INTRODUCTION TO CLIMATE CHANGE MODELING

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Schematic View of the Global Climate System

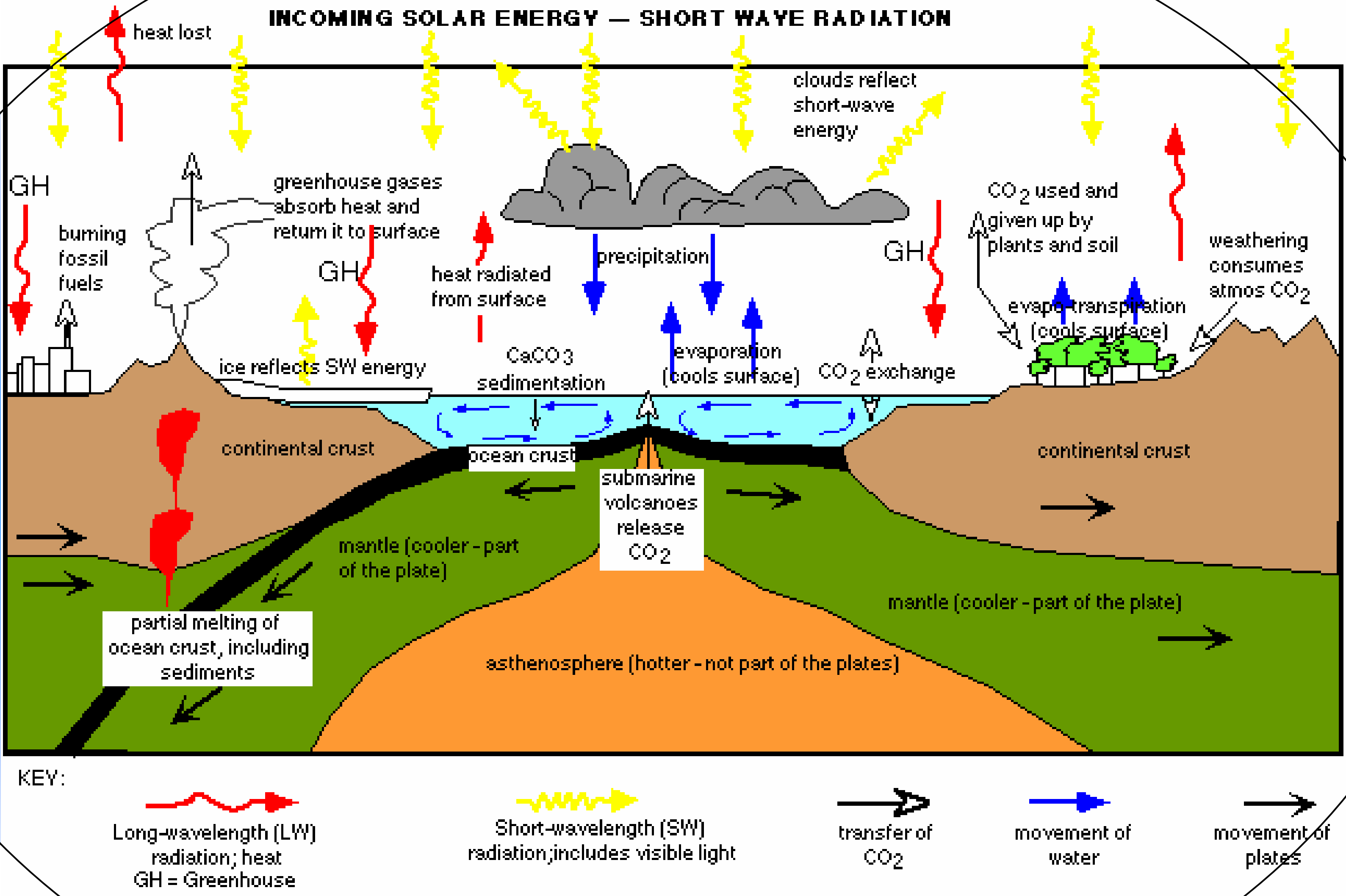


Figure 2 Basics of the global climate system showing the flows of energy, water, and CO_2 that are important in controlling the climate. Solar energy drives the global climate, but clouds, plants, volcanoes, ice, and the oceans all play important roles in regulating the Earth's greenhouse and determining what happens to the solar energy. CO_2 and water are the principle greenhouse gases that absorb heat emitted from the surface and then re-radiate the heat back to the surface; this process maintains the Earth's temperature at a comfortable level.

Schematic View of the Global Climate System

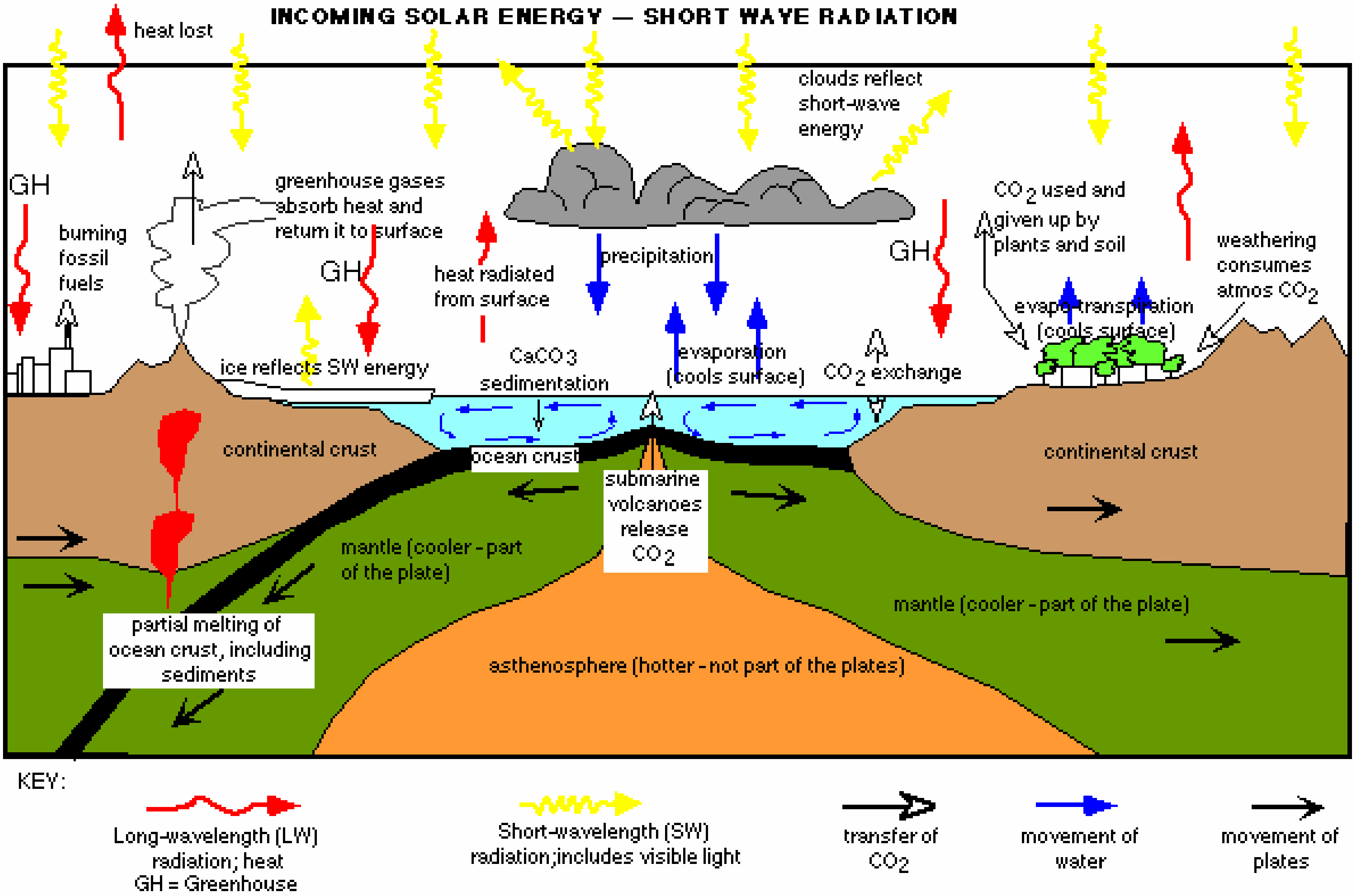
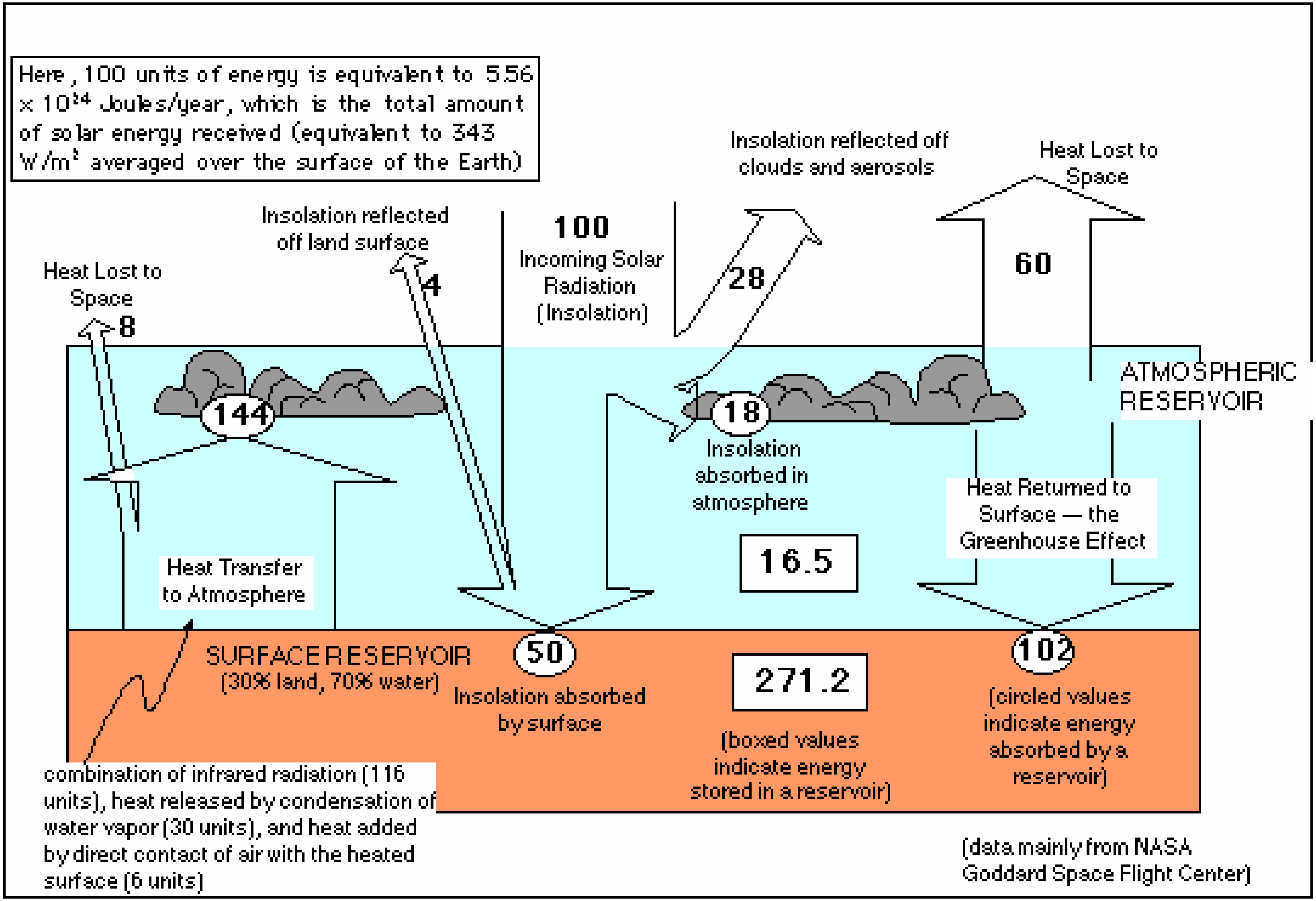


Figure 2 Basics of the global climate system showing the flows of energy, water, and CO$_2$ that are important in controlling the climate. Solar energy drives the global climate, but clouds, plants, volcanoes, ice, and the oceans all play important roles in regulating the Earth's greenhouse and determining what happens to the solar energy. CO$_2$ and water are the principle greenhouse gases that absorb heat emitted from the surface and then re-radiate the heat back to the surface; this process maintains the Earth's temperature at a comfortable level.

Simple Conceptual Model of Earth's Climate System



Here, 100 units of energy is equivalent to 5.56 x 10^{24} Joules/year, which is the total amount of solar energy received (equivalent to 343 W/m^2 averaged over the surface of the Earth)

(boxed values indicate energy stored in a reservoir)

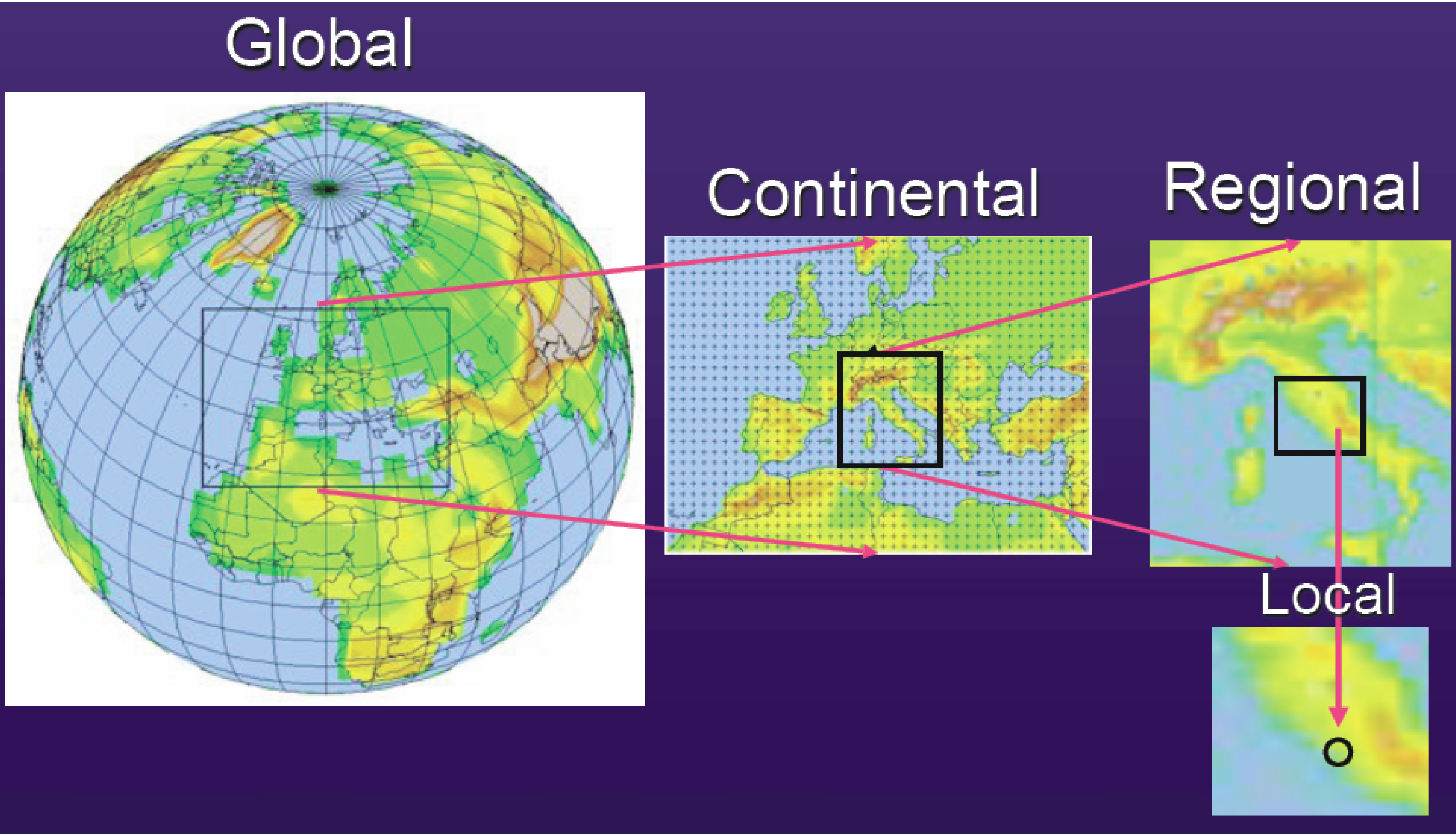
(circled values indicate energy absorbed by a reservoir)

combination of infrared radiation (116 units), heat released by condensation of water vapor (30 units), and heat added by direct contact of air with the heated surface (6 units)

(data mainly from NASA Goddard Space Flight Center)

Figure 3. Simple model of Earth's climate systemfocusing on energy flows and storage. Here, the units of energy are equivalent to the percentage of solar energy received by the Earth each year. In this model, energy is stored in just two reservoirs — the atmosphere and the surface of the Earth. The land surface consists of the upper 1 m of soil on land and the upper 35 m of water in the oceans. The huge disparity in the amount of energy stored in each of these reservoirs is due to the high heat capacity of water relative to most other materials. In general, 31% of the incoming solar energy is reflected back into space, while 69% is emitted as heat (infrared radiation). A key part of the system is the energy that is essentially recycled — sent back and forth between the atmosphere and the land surface.

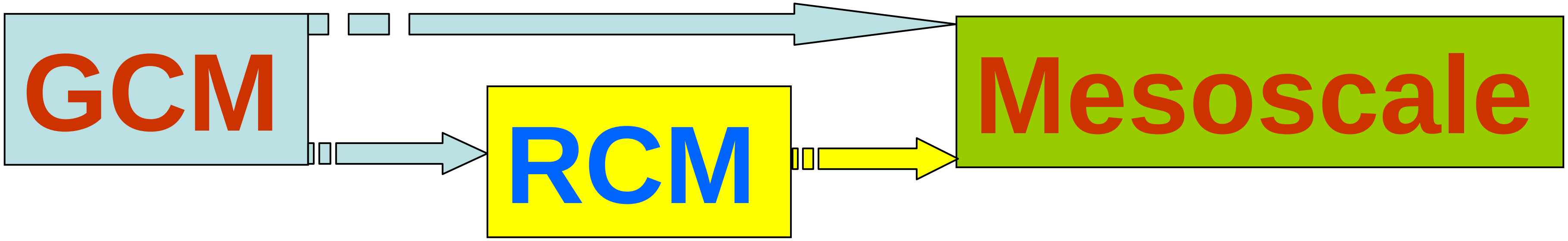
The spatial scales of climate processes



F. George

Types of climate models

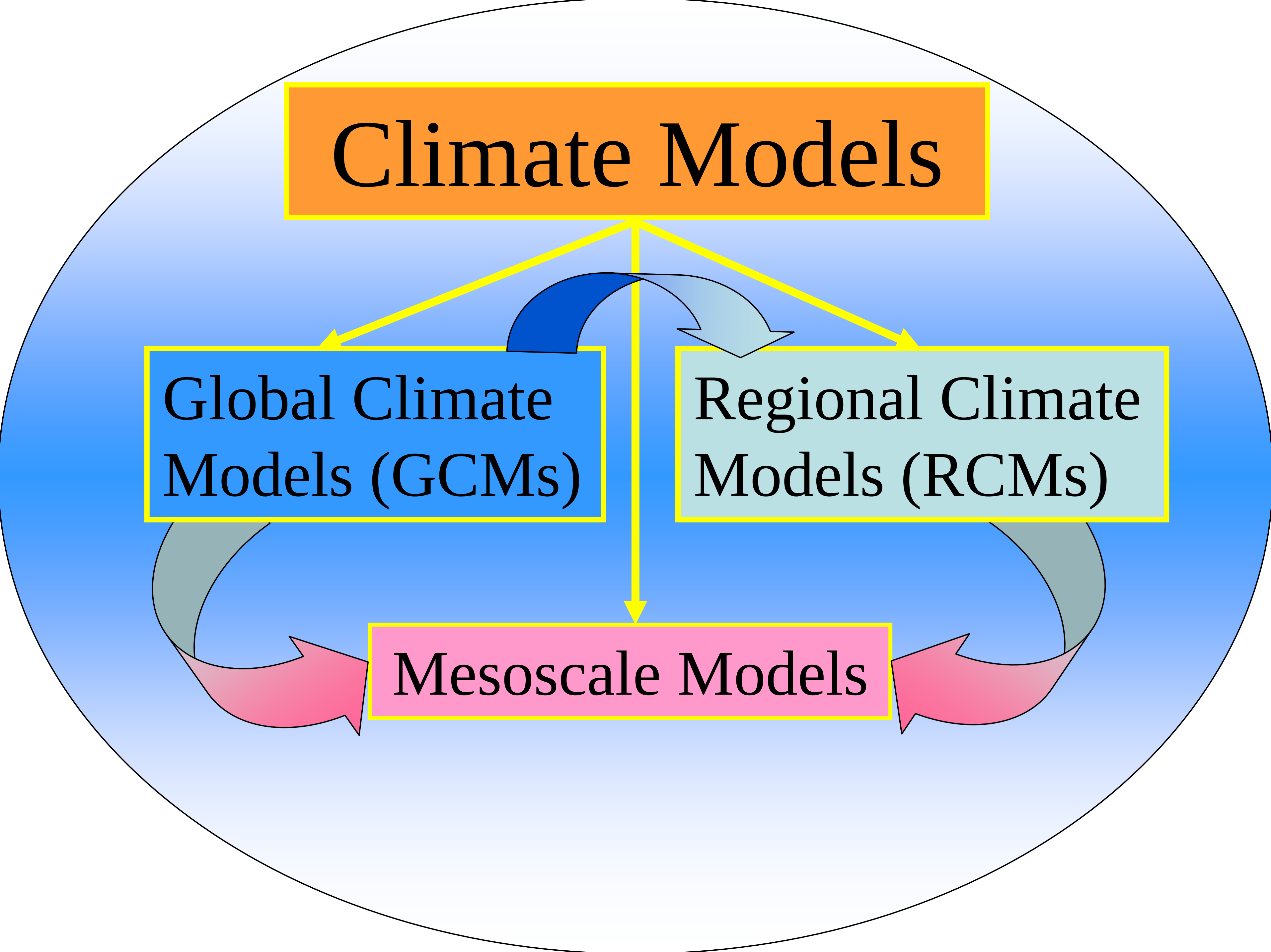
A computer model which includes many components of the climate system in detail takes a lot of computing resources. Consequently, to produce climate projections for many centuries into the future, one either needs a very powerful computer or a less complex model.



GCM

RCM

Mesoscale



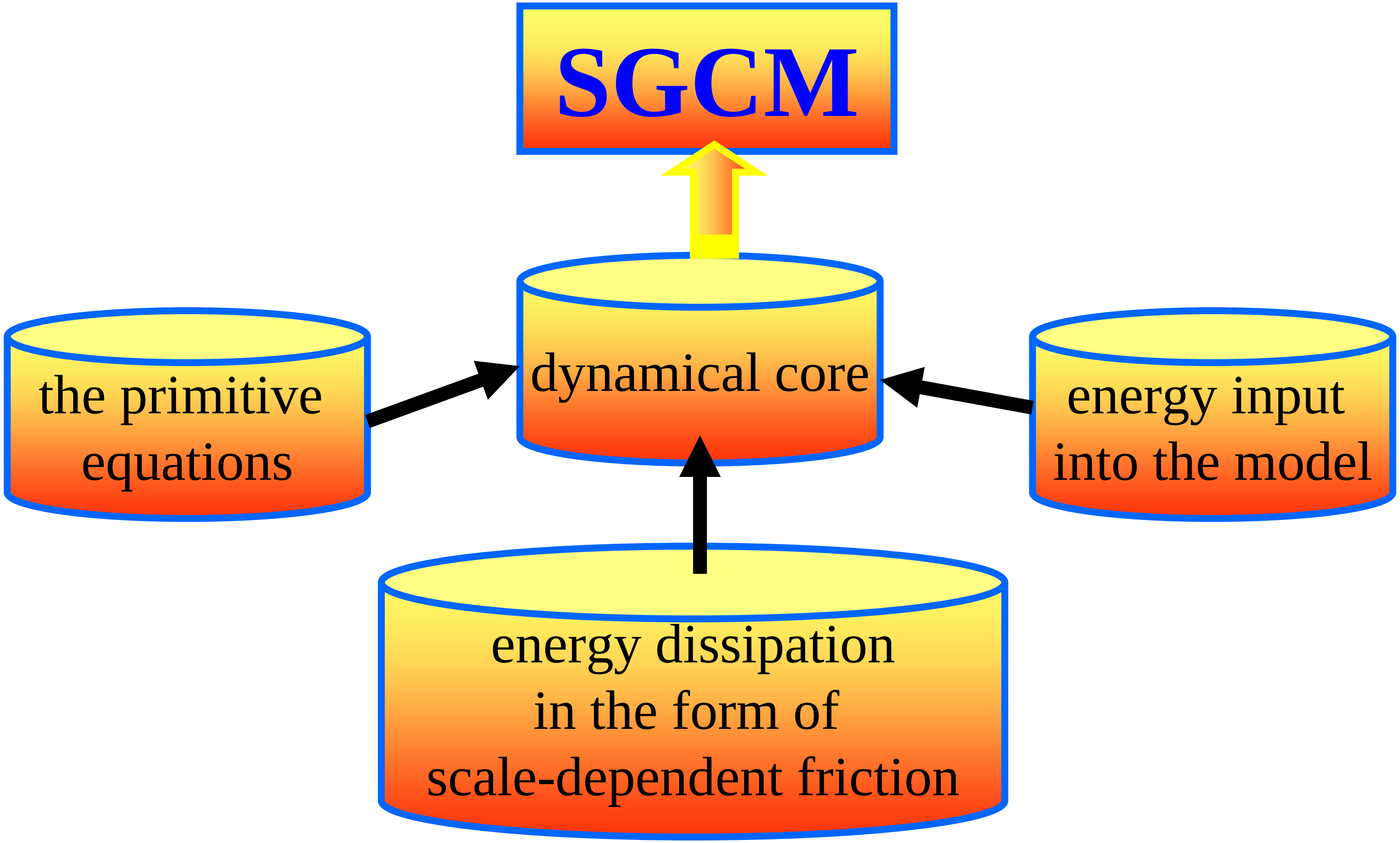
Climate Models

Global Climate Models (GCMs)

Regional Climate Models (RCMs)

Mesoscale Models

Simple General Circulation Model (SGCM)



SGCM

dynamical core

the primitive equations

energy input into the model

energy dissipation in the form of scale-dependent friction

Note: **SGCM** may be used to study atmospheric processes within a simplified framework but are not suitable for future climate projections

Are we Happy with SGCM?

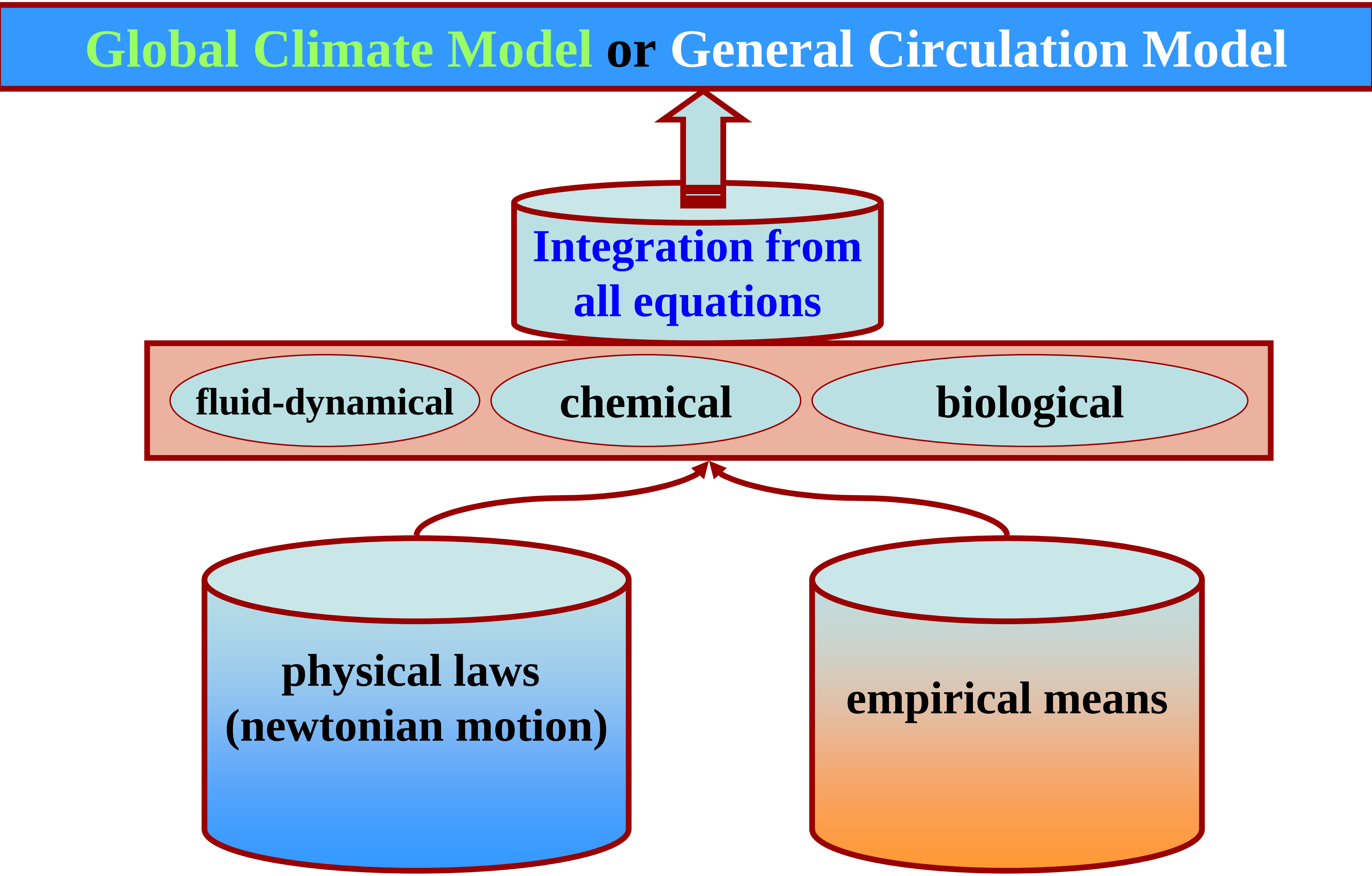
Answer may be NO!

We need **Global Climate Model (GCM)**

A recent trend in GCMs is to extend them to become Earth system models, that include sub-models for *atmospheric chemistry* or a *carbon cycle model* to better predict changes in carbon dioxide concentrations resulting from changes in emissions.

In addition this approach allows feedback between these systems to be taken into account. For example, *Chemistry-Climate models* allow the possible effects of climate change on the recovery of the ozone hole to be studied.

Global Climate Model (GCM)



Global Climate Model or **General Circulation Model**

Integration from all equations

fluid-dynamical

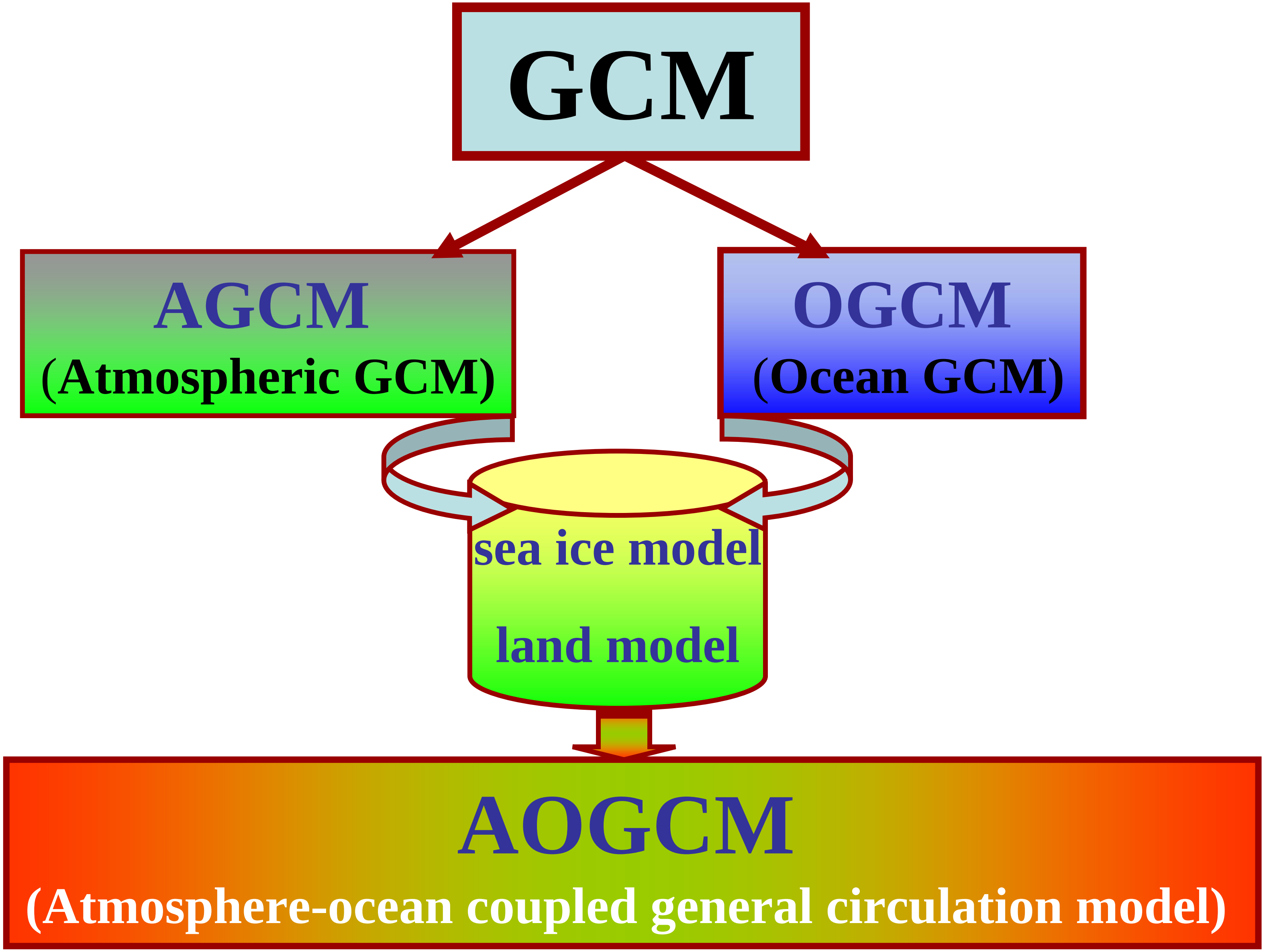
chemical

biological

physical laws (newtonian motion)

empirical means

Global Climate Model (GCM)



GCM

AGCM
(Atmospheric GCM)

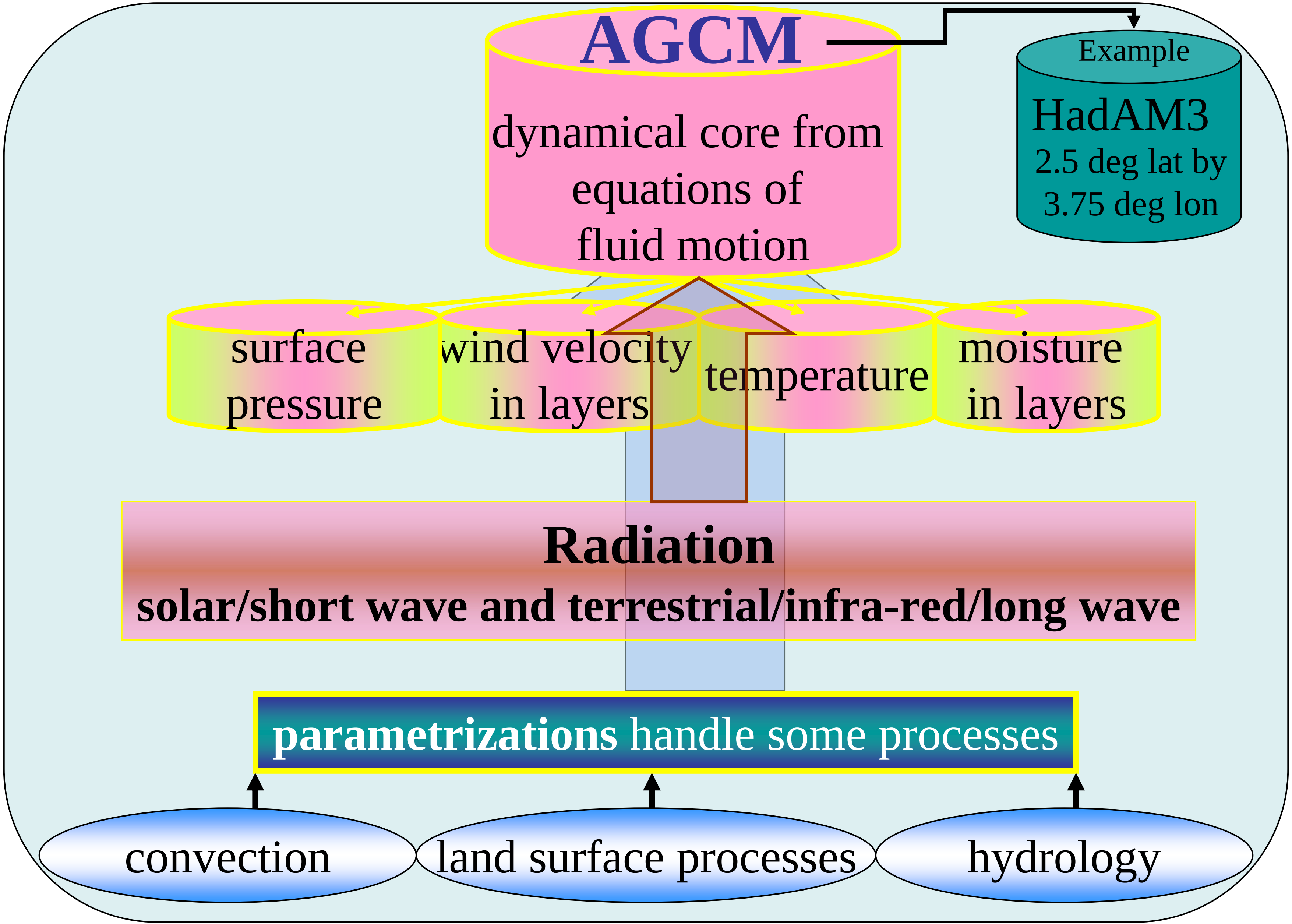
OGCM
(Ocean GCM)

sea ice model

land model

AOGCM
(Atmosphere-ocean coupled general circulation model)

Atmospheric GCM (AGCM)



AGCM

dynamical core from equations of fluid motion

Example

HadAM3

2.5 deg lat by 3.75 deg lon

surface pressure

wind velocity in layers

temperature

moisture in layers

Radiation

solar/short wave and terrestrial/infra-red/long wave

parametrizations handle some processes

convection

land surface processes

hydrology

AGCM

Atmosphere general circulation models (AGCMs)

AGCMs consist of a three-dimensional representation of the atmosphere coupled to the land surface and cryosphere. The AGCM has to be provided with data for sea-surface temperatures and sea-ice coverage. Hence an AGCM by itself cannot be used for climate prediction, because it cannot indicate how conditions over the ocean will change. AGCMs are useful for studying atmospheric processes, the variability of climate and its response to changes in sea-surface temperature.

AGCMs coupled to a 'slab' ocean

This type of model predicts changes in sea-surface temperatures and sea ice by treating the ocean as though it were a layer of water of constant depth (typically 50 m), heat transports within the ocean being specified and remaining constant while climate changes. This kind of model is useful for simulating what the climate would be like for some fixed level of carbon dioxide, but it cannot be used for predicting the rate of change of climate because this is largely determined by processes in the ocean interior.

Atmospheric chemistry models

The Hadley Centre has developed a three-dimensional global atmospheric chemistry model called STOCHEM. The chemical scheme is designed to include the main agents responsible for the production and destruction of ozone and methane in the lower atmosphere.

AGCM

Model features

The first generation atmospheric general circulation model evolved from an earlier 5-layer model (Boer and McFarlane,1979). The basic structure of the model is similar to that of the spectral forecast model of Daley et al. (1976), although some improvements have been made in the procedure for implementing the spectral algorithms and of course important additional physical processes have been included.

The equation governing horizontal motion are written in terms of vorticity and divergence of the horizontal wind. The remaining basic prognostic equations include the thermodynamic equation written in terms of a function of geopotential height, the moisture equation written in terms of dew-point depression, and the surface pressure equation. Temperature is determined diagnostically from the geopotential via the hydrostatic equation, and the vertical motion variable is determined from the mass continuity equation.

Boundary conditions

While initial conditions are unimportant for general circulation models, boundary conditions have an important effect on the simulated climate. The effect of large-scale topography on the simulated climate enters into the equations of motion through the specification of the geopotential height at the surface.

Surface temperatures are computed over land and oceanic pack-ice by solving the surface energy balance equation.

The parameterization of surface fluxes over land requires the specification of bulk transfer coefficients at neutral stability. The drag coefficient field is used for this purpose following Cressman (1960).

Surface albedo over land has a prognostic component that depends on snow cover. Background values of albedo over land, ocean and pack-ice obtained from Posey and Clapp (1964) are used.

Radiative transfer processes

Solar and terrestrial radiation provides the primary energy source and sink for the climate system. In the atmospheric general circulation model described here the specification of ocean surface temperatures implies that the fluxes of heat and moisture from the oceans do not depend directly on the radiative balance of the ocean surface. Thus the model is not sensitive to the radiative calculations as it would be if an interactive ocean were present.

The radiative processes that are included in the model result in heating or cooling in each atmospheric layer and at the surface which may be land or pack-ice. The radiative calculations are performed for two broad spectral regions - solar and thermal.

AGCM

Horizontal transfer processes

Major horizontal transfers in the atmosphere are accomplished by the large-scale flow, which is explicitly calculated in the model. Nevertheless, the effect of unresolved horizontal scales of motion on those that are explicitly resolved in the model must be included in the formation if the results are to be realistic.

While a complex physical system like the atmosphere cannot be expected to display exactly a simple turbulent behaviour, the approximate correspondence suggests that, in the absence of complete knowledge and theory concerning atmospheric behaviour, the turbulences concepts may provide useful guidance in parameterizing the effects of subgrid-scale processes on scales explicitly resolved in the model.

Precipitation and latent heat release

In the model, precipitation occurs and latent heat is released when the local relative humidity becomes large enough so that supersaturation can occur in a given atmospheric column. The latent heat release may be associated with moist convection when the atmosphere is locally conditionally unstable. Both condensation and convection are treated by a convective adjustment scheme and applied to individual atmospheric columns. All condensed liquid water falls to the surface as precipitation.

AGCM

Surface energy balance and hydrology

In the model the surface of the earth may be bare or snow-covered soil, glacial or sea ice, or open ocean. Surface temperatures are specified as a function of time over the open ocean. In all other cases surface temperatures are determined so as to satisfy the requirements of a surface heat balance.

The soil is considered to be completely snow covered when the snow mass per unit area exceeds a certain specified value. Surface albedo is allowed to depend on snow cover. Soil wetness and snow mass are prognostic variables in the model.

Over pack-ice, snow is evaporated first but afterward the pack itself acts as an infinite reservoir of frozen water for evaporation. Gloacial ice-packs such as those over Greenland and Antarctic subcontinent are represented as thick snow layers for surface hydrology calculations. Since the solar forcing for the simulation includes annual and diurnal variations, these snow layers never melt away.

Runoff is not explicitly calculated. When the total soil moisture reaches a value in excess of the field capacity the excess is assumed to run off and soil moisture is reset to unity. When rain falls on pack-ice it is assumed to run off immediately.

AGCM

Vertical discretization

The vertical discretization of the prognostic equations in AGCM2 differs from that in AGCM1. A hybrid vertical coordinate and a finite-element formulation (both discussed in Laprise and Girard, 1990) are used in the vertical discretization of the prognostic equations in AGCM. This formulation has a number of advantages over the vertical finite-difference scheme used in AGCM2 rather than in AGCM1, including flexibility in the choice of different layering schemes for thermodynamic and momentum variables and the conservation of energy and angular momentum in the absence of physical sources or sinks. AGCM2 has ten vertical levels and employs a triangular spectral truncation having 32 longitudinal waves (T32/L10).

Moisture variable

Specific humidity is the prognostic moisture variable in AGCM2, while dewpoint depression is used in AGCM1. This change of moisture variable was motivated mainly by the desire to ensure that the discretized prognostic equation for moisture is conservative in the absence of sources and sinks of water vapour. Such a conservation principle cannot be assured when dewpoint depression is used as the moisture variable.

AGCM

Parameterization of unresolved transfer processes, precipitation, and latent heat release

Representation of the effects of unresolved transfer processes and the generation of precipitation and latent heat release in AGCM2 are similar in many respects to those used in AGCM1.

The moist convective adjustment and large-scale precipitation algorithms are the same as those employed in AGCM1. However, the parameterization of vertical transfer processes at the surface and in the free atmosphere have been modified to some extent.

Turbulent vertical fluxes at the surface and in the free atmosphere

Vertical fluxes of momentum, heat and moisture due to turbulent transfer processes are represented using eddy diffusivity formulations in the free atmosphere, while those at the surface are represented in terms of drag coefficient formulations..

AGCM

Estimation of the temperature at screen level

To depict the effect of warming due to increased amounts of CO2, it is common to use either the temperature at the lowest model level or the surface temperature. These two temperature are usually different from each other, and neither is consistently more representative of the air temperature near the surface. The observed variable is, of course, the temperature at the screen level (2 m above the surface).

The version of AGCM2 used for control and doubled CO2 experiments has 10 levels in the vertical with the lowest prognostic level located at approximately 200 m above the surface.

AGCM2 uses a gradient profile relationship to estimate the air temperature at the screen level. The required gradient profile is obtained by noting that, in accordance with surface-layer theory, the vertical heat flux is not a function of height in the region between the surface and the screen level. In this region the diffusive representation used in the free atmosphere and the bulk formulation used at the surface are consistent with each other.

AGCM

Orographic gravity-wave drag

In particular, the effects of breaking and dissipation of unresolved orographically excited gravity waves is represented as an additional drag force on the resolved flow.

Surface energy balance and hydrology over land

The treatment of surface processes over land has been modified extensively in AGCM2. A single soil-layer is used as in AGCM1, but the properties of this layer now vary with location. In order to obtain more realistic simulations of the diurnal variation of surface temperatures the energy storage in the soil is represented using the force-restore method rather than the thermal inertia method used in AGCM1.

The land surface scheme in AGCM2 does not explicitly model the vegetation canopy. However, some of the effects of a vegetative canopy are represented in an approximate way by assigning spatially variable soil depths and evapotranspiration slope factors, with values being specified for each vegetation class.

AGCM

Clouds and radiation

Cloud coverage

In AGCM2 an interactive cloud scheme replaces the prescribed clouds of AGCM1. The optical properties of the clouds are also interactive variables. The fractional cloud cover is evaluated from the prognostic moisture and temperature fields through relative humidity.

Cloud optical properties

The optical properties of clouds are evaluated from the cloud liquid water content (LWC). In the current version the LWC is specified to be proportional to the adiabatic liquid water content that results when saturated air at ambient temperature is lifted vertically through a small distance. Cloud albedo is calculated using the delta-Eddington method (Joseph et al., 1976).

Solar radiation

The upward and downward solar irradiance profiles are evaluated in two stages. First the model calculates a mean photon optical path in a scattering atmosphere, including actual clouds, aerosols and Rayleigh diffusion. The reflectance and transmittance in clouds and aerosol layer are calculated using a delta-Eddington method (Joseph et al., 1976) and a two-stream approximation. Second, the scheme calculates the final downward and upward fluxes.

Terrestrial radiation

Emission and absorption of terrestrial radiation is computed using a scheme originally developed by Morcrette (1984) and currently used in the ECMWF model (Morcrette 1990, 1991). An innovative feature of this scheme is a correction method that allows for adequate treatment of the pressure and temperature dependencies of the longwave line absorption.

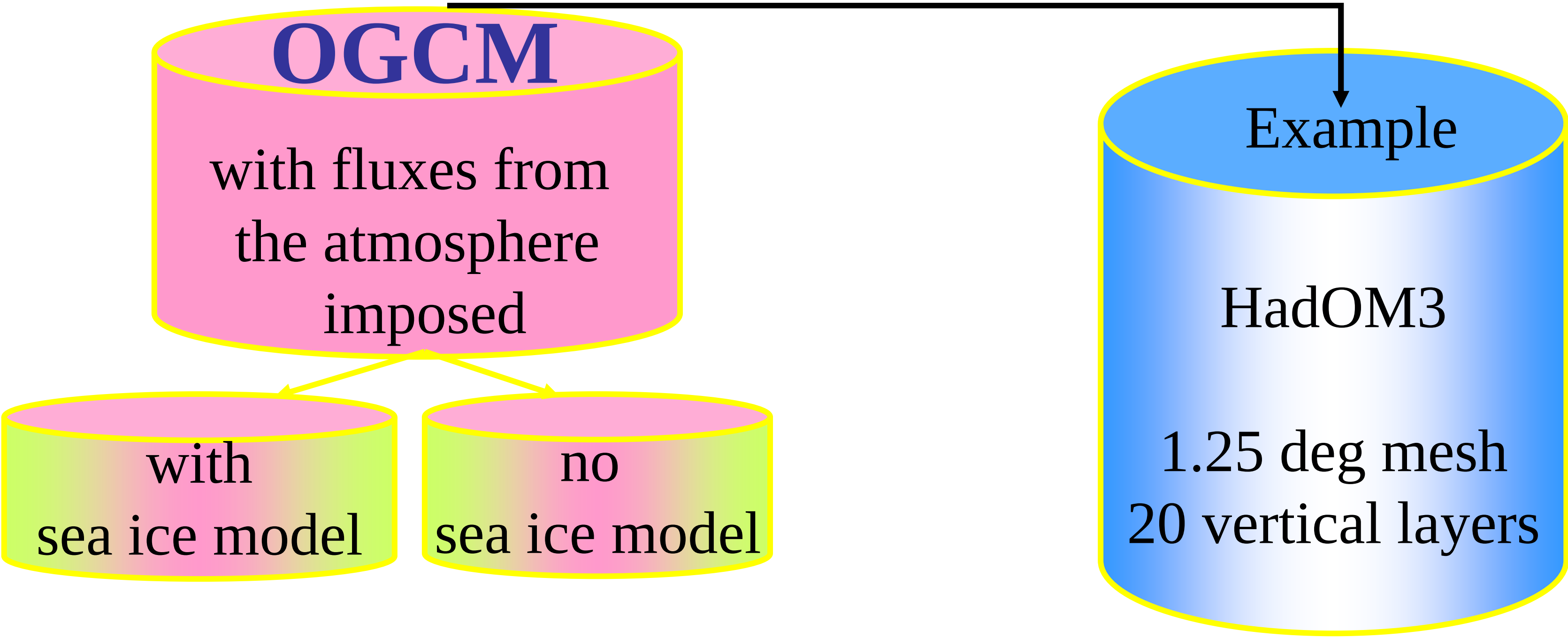
Surface albedo

The mean surface albedo is specified for the two spectral intervals used in the solar radiation scheme. Over bare, dry land a local value is specified in each grid square as a weighted average of the values for each of the 23 vegetation categories of the Wilson and Henderson-Sellers (1985) data. These values are reduced by as much as 7% for wet soil.

It is assumed that the land surface is covered with snow when sufficient snow mass has accumulated to give an average snow depth in excess of the snow masking depth.

Over oceans each of the spectral intervals has the same albedo. This is specified as a function of latitude and varies monotonically from 6% in the tropics (between 30°N and 30°S) to 17% poleward of 70° latitude in both hemispheres. The ocean surface is taken to be ice covered when a sufficiently large mass of sea ice has accumulated.

Ocean GCM (OGCM)



OGCM

with fluxes from the atmosphere imposed

with
sea ice model

no
sea ice model

Example

HadOM3

1.25 deg mesh
20 vertical layers

OGCM

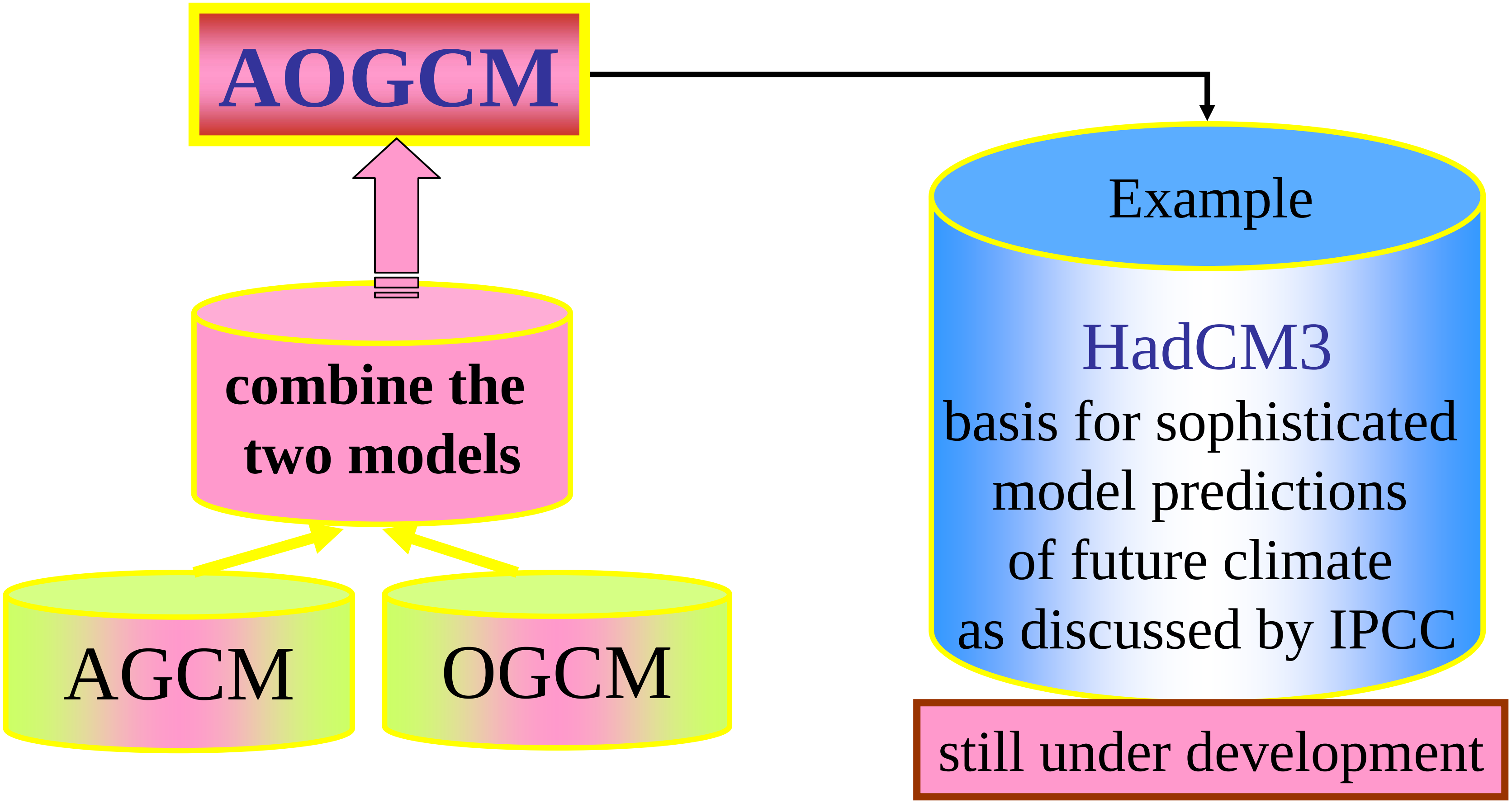
Ocean general circulation models (OGCMs)

An OGCM is the ocean counterpart of an AGCM; it is a three-dimensional representation of the ocean and sea ice. OGCMs are useful by themselves for studying ocean circulation, interior processes and variability, but they depend on being supplied with data about surface air temperature and other atmospheric properties.

Carbon cycle models

The terrestrial carbon cycle is modelled within the land surface scheme of the AGCM, and the marine carbon cycle within the OGCM. The carbon cycle model is needed in order to capture several important climate feedbacks on carbon dioxide concentration, for instance fertilization of plant growth by carbon dioxide and uptake or out-gassing of carbon dioxide by the oceans.

Coupled atmosphere-ocean GCM (AOGCM)



AOGCM

combine the two models

AGCM

OGCM

Example

HadCM3

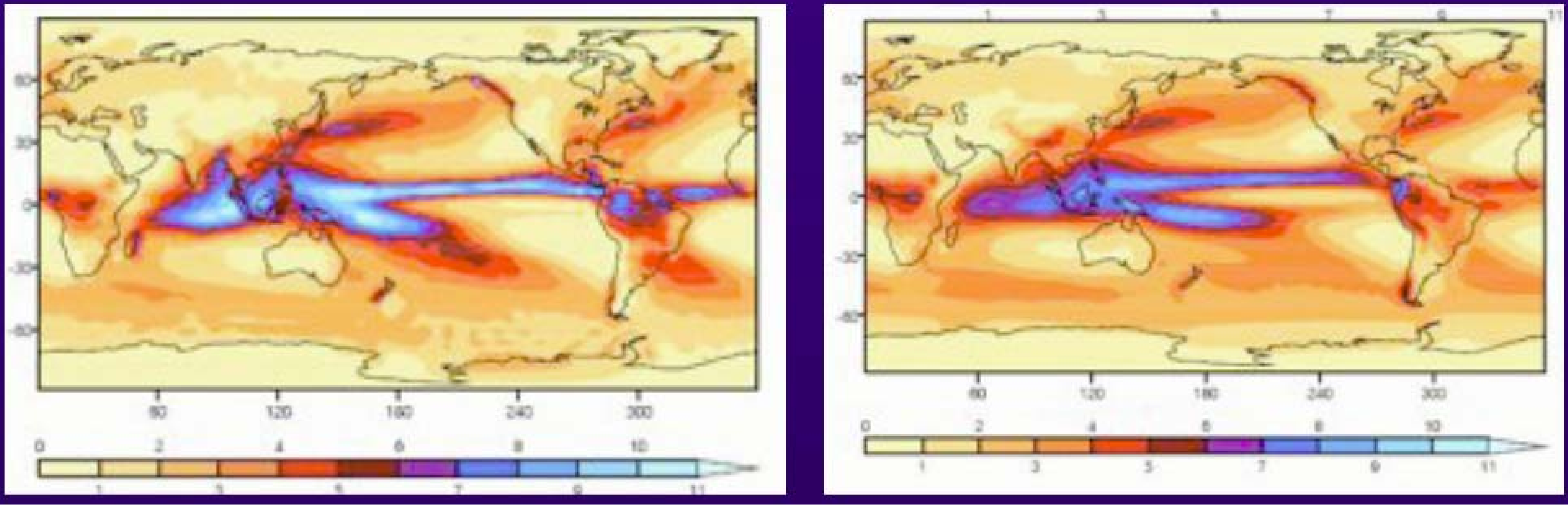
basis for sophisticated model predictions of future climate as discussed by IPCC

still under development

Performance of AOGCMs
Annual precipitation, 20 models

Observations

Model ensemble mean



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AOGCM

Coupled atmosphere-ocean general circulation models (AOGCMs)
AOGCMs are the most complex models in use, consisting of an AGCM coupled to an OGCM. Some recent models include the biosphere, carbon cycle and atmospheric chemistry as well. AOGCMs can be used for the prediction and rate of change of future climate. They are also used to study the variability and physical processes of the coupled climate system. Global climate models typically have a resolution of a few hundred kilometres. Climate projections from the Hadley Centre make use of the HadCM2 AOGCM (1994) and HadCM3 AOGCM (1998). Greenhouse-gas experiments with AOGCMs have usually been driven by specifying atmospheric concentrations of the gases, but if a carbon cycle model is included, the AOGCM can predict changes in carbon dioxide concentration, given the emissions of carbon dioxide into the atmosphere. At the Hadley Centre, this was first done in 1999. Similarly, an AOGCM coupled to an atmospheric chemistry model is able to predict the changes in concentration of other atmospheric constituents in response to climate change and to the changing emissions of various gases.

CGCM

The Third Generation Coupled Global Climate Model (CGCM3)

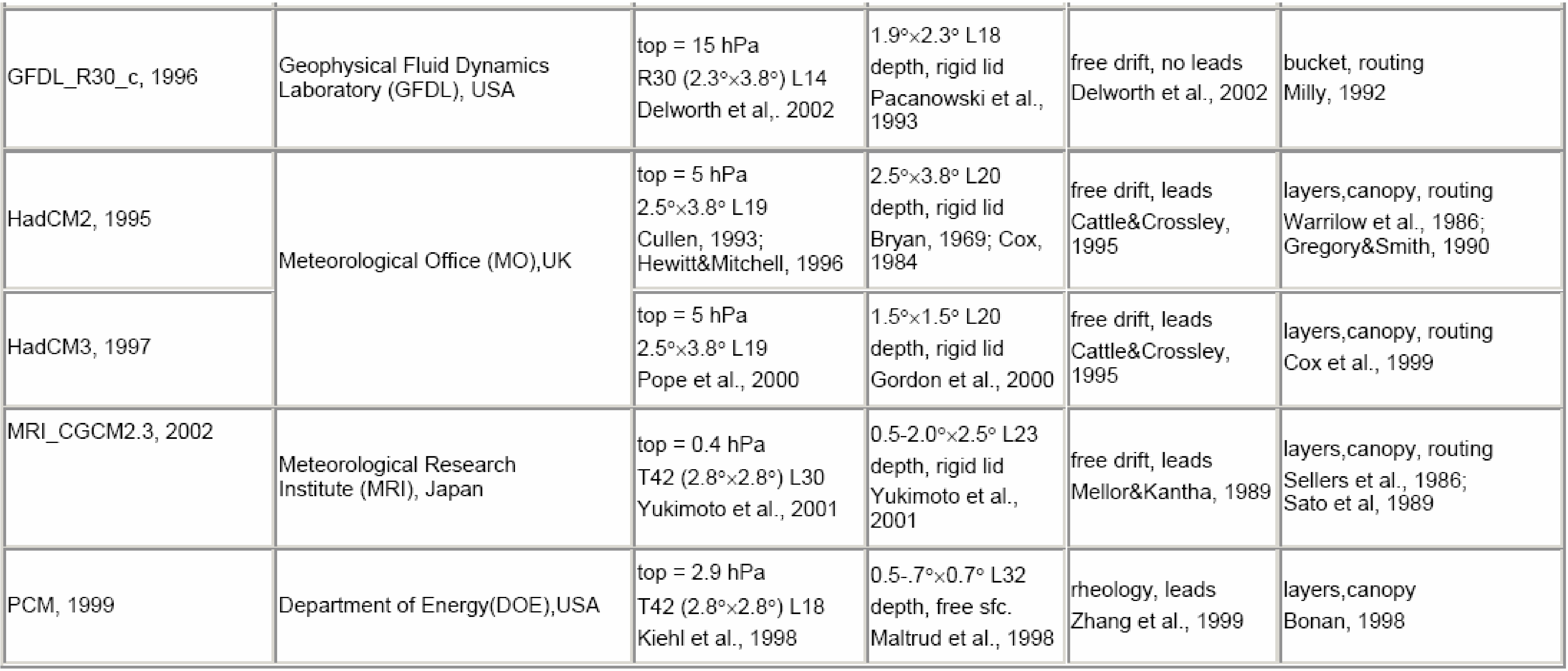
The third version of the Canadian Centre for Climate Modelling and Analysis (CCCma) Coupled Global Climate Model (CGCM3), makes use of the same ocean component as that used in the earlier CGCM2, but it makes use of the substantially updated atmospheric component AGCM3. The sea-ice component is a two-category model (mean thickness and concentration) with cavitating fluid dynamics (Flato and Hibler, 1992) and thermodynamics as in CGCM1 and CGCM2, except that a prognostic equation for ice concentration is included following Hibler (1979).

The initial version of CGCM3 was developed and ran on a NEC SX/6 vector supercomputer. A subsequent version, CGCM3.1, incorporates changes required to run efficiently on a new distributed memory IBM computer system. This latter version is the one used to produce an extensive suite of model simulations for use in the IPCC Fourth Assessment Report.

CGCM3.1 is run at two different resolutions. The **T47** version has a surface grid whose spatial resolution is roughly 3.75 degrees lat/lon and 31 levels in the vertical. The ocean grid shares the same land mask as the atmosphere, but has four ocean grid cells underlying every atmospheric grid cell. The ocean resolution in this case is roughly 1.85 degrees, with 29 levels in the vertical. The **T63** version has a surface grid whose spatial resolution is roughly 2.8 degrees lat/lon and 31 levels in the vertical. As before the ocean grid shares the same land mask as the atmosphere, but in this case there are 6 ocean grids underlying every atmospheric grid cell. The ocean resolution is therefore approximately 1.4 degrees in longitude and 0.94 degrees in latitude.

Table 2.1. Salient features of coupled ocean-atmosphere general circulation models (OAGCMs) entered in the 2004 PCMDI appraisal are listed alphabetically by model acronym along with the approximate year of the respective simulations ("vintage"). Also listed are the respective sponsoring institutions, the horizontal and vertical resolution of the model atmosphere and ocean as well as the pressure of the atmospheric top and the oceanic vertical coordinate and upper boundary condition. The representation of sea ice structure and dynamics, as well as the representation of soil moisture, vegetation, and runoff (e.g. discharge of fresh water to the ocean via a river routing model) also are indicated, with citations of references that describe further details of components of the coupled OAGCMs. See also the explanatory notes which follow the table on the next page.

Model, Vintage	**Sponsor, Country**	**Atmosphere: Resolution References**	**Ocean: Resolution Z Coord., TopBC References**	**Sea Ice: Dynamics, Structure References**	**Land: Soil, Plants, Rivers References**
BCM, 2002	University of Bergen (UB),Norway	top = 10 hPa T63 (1.9°×1.9°)L31 Deque et al., 1994	0.8-2.4°×2.4° L24 density, free sfc. Bleck et al., 1992	rheology, leads Drange&Simondsen, 1996; Hibler, 1979	layers,canopy,routing Douville et al., 1995; Mahfouf et al., 1995
CCCma_CGCM2, 2001	Canadian Centre for Climate Modelling &Analysis (CCCma), Canada	top = 5 hPa T32 (3.7°×3.7°)L10 McFarlane et al., 1992	1.9°×1.9° L29 depth, rigid lid, Pacanowski et al., 1993	rheology, leads Flato&Hibler, 1990	bucket, routing McFarlane et al., 1992
CCSM2.0, 2002	National Center for Atmospheric Research (NCAR),USA	top = 2.9 hPa T42 (2.8°×2.8°)L26 Collins et al., 2003	0.3-1.0°×1.0° L40 depth, free sfc. Smith&Gent, 2002	rheology, leads Briegleb et al., 2002	layers, canopy, routing Bonan et al., 2002; Branstetter&Erickson, 2003
CSIRO_Mk2, 1997	Comnwealth .Scientific & Industrial Research Organization (CSIRO), Australia	top = 21 hPa R21 (3.2°×5.6°)L9 McGregor et al., 1993	3.2°×5.6° L21 depth, rigid lid Hirst et al., 2000	rheology, leads O'Farrell, 1998	layers, canopy Kowalczyk et al., 1991, 94
ECHAM4_OPYC3, 1996	Max Planck Institut fur Meteorologie (MPI), Germany	top = 10 hPa T42 (2.8°×2.8°) L19 Roeckner et al., 1996b	0.5-2.8°×2.8° L11 density, free sfc. Oberhuber, 1993	rheology, leads Oberhuber, 1993	bucket, canopy, routing, Roeckner et al., 1996b
ECHO-G, 1999	Model & Data Group (M&D), Germany	top = 10 hPa T30 (3.9°×3.9°) L19 Roeckner et al., 1996b	0.5-2.8°×2.8° L20 depth, free sfc. Wolff et al., 1997	rheology, leads Wolff et al., 1997	bucket,canopy, routing Roeckner et al., 1996b



GFDL_R30_c, 1996	Geophysical Fluid Dynamics Laboratory (GFDL), USA	top = 15 hPa R30 (2.3°×3.8°) L14 Delworth et al,. 2002	1.9°×2.3° L18 depth, rigid lid Pacanowski et al., 1993	free drift, no leads Delworth et al., 2002	bucket, routing Milly, 1992
HadCM2, 1995	Meteorological Office (MO),UK	top = 5 hPa 2.5°×3.8° L19 Cullen, 1993; Hewitt&Mitchell, 1996	2.5°×3.8° L20 depth, rigid lid Bryan, 1969; Cox, 1984	free drift, leads Cattle&Crossley, 1995	layers,canopy, routing Warrilow et al., 1986; Gregory&Smith, 1990
HadCM3, 1997		top = 5 hPa 2.5°×3.8° L19 Pope et al., 2000	1.5°×1.5° L20 depth, rigid lid Gordon et al., 2000	free drift, leads Cattle&Crossley, 1995	layers,canopy, routing Cox et al., 1999
MRI_CGCM2.3, 2002	Meteorological Research Institute (MRI), Japan	top = 0.4 hPa T42 (2.8°×2.8°) L30 Yukimoto et al., 2001	0.5-2.0°×2.5° L23 depth, rigid lid Yukimoto et al., 2001	free drift, leads Mellor&Kantha, 1989	layers,canopy, routing Sellers et al., 1986; Sato et al, 1989
PCM, 1999	Department of Energy(DOE),USA	top = 2.9 hPa T42 (2.8°×2.8°) L18 Kiehl et al., 1998	0.5-.7°×0.7° L32 depth, free sfc. Maltrud et al., 1998	rheology, leads Zhang et al., 1999	layers,canopy Bonan, 1998

CCCma has develped a number of climate simulation models for climate prediction, study of climate change and variability, and to better understand the various processes which govern our climate system.

AGCM1	**The first generation atmospheric general circulation model.**
AGCM2	**The second generation atmospheric general circulation model.**
AGCM3	**The third generation atmospheric general circulation model.**
CGCM1	**The first generation coupled global climate model.**
CGCM2	**The second generation coupled global climate model.**
CGCM3	**The third generation coupled global climate model.**

CCCma also participates in several Climate Research Network model development projects including:

MAM	**The Middle Atmosphere Model.**
CRCM	**The Canadian Regional Climate Model.**

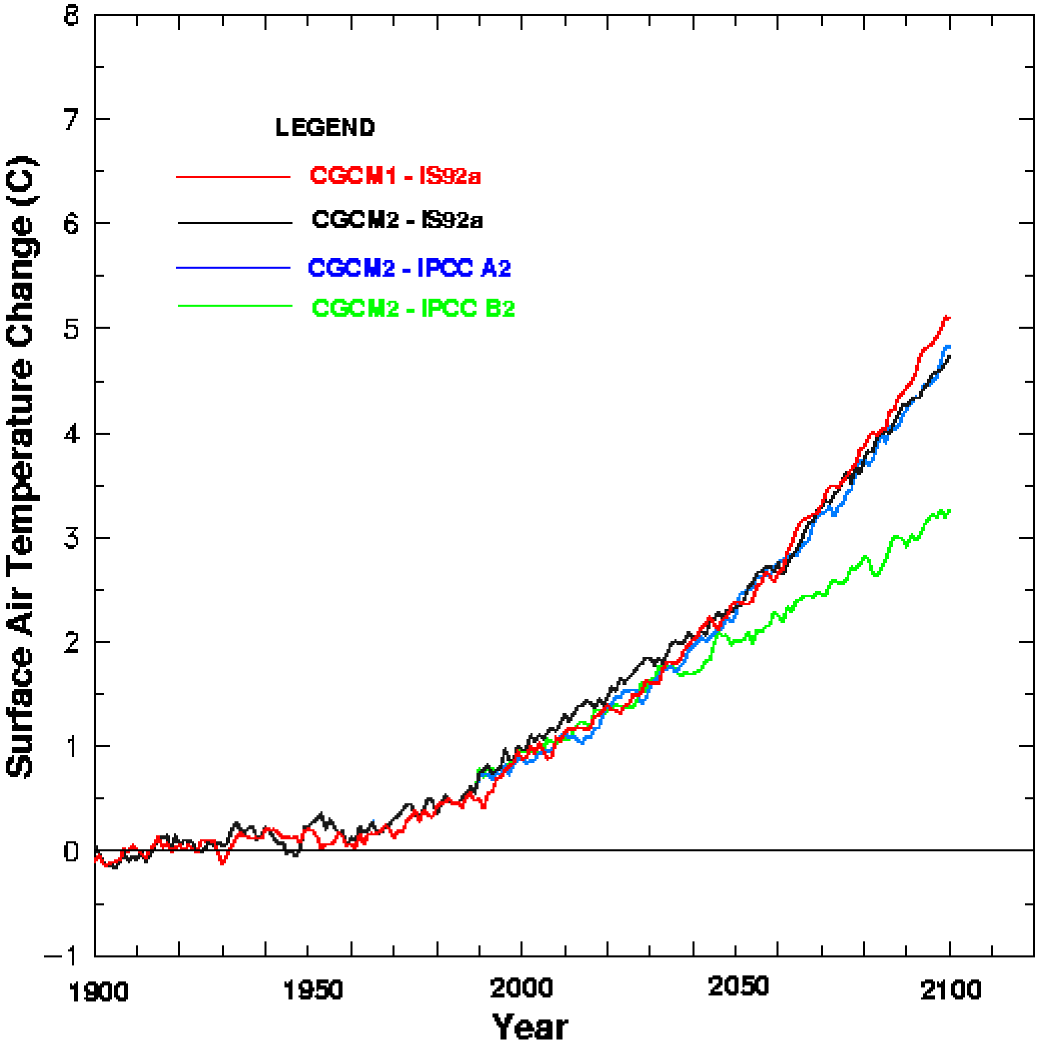


Figure : Global annual average surface temperature change, relative to 1900-1929 average as produced by CGCM1 and CGCM2 for various forcing scenarios.

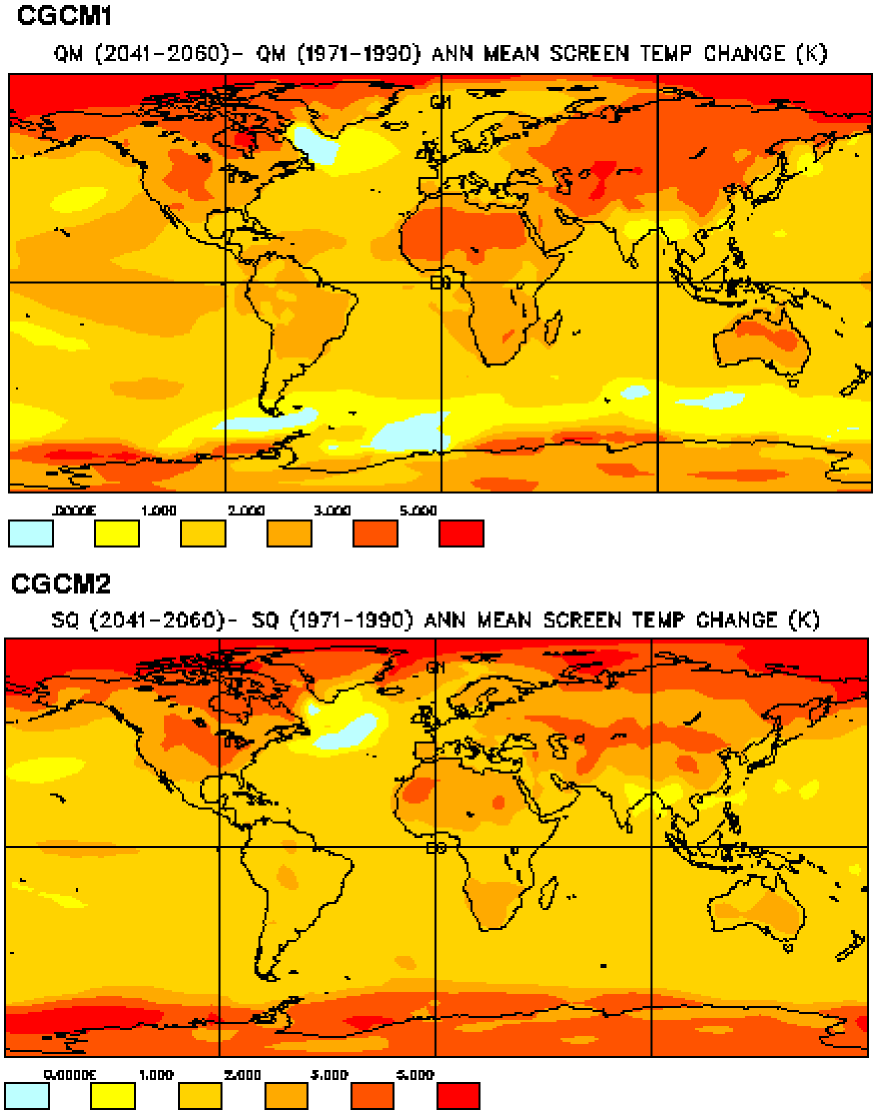
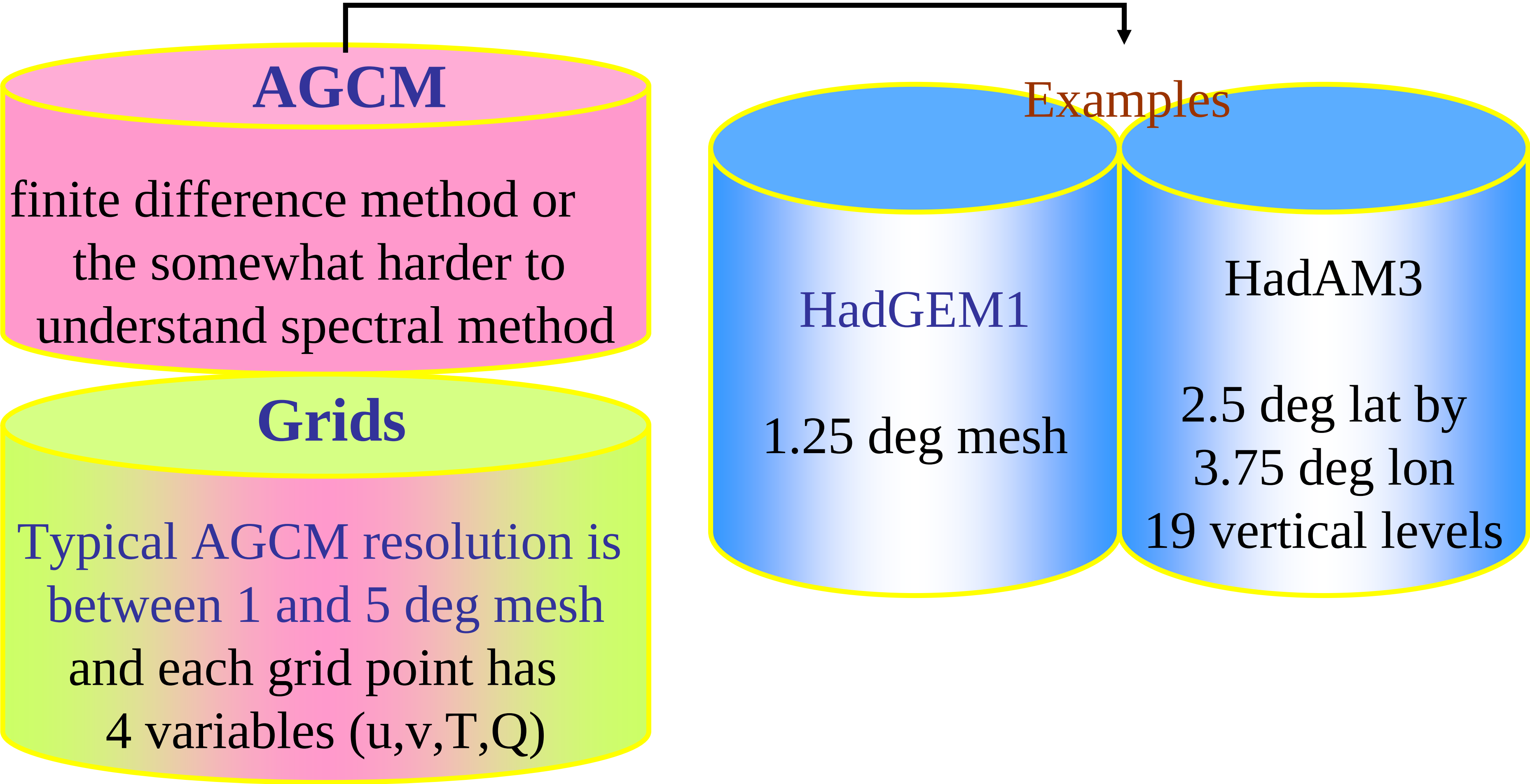


Figure : Annual mean surface air temperature change, 1971-1990 to 2041-2060 as projected by CGCM1 (upper panel) and CGCM2 (lower panel).

AGCM Model Grids



AGCM

finite difference method or the somewhat harder to understand spectral method

Grids

Typical AGCM resolution is between 1 and 5 deg mesh and each grid point has 4 variables (u,v,T,Q)

Examples

HadGEM1

1.25 deg mesh

HadAM3

2.5 deg lat by
3.75 deg lon
19 vertical levels

Is it possible to provide a **range of dynamical and statistical downscaling tools together with recommendations and guidance** regarding their use in order to encompass the needs of different impacts sectors for probabilistic high-resolution regional climate scenarios?

Can the best and most robust present-day state-of-art **statistical downscaling methodologies** be modified for integration into the ensemble prediction system?

Which, if any, of these sources of uncertainty have been reduced as a result of the ENSEMBLES work & which could be reduced with further work?

Answer may be Regional Climate Models (RCMs)

RCM

Regional Climate Models

There are now 8 RCMs from 6 groups:

ECPC	**RSM**
IRI	**RSM / MM5 / REGCM2**
GISS	**RCM**
FSU	**FSU spectral model**
NCEP	**ETA**
CPTEC	**ETA**

RCM

Regional climate models (RCMs)

Local climate change is influenced greatly by local features such as mountains, which are not well represented in global models because of their coarse resolution. Models of higher resolution cannot practically be used for global simulation of long periods of time. To overcome this, regional climate models, with a higher resolution (typically 50 km) are constructed for limited areas and run for shorter periods (20 years or so). RCMs take their input at their boundaries and for sea-surface conditions from the global AOGCMs.

The RCM Approach

The one-way nesting of limited area models (LAMs), suitably designed as Regional Climate Models (RCMs), within General Circulation Models (GCMs) is becoming a valuable downscaling technique for simulating the climate of a limited domain. They allow physically based and computationally affordable long-term integrations at high spatial resolution. RCMs are now been used in many climate research centres around the world.

RCM

Dynamical core (Laprise et al., 1997)

Fully elastic nonhydrostatic Euler equations.

Semi-implicit semi-Lagrangian: time filter (developed by Robert (1966) and analyzed by Asselin (1972)) and uncentring of semi-implicit scheme.

3-D staggered grid: Gal-Chen terrain-following vertical-coordinate (Gal-Chen and Sommerville, 1975) along with Polar-stereographic horizontal projection.

One-way nesting over the regional domain (limited area) with lateral boundary conditions following Davies (1976) and refined by Yakimiw and Robert (1990):

- -Horizontal winds U & V, air temperature, water vapour and pressure from the nesting model are imposed at the lateral boundary grid-points exactly, as interpolated onto the RCM's atmospheric levels.
- -Atmospheric horizontal winds U & V relaxed toward values of the driving data over the sponge zone (generally 9 grid points).

Nesting Strategy

A spectral nudging technique can be applied within the regional domain to keep the RCM's large-scale flow close to that of the driving data (Riette and Caya, 2002). The wavenumber of the smallest features passed to the nudging is user-defined, as well as the nudging intensity, which can vary according to height.

RCM

Physical parameterization

Radiative transfers

Solar: improved method with three bands in the near-infrared region and one band in the visible (replacing an earlier two-band parameterization) (Puckrin et al., 2004) @ 1-h interval

Terrestrial: improved treatment of the broadband emissivities and of the water vapour continuum (Puckrin et al., 2004) @ 6-h interval
Note: radiative effects of greenhouse gases are now considered separately for CO2, CH4, N2O, CFC11 and CFC12 (replacing equivalent CO2).

Vertical fluxes: heat, momentum and water vapour, turbulent eddy diffusion and surface fluxes revised turbulent transfer coefficients were introduced for surface exchanges of heat, moisture and momentum in line with AGCM3 (Abdella and McFarlane, 1996).

Gravity-wave drag: McFarlane (1987).

RCM

Land-surface scheme : CLASS 2.7 (Canadian LAnd Surface Scheme; Verseghy, 1991; Verseghy et al., 1993) : Starting from the surface, CLASS uses three soil layers with thicknesses of 0.1 m, 0.25m and 3.75 m, corresponding approximately to the depth influenced by the diurnal cycle, the rooting zone and the annual variations of temperature, respectively.

Physics adapted to finer resolution:

Choice of mesoscale convection scheme: Bechtold et al. (2001) or Kain and Fritsch (1990). Cloud cover onset dependent on local relative humidity and newly introduced dependence on static stability (from previous version 3.6) (Lorant et al., 2002).

Lake model:

A mixed-layer/thermodynamic-ice lake model for the Laurentian Great Lakes (Goyette et al., 2000) was coupled to the CRCM. It simulates the evolution of surface water temperature and ice cover, with mixed-layer depth that can vary spatially.

Climate prediction Uncertainties

Climate prediction uncertainties

in models

future course of industrial growth and technology (largest unknown, Ref. IPCC scenarios)

Progress has been made in incorporating more realistic physics in the models, but significant uncertainties and unknowns still remain there.

Which are the **most important sources of uncertainty** for high-resolution regional climate scenarios?

Can these sources of uncertainty be combined into a **single measure/distribution**, and communicated in terms that are appropriate for a range of **different audiences**, i.e., climate scientists, impacts scientists, stakeholders, policy and decision makers?

Can better quantitative estimates of the uncertainties be obtained by running **larger RCM ensembles**, i.e., with multiple runs of multiple RCMs for multiple GCMs and multiple emissions scenarios?

Will the availability of **transient RCM simulations for 1950-2050 and 1950-2100**, which provides the first opportunity for rigorous assessment of pattern-scaling techniques, allow us to demonstrate that these techniques can be used with confidence, e.g., to estimate changes in extremes in integrated assessment models?

How will impact-relevant climate parameters and meteorological extreme events such as heavy precipitation, drought, wind storms and heat waves **change in the future** and how do the projected changes compare with the range of **natural variability**?

Can more reliable high-resolution regional climate scenarios be constructed by **increasing RCM resolution from 50 km to 20 km**?

Answer may be **PRECIS** ! **RegCM!**

Different model has different advantages.

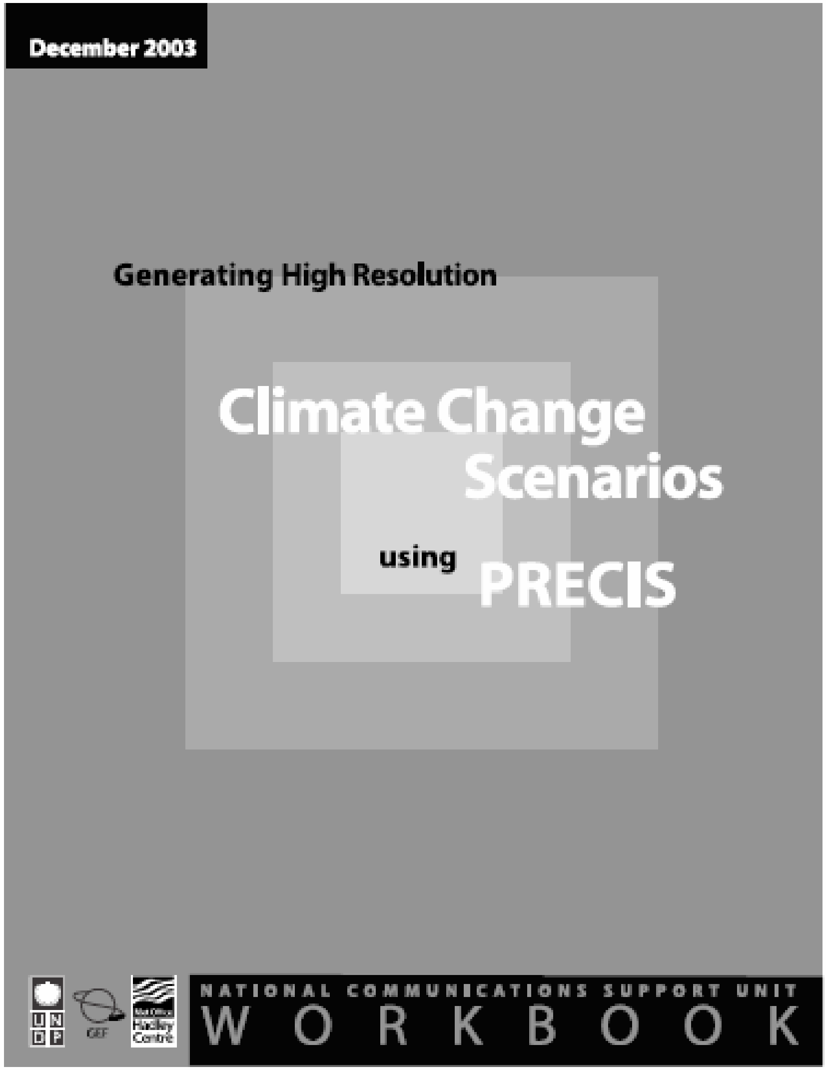
RCMs **PRECIS** (Providing Regional Climate Impact Studies) and **RegCM (Regional Climate Model)** will be discussed in this workshop in detail.

Generating High Resolution Climate Change Scenarios Using PRECIS

The Hadley Centre regional climate model **(RCM)** located over Europe is being used to provide the next generation of climate change scenarios for UK impacts assessments.

RCM is being used over southern Africa, India and Europe in collaborative projects with the UK.

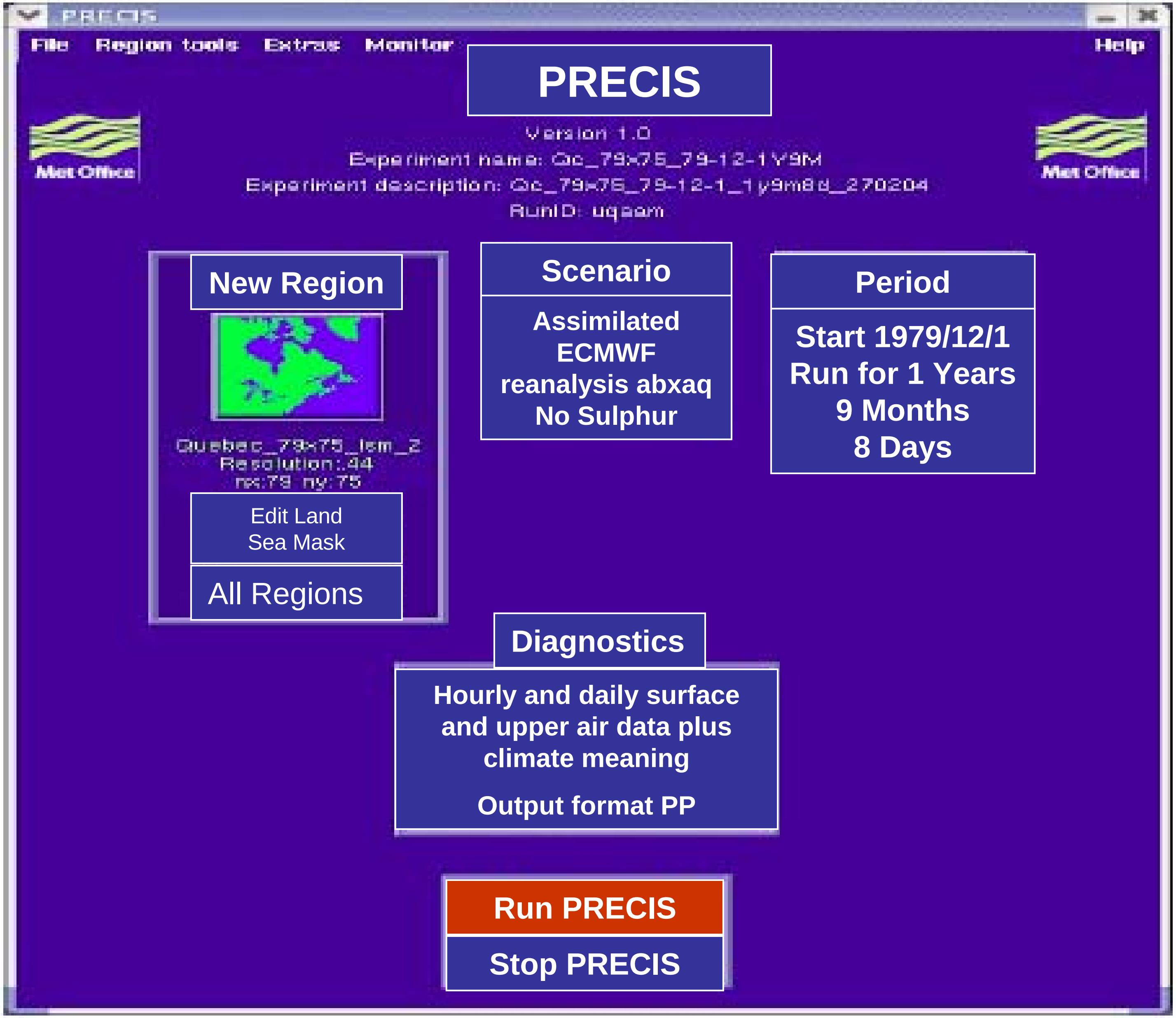
The Hadley Centre, under contract from the UK government departments DEFRA and DFID and from the UNDP, has developed a PC-based regional climate modelling system that emerges as **PRECIS** (providing Regional Climate Impact Studies).



December 2003

Generating High Resolution Climate Change Scenarios using PRECIS

NATIONAL COMMUNICATIONS SUPPORT UNIT WORKBOOK



PRECIS

Version 1.0

Experiment name: Qc_79x75_79-12-1Y9M

Experiment description: Qc_79x75_79-12-1_1y9m8d_270204

RunID: uqaem

Quebec_79x75_lsm_2
Resolution:.44
nx:79 ny:75

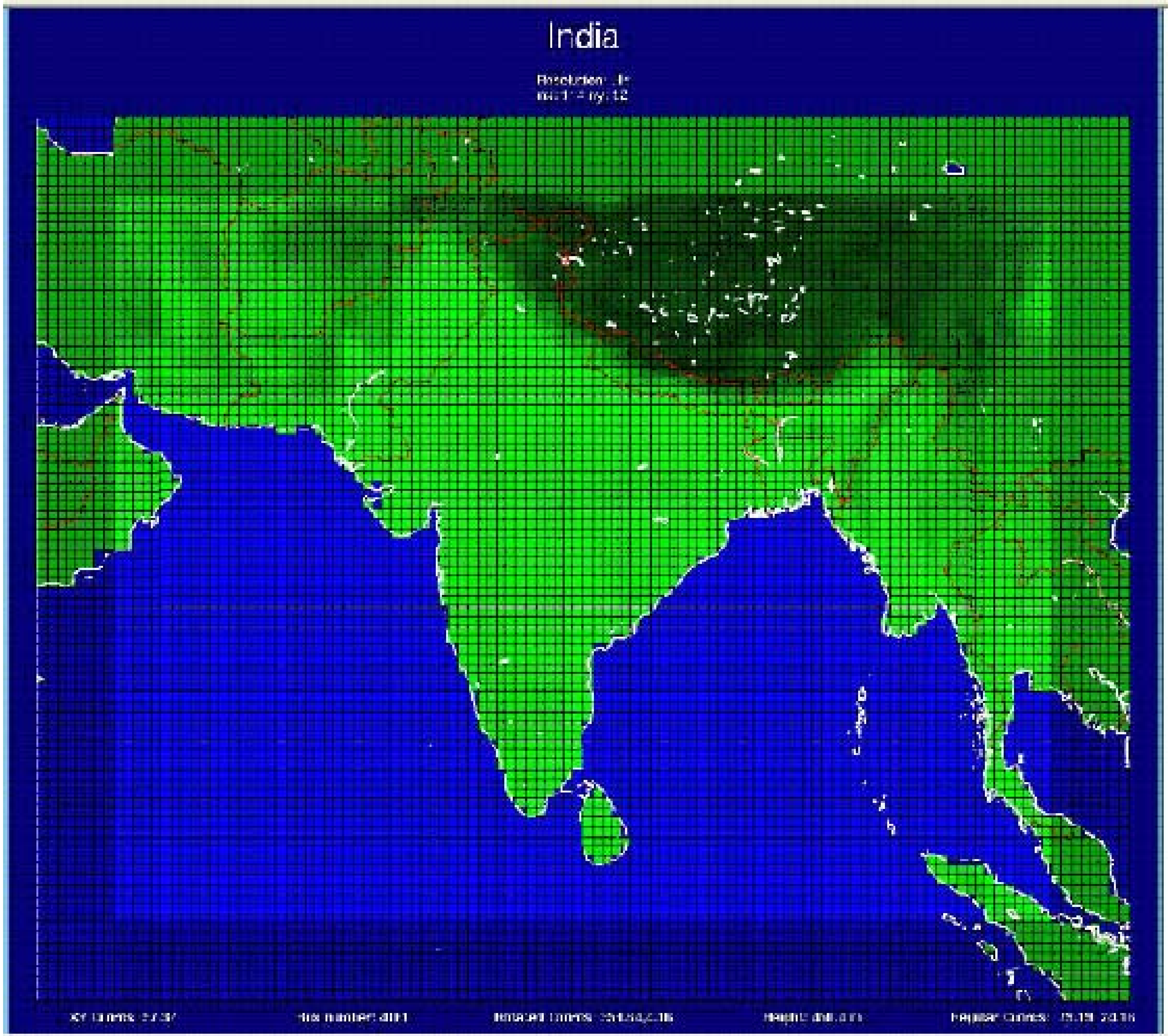
Scenario
Assimilated ECMWF reanalysis abxaq
No Sulphur

Period
Start 1979/12/1
Run for 1 Years
9 Months
8 Days

Diagnostics
Hourly and daily surface and upper air data plus climate meaning

Output format PP

Figure 2. A Graphical User Interface (GUI) controls all PRECIS operation


India
Resolution:

PRECIS Output format

Output data from PRECIS can be written in three different formats

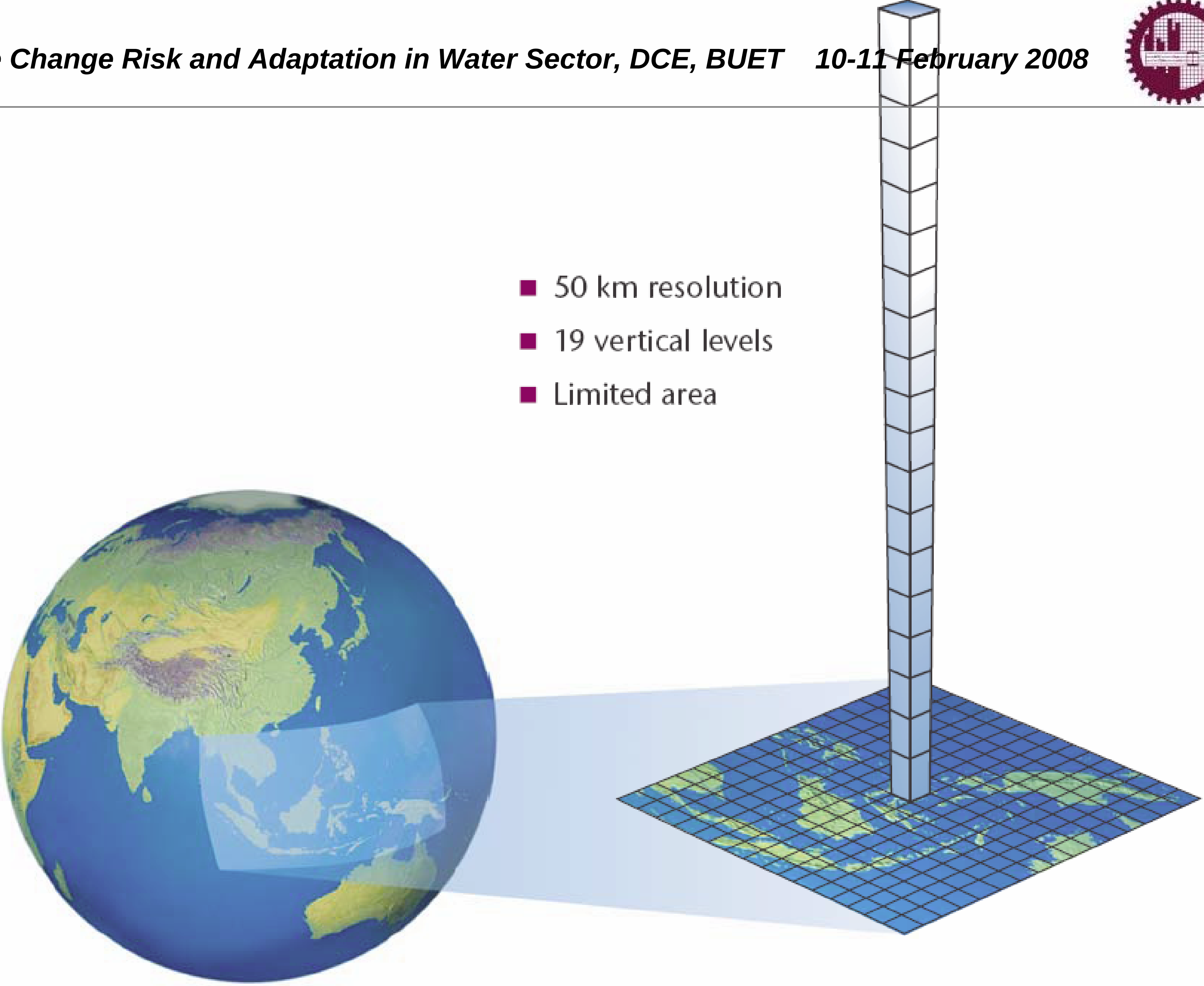
- PP (the UK Met Office's own data format)
- NetCDF
- GRIB

PP format data can be reformatted into either NetCDF or GRIB data at any point, but the reverse is not possible. This can then be converted later into NetCDF or GRIB and can be read by GrADS.

Note: GrADS does not recognize rotated coordinates as standard

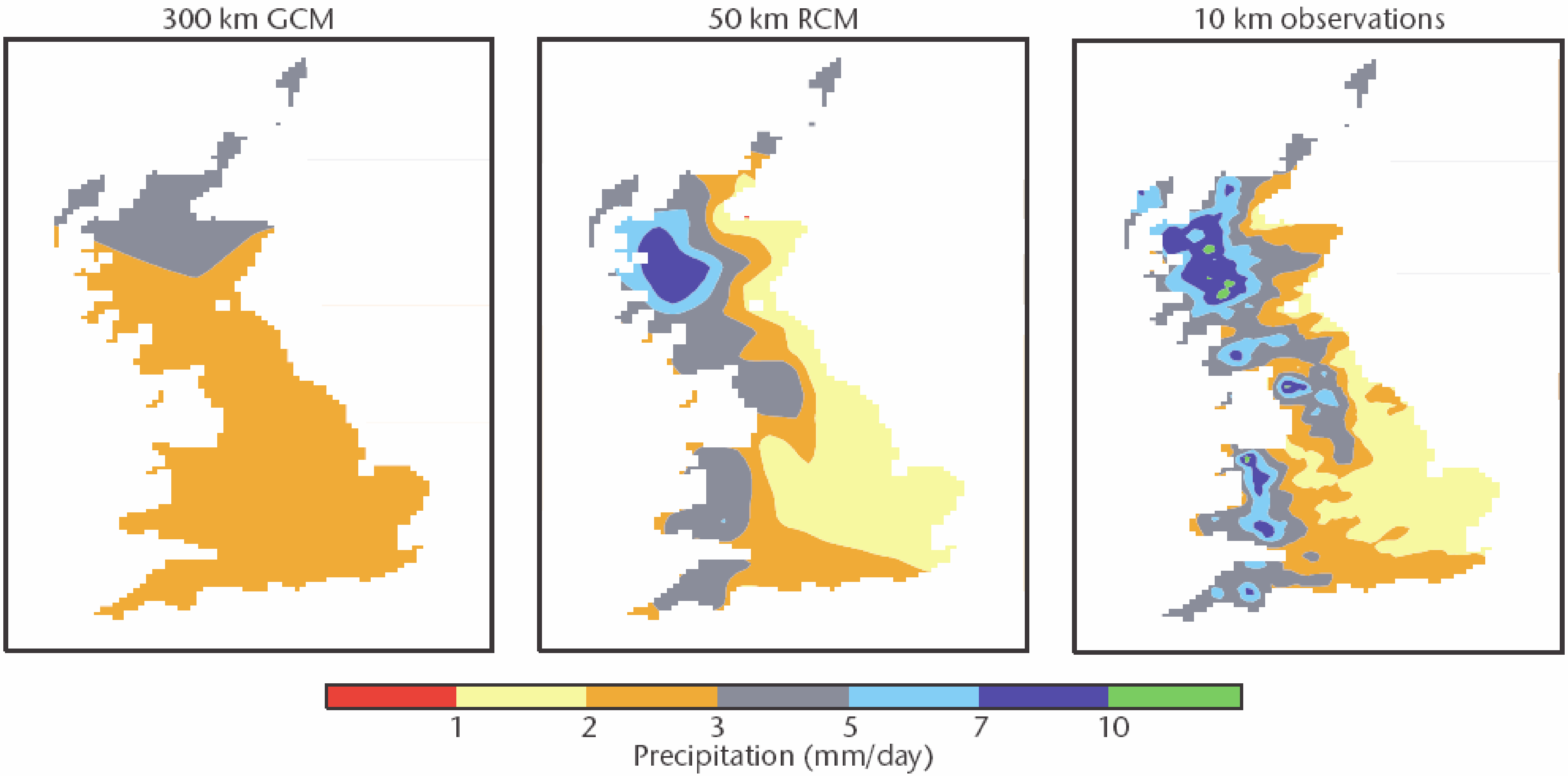
We have to convert all PRECIS output in real coordinate to make useful in GrADS

Why we need PRECIS?



- 50 km resolution
- 19 vertical levels
- Limited area

Schematic diagram of the resolution of the Earth's surface and the atmosphere in the Hadley Centre regional climate model.


300 km GCM

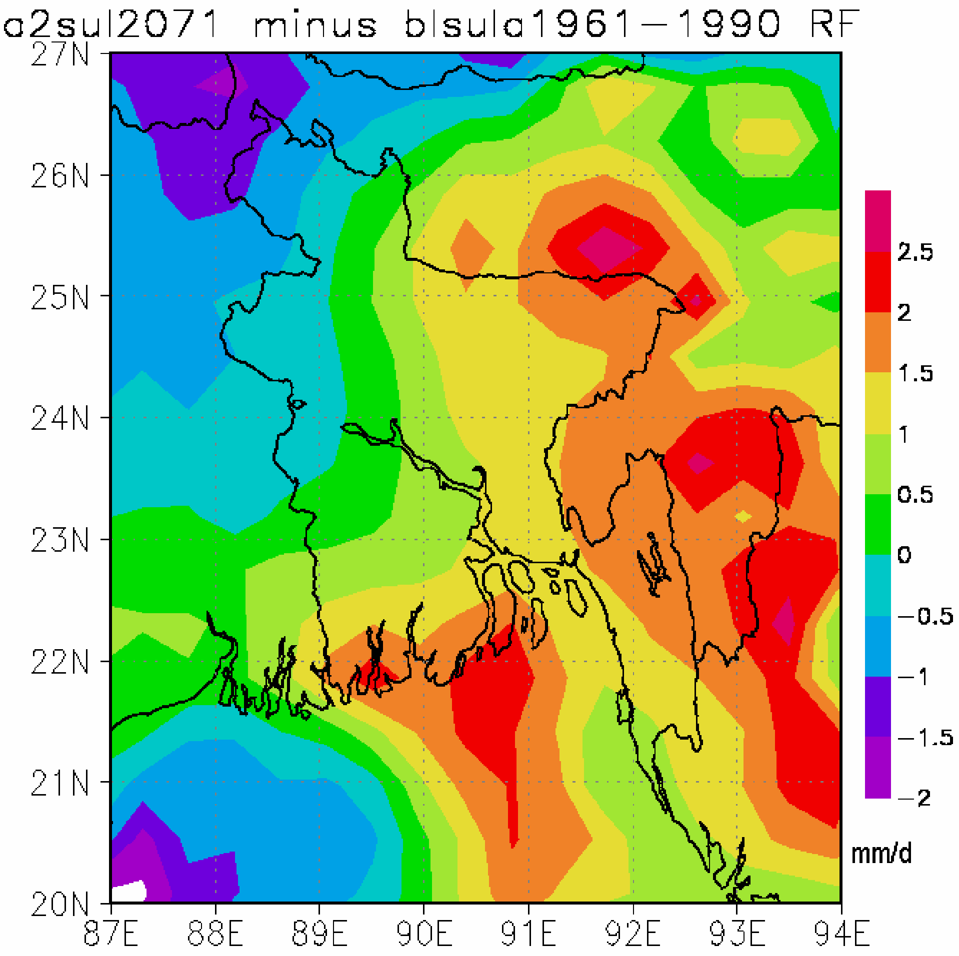
50 km RCM

10 km observations

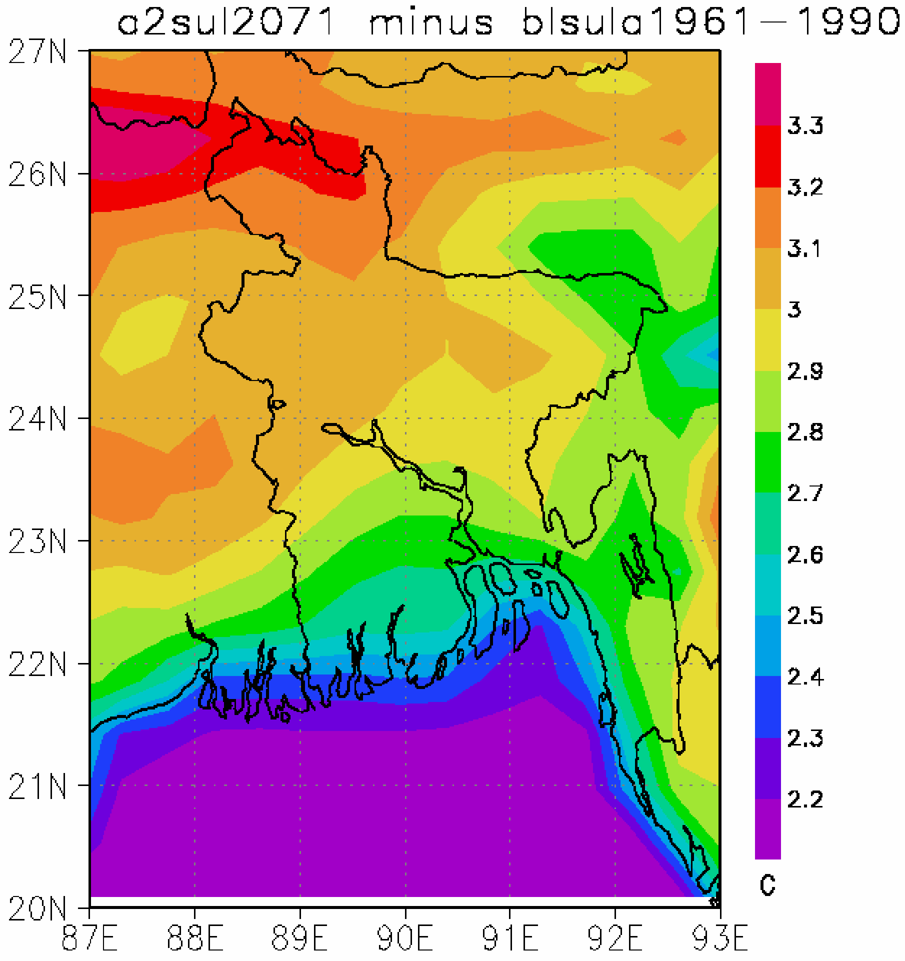
Patterns of present-day winter precipitation over Great Britain. Left, as simulated with the global model. Middle: as simulated with the 50 km regional model. Right, as observed.

What are Rainfall and Temperature in 2071 ?

PRECIS



Rainfall

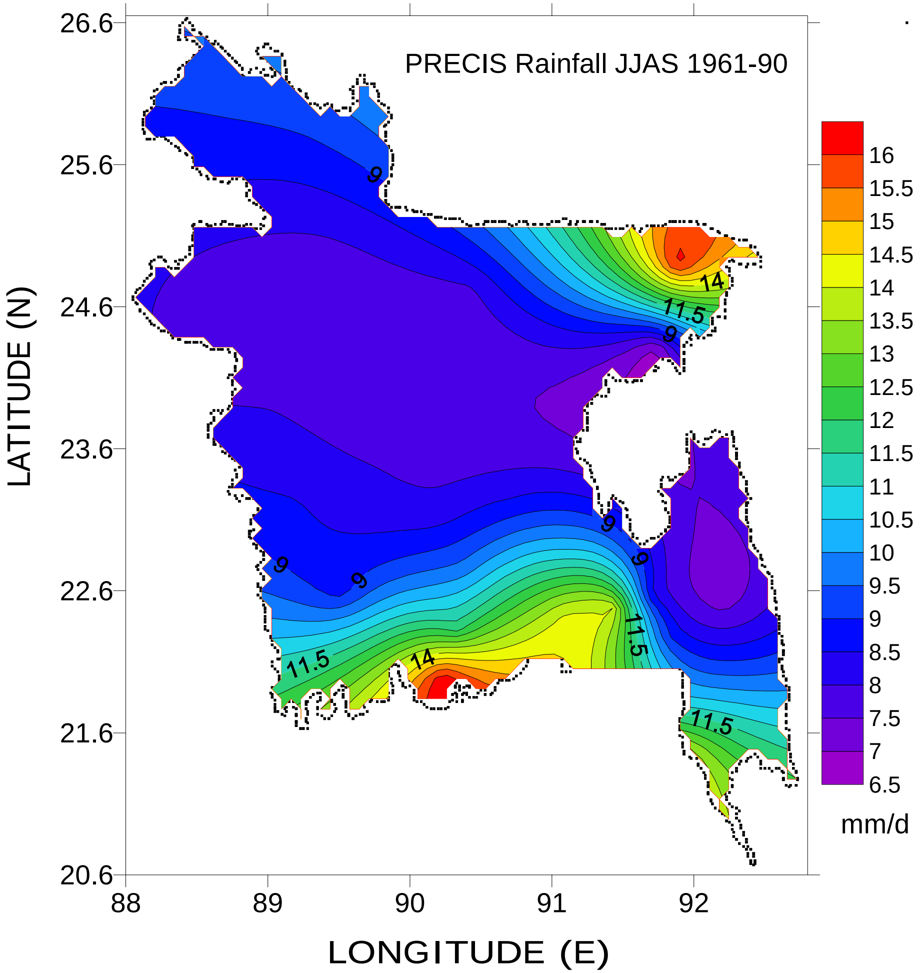


Temperature

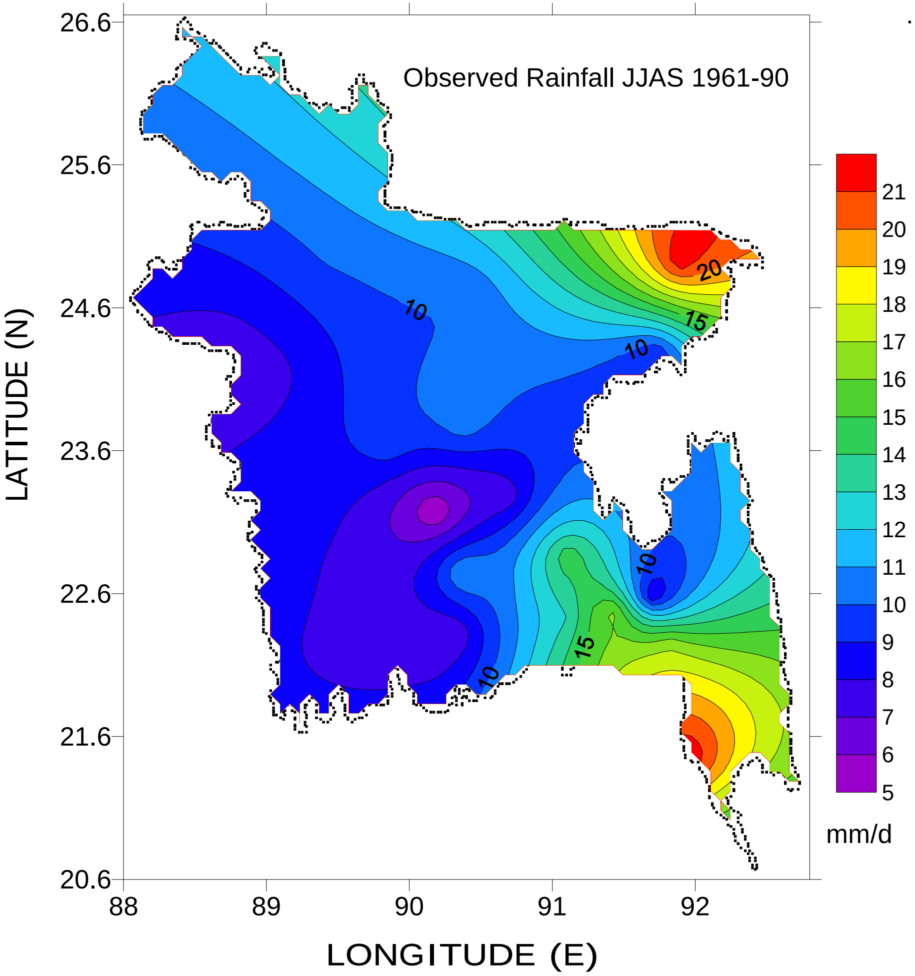
Islam et al.,2007, Int. J. Climatol. Wiley InterScience DOI:10.1002/joc.1559

Reasons to TRUST on Simulation

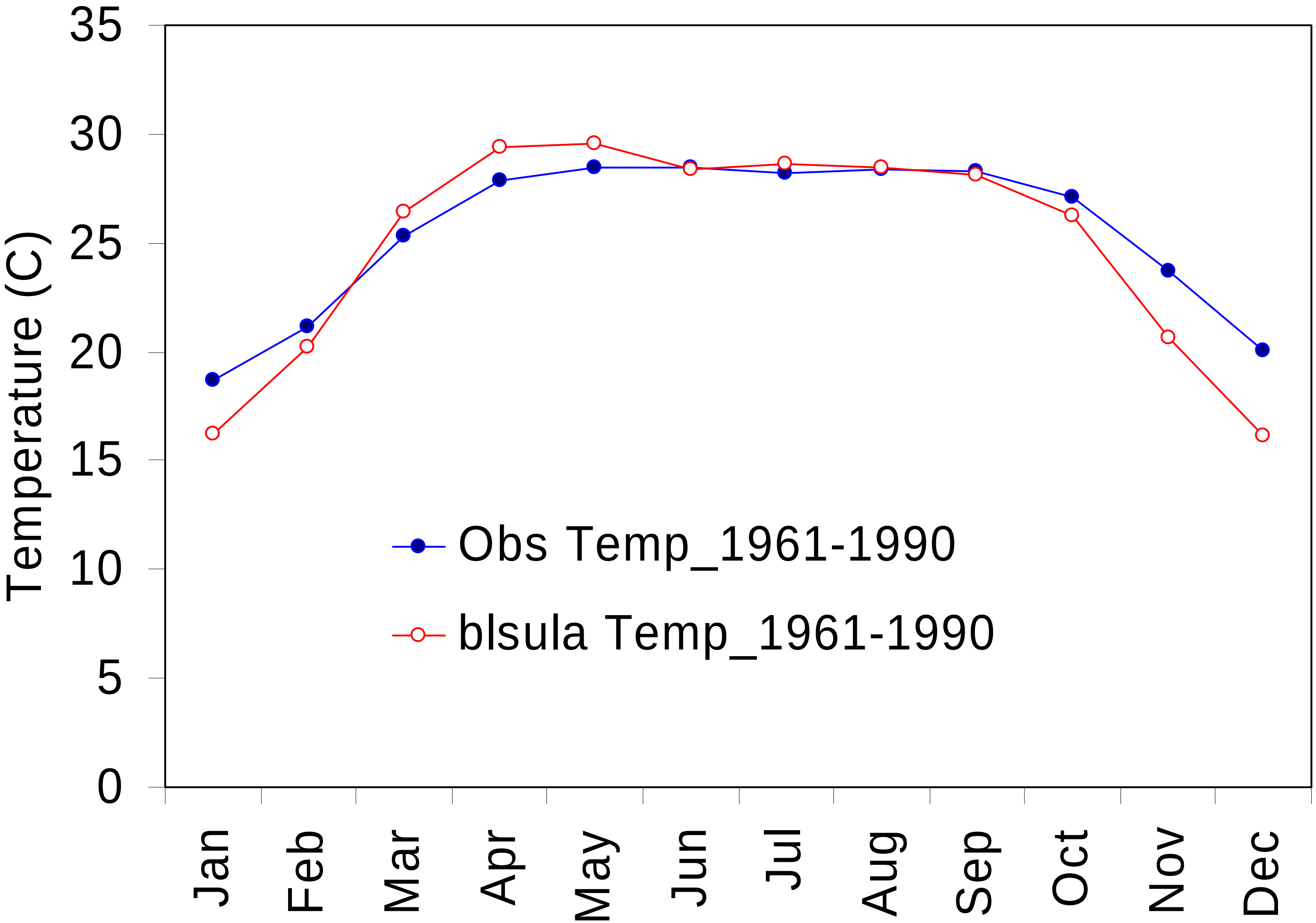
MODEL



OBSERVATION

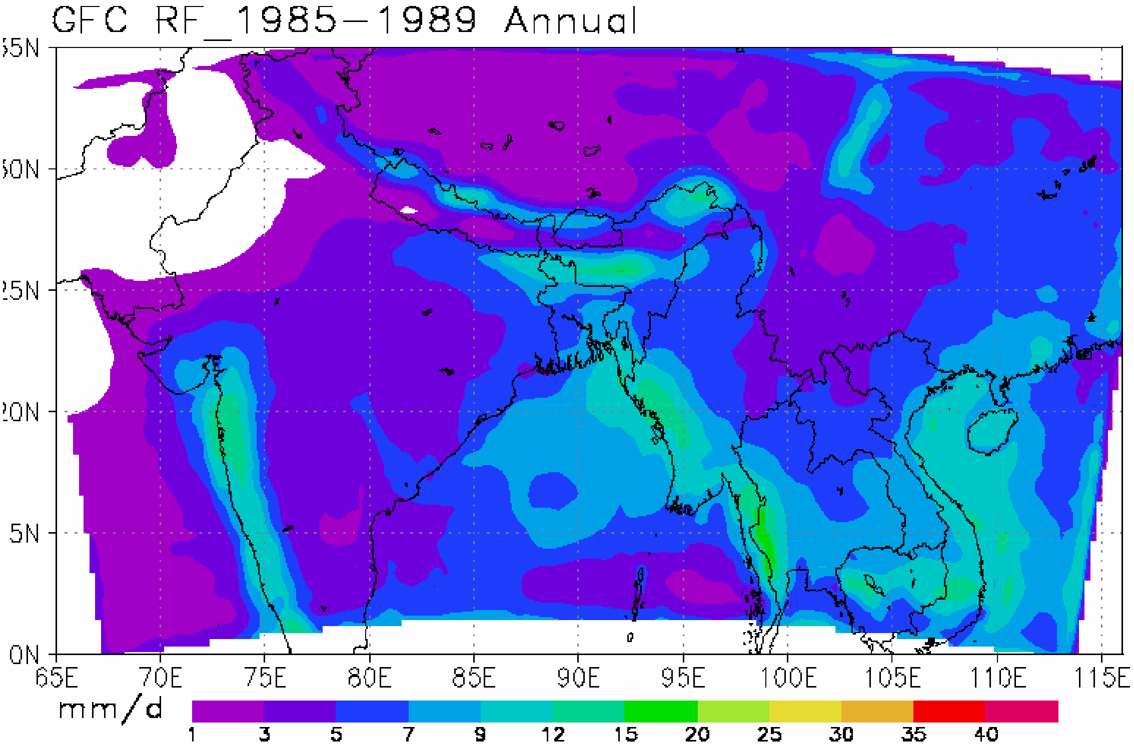


PRECIS TEMPERATURE

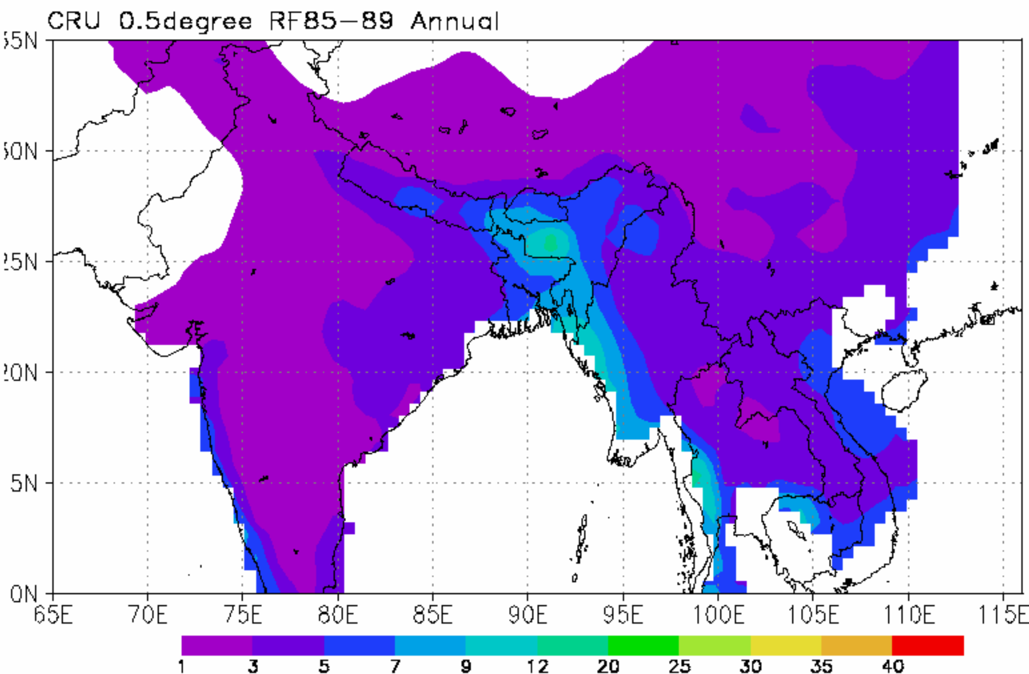


Islam et al.,2007, Int. J. Climatol. Wiley InterScience DOI:10.1002/joc.1559

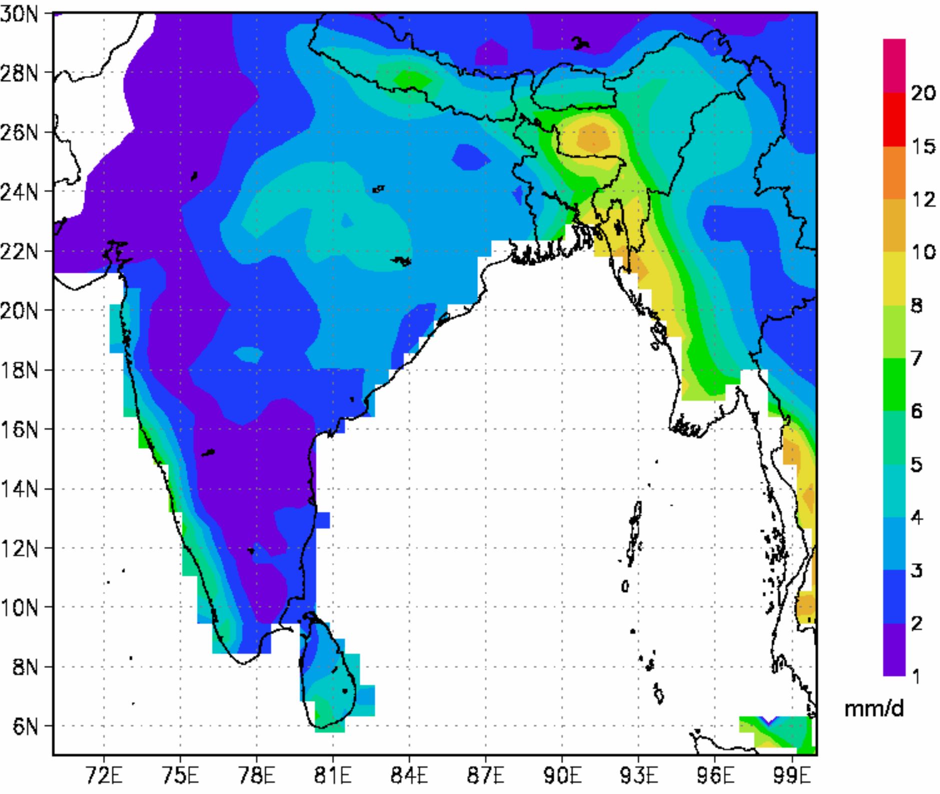
Why we need RegCM?

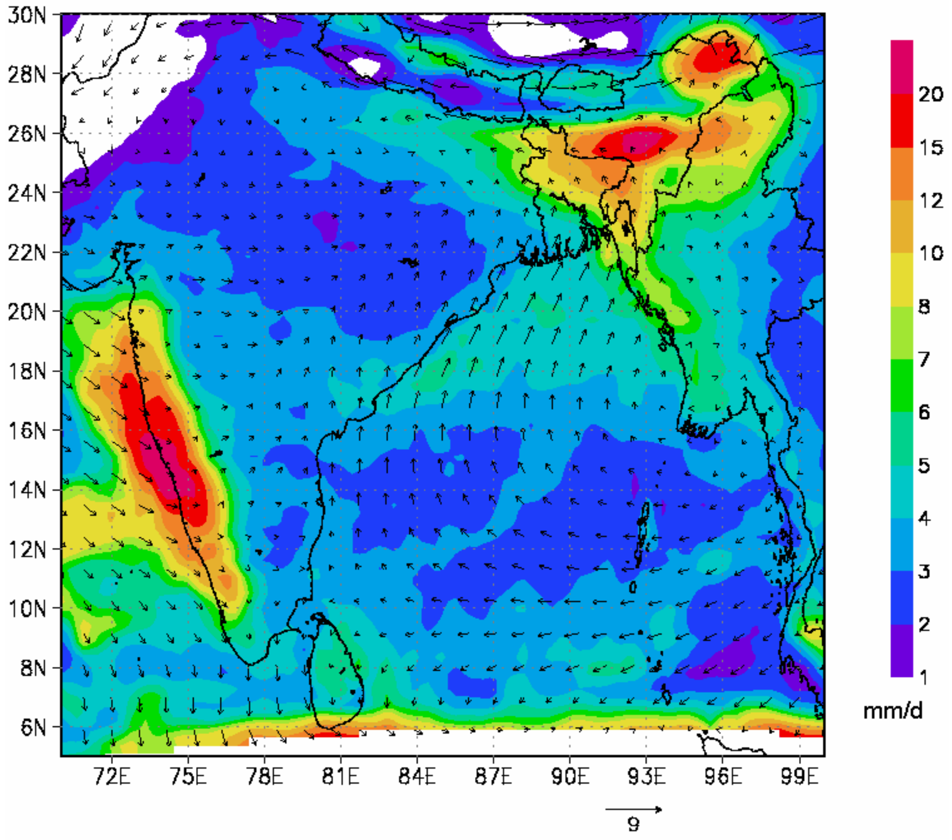


GFC RF_1985−1989 Annual



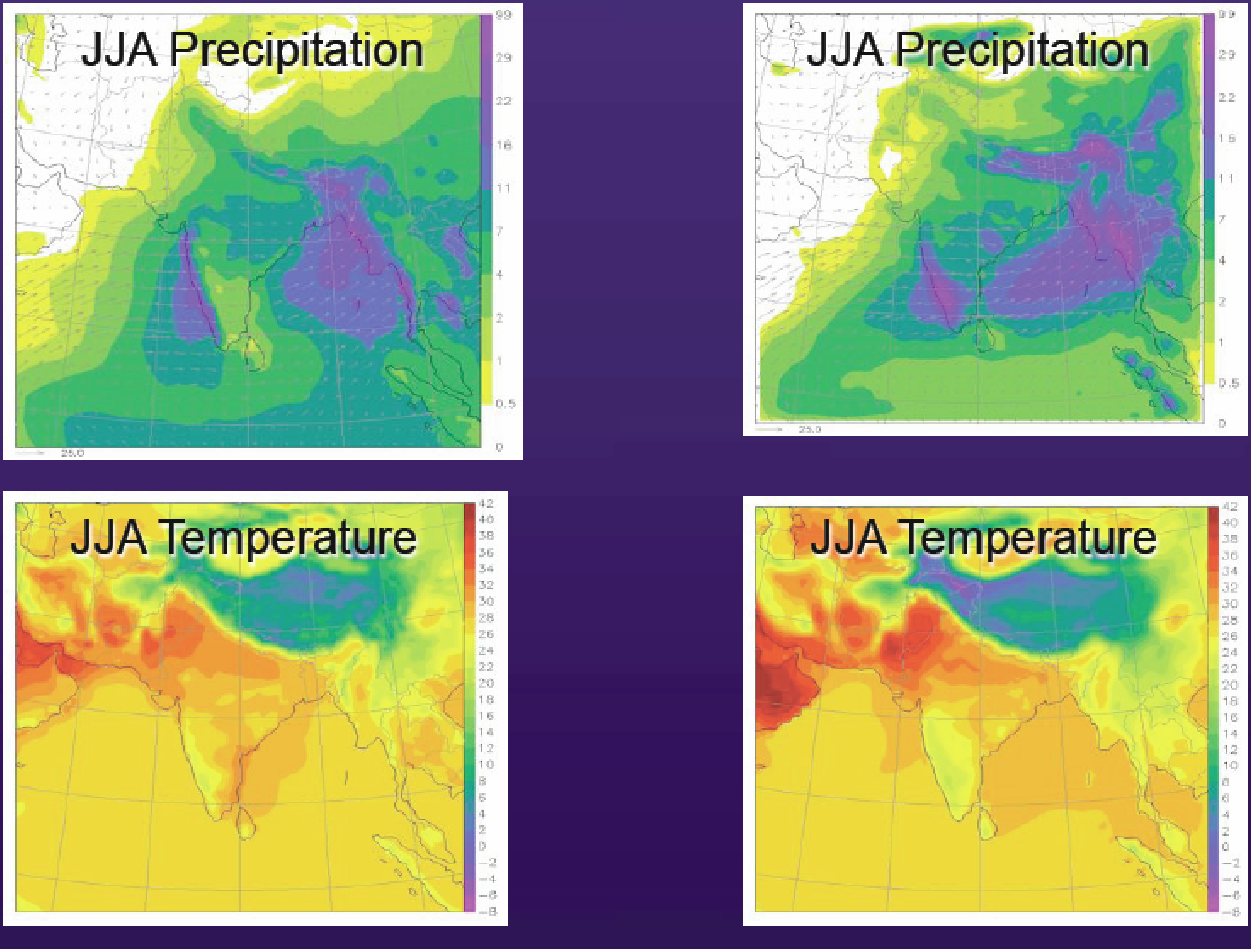
CRU 0.5degree RF85−89 Annual


CRU 1983 ANNUAL RF


GFC 1983 ANNUAL RF

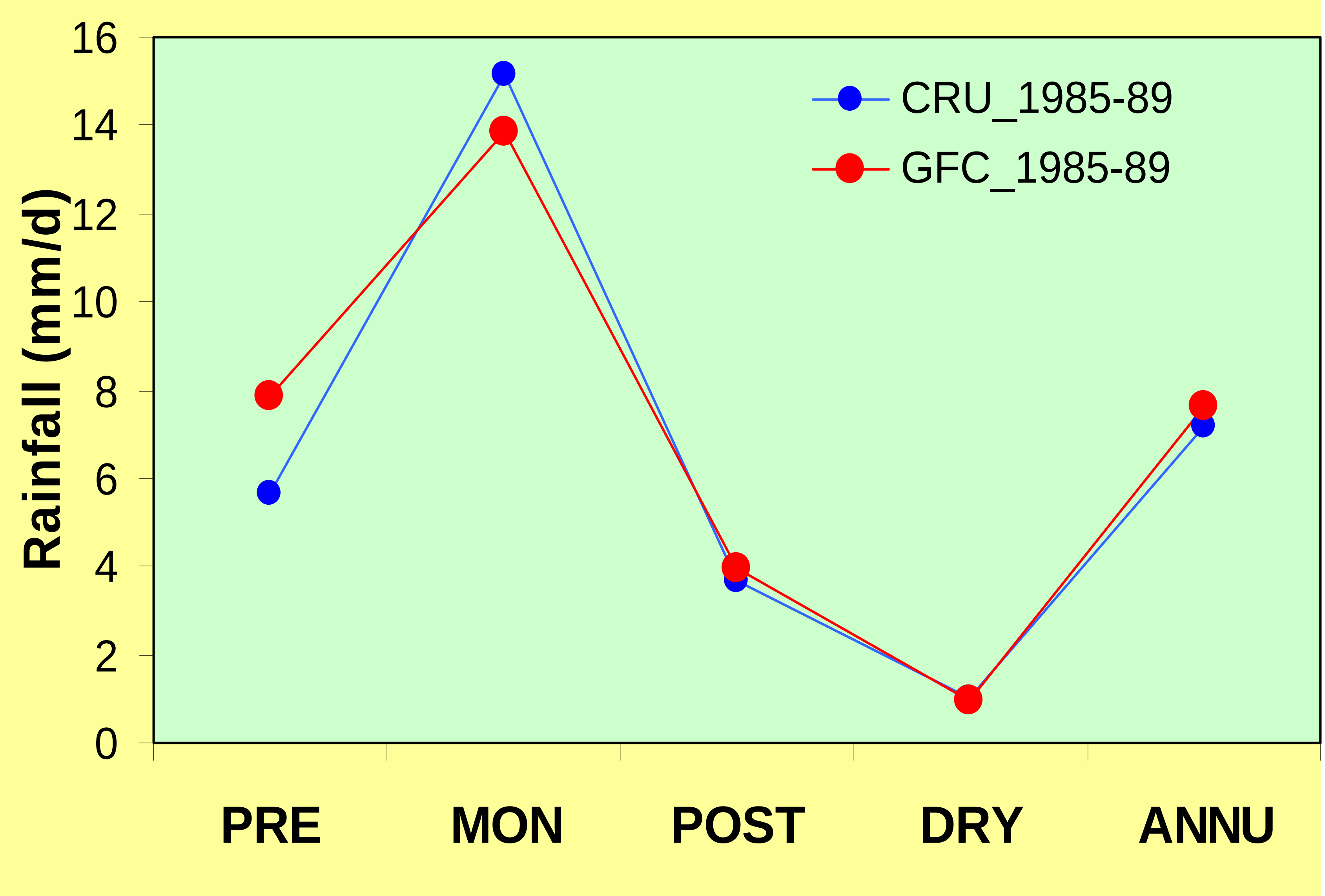
Performance of RCMs (1987-2000)

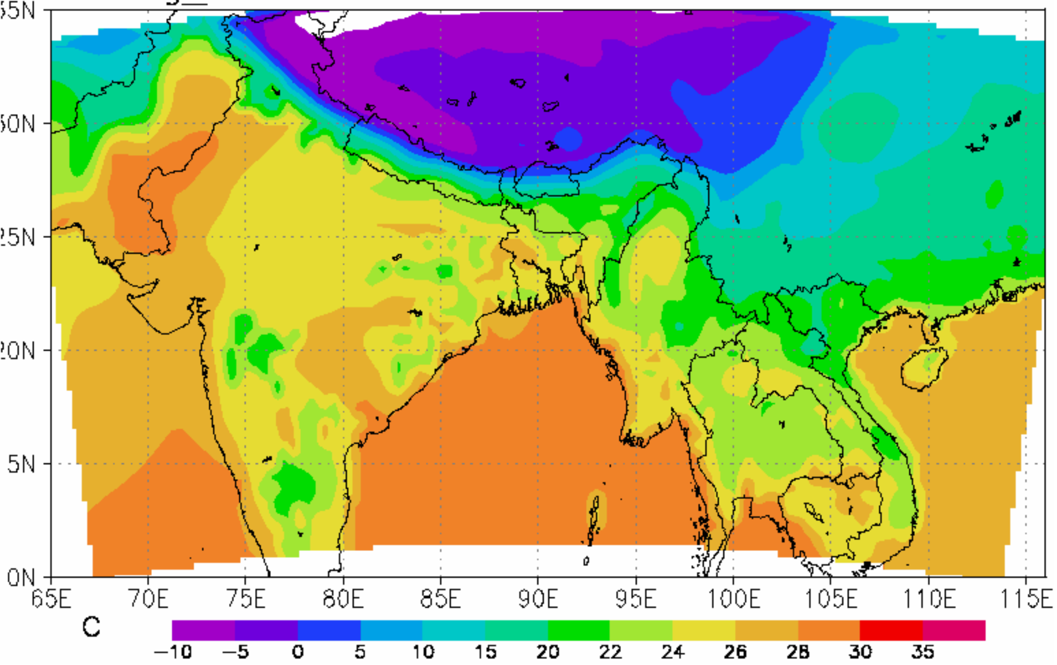
Observations RegCM3



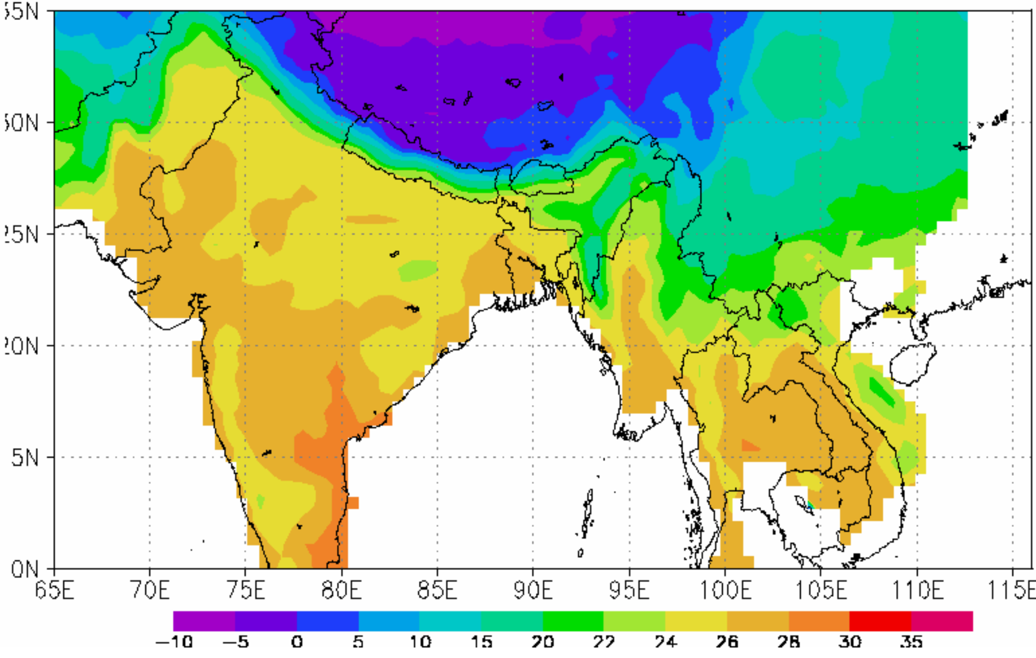
F. George

RegCM RAINFALL



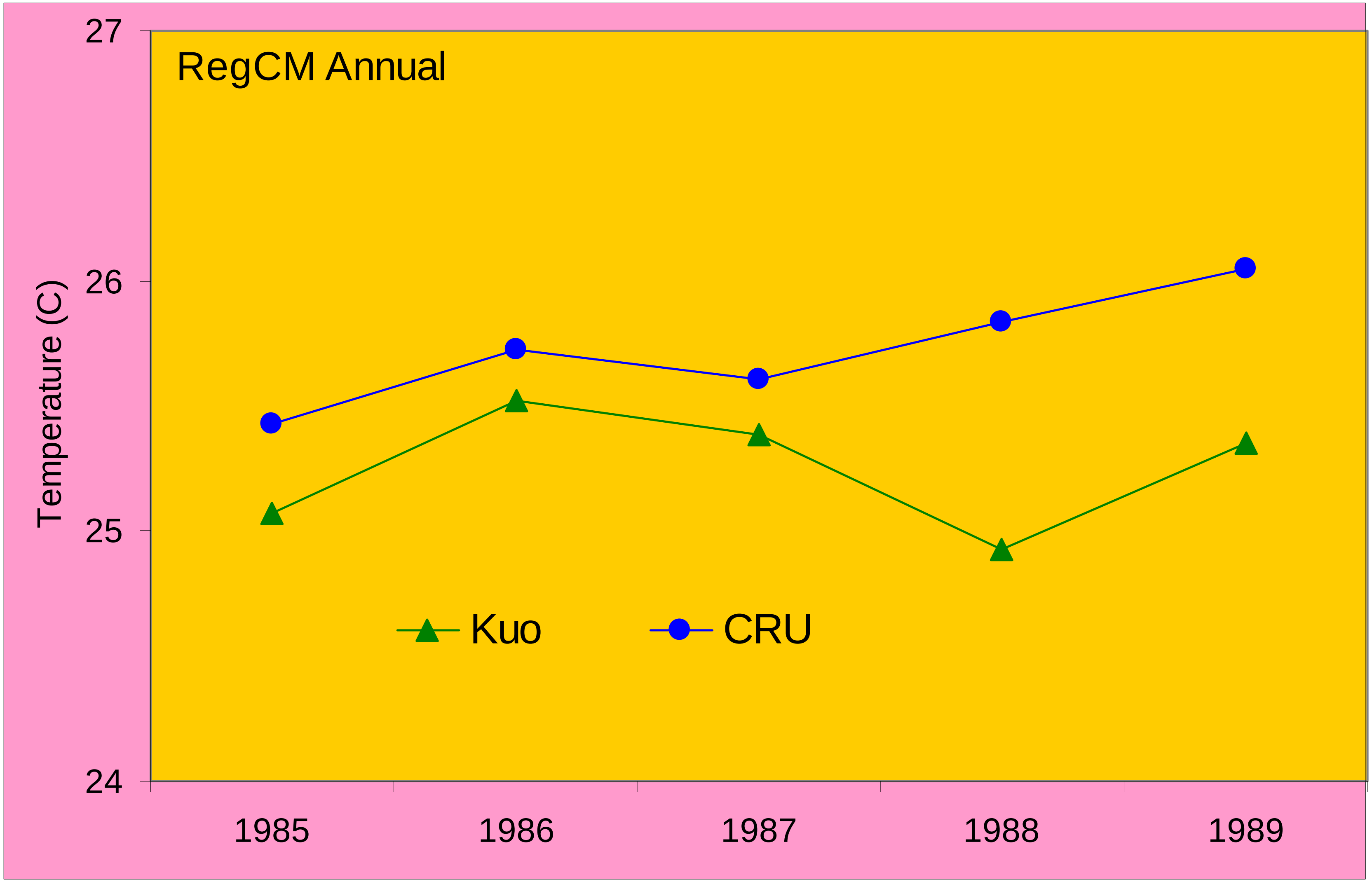


KFC tg_1985−1989 Annual

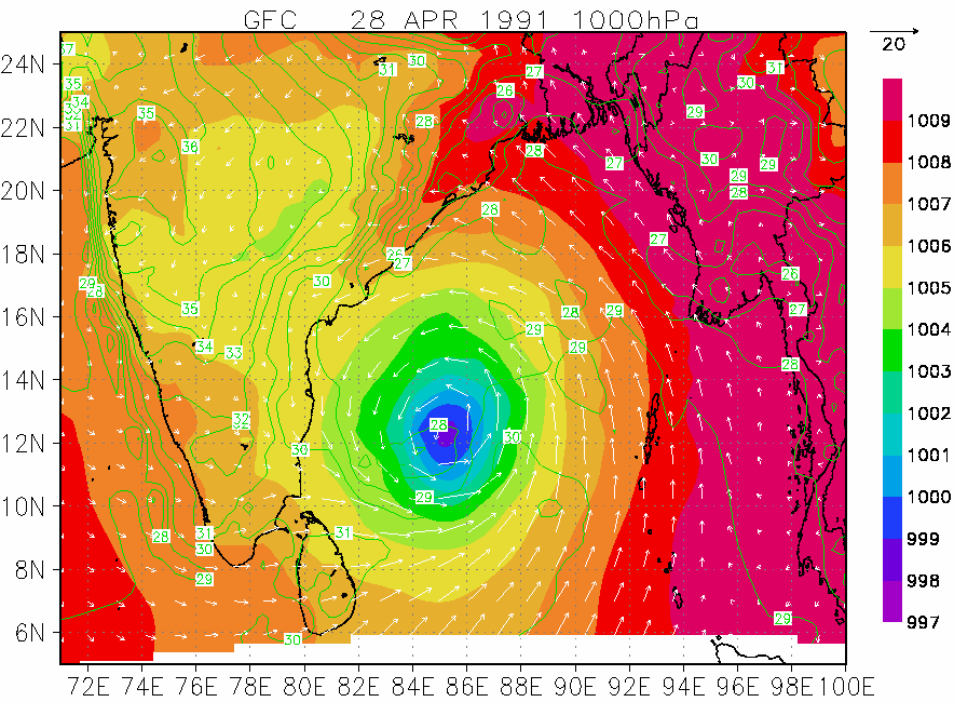


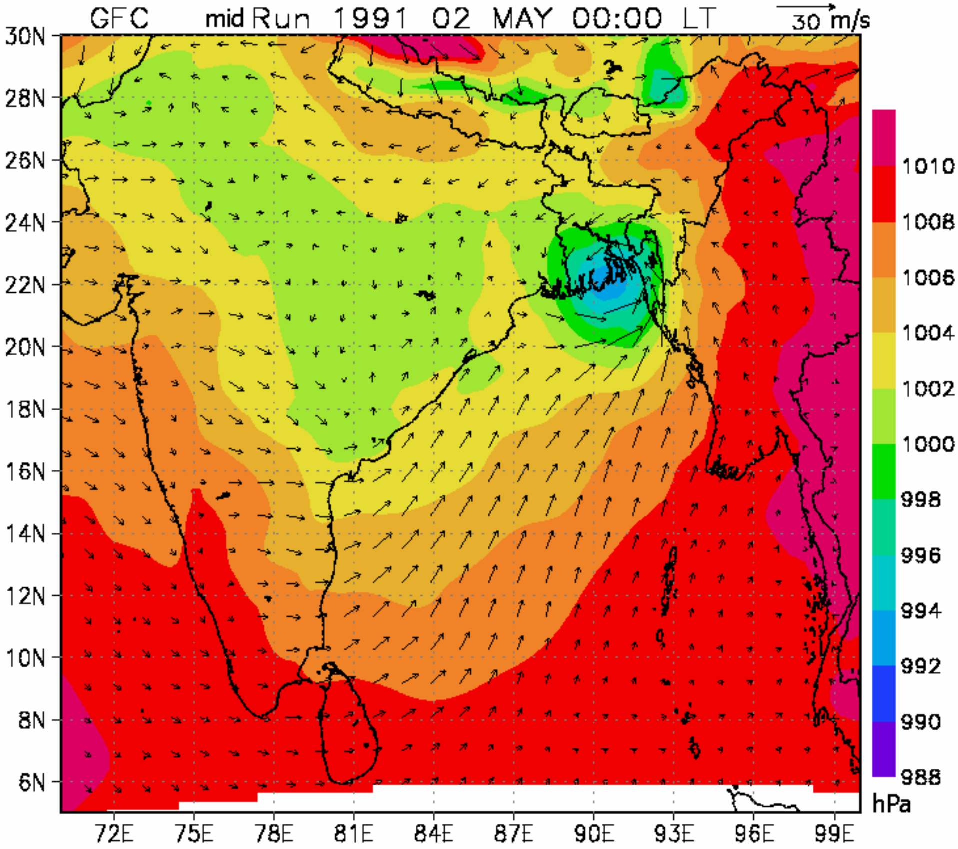
CRU 0.5degree Temp85−89 Annual

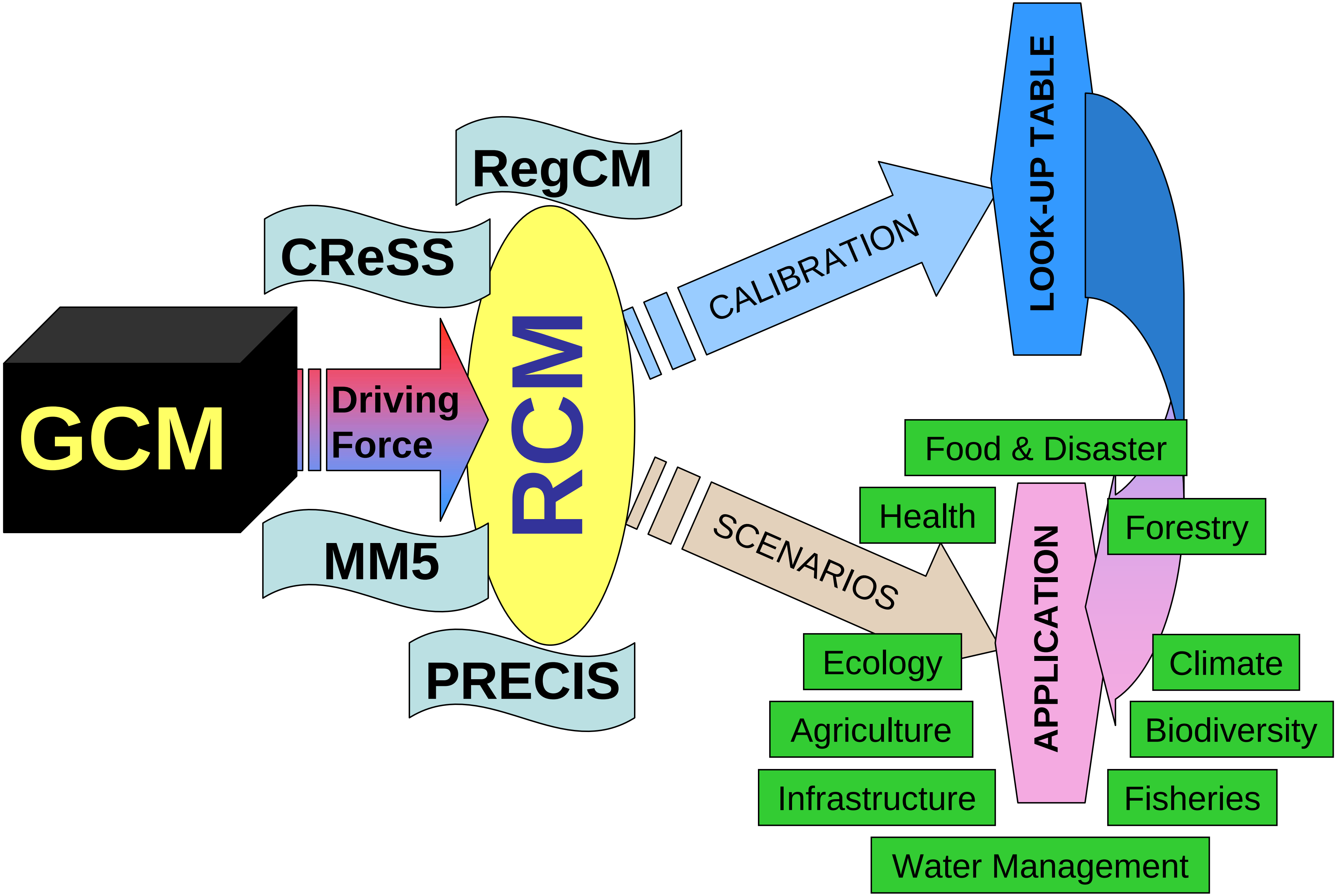
RegCM Temperature



Simulation of Killer Cyclone on 29 APRIL 1991







GCM

Driving Force

CReSS

RegCM

MM5

PRECIS

RCM

CALIBRATION

LOOK-UP TABLE

SCENARIOS

APPLICATION

Food & Disaster

Health

Forestry

Ecology

Climate

Agriculture

Biodiversity

Infrastructure

Fisheries

Water Management

Models are ready to GENERATE future scenarios

Waiting for the demand from ENDUSERS

2100 ?

2090 ?

2090 ?

2080 ?

2070 ?

2060 ?

2050 ?

2040 ?

2030 ?

2020 ?

2010 ?

Grid Size ?

50 km x 50 km

25 km x 25 km

More high resolution is also possible

Acknowledgements: All sources used in this presentation