2017 APCC Training Program on
"User-oriented Statistical Downscaling of Climate Information in Agriculture and Water Resources"

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Alberta Environment and Parks (AEP)

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Who am I?

- **Worked in APCC**
  - Sep. 2014 – Feb. 2017
- **Hydrologist in AEP**
- **Research Interests**
  - Statistical Downscaling
  - Hydrologic modelling
  - Climate change impacts on hydrologic systems
- **Current project**
  - Numerical modelling framework for assessment of cumulative environmental impacts

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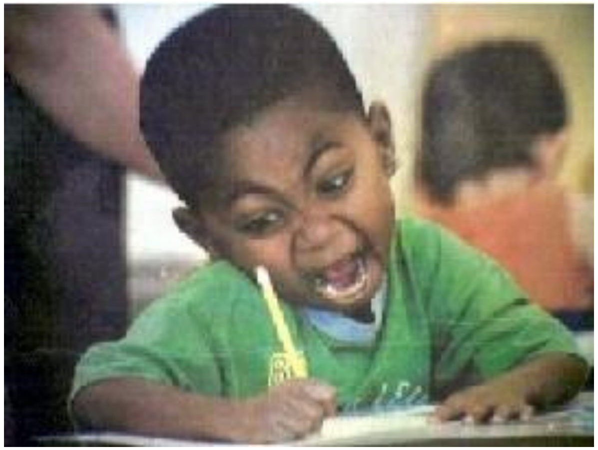
Please help me !!

- **Hard work!**



- **Attention to instructors**

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Please help me !!

- **Remain seated please !!**

- **Do not bring foods in Lotus…Please!!**

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Contents

- **Why do we need downscaling?**
- **Dynamical VS Statistical downscaling**
  - Pros and cons
- **Statistical downscaling methods**
  - Perfect Prognosis (PP)
  - Model Output Statistics (MOS)
  - Long-term trend preserving methods

Rubber suitable to road conditions

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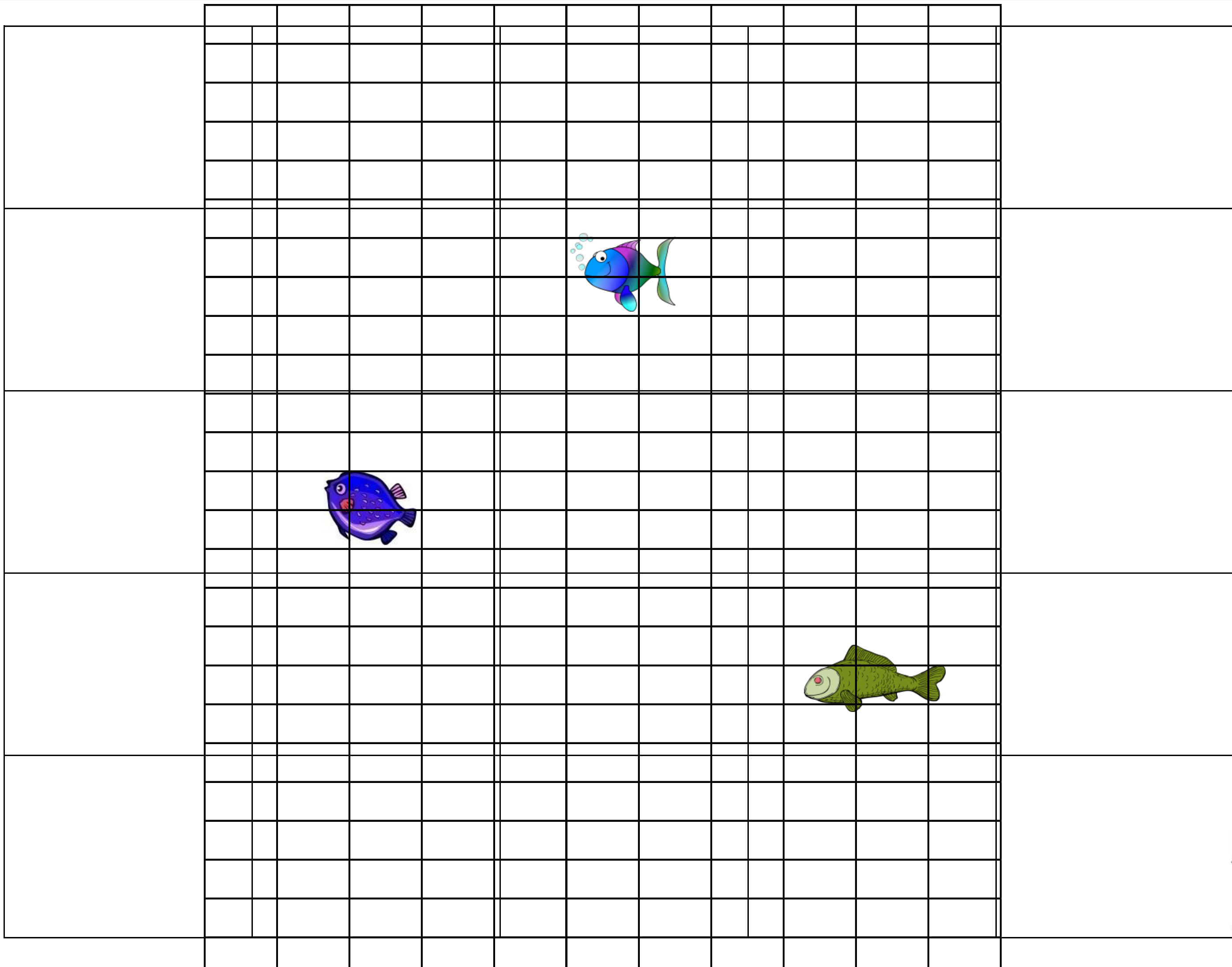
Properly Working?



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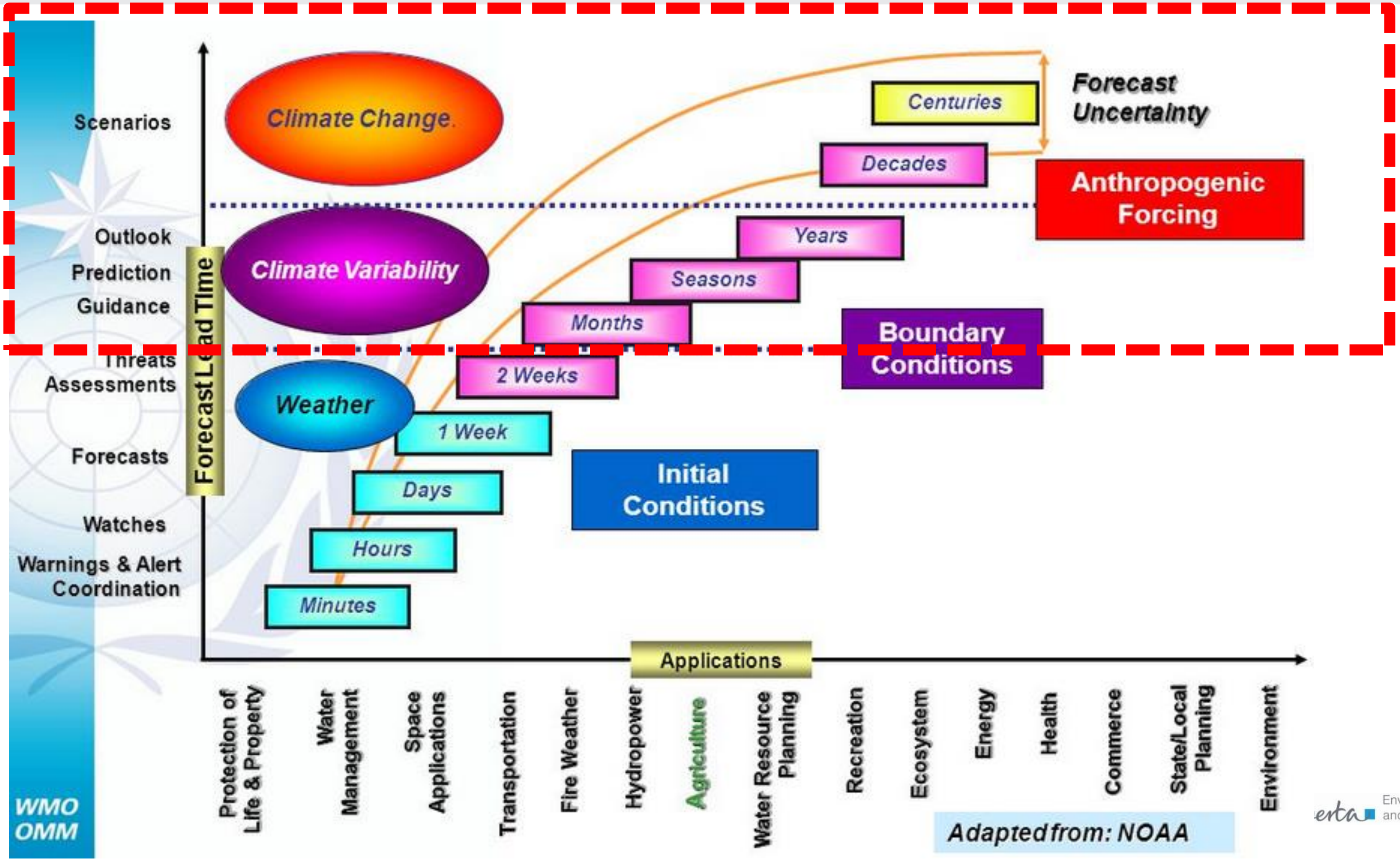
Climate prediction framework

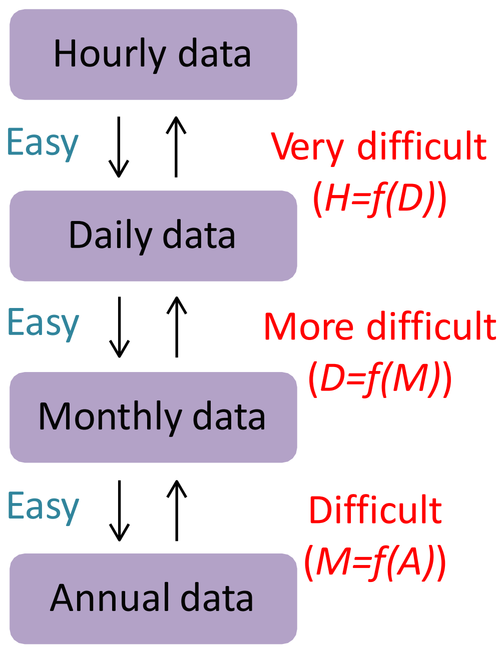


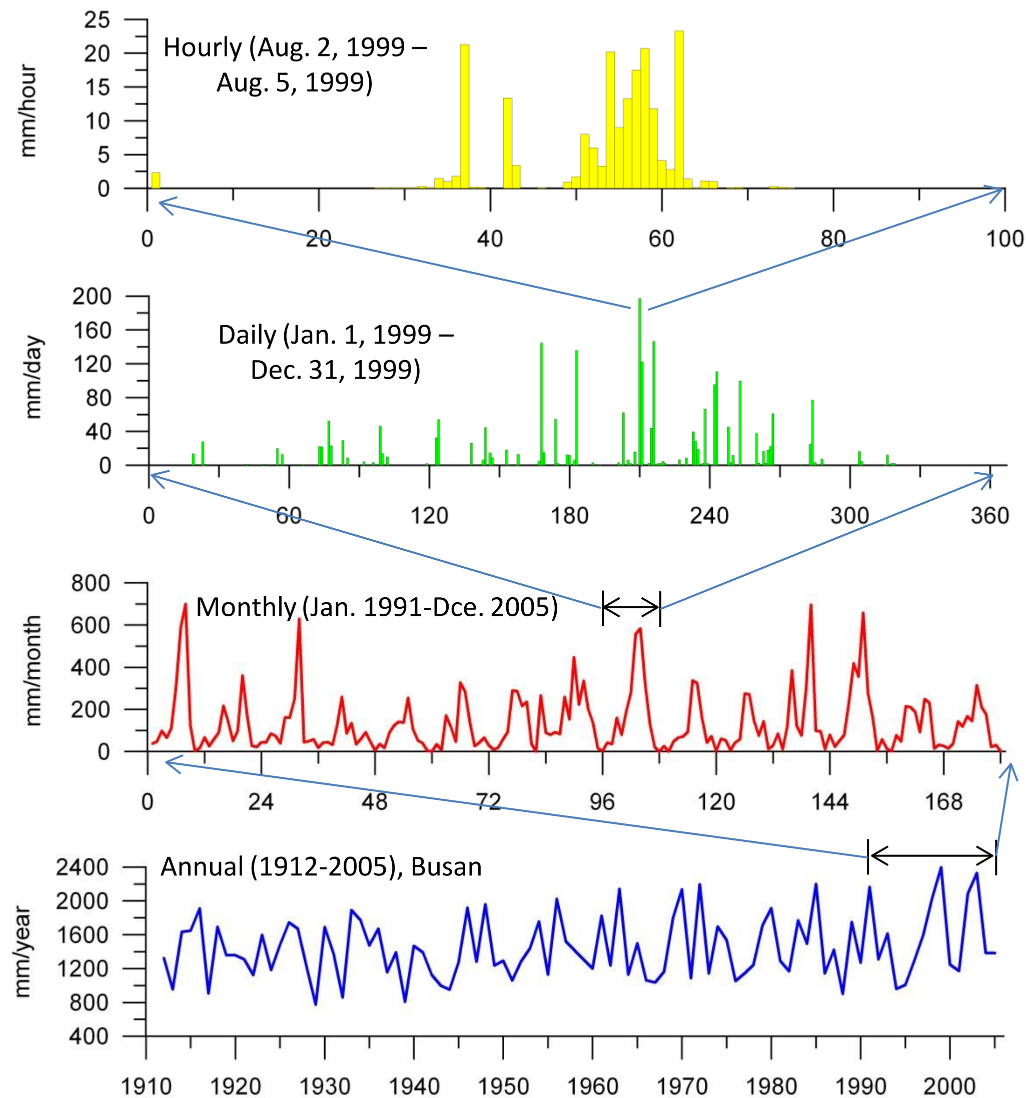
Temporal scale of GCMs

- **Temporal scales in climate forecasts**
  - Predictable signal of seasonal climate
    - Surface ocean and land condition on longer scales (monthly – seasonal)
  - Short time scales
    - Dominated by atmospheric "weather noise"
- **APCC Multiple Models Ensemble (MME)**
  - 6-month forecasts at monthly time step
- **Need of accurate sub-daily or daily climate information**
  - Agricultural or hydrologic applications

Temporal disaggregation

- **Temporal scale problem**

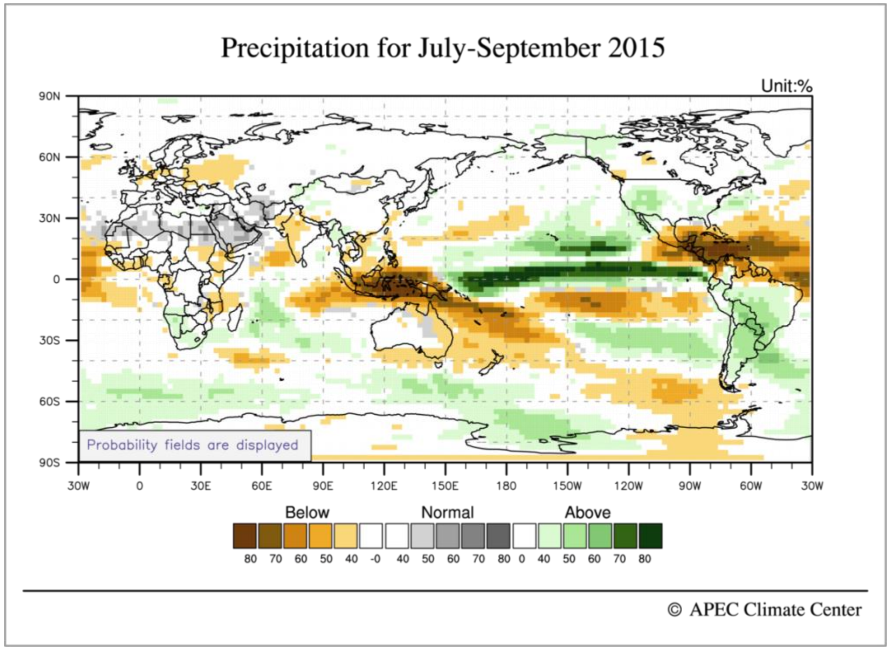


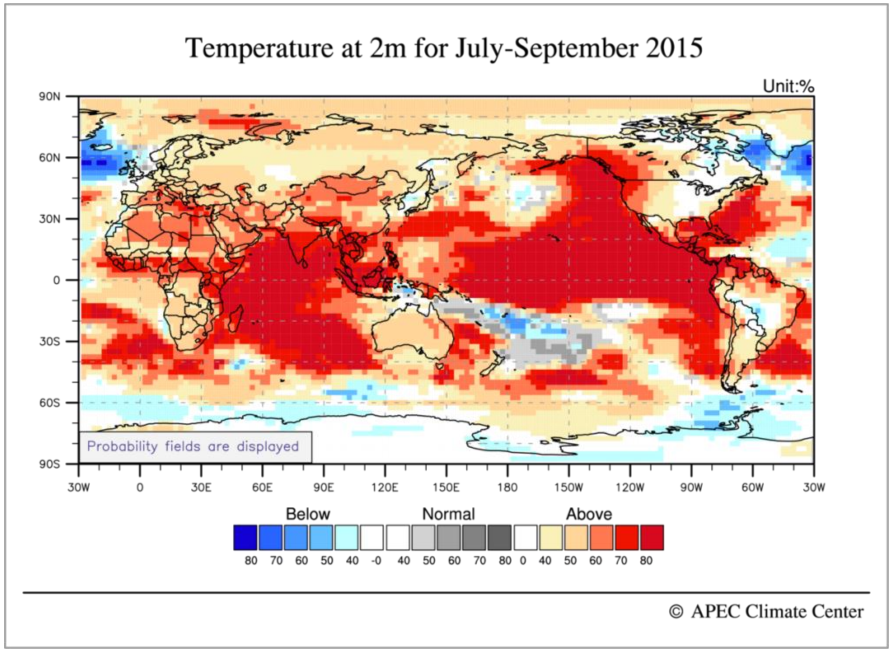


copyright@Jung (2013)

Spatial scale

- **Spatial scale in climate forecasts**
  - Horizontal resolution 100 to 300 km





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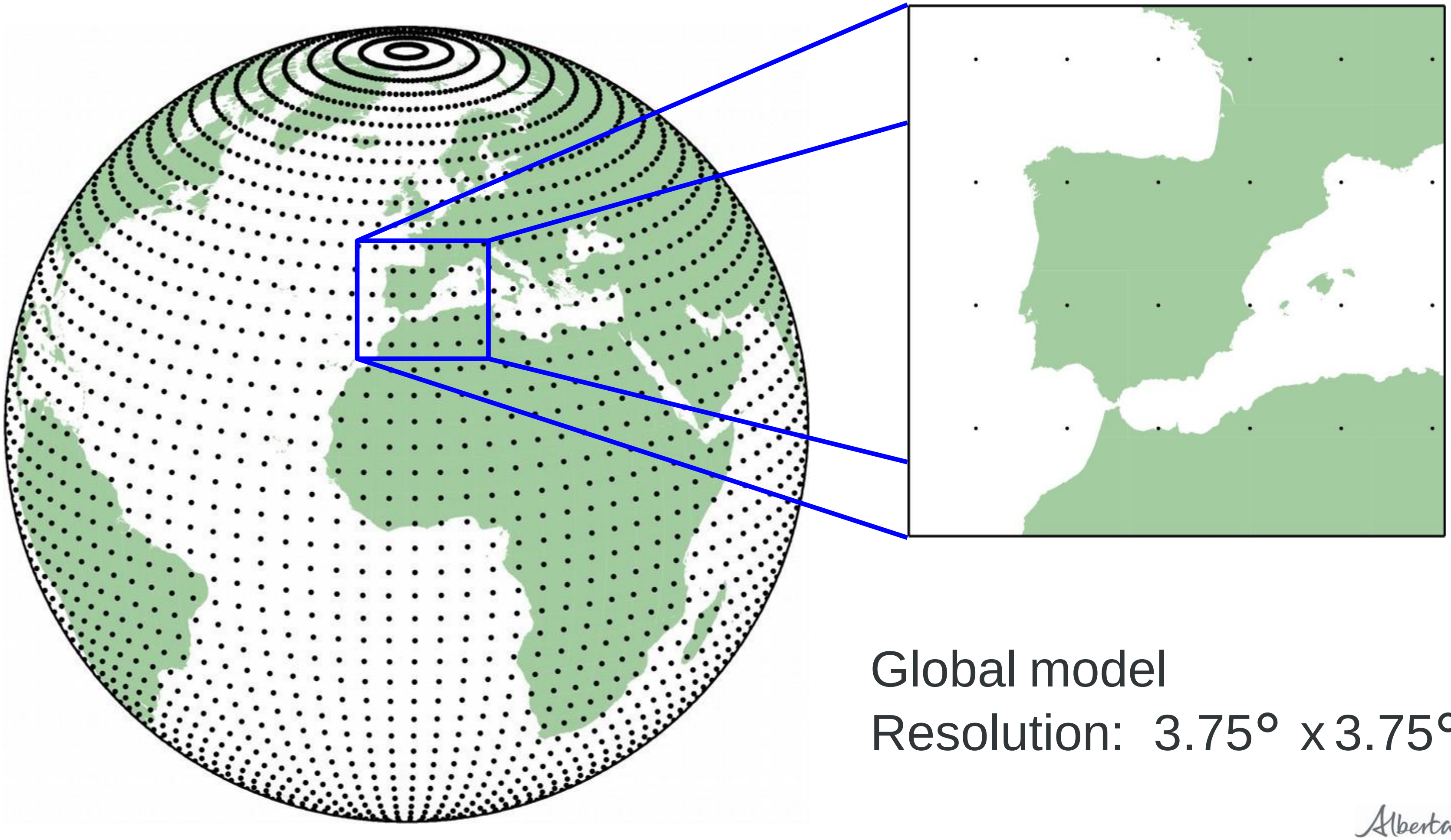
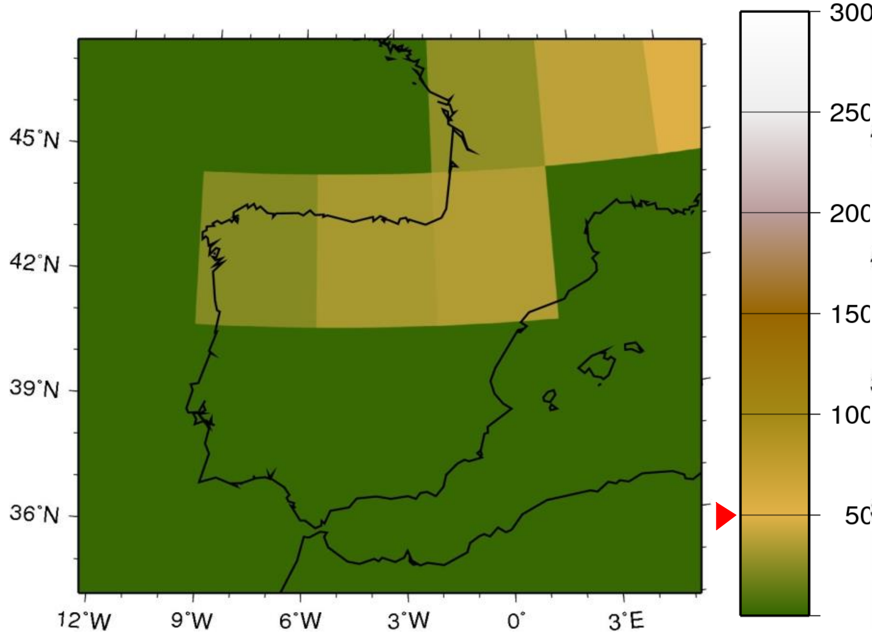
A GCM resolution



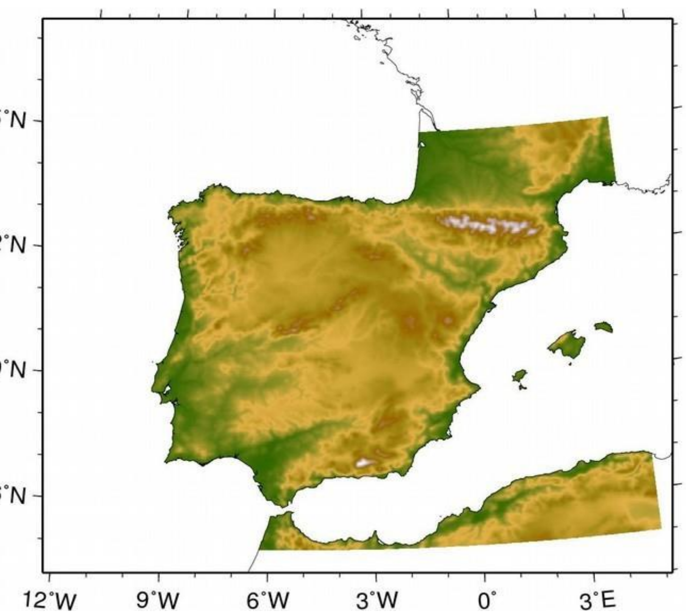
Global model
Resolution: 3.75° x 3.75°

Source: *http://www.meteo.unican.es*

Spatial resolution issue



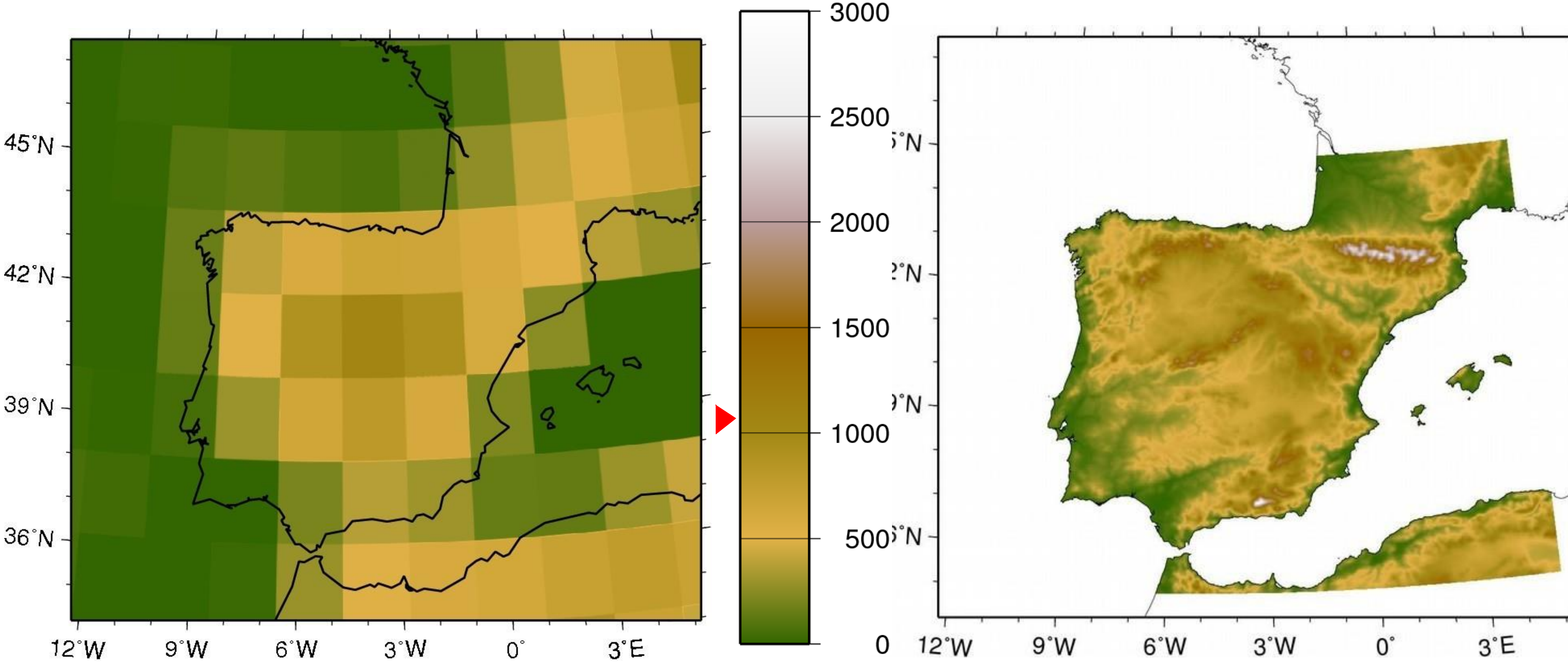
GCM at 3.75°



Real world

Source: http://www.meteo.unican.es

Spatial resolution issue



GCM at 2.5°

Real world

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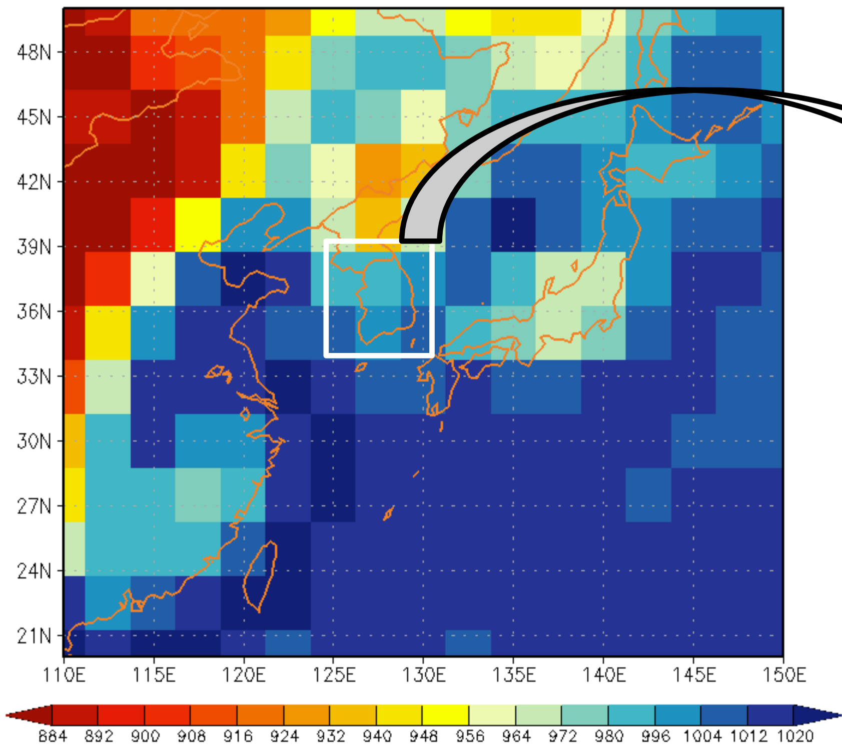
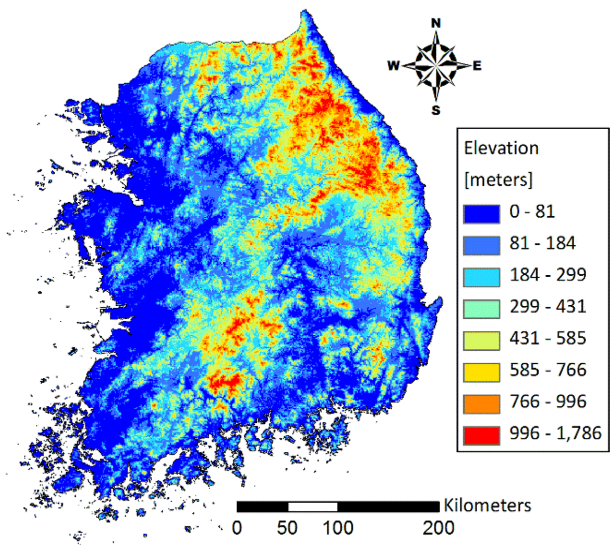
Source: http://www.meteo.unican.es

Spatial resolution issue



CFS at 2.5°



Real world

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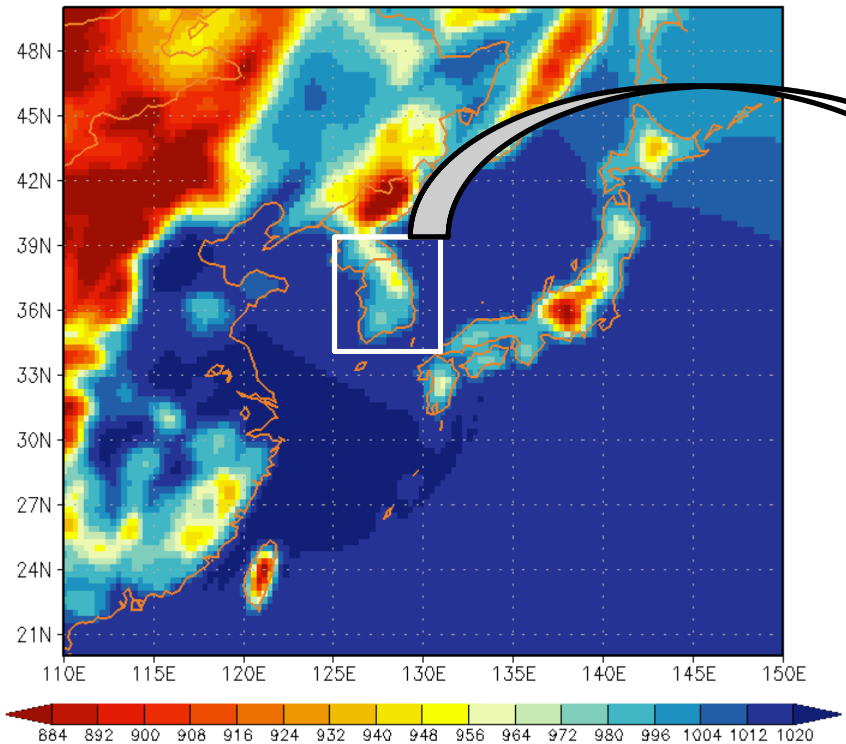
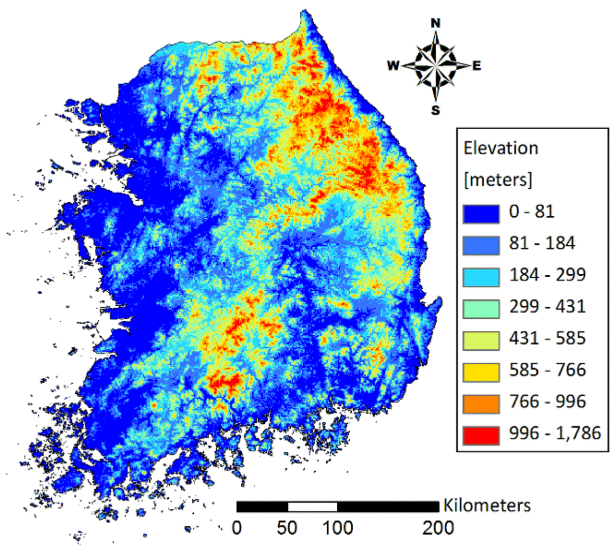
Spatial resolution issue



RCM (GRIMs) at 30 km



Real world

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The gap between climate predictions and regional applications (1)

➢ Spatial scale problem

Observed precipitation (10 X 10km)

1	2	3	4	2	9	5	10
5	4	6	7	2	7	6	11
10	10	10	11	9	11	6	14
13	15	16	15	4	12	8	16
6	11	10	5	1	2	8	5
9	2	9	12	12	13	13	6
10	7	3	10	10	15	15	6
3	12	14	1	10	9	8	7

Perfect GCM (20 X 20km)

3	5	5	8
12	13	9	11
7	9	7	8
8	7	11	9

(1+2+5+4)/4 = 3

Perfect GCM (40 X 40km)

8.25	8.25
7.75	8.75

(1+2+5+4+3+4+6+7+10+10+10+11+13+15+16+15)/16 = 8.25

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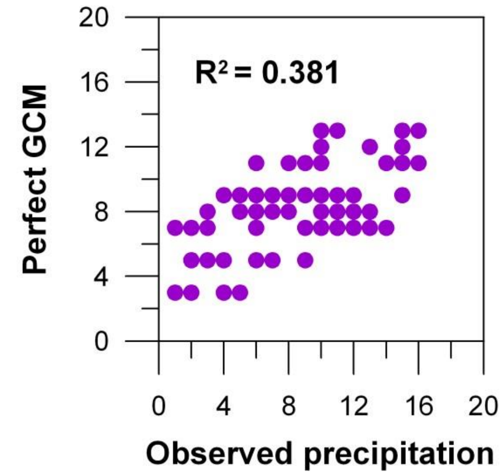
The gap between climate predictions and regional applications (2)

Perfect GCM (20 X 20km)

3	5	5	8
12	13	9	11
7	9	7	8
8	7	11	9

Spatial disaggregation →

3	3	5	5	5	5	8	8
3	3	5	5	5	5	8	8
12	12	13	13	9	9	11	11
12	12	13	13	9	9	11	11
7	7	9	9	7	7	8	8
7	7	9	9	7	7	8	8
8	8	7	7	11	11	9	9
8	8	7	7	11	11	9	9

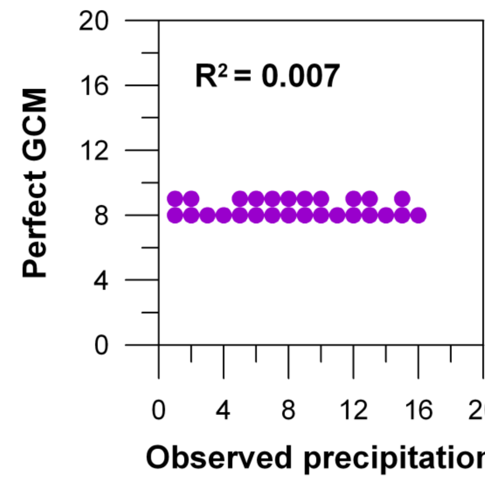


Perfect GCM (40 X 40km)

8	8
8	9

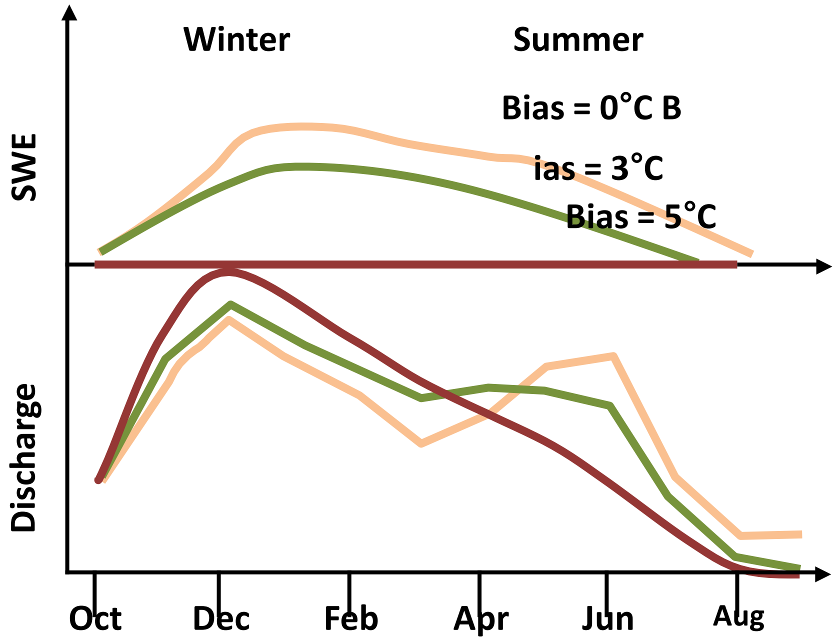
Spatial disaggregation →

8	8	8	8	8	8	8	8
8	8	8	8	8	8	8	8
8	8	8	8	8	8	8	8
8	8	8	8	8	8	8	8
8	8	8	8	9	9	9	9
8	8	8	8	9	9	9	9
8	8	8	8	9	9	9	9
8	8	8	8	9	9	9	9



Potential impacts of systematic bias (1)

➤ Warm bias in winter temperature



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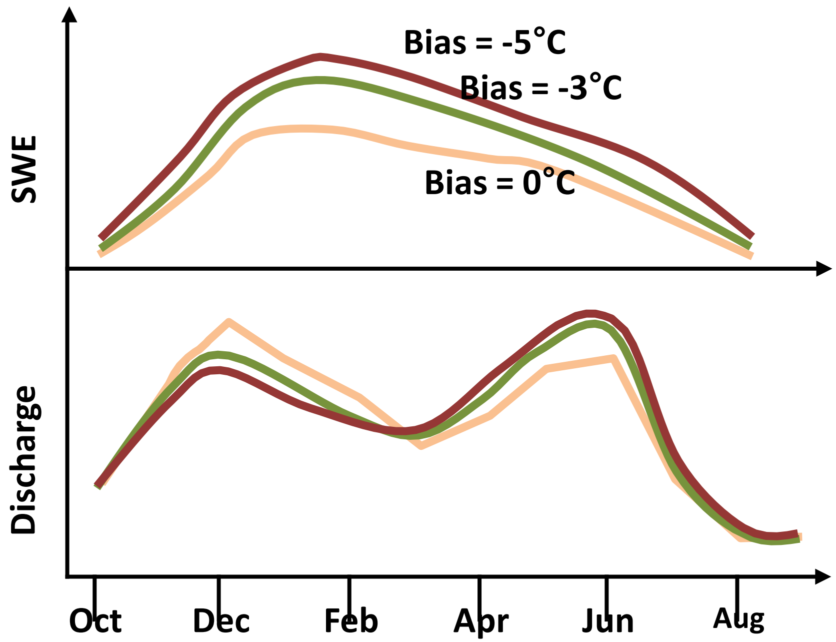
Potential impacts of systematic bias (2)

➢ **Cold bias in winter temperature**



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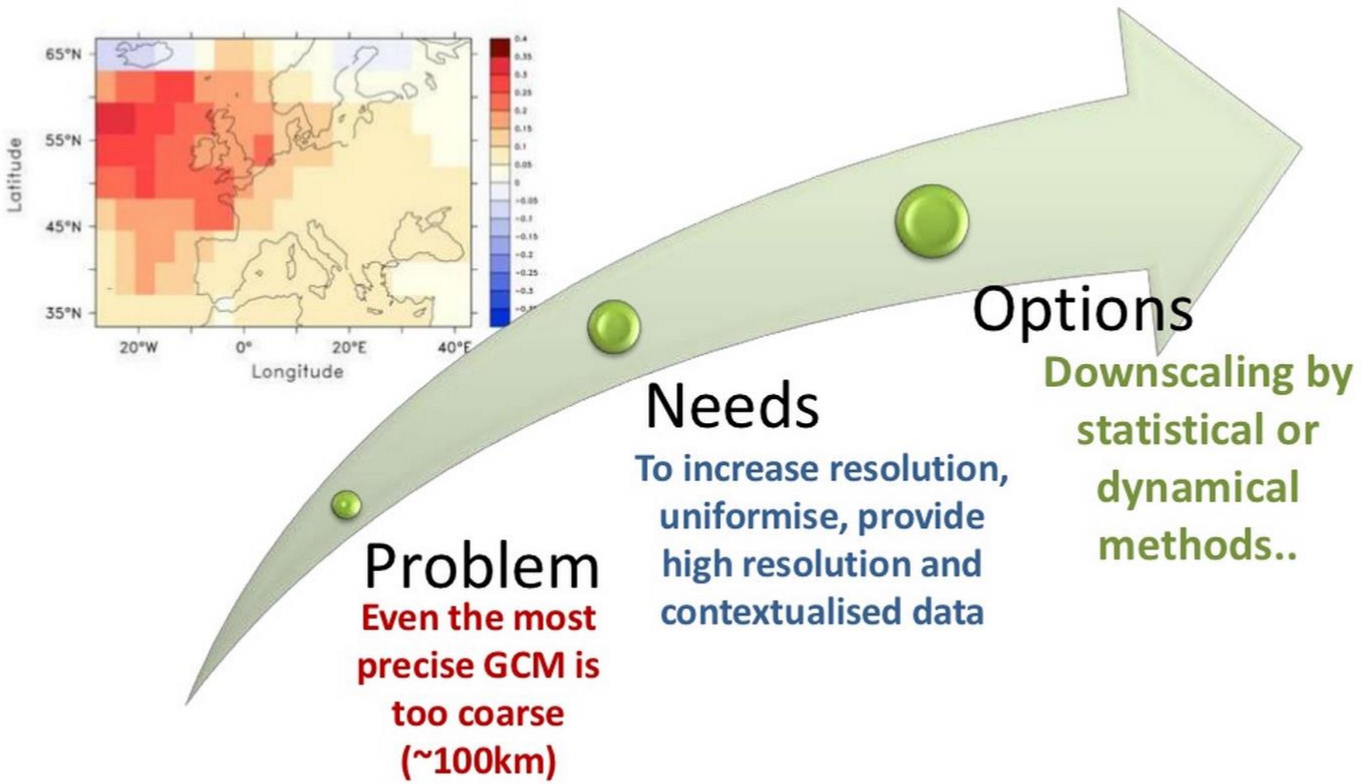
Needs & Options to use GCM's information

➢ Downscaling



Source: Navarro et al. (2012)

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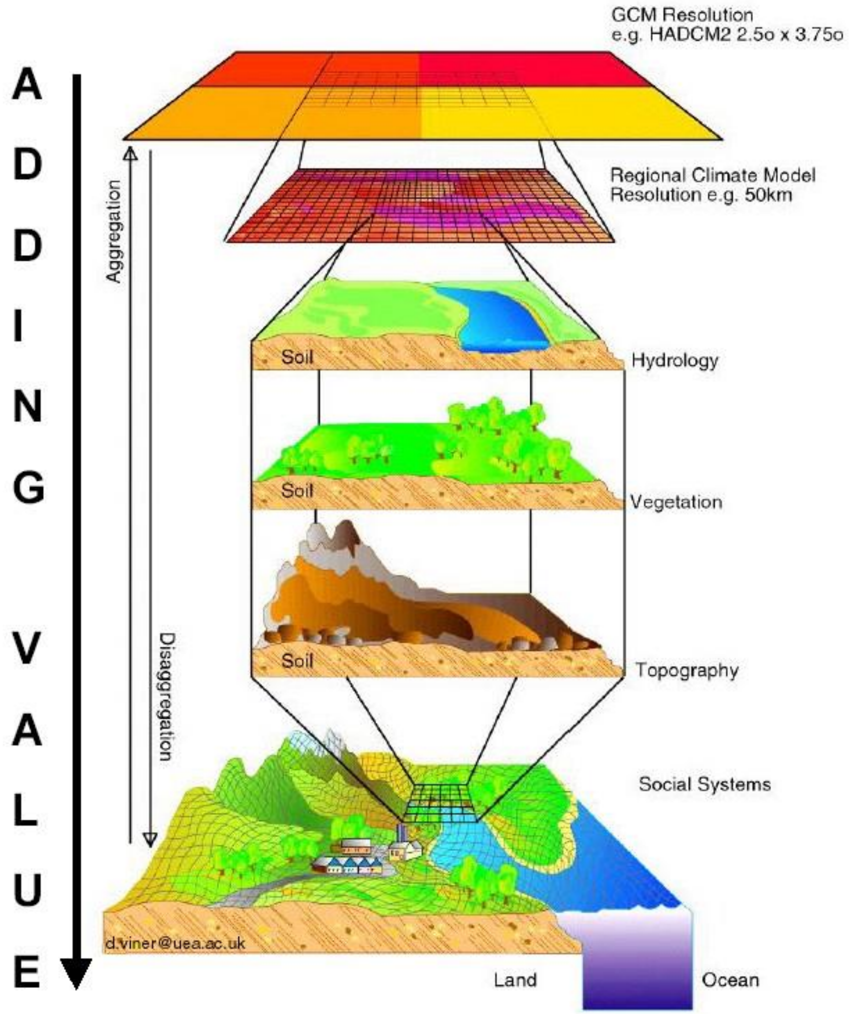
Downscaling



Downscaling techniques try to adapt the **coarse global model output to the local features** of a given region.

Source: ORASECOM 2010

Statistical Downscaling Methods

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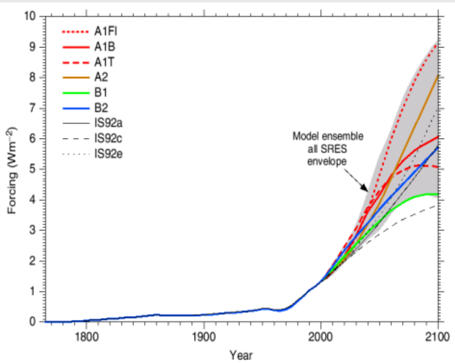
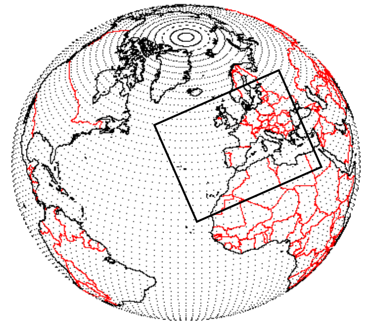
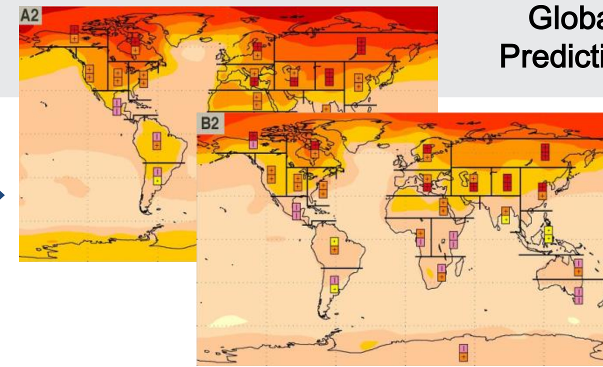
Downscaling techniques

Emission Scenarios



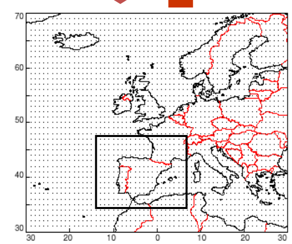
GCM





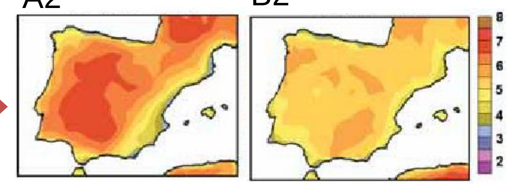
Global Predictions

RCM



Dynamical Downscaling *runs regi-onal climate models in reduced domains with boundary conditions given by the GCMs.*

A2 B2

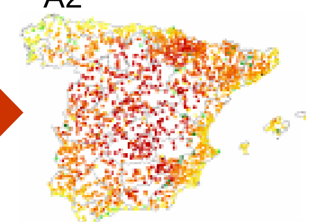


Historical Records

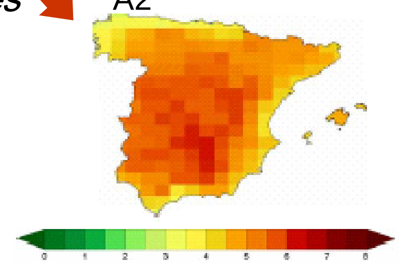
$$Y = f\,(X;\theta)$$

Different tecniques

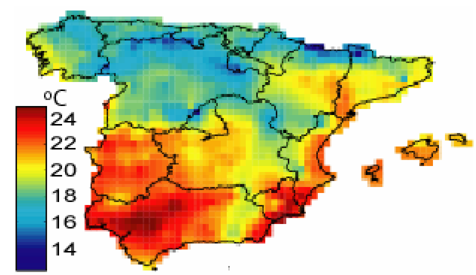
A2



A2



Climatology (1961-90)



Statistical Downscaling *is based on empirical models fitted to data using historical records.*

Source: http://www.mdm.unican.es

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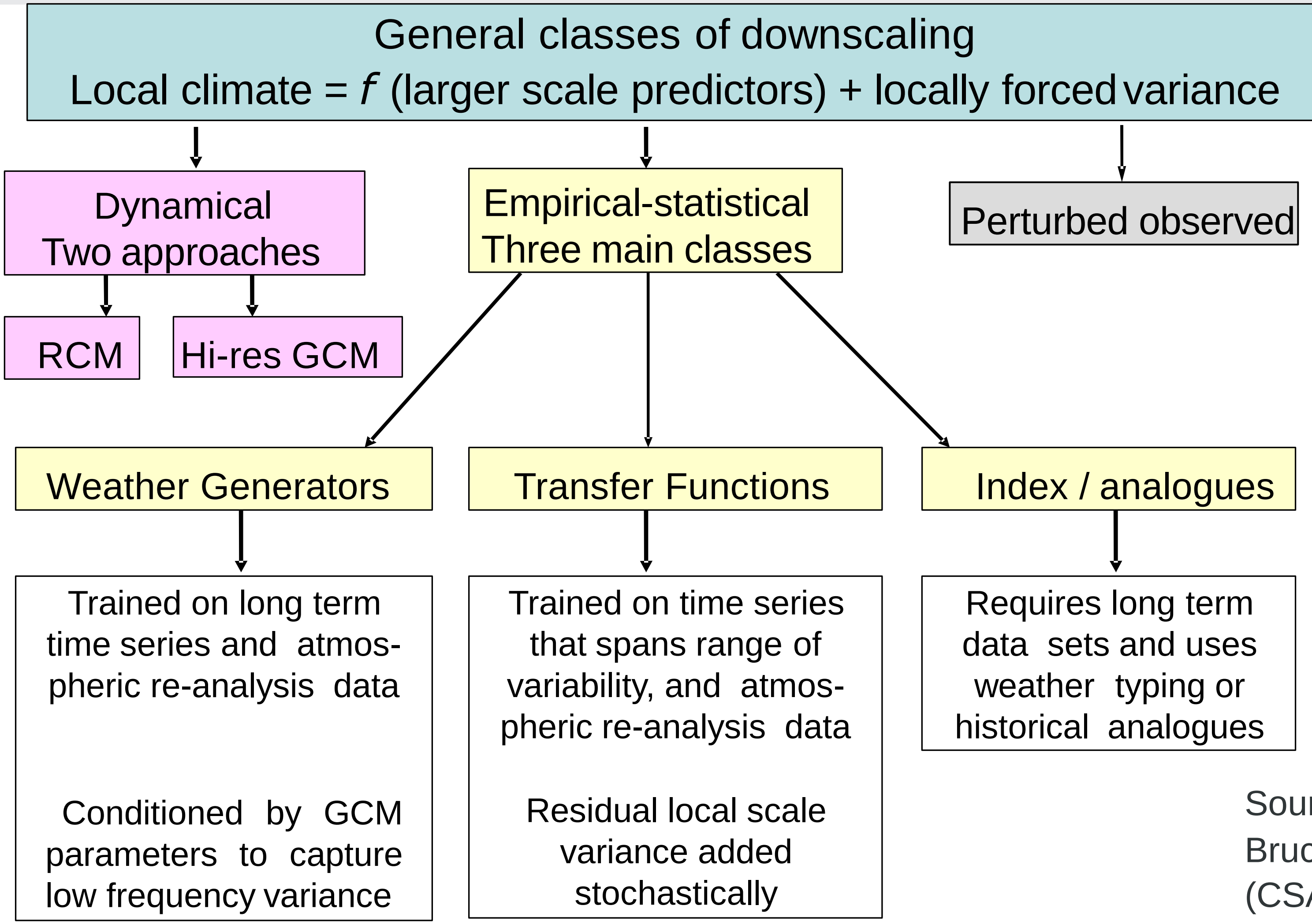
Downscaling techniques



Source:
Bruce Hewitson
(CSAG)

Pros and cons

➢ Dynamical and Statistical Downscaling

Method		
Statistical	• Easy and efficient to apply • Fine resolution • Able to directly incorporate observations into method • Apply to all GCMs	• Needs a reliable long-term observed data • Does not account for non-stationarity in the predictor-predictand and relationship • Dependent on choice of predictors
Dynamical	• Physical-based process • Produce numerous variables • Sub-daily data available • Providing climate information at un-gauged points	• Computationally intensive • Limited resolution (25-50km) • Dependent on RCM parameterization • Considerable internal-variability (systematic bias)

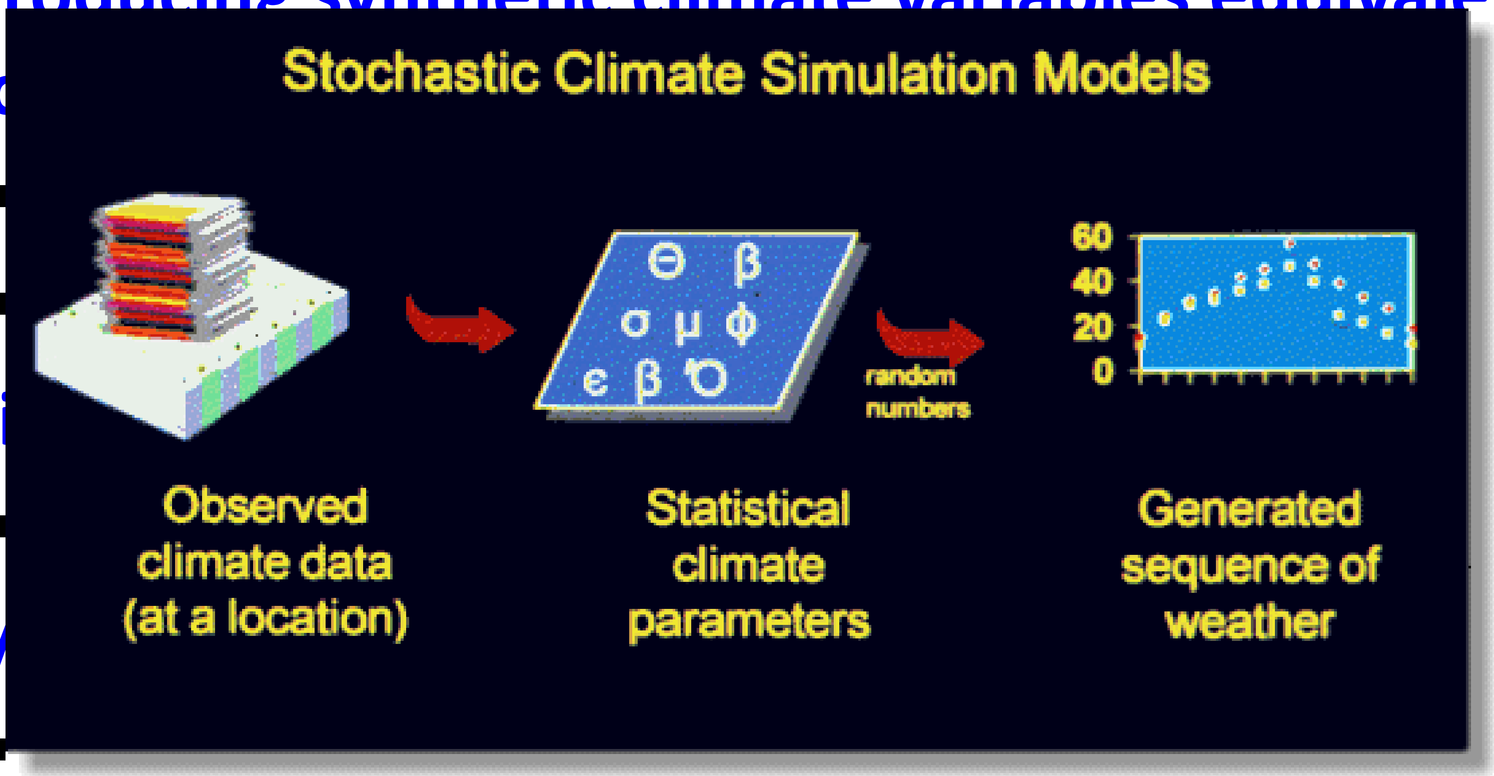
Reference: Cooney, 2012, Downscaling Climate Models: Sharpening the Focus on Local-Level Changes, *Environ Health Perspect* 120:a22-a28

Weather Generator (WG)

- Producing synthetic climate variables equivalent to

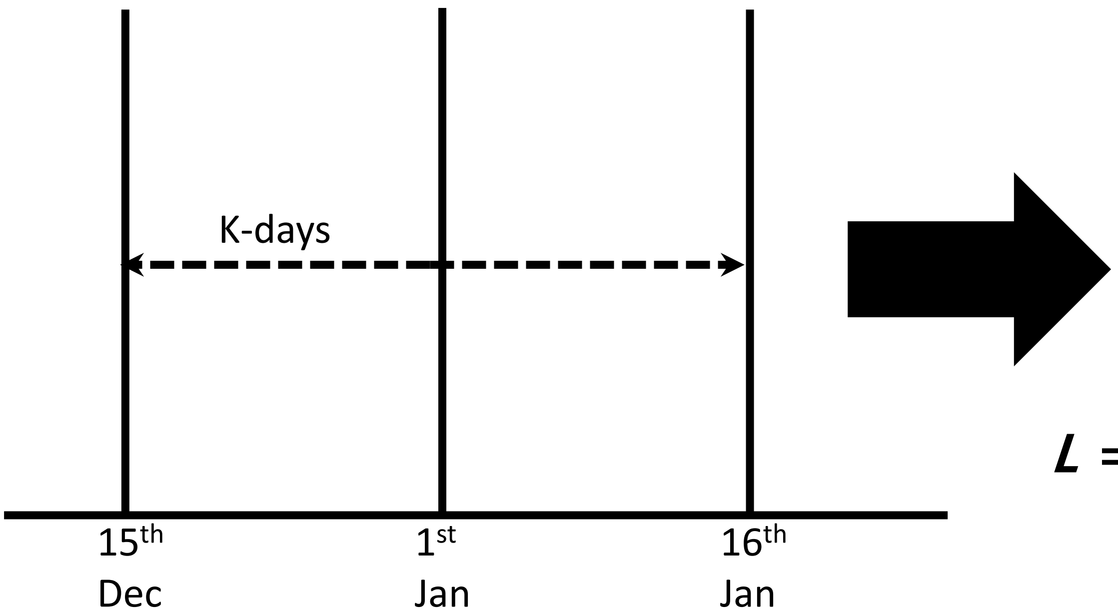
- Si

- M



Weather Generator (WG)

➢ K-nearest neighbor (K-NN) WG



Collecting historical data

$$\begin{cases} Dec15/1976 \\ Dec15/1977 \\ \vdots \\ Jan16/2015 \end{cases}$$

$$L = (k + 1) \times N - 1 \text{ days}$$

➢ Distance for all candidates

$$d_k = \sqrt{\left(\overline{X}_t - \overline{X}_k\right) C_t^{-1} \left(\overline{X}_t - \overline{X}_k\right)^{\mathrm{T}}}$$

K-nearest neighbor (K-NN) WG

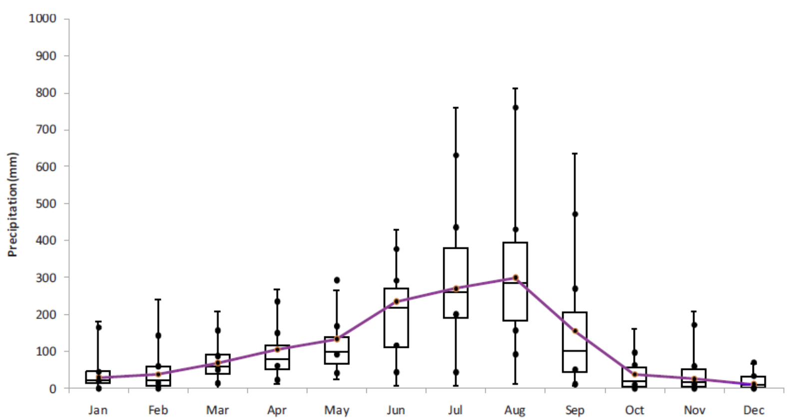
Table 1. Variable Combinations for the WG Models

WG models	WG-5Var	WG-4Var	WG-3Var	WG-2Var
Variables	Precipitation, temperature, relative humidity, wind speed, sea level pressure	Precipitation, temperature, relative humidity, wind speed	Precipitation, temperature, relative humidity	Precipitation, temperature

Table 2. Median Absolute Bias of Four WG Models

	Youngju		Gumi		Jinju	
WG models	Precipitation (mm)	Temperature (°C)	Precipitation (mm)	Temperature (°C)	Precipitation (mm)	Temperature (°C)
WG-2Var	10.10	0.18	7.12	0.10	9.84	0.23
WG-3Var	8.77	0.13	6.41[a]	0.18	9.54	0.09
WG-4Var	14.19	0.19	11.42	0.17	16.14	0.17
WG-5Var	12.36	0.19	8.09	0.17	14.70	0.17

[a]Best performance (lower number represents the better performance).



(a) WG-3Var

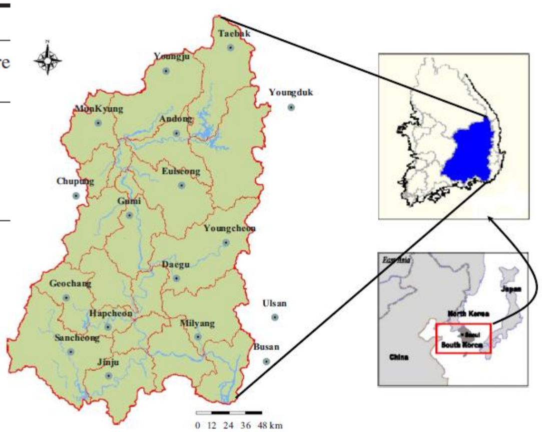


Fig. 1. Nakdong River Basin, Korea

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K-NN WG under Climate Change

Climate Change Impact Assessment Using K-Nearest Neighbor Weather Generator: Case Study of the Nakdong River Basin in Korea

Hyung-Il Eum[1]; Slobodan P. Simonovic, M.ASCE[2]; and Young-Oh Kim, M.ASCE[3]

Abstract: This study presents a methodology for assessing impacts of climate change in regional-scale hydrology using the K-nearest neighbor weather generator (WG) model in combination with the outputs of global circulation models (GCMs) and hydrologic rainfall-runoff model. The Nakdong River Basin in Korea is used as a case study. The study applies a systematic approach to select the variables for the WG model from five meteorological variables available in the basin. In addition, the GCMs' projections based on a B1 emission scenario are incorporated into the proposed WG model to reflect the impacts of climate change, consequently generating the meteorological series for 60 years. Meteorological data for historic and two climate scenarios (dry and wet) are generated. The generated time series of meteorological variables are used with the streamflow synthesis and reservoir regulation rainfall-runoff model to calculate the streamflow at 25 sub-basins. The results demonstrate that the WG models combined with the GCMs' outputs are able to provide future weather conditions for the assessment of climate change impacts. One of the major findings of the study is the potential severity of drought impacts that may increase the historical drought duration in the basin up to three times.

DOI: 10.1061/(ASCE)HE.1943-5584.0000251

CE Database subject headings: Climate change; Streamflow; Case studies; Korea, South.

Author keywords: Weather generator; Climate change; Streamflow.

Introduction

Climate change is generally defined as a long-term significant change in average weather that affects regional environment (IPCC 2007). Climate change research faces two major difficulties: uncertainty arising from the choice of emission scenarios and the necessity for regionally scaled assessments. To resolve these problems, many scientists have attempted to generate plausible, globally scaled scenarios over a long period of time which are then downscaled to investigate what will happen in the future at the regional scale.

General circulation models (GCMs) provide a range of feasible future climate conditions on a global scale employing various emission scenarios to consider the uncertainty of future conditions. The outputs of GCMs include meteorological data such as temperature, precipitation, wind speed, humidity, and pressure. However, GCMs currently use a very coarse grid size that is generally inappropriate for the regional-scaled assessments. Therefore, downscaling schemes are used to resolve the spatial resolution problem. Dynamic downscaling incorporates the GCMs' results directly as a boundary condition using the complex physical-based algorithms to describe atmospheric processes in limited-area models or regional climate models (Jones et al. 1995; Kidson and Thompson 1998; Wilby et al. 1998). The dynamic downscaling method cannot generate the regional series longer than the GCMs series and also requires significant computational effort and time to provide the proper regional-scaled results. Contrary to the dynamic downscaling, statistical downscaling methods are based on the statistical relationships between the GCM outputs and the observed historical data within a region (Wilby et al. 2000; Wood et al. 2002; Bardossy et al. 2005; Mehrotra and Sharma 2005, 2006a; Haylock et al. 2006). Therefore, statistical downscaling requires less effort when applied to a new region because of the simpler computational procedures.

Although many researchers have applied various statistical downscaling methods using mathematical tools such as linear and nonlinear regressions (Wilby et al. 1998), canonical correlation analysis (Landman et al. 2001), and artificial neural networks (Cannon and Whitfield 2002; Tripathi and Srinivas 2005), they still provide unreliable consequences in case of extrapolation beyond the historical data. The weather-typing approach, a category of statistical downscaling schemes, introduces the weather patterns (conditional probability density function, PDF) of the large-scale data (GCMs output) to couple with local measurements. Stochastic downscaling models incorporate daily GCM simulations and are able to model low-frequency variability using a range of formulations (Mehrotra and Sharma 2006b; Vrac and Naveau 2007). However, the main difference between stochastic downscaling techniques and the approach used in this paper is in the need for prior knowledge of conditional probability density function for successful implementation of stochastic downscaling approach. Recently, weather generator (WG) has been used as another downscaling procedure to generate meteorological data,

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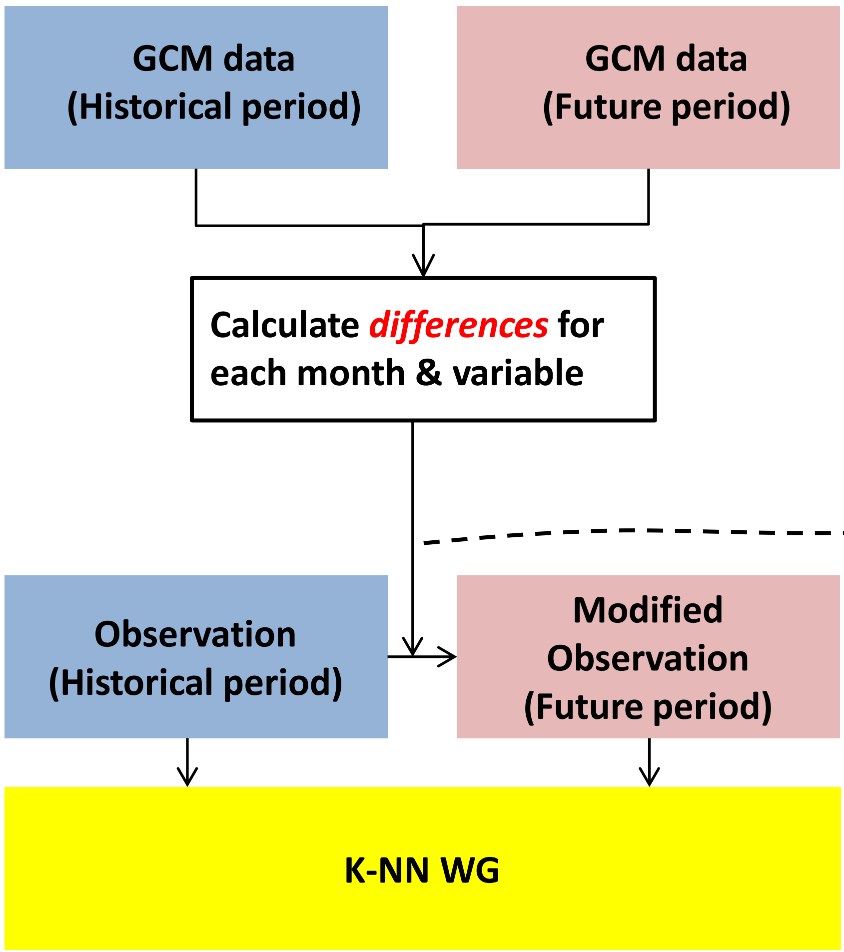
[3]Associate Professor, Dept. of Civil and Environmental Engineering, Seoul National Univ., 599 Gwanak-ro, Gwanak-gu, Seoul 151-742, Korea.

Note. This manuscript was submitted on January 12, 2009; approved on March 26, 2010; published online on April 14, 2010. Discussion period open until March 1, 2011; separate discussions must be submitted for individual papers. This paper is part of the *Journal of Hydrologic Engineering*, Vol. 15, No. 10, October 1, 2010. ©ASCE, ISSN 1084-0699/2010/10-772–785/$25.00.



$$P_{fut} = P_{his} \times P_{delta}$$

$$T_{fut} = T_{his} + T_{delta}$$

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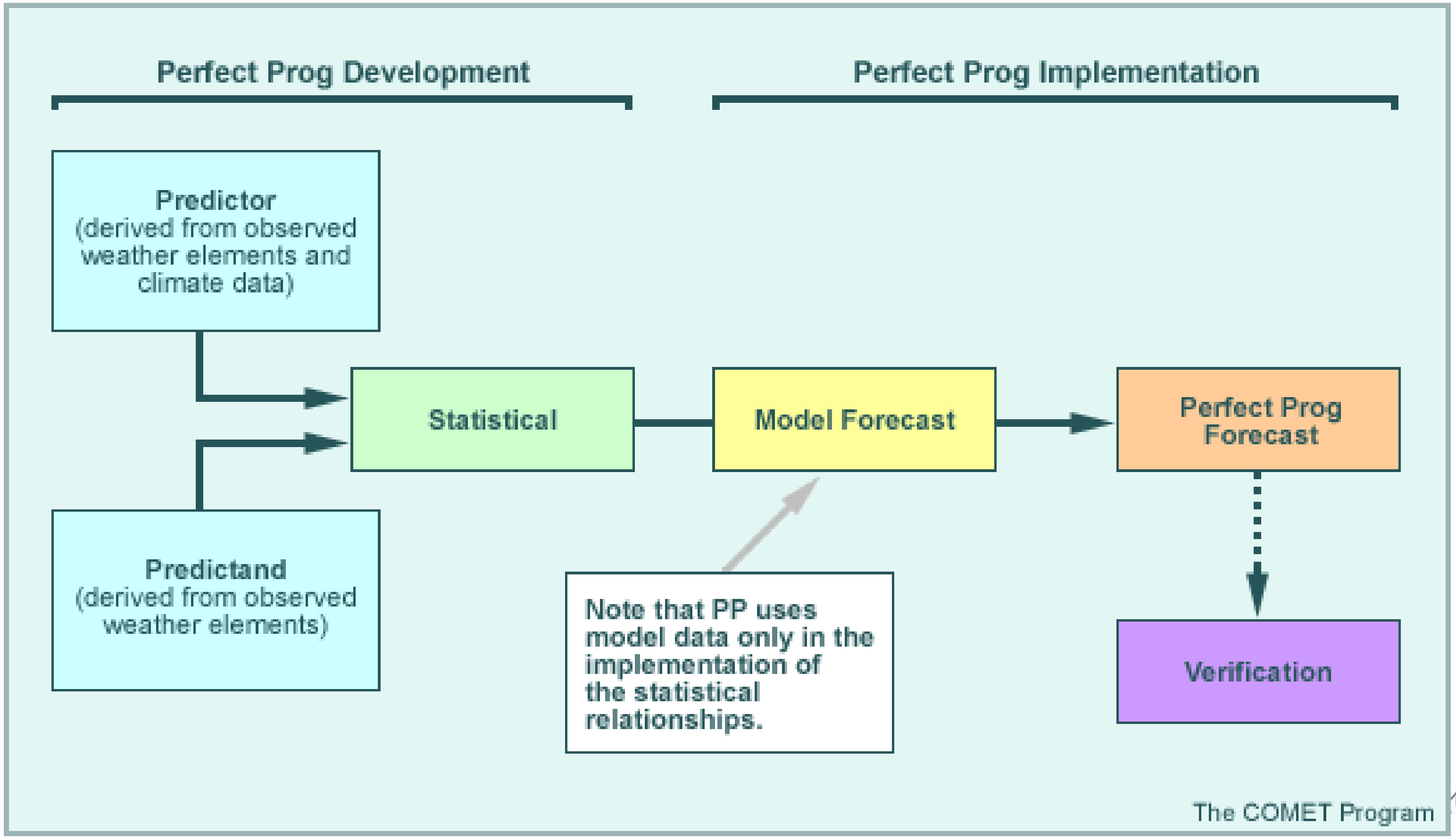
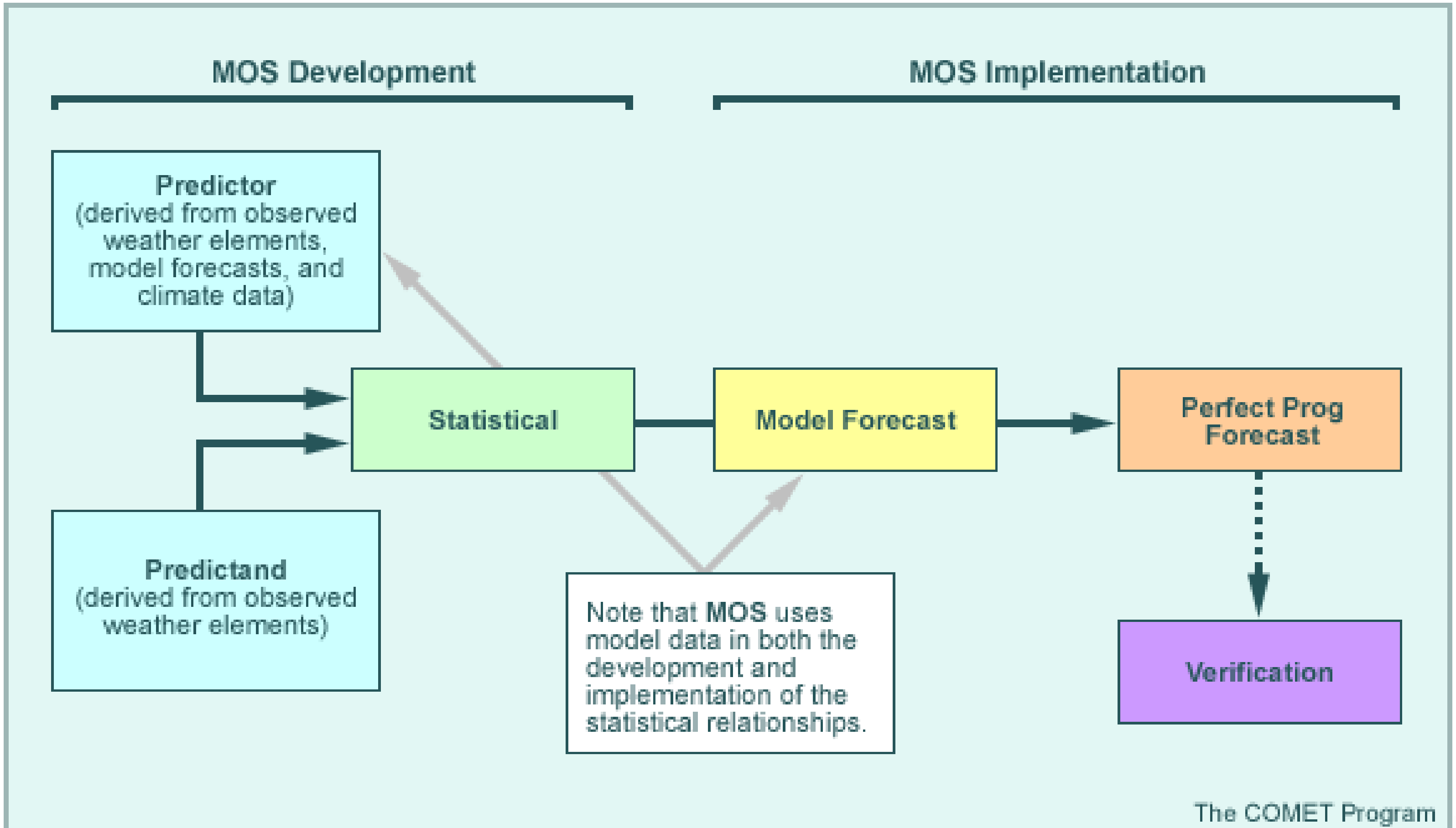
Statistical downscaling techniques

➢ Perfect Prognosis (PP)



Source: http://www.met.tamu.edu/class/metr452/models/2001/output.html#Statistical Weather Forecasting

Model Output Statistics (MOS)



Source: http://www.met.tamu.edu/class/metr452/models/2001/output.html#Statistical Weather Forecasting

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MOS

- **Predictors**
  - From the global (or regional) model for both training and downscaling phases
- **Need the model output**
  - Day-to-day correspondence with observations
- **These methods can work with the variable of interest as predictor**
  - Local precipitation can be derived from the direct model precipitation forecasts

MOS models

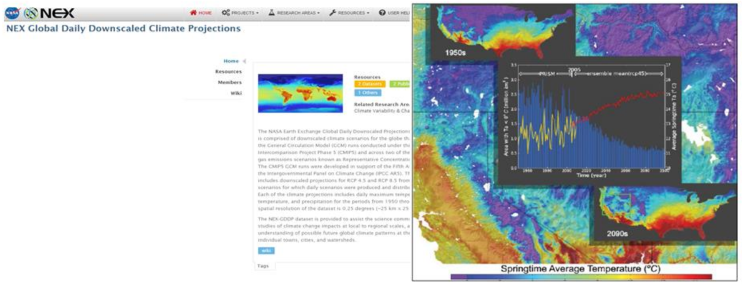
➢ Most popular

- Bias Correction/Spatial Disaggregation (BCSD)
- Bias Correction/Constructed Analogs (BCCA)

NASA Earth Exchange Global Daily Downscaled Projections (NEX-GDDP)

➢ **BCSD**

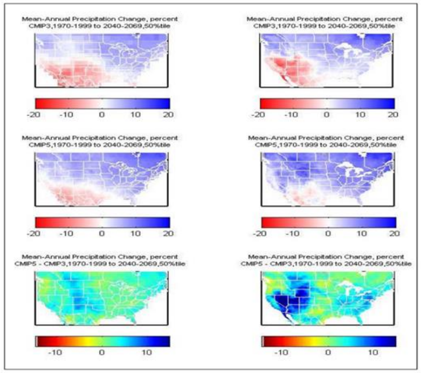
- 1950 through 2100 at 0.25 degrees (~25 km x 25 km)
- 21 GCMs × 2 RCPs



Downscaled CMIP3 and CMIP5 climate and hydrology projections (DCHP)

➢ **BCSD & BCCA**

- 1950-2099 at 1/8° (~12km)



http://gdo-dcp.ucllnl.org/downscaled_cmip_projections/dcpInterface.html#Welcome

Post Processing…Bias Correction

- **Adjusting GCM-driven values at a target point or region to better correspond to reference (e.g. observed) data**
  - bias-correction (systematic errors)
- **Biases in**
  - Single variable
    - Mean, variance, shape of distribution
  - Multiple variables
    - Dependence structure (Cross correlation)
- **Marginal distributions via quantile mapping**

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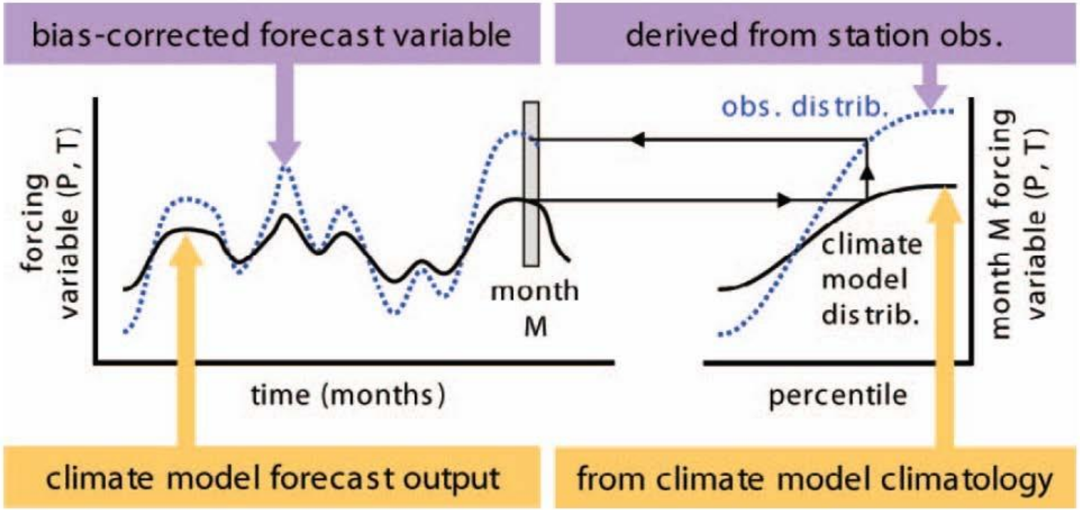
Bias Correction/Spatial Disaggregation (BCSD)

- **Statistical bias correction of GCM simulations**
  - Quantile mapping
- **Spatial downscaling to fine scale (i.e. stations)**
- **Temporal disaggregation from monthly to daily**



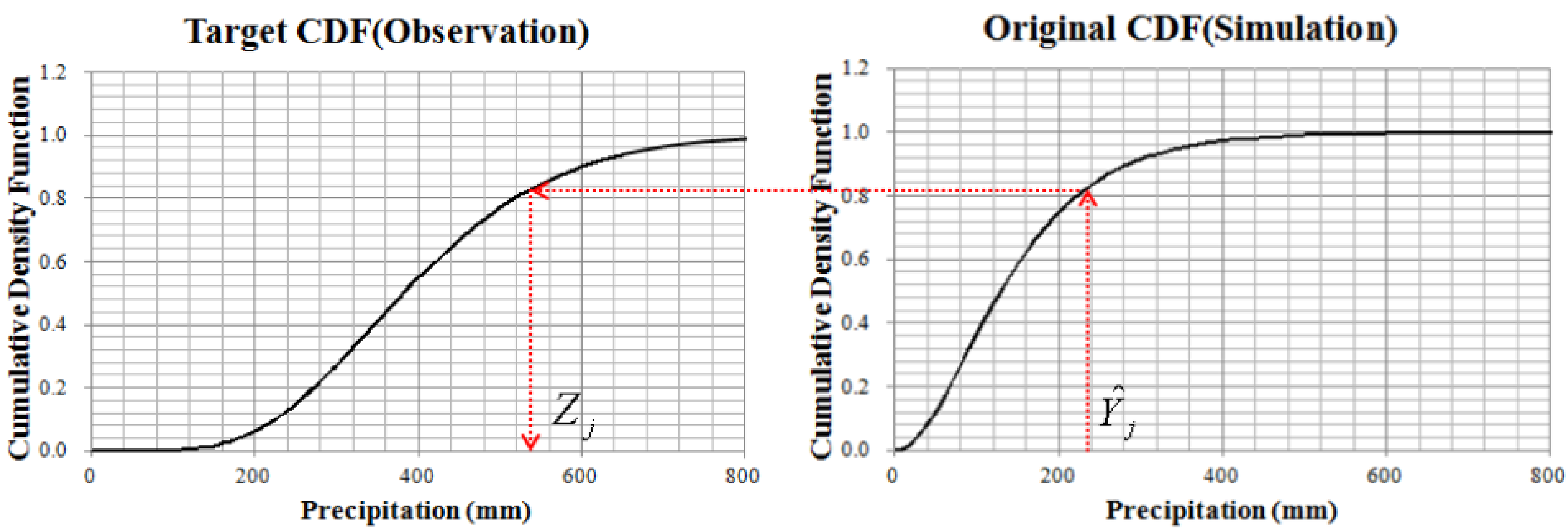
Source: Wood et al 2006, BAMS

Bias Correction/Spatial Disaggregation (BCSD)

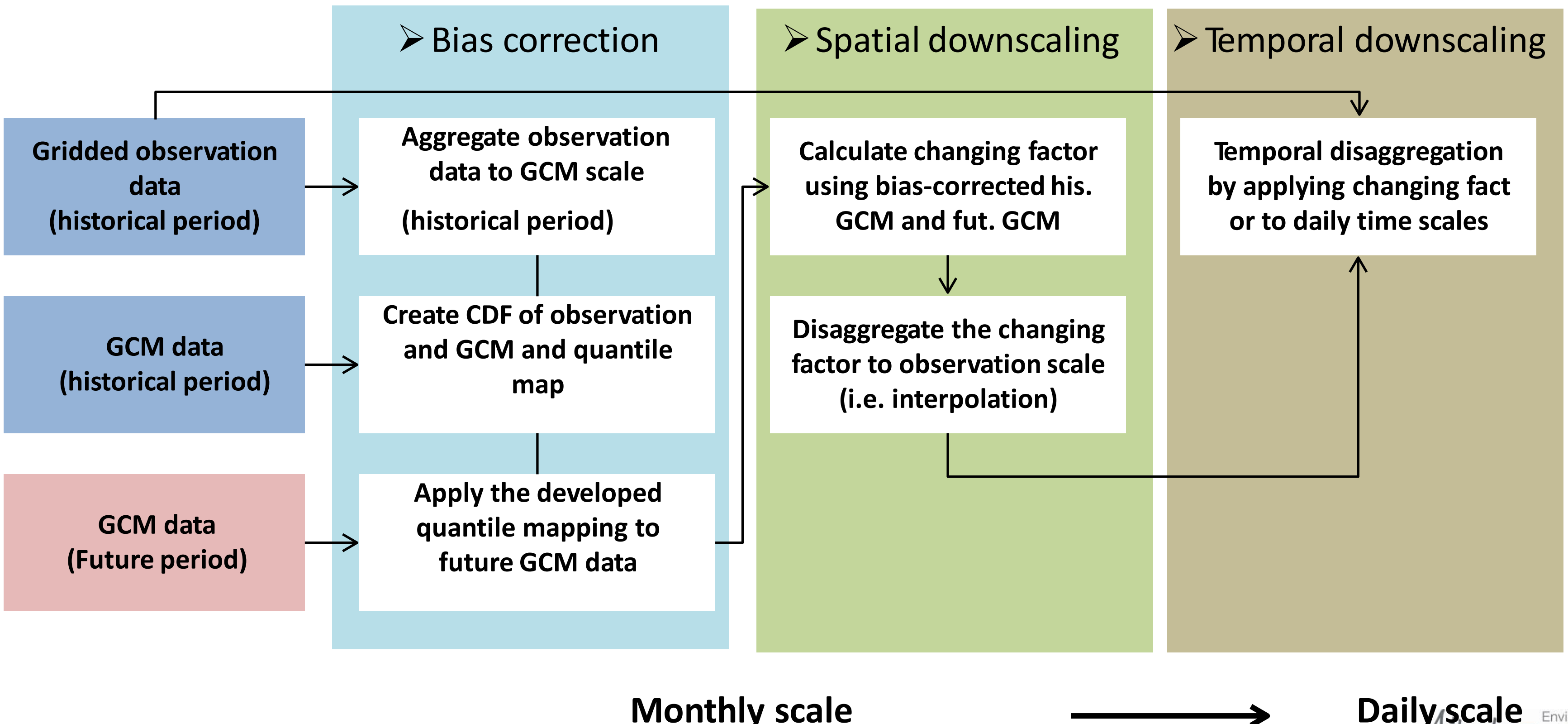
➢ Bias-correction: Quantile mapping

- Monthly data set at large grid points (e.g. GCM points)

$$Z_j(t) = F_{obs}^{-1}\left[F_m\{\hat{Y}_j(t)\}\right]$$



Bias Correction/Spatial Disaggregation (BCSD)



Daily BCSD (1)

- **Spatial disaggregation**
  - Interpolating daily GCM output to finer grid points
- **Bias correction**
  - Quantile mapping
    - Sample distribution of a moving window
      - ±15-day or a month
- **No need of temporal disaggregation**
- **Values out of historical range**
  - Gumbel for precipitation
  - Normal distribution for temperature

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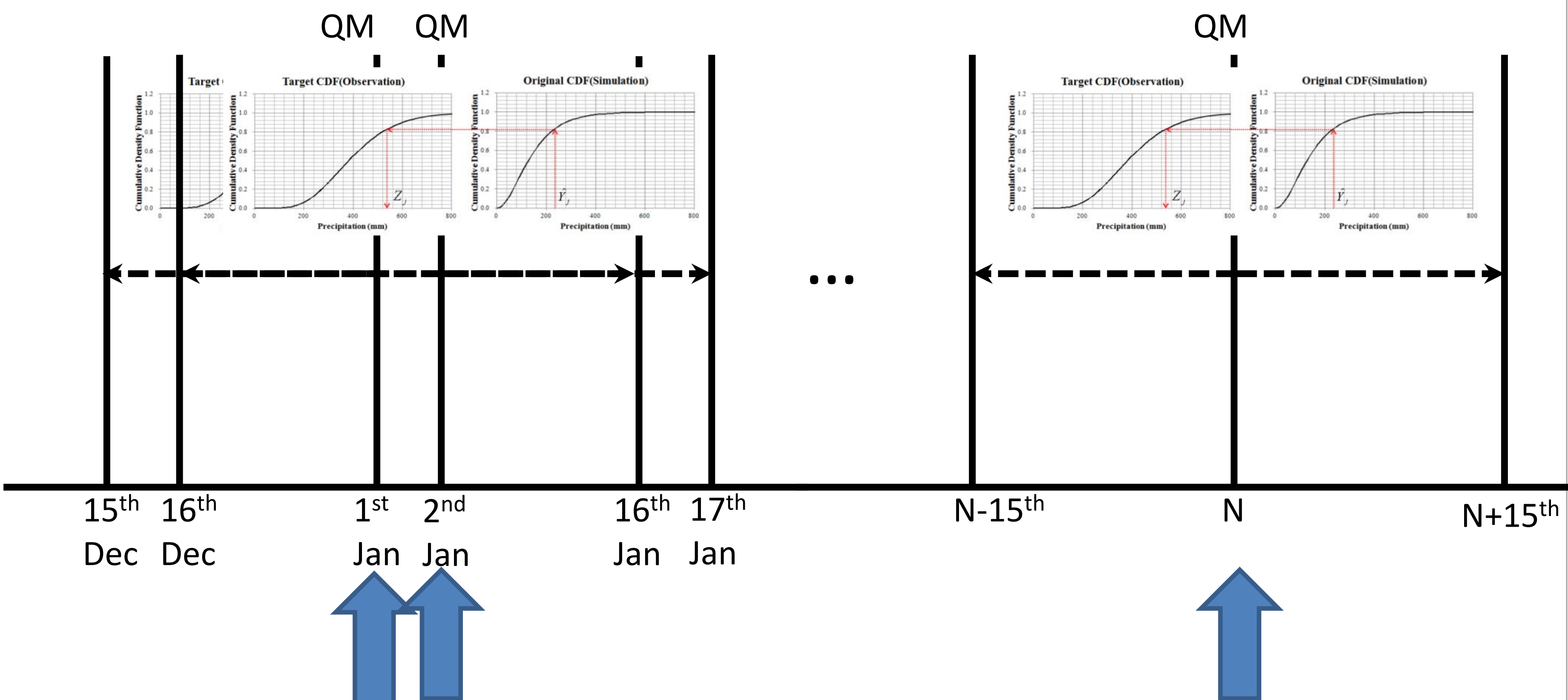
Daily BCSD (2)



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Simple Qunatile Mapping (SQM)

- **Sampling daily data to build ECDF for a month**
  - 12 ECDFs necessary

GCM data

- Historical (reference) Period
- Future Period

→

Spatial downscaling

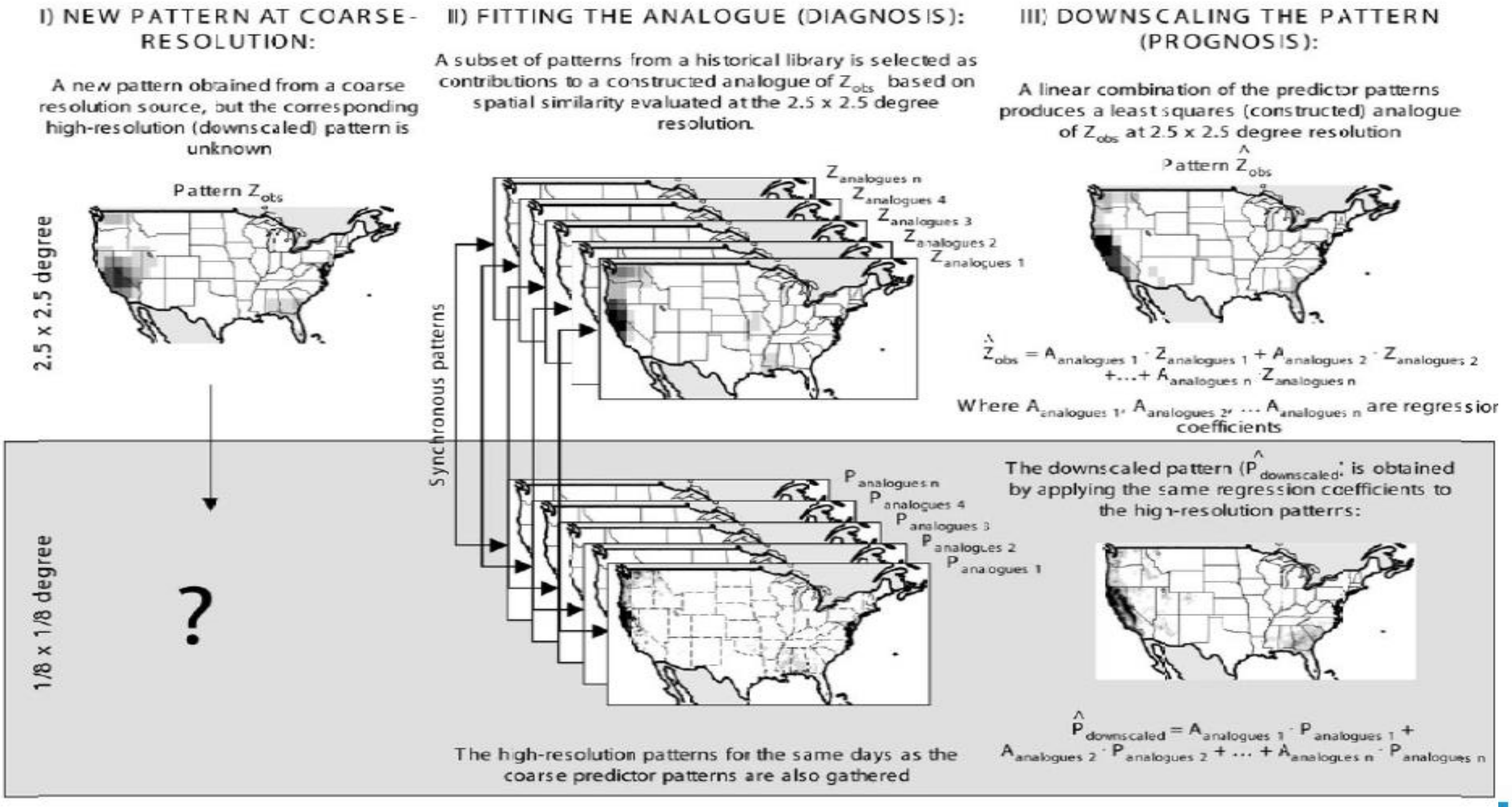
- Inverse distance weighting method
- Disaggregate GCM values to target points (e.g. stations)

→

Bias correction

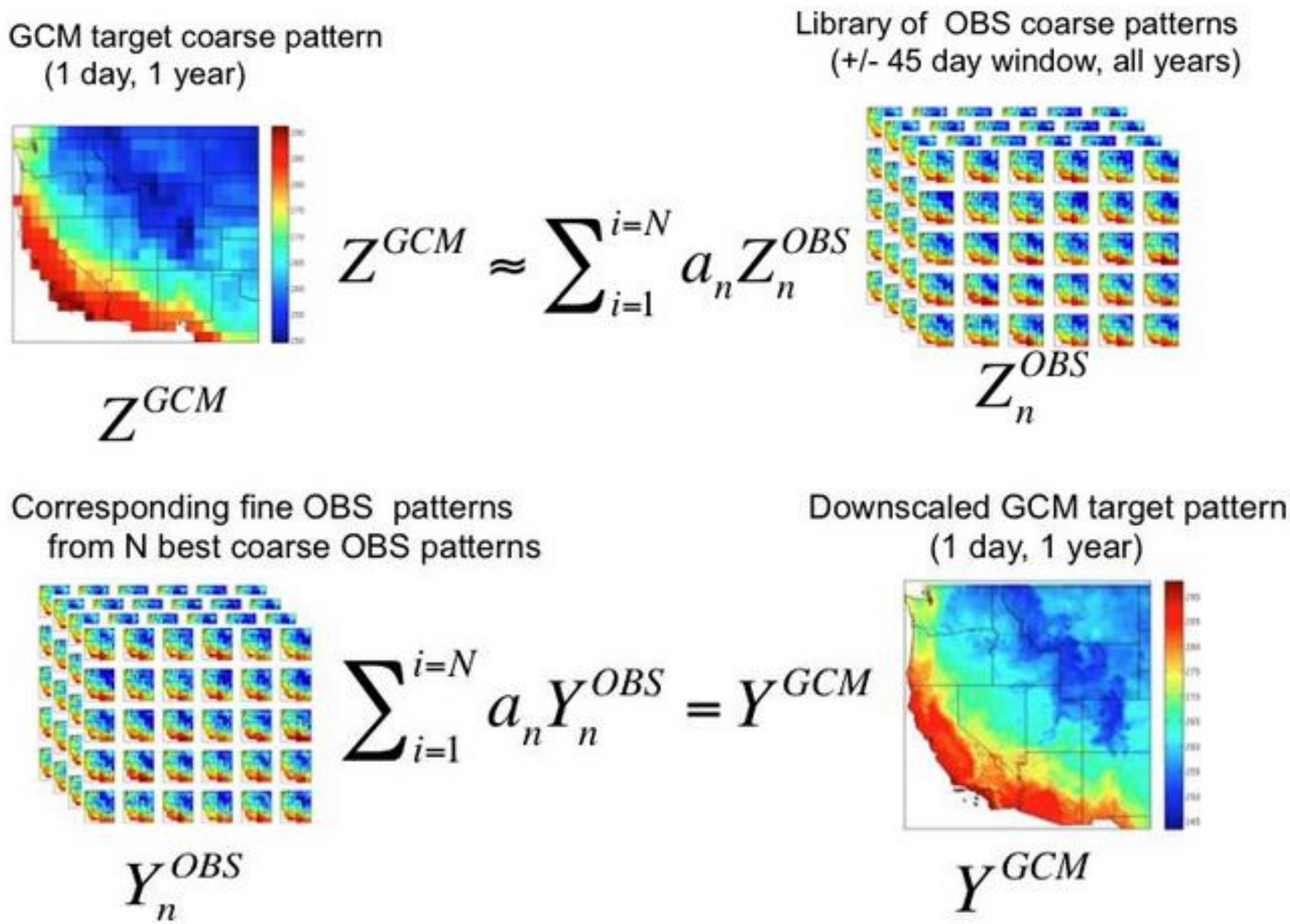
- Create CDFs of OBS and GCM and quantile map
- Apply the developed quantile mapping to future GCM data

BCCA (1)



Source: Hidalgo et al. (2008)

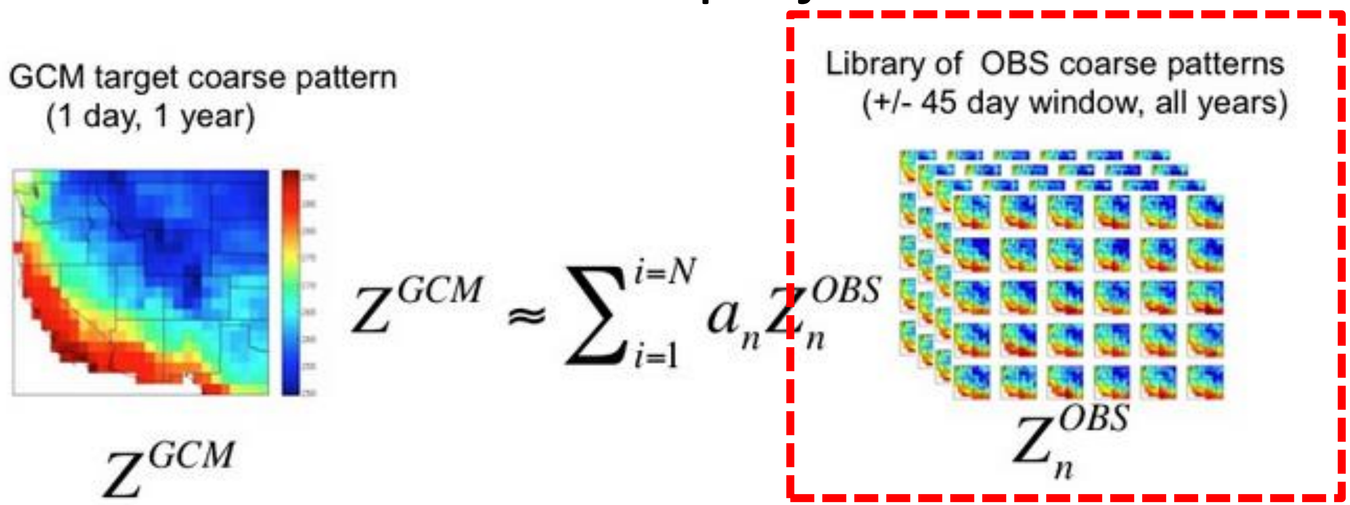
BCCA (2)



Source: http://climate.northwestknowledge.net/MACA/MACAmethod.php

Need to preserve spatial distribution in the future?

- **BCCA**
  - Hard to find similar weather patterns from historical data
  - Not reliable climate projections



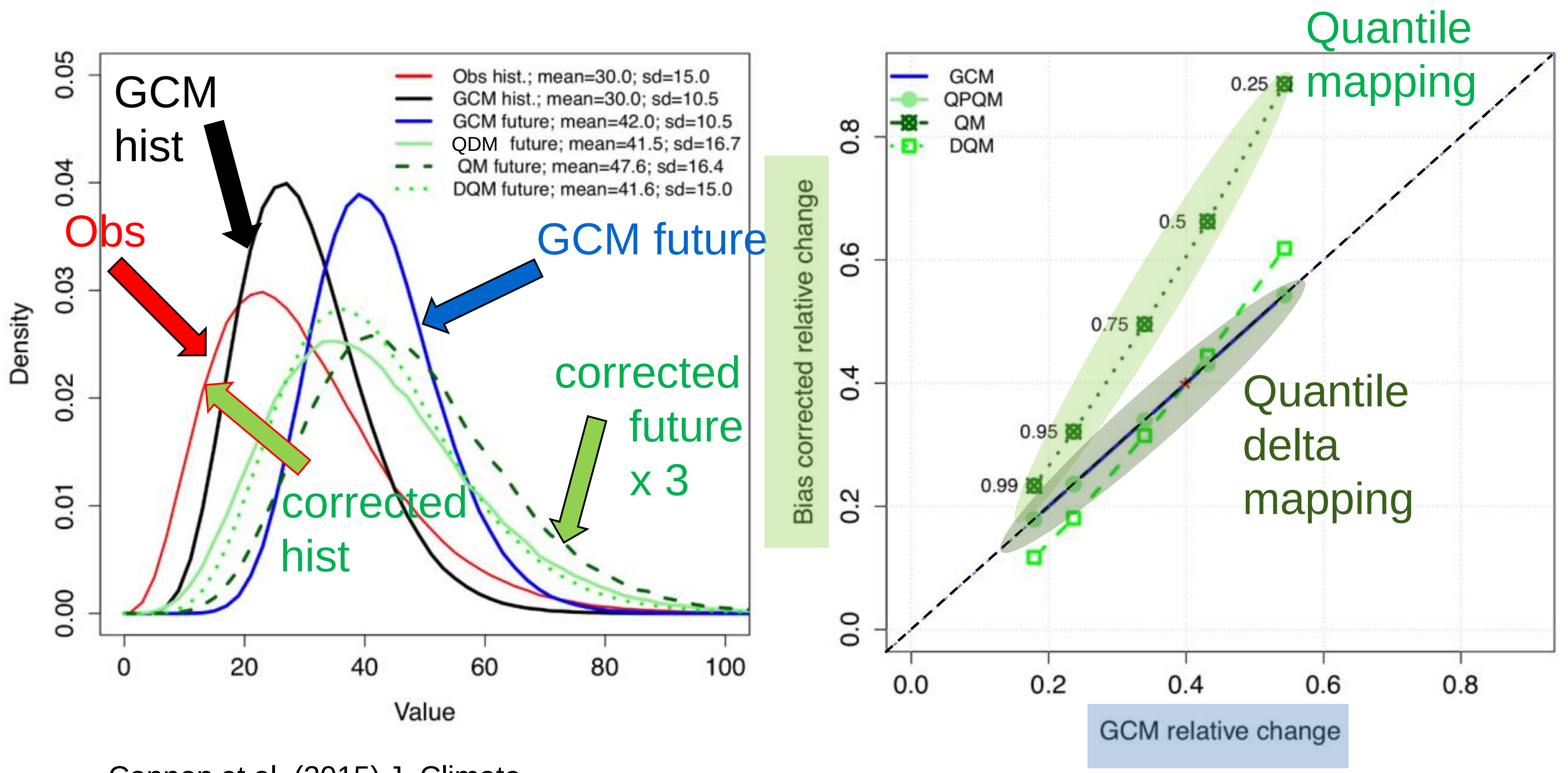
$$Z^{GCM} \approx \sum_{i=1}^{i=N} a_n Z_n^{OBS}$$

Z^{GCM} Z_n^{OBS}

Few analogs similar to future spatial structure

- **Spatial distribution may be altered by climate change**

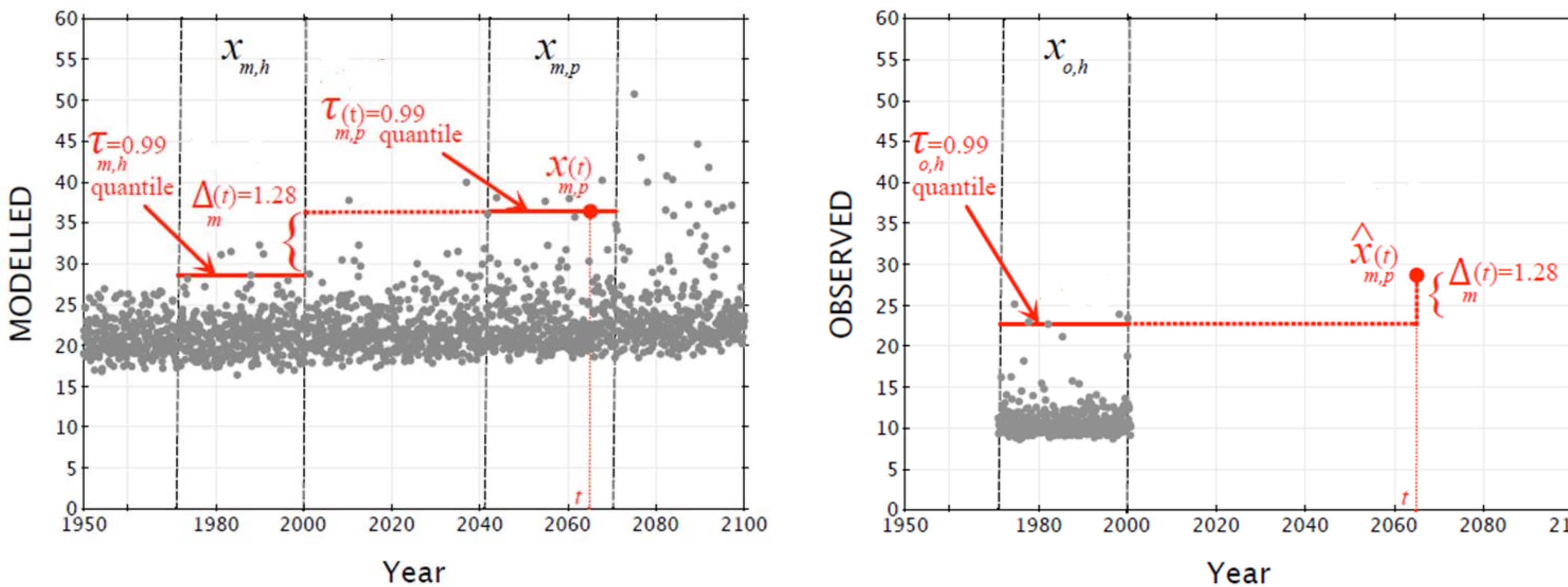
Unintended consequences…



Cannon et al. (2015) J. Climate

Quantile Delta Mapping (QDM)

- **Preserving model-projected relative changes in quantiles**
- **Correcting systematic biases in quantiles**



Source: Cannon et al. (2015)

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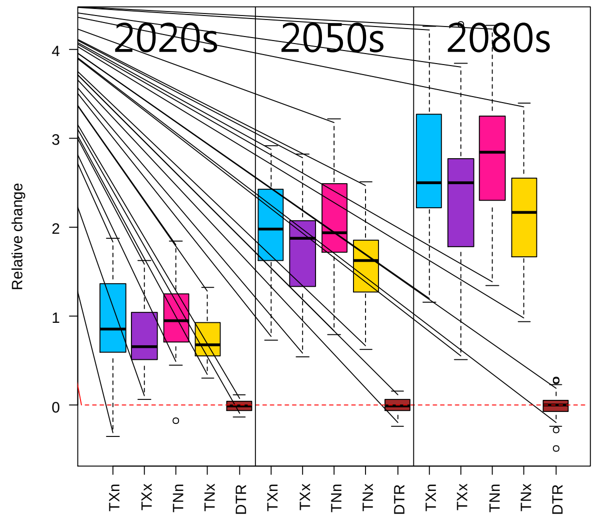
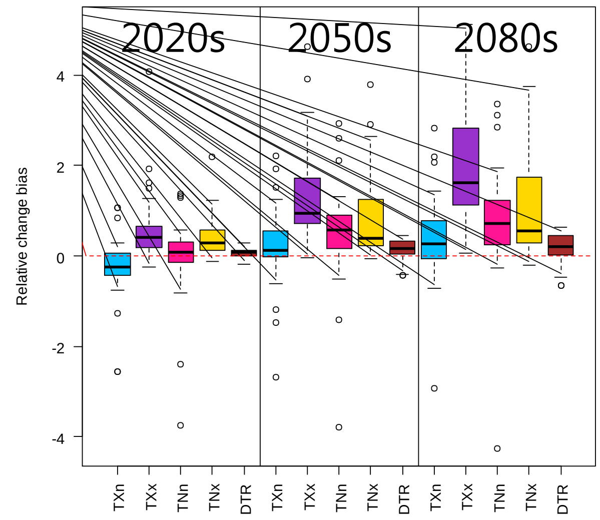
ETCCDI related to TMAX and TMIN

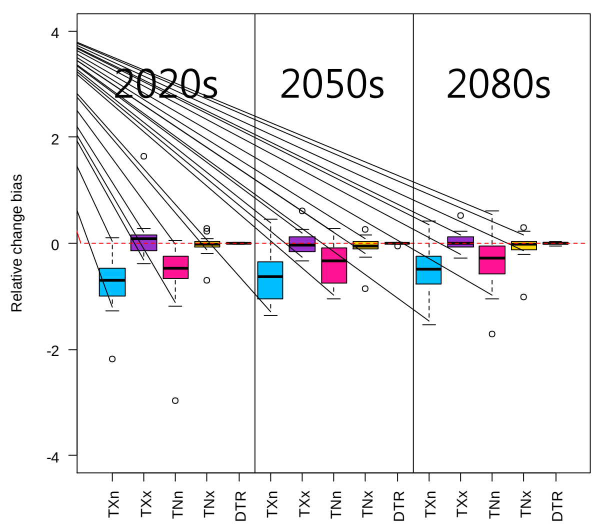
GCMs



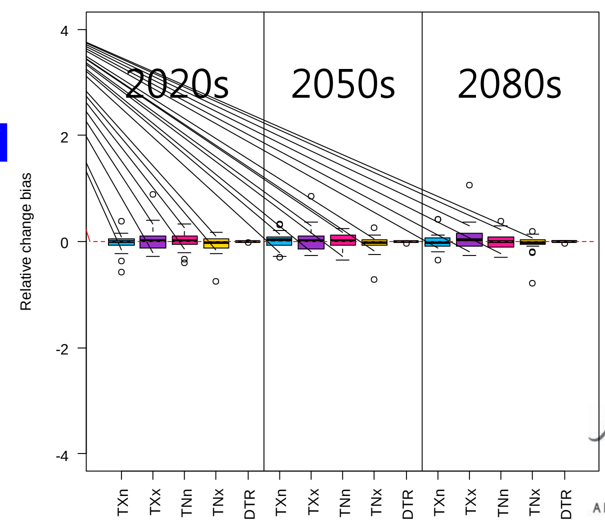
QM



DQM

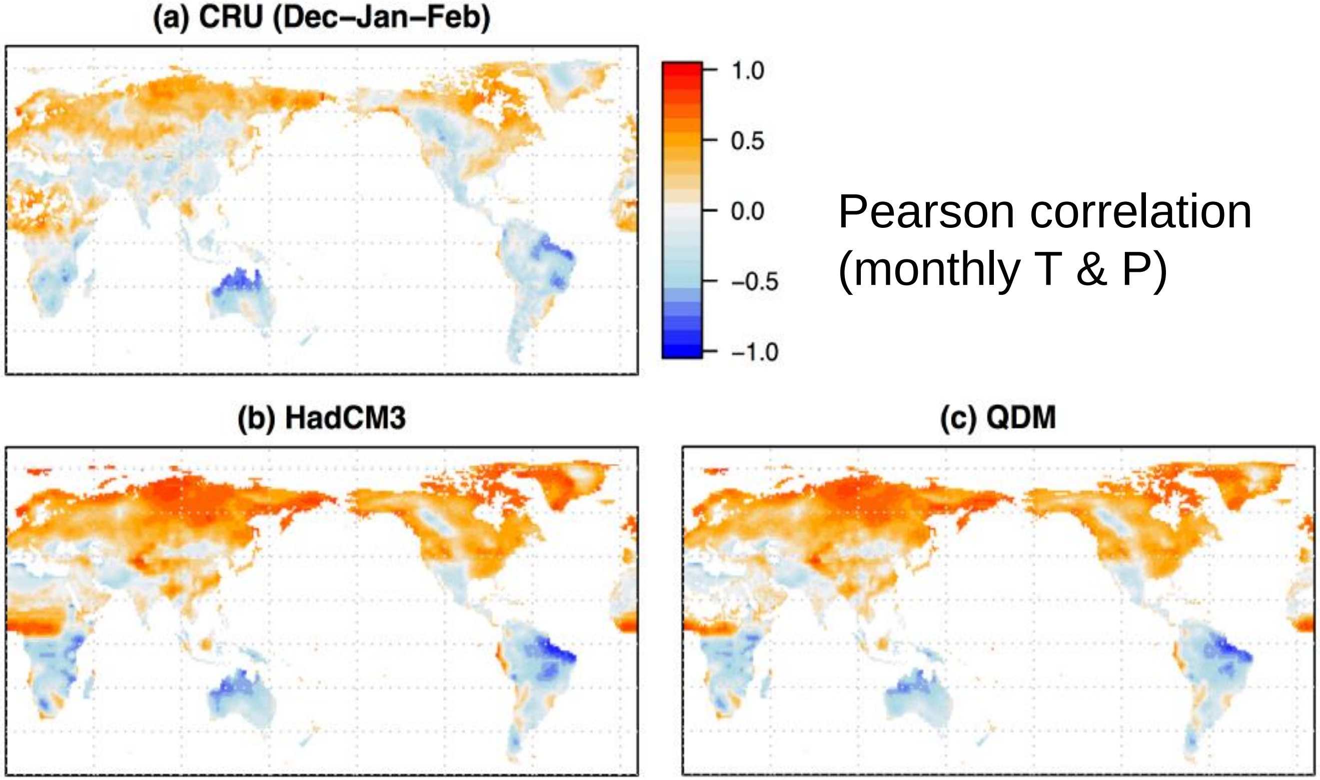


QDM



Univariate bias correction

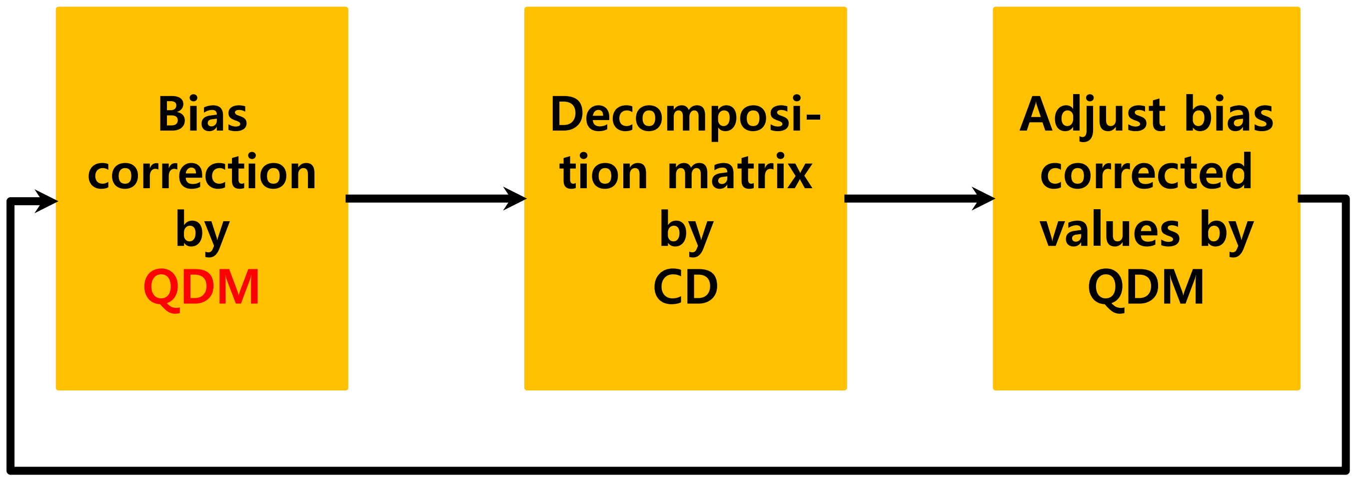
- **Can preserve dependence structure?**



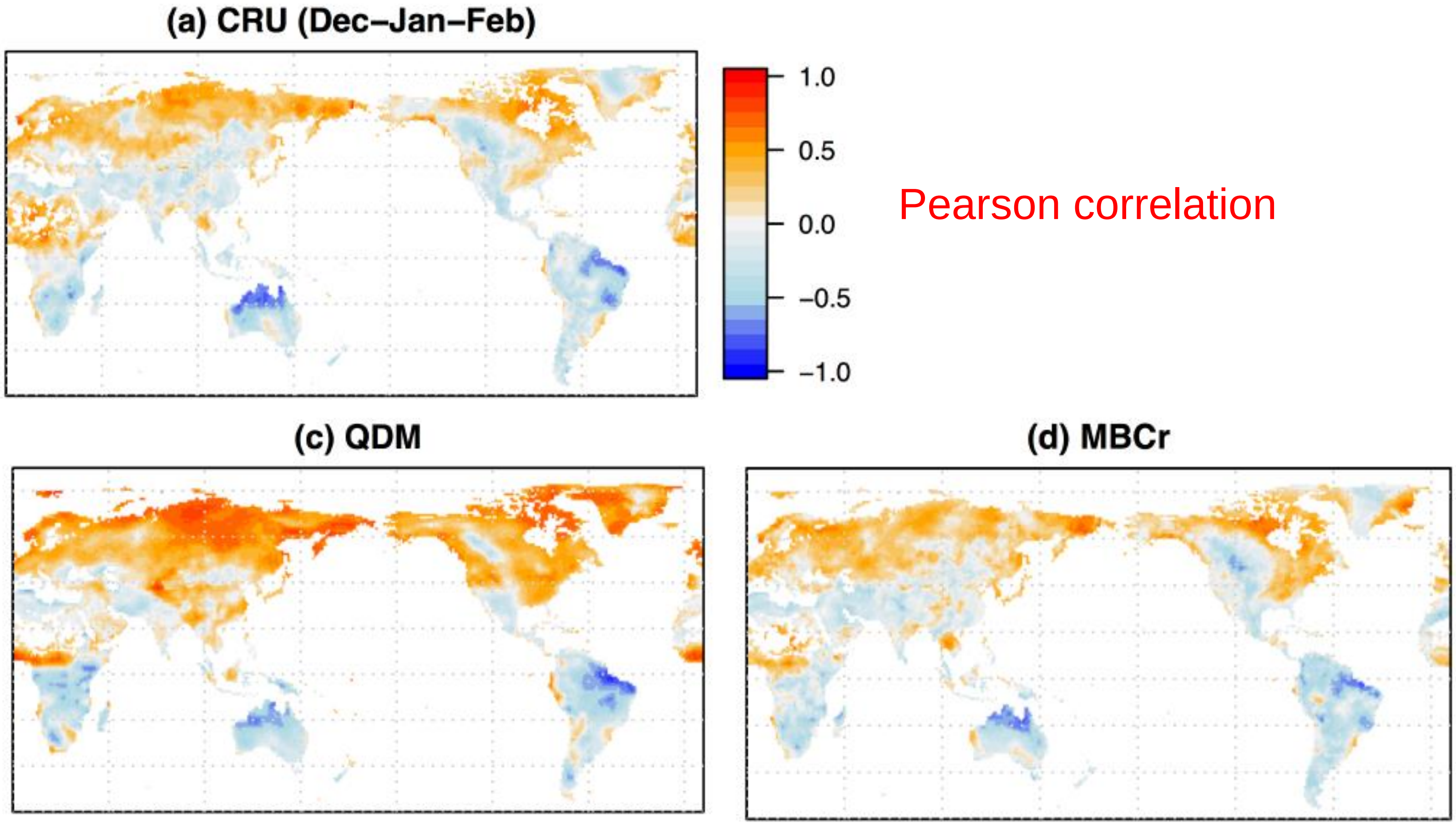
Pearson correlation
(monthly T & P)

Multivariate Bias Correction (MBC)

- **Cholesky Decomposition (CD)**
  - Preserve covariance between variables
- **Process**



Multivariate Bias Correction (MBC)



Pearson correlation

Applications of Statistical Downscaling Methods

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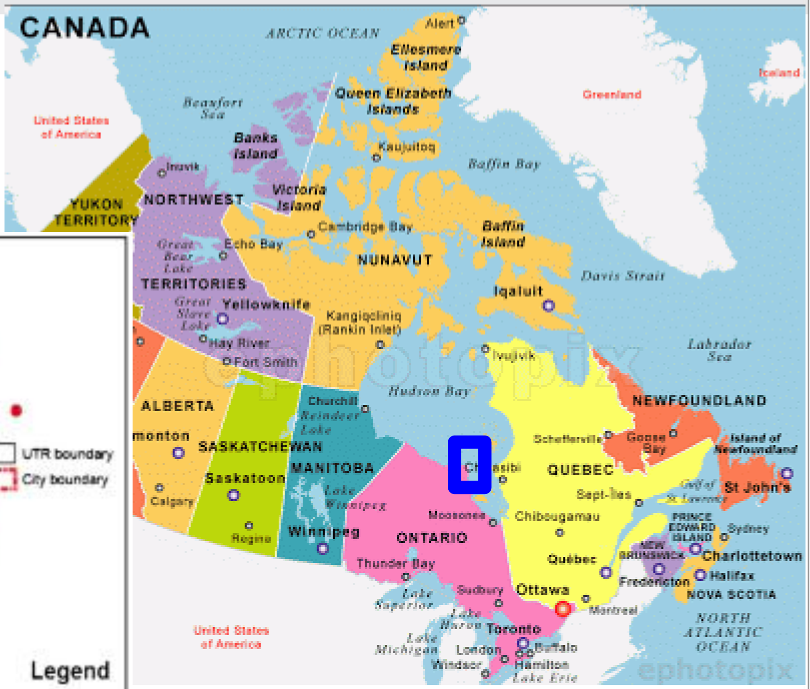
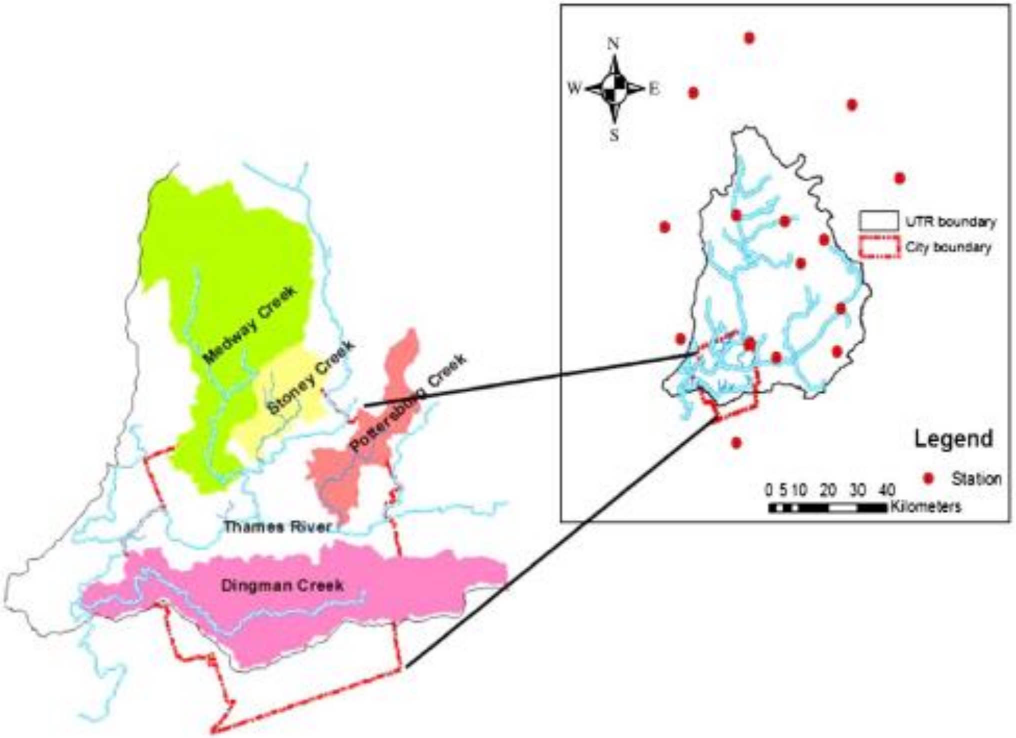
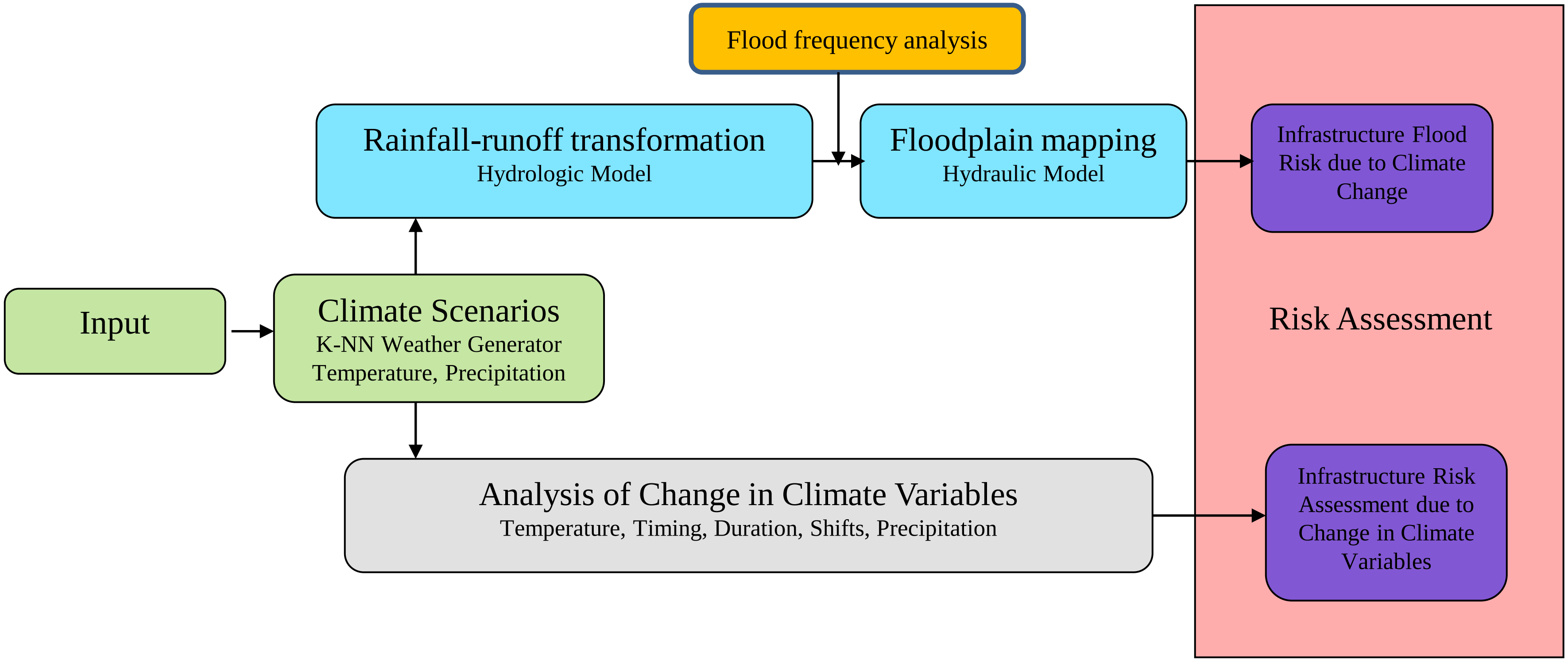
Case study 1: Vulnerability of Infrastructures to Climate Change

- **London, Ontario (Canada)**





Procedure for assessment of climate change



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Climate signal from a GCM (CCSRNIES B21)

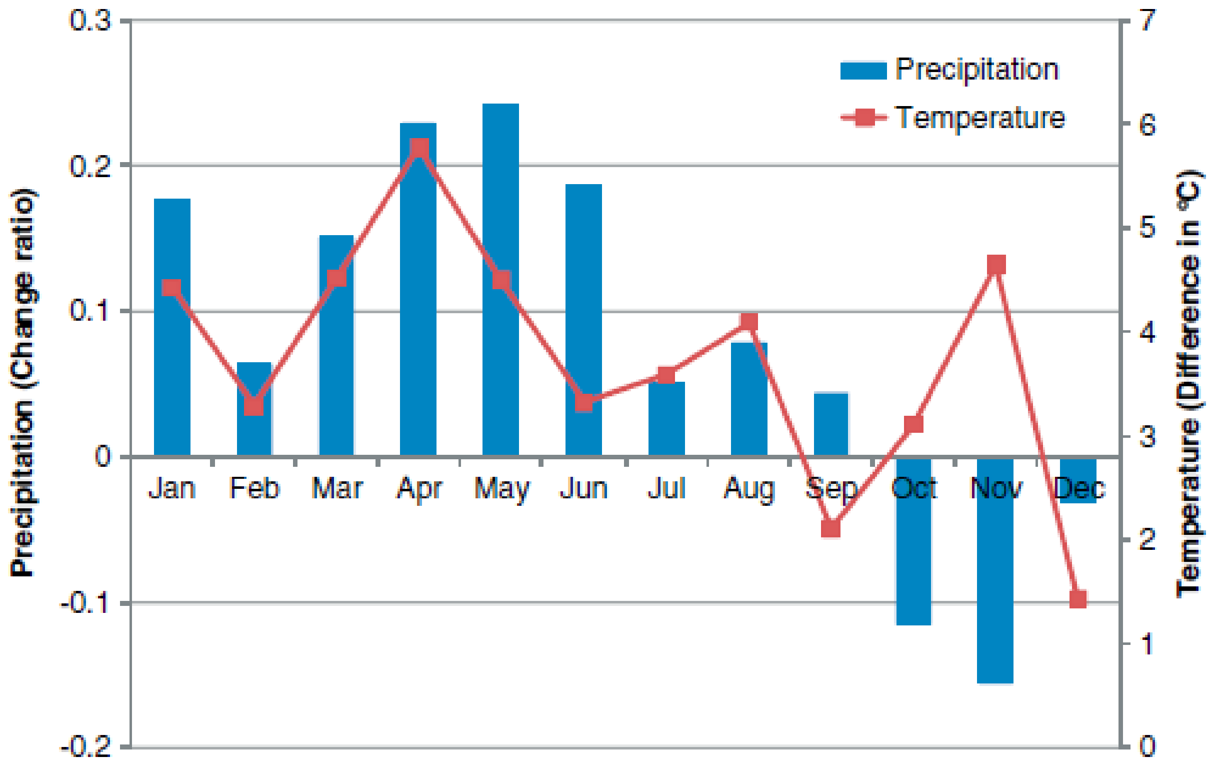

Figure 2. Monthly changes in precipitation and temperature for the CCSRNIES B21 GCM scenario

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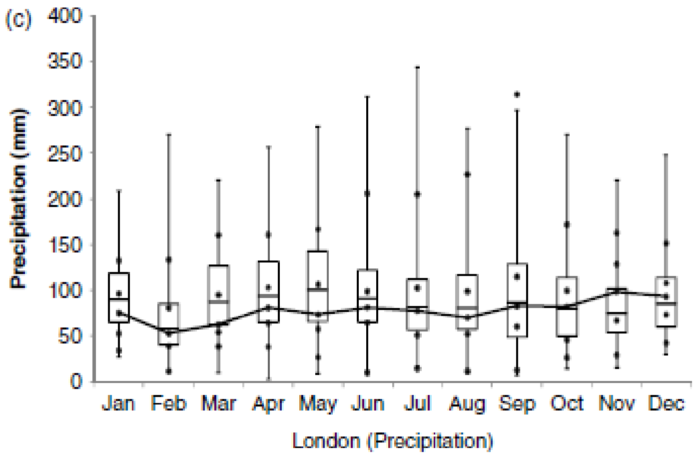
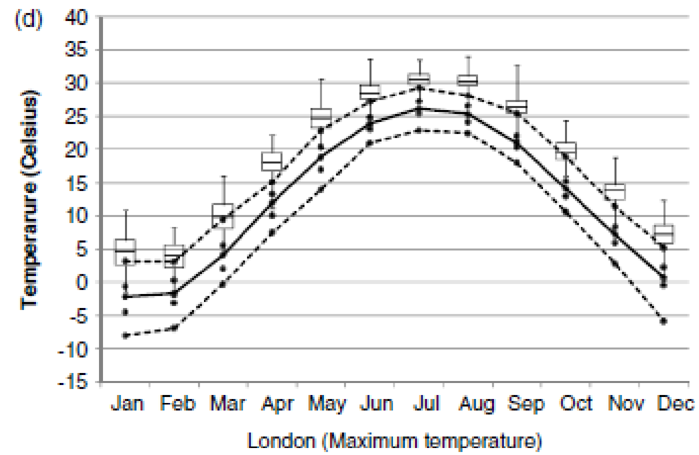
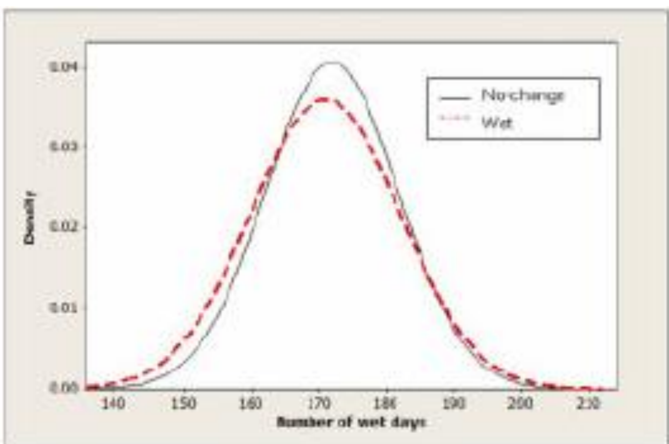
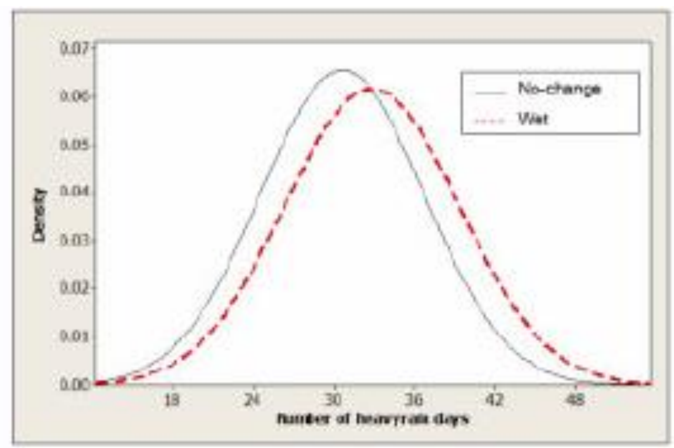
K-NN WG







London (Wet days)



London (Heavy-rain days)

Hydrologic model

- **Input data**
  - Hourly data from a temporal disaggregation technique
    - Method of fragment (Svanidze, 1977)
- **HEC-HMS**

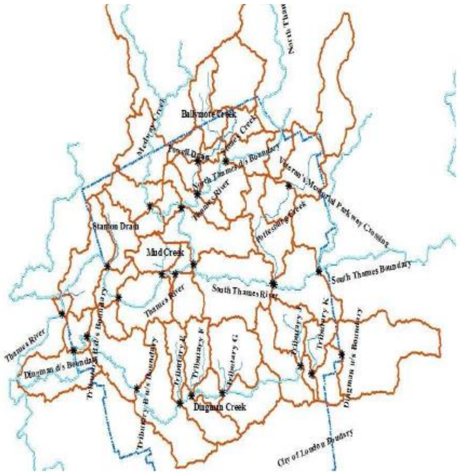


Figure 3.7 Delineation of the Thames River into sub-watersheds within the City of London

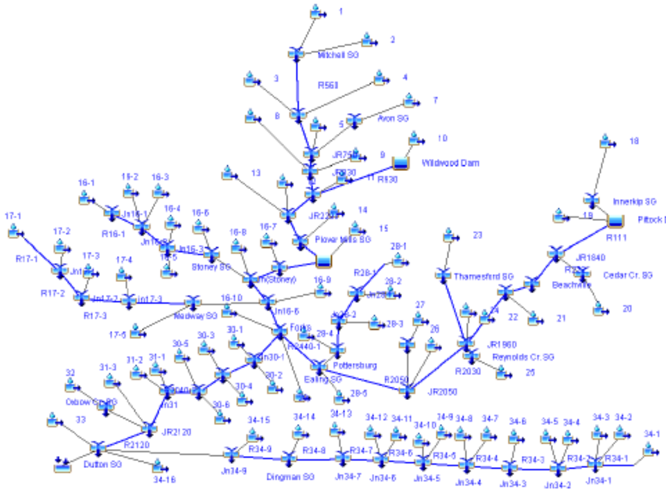
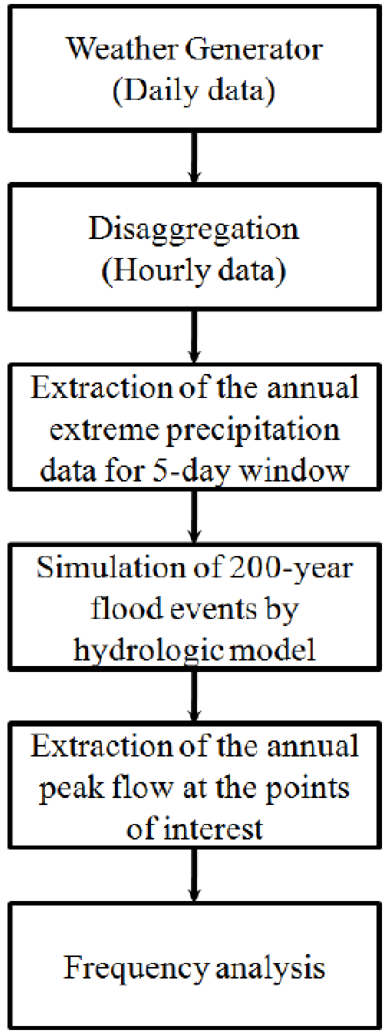
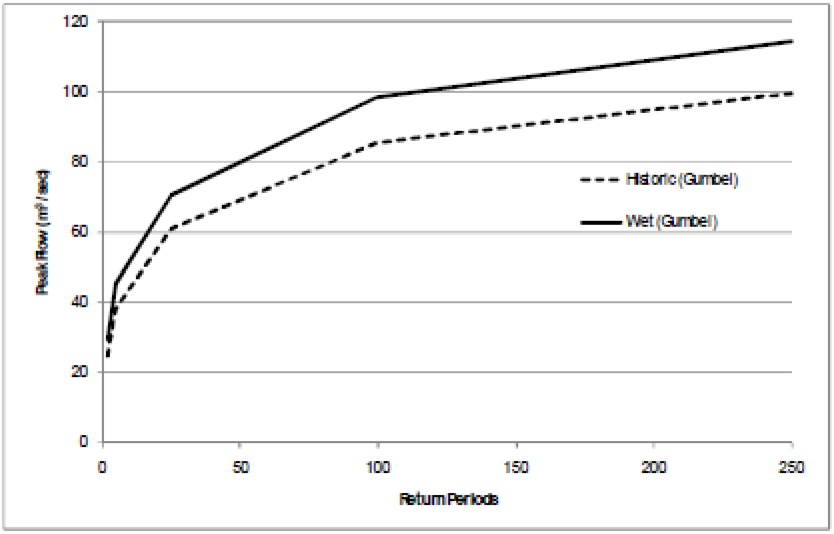


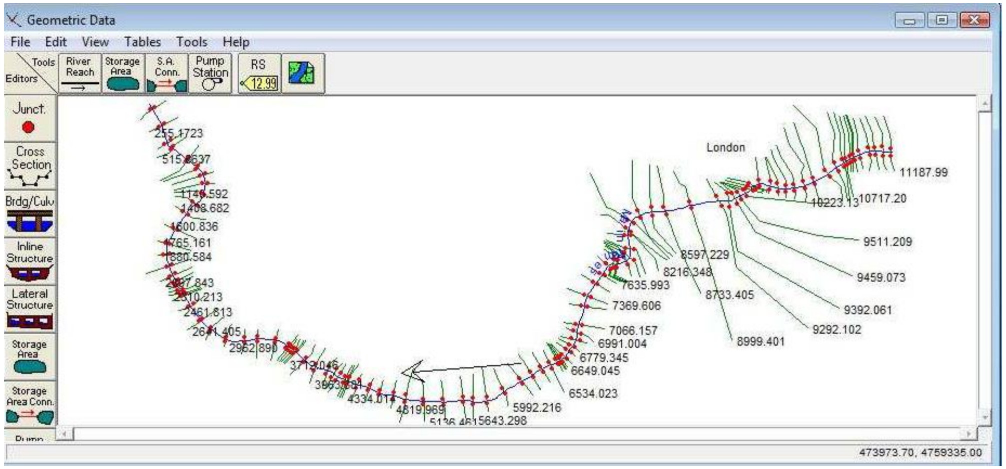
Figure 3.8 The HEC-HMS model structure

Frequency analysis

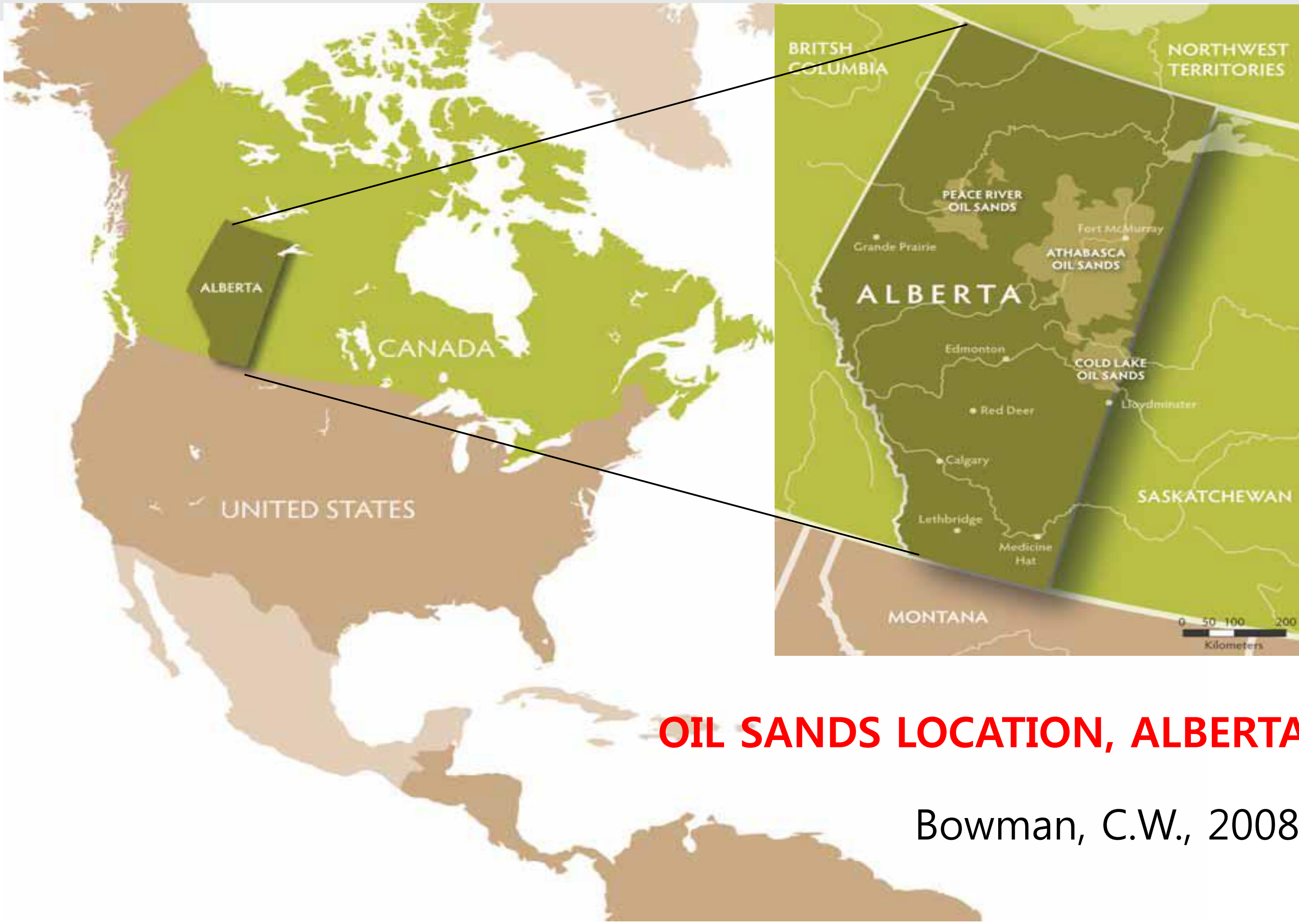


Flooding map





Case study 2: Water availability under climate change in the Alberta oil sands region



OIL SANDS LOCATION, ALBERTA, CANADA

Bowman, C.W., 2008

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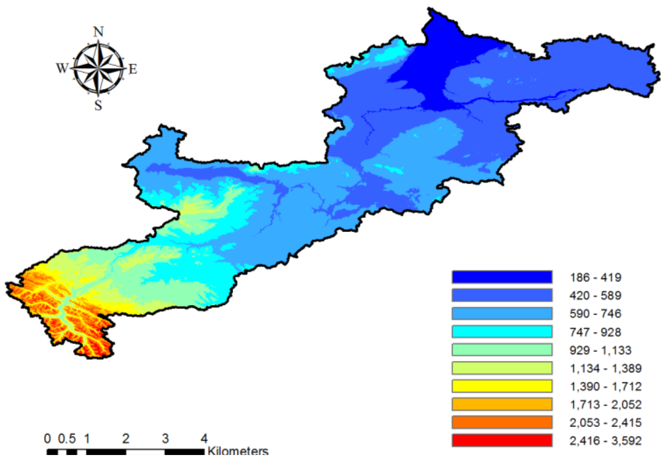
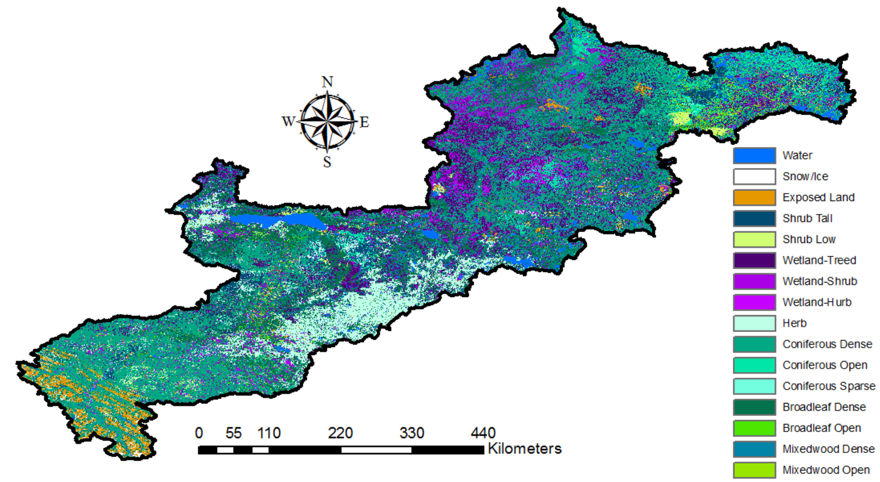
Athabasca River Basin

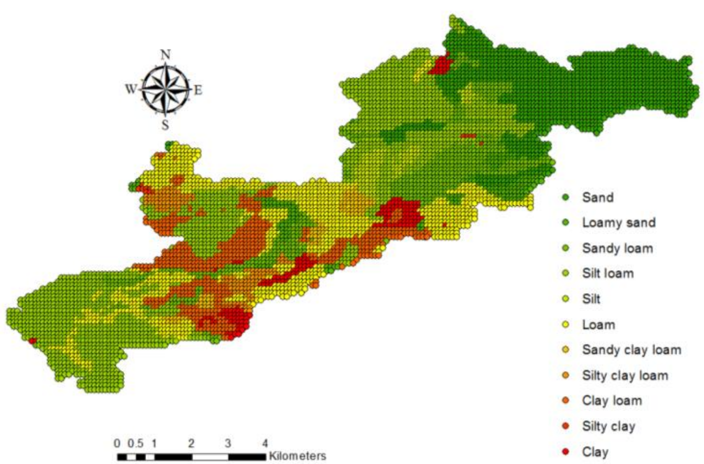
➢ Various topographic and physical characteristics



DEM



Land Cover (2000)



Soil Type

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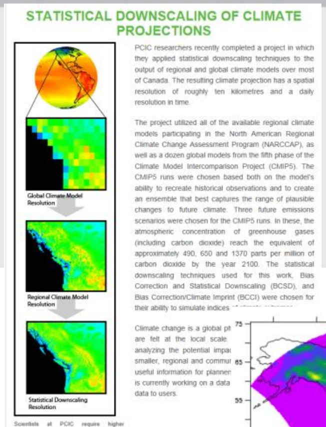
Climate data (1)

➢ **Statistical downscaling**

- PCIC (http://www.pacificclimate.org)
- Over Canada with 10 km resolution



STATISTICAL DOWNSCALING OF CLIMATE PROJECTIONS

PCIC researchers recently completed a project in which they applied statistical downscaling techniques to the output of regional and global climate models over most of Canada. The resulting climate projection has a spatial resolution of roughly ten kilometres and a daily resolution in time.

The project utilized all of the available regional climate models participating in the North American Regional Climate Change Assessment Program (NARCCAP), as well as a dozen global models from the fifth phase of the Climate Model Intercomparison Project (CMIP5). The CMIP5 runs were chosen based both on the model's ability to recreate historical observations and to create an ensemble that best captures the range of plausible changes to future climate. Three future emissions scenarios were chosen for the CMIP5 runs. In these, the atmospheric concentration of greenhouse gases (including carbon dioxide) reach the equivalent of approximately 490, 650 and 1370 parts per million of carbon dioxide by the year 2100. The statistical downscaling techniques used for this work, Bias Correction and Statistical Downscaling (BCSD), and Bias Correction/Climate Imprint (BCCI) were chosen for their ability to simulate indices

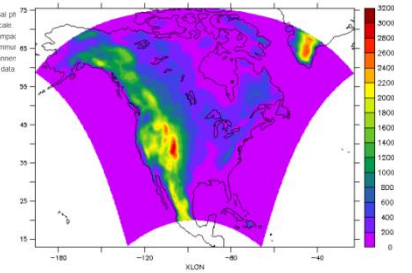
Climate change is a global ph
are felt at the local scale.
analyzing the potential impac
smaller, regional and commun
useful information for planner
is currently working on a data
data to users.

Global Climate Model Resolution

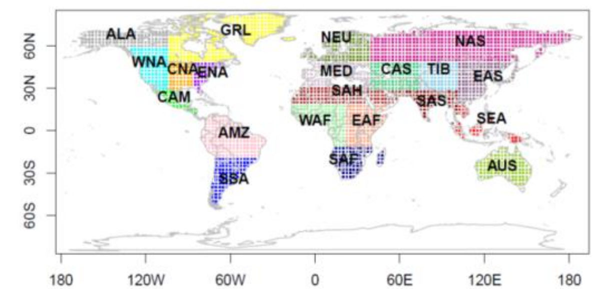
Regional Climate Model Resolution

Statistical Downscaling Resolution

Scientists at PCIC require higher



Order	WNA	ALA	CNA	ENA	GRL
1	CNRM-CM5-r1	CSIRO-Mk3-6-0-r1	CanESM2-r1	MPI-ESM-LR-r3	MPI-ESM-LR-r3
2	CanESM2-r1	HadGEM2-ES-r1	ACCESS1-0-r1	inmcm4-r1	inmcm4-r1
3	ACCESS1-0-r1	inmcm4-r1	inmcm4-r1	CNRM-CM5-r1	CanESM2-r1
4	inmcm4-r1	CanESM2-r1	CSIRO-Mk3-6-0-r1	CSIRO-Mk3-6-0-r1	CNRM-CM5-r1
5	CSIRO-Mk3-6-0-r1	ACCESS1-0-r1	MIROC5-r3	HadGEM2-ES-r1	ACCESS1-0-r1
6	CCSM4-r2	MIROC5-r3	HadGEM2-ES-r1	CanESM2-r1	CSIRO-Mk3-6-0-r1
7	MIROC5-r3	HadGEM2-CC-r1	MPI-ESM-LR-r3	MRI-CGCM3-r1	HadGEM2-ES-r1
8	MPI-ESM-LR-r3	MRI-CGCM3-r1	CNRM-CM5-r1	CCSM4-r2	MIROC5-r3
9	HadGEM2-CC-r1	CCSM4-r2	CCSM4-r2	MIROC5-r3	HadGEM2-CC-r1
10	MRI-CGCM3-r1	CNRM-CM5-r1	GFDL-ESM2G-r1	ACCESS1-0-r1	CCSM4-r2
11	GFDL-ESM2G-r1	MPI-ESM-LR-r3	HadGEM2-CC-r1	HadGEM2-CC-r1	MRI-CGCM3-r1
12	HadGEM2-ES-r1	GFDL-ESM2G-r1	MRI-CGCM3-r1	GFDL-ESM2G-r1	GFDL-ESM2G-r1



Trevor et al. (2013)

Method	Diagnostic 1- Sequencing		Diagnostic 2 - Distribution		Diagnostic 3 - Spatial	
	Rank	Performance	Rank	Performance	Rank	Performance
BCCI	1	✓	1 / 2	✓	3	X
BCCA	2	✓	3	X	2	OK
BCSD	3	X	1 / 2	✓	1	✓

Trevor et al. (2013)

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Climate data (2)

➢ CMIP5

- 6 GCMs x 2 SDMs x 2 RCPs = 24 scenarios

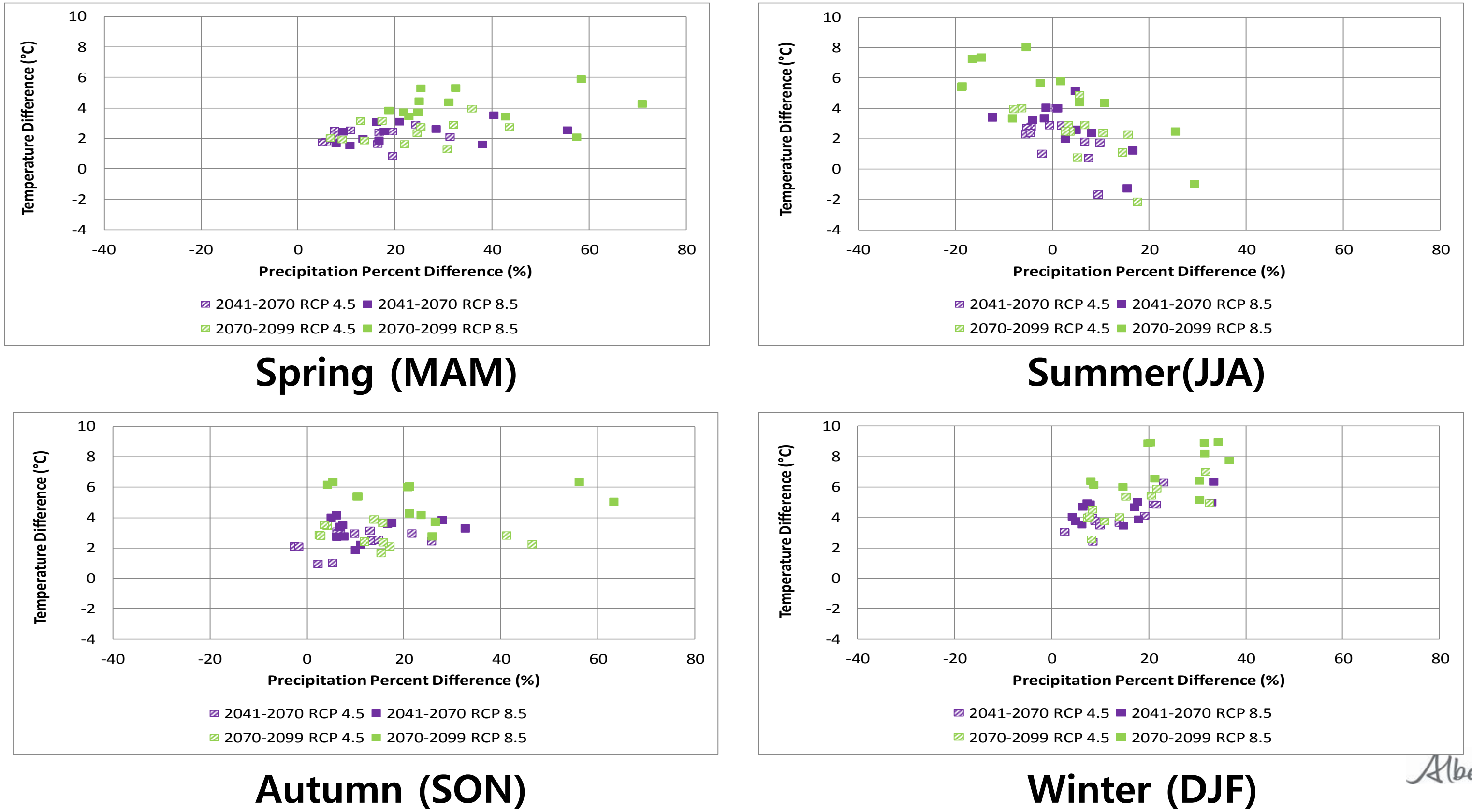
Model Abbreviation	Modelling Center	RCP/ Statistical downscaling method (SDMs)	Primary reference
CNRM-CM5.1	Centre National de Recherches Meteorologiques and Cerfacs	RCP4.5& RCP8.5/ BCCI & BCSD	Voldoire et al. (2013)
CanESM2	Canadian Centre for Climate Modelling and Analysis		Arora et al. (2011)
ACCESS1	Centre for Australian Weather and Climate Research		Marsland et al. (2013)
INMCM4	Institute of Numerical Mathematics of the Russian Academy of Sciences		Volodin et al. (2010)
CSIRO-Mk3.6.0	Commonwealth Scientific and Industrial Research Organisation		Jeffrey et al. (2013)
CCSM4	National Center for Atmospheric Research (NCAR)		Gent et al. (2011)

Indicators of Hydrologic Alterations (IHAs)

Hydrologic regime component	WRIs and IHAs	No	Examples of hydrologic influence	Examples of ecological influence
Magnitude and timing	Water resources indicators (WRIs) Annual volume (m^3), center of timing of annual flow (water year), median seasonal flow	6	Annual water balance, magnitude and timing of seasonal conditions	Availability and suitability of habitat for aquatic organisms
Magnitude and duration	Annual mean 1-day minimum and maximum (m^3/s)	2	Magnitude of annual flood and drought conditions	Duration of stressful conditions
Timing	Day of each annual 1-day minimum and maximum	2	Timing of annual flood and drought conditions	Spawning cues for fish; compatibility with life cycles of organisms
Magnitude and timing	Timing and amount of spring freshet initiation	2	Timing and magnitude of rapid melting	-
	Total	12		

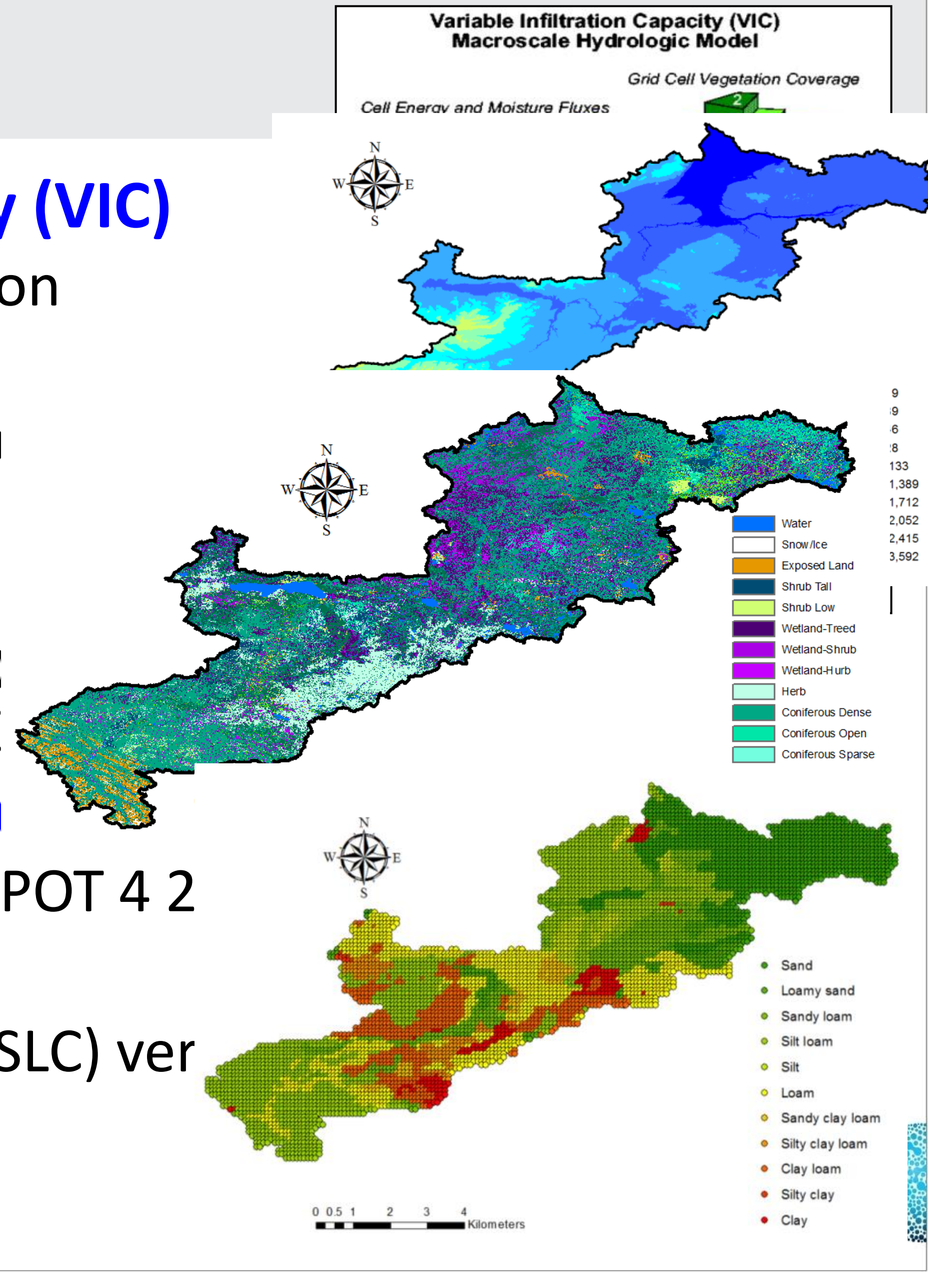
Seasonal changes in PPT & TEM

➢ Difference from the reference period (1981-2010)



Hydrologic model

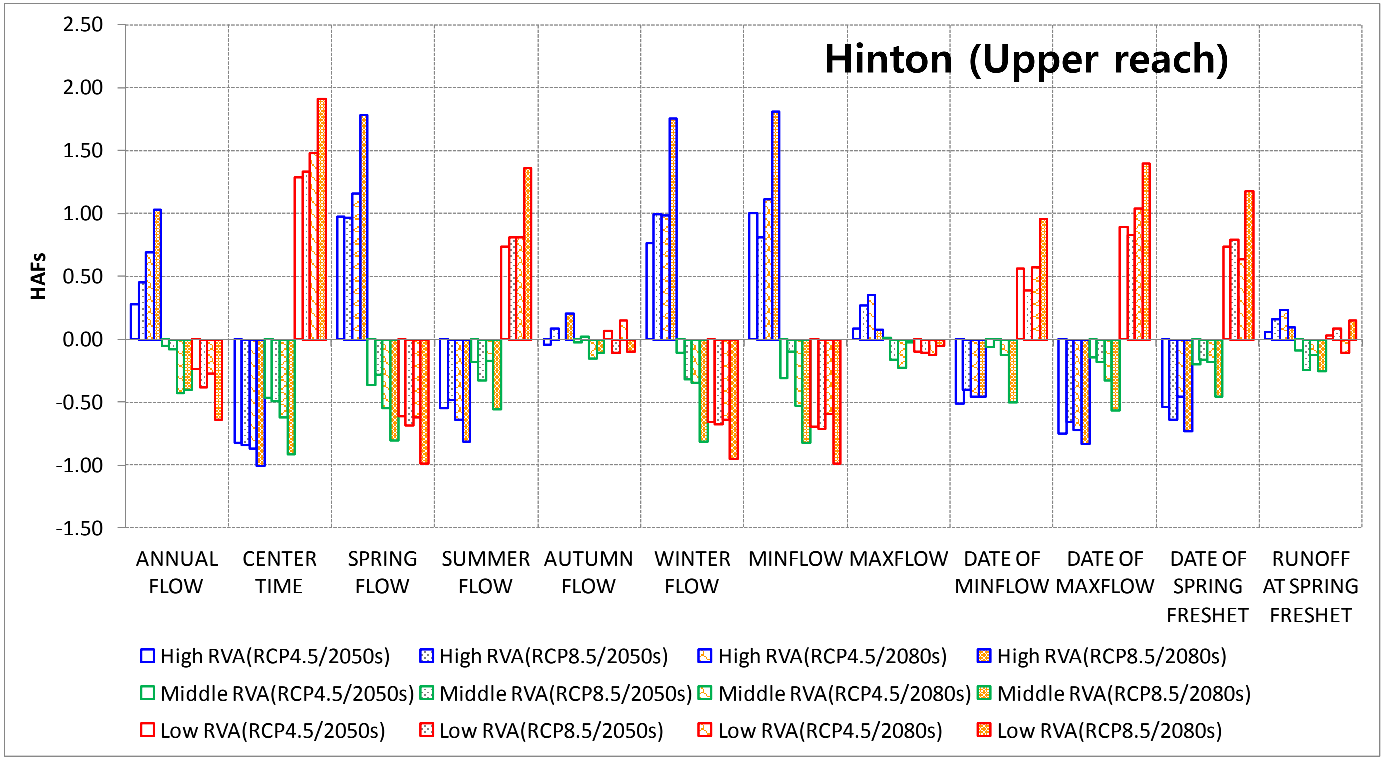
- **Variable Infiltration Capacity (VIC)**
  - 1/16 (~7km) spatial resolution
- **DEM**
  - Canadian Digital Elevation D
    - 3 arc second (≈ 90 m) spatial
- **Land cover**
  - 1 km resolution – circa 200C
    Sustainable Development, E
- **Monthly Leaf Area Index (LA**
  - Canada-wide 1-km 10-day SPOT 4 2
- **Soil parameters – 3 layers**
  - Soil Landscapes of Canada (SLC) ver



Hydrologic alteration factor (HAF)

➢ HAF

- (Projected frequency - Reference frequency) / Reference frequency



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Summary

- **Why do we need downscaling?**
- **Statistical or Dynamical**
- **MOS-based approaches**
  - Preserve GCM-driven long-term trend
- **Case studies**



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