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# CLIMATE CHANGE ANALYSIS BY DEVELOPING A COUPLED MODEL INTERCOMPARISON PROJECT

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## Abstract

The Coupled Model Intercomparison Project (CMIP) is a recent action of experimentation of much wider possibility and impact on climate change. The Coupled Model Intercomparison Project (CMIP) was set up to study and compare climate imitations. CMIP has enhanced our understanding of climate change and variability.

CMIP5 incorporated new standards for the development of future scenarios related to emission, presented experiments to discover carbon climate relations, and used only atmospheric set ups or models to bring more considerable local change in climate data. A set of trials was merged to help develop the understanding of the behavior of Earth pertaining to change in climate.

Insufficient knowledge of forcing has remained an issue with CMIP. It will be encountered with novel and innovative tactics in CMIP6 which will comprise of separate CMIP6-endorsed MIPs. CMIP-6 sees to build on the extended custom of outstanding science in former CMIP stages, nonetheless the tactics of CMIP6 can be fulfilled by the dedicated support and participation of scientists and researchers from throughout the world.

Currently the stage five (CMIP5), has shaped almost a large output from many of tests carried out by various climatic replicas accessible. So, it has progressed the climate understanding to a greater extent. In the meantime, CMIP5 has also provided appropriate responses to many vital scientific queries, hence paved the way for the systematic outline of the upcoming phases of CMIP that is, CMIP6.

**Keywords:** Coupled Model Intercomparison Project (CMIP), Climate Change, Representative Concentration Pathways, Climate Model

## 1. INTRODUCTION

The coupled model intercomparison project (CMIP) aids in coordinating and comparing of comprehensive models of climate (AMIP; gates 1992). The advancement and growth of climate science since 1990s, CMIP has contributed much to it. The main purpose of CMIP is to plan the worldwide simulations of the climate structure which is coupled and uses a large domain of model results to progress understanding of the climate change and variability. CMIP, was recognized underneath the World Climate Research Program (WCRP) as a usual experimental procedure to study the results of atmosphere-ocean general circulation models (AOGCMs).

The CMIP involves more than 30 groups around the world and sets standard for the specific experimental protocols. By using the same climate change scenarios, the climate outputs can be analyzed collectively resulting in better climate project. The CMIP models are the key to international climate assessment and negotiations such as IPCC assessment report.

When there is a variation in mean weather condition of a particular spatial extent and it shows variation for a prolonged period, we call it CLIMATE CHANGE. There are some natural factors like variation in sun's radiation, plate tectonics, biotic processes which are responsible for the climate change. Global warming, due to human beings is also found to be a major cause. According to the WMO which stands for World Meteorological Organization, "Change in climate indicates a substantial statistical variation either in the mean state or in its variability, continuing for a prolonged period ". "Change in climate might be because of internal processes that are natural or external forcing" [IPCC, 2013]. The UNFCCC, defines alteration in climate as: "a change of climate which is accredited directly or indirectly to human action that modifies the global condition of atmosphere as well as in addition to natural climate variability detected over similar time periods".

Climate forcing are the crucial factors that shape the climate. It includes varying solar radiation, atmosphere, oceans, continental drifts and changes in greenhouse gas concentrations. Forcing mechanism can be of two types: either internal or external. Natural processes as in wind circulation and temperature variation frames the internal forcing, wherein external forcing is mainly due to anthropogenic activities like high and increased emission of greenhouse gases and dust.

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Climate models that are coupled are arithmetical and physical arrangements of the atmosphere, ocean, land which are altogether coupled for interaction in order to mimic the three-dimensional circulation of the climate over the earth. These models are cast-off to project the future climate alteration because of anthropological activities. Results of simulation are globally used to check for susceptibilities and for the study of social influences that may have consequences. It is therefore very crucial for the science group to aptly evaluate the simulation competences of these models which is carried out in the form of CMIP.

This is systematized by the World Climate Research Programme (WCRP) under the Climate Variability and Predictability (CLIVAR) project. The CMIP involves many diverse groups around the world and specifies standard for the particular experimental protocols. By using the same climate change scenarios, the climate outputs can be examined jointly resulting in better climate project.

The CMIP outcomes are used for understanding climate change impacts for i.e., precipitation which is critical to agriculture and human living condition and also changes to biogeochemistry of oceans are critical for fisheries and oceans acidification which affects coral reefs. Many of the models were run at higher resolutions or would include additional processes that were not simulated in previous model. New CMIP evaluation tools allow researchers to analyze the data. Moreover, it also improves infrastructure and documentation to help them find whatever they are looking for.

## 2. LITRATURE REVIEW

A number of studies, formulation and research has been approved out in the past regarding the coupled modelling intercomparison project. Some of those are as follows

Gates et al (1999) contributed in setting up an AMIP configuration or set up for conducting AMIP experiments where the atmospheric composition, SST that is specified sea surface temperature and sea concentration are determined from observational products.

His work includes the simulations of CMIP5 and AMIP which provide an experimental protocol for models to proceed with atmospheric only simulations. For example, sea surface temperature for the year 2012 (the year for which the world experienced warming in United States great plain) were prescribed using AMIP.

Covey et al (2005) contributed to coupled modelled intercomparison project by showing results from model simulation responses to ideal increase in Carbon dioxide of 1 percent per year.

Meehl et al (2005) contributed in various phases of CMIP2 and CMIP2+ by collecting the model data and making it available for the analysis. He also collected model data from 1percent per year carbon dioxide increase experiments from coupled models. These results were presented in first workshop of CMIP. He also studied climate models showing simulation of decadal prediction experiments with their response.

Moss et al (2010) adopted a novel method by stipulating forthcoming states by describing RCPs (representative concentration pathways). Modelers were able to work in parallel in each working group because he separated the two uncertainties (uncertainty in each step while developing the scenarios and uncertainty of climate model response) as a part of implementation process.

Van Vuuren et al (2011) contributed by issuing a special issue of climate change representing the development of four RCPs.

Taylor et al (2012) contributed in the collection of model results as a part of CMIP (CMIP3 and CMIP5) and carried out the investigation of fast climate response to atmospheric carbon dioxide (CO2) concentration. He also concluded that RCPs as a part of CMIP5, produce forecasts of greatness and pattern of climate change over this era and 2300.

Kriegler et al (2012) explained the elements of integrated framework. RCPs were defined and advanced in aid with this integrated assessment modelling community.

Meehl et al (2014) outlined the three broad future specific scientific questions to be recommended for CMIP6.

## 3. CMIP OVERVIEW

### General

CMIP has evolved and expanded over the last two decades. The weights that CMIP places on the modelling groups has also evolved with advent of time. Recently the climate modelling community itself has evolved. Earlier the analysis of models was carried out in aid with individual working groups. Nowadays CMIP includes climate modelling clusters and community comprising of experts analyzing the consequences. Hence CMIP plays a crucial role in aiding these clusters in exchanging views.

CMIP's main aim is to progress understanding of earth and to be an important and treasured reserve for global as well as national climate assessments, including IPCC. In early phases of CMIP, the PCMDI basically provided with infrastructure and project management along with documentation backing for CMIP. PCMDI assisted in the setting up of good data standards and well-defined experimental protocols.

PCMDI that is also known as Program for Climate Model Diagnosis and Intercomparison serves to provide the key support to CMIP but the accountability of CMIP is more extensively united across through ESGF (Earth System Grid Federation) which states and distributes terra-scale data from simulations of numerous coupled atmosphere-ocean global climate model.

According to experience it is seen that analyzing the model yield from previous stages of CMIP is an ongoing process of coupled model intercomparison project without an exact or certain end date. Hence preparation of a brand-new stage needs to start even when the preceding stage is incomplete.

### CMIP-1

The first phase of CMIP, termed as CMIP-1, was targeted at collecting and analyzing the recent control runs from the models that were coupled that is the capability of system models to look into the current changes in climate. CMIP-1 conducted experiment that addressed processes in relation to changes in upcoming time periods to meridional overturning circulation (MOC) in the Atlantic. These trials addressed, developments of system models that are not properly and accurately represented with old comparison methods along with the results

In total there had been 10 CMIP-1 subprojects, with 6 of the 10 producing at least one peer-reviewed publication.

**CMIP-2**

The second phase of CMIP 2 which composed model figures from 1% per year CO2 increase experimentations from the combined models that is model simulations of climate change due to an ideal alteration in forcing (a 1% per year CO2 rise).

The other stage of CMIP was named CMIP2, with the objective to gather all statistics produced from device and one percent CO2 rise trials for the ocean, surface of land, sea ice and atmosphere. This signified a very crucial and large storage of data and application.

There had been 22 CMIP-2 subprojects, moreover during the period of its second Workshop in September in the year 2003, 12 out of 22 had fashioned a minimum of one peer-studied journal. The statistics were accessible in the beginning of 2001.

**CMIP-3**

As a result of proposed activity of WCRP, the WGCM, PCMDI aided to gather output from the models given by the leading centers everywhere the globe. Model outputs from imitations of former, present and future climate was taken by PCMDI frequently through years 2005 and 2006 and the data prepared constitute stage 3 of CMIP (CMIP3).

The gathering of recent output from models is formally acknowledged as the WCRP, data set produced from CMIP-3. Its purpose is to assist IPCC's working group 1 which in turn concentrates on physical climate -land surface, atmosphere, ocean and sea ice.

**CMIP-4**

The inter-mediate but not globally popular CMIP phase (CMIP-4) aided the experiments happened in CMIP3. These kinds of trials have been basis of recognition and acknowledgement studies. An extra issue for CMIP4 was the the ordering of the stages of CMIP with the valuations reports of IPCC. Since, not having a big CMIP phase named CMIP-4 neglected any undesired dilemma with the existing intercomparison project so called MIPs.

**CMIP-5**

Cmip-5 contributed in setting up an AMIP configuration or set up for conducting AMIP experiments where the atmospheric composition, specified SST and sea concentration are determined from observational products.

Here the work includes the simulations of CMIP5 and AMIP which deliver an experimental procedure for models to proceed with atmospheric only simulations. For example, sea surface temperature for the year 2012 (the year for which the world experienced warming in United States great plain) were prescribed using AMIP.

*Lessons from Cmip-5*

In accordance with the IPCC's 5th assessment report, a set of new scenarios was defined to consider the growing complexity of model calculations and to analyze the effect of various political measures. AR5 Scenarios are based on the scenario of the CMIP-5 which have been inculcated in Taylor et al. (2012).

The Representative Concentration Pathways (RCPs) are the greenhouse gas concentration trajectories (not emissions) approved by the IPCC for its fifth Assessment Report (AR5). The four RCPs namely RCP 2.6, RCP 4.5, RCP 6.0, and RCP 8.5 are nomenclature after a possible range of radiative forcing values in the year 2100.

**CMIP-6**

The technical background for CMIP6 is the WCRP Science challenges which are as follows

- Melting of Ice and Global Consequences
- Clouds, Climate Sensitivity and Circulation
- Feedbacks of carbon in the Environment System
- To understand and predict the Weather and Climate Extremes
- Water required for the Food Baskets of World
- Coastal Impacts and Regional Sea-Level Change
- Near-term Climate Prediction

Main criteria for endorsement of CMIP-6:

- The MIP and their experimentations report at minimum one of the important science queries of CMIP6.
- The MIP (Model Intercomparison Project) follows the CMIP modelling organization conventions and standards.
- All experiments are definite, and quite beneficial in a multi-model setting and they do not coincide with extra trials of CMIP-6.
- The MIP shows an examination plan explaining how it uses all future trials, any important observations, and ask for model yield for evaluating the models and addressing its science questions.

**Simulations within the Framework of CMIP5 and for the 5$^{th}$ Climate Assessment Report (IPCC AR5)**

In coordination with the IPCC, a comparison project was launched by the international research community known as CMIP5. IPCC is the main governing body for assessing the change in climate. Under this project, many coordinated experiments with the climate and earth system models were carried out for the sake of research and answering queries about the mechanisms and characteristics of climate change.

Certain topics which have been included are

- Experiments from the period between 1850 and 2005.
- Projections for scenarios which ranges from period of 2100 to 2300

- Predictions of decadal climate
- Function of the cycle of carbon in changing climate.
- More vivid past, as in case the years from 850 to 1850.

**The Scenarios (IPCC AR5)**

In accordance with the IPCC's 5th assessment report, a set of new scenarios was defined to consider the growing complexity of model calculations and to analyze the effect of numerous political measures. AR5 Scenarios are based on the scenario of the CMIP-5 which have been inculcated in Taylor et al. (2012).

These are the group of four novel paths which has been intended for the use of climate modelling community which will serve as a foundation for the near term and long-term modelling researches. The usage of the word "concentration" in place of "emissions" shows that concentrations are being used as the main artefact of the RCPs, intended as input to models that represent climate. They represent a complete bandwidth of future emission trajectories. For the period ranging from 1850 to 2005, the progression of radiative forcing or GHGs concentration match the observed past. For the years 2006 to 2100, the representative concentration pathways show different future scenarios.

In addition to it, the RCPs are complemented with extensions hence named as Extended concentration pathways which paves the way for the experiments modelling the climate change through the year 2300. The RCPs are very crucial for the progress in research pertaining to climate variations. Moreover, it offers a groundwork for future continuing research and valuation.

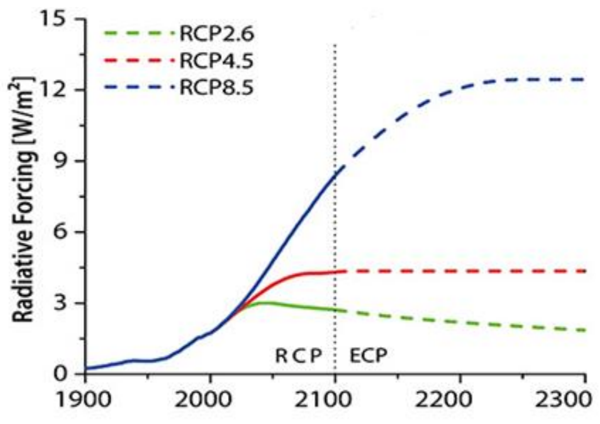


*Figure 1 Representative concentration pathways (Van Vuuren et al 2011)*

Many simulations were achieved with the help of Earth System Model MPI-ESM, in accordance with CMIP-5 and IPCC AR5, are the important key to various science projects for upcoming years. The simulations of CMIP-5 were carried out by DKRZ and MPI-M using the latest MPI-ESM (Earth system model), designed by MPI-M. A total of 650 terabytes simulation data was produced.

By showing an effective and comprehensive visualization for various key climate variables and for different scenarios, it illustrates to provide bandwidth of future changes in climate.

***Global Mean Temperature***

It is the key climate parameters directly influenced by increased radiation from rapidly rising greenhouse gases.

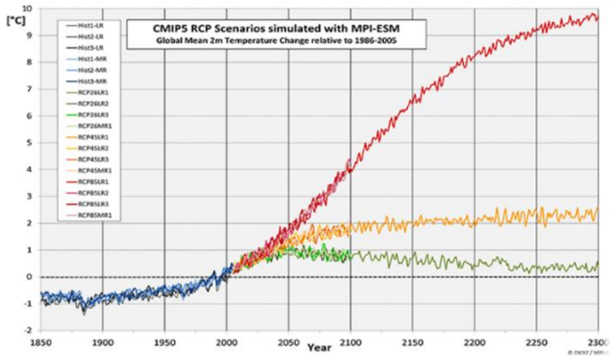


*Figure 2 Global mean 2m temperature change (https://www.dkrz.de)*

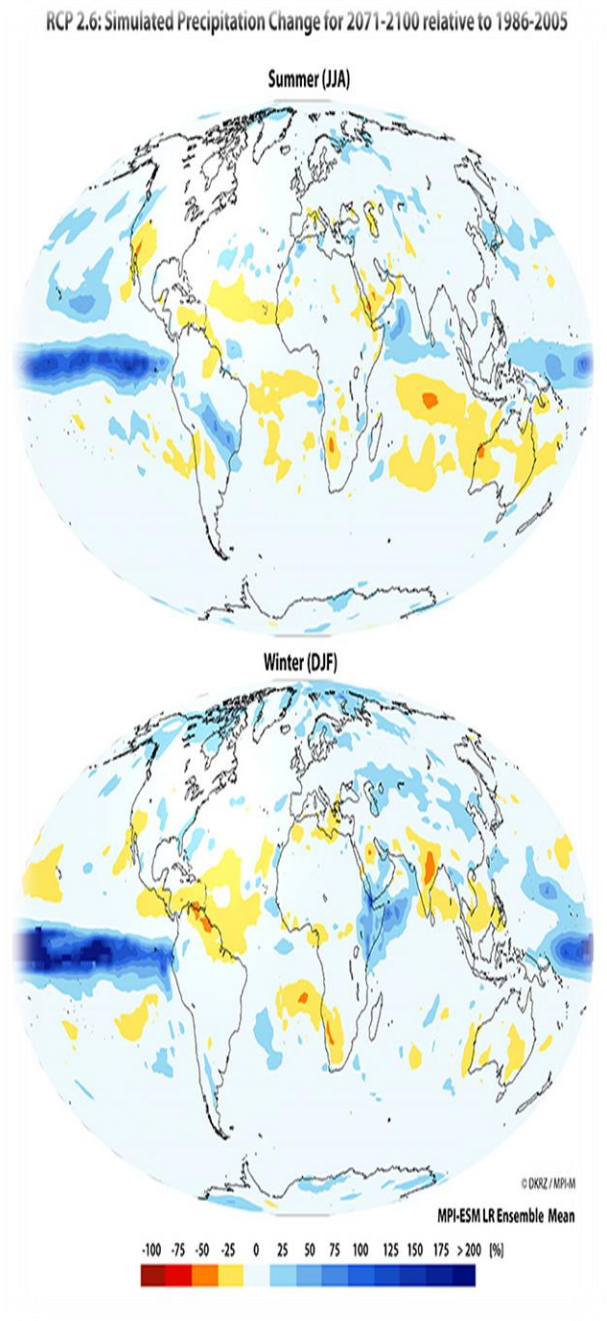


*Figure 3 Simulated precipitation change in accordance with RCP 2.6 (https://www.dkrz.de)*

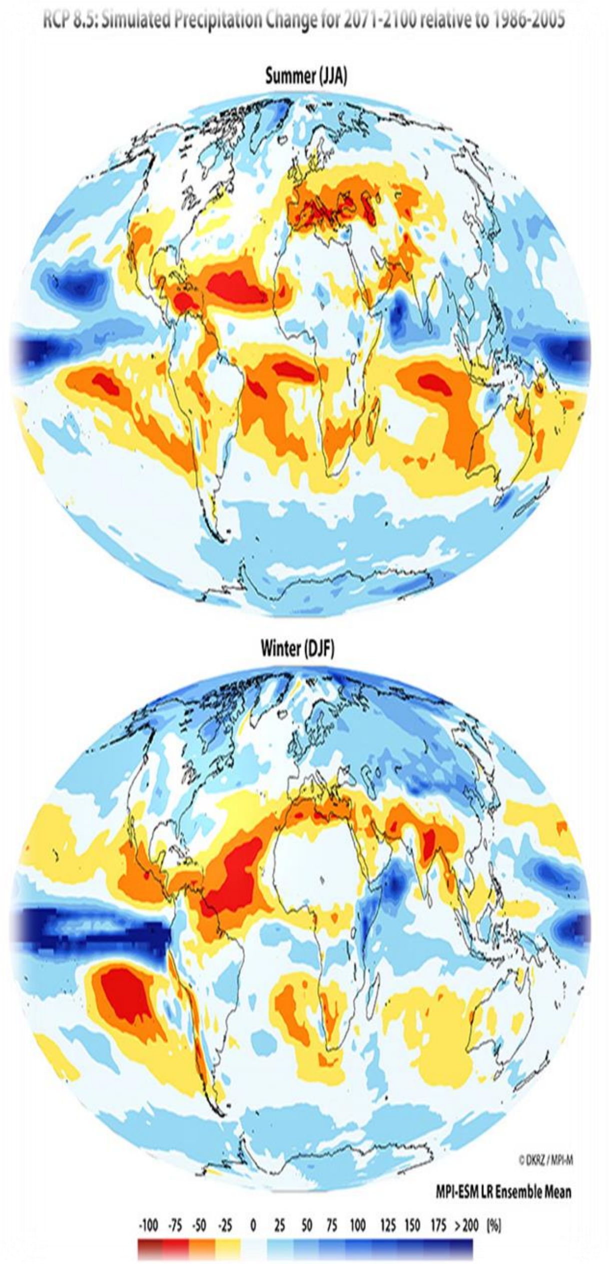


*Figure 4 Simulated precipitation change in accordance with RCP 8.5 (https://www.dkrz.de)*

The figure 2 illustrates the curves of temperature for three different understandings, RCP scenarios, and the past for the 2005-2100 time. For the scenarios that are extended up to 2300 in the so-called ECPs, the changes in for the simulated climate impact prove to be more enlarged and risen. Here MPI-ESM outlines were utilized for simulating the historic past and likely advances in future.

While ECPs (Extended concentrated pathways-extensions of the RCPs) 2.5 shows a slightly reduction in the 2050 temperature level, ECP4.5 and ECP8.5 foresees a more surge in temperature between 2100 and 2300. In ECP4.5, the temperature rises spreads approximate to 2.3 degrees by the year 2300 as related to 1986-2005, whereas in the scenario of ECP8.5, the temperature increases almost by 10 degrees.

**Precipitation**

Due to the increase in temperature, the water cycle gets intensified, hence global mean precipitation increases. However, there is a redistribution because of which some areas receive more precipitation and others less.

The above figure shows the variations in precipitation for the mean summertime and winter seasons of 2071-2100 relative to 1986-2005. They show that more the stronger the changes in temperature, the greater the precipitation anomalies are. In RCP 4.5 noticeably stronger precipitation changes are simulated as compared to RCP 2.6 for example, a superior than 25 percent decline in rainfall in both the summer as well as winter months in the Mediterranean Sea area. In the RCP8.5 scenario, this trend is augmented to illustrate even more drastic changes.

*Sea Ice*

In the figure above, the development of mean sea ice cover in the North Hemisphere is shown for both the months of September (sea ice lowest) and March (sea ice extreme) for the years ranging from 1975-2300.

The RCP2.6 simulation illustrates that, though reduced, the arctic sea ice will be there throughout the year, while the extreme RCP8.5 simulation shows a complete disappearance of the arctic ice in the long run. The summer sea ice, represented in light blue colour would continue to decline completely melting away in 2060, while the winter sea ice will slightly reduce in RCP 4.5 scenario and finally the formation of sea ice will completely stop around 2130. So, after 2130 basically the northern hemisphere will remain ice free year-round. Thus, the white areas representing the winter sea ice will diminish, leaving us with a complete decline of sea ice.

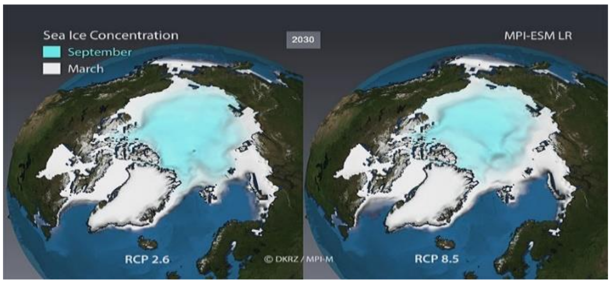


*Figure 5 Development of ice cover (2030) -www.dkrz.de*

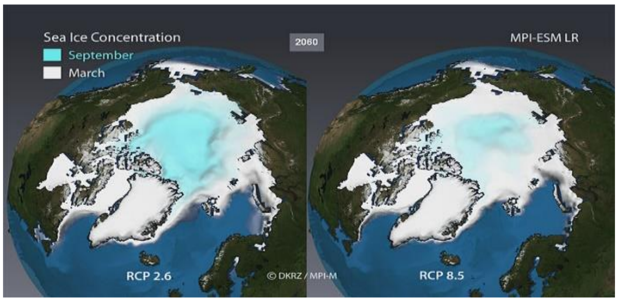


*Figure 6 Development of ice cover (2060)- www.dkrz.de*

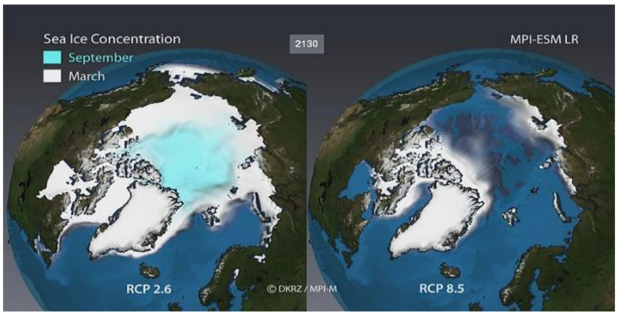


*Figure 7 Development of ice cover (2130)-www.dkrz.de*

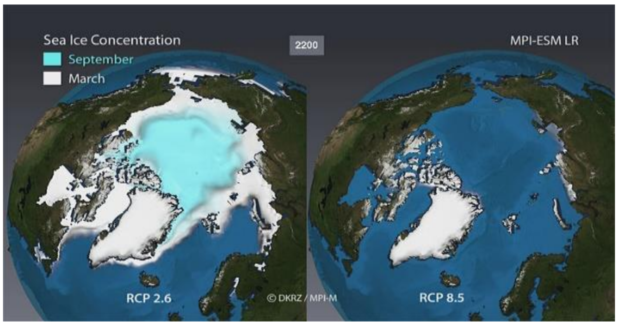


*Figure 8 Development of ice cover (2200)- www.dkrz.de*

*Sea Level*

Since the increase in temperature causes the water to expand and hence cause the sea level to rise.

The graph shows that the sea level is expected to rise by

a. 20-30 cm by 2100

b. 0.3-1.6 m by 2300

In the RCP8.5 simulation, the world-wide average sea level is expected to increase by 40 cm by 2100 because of the rise in water temperatures.

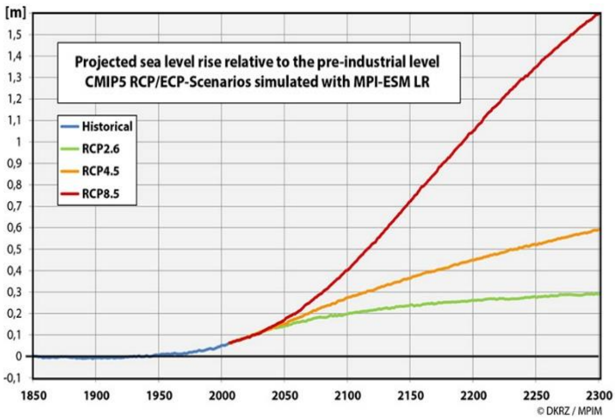


*Figure 9 Projected Sea Level Rise in Accordance to RCP 2.6, 4.5, 8.5. (www.dkrz.de)*

**Work of Coupled Modelled Intercomparison Project in India**

In India maximum of the case studies have been approved out for statistical downscaling using the CMIP3 prototypical information such as:

Salvi et al (2015) discussed the reliability of statistical downscaling under non immobile climate to venture Indian monsoon precipitation at a resolution of 0.5° by means of the information from CMIP-3 modelled by CCCma which stands for Canadian Centre for climate modelling and analysis.

Kannan and Ghosh discussed a non-parametric kernel regression model for downscaling multisite daily rainfall in Mahanadi Basin in 2013.

Shashikanth et al resolved that the rainfall from Indian monsoon which resulted from CMIP-5 data are less uncertain than the CMIP-3 consequences in his paper that presented whether the Indian precipitation simulation from CMIP-5 fluctuate from those of CMIP-3 simulation. There has also been a study on statistical downscaling over the multisite daily rainfall for Tapi river basin at a very small resolution of 0.25 degree from CMIP-5 GCM data carried out by Timbadiya et al. The 4 scenarios of the CMIP-5 are grounded on the aforementioned RCPs. Downscaling of the rainfall at a much finer resolution of 0.25 degree by data of CMIP-5 GCM of scenario 4.5 (most likely to happen scenario) and RCP8.5 (bearing in mind as the worst set-up) for enumerating the influence of climate alteration on water assets of Tapi basin was the main attempt here.

Moreover Knutti and Sedlacek(2012) found out that the mean temperature using the data of CMIP-3 is more uncertain than CMIP-5 data .

## 4. GAP AREAS IN RESEARCH

Previously the Global Circulation Models used in India were selected from the CMIP-3 experiments and the studies showed that these models have more ambiguity and biases as compared to the models from CMIP-5. Moreover, the design of experiments in first and second stages of CMIP was simple where no variations in climate forcing were permitted.

Besides, the studies show that the uncertainty has been significantly reduced from the CMIP5 experiments as compared to CMIP-3 and the models from CMIP 5 (Taylor et al,2012) simulate the Indian summer monsoon rainfall more appropriately in relation to the experiments from CMIP 3 (Shashikanth et al 2014). In the earlier stages the model results were not available in sufficient numbers unlike today, which permits the use of these results to a much vast climate community.

Currently CMIP 6 is ongoing which can deliver the scientific community with more realistic and real-time GCM simulated climatic variables of interest unlike earlier stages of CMIP.

The information from the CMIP-6 models can be used to provide more precise forecasts which will account for a huge range of particular queries related to change in climate and should cover up the scientific gaps of the former CMIP segments.

It will also provide the space for the uncertainty rising from the diverse sources which will be very helpful in filling the research gaps due to inadequate or incomplete information hence delivering more realistic and real-time forecasting.

## 5. CONCLUSIONS

It is quite useful to differentiate between coupled as well as uncoupled parts such as denoted by different model inter-assessment efforts of AMIP, CMIP.

The dataset obtained by CMIP gives us the evaluations of probable forthcoming climate change and helps in quantifying the inaccuracies by the estimations of observed sensitivity.

There would be a considerable expansion of computer and human resources for the upcoming variations in climate.

The traditional CMIP-forcing 1 percent carbon dioxide increase experiment will be deciding to these comparisons for the Assessment report 4, then such as in IPCC assessments.

CMIP connected actions will play a crucial part in IPCC process.

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