Aqua Climate

A Review of Climate Change Model Predictions and Scenario Selection

NACA

Akvaplan niva

Kasetsart University

Bioforsk

List of Authors

Mr. Patrick White
Dr. Flaviana D. Hilario
Ms. Rosalina G. de Guzman
Ms. Thelma A. Cinco
Dr. Nigel W. Abery
Dr. Sena S. De Silva

TABLE OF CONTENTS

LIST OF TABLES AND FIGURES

Executive Summary

Decision-makers and resource managers require information regarding future changes in climate average and variability to better anticipate potential impacts of climate change. However, in order to formulate adaptation policies in response to climate change impacts, reliable climate change information is usually required at finer spatial scales. Although GCMs provide adequate simulations of atmospheric general circulation at the continental scale, they do not capture the detail required for regional and national assessments. The ability of the model to simulate the present climate conditions is an important consideration taken into account in the selection of GCM used in this study. In general, GCMs are validated for their ability to reproduce spatial patterns (McKendry et al. 1995, Huth 1997) of selected variables and their annual cycles (Nemesova & Kalvova 1997, Nemesova et al. 1999).

As climate models have developed, there has been a general tendency toward increased spatial resolution. Worlclim provides a number of outputs that have been statistically downscaled from global climate models. WorldClim provides projected climate data over the global land areas in geodetic coordinate system and in four different spatial resolutions; the highest of which is 30 seconds or about 0.86 km2 at the equator. A resolution of 1 km will be used for the case study areas (in Viet Nam, Philippines, India and Indonesia) to provide more detail. Data at this resolution will take a little more time to process the data the first time but it will be done only once and will allow detailed analysis for the case study areas and other areas in the future. Because the models are global, they can "wash out" finer distinctions at the regional scale.

A requirement for the inclusion of a model in climate projections is that it adequately simulates present-day climate conditions. Therefore, statistical methods were used to test the reliability with which individual models simulate observed climate conditions over the Asia/Pacific region. Having described some of the options available for climate model and scenario selection and the information available from the WORLDCLIM and IPCC Distribution Center, the next vital step in an impact assessment is the choice of model to be used. An initial selection of experiments from three modelling centers was made based on their availability, resolution and performance. In this study, we assessed the performance of three climate models (HadCM3, CSIRO and CCMA) using two statistical metrics. Correlation pattern and RMSE of the three climate variables (rainfall, temperature, MSLP) were extracted and compared. Pattern correlation from the three models shows significant results indicating it was able to simulate the pattern of rainfall, MSLP and temperature in the Asia Pacific region, however the choice was narrowed down to one after ranking which has the highest correlation pattern in all the seasons evaluated. Correlation pattern for the three parameters are higher in CSIRO compared with HadCM3 and CCMA in majority of the seasons evaluated. Based on the correlation pattern of the 3 GCM models it is recommended that CSIRO be used in this study, however it is also prudent to consider the output of the three models available in the Worldclim in future studies because of the uncertainties inherent in any individual climate projection.

Emission scenario's is identified as one of the major cause of uncertainty in projected future climates. Inherent uncertainties exist in the key assumptions in regard to relationships between future population, socioeconomic development and technical changes, which form the base for the IPCC SRES Scenarios. Making climate projections for a range of SRES scenarios such as the presently available in Worldclim, A2 and B2 emission scenario families can be one way to consider the uncertainties in emission scenarios. B2 emission scenarios for carbon dioxide emission rates are more than double in A2 scenario as compared to A1B and B2 scenarios towards the end of the century. B2 scenario may be a more realistic scenario, particularly after the recent credit crunch and specifically A2a (business as usual) and is the recommended choice. However, use of a range of scenarios may be a better approach to understand the range of possibilities (including the worst and best case scenarios) though this may not always be possible due to time and budget constraints.

The use of other SRES scenarios (A1B, A2, B1, B2) can be important for assessing future impacts and vulnerability to climate change and also one way of addressing uncertainty. Research efforts are needed to quantify future climate changes scenarios for Southeast Asia under different SRES emission scenarios.

A review of climate change model predictions and scenario selection

I. Introduction

Decision-makers and resource managers require information regarding future changes in climate average and variability to better anticipate potential impacts of climate change. However, in order to formulate adaptation policies in response to climate change impacts, reliable climate change information is usually required at finer spatial scales than that of a typical GCM grid-cell (which is usually about 300 x 300 km). Although GCMs provide adequate simulations of atmospheric general circulation at the continental scale, they do not capture the detail required for regional and national assessments.

Climate models are mathematical representations of the climate system, expressed as computer codes and run on powerful computers. One source of confidence in climate models comes from the fact that model fundamentals are based on established physical laws along with wealth of observations. Models show significant and increasing skill in representing many important mean climate features, such as the large-scale distributions of atmospheric temperature, precipitation, radiation and wind, and of oceanic temperatures, currents and sea ice cover. A second source of confidence comes from the ability and skill of models to simulate important aspects of the current climate. Global Climate Models (GCMs), which are built on well-established physical principles, have shown convincing skill in reproducing observed features of current climate and its changes in the past.

Models are routinely and extensively assessed by comparing their simulations with observations of the atmosphere, ocean, cryosphere and land surface. There is considerable confidence that Atmosphere-Ocean General Circulation Models (AOGCMs) provide credible quantitative estimates of future climate change, particularly at continental and larger scales (adapted from IPCC, 2007). However, the use of AOGCMs is limited in projecting climate change at the regional and sub-regional level, because significant differences in climate occur at a scale below the resolution of the AOGCMs. However, even given the limitations and uncertainties associated with modelling, global circulation models and regional climate models can be applied usefully to identify a range of uncertainties allowing strategic policy-making for adaptation.

The predicted climate changes for the selected years will depend greatly on the model and scenario selected. The wrong choice will result in false predictions which are difficult, costly, and often impossible to change at a later date. For that reason this review of the different climate change models and scenarios is being undertaken since detailed foreknowledge of the problems likely to be encountered is essential at the outset to make sure that the choices have been made as wisely and with as much understanding and forethought as practicable. This is also the case for the decision with respect to the spatial extent of the assessment and the length of time into the future. The choice of climate scenarios and related non-climatic scenarios is important because it can determine the outcome of a climate impact assessment. Extreme scenarios can produce extreme impacts; moderate scenarios may produce more modest effects (Smith and Hulme, 1998). It follows that the selection of scenarios can also be controversial, unless the fundamental uncertainties inherent in future projections are properly addressed in the impact analysis.

Studies of the regional impacts of climate change must confront the problem of choosing climate-change scenarios. The task of downscaling global climate model simulations is often so demanding that only a limited selection of models and greenhouse gas emission scenarios may be considered. However, it is preferable to consider a range of scenarios in climate impacts studies (see, for example, IPCC, 2001, page 741). The use of several models and emissions scenarios better reflects the uncertainty in the range of possible future climate change. Furthermore, model performance varies for different regions or process under consideration. Thus, impacts studies must consider several model simulations and must evaluate model performance, using simulations of present-day conditions. The recent Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report concluded that there is considerable confidence that current fully coupled global models can provide credible quantitative estimates of future climate change, particularly at continental and larger scales (IPCC 2007).

II. History of climate change model development

Numerical weather prediction was developing in the 1950s as one of the first computer applications. Almost immediately it became evident that computers could be used for numerical simulation to study climate. This was first demonstrated by Norman Phillips in 1956. Early weather models focused on fluid dynamics rather than on radiative transfer and the atmosphere's energy budget, which are centrally important for climate simulations. However, since climate simulation focuses on time scales longer than a season, oceans and sea ice were included in the modelling system. Thus, ocean and ice models were coupled with atmospheric models. The first ocean Global Climate Models (GCMs) were developed by Bryan and Cox in the 1960s and then coupled with the atmosphere by Manabe and Bryan in the 1970s. Paralleling events in the United States, the 1960s and 1970s also were a period of climate- and weather model development throughout the world, with major centers emerging in Europe and Asia.

These groups gathered in Stockholm in August 1974, under the sponsorship of the Global Atmospheric Research Programme to produce a seminal treatise on climate modelling (GARP 1975). This meeting established collaborations that still promote international cooperation today. The use of climate models in research on carbon dioxide and climate began in the early 1970s. The important study, "Inadvertent Climate Modification" (SMIC 1971), endorsed the use of GCM-based climate models to study the possibility of anthropogenic climate change. With continued improvements in both climate observations and computer power, modelling groups furthered their models through steady but incremental improvements. By the late1980s, several national and international organizations formed to assess and expand scientific research related to global climate change.

These developments spurred interest in accelerating the development of improved climate models. The primary focus of Working Group 1 of the United Nations Intergovernmental Panel on Climate Change (IPCC), which began in 1988, was the scientific inquiry into physical processes governing climate change. IPCC's first Scientific Assessment (IPCC 1990) stated, "Improved prediction of climate change depends on the development of climate models, which is the objective of the climate modelling programme of the World Climate Research Programme."

III. Climate change model construction

Global climate models incorporate the latest scientific understanding of the physical processes at work in the atmosphere, oceans, and Earth's surface and how they are all interconnected. A global climate model can produce projections of precipitation, temperature, pressure, cloud cover, humidity, and a host of other climate variables for a day, a month, or a year. Models were selected for use in the research based on a rigorous set of criteria, including the model's effectiveness in reproducing past and current climate within our region. If a model can replicate known historical conditions in the Asia Pacific region, we have higher confidence when projecting the future climate. While there are many global climate models available, the analyses described on this paper used a core set of models that performed best.

Comprehensive climate models are constructed using expert judgments to satisfy many constraints and requirements. Overarching considerations are the accurate simulation of the most important climate features and the scientific understanding of the processes that control these features. Typically, the basic requirement is that models should simulate important features, particularly surface variables such as temperature, precipitation, windiness, and storminess. This is a less-straightforward requirement than it seems because a physically based climate model also must simulate all complex interactions in the coupled atmosphere– ocean–land surface–ice system manifested as ultimate variables of interest. The models should also be capable of simulating changes in statistics caused by relatively small changes in the Earth's energy budget that result from natural and human actions. Climate processes operate on time scales ranging from several hours to millennia and on spatial scales ranging from a few centimeters to thousands of kilometers. Principles of scale analysis, fluid dynamical filtering, and numerical analysis are used for intelligent compromises and approximations to make possible the formulation of mathematical representations of processes and their interactions. These mathematical models are then translated into computer codes executed on some of the most powerful computers in the world. Available computer power helps determine the types of approximations required.

As a general rule, growth of computational resources allows modelers to formulate algorithms less dependent on approximations known to have limitations, thereby producing simulations more solidly founded on established physical principles. These approximations are most often found in "closure" or "parameterization" schemes that take into account unresolved motions and processes and are always required because climate simulations must be designed so they can be completed and analyzed by scientists in a timely manner, even if run on the most powerful computers.

The increase confidence in attribution of global scale climate change to human induced greenhouse emissions, and the expectation that such changes will increase in future, has lead to an increased demand in predictions of regional climate change to guide adaptation. Although there is some confidence in the large scale patterns of changes in some parameters, the skill in regional prediction is much more limited and indeed difficult to assess, given that we do not have data for a selection of different climates against which to test models. Much research is being done to improve model predictions, but progress is likely to be slow. Despite their limitations, climate models provide the most promising tool of providing information on climate change. This will include assessments of the ability of the models used to predict current climate, and the range of predictions from as large a number of different models as possible.

Climate models have shown steady improvement over time as computer power has increased, the understanding of physical processes of climatic relevance has grown, datasets useful for model evaluation have been developed, and the computational algorithms have improved. Model ranking according to individual members of this basket of indicators varies greatly, so this aggregate ranking depends on how different indicators are weighted in relative importance. Nevertheless, the conclusion that models have improved over time is not dependent on the relative weighting factors, as nearly all models have improved in most respects. The construction of metrics for evaluating climate models is itself a subject of intensive research.

IV. Model selection criteria

The ability of the model to simulate the present climate conditions is an important consideration taken into account in the selection of GCM to be used in this study. The performance of individual GCMs may differ for individual climate variables as well as for different regions of the world. Typically, GCMs are validated for their ability to reproduce spatial patterns (McKendry et al. 1995, Huth 1997) of selected variables and their annual cycles (Nemesova & Kalvova 1997, Nemesova et al. 1999). GCMs are run by a number of research centres. Some differences exist among the models, which result in various climate sensitivities in a range likely between 1.0℃ and 3.5℃ (Figure 1) with a best estimate value of 2.0℃ over a 80 year simulation period. However, selecting appropriate models is difficult especially when many models are available with different projection results.

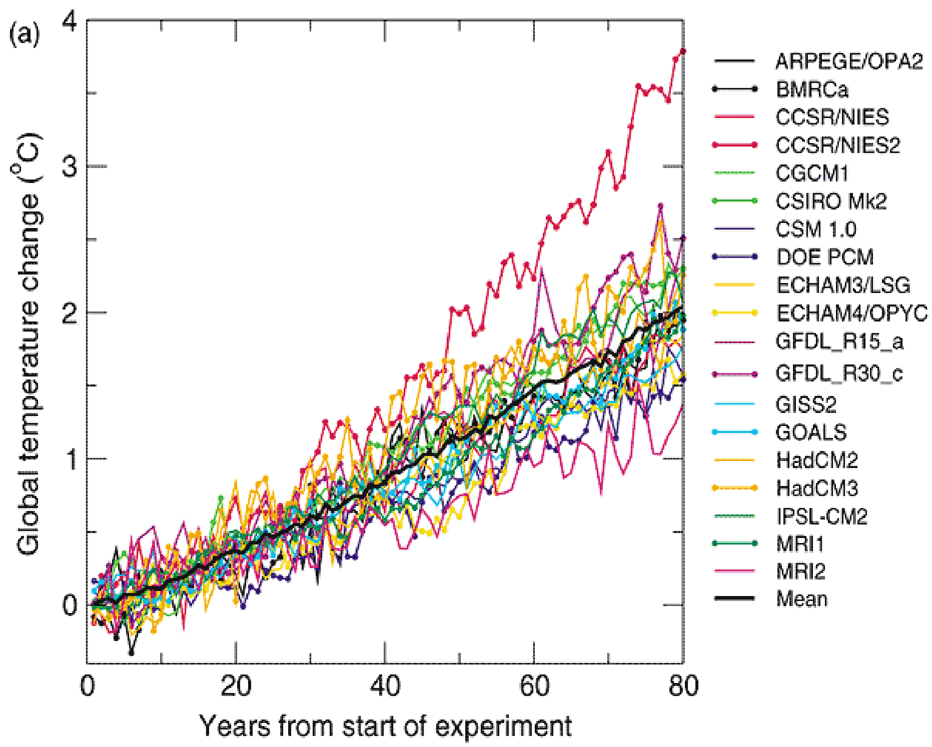


Figure 1: 80 year simulation of temperature using different GCM Models

Some criteria for selecting climate models are suggested in Smith and Hulme (1998) and IPCC TGICA (2007):

- **Vintage**. Recent models are likely to be more reliable as they incorporated the latest knowledge in their construction.
- **Resolution**. Recent models tend to have finer resolution than older models. Higher resolution models contain more spatial details (eg complex topography, better-defined land–sea boundaries etc) and some key processes of climate variability such as ENSO events are better represented. However, finer resolution does not necessarily guarantee better model performance.
- **Validity**. Selection of models is based on how well they simulate present day climate. The validity of a model is assessed by comparing observed data with simulated data. The easy method is by 'upscaling' the observed data to a GCM grid size to compare it with the GCM simulated data. Statistical measures such as standard deviation, standard error, etc are useful for this analysis (Giorgi and Mearns 1991; Murphy et al. 2004).
- **Representativeness of results**. Preferably, results from more than one GCM are to be applied in an impact assessment. Selecting some representative GCM results helps in illustrating a range of changes in a key climate variable in the study region. For example, if a number of models show less annual precipitation, no change in precipitation and more annual precipitation, users can choose one for each cluster of the simulation results for illustrating future potential impacts of their studies.

Other criteria that should be met by climate scenarios if they are to be useful for impact researchers and policy makers are as follows:

- **Applicability in impact assessments**. They should describe changes in a sufficient number of variables on a spatial and temporal scale that allows for impact assessment. For example, impact models may require input data on variables such as precipitation, solar radiation, temperature, humidity and wind speed at spatial scales ranging from global to site and at temporal scales ranging from annual means to daily or hourly values.
- **Accessibility**. They should be straightforward to obtain, interpret and apply for impact assessment. Many impact assessment projects include a separate scenario development component which specifically aims to address this last point.

V. Hindcasting to gauge accuracy of the model

Hindcasting is a way of testing a mathematical model. Known or closely estimated inputs for past events are entered into the model to see how well the output matches the known results. An example of hindcasting would be entering climate forcings (events that force change) into a climate model. If the hindcast accurately showed weather events that are known to have occurred, the model would be considered successful.

The various IPCC model outputs are evaluated and rated, based on the reliability of their hindcasts in terms of replicating observed conditions. The errors in these hindcasts are computed for individual parameters and for specific regions. Multiple criteria are considered for each parameter, including replication of the means, as well as modelled vs. observed variances and potentially additional measures, such as trends and seasonality. The errors are then used to construct “distances” between the model and observations for each model simulation.

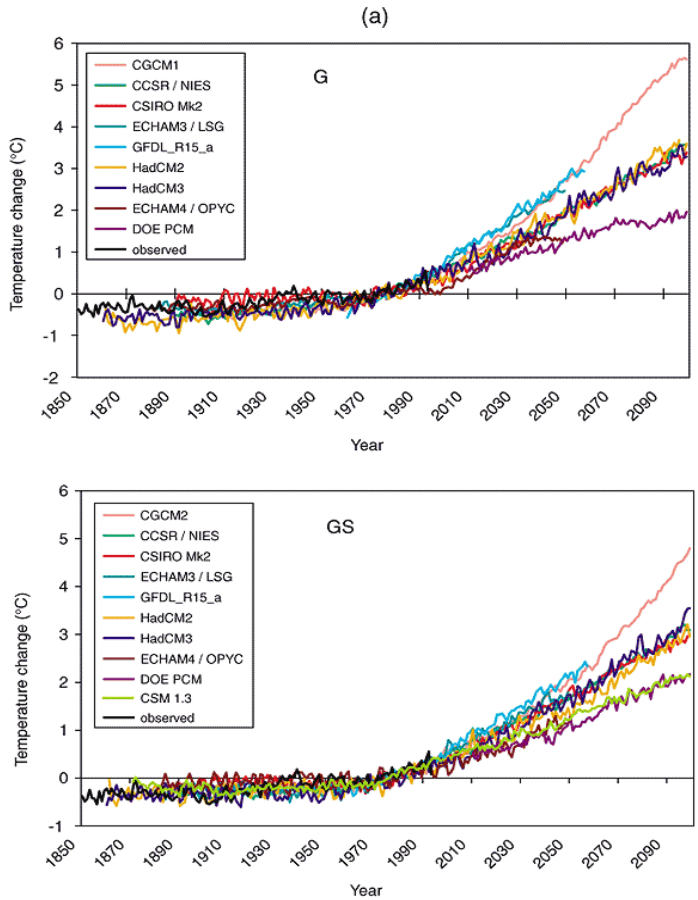


Figure 2: Simulation of temperature vs. observed using 9 GCM Models

Figure 2 shows the simulation of temperature vs. observed from 9 GC models. Results indicate that most of the models were able to reliably simulate the observed temperature from 1850 up to present. Simulation of the various GC models shows different temperature projections beyond 2010.

VI. Global Climate Model Selection for Asia Pacific region

Twenty-three different climate model simulations were undertaken for the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. These model simulations were acquired from the program for Climate Model Diagnosis and Intercomparison and were used to generate climate change projections for the Asia/Pacific region. These model simulations were individually evaluated with respect to their abilities to faithfully reproduce observed seasonal patterns of mean sea-level pressure, temperature, and rainfall over the Asia/Pacific (60–180ºE, 55ºN–25ºS) region for a 30-year period (1961-1990).

Simulations with 23 different climate models have been undertaken for the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. These model simulations were acquired from the Program for Climate Model Diagnosis and Intercomparison and used to generate climate change projections for the Asia/Pacific region. (See http://www-pcmdi.llnl.gov/ipcc/about_ipcc.php) The 16 most accurate models for the Asia pacific region were selected applying reliability criteria are shown in bold;

Climate Modelling Group & Country	Model Symbols	Horizontal resolution (km)
Beijing Climate Center, China	BCC	~200-
Bjerknes Centre for Climate Research, Norway	**BCCR**	~200
Canadian Climate Centre, Canada	**CCMA T47**	~300
Canadian Climate Centre , Canada	**CCMA T63**	~200
Meteo-France, France	**CNRM**	~200
CSIRO, Australia	**CSIRO-MARK3**	~200
Geophysical Fluid Dynamics Lab, USA	**GFDL 2.0**	~300
Geophysical Fluid Dynamics Lab, USA	**GFDL 2.1**	~300
NASA/Goddard Institute for Space Studies, USA	**GISS-AOM**	~300
NASA/Goddard Institute for Space Studies, USA	GISS-E-H	~400
NASA/Goddard Institute for Space Studies, USA	GISS-E-R	~400
LASG/Institute of Atmospheric Physics. China	**IAP**	~300
Institute of Numerical Mathematics, Russia	**INMCM**	~400
Institut Pierre Simon Laplace, France	IPSL	~300
Centre for Climate Research, Japan	MIROC-H	~125
Centre for Climate Research, Japan	**MIROC-M**	~300
Meteorological Research Institute, Japan	**MRI**	~300
Max Planck Institute for meteorology DKRZ, Germany	**MPI-ECHAM5**	~200
Meteorological Institute of the University of Bonn, Meteorological Research Institute of KMA, Germany/Korea	**MIUB**	~400
National Center for Atmospheric Research, USA	**NCAR-CCSM**	~150
National Center for Atmospheric Research, USA	NCAR-PCM	~300
Hadley Centre, UK	HADCM3	~300
Hadley Centre, UK	**HADGEM1**	~125

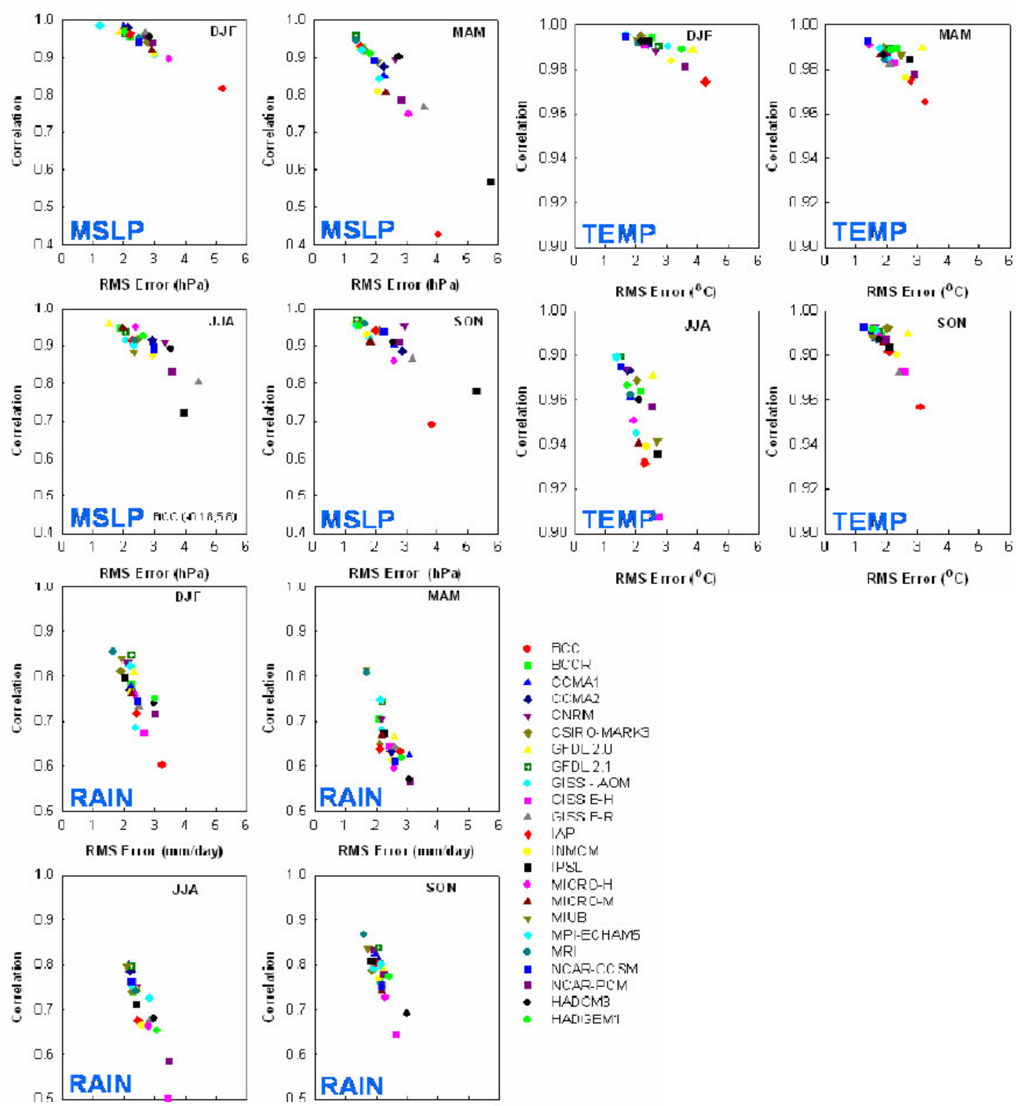
Source: Climate Change in Asia Pacific

Table 1: Summary of GCM models used in the Asia Pacific for AR4

the fidelity with which individual models simulate observed climate conditions over the Asia/Pacific region. Two statistical metrics, pattern correlation and root mean square error, were used to measure model performance for the AR4 report. A pattern correlation coefficient of 1.0 indicates a perfect match between the observed and simulated spatial pattern, and a root mean square error of 0.0 indicates a perfect match between the observed and simulated magnitudes. Since the selected area is large with strong spatial variations, root mean square errors for temperature and rainfall among the different models were relatively large. Similarly, for rainfall, pattern correlations for most of the climate models were less than 0.8. Therefore, only the pattern correlations were used to select a set of models. Models corresponding with pattern correlations greater than 0.8 for mean sea level pressure and temperature, and greater than 0.6 for rainfall were selected, resulting in a set of 16 models.

Based upon these tests, a set of 16 climate models were selected for use in generating climate projections for the Asia/Pacific region (See table 1 below). Realistic simulations of mean sea level pressure patterns are important as they are implicitly linked to atmospheric circulation (i.e. wind, moisture, etc) patterns. Figure 3 shows pattern correlations and root mean square errors for the Asia/Pacific region for December to February (DJF), March to May (MAM), June to August (JJA) and September to November (SON). The closer a model result lies to the top left corner, the better its performance, with strong pattern correlations and small root mean square errors, while models in the bottom right corner are poorer performers.

Strong correlations, greater than 0.8, between observed and simulated patterns suggest that most of the models capture large-scale circulation features of this region. However, models such as BCC, GISS E-R and IPSL show poor performance in most cases. Pattern correlations and root mean square errors for seasonal temperature are shown in Figure 3. This figure shows that most of the models capture the observed spatial pattern of temperature over the Asia Pacific region very well, yielding a pattern correlation of at least 0.9 for all seasons. However, the root mean square error exceeds 3℃ for some models in DJF. In JJA, there is a considerable spread in the pattern correlation among different models that could be related to the influence of the summer monsoon and the topography of this region. Other seasons show small variations. Rainfall simulations are more complex than the simulations of mean sea level pressure and temperature as rainfall is strongly influenced by dynamical and topographical characteristics of the region. Temporal and spatial patterns of rainfall during JJA are influenced by the summer monsoon, and rainfall patterns during DJF are influenced by the winter monsoon. Rainfall associated with convective systems dominate MAM, and in SON, rainfall is received from thunderstorms and tropical cyclones. Figure 3 depicts the pattern correlations and root mean square errors for observed and simulated rainfall. Pattern correlations are relatively high in all seasons, greater than 0.6 for most of the models.



Source: Climate Change in Asia Pacific

Fig 3: Pattern correlation and root mean square errors for observed versus model seasonal mean sea level pressure, temperature, and rainfall for the Asia/Pacific region. Details of models are given in Table 1. In these diagrams, values in the top-left indicate better performance, while values in the bottom right indicate poorer performance.

VII. Data availability and cost

WORLDCLIM data set was chosen in favor of the data from the IPCC Distribution center because of the higher resolution data set available in WORLDCLIM that can be readily applied for impact studies. WORLDCLIM provides a number of outputs that have been downscaled from Global Circulation Models at no cost and the database has 400 times higher spatial resolution than previously available surfaces (New et al., 2002). Data is based on interpolated climate surfaces for global land areas in four different spatial resolutions; 30 seconds (about 0.86 km2 at the equator), 2.5 minutes, 5 minutes, and 10 minutes (about 344 km2 at the equator) and can easily be exported to GIS.

IPCC Data Distribution Centre

The following information has been extracted from IPCC-TGICA (2007).IPCC Data Distribution Centre (DDC) was established in 1998, following a TGICA recommendation to facilitate the timely distribution of a consistent set of up-to-date scenarios of changes in climate and related environmental and socio-economic factors for use in climate impact and adaptation assessment.

The DDC is a shared operation between the British Atmospheric Data Centre in the UK, the Max-Plank Institute for Meteorology in Germany, and the Center for International Earth Science Information Network at Columbia University, New York, USA. It provides three main types of data and guidance, which meet certain criteria established by the TGICA. They are: socio-economic data and scenarios that follow the assumptions used for the construction of SRES emission scenarios (see Box 2); climate observations and scenarios; and data and scenarios for other environmental changes.

The climate observation data set contains 0.5° latitude/longitude gridded monthly global land surface of 11 climate variables for the period 1901–2000 supplied by the Climatic Research Unit. The data set can be used to examine climate variability over the 20th century, to evaluate the simulations of various GCMs over the period 1961-1990, and to combine observed data with GCM projections. The variables are precipitation and wet-day frequency; mean, maximum and minimum temperatures; vapour pressure and relative humidity; sunshine percent and cloud cover; frost frequency; and wind speed. The monthly averaged results from climate change simulations by a number of climate modelling centres are also available. The results have been extracted from transient AOGCM simulations which include greenhouse gas only and combined greenhouse gas and sulphate aerosol forcings. Ensembles and time-slice experiments are also being provided. Main variables that are available are cloud cover, diurnal temperature range, precipitation, solar radiation, mean temperature, minimum temperature, vapour pressure, and wind speed.

IPCC TGICA applied some criteria for GCM experiment results could be placed at the DDC, which follows criteria set by Parry (2002). The climate models should

- be full 3D coupled ocean-atmospheric GCMs,
- be documented in the peer-reviewed literature,
- have performed a multi-century control run (for stability reasons) and
- have participated in the Second Coupled Model Inter-comparison Project (CMIP2).

In addition, the models should

- have performed a 2×CO2 mixed layer run,
- have participated in the Atmospheric Model Inter-comparison Project (AMIP),
- have a resolution of at least T40, R30 or 3° × 3° latitude/longitude and
- consider explicit greenhouse gases (eg CO2, CH4 etc).

Downscaling

There is an increasing need for detailed, high-resolution regional information regarding future climate. Such information is needed by scientists in disciplines that require climate information (e.g. hydrologists), decision- and policy-makers, and by those assessing climate change impacts, adaptation and vulnerability. Although climate change projections must necessarily be undertaken with global models, such models will never have sufficient spatial detail for all applications. Constraints on available computing resources will always limit model resolution; therefore, various techniques have been developed for ‘downscaling’ global climate projections (and shorter-term climate predictions) and for producing fine-scale regional climate information.

Downscaling is the general name for a procedure to take information known at large scales to make predictions at local scales. It is a method for obtaining high-resolution climate or climate change information from relatively coarse-resolution global climate models (GCMs). Typically, GCMs have a resolution of 150-300 km by 150-300 km and are unable to resolve important sub-grid scale features such as clouds and topography. Downscaling is required because many impacts models require information at scales of 50 km or less.There are two commonly used downscaling techniques for obtaining regional climate change projections: statistical and dynamical. Dynamical downscaling involves the use of a limited-area, high resolution Regional Climate Model (RCM) nested within and driven time dependent lateral and lower boundary conditions from a global climate model. Statistical downscaling may be used in climate impacts assessment at regional and local scales and when suitable observed data are available to derive the statistical relationships.

RCMs are full climate models, and as such are physically based. These numerical models are similar to global climate models, but are of higher resolution and therefore contain a better representation of, for example, the underlying topography within the model domain and, depending on the model resolution, may also be able to resolve some of the atmospheric processes which are parameterised in a global climate model. They represent most if not all of the processes, interactions and feedbacks between climate system components represented in GCMs. They produce a comprehensive set of output data over the model domain. This makes for a more accurate representation of many surface features, such as complex mountain topographies and coastlines. It also allows small islands and peninsulae to be represented realistically, where in a global model their size (relative to the model gridbox) would mean their climate would be that of the surrounding ocean.

PRECIS is an example of RCM based on the Hadley Centre's regional climate modelling system. It has been ported to run on a PC (under Linux) with a simple user interface, so that experiments can easily be set up over any region. It was developed in order to help generate high-resolution climate change information for as many regions of the world as possible. The intention is to make PRECIS freely available to groups of developing countries in order that they may develop climate change scenarios at national centres of excellence, simultaneously building capacity and drawing on local climatological expertise.

Statistical downscaling is a two-step process basically consisting of i) development of statistical relationships between local climate variables (e.g., surface air temperature and precipitation) and large-scale predictors, and ii) application of such relationships to the output of GCM experiments to simulate local climate characteristics. A range of statistical downscaling models have been developed (IPCC 1996, WG I), mostly for U.S., European, and Japanese locations where better data for model calibration are available. The main progress achieved in the last few years has been the extension of many downscaling models from monthly and seasonal to daily time scales, which allows the production of data more suitable for a broader set of impact assessment models (e.g., agriculture or hydrologic models).

Statistical downscaling is based on the view that the regional climate is conditioned by two factors: the large scale climatic state, and the regional/local physiographic features (e.g. topography, land-sea distribution and land use. Von Storch, 1995, 1999). From this perspective, regional or local information is derived by first determining a statistical model which relates large-scale climate variables (or predictors) to regional and local variables (or predictands). Then the large-scale output of a GCM simulation is fed into this statistical model to estimate the corresponding local and regional climate characteristics. One of the primary advantages of these techniques is that they are computationally inexpensive, and thus can be easily applied to output from different GCM experiments. Another advantage is that they can be used to provide site-specific information, which can be critical for many climate change impact studies. The major theoretical weakness of SD methods is that their basic assumption is not verifiable, i.e., that the statistical relationships developed for the present day climate also hold under the different forcing conditions of possible future climates- a limitation that also applies to the physical parameterisations of dynamical models.

A variety of statistical downscaling methods have been developed, ranging from seasonal and monthly to daily and hourly climate and weather simulations on a local scale. The majority of methods have been developed for the US, European and Japanese locations, where long-term observed data are available for model calibration and verification. A description of various statistical downscaling methods and their over-arching assumptions are presented in Wilby et al. (1998). Additional information about downscaling methods can be found in Haylock et al.(2006), Fowler et al.(2007)and other articles published in the 2007 special issue of International Journal and Climatology.

WorldClim

Worlclim provides a number of outputs that have been statistically downscaled from global climate models. It was developed by a team from the Museum of Vertebrate Zoology, University of California, Berkeley in collaboration with Centro International de Agricultura Tropical (CIAT) and The Cooperative Research Centre for Tropical Rainforest Ecology and Management.

WorldClim provides projected climate data over the global land areas in geodetic coordinate system and in four different spatial resolutions; 30 seconds (about 0.86 km2 at the equator), 2.5 minutes, 5 minutes, and 10 minutes (about 344 km2 at the equator). Climate variables for download are monthly total precipitation, and monthly mean, minimum and maximum temperatures (and 19 derived bioclimatic variables), which are projected for years 2020, 2050 and 2080 derived from climate models of three different centres (CCCma, HadCM3 and CSIRO). The projections use emission scenarios A2 and B2.

The Worldclim data have been produced with a simple downscaling technique. First, projected changes in a climate variable, which are the absolute or relative differences between the outputs of the GCM simulated baseline data (typically averaged data of 1960–1990) and the simulated target years (eg 2050), are developed. Then, these changes are interpolated to grid cells with 30 arc-second resolution. Finally, these high resolution changes are applied to interpolated observed climate data of current period (WorldClim data set) to get high resolution projected climate data of the target years.

The WorldClim interpolated climate layers were made using:

- Major climate databases compiled by the Global Historical Climatology Network (GHCN), the FAO, the WMO, the International Center for Tropical Agriculture (CIAT), R-HYdronet, and a number of additional minor databases for Australia, New Zealand, the Nordic European Countries, Ecuador, Peru, Bolivia, among others.
- The SRTM elevation database (aggregeated to 30 arc-seconds, "1 km")
- The ANUSPLIN software. ANUSPLIN is a program for interpolating noisy multi-variate data using thin plate smoothing splines. We used latitude, longitude, and elevation as independent variables.

The database in the WORLDCLIM consisted of precipitation records from 47,554 locations, mean temperature from 24,542 locations, and minimum and maximum temperature for 14,835 locations. Input data were gathered from a variety of sources and, where possible, were restricted to records from the 1950–2000 period. We used the thin-plate smoothing spline algorithm implemented in the ANUSPLIN package for interpolation, using latitude, longitude, and elevation as independent variables.

More information is available at http://www.worldclim.org/.

Current conditions (~1950-2000)

30 arc-seconds (~1 km)					
	Min. Temperature	Max. Temperature	Precipitation	Bioclim	Altitude
2.5 arc-minutes					
	Min. Temperature	Max. Temperature	Precipitation	Bioclim	Altitude
5 arc-minutes					
	Min. Temperature	Max. Temperature	Precipitation	Bioclim	Altitude
10 arc-minutes					
	Min. Temperature	Max. Temperature	Precipitation	Bioclim	Altitude

This data is available in the following formats

- Generic grids . These grids can be imported into most GIS applications
- ESRI grids. These grids can be used in ArcMap and ArcInfo (with the GRID module) and ArcView (with the Spatial Analyst extension).

	a2a	b2a
30 arc-seconds (~1 km)		
2020:	tmin tmax prec bio 1-9 10-18	tmin tmax prec bio 1-9 10-18
2050:	tmin tmax prec bio 1-9 10-18	tmin tmax prec bio 1-9 10-18
2080:	tmin tmax prec bio 1-9 10-18	tmin tmax prec bio 1-9 10-18
2.5 arc-minutes		
2020:	tmin tmax prec bio 1-9 10-18	tmin tmax prec bio 1-9 10-18
2050:	tmin tmax prec bio 1-9 10-18	tmin tmax prec bio 1-9 10-18
2080:	tmin tmax prec bio 1-9 10-18	tmin tmax prec bio 1-9 10-18
5 arc-minutes		
2020:	tmin tmax prec bio 1-9 10-18	tmin tmax prec bio 1-9 10-18
2050:	tmin tmax prec bio 1-9 10-18	tmin tmax prec bio 1-9 10-18
2080:	tmin tmax prec bio 1-9 10-18	tmin tmax prec bio 1-9 10-18
10 arc-minutes		
2020:	tmin tmax prec bio 1-9 10-18	tmin tmax prec bio 1-9 10-18
2050:	tmin tmax prec bio 1-9 10-18	tmin tmax prec bio 1-9 10-18
2080:	tmin tmax prec bio 1-9 10-18	tmin tmax prec bio 1-9 10-18

Table 2: WorldClim Dataset

Selection of prediction dates

Climatological baseline

It is typical in impacts assessment to use a period of years of observed meteorological data to define a “current climate baseline”. This set of years can be used to calibrate impacts models and to quantify baseline climate impacts, e.g., production under current climate. A 30-year continuous record of recent climate data is widely used for creating a baseline and is likely to contain wet, dry, warm, and cool periods and is therefore considered to be sufficiently long to define a region’s climate. The 30-year “normal” period as defined by the World Meteorological Organisation (WMO) is recommended by the Intergovernmental Panel on Climate Change (IPCC) for use as a baseline period. The baseline period is usually selected according to the following criteria (IPCC, 1994):

- representative of the present-day or recent average climate in the study region of a sufficient duration to encompass a range of climatic variations, including a number of significant weather anomalies (e.g. severe droughts or cool seasons)
- covering a period for which data on all major climatological variables are abundant, adequately distributed over space and readily available;
- including data of sufficiently high quality for use in evaluating impacts

- consistent or readily comparable with baseline climatologies used in other impact assessments.

Short-term and long-term forecasts
Although it is not possible to predict the temperature, precipitation, or sea level for a particular day, month, or even specific year due to fundamental uncertainties in the changing climate system, GCMs are a valuable tool for projecting the likely range of changes over decadal to multi-decadal time periods. Some climate models, or closely related variants, have also been tested by using to predict weather and make seasonal forecasts. These models demonstrate skill in such forecasts, showing they can represent important features of the general circulation across shorter time scales, as well as aspects of seasonal and interannual variability. Models' ability to represent these and other important climate features increases our confidence that they represent the essential physical processes important for the simulation of future climate change. By selecting the required time horizon (present, the year 2020 and the year 2050), the transient climate change forecast can be extracted.

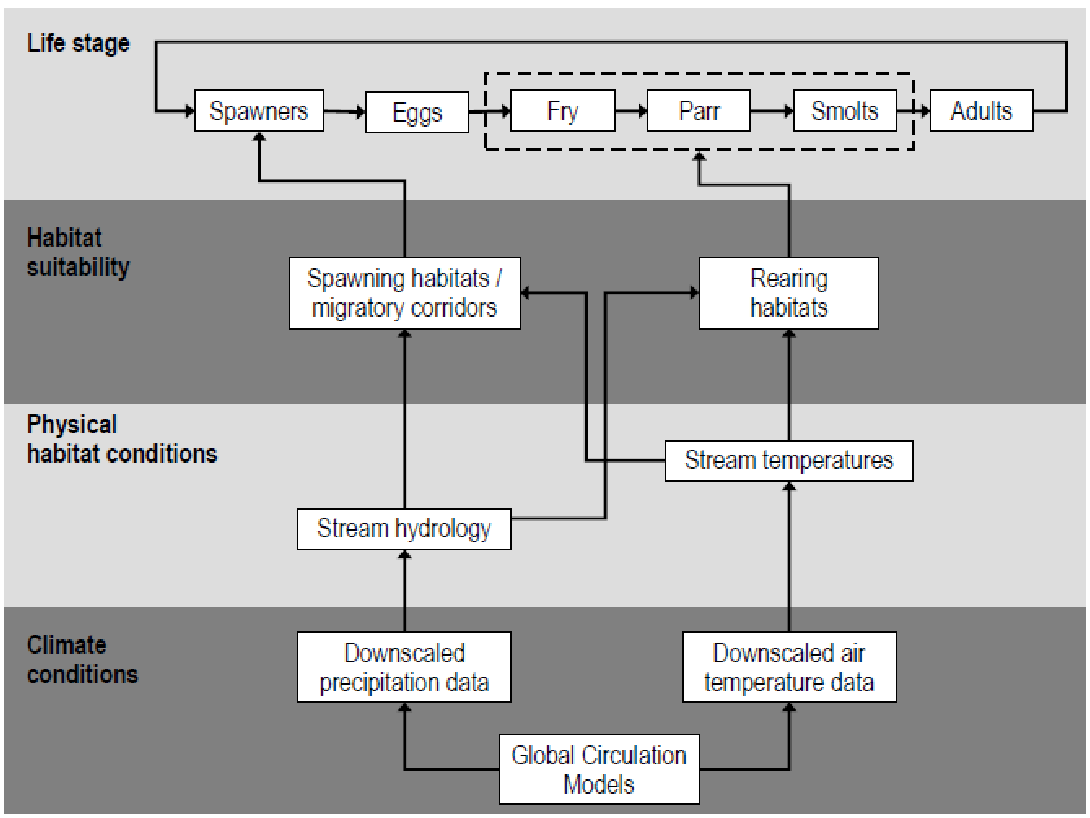
These projections, known as time slices, are expressed relative to the given baseline period, 1971-2000. The time slices are centered around a given decade, for example, the 2050s time slice refers to the period from 2040-2069.Thirty-year time slices (10-year for sea level rise) are used to provide an indication of the climate 'normals' for those decades; by averaging over this period, much of the random year-to-year variability, or 'noise', is cancelled out, while the long-term influence of increasing greenhouse gases, or 'signal', remains. Thirty-year averaging is the standard used by the meteorological and climate communities. Most impact studies used near term (2020) and 2050 (midterm) projections for vulnerability and assessment studies.

VIII. Model most suitable for aquatic environments
Climatic factors, such as air and water temperature, and precipitation and wind patterns, strongly influence fish health, productivity and distribution. Changes such as those associated with a 1.4 to 5.8℃ increase in global temperature, as have been projected by the Intergovernmental Panel on Climate Change (IPCC) for the current century, could have significant impacts on fish populations. This is because most fish species have a distinct set of environmental conditions under which they experience optimal growth, reproduction and survival. If these conditions change in response to a changing climate, fish could be impacted both directly and indirectly. Some potential impacts include shifts in species distributions, reduced or enhanced growth, increased competition from exotic species, greater susceptibility to disease and/or parasites, and altered ecosystem function. These changes could eliminate species from all or part of their present ranges and would affect sustainable harvests of fish.

There are a number of key considerations with regards to assessing what model to be used in determining the impacts of climate change for aquatic environments. In developing scenarios of future climate change, a first task was to select the appropriate Global Climate Models (GCMs), emissions scenarios, and time periods over which to generate projections. The approach to assessing vulnerability of freshwater habitats involved linking outputs from a series of readily available quantitative models. The second step involved downscaling climate projections from Global Climate Models (GCM) and emissions scenarios. Predictions of future air temperatures and precipitation will be used as inputs for a physically-based model. A simplified conceptual model illustrating the linkages among climate, physical habitat conditions, habitat suitability, and Pacific salmon life stages is shown in Figure 2. This conceptual model was used in evaluating the vulnerability of freshwater fish habitats to the effects of climate change in Canada. A similar framework can be developed to assess the projected impacts of climate change on aquatic environments in the Asia Pacific.

The 16 models used in the Asia Pacific and scenarios from the Intergovernmental Panel on Climate Change (IPCC) Special Report on Emissions Scenarios (SRES) were considered in our initial list. Recognizing that all 16 GCM models and the emission scenarios are plausible futures, our goal was to narrow down the list to models and scenarios that represented a reasonable range of changes in air temperature and precipitation. For comparison purposes, it was also important to select models, scenarios, and time periods that were comparable and consistent with similar studies. Current studies investigating the effects of climate change on fish populations and fish habitats in the Pacific Northwest used the Canadian (cccma_cgcm3) and United Kingdom ukmo_hadcm3) climate models. A set of IPCC emissions scenarios – A1B, A2, and B1and the commonly considered time periods – 2020s (2010-2039), 2050s (2040-2069), and 2080s (2070-2099) were also consider in the study.

To select the appropriate model and scenario combinations, the differences in summer climate conditions for different time periods should be analyzed across models and scenarios for the Asia Pacific. The analysis should focused on summer because it was the season of most interest for fish habitat modelling, and explored model differences during the 2080s because differences due to emissions scenarios tend to be more detectable at this time than in the 2050s (Nelitz et al.2009). Result of studies done in evaluating the vulnerability of freshwater fish habitats to the effects of climate change in the Cariboo-Chilcotin used GCM models from ukmo_hadcm3 and cccma_cgcm3.



Source: Climate Change in Asia Pacific

Figure 4. Simplified conceptual model illustrating the linkages among climate, physical habitat conditions, habitat suitability, and Pacific salmon life stages.

IX. Output Resolution

Selection of appropriate spatial resolutions in assessing impacts or ecosystem response to climate change depends on the objective of the modelling and accompanying technical factors. In general, finer resolution data are better than coarser ones for the purpose of database building to serve various studies and impact assessments of different scales, but finer resolution data need bigger data storage capacity than coarser data.

Users of climate model results have long been dissatisfied with the inadequate spatial scale of climate scenarios produced from coarse resolution global climate model (GCM) output for many regional and local applications,. (Gates, 1985; Robinson and Finkelstein, 1989; Lamb, 1987; Smith and Tirpak, 1989; Cohen, 1990) This concern emanates from the perceived mismatch of scale between coarse resolution GCMs (100s of km) and the scale of interest for regional impacts (an order or two orders of magnitude finer scale) (IPCC, 1994; Hostetler, 1994).

As climate models have developed, there has been a general tendency toward increased spatial resolution. Climate models covering the south and Southeast Asia region will be at a resolution of 1 km to reduce the size of the data to be processed. A resolution of 1 km will also be used for the case study areas (in Viet Nam, Philippines, India and Indonesia) to provide more detail. Data at this resolution will take a little more time to process the data the first time but it will be done only once and will allow detailed analysis for the case study areas and other areas in the future. Because the models are global, they can "wash out" finer distinctions at the regional scale. Grid cells can range in size from 50 to 250 miles per side but, in reality, people don't live globally; they live in a particular place—a state or region. To be meaningful for people's lives, the global model projections must then be adjusted down to a more regional scale. These reports use several well-regarded downscaling techniques to transform global climate model results into projections based on tens of miles rather than hundreds. Data from WORLDCLIM provides a resolution of 1 km.

X. Model data exportable to GIS

Another factor that was considered in choosing the model is that the output can be effectively used in combination with GIS. GIS facilitates the analysis of multiple layers of data and allows statistical analysis of multiple factors while maintaining their spatial representation. In terms of high resolution climate change model output, the data processing requirements of GIS are high.

The application of a GIS in climate change impact assessments includes

(1) depicting past, present, or future climate patterns;
(2) using simple indices to evaluate present-day regional potential for different activities based on climate and other environmental factors;
(3) mapping changes in the patterns of potential induced by a given change in climate, thus showing the extent and rate of shifts;
(4) identifying regions that may be vulnerable to changes in climate; and

Consistency between sectors, systems, and regions

There is an increasing need for detailed, high-resolution regional information regarding future climate. Such information is needed by scientists in disciplines that require climate information (e.g. hydrologists), decision- and policy-makers, and by those assessing climate change impacts, adaptation and vulnerability. Although climate change projections must necessarily be undertaken with global models, such models will never have sufficient spatial detail for all applications. Constraints on available computing resources will always limit model resolution; therefore, various techniques have been developed for ‘downscaling’ global climate projections (and shorter-term climate predictions) and for producing fine-scale regional climate information. These include nested regional climate models, variable resolution global models, global uniform high-resolution time-slice simulations, statistical downscaling, and/or combinations of these methods.

At present, there is a need for more information in order that users are better able to evaluate the adequacy or applicability of these various methods for a particular problem. The need has also been expressed for a strong coordinated program aimed at evaluating and improving downscaling methods as well as improving the production of the next generation regional climate change projections. Experience in the global climate modelling community has shown the immense value of internationally coordinated model experiments, and the value of the resulting multi-model ensemble in producing credible climate change information and associated measures of uncertainty. Ensemble results from global coupled models have been used extensively in the IPCC assessment reports, but similar ensemble results from regional models or other downscaling methods have not been widely available for most regions of the world. This has limited the use of downscaling products in climate change impact assessment and adaptation studies.

Comparative sectoral climate change impact studies need to be consistent in terms of the methodology used. Establishing such consistency requires that sector studies be conducted in a coordinated fashion. This will be secured by using the same socio-economic, technological, environmental and economic data collection and analysis methodology. The nature of such co-ordination requires that socio-economic, technological, environmental scientists and coordinate and cooperate with their data collection and analysis. Interdisciplinary co-operation implies that a mutual understanding is developed, and that adjustments, perhaps even concessions, need to be made.

XI. Recommended climate change model to be used in this study

Model choice

Climate models, which can provide an early warning of climate change, are used to help determine what environmental changes the climate may bring in the future. Having described some of the options available for climate model and scenario selection and the information available from the WORLDCLIM and IPCC Distribution Center, the next vital step in an impact assessment is the selection, interpretation and application of appropriate models and scenarios to be used. An initial selection of experiments from three modelling centres were made based on their availability, resolution and performance but the choice was narrowed down to one after ranking the performance of the models. Two statistical metrics, pattern correlation and root mean square error, were used to measure model performance. A pattern correlation coefficient of 1.0 indicates a perfect match between the observed and simulated spatial pattern, and a root mean square error of 0.0 indicates a perfect match between the observed and simulated magnitudes. In this study, we assessed the performance of three climate models by extracting and comparing their correlation pattern and RMSE (Table 2). As shown in Table 2 CSIRO, HadCM3 and CCMA were able to simulate both rainfall and temperature in the Asia Pacific. However correlation pattern for rainfall is higher in CSIRO compared with HadCM3 and CCMA in majority of the seasons evaluated.

Based on the correlation pattern of the 3 GCM models it is recommended that CSIRO be used in this study, however it is also prudent to consider the output of the three models available in the Worldclim in future studies because of the uncertainties inherent in any individual climate projection. It is increasingly apparent that it is not possible to concentrate on simply using the most comprehensive and 'accurate' model for such work. Climate projections depend in large part on two factors: (1) how much and how quickly greenhouse gases are emitted into the atmosphere; and, (2) how the climate, oceans, and terrestrial systems respond to rising atmospheric concentrations of these gases. Scientists have developed a range of potential scenarios for future greenhouse gas emissions based on different assumptions about socioeconomic development. These scenarios represent the first source of uncertainty noted above. The second source of uncertainty is presented by the behavior of different climate models, which project different levels of temperature increase and different patterns of precipitation change for the same emissions scenario.

Models	Correlation MSLP (DJF)	RMSE	Correlation MSLP (MAM)	RMSE
HADCM3	0.95	3	0.9	3
CSIRO	0.94	2.5	0.92	2
CCMA1	0.99	2	0.85	2.2

Models	Correlation MSLP (JJA)	RMSE	Correlation MSLP (SON)	RMSE
HADCM3	0.89	3.6	0.90	2.8
CSIRO	0.90	2.3	0.95	2
CCMA1	0.90	2.8	0.90	2.5

Models	Correlation TEMP (DJF)	RMSE	Correlation TEMP (MAM)	RMSE
HADCM3	0.98	2	0.982	2
CSIRO	0.99	2	0.982	2.5
CCMA1	0.98	2.2	0.981	2

Models	Correlation TEMP (JJA)	RMSE	Correlation TEMP (SON)	RMSE
HADCM3	0.96	2.1	0.987	1.8
CSIRO	0.964	2.1	0.95	2.1
CCMA1	0.96	1.9	0.94	1.8

Models	Correlation RAIN (DJF)	RMSE	Correlation RAIN (MAM)	RMSE
HADCM3	0.77	3	0.56	3
CSIRO	0.82	2.2	0.64	2
CCMA1	0.78	2	0.62	2.2

Models	Correlation RAIN (JJA)	RMSE	Correlation RAIN(SON)	RMSE
HADCM3	0.66	3	0.7	3
CSIRO	0.73	2.2	0.79	2
CCMA1	0.79	2.2	0.80	2.1

Table 3 Pattern Correlation and RMSE of HadCM3, CSIRO and CCMA for MSLP, Temperature and Rainfall for DJF, MAM, JJA, SON

XII. Choice of emission scenario

Emissions scenarios represent how greenhouse gas (carbon dioxide, methane, nitrous oxide) emissions, and thus the accumulation of greenhouse gases in the atmosphere, might unfold over the next century. The IPCC has developed a suite of emissions scenarios that are widely used to generate climate projections from GCMs. These are reported in the IPCC Special Report on Emissions Scenarios (SRES). The SRES emissions scenarios are based upon the many factors that will determine the future level of GHGs in the atmosphere: population growth, economic development, technological innovation, energy consumption, land-use, agricultural development, and environmental policy.

Scenarios are often based on a combination of expert judgement, extrapolation of trends, international comparisons, and model runs. Historical developments are a good guide for future developments. The scenarios are based on a set of four narrative story lines labelled A1, A2, B1 and B2. The storylines combine two sets of divergent tendencies: one set varies its emphasis between strong economic development and strong environmental protection; the other set between increasing globalization and increasing regionalization. The storylines can be briefly described as follows:

A1

- very rapid economic growth,
- global population that peaks in mid-century and declines thereafter,
- rapid introduction of new and more efficient technologies.
- Convergence among regions, capacity-building, and increased cultural and social interactions,
- substantial reduction in regional differences in per capita income.

A2

- a very heterogeneous world.
- self-reliance and preservation of local identities.
- Fertility patterns across regions converge very slowly, which results in continuously increasing population.
- Economic development is primarily regionally oriented
- per capita economic growth and technological change more fragmented and slower than other storylines.

B1

- a convergent world,
- global population peaks in mid-century and declines thereafter,
- rapid change in economic structures toward a service and information economy,
- reductions in material intensity and the introduction of clean and resource-efficient technologies.
- Global solutions to economic, social and environmental sustainability, including improved equity,
- without additional climate initiatives.

B2

- local solutions to economic, social and environmental sustainability.
- Increasing global population, at a rate lower than A2,
- intermediate levels of economic development,
- less rapid and more diverse technological change than in the B1 and A1 storylines.
- oriented towards environmental protection and social equity

Table 4: Summary of Emission Scenarios

	A1	A2	B1	B2
Economic growth	Very rapid. Converging.	Regionally based. Fragmented and slow	Converging. Service and information economy	Intermediate economic growth. local solutions
Population growth	Peaks mid century	Continues increasing at same pace	Peaks mid century	Continues increasing slowly
technologies	new and more efficient	technological change more fragmented and slower	clean and resource-efficient technologies	less rapid and more diverse technological change
Regional differences	reduction in regional differences	self-reliance and preservation of local identities	Global solutions	local solutions
Environment			Global environmental solutions	oriented towards environmental protection
Climate			without additional climate initiatives	

SRES scenario quantifications (IPCC, 2000); numbers are for 2100

	Storyline			
	A1	A2	B1	B2
Population growth	Low ~7 billion	High ~15 billion	Low ~7 billion	Medium ~10 billion
GDP growth	Very high 525–550[a]	Medium 243	High 328	Medium 235
GDP per capita[b]	Ind.: US$107,300 Dev.: US$66,500	Ind.:US$46,200 Dev.: $11,000	Ind.: US$72,800 Dev.: US$40,200	Ind.: US$54,400 Dev.: US$18,000
Energy use	Very high/high	High	Low	Medium
Land use changes	Low-medium Cropland + 3% Forest + 2%	Medium-high —	High Cropland −28% Forest + 30%	Medium Cropland + 22% Forest + 5%
Resource availability	High/medium	Low	Low	Medium
Pace and direction of technological change	Rapid	Slow	Medium	Medium
Favoured energy	Fossil/balanced/non-fossil	Regional diversity	Efficiency and dematerialisation	"Dynamics as usual"

Note: There are three variants of the A1 storyline, representing different energy uses.
[a] World GDP (trillion 1990 US$) in 2100.
[b] GDP per capita in 1990 US$, market exchange prices.

Population Forecast

World population estimates

The future population growth of the world is difficult to predict. The UN and US Census Bureau give different estimates. Birth rates are declining slightly on average, but vary greatly between developed countries (where birth rates are often at or below replacement levels), developing countries, and different ethnicities.

Death rates can change unexpectedly due to disease, wars and catastrophes, or advances in medicine.

Table 5: U.N and U.S Census Bureau estimates

UN and U.S. Census Bureau estimates				
Year	**UN est (billions)**	**Diff.**	**US est (billions)**	**Diff.**
2000	6.0	-	6.0	-
2010	6.8	0.8	6.9	0.9
2020	7.5	0.7	7.7	0.8
2030	8.1	0.6	8.4	0.7
2040	8.6	0.5	9.0	0.6
2050	8.9	0.3	9.5	0.5

Other projections are that the world's population will eventually crest, though it is uncertain when or how. In some scenarios, it will crest as early as around 2050 at just under 9 billion, or 10 to 11 billion, due to gradually decreasing birth rates.

Table 6: Estimate of World Population

UN estimates (in thousands).							
Year	**World**	**Africa**	**Asia**	**Europe**	**Latin America**	**US and Canada**	**Oceania**
2000	6,070,581	795,671 (13.1%)	3,679,737 (60.6%)	727,986 (12.0%)	520,229 (8.6%)	315,915 (5.2%)	31,043 (0.5%)
2005	6,453,628	887,964 (13.8%)	3,917,508 (60.7%)	724,722 (11.2%)	558,281 (8.7%)	332,156 (5.1%)	32,998 (0.5%)
2010	6,830,283	984,225 (14.4%)	4,148,948 (60.7%)	719,714 (10.5%)	594,436 (8.7%)	348,139 (5.1%)	34,821 (0.5%)
2015	7,197,247	1,084,540 (15.1%)	4,370,522 (60.7%)	713,402 (9.9%)	628,260 (8.7%)	363,953 (5.1%)	36,569 (0.5%)
2020	7,540,237	1,187,584 (15.7%)	4,570,131 (60.6%)	705,410 (9.4%)	659,248 (8.7%)	379,589 (5.0%)	38,275 (0.5%)
2025	7,851,455	1,292,085 (16.5%)	4,742,232 (60.4%)	696,036 (8.9%)	686,857 (8.7%)	394,312 (5.0%)	39,933 (0.5%)
2030	8,130,149	1,398,004 (17.2%)	4,886,647 (60.1%)	685,440 (8.4%)	711,058 (8.7%)	407,532 (5.0%)	41,468 (0.5%)
2035	8,378,184	1,504,179 (18.0%)	5,006,700 (59.8%)	673,638 (8.0%)	731,591 (8.7%)	419,273 (5.0%)	42,803 (0.5%)
2040	8,593,591	1,608,329 (18.7%)	5,103,021 (59.4%)	660,645 (8.0%)	747,953 (8.7%)	429,706 (5.0%)	43,938 (0.5%)
2045	8,774,394	1,708,407 (19.5%)	5,175,311 (59.0%)	646,630 (7.4%)	759,955 (8.7%)	439,163 (5.0%)	44,929 (0.5%)
2050	8,918,724	1,803,298 (20.2%)	5,217,202 (58.5%)	653,323 (7.3%)	767,685 (8.6%)	447,931 (5.0%)	45,815 (0.5%)

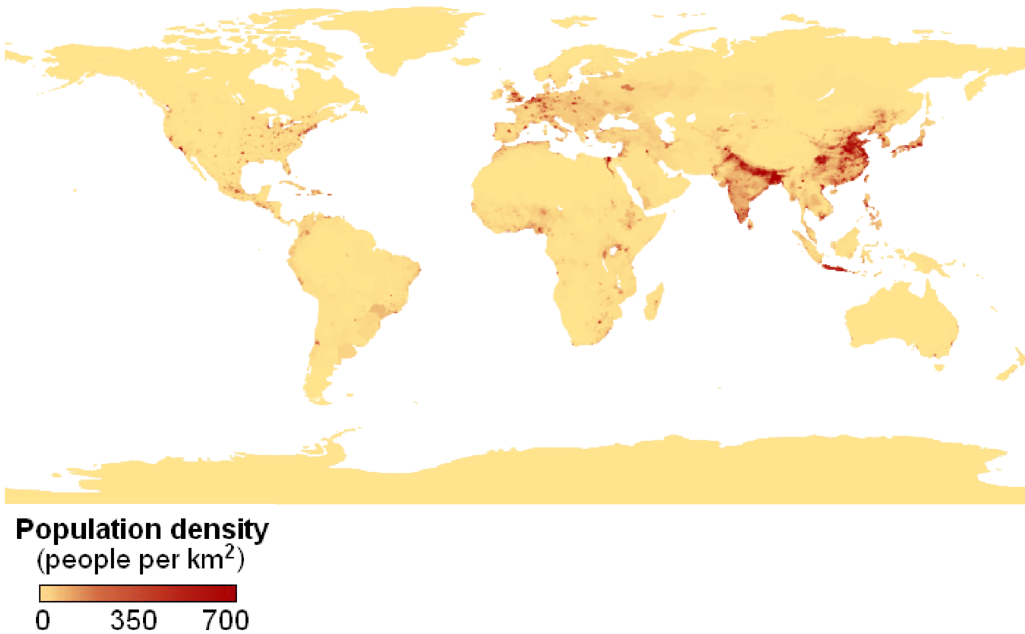


Figure 5: Population Density

This figure above shows the number of people per square kilometer around the world in 1994. The data were derived from population records based on political divisions such as states, provinces, and counties.

Predictions based on population growth

From 1950 to 1984, as the Green Revolution transformed agriculture around the world; grain production increased by 250%. The world population has grown by about four billion since the beginning of the Green Revolution

The energy for the Green Revolution was provided by fossil fuels in the form of fertilizers (natural gas), pesticides (oil), and hydrocarbon-fueled irrigation. However world hydrocarbon production is peaking (Peak oil). But this may be offset by biofuels but at the expence of crop production for food.

Agricultural productivity may also be affected by climate change loss of agricultural land to residential and industrial development.

Rate of population increase

Different regions in the world have different rates of population growth. According to the table below, the growth in population of the different regions from 2000 to 2005 was:

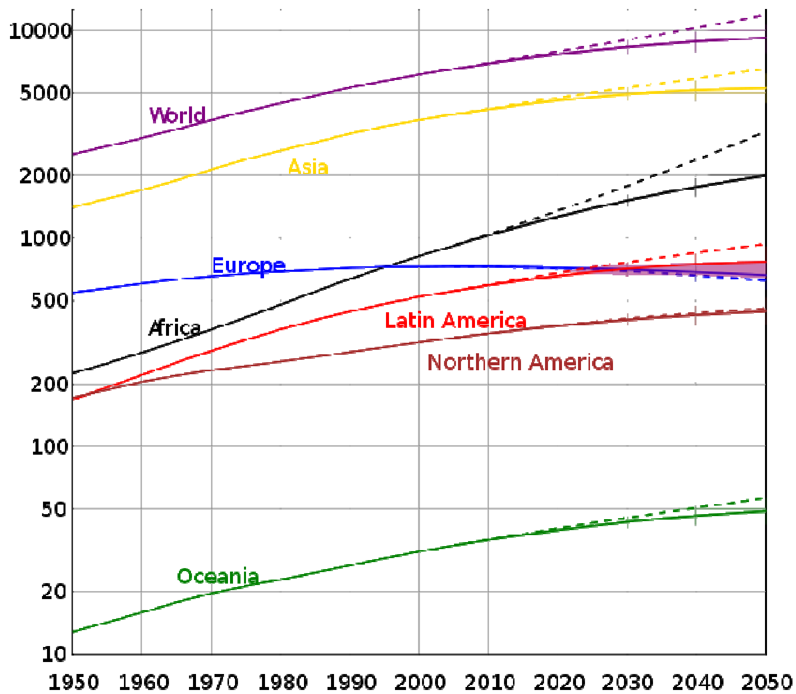
237.771 million in Asia
92.293 million in Africa
38.052 million in Latin America
16.241 million in Northern America
1.955 million in Oceania
-3.264 million in Europe
383.047 million in the whole world

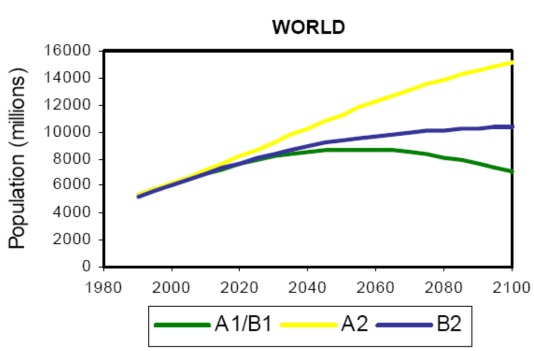
In the 20th century, the world saw the biggest increase in its population in human history due to lessening of the mortality rate in many countries due to medical advances and massive increase in agricultural productivity attributed to the Green Revolution.

Globally, the population growth rate has been steadily declining from its peak of 2.19% in 1963, but growth remains high in Latin America, the Middle East and Sub-Saharan Africa.[24]

In some countries there is negative population growth (i.e. net decrease in population over time), especially in Central and Eastern Europe (mainly due to low fertility rates) and Southern Africa (due to the high number of HIV-related deaths). Within the next decade, Japan and some countries in Western Europe are also expected to encounter negative population growth due to sub-replacement fertility rates.

Figure 6 shows the population evolution in different continents. The vertical axis is logarithmic and is millions of people.





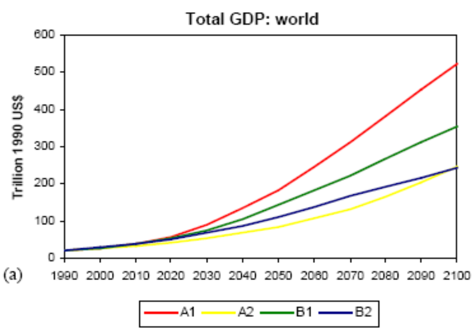
Gross Domestic Product (GDP)
The economic growth rate is a key assumption in each SRES scenario family. Economic growth rates were assumed to be "very high" for the A1 family, "medium" for the A2 family, "high" for the B1 family and "medium" for the B2 family (IPCC, 2000). Quantitatively these assumptions translated into world GDP for 2100 of approximately 525–550 trillion US1990$/year for the A1 family, 243 trillion US1990$/year for the A2 family, 328 trillion

US1990$/year for the B1 family and 235 trillion US1990$/year for the B2 family, with the precise amount depending on the integrated assessment model used to simulate economic changes.

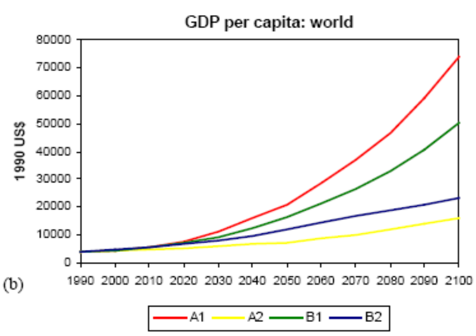
Fig. 5a shows the rate of change of global GDP (assuming market exchange rate: GDPMER). Per capita GDPMER growth rates depend, of course, on the assumed rate of population growth, and Fig. 5b shows per capita GDPMER (again in US1990$) under the four SRES scenario families. Fig. 6 shows the per capita GDPMER for four world regions. It is also possible to compare and combine national GDP figures using Purchasing Power Parity (PPP). This reduces the difference between rich and poor countries, but estimates of future PPP depend very much on assumed future purchasing preferences in different countries.

The SRES authors therefore used GDPMER to determine emissions scenarios. Global and regional GDP estimates based on PPP were actually provided in the SRES report (IPCC, 2000) for the A1T and B2 marker scenarios (based on the MESSAGE integrated assessment model). There is little difference between GDPMER and GDPPPP after 2050, but before then the OECD countries are relatively less rich, and the rest of the world less poor, with GDPPPP.

1990 was selected as the base year by the SRES authors because it is the most recent year with consistent high-quality data available at the national scale.



(a)



(b)

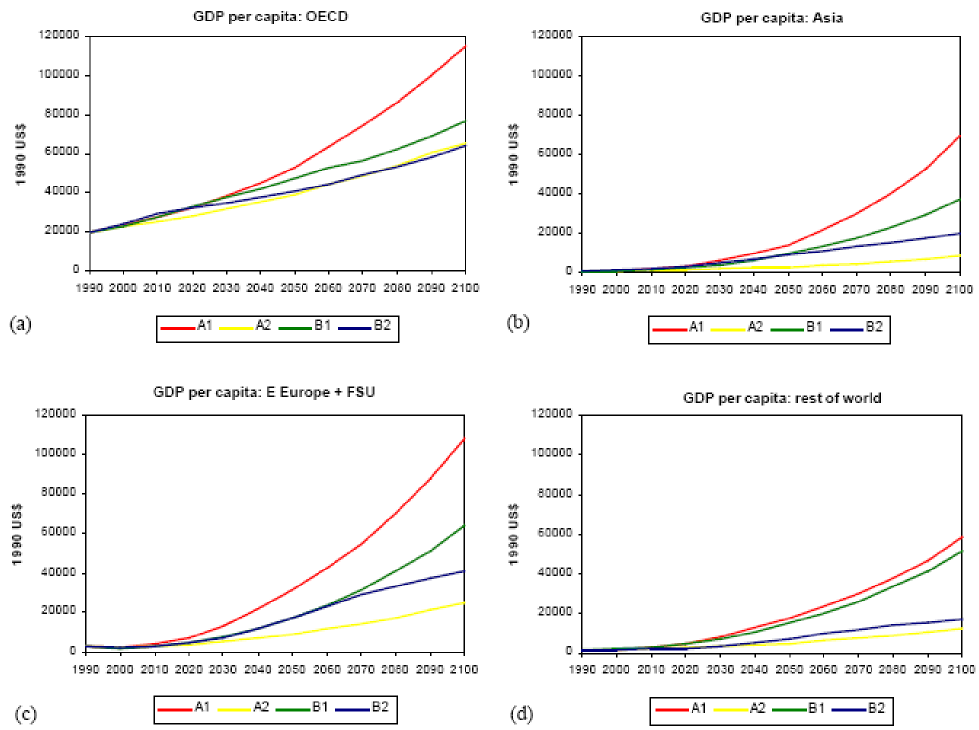


Figure 7: GDP per capita from different emission scenarios

Recommended Scenario

Emission scenario is identified as one of the major cause of uncertainty in projected future climates. Inherent uncertainties exist in the key assumptions in regard to relationships between future population, socioeconomic development and technical changes, which form the base for the IPCC SRES Scenarios. Making climate projections for a range of SRES scenarios such as the presently available in Worldclim, A2 and B2 emission scenario families can be one way to consider the uncertainties in emission scenarios. B2 emission scenarios for carbon dioxide emission rates are more than double in A2 scenario as compared to A1B and B2 scenarios towards the end of the century. A2 scenario is the more realistic scenario, particularly after the recent credit crunch and specifically A2a (business as usual) and is the recommended choice. However, use of a range of scenarios may be a better approach to understand the range of possibilities (including the worst and best case scenarios) though this may not always be possible due to time and budget constraints.

The use of other SRES scenarios (A1B, A2, B1, B2) can be important for assessing future impacts and vulnerability to climate change and also one way of addressing uncertainty. Research efforts are needed to quantify future climate changes scenarios for Southeast Asia under different SRES emission scenarios.

XIII. Consistency in scenarios and data

It is important to try to establish coherence and consistency between sectoral impact studies. Comparability of results will secured by using the same scenarios (for climate, population, economics, and so on) and use the same reference year, the same units, and consistent data bases for all case studies.

References

Congwen and Park (2008) Statistical Downscaling for Multi-Model Ensemble Prediction of Summer Monsoon Rainfall in the Asia-Pacific Region Using Geopotential Height Field Advances in Atmospheric Sciences VOL. 25, NO. 5, 2008, 867{884}

Humans, et al. (2005) Very High Resolution Interpolated Climate Surfaces for Global Land Areas Int. J. Climatol. 25: 1965–1978 (2005)

Lu, X. (2006), Guidance on the Development of Regional Climate Scenarios for Application in Climate Change Vulnerability and Adaptation Assessments

Luers and Mastrandrea (2008) Climate Change in California: Scenarios for Adaptation

New M, Lister D, Hulme M, Makin I. 2002. A high-resolution data set of surface climate over global land areas. Climate Research 21: 1–25.

Preston, et al. (2006) Climate Change in the Asia/Pacific Region. A Consultancy Report Prepared for the Climate Change and Development Roundtable: Climate Change Impacts and Risk , CSIRO Marine and Atmospheric Research : 65-67

Santoso, et al. (2008) Climate scenarios: What we need to know and how to generate them? CIFOR Working Paper No. 45, 9-17