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Regional climate change scenarios for México

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RESUMEN

En este trabajo se presentan los escenarios de cambio climático regionales empleados en los estudios de impactos potenciales en México en los sectores de agricultura, ganadería, forestal, recursos hídricos y en los de asentamientos humanos y de biodiversidad. Estos estudios se realizaron dentro de los trabajos para la Cuarta Comunicación de México ante la Convención Marco de Cambio Climático, coordinados por el Centro de Ciencias de la Atmósfera. Para la generación de estos escenarios se emplearon los modelos presentados por el Panel Intergubernamental sobre el Cambio Climático en su último Reporte de Evaluación y los criterios establecidos por el Grupo de Trabajo sobre Datos y Escenarios para el Análisis de Impactos y Clima. Específicamente, los escenarios de cambio climático fueron generados para la República Mexicana utilizando las salidas de los modelos ECHAM5, HADGEM1 y GFDL CM2.0, para la temperatura y precipitación mensuales, para los horizontes 2030 y 2050, y para los escenarios de emisiones A1B, A2, B2 y B1. Estos escenarios fueron generados utilizando dos resoluciones espaciales: baja (2.5º x 2.5º), y alta (5' x 5'). Las bases de datos y los mapas correspondientes se encuentran disponibles en la página: www.atmosfera.unam.mx.

ABSTRACT

In this paper we present the regional climate change scenarios that were used for the assessment of the potential impacts in México on agriculture, livestock, forestry, hydrological resources as well as on human settlements and biodiversity. Those studies were developed for the Fourth Communication of México for the United Nations Framework Convention on Climate Change and coordinated by the Centro de Ciencias de la Atmósfera. The climate change scenarios were generated combining the models presented in the Fourth Assessment Report of Intergovernmental Panel on Climate Change and the criteria established by the IPCC's Task Group on Data and Scenario Support for Impact and Climate Analysis. Specifically, climate change scenarios for México for the time horizons 2030 and 2050 were generated using the outputs from ECHAM5, HADGEM1 and GFDL CM2.0 models. The variables considered were monthly temperature and precipitation and the emissions scenarios A1B, A2, B2 and B1. These scenarios were generated using two spatial resolutions: low (2.5º x 2.5º), and high (5´x 5´). The corresponding databases and maps are available at the webpage: www.atmosfera.unam.mx.

Keywords: uncertainty, emission scenarios, Fourth National Communication.

1. Introduction

The best resource available for climatic studies is the set of coupled Atmospheric-Ocean General Circulation Models (AOGCM). The contribution of the Working Group I of the Intergovernmental

Panel on Climate Change (IPCC-WGI, 2007) to the Fourth Assessment Report (AR4) describes 23 models that are being used in on-going climate change studies.

These models, based on fundamental laws of physics, simulate a great variety of processes that occur in a wide range of spatial and temporal scales, as well as in diverse climate subsystems. Such models have different spatial resolutions which have been increased in recent years (resolutions available now range up to $1^o \times 1^o$), allowing its use at regional scales.

A key factor for defining a hierarchy of models is, therefore, their spatial resolution. According to IPCC, the regional scale for climate change studies is defined as the one describing climate in a 10^4 to 10^7 km^2 range (Giorgi *et al.*, 2001). The top limit of this range is called sub-continental scale, and its scope is limited by climate inhomogeneities that occur in that scale. Conditions occurring at larger scales than 10^7 km^2 are defined as global scale, and are dominated by general circulation processes and their interactions. Scales smaller than the inferior limit (10^4 km^2), are representative of scales used in regional studies.

For some studies, the information provided by AOGCM might be sufficient. In other cases, it is necessary to apply scale reduction (downscaling) techniques in order to use data provided by AOGCM to characterized climate at regional and local scales. Some of the methods applied for this purpose are 1) high resolution general circulation models; 2) regional models or nested limited area models (RCM); and 3) empirical (-statistical or dynamic-) statistical models. Nevertheless, it is important to keep in mind that AOGCM still have great problems to simulate climate at regional scales of less than 10^4 km^2. It is necessary to consider that any method selected to reduce the scale will necessarily introduce additional uncertainty into any scenario. Thus, generating regional climate change scenarios is a current research topic, and it will continue to be a topic of scientific debate in the future.

In any case, AOGCM have proven to simulate some characteristics of recently observed climate (Randall *et al.*, 2007; Hegerl *et al.*, 2007) as well as changes in the past climate (Jansen *et al.*, 2007). There is high confidence on the possibility that AOGCM can provide credible quantitative estimations on future climate change, particularly at global and continental scales. Confidence on these estimations is greater for temperature than for other climatic variables (e.g. precipitation).

Results obtained from the AOGCM –when used in climate change conditions, especially when greenhouse gases concentration is doubled– provide a set of climate change scenarios for diverse variables and different time horizons. Surface temperature and precipitation are the most relevant variables due to their undisputable importance, and it is common that projection horizons span up to 2100.

To create climate change scenarios it is necessary to use greenhouse gases (e.g. CO_2, CH_4, N_2O) emission scenarios. For this purpose, the IPCC uses the Special Report on Emissions Scenarios (SRES; Nakicenovic *et al.*, 2000). From these emissions scenarios, it is possible to calculate global concentrations and the corresponding radiative forcing, in order to project global temperature changes using a climate model. These emission scenarios consider a range of possible paths for global development in the next 100 years, and they are, in a broader sense, scenarios for the state and growth of population and economy (Tol, 1998).

In general, climate change studies use different climate models and a set of emissions scenarios to reflect the uncertainty range caused by different assumptions related to changes in greenhouse gases emissions, technological change, population, economic development, physical parameterizations, among others. Hence, each scenario represents an alternative of how the future might unfold.

There are two big families of emissions scenarios: “A” which are scenarios that describe a future world with a greater emphasis on economic development, while “B” scenarios consider future paths that put more emphasis on sustainable development. Families A1 and B1 assume that globalization will continue and that economies will show economic convergence. These families imply a greater economic development for the 21th century than the one that was observed in the 20th century, with average annual growth rates of around 3%. In the A2 and B2 families, economic growth is achieved through regional development, not from globalization. All families propose different sets of assumptions about the evolution of the variables driving climate change (population, technology, economy, land use, agriculture, and energy) at global and regional levels. The level of petroleum and coal reserves allows the assumption that in these scenarios those will continue to be an energy source for at least the next 100 years.

The concept of scenario should not be confused with the concept of forecast, since they have different objectives and causes. As such, each of them requires different strategies for uncertainty communication and management. According to the IPCC (IPPC-WGI, 2007), climate scenarios are defined as “a plausible and often simplified representation of the future climate, based on an internally consistent set of climatological relationships that has been constructed for explicit use in investigating the potential consequences of anthropogenic climate change, often serving as input to impact models”.

The character of uncertainty in climate change scenarios is different to forecast uncertainty, since the first is dominated by epistemic uncertainty, while the second is predominantly aleatory. Consequently, the nature of probabilities in each case is different, as also is the management of uncertainty (see, for example, Estrada *et al.*, 2008; Gay and Estrada, 2010). This fact has generated an important and long debate on the type of probabilities (frequentist or subjective) that are appropriate for producing probabilistic climate change scenarios (Schneider, 2001, 2003; Allen, 2003; Kinzig Starret *et al.*, 2003; IPCC-WGI, 2007; Gay and Estrada, 2010) and even on the impossibility of producing such scenarios (Grübler and Nakicenovic, 2001). In fact, chapter 10 of the AR4 (IPCC-WGI, 2007) underlines some of the problems related to the use of the frequentist approach, and particularly to the use of central tendency and dispersion measures for describing uncertainty in climate change scenarios. For example, the ensembles used in AR4 (as happens in most climate change studies) are “ensembles of opportunity”, i.e. the models and simulations that were included, were the ones that were available at the time: no sampling method was used for selecting them. This, among other things, causes that the obtained sample does not necessarily reflect the complete possible range of uncertainties, and that its statistical interpretation is problematic (IPCC-WGI, 2007).

This problem, in addition to the lack of independence among models (due to the existence of “families of models”, and in the use of similar modeling strategies and databases) complicates even more the frequentist interpretation of probabilities. In the light of such arguments, even if averages of multi-model ensembles could be capable of reproducing the current climate better than the individual members of the ensemble can (which is not necessarily true for all regions), there is no guarantee that the multi-model average will continue to perform in the future as well as it does now. Also, as a result of the lack of independence among models, there is no reason to think that the individual model biases will cancel out. Therefore, the use of the ensemble mean or median will not offer better results.

The Centro de Ciencias de la Atmósfera from the Universidad Nacional Autónoma de México (CCA-UNAM) has developed climate change scenarios for the National Communications of

México to the United Nations Framework Convention on Climate Change (UNFCCC). These scenarios have been used in potential impact studies for different sectors and regions in México from the First National Communication (Conde *et al.*, 1994; Gay, 2000) to the Fourth National Communication (Conde *et al.*, 2008).

For the First National Communication (Gay, 2000), climate change scenarios were generated using outputs produced by two general circulation models (GCM): GFDLR30 (Geophysical Fluids Dynamics Laboratory) and CCC (Canadian Climate Center) for a doubling of atmospheric carbon dioxide concentrations. These models had a very low resolution (2.22º x 3.75º and 3.75º x 3.75º, correspondingly), and the modeling of oceans included in them was quite simple. Using these two models, monthly scenarios for precipitation, temperature and solar radiation on surface were obtained for the 18 climate regions in México defined by A. Douglas (Magaña *et al.*, 1997). Douglas used a database for the period of 1948-1988 which included 92 stations for temperature and from 279 stations for precipitation. The base scenario was generated using averages from the series 1951-1980.

In the Third National Communication (SEMARNAT-INE, 2006), climate change scenarios were generated for agricultural and forestry ecosystems using MAGICC/SCENGEN 4.1 software, that consisted of two modules. The first one is a simple climate model (MAGICC, Model for Assessment of Greenhouse-Gas Induced Climate Change; Hulme *et al.*, 2000; Wigley, 2003) that allows the estimation of global temperature changes for different time horizons (from 2000 to 2100), based on different greenhouse gases (GHG) emissions scenarios (included in the model).

The second module (SCENGEN) combines the latter with results from AOGCM in order to be able to display the information (mainly temperature and rainfall) in a reticular map. The resolution of SCENGEN was 5º x 5º, and two time horizons were 2020s and 2050s, which correspond to 30 years averages (e.g. 2010-2039 for 2020s and 2040-2069 for 2050s).

MAGICC is capable of reasonably emulating a great variety of models. This is the main reason why the IPPC continues to use it –even in the AR4– to produce projections of global temperature and sea level rise.

For that Third National Communication the models HADLEY3TR00, ECHAM4TR98 and GFDLTR90 were chosen according to their performance in reproducing observed regional climate, and to the fact that these models were used by other countries from the same geographic region of México. The selected emissions scenarios were A2, B2 (Conde, 2003) and the time horizons used were the 2020s and the 2050s.

In some studies (Palma *et al.*, 2007), besides the scenarios mentioned above, the outputs from the Regional Climate Model *Precis* (Providing Regional Climates for Impacts Studies; http://www.precis.orh.uk/) were also used; this is a dynamic model, for which climate simulations are available for México, Central America and the Caribbean at: http://precis.insmet.cu/Precis-Caribe.htm. The resolution of this model is about 50 km, and this is one of the reasons why its outputs were used for the State Action Plan of Veracruz (http://www.atmosfera.unam.mx/cclimat/index.php?option=com_content&view=article&id=77&Itemid=74). However, outputs of this model exist only for the HadAM3P model and for the A2 emissions scenario. These simulations were not considered in the Fourth Communication, since they did not meet the criteria (see the section on methods below) established for the present study. Moreover, although surely having access to this type of dynamic models will be quite useful in the future, they still require a computing capacity and data processing that hardly exists in most of Latin America for impact, vulnerability and adaptation studies.

The potential impacts of climate change can be simply assesed by comparing the system or sector (agriculture, hydrology, forestry, etc.) under study in the absence and under climate change conditions. It is important to notice that the systems under study are not static, they can adjust automatically to certain changes and they have strong interrelations; therefore, the impacts in a system can be enhanced by the impacts in other systems. It is necessary first to create baselines or base scenarios that describe the prevailing situation, not only with respect to climatological, but also to environmental and socio-economical conditions as well.

For the assessment of impacts it is required to have an observed climate database that allows the characterization of climate in the region of study (basically through temperature and precipitation variables), and that also describes the behavior of the system under study, i.e. its response to certain climatic conditions. With these sets of data it is possible to calibrate impact models with respect to the base scenario, and to validate the use of the methods and tools selected for each system or sector.

It is important to highlight that climate change scenarios are themselves a research topic, that is being developed and that presents constant changes. There is no agreement yet on the way to use them; for example, the IPCC (2009) is currently discussing what guidelines will be followed for the Fifth Assessment Report (AR5). It is a fact that there is a gap between the progress made by the IPCC´s Working Group I (WGI) and the Working Group II, which focuses on impact, vulnerability and adaptation studies (IPCC-TGICA, 1999; IPCC-WGII, 2007). In any case, climate change scenarios must be useful for potential impacts assessments in different sectors and regions. Unfortunately, the most advanced methods for generating climate change regional scenarios could be beyond the capabilities of the methods and tools currently applied for impact, vulnerability and adaptation studies.

2. Methods

The methodologies used for generating climate change scenarios for our contribution to the Fourth National Communication came from Working Group I and Working Group II of the Fourth Assessment Report (AR4), and mainly from the updated methodology published in June 2007 by the IPCC's Task Group on Data and Scenario Support for Impact and Climate Assessment (TGICA) entitled *General Guidelines on the Use of Scenario Data for Climate Impact and Adaptation Assessment Version 2* (IPCC-TGICA, 2007). The main reason for using such methodology is that it is proposed by the IPCC for the specific objective of providing guidelines for the generation of climate change scenarios for impact and adaptation assessments (which is the central purpose of the studies conducted for Climate Action Plans at the state-level in México, for example). This TGICA proposal takes into account the advances in both the WGI and the WGII of the AR4.

Some of the most relevant considerations in the IPCC-TGICA (2007) methodology are that regional climate change scenarios must meet the following criteria:

- Regional consistency with global projections.
- Physically plausible.
- Applicable for impact assessments, in terms of their resolution, time horizon and variables.
- Represent the potential range of future regional climate change, i.e. the selected scenarios should provide a fair representation of the uncertainty of possible future changes.

- Represent the state-of-the-art of climate modeling and be based on the latest simulations.
- Have an adequate spatial resolution.
- Validity, i.e. the chosen models must show a good performance in simulating the observed climate.
- Ensure comparability with previous and other regional studies.
- Useful for impact, vulnerability and adaptation (IVA) studies.

In order to guarantee the fulfillment of the usefulness criterion of climate change scenarios for IVA assessments, a sequential process was conducted. First, an initial low resolution, monthly frequency, set of temperature and precipitation scenarios for the time horizons 2030 and 2050 were provided to the impact assessment experts. Then, these scenarios were modified according to what the research groups focused on impacts estimation required in terms of climate variables, as well as of the spatial and time resolutions needed. These groups also were provided with a monthly baseline climatology. A second step consisted on conducting a workshop in which different groups presented their research proposals and climatological and climate change scenario requirements. Using this information, initial scenarios were tailored and completed according to the information needs pointed out during the workshop.

It is fundamental to consider that climate change scenarios must be a product of joint work among scenarios generators and the researchers that are going to apply them for IVA assessments, so that they can be useful and meet their information needs. In other words, climate change scenarios must be a "tailor made" product, according to users' needs and not a generic product that pretends to satisfy any user.

To address the criteria of relevance, consistency and plausibility for scenarios generation, two sources of information were used which were also used in AR4 (by both WGI and WGII); these are the MAGICC-SCENGEN 5.3 software and GCM outputs generated for the AR4 that are available, for example, in the Pacific Climate Impacts Consortium (http:www.pacificclimate.org/tools/select).

The Working Group I of the IPCC's AR4 accomplished a very important progress in terms of climate change projections, since it provided a larger number of climate simulations, obtained from a broader variety of models (23). For the AR4, climate change scenarios were developed using "marker" emissions scenarios, corresponding to three of the six SRES emissions families (A1B, A2 and B1) for the 2000-2100 period (Fig. 1). For the Fourth National Communication of México, the B2 emissions scenario was also considered in addition to the mentioned emissions scenarios, in order to use more recent available estimations (corresponding to scenarios A1B, A2 and B1)[1] and to make the new studies comparable with previous ones (which used the B2 as well).

Additionally, although none of the SRES includes actions to mitigate climate change, nor they are stabilization scenarios, scenarios A1B (medium-high emission in SRES range), B2

[1]Since B2 scenario was not chosen for the AR4, the most recent estimations for this B2 scenarios can be obtained either through an approximation of the most recent MAGICC-SCEGEN or through estimations done for the IPCC´s Third Assessment Report. For studies done for the Fourth National Communication, MAGICC-SCENGEN 5.3 was used for B2.

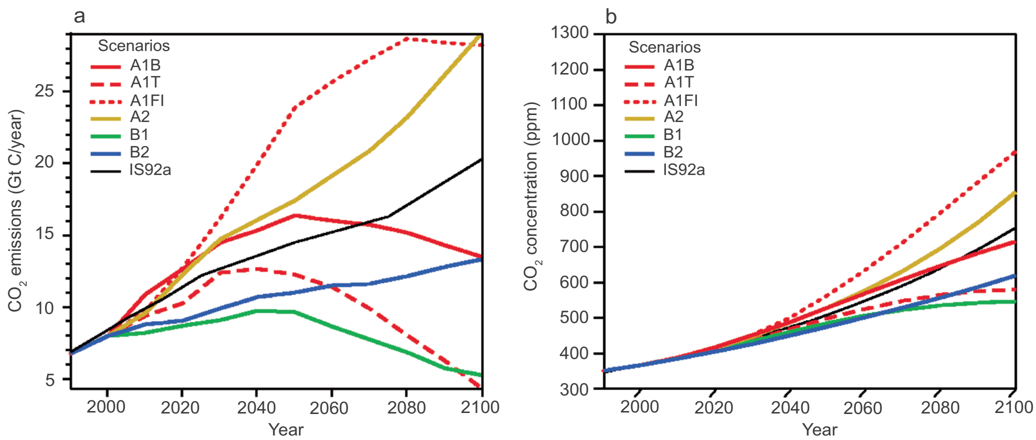

Fig. 1. Emissions scenarios (a) and concentrations (b) used in AR4.
Source: IPCC-WGI, 2007.

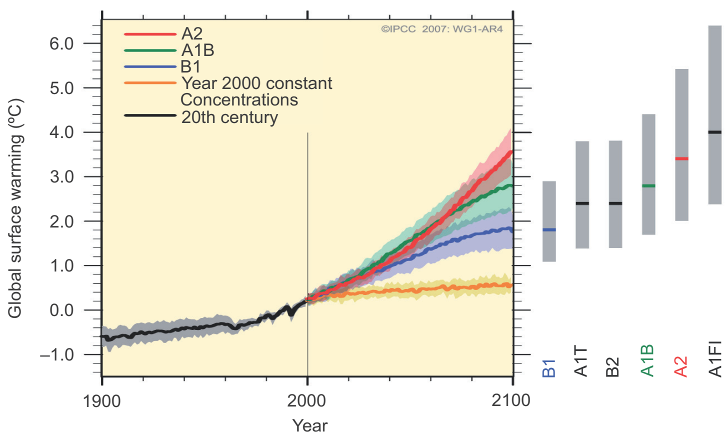

Fig. 1c. Temperature scenarios used in AR4.
Source: IPCC-WGI, 2007

(medium-low emissions in SRES range) and B1 (lowest emission in SRES range), offered the advantage that they can be used as substitutes of stabilization scenarios at 750, 650 and 550ppm, respectively, due to their similarities in their trajectories (Swart *et al.*, 2002; IPCC-WGII, 2007). The A2 scenario represents a high emissions trajectory in the SRES, and it is in no way similar to any stabilization scenario. In this way, and without having to repeat the work for the stabilization scenarios, the study offered an approximate assessment of the potential climate change impacts in México for stabilization of atmospheric concentrations of CO_2 at 550, 650 and 750 ppm. These results were contrasted with corresponding emissions scenario A2, that represents a case of inaction.

Also, climate change scenarios were generated for the 18 Douglas regions, using the following models (22 in total); MIROC32-HIRES, NCAR-CCSM30, UKMO-HADGEM1, CSIRO-MK30, MPI-ECHAM5, GFDL-CM20, GFDL-CM21, CCCMA-CGCM3-T63, IAP-FGOALS10G, MRI-CGCM232A, BCCR-BCM20, CNRM-CM3, NCAR-PCM1, CCCMA-CGCM3, UKMO-

HADCM3, MIROC32-MEDRES, IPSL-CM4, GISS-AOM, MIUB-ECHOG, GISS-EH, GISS-ER, INMCM30.

The purpose of generating all these scenarios consisted on providing an estimate of the uncertainty range in climate change scenarios. We consider that it is important to present the uncertainty range to decision-makers and stakeholders in order not to conceal potentially crucial information for impact assessment, as well as for decision-making. In this way, sufficient elements were generated to address the representativeness criterion.

Once a range for possible changes in climatological variables was obtained for the 2030s and the 2050s horizons, and due to the fact that most available methodologies for impact estimation are yet not capable of appropriately managing uncertainty (see, e.g. Estrada *et al.*, 2008; UNFCC, 2008), we proceeded to apply a set of criteria for the selection of models that guaranteed that the range of possible changes was fairly represented.

3. Results and discussion

The statistics used (from MAGICC/SCENGEN 5.3) for evaluating the performance of the different models to reproduce the observed climate at global scale and for the region of México were: pattern correlation (r), root mean square error (RMSE), bias and root mean square error corrected by bias (RMSE-corr) (Wigley, 2008). All statistics were weighed for the cosine function, in order to consider the change in the area for the squares in the grids that depend on the latitude. The 7 models that showed the best performance were given a score of one point (+1), and a minus 1 was assigned to the 7 models that showed the worst performance. Considering the global level and the regional level for México, the highest possible score was 8, and lowest was −8. Tables I and II show the scores for 20 models in terms of their global performance as well as their performance for México. Table III shows the scores and the corresponding ranking. In each of these tables, numbers in bold indicate the seven models with the best performance; in bold and underlined, the three best; in italics the seven worst, and in italics and underlined the three worst.

As observed in tables I and II, NCAR-CCSM30, (CCSM30, hereafter) MIROC32-HIRES and ECHAM5 (ECHAM5, hereafter) models have better performance at a global level and for the region of México than all other models, and therefore they have a better general ranking. It is also interesting to notice that the average of the twenty models (MODBAR), has a considerably lower punctuation than any of the three cited models.

An additional criterion considered was the spatial resolution of the different models. Table IV shows the number of cells in the grid that correspond to the region of México. As it can be observed, the model with the highest resolution is MIROC32-HIRES with 162 cells, followed by CCSM30 with 105, while ECHAM5 has 61 cells. Models with lower resolution have barely 13 cells for México.

Although its good performance and high resolution, MIROC32-HIRES model has an inconvenience: its sensibility is 5.6 ºC, way higher than the 3 ºC marked as *"best estimate"* in IPCC´s AR4 (Wigley, 2008). On the other hand, model CCSM30 does not have simulations for all the AR4 emissions scenarios (A1B, A2 and B1), nor for B2.

Taking into account the representativeness criterion suggested by IPCC-TGICA (2007), 3 models were chosen to reasonably represent the uncertainty range. These models provide broad range of possible temperature increases and, more importantly, they provided increases as well as reductions in precipitation. In this way, and for the impacts studies for the impacts studies, climate change

Table I. Global performance of models.

Model	r	RMSE	BIAS	RMSE-corr	Score	Ranking
		ºC				
CCSM-30	**0.995**	**1.396**	**–0.294**	**1.364**	4	1
MIROC-HI	**0.994**	**1.665**	**–0.536**	**1.576**	4	1
MPIECH-5	**0.996**	**1.473**	**–0.257**	**1.450**	4	1
MRI-232A	**0.995**	**1.889**	**–0.811**	**1.706**	4	1
MODBAR	**0.996**	**1.783**	–1.236	**1.285**	3	2
UKHADCM3	**0.994**	**2.051**	–0.901	**1.842**	3	2
ECHO-G	0.990	**2.029**	**0.307**	2.006	2	3
GFDLCM21	**0.992**	2.299	–1.470	**1.767**	2	3
CNRM-CM3	0.990	2.680	–1.756	2.025	0	4
CSIR0-30	0.991	2.649	–1.772	1.969	0	4
MIROCMED	0.991	2.198	–1.059	1.926	0	4
GISS-EH	*0.983*	2.710	**0.620**	*2.638*	–1	5
GISS-ER	*0.988*	2.296	**–0.499**	*2.241*	–1	5
IPSL-CM4	*0.989*	2.782	–1.789	2.130	–1	5
NCARPCM1	0.990	*2.977*	*–2.138*	2.071	–2	6
UKHADGEM	0.992	*2.900*	*–2.109*	1.991	–2	6
CCCMA-31	0.990	*3.011*	*–1.805*	*2.411*	–3	7
BCCRBCM2	*0.988*	*3.274*	*–2.216*	*2.411*	–4	8
FGOALS1G	*0.973*	*4.393*	*–1.994*	*3.915*	–4	8
GFDLCM20	*0.989*	*3.120*	*–2.278*	*2.132*	–4	8
INMCM-30	*0.987*	*3.019*	*–1.969*	*2.288*	–4	8

Table II. Models' performance for the region of México.

Model	r	RMSE	BIAS	RMSE-corr	Score	Ranking
		ºC				
CCSM-30	**0.920**	**1.714**	**–1.117**	**1.300**	4	1
MIROC-HI	**0.972**	**1.512**	**–0.818**	**1.272**	4	1
MPIECH-5	**0.941**	**1.330**	**–0.054**	**1.329**	4	1
GISS-ER	0.841	**2.081**	**–1.258**	1.658	2	2
MODBAR	0.916	**2.108**	–1.687	**1.265**	2	2
UKHADGEM	**0.938**	2.644	–2.173	**1.507**	2	2
MRI-232A	*0.806*	**1.864**	**–0.011**	1.864	1	3
BCCRBCM2	**0.928**	*3.777*	*–3.525*	**1.357**	0	4
CNRM-CM3	**0.932**	*3.992*	*–3.773*	**1.302**	0	4
ECHO-G	*0.739*	**2.063**	**0.059**	*2.062*	0	4
UKHADCM3	0.871	2.360	–1.564	1.767	0	4
GFDLCM20	**0.938**	*3.865*	*–3.519*	1.599	–1	5
MIROCMED	*0.739*	2.110	**0.243**	*2.096*	–1	5
CCCMA-31	0.854	*3.683*	*–3.316*	1.602	–2	6
CSIR0-30	0.870	3.287	–2.309	*2.340*	–2	6
FGOALS1G	*0.781*	2.584	–1.737	*1.913*	–2	6
GFDLCM21	0.917	*3.809*	*–3.329*	1.851	–2	6
INMCM-30	*0.755*	3.209	–2.280	*2.258*	–2	6
IPSL-CM4	*0.785*	2.418	–1.476	*1.915*	–2	6
NCARPCM1	0.836	*4.109*	*–3.672*	1.844	–2	6
GISS-EH	*0.526*	*3.380*	1.893	*2.800*	–3	7

(Some models´names are simplified)

Table III. General score and performance of models.

Model	Score	Ranking
CCSM-30	8	1
MIROC-HI	8	1
MPIECH-5	8	1
MODBAR	5	2
MRI-232A	5	2
UKHADCM3	3	3
ECHO-G	2	4
GISS-ER	1	5
CNRM-CM3	0	6
GFDLCM21	0	6
UKHADGEM	0	6
MIROCMED	−1	7
CSIR0-30	−2	8
IPSL-CM4	−3	9
BCCRBCM2	−4	10
GISS-EH	−4	10
NCARPCM1	−4	10
CCCMA-31	−5	11
GFDLCM20	−5	11
FGOALS1G	−6	12
INMCM-30	−6	12

(Some models´names are simplified)

Table IV. Spatial resolution for the region of México of the different considered models.

Model	Number of squares in the region
MIROC-HIRES	162
NCAR-CCM30	105
UKMO-HADGEM1	92
CSIR0-MK30	71
MPI-ECH5	61
GFDL-CM20	45
GFDL-CM21	40
CCMA-CGCM3-T63	34
IAP-FGOALS10G	32
MRI-CGCM232A	31
BCCR-BCM20	29
CNRM-CM3	28
NCAR-PCM1	28
CCCMA-CGCM3	27
UKMO-HADCM3	27
MIROC32-MEDRES	26
IPSL-CM4	25
GISS-AOM	21
MIUB-ECHOG	19
GISS-EH	13
GISS-ER	13
INMCM-30	13

(Some models´names are simplified)

scenarios were generated using the ECHAM5, UKMO-HADGEM1 (HADGEM1, hereafter) and GFDL-CM2.9 models, with resolutions of 2.5º x 2.5º and of 5´x 5´(approximately 10 x 10 km). These regional climate change scenarios for México and Central America are available on CCA-UNAM website: http://www.atmosfera.unam.mx/cclimatico/scenarios/Escenarios_de_cambio_climatico:México:2008.htm.

Also, we made publicly available a Guide for the Generation of Climate Change Scenarios (Conde *et al.*, 2008) which describes a range of tools for the generation of regional scenarios. In addition to the considerations included in the IPCC-TGICA (2007), we believe that for climate change scenario generation it is fundamental to explicitly state the criteria for selecting among different models, emissions scenarios and time horizons.

During the workshop *Promotion of Capacities and Technical Assistance to States' Specialists that will create State Climate Change Programs*, which was part of the research work carried out for México's Fourth National Communication coordinated by the CCA (http://www.atmosfera.unam.mx/cclimat/index.php?option=com_content&view=article&id=130Itemid=77), the following public tools were used:

1. Outputs of reported models in the AR4, available at:
   a. http://www.pacificclimate.org/tools/select from Pacific Climate Impacts Consortium, in Canada.

b. http://www.ipcc-data.org from the distribution Data Center of the IPCC.

c. http://climexp.knmi.nl/ from the Royal Netherlands Meteorological Institute KNMI.

2. MAGICC/SCENGEN 5.3 version.

Climate change scenarios with a spatial resolution of 10 x 10 km were generated using the global high resolution climatology of Hijmans *et al.* (2005) for the period 1950-2000 as a baseline scenario, which is available at http://www.worldclim.org at a maximum resolution of 30" (approximately 1 km^2) as well as 2.5, 5 and 10´. Using the data with spatial resolution of 5´, a climatology was generated for México with an approximate resolution of 10 km, for both latitude and longitude. GCM have an average spatial resolution of approximately 2.5º x 2.5º. The downscaling method was to interpolate the original climate change scenarios using *splines* to the same grid resolution of the 5´x 5´(approximately 10 x 10 km) climatology.

If we consider, for example, that Chiapas area is completely covered by only two cells used by AOGCM, it is clear that it is not trivial to determine the way in which we should project one or two values over all the state's extension. Clearly, local orography is a very important factor that is not considered in the numerical simulations of the AOGCM. This factor, however, is already considered in high resolution climatology, thus a very simple way to proceed is to add the anomaly of models (already interpolated) to this high resolution climatology. By doing this, we assumed that the difference between the two contiguous cells in the model is distributed homogenously, which implies that the existing gradients in the simulations are preserved exactly the same. In zones where there are complex orographic structures, this assumption is highly idealized, but at least is consistent with the dynamics imposed by general circulation models, which do not solve the local orographic factor. It would be a better alternative to use regional climate models, but this would imply an enormous computing effort, that could be done in future research.

Figures 2a to 2e show some examples of climate change scenarios that used the described methodology and sources of information that were consulted.

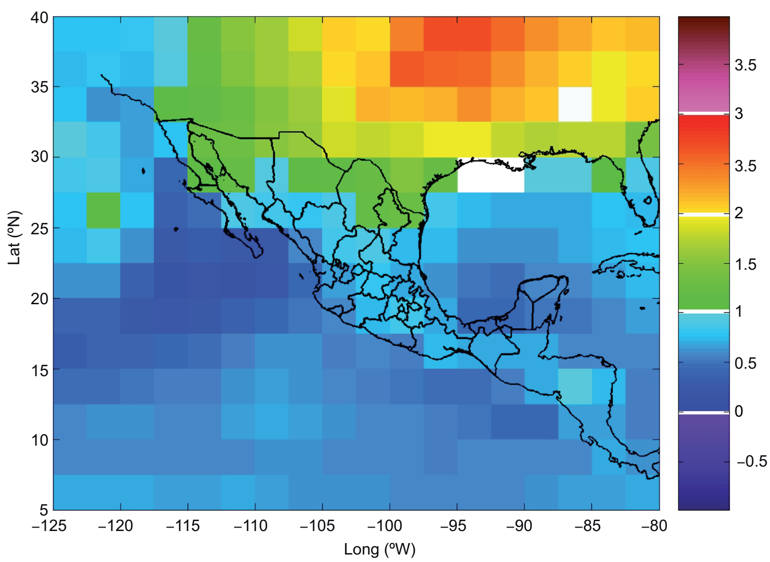

Fig. 2a. Differences in temperature (ºC) for October, 2030. Model

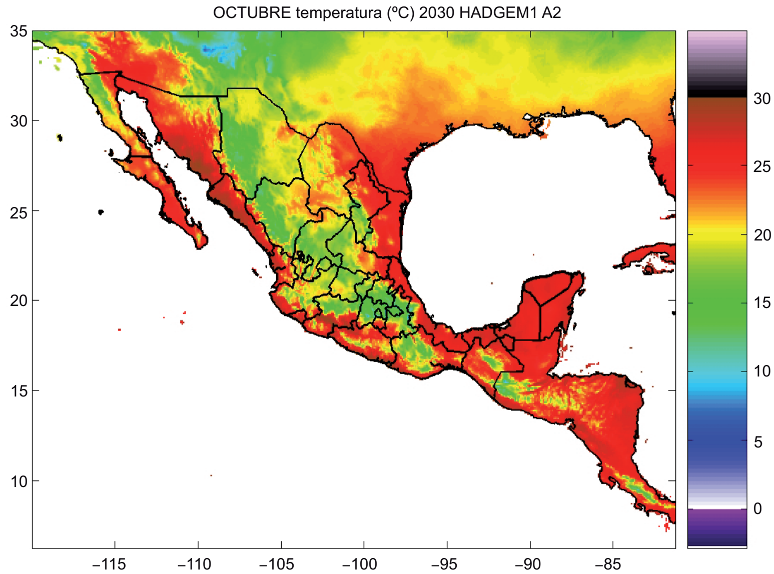

Fig. 2b. Differences in temperature (ºC) for October, 2030. Model HADGEM1, emissions scenario A2. Resolution: 5' x 5'.

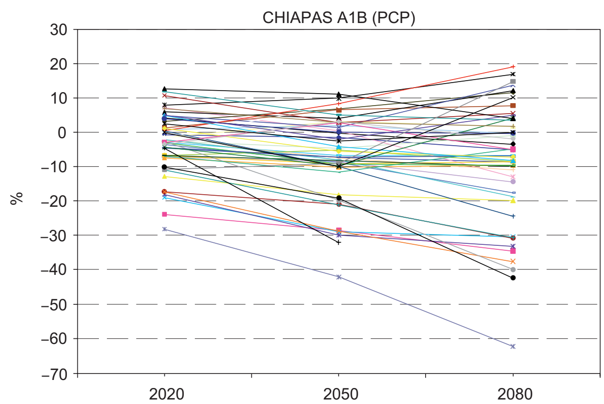

Fig. 2c. Precipitation scenarios for Chiapas and for the 2020, 2050 and 2080 horizons, using all models referred to in AR4, and emissions scenario A1B.

4. Conclusions

Regional climate change scenarios for México are the starting point for the assessment of the potential impact, as well as for conducting vulnerability and adaptation analyses under climate change conditions.

In this paper, climate change scenarios generated for México are presented using the outputs of the models ECHAM5, HADGEM1 and GFDL CM2.0, for monthly temperature and precipitation, for 2030 and 2050 time horizons, and for the emission scenarios A1B, A2, B2, and B1. These scenarios were generated with a low resolution (2.5º x 2.5º) and also with a resolution of 10 km x 10 km. Corresponding databases and maps are available at CCA website (http://www.atmosfera.unam.mx/cclimat/index.php?option=com_content&view=article&id=44&Itemid=63).

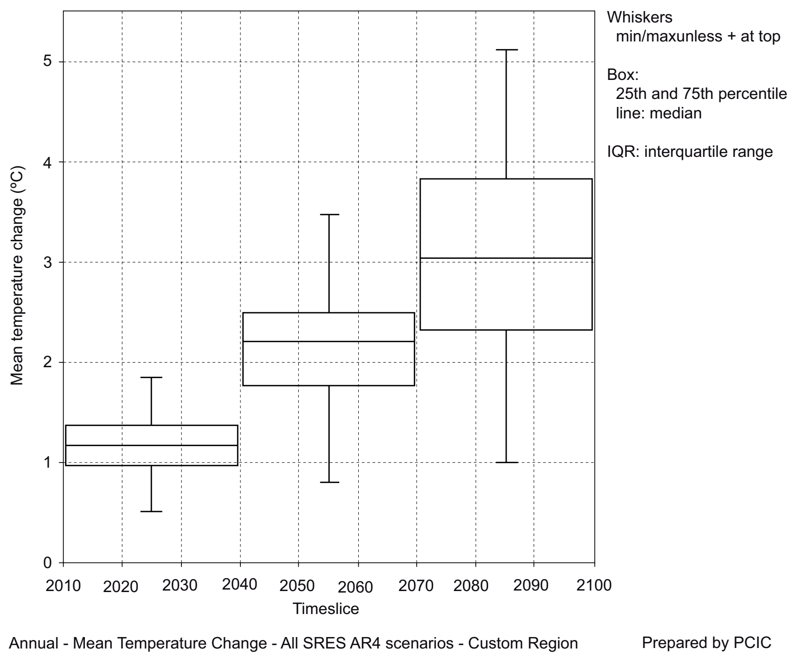

Fig. 2d. Mean Annual Temperature change scenarios in México, for 2020, 2050 and 2080 horizons, using all models mentioned in AR4, and emissions scenarios A2, A1B and B1.

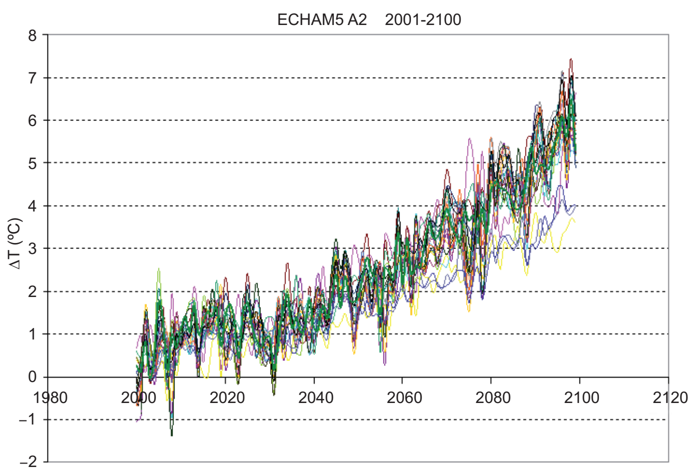

Fig. 2e. State-level simulations of annual average temperature (2001-2100), using ECHAM5 model and the A2 emissions scenario.

It is fundamental that the models and tools that are applied for generating baseline and climate change scenarios are made publicly available; moreover, they have to meet the criteria of consistency, physical plausibility, appropriate and sufficient information for impact studies, representativeness, relevance, spatial resolution, validity, comparability with previous studies and, most importantly, they must be useful for impact, vulnerability, and adaptation studies. Potential users must take into account the limitations of these scenarios, in order to be able to adapt them in their sector and regional assessments. The most difficult step for these studies is the interaction among experts of different sectors with the experts on climate change scenarios, since creativity is required (and possibly generosity) from both fields of study. Climate change scenarios presented here were used in studies on biodiversity, human settlements and in the fields of agriculture, livestock, forestry and hydrological resources. Such scenarios used models and criteria established by the IPCC in its latest assessment report and in its recent technical documents.

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