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
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

Mean august temperature (C), averaged over 1970-2000

Gridded Data are Estimated from Climate Stations

Global Climate Network Temperature Stations

- Active sites
- Historical sites

Length of Station Record (years)

Credit: Robert Rohde/Global Warming Art
Gridded ‘Observations’ Are Still Estimates

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

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

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 Version 2**

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 km²) to 10 minutes (~340 km²). Each download is a "zip" file containing 12 GeoTiff (.tiff) files, one for each month of the year (January is 1, December is 12).

<table>
<thead>
<tr>
<th>variable</th>
<th>10 minutes</th>
<th>5 minutes</th>
<th>2.5 minutes</th>
<th>30 seconds</th>
</tr>
</thead>
<tbody>
<tr>
<td>minimum temperature (°C)</td>
<td>tmin 10m</td>
<td>tmin 5m</td>
<td>tmin 2.5m</td>
<td>tmin 30s</td>
</tr>
<tr>
<td>maximum temperature (°C)</td>
<td>tmax 10m</td>
<td>tmax 5m</td>
<td>tmax 2.5m</td>
<td>tmax 30s</td>
</tr>
<tr>
<td>average temperature (°C)</td>
<td>tavg 10m</td>
<td>tavg 5m</td>
<td>tavg 2.5m</td>
<td>tavg 30s</td>
</tr>
<tr>
<td>precipitation (mm)</td>
<td>prec 10m</td>
<td>prec 5m</td>
<td>prec 2.5m</td>
<td>prec 30s</td>
</tr>
<tr>
<td>solar radiation (kJ m² day⁻¹)</td>
<td>snrad 10m</td>
<td>snrad 5m</td>
<td>snrad 2.5m</td>
<td>snrad 30s</td>
</tr>
<tr>
<td>wind speed (m s⁻¹)</td>
<td>wind 10m</td>
<td>wind 5m</td>
<td>wind 2.5m</td>
<td>wind 30s</td>
</tr>
<tr>
<td>water vapor pressure (kPa)</td>
<td>vapr 10m</td>
<td>vapr 5m</td>
<td>vapr 2.5m</td>
<td>vapr 30s</td>
</tr>
</tbody>
</table>

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 (.tiff) files, one for each month of the variables.

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<td>bio 5m</td>
<td>bio 2.5m</td>
<td>bio 30s</td>
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</tbody>
</table>

Worldclim.org; http://metadata.northwestknowledge.net/
Derived Variables Are Becoming More Easily Accessible

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

Climate Model Output Is Rarely Used Directly in Ecological Studies

- Bias

- Coarse Spatial Scale
Bias-Correction Is Often Based on Quantile Mapping

From MACA Website: http://maca.northwestknowledge.net/MACAmeth...
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 Version 2

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 to 1 minute (~340 km²). Each download is a “zip” file containing 12 GeoTiff (.tiff) files of the year (January is 1; December is 12).

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<td>min 5m</td>
<td>min 2.5m</td>
</tr>
<tr>
<td>max temp.</td>
<td>max 10m</td>
<td>max 5m</td>
<td>max 2.5m</td>
</tr>
<tr>
<td>avg temp.</td>
<td>avg 10m</td>
<td>avg 5m</td>
<td>avg 2.5m</td>
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<tr>
<td>precipitation</td>
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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

https://na-cordex.org/

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

Evaporative Water Loss

Temperature (°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 | MO | MS | MT | NB | NC | ND | NE | NH |
|------------|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|
| INM-CM4    | 3.0| 1.5| 1.4| 1.2| 1.0| 1.2| 1.6| 1.7| 1.7| 1.7| 1.8| 2.0| 1.4| 1.3| 1.5| 1.5| 1.3| 0.8| 0.9| 1.7| 1.0| 1.2| 1.4| 1.4| 1.4| 1.2| 0.9| 1.1| 2.1| 1.1| 1.4| 1.7| 1.4| 1.3|
| CNRM-CM5   | 2.3| 3.1| 3.1| 2.9| 2.7| 2.7| 2.6| 2.5| 2.5| 2.2| 2.2| 2.2| 2.0| 2.0| 2.1| 2.4| 2.4| 2.1| 2.1| 2.1| 2.2| 2.2| 2.2| 2.2| 2.2| 2.2| 2.2| 2.2| 2.2| 2.1| 2.1| 2.1| 2.1| 2.1|
| CCSM4      | 3.0| 2.8| 2.6| 2.3| 2.2| 2.0| 1.9| 1.9| 1.9| 1.9| 1.9| 1.8| 2.0| 2.0| 2.1| 2.1| 2.1| 2.1| 2.1| 2.1| 2.2| 2.2| 2.2| 2.2| 2.2| 2.2| 2.2| 2.2| 2.2| 2.2| 2.2| 2.2| 2.2| 2.2|
| MPI-ESM-LR | 3.0| 3.0| 3.0| 3.0| 2.8| 2.8| 2.8| 2.8| 2.8| 2.8| 2.8| 2.8| 2.8| 2.8| 2.8| 2.8| 2.8| 2.8| 2.8| 2.8| 2.8| 2.8| 2.8| 2.8| 2.8| 2.8| 2.8| 2.8| 2.8| 2.8| 2.8| 2.8| 2.8| 2.8|
| IPSL-CM5A-LR| 3.0 | 3.2 | 2.9 | 2.9 | 2.8 | 2.7 | 2.7 | 2.7 | 2.7 | 2.7 | 2.7 | 2.7 | 2.7 | 2.7 | 2.7 | 2.7 | 2.7 | 2.7 | 2.7 | 2.7 | 2.7 | 2.7 | 2.7 | 2.7 | 2.7 | 2.7 | 2.7 | 2.7 | 2.7 | 2.7 | 2.7 | 2.7 | 2.7 | 2.7 |
| HadGEM2-ES | 3.1 | 3.7 | 3.7 | 3.7 | 3.7 | 3.7 | 3.7 | 3.7 | 3.7 | 3.7 | 3.7 | 3.7 | 3.7 | 3.7 | 3.7 | 3.7 | 3.7 | 3.7 | 3.7 | 3.7 | 3.7 | 3.7 | 3.7 | 3.7 | 3.7 | 3.7 | 3.7 | 3.7 | 3.7 | 3.7 | 3.7 | 3.7 | 3.7 | 3.7 |
| GFED-CM3   | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 |

ClimateNA: [http://tinyurl.com/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

Sofaer et al. 2017 Global Change Biology
If Extremes Are Key Drivers: Consider 'Model Space'

The diagram illustrates the process of comparing ecological predictions based on climate covariates calculated from GCM historical and GCM future simulations. This approach can capture changes in additional dimensions of climate, including climate extremes. An additional evaluation step is required.

Sofaer et al. 2017 Global Change Biology
Questions?

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