

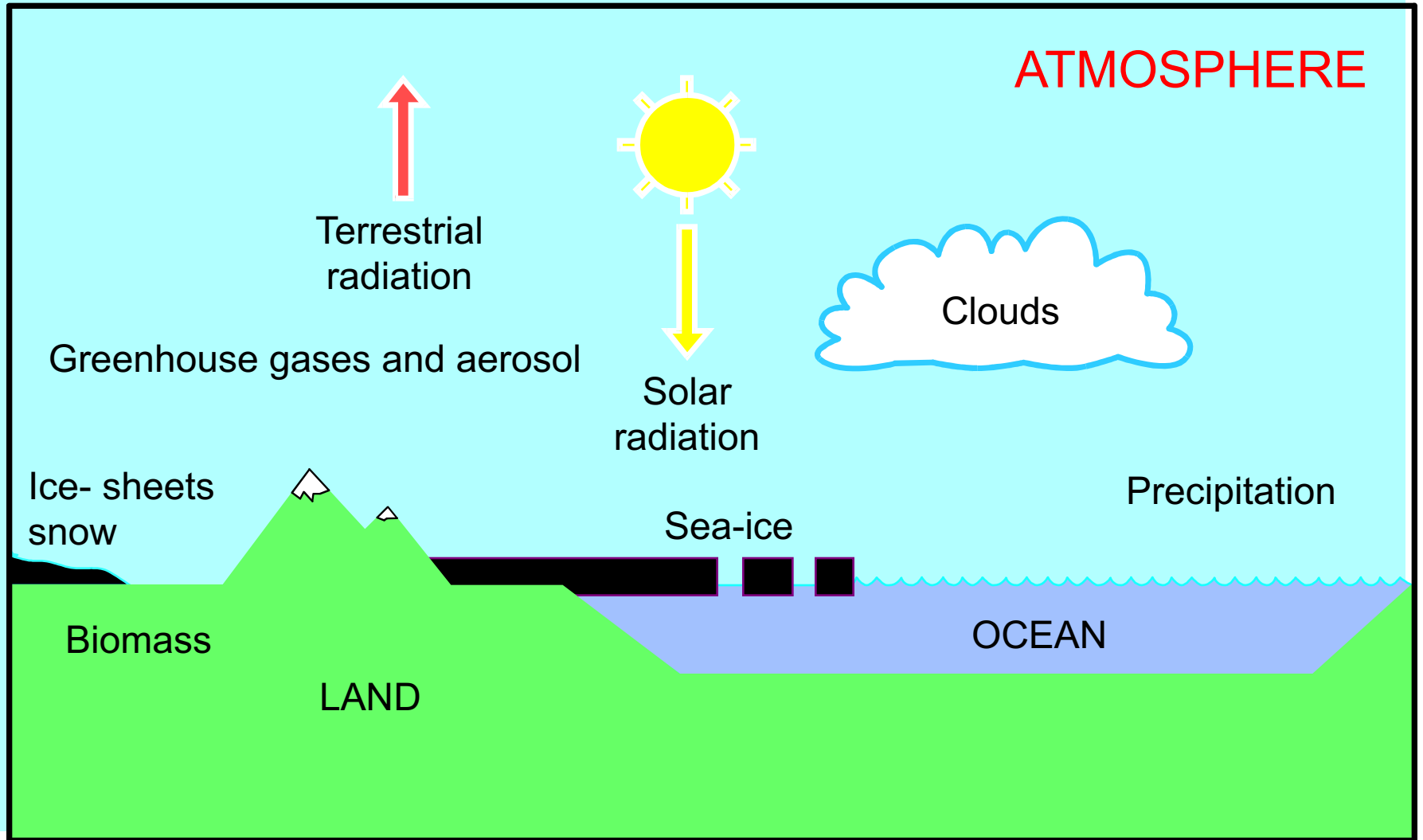
Review of Statistical Downscaling

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The Climate System



Atmosphere, hydrosphere, cryosphere, land surface and biosphere

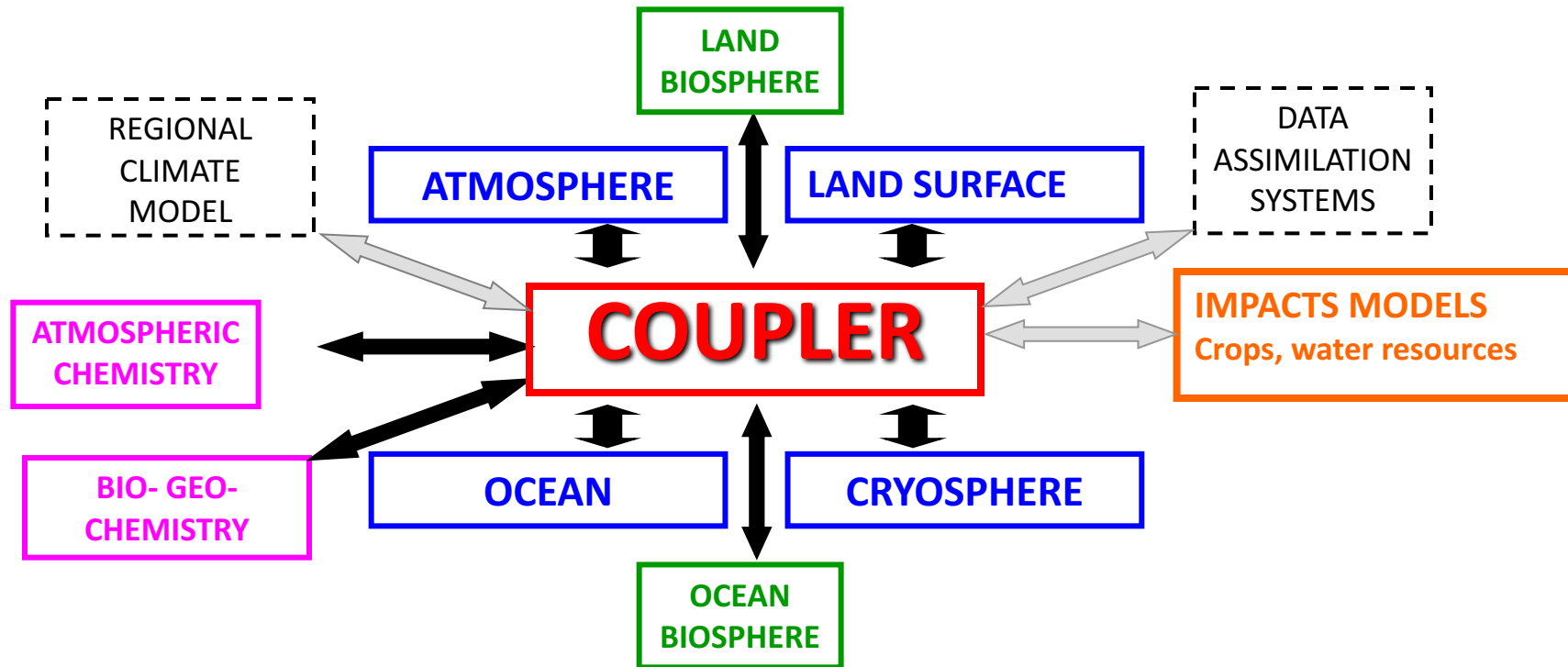
Climate Models

- attempt to simulate the behaviour of the climate system.
- Objective is to understand the key physical, chemical and biological processes which govern climate.
- Through understanding the climate system, it is possible to:
 - *obtain a clearer picture of past climates by comparison with empirical observation*
 - *predict future climate change.*
- Models can be used to simulate climate on a variety of spatial and temporal scales.

(McGuffee – Handerson Sellers ; Kiehl-Ramnathan eds ; Washington-Parkinson)

Climate Change: Modular Earth System Modelling

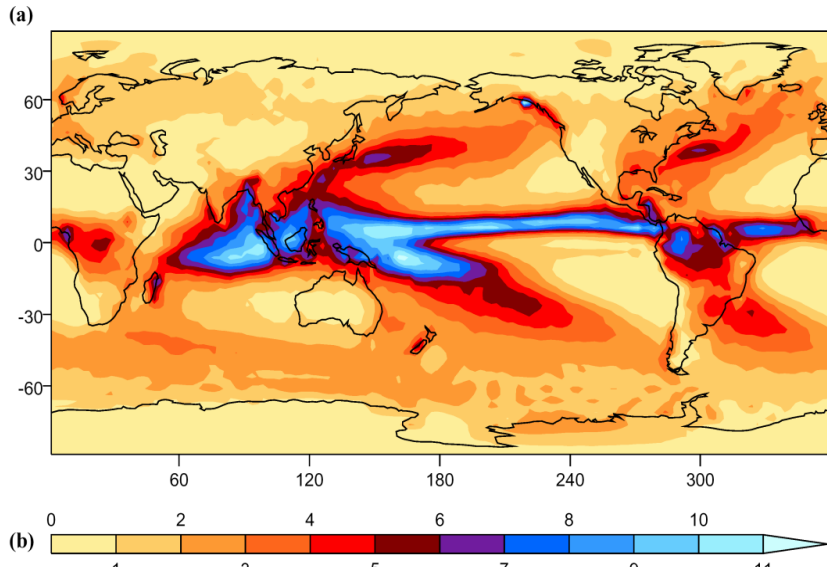
A new approach for modelling and understanding the coupled system



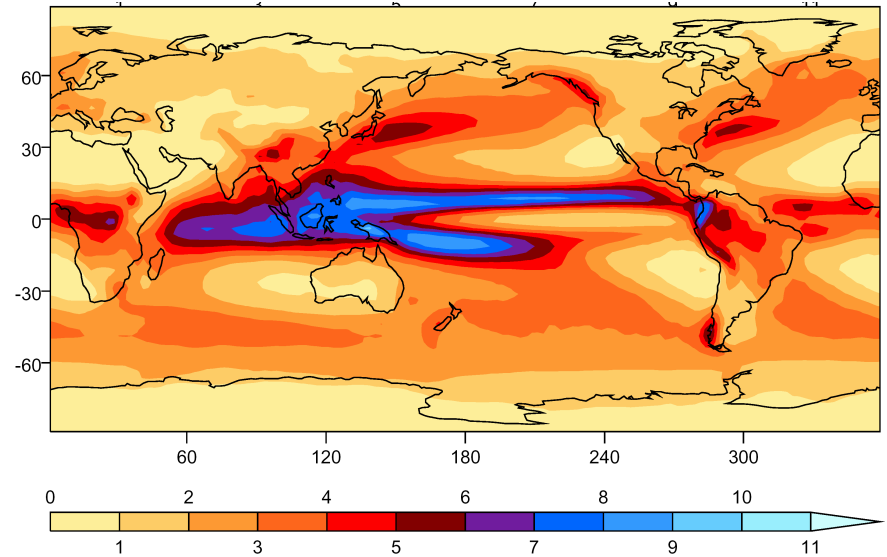
The core of the model is the coupler which exchanges information between different components of the earth system.

Climate models work ...

- Most of the time.
- All models are not equally good. Performances vary.
- No single measure of model performance presently exists
- stunningly well at large spatial scales [continental to global
- Superbly on long time scales [seasonal to multi-annual averages

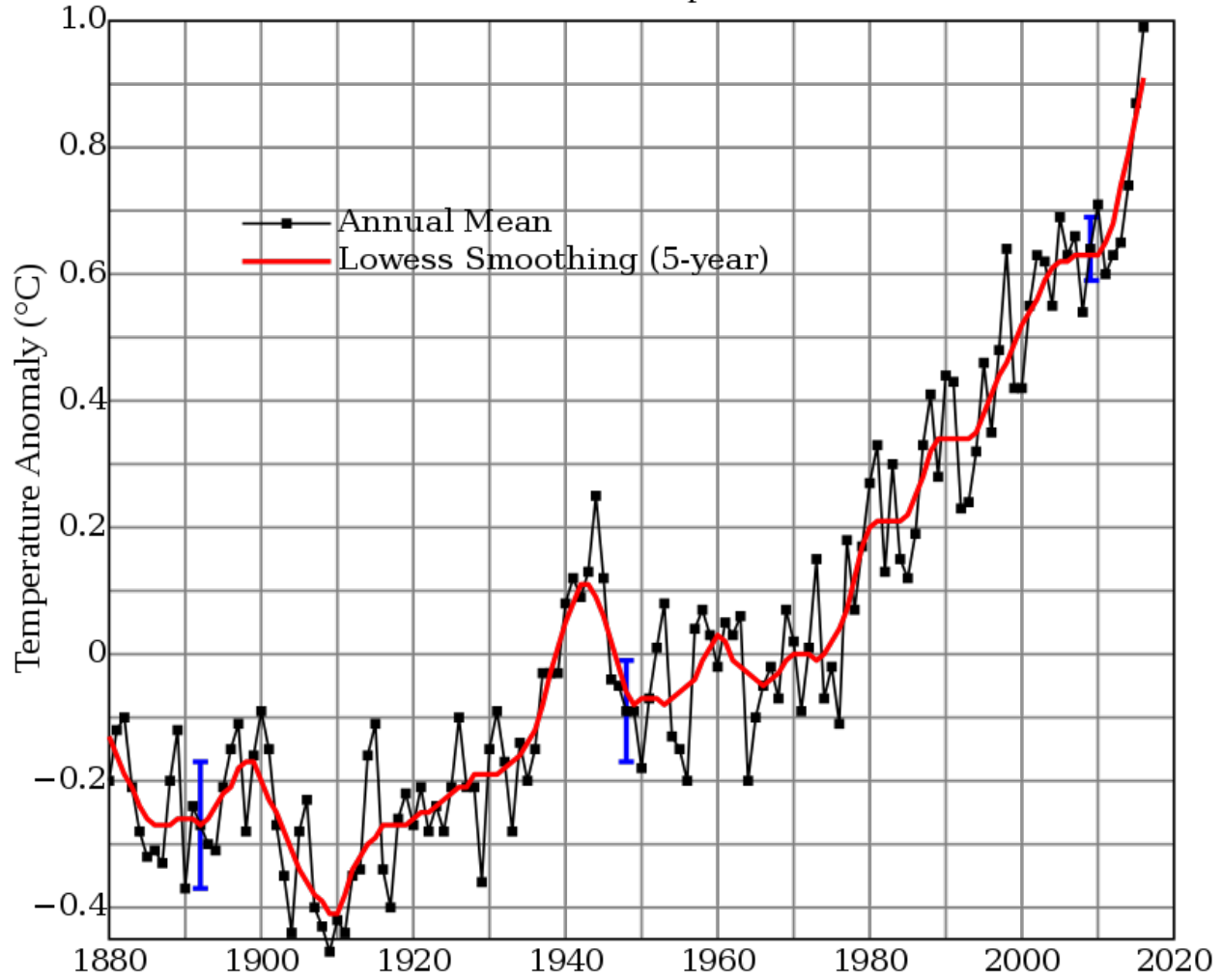


Annual Rainfall observed

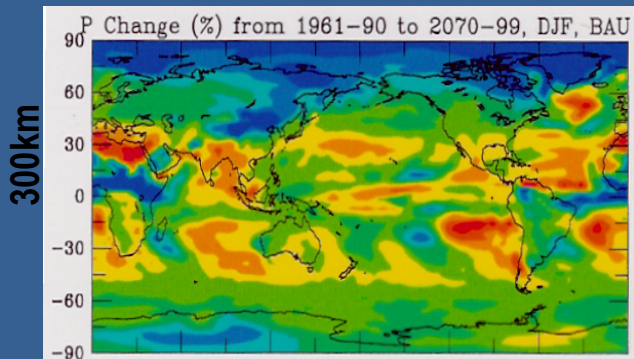


Annual rainfall modelled

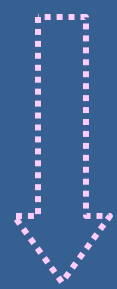
Global Land–Ocean Temperature Index



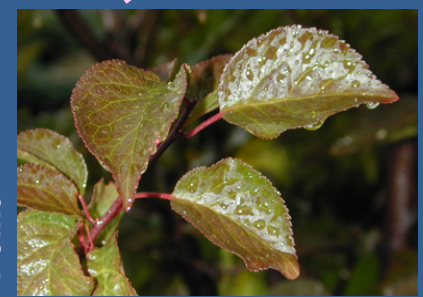
Why regionalisation and downscaling?



Impact models require ...



General Circulation Models supply...



mismatch of scales

between what climate models can supply and environmental impact models

require.

Why Downscaling?

GCM outputs

- are of insufficient spatial and temporal resolution.
- Results in, for example, insufficient representation of orography and land surface characteristics,
- consequent loss of some of the characteristics which may have important influences on regional climate.

- methodologies to derive more detailed regional and site scenarios of climate change for impacts studies : downscaling techniques
- generally based on GCM outputs
- designed to bridge the gap between the information that the climate modelling community can currently provide and that required by the impacts research community

- To overcome this scale mismatch three approaches have been suggested

(1) Develop finer resolution regional climate models that are driven by boundary conditions simulated by global GCMs at coarser scales

- computationally costly

- feedbacks from Regional model into GCMs are not usually incorporated

(2) Use time slice GCMs

Here high resolution atmospheric GCM is forced by boundary conditions for atmosphere generated in coupled integration of low resolution coupled GCM

(3) Derive statistical models from observed relationship between the large scale atmospheric fields and local variables

STATISTICAL DOWNSCALING

Essentially the idea of the statistical downscaling consists in using the observed relationships between the large-scale circulation and the local climates to set up statistical models that could translate anomalies of the large-scale flow into anomalies of some local climate variable (von Storch 1995).

Assumptions in SDS methods

- Regional climate is conditioned by two factors : the large scale climate state and regional/local physiographic features
- GCMS are able to simulate large scale circulation patterns realistically
- There is strong, stable and physically meaningful relationship between predictor(large scale climate variable) and predictand (regional/local variables)
- The relationships remain unchanged in future climate also
- Consistent relationship exists between circulation patterns and surface climate variables.

- Typical predictand is single site daily precipitation/temperature
- Typical predictors are derived from sea level pressure, surface pressure, geopotential heights, wind fields, absolute/relative humidity and temperatures

Spatial downscaling

- Spatial downscaling refers to the techniques used to derive finer resolution climate information from coarser resolution GCM output.
- assumes that it will be possible to determine significant relationships between local and large-scale climate (thus allowing meaningful site-scale information to be determined from large-scale information alone)

Temporal Downscaling

- Temporal downscaling refers to the derivation of fine-scale temporal data from coarser-scale temporal information, e.g., daily data from monthly or seasonal information.
- The simplest method for obtaining daily data for a particular climate change scenario is to apply the monthly or seasonal changes to an historical daily weather record for a particular station.

Typical steps in Statistical Downscaling are

1. Selection of atmospheric domain and local climate data
2. Reduction of atmospheric data : EOF
3. Comparison of GCM circulation with observed circulation
4. Optional temporal smoothing of atmospheric and local variables
5. Derivation of transfer functions between atmosphere and local climate data
6. Testing of relationship
7. Application to projected circulation data and evaluation against local climates derived from observed circulation data

That is

- Identify the large scale parameter G which controls the local parameter L
- If the intent is to calculate L for climate experiments, G should be well simulated by climate models
- Find statistical relationship between L and G
- Validate the relationship with independent data
- If the relationship is confirmed, G can be derived from GCMs to estimate L .

Statistical Downscaling

Advantages

- Computationally inexpensive;
- Provides local information most needed in many climate change impact applications

Disadvantages

- Non-verifiable basic assumption - statistical relationship developed for present day climate holds under the different forcing conditions of possible future climates;
- Data required for model calibration might not be readily available in remote regions or regions with complex physiographical features;
- Empirically-based techniques does not account for possible systematic changes in regional forcing conditions or feedback processes;
- Hard to systematically assess the types of uncertainties;
- Difficult to compare with other downscaling techniques

Main Features of SDM

- Only small computers are needed for the computations
- No need for detail knowledge of physical processes
- Long and homogeneous time series are needed for fitting and confirming the statistical relationship

Unfortunately such series exists for few parameters only

Issues for SD

1. Choice of method

determined by the nature of local variable

2. Choice of predictors

The local variable should be well correlated with large scale predictors and the relationship should not alter in perturbed climate

3. Extremes

SD generally captures mean signal and are not always appropriate for handling extreme events (STARDEX)

4. The tropical regions

These are more complex than midlatitudes because

- Ocean plays dominant role in tropical variability
- the relationship between predictand and predictor may vary strongly within annual cycle so we may need statistical models specially designed for particular months (eg June-September)

5. Feedbacks

Under weak synoptic forcings, other climate subsystems such as vegetation may come into play in changed climate. Their role is very critical in feedback processes eg onset, development of extreme convective systems etc Response of these processes may compromise downscaling models.

When to use SD method

- Particularly useful in heterogeneous environments with complex physiography or steep gradients like mountainous regions or islands
- For generating climate scenarios for point scale processes such as soil moisture
- When there is need for better sub-GCM grid-scale information on extreme events such as heat waves, heavy precipitation or localized flooding
- When computational resources are limited eg in developing countries
- When scenarios are needed on very fine spatial and temporal scales

SD Methods should not be used

- When long time series of observed local variable is not available
- When land-surface feedbacks are important (eg vegetation, human modified natural landscapes etc)
- When the statistical transfer function is temporally unstable

Statistical Downscaling

Three categories of techniques:

Transfer function;

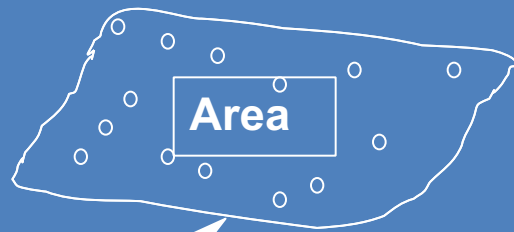
Weather typing;

Weather generator

Methods for SD

- Analogues
- Weather Classification Schemes
- Regression Models
- Multiple regression, Canonical Correlations and Singular Value Decomposition
- Stochastic Weather Generators

Statistical Downscaling - *Transfer function*



Predictor variables
e.g., MSLP, 500, 700 hPa geopotential heights, zonal/meridional components of flow, areal T&P

Select predictor variables

Extract predictor variables from GCM output

Transfer function
e.g., *Multiple linear regression, principal components analysis, canonical correlation analysis, artificial neural networks*

Calibrate and verify model

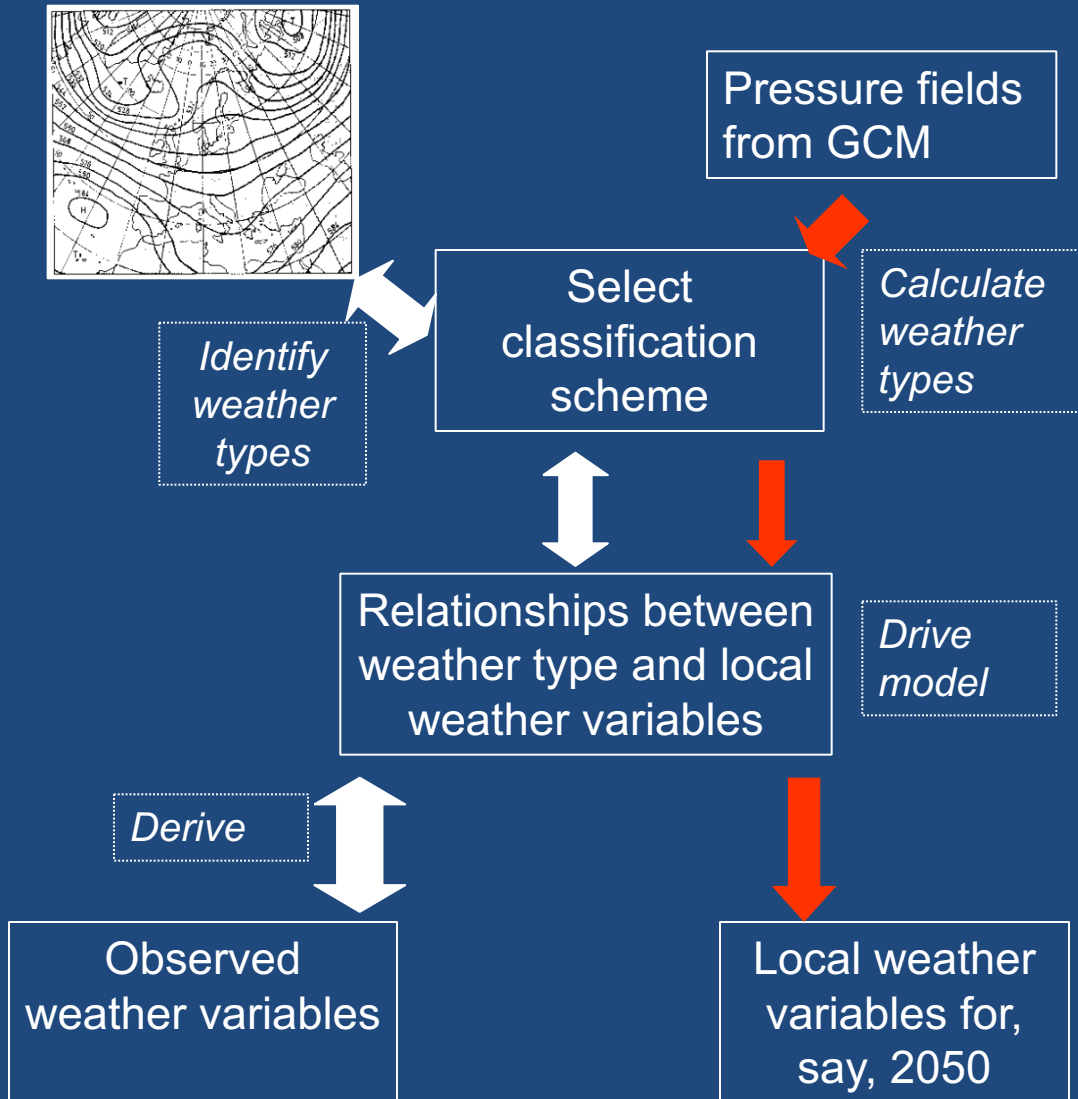
Drive model

Observed station data for predictand, e.g., temperature, precipitation

Site variables, e.g., temperature and precipitation for future, e.g., 2050



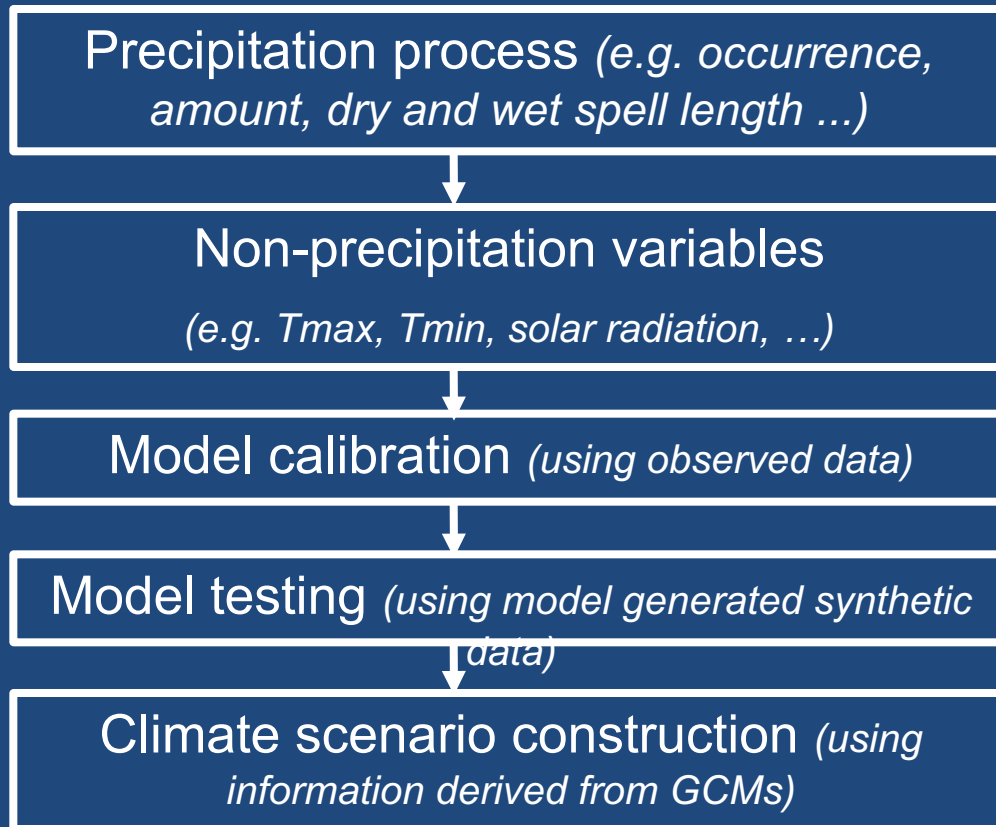
Statistical Downscaling - Weather Typing



Statistically relate observed station or area-average meteorological data to a weather classification scheme.

Weather classes may be defined objectively (e.g. by PCA, neural networks) or subjectively derived (e.g., Lamb weather types [UK], European Grosswetterlagen)

Statistical Downscaling - Weather Generator



Analogues

- The large-scale atmospheric circulation simulated by a GCM is compared to each one of the historical observations and the most similar is chosen as its analog. The simultaneously observed local weather is then associated to the simulated large-scale pattern.

(Zorita et al 1995; Zorita-Storch 1999; Teng et al 2012; Charles et al 2013; Guitereze et al 2013 ; Timbal-Jones 2008; Timbal-McAvaney 2012...)

Weather Classification Schemes

- A classification scheme of the atmospheric circulation in the area of interest is developed and a pool of historical observations is distributed into the defined classes.
- The classification criteria are then applied to atmospheric circulations simulated by a GCM, so that each circulation can be classified as belonging to one of the classes.
- To each observed circulation there exists a simultaneous observation of the local variable.
- Some methods are SOM, CART, Fuzzy etc

(Zorita et al 1995; Goodess-Jones 2002; Ghosh-Mujumdar 2006; Boe et al 2006; Donofrio et al 2010; Guitereze et al 2013)

Regression Models

- These methods give simple way of representing linear or nonlinear relationships between predictand and large scale atmospheric forcing

Multiple regression, Ridge Regression, logistic regression, Kernel Regression, Censored quantile regression, multivariate autoregressive model, Canonical Correlations, Singular Value Decomposition after EOF, CART

(Easterling 1999; Solomon 1999; Busoić et al 2001; Wetterhall 2005; Ghosh-Mujumdar 2006; Friederichs-Hense 2007; Cannon 2009; Li et al 2009; Huth 1999, 2000; Nicholas-Battisti 2012; Simon et al 2013; Alaya and Chebana 2015; Singh et al 2016)

Most Recent techniques

- **Bias Corrected Spatial Disaggregation** Wood et al 2002, 2004
- **Bias Corrected Constructed Analogues** Hidalgo et al 2008; Maurer-Hidalgo 2010
- **Localised Constructed Analogues** Pierce et al 2014
- **Hidden Markov Models** Robertson et al 2004
- **Pattern Projection Downscaling** Kang et al 2009
- **Asynchronous Regression** Stoner
- **Multivariate Multi-site Downscaling** Jeong et al 2012
- **Quantile based downscaling using genetic programming** Hassazadeh et al 2014

Temporal Downscaling

- The most useful way of obtaining daily weather data from monthly scenario information is to use a stochastic weather generator - a statistical model which generates time series of artificial weather data with the same statistical characteristics as the observations for the station
- **Stochastic Weather generators**

Two main reasons to develop WG

- To provide means of simulating synthetic weather time series with certain statistical properties which are long enough
- To provide means of extending the simulation of weather time series to unobserved locations

(Mason 2004; Kim et al 2016)

Wilby, Wilby-Wigley, Wilby – Dawson, Wilby et al
1994, 1998, 2002, 2004, 2012, 2014.....

Softwares/Portals

- SDSM
<http://co-public/lboro.ac.uk/cocwd/SDSM>
- Clim.pact
<http://cran.r-project.org>
- ENSEMBLE
<http://www.meteo.unican.es/ensembles/>
- CHAC
<http://sourceforge.net/projects/chac>
- LARS-WG
<http://www.iacr.bbsrc.ac.uk/mas-models/larswg.html>

<http://www.cru.uea.ac.uk/projects/ensembles/ScenariosPortal/Downscaling2.htm>
- [ESD : R Package](#)

EMPIRICAL STATISTICAL DOWNSCALING

RE Benestad , D Chen, I Hansen-Bauer
2007

THANK YOU !!