



UNCERTAINTIES

Reference: WG1 2007, Friedlingstein et al. 2006, Livre blanc Escrime, Dufresne and Bony 2008, Terray and Boé 2007, Using the IPCC Climate Models Fact Sheet

This sheet does not address all the uncertainties associated with a particular impact study that combines, in what is called “uncertainty explosion” the uncertainty of climate change with the uncertainties of each zoom-in. It aims to describe uncertainties associated with large-scale climate parameters fields used as inputs for the impact studies.

Here, the uncertainties are classified according to the different levels addressed by the IPCC AR4 report (see **DIAGRAM 1** of the preface sheet on the use of IPCC climate models, IPCC 2007). One important point to remember is that the qualification and quantification of uncertainties is an integral part of ongoing climate research. Many sources of uncertainty are still poorly understood and therefore difficult to quantify.

1 Sources of uncertainty

1.1 Socio-economic scenarios

An initial source of uncertainty in the climate projections is related to socio-economic scenarios. Several scenarios are studied as they are based on strong assumptions on demographic and technological development, technology transfers and economic dynamics. Uncertainty due to socio-economic factors (e.g. social behaviour, and new inventions) is difficult to quantify. However, the approach using contrasting socio-economic scenarios distinguishes several SRES emissions scenarios¹ (low, medium and high), which should make it possible to identify the potential range of changes. The IPCC group 1 scientists considered the SRES scenarios as equiprobable in the absence of consensus on the probability of these scenarios. The results of the simulations presented in the AR4

indicate that on the century time scale, the choice of scenarios is the dominant factor explaining the dispersion of results between the different models.

1.2 Uncertainties related to the modelling tool

Uncertainties related to models are sometimes called “structural uncertainties”. They stem from models that are very similar in their design, and take into account the same range of phenomena on the whole. However, these models differ in their geometric, algorithmic and especially physical concepts (different parameterisations). This is a first set of uncertainties, which may be quantified in some studies using error bars. A second set of unquantifiable uncertainties stems from climate phenomena which are not yet taken into account in models. Another source of uncertainty stems from the climate-biogeochemical cycle coupling. Below are, some examples of uncertainty sources

¹. See sections 2 and 3 of the preface for further information.



related to processes (1.2.1), feedback (1.2.2) and climate-biogeochemical cycle coupling (1.2.3).

1.2.1. Processes

Structural uncertainty partly stems from insufficient knowledge of certain processes, and may lead to systematic errors in the models. For example, the global and regional models do not correctly represent the geographical distribution of the Intertropical Convergence Zone² or clouds (see **FIGURE 1B**). It results in differences in observations and possibly affects the realism of the representation of the climate and its variability. An initial quantification of this source of uncertainty is obtained comparing results of several models. Although each model describes the physical processes in a different way, the reality that each model attempts to represent remains the same. Thus, the dispersion between the models makes it possible to determine the regions and climate phenomena that are accurately represented and those whose representation varies considerably between models.

2. A belt of low pressure girdling Earth near the equator, formed by the convergence of warm and wet air masses from the tropics.

Moreover, some processes are not completely taken into account. For example, the current models incorporate of the first direct impact (impact on solar radiation) of aerosols, but not the indirect effects (e.g. the impact on cloud characteristics). Likewise, ice caps are only partially taken into account and a complete modelling of their dynamics is not yet included (which is why the AR4 highlights the lack of ice cap dynamics as an important issue).

1.2.2. Feedback

FIGURE 1 shows the relative importance of the different processes leading to a modification of the Earth radiative equilibrium for CO₂ doubling.

GRAPH 1A indicates that this forcing induces an increase of the surface temperature by around 2.0°C (after climate equilibrium is reached). This temperature change is due to several processes. The quantity called the “Planck response” is the direct response of the temperature increase to CO₂ doubling, excluding feedback.³ The other processes involve the different feedbacks within or between

3. A positive feedback amplifies the initial disturbance; a negative feedback reduces and absorbs it.

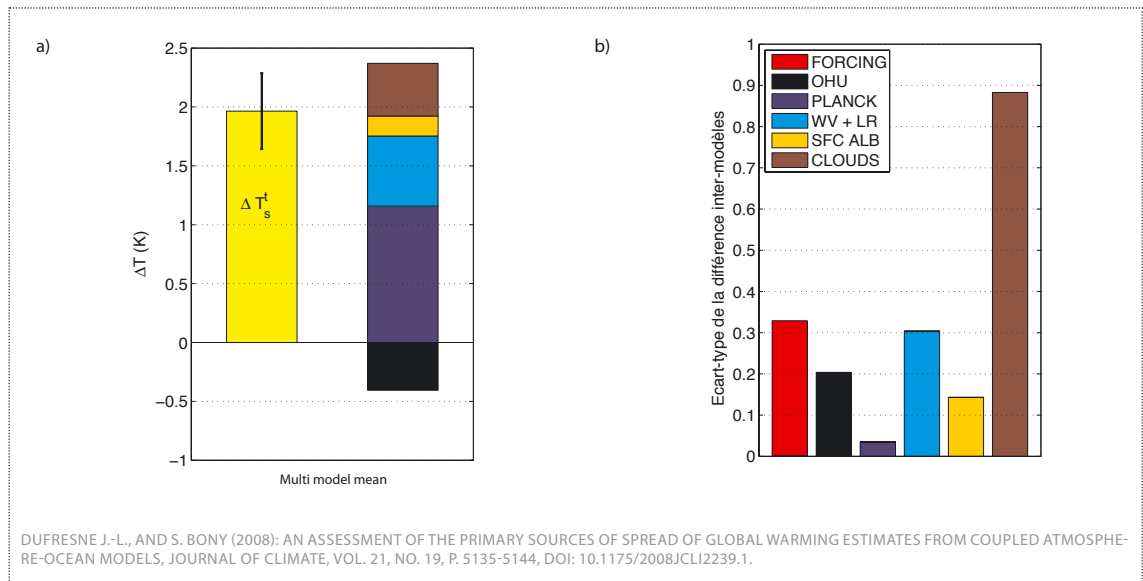


FIGURE 1 For a CO₂ doubling, (a) multi-model mean \pm 1 standard deviation (thick line) and 5%-95% interval (thin line) of the transient temperature change (ΔT_s) and contributions to this temperature change associated with

the Planck response, ocean heat uptake (OHU), combined water vapor and lapse rate (WV+LR) feedback, surface albedo feedback and cloud feedback. (b) inter-model standard deviation of the transient temperature change estimates as-

sociated with inter-model differences in radiative forcing, Planck response, ocean heat uptake and the various feedbacks normalized by the inter-model standard deviation of the transient temperature change ΔT_s .



components of the climate system (e.g. the atmosphere, ocean, and continental areas). The negative contribution associated with ocean heat uptake contrast with the positive feedbacks linked to clouds, surface albedo, water vapour and its quantity in the atmospheric column. All feedback illustrated in the diagram is of a significant magnitude.

GRAPH 1B indicates the differences between the models in the amplitude of the different temperature feedbacks (°K). The direct earth system response (to CO₂ doubling) is highly restricted. On the other hand, the positive cloud feedback is the main source of difference between the models. This stems from the difficulty to accurately represent clouds and associated microphysics in the models.

1.2.3. The climate-biogeochemical cycle coupling

A model that includes the carbon cycle can be used to calculate the atmospheric greenhouse gas concentrations according to a given emissions forcing (SRES scenarios). These greenhouse gas concentrations can then be used to force the AR4 climate models.

For the “standard” AR4 models, this calculation of concentrations was previously done using a simple carbon cycle model. For the AR4 coupled climate-carbon models⁴ (C₄MIP, Coupled Carbon Cycle Climate Model Intercomparison Project), this calculation is done during the simulation, with the carbon cycle therefore incorporating the evolution of the climate. This new approach is more realistic.

Research is underway on this subject and a good deal of studies attempt to understand the phenomena involved in the carbon cycle. Currently, there is a phenomenon that is certain: carbon sinks (oceanic and continental) tend to diminish when temperature increases, resulting in an amplification of the additional greenhouse effect. Moreover, the main source of uncertainty stems from the lack of knowledge of the biogeochemical processes in the oceans even more on the continents.

Certain IPCC studies attempt to define the uncertainties related to our lack of knowledge of the carbon cycle. Yet its response to climate change is important as global temperatures may increase by up to 1.5°C with the incorporation of the carbon cycle

in global models (Friendlingstein et al., 2006). The uncertainty related to the carbon cycle component is therefore significant.

Other uncertainties are also linked to different biogeochemical cycles that are not considered. For example, in the latest IPCC report, none of the studies take into account the methane cycle. Given that methane is potentially a stronger greenhouse gas than CO₂, and that there are many permafrost regions (land that remains frozen year-round) that trap methane in soil that is likely to warm, the effect of a methane release would lead to further temperature increases. However, the life span of CH₄ in the atmosphere is shorter than that of CO₂. No studies to date allow the quantification of other greenhouse gases.

1.3 Intrinsic natural variability of chaotic origin

Intrinsic natural variability of chaotic origin, which is linked to the very nature of fluid flows⁵ where there are non-linear interactions in the fluid or between the different components of the model, may lead to very different climate states for a given external forcing. This uncertainty is unobservable. Furthermore, there are many modes of natural variability such as the North Atlantic Oscillation for Europe and the North Atlantic, and El Niño. For these modes, the model representation of current climate characteristics is better, but there is still disaccord between the results of model simulations and the way they will evolve in the future.

1.4 Downscaling

Downscaling is a general term used to describe the methods that attempt to obtain local climate values or characteristics from large-scale information such as AOGCM output (300-400 km resolution). This downscaling may thus prove very useful in assessing climate change on a local scale.

There are several methods for computing these climate values at an appropriate scale for impacts: statistical methods (understanding statistical disaggregation from observations), dynamic methods which consist in forcing a regional model with a global model, and the mixed method which combines these two first methods.

4. Coupling consists in making two entities (climate modules) dependent on one another. Coupling generally introduces feedbacks.

5. Fluid dynamics or flows is the study of fluids in motion, whether solid or gaseous. The solution of a fluid dynamics problem typically involves calculation of various properties of the fluid, such as velocity, pressure, density, and temperature, as functions of space and time. Fluid dynamics is the basis of the atmospheric and ocean dynamics contained in the climate models.



The sources of uncertainty in statistical methods are related to the assumptions inherent to this kind of approach (the need for large, homogeneous series, assumptions on temporal behaviour such as stationarity or the Gaussian distribution⁶). Often these methods under-estimate climatic variability.

The uncertainties in regional simulations are heavily dependent on the uncertainties in the global climate models that restrict them. Uncertainties are even greater in the regions where these models diverge the most. This is particularly the case

for the African and Asian monsoon regions. On the contrary, the models converge considerably for Europe, with however a greater dispersion of results, in certain sub-regions and in certain seasons such as central Europe in the summer. Besides the uncertainties due to the global models, there are also uncertainties related to the scenarios, to the structures of the regional models themselves, and to the intrinsic variability in an order that depends on the nature of the climate change studied. For example, the uncertainty related to variability becomes predominant if we focus on the projections of extreme climate events such as heatwaves in France in only a few decades time.

6. Bell-shaped distribution. See sections 1.1 and 1.3 of the technical fact sheet for further information.



2 Representing uncertainty

The best representation of uncertainty takes into account the dispersion of all the IPCC models, which can be shown by the temperature envelope simulated by all the global climate models (see **FIGURES 2 AND 4**).

The points of validity given at the global scale (see **FIGURE 2** of the global temperatures fact sheet or **FIGURES 1 AND 2** of the global precipitation fact sheet) also give validity for temperature and precipitation projections at the local level.

The temperature changes are notably greater in Europe and China than over the rest of the Earth's land regions, as indicated by the **TABLE 1**. The mean

value is higher and the error bars are larger.

Nevertheless, uncertainty is currently likely to be underestimated because the number of models and simulations enabling analysis at the regional scale are still relatively limited. Furthermore, certain processes or feedbacks (for example carbon) are not always taken into consideration.

Another complementary approach consists in focusing on probability distributions. **FIGURE 3** indicates that the distribution of mean and global temperatures obey a normal (Gaussian) law. The mean temperature of the Earth's surface will be higher in both the near and distant future than in the pe-

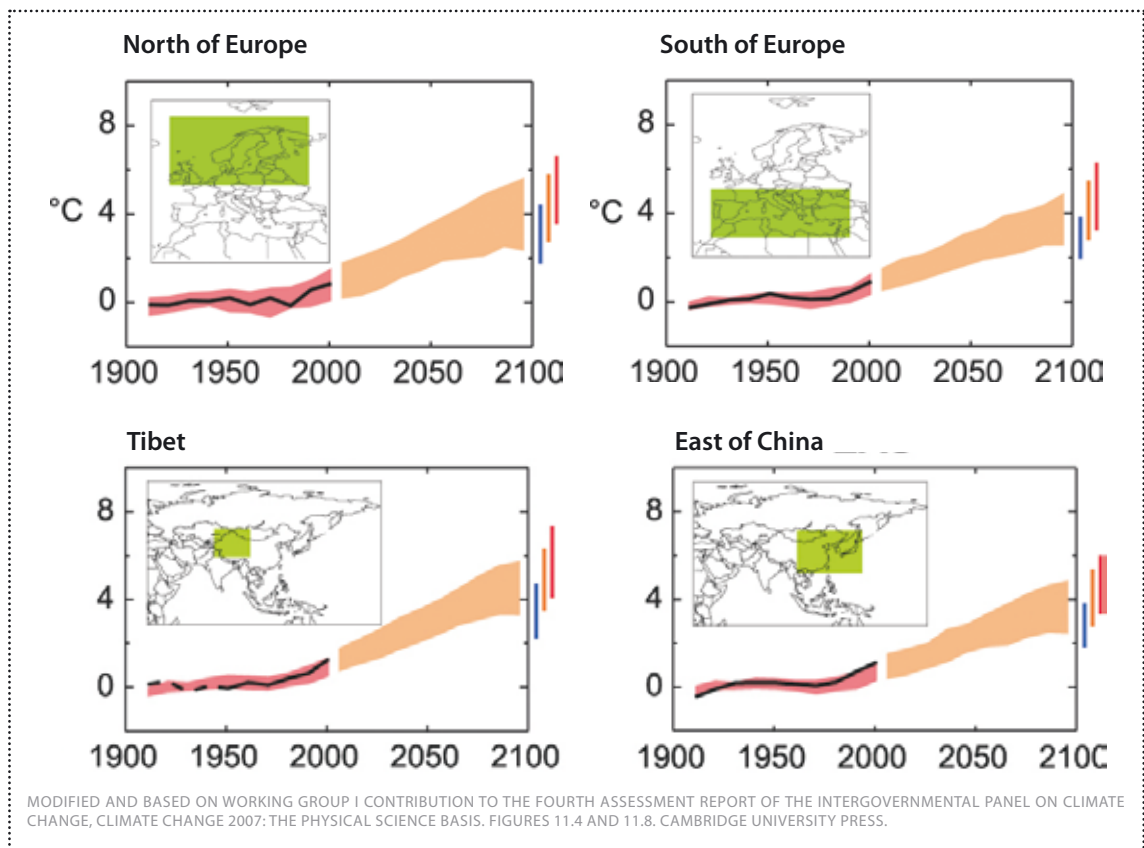


FIGURE 2 Temperature anomalies with respect to 1901 to 1950 for two European (top) and two Asian (bottom) land regions for 1906 to 2005 (black line) and as simulated (red envelope) by a multi-model data set incorpora-

ting known forcings; and as projected for 2001 to 2100 by multi-model data set for the A1B scenario (orange envelope). The bars at the end of the orange envelope represent the range of projected changes for 2091 to 2100 for

the B1 scenario (blue), the A1B scenario (orange) and the A2 scenario (red). The black line is dashed where observations are present for less than 50% of the area in the decade concerned.

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riod 1980-1999 for every percentile of the distribution. The bold line distribution is a simple Gaussian fit of the results of the global coupled climate models used for the AR4; the others correspond to specific studies based on other simulation set, including simplified climate models. We observe that the most likely warming value for the first

period is close to 1°C, irrespective of the scenario. However, at the end of the century, the most likely warming value varies considerably depending on the scenario (between 1.8 and 4° according to the IPCC, when all scenarios are considered, including the A1F1 scenario, which is not reproduced on the figure). Unsurprisingly, the distribution increase as time goes on, reflecting an increase in uncertainty for mean global warming. The change in the shape of the curve (bold line) reflects the increase in uncertainties over time.

Mean temperature anomalies (°C) and uncertainty bars 2080-2099 relative to 1980-1999	Global	Europe		China	
		North	South	East	Tibet
SRES B1	1.8 (1.1-2.9)				
SRES A1B	2.8 (1.7-4.4)	3.2 (2.3-5.3)	3.5 (2.2-5.1)	3.3 (2.3-4.9)	3.8 (2.8-6.1)
SRES A2	3.4 (2.0-5.4)				

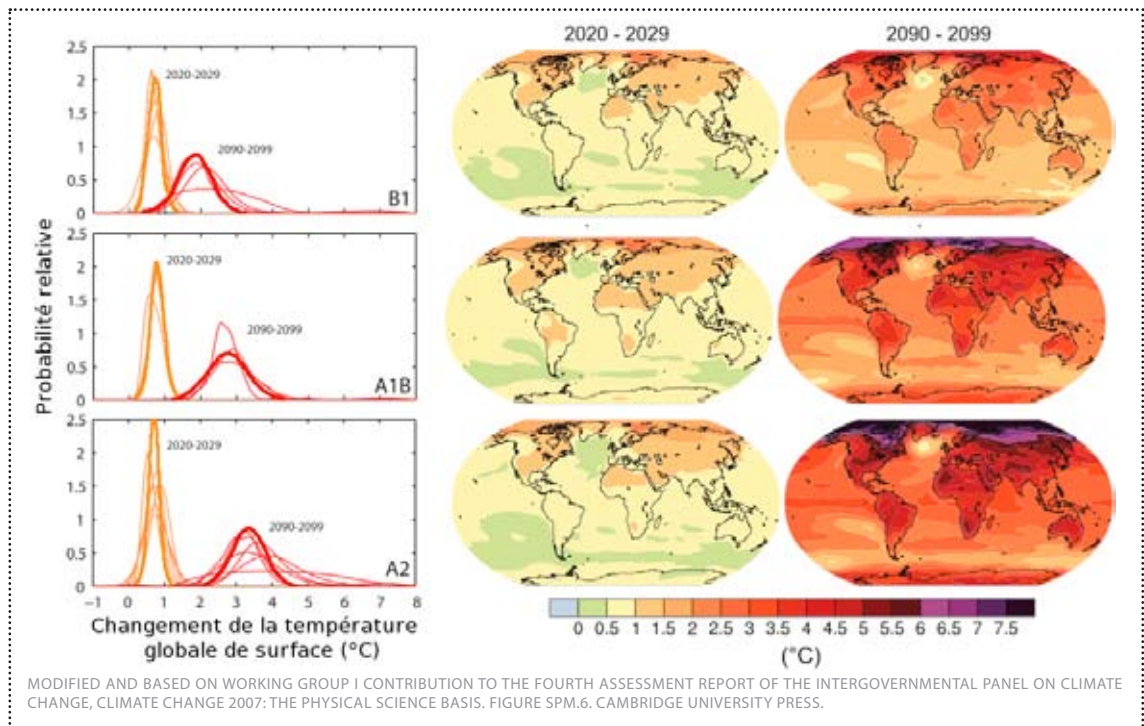


FIGURE 3 Projected surface temperature changes for the early and late 21st century for the period 1980–1999. The central and right panels show the AOGCM multi-model average projections for the B1 (top), A1B (middle) and A2 (bottom) SRES scenarios averaged over the decades 2020–2029 (centre)

and 2090–2099 (right). The left panels show corresponding uncertainties as relative probabilities of estimated global average warming from several different AOGCM (bold curves) and Earth System Model of Intermediate Complexity studies averaged for the same periods. Some studies pre-

sent results for only a subset of the SRES scenarios, or for various model versions. The difference in the number of curves shown in the left-hand panels is uniquely due to differences in the availability of results.



3 Conclusions and perspectives

Currently there is no full characterisation of uncertainty that exists. However, a better quantification of uncertainty should be obtained in the following manner:

- Maximising chaotic uncertainties and minimising structural uncertainties. For example, we need better understanding of the origin of structural uncertainties, ranging from the large scale (ocean temperature and salinity, for example) to the local scale (cloud formation from aerosols, for example). The accumulation of data at all scales is essential in order to compare the models with observations, to identify processes that are poorly represented or not represented at all, and to correct the models. **FIGURE 4** gives an example over France of annual temperature dispersion among the global models for France.
- Adopting an overall study approach based on

sets of models that combine global and regional models that are restrictive for regional climate projections; sets of simulations that study the sensitivity of a given model.

This approach makes it possible to identify the processes contributing to climate change. It allows a better understanding of how the model works, but not necessarily of how the real system functions (the sensitivity of the climate and that of the model should not be confused). For example, the evapotranspiration process⁷ is, particularly in central Europe in spring, one of the processes responsible for the dispersion of results. It is important to quantify these processes, their localisation and their variability for each season.

7. Quantity of total water that is released from the Earth land surface into the atmosphere by evaporation and plant transpiration.

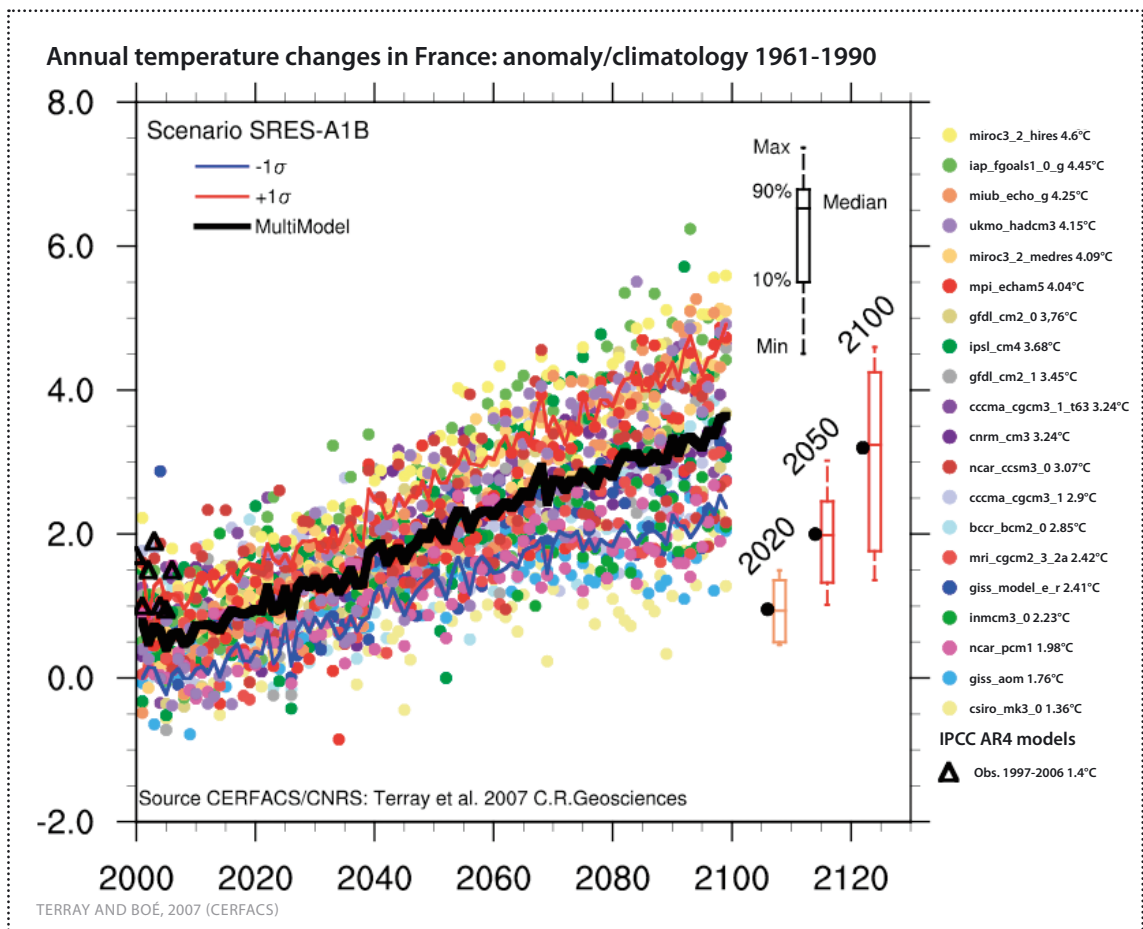


FIGURE 4 Annual temperature changes in France in the 21st century as compared with the 1961-1990 period. The dots represent the different AR4 IPCC

climatic models (IPCC AR4, 2007); black curve is the multi-model mean; Red and blue curves denote the variance (positive or negative). The boxes on

the right show the multi-model averaged 10th, 50th and 90th percentiles, and also the maximum and minimum value of all the models.



The validation of models for the present climate is not however a sufficient condition for increasing the degree of confidence for climate projections. Many studies have shown that we cannot simply connect the capacity of models to reproduce the current climate and the future simulated climate. However, analyses combining the results of several models make it possible to make this link in certain cases, provided a particular aspect of the simulated climate change is targeted.

It is sometimes even possible to identify the mechanisms dominating the model response and to thereby infer the associated sources of uncertainty.

- Construing climate change probability distributions based on very broad sets of multi-model simulations incorporating parameters other than mean global temperature, for varied parameters and regions, selected according to the impact studies to be carried out.