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To What Extent, And Why, Are Climate Projections For The 21st Century Uncertain And Does The Uncertainty Matter?

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Abstract

Uncertainties in global and regional future climate change has got attention to a great extent. Greenhouse gas (GHG) emissions scenario, modelling design and biases, internal climate volatility due to irregular pattern of the earth's climate are specifically named as sources of uncertainty. Different parameters like time scale of projections and multiple variables have significant role in identifying the key sources of uncertainty in the 21st century climate projections. Concerning climate change over such a long time period, scenario and model design uncertainty tends to predominate particularly at the worldwide scale. For shorter-term forecasts and higher-order climatic statistics, internal variability becomes increasingly important in first few decades of the 21st century. These uncertainties need a probabilistic rather than deterministic approach to the climate forecast issue. This paper highlights Knowledge Uncertainty that is attributable to our limited understanding and misrepresentation of the situation and the Intrinsic Uncertainty that is inherently connected to the problem itself. While the first may be dealt with by better scientific understanding and the later needs to be defined as thoroughly as possible so that all consequences are taken into consideration. The main analysis of the paper is on the key sources of uncertainty in future climate projections.

keywords: *climate change, 21st century, greenhouse, modelling design, uncertainty, climate forecasts, irregular pattern, climate projections.*

1. Introduction

Matter of the fact that the word "uncertainty" tends to evoke negative opinion since it suggests that our lack of information about the issue necessitates urgent action to rectify the situation through increased study. Some forms of doubt, which we might collectively call "Knowledge Uncertainty", clearly fall under this category (Eden, 1998). However, as will become[1] apparent in the discussion that follows, some components of uncertainty are inherent to global climate issue. Therefore, it is essential that they are completely characterized in order to present the complete spectrum of expected consequences. This phenomenon, which may paradoxically lead to more uncertainty with less precision or speed of change is what we call intrinsic uncertainty.

This paper examines the key sources of uncertainty in climate change. Uncertainty is mainly related to global average temperatures which influence mitigation policy. However, there is a degree of spatial variability in the magnitude of uncertainty in different regions of the world. Some models produce much stronger signals than other models. However, there are some models which don't agree even on four degrees rise in temperature by the end of the 21st century particularly in some regions. So, uncertainty mainly about global average temperatures

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has been focused in this paper. However, when we look at it regionally and particularly for other variables, the uncertainty is much higher. We wrap up with a discussion on how this uncertainty matters and what the present day world need to do to minimize the level of uncertainty?

1.1 To what extent, the future climate projections are uncertain?

There is a wide range of projections for the future climate. Some projections mention 1.5-degree warming while others argue up to 5.5 degrees or 6 degrees global warming. This range of uncertainty by the close of the twenty-first century is basically due to three reasons. Firstly, there is a range of different climate scenarios or emissions scenarios. Secondly, for a given forcing, we get a range of values because of models and there are multiple models. If we had one climate model we would have one value of temperature change for each scenario. Because we have 35 or 40 different climate models so we get 35 or 40 different answers for a given scenario. Hence the range of uncertainty is because the models are presenting feedback differently. For the sake of assessment of the magnitude of uncertainty in climate projections, it is vital to take into account global to regional-scale projections of climate change in next ten decades due to growing emissions of greenhouse gases and aerosol levels caused by anthropogenic forcing. (Knutti R., 2008)

On the other hand, natural forcings, such as variations in natural variability and natural uncontrolled fluctuations of the climate system can also contribute to climate change till the other two scenarios get stronger in the 2nd half of the 21st century. So, climate forecasts must take into consideration all these natural and anthropogenic causes as well as the uncertainties that define them. There are different types of models used to make climate forecasts, from the coupled Atmosphere- Ocean Global Climate Models (AOGCMs) to statistics and dynamical downscaling methods like Regional Climate Models-RCMs (Kundzewicz et al., 2018). Our imprecise understanding and description of critical steps in the climatic changes also have a significant impact on the accuracy of these instruments. Therefore, several factors contribute to the ambiguity around 21st -century climate change forecasts. The comprehensive characterization of these uncertainties is a crucial component of the global climate change challenge because it allows for an accurate evaluation of the risks linked to climate change as well as the costs of mitigation and adaptation strategies. More and more research over the past decade or so has focused on quantifying and representing the uncertainty in climate change estimates for better policy guidelines to risk assessments.

1.2 21st-Century uncertainty in climate forecasts

As par Dobler et al. (2012), future climate projections mainly stem from three sources of uncertainty. Firstly, the future for things themselves will remain very uncertain depending upon the way in which society evolves the forces in terms of greenhouse gases and aerosols. Secondly, even for a single projection of forces, a particular scenario may get a range of different outcomes in terms of projected climate. Thirdly, in terms of global average temperature or any other variable, models themselves do not agree on the magnitude of feedback which is called model uncertainty. Moreover, there will be uncertainty related to internal variability. The behavior of the ocean -atmosphere system and decadal variability in terms of Pacific digital oscillations, etc. will produce variations from year to year or decade to decade in the magnitude of warming as it was seen during a hiatus type of period. And then after the hiatus ended, we had an acceleration of warming which the world has been experiencing in recent years.

There are hundreds of scenarios for the future climate. There are a lot of other climate uncertainties globally and regionally with different variables. The focus is on uncertainties in global average temperature as being the indicative metric of climate although there is much more uncertainty in regional climate regarding spatial patterns of temperature and precipitation uncertainty (Lehner et al, 2020). We always have land warming faster than the ocean and high latitudes warming faster than Low latitudes. That is why the global average temperature is quite a reasonable indicator of uncertainties in future climate projections. The magnitude of the main sources of climate change projections has been highlighted in the following diagram.

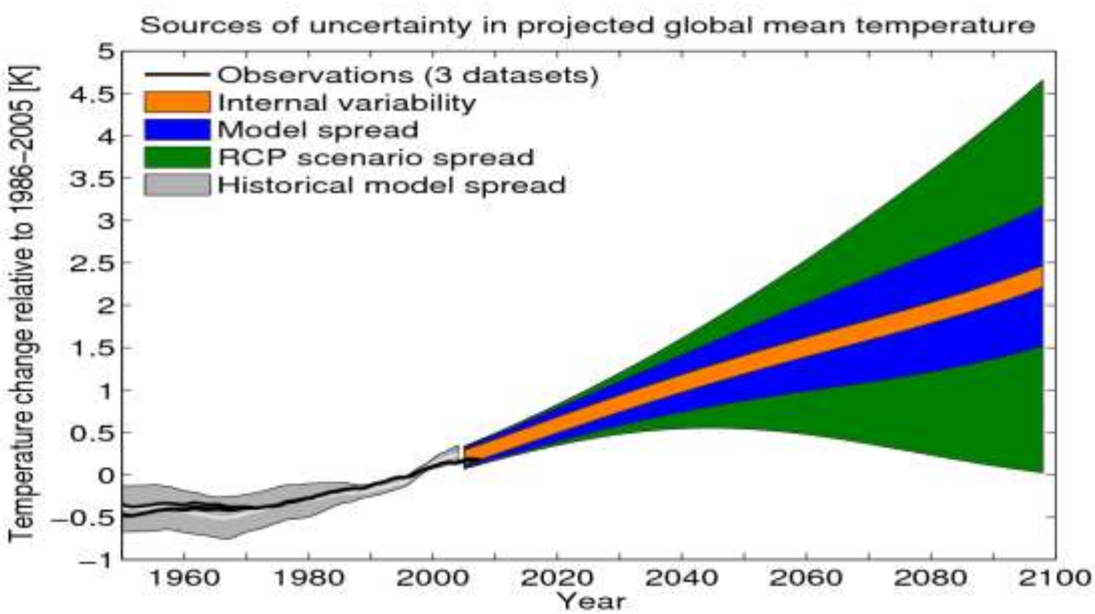


Figure: 1.3

Source: Sources of uncertainty in CMIP5 projections, Ed Hawkins, 2013: https://www.climate-lab-book.ac.uk/2013/sources-ofuncertainty/

2. Main sources of uncertainty

The three main sources of uncertainty as maintained in the above diagram include internal variability which is most relevant to uncertainty in next decade or two when the effects of internal modes of variability like Pacific decadal patterns will constitute a bigger proportion of temperature variations before climate signal becomes stronger. Secondly, model uncertainty includes climate feedback strengths like water vapour, clouds, albedo and Carbon cycle etc. Lastly, emission scenario uncertainty for example the various SSP scenarios (Visser, 2000). All three sources of uncertainty have been discussed in more detail as below

2.1 Natural internal Climate Variability

Internal atmospheric variability labeled as "climate noise" (Feldstein 2000) comes out from non-linear emphatic processes congenital to the atmosphere. The climate of the Earth is subject to some unpredictable natural fluctuations even when there is no change in the concentration of greenhouse gases in the atmosphere (Tao et al., 2018). Without a shift in greenhouse gas concentrations, significant unpredictable natural variations still affect our climate. Semi-cyclical events, such as El Nio and the North Atlantic Oscillation contribute to the climate's inherent instability. Since such unpredictability is intrinsic to Earth's climate system scientists have accounted for it as accurately as possible in climate models (Van Ruijven et al., 2019). Volcanic activity and variations in solar output are some other examples of exogenous factors that influence climate variability. Since their presence and effect on climatic changes cannot be reliably measured they are typically left out of future climate simulations but are accounted for in historical climate simulations. The internal transformations in the climate variables can greatly be influenced by some external inevitable forcing (Brown et al., 2017).

Within the spectrum of internal variables, Variations in the energy as well as the atmospheric circulation patterns are great source of future climate uncertainty. Surface shifts in atmospheric circulation can be detected by measuring the pressure at sea level. Consistent with prior evaluations, the trend of change is characterized by a reduction in higher elevations and an increase in the mid-latitudes. This is in turn linked to pole ward changes in the SH semi storm tracks, favorable developments in the annular modes and an enlargement of the Hadley Cell. These trends are influenced by internal climate variability. Similar trends of sea level change in pressure are found over recent decades implying an already detectable change (Gorris et al., 2019). Uncertainties in projected future sea level pressure especially at higher latitudes have been found to be influenced by internal variability. When austral summer rolls around, the SH predictions feel the full force of the opposing influence of a recovering stratospheric ozone layer. Expected effects from ozone recovery are reflected in lower sea level pressures over the SH mid-latitudes and higher sea level pressures over the SH high-latitudes under the lesser GHG emissions of RCP2.6 (Trisos et al., 2020).

Furthermore, a variety of processes such as precipitation, evaporation, transpiration, drainage, downstream flow, and ill-defined surface and subsurface system features combine to produce near-surface soil moisture. Though these phenomena are predictable there is still a lot of room for error in regional to global scale future predictions of moisture in the soil and drought. Soil moisture simulation assessments for global-scale models have not improved since they were highlighted as a need in the AR4 report (Lehner et al., 2020). Since the depth of the soil is represented differently in different climate models, it is challenging to create reliable multi-model estimations of total soil moisture. This new CMIP5 standard is of particular interest since it provides a uniform depth description of soil moisture throughout all CMIP5 models. The major trends are rather constant from across RCPs, with an upward trend in intensity as forcing strength increases. Predictions of wetter surface soils have very little credibility.

Droughts have been predicted for the Mediterranean region, northeast and southwest South America, southern Africa, and the southwestern United States under RCP8.5-the scenario with the highest projected change among the individual ensemble members (Kundzewicz et al., 2018). In broad regions, like central Asia or the high latitudes, ensemble members have indicate disagreement on the sign of change. Soil moisture estimates from CMIP3 and CMIP5 suggest that changes in future forcing are the biggest source of the uncertainty in above five drought-prone regions.

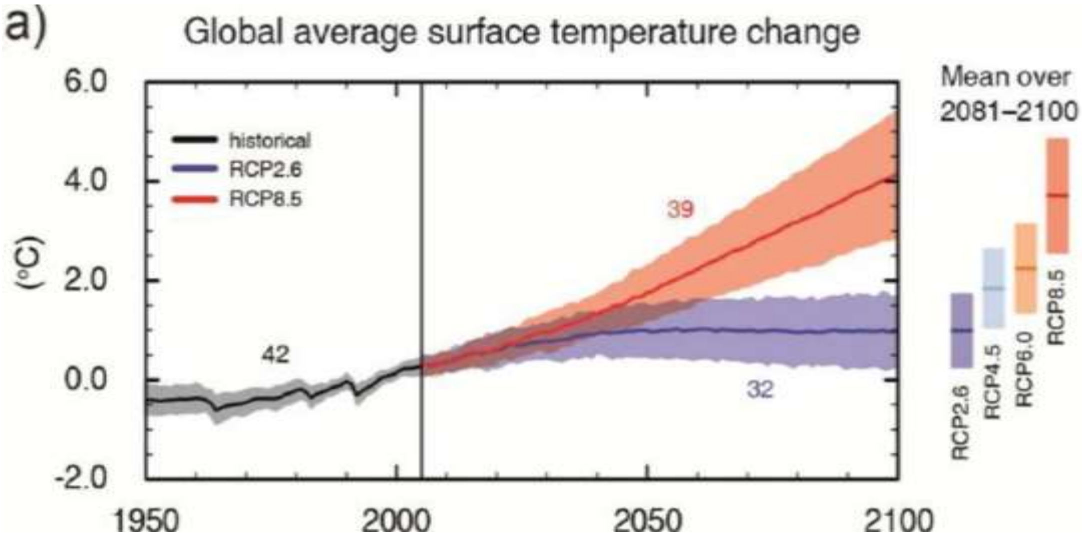
2.1.1 Uncertainty in hydrological cycle

Water in all its forms stored on Earth is part of the hydrological cycle. In addition to its gaseous form, water can be found in the form of water vapour as well as the solid frost and liquid water seen in clouds in the atmosphere. A portion of the ocean is frozen over in the Polar Regions but the vast majority of the oceans contain liquid water. The changes to the water cycle in the future are much more complicated to predict than rising temperatures. Hydrological activity may diminish in certain parts of the planet and grow in others (Thuiller et al., 2019). The water cycle's reaction to global warming varies significantly by location and time of year. Water cycles predicted by CMIP3/5 models might appear contradictory at first glance, especially at regional sizes. Differences in projections are exacerbated by the fact that anthropogenic adjustments to the water cycle are overlaid on the already complicated naturally varying mechanisms of the climate (such as the El Nio-Southern Oscillation (ENSO), the Atlantic Oscillation (AO) and the Pacific Decadal Oscillation PDO (Deser C., 2020). However, the water cycle's interaction with changes in other variables of the climate system is projected to be very complex. There is a great deal of uncertainty in this whole process and it is evident from the changes in the precipitation patterns in recent times. The intensity in variations in rainfall in different regions testifies the level of future uncertainty in hydrological cycle. Floods in Pakistan are the recent example of this uncertainty in 21st-century climate projections.

2.2 Model uncertainty

Model uncertainty is labelled as response uncertainty that works to the dispersal between multiple climate feedbacks originally received through multiple models. Model uncertainty is mainly related to global climate models (GCMs) however it is also relevant to regional downscaling models (RDMs) which aim at focusing on different climate scenarios in different regions of the world. Model, as well as scenario uncertainty, have traditionally been explored via multimodal and multi-scenario examinations (Solomon et al. 2007). There is a plethora of climate models. The spread may go to multiple models. These models are extremely useful but at the same time, these models are highly complex as well. They are being updated to reflect new information and growing knowledge of climate change (Lehner et al., 2020). In this process, Climate model simulations may deviate from reality and may respond differently to shifts in forcings. Indeed, there are a wide variety of differences between different climate models including the degree of simplicity, the grid size, and the depiction of physical events, especially those that are simply too small to be directly replicated (Lotze et al., 2019). Even if the same assumptions for greenhouse gas emissions are used in each model run the resulting forecasts will still range slightly different from one another. To better prepare for the consequences of climate change uncertainty, scientists frequently employ ensembles or groups of climate models to compare where the models agree to the spectrum of possible futures.

The figure below reflects model and scenario-based uncertainty. The average changes in RCPs indicate the scenario uncertainty, the bands around show the model uncertainty. The three numeric letters within the boundary mark are related to the number of climate model simulations in whole process. As the models may not be representing all possible outcomes properly hence there is uncertainty regarding future climate projections to a great extent.s



Global temperature rise in IPCC models (IPCC, 2013).
(Figure:2)

Some numerical models have suggested that the warming of the planet will not be limited to temperature in uniform pattern. On the basis of the perent knowledge, they have indicated that the warming will be much high in high latiitude with some seasonal variation in tropical areas. The data focused much on agrrement among different models with respect to temperature however there is little agrement on the future hydrological cycle. Hence the uncertainity regarding the future ocean atmosphere system and clouds feedback pattern is quite high. These numerical models are still working on the representation of clouds in the prediction pattern of futite climate models. In climate models uncertasinity, the major variables are climate feedbacks. Climate feedback uncertainty is infact related to some structural changes among different models and their response to outer forcings. The uncertainty between different climate models and observations is quite high and any decrease in this uncertainty moves at slow pace and it may be influenced by the limits posed by some positive feedbacks which determine climate sensitivity (Roe and Baker, 2007). To illustrate, climate models system is influenced by different factors that include solar radiations impact as well as greenhouse effect, etc. To sum it up, model uncertainty is mainly related to water vapor feedback, snow-ice albedo, clouds feedback as well as carbon cycle.

2.2.1 Water vapour feedback

Water vapour feedback is one of the good source of learning model uncertainty and the response is somehow complex to understand in terms of patterns for next ten decades. The increase in the concentration of CO2 in result into more global warming that produces an interactive effect. The heated atmosphere holds more water vapour which itself is a greenhouse gas. Hence an increase in one greenhouse gas (CO2) induces an increase in yet another greenhouse gas like water vapour. This phenomenon results into a positive feedback mechanism. Different models have struggled to quantify the level of water vapors concentration in atmosphere in future however there are multiple models and all have different response. They may predict the global pattern of warning due to water vapour feedback but there is an uncertainty regarding the future discourse of climate models owing to the water vapour feedbacks.

2.2.2 Snow-Ice albedo effect clouds feedback

Another important positive feedback is snow-ice albedo impact. It is indeed a phenomenon in which the ice cover will be depleted in future due to increase in global warming. Resultantly, the reflective effect of radiation back into the outer atmosphere by the snow cover will greatly be effected. This phenomenon will result into absorption of more solar radiation wherein the amount of carbon dioxide into the atmosphere may be enhanced. The circulation models predict polar shift of the warming in winter season terming it as snow-ice albedo feedback. Different models have different projections of this feedback. Hence, the feedbacks are quite uncertain in the longer run by the close of the 21st century.

Feedback mechanism pertaining to clouds is highly complex. To understand this, it is necessary to take into account the impact of clouds on the current climate patterns. These involved radiative forcings cloud impact on the earth climate system. Notwithstanding the fact that clouds contribute to heating the atmosphere by absorbing greenhouse gases but on the other hand, they absorb and reflect the incoming solar heat waves and thus produce cooling effect as well. Hence the net annual effects of clouds feedback depend upon clouds spread, distribution, depth as well as amount of droplets. To emphasize, if cloud amount is lessened due to global temperature rise as happen in routine circulation model simulations then it would decrease the infrared greenhouse effect linked to clouds. The decrease in the amount of clouds in the atmosphere will cause less reflection of the incoming solar heat waves. Hence, this phenomenon will have much more uncertainty the on global climate pattern. So, there are no simple ways to deal with these feedback components. On the other hand, the vertical distributions of clouds especially in colder and higher regions of the atmosphere may produce positive feedback. This is due to the fact that clouds over such regions would emit lower radiation and more greenhouse effect. Some studies speculate that a rise in temperature would enhance water saturation in clouds and consequently brighter clouds would be developed that would result in a negative cloud feedback.

Keeping in view of the above discussion, it can be illustrated that such complex levels linked to cloud feedback and uncertainties in different model projections need much more emphasis in different climate models. So, some sort of multi-dimensional climate models can address these feedback mechanisms linked to both snow ice albedo as well as clouds. Clouds are indeed essential part of whole climate which critically affect the shortwave as well as long wave radiation budget. However, this whole process is quite complicated. Clouds height, size and composition vary in space and time. These affect their Shortwave and Long wave radiative impact like high thin cirrus clouds may have cooling effect depending upon season like in high latitude winter season, the Shortwave effect of clouds may not be strong but Long wave will be strong as it works as blanket in long winter nights. These phenomenon suggest that as whole, shortwave cooling effect of clouds outweighs the long wave effect. Such characteristics of cloud feedback may alter in drastic way as the world gets warmer. Although climate projections are taking into account the magnitude of the cloud feedback still it remains one of the biggest sources of uncertainty in future climate sensitivity.

2.2.3 Carbon cycle models/feedbacks

The analysis of climate models and associated feedbacks demonstrate that the biggest issue for future climate research is to study and forecast the accuracy in time and intensity of climate driven risks associated with both natural and human actions. The magnitude of global and regional climate very much depends on radiative forcings and climate feedbacks. The global carbon cycle affects both. Firstly, emissions of CO_2 are directly absorbed by carbon sinks on land and ocean which moderates anthropogenic radiative forcing. Secondly, same natural carbon sinks and sources will evolve as the climate changes and may invoke either positive or negative feedbacks. Thus, understanding the behavior of the global carbon cycle is central to essential to predict future changes to climate, and informing policy on reductions of global carbon emissions from many sources. Global carbon cycles are indeed very complicated.

There are three main components of carbon cycle namely; biosphere, atmosphere and ocean. Each component has different controlling factors while interacting with the others. There are large uncertainties in understanding all these component. This high uncertainty is regarding understanding how terrestrial carbon cycle dynamics like Soil carbon decomposition under warming climate, Migration of different species of trees, Impacts on biodiversity will respond to global climate change projections. Furthermore, there is large uncertainty on understanding of oceanic carbon cycle dynamics as well such as the role of deep oceans like N. Atlantic Ocean Impacts of increasing ocean heat content (Dorheim, 2022). Lack of observations in oceans climate system also count to uncertainty into future climate projections.

Due to increase in the concentration of CO2 into the atmosphere, the earth temperature is expected to increase considerably. Some models have predicted the rise up to 6 degree as well. Though there is much concentration on accurate prediction of future climate projections through different models however, the wide range of uncertainty has not satisfactorily decreased over the past 30 years. In nutshell, the strength of all above mentioned feedbacks varies greatly. Water vapor provides the largest positive feedback and vertical variations in water vapour and temperature are focused in many climate models. Furthermore, the feedbacks are also well articulated by various climate models. Cloud feedbacks related to clouds are indeed major source of uncertainty in the present day predictions of climate sensitivity.

2.3 Future Emissions uncertainty:

Different emissions analysts use the term “scenarios” to focus on expected pathways for future emissions. These scenarios may not be ruled out by the present day understanding of the leading factors behind emissions. Projecting future emissions is different than all other types of predictions. The whole planetary systems work in a set orbit or motions hence predicting their behavior in next many decades is quite impressive work. Hence, there lies uncertainty in all predictions. Sometime this uncertainty may be high while some other time it may be low. Future anthropogenic emissions are linked to some social and economic systems and hence highly unpredictable.

Scenario uncertainty may be somehow quantified by making a comparison of some large set of climate models which run under multiple emissions scenarios. The emissions scenarios indeed are related to the accumulation of greenhouse gases in the atmosphere. Future greenhouse gas (GHG) emissions are the outcome of a complex systems, wherein the main forces include demographic changes, socio-economic advancement and technological progress. The future prediction about all these variables is highly unpredictable and uncertain. As the future of emission of greenhouse gases is unknown hence precise projections cannot be made at this time. Therefore, multiple emission trajectories called Representative Concentration Pathways (RCPs) are used in model runs based on different assumptions about driving variables such as technological progress, population growth, economic development, land use, and the interplay between these factors. Since RCPs offer several scenarios for how the future could play out, they can affect the accuracy of climate estimates (Littlefield et al., 2019).

The future climate change projection is quite uncertain due to their dependence on multiple emissions scenarios caused by human doings as well as linkage to other natural forcings, internal climate variability, and inter-model differences. To deal with the changing demographic cycle, socio-economic developments, twenty-first century Shared Socioeconomic Pathways (SSPs) emission scenarios within the Coupled Model Inter-comparison Project Phase 6 (CMIP6) are of much importance. In the past, several scenarios were developed under

Special Report on Emission Scenarios (Nakicenovic et al., 2000), followed by the scenarios from Representative Concentration Pathways (Vuuren et al., 2011). However, in recent times, the SSP forcing scenarios have been focused to carry out more plausible assessments of feedback associated with emission scenarios to multiple strategies related to mitigations as well as adaptations to climate change (O'Neill et al., 2016). Although these SSP scenarios are based on some plausible pathways however, there need further study for accurate prediction of future climate projections.

On the basis of SSP scenario, future emissions projections is identical to asking how different societies would produce, transform, and consume energy and on the same time how they will extract and use planet's resources for the 21st century? There are manifold reply to these complex questions. Hence, uncertainty arises in all aspects of the problem to build long run scenarios. Apart from these uncertainties, some unforeseen and unplanned events such as any radical breakthrough in the sphere of technology or any geopolitical and geophysical shift may take place and affect future emission to a great extent. In this backdrop, the predicted scenario will be altered altogether. Hence, the uncertainty is very much there regardless of the fact that the climate science has excelled to an exemplary level in projecting future scenarios by using different SSP models.

The study of various models and scenarios suggests that in the first few decades, internal variability may contribute less in the tropical areas and more in the high latitudinal areas. By the mid-century, internal variability contribution may become negligible almost everywhere. On the other hand, Scenario uncertainty becomes more certain in the tropical areas (Hawkins et al., 2020). However, near the end of the twenty first century, scenario uncertainty will dominate in most part of the world other than sub polar North Atlantic and the Southern Ocean whereas the patterns largely remain consistent between the model generations (Maher et al., 2020).

3. Does Uncertainty Matters?

The only certain thing about future climate projection is that it is uncertain. There is no denying the fact the most of the climate changes are being driven by human activities (Intergovernmental Panel on Climate Change, (IPCC, 2014). However, this complex phenomenon is not much clear with respect to the consequences like to what extent, where and when the impact will be witnessed

The uncertainty of future climate projects, emissions of greenhouse gases, complex socio-economic and climate feedback loops and untraceable tipping points complicate projections to a large extent. For instance, it is not clear to what extent temperature rise in ocean water will adversely affect global sea food supplies, and to what extent, such changes may have ill consequences for the larger food system and national economies. Like this, the impacts of heat waves may adversely affect human health.

Hence, the climate scientists cannot predict the future with accuracy. However, it does not necessarily mean that the world ought not to prepare for it. Acknowledgement of the fact that uncertainty is very much present and may affects decision-making will be the crucial thing for the national governments. Future uncertainty in climate projections in worst case scenario would be catastrophic. Six degree global warming at the end of the twenty first century means land temperature would be higher than normal. The rate at Arctic temperatures would also be higher than average. This would be catastrophic and all feedbacks would then become huge risk.

4. Conclusion

To sum it up, The fundamental sources of uncertainty in global temperature projections seems to be the vary uncertainty in radiative forcing models. With reference to greenhouse gas forcing modules, the emphasis is on the emission of CO2. The future research related to climate uncertainity should focus on all sources from emissions to global temperature change. It ought to involve both scientif as well as socio economic reasons. The analysis shows that the uncertainity of fututre climate projection may be minimised by following low emission paths. Apart from this, the future climate projection need further analysis to deal with the uncertainity of extreme events and intensity of the climate changes associated with these phenomenons. The recent flooding in Pakistan and heatwate in England are some examples of the intensity of uncertainity associated with climate change. The focus of policies ought to be on low emission scenarios as the less emissions will lead to low global warming in the long run. Some governments are trying to control emission but not managing very effectively. The stronger the emissions the bigger the uncertainty will be. The uncertainty range around one scenario may be much bigger than the uncertainty range around the other scenario. So if governments want to reduce uncertainty they have to lower emissions instantly. From common man to businessmen to a climate scientist nobody likes uncertainty. Hence, if we want to reduce uncertainty in future climate we have to keep check on carbon emission and reduce emissions as low as possible. The stronger the emissions the faster the rate of temperature increase will be. The more we are playing with this temperature fire will potentially have more uncertain outcomes in future climate projections.

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