GEOG 401
Climate Change

Climate Downscaling
GCMs have coarse resolution

Spatial resolution of global models continues to improve. But, they are still not sufficiently resolved to accurately represent processes at regional and local scales.
CMIP5 high-resolution models: 1 – 5 deg resolution

<table>
<thead>
<tr>
<th>Model Configuration</th>
<th>Period</th>
<th>Experiment</th>
<th>Model Resolution</th>
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</thead>
<tbody>
<tr>
<td>CMCC-CM</td>
<td>300 years</td>
<td>piControl (pre-industrial)</td>
<td>T159L31 (~80 km)</td>
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<td>1850-2005</td>
<td>Historical</td>
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<td>RCP8.5 (scenario)</td>
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<td>140 years</td>
<td>1pctoCO2 (scenario)</td>
<td>T159L31 (~80 km)</td>
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<td>480 years</td>
<td>Decadal predictions (short term projections)</td>
<td>T159L31 (~80 km)</td>
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<td>1979-2008</td>
<td>AMIP (prescribed SST)</td>
<td>T159L31 (~80 km)</td>
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<tr>
<td>CMCC-CESM</td>
<td>277 years</td>
<td>piControl (pre-industrial)</td>
<td>T31L39 (~400 km)</td>
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<td></td>
<td>1850:2005</td>
<td>Historical</td>
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<tr>
<td>CMCC-CMS</td>
<td>300 years</td>
<td>piControl (pre-industrial)</td>
<td>T65L95 (~200 km)</td>
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</table>
Downscaling

Downscaling Strategies:
- Statistical
- Dynamical
Rationale for downscaling in Hawai‘i:
Complexities in rainfall generation processes and the resulting steep gradients cannot be represented in global models.

Approaches to Downscaling

• Statistical downscaling: establish statistical relationships between weather patterns in global model and variations in weather at a point

• Dynamical downscaling: apply dynamical climate model at high spatial resolution within a regional domain

• Intermediate complexity downscaling: substitute parameterizations to represent some processes in dynamical model to reduce computer requirements
Statistical Downscaling

• Climate variability at a point is related to large-scale atmospheric patterns of circulation, moisture transport, and stability
• Global models are skillful at representing the large scale patterns
• By establishing statistical relationships between the circulation/transport/stability patterns and climate at a station, projections can be made of past or future climate variations at the station based on variations in the patterns.
• Assumes that the relationships between spatial patterns and climate at a point do not change as a result of climate change: **stationarity assumption**
Data Assimilation

- Global climate models are not expected to reproduce actual sequences of hour to hour or day to day weather patterns beyond forecast periods of a 1 to 2 weeks.
- Beyond that, the models are expected to produce plausible sequences of weather patterns with statistical properties similar to actual weather patterns.
- When global models are used for historical periods, they can be operated in the same way as model runs of the future, i.e., without benefit of observations except for those used to specify the model initial conditions, or observations can be systematically incorporated to keep the model on track to represent the actual sequence of weather patterns.
Reanalysis Data Sets

- Weather observations are relatively sparse and irregularly located
- Many important variables, such as solar radiation, are measured at only a few stations
- Observations at levels above the ground are available only at radiosonde stations
- **Reanalysis Data Sets** are global gridded estimates of past weather produced by global climate models constrained by assimilating observations from ground stations, radiosonde profiles, and satellite data
- Reanalysis provides spatially and temporally complete data sets of all weather variables for historical periods
- Reanalysis data sets are extremely valuable for numerous applications including downscaling
CFSR Atmospheric Precipitable Water [kg/m^2]
00Z01MAR1993
Statistical Downscaling: Hawai‘i Example
Elison Timm et al. (2015)

Climate Change Circulation pattern in the Pacific Sector around Hawai‘i

Principal Component Analysis used to reduce complexity

Geopotential height anomaly (pressure pattern) at 500 hPa level

Dominant mode of variability in 32-member ensemble simulation at RCP8.5
Climate Change Circulation pattern in the Pacific Sector around Hawai‘i

Moisture transport at 700 hPa level

Dominant mode of variability in 32-member ensemble simulation at RCP8.5
Climate Change Circulation pattern in the Pacific Sector around Hawai‘i

Temperature difference 1000hPa minus 500hPa

Dominant mode of variability in 32-member ensemble simulation at RCP8.5
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Temperature difference 1000hPa minus 500hPa
Translating large-scale climate anomalies into rainfall estimates.
Composite Pattern Geopotential Height 500hPa
(1000hPa in contours)
Composite Pattern 700hPa Moisture Transport

Slide adapted from Oliver Elison Timm
Calibration Skill for Rainfall 1978-2007
(Nov-Apr season)

(b) Oahu

Correlation between observed & statistically downscaled rainfall
Calibration Skill for Rainfall 1978-2007 (Nov-Apr season)

Correlation between observed & statistically downscaled rainfall
CMIP5 Future Circulation Changes Projected onto the Composite Pattern

Slide adapted from Oliver Elison Timm
Statistical downscaling results
CMIP5 RCP8.5  2041-2070
30-yr average rainfall changes (Nov-Apr. season)
Projected Change in Wet Season Rainfall Based on Statistical Downscaling

CMIP5 ECP8.5 ensemble median scenario for late 2071-2099 average (Elison Timm et al. 2015).
Latest Projections

- Elison Timm et al. (2015) produced maps of seasonal-mean rainfall changes in Hawai‘i
- Wet-season results show higher skills than dry season
- Overall scenario for 21st century:
  - dry regions get drier, the wet regions remain wet or get wetter
Dynamical Downscaling

• Utilizes the same type of numerical model used for global climate simulations and regional weather prediction: a regional climate model.
• A regional domain is used allowing much higher spatial resolution; nested domains with successively higher resolution often used.
• Psuedo Global Warming method is a common strategy; historical reanalysis is used to define the lateral boundary conditions; “global warming increments” used to modify conditions inside domain to represent future conditions.
• PGW approach assumes no change in climate variability.
• Computationally intensive, thus limiting number of test runs and global models used.

SST Increment: RCP4.5

Fig. 2. Differences in annual average SST between the end of the twenty-first-century (2090–99) and late-twentieth-century conditions (1990–99) in the Pacific Ocean. Shown are the results of individual CMIP5 models for the RCP4.5 scenario as well as (bottom, right center) the CMIP5 multimodel mean averaged over all 10 individual models. In addition, the (bottom right) observed SSTs for 2000–2002 are shown. Land surfaces are drawn in black. The dashed boxes show the HRCM domain with the Hawaiian Islands in the center.

Lauer et al. (2013)
SST Increment: RCP8.5

Fig. 3. As in Fig. 2, but for the RCP8.5 scenario.

Lauer et al. (2013)
Air Temperature Increment

Fig. 4. PDFs of the daily mean 2-m temperature $T_{2m}$ averaged over all land grid cells in the Hawaii region (160.9°–153.2°W, 18.1°–23.1°N) with an elevation of less than 300 m. Shown are HCRM results from 3 years (2000–02) using the warming increments from 10 individual CMIP5 models and the (bottom right) CMIP5 multimodel mean. The black curves show the present-day results, and the blue and red lines curves are for the RCP4.5 and RCP8.5 scenarios, respectively. The area shaded in gray shows the PDF of present-day daily maximum $T_{2m}$. The numbers in the top right of the panels give the 3-yr annual mean $T_{2m}$.

Lauer et al. (2013)
Precipitable Water Vapor Increment

Fig. 5. As in Fig. 4, but for the 6-hourly WVP values averaged over all grid cells in the Hawaii region (160.9°–153.2°W, 18.1°–23.1°N).

Lauer et al. (2013)
Change in Mean Annual Precipitation: RCP4.5

Lauer et al. (2013)
Change in Mean Annual Precipitation: RCP8.5

Lauer et al. (2013)
Results Summary for RCP4.5

Lauer et al. (2013)
Results Summary for RCP8.5

Fig. 13. As Fig. 12, but for the RCP8.5 scenario.

Lauer et al. (2013)
Changes in TWI Height

Fig. 8. As in Fig. 4, but for the TWI height 6-hourly values averaged over all grid cells in the Hawaii region. The numbers in the top right of the panels give the frequency of a TWI occurrence ("presence") and the 3-yr annual mean TWI height.

Lauer et al. (2013)
Dynamical Downscaling

Does the PGW approach adequately represent the important effects of global warming on regional and local precipitation?

What this shows is that the future projection based on the pseudo global warming approach is constrained by being tied to the historical variability. The frequency of disturbances is determined by the historical data which are used to give the time-dependent boundary conditions at the lateral boundaries of the model domain.

Monthly mean rainfall data from the APDRC web page Chunxi Zhang (IPRC, UHM). One for present day, one for future.

Averaged the monthly mean rainfall in the 3-km resolution data over the Hawai‘i region (160W-155W 18.5N-23.5N)
Mean Annual **Rainfall Change**

2071-2200, RCP 8.5

**Statistical Downscaling**

Elison Timm et al. (2015)
Percent Change in Seasonal Rainfall at the End of the Century: O'ahu, Statistical vs. Dynamical Downscaling

(a) Statistical Downscaling Wet Season
   Ellison Timm et al. 2015
   CMIP5, RCP 8.5, 2071-2100

(b) Statistical Downscaling Dry Season
   Ellison Timm et al. 2015
   CMIP5, RCP 8.5, 2071-2100

(c) Dynamical Downscaling Wet Season
   Zhang et al. 2012
   CMIP3, A1B, 2080-2099

(d) Dynamical Downscaling Dry Season
   Zhang et al. 2012
   CMIP3, A1B, 2080-2099

Created by Abby Frazier, 09/09/2016
UH Mānoa Department of Geography
Funding by PICSC

Percent Change End of Century

-90% to -70%
-70% to -60%
-60% to -50%
-40% to -30%
-20% to -10%
-10% to 0%
0% to 10%
10% to 20%
20% to 30%
30% to 40%
40% to 50%
50% to 60%
60% to 70%
70% to 90%
Rainfall Change
2080-2099, CMIP3, A1B
Dynamical Downscaling
Zhang et al. (2016)
Characterizing Uncertainty in Downscaled Products

• Sources of uncertainty:
  – Uncertainty in GCM simulations
  – Uncertainty in GHG scenarios
  – Added uncertainty in downscaling

• Characterizing uncertainty:
  – Use many GCM simulations
  – Use different RCPs
  – Use different downscaling approaches
  – Use different methods of estimating patterns of present (historical) climate

• Characterizing uncertainty requires large number of downscaling simulations
  – Easy to do with statistical downscaling
  – Difficult to do with dynamical downscaling
  – Need an intermediate method
Discrepancies Between Statistical and Dynamical Downscaling Results for Hawaii.

- Resource managers are frustrated
- Workshops held last September 2016 and April 2017 to help answer questions
- Other alternatives being sought, e.g. additional statistical and dynamical downscaling results and use of models of intermediate complexity

AMS Mountain Net Conference presentation by Ethan Gutman:
https://ams.confex.com/ams/16MountMet/webprogram/Paper251640.html