Oficina Regional de Ciencia para América Latina y el Caribe

Organización de las Naciones Unidas para la Educación, la Ciencia y la Cultura

Programa Hidrológico Internacional

CAZALAC

Flemish government

Introduction to the framework for the simulation of regional decadal variability for water management

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Introduction

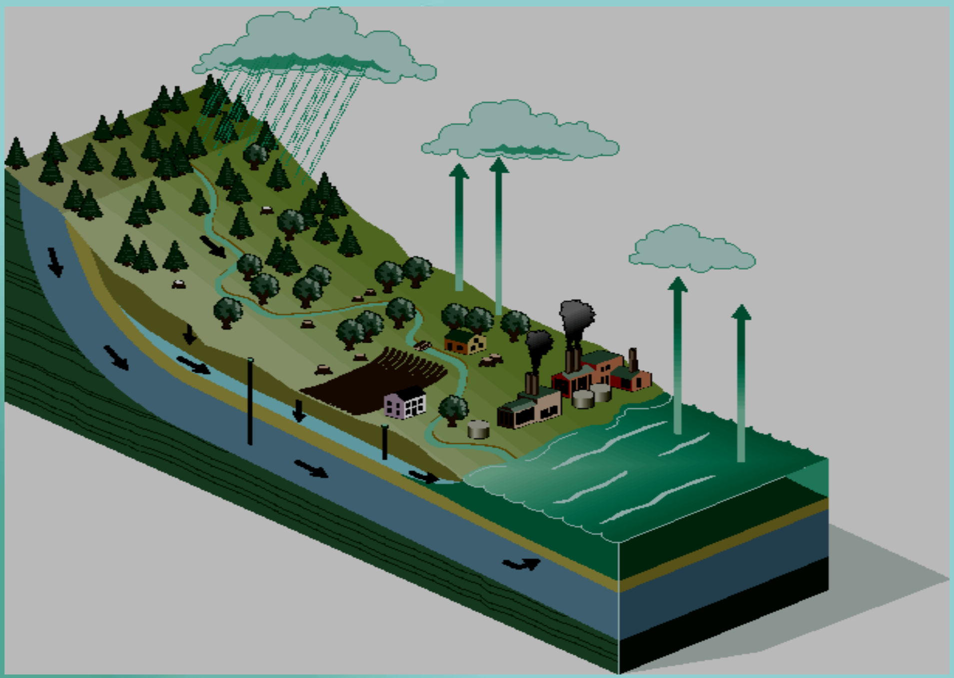
Objective

The goal of this activity is to contribute to the development of strategies that can increase water productivity – in view of near-term climate change scenarios for different areas of the South Cone, and will focus on three likely areas for action: water shortage (drought), excess rainfall and/or increase in the frequency of extreme events (floods).

Specific outcomes

1. A new tool to decompose climatic variability and project it to near term climate conditions available for download
2. Water management models for three different water basins in place and well calibrated
3. Future climate data series downscaled to the measurement stations in the pilot areas available for download
4. Future water resources at the station level visualized by online interactive maps

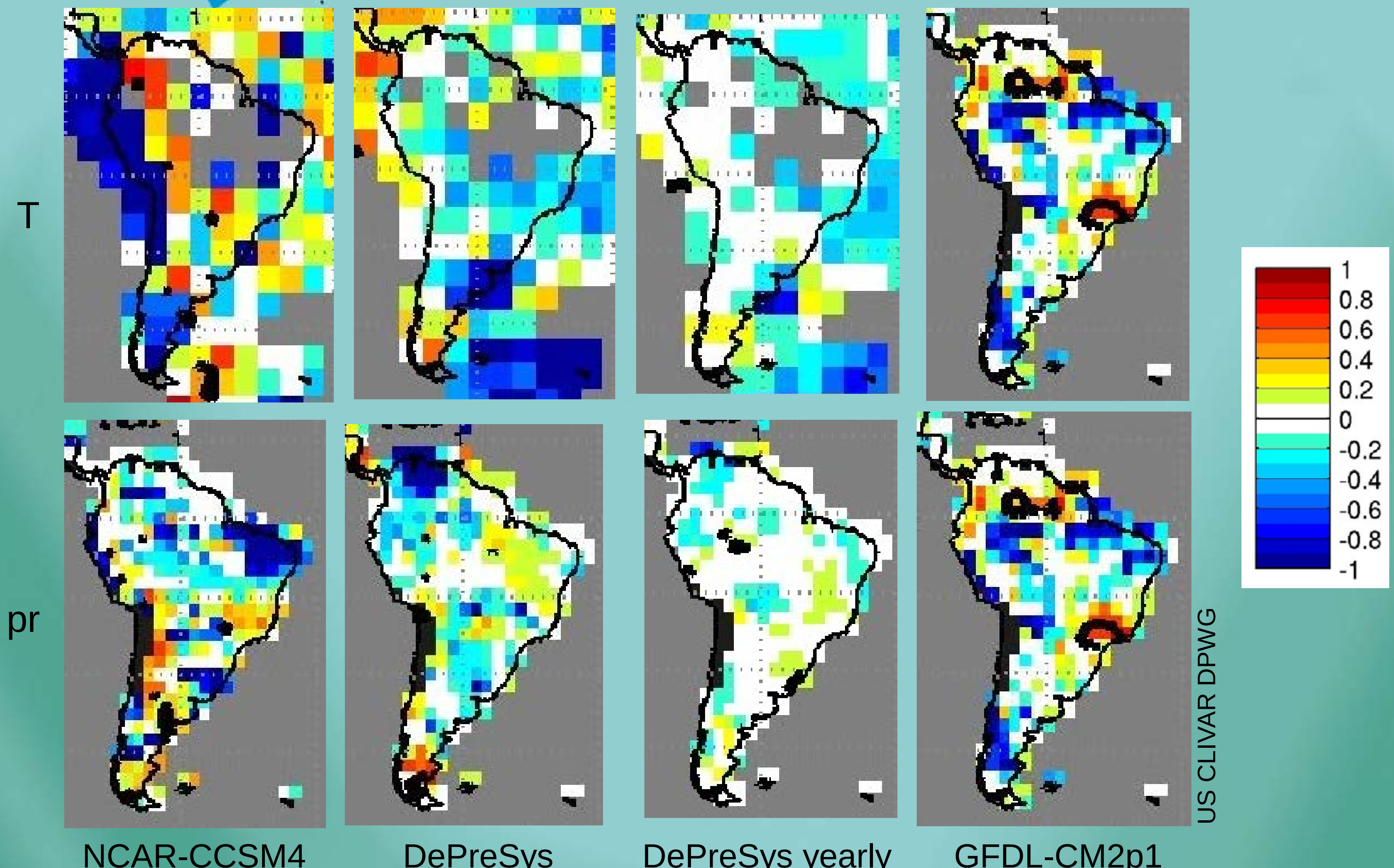
Questions we like to address in relation to future water resources



- Suficient water resources?
- What is the frequency of droughts?
- What about extreme events?

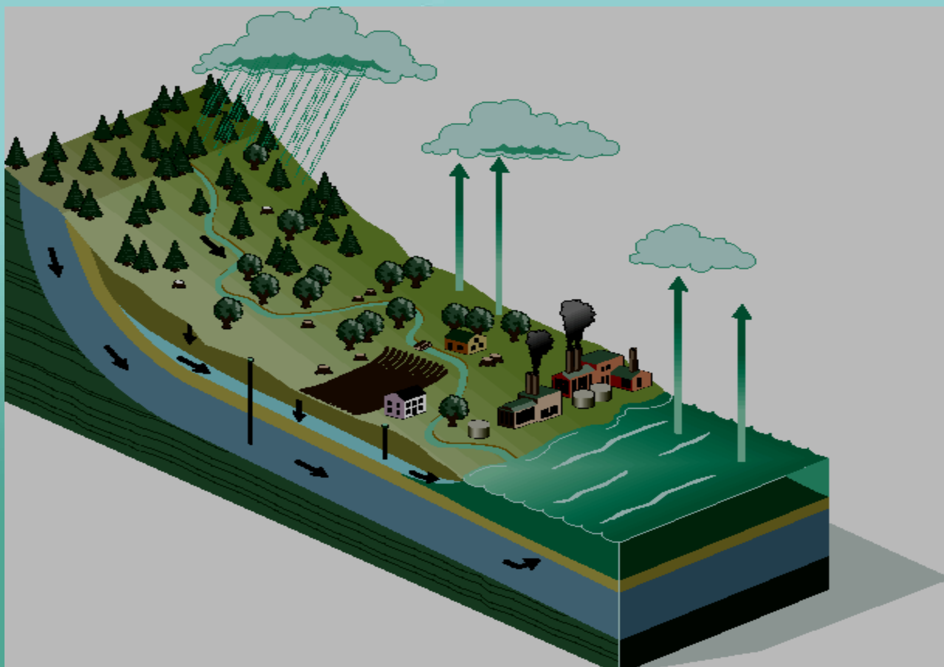
- Skillful <u>decadal forecasts</u>, particularly at regional scales (and over land), still lie in the <u>future</u>.

Dynamical decadal prediction skill: Still to be demonstrated



MSSS for mean of years 2-5, initialized vs. uninitialized models

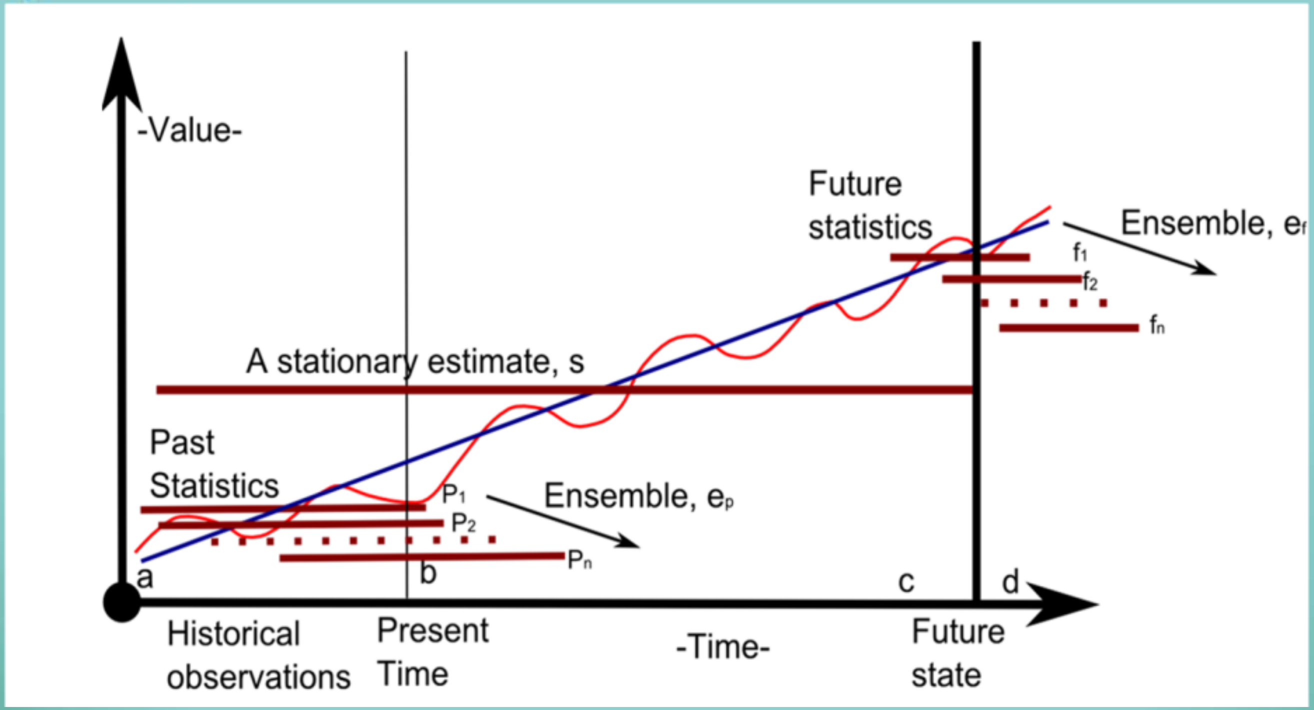
Questions we like to address in relation to future water resources



- Suficient water resources?
- What is the frequency of droughts?
- What about extreme events?

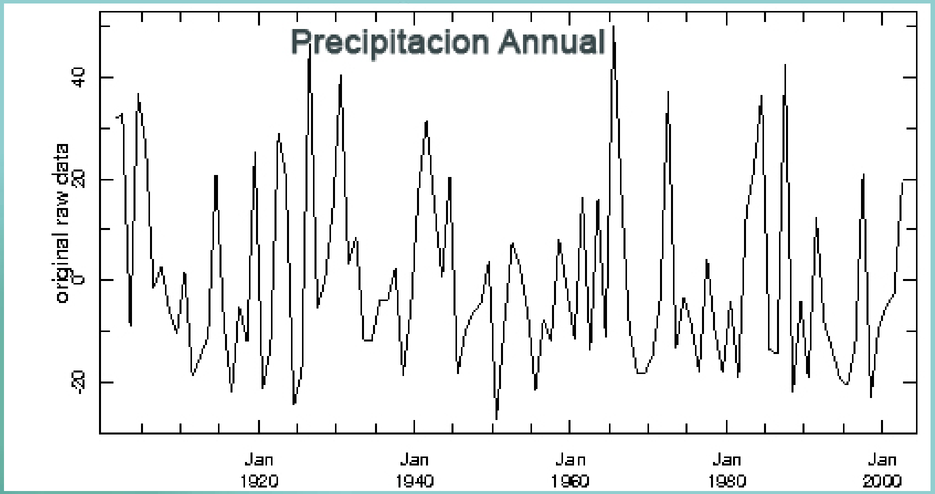
- Skillful decadal forecasts, particularly at regional scales (and over land), still lie in the future.
- A potentially useful alternative: Synthetic data sequences, conditioned by observations and including a regional climate change component.

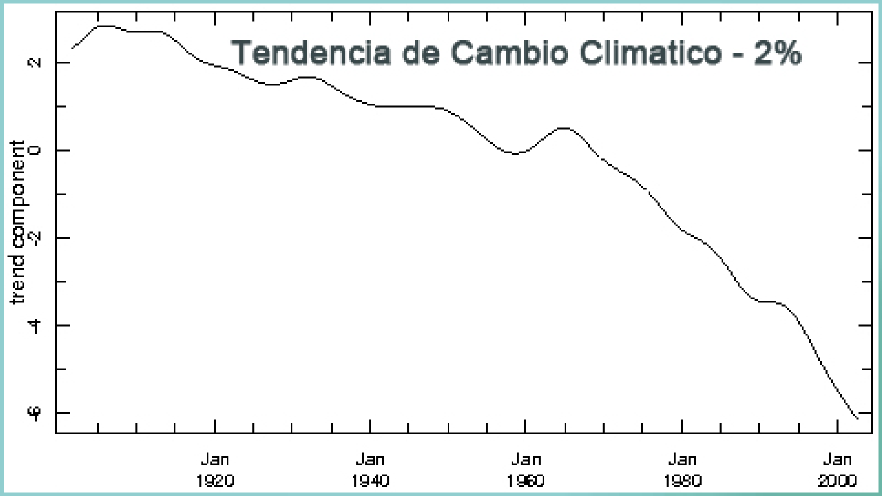
Why do we need stochastic sequences?

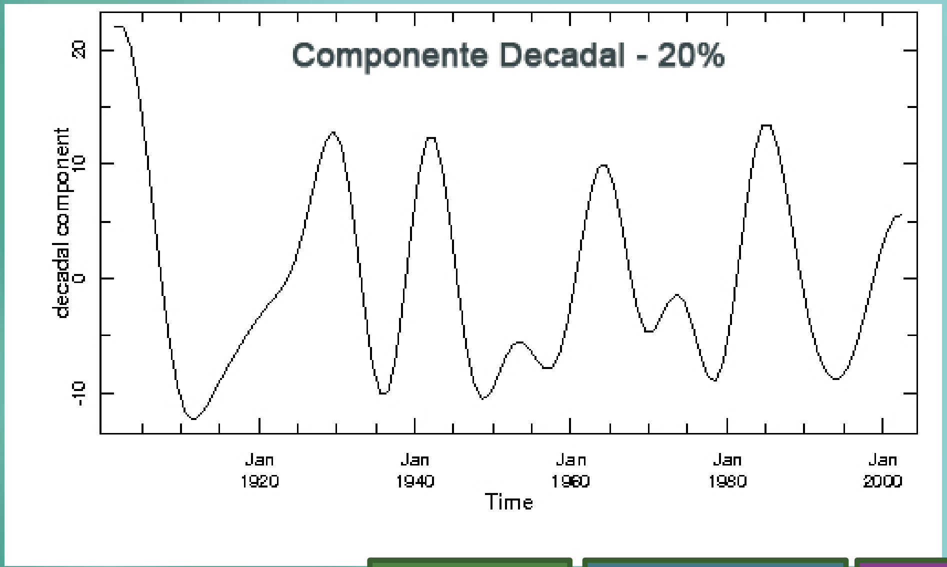


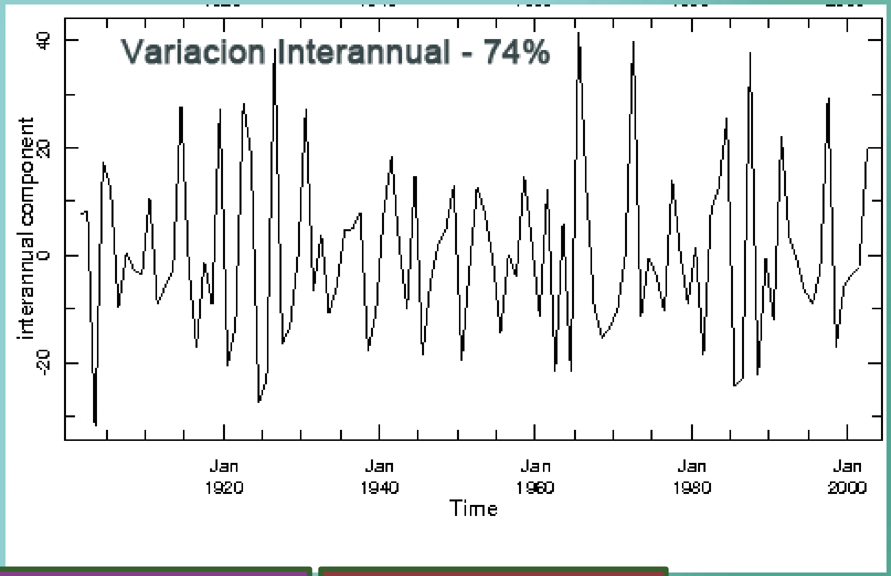
- No stationarity
- Statistics of "short stationary segments"
- Need for ensembles or stochastic sequences
- No 'prediction of the future' but a characterization of future climatic uncertainty over the next few decades

What are the components of variability?



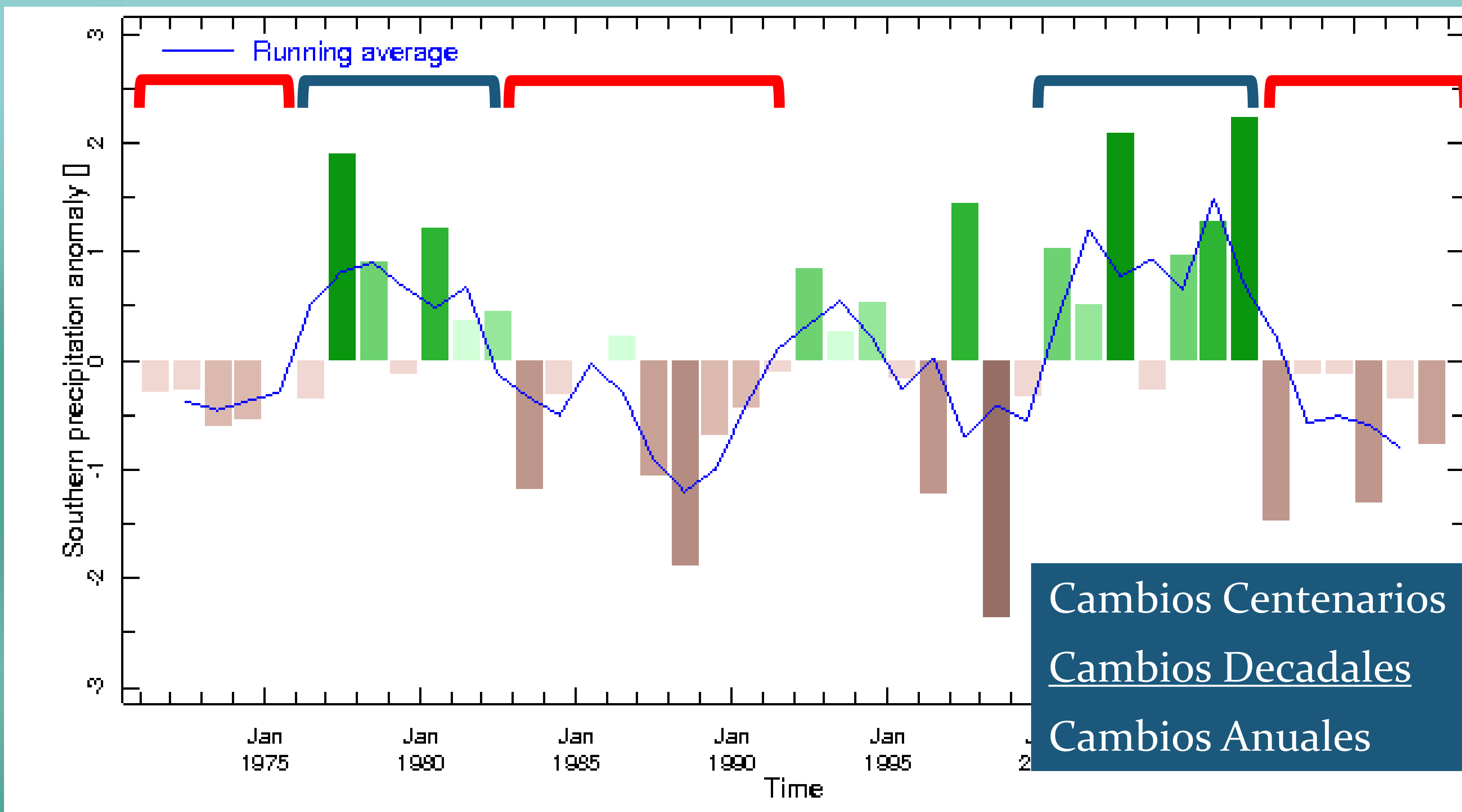






TREND | DECADAL | INTER-ANNUAL | SUB-ANNUAL

What is the importance of Decadal Variability?



Cambios Centenarios	2%
Cambios Decadales	19%
Cambios Anuales	79%

Why considering these three types of variation?

Definition of the Modeling Framework

Trends provide a slowly-changing background state on which decadal, and by extension, higher-frequency fluctuations are superimposed.

Acting in concert, these influences can provide <u>a better description of the expected range of near-term climate variations</u>, and their potential impacts on statistics of interest for water management or agriculture, <u>than either considered alone.</u>

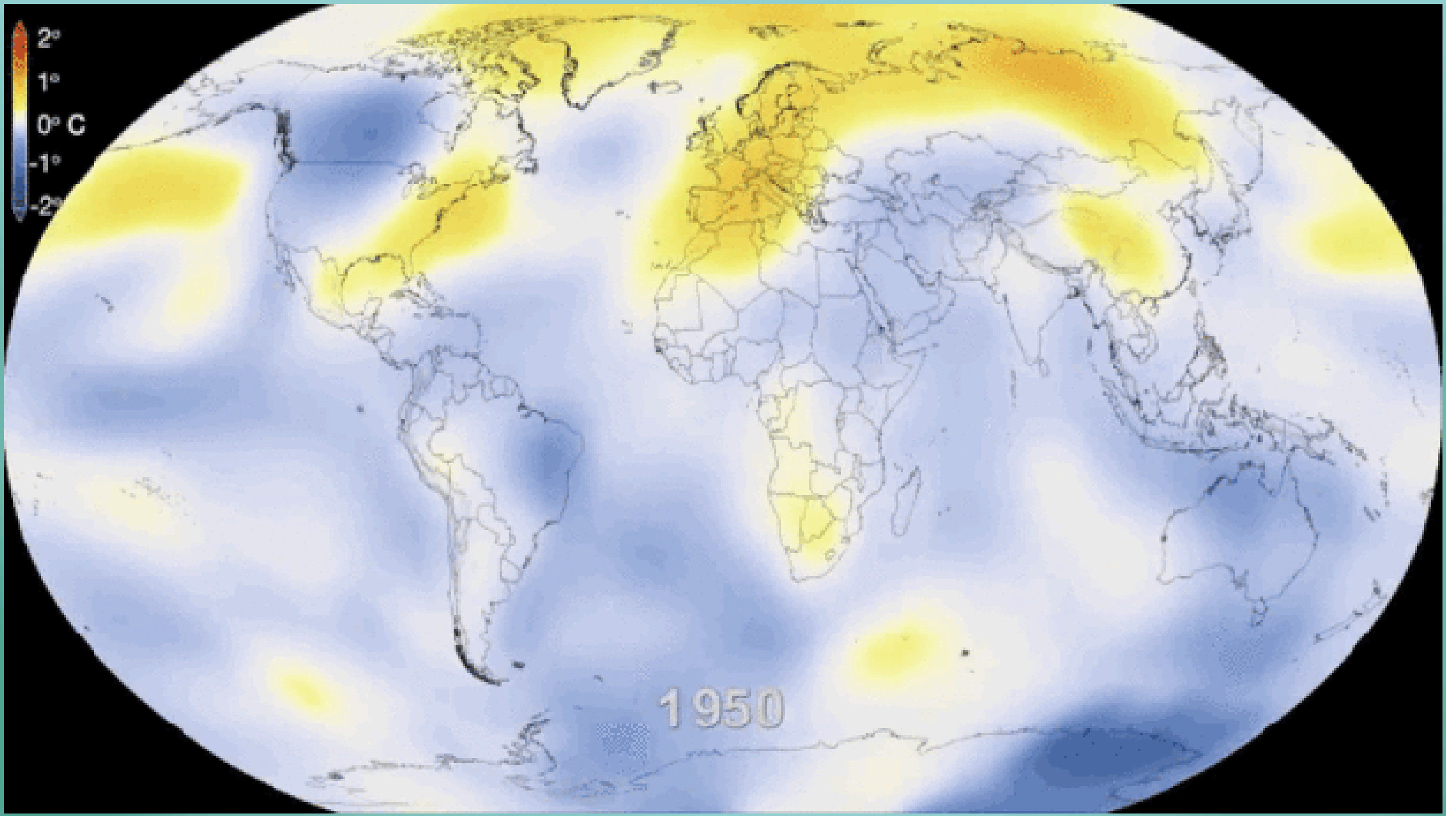
What do we know about each of these components?

TREND

Theoretical Background

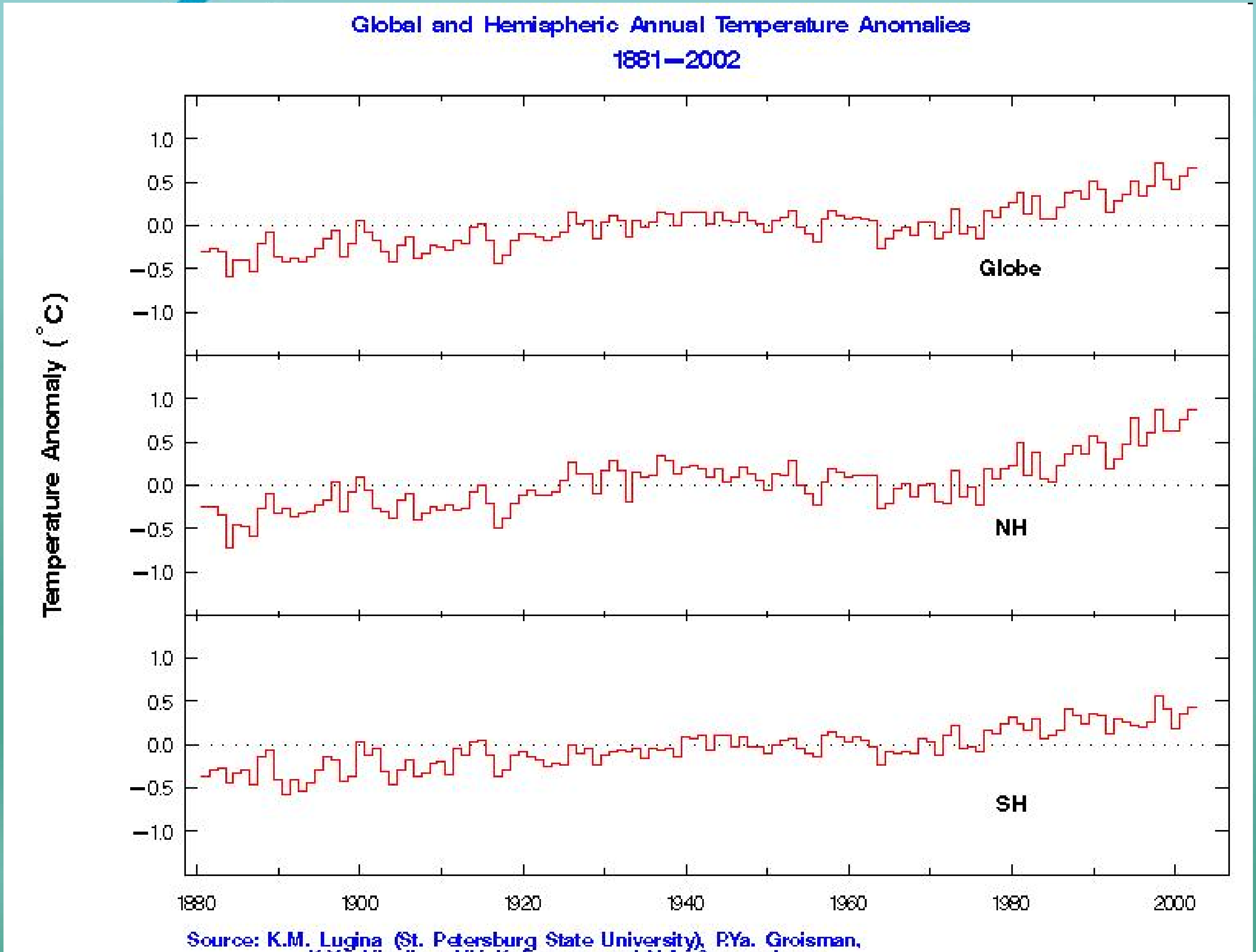
1. Climate change

What is the Temperature Trend?



NASA, 2013

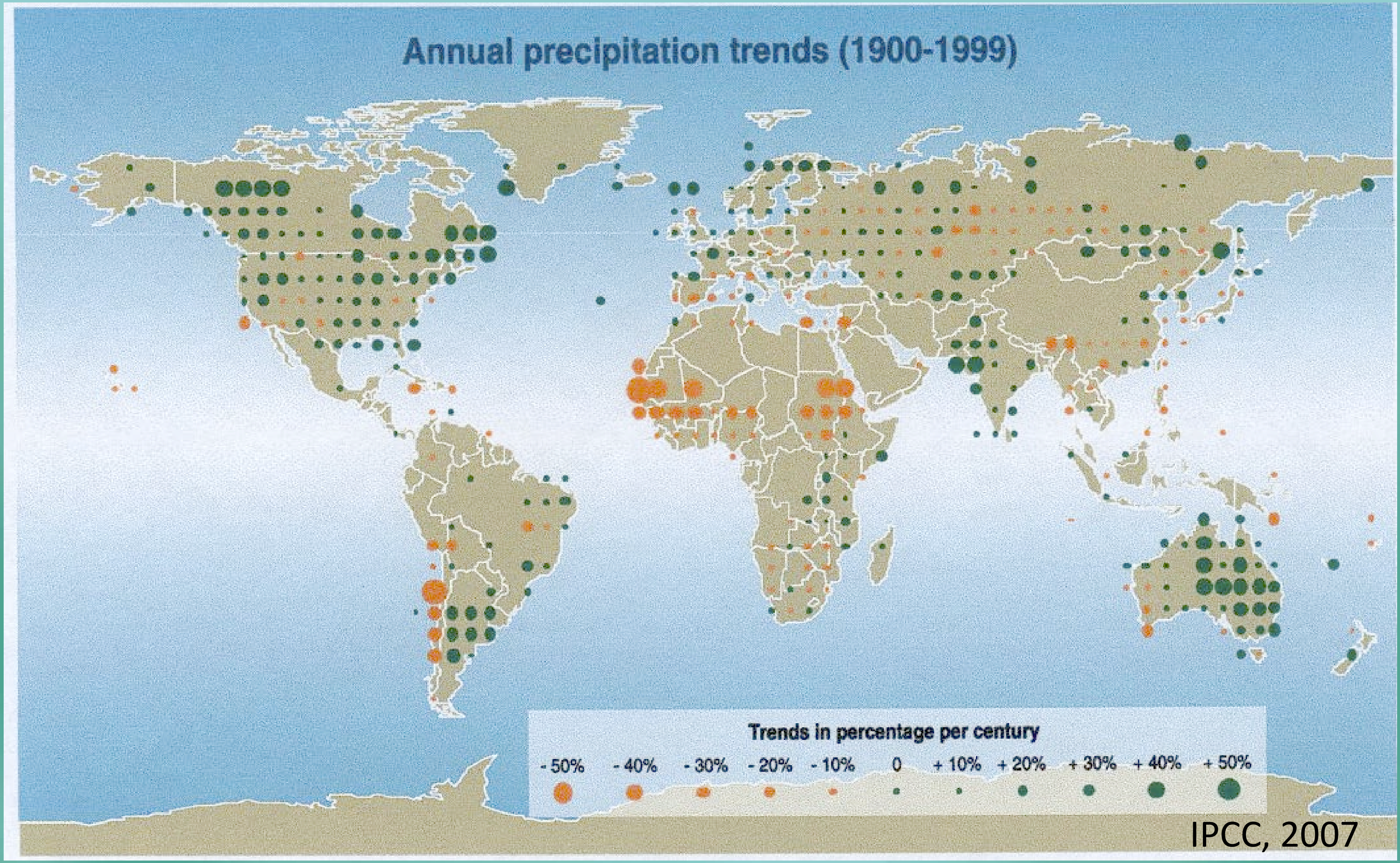
Theoretical Background



TREND

Cuál es la tendencia en la precipitación?

Tendencia histórica y actual de reducciones de precipitación



IPCC, 2007

SUB-ANNUAL

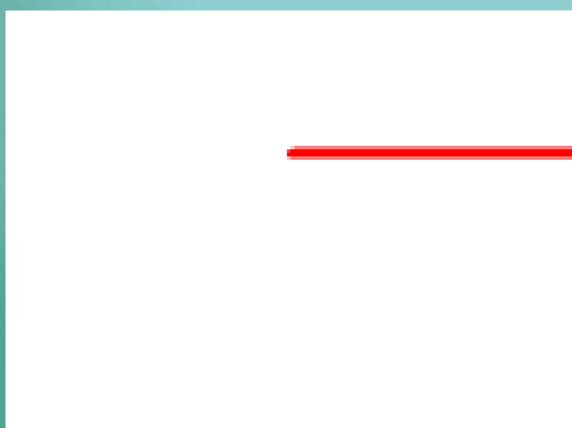
Theoretical Background

2. Subannual variations

The seasonal cycle ➡ Earth's inclination and orbital motion around the sun

Daily weather fluctuations ➡ Atmospheric instabilities of various kinds

'Chaos theory'



"weather generators"
= realistic sequences of synthetic data

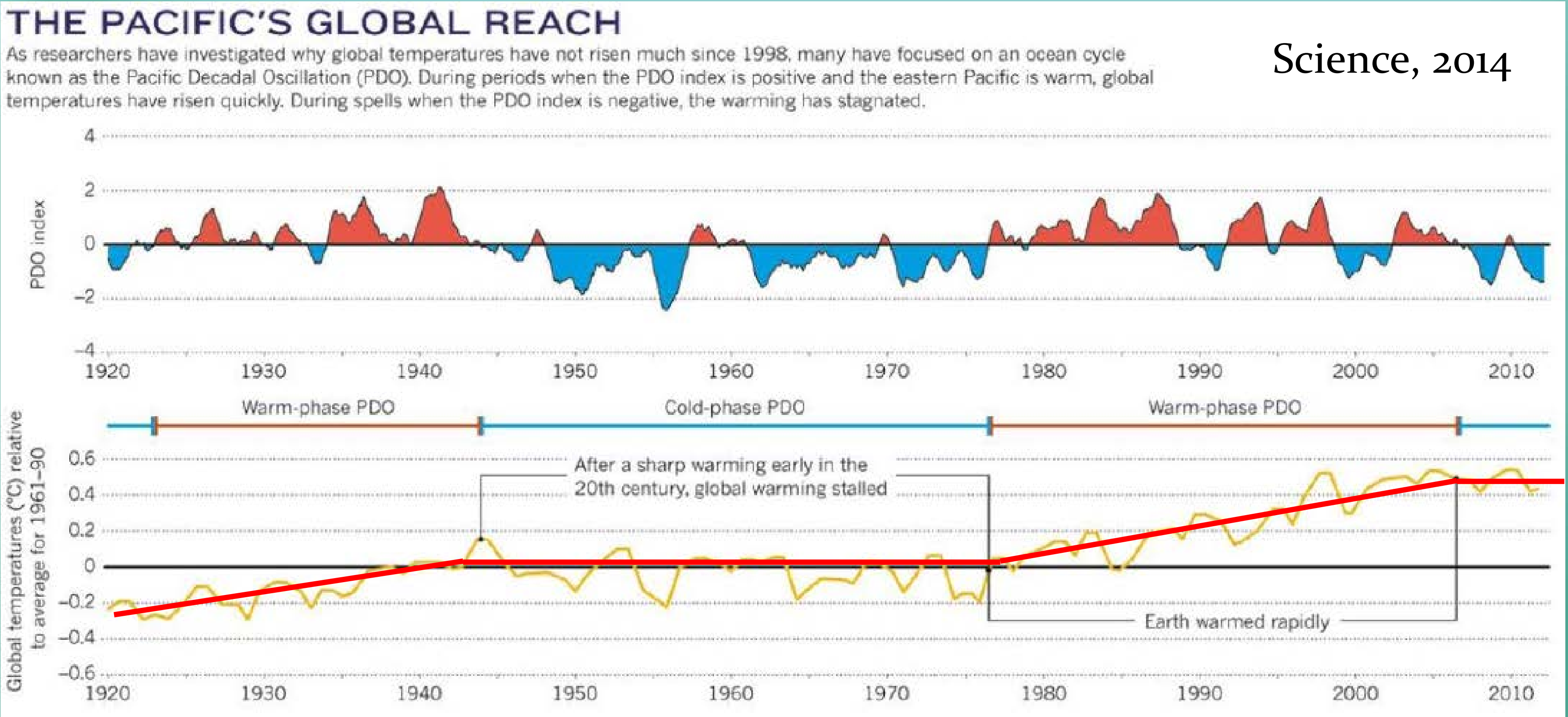
DECADAL

Theoretical Background

Decadal Variability ≠ Climate Change

Climate Change: response of the land-ocean-atmosphere system to external forcing (anthropogenic changes to the radiative properties of the atmosphere)

Decadal variability: Intrinsic, or internal, to the climate system.



Science, 2014

DECADAL

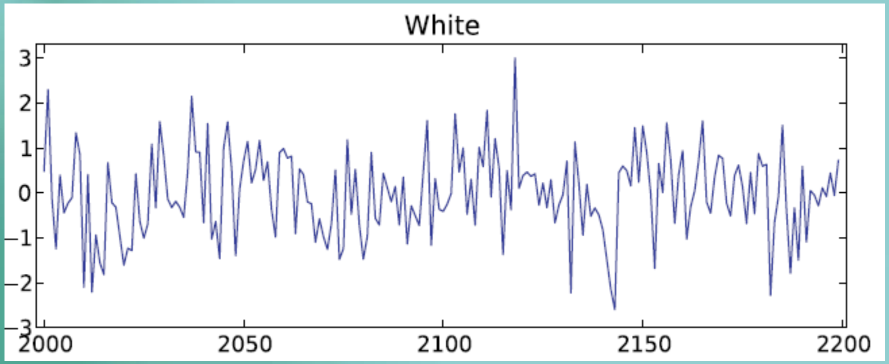
INTER-ANNUAL

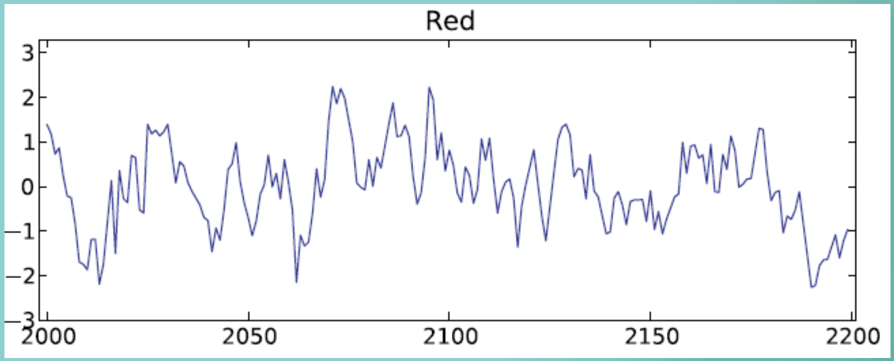
Theoretical Background

Noise: white and red

Rapid fluctuations of daily weather and the slower variations of decadal variability

expressions of r*andomness* within the climate system.





<u>White Noise</u>: 'atmosphere-like'

- Fluctuations are uncorrelated:

The value at any time t is unrelated to its value at any other time.

- Completely unpredictable from a knowledge of its own history.
- Defined by its mean and variance

<u>Red Noise</u>: 'Ocean-like'

- Exhibits a degree of serial autocorrelation
- Some memory

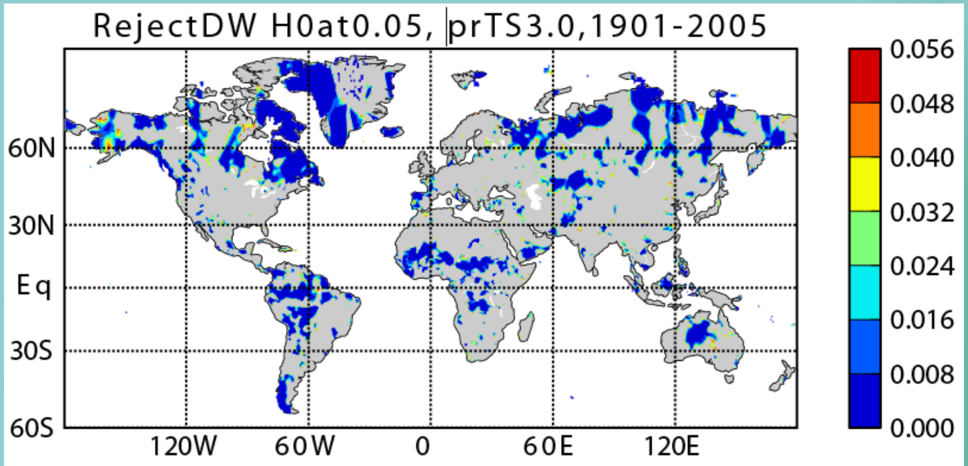
DECADAL
INTER-ANNUAL

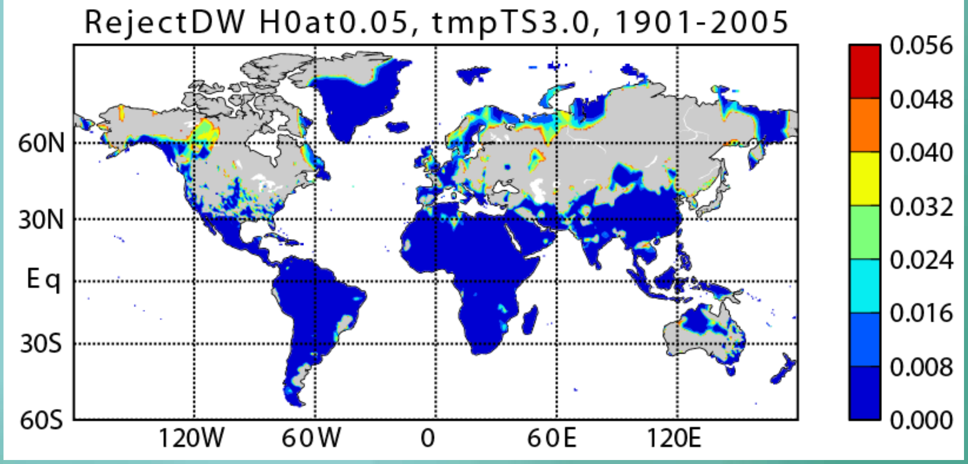
Theoretical Background

Noise: white and red

<u>Where is redness?</u>

- p-value for rejecting H0: Residuals are not lag-1 autocorrelated.
- Regression is on the MMM global mean temperature.
- Annual mean precip (top), temperature (below).
- NOT screened for filled data…





DECADAL

INTER-ANNUAL

Theoretical Background

Evidence of Redness in historical records?

Nilometer at the sland of Rhoda

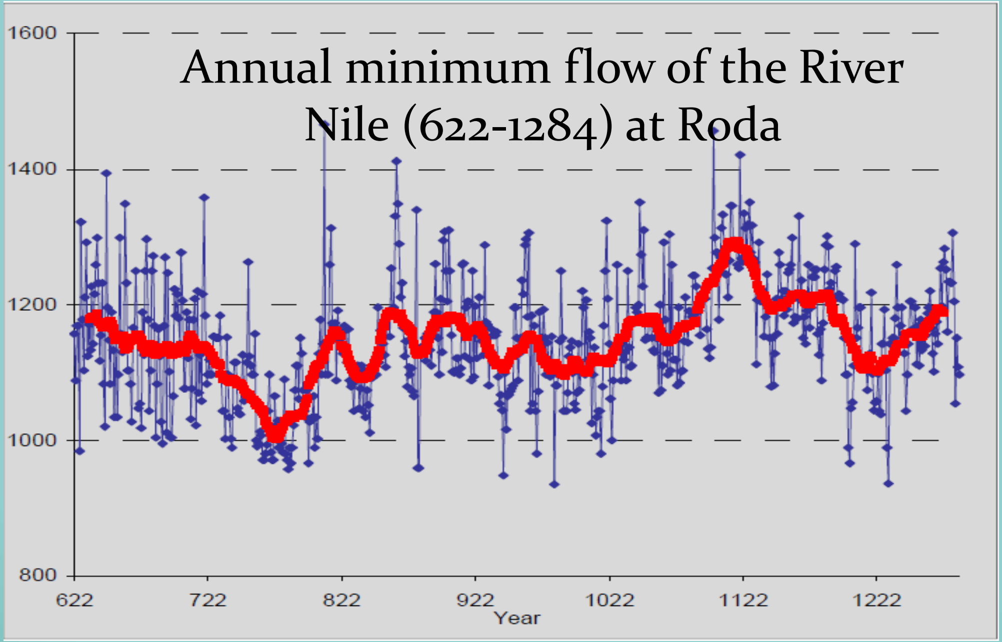
Long-term monitoring: <u>600 years</u>!

DECADAL

INTER-ANNUAL

Theoretical Background

Evidence of Redness in historical records?



- Huge ***climatic variability*** at large time scales
- Discovery of the **Hurst Phenomenon**:

Theoretically, ***h*** should have a value of 0.5 for normally (or log-normally) distributed sequences of independent random values

Nile minima: h=0.75 ➔memory or autocorrelation

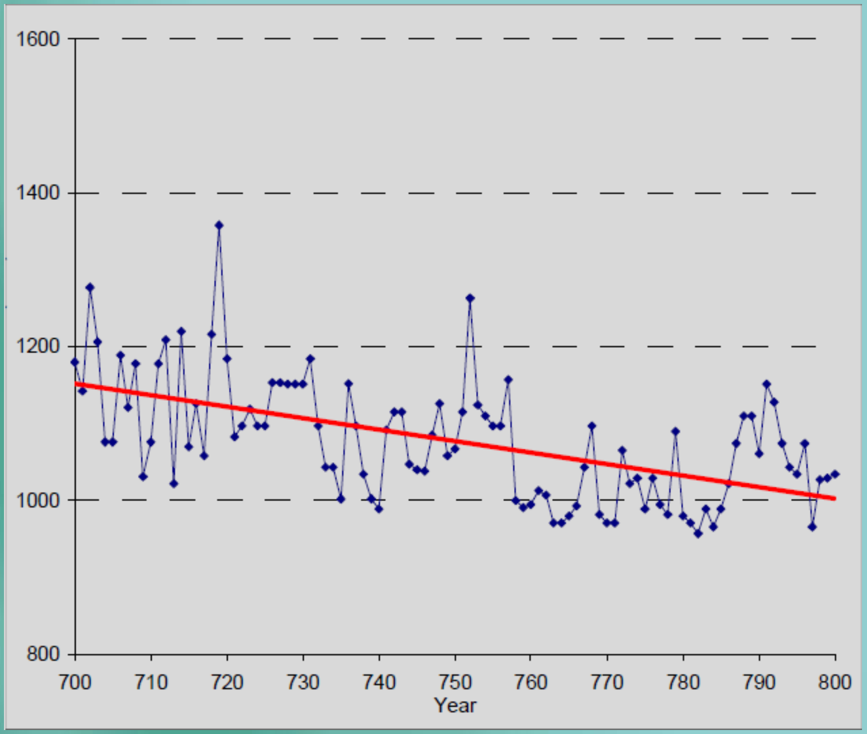
DiBaldassare, 2012

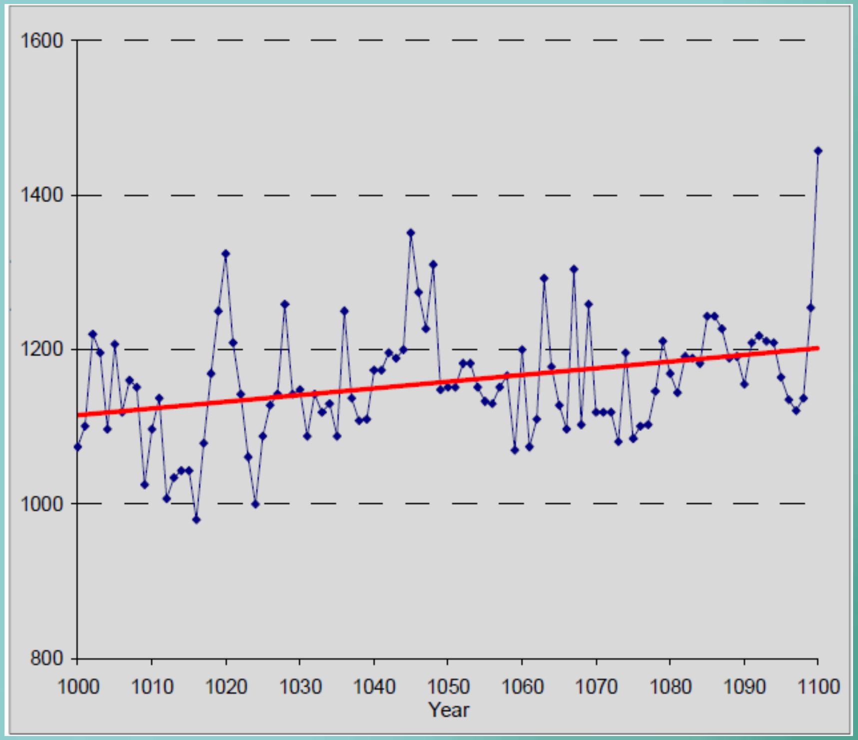
TREND

Theoretical Background

Evidence of **<u>Trends</u>** in historical records?

Multiple trends at large time scales: take care interpreting short record lengths!





Non-random processes are active – ocean influences

DiBaldassare, 2012

Theoretical Background

How does this understanding impact the Modeling Framework?

Recognize that the oceans are a likely source, through their "teleconnections" with terrestrial climates, of the variations that we wish to emulate in our stochastic sequences.

We should not be surprised, therefore, if we find that this variability has the character of red noise, or if such noise is present as a background against which more "deterministic" processes play out.

Theoretical Background

Role of Observational Data – **GCM's**

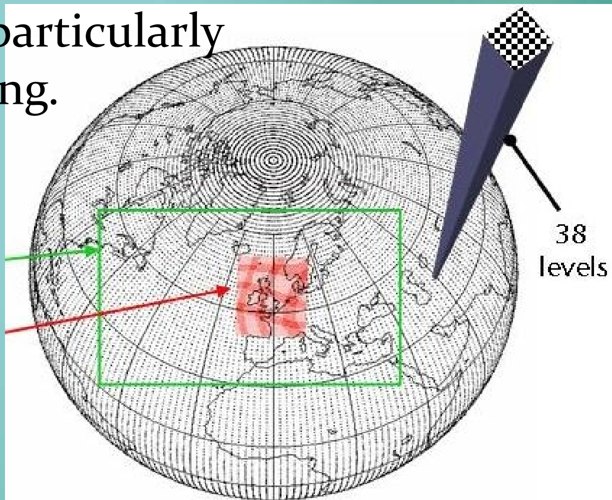
Can GCMs replace station-based observational records?

Observational data are *required* for the validation of GCM simulations.

"Internal" variability of GCMs is often of questionable realism:

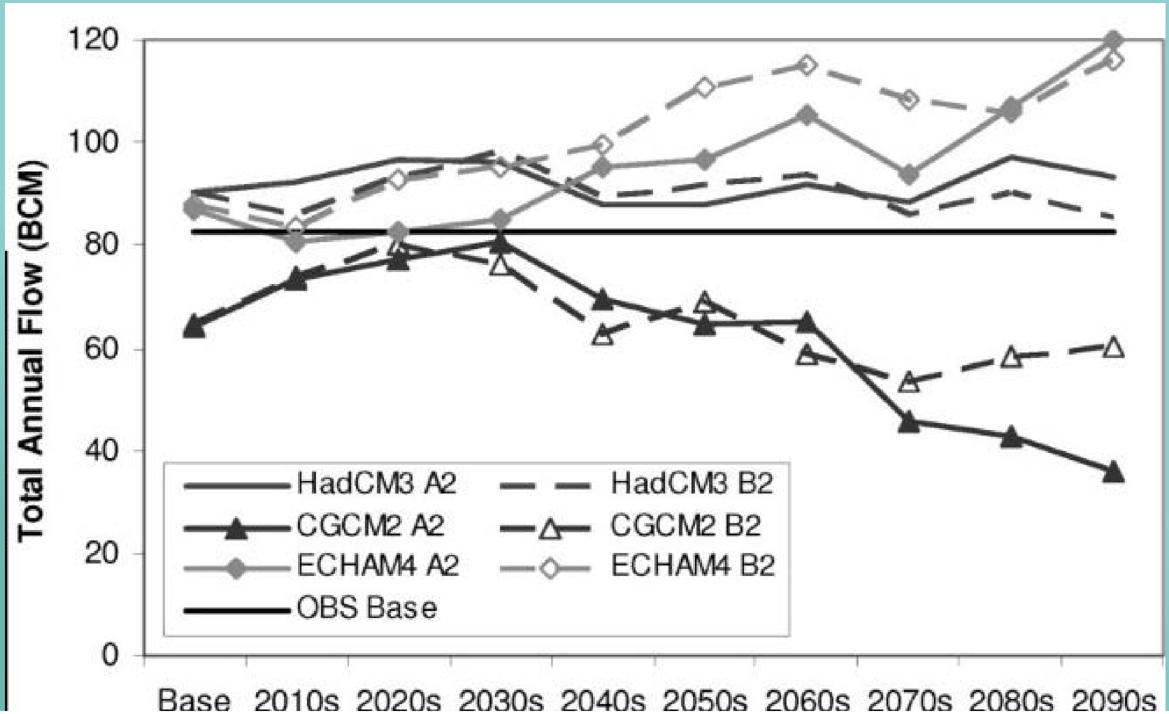
- biases in signal amplitudes, time scales, spatial patterns
- Inadequate representation of natural variability

No substitute for good-quality observational records, particularly on the small spatial scales relevant for impacts modeling.



Theoretical Background

Why can't we just use GCMs for projections ?



6 GCM projections for Total Annual Flow in the Nile Basin

Decision Making?

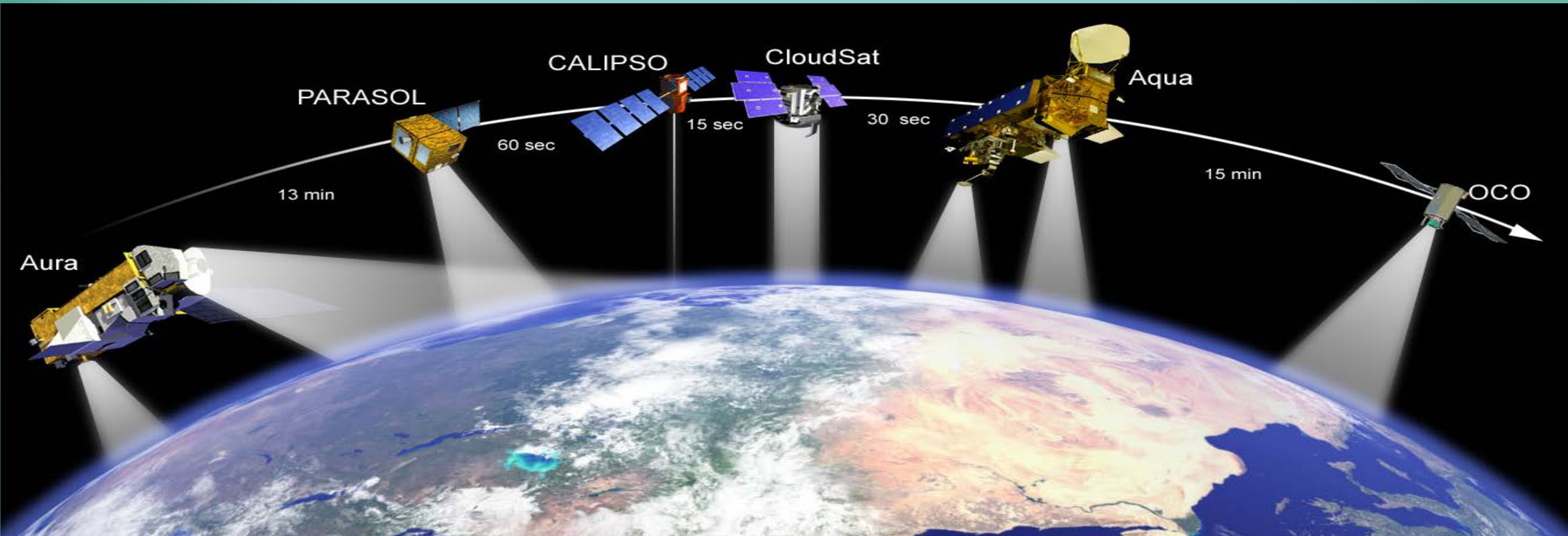
Entire modelling chain (climate modelling, spatial and temporal downscaling, hydrological modelling, and impact assessment) is affected by <u>large uncertainty</u>

DiBaldassare, 2012

Theoretical Background

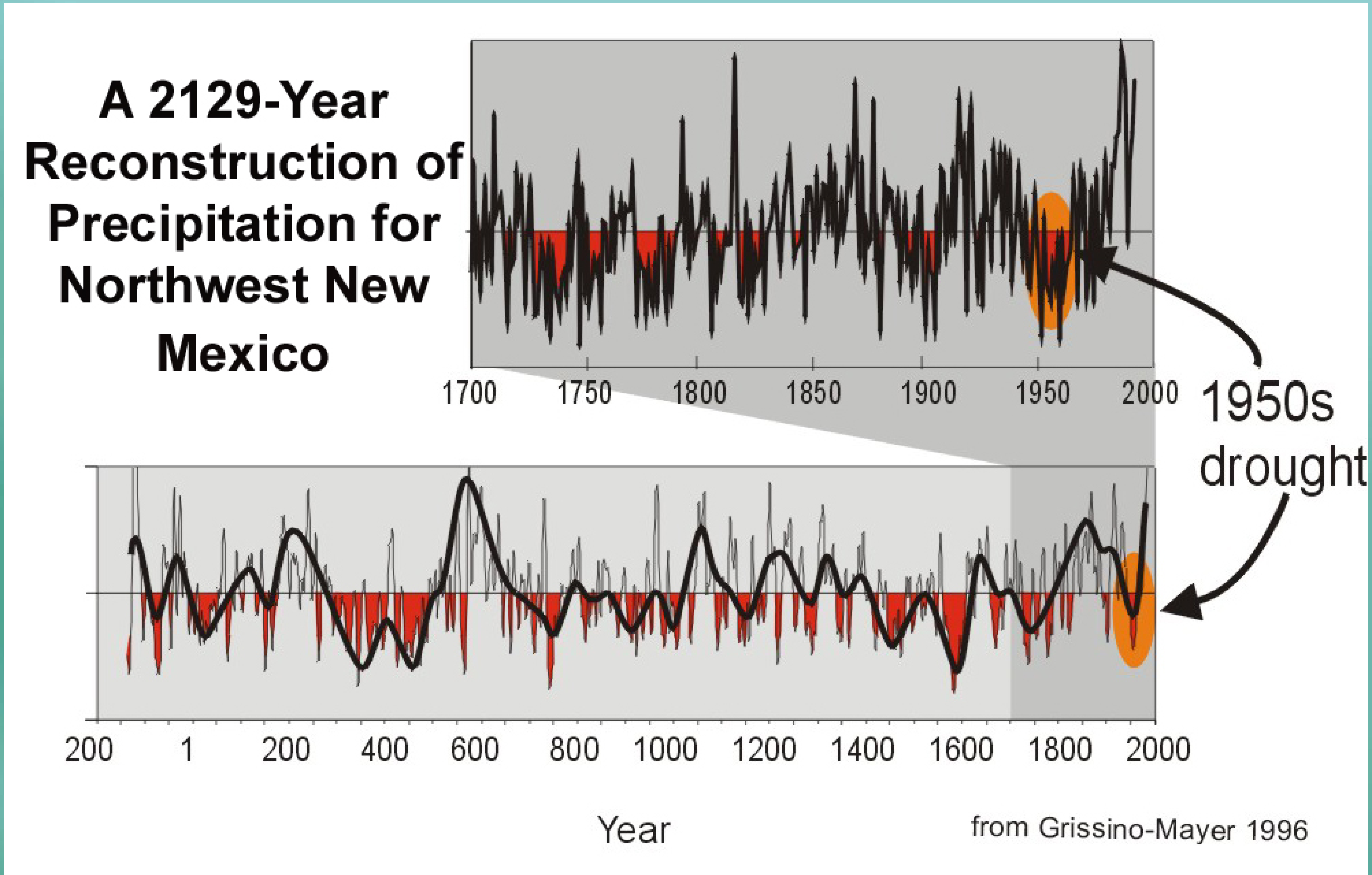
Role of observational Data - Satellites

- Widely available
- Limited alternative to observational records
- “ground truth” is required for their validation
- Satellite records commence only around 1979: too short for most decadal signals



Theoretical Background

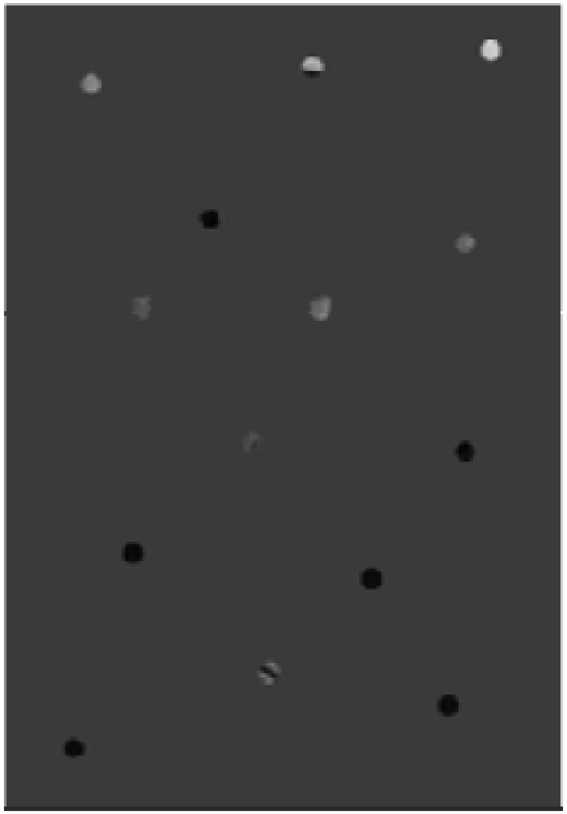
Role of Observational Data - Paleodata



Model Development

Role of observational Data - Importance of spatial coverage

Point observations (rain gauges)

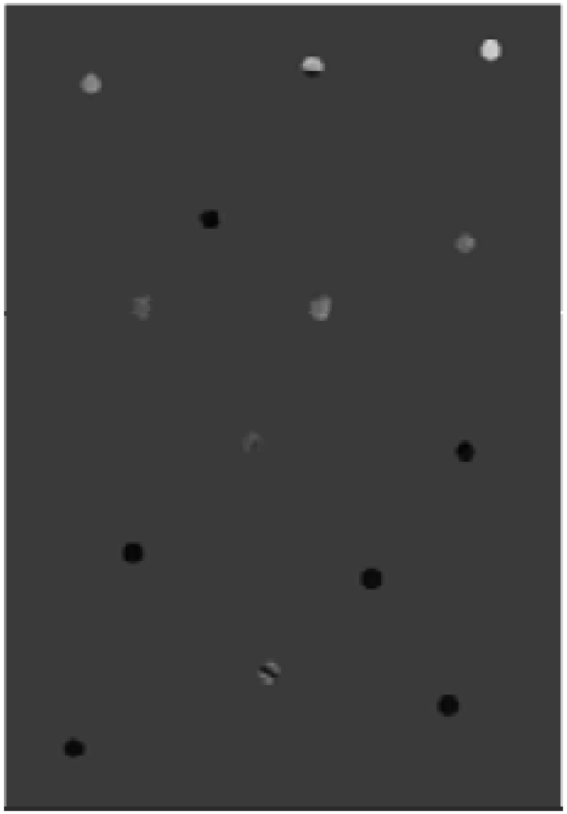


A. Bardossy

Model Development

Role of observational Data - Importance of spatial coverage

Point observations (rain gauges)



Nature ?

A. Bardossy

Model Development – "SIMGEN"

TREND | DECADAL | INTER-ANNUAL | SUB-ANNUAL

Deterministic

1 - A forced component, expressed as long-term trend and presumably owing to anthropogenic influence

2 - A low-frequency, or decadal component, reflecting unforced, "natural" variability intrinsic to the climate system and ultimately deriving from the slow variations characteristic of oceanic processes,

3 – Interannual variations (f.e. ENSO)

Random

4 - Subannual high-frequency variations (weather /seasonal cycle).

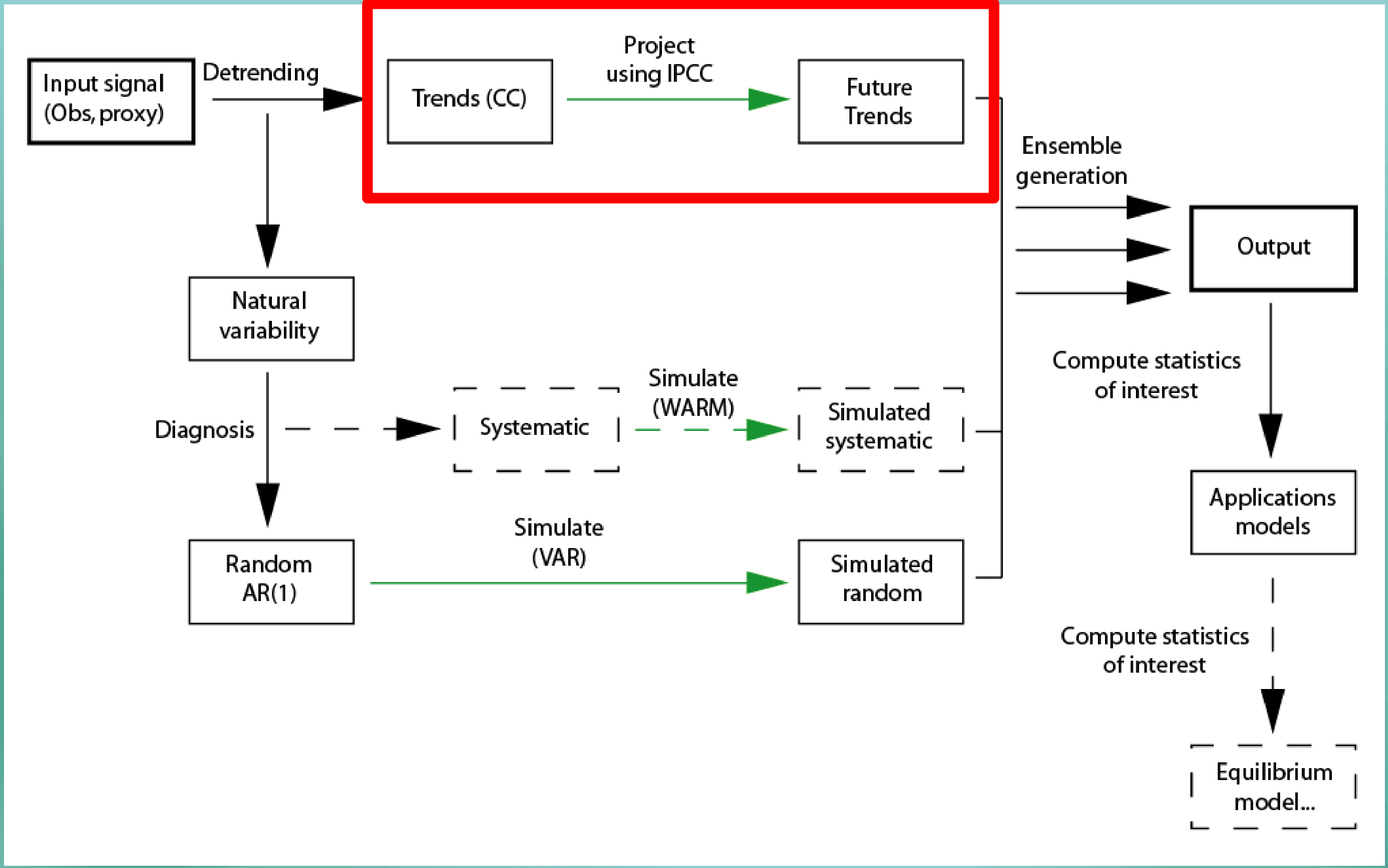
A) Fully random components

B) Random components with some memory or 'redness'

(reddening of atmospheric noise through interaction with the ocean)

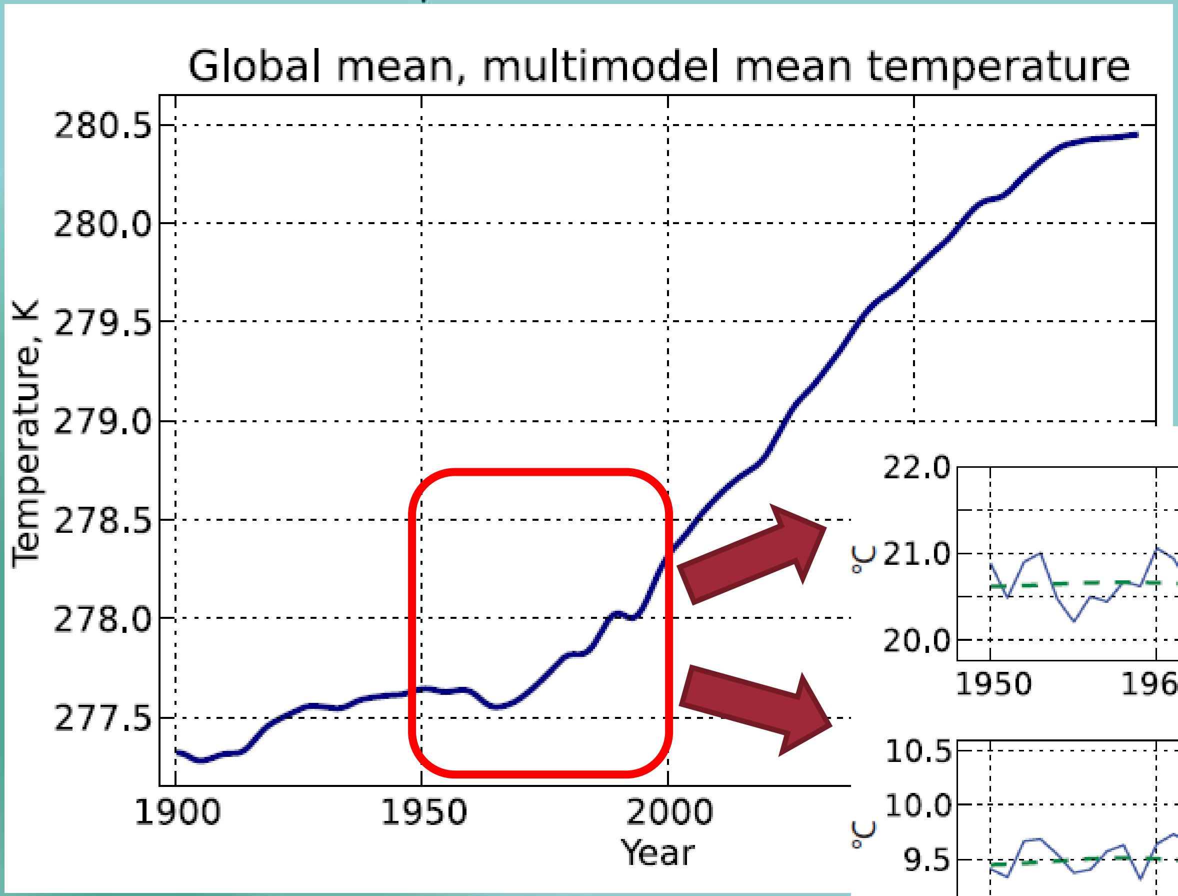
Methodology

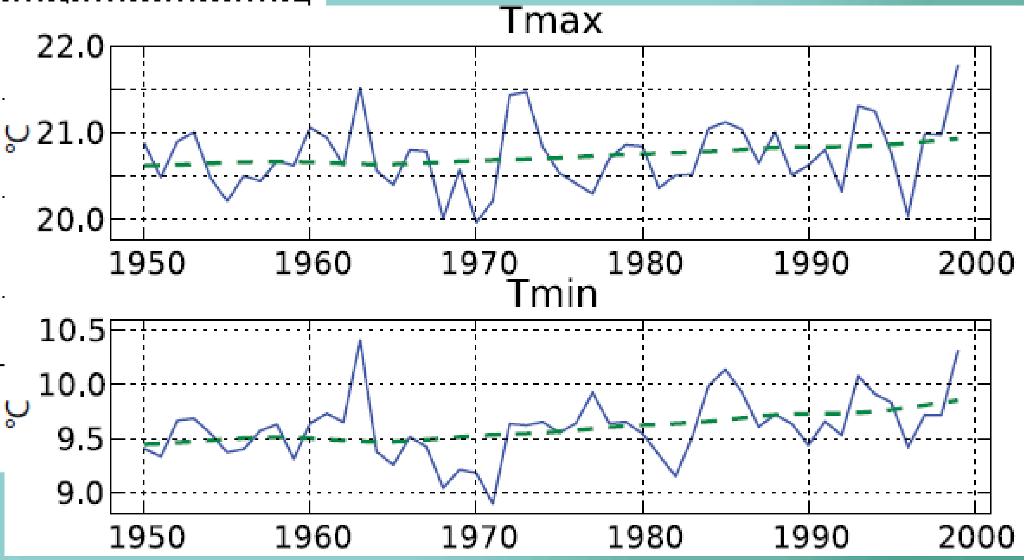
Step 1: Selection of the CC component



The SIMGEN Modeling Framework

Climate change trends: Temperature





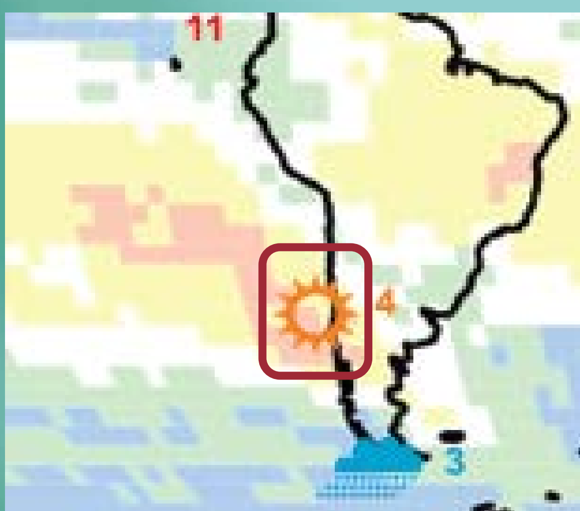
Parameterize trend in terms of *climate sensitivity.*

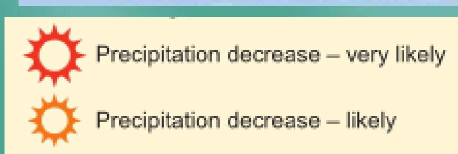
Climate change trends: Precipitation

<u>Chile</u> - Which century to trust?

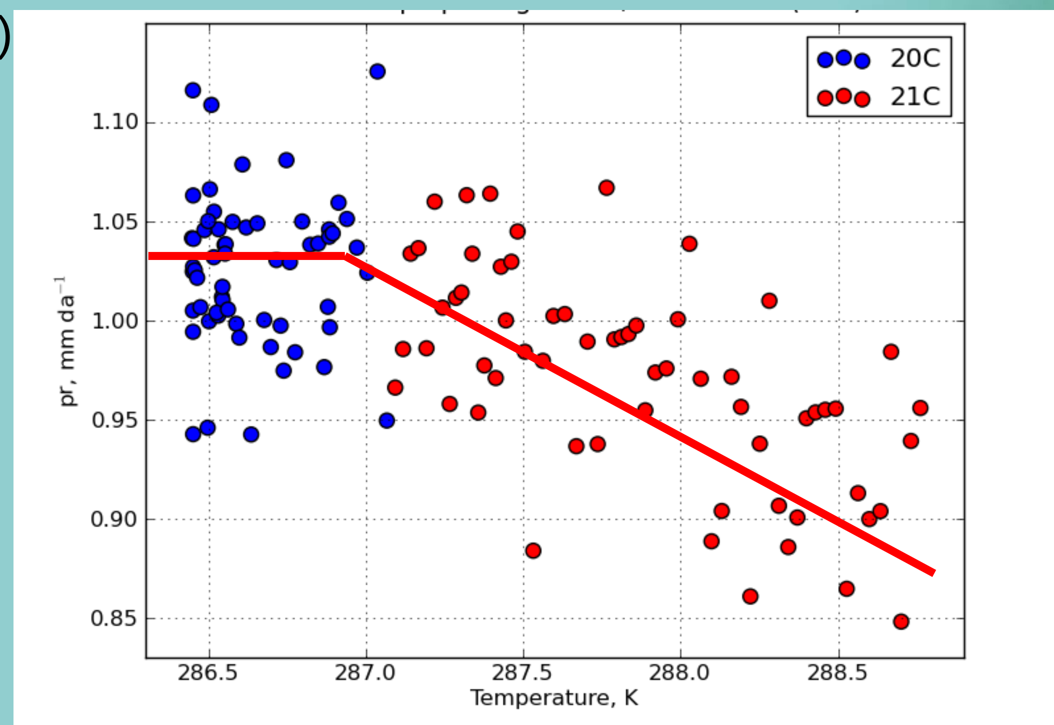
Regional precipitation response to global mean temperature change:

- Weak in 20th Century
- Negative in 21st Century (GCMs)





IPCC, 2007



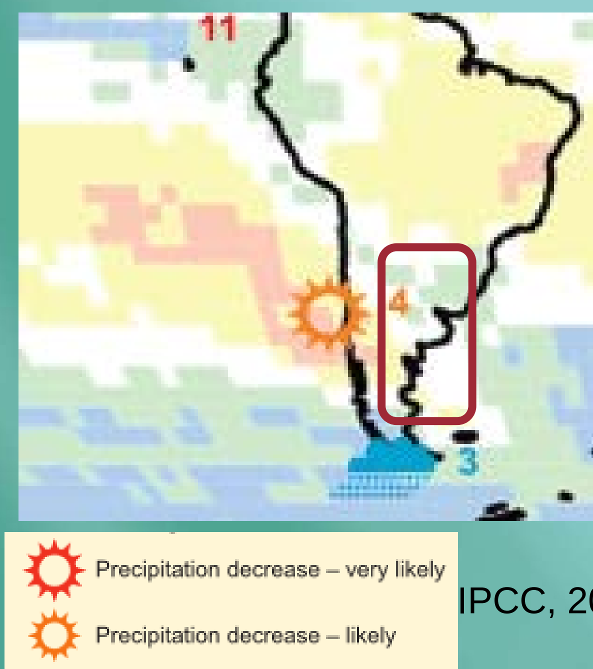
Trend in terms of *temperature sensitivity*

Climate change trends: Precipitation

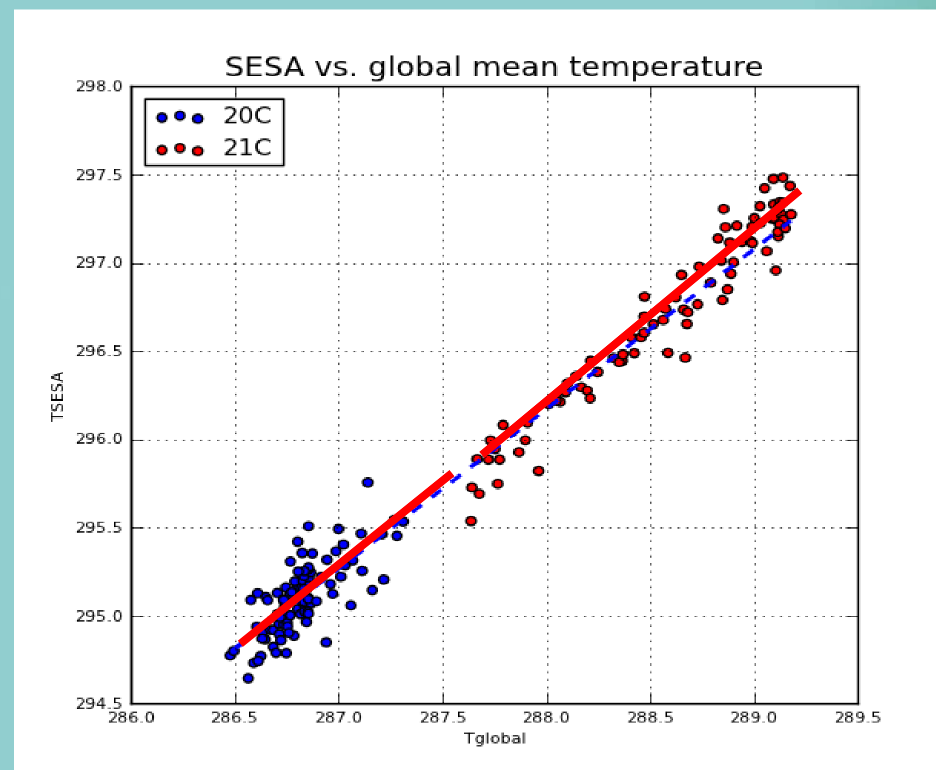
<u>SESA</u> – Consistent between centuries

Regional precip response to global mean temperature change:

- <u>Positive</u> in 20th Century
- <u>Positive</u> in 21st Century (GCMs)



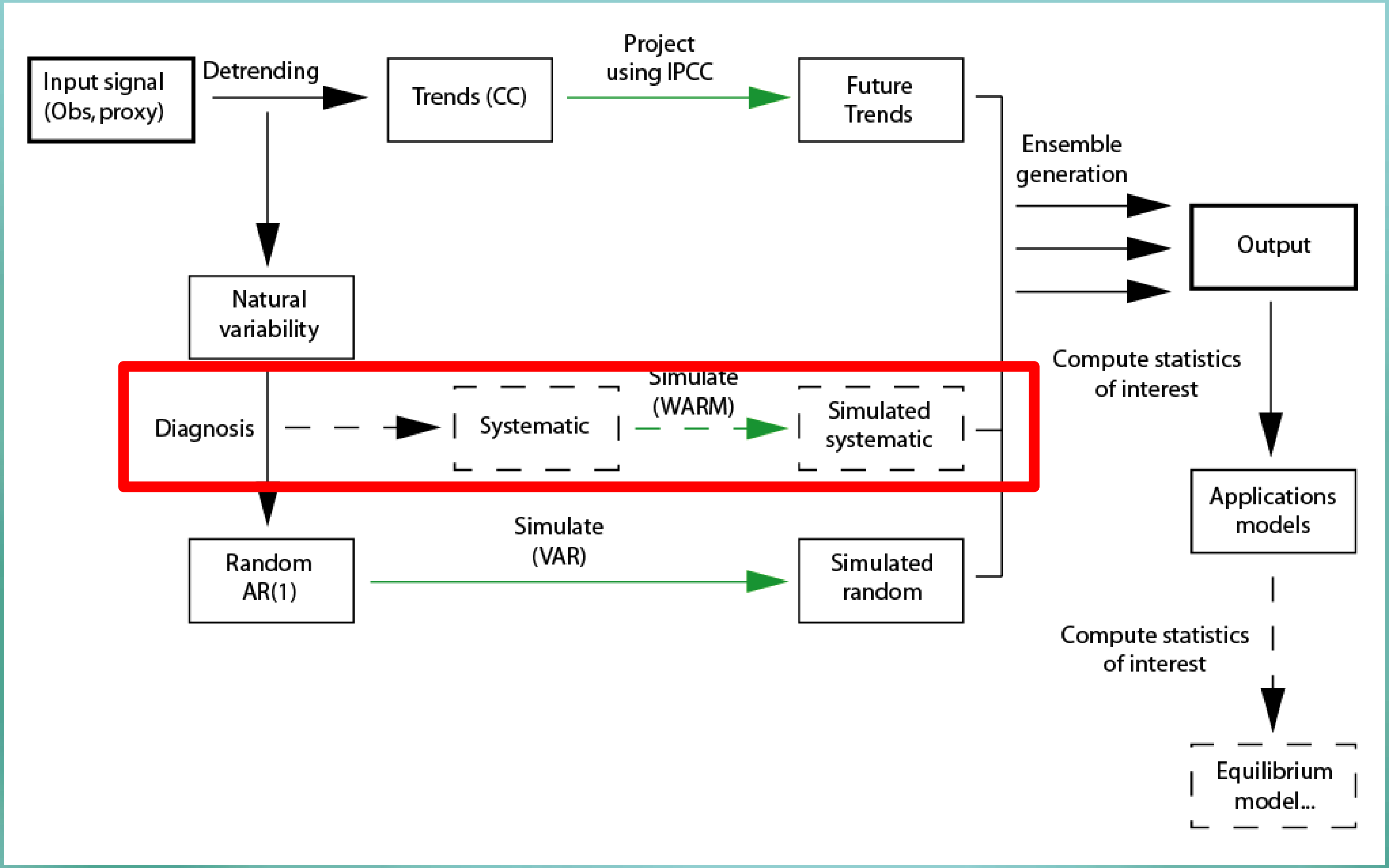
IPCC, 2007



Trend in terms of *temperature sensitivity*

Methodology

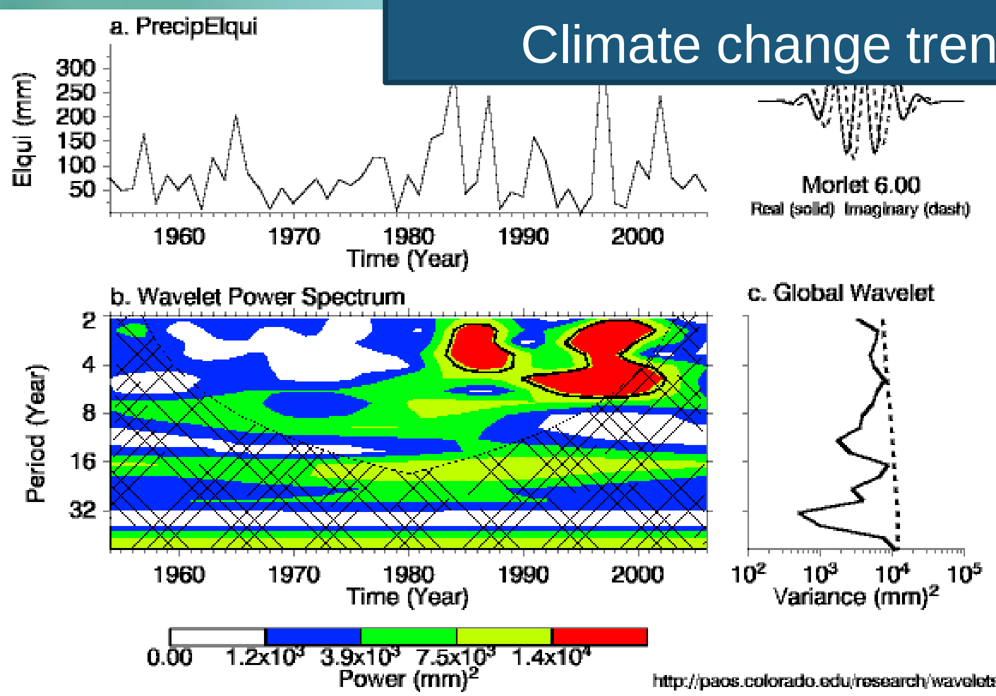
Step 2: Selection of the Decadal deterministic component

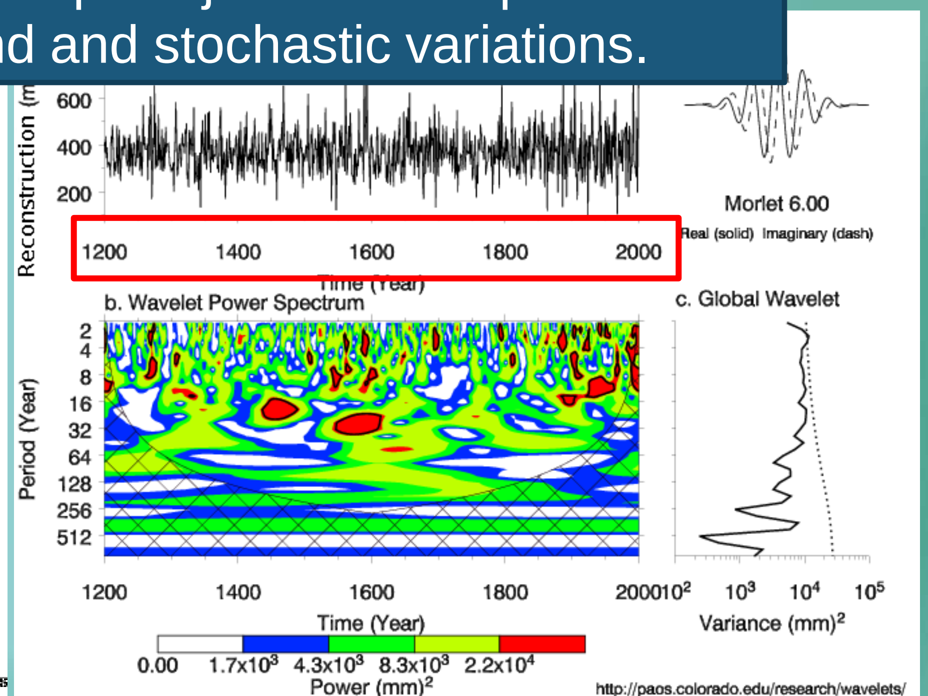


How do we find deterministic decadal patterns?

- (Schulz, Boisier and Aceituno, 2011) - Regarding the interannual variability, rainfall seems to be modulated to a large extent by ENSO, while the pronounced low-frequency changes during the past century appears to be linked to the Interdecadal Pacific Oscilation.
- Wavelet spectra of precipitation or tree rings allow identifying deterministic components

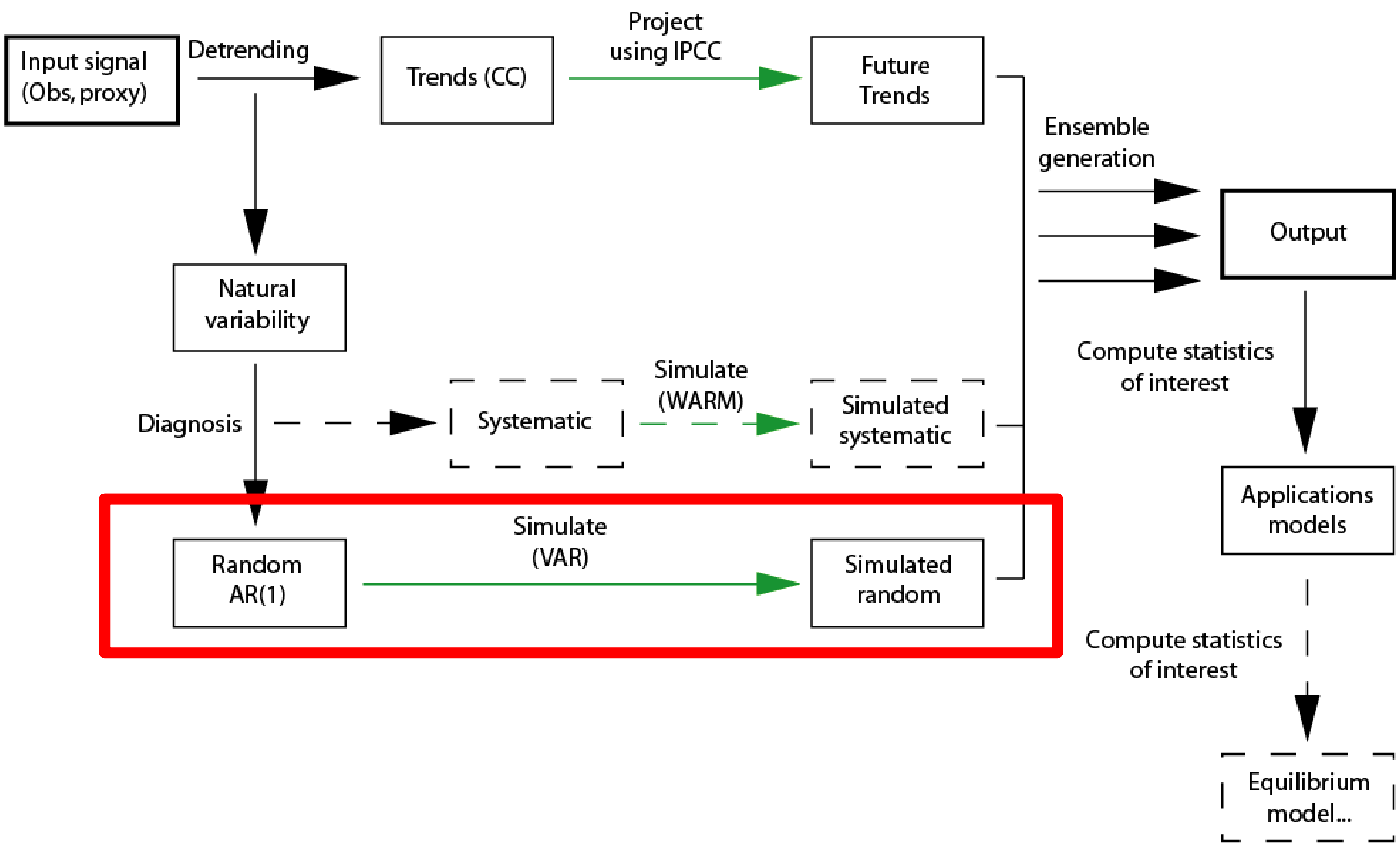
Simulations will then comprise just two components: Climate change trend and stochastic variations.



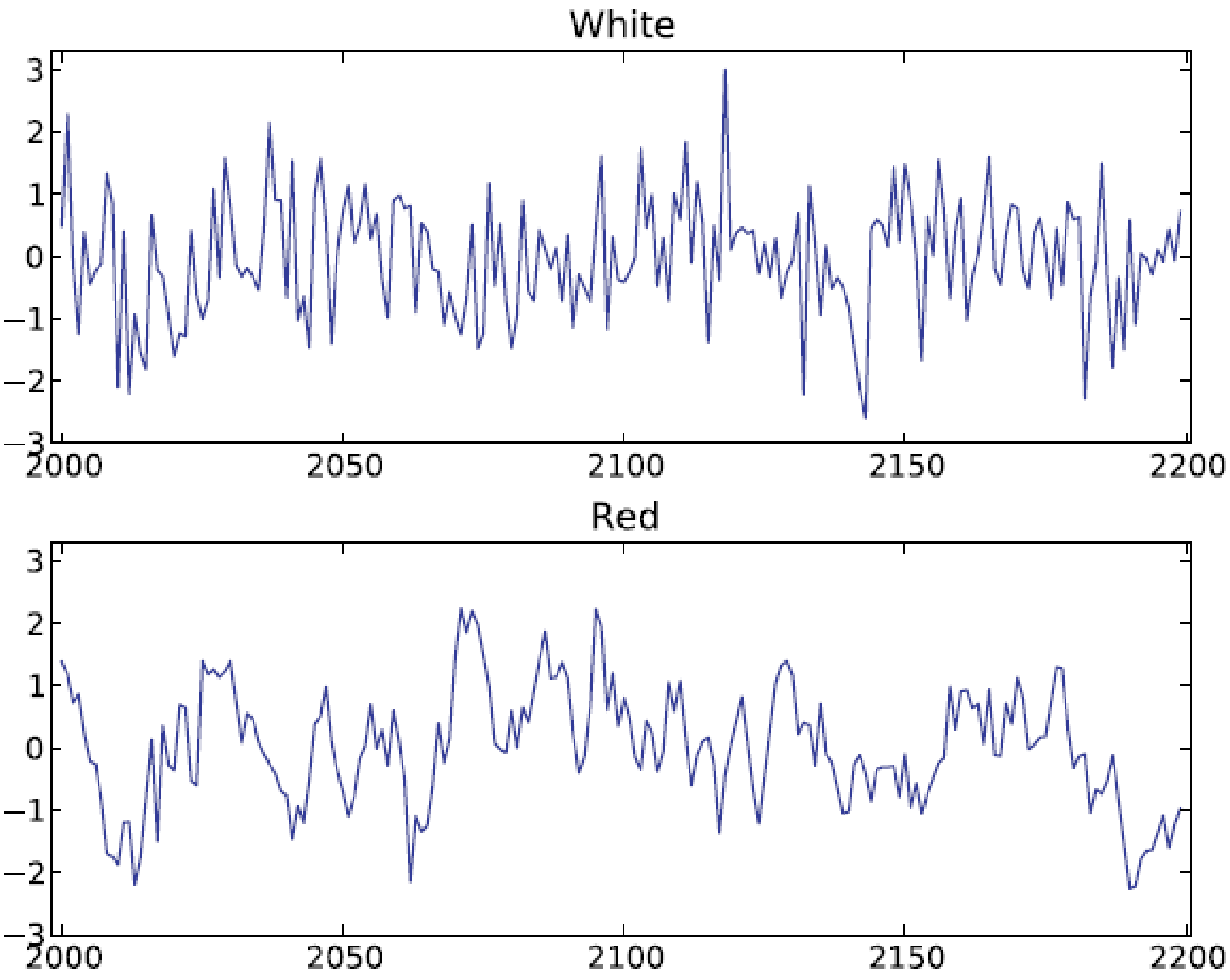


Methodology

Step 3: Selection of the Decadal stochastic component



Vector autoregressive (VAR) model



Random variability

Some ‘memory’

Vector autoregressive (VAR) model

Formally, $\mathbf{y}_t = \mathbf{A}\mathbf{y}_{t\text{-}1} + \mathbf{e}_t$, where

$\mathbf{y}_t$ is a <u>three-component vector (pr, Tmax, Tmin)</u> at time t,

A is a (3 x 3) matrix of coefficients,

$\mathbf{y}_{t\text{-}1}$ is the same vector one time step (year) previous,

$\mathbf{e}_t$ is a white-noise process with covariance matrix Σ, which may have nonzero off-diagonal elements.

For our purposes, two data characteristics are of primary concern: <u>Inter-variable correlation</u> and <u>serial autocorrelation</u> in the individual variables.

Modeled variables maintain their correlation and are consistent with past conditions

Intervariable correlation

Observations

	pr	Tmax	Tmin
pr	1.000		
Tmax	-0.447	1.000	
Tmin	0.068	0.733	1.000

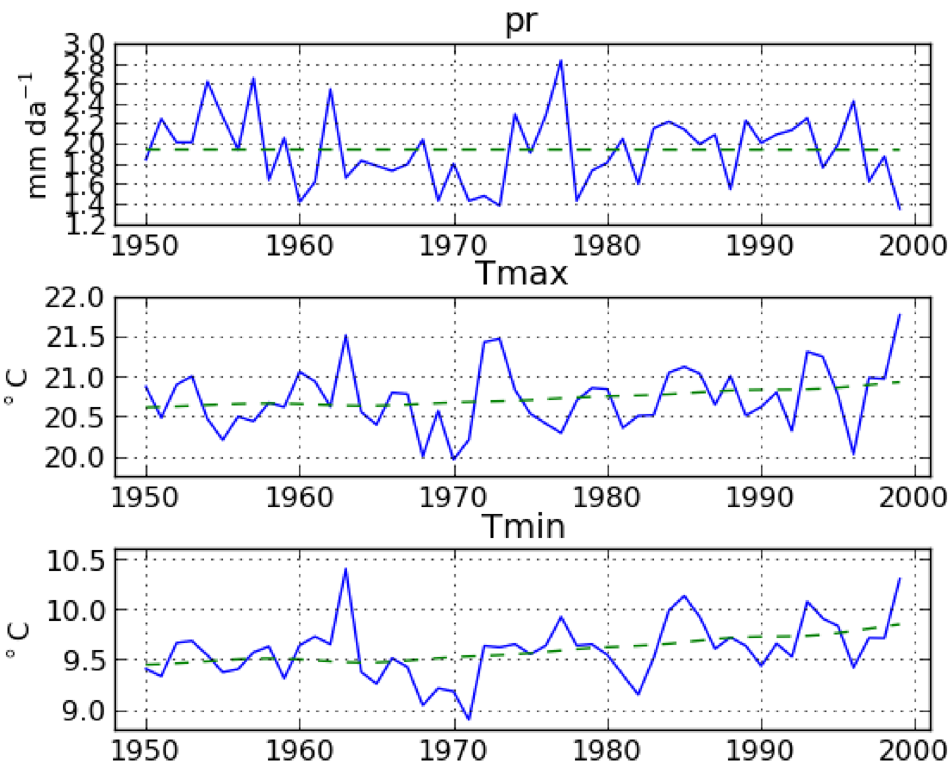
Simulation

	pr	Tmax	Tmin
pr	1.000		
Tmax	-0.445	1.000	
Tmin	0.068	0.733	1.000

Serial autocorrelation

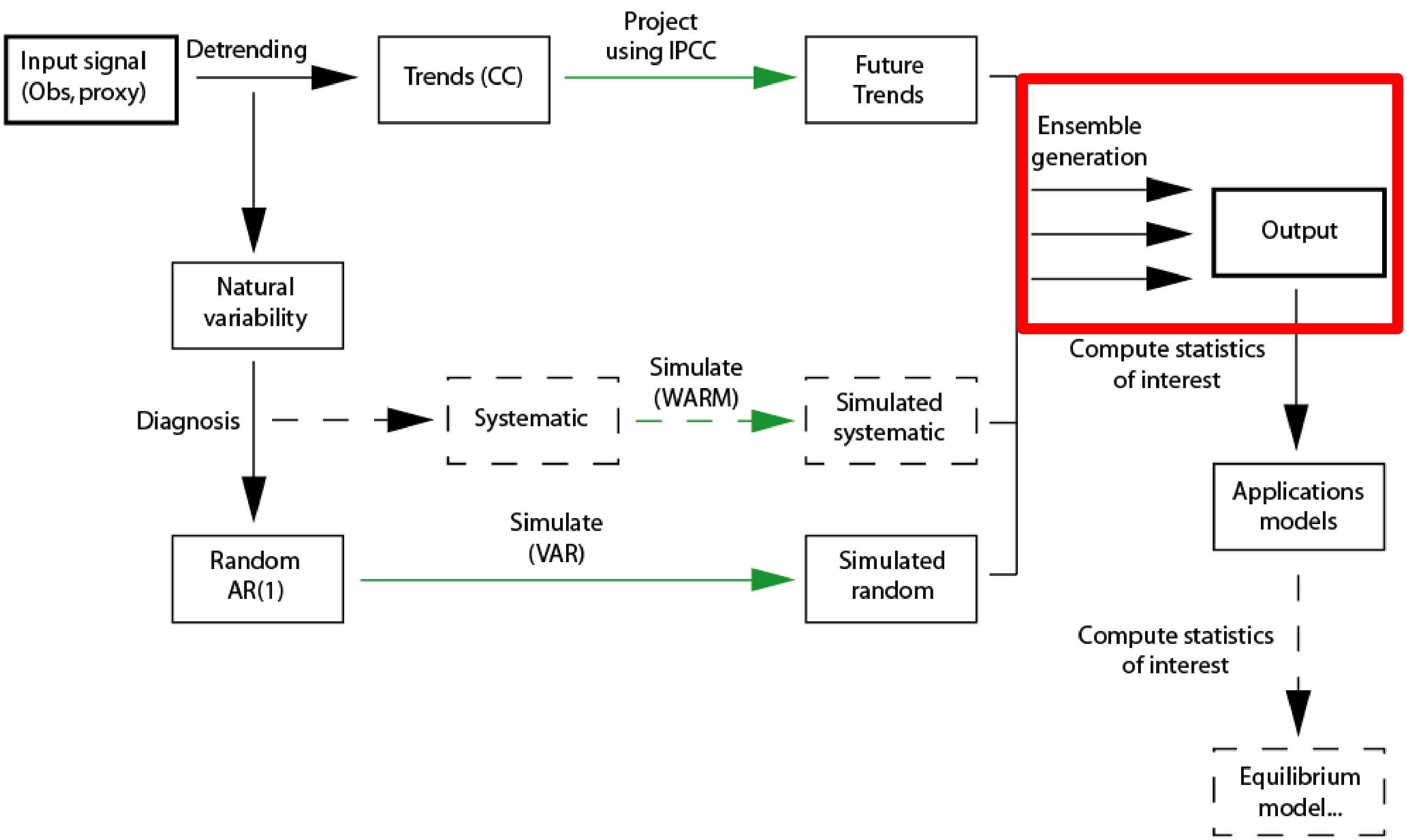
	pr	Tmax	Tmin
Obs	0.004	0.168	0.297
Sim	-0.008	0.176	0.303

Annualized data (171-station means)

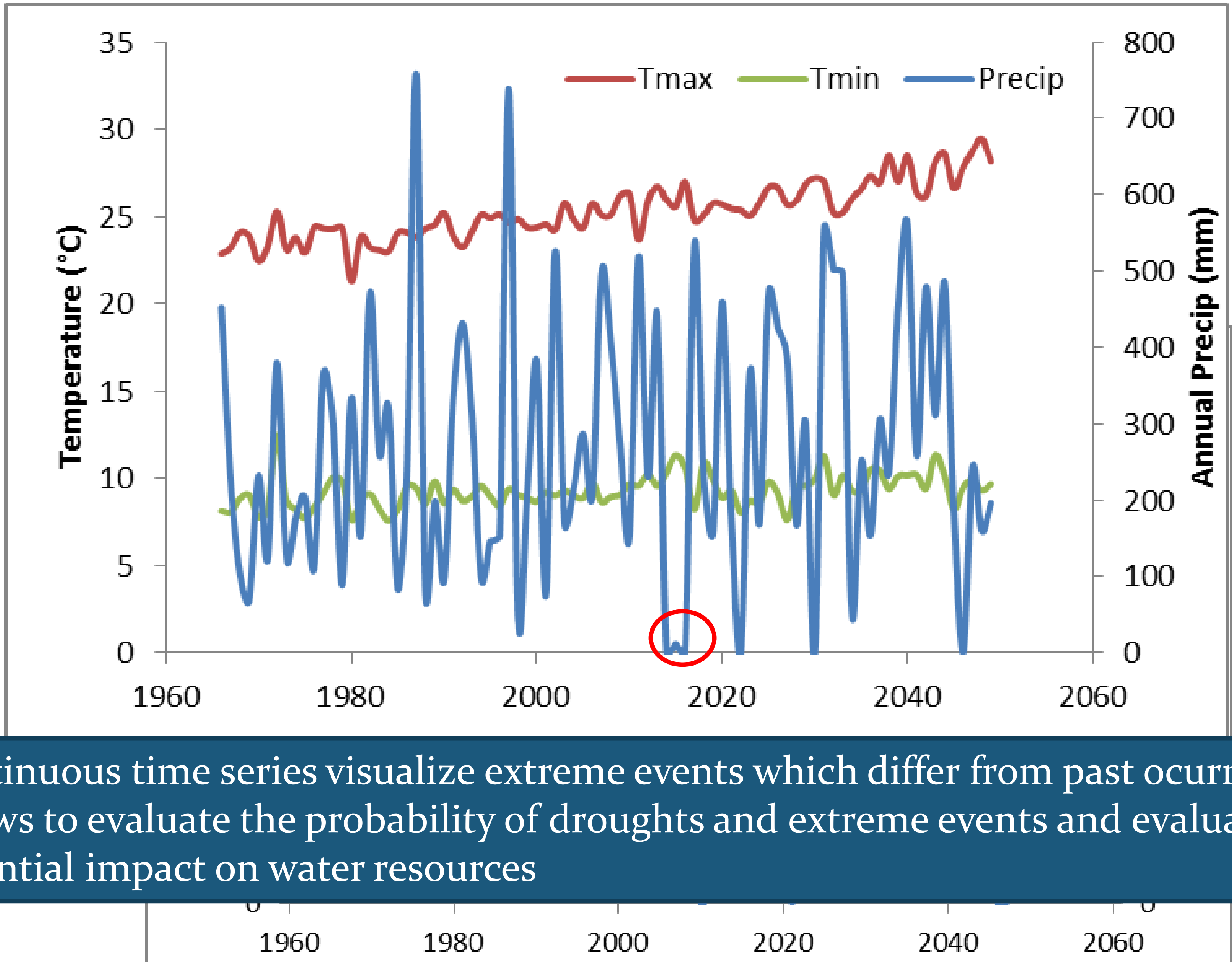


Methodology

Step 4: Generate stochastic simulations of projected Precip, Tmin, Tmax



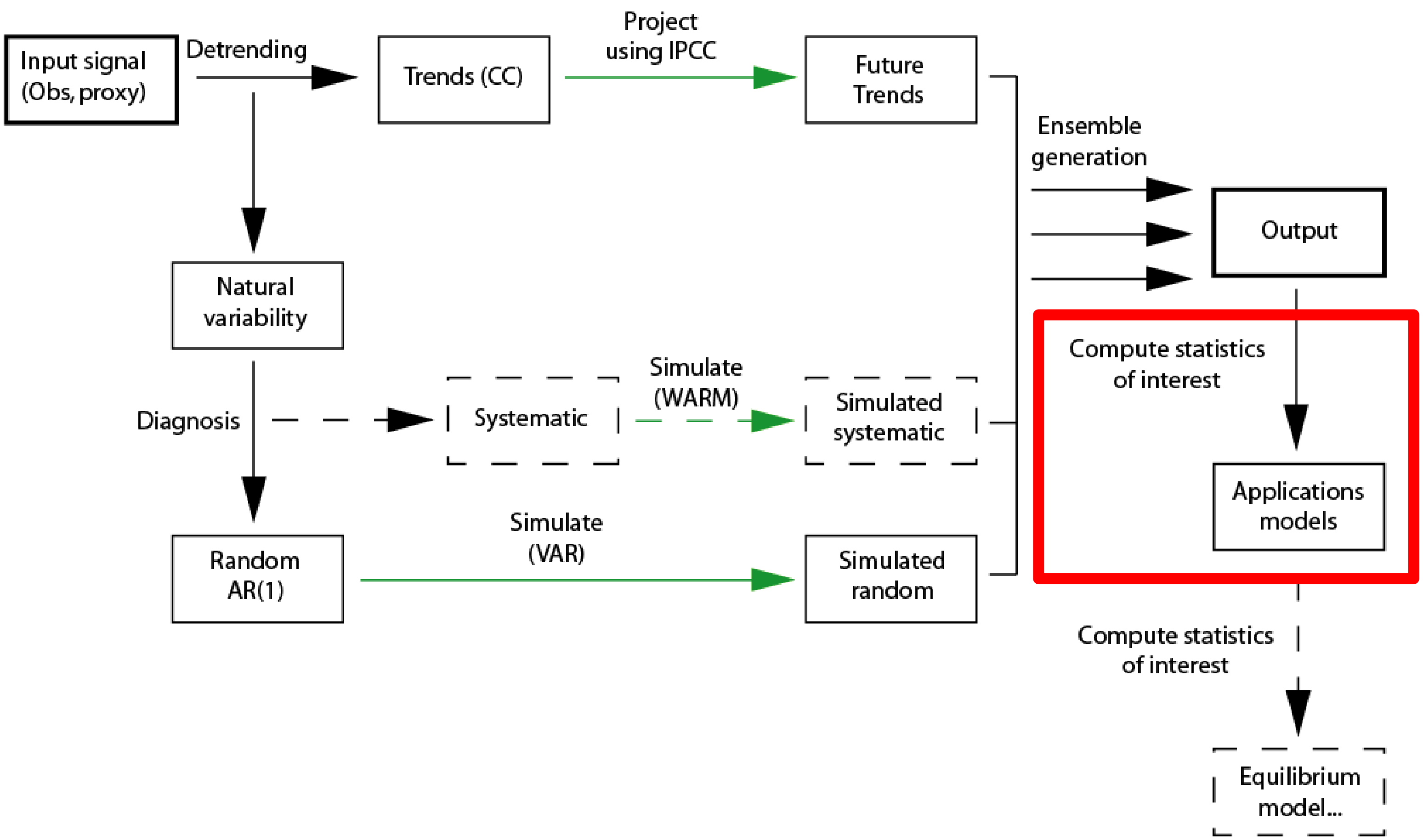
Downscaling of simulations to the local level



- Continuous time series visualize extreme events which differ from past ocurrences
- Allows to evaluate the probability of droughts and extreme events and evaluate the potential impact on water resources

Methodology

Step 5: Run projected series through an integrated water management model



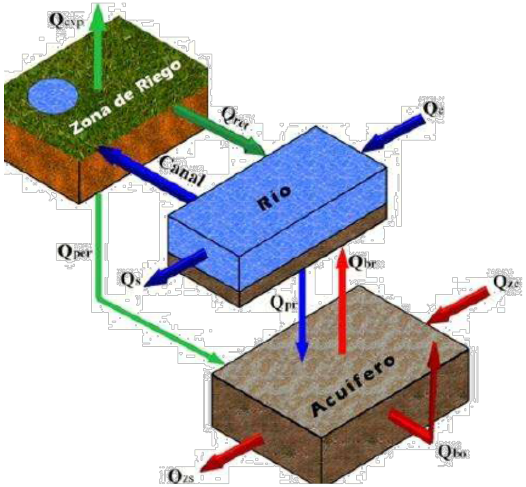
What kind of model?

- Water resources in drylands are under increasing stress due to increased demand, while water availability shows higher variability
- This requires improved water resources management to optimize water use efficiency of all users
- Periods of prolonged drought increase and worsen possible conflicts related to water resources, especially without the tools to manage the water resources.
- Integrated Water Resources Management models can provide support for decision makers and water users to evaluate current vulnerabilities and future challenges.

Example model application: MAGIC model

(Modelación Analítica Genérica Integrada de Cuencas)

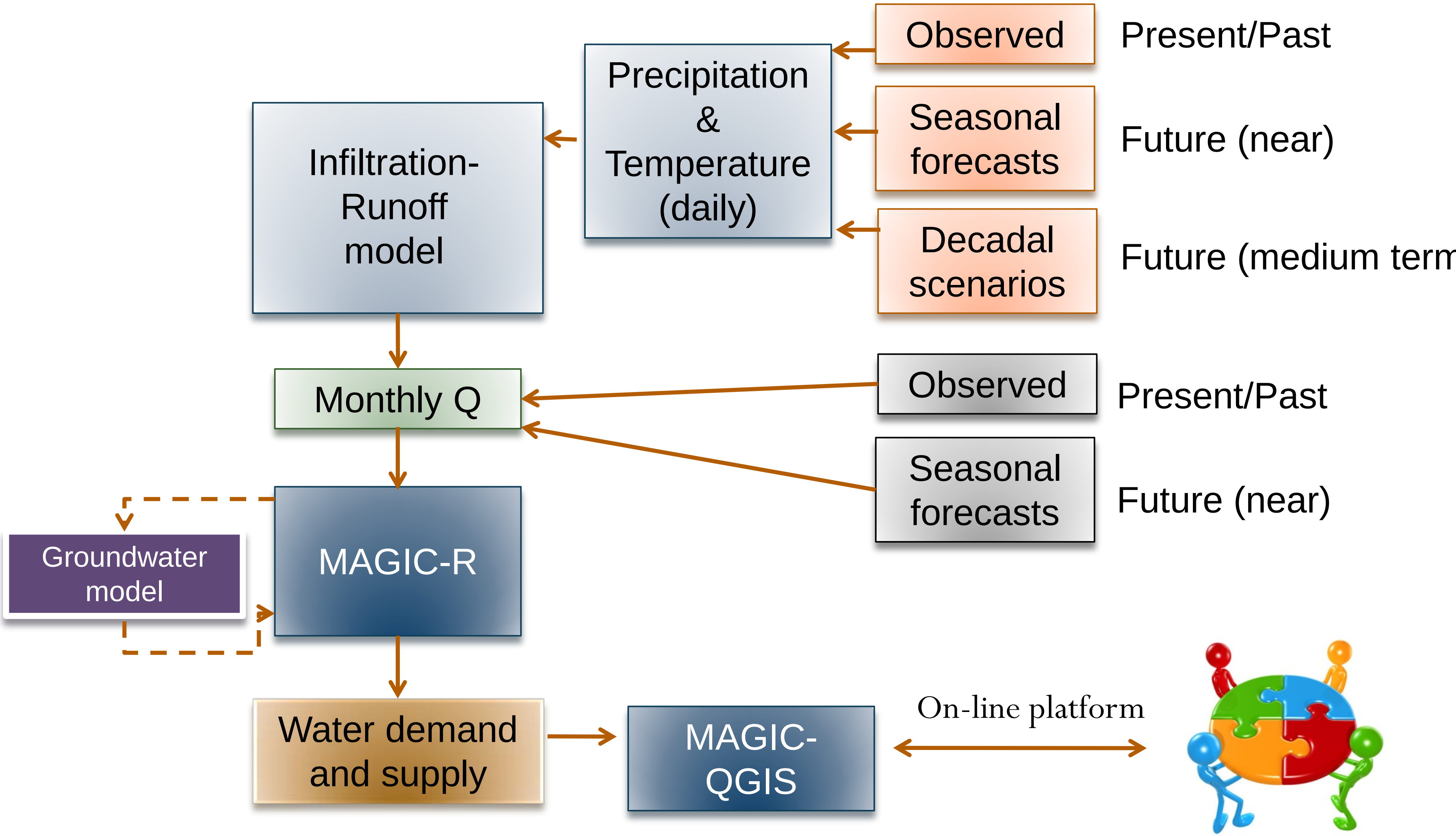
- Developped in Chile
- Extensive experience in Region IV-V-VI



Actual model:
Language: **Delphi 7.0™**
GIS Platform is **ESRI™**

Open source software: R
On-line GIS platform : QGIS

A framework for water resources management



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Introduction to the framework for the simulation of regional decadal variability for water management

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Earth Institute | Columbia University