REGIONAL CLIMATE DOWNSCALING

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DEFINITION OF DOWNSCALING

☐ COARSE RESOLUTION (> 100 KM) ATMOSPHERIC DATA OR GLOBAL CLIMATE MODEL (GCM) OUTPUT

☐ LOCAL TO REGIONAL SCALE (10-100 KM) CLIMATE INFORMATION

☐ GOAL: CORRECT FOR SYSTEMATIC BIASES

☐ REGIONAL CLIMATE MODELS (RCMS): TENS OF KM

☐ IMPACT MODELS: POINT CLIMATE OBSERVATIONS
GENERAL APPROACH

LOCAL CLIMATE INFLUENCED BY VARIATIONS IN:

- TOPOGRAPHY
- LAND COVER
- WATER BODIES

SOURCE CCCSN
BASIC APPROACHES

- Interpolation of GCMS: EASY AND FAST IMPLEMENTATION, DISREGARD LOCAL FEATURES OF CLIMATE
- «CHANGE FACTOR», «DELTA CHANGE» OR «PERTUBATION» METHODS
- QUANTILE-QUANTILE METHODS
DELTA METHODS

TEMPERATURE

- A Reference Climatology: E.g. Series of Daily Max Temperature 1961-1990:

  Baseline Scenario \( Y_{1961}, \ldots, Y_{1990} \)

- Compute Changes in the Temperature Variable for the GCM Closest Grid-Box:

  \[ \Delta Y = \bar{Y}_{GCM: future} - \bar{Y}_{GCM: reference} \]

- Add to the Reference Climatology:

  Scaled Scenario \( Y_{1961} + \Delta Y, \ldots, Y_{1990} + \Delta Y \)
A reference climatology: e.g. series of daily max precipitation 1961-1990:

Baseline scenario \( Y_{1961}, \ldots, Y_{1990} \)

Compute changes in the precipitation variable for the GCM closest grid-box:

\[
\Delta Y = \left( \bar{Y}_{GCM:future} - \bar{Y}_{GCM:reference} \right) / \bar{Y}_{GCM:reference}
\]

Multiply to the reference climatology:

Scaled scenario \( Y_{1961} \times \Delta Y, \ldots, Y_{1990} \times \Delta Y \)
DELTA METHODS

PITFALLS

- Scaled and baseline scenarios only differ in their means, maxima and minima.
- Range and variability remain unchanged.
- Spatial pattern of present climate remains unchanged.
- For precipitation: affect the number of rain days and the size of extreme events.
- Temporal sequencing is unchanged: do not account for changes in wet-/dry-spell lengths.
- Choice of GCM grid-box (drift issue).
QUANTILE-QUANTILE METHODS

- Select predictor(s): Observed large-scale atmospheric variable(s)

- Convert predictand and predictor into quantiles:
  
  Rank according to percentile \( F(Y) = p \)

  Sort in ascending order when equal number of observations
QUANTILE-QUANTILE METHODS

ASSOCIATE GCM VALUES TO LOCAL VALUES

- EITHER BY FITTING A REGRESSION
- OR BY USING A NON-PARAMETRIC RELATION

\[ F_{GCM}(Y_{GCM}) = F_{local}(Y_{local}) \]

\[ Y_{local} = F_{local}^{-1}(F_{GCM}(Y_{GCM})) \]

EXTRAPOLATION BEYOND INITIAL DATA RANGE IS DIFFICULT

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CDF-TRANSFORM

- Can be seen as an extension of quantile-quantile which takes into account the distribution of the future data set.

- Assume there exists a transformation $T$ such that:

$$T(F_{GCM:ref}(y)) = F_{loc:ref}(y)$$

Letting:

$$y \leftarrow F_{GCM:ref}^{(-1)}(u)$$

$$T(u) = F_{loc:ref}(F_{GCM:ref}^{(-1)}(u))$$

Assuming this remains valid in the future:

$$F_{loc:fut}(y) = T(F_{GCM:fut}(y))$$

$$\Rightarrow F_{loc:fut}(y) = F_{loc:ref}(F_{GCM:ref}^{(-1)}(F_{GCM:fut}(y)))$$

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CDF-TRANSFORM

- Non-parametric estimation of CDFs:
  \[ F_{\text{loc:ref}}(\cdot), F_{\text{GCM:ref}}(\cdot), F_{\text{GCM:fut}}(\cdot) \]

- We obtain a CDF for future local obs \( F_{\text{loc:fut}}(\cdot) \)

- We can either sample from the CDF or apply quantile-quantile:
  \[ Y_{\text{loc:fut}} = F_{\text{loc:fut}}^{(-1)}(F_{\text{GCM:fut}}(Y_{\text{GCM:fut}})) \]

Extrapolation beyond initial data range is difficult
DOWNSCALING MODELS

Regional climate is conditioned by large-scale climatic state and forcing by local features (topography, land use, ...)

- Dynamical downsampling
- Statistical downsampling
  - Weather typing
  - Transfer function
  - Weather generator
REGIONAL CLIMATE MODELS

**DYNAMICAL DOWNSCALING**

- RCMS simulate climate at resolution of 50km or less
- GCMS provide boundary conditions to RCMS
- RCMS model physics and dynamics however they are computationally demanding and not easily transferred to other regions
- RCMS are sensitive to initial conditions
REGIONAL CLIMATE MODELS

DYNAMICAL DOWNSCALING

☐ Check for bias: testing of RCMS using reanalysis data

Gridded quasi observational data produced by assimilating actual meteorological obs. into a GCM

☐ Even at resolution of 20km, topography is smoothed out

☐ RCMS tend to overestimate precipitation and to underestimate temperature and vice versa

☐ Even with a resolution of 10km, convective processes operating at 1km won't be represented
STATISTICAL DOWNSCALING

STATISTICAL RELATIONSHIP BETWEEN

- LARGE-SCALE ATMOSPHERIC VARIABLES PREDICTORS
  SEA-LEVEL PRESSURE, GEOPOTENTIAL HEIGHT, WIND FIELDS, ABSOLUTE OR RELATIVE HUMIDITY OR TEMPERATURE VARIABLES

- AND LOCAL SURFACE VARIABLES PREDICTANDS
  SINGLE-SITE DAILY PRECIPITATION

CALIBRATION

ERA OR NCEP/NCAR REANALYSIS DATA AT RESOLUTION OF 300-500KM

PROJECTION

GCM OUTPUTS MIGHT NOT HAVE THE SAME GRID SPACING
WEATHER TYPING

STATISTICAL DOWNSCALING

- Weather patterns: Anticyclonic, Easterly, etc...

- Assumption: Given a weather pattern, we observe similar local-scale meteorological conditions

TWO STEPS

1) Identify weather patterns: Clustering of large-scale variables, non-homogeneous hidden Markov models

2) Define distribution of local variables: Analogue approach, distribution/regression conditioned on the weather pattern
EDF WEATHER TYPES
WEATHER TYPING

STATISTICAL DOWNSCALING

ANALOGUE APPROACH

☐ SAMPLE FROM PAST LOCAL OBSERVATIONS WITH THE SAME WEATHER PATTERN

☐ DIFFICULT WHEN THE POOL OF TRAINING OBS. IS LIMITED OR WHEN THE NUMBER OF PREDICTORS IS LARGE

☐ WELL SUITED TO MULTISITE AND MULTIVARIATE DOWNSCALING
WEATHER TYPING

STATISTICAL DOWNSCALING

- Climate change is evaluated via changes in the frequency of weather patterns.
- Characteristics of weather patterns do not change.
- Can downscale highly non-linear predictor-predictand relationship as well as relationships between predictands.
- Assumption that the same weather patterns will deliver the same local responses.
- GCMS are assumed to replicate the same weather patterns.
TRANSFER FUNCTION

STATISTICAL DOWNSCALING

\[ x_i = h(y_i) \]

- **SEVERAL LARGE-SCALE VARIABLES CAN BE CONSIDERED AT SEVERAL GRID-BOXES**

- **DIMENSION REDUCTION IS PERFORMED (PCA)**

- **PICK YOUR FAVOURITE REGRESSION METHOD: MULTIPLE LINEAR REGRESSION, CANONICAL CORRELATION ANALYSIS, ARTIFICIAL NEURAL NETWORKS, GENERALIZED LINEAR MODELLING, SINGULAR-VALUE DECOMPOSITION**
TRANSFER FUNCTION

STATISTICAL DOWNSCALING

CAVEATS

- UNDERESTIMATE EXTREME EVENTS (REGRESSION ESTIMATES THE CONDITIONAL EXPECTATION $E[Y|X = x_i]$)

- PROVIDE ONLY POINTWISE PREDICTION, NO CONFIDENCE INTERVAL OR OTHER MEASURE OF UNCERTAINTY

- DO NOT ACCOUNT FOR TRENDS IN THE VARIABILITY (SO-CALLED HETEROSCEDASTICITY)
WEATHER GENERATOR

STATISTICAL DOWNSCALING

☐ Model the distribution of the local variable

☐ Goal is to reproduce statistical properties of local obs. (mean, variance, extreme values, correlation, ...)

☐ Downscaling: condition the distribution parameters on large-scale variables or on weather patterns

☐ Rainfall occurrence is modelled with a Markov chain and rainfall intensity with a Gamma or Log-normal distribution
MAJOR CAVEATS

NO UNIVERSALLY SUPERIOR DOWNSCALING TECHNIQUES

☐ Predictors should be adequately reproduced by GCMS at the relevant spatial and temporal scales.

☐ Stationarity assumption: relationship remains unchanged in changed climate.

☐ Predictors capture the climate change signal.

☐ Predictors have significant predictive power (no consensus, atmospheric circulation variables s.a. SLP or HG are well reproduced by GCMS however atmospheric humidity predictors s.a. humidity indices or GCM precipitation are also needed).

☐ Choice of predictor domain: single grid point or set of optimal grid points?
INTERCOMPARISON STUDIES

- GCM PREDICTOR SET IS THE MAIN SOURCE OF UNCERTAINTY
- DIFFERENT DOWNSCALING METHODS CAN YIELD DIFFERENT RESULTS EVEN WHEN USING THE SAME SET OF PREDICTORS
- THERE ARE NO UNIVERSALLY OPTIMUM SET OF PREDICTORS
- DOWNSCALING EXTREMES IS MOST PROBLEMATIC
- THE ABILITY TO DOWNSCALE PRESENT CLIMATE DOES NOT IMPLY ACCURACY AT DOWNSCALING FUTURE CLIMATE
- STATISTICAL AND DYNAMICAL DOWNSCALING ARE COMPLEMENTARY
Uncertainty

Future Society Emissions Pathway Climate Model Regional Scenario Impact Model Impacts Adaptation Responses

Not much is known about the significance of impacts model uncertainty.