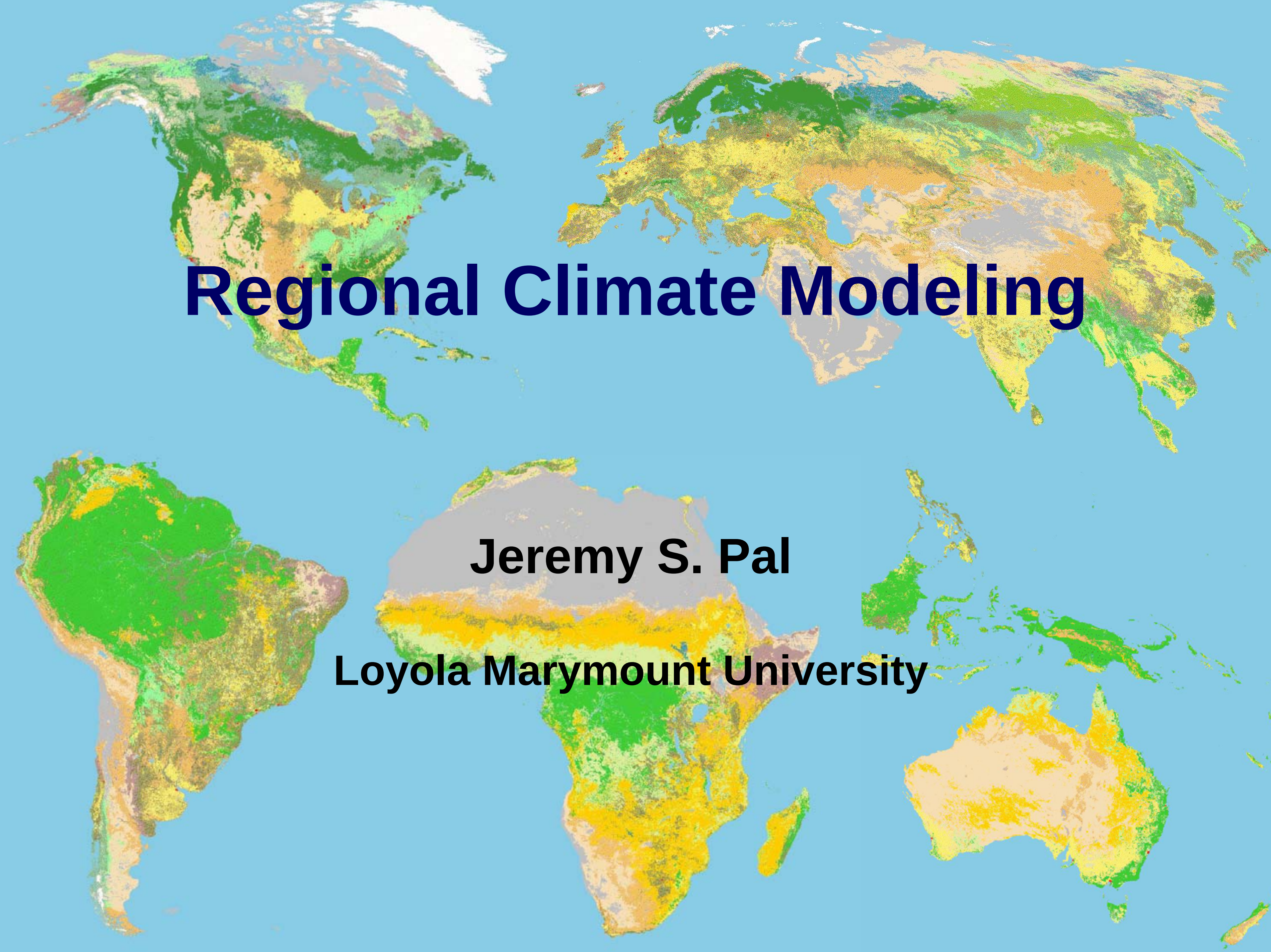


Regional Climate Modeling

Jeremy S. Pal

Loyola Marymount University

Science Editorial

C. Huntingford and J. Gash

16 September 2005

EDITORIAL

Climate Equity for All

Recent natural catastrophes have catapulted climate into the headlines again. As we witness the devastation wreaked by Hurricane Katrina, we are also reminded of numerous floods, droughts, and storms seen across the world in recent years. Are these linked to climate change? Questions about climate change, its global effects, and whether and how we can tackle this issue can no longer be avoided. Fortunately, this summer at the G8 Summit in Scotland, the leaders of the world's major industrialized nations agreed on the need to reduce carbon emissions; and although there is argument about the mechanism and timing, the case for moving to a low-carbon economy is essentially won. But we are faced with a rapidly changing global economy. As developing countries industrialize—China and India in Asia and Brazil and Mexico in Latin America—greenhouse gas–related climate stresses are expected to increase. At the same time, the environments, economies, and societies of the least-developed countries, such as those in Africa, are the most vulnerable to climate change because their ability to adapt is poor. Reaching international agreement on actions to minimize the dangerous impacts of climate change requires not only negotiations among developed nations but dialogue with the developing world. How do we involve these developing countries in the ongoing climate change discussions, and what information is needed to inform both developing-country policies and international decisions?

Local scientists could help formulate developing-country perspectives on climate change by conducting regional climate model experiments. These are essentially high-resolution weather forecast models that are used to calculate the environmental impacts of predicted changed weather patterns. Only when there are estimates of the economic and social impacts of changes in flood and drought frequency can possible increases in global mean temperature be translated into estimates of changes in food security and livelihoods. Scientists in the developing countries concerned are best placed to undertake these detailed local analyses. This work would also provide incentives to governments to maintain the long-term climate data sets that are needed for verification of climate simulations at the present levels of greenhouse gas concentrations.

Technologies to run modeling experiments are now being made available to scientists in developing countries. But this initial technical capacity is of little use without the human scientific capacity to design and interpret the experiments. Creating this expertise is a long process that, for each individual, requires continual personal development in a vibrant research environment. There is strong argument for concentrating scientists at centers of excellence in the developing world. When Carlos Nobre directed the Brazilian Center for Weather Forecasting and Climate Research in the 1990s, he initiated collaborations with experts in the United Kingdom and United States, building a critical mass of local expertise. As a result, Brazil now includes climate change in its long-term planning for economic and land use development.

Earlier this year, speakers at a Royal Society meeting in London indicated that climate change is likely to increase the frequency of crop failure in Africa. Other research presented this month at the British Association's Festival of Science in Dublin warned that an extra 50 million people will be at risk of hunger by 2050, and the majority of these will be in Africa. This alarming forecast begs for an Africa-based research program to investigate the possible impacts of regional climate change.

This need to strengthen climate change research in the developing world can be filled by establishing regional centers of excellence in developing countries and arranging training, staff exchanges, and shared research projects with developed nations. The Global Environment Facility, which provides grants to developing countries for projects that benefit the environment, has a mandate to address the issue of climate change. It is well placed to fund this initiative by either financing new institutions or strengthening and expanding existing organizations. The African Centre of Meteorological Application for Development, a pan-African center located in Niger, is one clear candidate for this role.

Developing countries need to become more engaged and empowered in the international negotiations on managing global climate change. This should be done quickly if we are to outrun the pace of that change.

Chris Huntingford and John Gash

Chris Huntingford and John Gash are at the Centre for Ecology and Hydrology, Wallingford, UK.

10.1126/science.1115898

Local scientists could help formulate developing country perspective on climate change by conducting regional climate model experiments.

Benefits of a Regional Climate Model

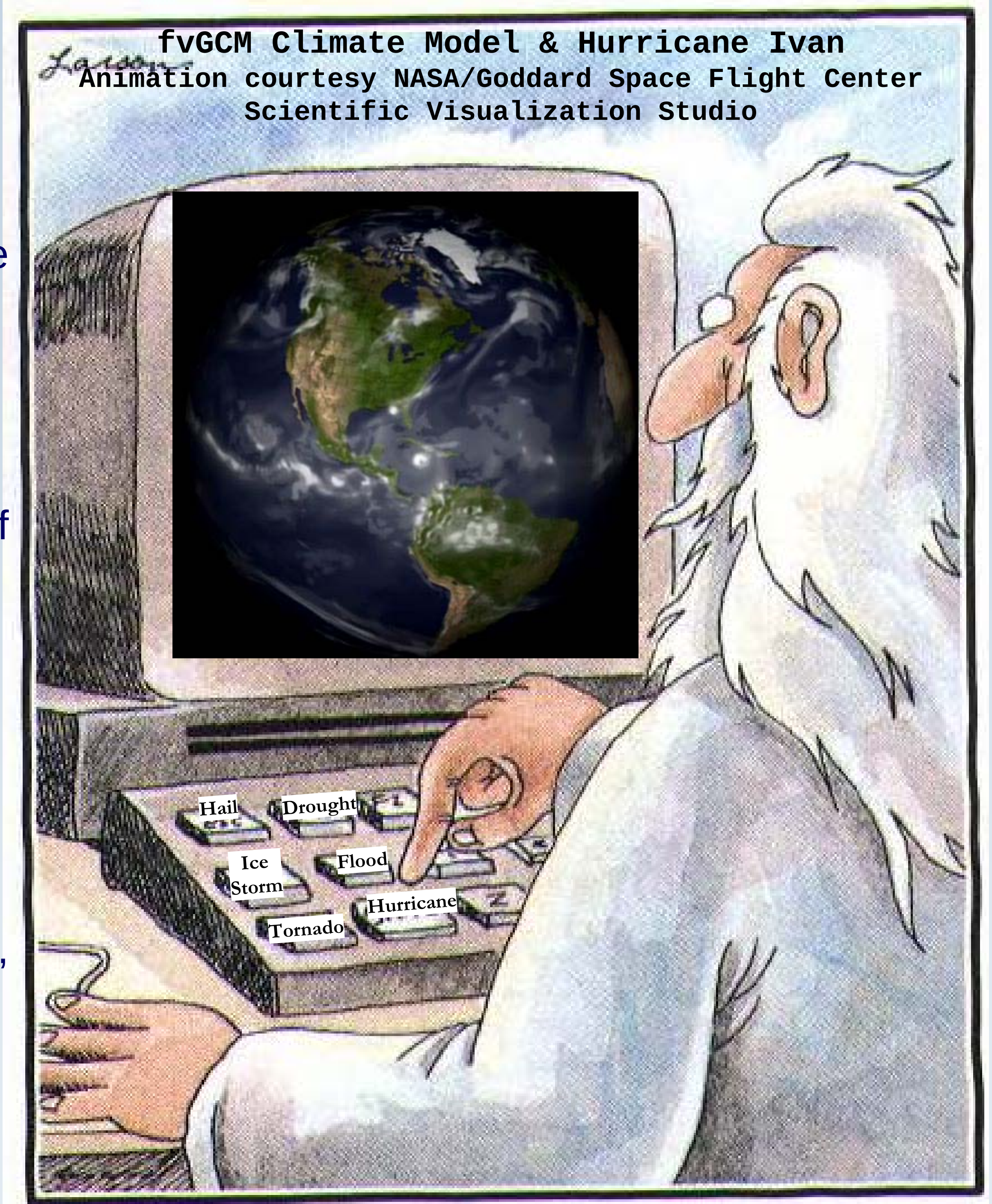
The editorial by C. Huntingford and J. Gash encouraging regional climate modeling studies in developing countries ("Climate equity for all," 16 Sept., p. 1789) perfectly captures the objectives of the Regional Climate Network (RegCNET) (see www.ictp.trieste.it/RegCNET/). Based at the International Centre for Theoretical Physics (ICTP) in Trieste, Italy, F. Giorgi, J. Pal, X. Bi, and others have developed and supported the use of the regional climate model RegCM via a listserv, workshops around the world, time on ICTP computers, and personal correspondence with users. At last count, RegCM is used by scientists in over 40 mostly developing countries or countries with economies in transition, including Egypt, Iran, Pakistan, India, Nigeria, Cameroon, Ghana, Bangladesh, China, Vietnam, the Philippines, Estonia, Peru, and Brazil. The benefits of support to these climate scientists cannot be overstated, as many of the smaller countries would not even show up in the geography of a global climate model, yet they are at considerable risk from climate change. Furthermore, the model itself benefits as developers strive to make it perform in regions influenced by monsoons, tropical convection, dramatic topography, and large lakes. Funding the efforts of climate scientists already working at the regional level and encouraging them to collaborate with those assessing impacts would be an expedient way to achieve more local capacity for climate prediction and adaptation.

LARA M. KUEPPERS

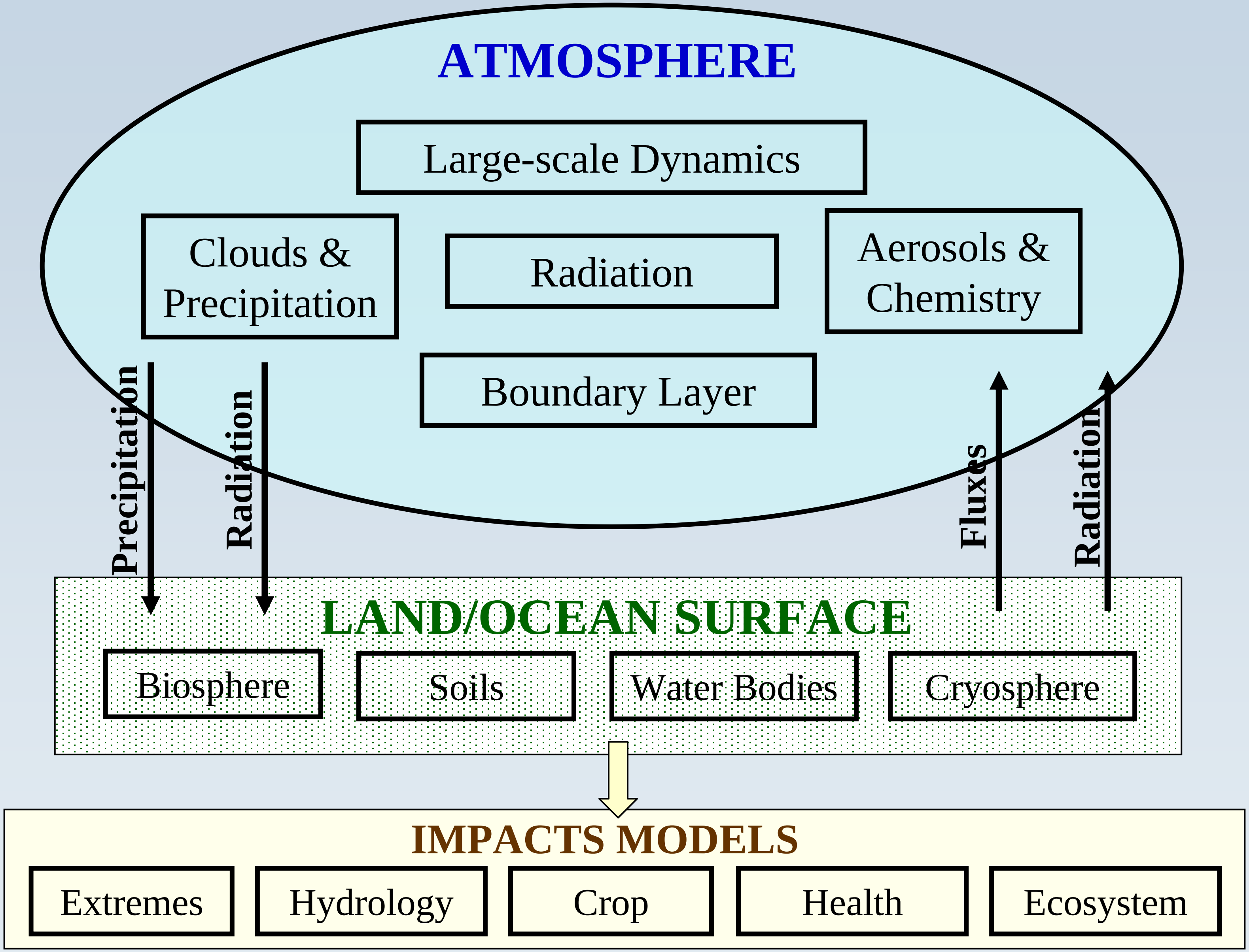
Department of Earth Sciences, University of California, Santa Cruz, 1156 High Street, Santa Cruz, CA 95064, USA.

Why Climate Models?

- Climate models help us understand the physical processes that govern climate and enable us to predict climate changes.
- They range from conceptual models to models of intermediate complexity to comprehensive 3D models with sophisticated representations of the major components of the Earth System.
- The 3D models typically quantify the interactions of the atmosphere, oceans, land surface, and ice.
- Can be used to simulate a variety of processes and feedbacks (e.g. climate change, land cover change).



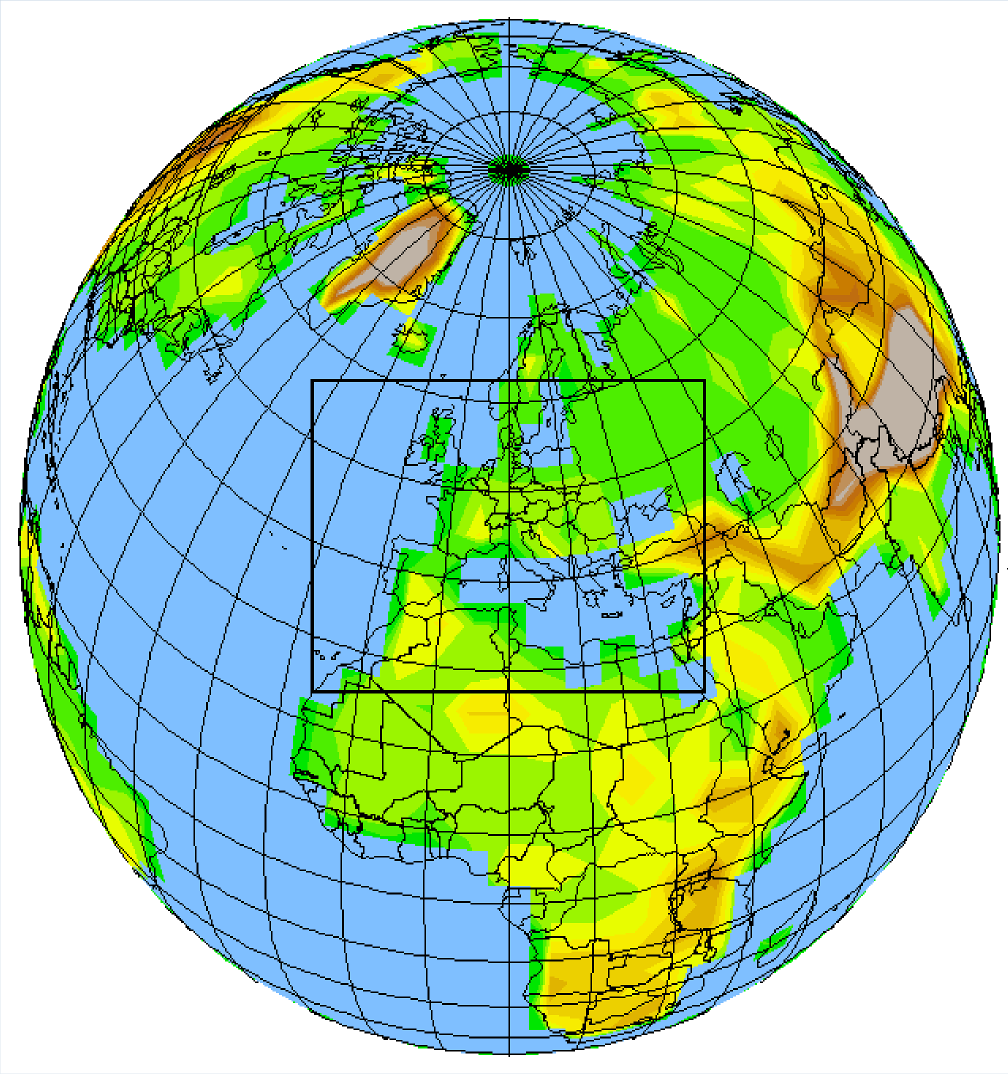
Schematic of the Modeling System



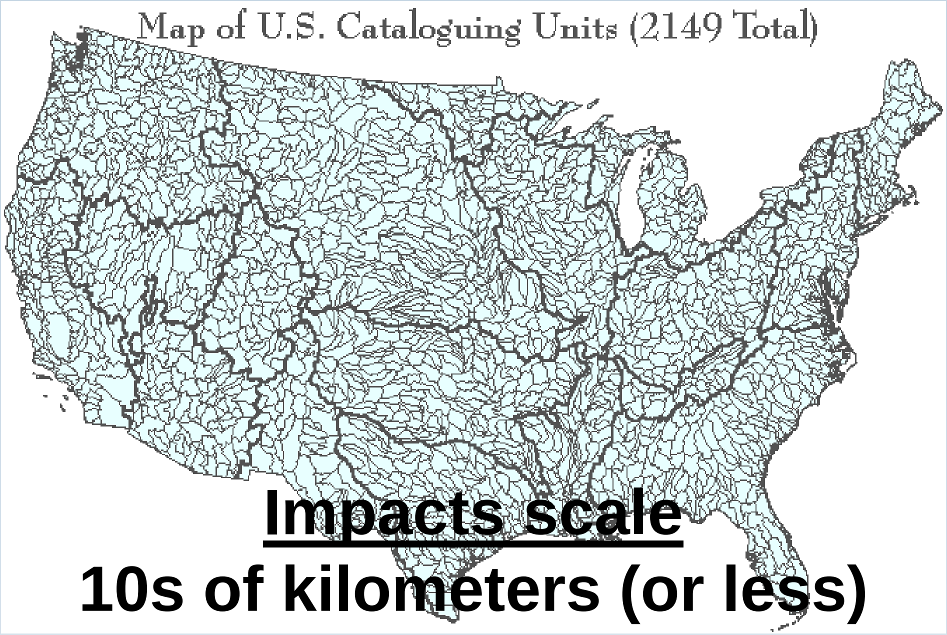
General Circulation Models (GCMs)

- **Coupled Atmosphere-Ocean General Circulation Models (AOGCMs) are the most advanced tools today available for climate simulation.**

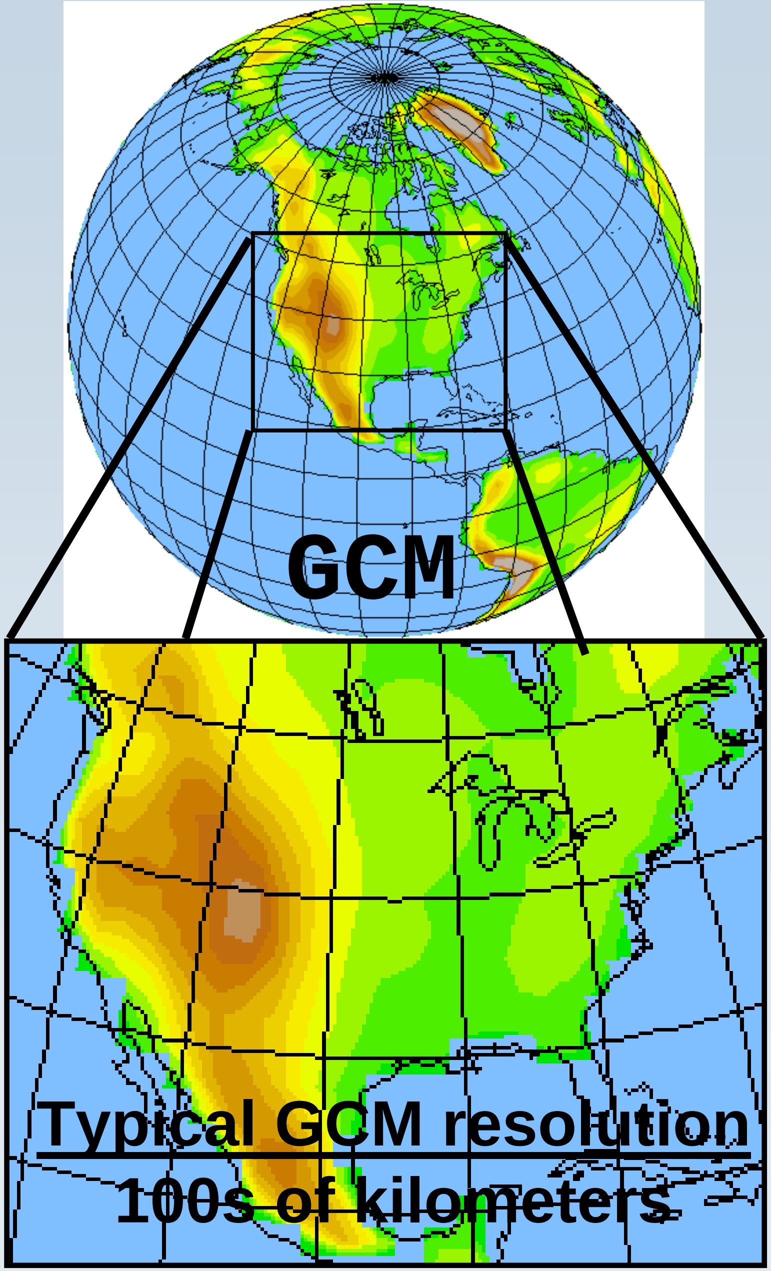
- **However, their resolution (100 – 300 km) is still too coarse to provide fine scale regional climate information useful for impact studies.**



Bridging the Scaling Gap



Impacts scale
10s of kilometers (or less)



Typical GCM resolution
100s of kilometers

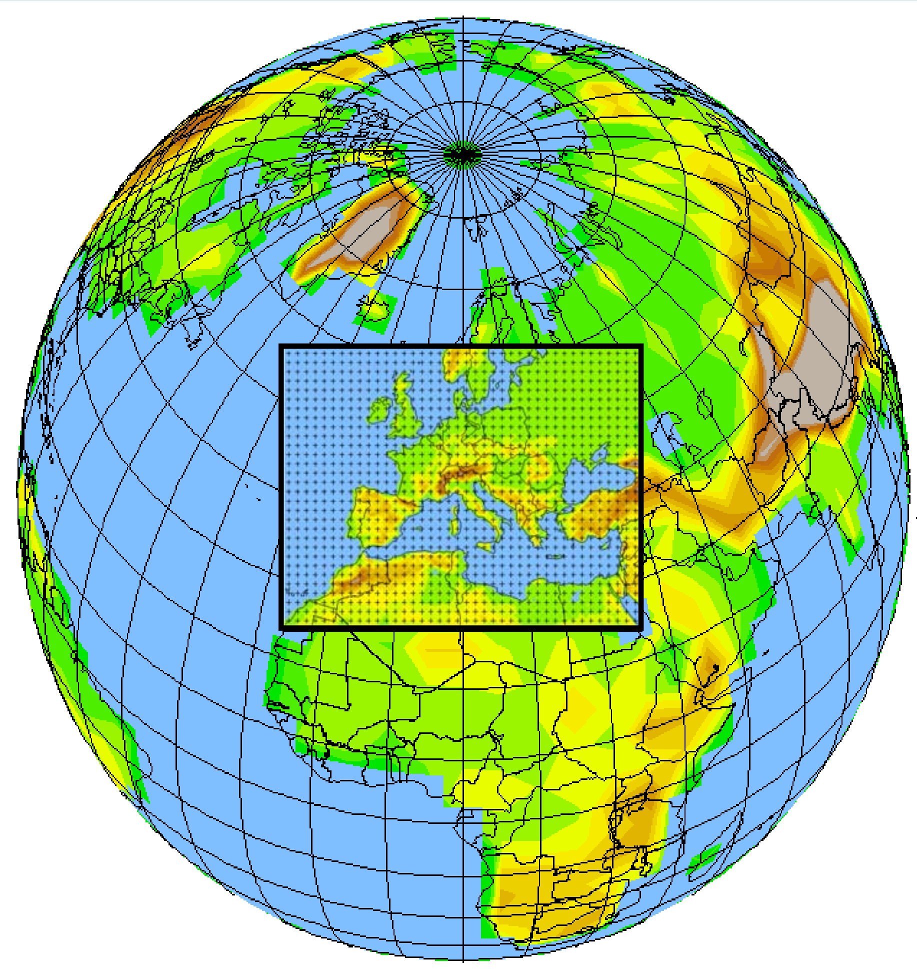
How do we go from the GCM scale to the impacts scale?

Regional Climate Modeling is an Option

- **Regional Climate Models (RCMs) can be "nested" within a AOGCM in order to increase the resolution (10s km) of a climate simulation.**

- **Initial conditions (ICs) and lateral boundary conditions (LBCs) for the RCM are obtained from the AOGCM.**

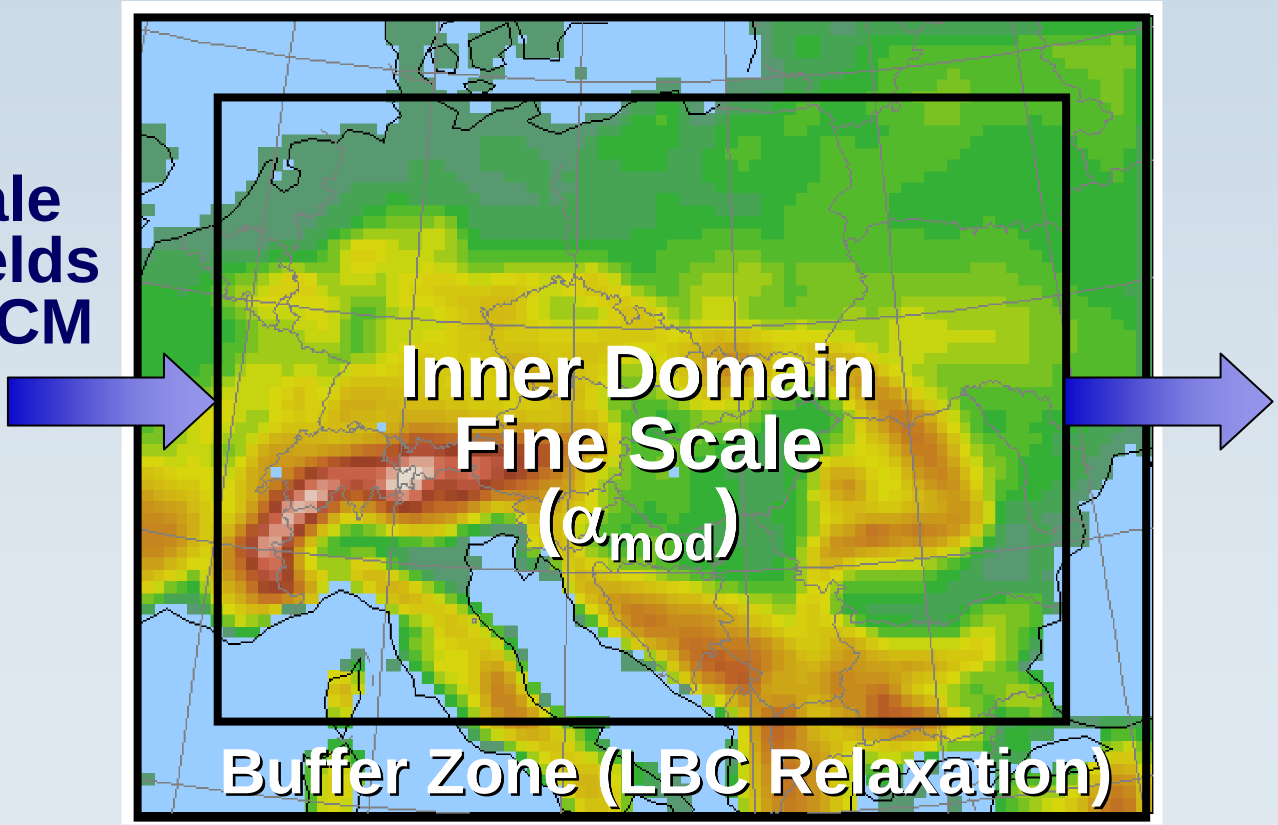
- **RCMs are intended to enhance the AOGCM simulation.**



RCM Nesting

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

Large Scale Forcing Fields from the GCM (α_{LBC})



Regional Climate Modeling: Advantages and Added Value

- Improved resolution of coastlines and topography.
- Improved simulation of mesoscale systems
- Improved simulation of extreme events
  - e.g. floods, wind storms, heat waves
- Improved resolution for Impacts models
  - e.g. agriculture, hydrology, air quality, storm surge
- Can be used for process studies to understand mechanisms
  - e.g. land-surface, sea surface temperatures, glacial/snow albedo
- Can include additional processes not included by the GCM simulations.
  - e.g. land cover changes, aerosols, lake effects, glacial melting
- Can be used on PCs.

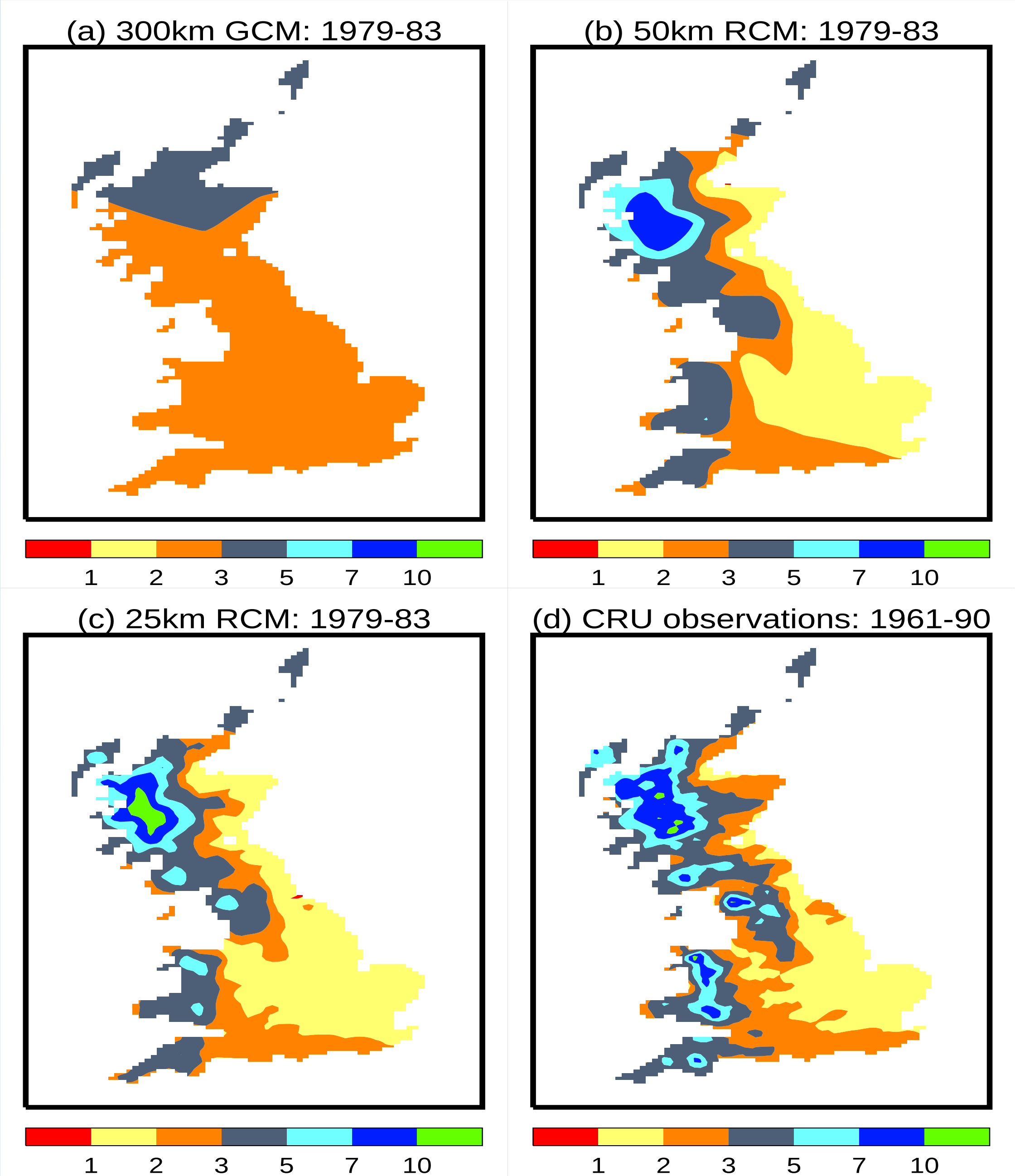
Regional Climate Modeling: Limitations

- One-way nesting (most of the time)
  - No regional-to-global feedbacks
- Technical issues in the nesting technique
  - Domain, LBC procedure, physics, etc.
- Not intended to correct systematic errors in the large scale forcing fields
  - Garbage in, garbage out.
  - Always analyze first the forcing fields
- Computationally demanding

Winter Precipitation over Britain

300km GCM

50km RCM



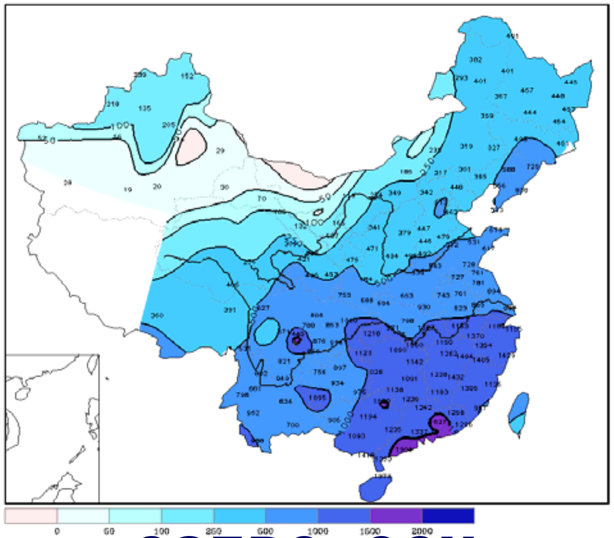
25km RCM

Observed

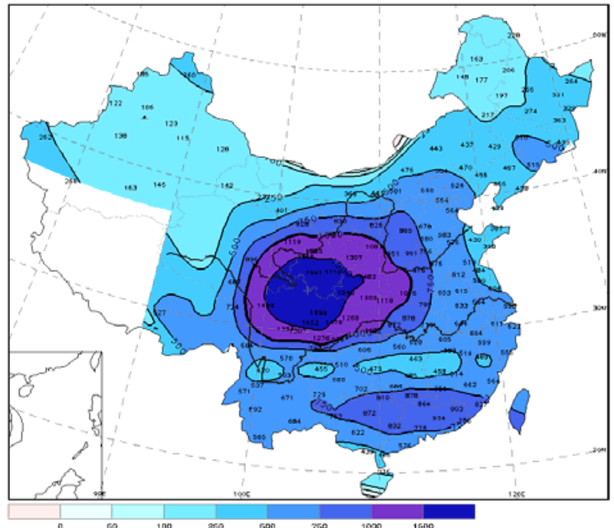
Figure Courtesy: Hadley Centre

Impact of Horizontal Grid Spacing

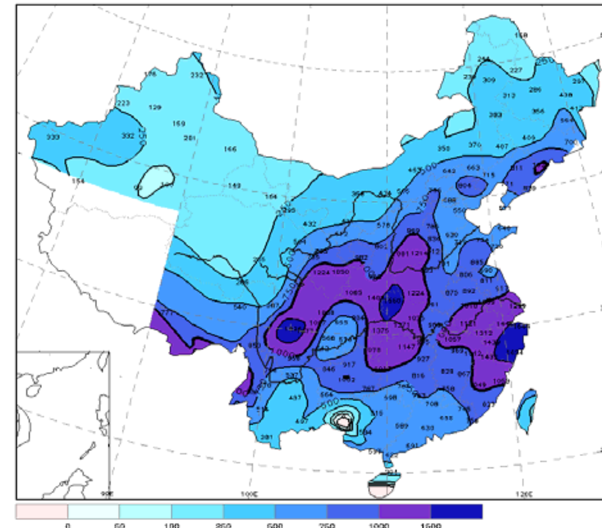
OBSERVATIONS



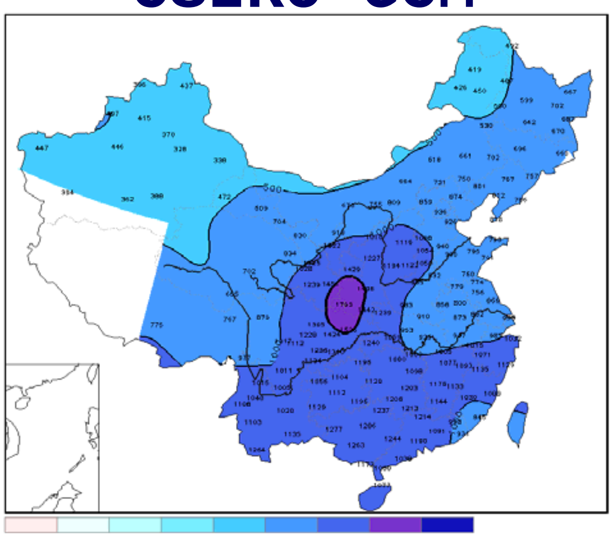
Dx = 360 km



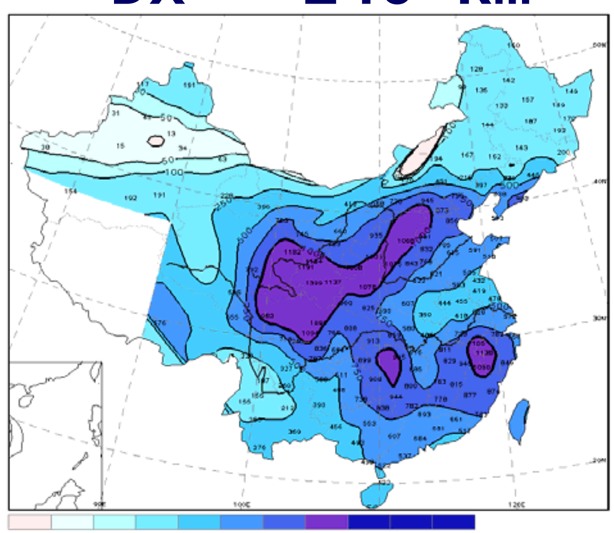
Dx = 120 km



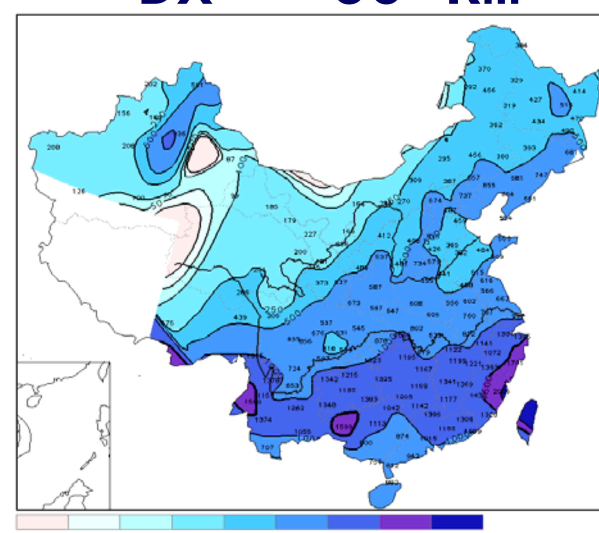
CSIRO GCM



Dx = 240 km

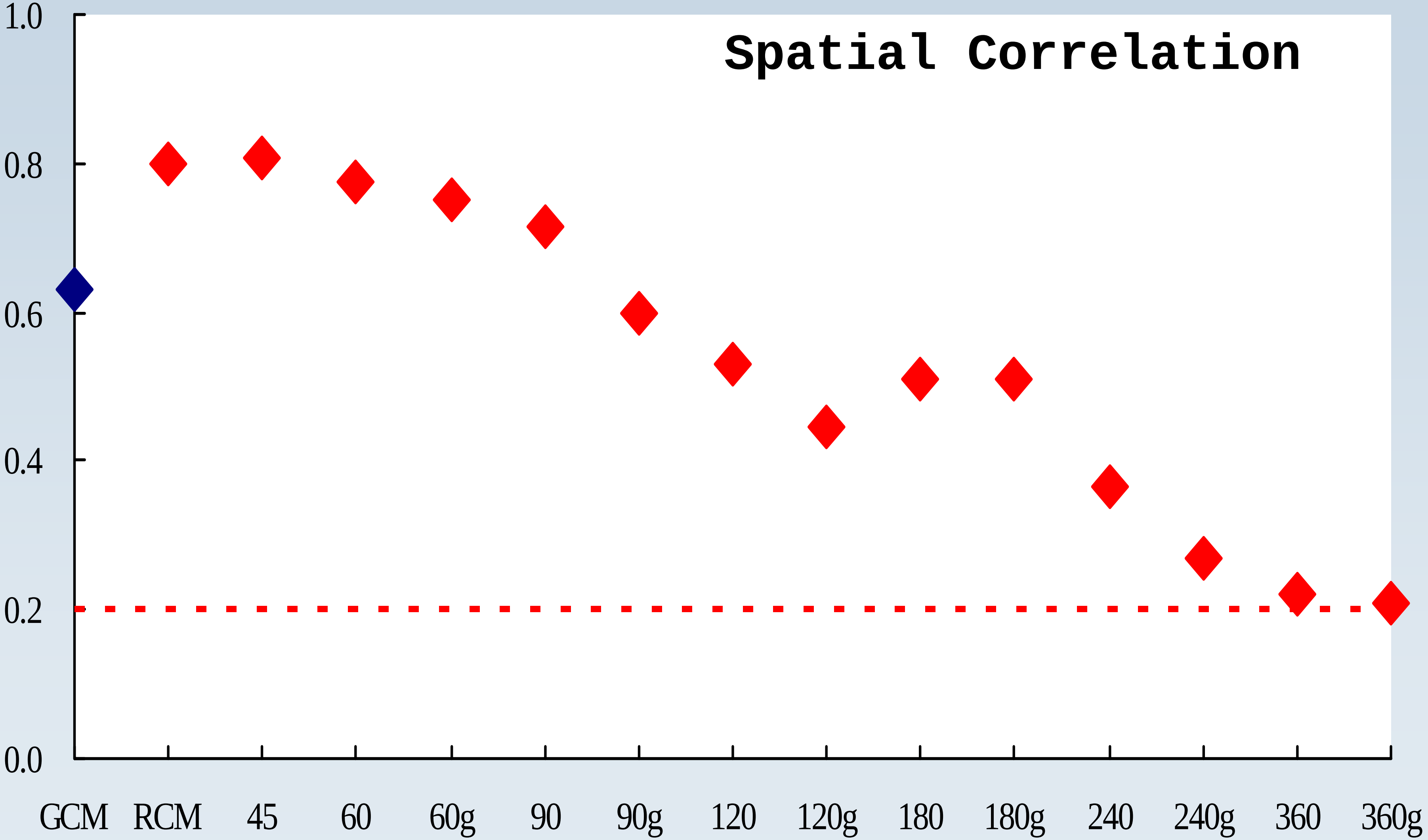


Dx = 60 km



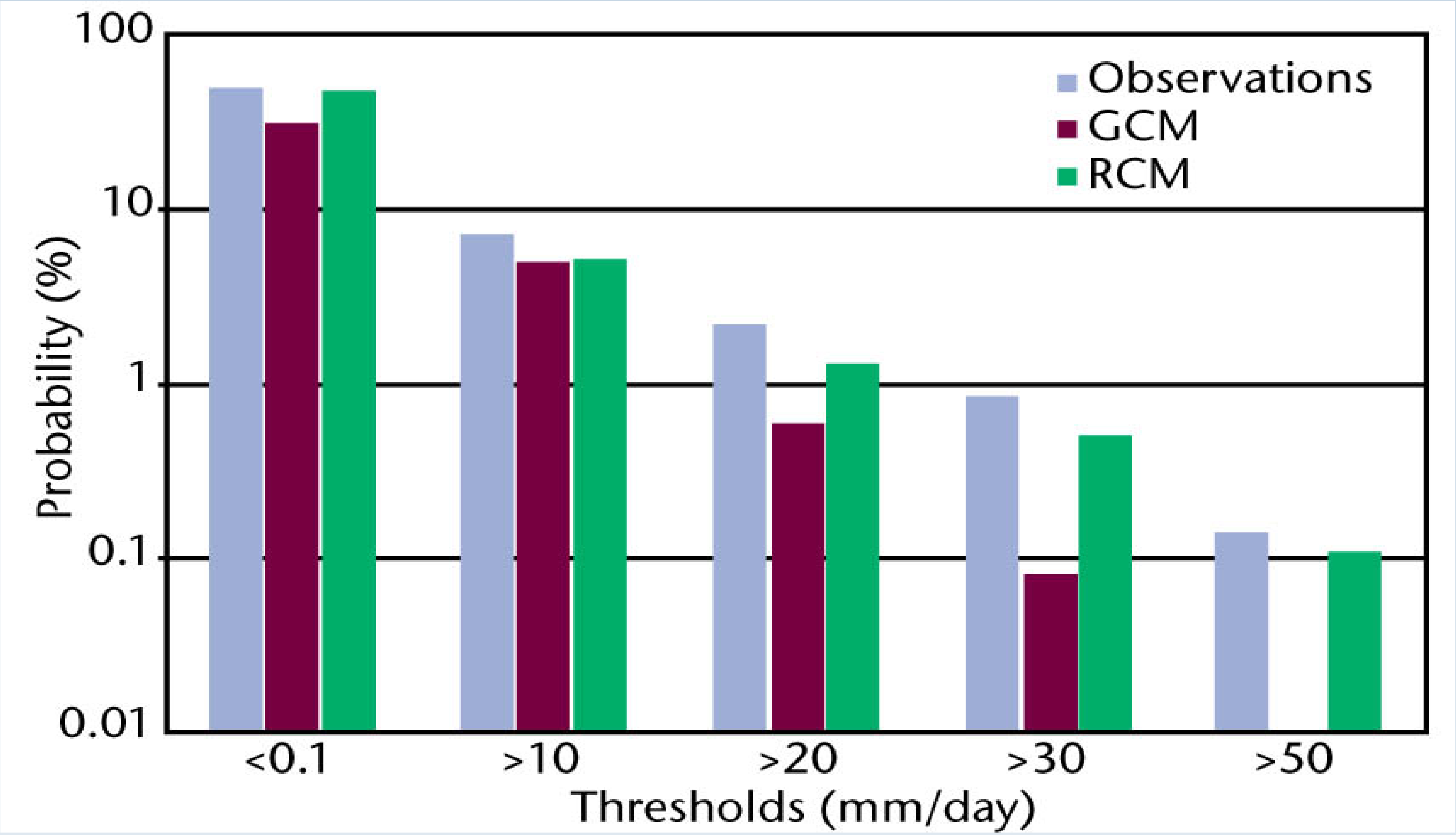
Gao et al 2006a

Impact of Horizontal Grid Spacing



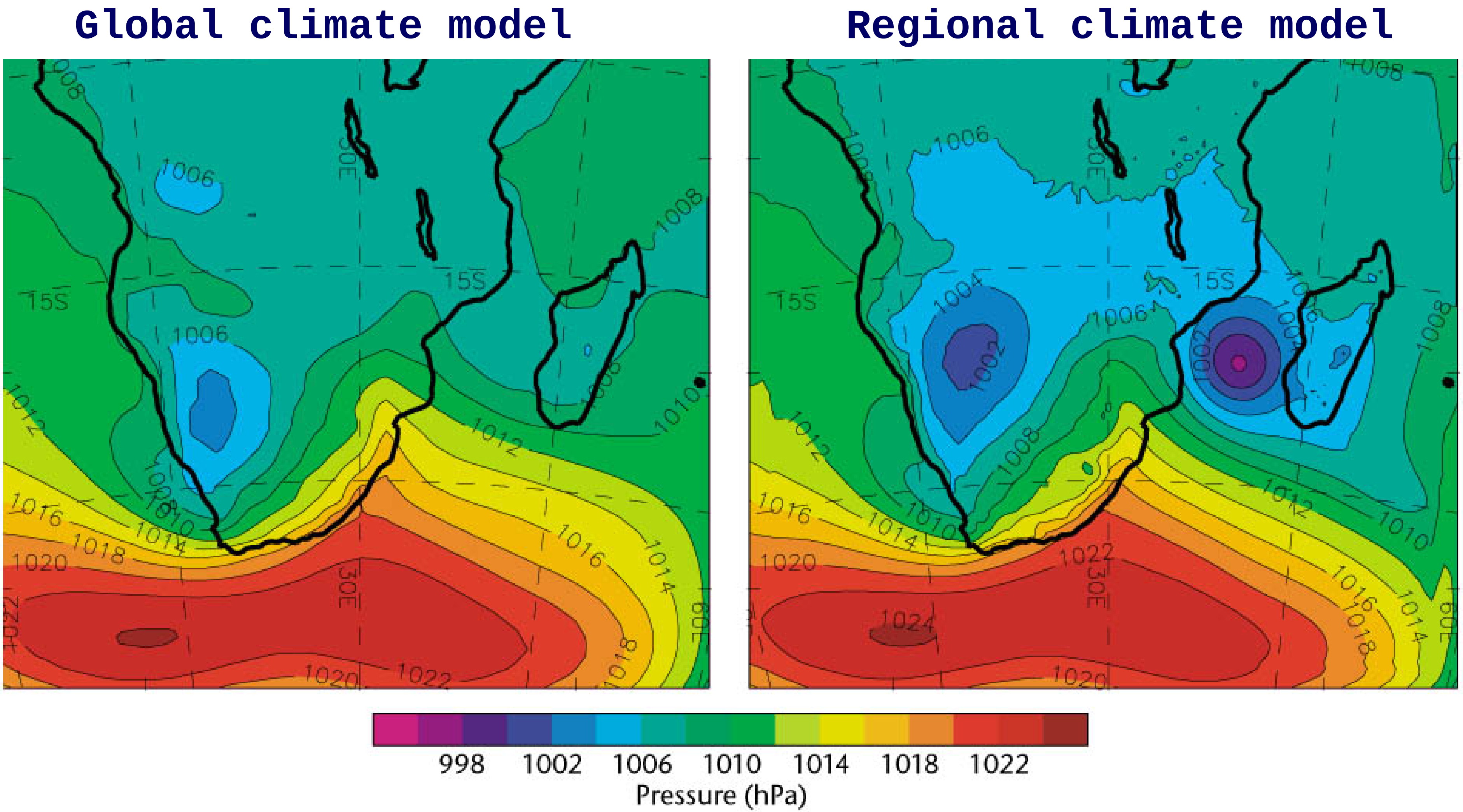
Gao et al 2006a

Winter Daily Precipitation over the Alps



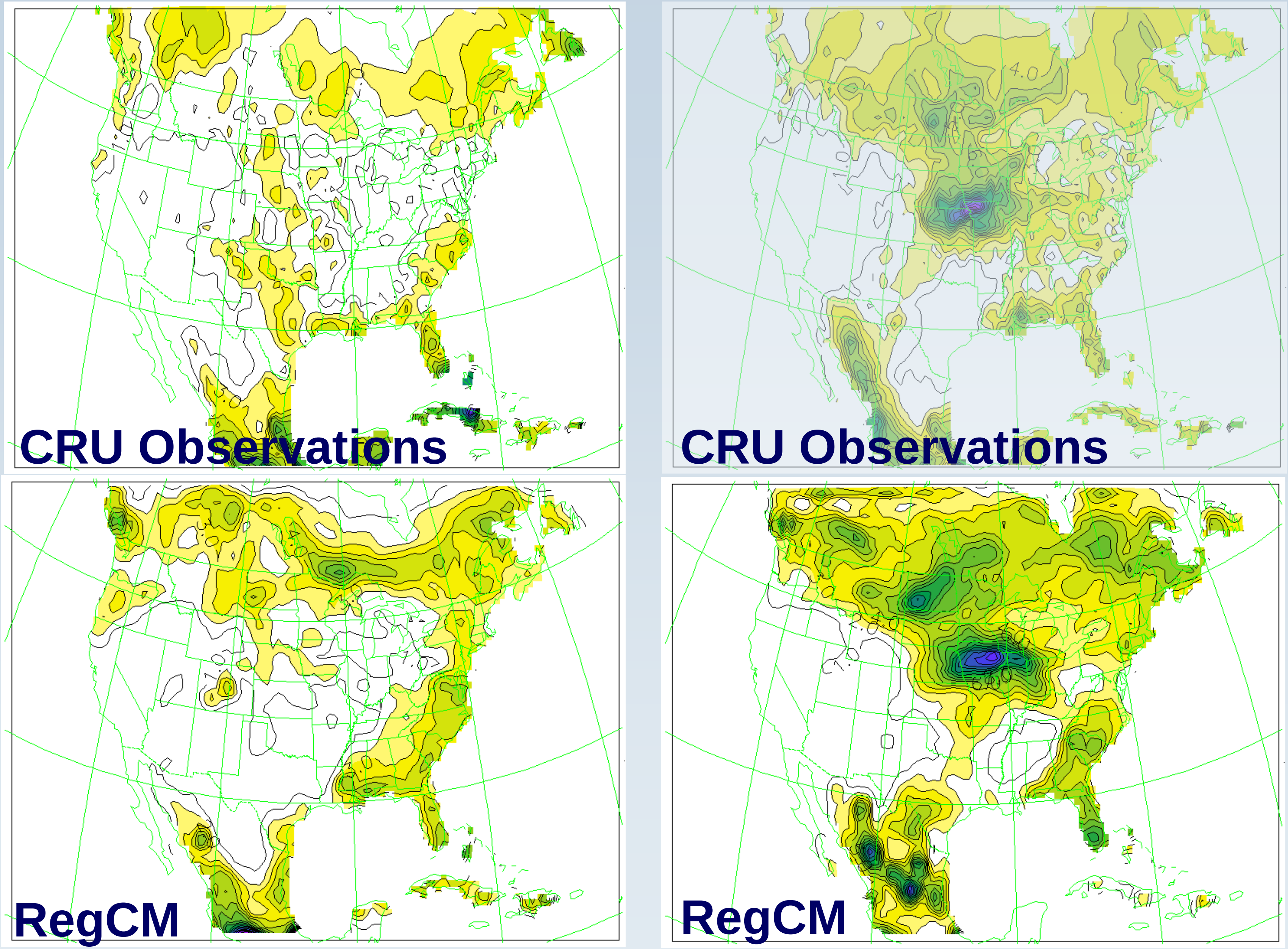
RCMs typically simulate extreme preciptiation better than GCMs. They also tend to better simulate interseasonal variability.

Simulation of a Tropical Cyclone



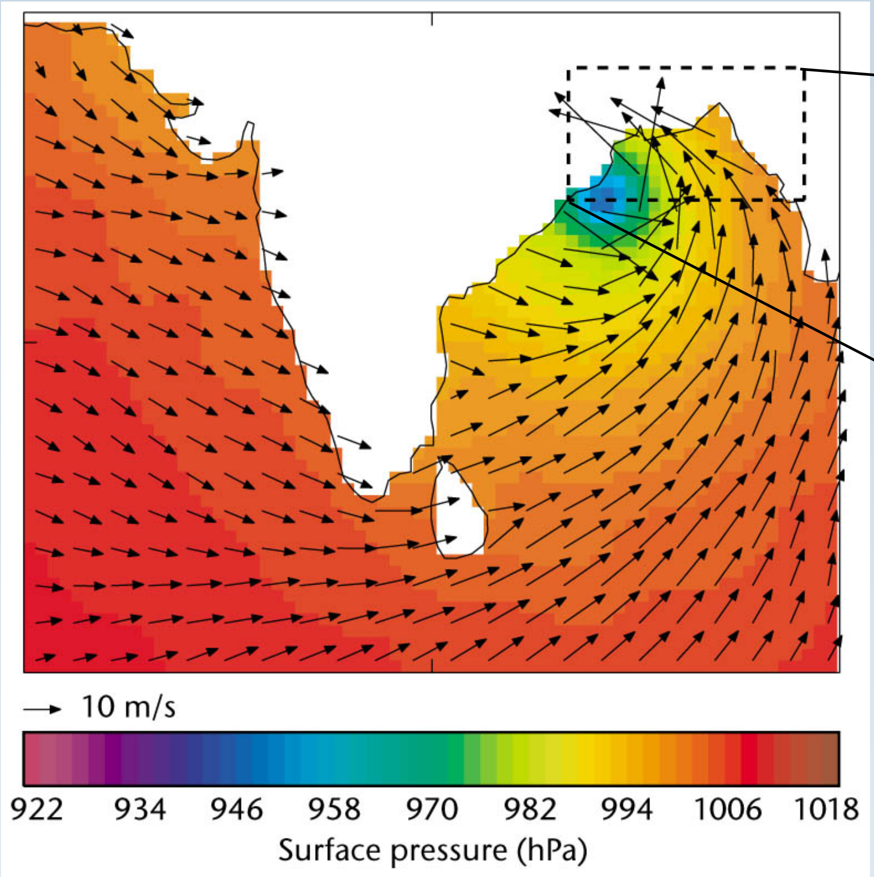
RCMs can simulate circulation features not resolved by GCMs

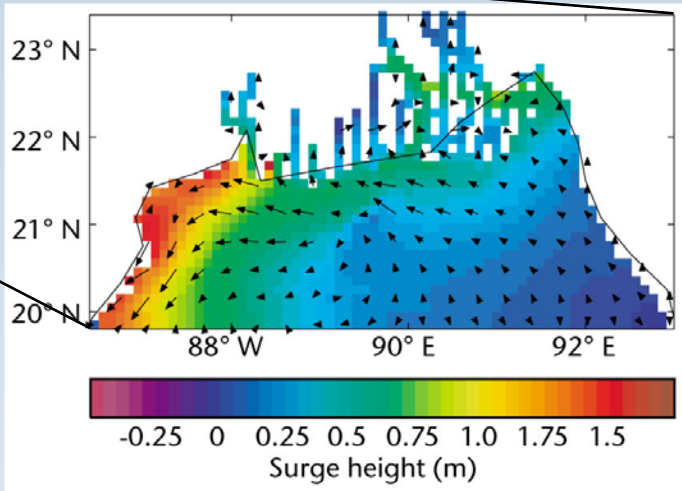
1988 Drought (MJ) | 1993 Flood (JJ)



(Pal & Eltahir 2003)

Bay of Bengal Cyclone and Resulting Storm Surge





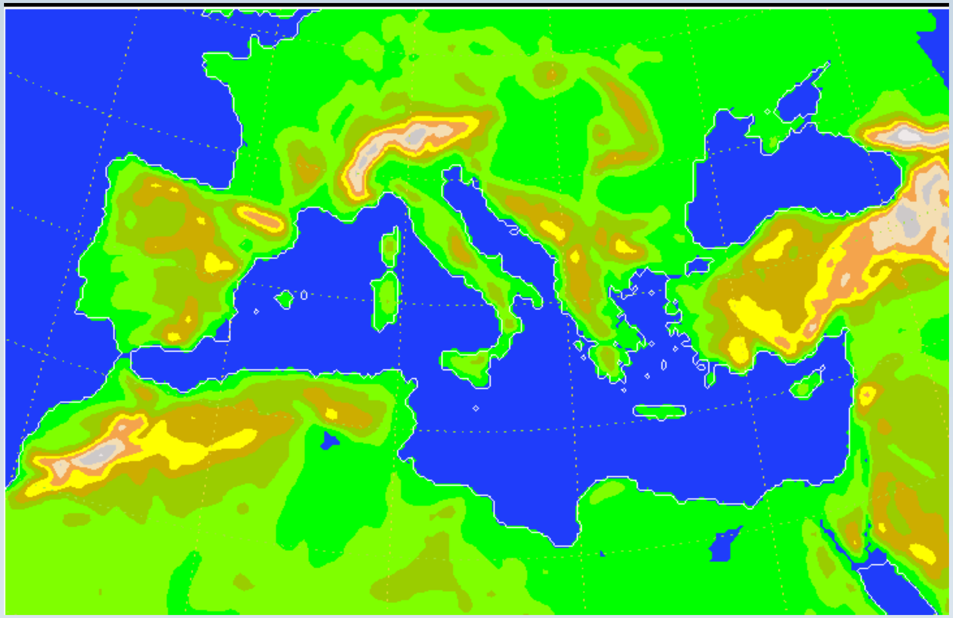
Resulting storm surge simulated using the Proudman Oceanographic Laboratory model

RCM data is useful for simulating climate impacts models

High resolution double-nested simulations

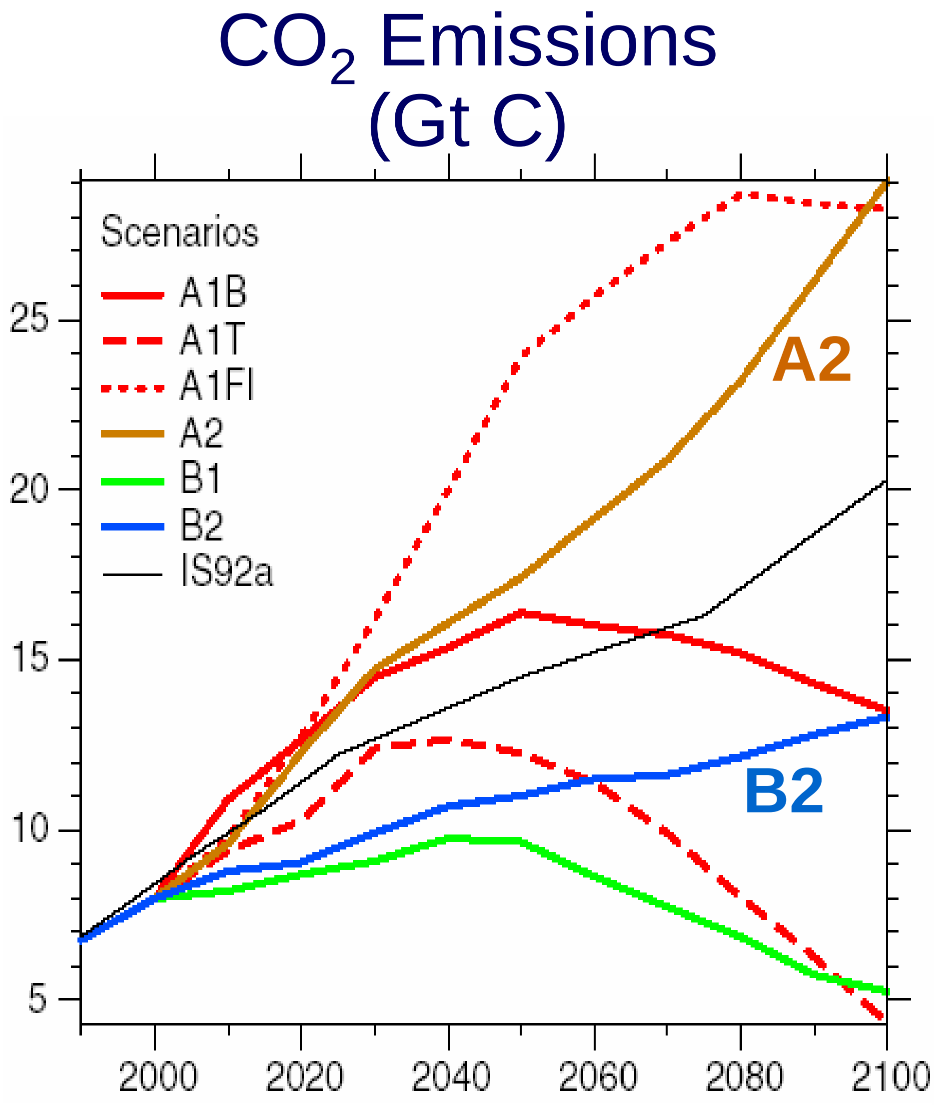
- **Model configuration**
  - 20-km grid point spacing
  - Full Mediterranean domain

- **Experiment design**
  - Forcing fields from PRUDENCE RegCM simulations
  - Reference simulation (1961-1990)
  - A2, B2 scenarios (2071-2100)

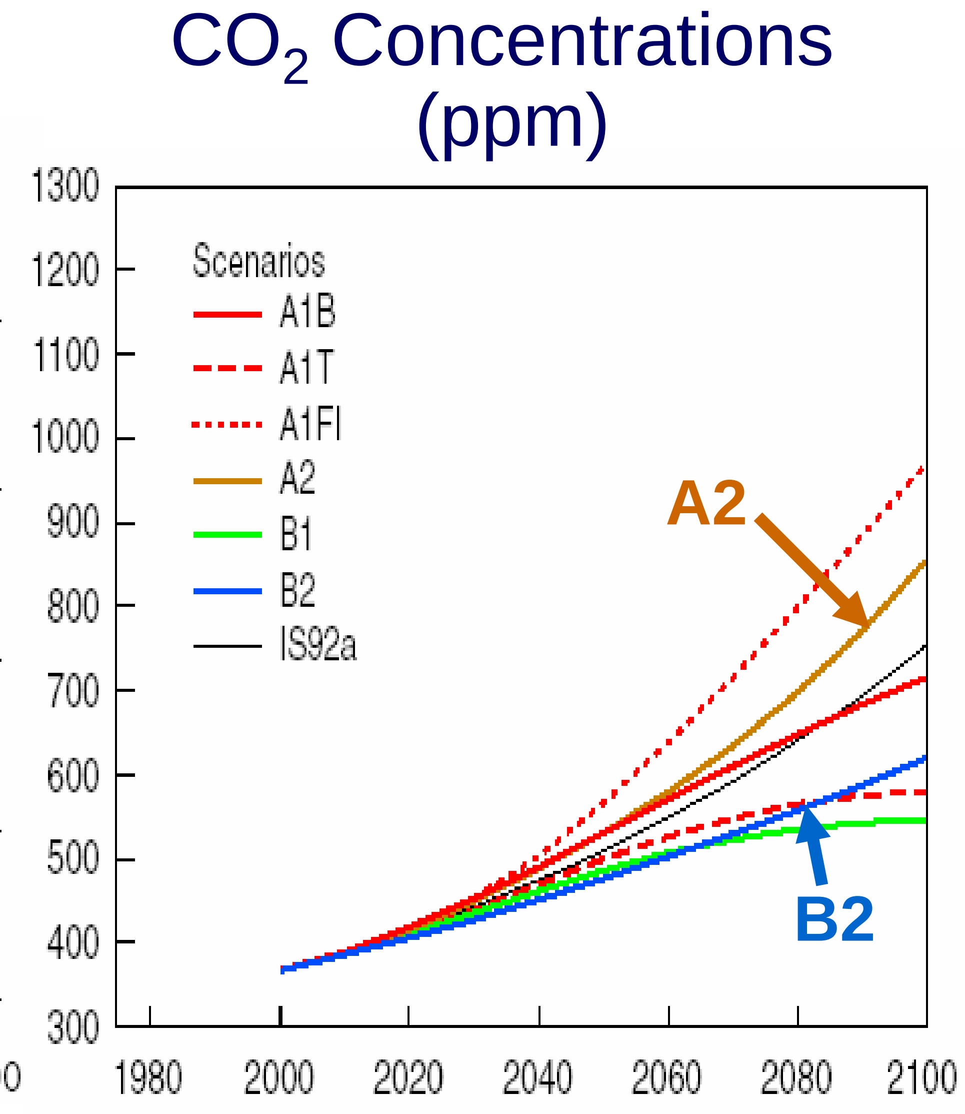


Gao et al 2006b

SCENARIOS



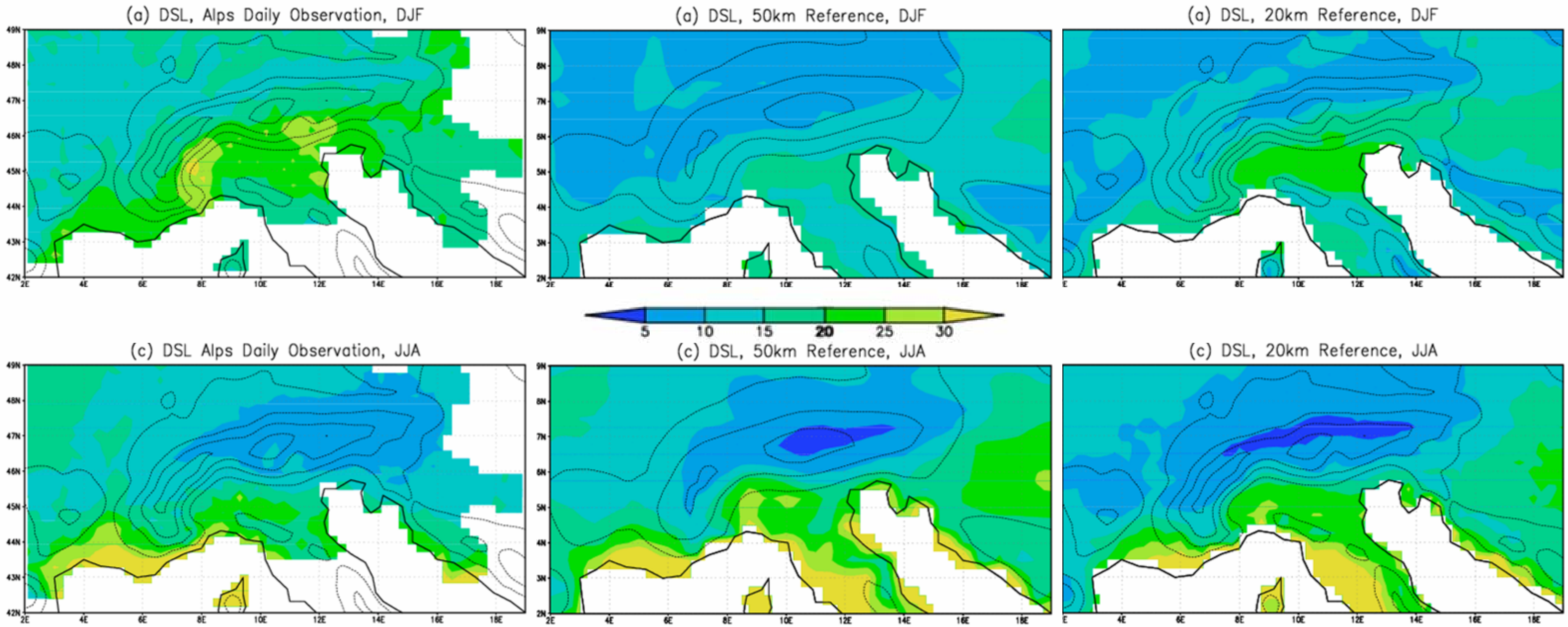
CO2 Emissions
(Gt C)
Scenarios
A1B
A1T
A1FI
A2
B1
B2
IS92a
A2
B2
25
20
15
10
5
2000
2020
2040
2060
2080
2100



CO2 Concentrations
(ppm)
Scenarios
A1B
A1T
A1FI
A2
B1
B2
IS92a
A2
B2
1300
1200
1100
1000
900
800
700
600
500
400
300
1980
2000
2020
2040
2060
2080
2100

Maximum Dry Spell Length (1961-1990)

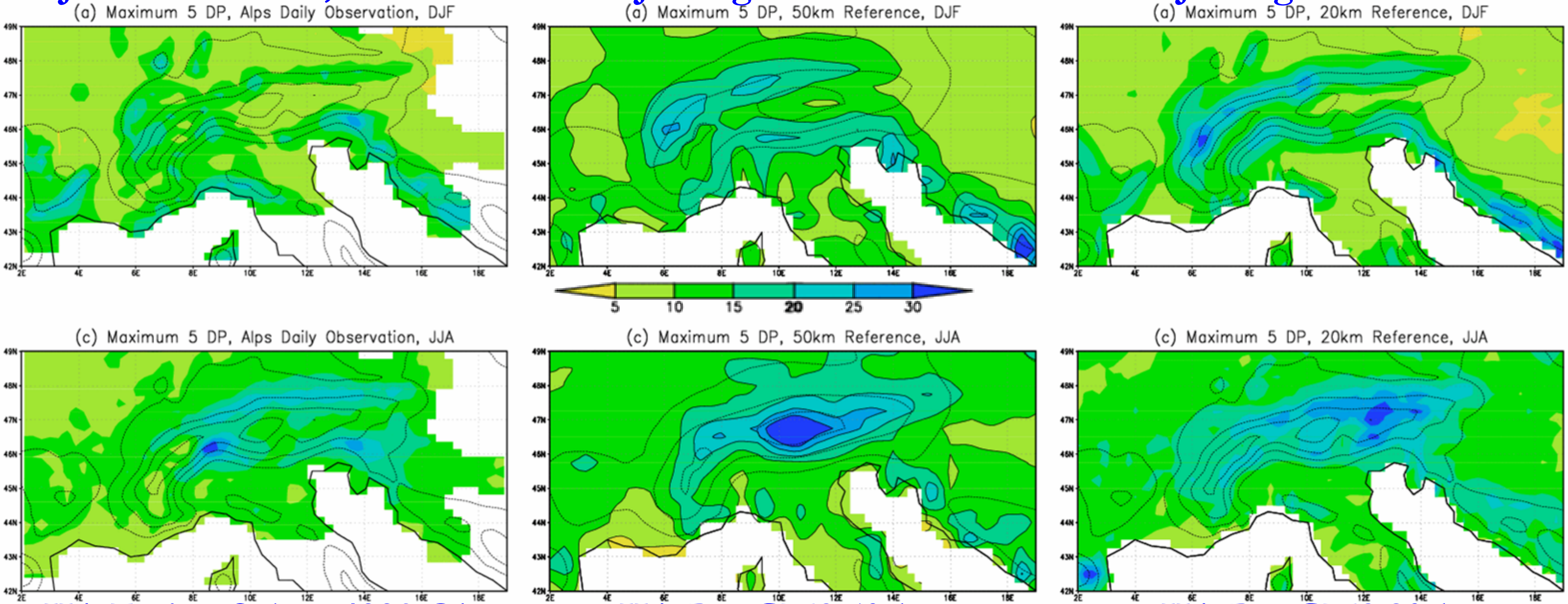
DJF Frei & Schär, 1998 Obs — DJF RegCM3 50-km — DJF RegCM3 20-km



JJA Frei & Schär, 1998 Obs — JJA RegCM3 50-km — JJA RegCM3 20-km

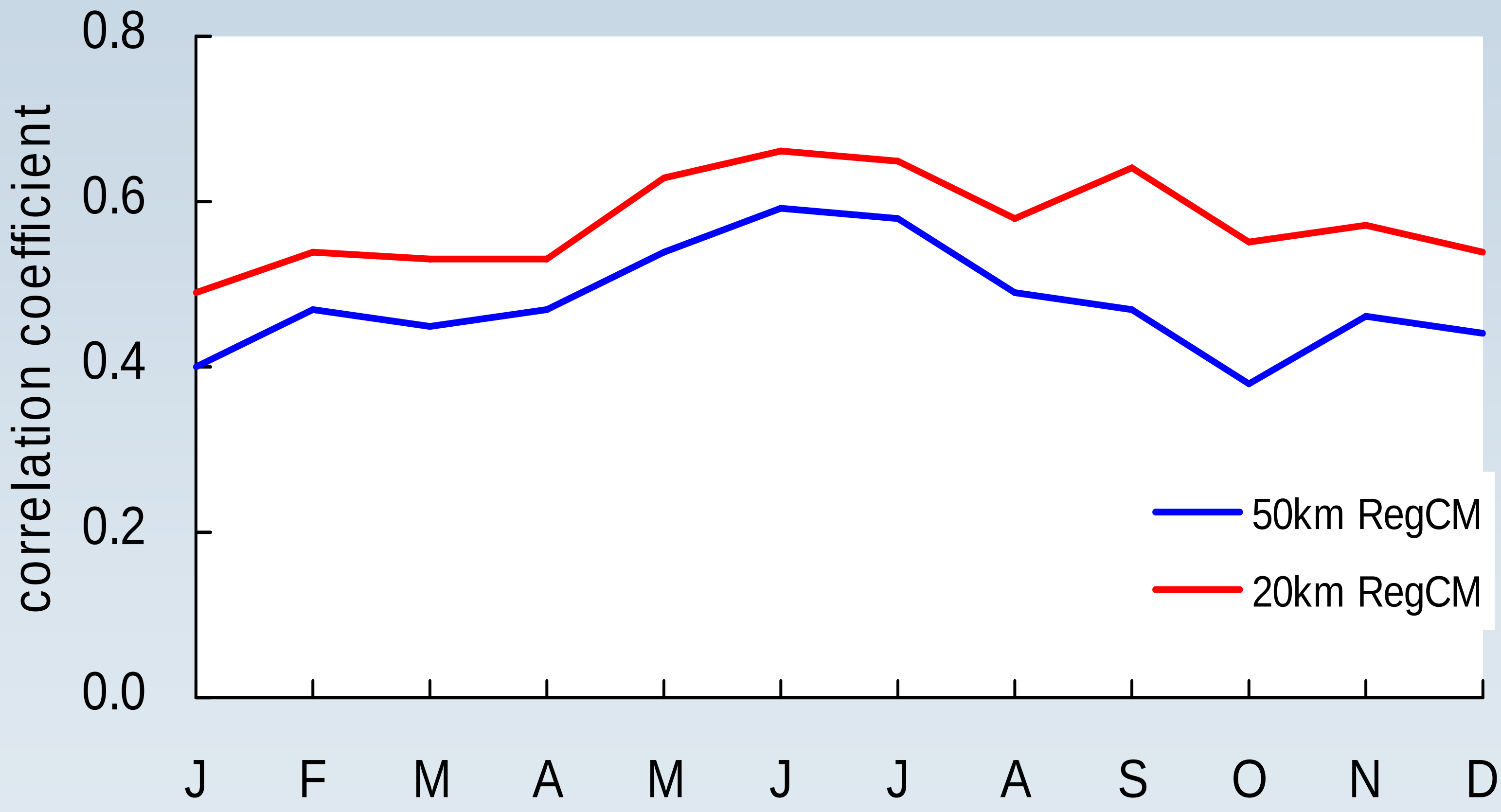
Maximum 5 Day Precipitation (1961-1990)

DJF Frei & Schär, 1998 Obs | DJF RegCM3 50-km | DJF RegCM3 20-km



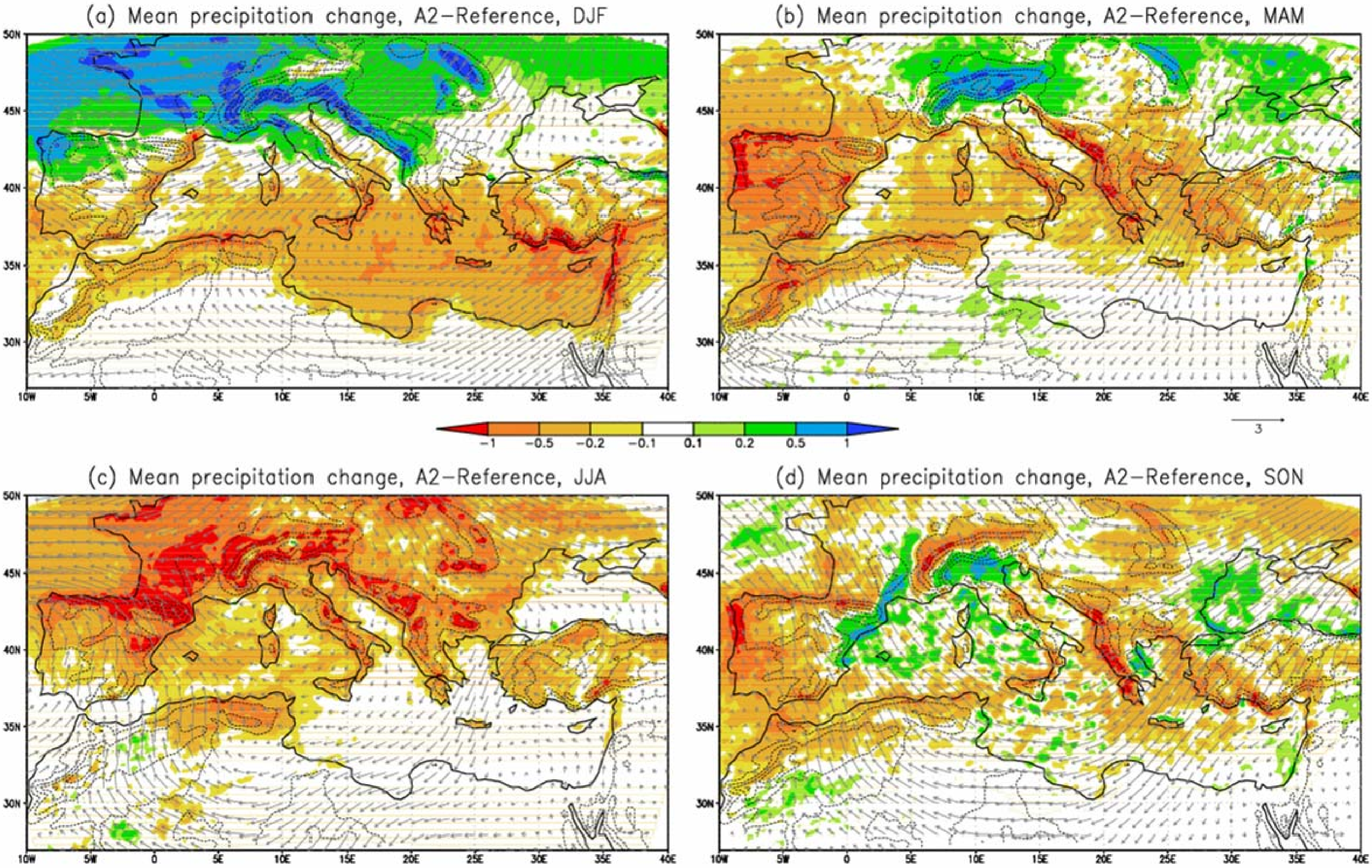
JJA Frei & Schär, 1998 Obs | JJA RegCM3 50-km | JJA RegCM3 20-km

Spatial Correlation Coefficient:
Simulated precipitation and Frei & Schär (1998)



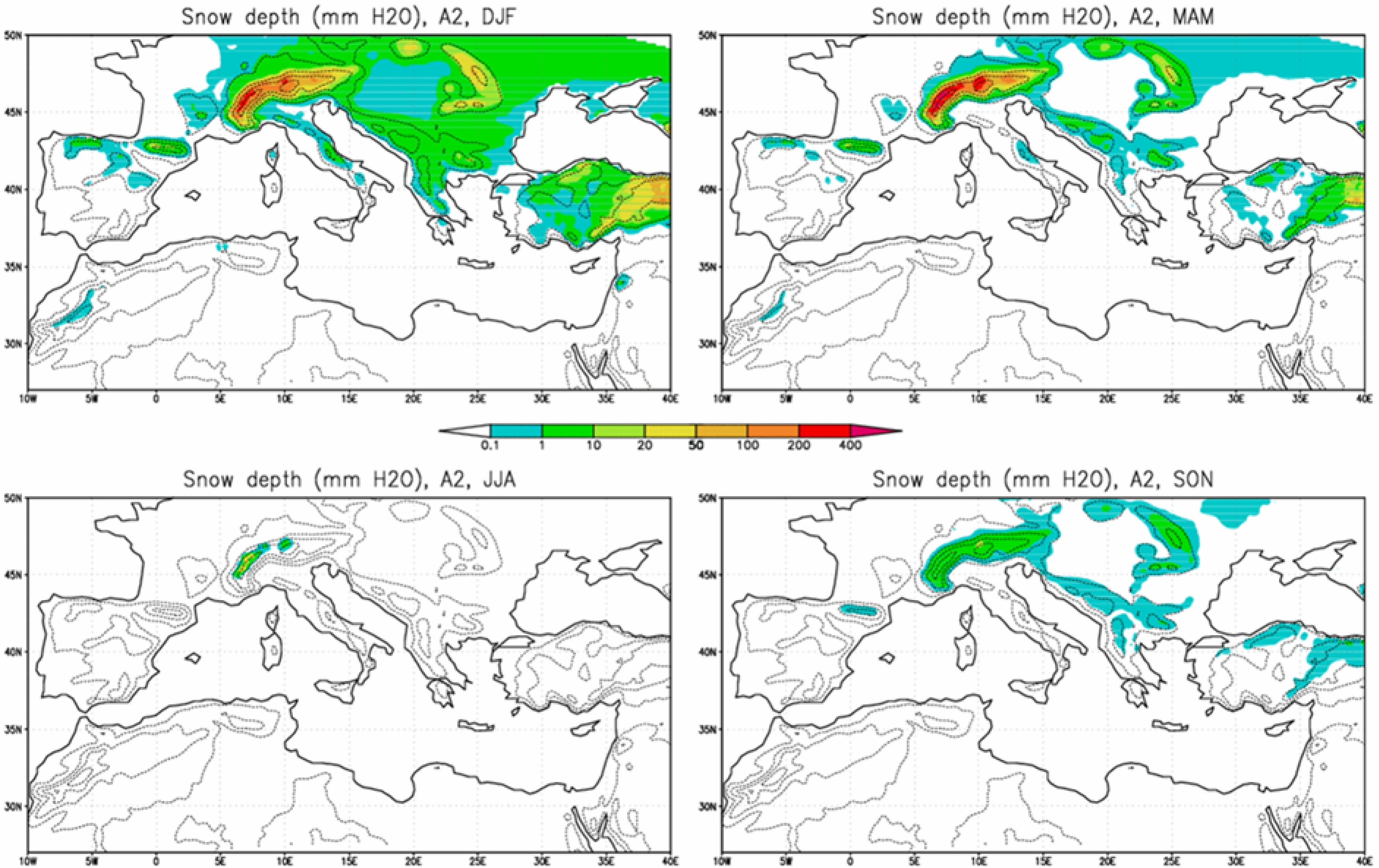
Mean of the 12 Months: 0.58 vs 0.48

Precipitation Change: A2-REF



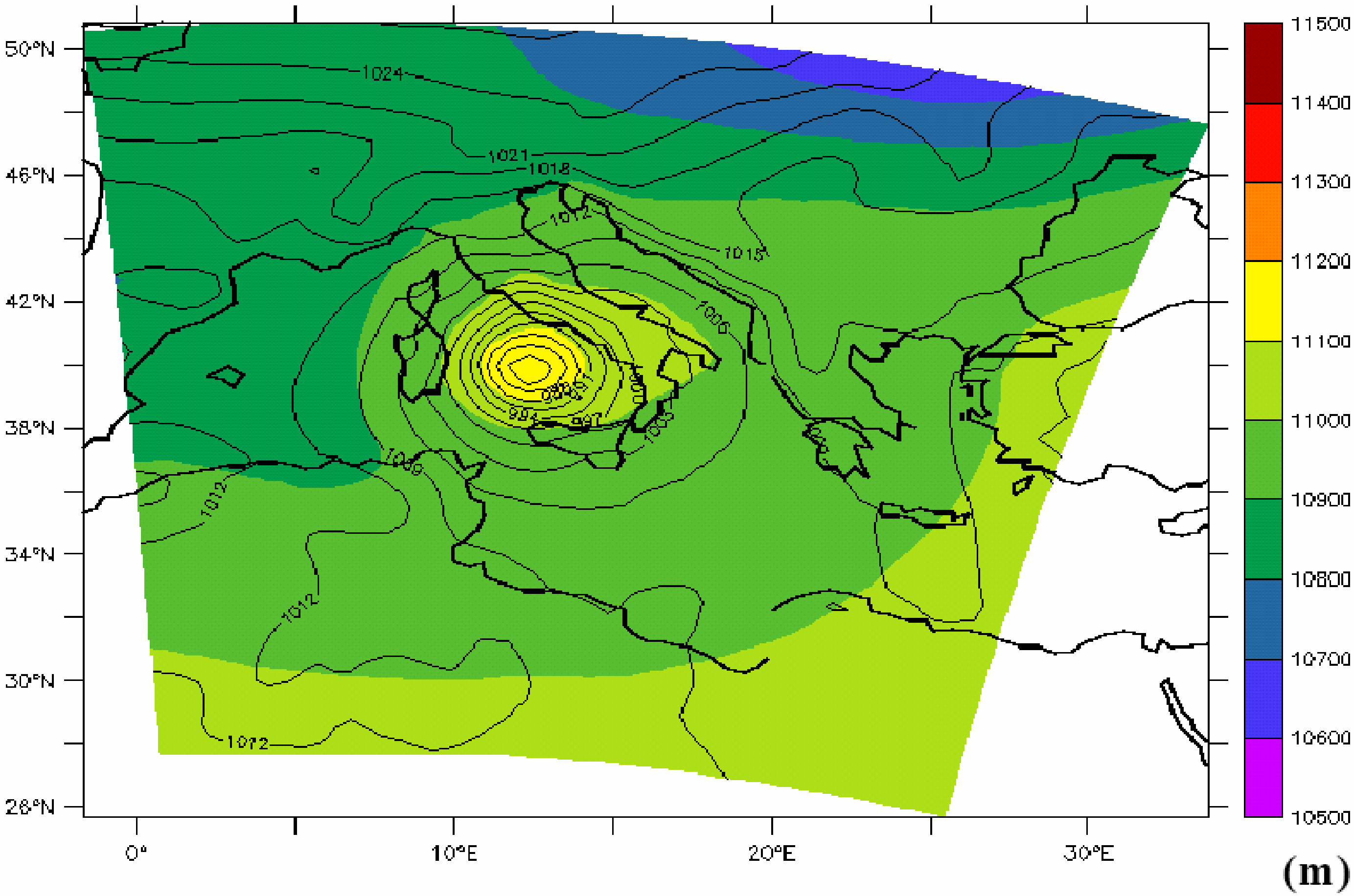
Gao et al 2006b

Snow Change: A2-REF



A tropical cyclone in an A2 simulation with PROMES RCM

29 August 2100



SLP and thickness (850-200 hPa) - Exp. 1

Lifetime: 10 days

Min. SLP: 979 hPa

Max. wind: 27 m/s

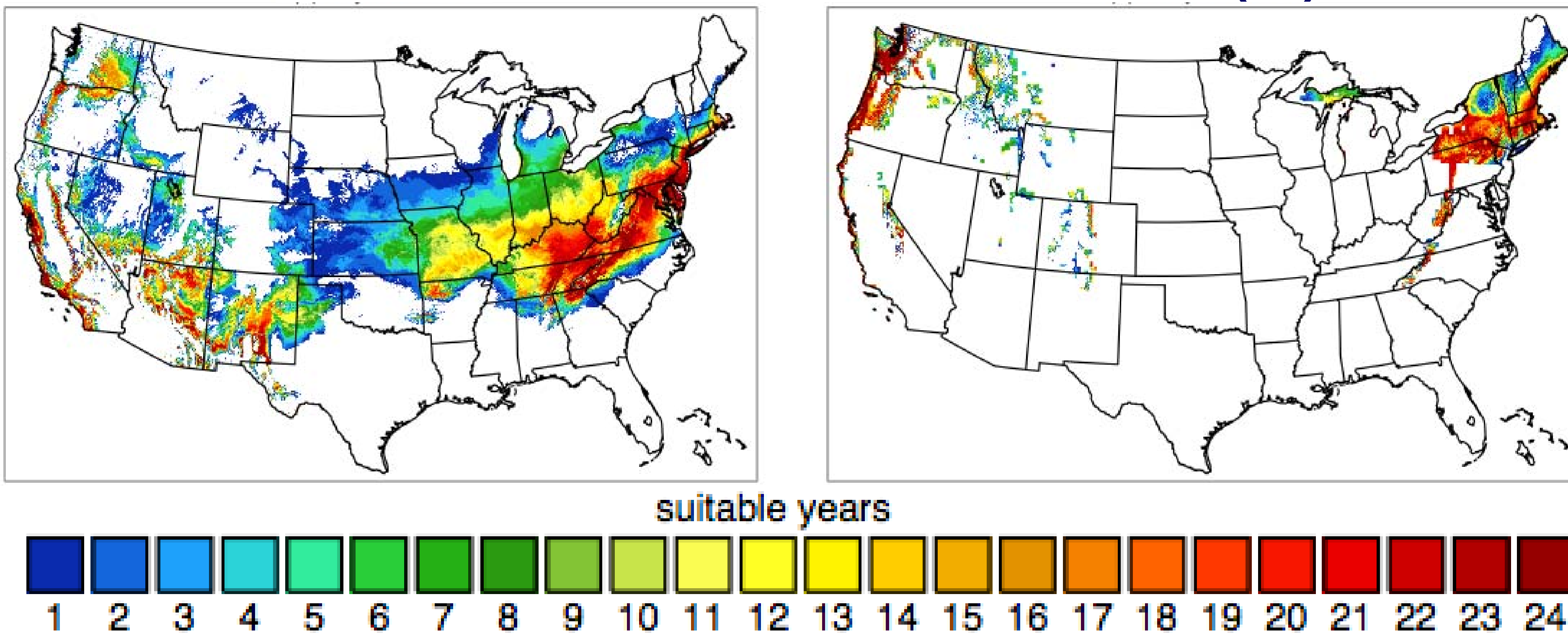
Accum. precip. (10 day): 200 mm (southern Italy), max. 900 mm

Courtesy PRUDENCE Project

Premium Grape Production:
Suitable Years (out of 24)

Heat Tolerant & Cold Tolerant Grapes

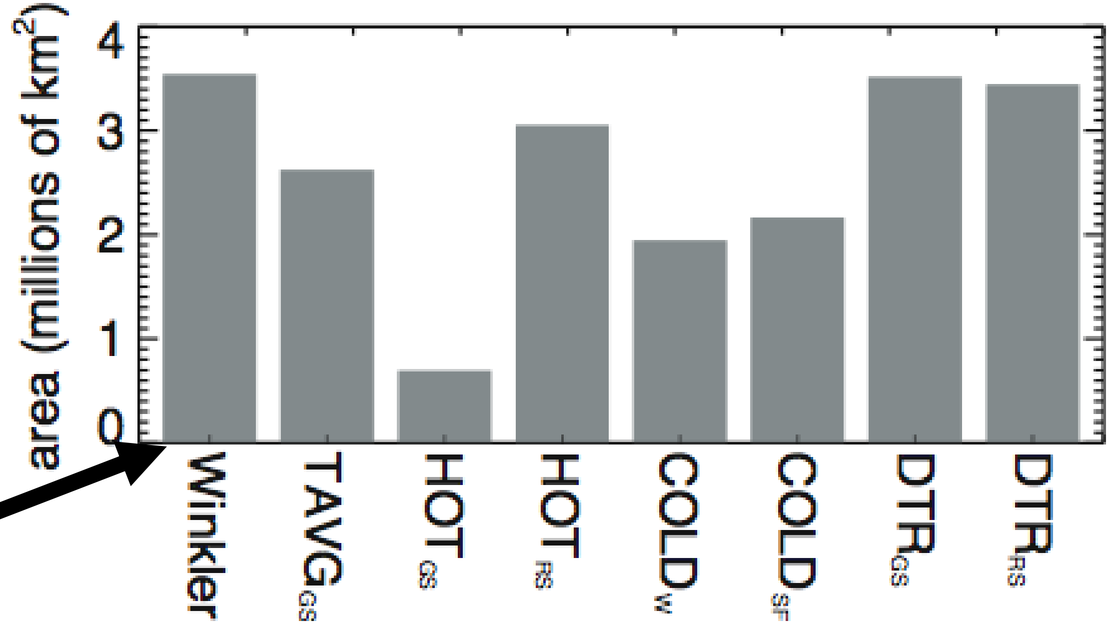
Reference **Future (A2)**



White et al 2006, PNAS

Premium Wine Production:
Single Factor Reductions

Heat Tolerant
Cold Tolerant

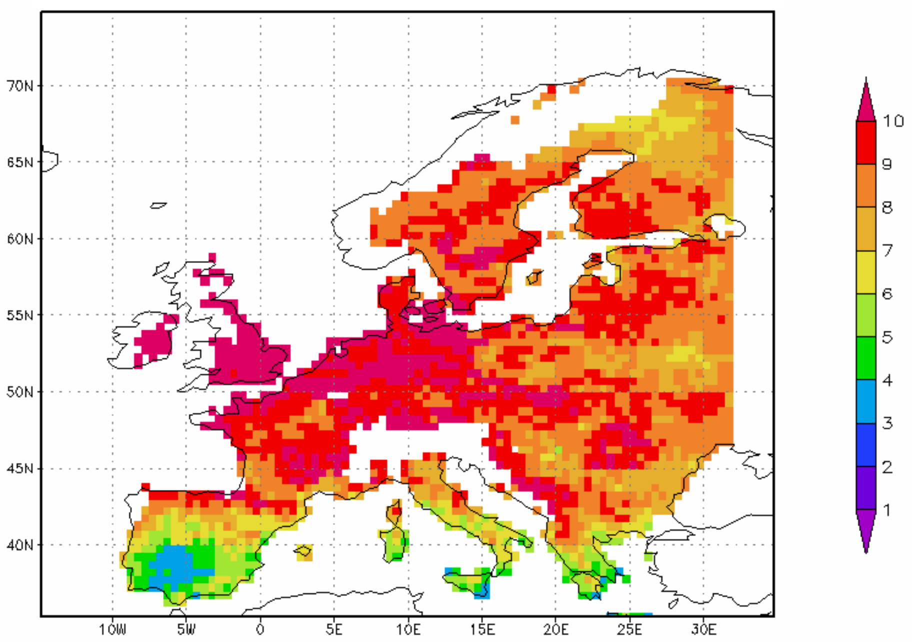


Winkler Based on Growing Degree Days (i.e., mean climate only)

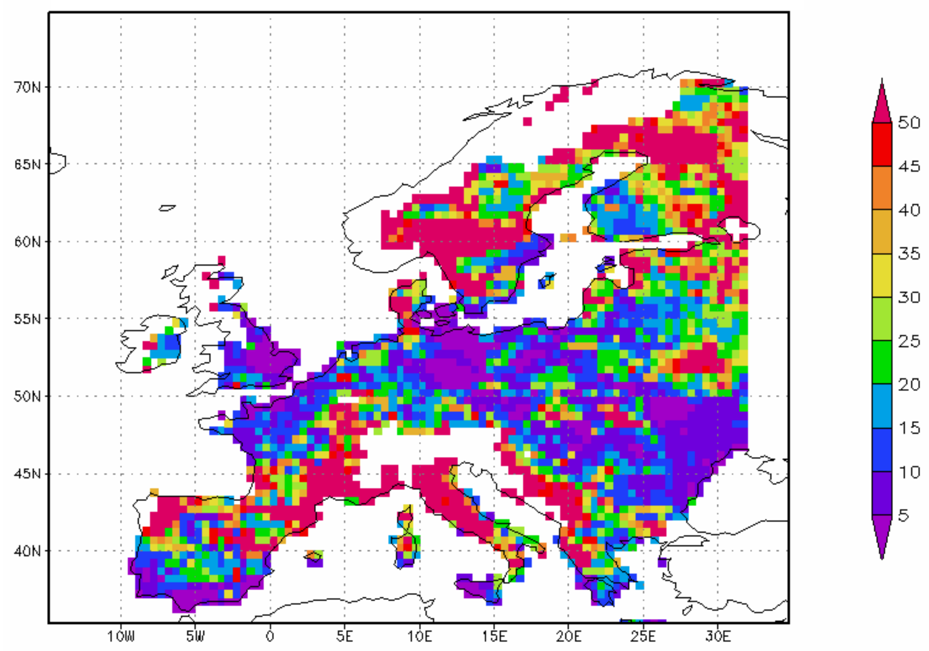
	Heat tolerant cold tolerant
GS growing degree days	1111-2499
GS average temperature	13-20°C
GS & RS hot days (> 35C)	14
W & S/F cold days (<-12C & <-7C)	14
GS & RS diurnal temperature range	20°C

Climate Change & Agriculture

Wheat Yield

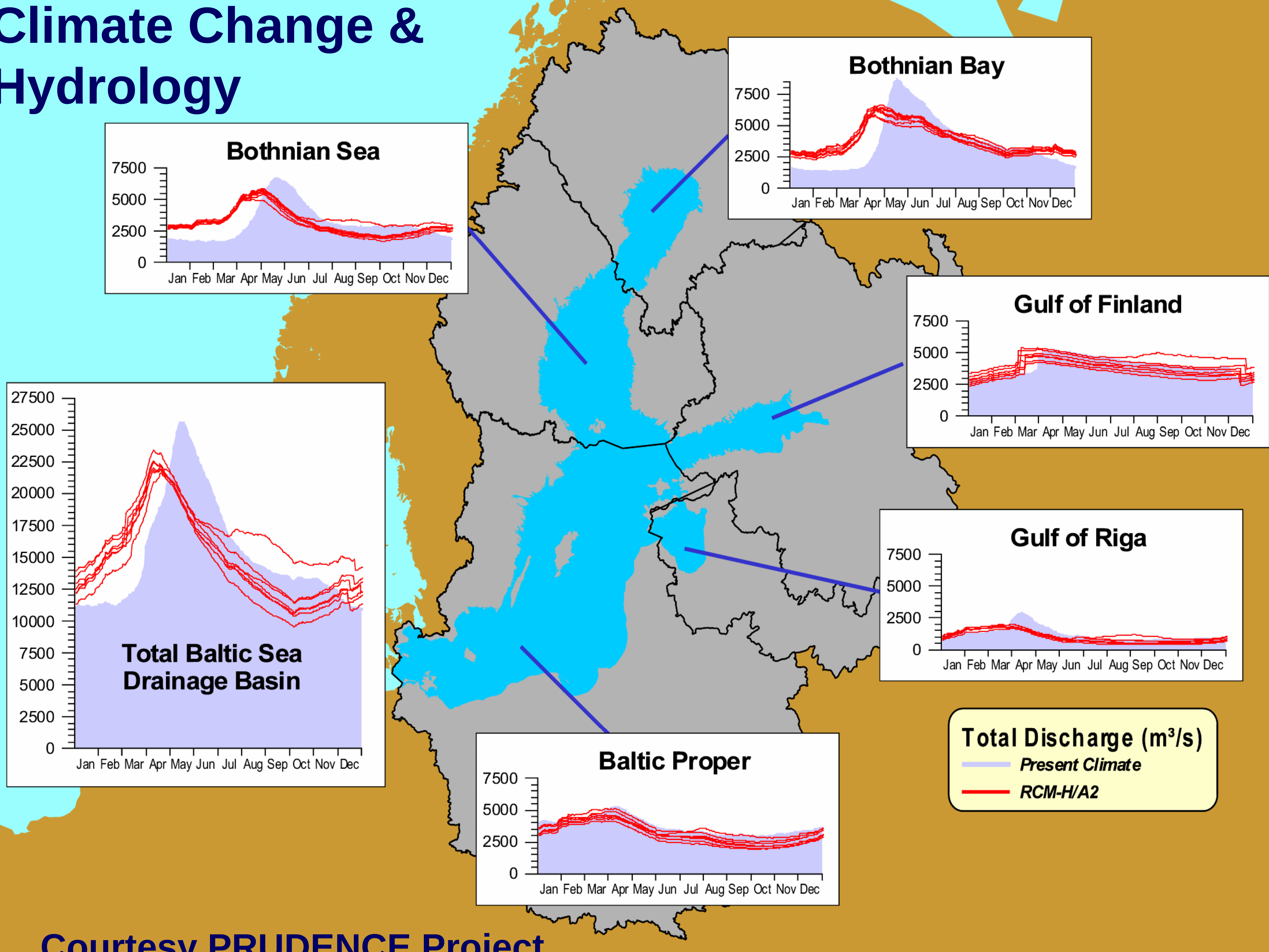


Nitrate Leaching



Courtesy PRUDENCE Project

Climate Change & Hydrology



Courtesy PRUDENCE Project

Strategy for Regionalize Climate Change Projections

1. "Perfect Boundary" Condition RCM Experiments
   - Need to make sure that the RCM performs well.
   - Model optimization (or customization) may be necessary
   - IMPORTANT: reanalysis products have problems
2. Analysis of GCM present-day simulations
   - "Garbage" in, "garbage" out
   - Select best available GCMs
3. "Non-perfect" boundary condition RCM experiments
   - May require further customizations to match driving model
   - Assess "added-value" of the RCM simulations
   - Decide what additional processes to include (e.g. aerosols, land cover changes)
4. GCM driven present-day and future simulations
   - Decide Scenario (e.g. A1B, A2, B2)
5. Analyze results and supply data to impacts models.

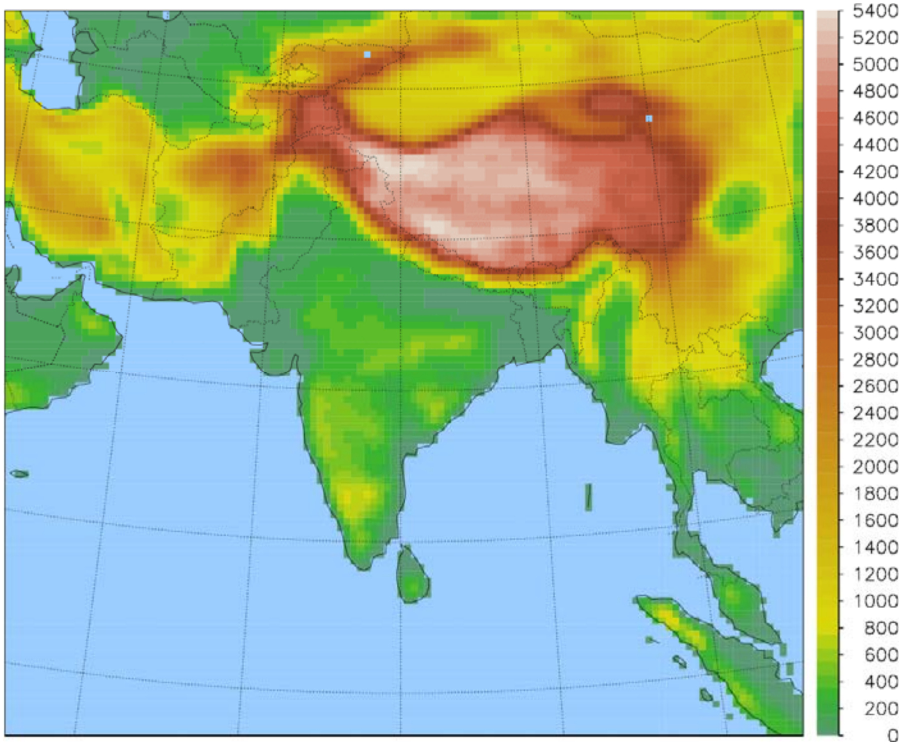
ICTP Regional Climate Model, RegCM3

- **Dynamics:**
  MM5 Hydrostatic (Grell et al 1994)
- **Radiation:**
  CCM3 (Kiehl 1996)
- **Large-Scale Clouds & Precipitaion:**
  SUBEX (Pal et al 2000)
- **Cumulus convection:**
  Grell (1993)
  Anthes-Kuo (1977)
  MIT (Emanuel 1991)
- **Boundary Layer:**
  Holtslag (1990)
- **Tracers/Aerosols:**
  Solmon et al 2005
  Zakey et al 2006
- **Land Surface:**
  BATS (Dickinson et al 1993)
  SUB-BATS (Giorgi et al 2003)
  CLM3 (Bonan; In progress)
- **Ocean Fluxes**
  BATS (Dickinson et al 1993)
  Zeng et al (1998)
- **Computations**
  Parallel Code
  Multiple Platforms
  More User-Friendlier Code

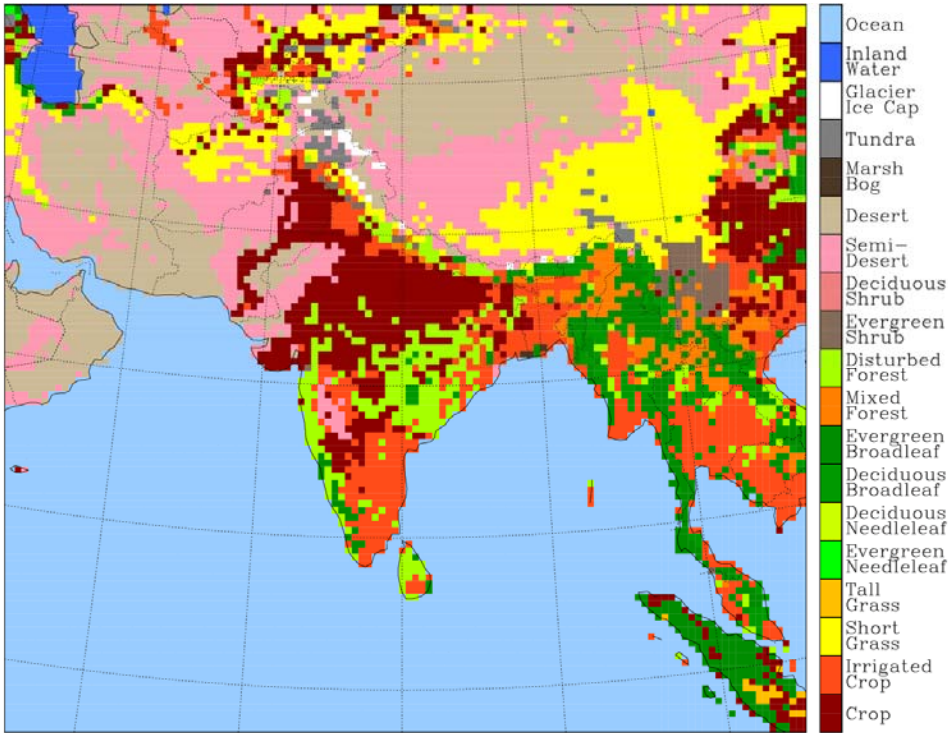
Pal et al 2006

South Asia Domain

- Topography (m)



- Landuse

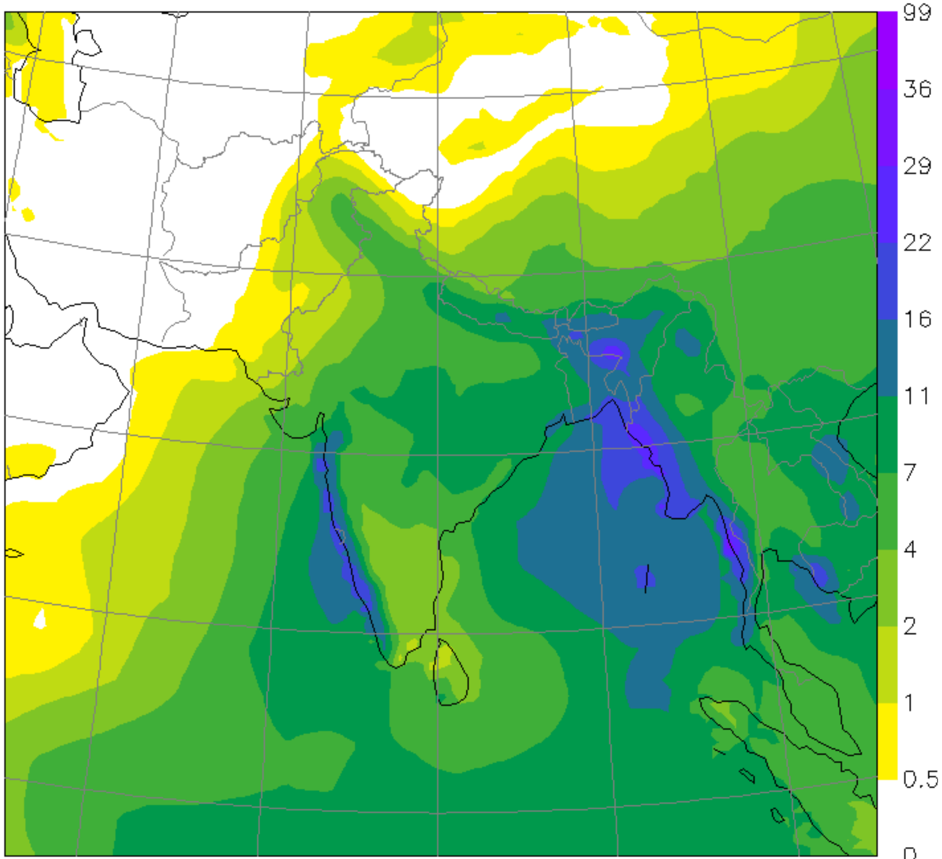


Domain: 120 x 111 x 18 at 50-km
Simulation: 1987-2000 ERA40

Monsoon Precipitation & Winds

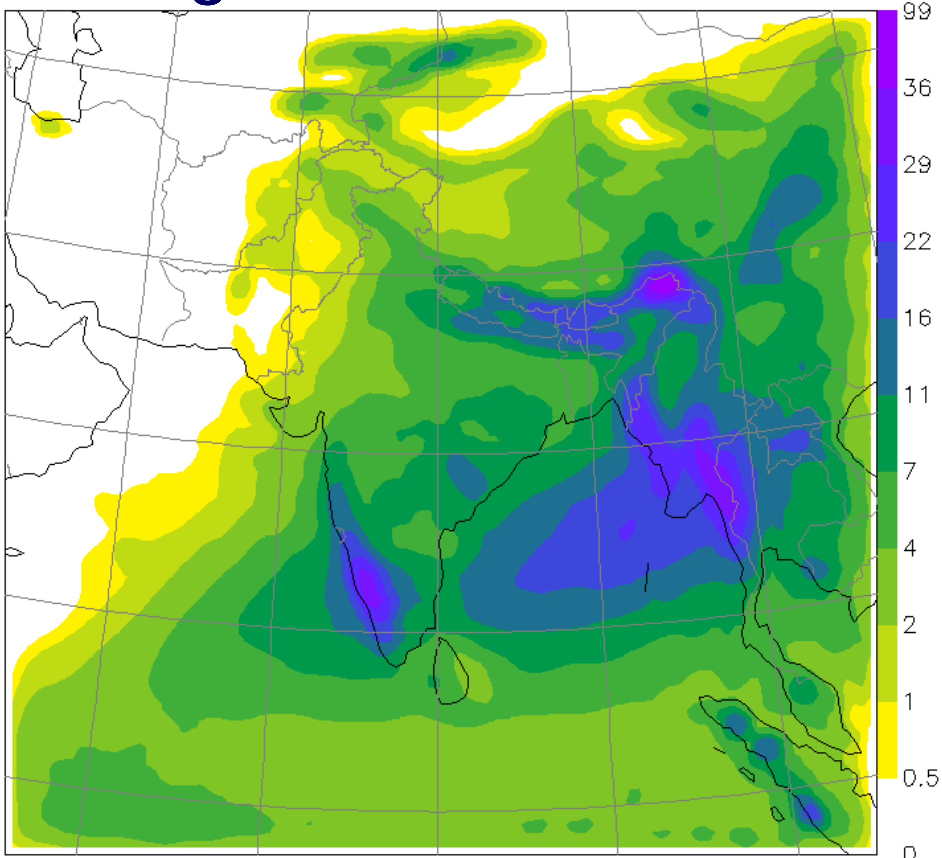
1987-2000 Climatology (JJAS)

- CRU/CMAP/ERA40



Precipitation: Land=CRU; Ocean=CMAP
Winds: Sigma 0.910 ERA40

- RegCM3

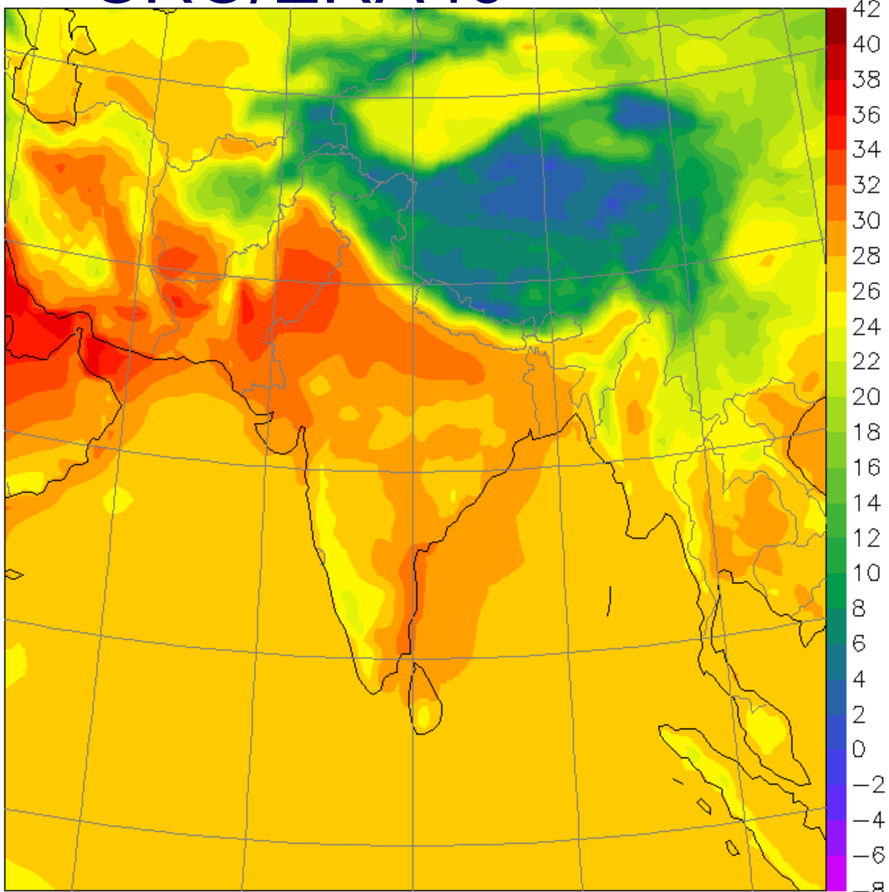


Precipitation: RegCM3
Winds: Sigma 0.910 RegCM3

Monsoon Temperature

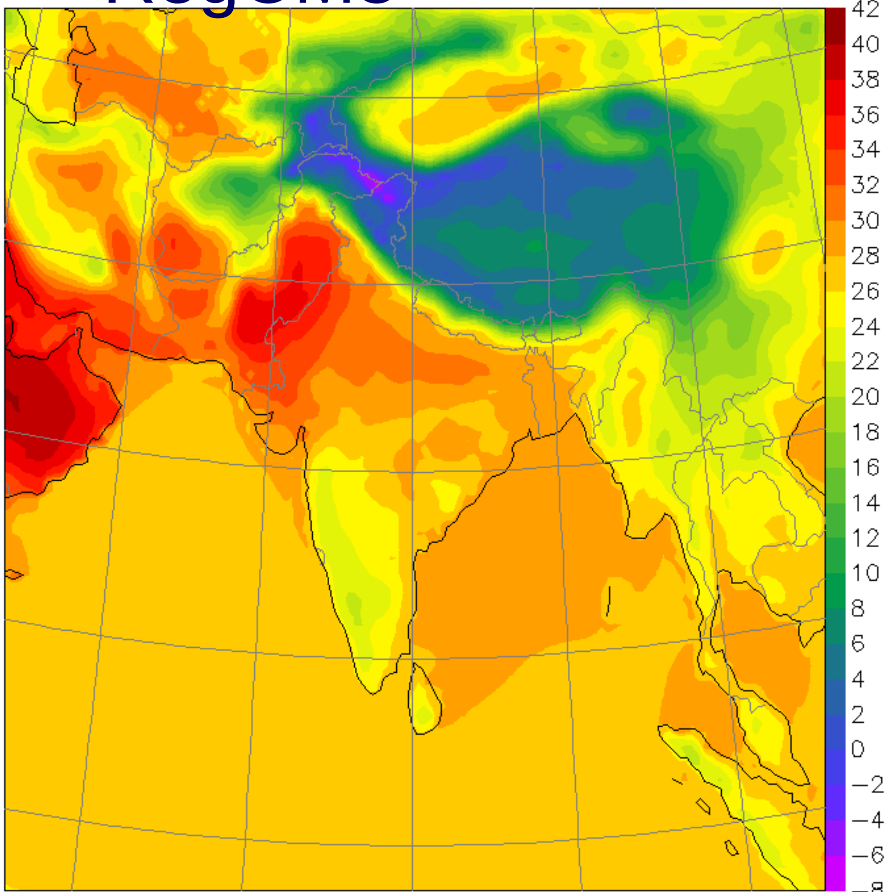
1987-2000 Climatology (JJAS)

- CRU/ERA40



Land: 2m CRU
Ocean: Sigma 0.995 ERA40

- RegCM3



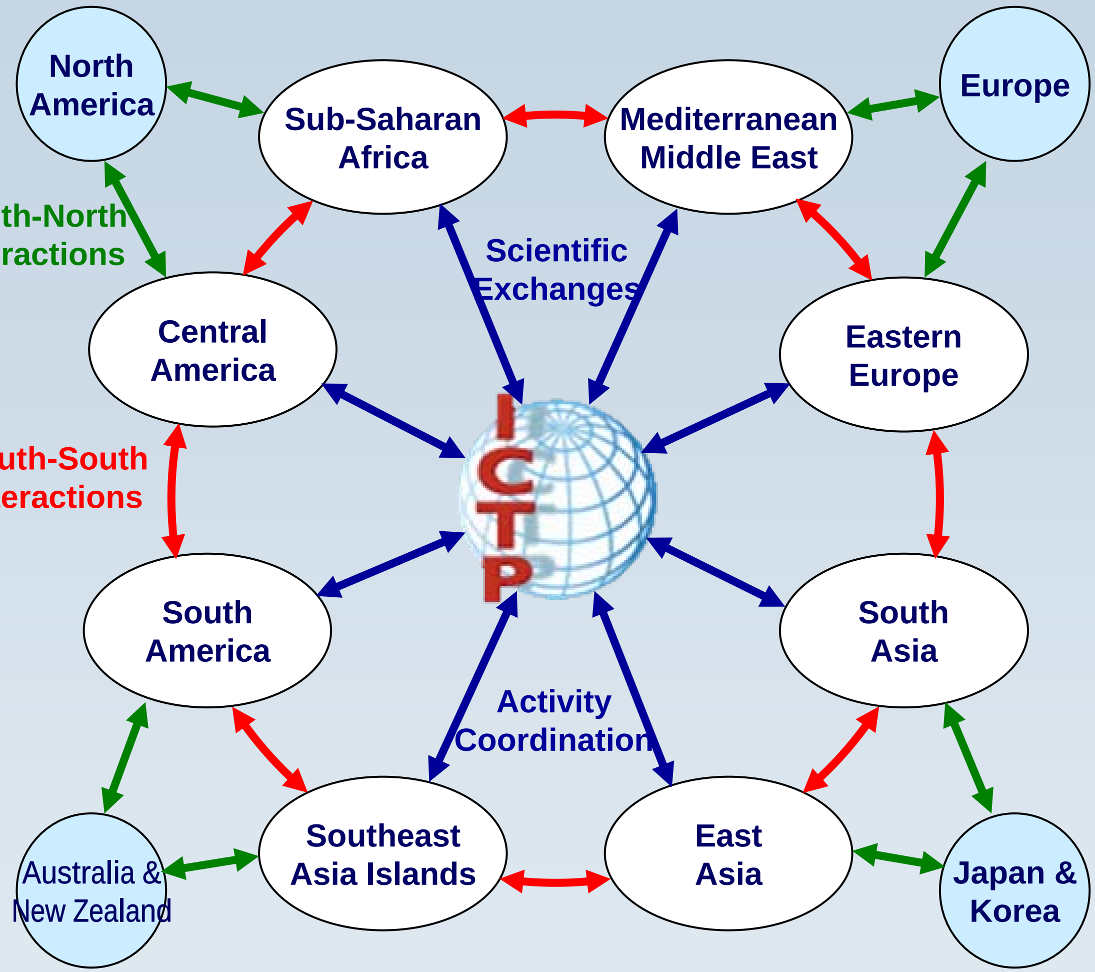
Land: 2m RegCM3
Ocean: Sigma 0.995 RegCM3

The ICTP REGional Climate research NETwok

Workshops at ICTP and off-site

Use of ICTP model tools and datasets

Collaborative research projects



RegCNET email group

Visitor program

Interactions with other international programs

OVERALL GOAL: Foster "north-south" and "south-south" scientific interactions on the topic of regional climate and impacts research.

The ICTP REGional Climate research NETwok

Regional Modeling

Weather Prediction

Seasonal Prediction

Climate Change

Flood • Drought • Water Resources • Energy • Agriculture • Land Cover Change • Biomass Burning • Pollution • Human Health • Fisheries • Ecosystems