Methods and Application of Downscaling

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WHY WE NEEDS DOWNSCALING?
Some Gaps between Climate and Application Community

What the climate research center is providing?

There are some GAPS!

What other communities need?
WHY WE NEEDS DOWNSCALING- SOME JUSTIFICATIONS

...studies of the impacts of projected global warming on a regional scale...necessitates the development and application of scenarios to specific problems... Cohen (1990)

...Even if global climate models in the future are run at high resolution there will remain the need to ’downscale’ the results from such models to individual sites or localities for impact studies... DOE (1996)

...‘downscaling’ techniques, [are] commonly used to address the scale mismatch between coarse resolution global climate model (GCM) output and the regional or local catchment scales required for climate change impact assessment and hydrological modelling... Fowler & Wilby (2007)
Downscaling Approaches

Coarse atmospheric data (T, Q, winds, pressure etc)

• **Dynamical**: Numerical models at high resolution over region of interest
  - high resolution AGCM, limited area model (regional climate model)

• **Statistical**: based on statistical relationship between large- and local-scale

\[ \text{fine scale value} = F(\text{large-scale variables}) \]

Local atmospheric data (T, Q, winds, pressure etc)

Applications of Downscaling:
• Impact Assessment: Long-term CC Projections
• Medium range to Seasonal Weather and Climate Forecasts at fine scales
• Diagnostic Studies

50km-1km: region, city, fields etc.

100-300km

Source: Met Office Hadley Center
GENERAL PROCEDURE OF DOWNSCALING

GCM

RCM or LAM (Dynamic Downscaling)

Statistical Models (Statistical Downscaling)

Stochastic Weather Generators

Weather Typing or Classification

Regression Models

Impact Models (Hydrologic Models)

Scenarios

low resolution

~ 300 km

month, season, year

high resolution

1 km

day, hour, minute
Different Resolution Across Models

Résolution de 400 km
GCM view of Quebec

Résolution de 200 km

Résolution de 45 km
(Actual Resolution of the Canadian RCM for Climate Projections)

Résolution de 10 km

From Regional climate downscaling theory
COMPLEX TOPOGRAPHY THROUGH RCM

- A RCM considers complex topography as below:

Source: Ferranti (2007)

From Regional climate downscaling theory
**Dynamic Downscaling Skill (RCM)**

- Observed (left column) and RegCM3 simulation (right column) of near surface winds, precipitation and surface temperature for summer 1987-2000.
  
  - *Source: Pal et al. (2007)*

*From Regional climate downscaling theory*
CONCLUSION OF REGIONAL CLIMATE MODELS

● Strengths
  — Enhanced spatial and temporal resolution compared with GCMs
  — Responsive to multiple drivers (atmospheric, land-surface)
  — Multivariate output across domain and levels in atmosphere
  — Generates internally consistent maps of change

● Weaknesses
  — Results depend on the quality of GCM inputs
  — As computationally demanding as GCMs
  — Results depend on domain location and size
  — Results depend on method of boundary forcing
  — Technically demanding to set up and run

From Regional climate downscaling theory
STATISTICAL DOWNSCALING
Statistical Downscaling

- Estimating some statistics of a weather or climate or hydrologic variable at a location (point or area) of interest given some “climate information”
- “climate information”
  - Usually Climate Model Output of some ocean or atmosphere data fields integrated over time given some initial and boundary conditions. Climate Change or Seasonal Forecast or Hindcast Experiment (includes Re-analysis)
  - Climate state variables (winds, pressure, SST, rainfall) recorded at the same time or at a preceding time
Statistical Downscaling

- “target variable”
  - Can be single or multiple variables and at one or multiple locations.
  - Could be a statistic of the variable – e.g., seasonal mean or variance, or daily rainfall probability, or year in which a shift in the mean occurs.
- Statistical GOAL: *Estimate the conditional distribution of the local statistic given larger scale information*.
- Assumption: The conditional distribution estimated from concurrent historical climate (model) and at site data will still hold in the future.
From global to local climate ....

- **Key issues**
  - Predictor selection
  - Stationarity of scaling
  - Predictor domain
  - GCM biases

... from a GCM grid to the point of interest.
Methods of Statistical Downscaling

• Delta Method
  – Delta addition
  – Bias Correction
• Quantile Mapping
• Transfer Function (regression)
• Asynchronous Linear Regression
• Weather Typing/ Weather Classification
Delta method
(Delta addition)

\( Y_0 \): present observation, \( X_0 \): present simulation, \( X_1 \): future simulation

\[ Y_1 = Y_0 + \bar{X}_1 - \bar{X}_0 \]

- (future climate) = (present observation) + (mean difference between \( Y_0 \) and \( Y_1 \))
Delta method
(Bias correction)

\( Y_0: \) present observation, \( X_0: \) present simulation, \( X_1: \) future simulation

\[ Y_1 = X_1 + Y_0 - \bar{X}_0 \]

- \((\text{future climate}) = (\text{future simulation}) + (\text{mean bias})\)
Delta method (addition vs Bias correction)
Quantile mapping

$Y_0$: present observation, $X_0$: present simulation, $X_1$: future simulation

$Y_1 = f(X_1)$ where $f$ is bias correction function for each quantile ($Y_0 = f(X_0)$).

- (future climate) = (bias corrected future simulation)
- Bias is corrected for each quantile.
Transfer Function

From Downscaling: An Introduction, Elaine Barrow,
Asynchronous linear regression

$Y_0$: present observation, $X_0$: present simulation, $X_1$: future simulation

$Y'_0, X'_0, X'_1$: sorted in ascending order

$Y'_1 = a \hat{X}'_1 + b$ where $Y'_0 = a \hat{X}'_0 + b$. $a$ and $b$ are the slope and intercept for the least square regression line.

- The linear relationship between observation and present simulation is determined after sorting them in ascending order.
Weather Typing/Classification: Analogue method

- The local variable is predicted based on large-scale atmospheric “states.”
- The future atmospheric state is matched with historical atmospheric state.
- The selected historic atmospheric state then corresponds to a value or a class of values of the local variable, which are then replicated under the future atmospheric state.
Example

GIVEN THE COARSE RESOLUTION CLIMATE FIELD
FOR A FUTURE DATE

FIND HISTORICAL DAYS WITH SIMILAR MAPS

NEW 1/21/2055
Large-scale Map

Large-scale Map 1/22/55
Large-scale Map 1/21/1980
Large-scale Map 1/20/1972
Large-scale Map 1/22/1995
FIND COEFFICIENTS $a, b, c, d, e, ...$
such that
THEN APPLY THE SAME a, b, c, d, e,... TO THE FINE-SCALE MAPS FOR THE SAME DAYS TO OBTAIN THE CONSTRUCTED FINE-SCALE ANALOG OF NEW MAP
Downscaling using Analogue

Key points

• Selection of Domain
• Selection of suitable predictor variables i.e. Z700, Z500, Tavg, P, SLP
• Selecting number of analogues
CONCLUSION OF STATISTICAL DOWNSCALING MODELS

● Strengths
  — Computationally undemanding thus easy to produce even using your laptops.
  — Simultaneous generation of several meteorological variables
  — Impact-relevant variables not simulated by climate models can be downscaled

● Weaknesses
  — Assumes stationarity of conditional relationships
  — Precipitation amounts highly sensitive to choice of probability distribution function
  — Small scale dynamics and climate feedbacks are not reflected.
  — Requires a sufficient amount of high quality observational data
THANKS