radiation (kJ m^{-2} day^{-1})	srad 10m	srad 5m	srad 2.5m	srad 30s
wind speed (m s^{-1})	wind 10m	wind 5m	wind 2.5m	wind 30s
water vapor pressure (kPa)	vapr 10m	vapr 5m	vapr 2.5m	vapr 30s

Below you can download the standard (19) WorldClim Bioclimatic variables for WorldClim version 2. They are the average for the years 1970-2000. Each download is a "zip" file containing 19 GeoTiff (.tif) files, one for each month of the variables.

variable	10 minutes	5 minutes	2.5 minutes	30 seconds
Bioclimatic variables	bio 10m	bio 5m	bio 2.5m	bio 30s



University of Idaho
Gridded Surface Meteorological Data
(UofI METDATA)

HOME | EXAMPLE FIELDS | DERIVED FIELDS | DOWNLOAD DATA | UPDATES | REFERENCES | CONTACT

UofI Gridded Surface Meteorological Dataset

Landscape-scale modeling has been hindered by suitable high-resolution surface meteorological datasets that include temperature, precipitation, downward shortwave radiation, humidity and winds. To overcome these limitations, desirable spatial attributes of gridded climate data from PRISM are combined with desirable temporal attributes of regional-scale reanalysis and daily gauge-based precipitation from NLDAS-2 to derive a spatially and temporally complete, high-resolution (1/24th degree ~4-km) gridded dataset of surface meteorological variables required in modeling for the coterminous United States from 1979-present.

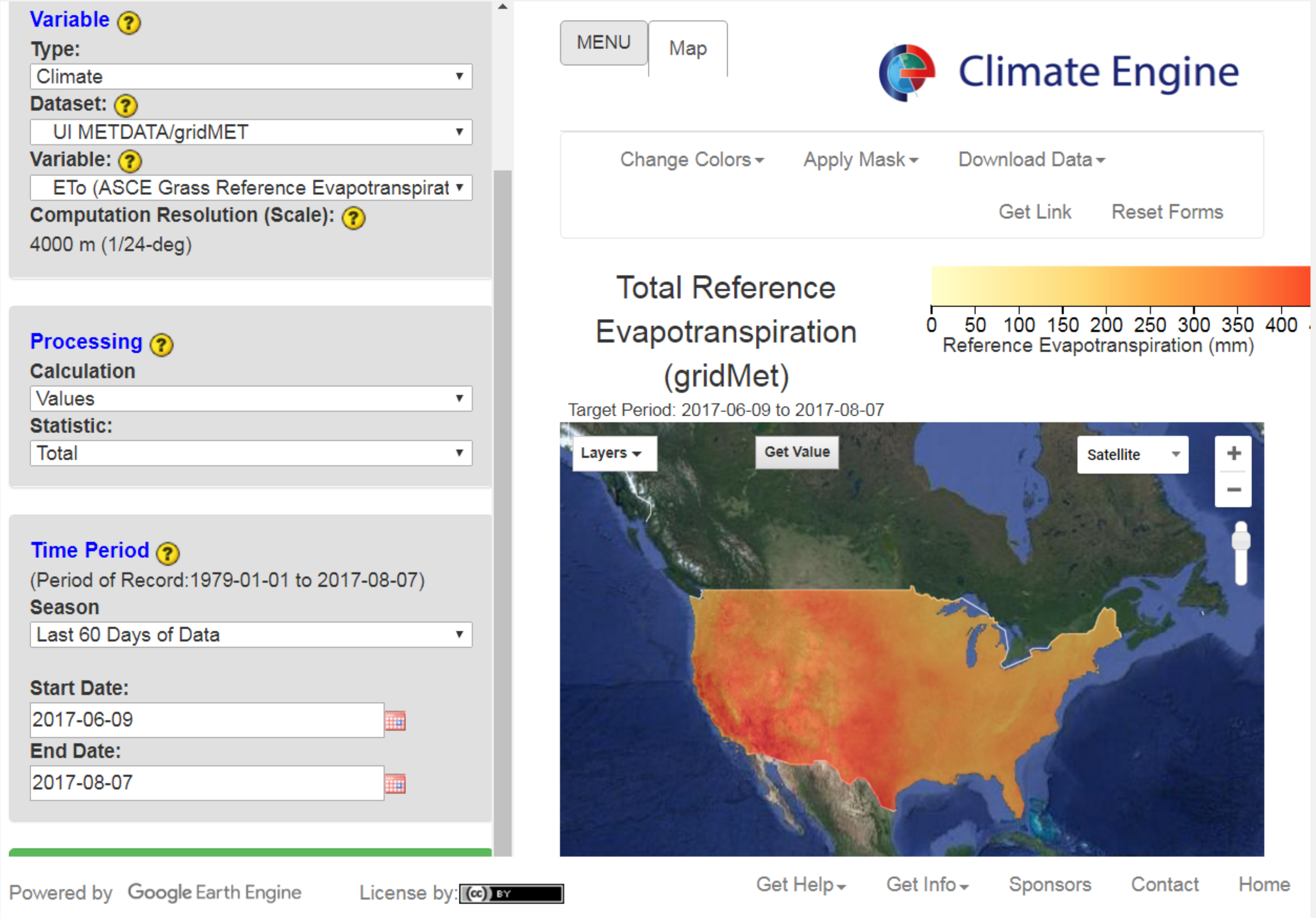
Validation of the resulting gridded surface meteorological data was conducted against an extensive network of weather stations including RAWS, AgriMet, AgWeatherNet and USHCN-2. For more information on validation measures see Abatzoglou (2011).

This Dataset has the following features:

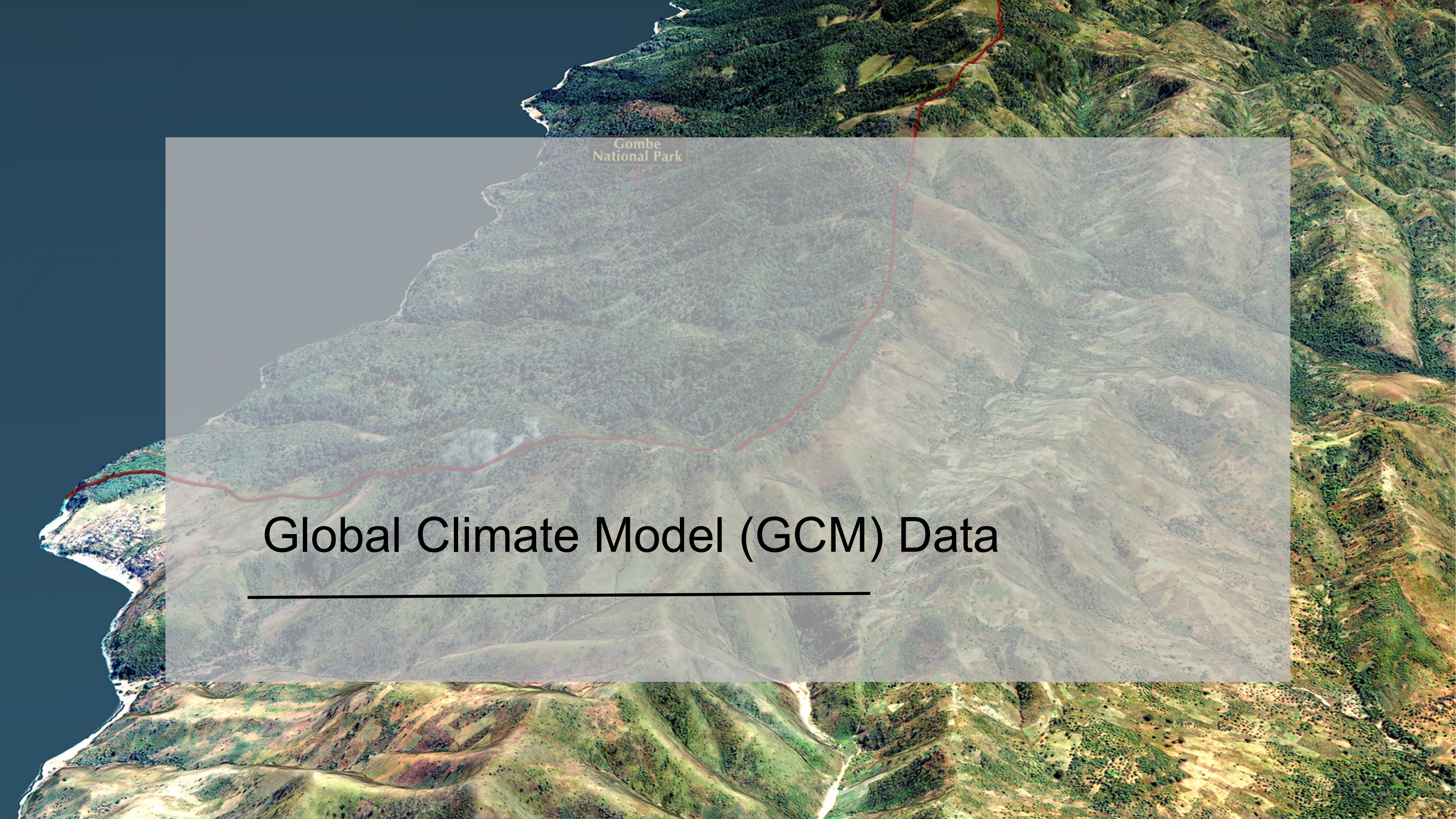
- Spatial Resolution: 4-km (1/24-degree) grid
- Spatial Extent: Coterminous United States
- Temporal Resolution: Daily (some sub-daily)
- Temporal Extent: 1979-present (1-2 day lag)
- Variables: (all variables are daily extrema/sums/means over a given calendar day)
  - Precipitation
  - Temperature (maximum and minimum)
  - Humidity (maximum and minimum relative humidity and specific humidity)
  - Surface downward shortwave radiation (daily mean)
  - 10-meter Wind velocity (daily mean)
  - Reference evapotranspiration
  - NFDRS fire danger indices
- Definition of day: ie. Jan 21 is 6Z Jan 21 to 6Z Jan 22
- Format: netCDF adhering to Climate and Forecasting Metadata standards

Worldclim.org; http://metdata.northwestknowledge.net/

Derived Variables Are Becoming More Easily Accessible

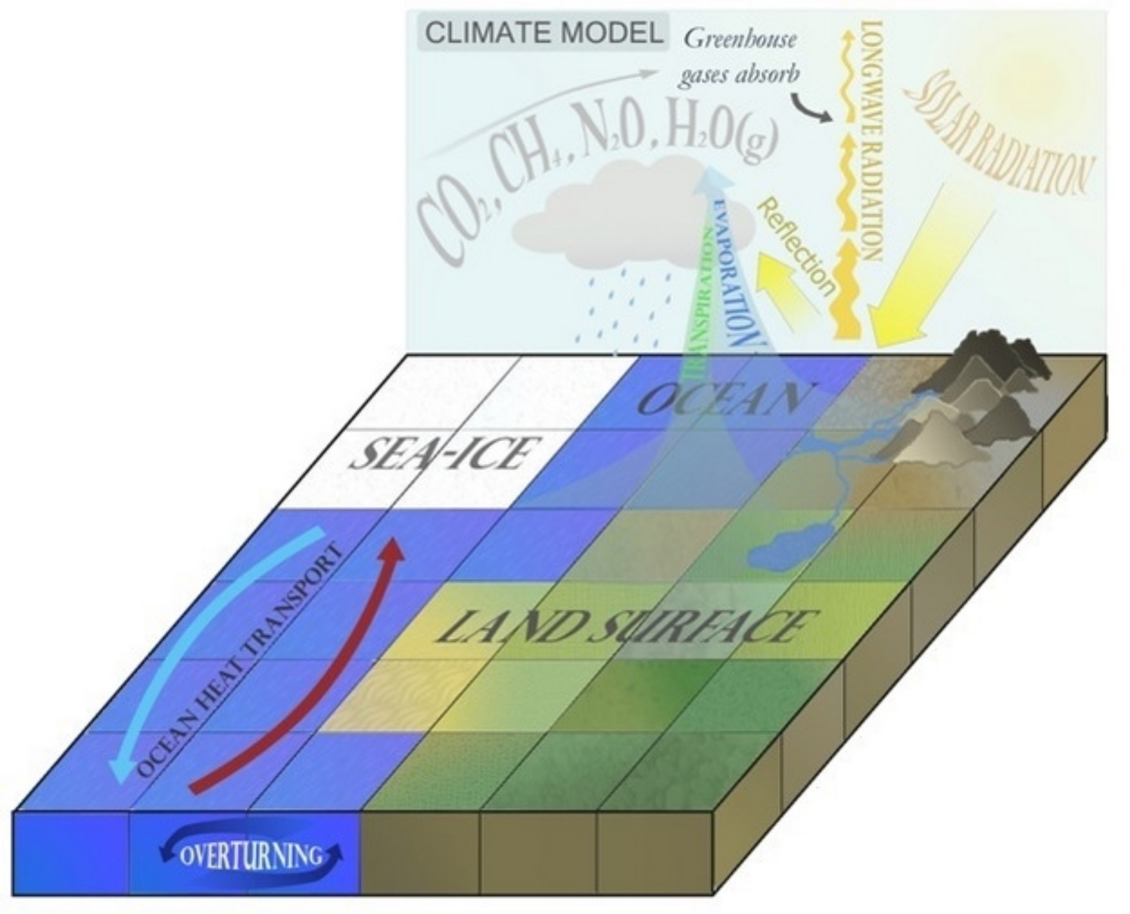


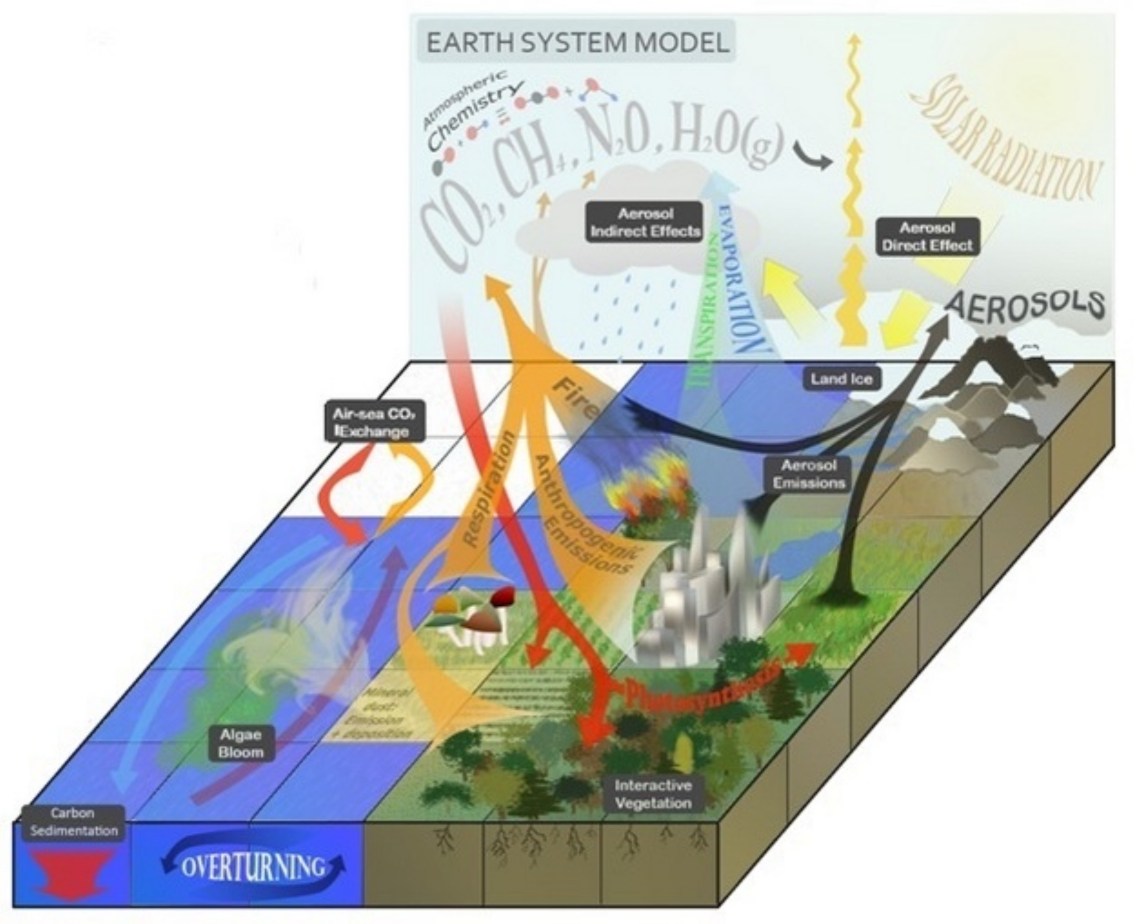
Climate Engine: http://clim-engine.appspot.com/; Huntington et al. 2017 Bulletin of the American Meteorological Society



Global Climate Model (GCM) Data

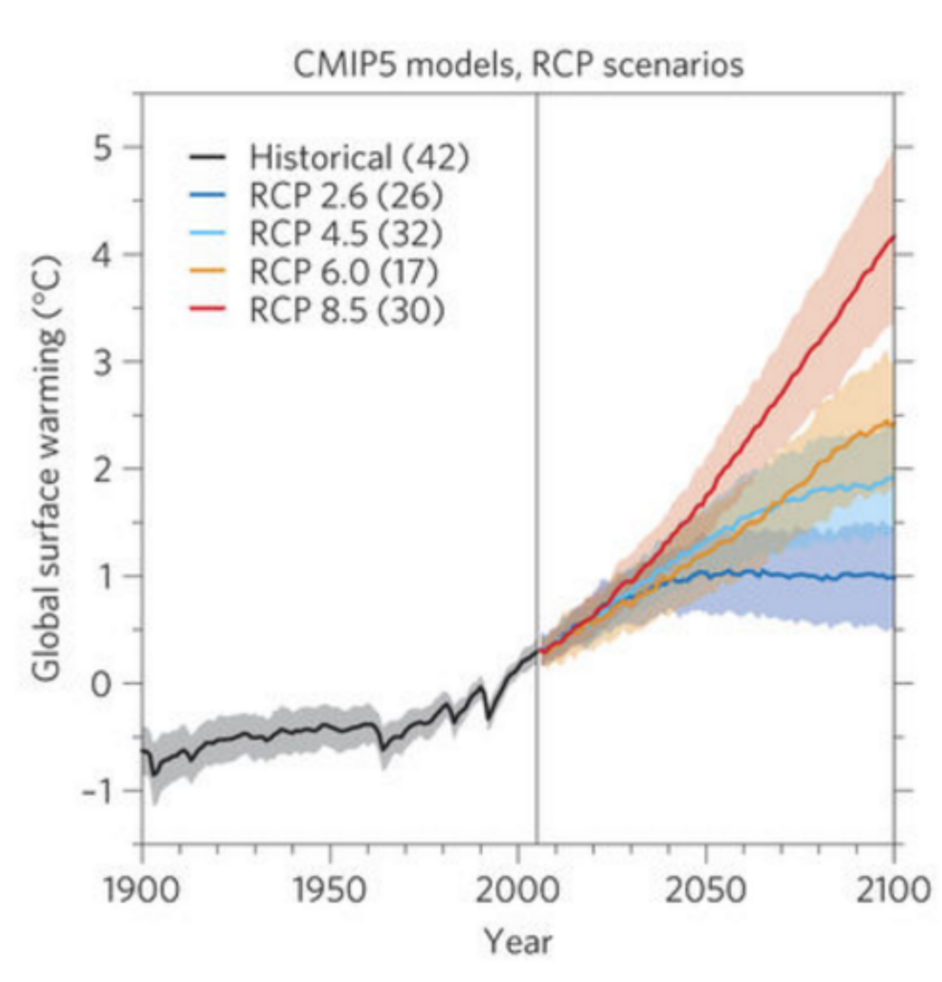
Global Climate Models





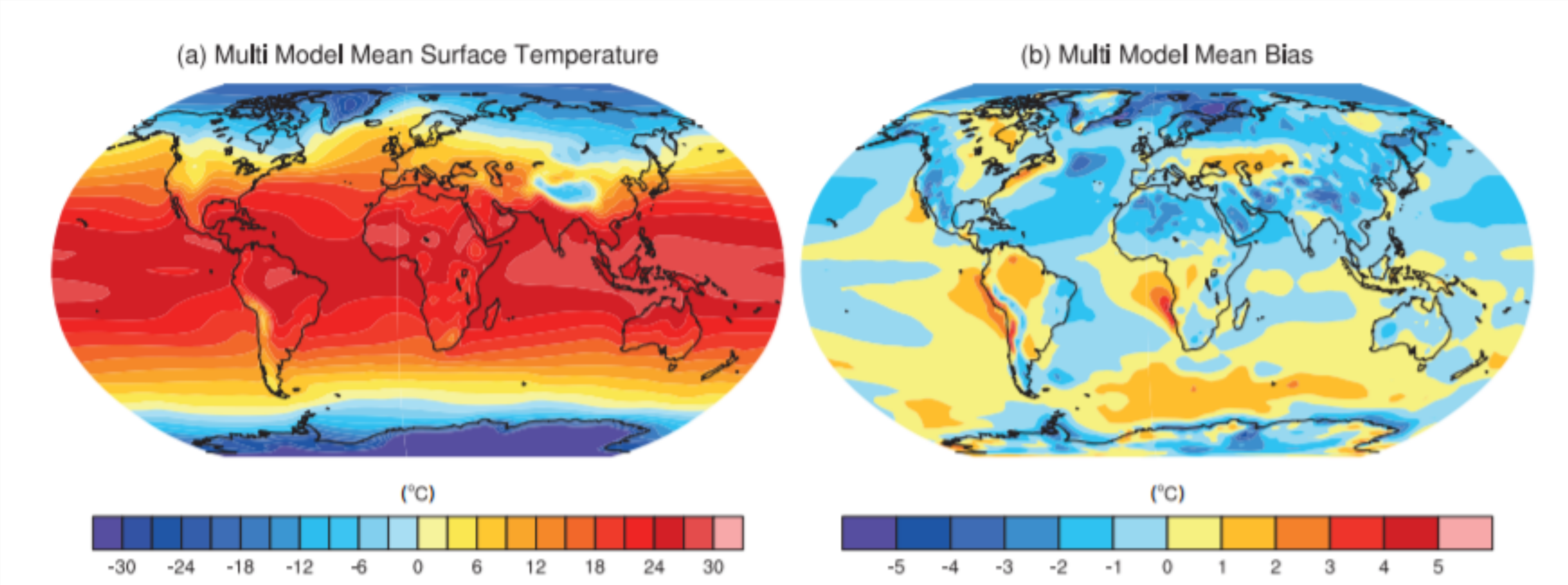
Heavens et al. 2013 Nature Education Knowledge

Representative Concentration Pathways



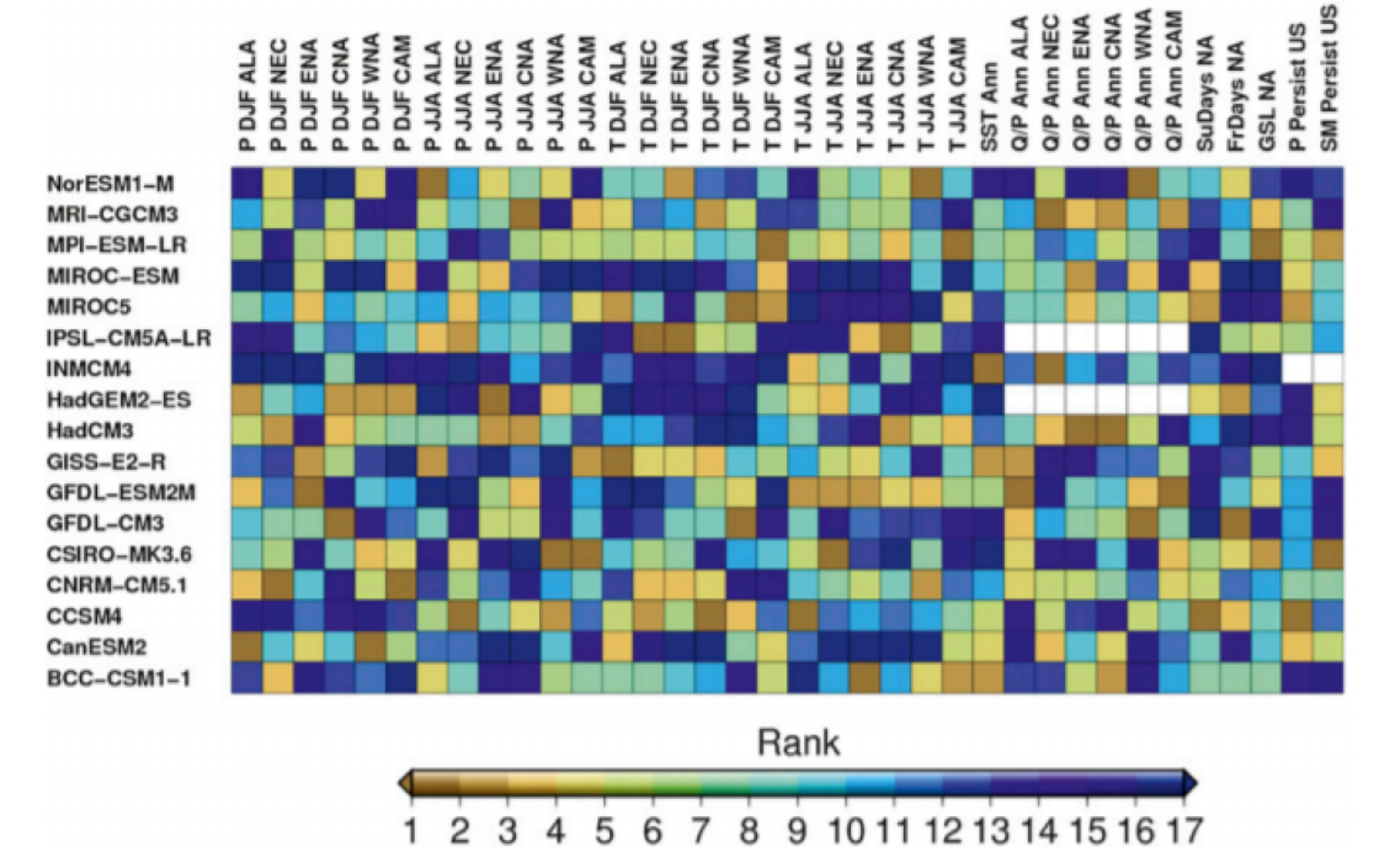
Knutti and Sedlacek 2013 Nature Climate Change

Climate Models Reproduce Broad-Scale Spatial Patterns Well



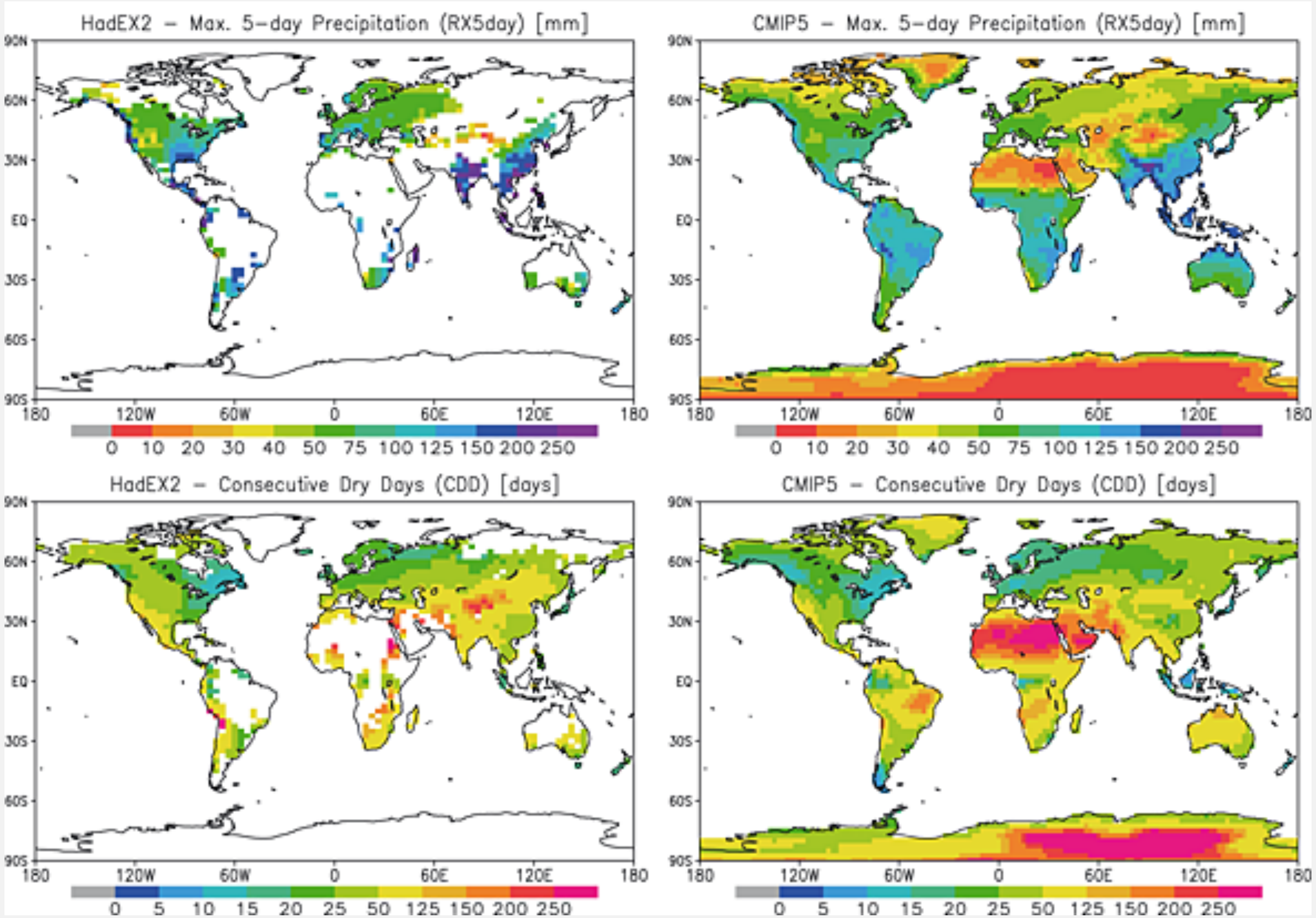
Flato et al. 2013. Evaluation of climate models. Ch. 9 of IPCC Physical Science Basis

Model Performance Varies Among Regions and Metrics



Sheffield et al. 2013
Journal of Climate

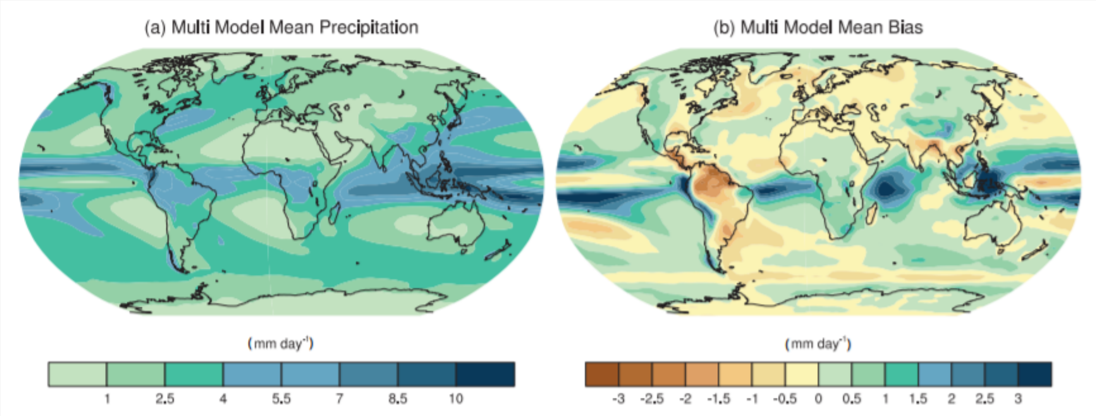
Lack of Observations Can Make It Hard to Assess Models



Sillmann et al. 2013 Journal of Geophysical Research: Atmospheres

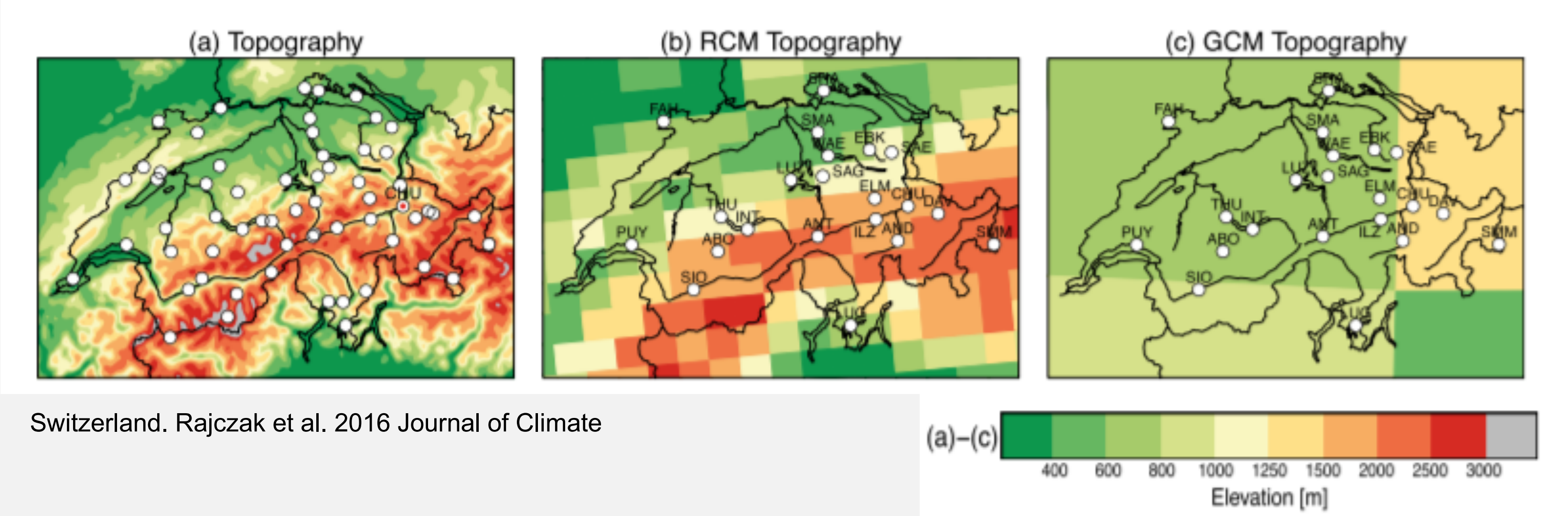
Climate Model Output Is Rarely Used Directly in Ecological Studies

- Bias



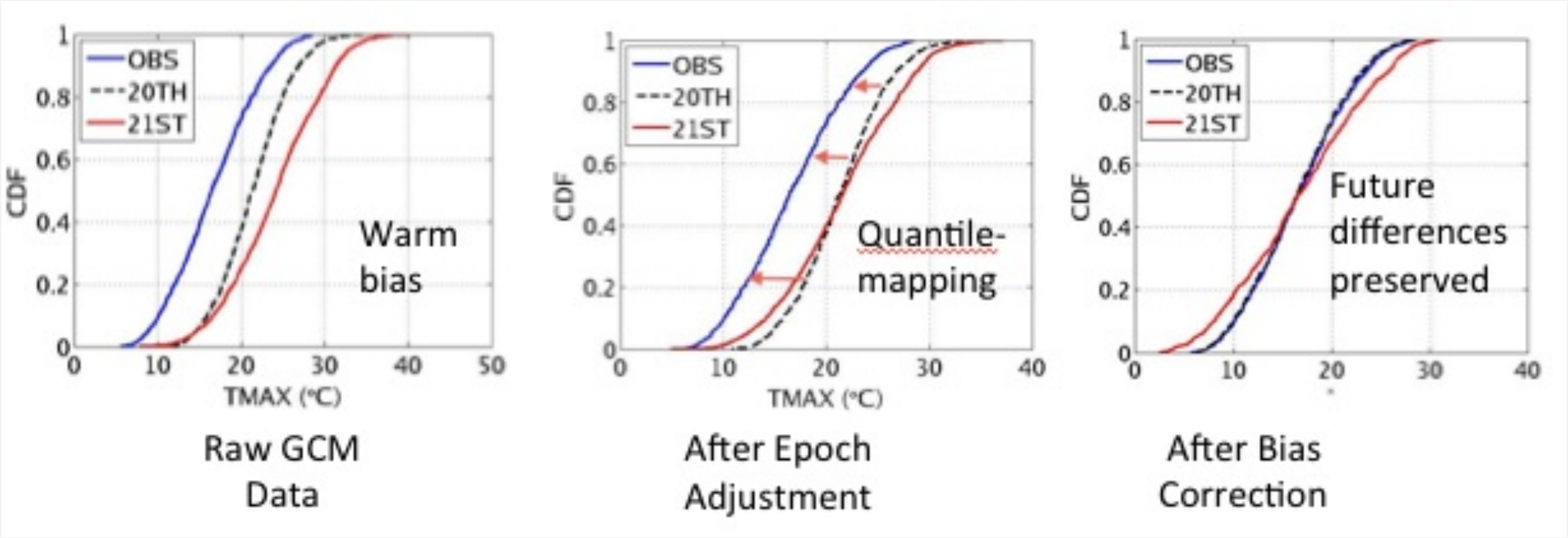
Flato et al. 2013. Evaluation of climate models. Ch. 9 of IPCC Physical Science Basis

- Coarse Spatial Scale



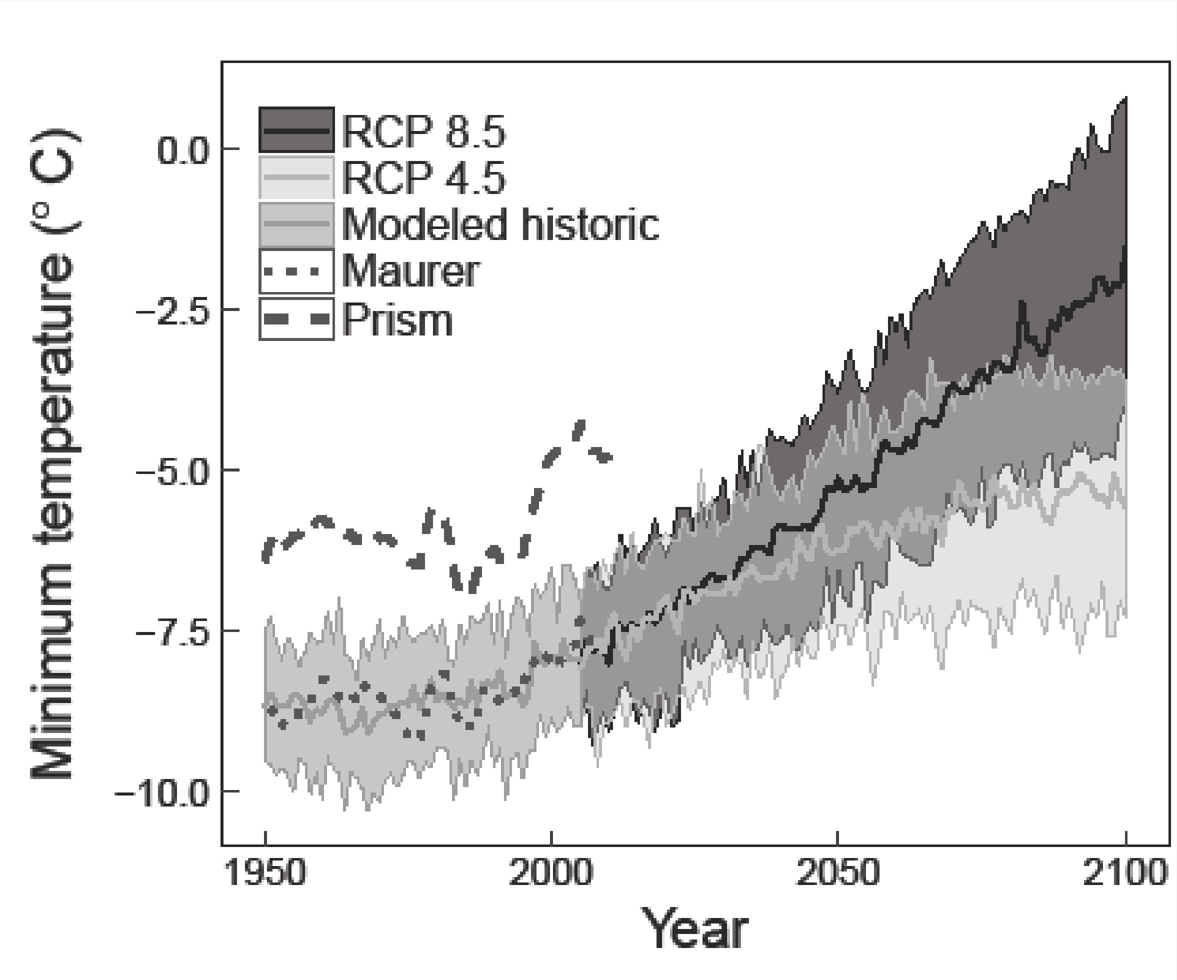
Switzerland. Rajczak et al. 2016 Journal of Climate

Bias-Correction Is Often Based on Quantile Mapping



From MACA Website: http://maca.northwestknowledge.net/MACAmethod.php; Abatzoglou and Brown 2012 International Journal of Climatology

Climate Data Are Bias-Corrected to a Particular Observational Dataset

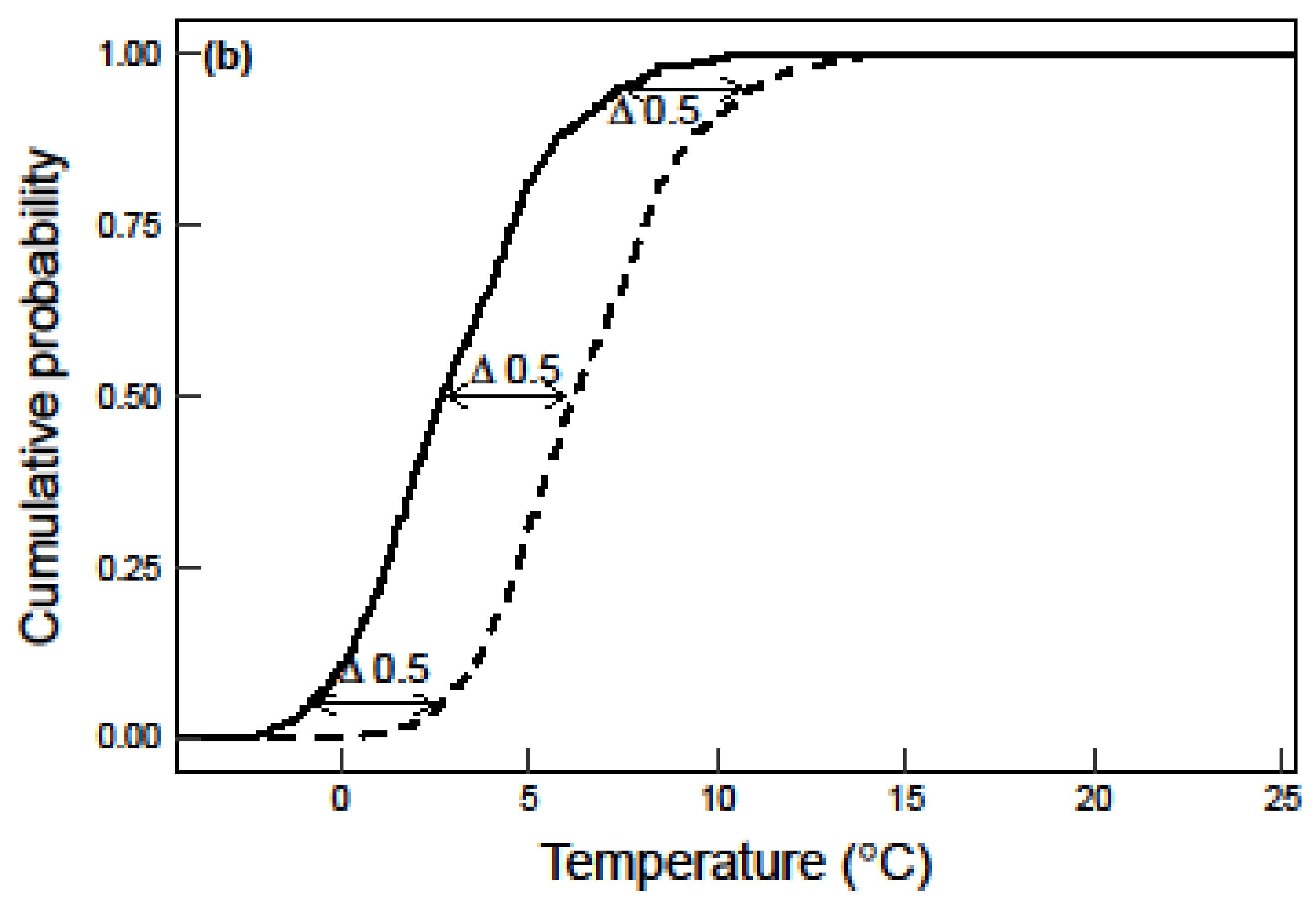


Sofaer et al. 2017 Global Change Biology

Projections at Finer Spatial Resolutions: Downscaling Methods

- Delta method
  - Apply change in GCM to historical climate data
- Statistical downscaling
  - Model relationship between broad-scale and fine-scale climate
  - Many different methods
- Dynamical downscaling
  - Based on a Regional Climate Model

Delta Method: Applies Mean Change in GCM to Historical Climate



Sofaer et al. 2017 Global Change Biology

Widely-Used Datasets Are Based on the Delta Method

WorldClim Version2

WorldClim version 2 has average monthly climate data for minimum, mean, and n
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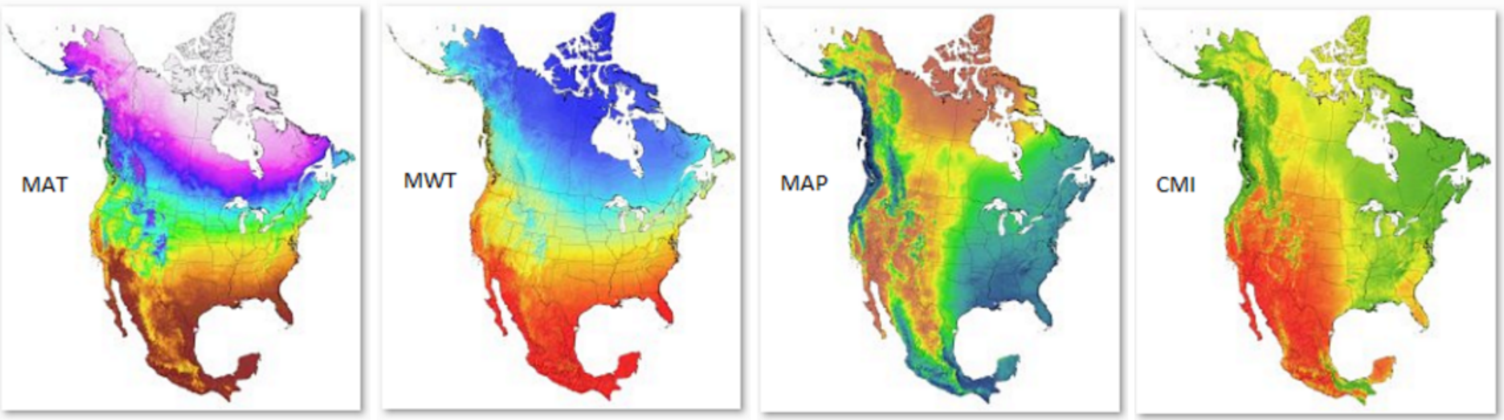
Bioclimatic variables	bio 10m	bio 5m	bio 2.5m	bio 30s

Historical and projected climate data for North America (ClimateNA)

The software, downloadable from this web page, can be used to estimate more than 50 monthly, seasonal, and annual variables, including many economically or biologically relevant variables such as growing and chilling degree days, heating and cooling degree days, Hargrave's moisture deficit and reference evaporation, beginning and end of the frost-free period, etc.

Click on the thumbnails below and use the zoom tool to see high resolution images of mean annual temperature (MAT), mean winter temperature with inversions in northern mountain valleys (MWT), mean annual preciptiation with leeward rainshadows (MAP), and a climate moisture index (CMI):

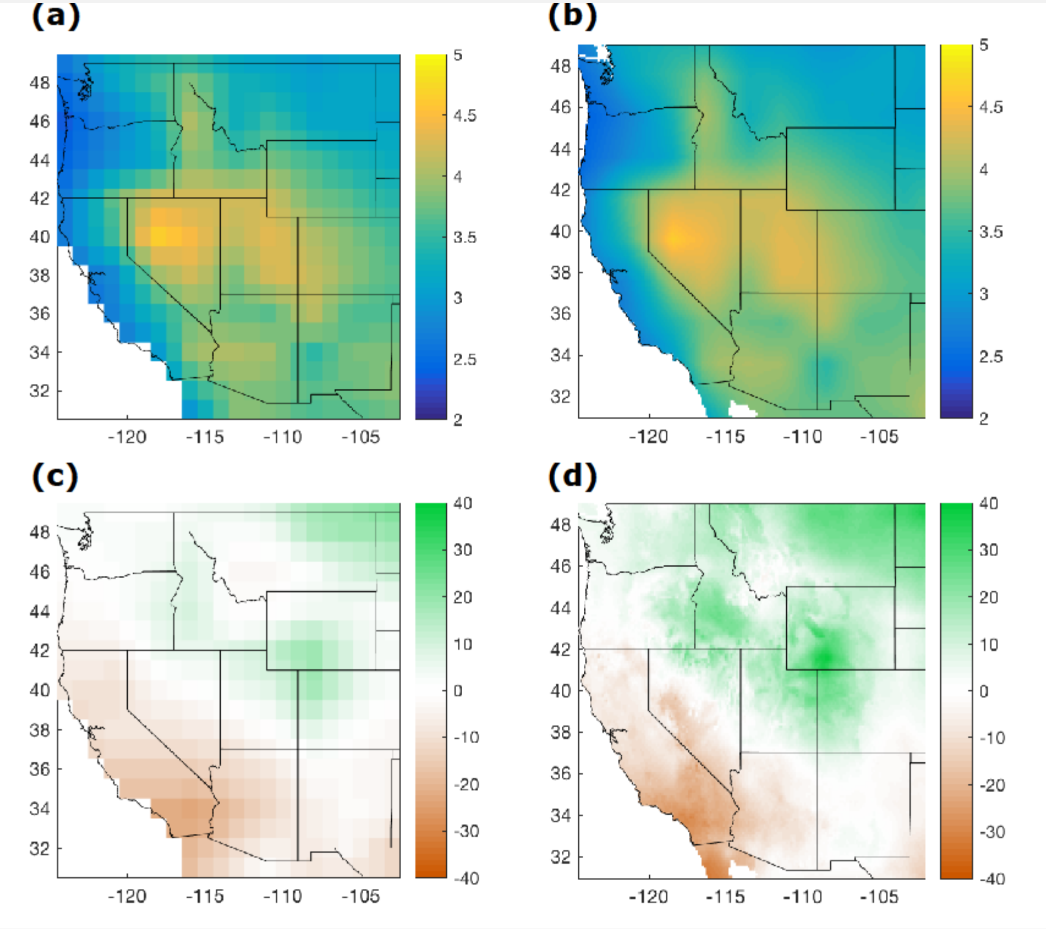


Worldclim.org; ClimateNA: http://tinyurl.com/ClimateNA

Statistical Downscaling

GCM: projected change in temp (°C)

GCM: projected change in precipitation (mm)

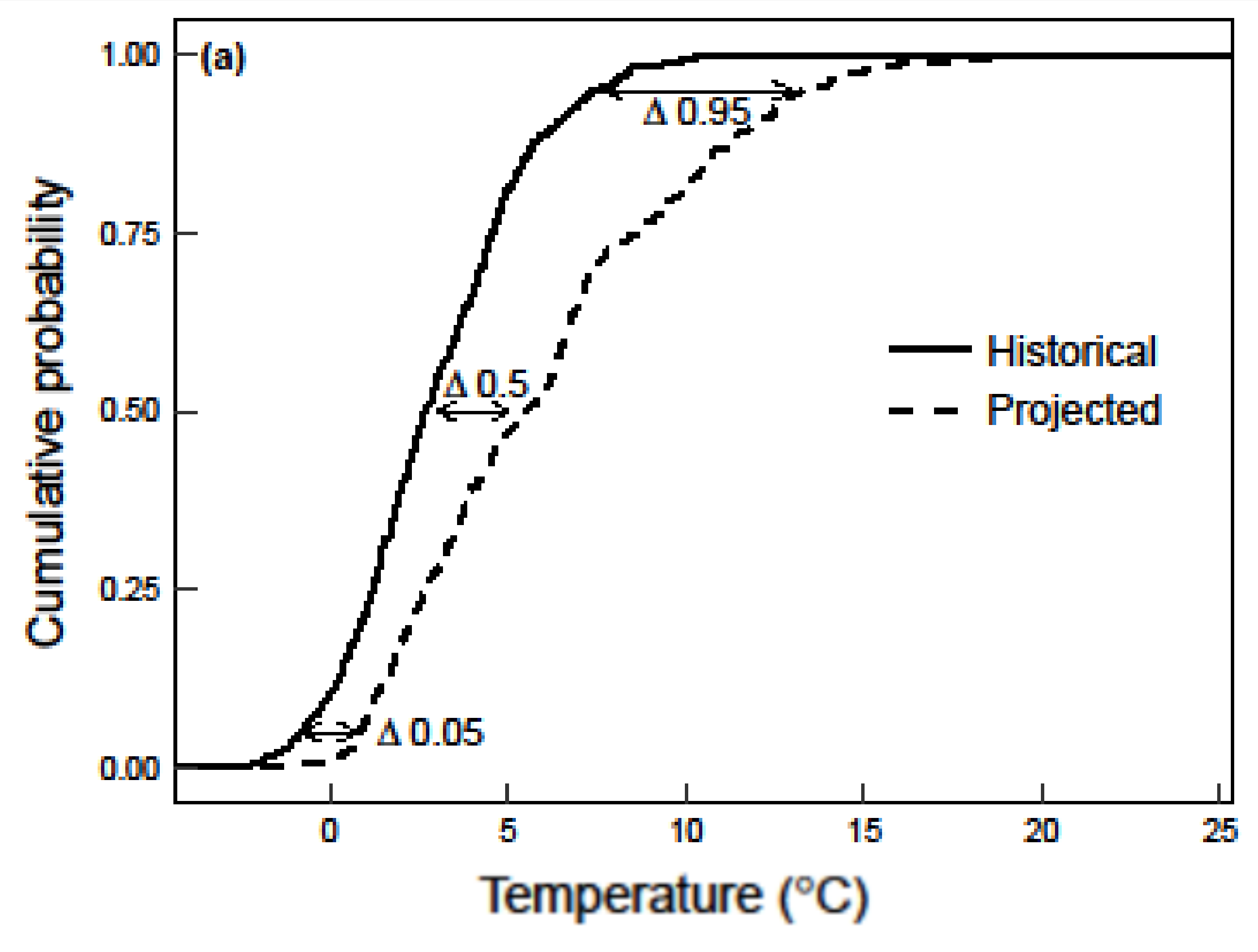


Statistically downscaled: projected change in temp (°C)

Statistically downscaled: projected change in precipitation (mm)

Sofaer et al. 2017 Global Change Biology

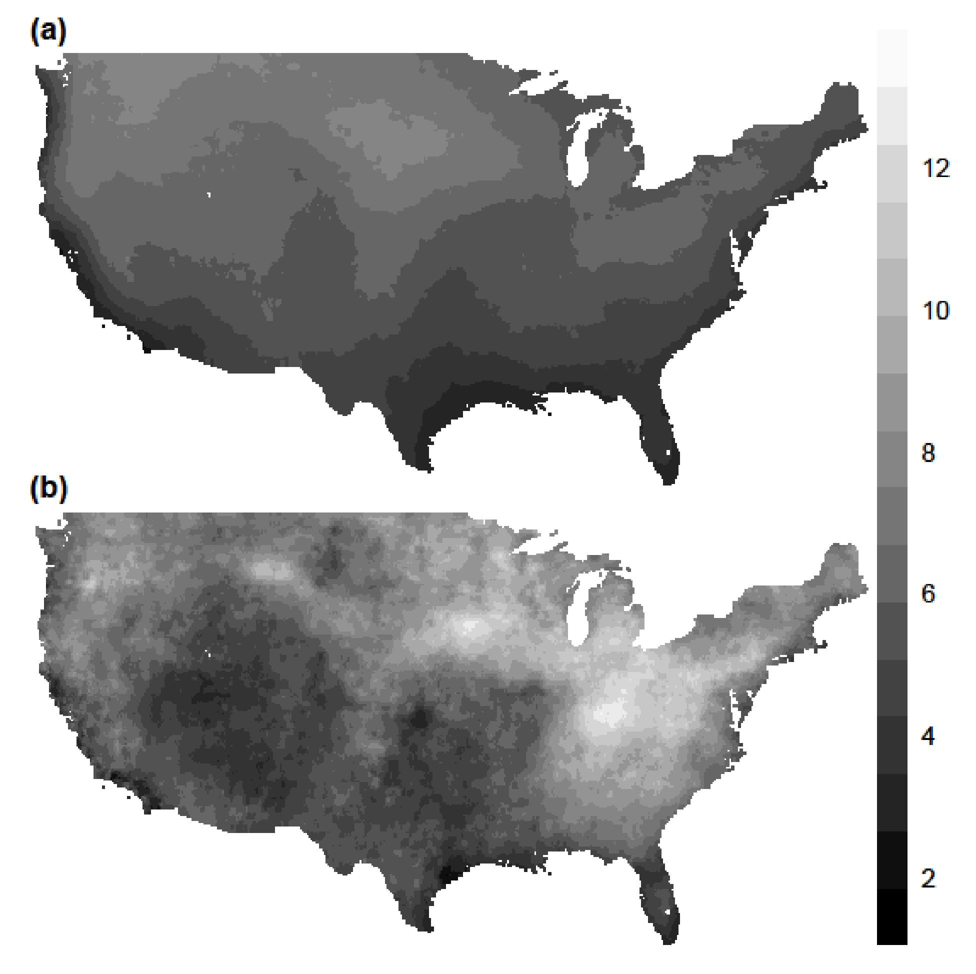
Preserves Projected Differences in Means and Extremes



Means and Extremes Can Change at Different Rates

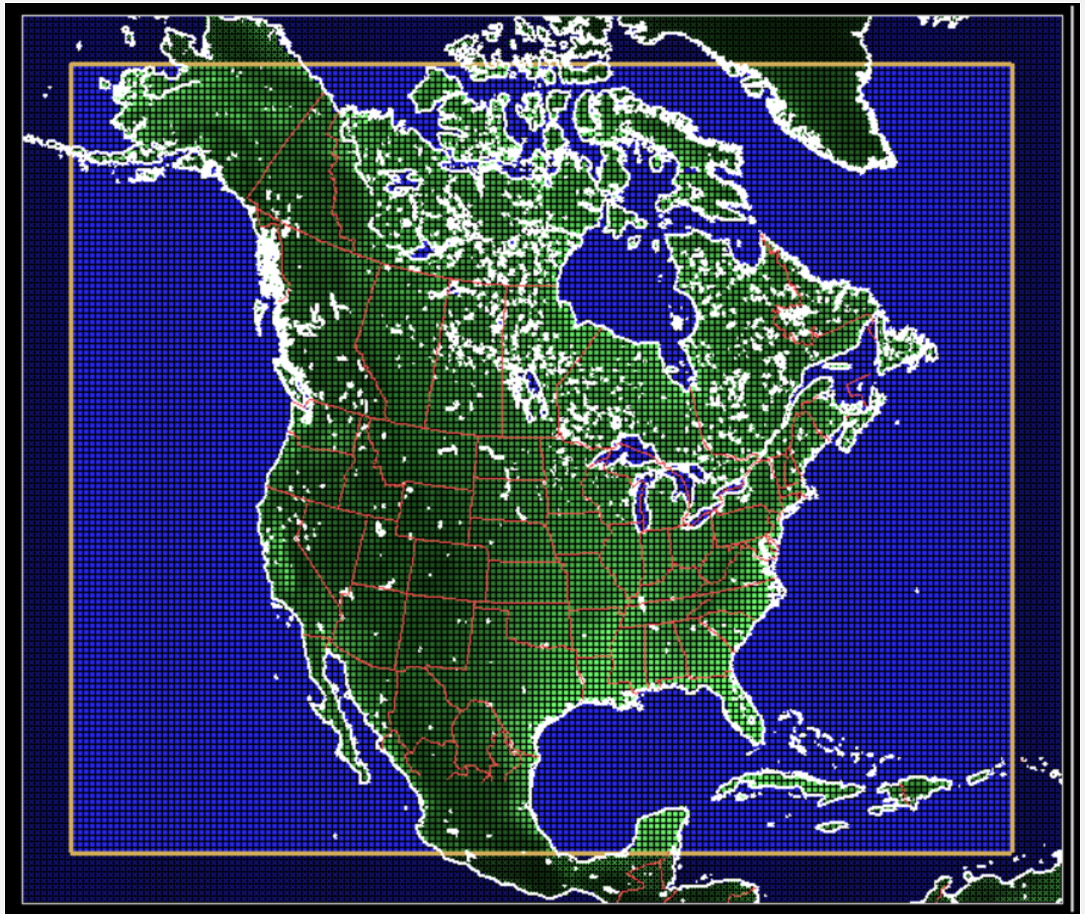
Projected change in mean July temperature (°C)

Projected change in hottest day expected in July in 10-yr period (°C)



Sofaer et al. 2017 Global Change Biology

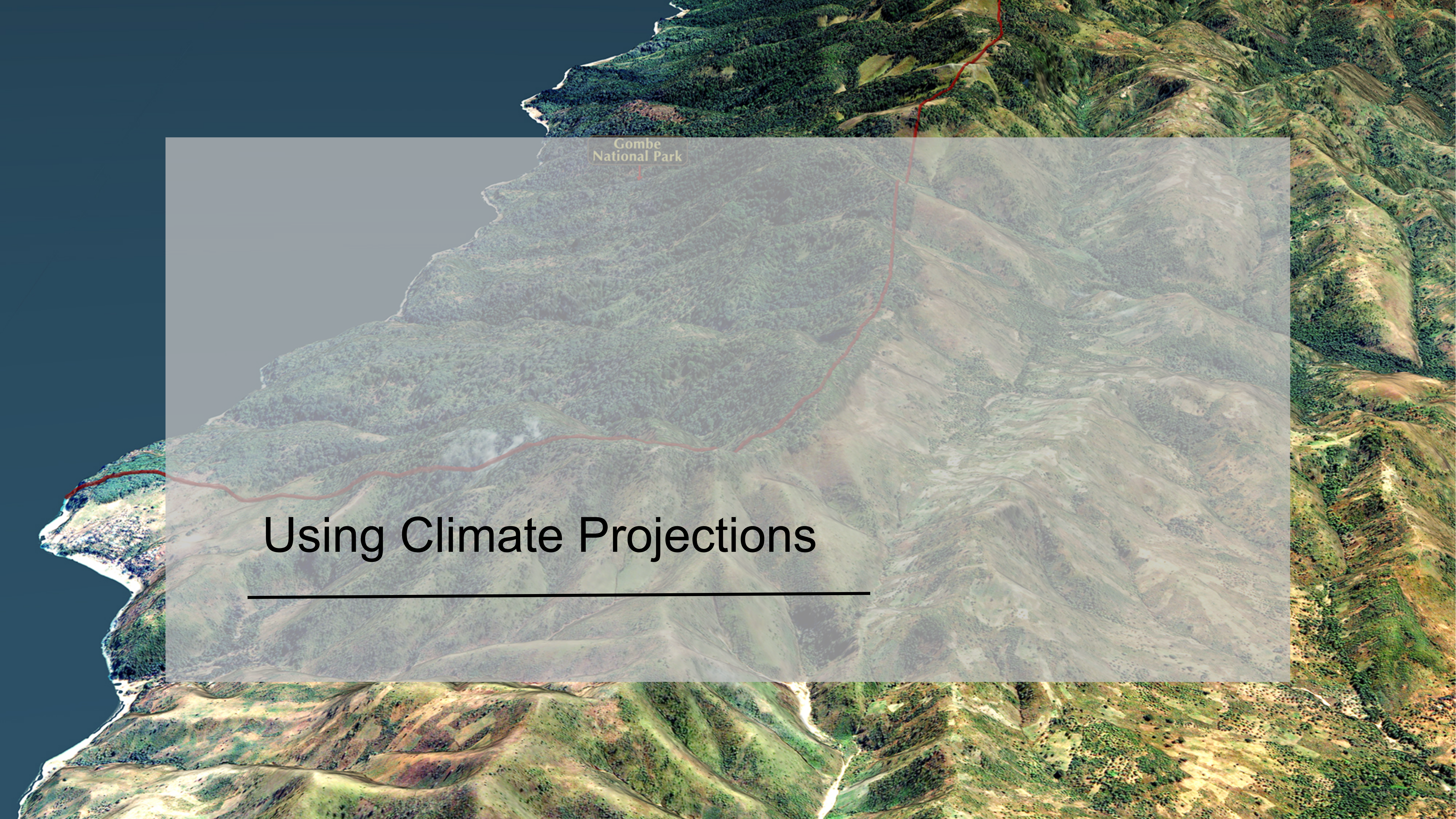
Dynamical Downscaling Can Capture Processes That GCMs Miss



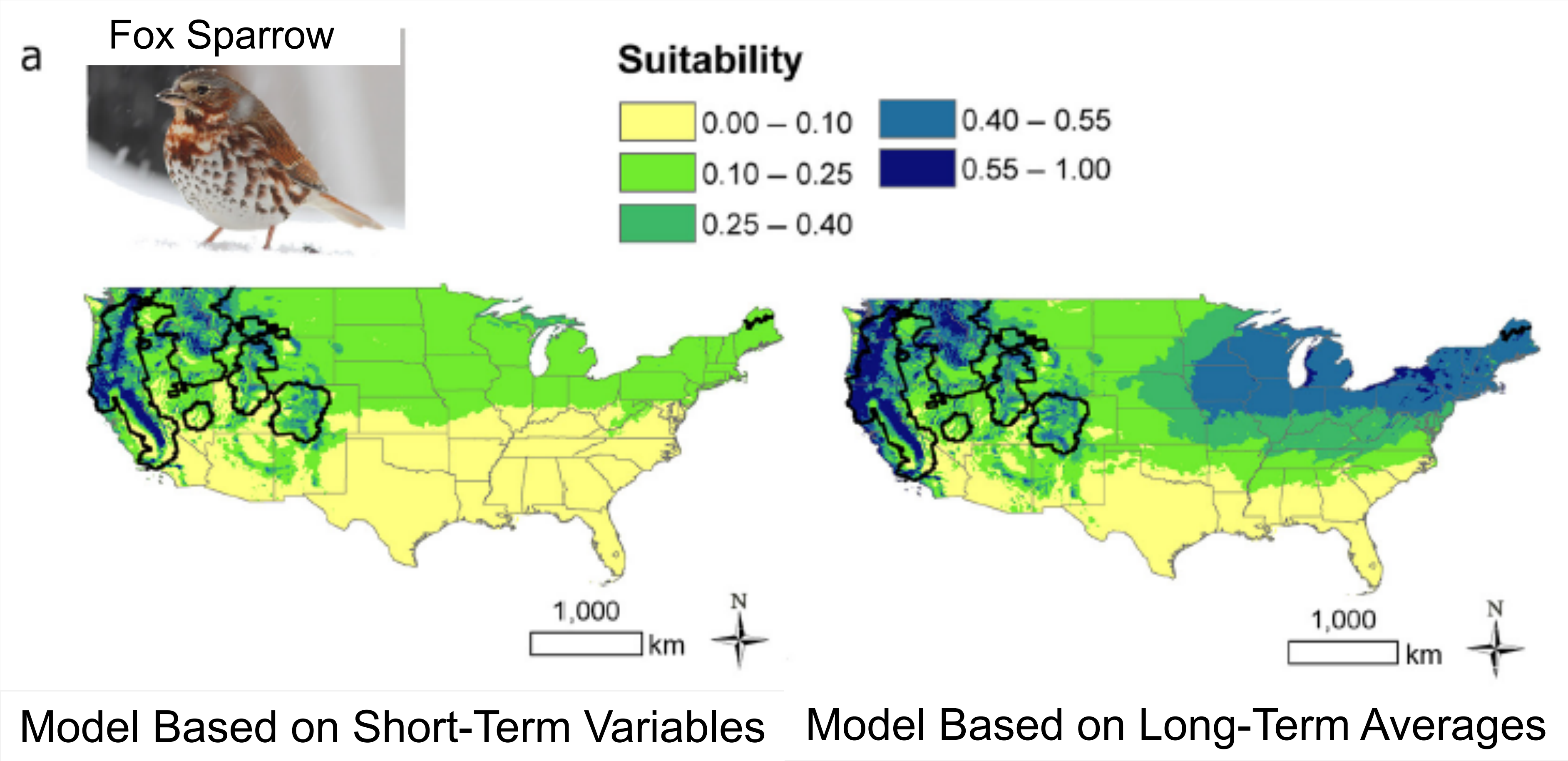
CORDEX-NA simulation domain, 0.44°/50km resolution

https://na-cordex.org/

Using Climate Projections

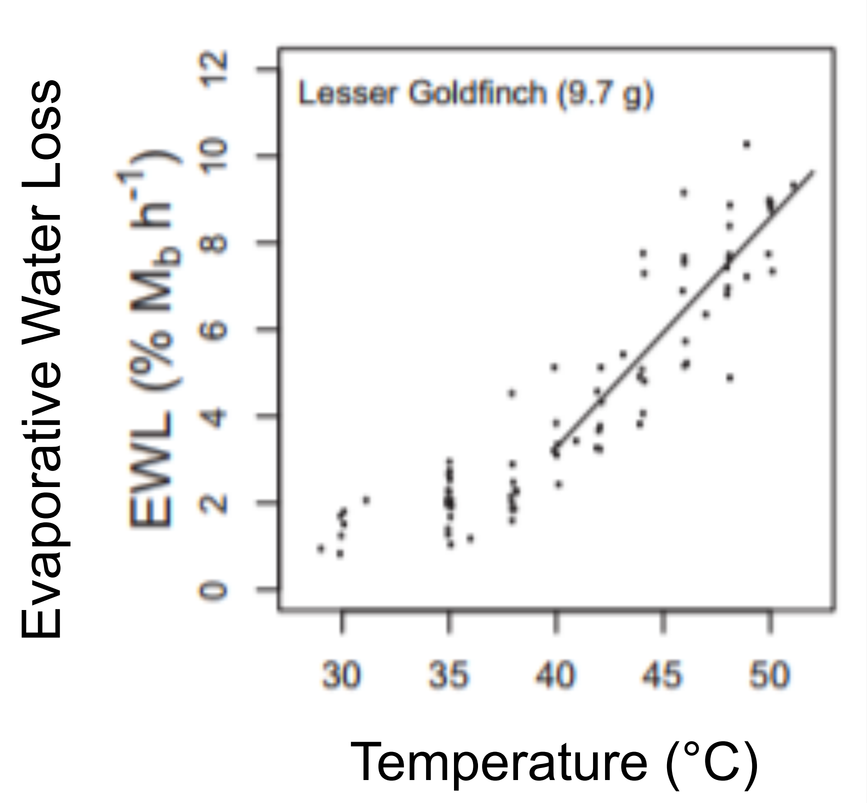


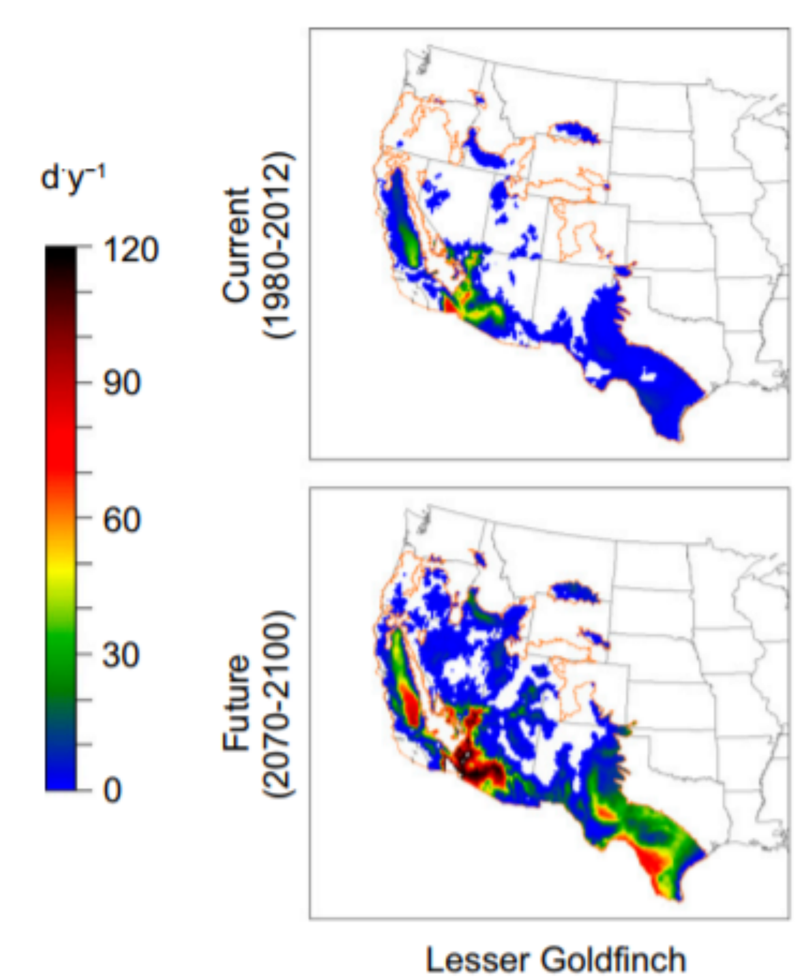
First identify key climatic drivers of your system



Bateman et al. 2016 Ecological Applications

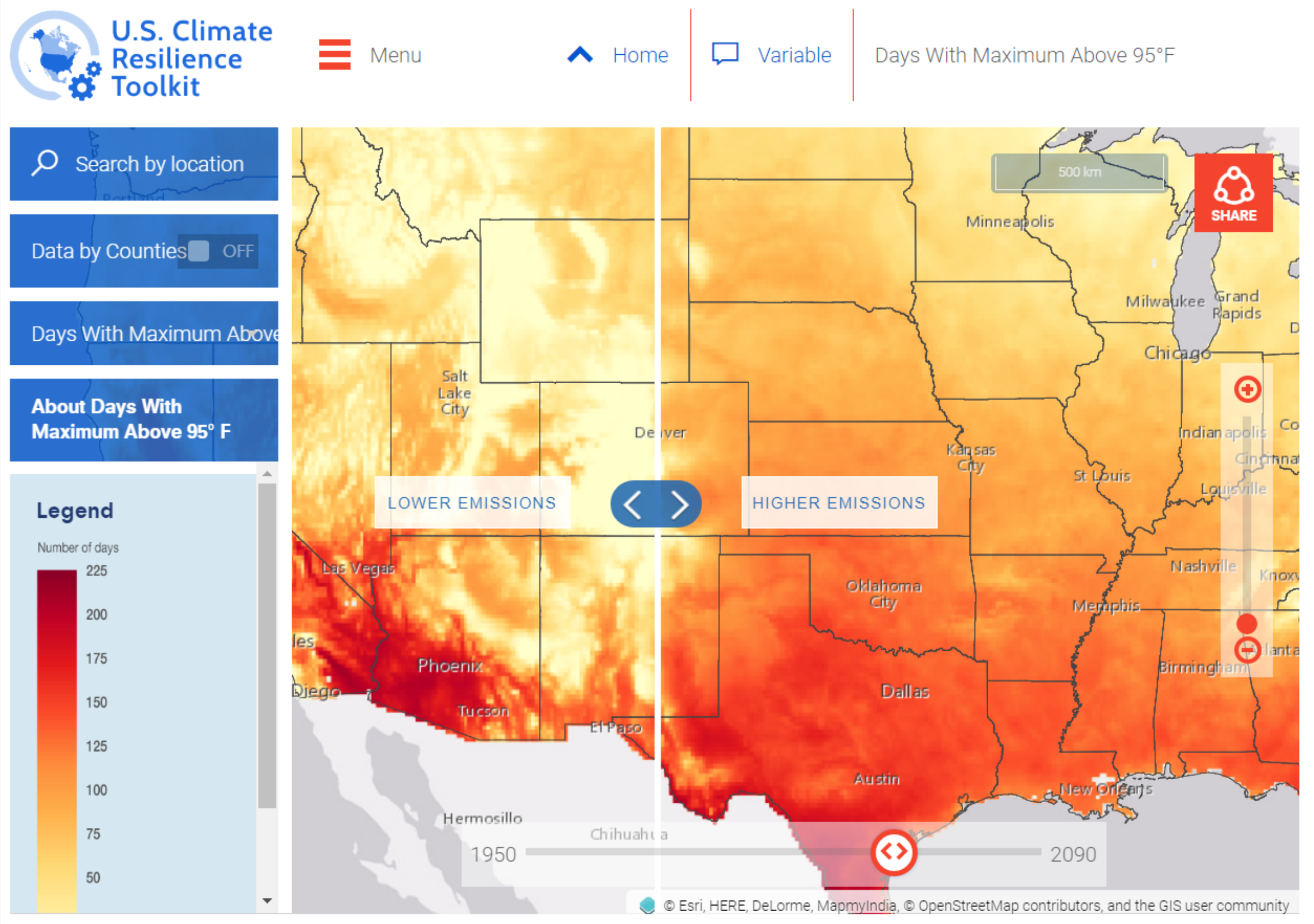
Consider Simple Sensitivity Analyses (e.g. + 4°C)





Albright et al. 2017 PNAS

Spatial Scale: Don't Interpret Cell by Cell!



U.S. Climate Resilience Toolkit:
Climate Explorer:
https://toolkit.climate.gov/#climate-explorer

How Many and Which Models and Pathways to Choose?

- Representative Concentration Pathways (RCPs):
  - Focus on one RCP if projections are to midcentury or earlier
  - Common to use 4.5 and 8.5 for end of century
- Climate models:
  - Cull models that perform poorly in region or for variables of interest
    - Using 'raw' output
  - Strategies:
    - As many GCMs as feasible / available
    - Span range of GCM projected changes

Consider Amount of Change Projected by Different Models

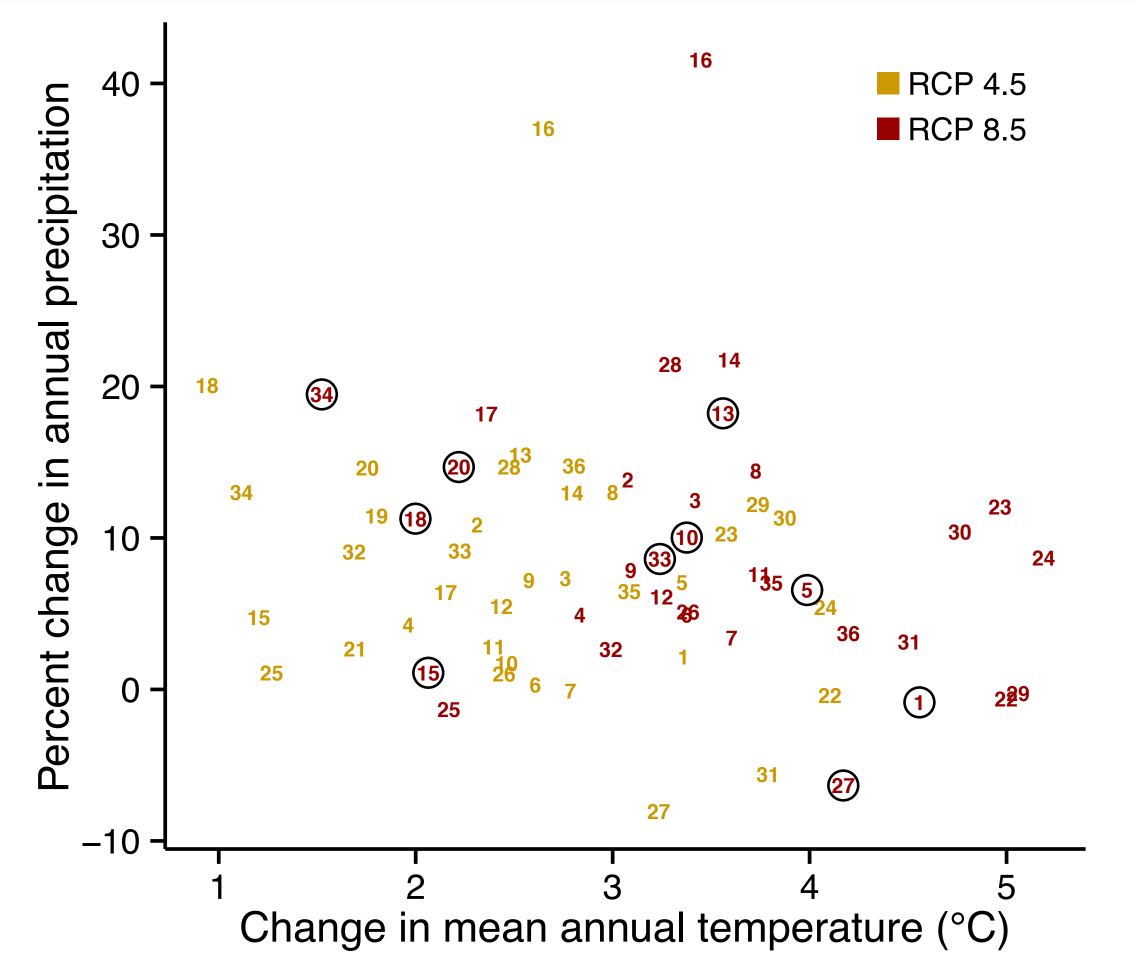
Mean annual temperature change for states and provinces of North America projected for the 2050s under the RCP4.5 scenario. States and provinces are alphabetically sorted from left to right, AOGCMs are sorted by magnitude of projection for North America from top to bottom.

AOGCM	AB	AK	AL	AR	AZ	BC	CA	CO	CT	DC	DE	FL	GA	IA	ID	IL	IN	KS	KY	LA	MA	MB	MD	ME	MI	MN	MO	MS	MT	NB	NC	ND	NE	NH
INM-CM4	1.9	2.3	1	1.2	1.1	1.7	1.1	1.2	1.1	1.2	1	0.8	0.9	1.7	1.4	1.5	1.4	1.4	1.2	0.9	1.1	2	1.1	1.4	1.7	1.8	1.4	1	1.4	1.4	0.9	1.7	1.4	1.3
CNRM-CM5	2.3	3.1	1.7	1.9	2.3	2.1	1.9	2.4	2.2	2.1	2	1.3	1.7	2.2	2.3	2.1	2.2	2.1	2	1.7	2.3	3	2	2.4	2.6	2.5	1.9	1.7	2.4	2.5	1.8	2.6	2.3	2.4
CCSM4	2.8	3.6	2.1	2.2	2.2	2.7	1.9	2.3	2.2	2.2	2.1	1.7	2	2.7	2.7	2.3	2.3	2.3	2.3	1.9	2.3	3	2.2	2.4	2.6	2.9	2.3	2.1	2.6	2.4	2.1	2.9	2.4	2.5
MPI-ESM-LR	3	3.7	1.7	1.9	2.3	2.8	2	2.3	2.3	2.1	2	1.5	1.7	2.6	2.4	2.3	2.2	2.3	2	1.6	2.4	3.4	2.1	2.5	2.7	2.9	2.2	1.7	2.3	2.6	1.8	3	2.5	2.5
IPSL-CM5A-LR	3.2	3.6	2.5	2.7	2.9	3.2	2.7	3.1	2.9	2.8	2.7	2.1	2.4	3.3	3.3	3	2.9	2.8	2.7	2.5	2.9	3.3	2.7	3.2	3.1	3.4	2.9	2.6	3.2	3.3	2.5	3.4	3	3.2
HadGEM2-ES	3.6	4.7	2.9	3.2	2.9	3	2.6	3	3.2	3.3	2.9	2.3	2.8	3.3	3.1	3.4	3.5	3.2	3.4	2.9	3.3	4.2	3.2	3.4	3.6	3.5	3.3	3.1	3.1	3.5	2.8	3.7	3.2	3.4
GFDL-CM3	3.2	5.5	2.7	2.8	3.1	3.6	2.8	3.6	3.4	3.3	3.1	2.4	2.6	3.2	3.7	3.1	3.2	3.1	3.2	2.5	3.4	4.2	3.2	3.9	3.6	3.5	3.1	2.6	3.2	4	2.9	3.2	3.1	3.8

AOGCM	NJ	NL	NM	NS	NT	NV	NY	OH	OK	ON	OR	PA	PE	QC	RI	SC	SD	SK	TN	TX	UT	VA	VT	WA	WI	WV	WY	YT	**Can**	**USA**	**ContUSA**	**NorAm**
INM-CM4	1.1	1.2	1.1	1.1	2	1.2	1.4	1.3	1.2	1.8	1.1	1.3	1.3	1.4	1	0.8	1.5	2	1.2	1.1	1.3	1.1	1.4	1.1	1.8	1.2	1.3	2.1	**1.9**	**1.5**	**1.3**	**1.7**
CNRM-CM5	2.1	2.3	2.4	2.3	3.3	2.5	2.3	2.2	2	2.8	2.1	2.2	2.5	2.8	2.2	1.7	2.4	2.6	1.8	2	2.6	1.9	2.4	2	2.4	2.1	2.3	2.6	**2.9**	**2.4**	**2.2**	**2.7**
CCSM4	2.2	2.5	2.1	2.1	3.7	2.5	2.5	2.3	2.1	2.7	2.2	2.4	2.3	2.9	2.1	2	2.7	2.9	2.3	1.9	2.7	2.2	2.5	2.3	2.8	2.3	2.6	3.2	**3.3**	**2.7**	**2.3**	**3**
MPI-ESM-LR	2.1	3	2.2	2.4	3.8	2.2	2.4	2.2	2.1	3	2.1	2.3	2.6	3.2	2.3	1.7	2.6	3.2	1.9	2	2.4	2	2.5	2.2	2.7	2.1	2.3	3.3	**3.4**	**2.6**	**2.2**	**3.1**
IPSL-CM5A-LR	2.8	3.3	3	2.9	3.5	3.3	3.2	2.9	2.8	3.2	2.9	2.9	3.3	3.4	2.8	2.4	3.2	3.3	2.6	2.7	3.4	2.7	3.3	2.9	3.3	2.8	3.1	3.2	**3.4**	**3.1**	**3**	**3.3**
HadGEM2-ES	3.1	3.6	2.9	3.3	5.5	3	3.6	3.6	3	3.9	2.7	3.5	3.8	4.1	3.1	2.8	3.4	3.8	3.2	2.9	3.2	3.1	3.6	2.9	3.5	3.4	3.1	4.1	**4.6**	**3.5**	**3.1**	**4.2**
GFDL-CM3	3.3	5	3.2	3.5	7.3	3.5	3.8	3.4	3	4.3	2.9	3.5	3.8	5.6	3.2	2.7	3.1	3.6	3	2.8	3.9	3.2	3.9	2.9	3.5	3.4	3.4	4.7	**5.7**	**3.8**	**3.2**	**5**

ClimateNA: http://tinyurl.com/ClimateNA

Consider Amount of Change Projected by Different Models

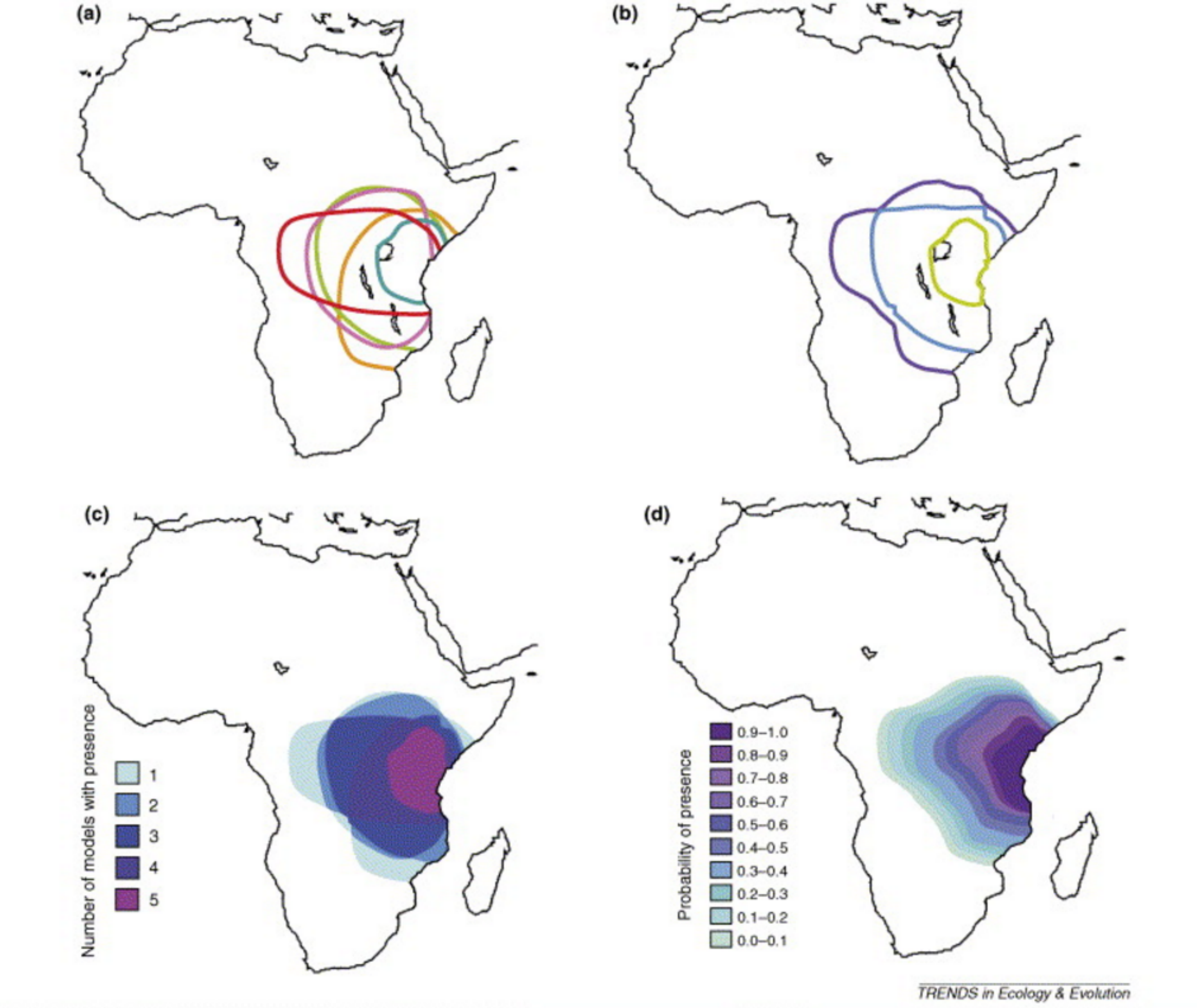


Projected change between 1971-2000 and 2041-2070

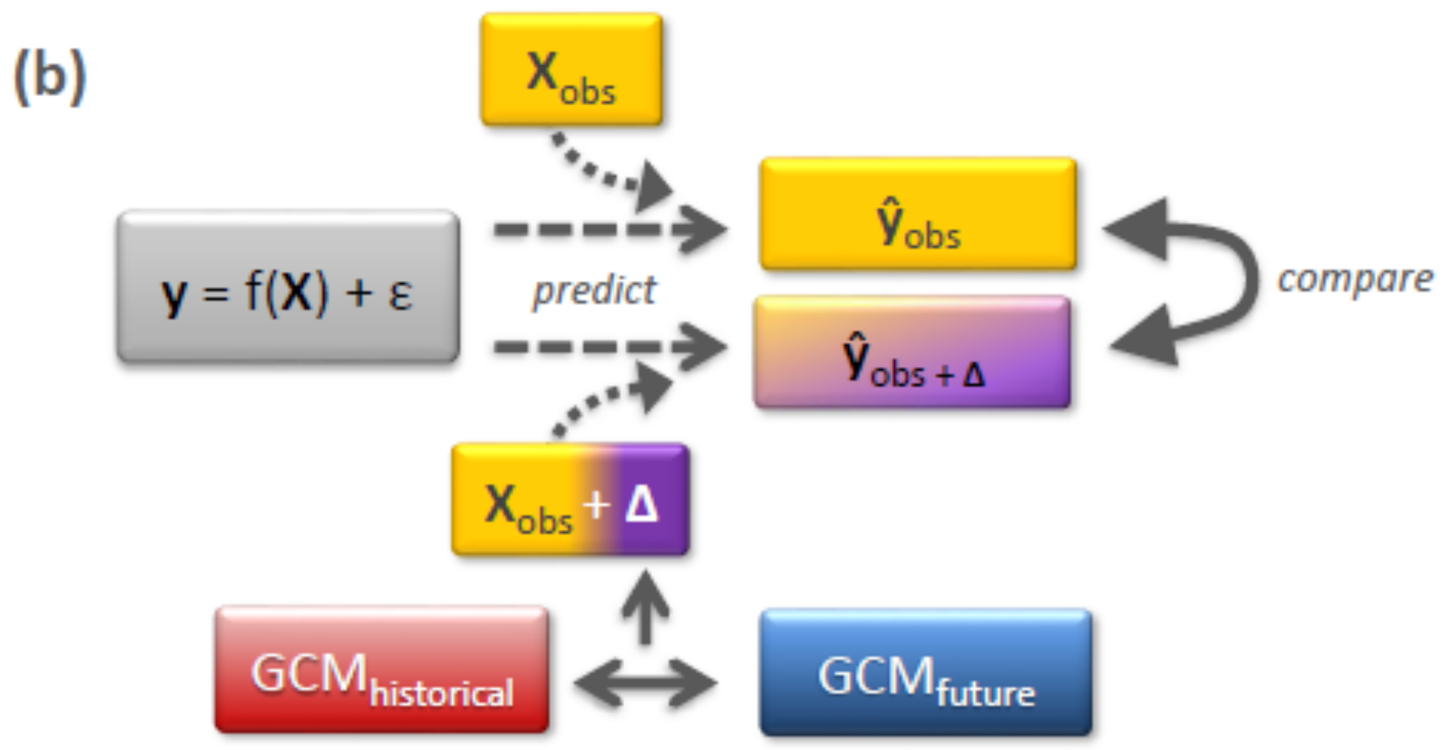
Sofaer et al. 2016 Ecological Applications

Developing and Summarizing Ecological Projections

- Predict to each climate model / RCP separately
  - Can average ecological results, but not climate inputs
  - Show the variability!



If Long-Term Means Are Key Drivers: Use Delta Method

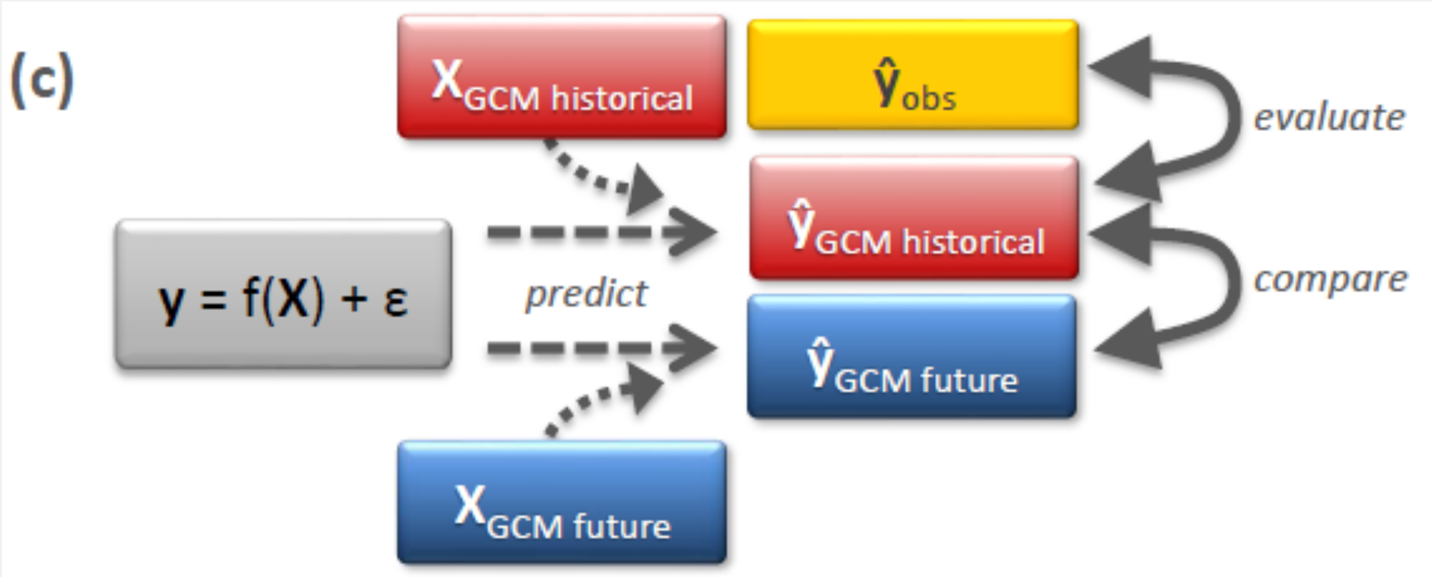


Delta Method

Shifts or scales observed climate covariates by mean change projected by each GCM. Compares ecological predictions between observed and shifted covariates. Appropriate for assessing impacts of projected changes in mean climatic conditions.

Sofaer et al. 2017 Global Change Biology

If Extremes Are Key Drivers: Consider 'Model Space'



'Model Space'

Compares ecological predictions based on climate covariates calculated from GCM historical and GCM future simulations. Can capture changes in additional dimensions of climate, including climate extremes. Additional evaluation step required.

Sofaer et al. 2017 Global Change Biology

Questions?

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