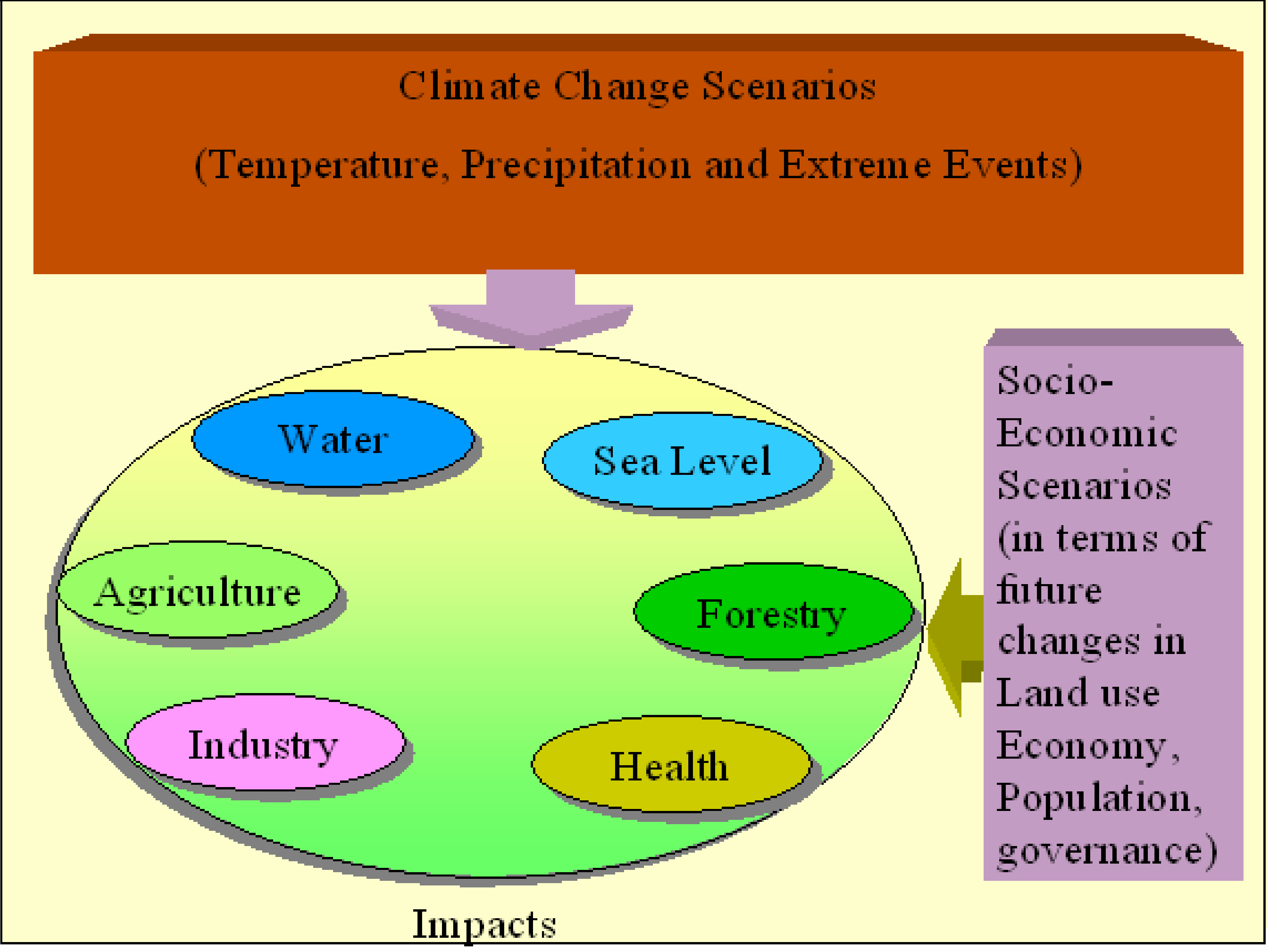
10th AIM Workshop, NIES, Japan: Mar 10-12, 2005

Approaches to Development of High Resolution Climate Change Scenarios for Integrated Impact Assessment

M. Lal

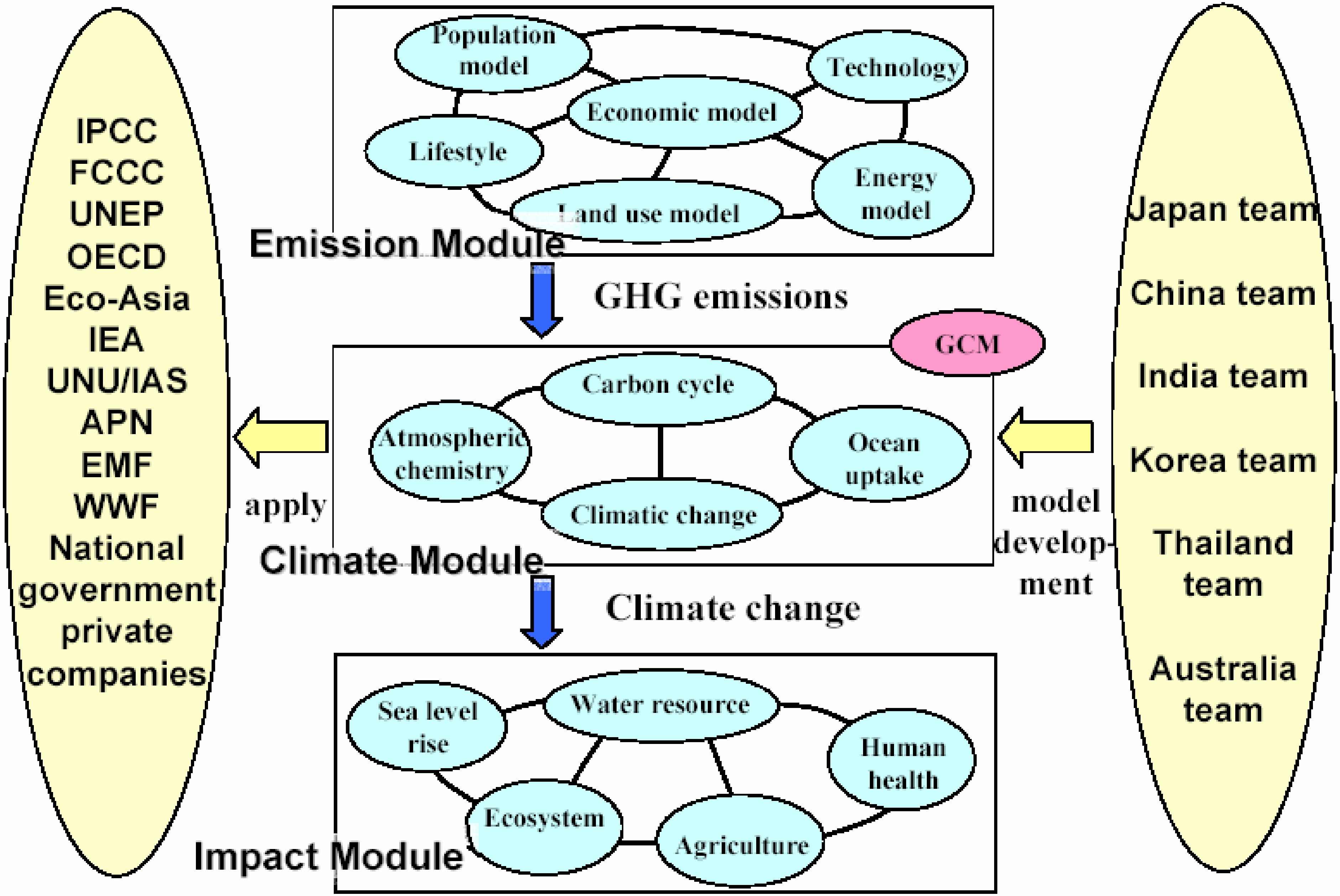
Pacific Centre for Environment & Sustainable Development

The University of the South Pacific

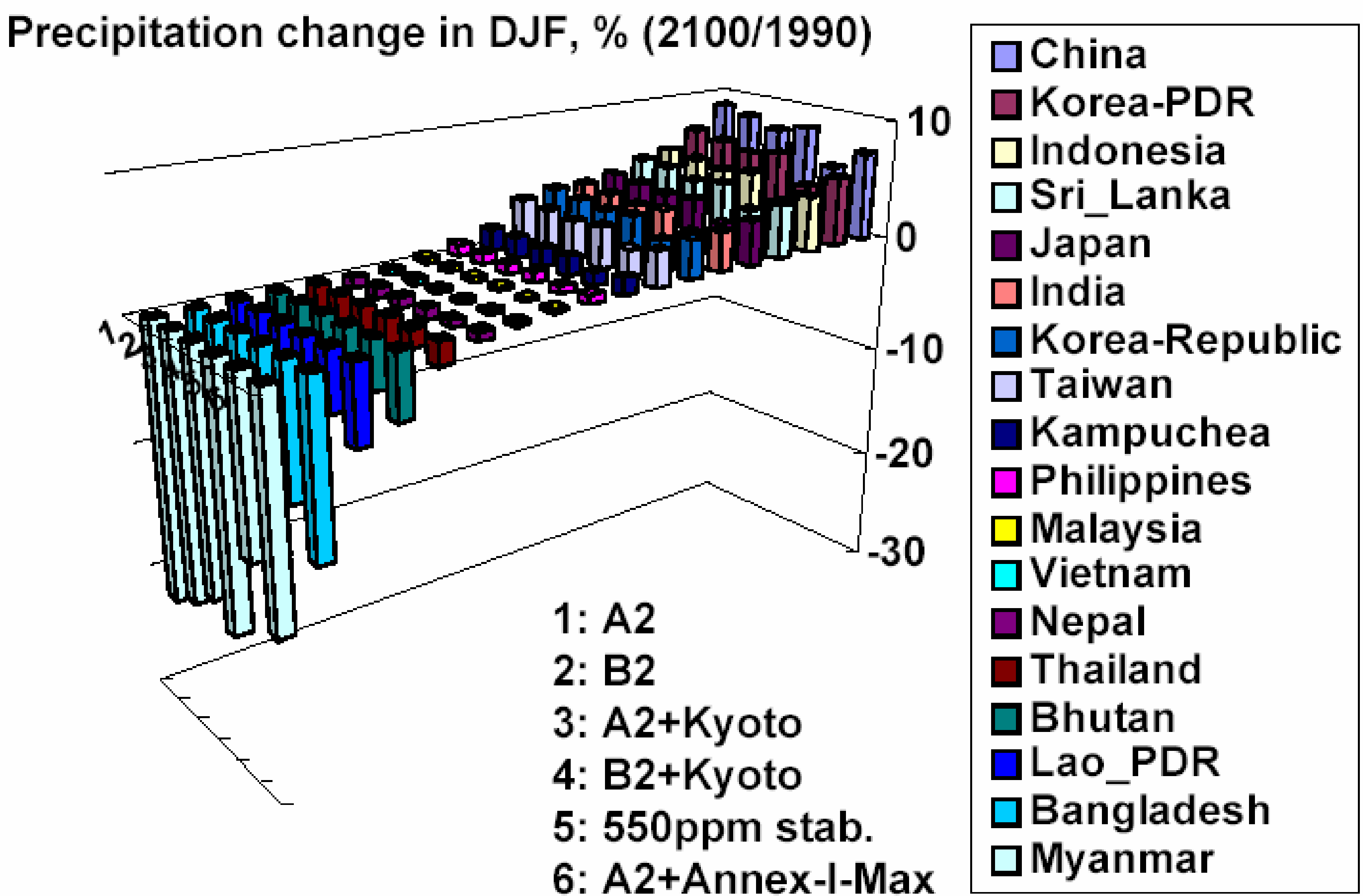


Climate Change Scenarios
(Temperature, Precipitation and Extreme Events)
Water
Sea Level
Agriculture
Forestry
Industry
Health
Socio-Economic Scenarios (in terms of future changes in Land use Economy, Population, governance)
Impacts

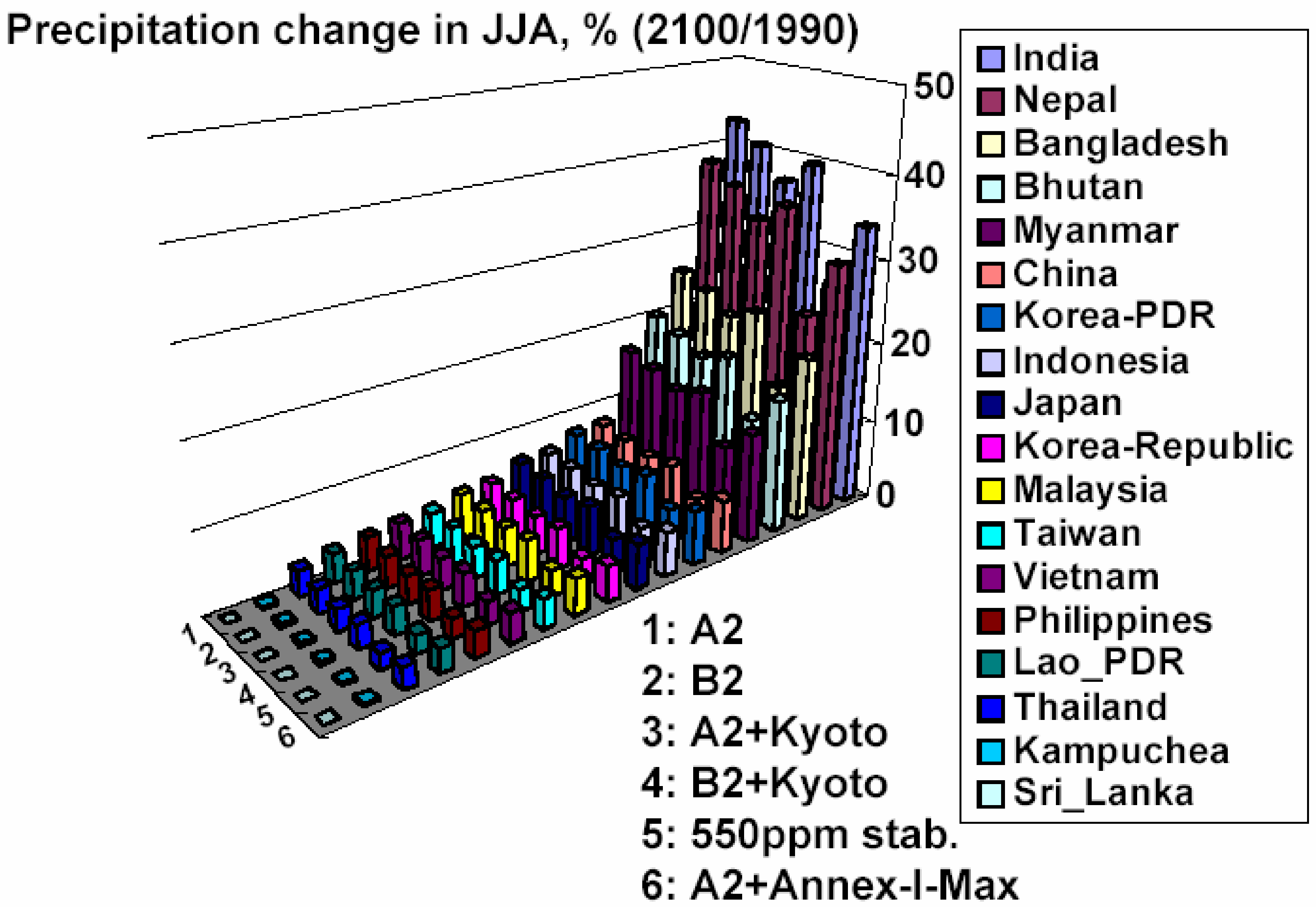
Outline of AIM for climate change analysis



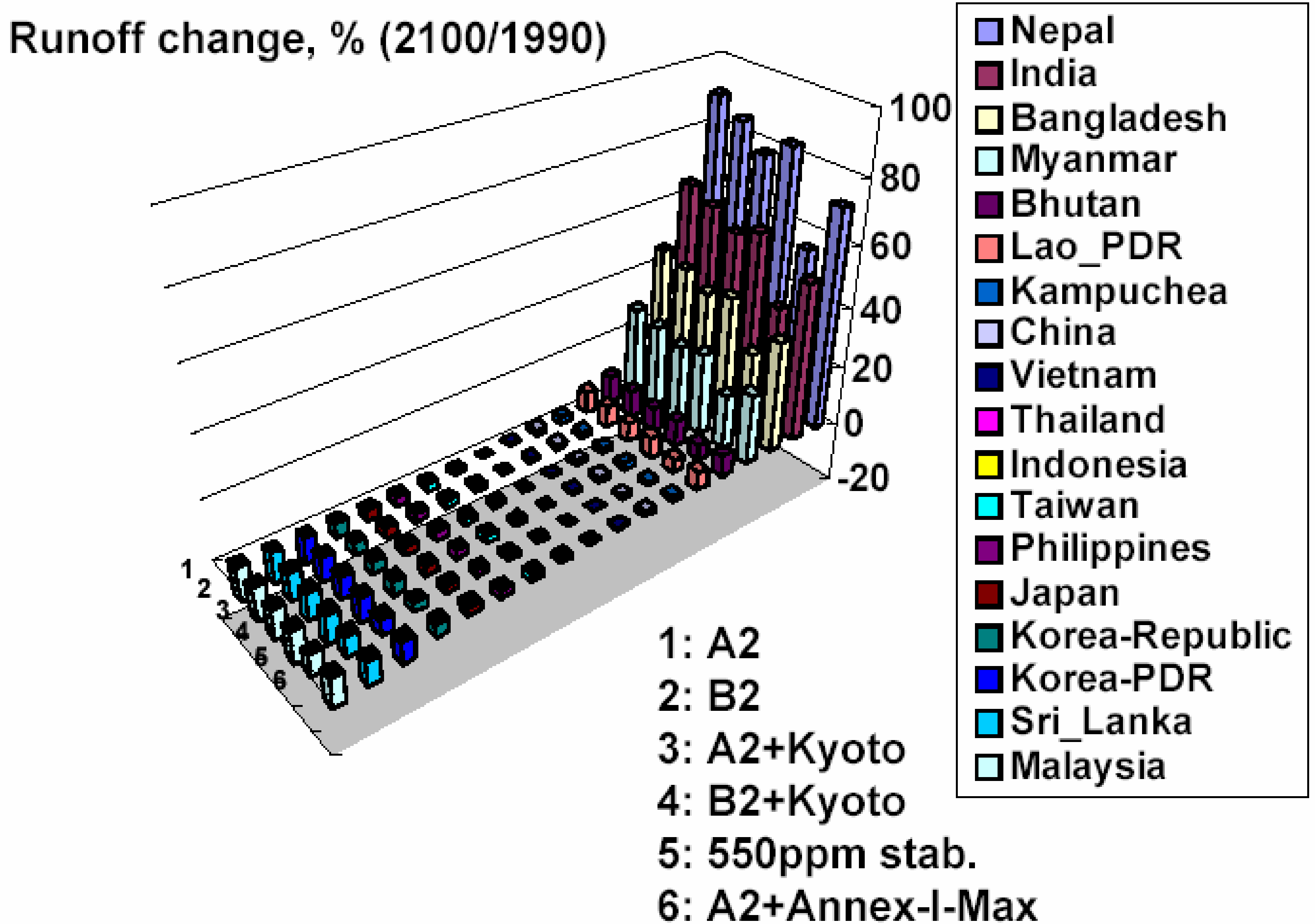
Climate change based on present international agreement



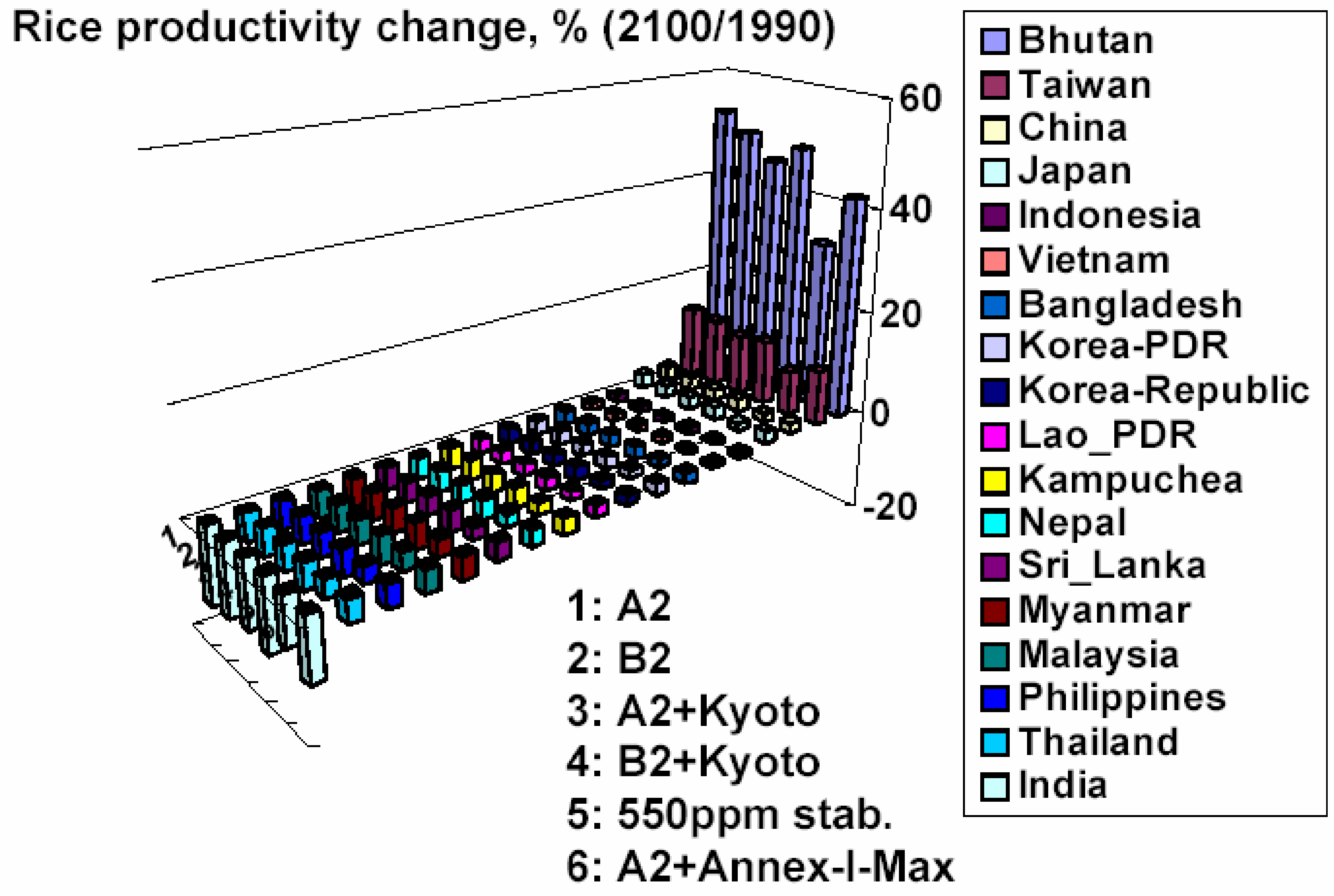
Climate change based on present international agreement



Climate change based on present international agreement



Climate change based on present international agreement



Obtaining reliable projections of climatic change at the regional scale is the central issue within the global change debate.

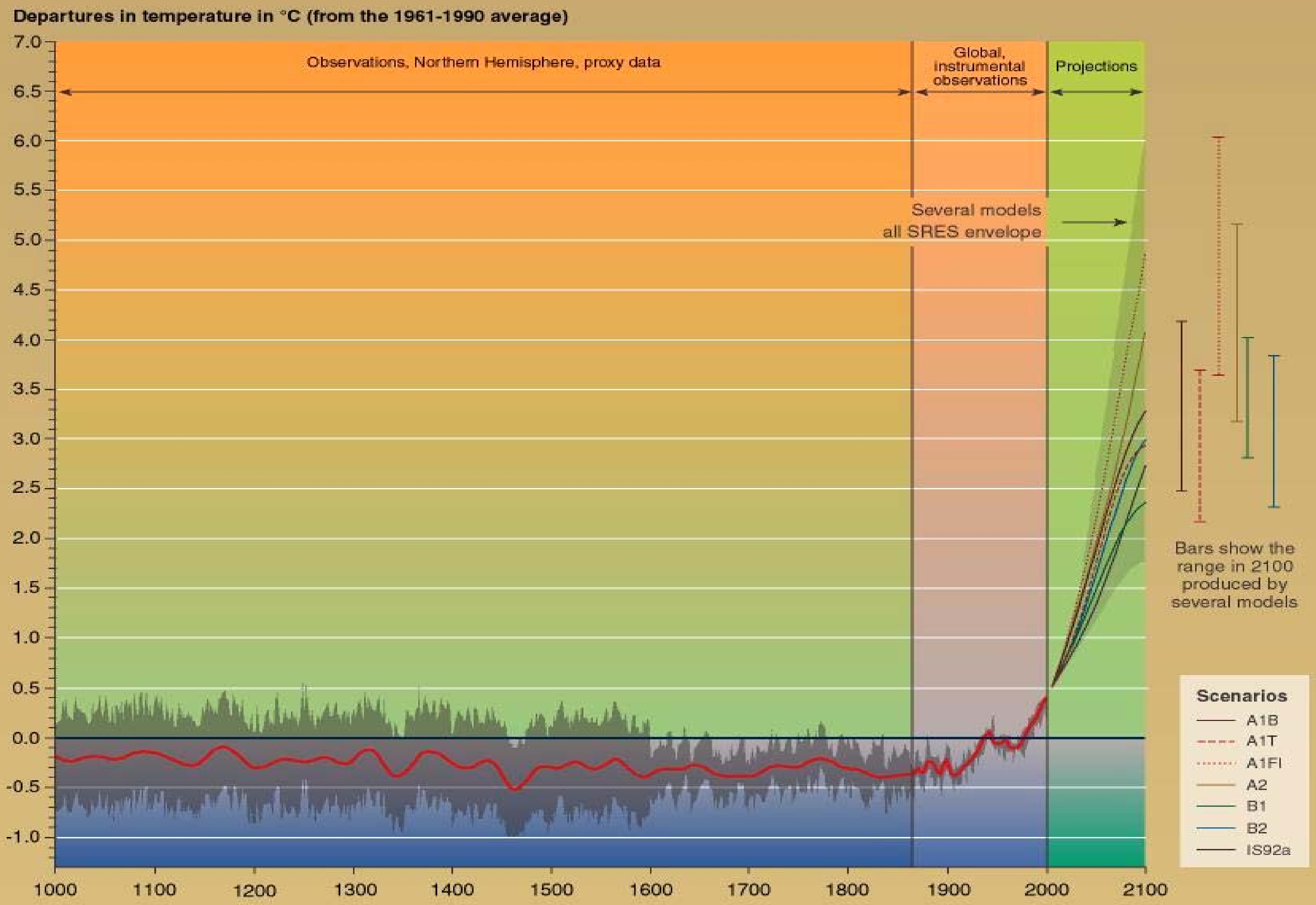
In order to assess the social and environmental impacts of climate change and to develop suitable policies to respond to such impacts, information about climate change is needed not only at a national level, but on a regional and local scale as well.

Future Climate Change Scenarios

The estimates of human induced global warming by the IPCC are based on the premise that the growth rate of atmospheric greenhouse gases will accelerate in the future.

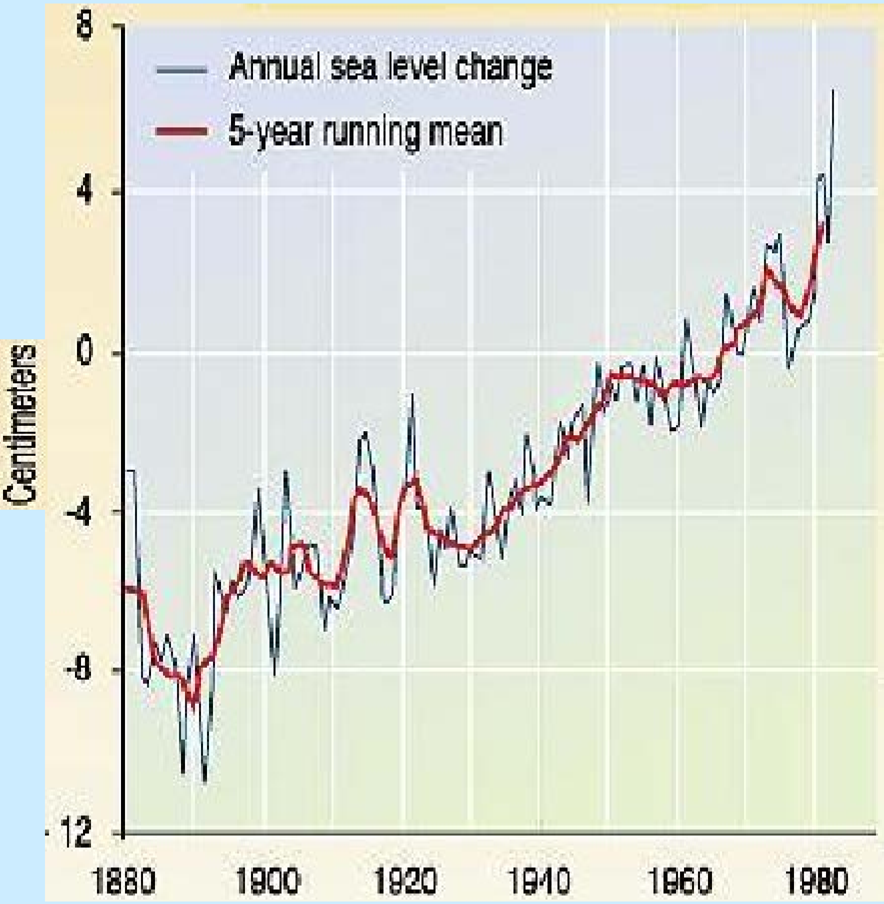
According to most recent estimates by IPCC, the average global surface temperature is projected to **increase** by between **1.4°** and 3° C above 1990 levels **by 2100** for low emission scenarios and between 2.5° and **5.8°** C for higher emission scenarios of greenhouse gases in the atmosphere.

Variations of the earth's surface temperature: 1000 to 2100

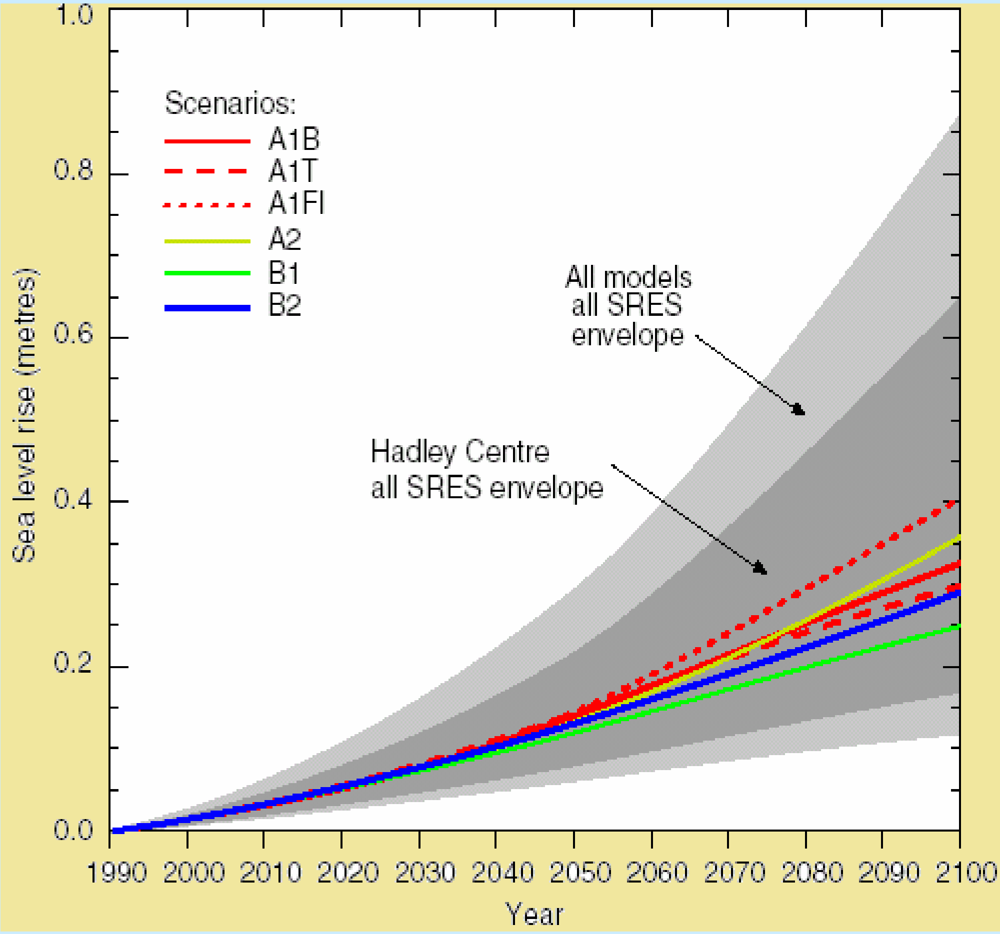


Sea level rise due to global warming

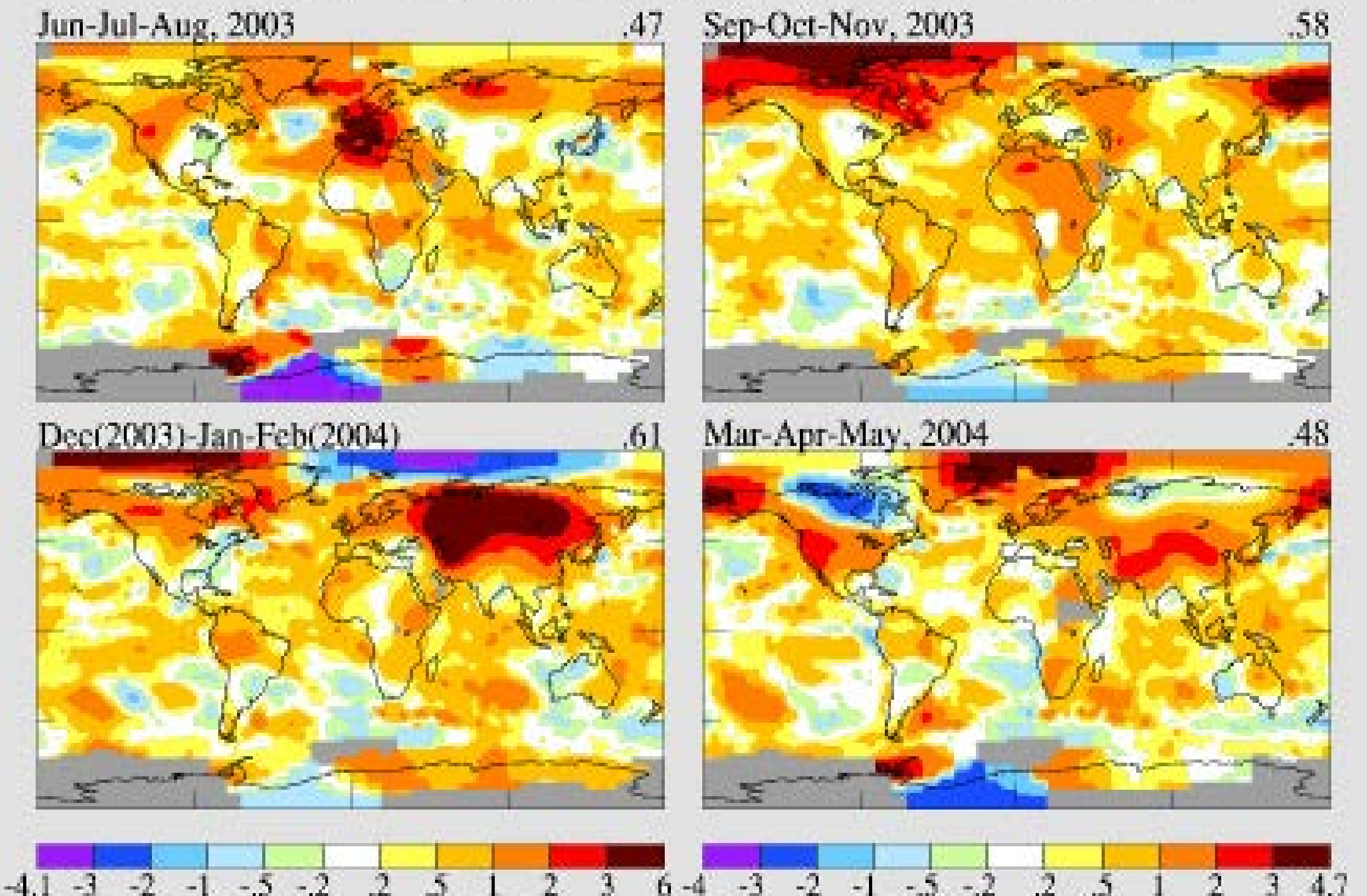
Sea level rise over the last century

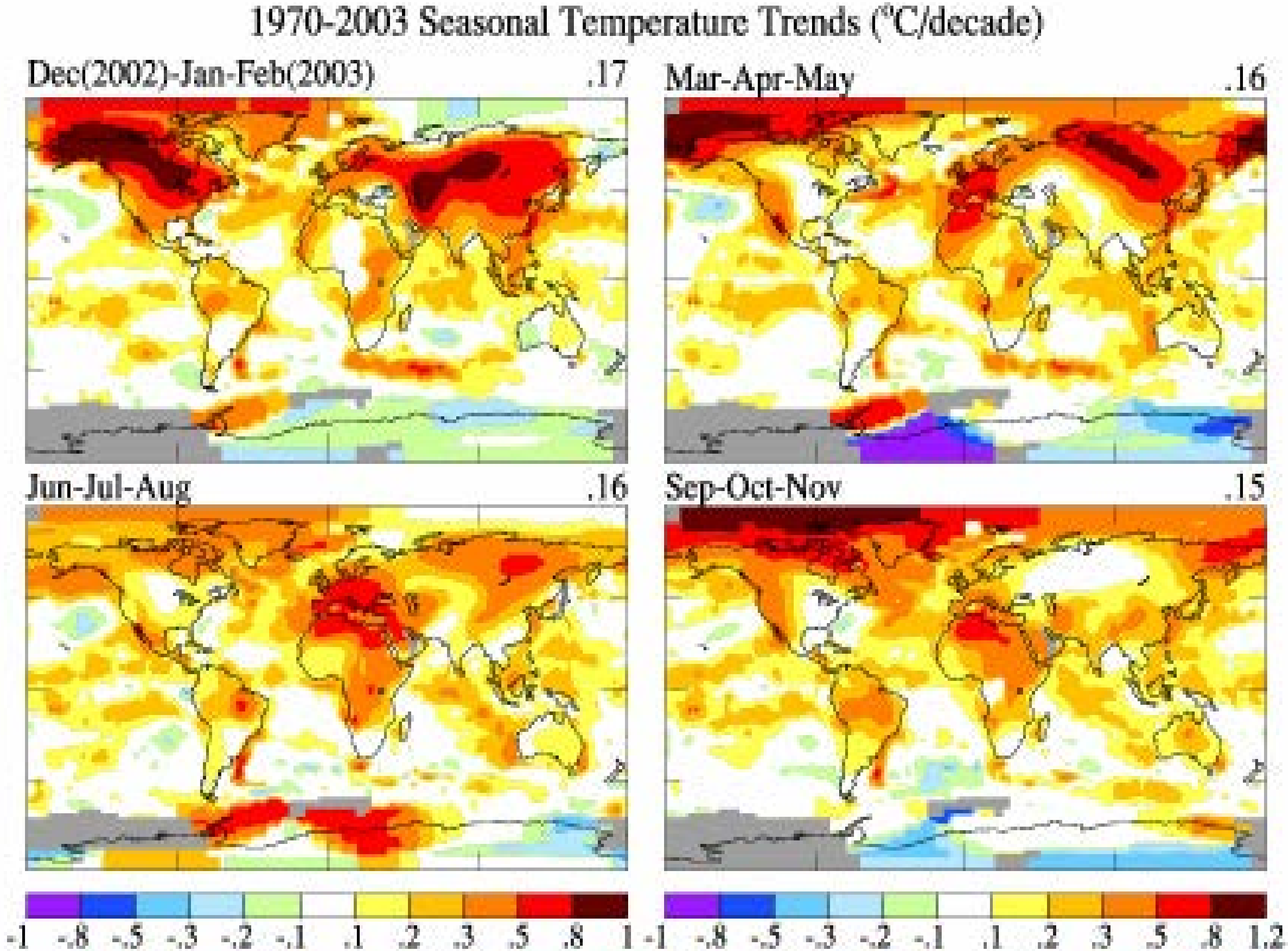


Sea level rise scenarios for 2100

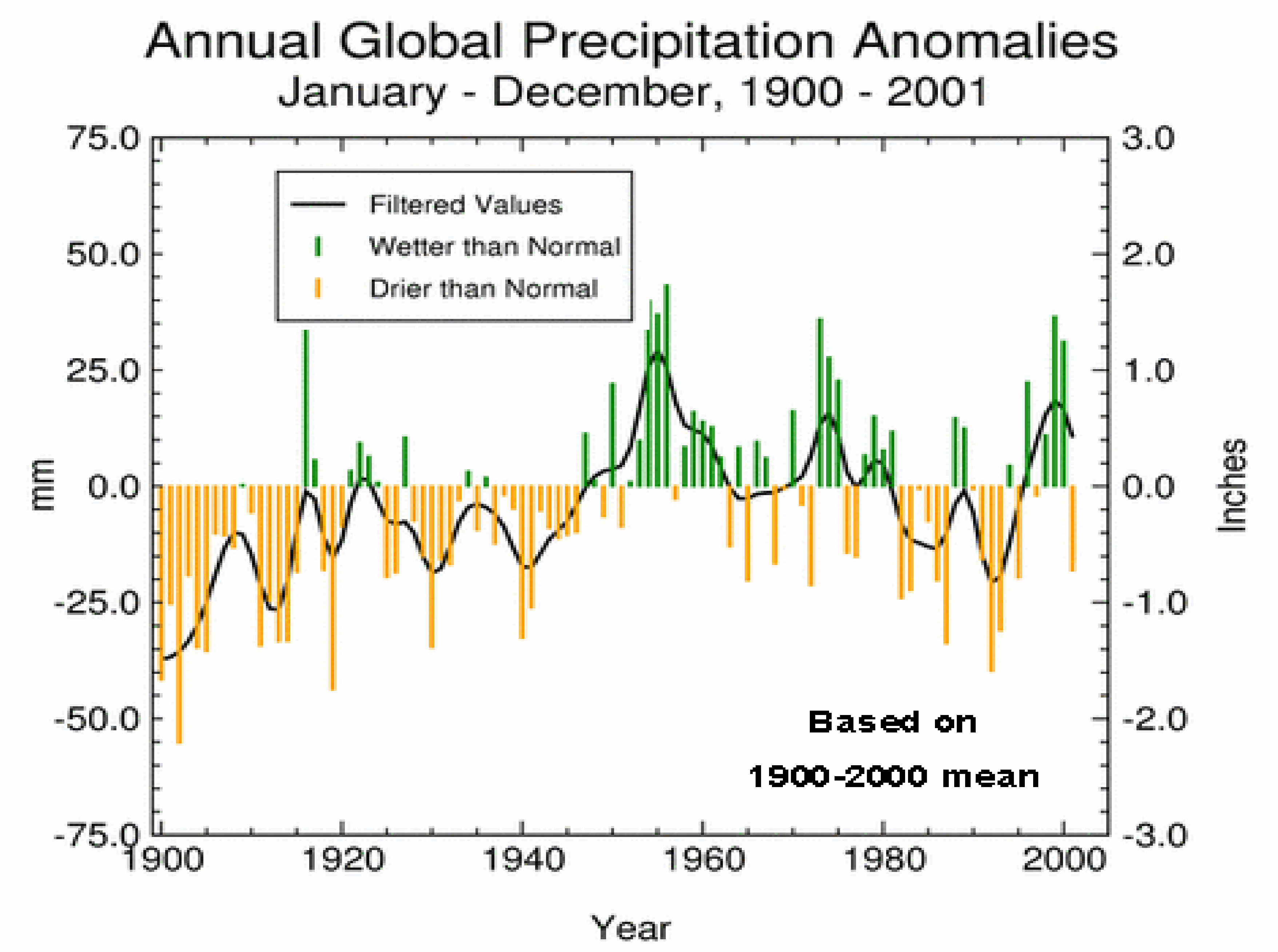


Seasonal Temperature Anomalies (°C) [Base Period 1951-80]



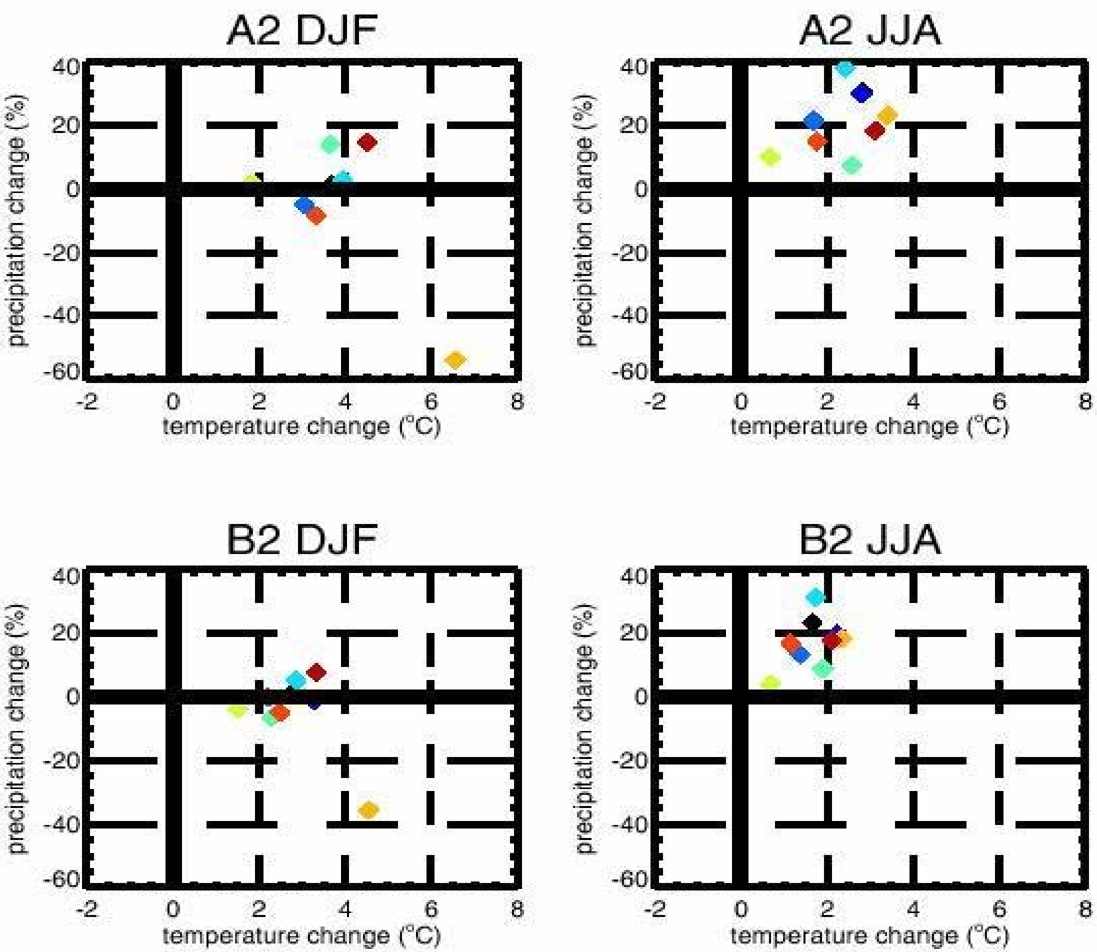


1970-2003 Seasonal Temperature Trends (°C/decade)
Dec(2002)-Jan-Feb(2003)
.17
Mar-Apr-May
.16
Jun-Jul-Aug
.16
Sep-Oct-Nov
.15
-1 -.8 -.5 -.3 -.2 -.1 .1 .2 .3 .5 .8 1
-1 -.8 -.5 -.3 -.2 -.1 .1 .2 .3 .5 .8 1.2



Annual Global Precipitation Anomalies
January - December, 1900 - 2001
Filtered Values
Wetter than Normal
Drier than Normal
Based on
1900-2000 mean
75.0
50.0
25.0
0.0
-25.0
-50.0
-75.0
mm
3.0
2.0
1.0
0.0
-1.0
-2.0
-3.0
Inches
1900
1920
1940
1960
1980
2000
Year

INDIAN SUBCONTINENT
Climate Change in 21st Century



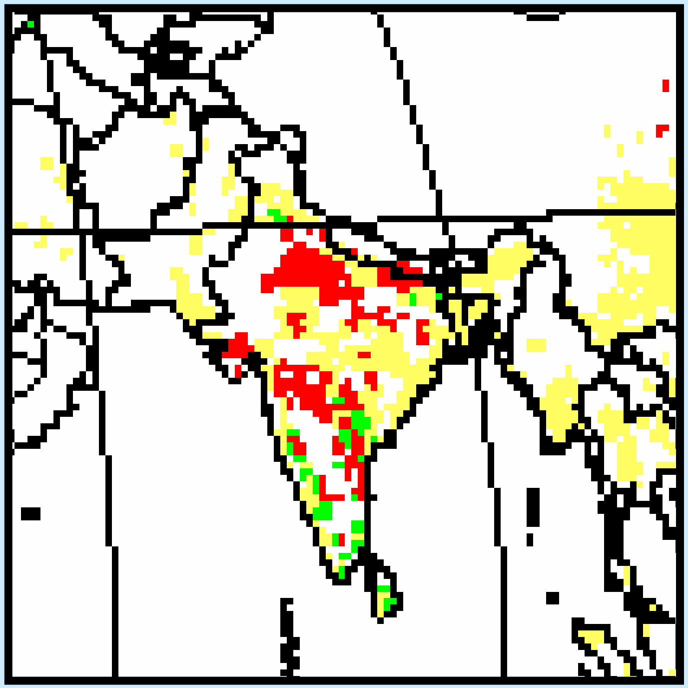
KEY to models

CGCM2	Canada
CSIRO mk 2	Australia
CSM 1.3	USA
ECHam4	Germany
GFDL R15 b	USA
MRI2	Japan
CCSR/NIES 2	Japan
DOE PCM	USA
HadCM3	UK

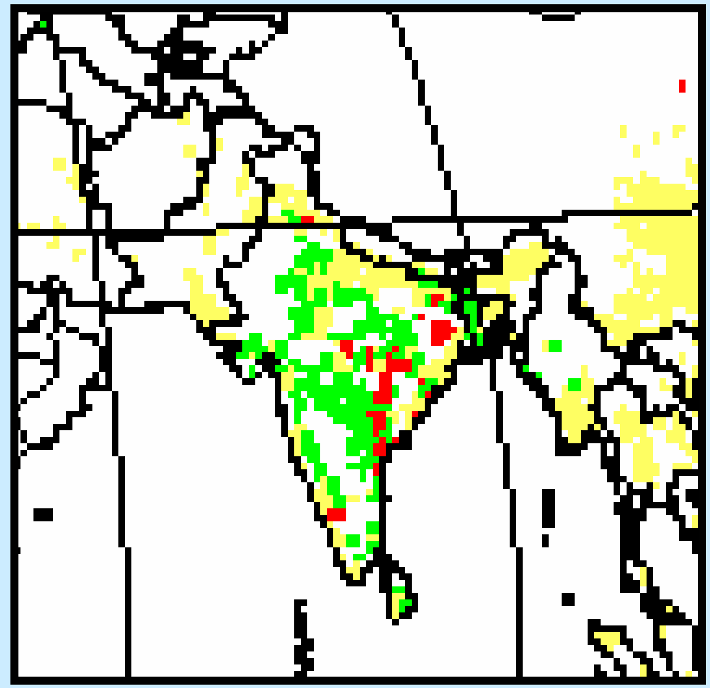
INFORMATION

The values are the changes between the end of the 20th (1961-90) and 21st (2070-99) centuries from 9 climate models reviewed by the IPCC.

Regional Pattern of Changes in Maize Yield by 2080s



Hadley Centre, UK



M P I, Germany

Yield forecasts due to inter-model variance in climate projections

Reduced

No Change

Increased

Global climate modeling has undergone a steady development during the last three to four decades.

However, <u>current uncertainties</u> remain <u>very high</u> in the projection of regional climate change.

This is due to the complexity of the processes that determine regional climate change, and the need for more comprehensive modeling tools and research strategies to address this problem.

Both topography and the land surface conditions strongly affect the surface climate change signal at scales smaller than the grid interval of A-O GCMs.

This implies that the information obtained from A-O GCMs needs to be used cautiously in studies of the impacts of climate change, particularly in regions that are characterized by pronounced variability in forcings on fine scales.

The potentials and limitations of different regionalisation techniques need to be well understood before they are applied to the construction of specific regional climate change scenarios.

The primary tools today available to simulate long-term climate change are known as coupled A-O GCMs.

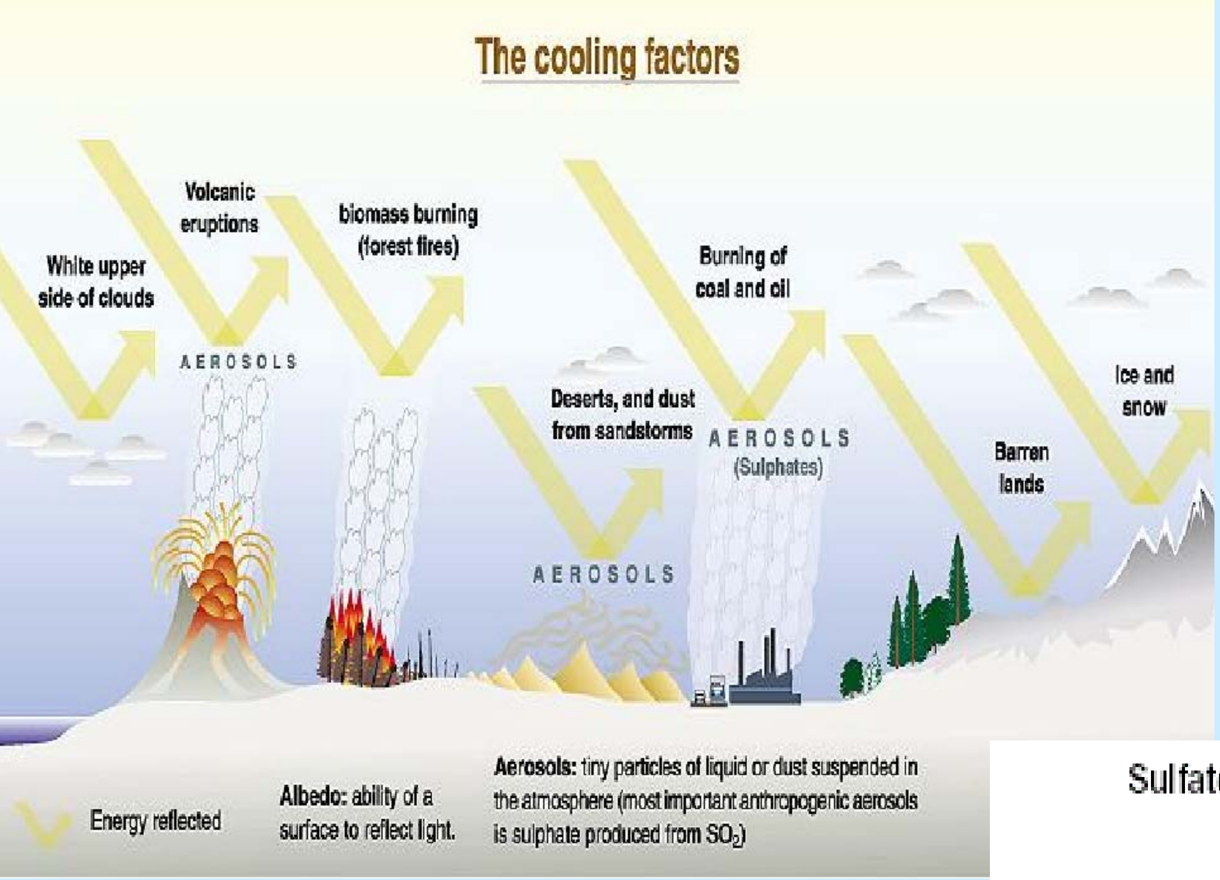
These are 3-D mathematical representations of the global atmosphere-ocean-sea ice system.

Limitations in computer power force the horizontal grid interval of present day A-O GCMs to be about a few hundred kilometres.

As a result, processes and atmospheric circulations occurring at smaller scales cannot be explicitly described.

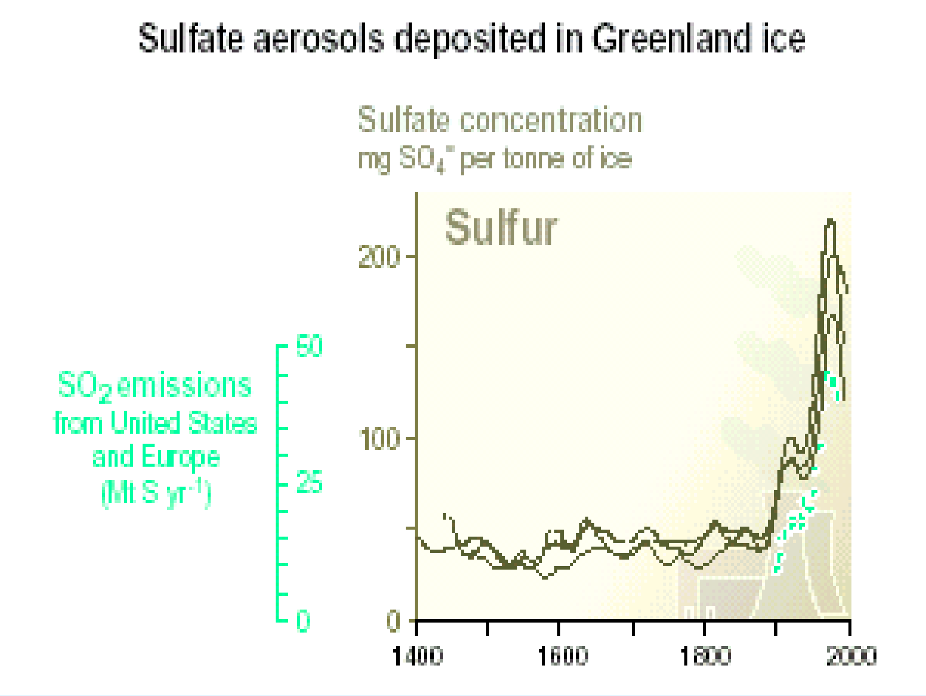
None-the-less, current A-O GCMs have performed relatively well in reproducing many basic characteristics of the general circulation, such as major belts of precipitation in the tropics or the seasonal migration of mid-latitude storm tracks.

These climate models have also shown some success in describing the El Niño Southern Oscillation and North Atlantic Oscillation phenomena and related teleconnection patterns, although significant improvements are still needed.



The smoke from biomass burning inhibits cloud formation in the tropics.

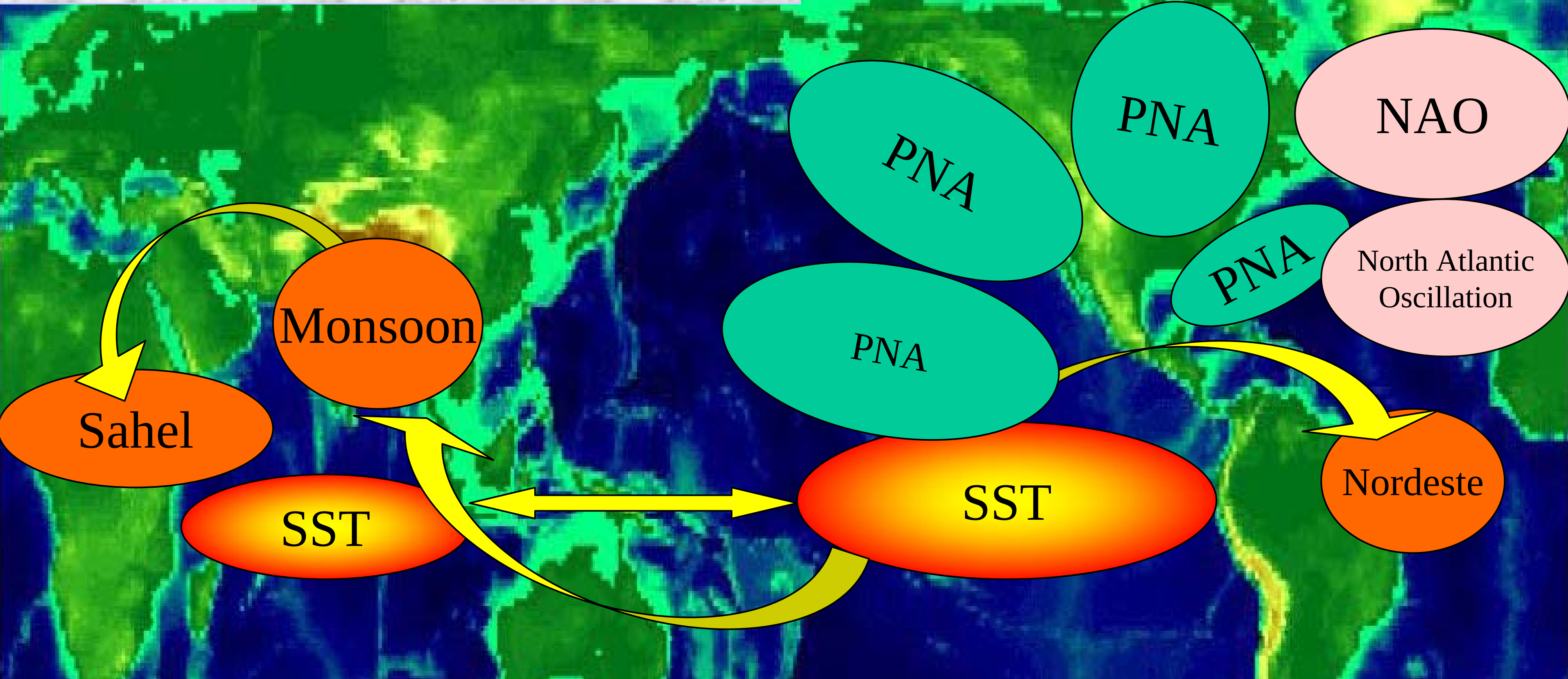
The recent model simulations suggest that the aerosols made up of black carbon lead to a <u>weaker hydrological cycle</u>, which connects directly to water availability and quality.



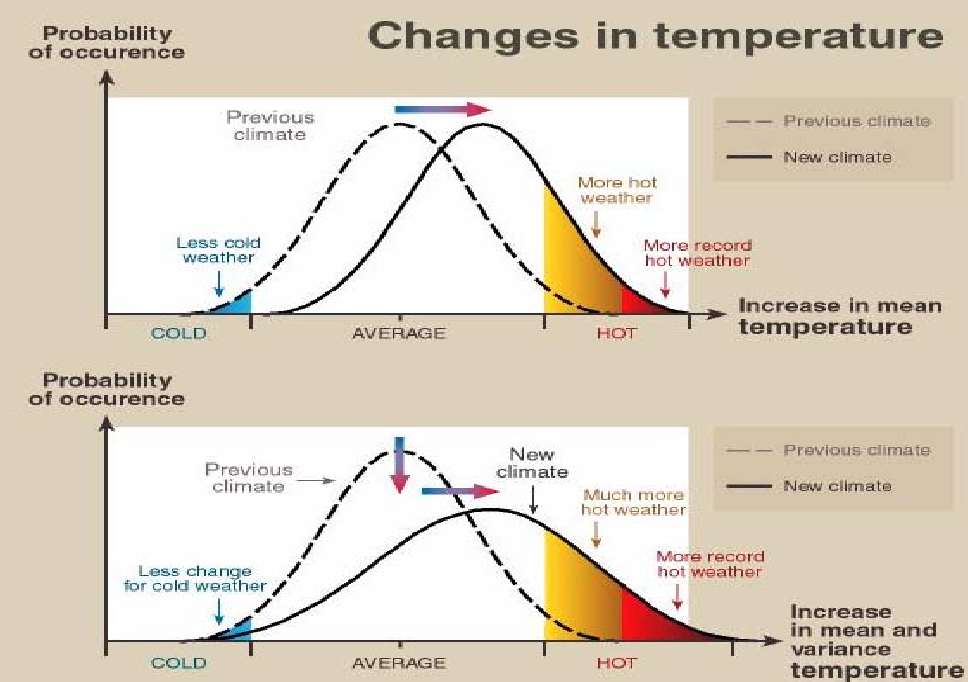
Devastating Indonesian forest fire in 1997-98


Haze over Indian subcontinent

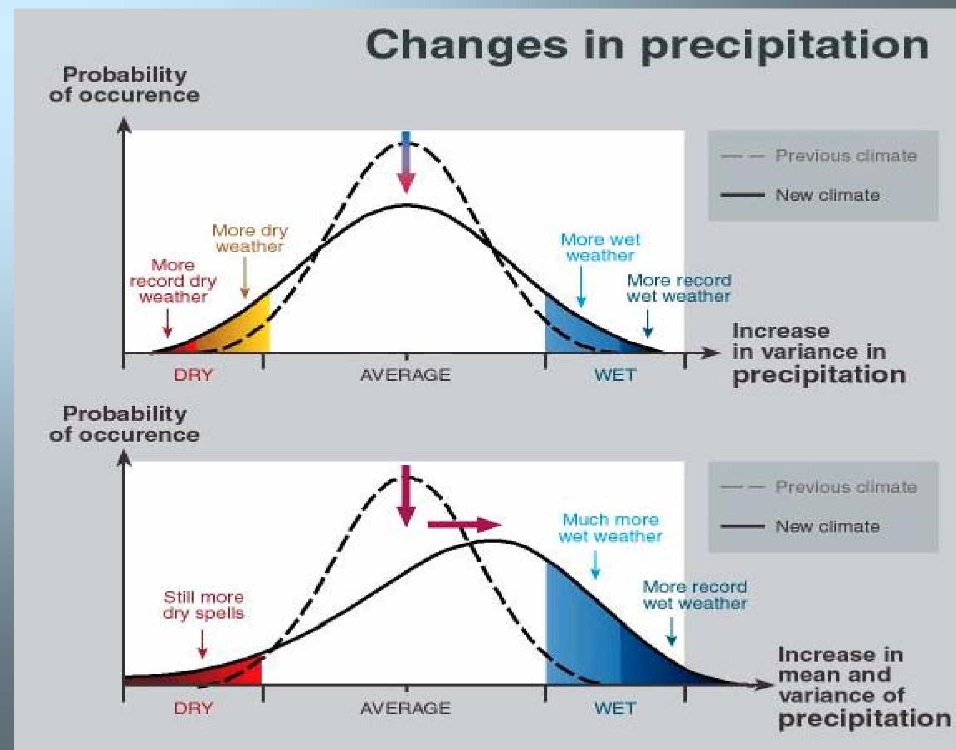
Climate Variability



The interactions between atmosphere and oceans in the tropics dominate the variability at inter-annual scales. The main player is the variability in the equatorial Pacific. Wave-trains of anomaly stem from the region into the mid-latitudes, as the Pacific North American Pattern (PNA). The tropics are connected through the Pacific SST influence on the Indian Ocean SST and the monsoon, Sahel and Nordeste precipitation. It has been proposed that in certain years the circle is closed and and a full chain of teleconnections goes all around the tropics. Also shown is the North Atlantic Oscillation a major mode of variability in the Euro-Atlantic sector whose coupled nature is still under investigation.



Changes in temperature
Probability of occurence
Previous climate
Previous climate
New climate
Less cold weather
More hot weather
More record hot weather
COLD
AVERAGE
HOT
Increase in mean temperature
Probability of occurence
Previous climate
New climate
Previous climate
New climate
Much more hot weather
More record hot weather
Less change for cold weather
COLD
AVERAGE
HOT
Increase in mean and variance temperature



Changes in precipitation
Probability of occurence
Previous climate
New climate
More dry weather
More record dry weather
More wet weather
More record wet weather
DRY
AVERAGE
WET
Increase in variance in precipitation
Probability of occurence
Previous climate
New climate
Much more wet weather
More record wet weather
Still more dry spells
DRY
AVERAGE
WET
Increase in mean and variance of precipitation

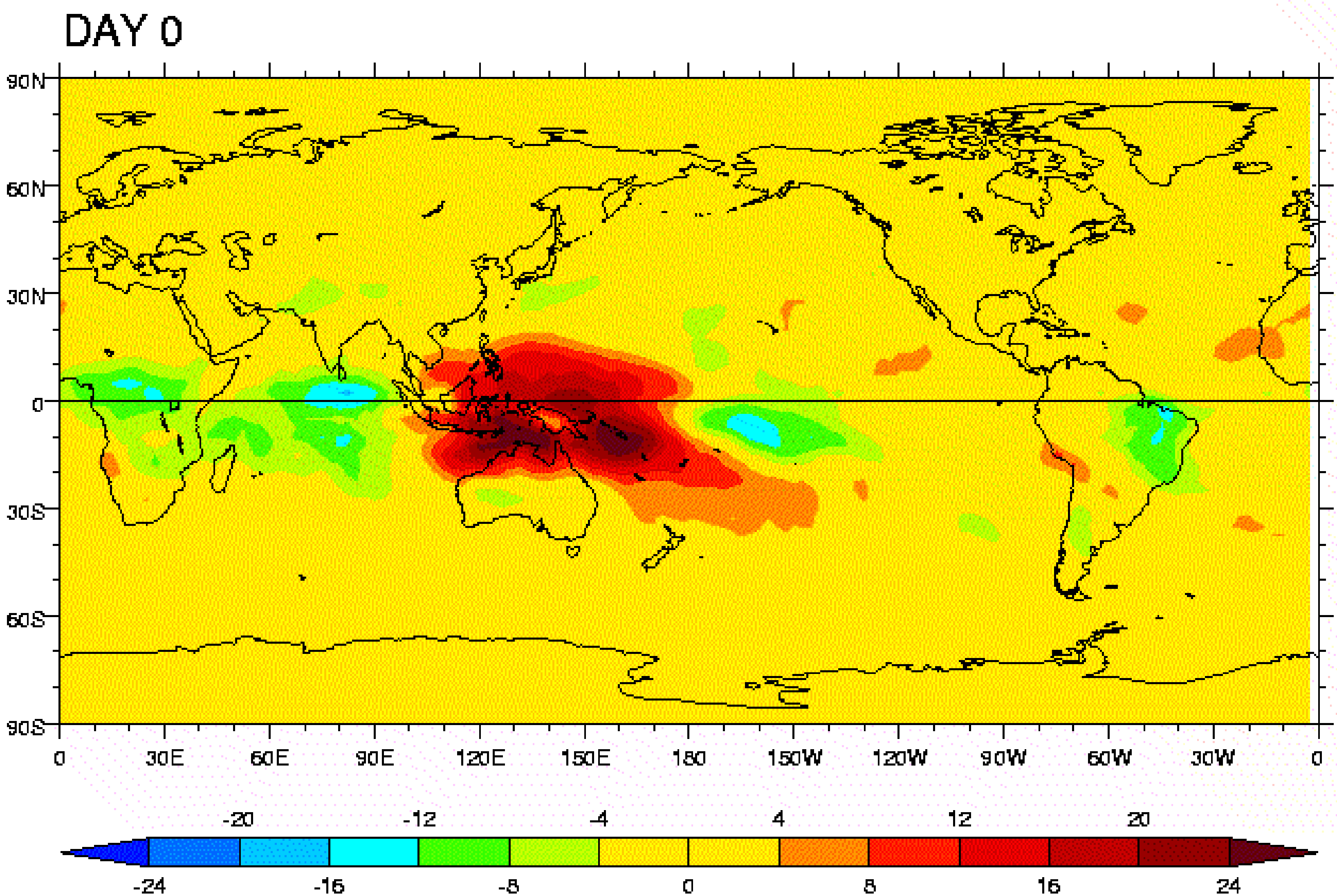
Droughts

Floods

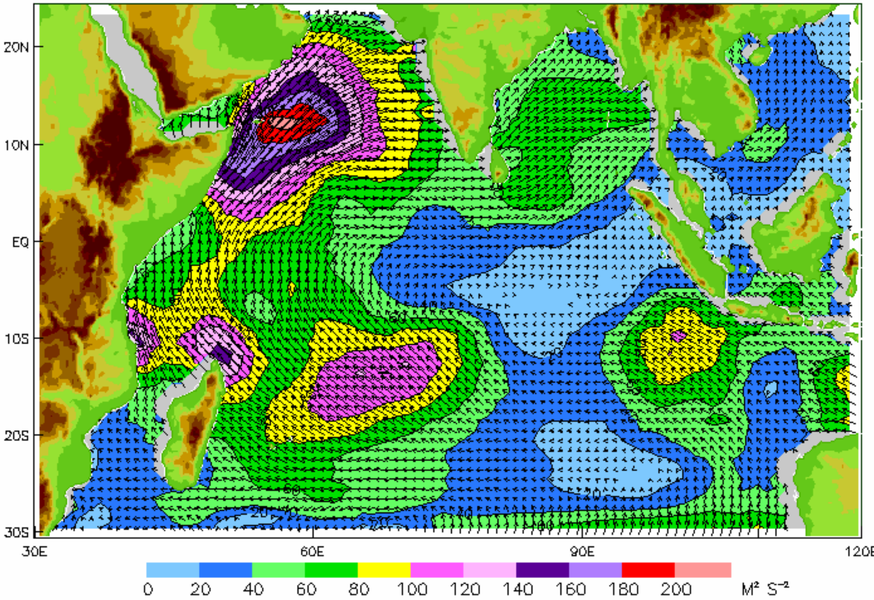
Indian Ocean temperatures affect intensity of the Indian monsoon and rainfall

- **A phenomenon "the Madden Julian Oscillation (MJO)" in the atmospheric circulation explains variations of weather in the tropics and regulates the intensity of rainfall and break conditions associated with the south Asian monsoons.**

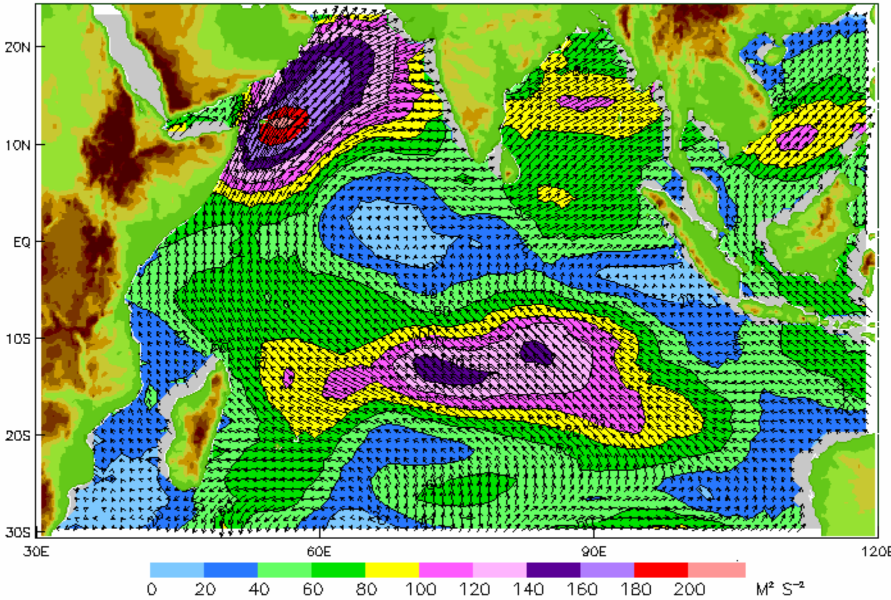
- **The fluctuations the MJO involve variations in wind, SST, cloudiness, and rainfall. The MJO can be characterized by a large-scale eastward movement of air in the upper troposphere with a period of about 20-70 days, over the tropical eastern Indian and western Pacific Oceans at approximately 200 hPa in the upper troposphere.**


DAY 0
90N
60N
30N
0
30S
60S
90S
0
30E
60E
90E
120E
150E
180
150W
120W
90W
60W
30W
0
-20
-12
-4
4
12
20
-24
-16
-8
0
8
16
24

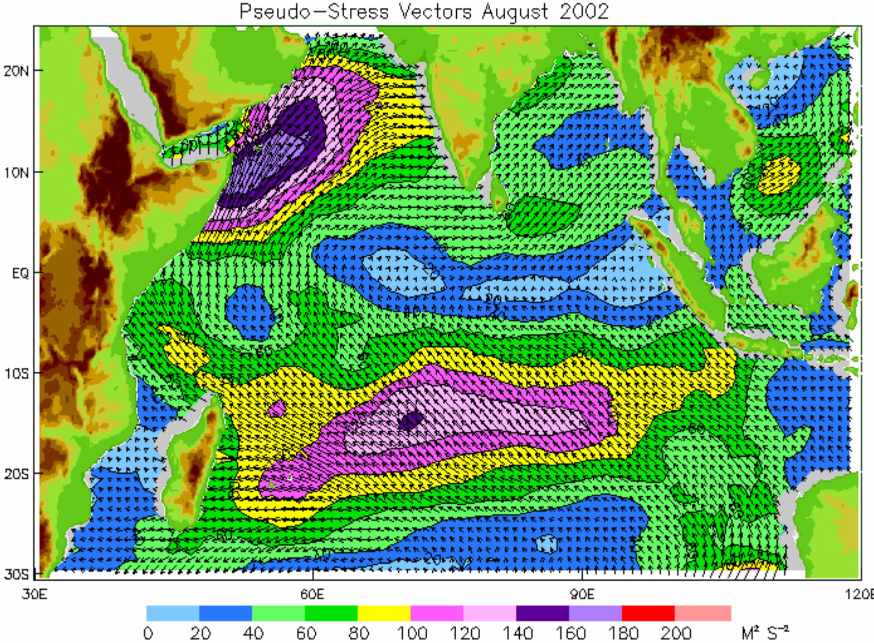
Pseudo-Stress Vectors June 2002



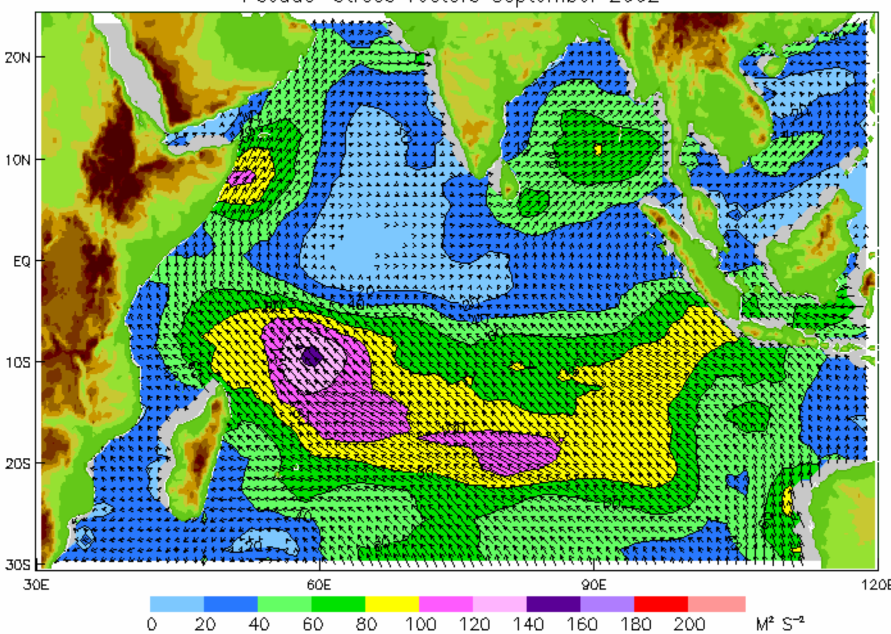
Pseudo-Stress Vectors July 2002



Pseudo-Stress Vectors August 2002



Pseudo-Stress Vectors September 2002



While drought conditions prevailed in Vidarbha (in the state of Maharashtra) during June and July 2002, heavy downpours in August amounted to 80 cm of rainfall, compared to 95 cm of normal seasonal rainfall.

On 2-3 September, 25 cm of rainfall was recorded, which lifted the water level of Sardar Sarovar dam along the Narmada River to 12 m above its full capacity of 95 m, inundating hundreds of villages in the region.

The monsoon wreaked havoc in seven districts of Maharashtra from 1 to 3 September 2002, claiming 35 lives and causing massive damage to crops and throwing normal life out of gear.

Different ‘regionalisation’ techniques have therefore been developed over the last decade or so to improve the regional information provided by coupled A-O GCMs, and to provide climate information at a finer scale.

Such techniques can be classified into three categories:

1. Statistical downscaling methods;
2. ‘Nested’ limited area (or regional) climate models;
3. High and variable resolution ‘time-slice’ AGCM experiments.

Statistical Downscaling

Under this approach, regional or local climate information is derived by first developing a statistical model which links large-scale climate variables (or 'predictors') to regional and local variables (or 'predictands').

The large-scale output of an *A-O* GCM simulation is then fed into this statistical model in order to estimate the corresponding local and regional climate characteristics.

A range of such statistical downscaling models have been developed for regions where sufficiently good datasets are available to allow the models to be properly calibrated. These techniques are currently used for a wide range of climate applications.

One of the main advantages of statistical downscaling techniques is that they do not require large amounts of computational resources. Another advantage is that they can be used to provide information at specific locations.

However, statistical downscaling methods are based on empirical models and not on models that explicitly describe the physical processes that affect climate and this may limit their applicability.

In addition, the major theoretical weakness of statistical downscaling methods is that the fundamental assumption on which they are based — that the statistical relationships developed for present-day climate also hold under the different forcing conditions of possible future climates — is often not verifiable.

Nested Regional Climate Models

These can be visualized as providing a high-resolution zoom in effect over a selected region.

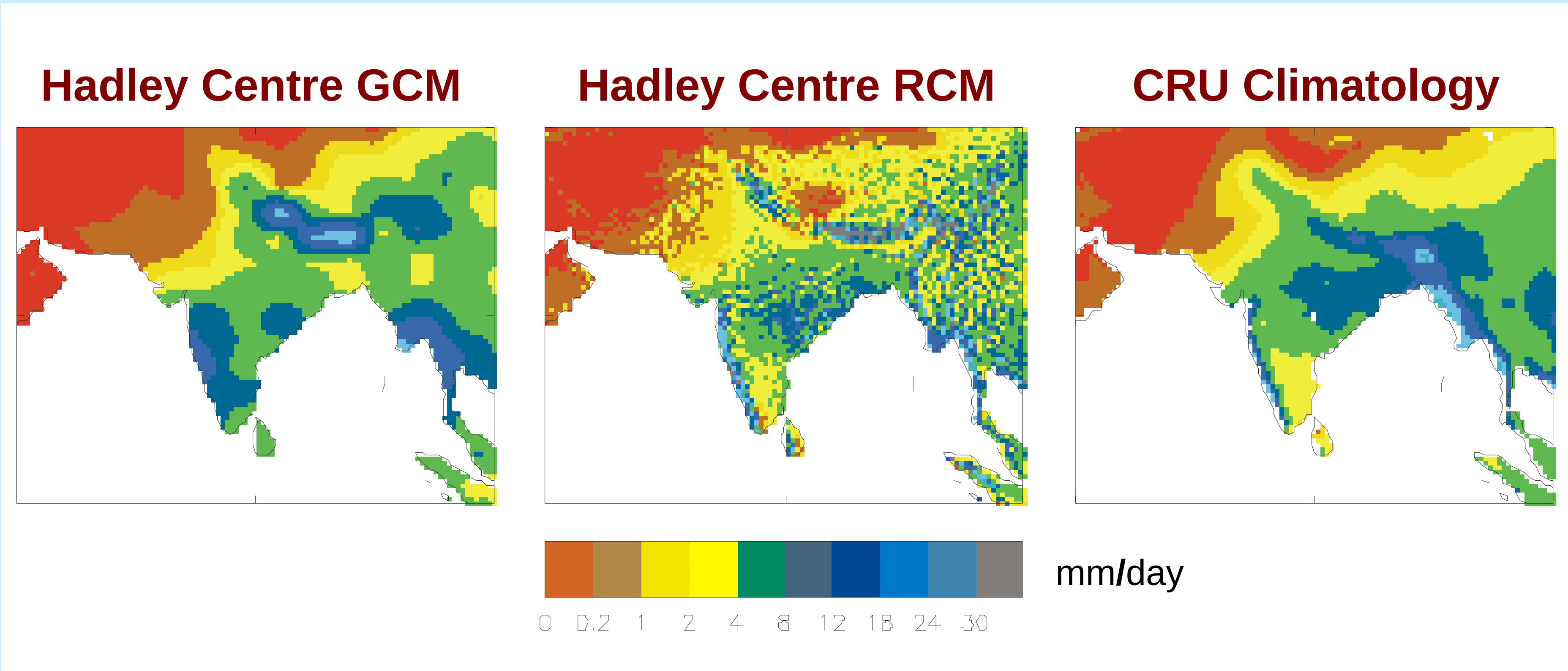
Up to now, this technique has only been used in one direction, that is with no feedback from the regional climate model to the global climate model.

These have proven to be flexible tools, capable of reaching high resolution (down to 10-20 km or less) and simulation times of several decades.

They have also been able to describe successfully climate feedback mechanisms acting at the regional scale.

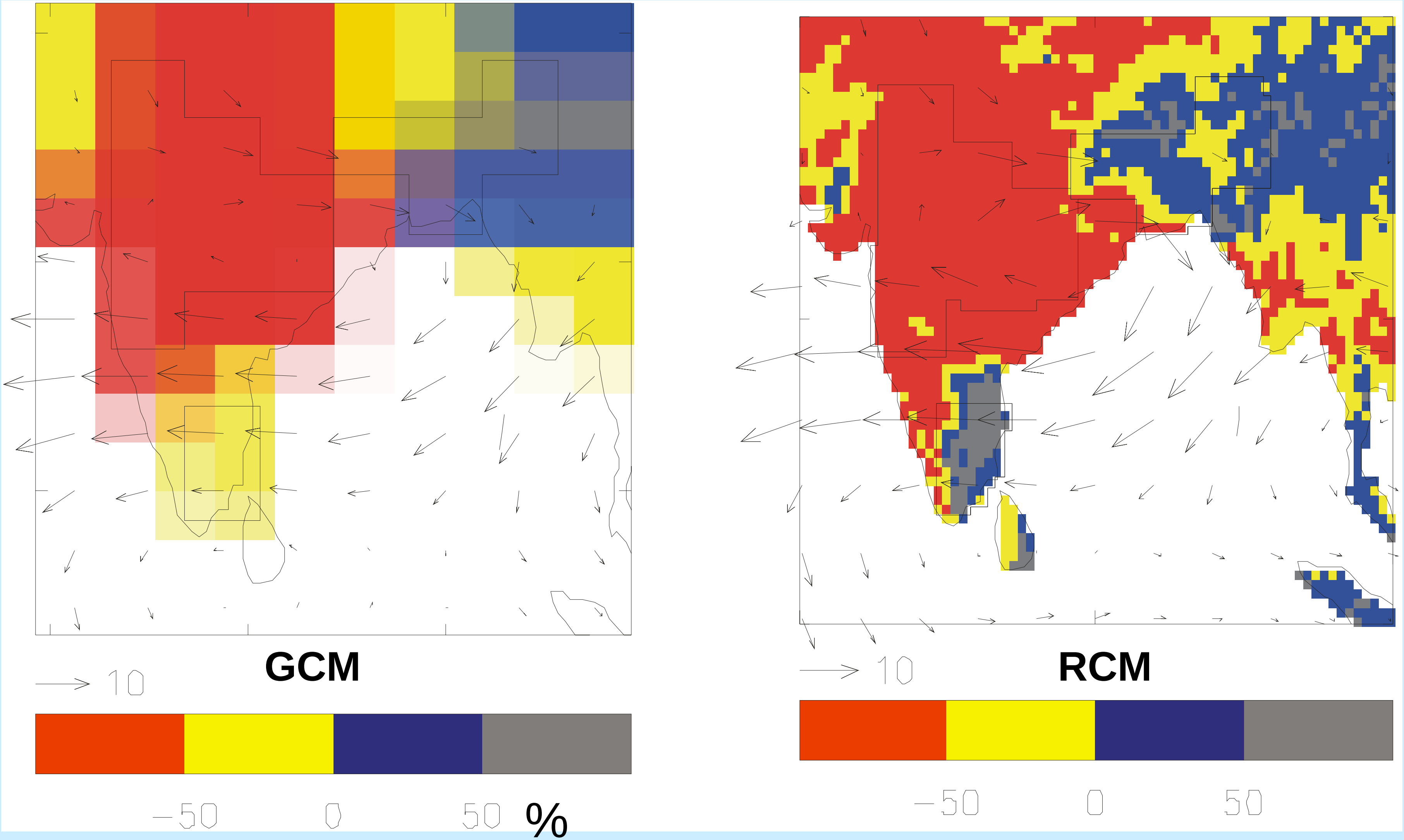
PRECIPITATION PATTERNS

JJAS from GCM and RCM control climates, and observations



BREAK-ACTIVE PRECIPITATION

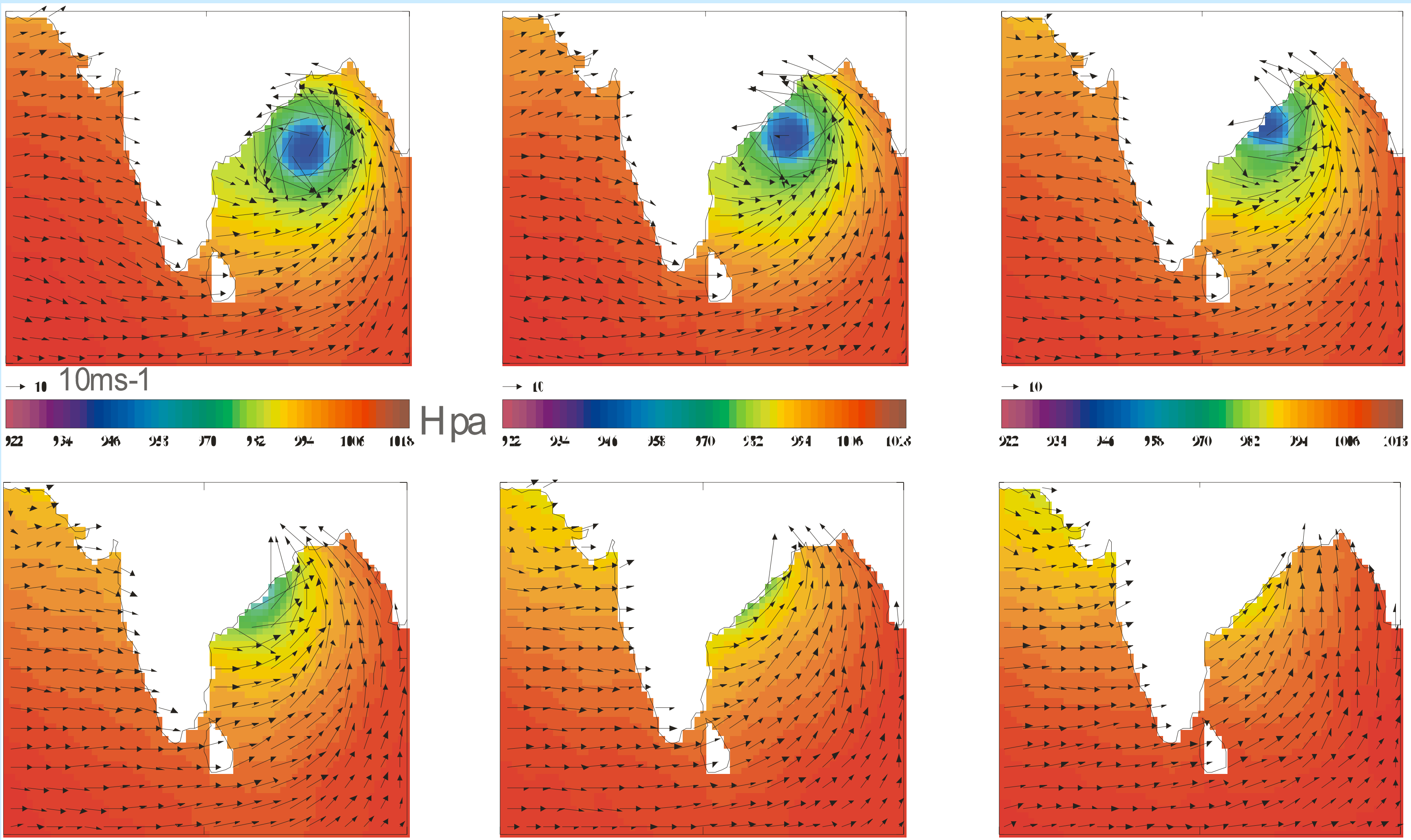
wind vectors (m/s) are (mean active) - (mean break)



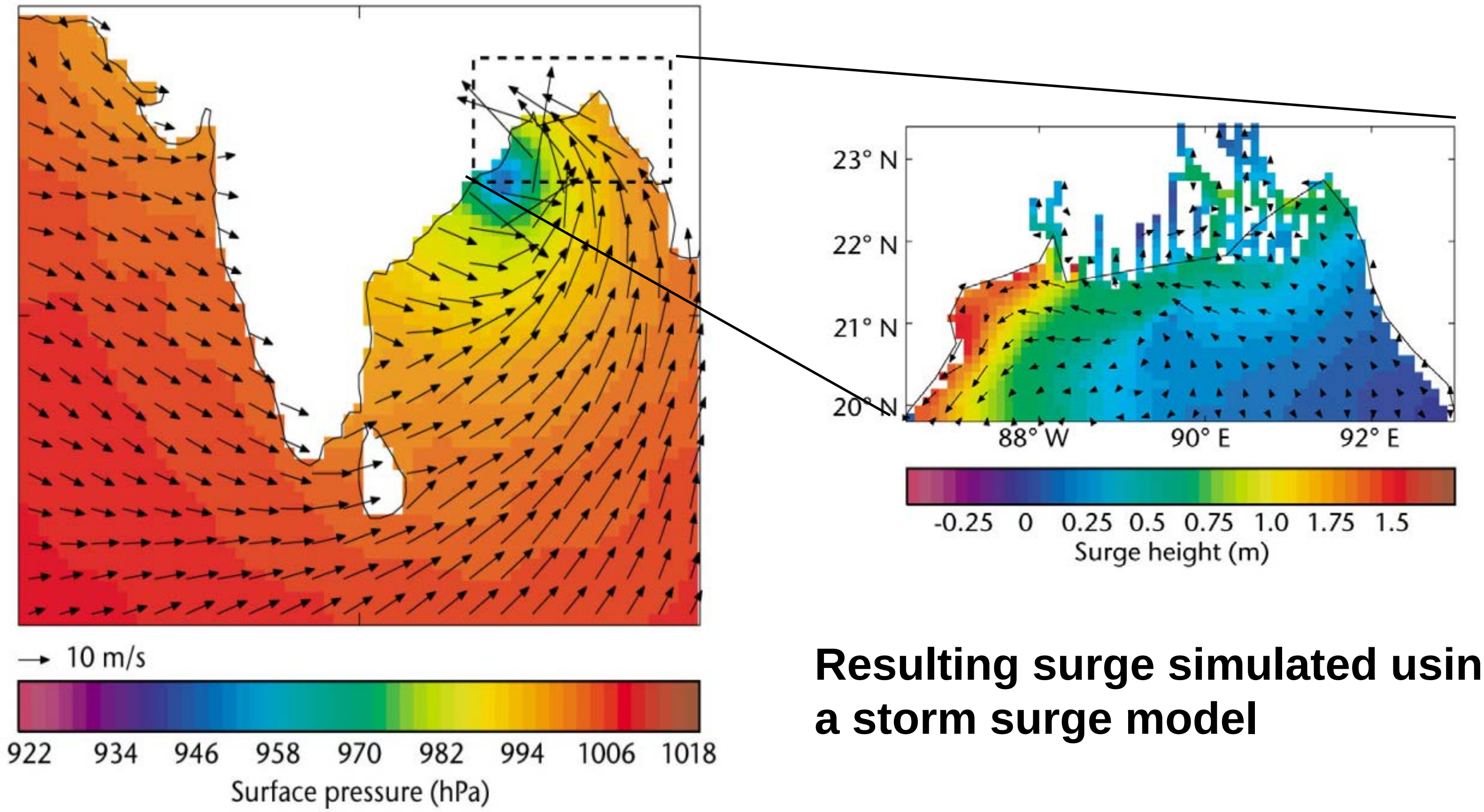
More rainfall in Tamil Nadu during monsoon break event

CYCLONE SIMULATION

Pressure (hPa) and wind fields (m/s) every 6h from control run



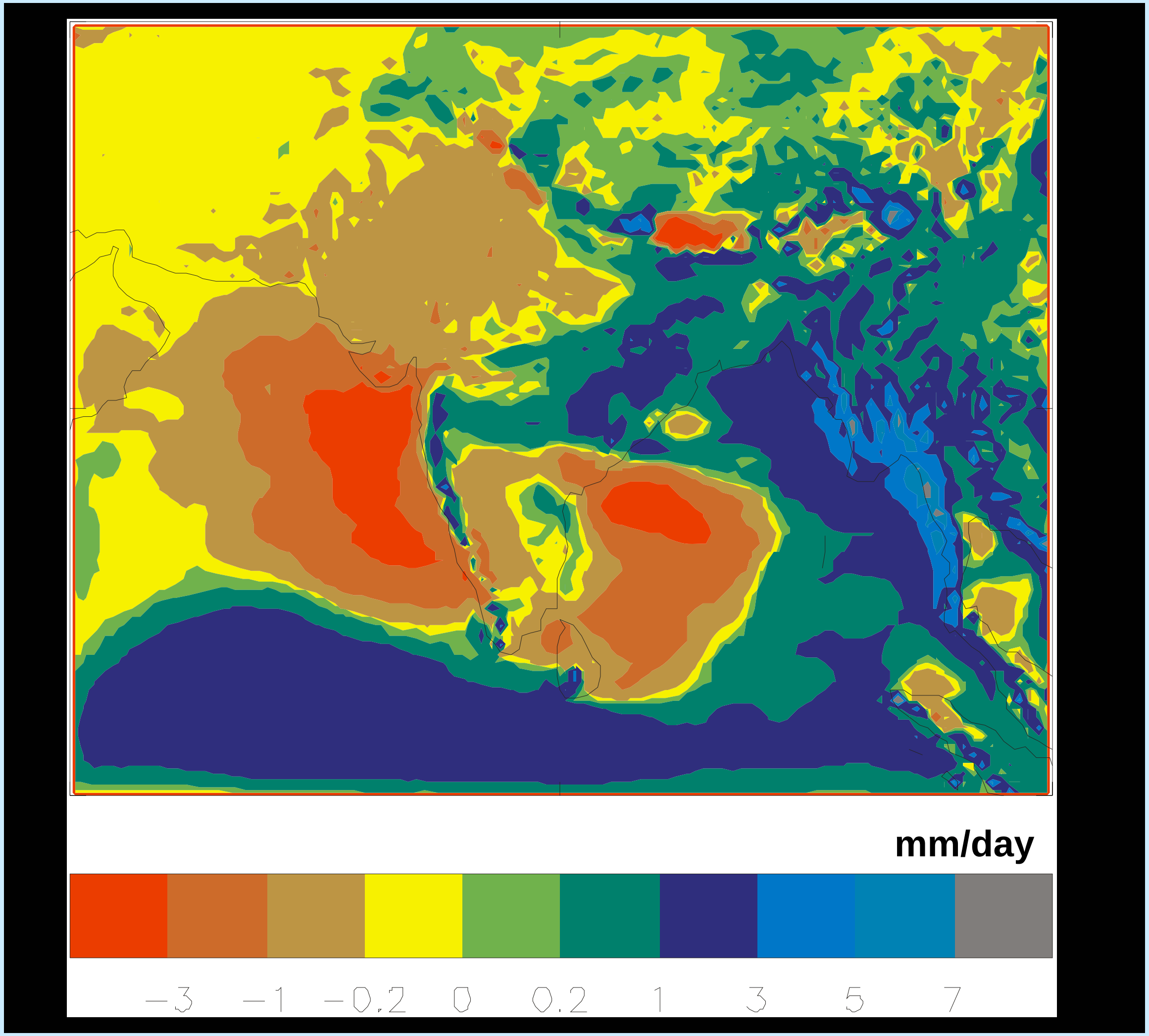
COASTAL SURGES DUE TO TROPICAL STORMS IN BAY OF BENGAL CAN BE PREDICTED



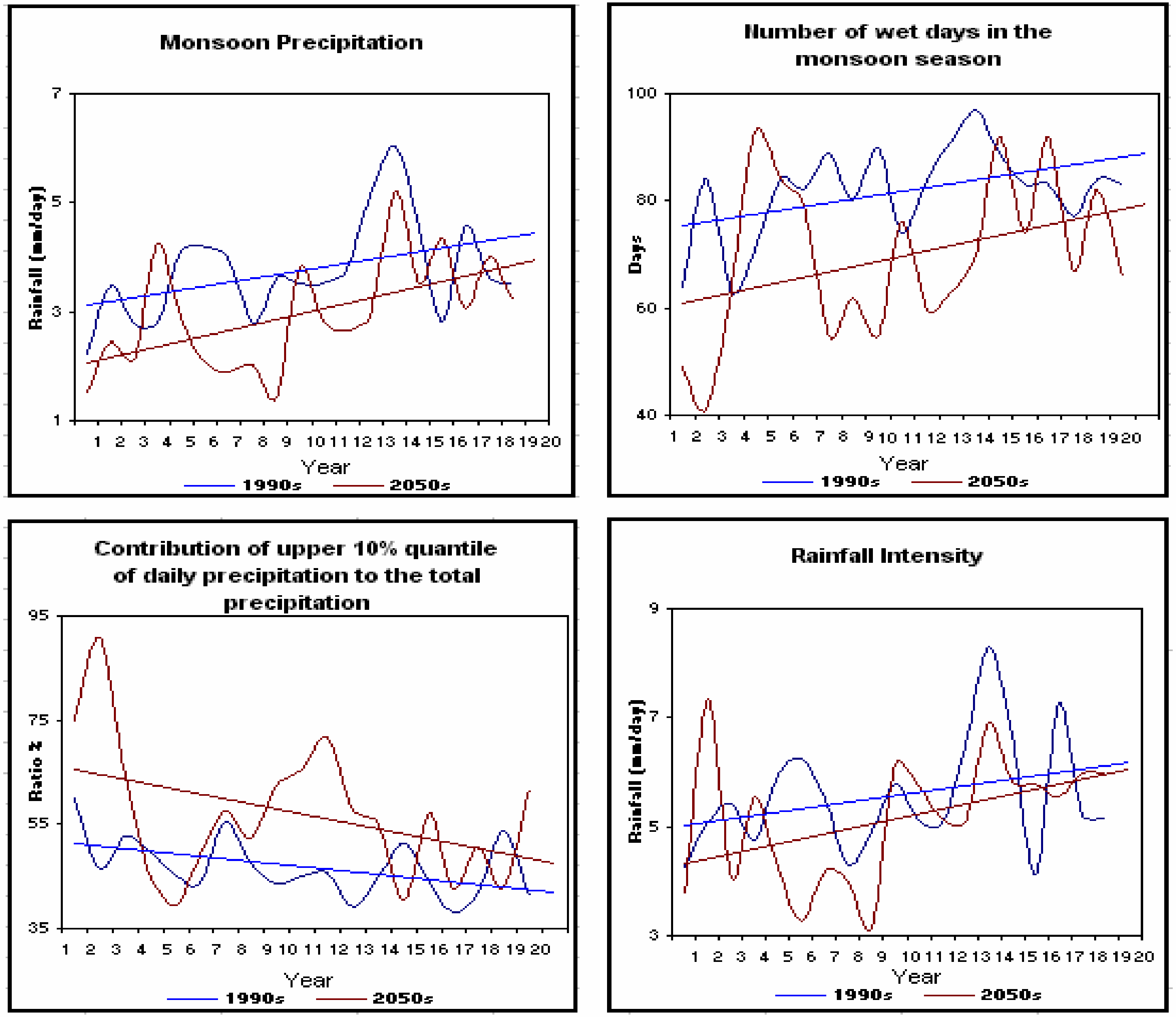
Resulting surge simulated using a storm surge model

RAINFALL CHANGE OVER SOUTH ASIA

as simulated by Regional Climate Model

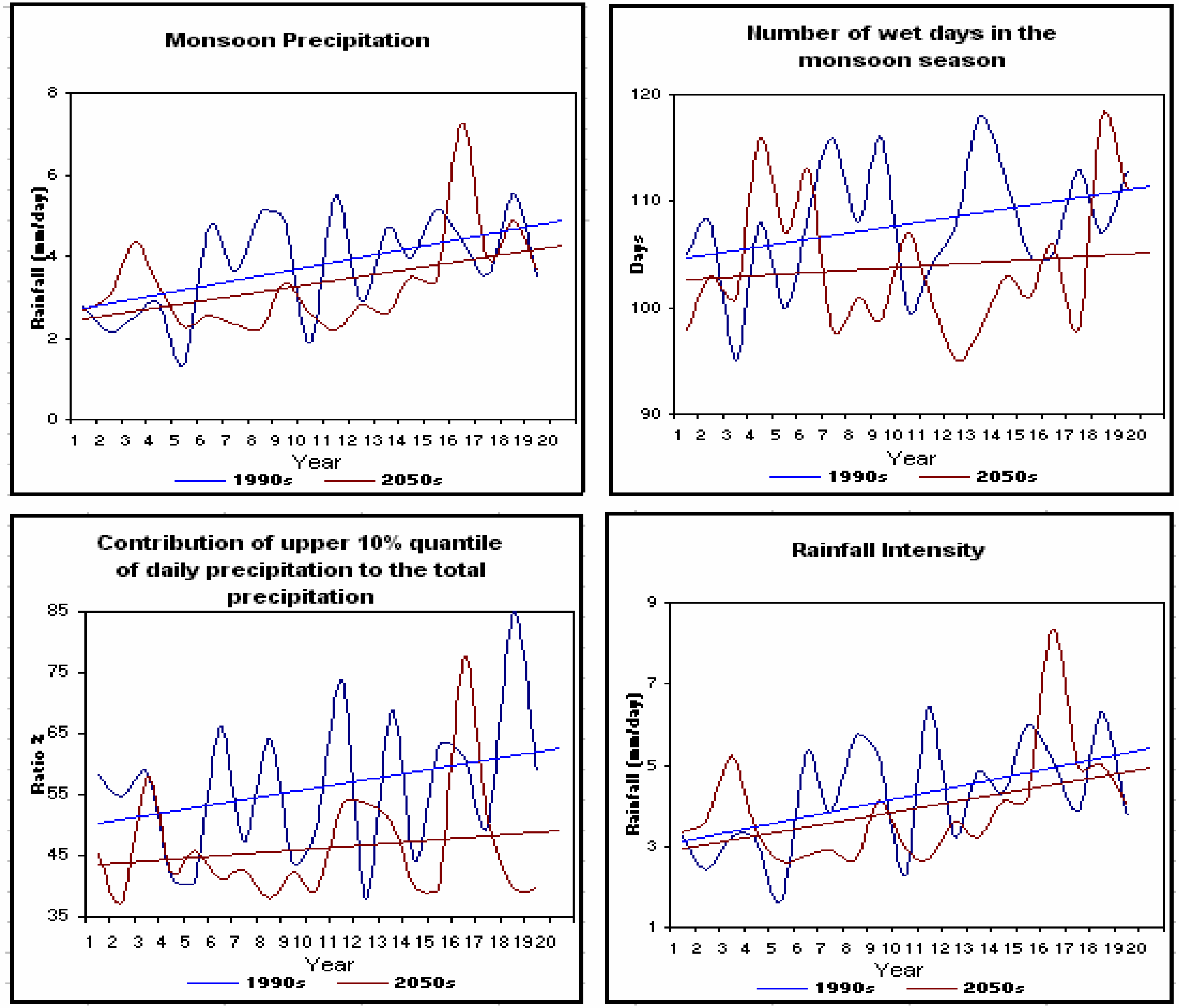


DELHI



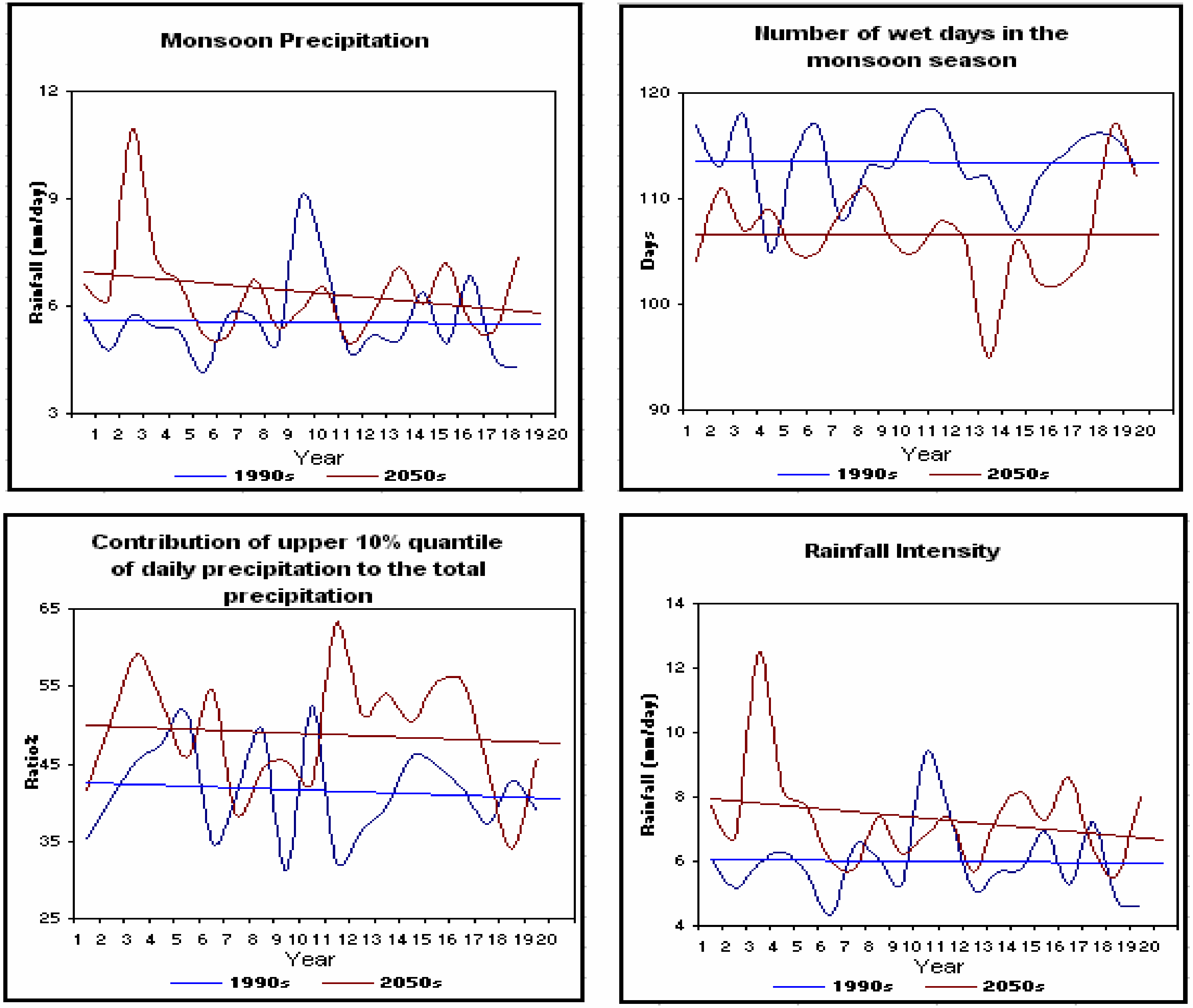
Key characteristics of summer monsoon rainfall over Delhi as simulated by the RCM nested in the GCM for the present day (1990s) and for the mid-Century (2050s) due to anthropogenic radiative forcings

BANGALORE



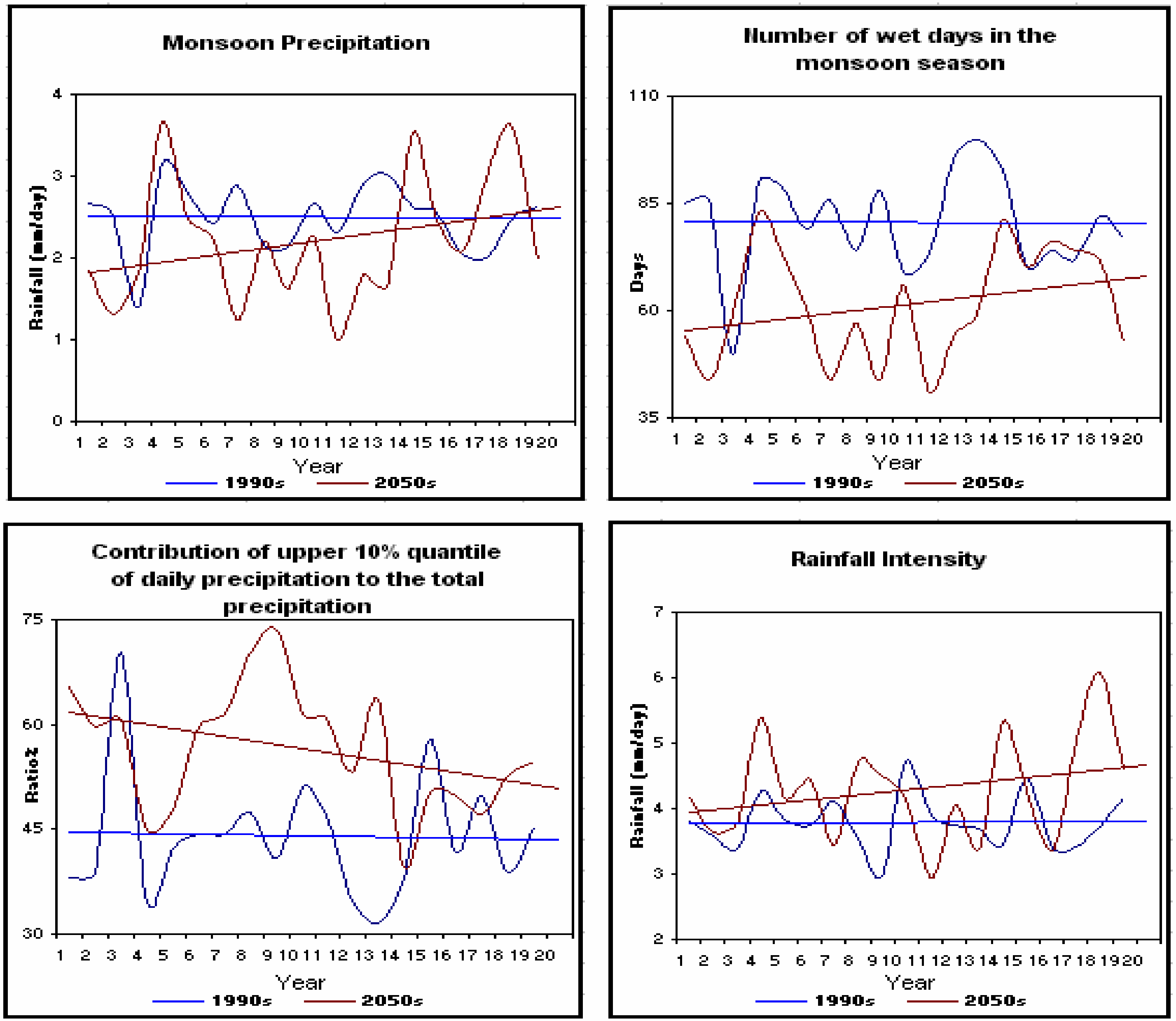
Key characteristics of summer monsoon rainfall over Bangalore as simulated by the RCM nested in the GCM for the present day (1990s) and for the mid-Century (2050s) due to anthropogenic radiative forcings

JORHAT



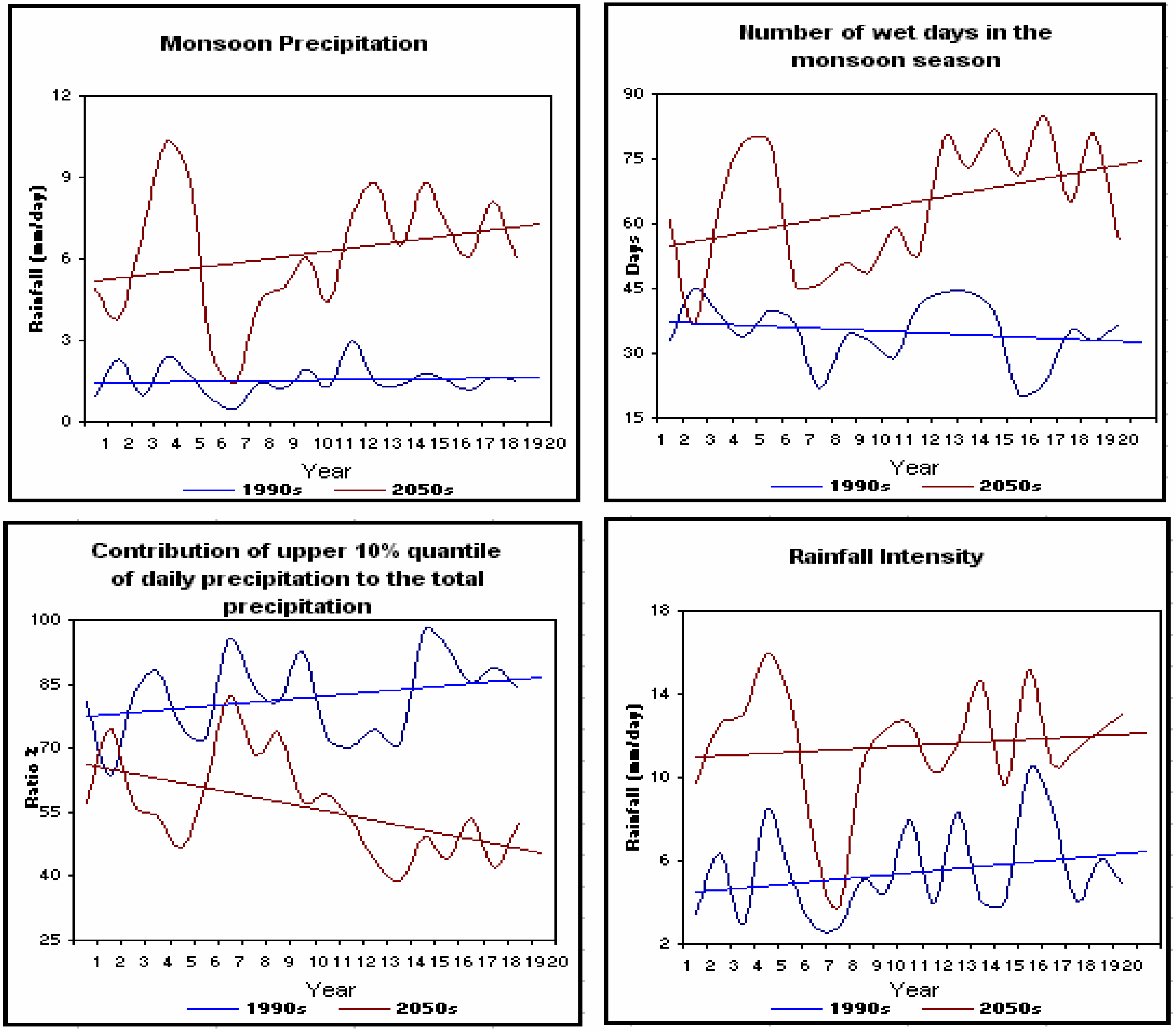
Key characteristics of summer monsoon rainfall over Jorhat as simulated by the RCM nested in the GCM for the present day (1990s) and for the mid-Century (2050s) due to anthropogenic radiative forcings

UDAIPUR



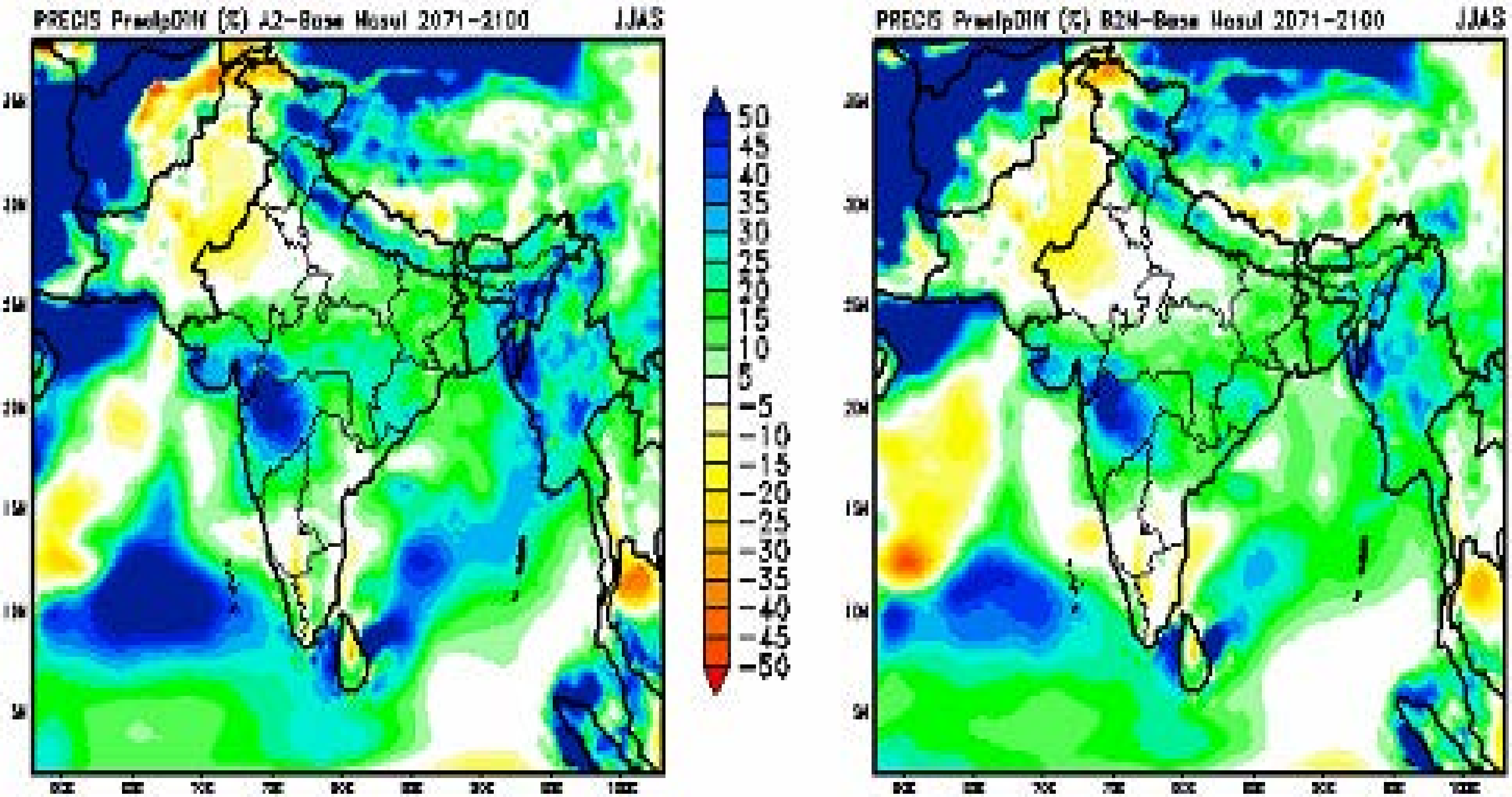
Key characteristics of summer monsoon rainfall over Udaipur as simulated by the RCM nested in the GCM for the present day (1990s) and for the mid-Century (2050s) due to anthropogenic radiative forcings

SRINAGAR

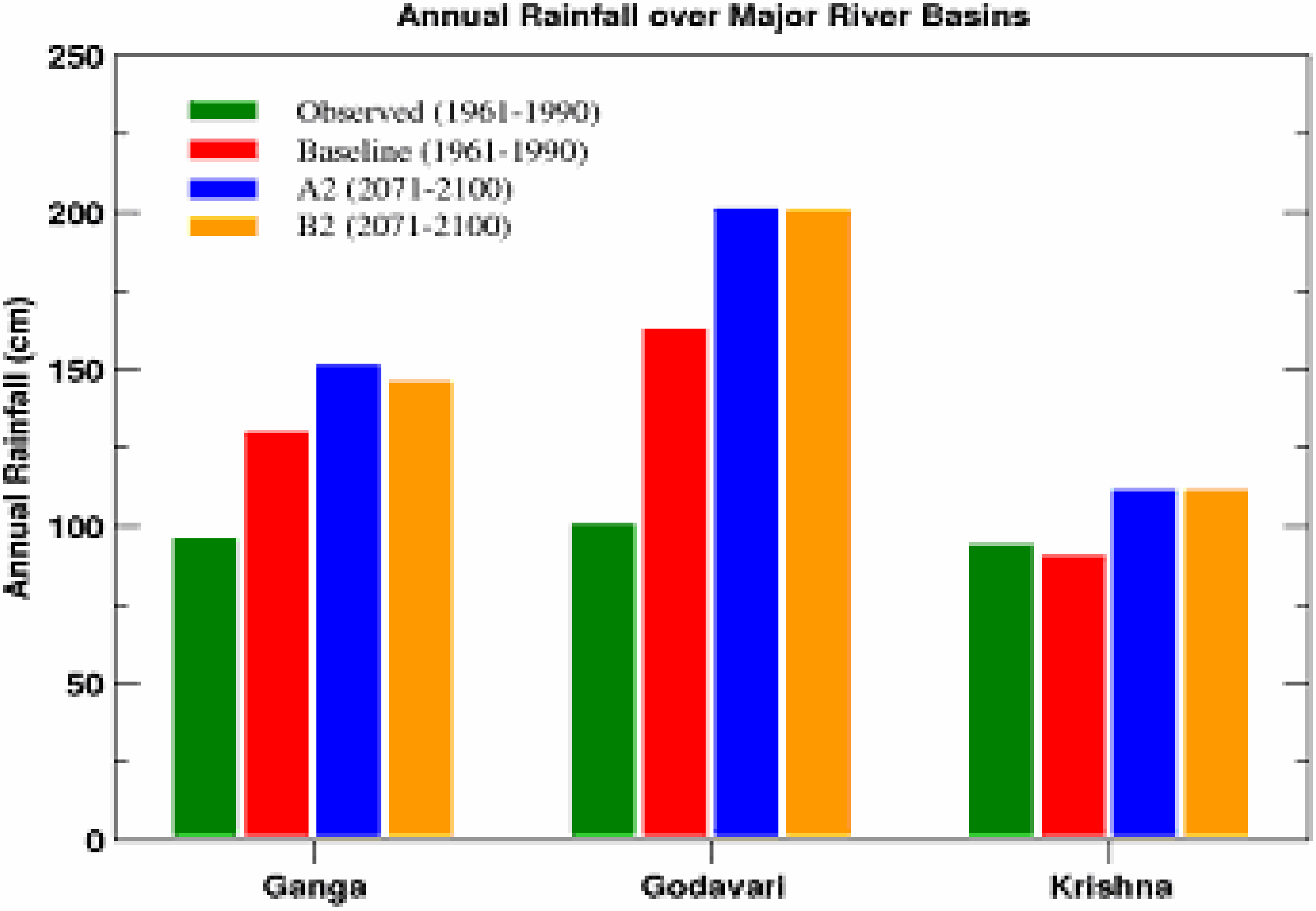


Key characteristics of summer monsoon rainfall over Srinagar as simulated by the RCM nested in the GCM for the present day (1990s) and for the mid-Century (2050s) due to anthropogenic radiative forcings

21st Century Changes in Monsoon Rainfall under A2 and B2 Scenarios



PRECIS Simulations of Present and Future Precipitation



Nested Regional Climate Modeling approach, however, has some theoretical limitations.

For example, the regional model simulations are affected by systematic errors in the driving meteorological fields provided by global models, and two-way interaction between regional and global climate is not described.

In addition, for each application, careful consideration needs to be given to the ways that the models are configured.

From the practical viewpoint, regional model simulations can be demanding on computational resources, both in terms of computation power and data storage.

Variable Resolution Models

The main advantage of this tool is that the resulting simulations are globally consistent and capture the feedback from the regional high resolution atmospheric circulations on the global climate.

The use of this technique is based on the assumption that the large-scale circulation patterns in both the coarse and high resolution GCMs are not very different from each other.

Conformal-cubic model features

· 2-time-level semi-implicit hydrostatic (recently, has non-hydrostatic option)

· semi-Lagrangian horizontal advection with bi-cubic spatial interpolation

· total variation diminishing (TVD) or semi-Lagrangian vertical advection

· unstaggered grid, with winds transformed to/from
·C-staggered positions before/after gravity wave calculations using reversible interpolation

· minimal horizontal diffusion needed:
·Smagorinsky style; zero is fine

· weak off-centering (in time) used to avoid semi-Lagrangian "mountain resonances"

· careful treatment of surface pressure and pressure-gradient terms near terrain
· *a posteriori* conservation of mass and moisture

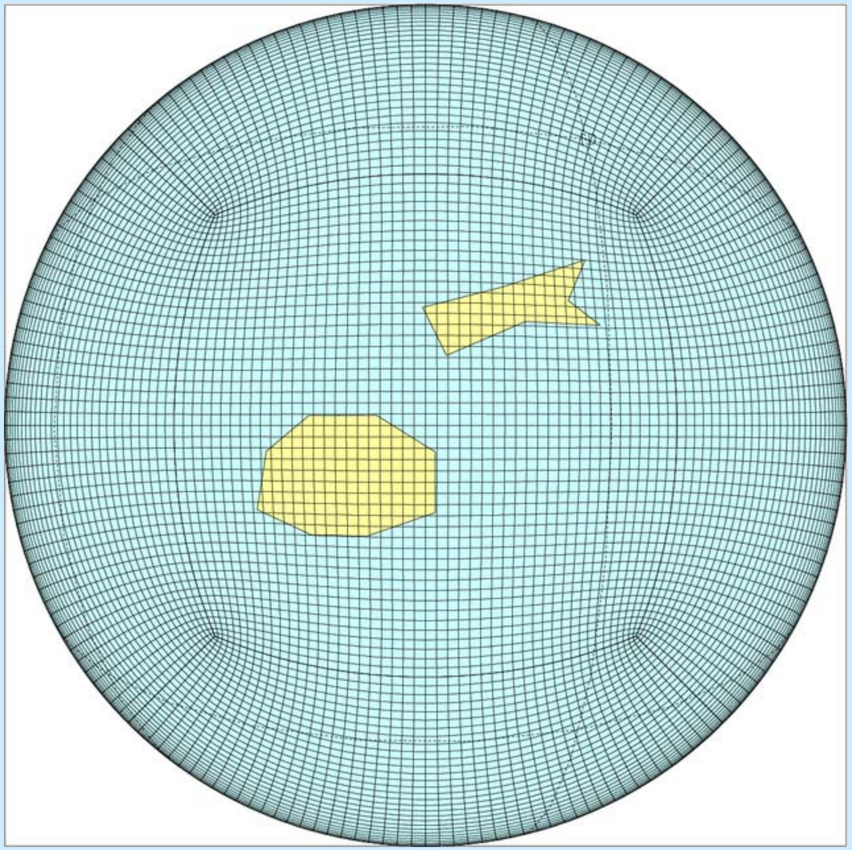
· grid is isotropic

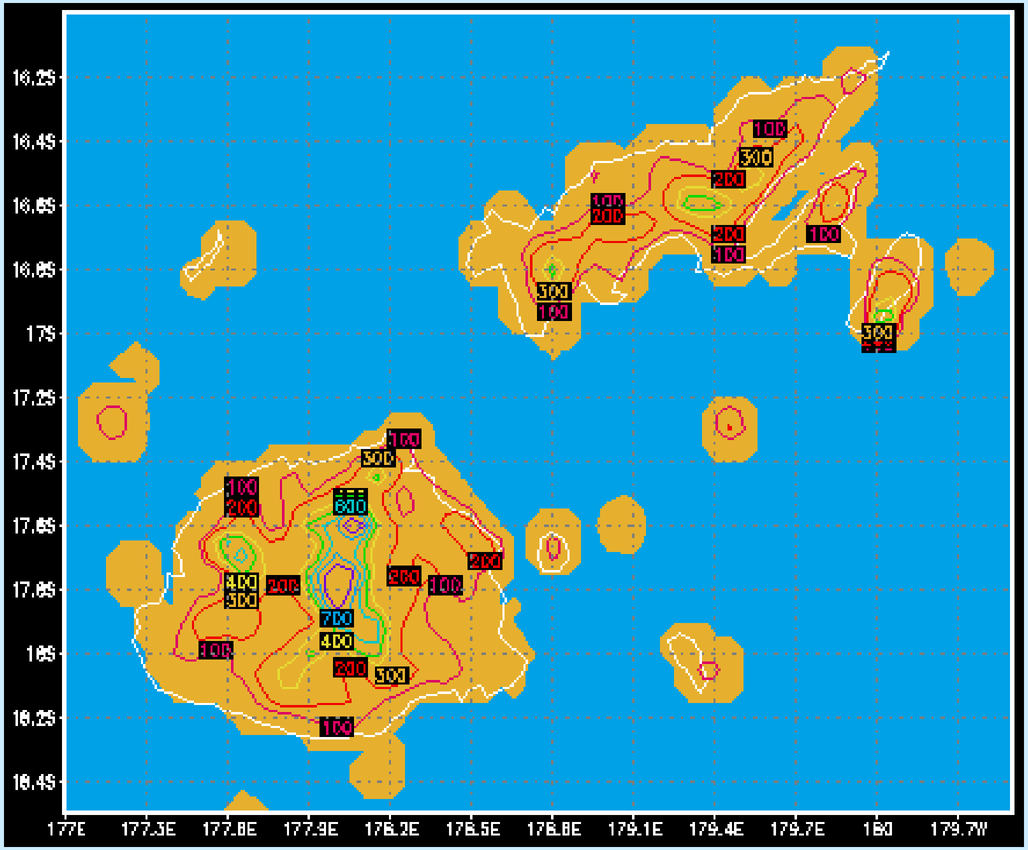
Physical Parameterizations

- cumulus convection:
  - -new CSIRO mass-flux scheme, including downdrafts
- includes advection of liquid and ice cloud-water
- interactive cloud distributions
  - derived prognostically from liquid water
- GFDL parameterization for long and short wave radiation
- gravity-wave drag scheme
- stability-dependent boundary layer and vertical mixing with non-local option
- vegetation/canopy scheme
  - 6 layers for soil temperatures
  - 6 layers for soil moisture (Richard's equation)
- option for cumulus mixing of trace gases
- diurnally varying skin temperatures for SSTs

8 km trial simulation over Fiji

Model uses NCEP fields at all grid points.





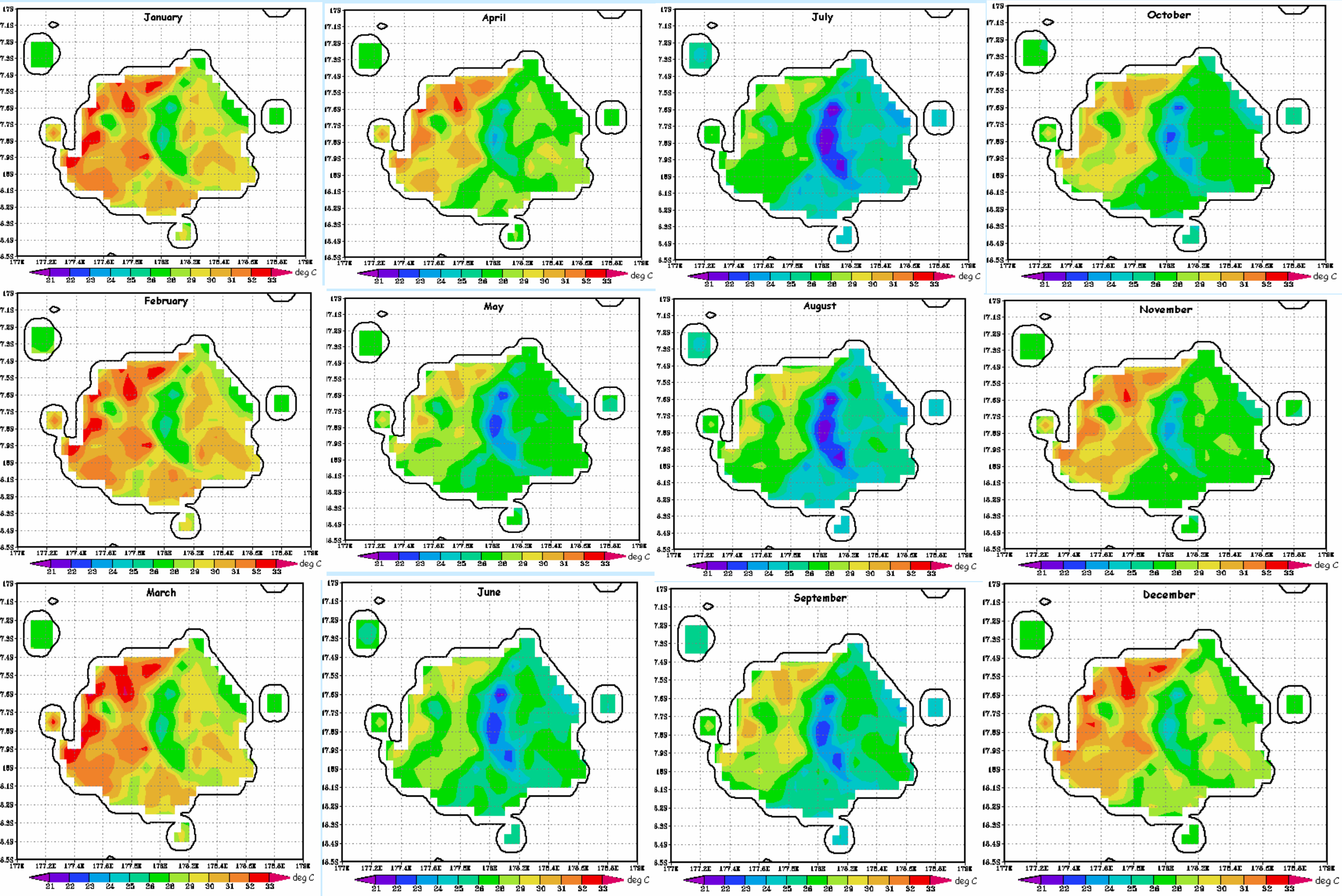
C48 grid

Model orography

For these fine-resolution simulations, "global nudging" from the broad-scale fields is the preferred strategy. All the Fiji land points have soil type 3 (fine clay) and vegetation type 32 - broadleaf evergreen trees (tropical forest).

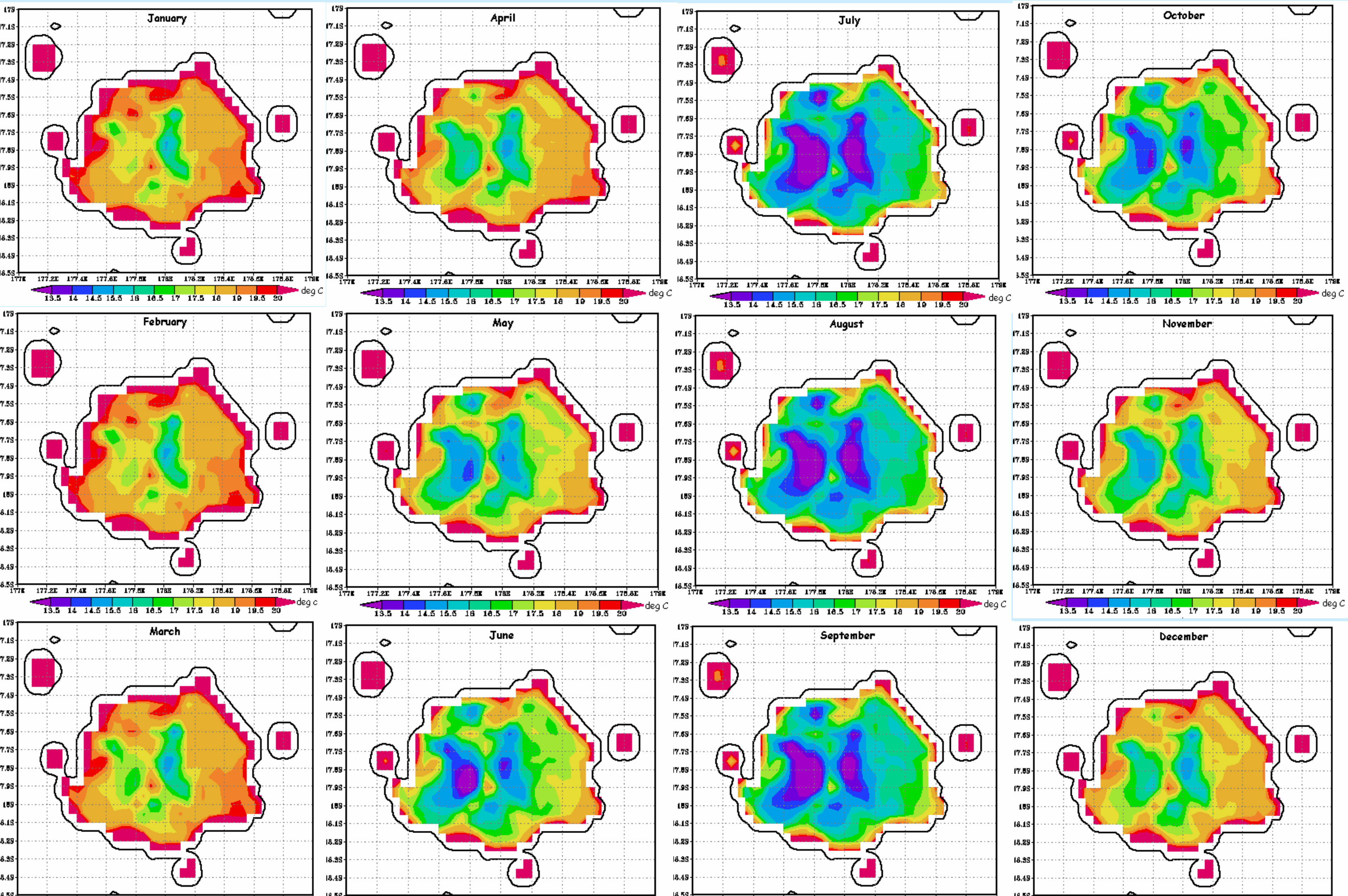
Monthly Simulated Maximum Surface Air Temperature Climatology – Fiji

(The observed temperature gradients between western and central divisions during the year and low temperatures at high altitude are realistically simulated by the model)

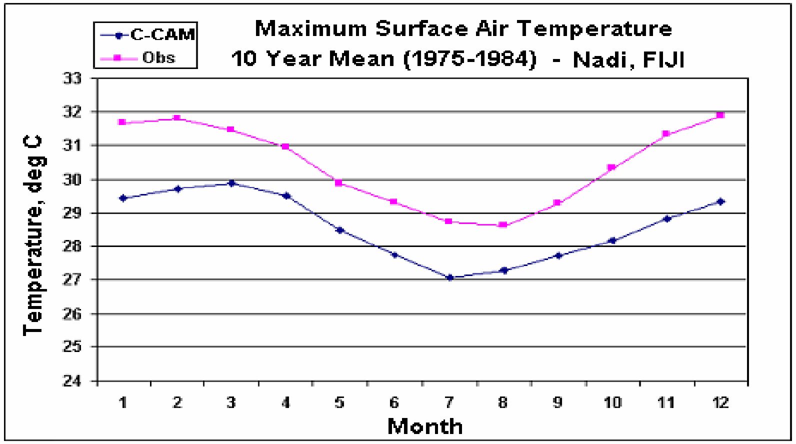


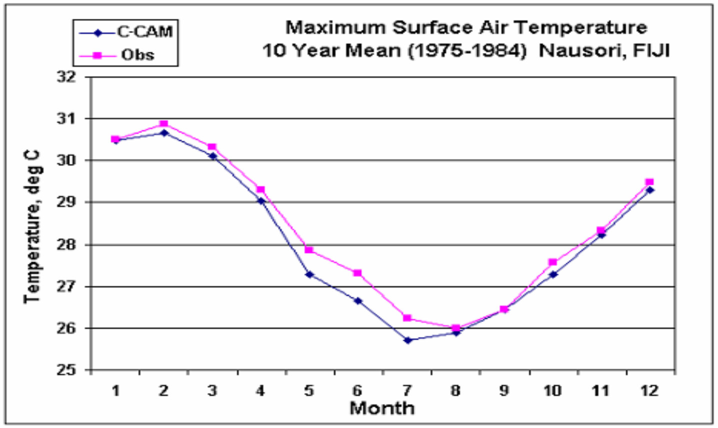
Monthly Simulated Minimum Surface Air Temperature Climatology – Fiji

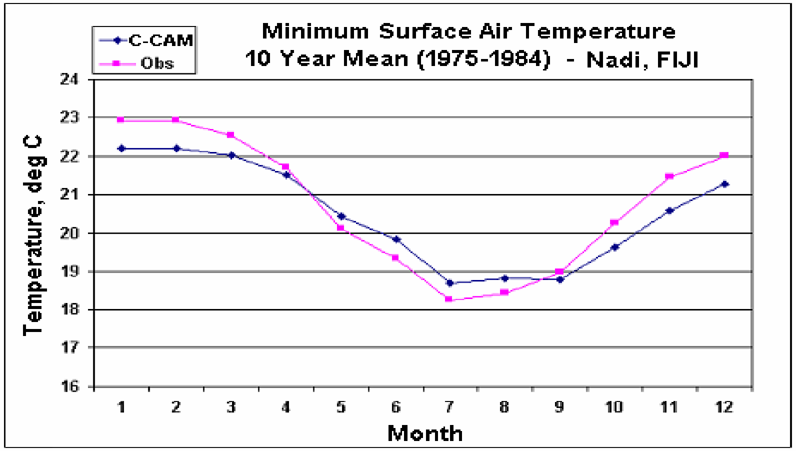
(The observed temperature gradients between western and central divisions during the year and low temperatures at high altitude are realistically simulated by the model)

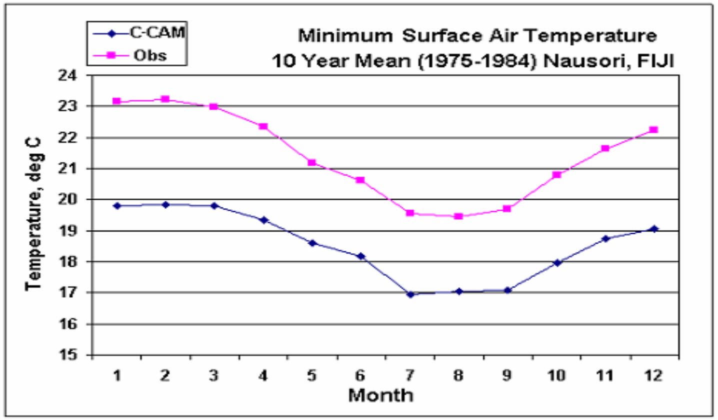


Comparison of observed and simulated average monthly surface air temperatures

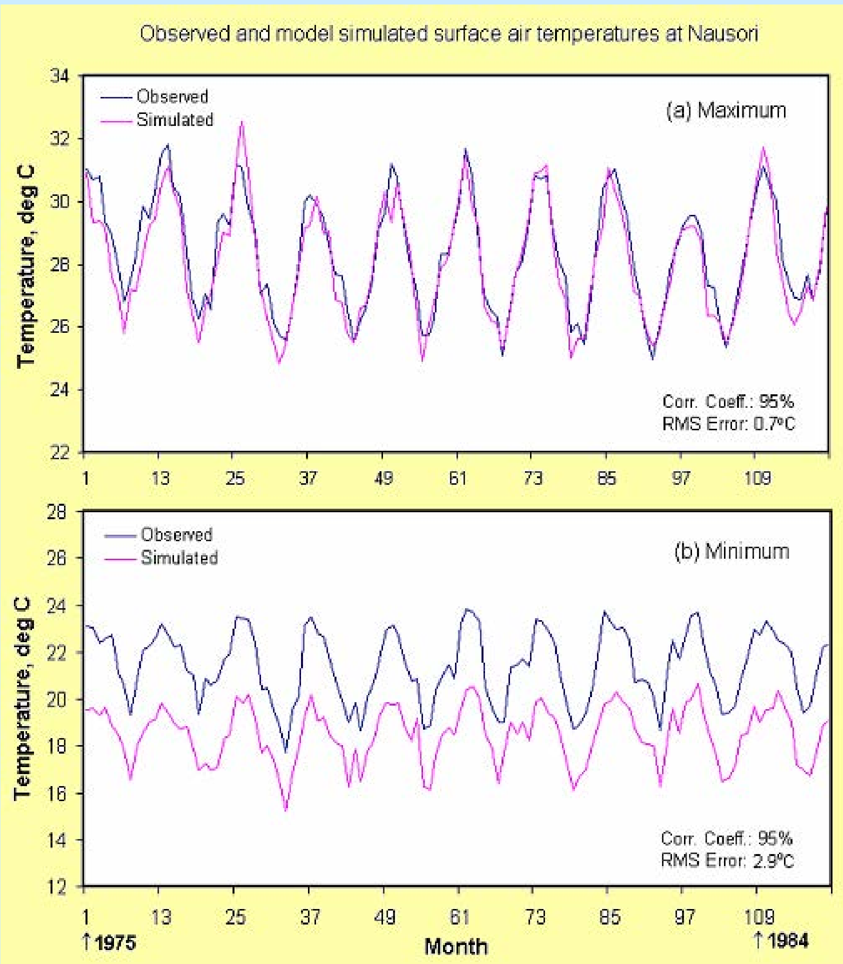


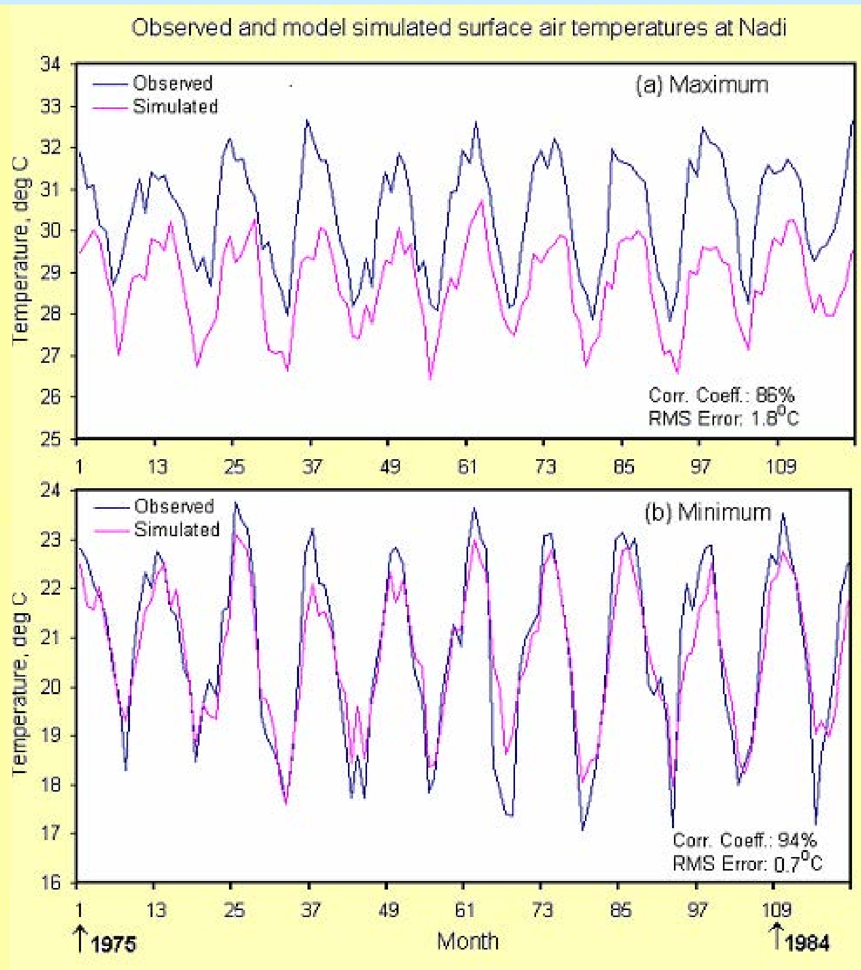




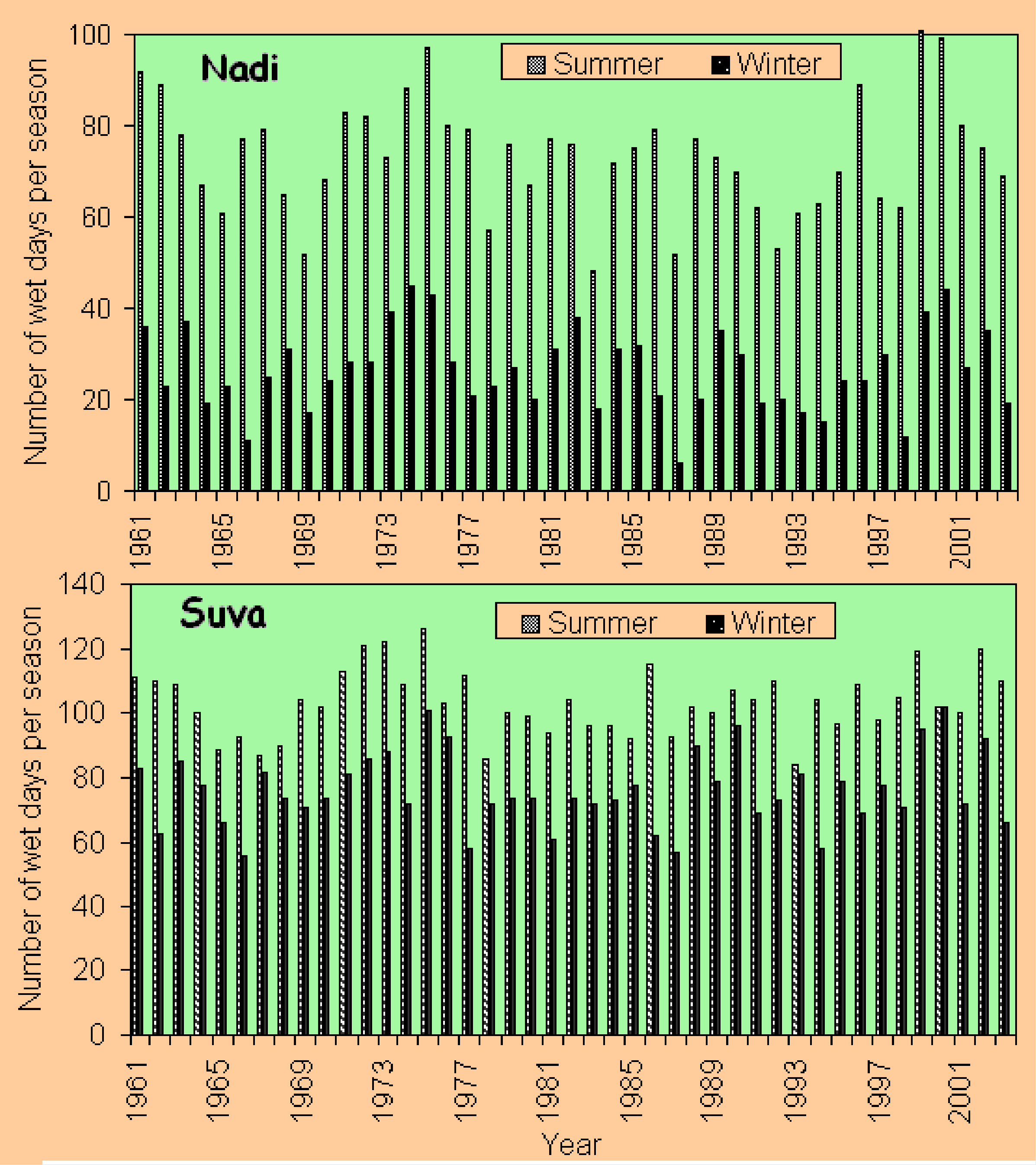


Comparison of intraseasonal and interannual variability in monthly mean simulation of surface air temperatures at Nadi and Nausori



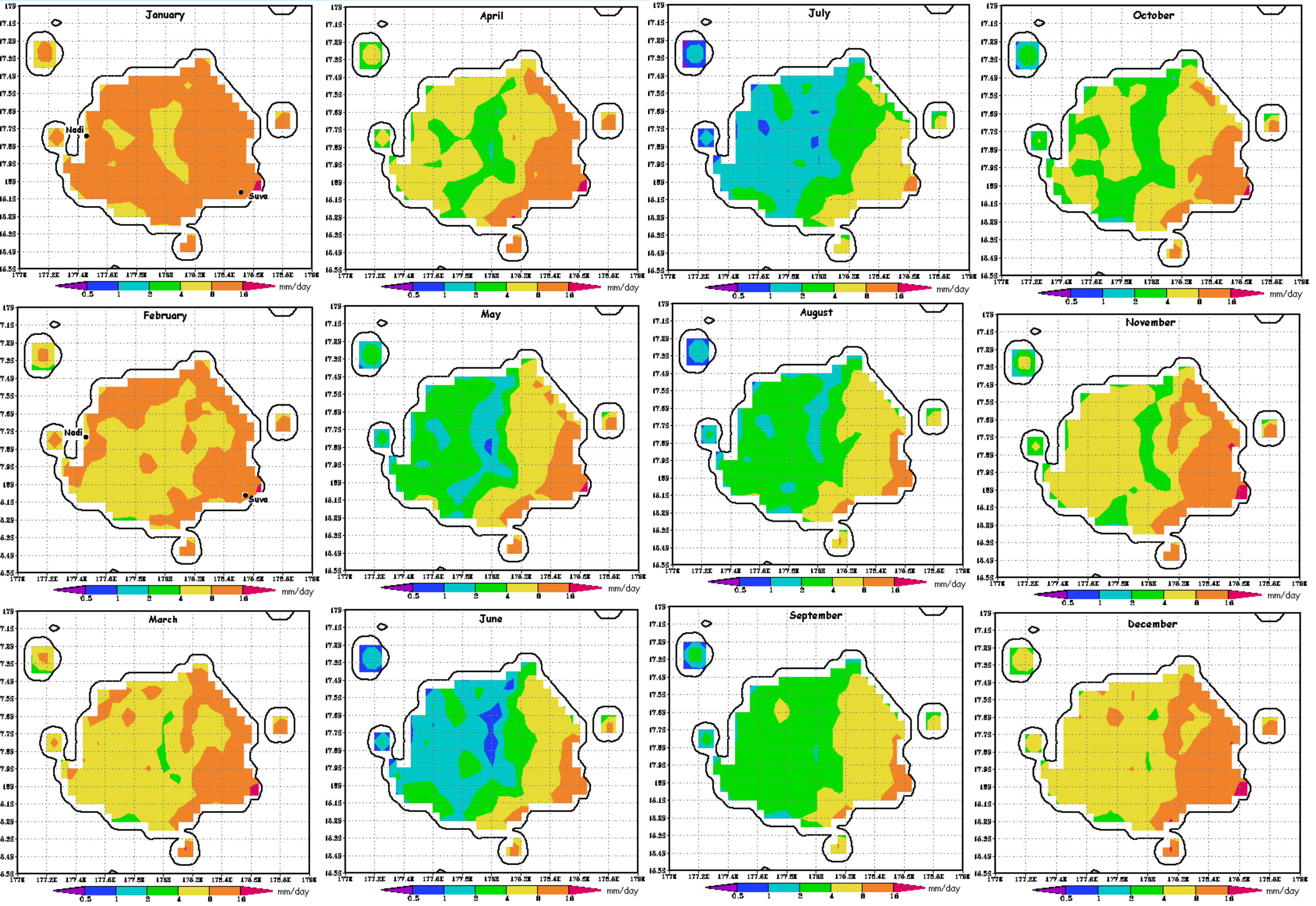


In Fiji, Nadi (western division) has a marked seasonality in rainfall as compared to Suva (central division) which has year round rainfall under the influence of trade winds (resulting in more number of wet days). The marked differences in rainfall seasonality at these two locations in Fiji has been reproduced in the model simulations.



Monthly Simulated Rainfall Climatology – Fiji

(The observed rainfall gradients between western and central divisions during the year, marked seasonality in rainfall in the western division and less rainfall at the leeward side of mountains are realistically simulated by the model)

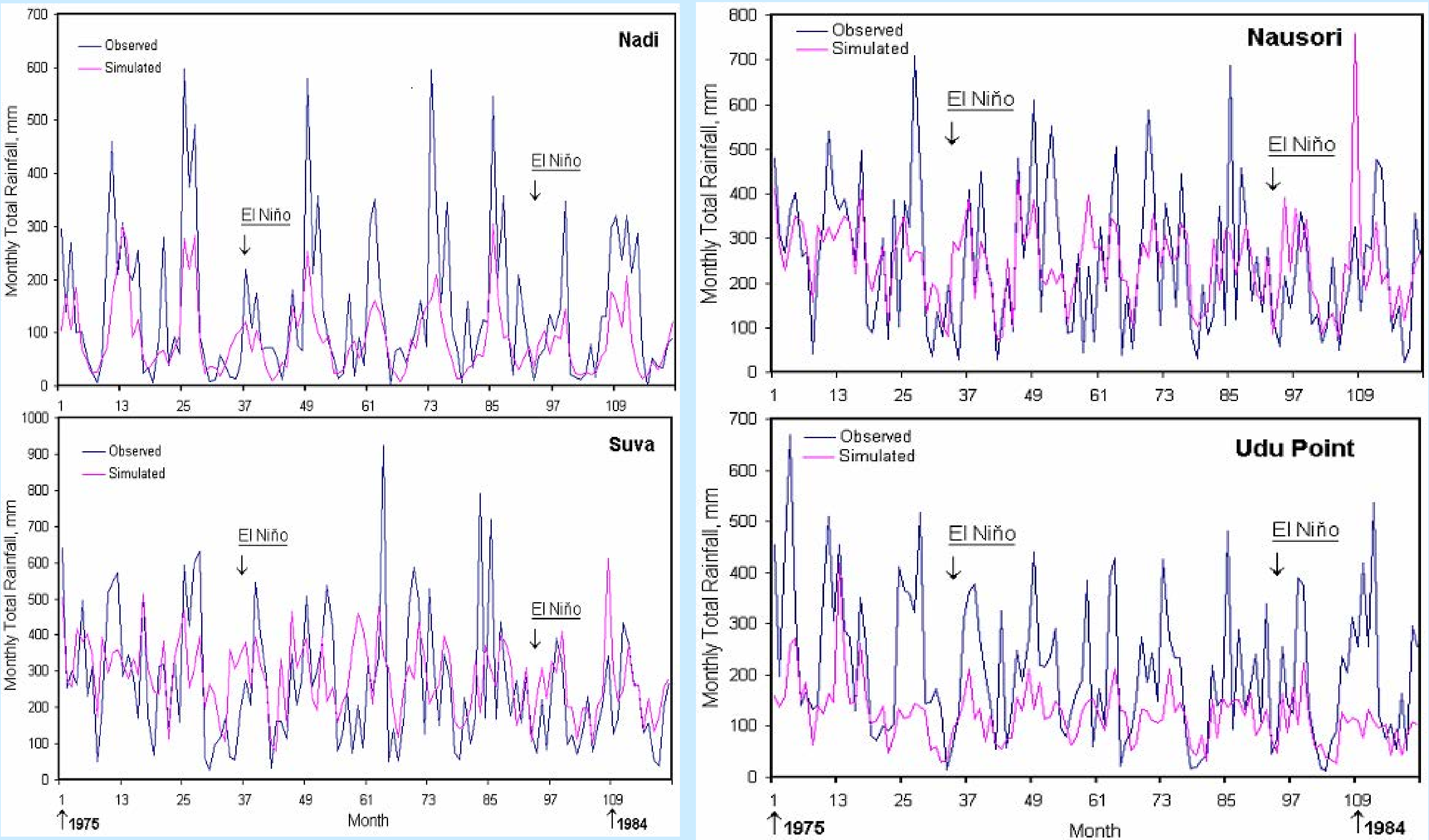


Comparison of observed and model-simulated annual and seasonal mean rainfall (mm) at selected stations in Fiji

		Observed	Simulated (Expt. 1)	Simulated (Expt. 2)
Nadi	**Annual**	1701±344.7#	1066±164.1 (0.74)*	1262±224.1 (0.73)
	Summer	1242±338.8	808±147.0	954±171.6
	Winter	459±167.0	258±56.1	308±76.2
Suva	**Annual**	3175±599.9	3395±387.3 (0.45)	2814±403.8 (0.52)
	Summer	2011±401.6	1971±178.7	1789±272.9
	Winter	1164±401.3	1424±282.8	1024±237.3
Nausori	**Annual**	2971±456.8	2950±289.9 (0.55)	2416±355.9
	Summer	1916±225.4	1761±161.0	1582±265.8
	Winter	1056±294.1	1190±258.4	834±188.8
Udu Point	**Annual**	2545±533.3	1450±304.7 (0.56)	1804±311.4 (0.59)
	Summer	1737±366.8	861±142.9	1152±178.5
	Winter	808±264.8	589±184.2	653±168.4

*# Standard deviation for 10 year rainfall data; * Correlation Coefficient with observed monthly rainfall data*

Observed and Simulated interannual variability of monthly total Rainfall at selected locations in Fiji



- Variable-resolution global models are well-suited to perform the simulations “traditionally” performed by limited-area RCMs, whilst avoiding the usual lateral boundary problems.
- The variable-resolution global model C-CAM has demonstrated substantial skill in reproducing many observed features of the Fiji’s climatology (precise reasons for biases in temperature/rainfall are being investigated).
- Recent modelling advances and greater computing power can now allow regional climate simulations down to around 8 km resolution (very relevant for Pacific Island Countries).

To Conclude:

A coherent picture of regional climate change for its application to impact assessments, achieved through available regionalisation techniques, will require more coordinated efforts to evaluate the different methodologies, compare methods and models to each other and apply these methods to climate change research in a comprehensive strategy that involves a range of A-O GCM and regionalisation experiments.

Thanks