The Abdus Salam International Centre for Theoretical Physics

2453-21

**School on Modelling Tools and Capacity Building in Climate and Public Health**

***15 - 26 April 2013***

# Regional climate modeling and The COordinated Regional Downscaling Experiment CORDEX

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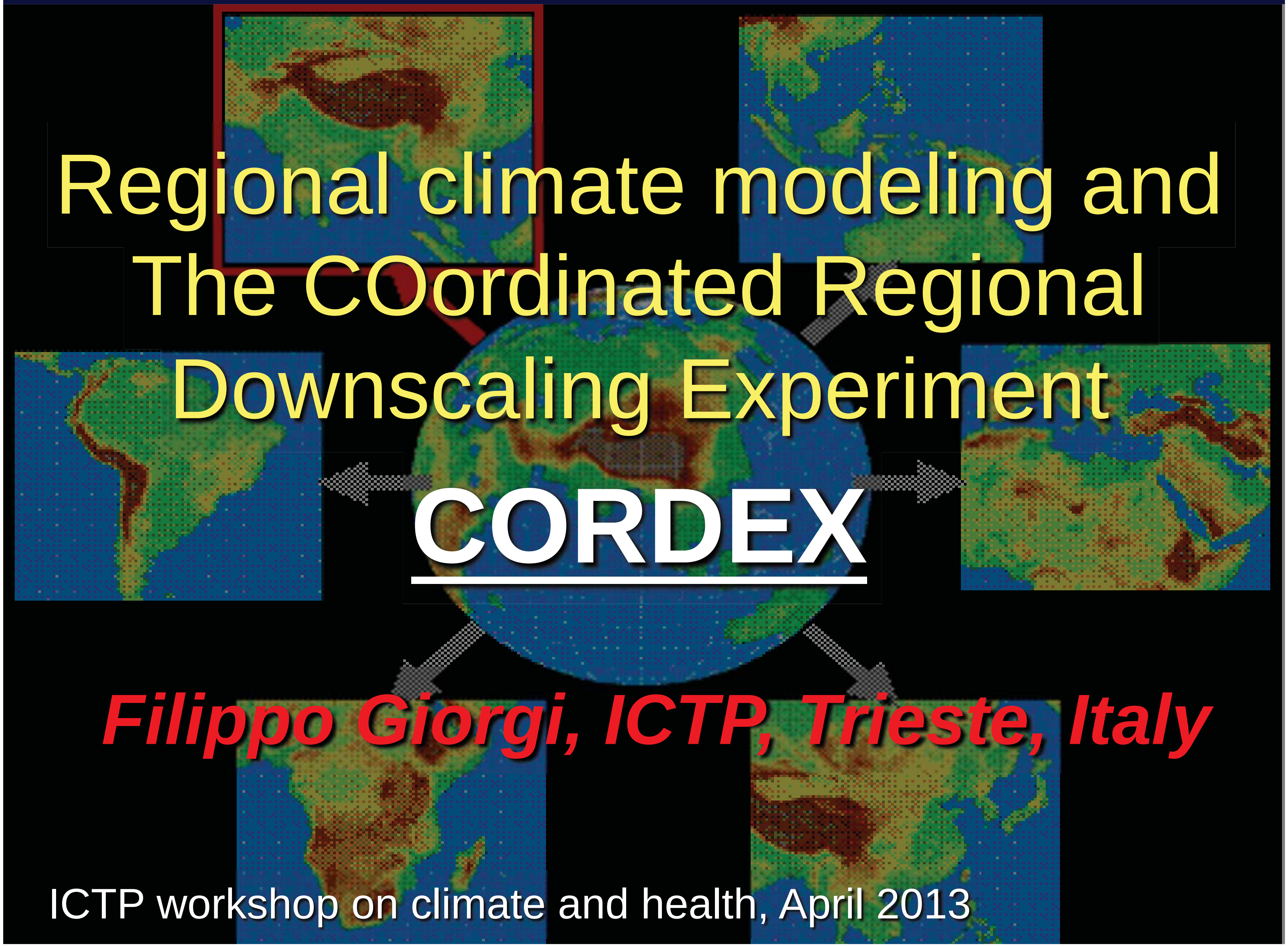
*ITALY*



# Regional climate modeling and The COordinated Regional Downscaling Experiment

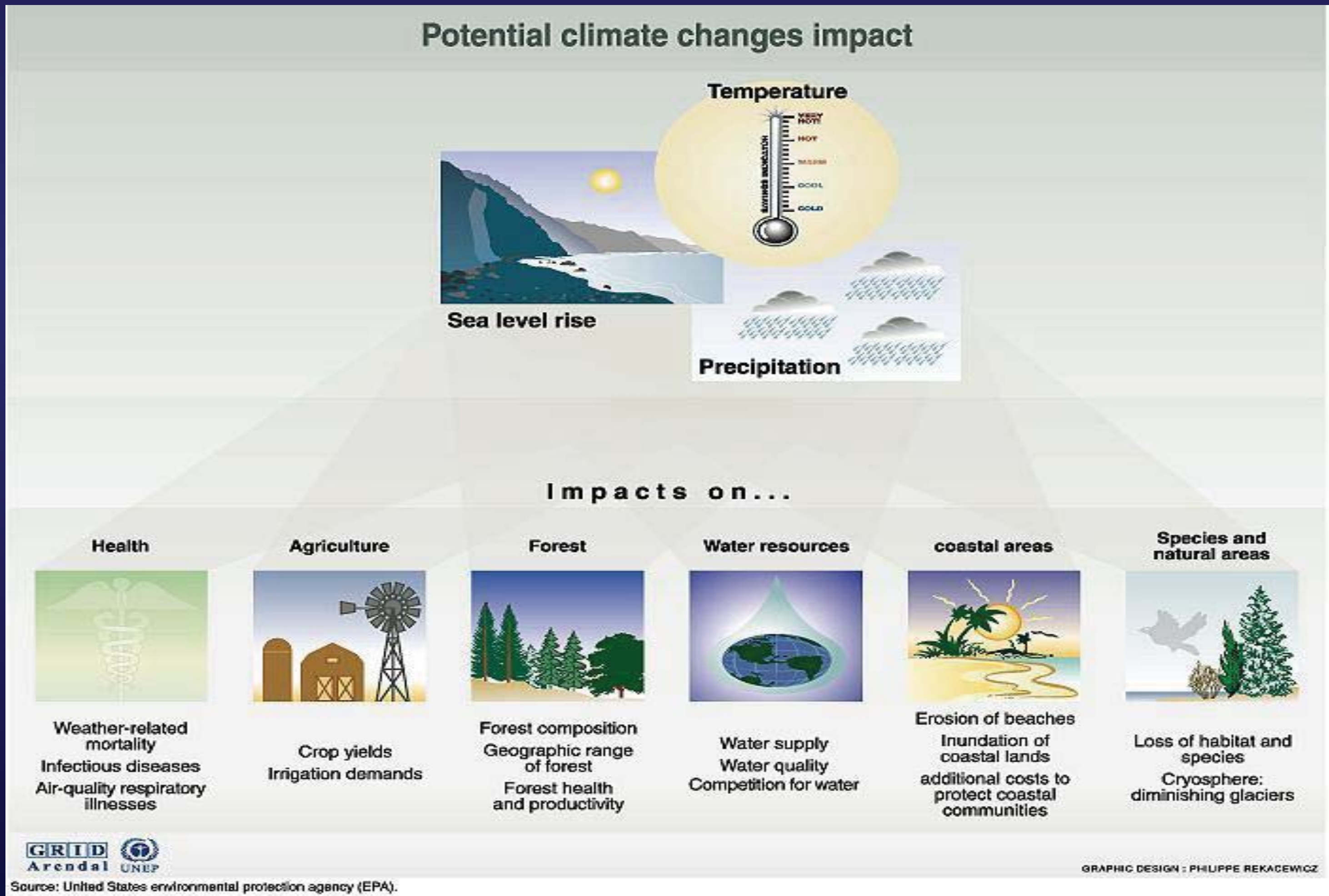
## CORDEX

***Filippo Giorgi, ICTP, Trieste, Italy***

ICTP workshop on climate and health, April 2013

# Regional climate information is critical to assess impacts

## Information is needed at the regional to local scale

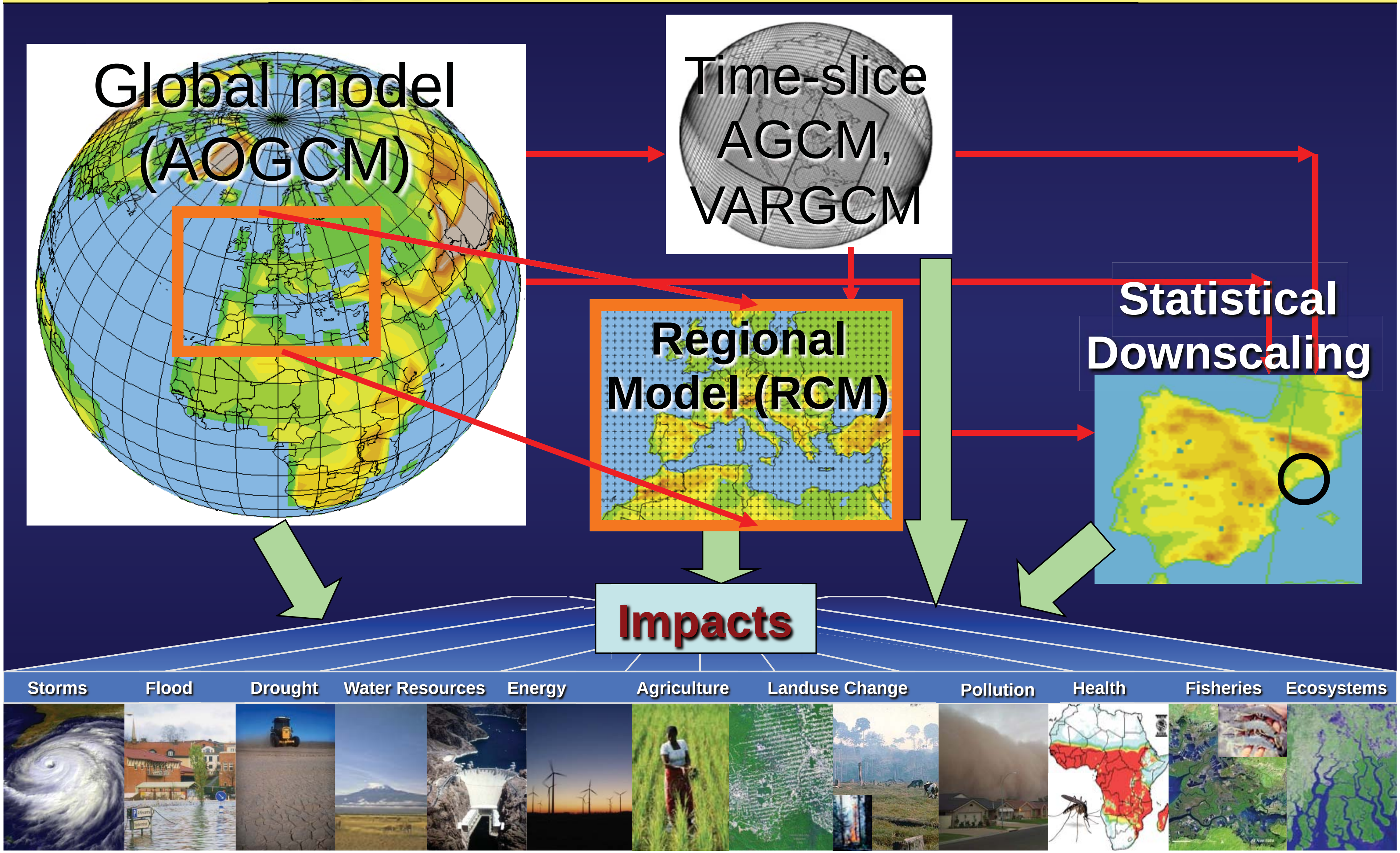



Human factors
Greenhouse gases
Radiated
to space
Infra-red radiation from surface
Atmospheric aerosols
Aerosol
Mineral Dust
$SO_2$, Soot, Organics
DMS Sea Salt
Land-use change
The Earth's climate can change because of anthropogenic or natural factors, large scale or local forcings
Volcanic activity
Natural factors
Incoming solar radiation
Variations of Solar radiatios
El Nino Conditions December 1997
Natural variability (ENSO, NAO)
60°N
40°N
20°N
0°
20°S
40°S
60°S
100°E 140°E 180° 140°W 100°W 60°W
32 28 24 20 16 12 8 4 0
TAO Project Office/PMEL/NOAA

# Regional climate modeling: Why?

- Regional climates are determined by the interactions of planetary/large scale processes and regional/local scale processes
  - Planetary/large scale forcings and circulations determine the statistics of weather events that characterize the climate of a region
  - Regional and local scale forcings and circulations modulate the regional climate change signal, possibly feeding back to the large scale circulations
- In order to simulate climate (and more specifically climate change) at the regional scale it is thus necessary to simulate processes at a wide range of spatial (and temporal) scales

# Several tools are available for producing regional climate information



# “Nested” Regional Climate Modeling: Technique and Strategy

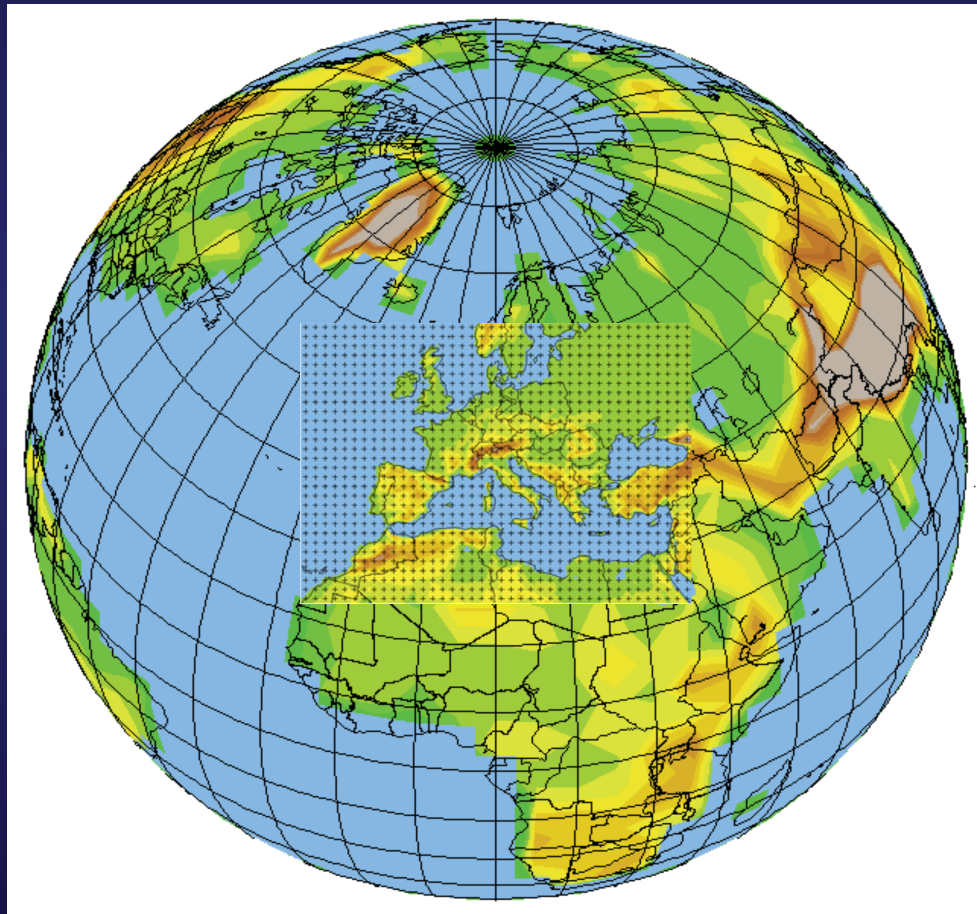
Motivation: The resolution of GCMs is still too coarse to capture regional and local climate processes

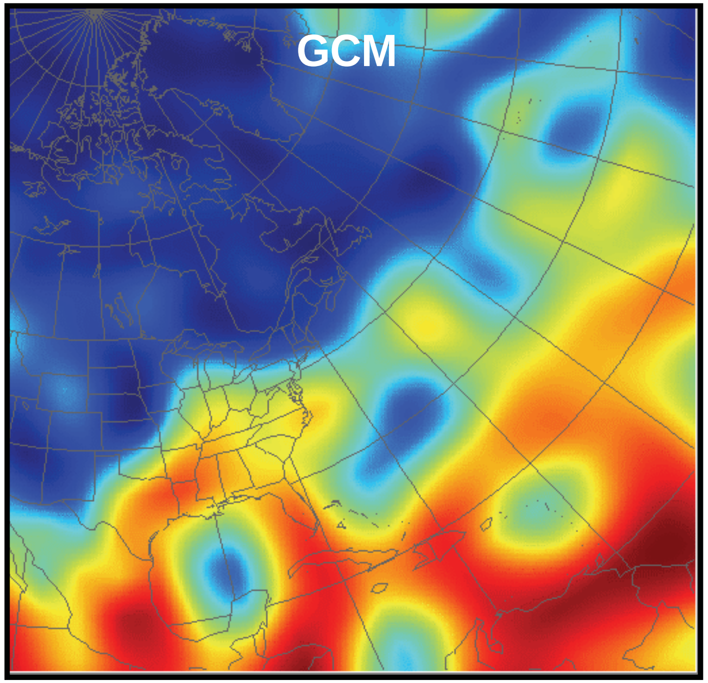
Technique: A “Regional Climate Model” (RCM) is “nested” within a GCM in order to locally increase the model resolution.

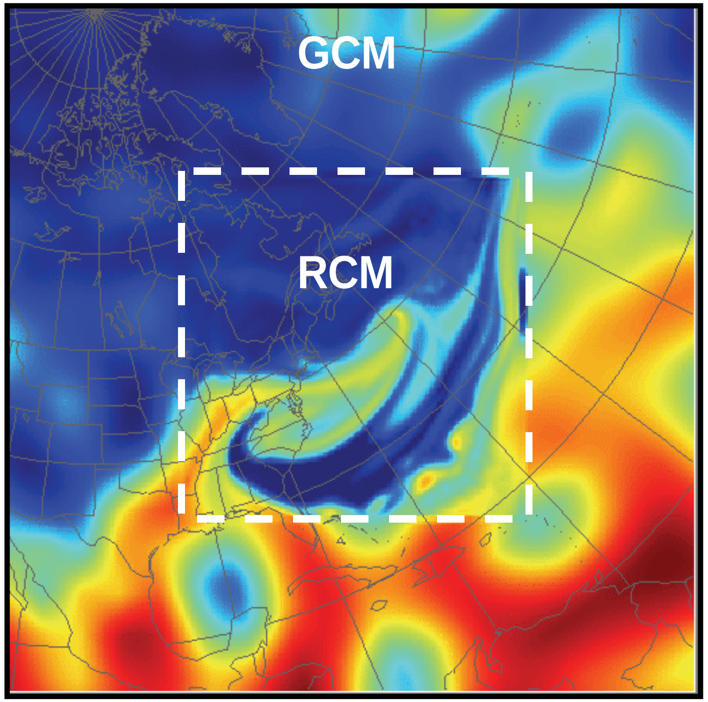
- Initial conditions (IC) and lateral boundary conditions (LBC) for the RCM are obtained from the GCM (“One-way Nesting”) or analyses of observations (perfect LBC).

Strategy: The GCM simulates the response of the general circulation to the large scale forcings, the RCM simulates the effect of sub-GCM-grid scale forcings and provides fine scale regional information

- Technique borrowed from NWP

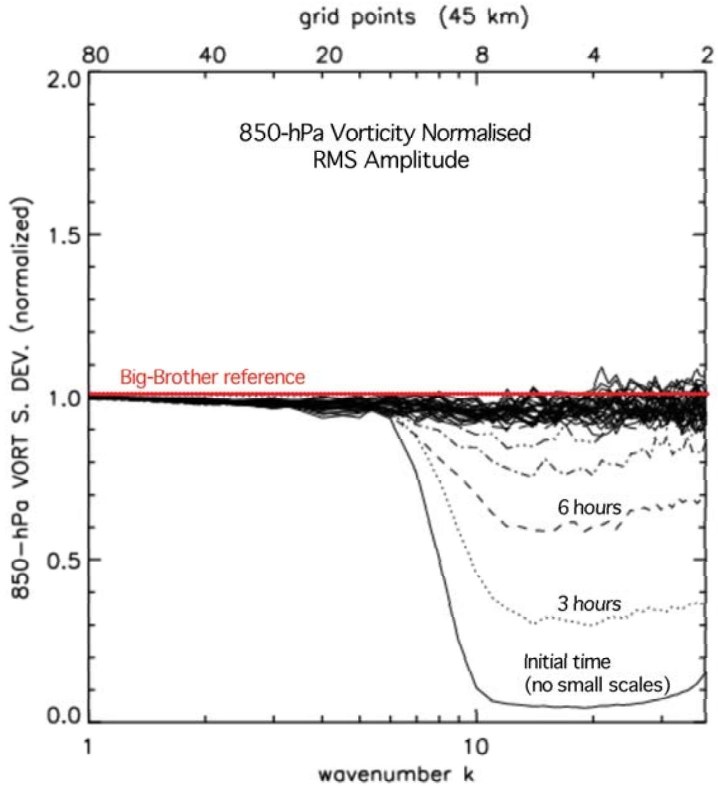





# Dynamical Downscaling

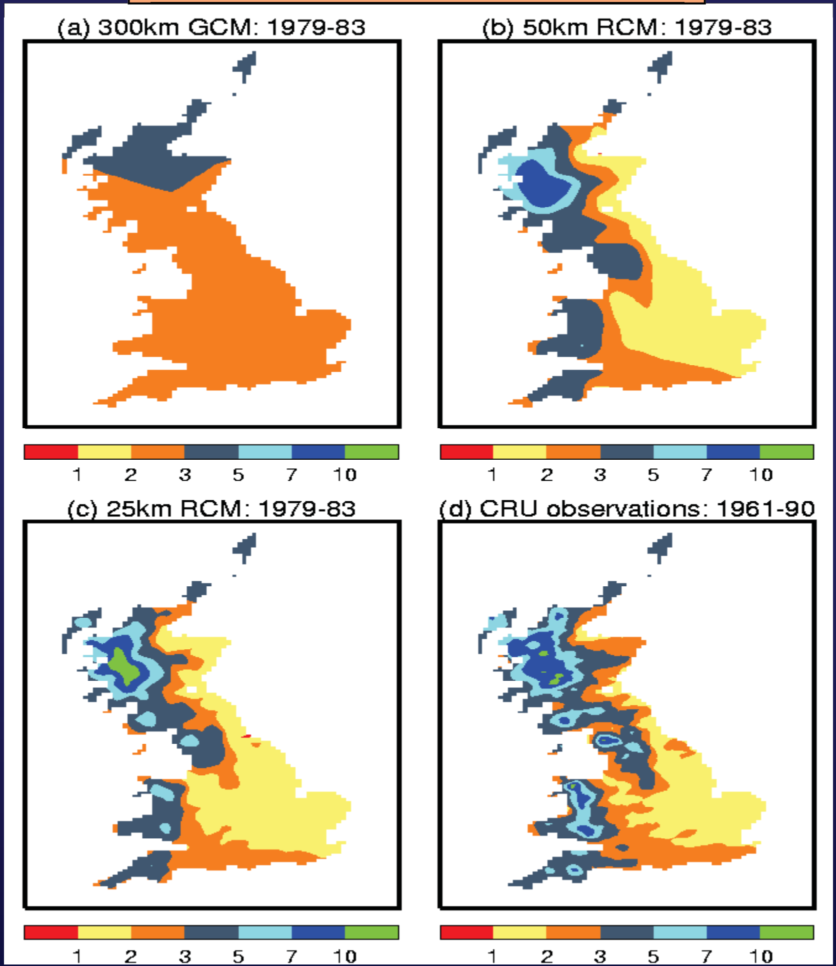
## Generation of small scales by a high-resolution RCM driven by low-resolution GCM data (900 hPa specific humidity)



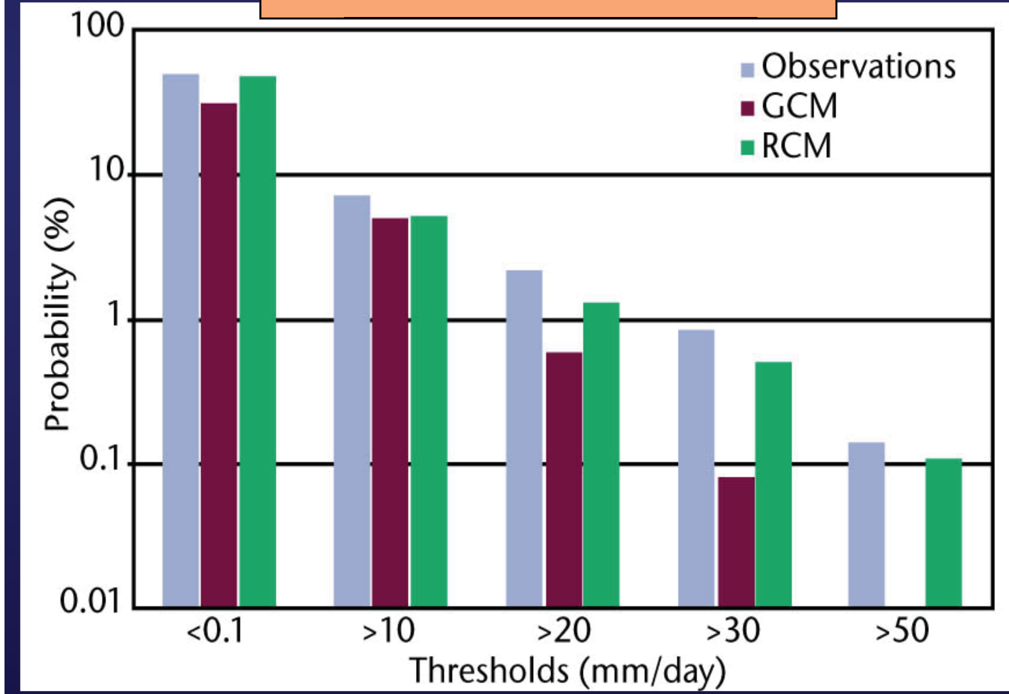

**Large scales Short scales**

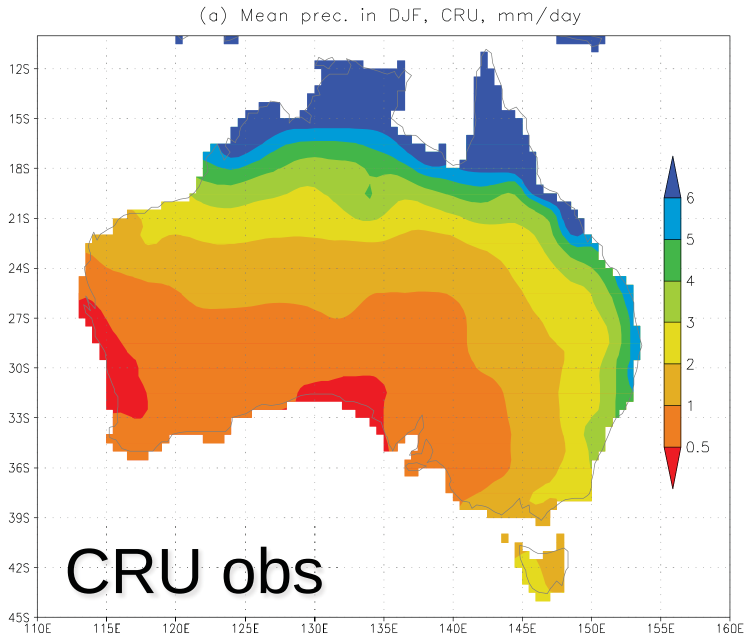
# The added value of RCMs

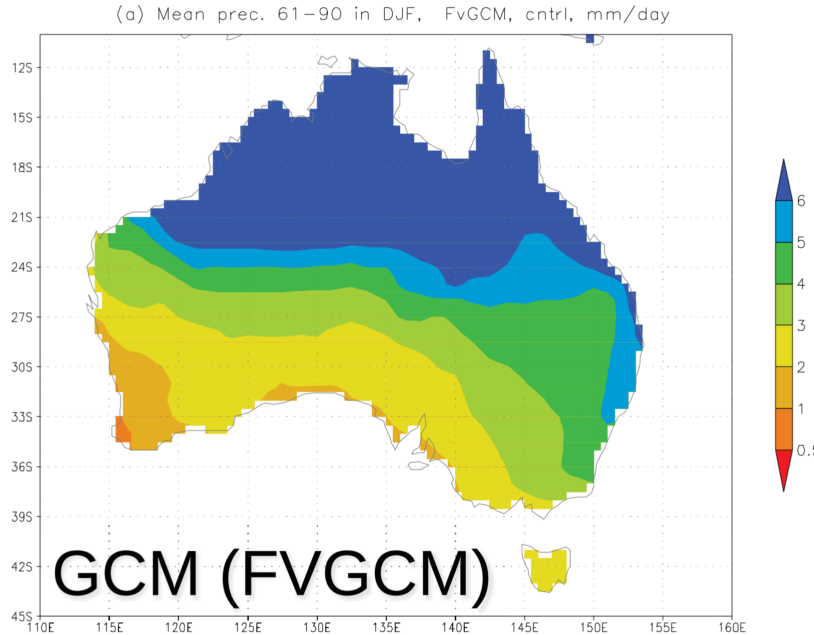
**Topographic forcing**

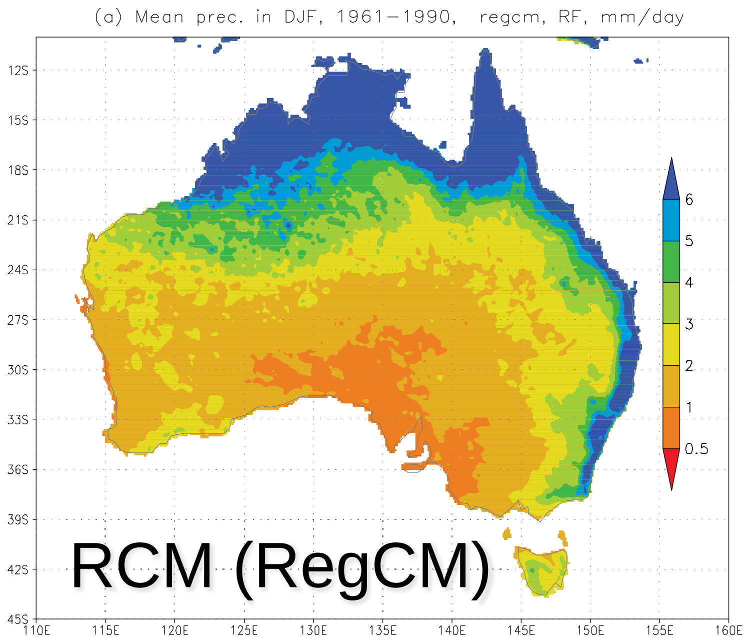



**Extreme events**





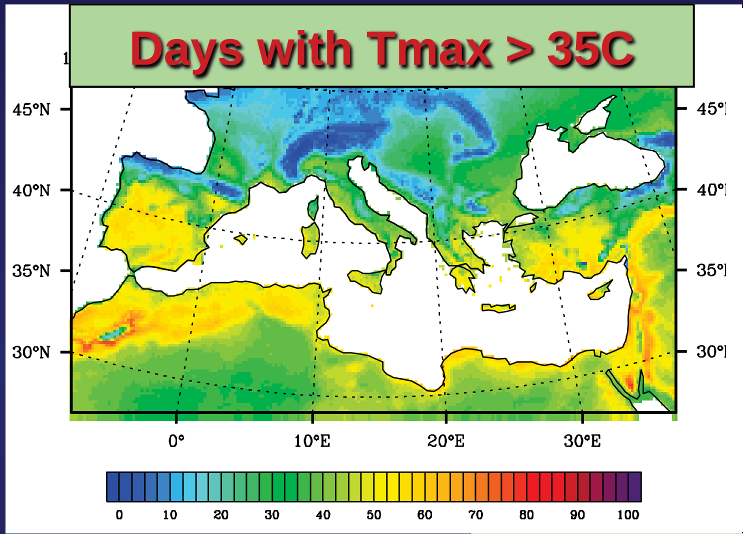



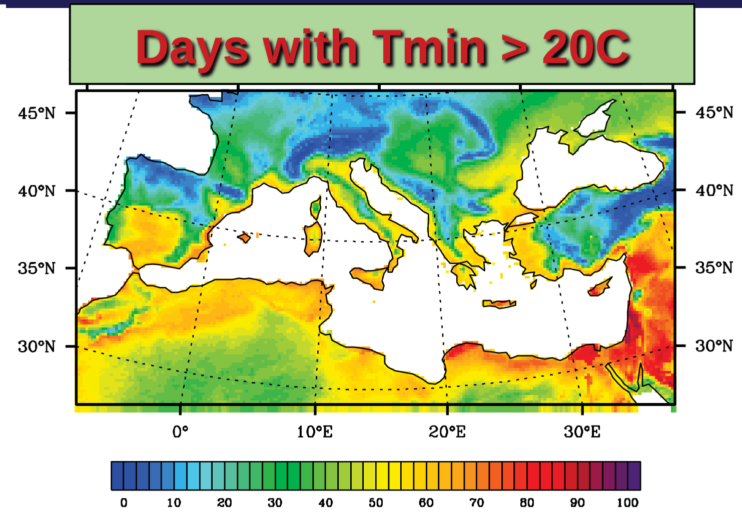

DJF precipitation
30-year nested
RCM simulation,
1961-1990,
20 km grid spacing

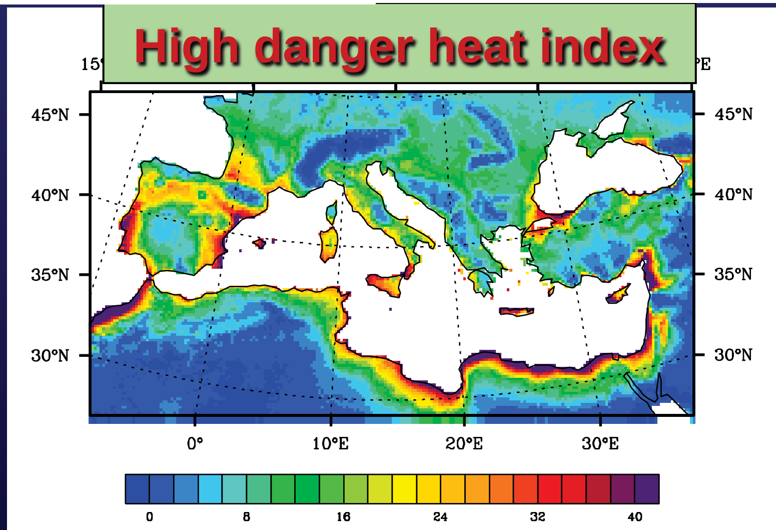
**Courtesy of X. Gao**

# Additional regional effects: Coastlines

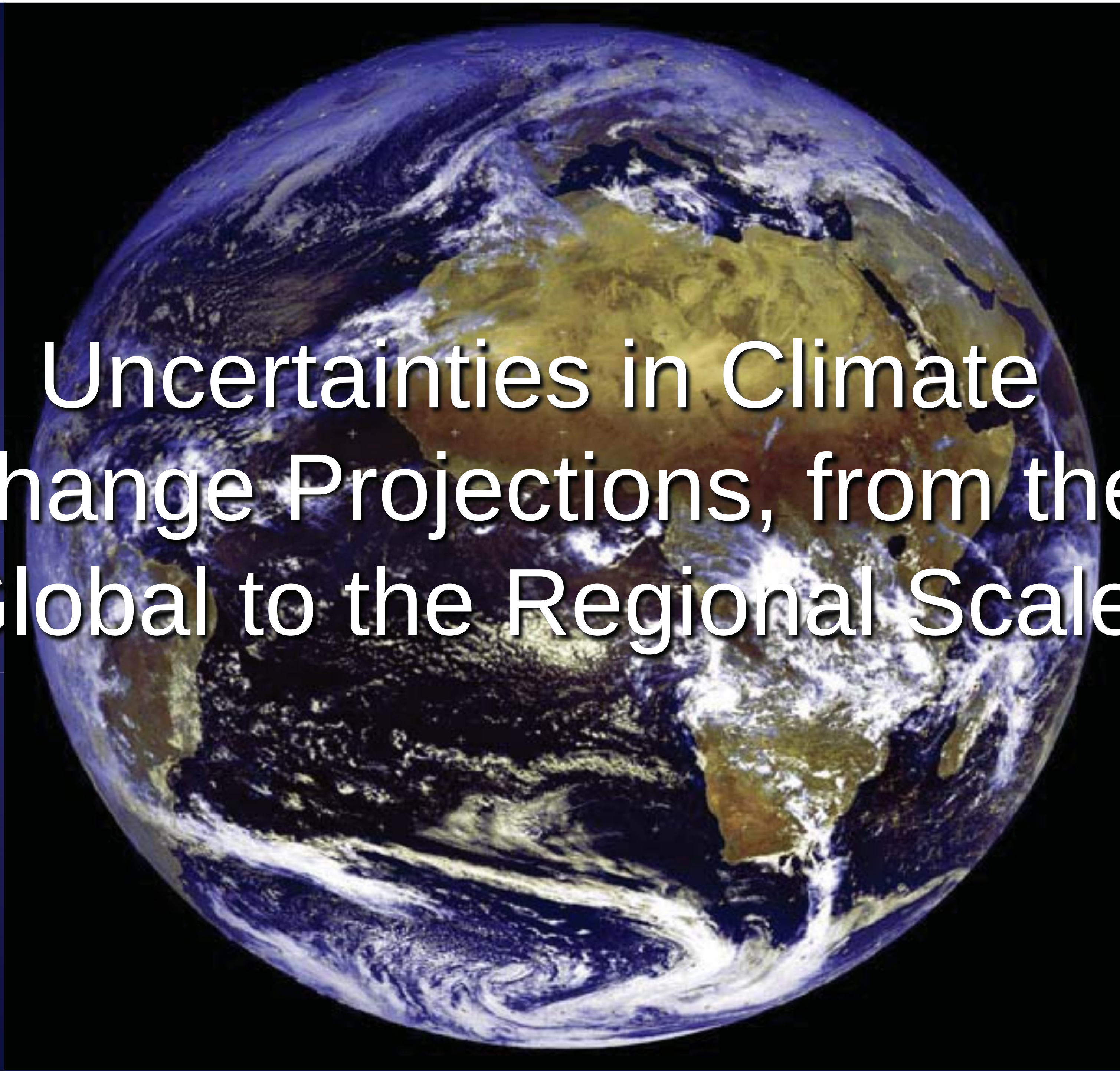
## Change in heat related indexes, A2 minus Reference



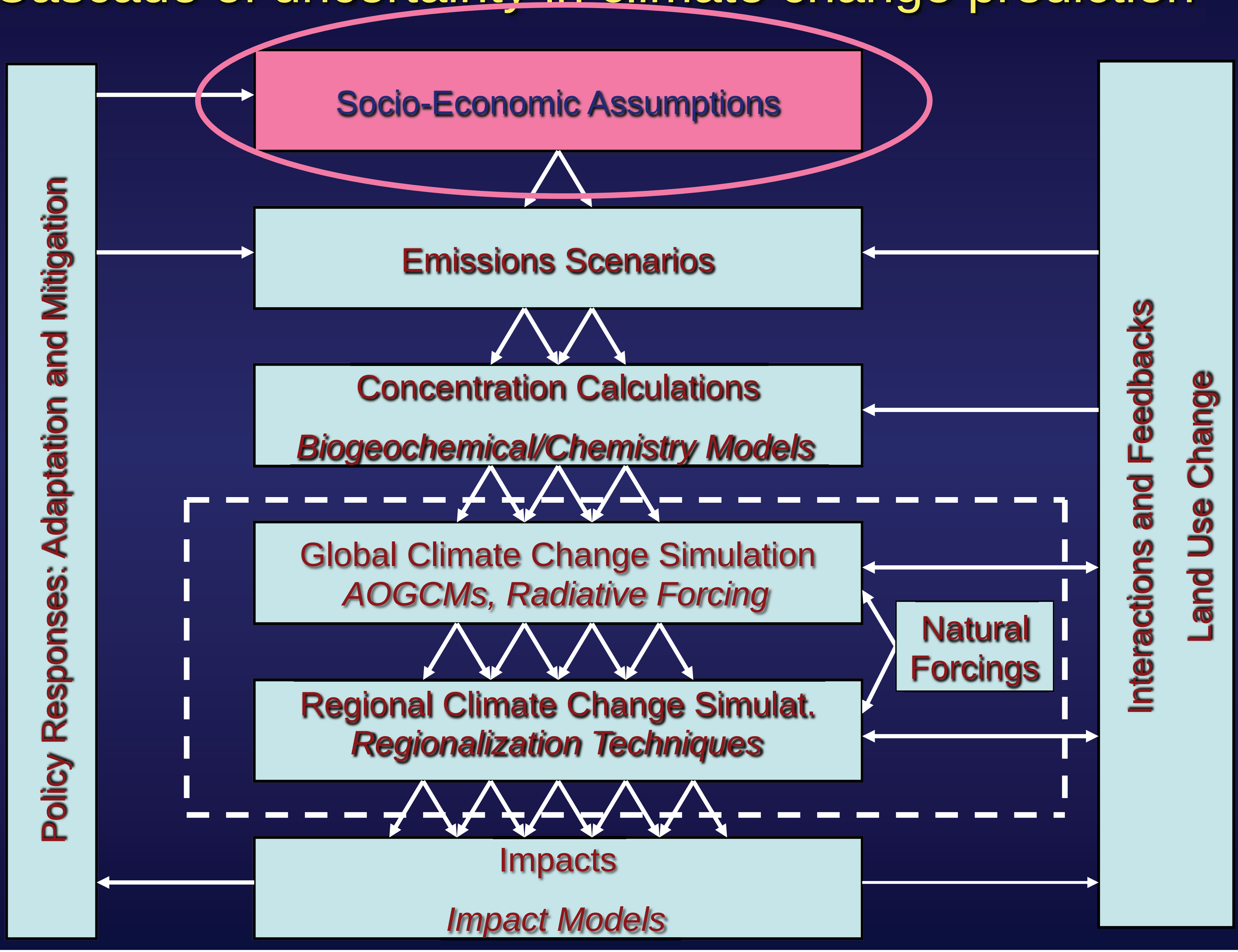




Diffenbaugh
et al. 2008

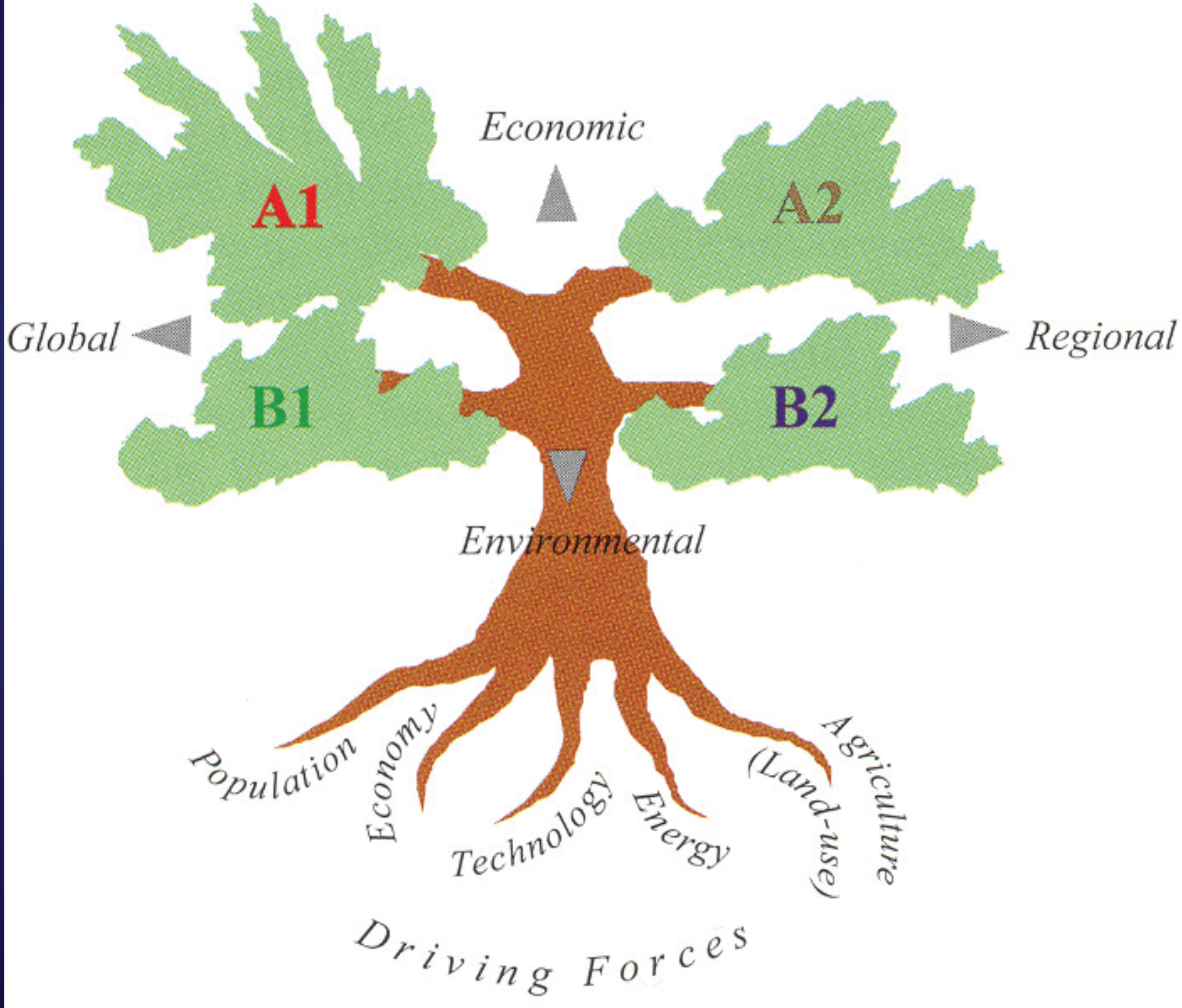


# Uncertainties in Climate Change Projections, from the Global to the Regional Scale

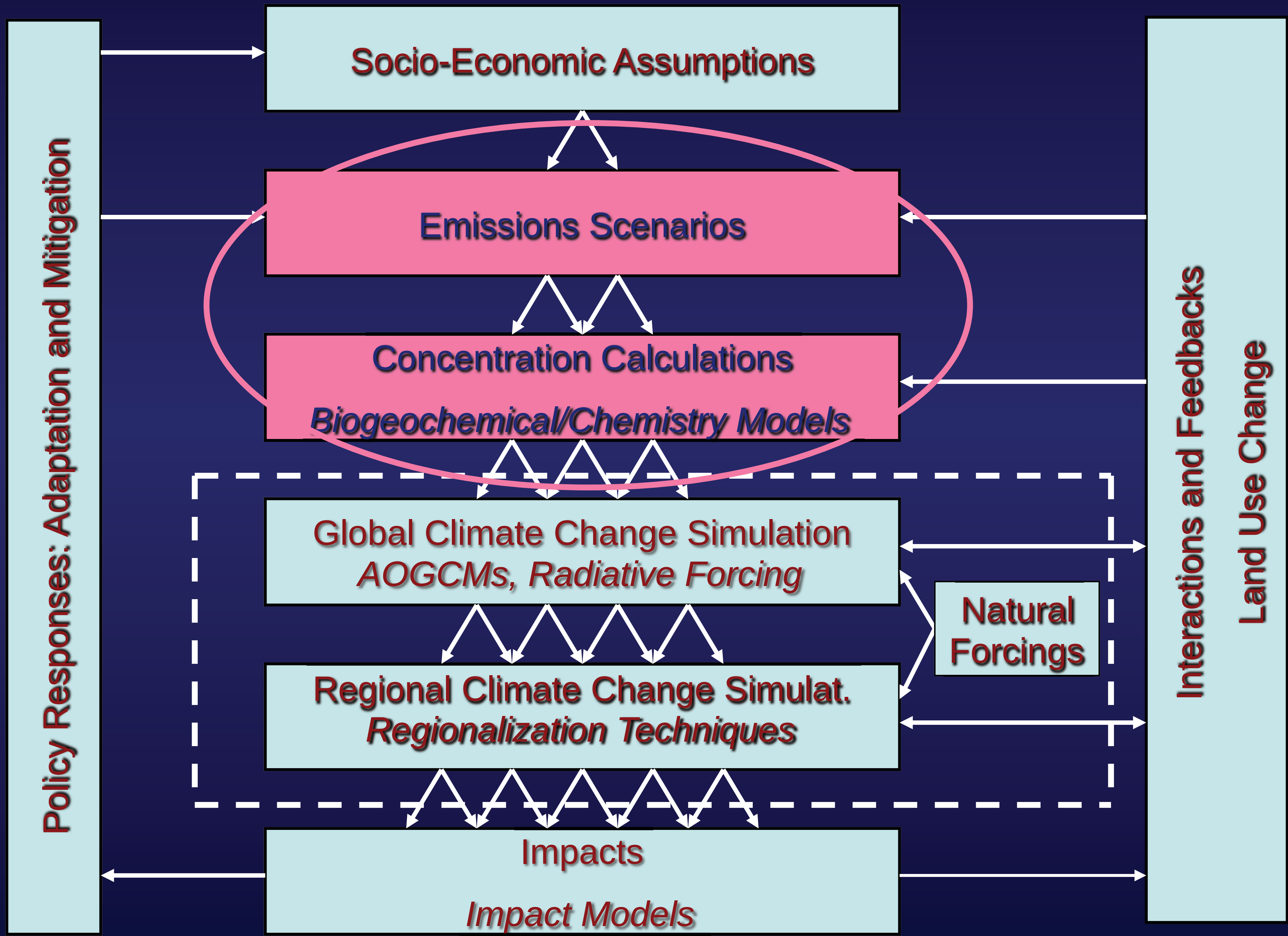
# Cascade of uncertainty in climate change prediction



# SRES Emission Scenarios

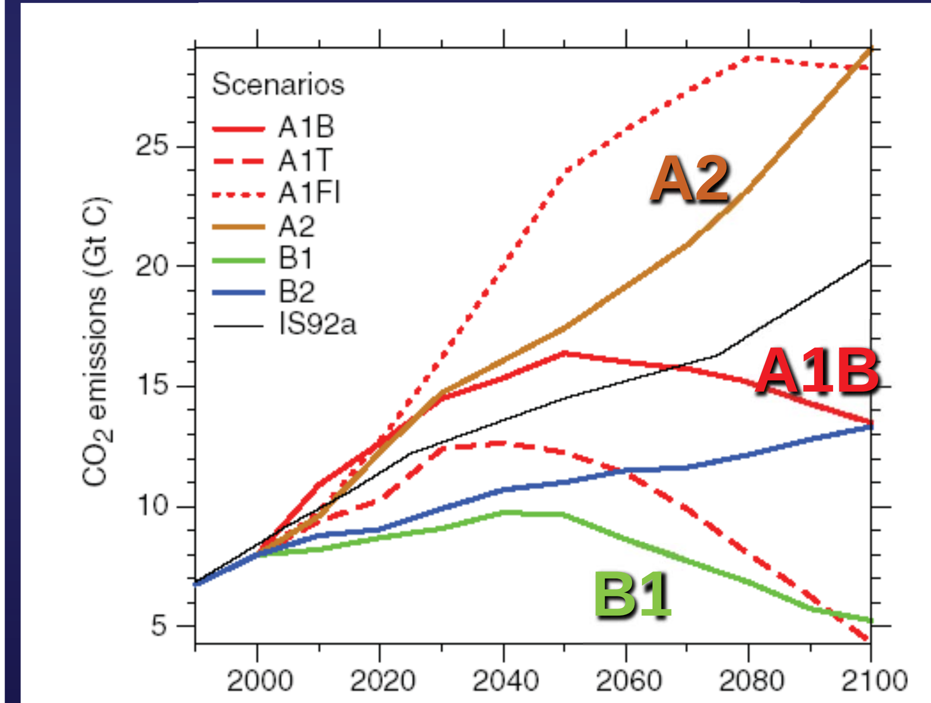


# Cascade of uncertainty in climate change prediction

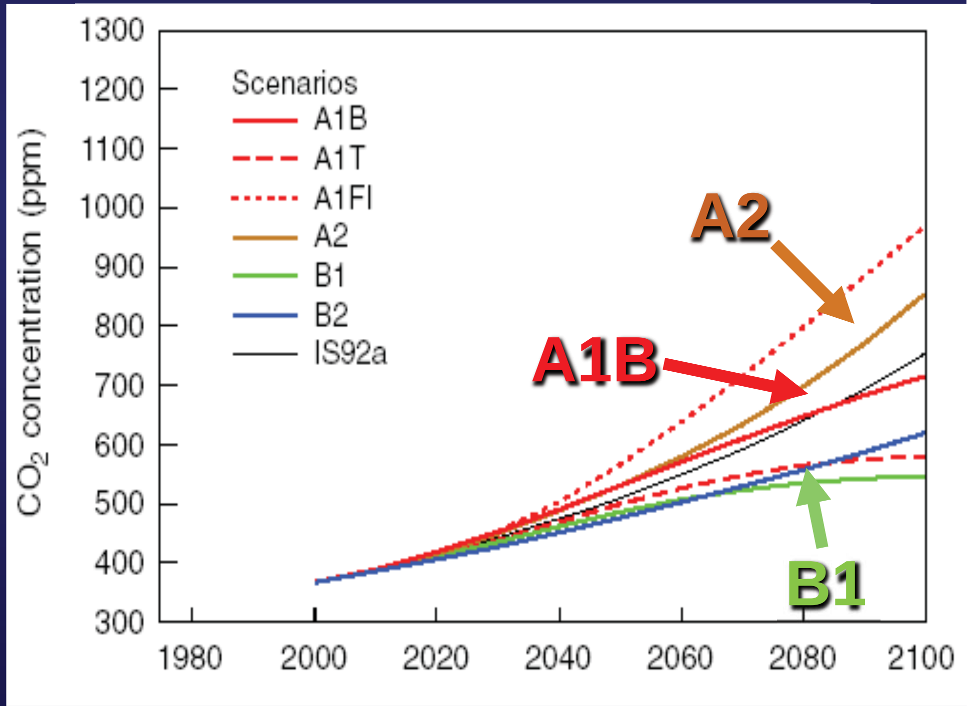


# Greenhouse gas emission and concentration scenarios (IPCC-2000)

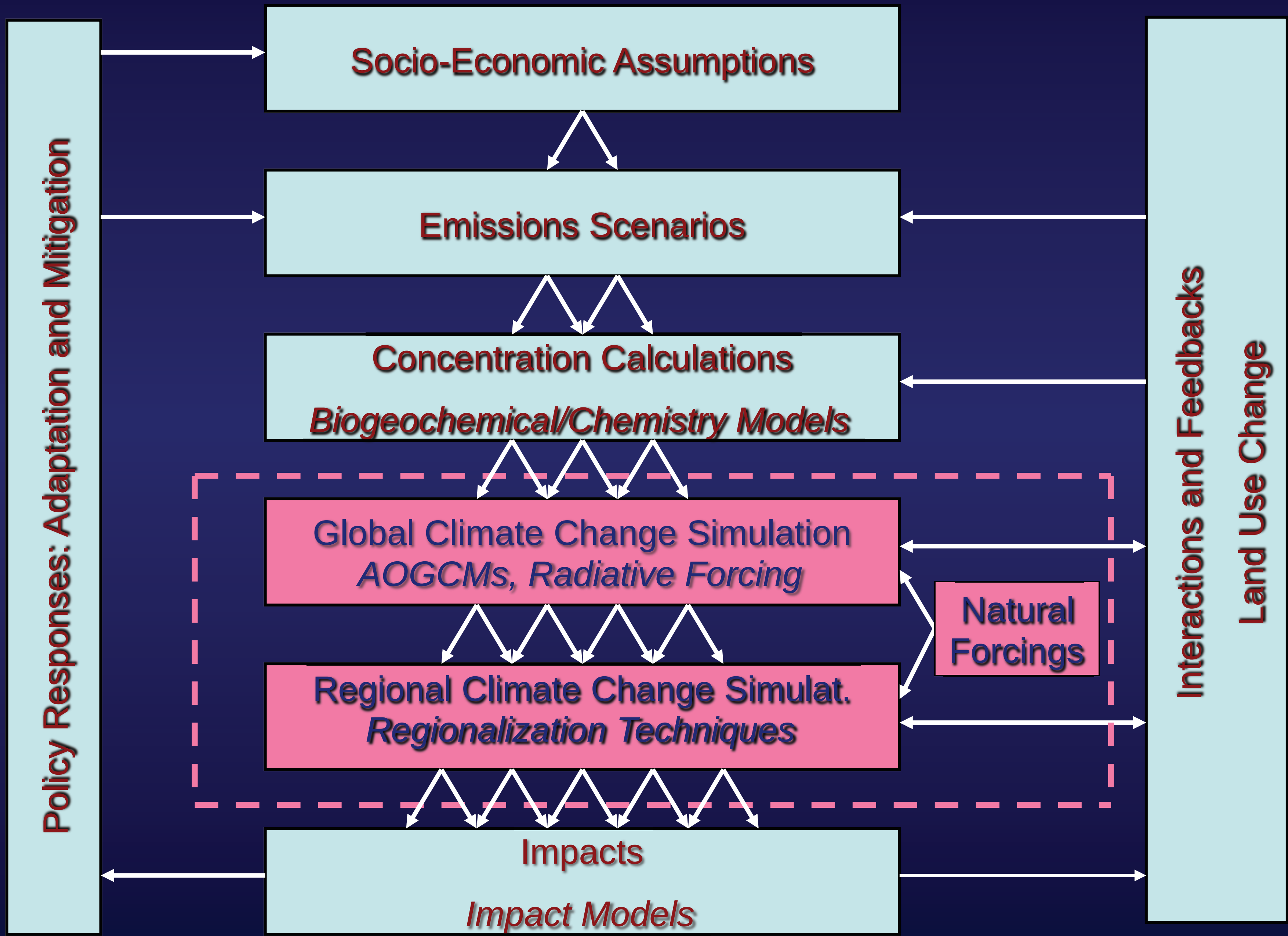
## CO2 emissions



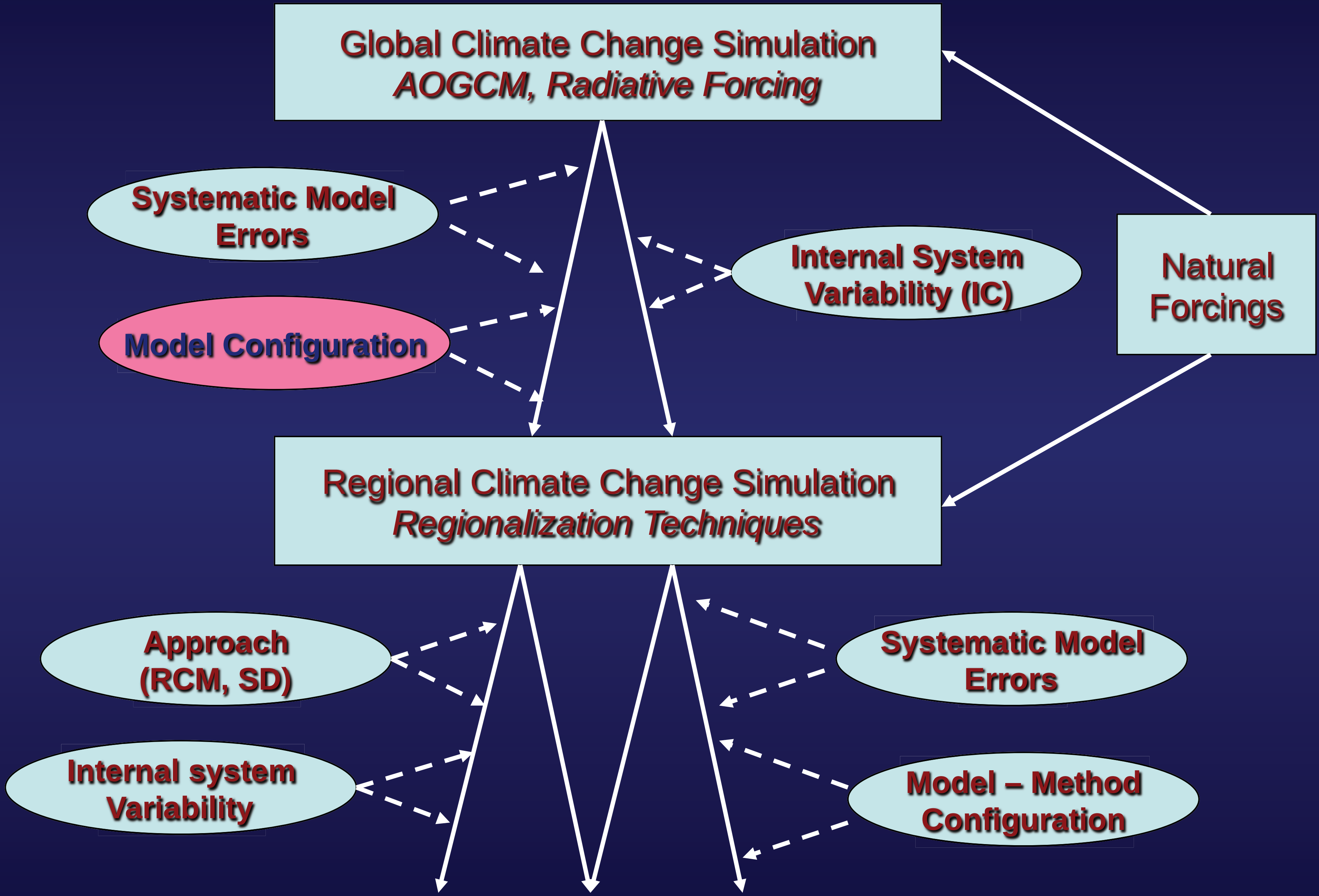

## CO2 Concentrations



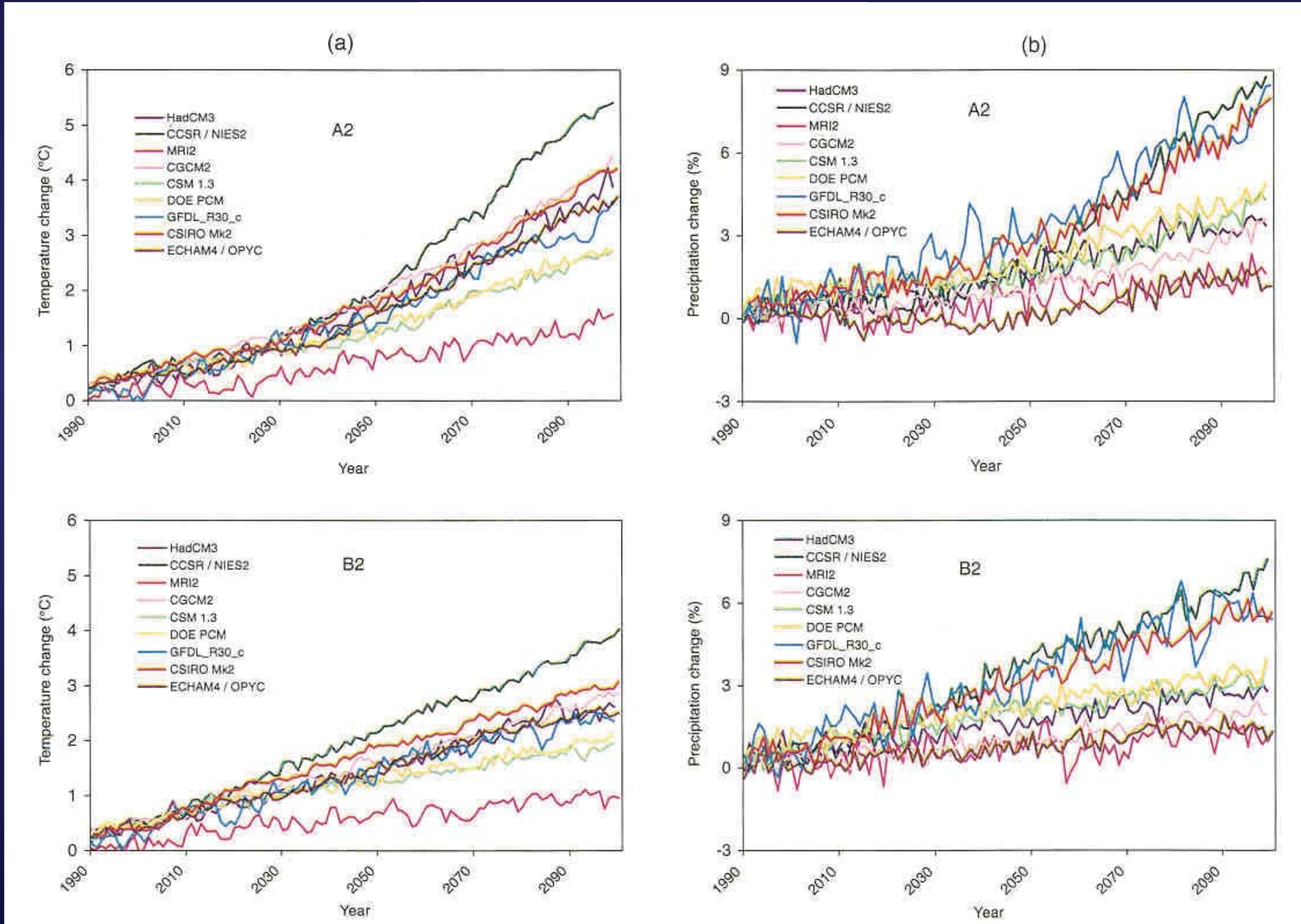
# Cascade of uncertainty in climate change prediction



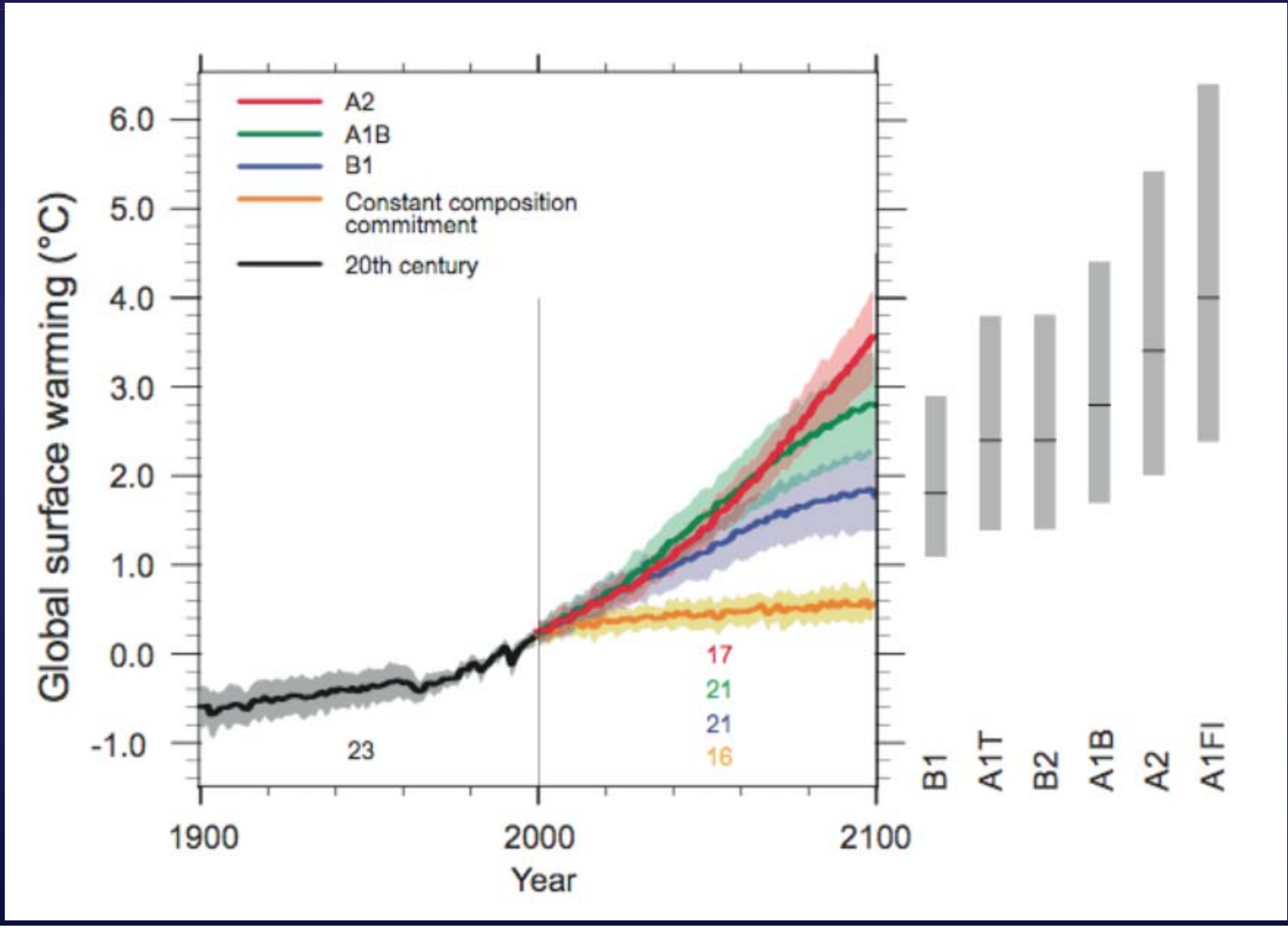
# Climate Simulation Segment of the Uncertainty Cascade



# Model configuration uncertainty
# Global scale

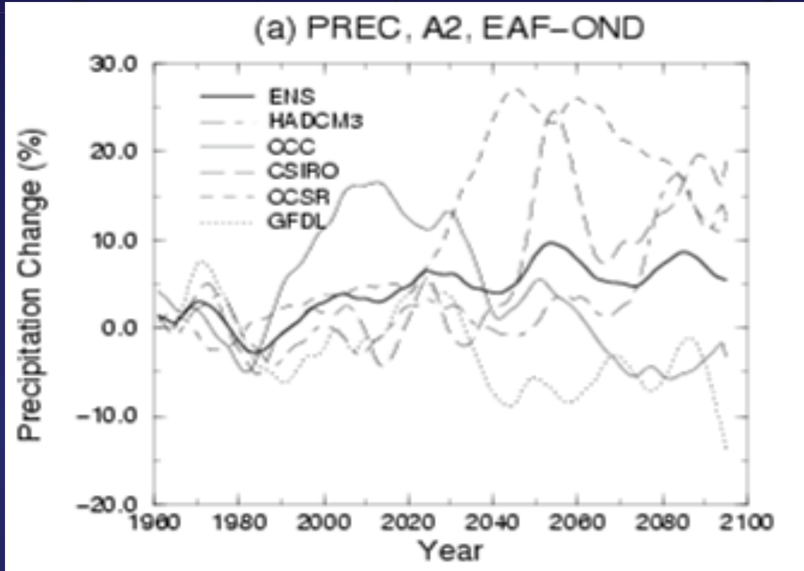


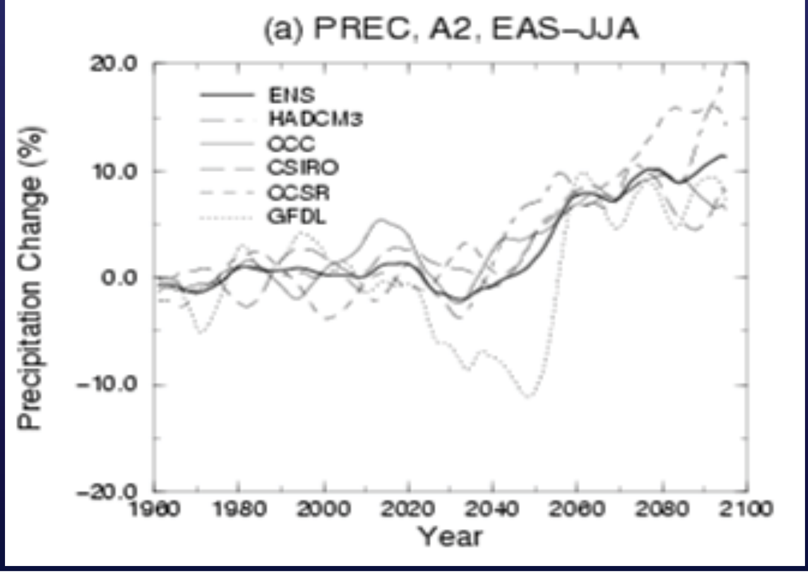
# IPCC – 2007: Global temperature change projections for the 21st century



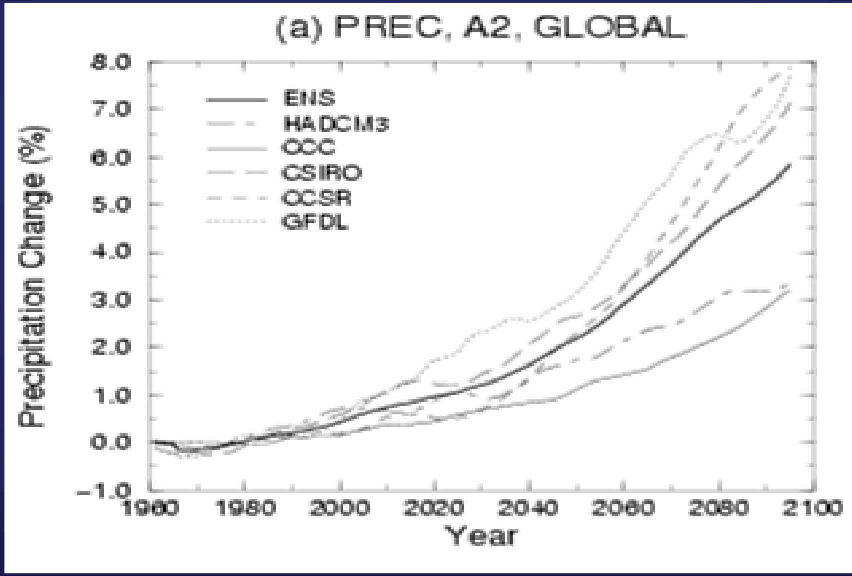
# Global vs. regional climate change

Regional precipitation change



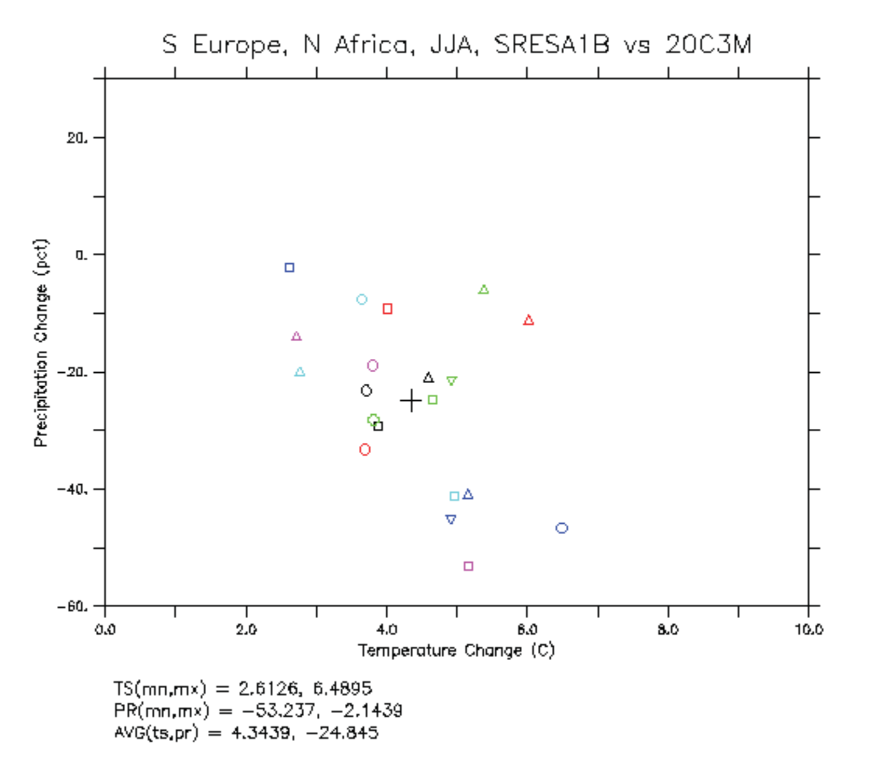

Global precipitation change



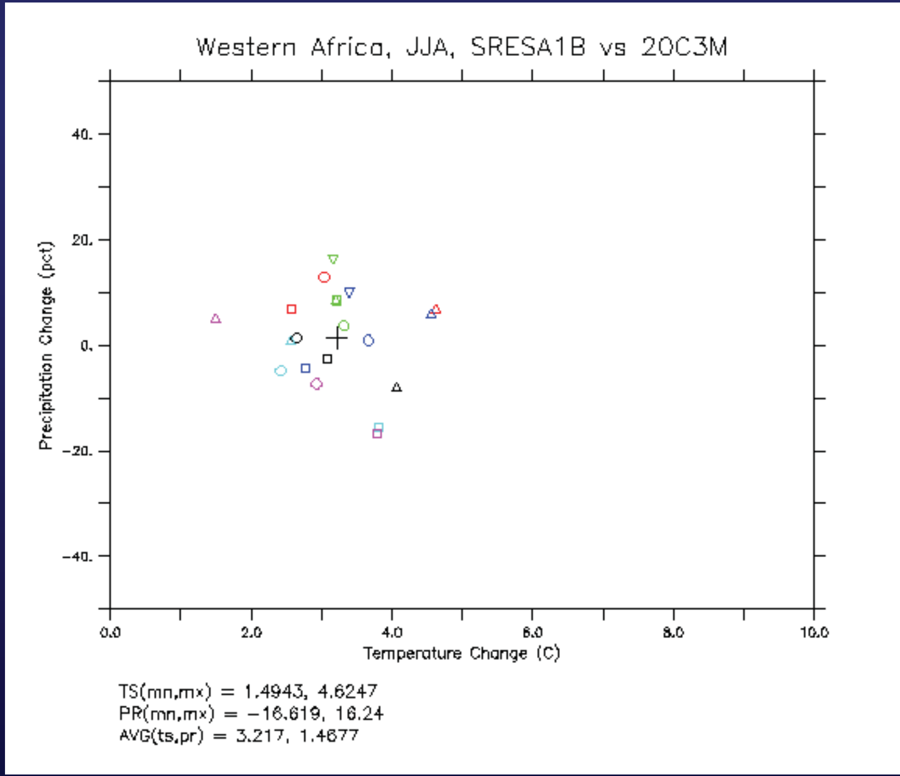
# Model configuration uncertainty at the regional scale (AOGCMs)

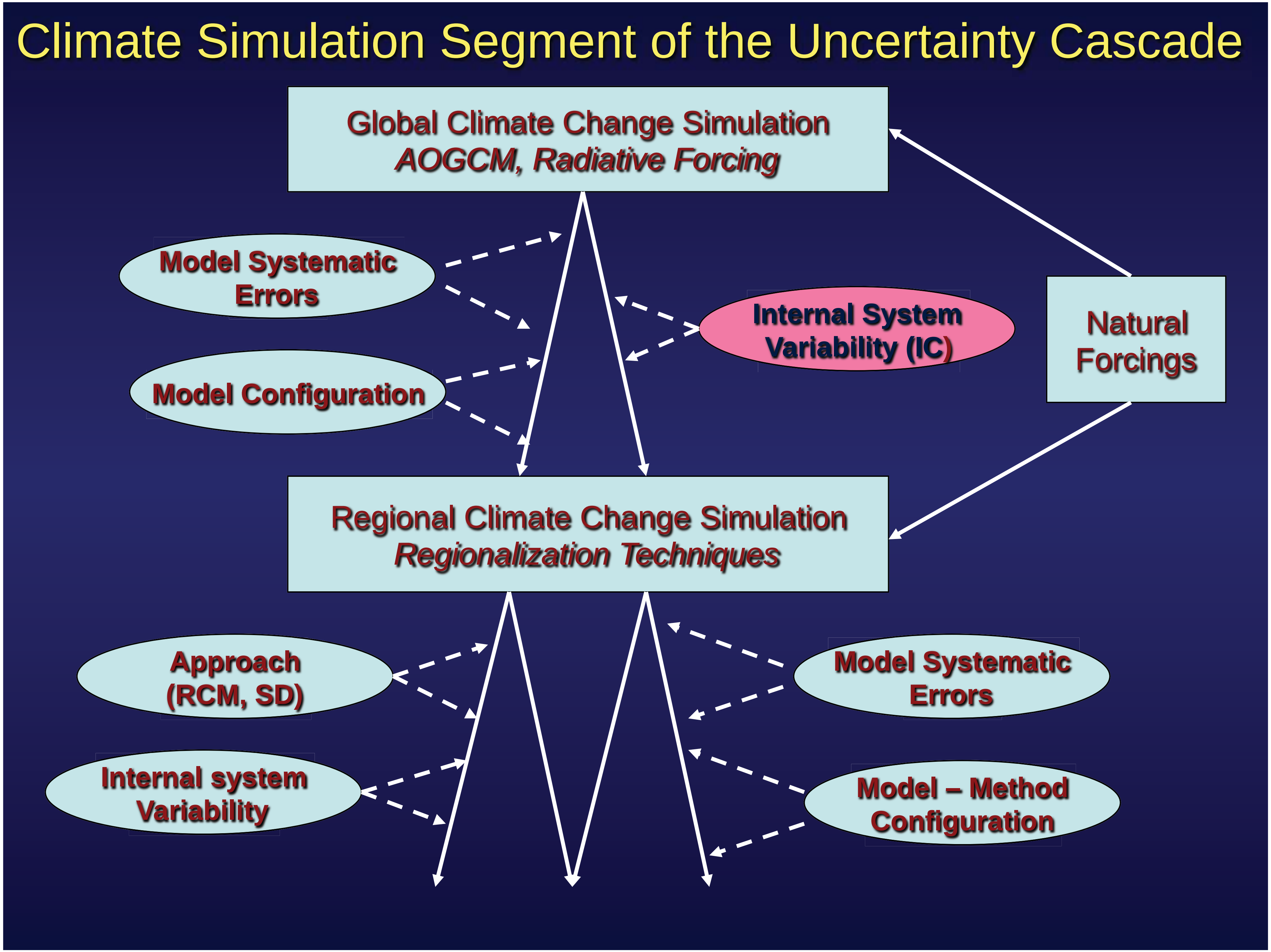
## Regional precipitation vs. temperature change

Mediterranean warm season

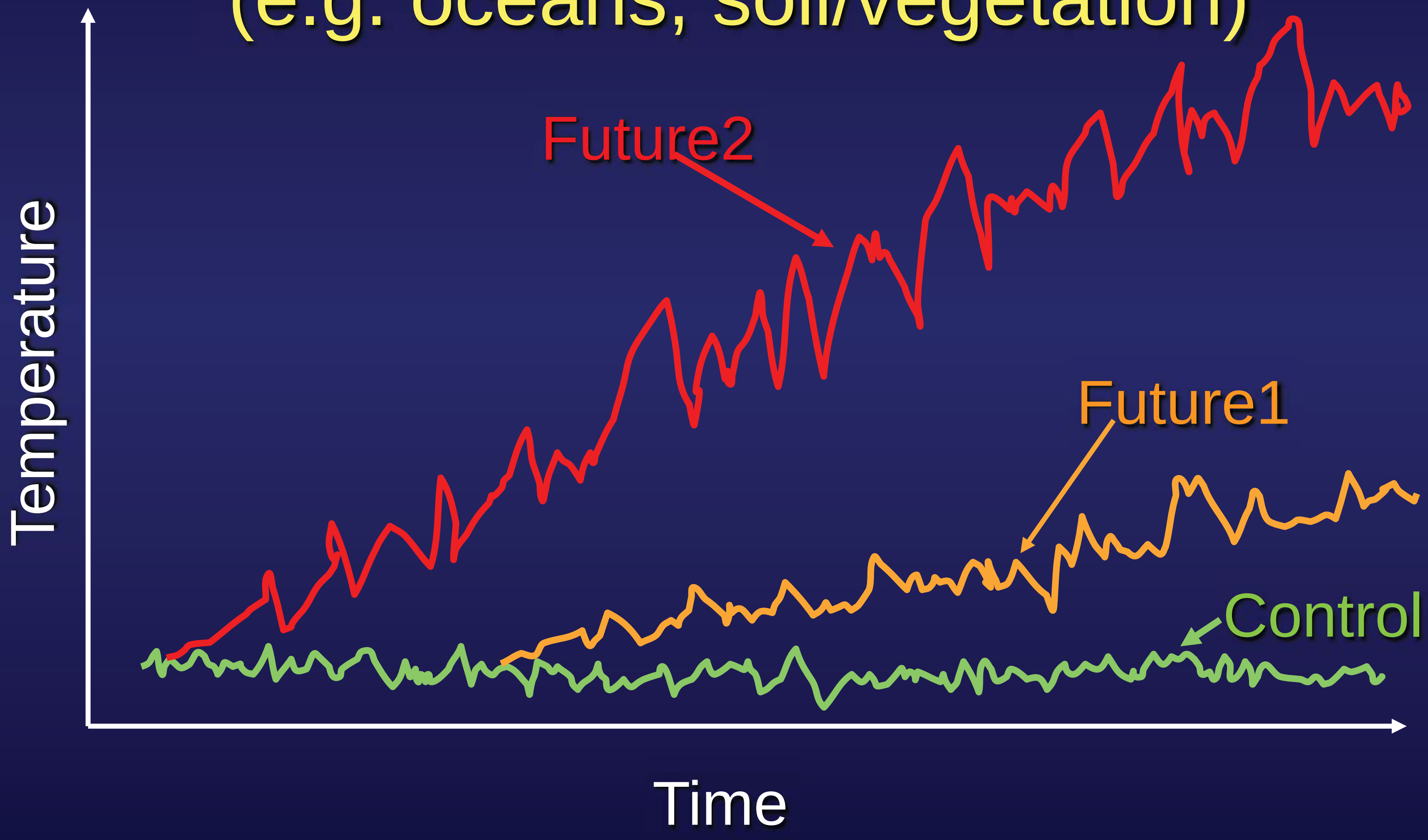



West Africa monsoon season




Climate Simulation Segment of the Uncertainty Cascade
Global Climate Change Simulation
AOGCM, Radiative Forcing
Model Systematic Errors
Internal System Variability (IC)
Natural Forcings
Model Configuration
Regional Climate Change Simulation
Regionalization Techniques
Approach (RCM, SD)
Model Systematic Errors
Internal system Variability
Model – Method Configuration

# Climate can evolve differently depending on the initial conditions of its slow components (e.g. oceans, soil/vegetation)

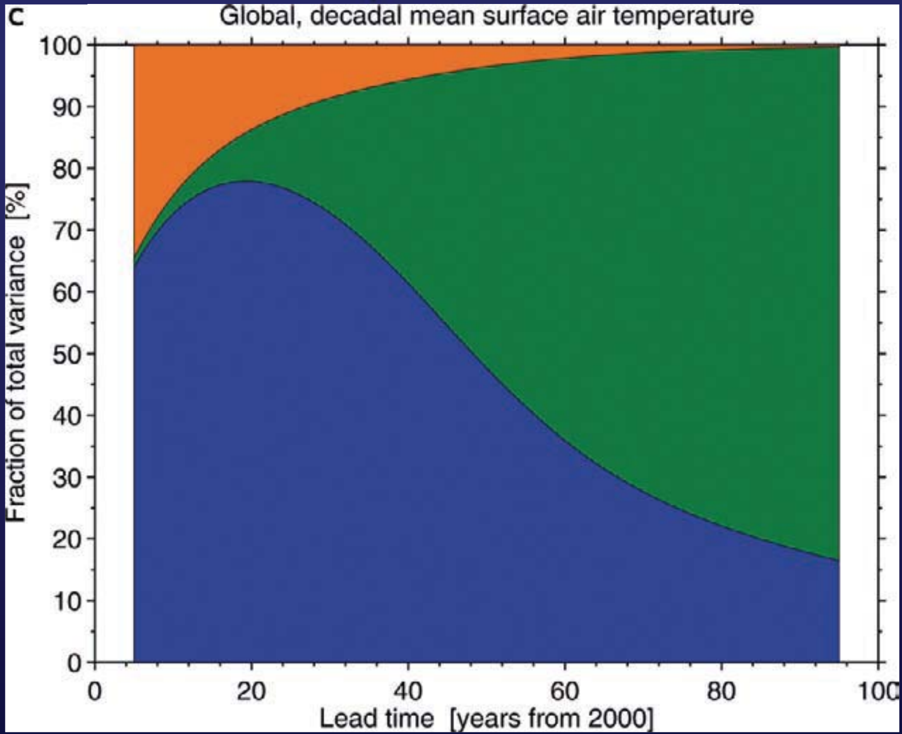


# Fraction of uncertainty explained by different sources as a function of lead time

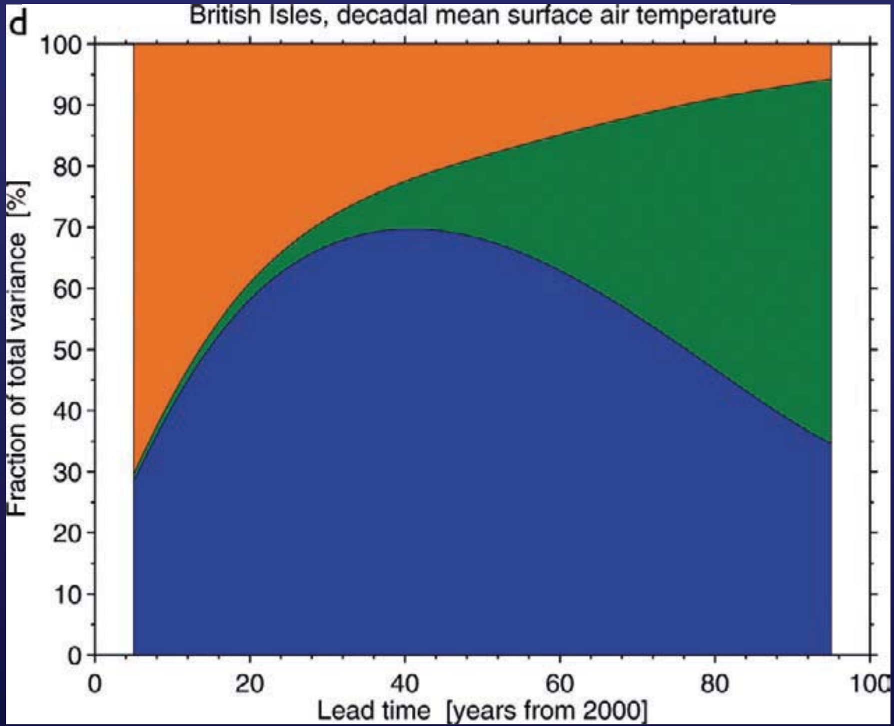
Internal variability
Scenario uncertainty
Model configuration uncertainty

Hawkins and Sutton 2009

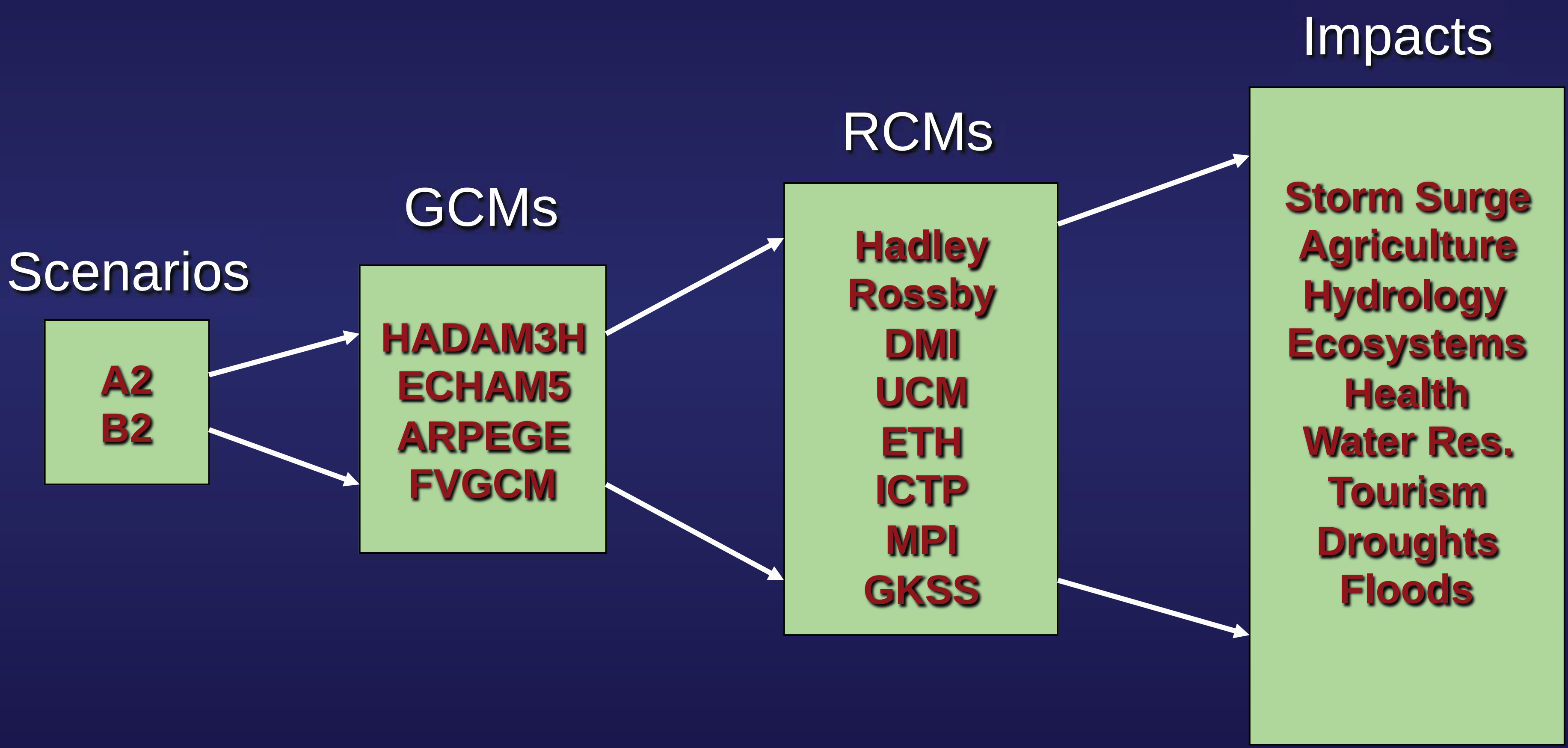
Decadal temperature - Global




Decadal temperature – British Isles

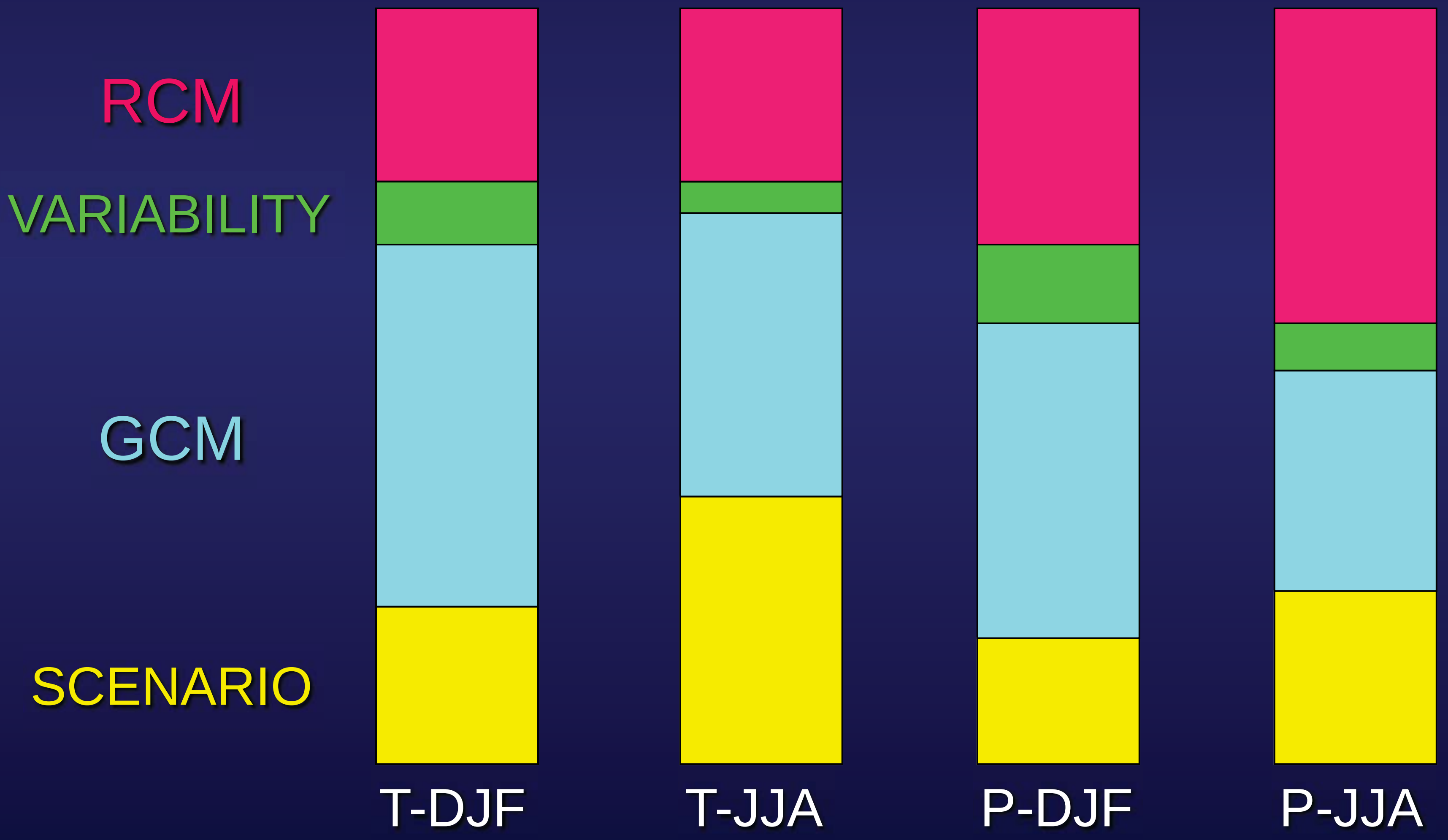


# Uncertainties in regional climate change projections: The PRUDENCE strategy

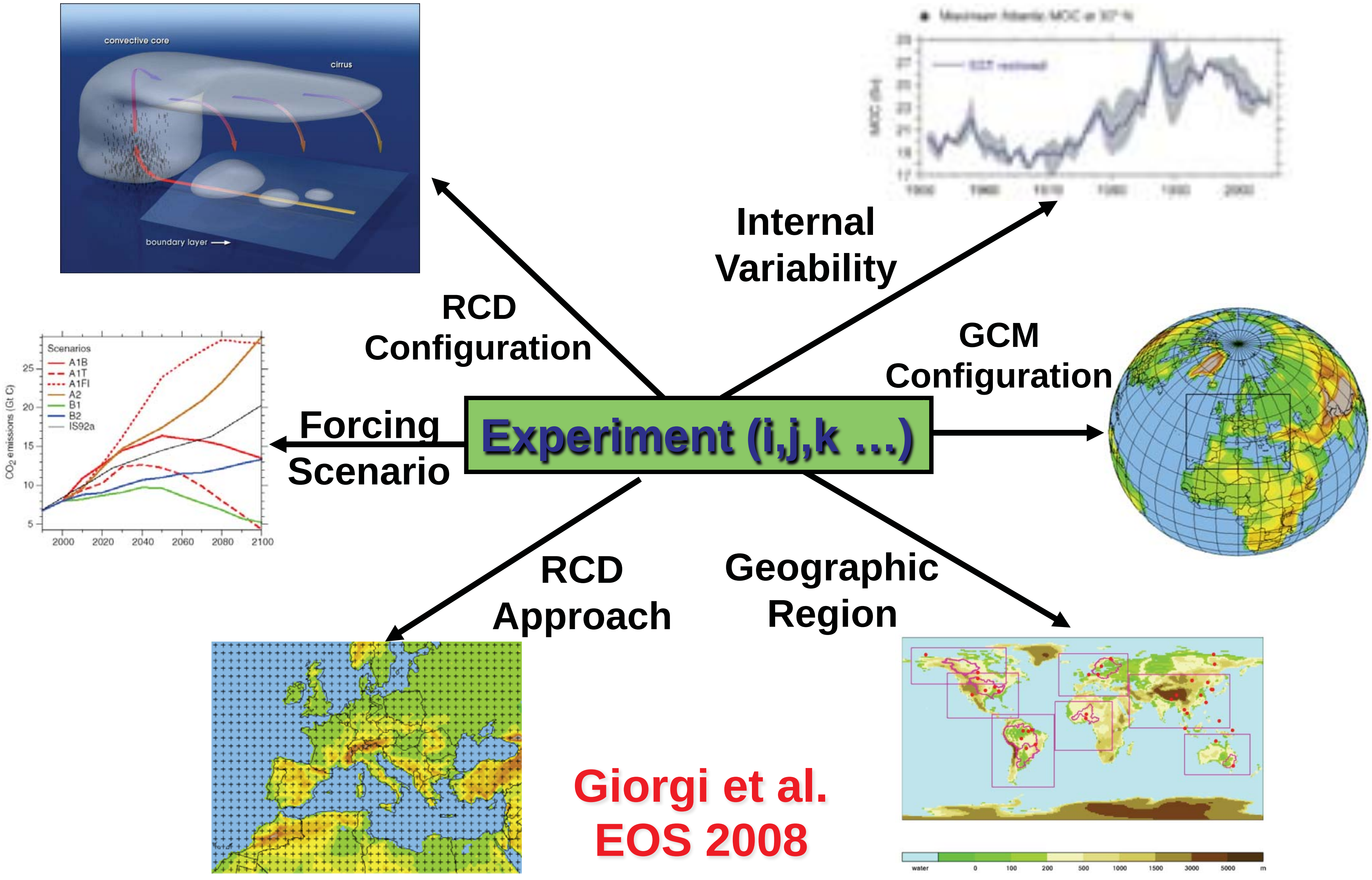


# Sources of uncertainty in the simulation of temperature and precipitation change (2071-2100 minus 1961-1990) by the ensemble of PRUDENCE simulations (whole Europe)

(Note: the scenario range is about half of the full IPCC range, the GCM range does not cover the full IPCC range) (Adapted from Deque et al. 2006)

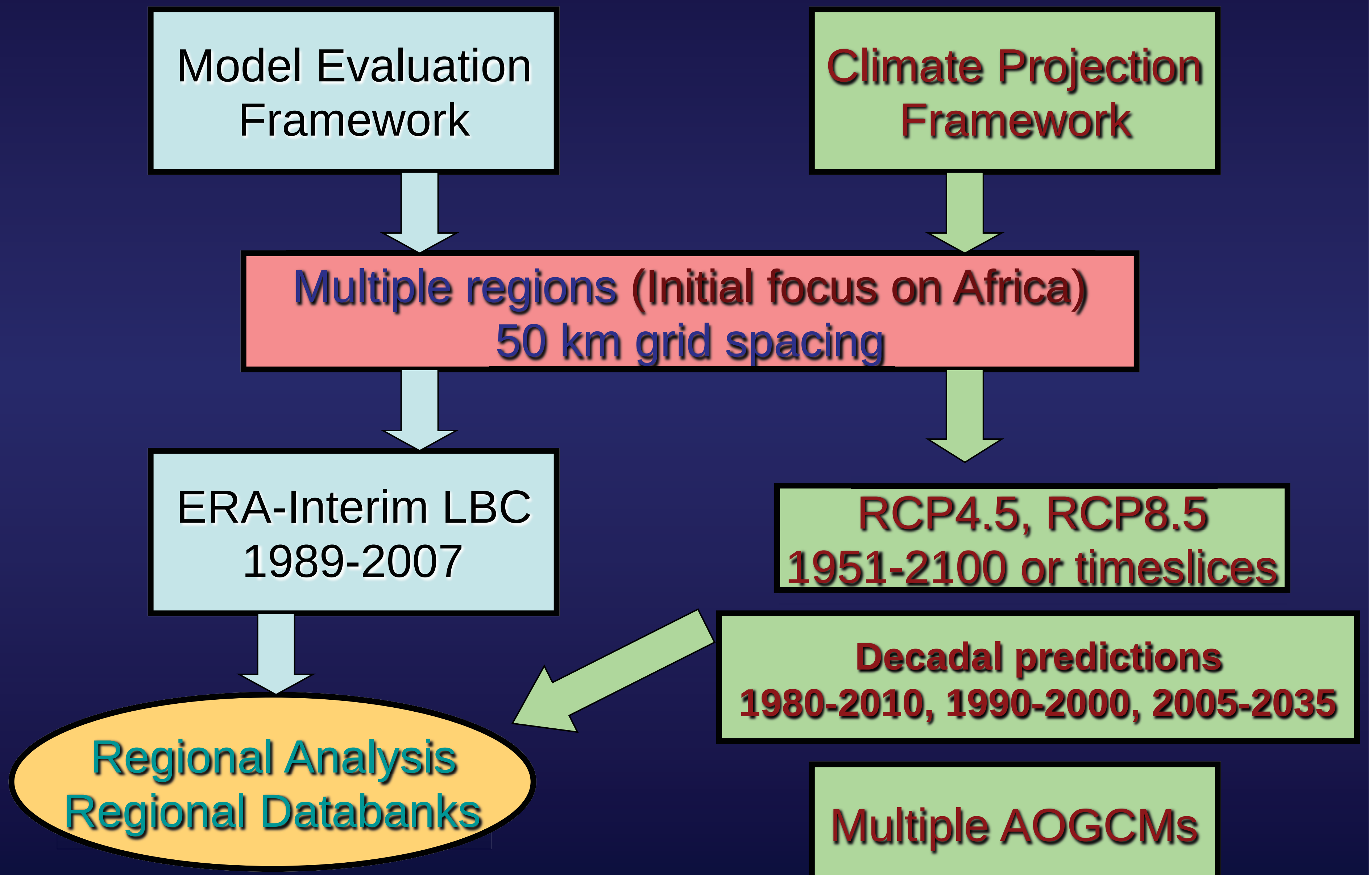


# Large ensembles of simulations are necessary to properly explore uncertainty in regional projections (→CORDEX)

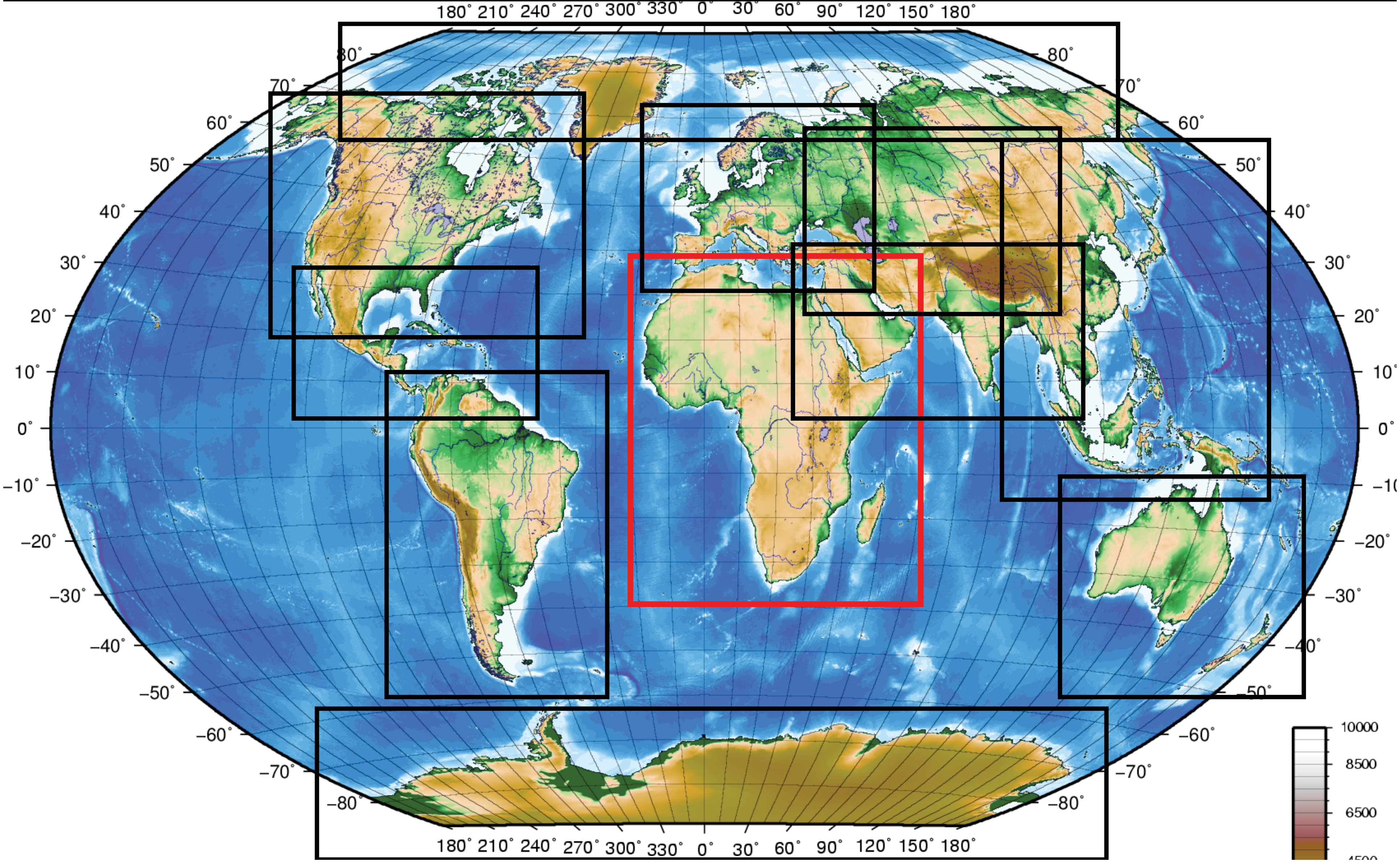



Giorgi et al. EOS 2008

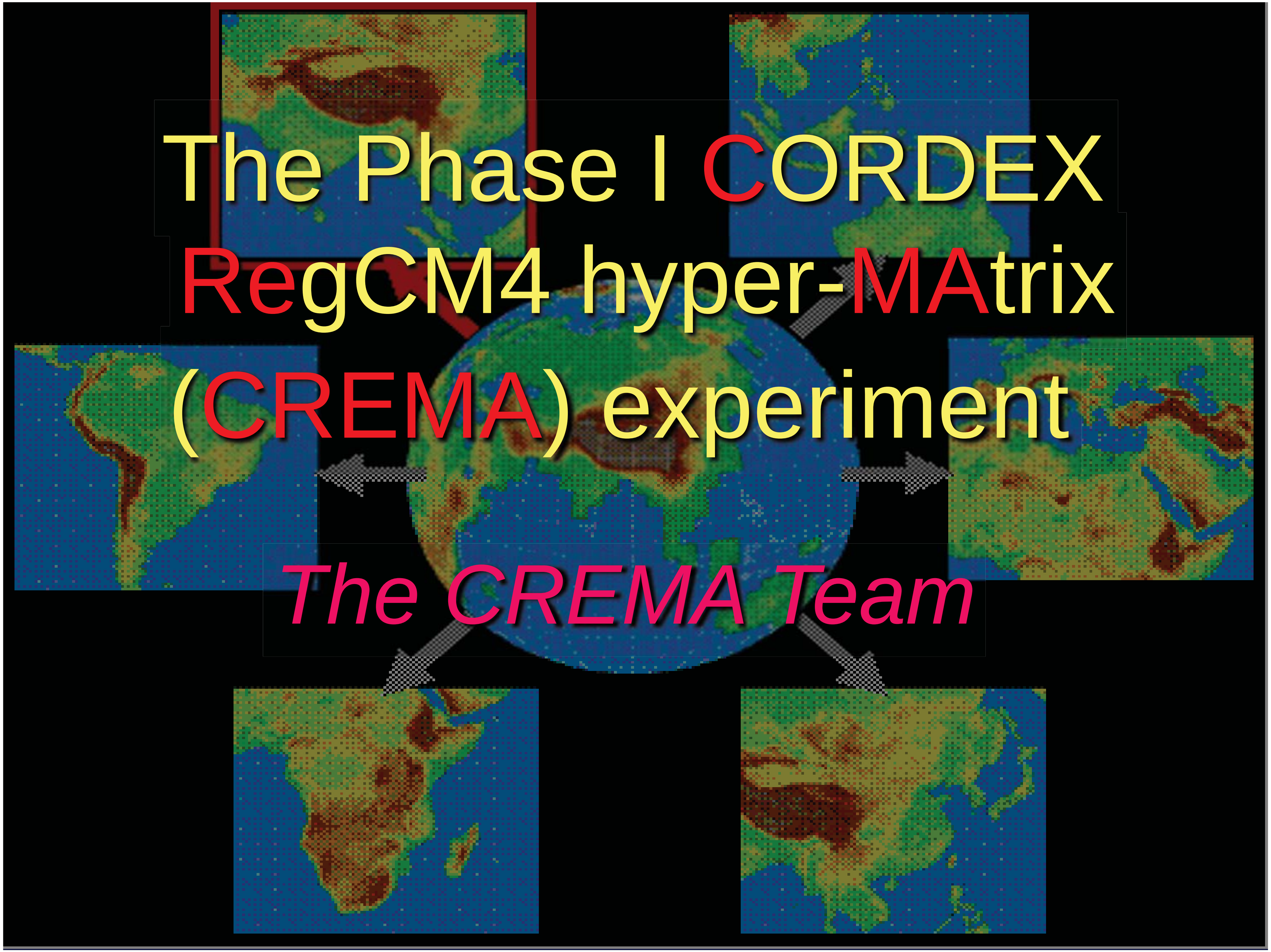
# CORDEX Phase I experiment design



# CORDEX domains



# The Phase I CORDEX RegCM4 hyper-MAtrix (CREMA) experiment



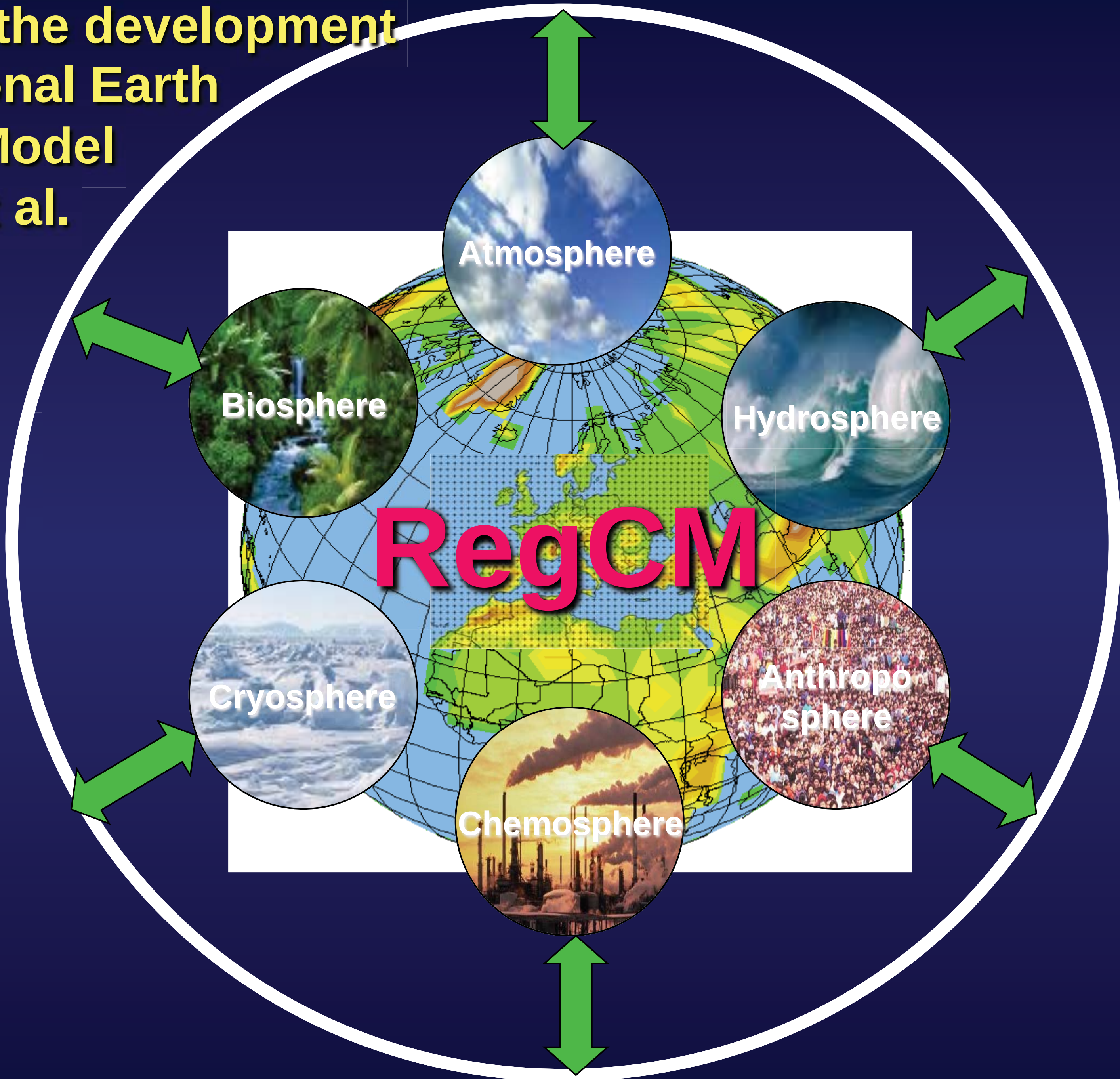
*The CREMA Team*

# Contributors to the Phase I CREMA experiment

- F. Giorgi, E. Coppola, I. Diallo, N. Elguindi, G. Giuliani, L. Mariotti, F. Raffaele, G. Tefera-Diro, C. Torma (ICTP)
- R. Fuentes-Franco, E. Pavia, F. Graef (CICESE, Mexico)
- M. Llopart-Pereira, R. Porfirio Da Rocha (U. San Paolo, Brasil)
- A. Mamgain, S.K. Dash (IIT, India)
- I. Guettler, C. Brankovic (DHMZ, Croatia)

Simulations carried out on dedicated CPUs at the ARCTUR HPC centre, Gorjansko, Slovenia

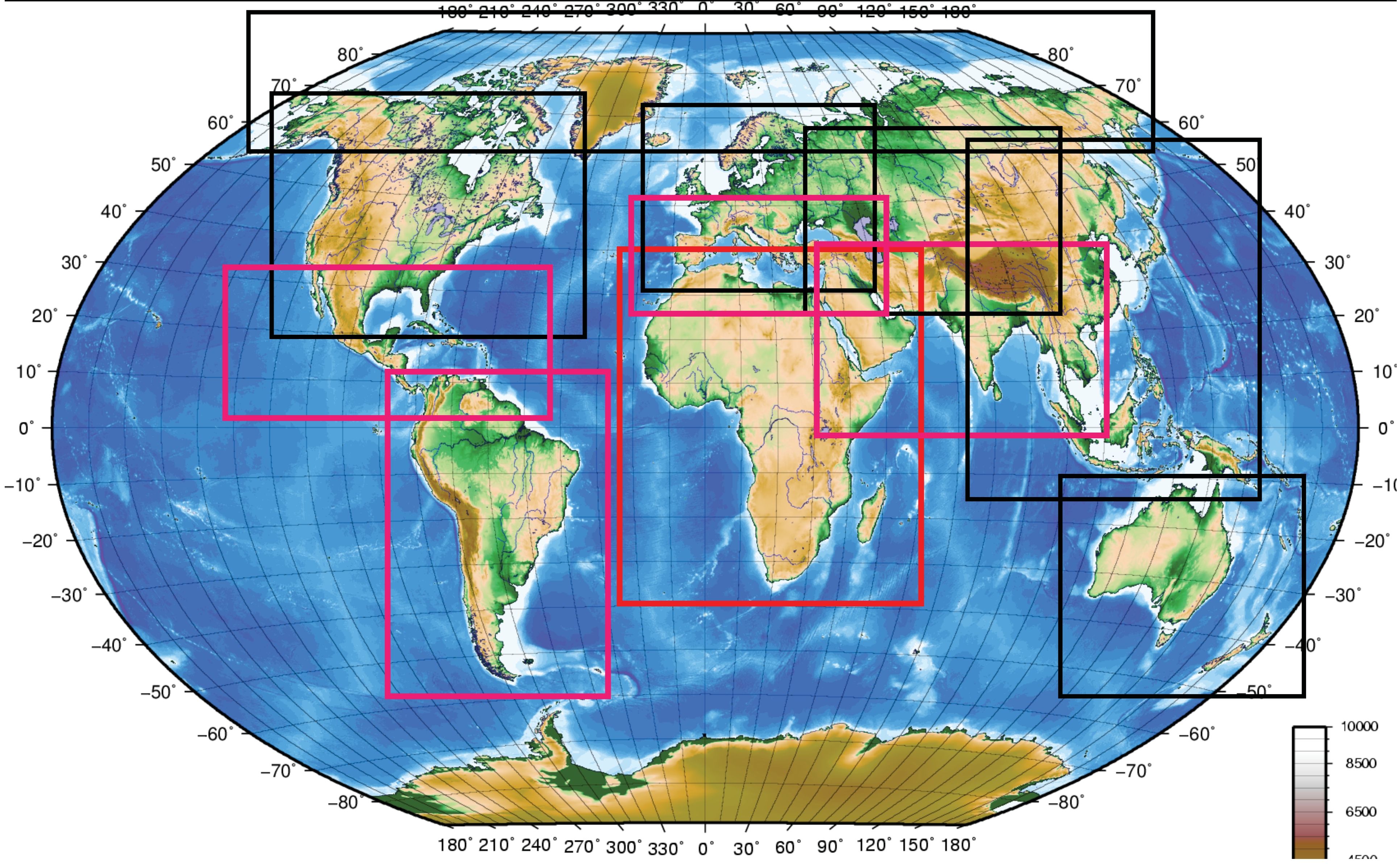
Towards the development of a regional Earth System Model (Giorgi et al. 2012)



# ICTP Regional Climate Model
# CREMA Parameterization tested

- **Dynamics:**
  Hydrostatic (Giorgi et al. 1993a,b)
  Adaptable to any region
  Non-hydrostatic in progress
- **Radiation:**
  **CCM3 (Kiehl 1996)**
- **Large-Scale Clouds & Precipitaion:**
  SUBEX (Pal et al 2000)
- **Cumulus convection:**
  **Grell (1993)**
  Anthes-Kuo (1977)
  **MIT (Emanuel 1991)**
  **Mixed convection**
  Tiedtke (in progress)
- **Planetary boundary layer:**
  **Modified Holtslag, Holtslag (1990)**
  UW-PBL (O'Brien et al. 2011)
- **Land Surface:**
  **BATS (Dickinson et al 1993)**
  SUB-BATS (Giorgi et al 2003)
  **CLM (Oleson et al. 2008)**
- **Ocean Fluxes**
  **BATS (Dickinson et al 1993)**
  **Zeng (Zeng et al. 1998)**
  Diurnal SST
- **Configuration**
  Adaptable to any region
  Tropical belt configuration
- **Extensive code remake**

# CREMA domains



# CREMA Experiment set-up

- CORDEX domain specifications
- Simulation period
  - 1970-2100
  - Reference: 1976-2005
- Greenhouse gas scenarios
  - RCP8.5, RCP4.5
- Driving GCMs
  - HadGEM2-ES
  - MPI-ESMMR
  - GFDL-ESM
- Observations
  - CRU, GPCP, TRMM

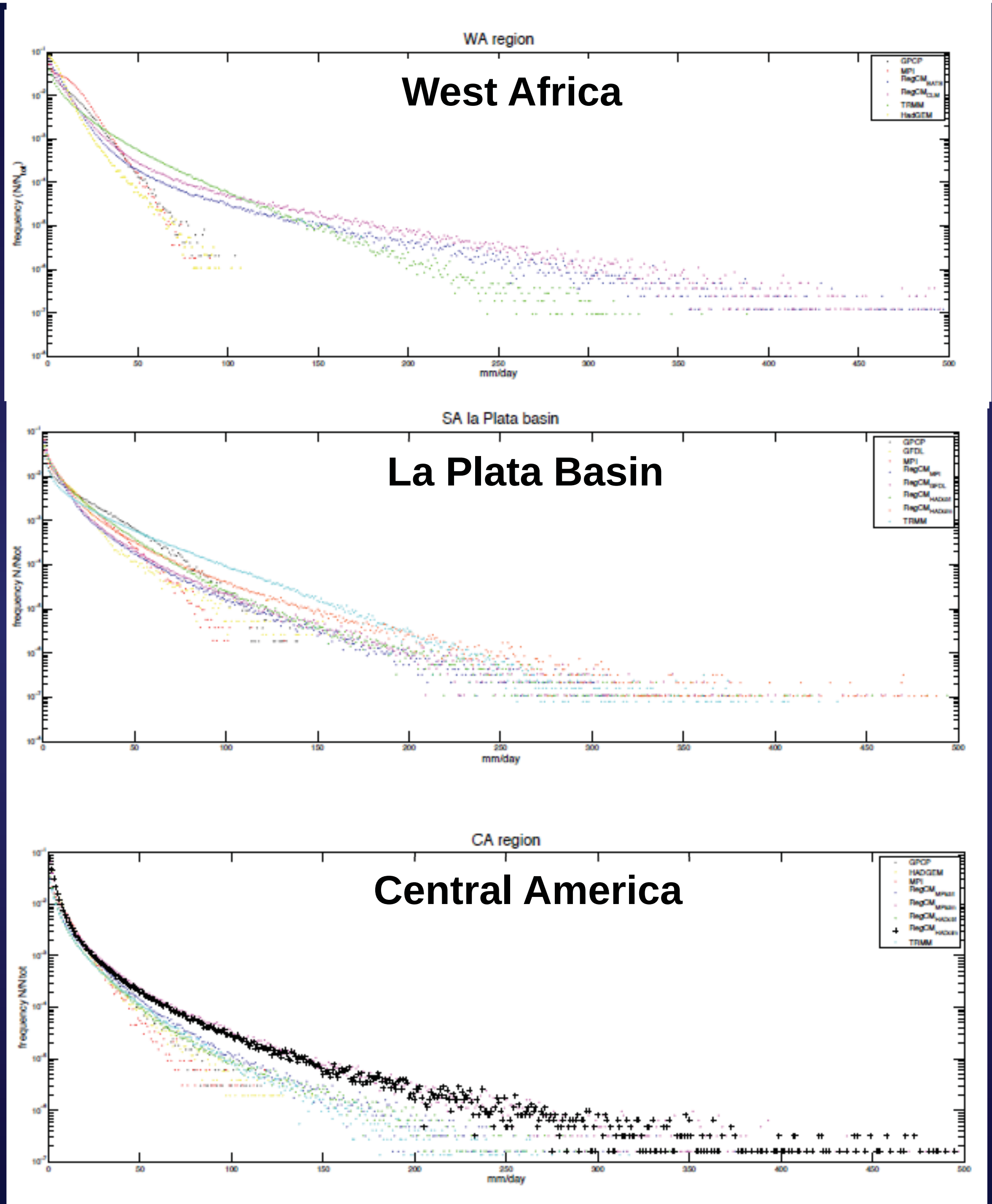
# The CREMA Phase I Matrix

| | Africa | C America | India | Med | S. America |
|---|---|---|---|---|---|
| HAD-CLM-GE | 2 | | | 1 | |
| HAD-CLM-E | | 2 | | | 2 |
| HAD-BATS-G | | 2 | | 3 | |
| HAD-BATS-GE | | | | 3 | 2 |
| MPI-CLM-E | | 1 | 1 | | 1 |
| MPI-BATS-G | 1 | 1 | | 3 | |
| MPI-BATS-GE | | | | 3 | |
| MPI-CLM-GE | | | | 1 | |
| GFDL-CLM-E | | | 2 | | 1 |
| GFDL-CLM-EG | | | 2 | | |

Table 1 The CREMA simulation ensemble divided by land-surface (CLM or BATS) and convection scheme (G=Grell, E=Emanuel, GE=Grell over land-Emanuel over ocean, EG=Emanuel over land Grell over ocean). 1 indicates only the RCP 8.5 scenario was completed, 2 indicates that both the RCP 8.5 and 4.5 scenarios were completed.

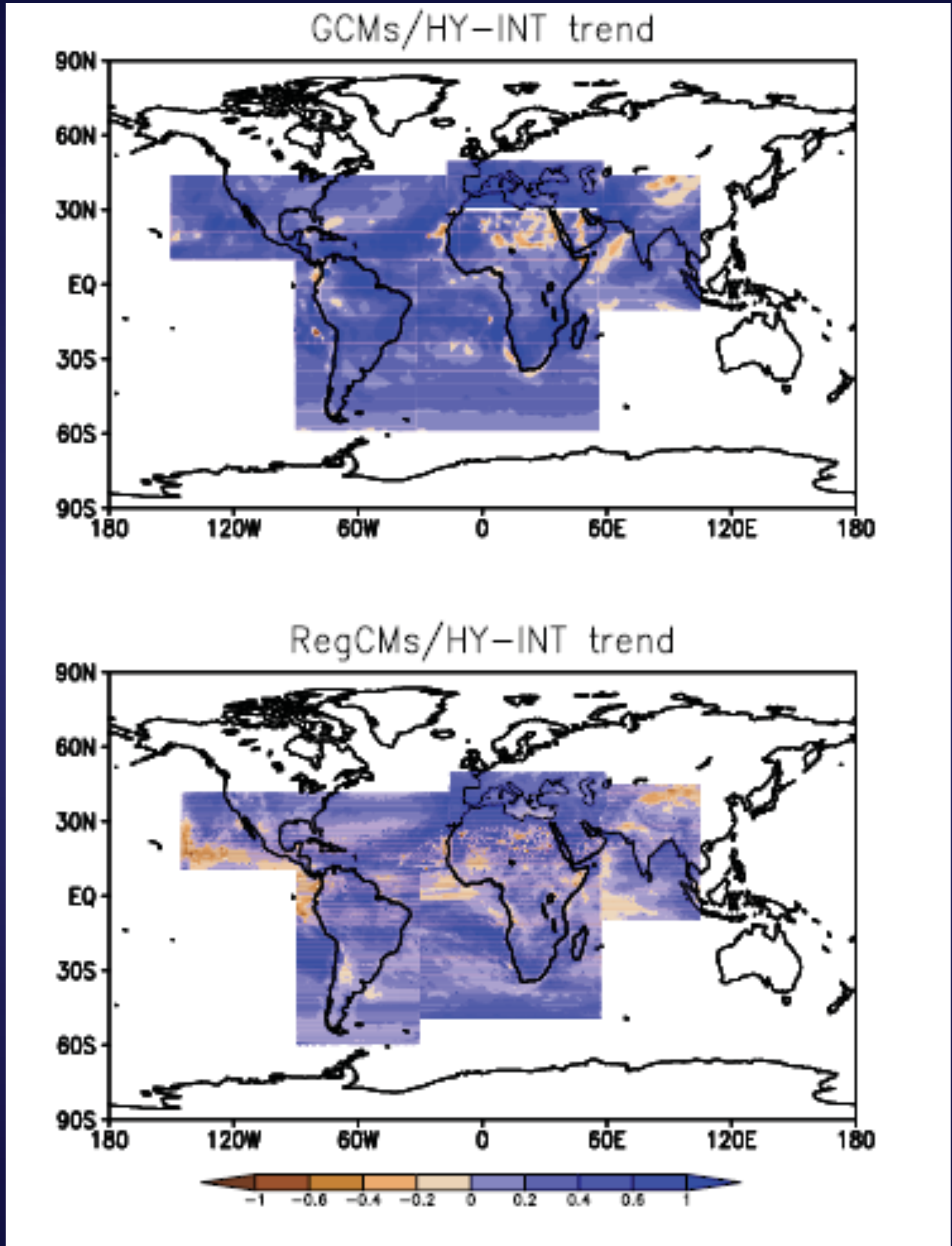
# Special Issue of Climate Change

- Coppola et al.
  - Basic analysis of change and biases
- Giorgi et al.
  - Hydroclimatic extremes
- Fuentes-Franco et al.; Diro et al,
  - Central America + Tropical storms
- Mariotti et al.
  - Changes in African monsoon
- Dash et al.
  - Weakening of the India monsoon
- Llopart et al.
  - Climate land surface feedbacks over S. America
- Torma et al.; Guttler et al.
  - Sensitivity of change signal to physics schemes




Empirical PDFs of daily precipitation events in models and observations (GPCP, TRMM)

Giorgi et al. (2013)

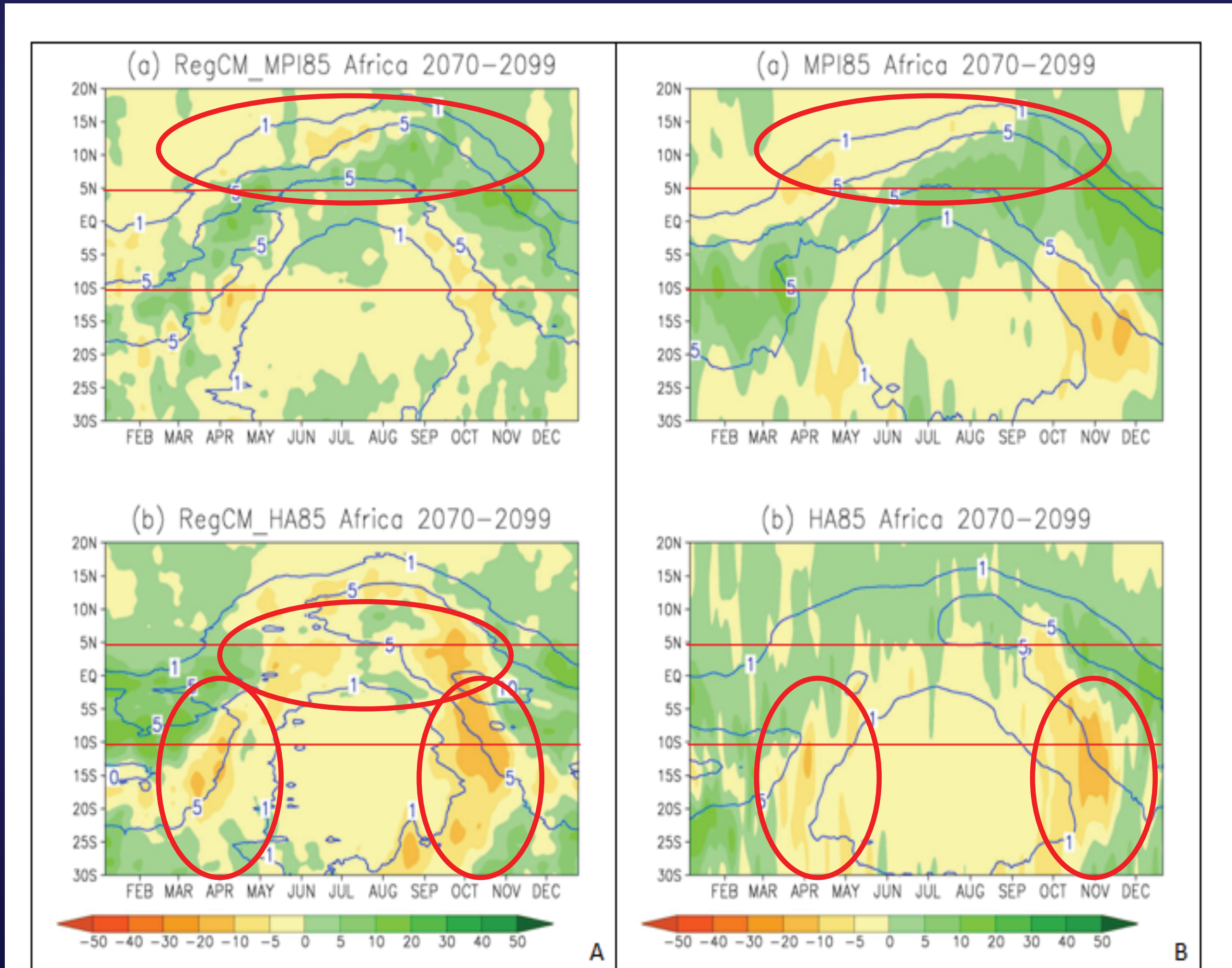


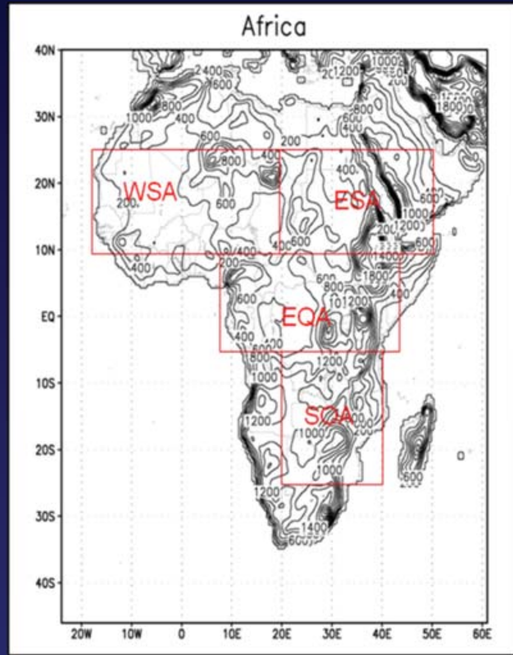

21st Century trends in the hydroclimatic regime index HY-INT ( I x DSL )

Giorgi et al. (2013)

Global warming leads to more Intense, less frequent events

# Hovmoller diagram of change in daily precipitation over Africa

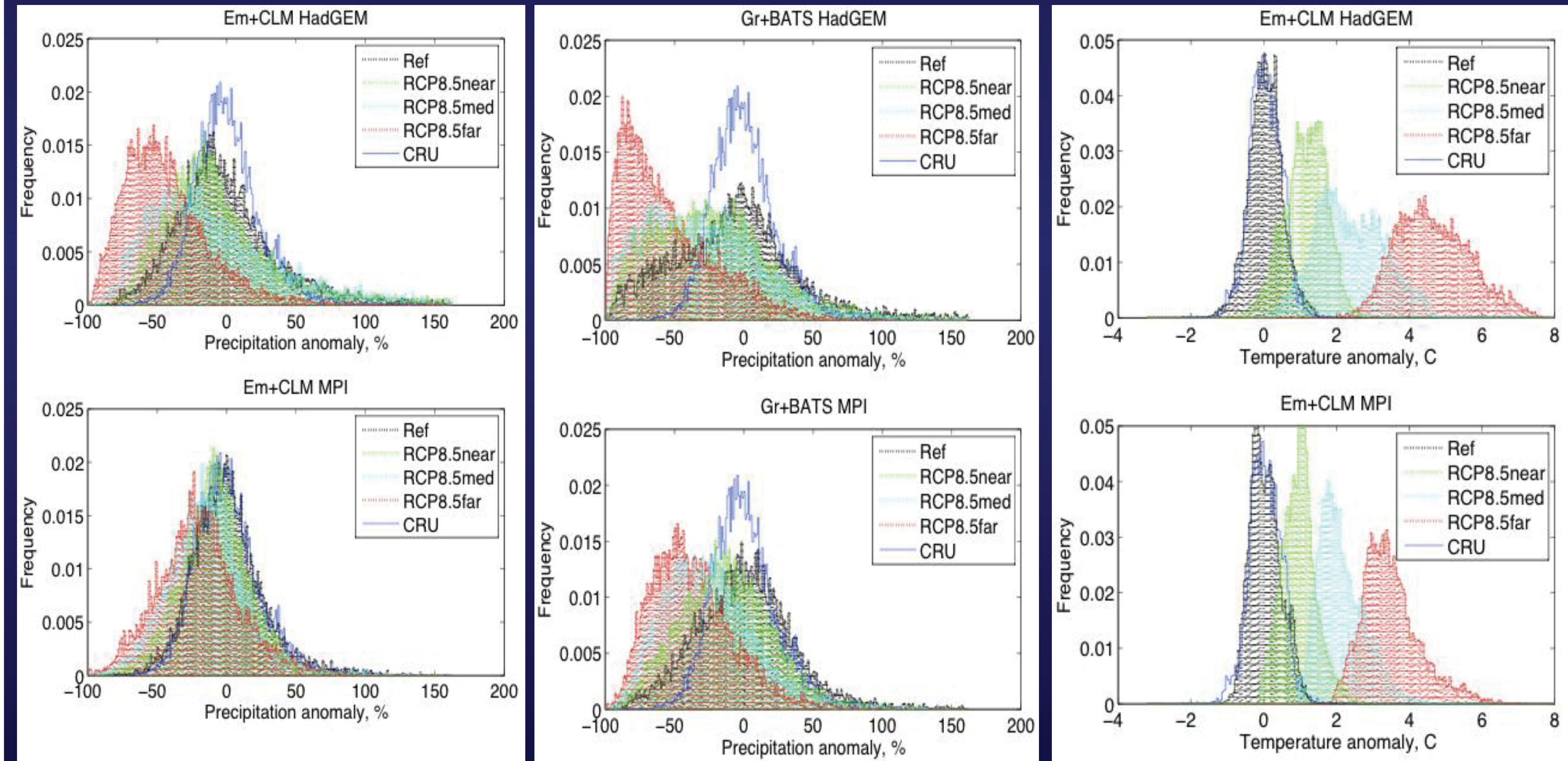


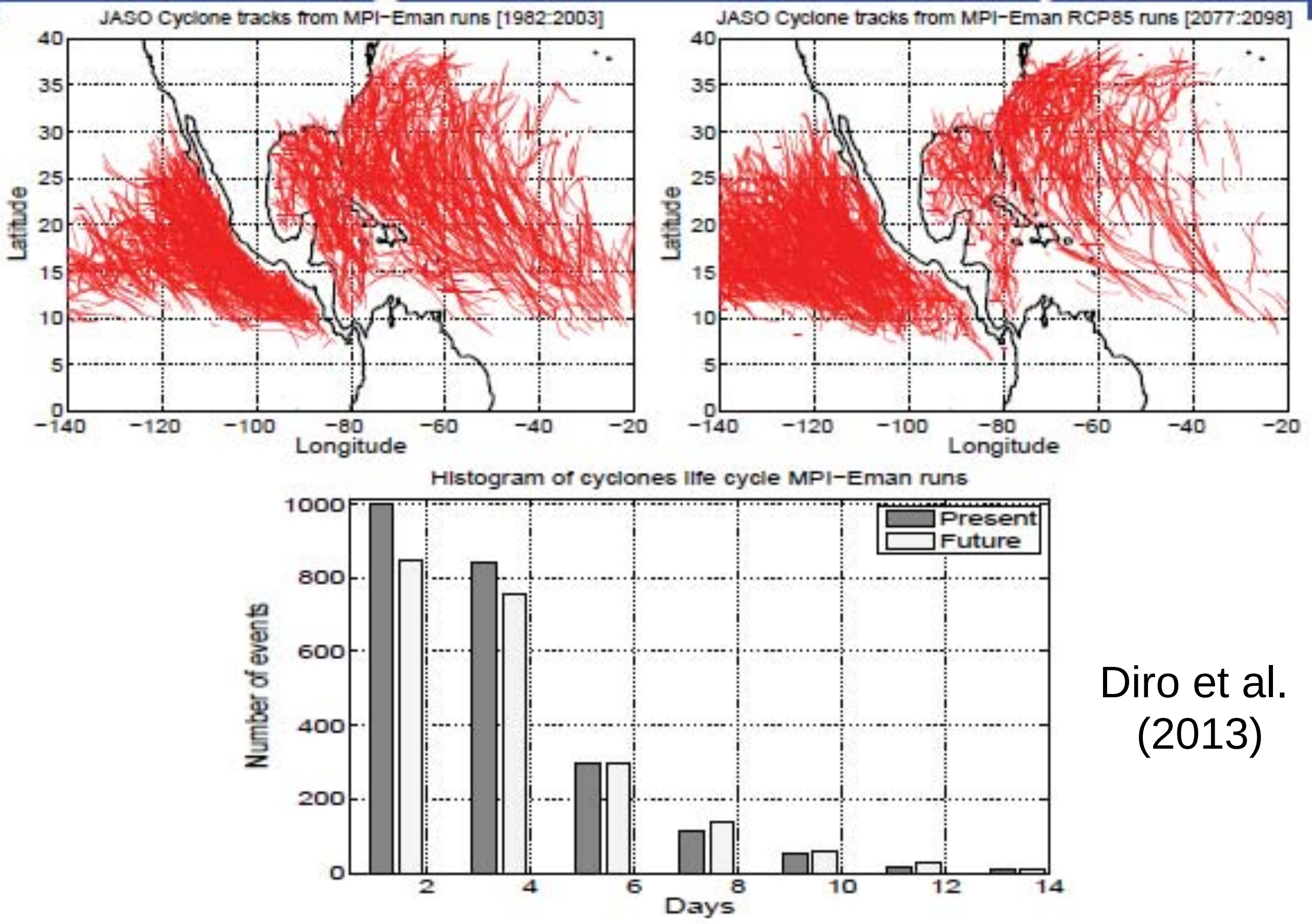

Mariotti et al (2013)

Poster No. Z244

# Empirical PDFs of present day and future seasonal precipitation and temperature anomalies over Central America (Fuentes-Franco et al, poster No, Z206)



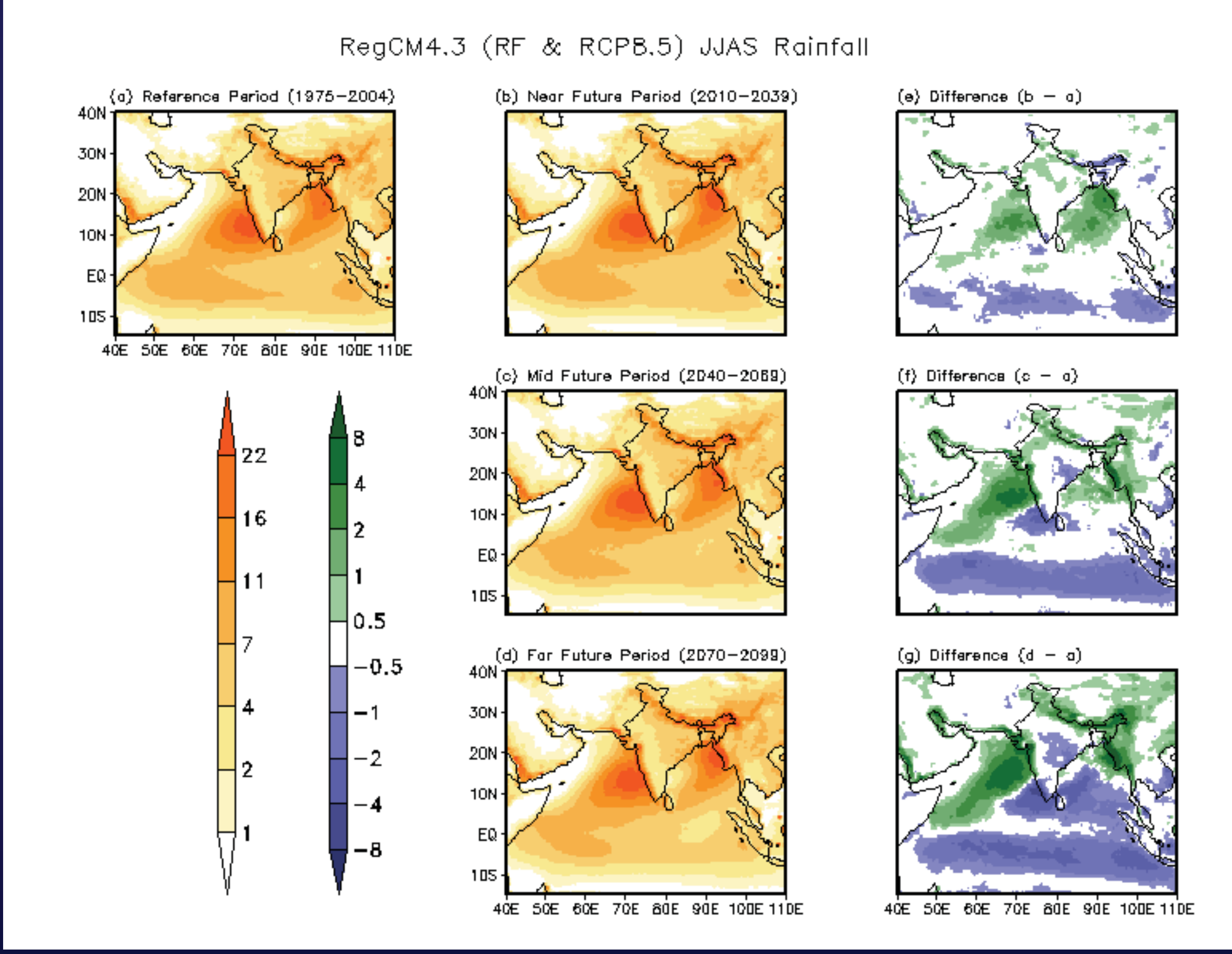
# Future Changes: Tracks and life cycle

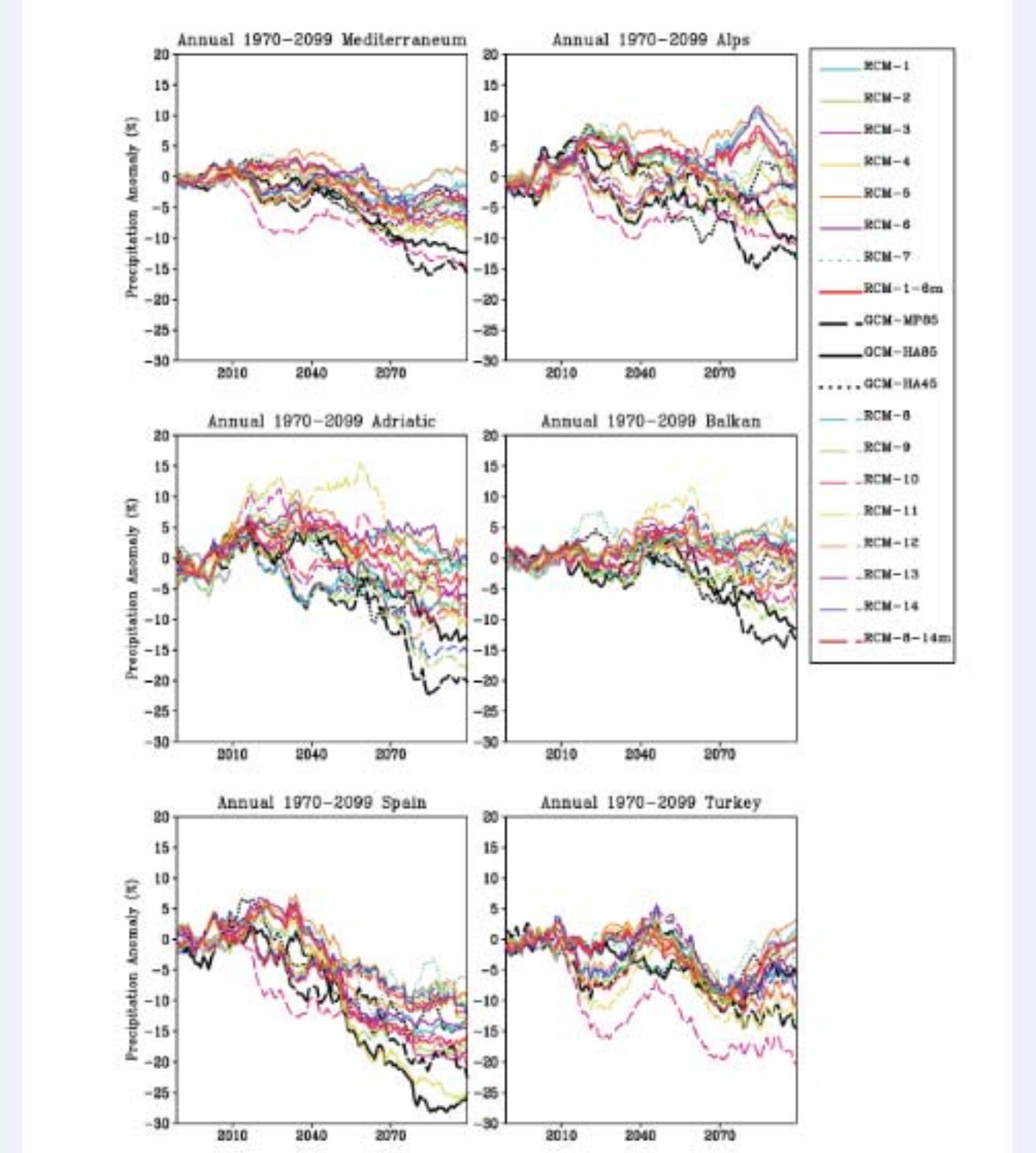



Diro et al. (2013)

The frequency of short lived TCs decreases, the number of TCs that lasts longer than a week, however, shows a slight increase

# Weakening of monsoon precipitation over India
(Dash et al, poster No, Z251)

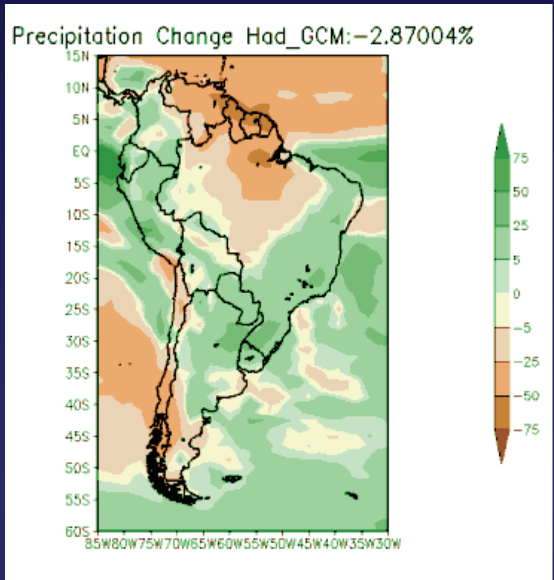


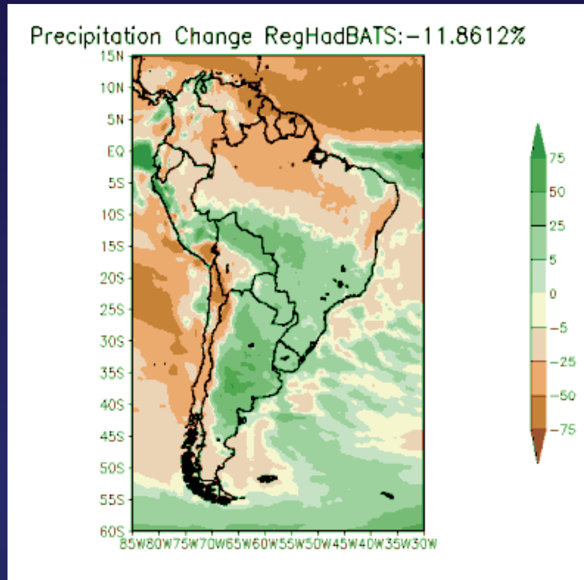


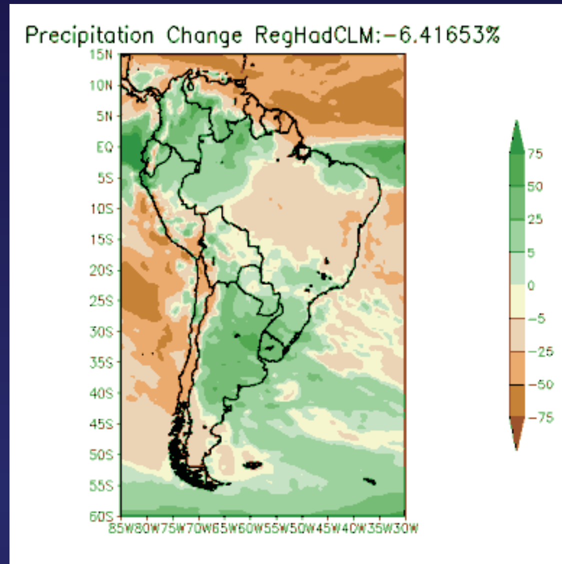

Ensembles of 21st century projections over the MED-CORDEX domain with different model physics schemes

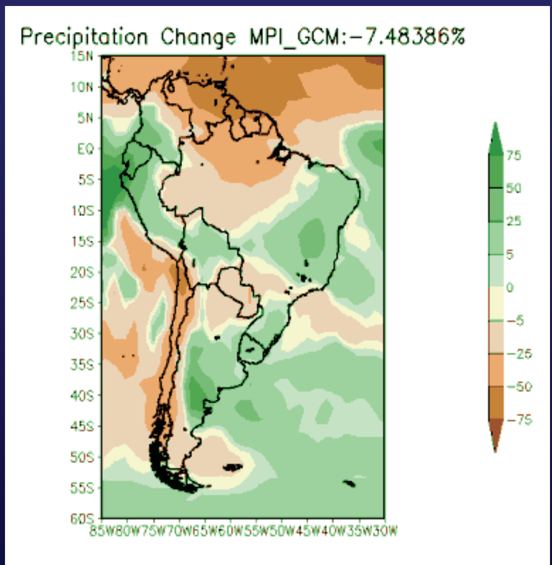
Torma et al. Poster No. Z219

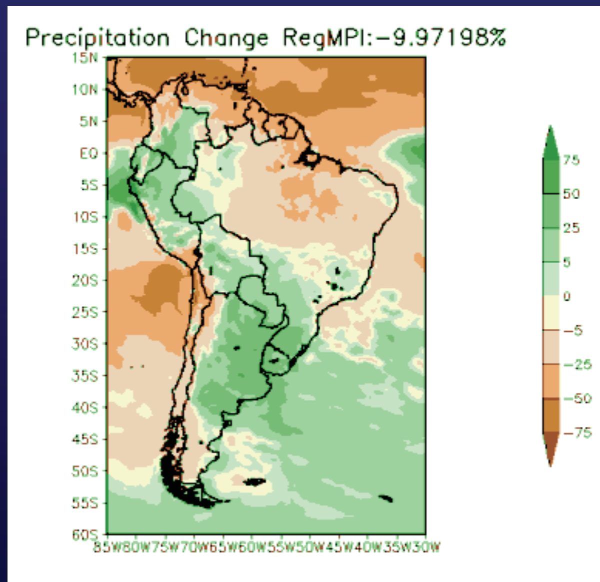
# Effects of land surface feedbacks on precipitation change over South America



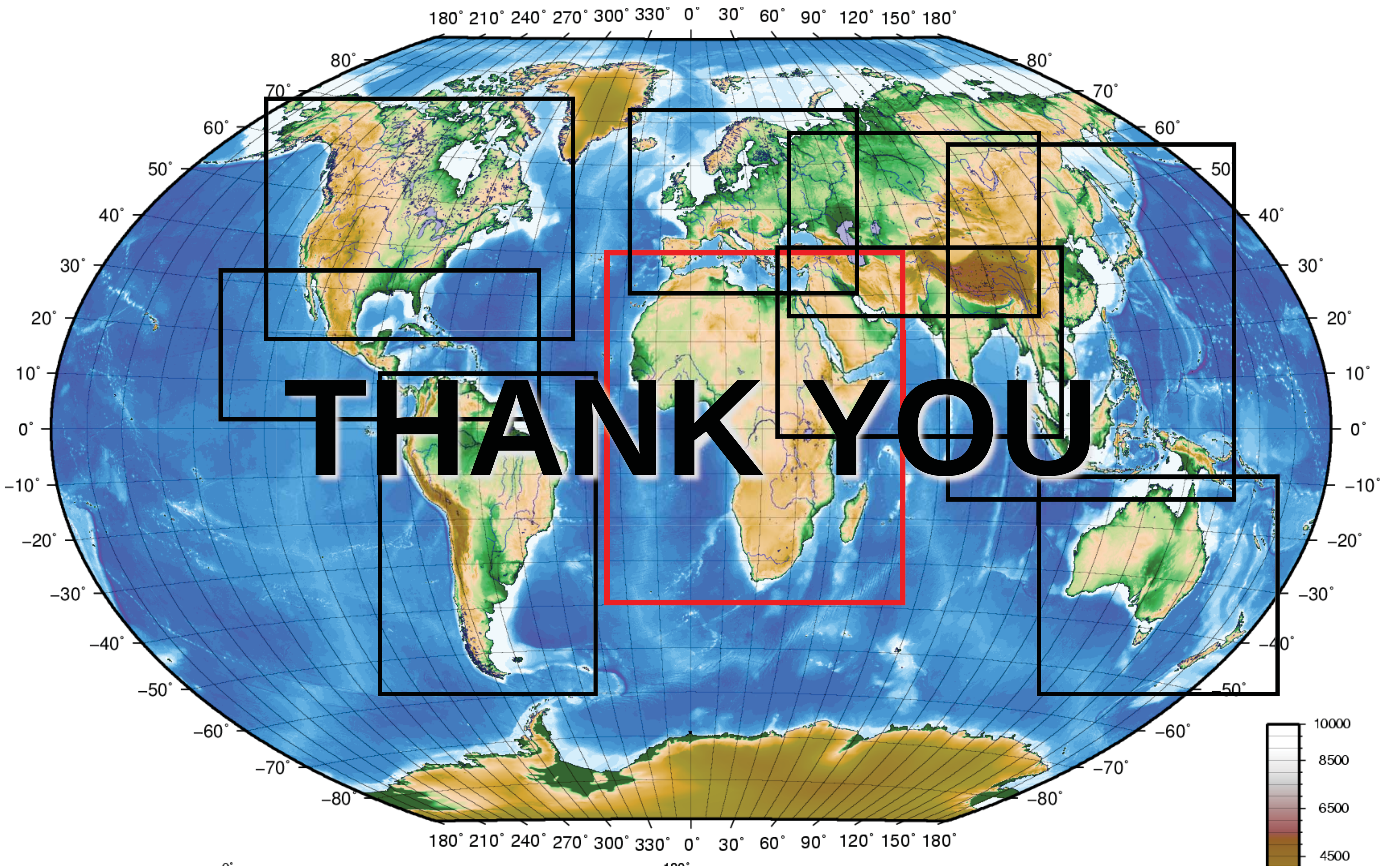




Llopart et al (2013)

Poster No. Z226

# Conclusions

- A new ensemble of 34 21st century climate projections over five CORDEX domains is available: The Phase I CORDEX RegCM hyper-Matrix (CREMA) experiment.
  - Africa, Med-CORDEX, South America, Central America, South Asia
- The ensemble includes different GHG RCPs, driving GCMs and RegCM4 physics configurations
- The projections showed substantial sensitivity to all these three factors (sources of uncertainty).
- A special issue of Climatic Change currently under way will provide a first basic analysis of this ensemble
- The output from these simulations (about 200 TB) will be made available into the CORDEX data nodes for further analysis and for use in impact assessment studies


THANK YOU
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# The equations of a climate model

$$\frac{\partial \overline{V}}{\partial t} + \overline{V} \cdot \nabla \overline{V} = -\frac{\nabla p}{\rho} - 2\overline{\Omega} \times \overline{V} + \overline{g} + \overline{F}_{\overline{V}}$$

Conservation of momentum

$$C_p\left(\frac{\partial T}{\partial t} + \overline{V} \cdot \nabla T\right) = \frac{1}{\rho}\frac{dp}{dt} + Q + F_T$$

Conservation of energy

$$\frac{\partial \rho}{\partial t} + \overline{V} \cdot \nabla \rho = -\rho \nabla \cdot \overline{V}$$

Conservation of mass

$$\frac{\partial q}{\partial t} + \overline{V} \cdot \nabla q = \frac{S_q}{\rho} + F_q$$

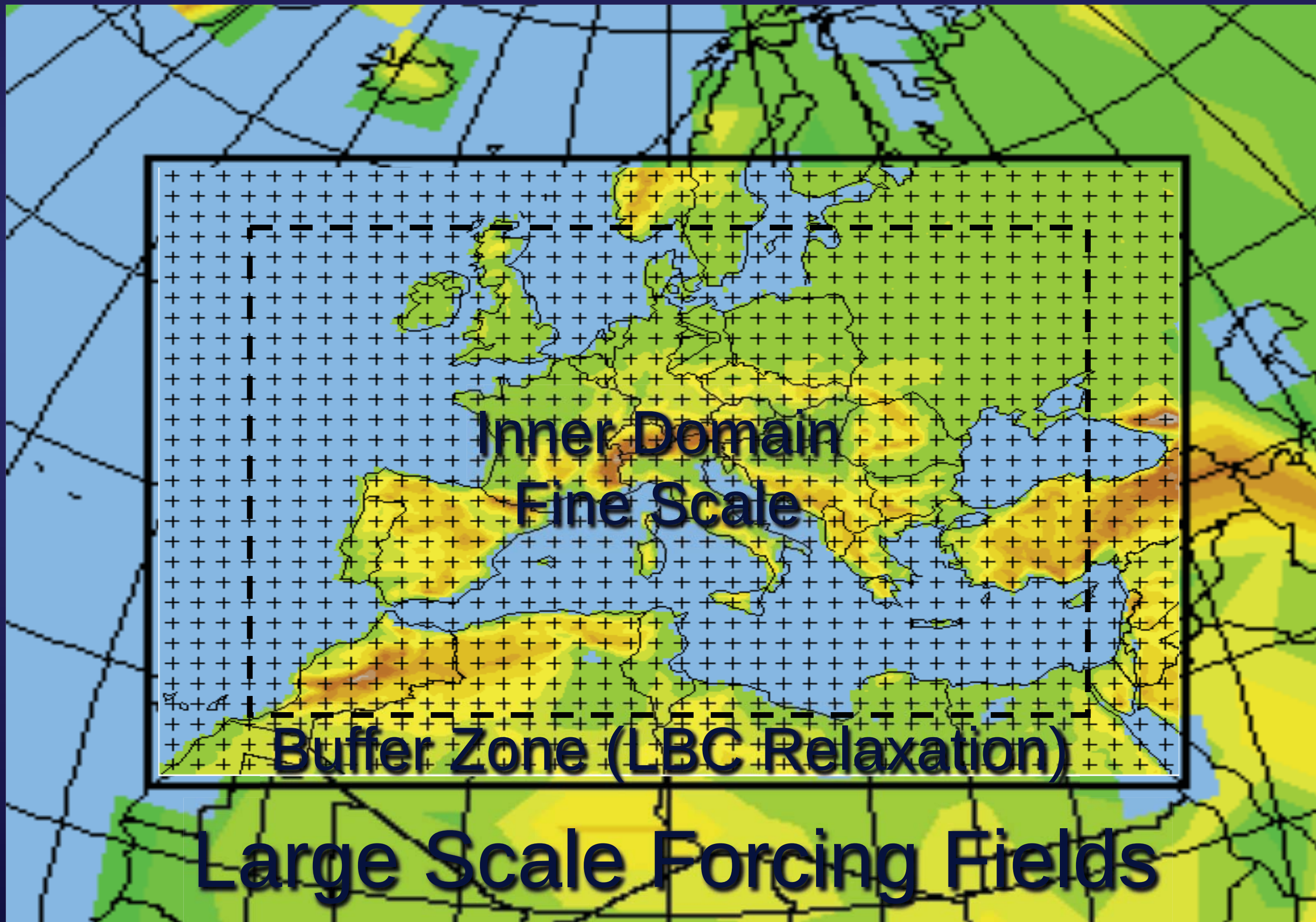
Conservation of water

$$p = \rho R T$$

Equation of state

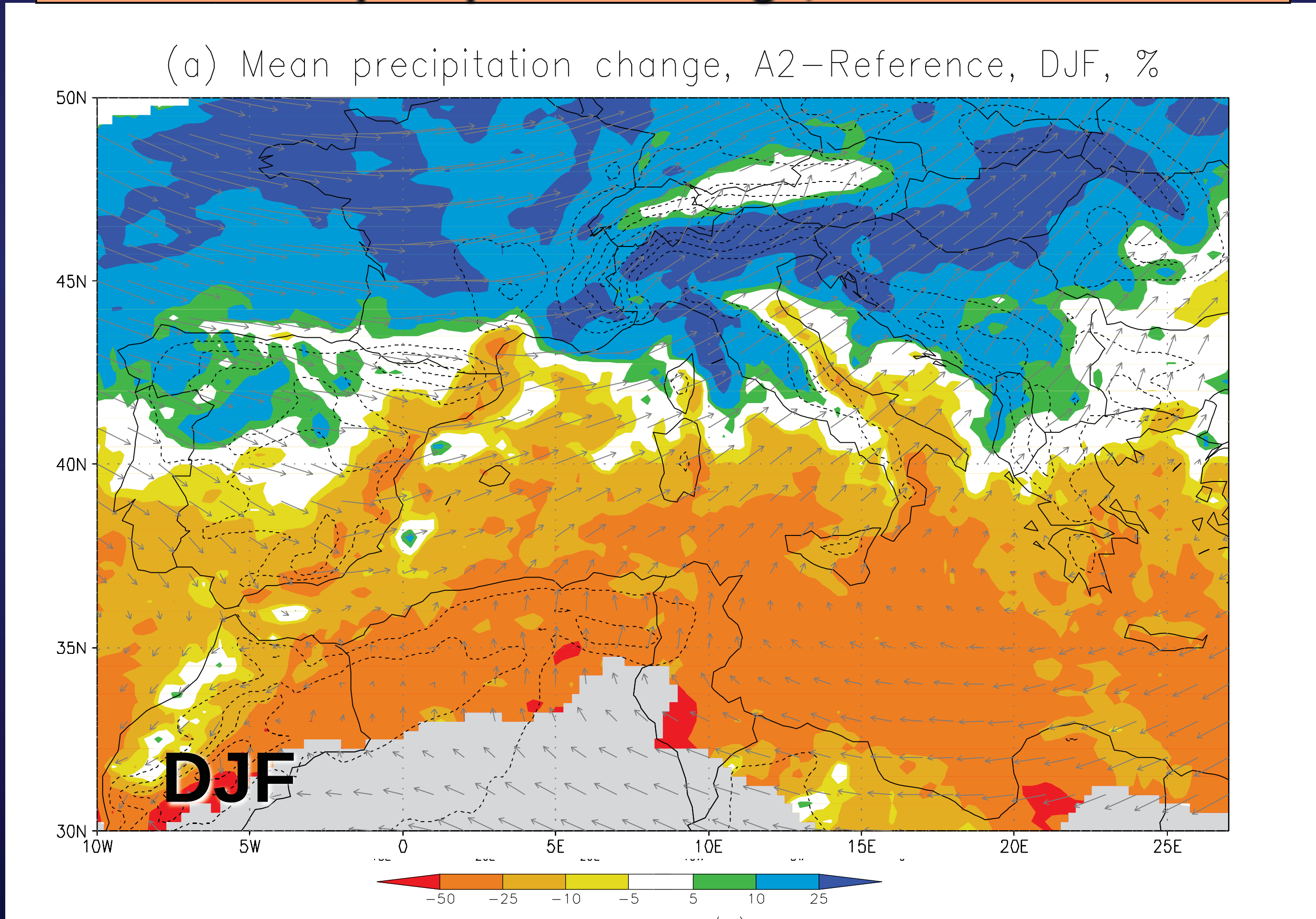
# RCM Nesting procedure

$$\frac{\partial \alpha}{\partial t} = F(n)F_1 \cdot (\alpha_{LBC} - \alpha_{mod}) - F(n)F_2 \cdot \Delta_2(\alpha_{LBC} - \alpha_{mod})$$



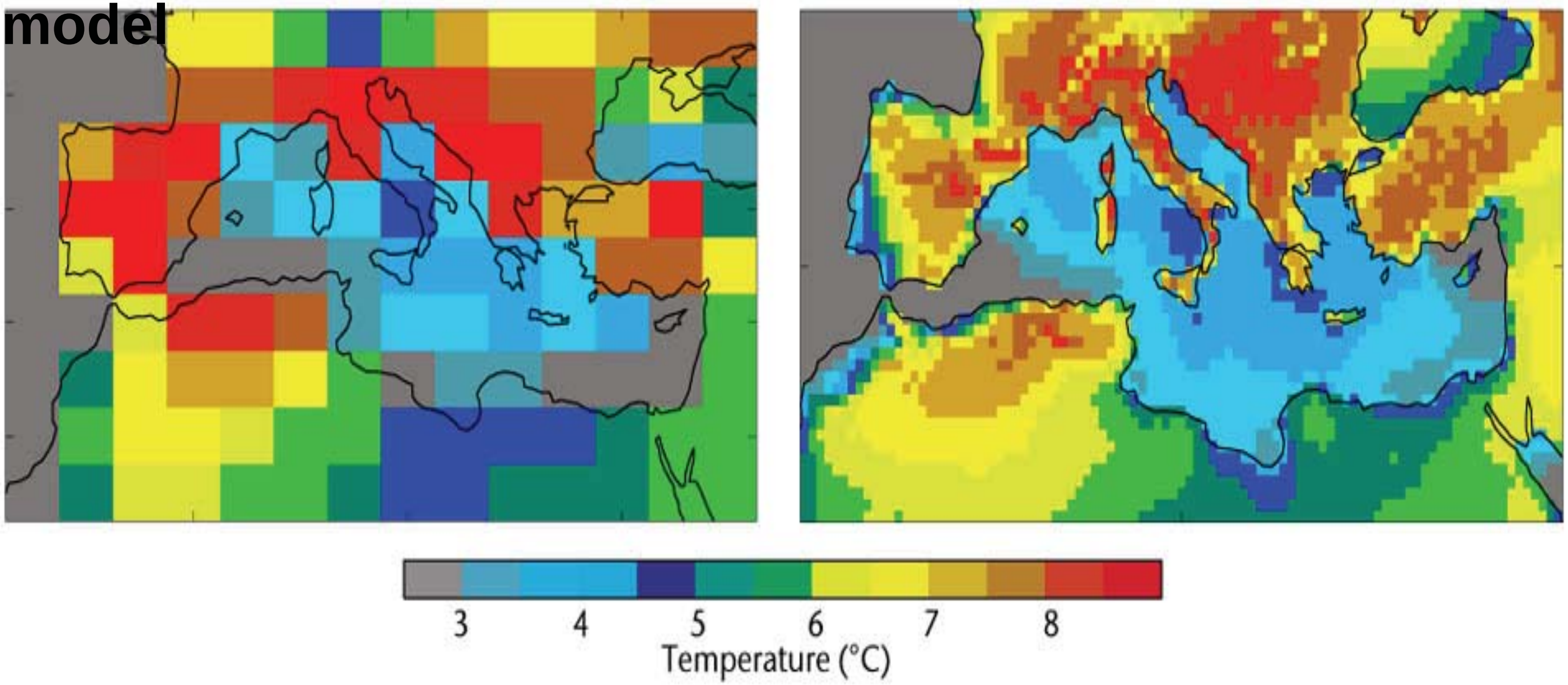
# The effect of topography on the climate change signal (Gao et al. 2006)

**Mean precipitation change, A2 – Present**



# SUMMER TEMPERATURES in the 2080s
## compared to the present day, due to A2 emissions

[redacted]




**Climate on islands changes very differently to the surrounding Mediterranean Sea, and can only be predicted using an RCM**