Evaluation of surface air temperature change due to the greenhouse gases increase with a statistical-dynamical model

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[1] A statistical-dynamical climate model is used for investigating the relative contribution of the changes in the radiation budget and surface air temperature due to the increase of the anthropogenic greenhouse gases predicted for 2100 on the basis of IPCC SRES A1FI (the highest greenhouse level scenario). Five experiments are performed considering the changes in concentrations of (1) CO₂, (2) CH₄, (3) N₂O, (4) tropospheric O₃, and (5) all the changes together. The results show that the mean global planetary absorbed solar radiation increases in response to the predicted conditions according to the scenario A1FI for year 2100 (A1FI-2100). This is due to the effect of O₃ absorptions. This increase leads to a decrease in the mean global planetary net thermal infrared radiation emitted to space by the Earth-atmosphere system to space and to an increase in mean global planetary net radiation. These changes are controlled mainly by the increase in CO₂ concentration. The changes in the radiation budget due to N₂O and CH₄ are small. The mean global surface air temperature response to the predicted conditions for A1FI-2100 was +0.59°C. The change in CO₂ concentration is responsible for an increase of +0.49°C. The higher increases occur in the polar regions: +2.15°C (at 85°S) and +1.55°C (at 85°N) in the case of the predicted conditions for A1FI-2100. Additional experiments indicate that the changes in surface air temperature are similar in the cases of the predicted conditions for A1FI-2100 and 4 × CO₂, 2 × CO₂ and 4 × N₂O, and in 2 × N₂O and 4 × CH₄.


1. Introduction

[1] An increase of 0.7°C in the mean annual global surface temperature has been observed in the last 100 years (http://www.globalchange.org/featall/2000spring2.htm). This has been attributed to the increase of greenhouse gases concentration due to anthropogenic use. Greenhouse gases have high transmissivity to solar radiation and high absorptivity to thermal infrared radiation. This implies in smaller planetary outgoing thermal infrared radiation flux to space and, consequently, warming of the climate system. The main greenhouse gases are water vapor, carbon dioxide (CO₂), ozone (O₃), nitrous oxide (N₂O) and methane (CH₄). Without the presence of those gases in the atmosphere the mean temperature of the Earth- atmosphere system would be 33°C lower [Houghton et al., 1996]. The water vapor has been responsible for an increase of 20°C in the mean temperature. Among the anthropogenic gases CO₂ has more influence in the increase of mean temperature (7°C), followed by O₃ (2 – 3°C), N₂O (1.4°C), CH₄ (0.8°C) and the remainder gases (0.6°C) (http://rrz.uni-hamburg.de/ klima2000/eng/eng_hef.html).

[1] The concentration of all greenhouse gases has been increased because of anthropogenic cause since the beginning of the preindustrial era, except in the case of the water vapor and O₃ in the stratosphere. CH₄ showed higher increase of concentration, mainly from 1990. More than a half of the emission of CH₄ to the atmosphere is due to anthropogenic origin. According to IPCC Third Assessment Report (TAR) [Houghton et al., 2001] the residence time of CO₂ (around 120 years) is higher compared to that of CH₄ (around 12 years). Anthropogenic CO₂ is released by both burning of fossil fuels and changes in land use. Burning of fossil fuels is responsible for 77% of the CO₂ emission to the atmosphere while in the case of change in land use, deforestation plays a principal role in the CO₂ emission, mainly in the tropical region [Barnes, 2004; Schimel et al., 1996]. According to the IPCC TAR [Houghton et al., 2001] and the Special Report on Emission Scenarios (SRES) [Nakicenovic et al., 2000] the concentration of CO₂ in the scenario A1FI for year 2100 (hereafter called as A1FI-2100) will vary from 540 to 970 ppm while the concentration of CH₄ will
change between –190 to +170 ppb relative to its year 2000 value. The values of the concentration of CO2 and CH4 for the year 2000 are 360 ppm and 1760 ppb, respectively [Houghton et al., 2001]. The radiative forcing of N2O is lower than those of CO2. According to the IPCC Assessments the term “radiative forcing” denotes an externally imposed perturbation in the radiative energy budget of the Earth’s climate system, which may lead to changes in climate parameters [http://www.grida.no/climate/ipcc_tar/wg1/2.12.htm]. Although the emission of tropospheric N2O has increased at a lower rate than that of CH4, its residence time is higher (around 114 years) [Houghton et al., 2001]. The main anthropogenic sources of N2O are from agriculture and industrial sources including adipic acid and nitric acid production [Schimel et al., 1996]. The concentration of N2O for the year 2000 is 316 ppb [Houghton et al., 2001]. The concentration of O3 in atmosphere greatly varies in time and space because of the interactions between the movements and chemical reactions in the atmosphere and its residence time is a few weeks. The increase of the O3 in the troposphere is caused by photochemical processes and burning of fossil fuels and biomass [Houghton et al., 1996]. It is estimated that the total amount of tropospheric O3 has increased by 35% since 1750. The radiative forcing of the year 2000 is around 0.38 Wm^-2. According to the TAR the maximum concentration of N2O in A1FI-2100 will be +14 ppb above its year 2000 value and the tropospheric O3 will increase by 62% relative to its year 2000 value [Houghton et al., 2001].

The impact of the increase of anthropogenic greenhouse gases concentration on climate can be projected using mathematical models that simulate future additions. In 1992, the IPCC released emission scenarios (IS92) to be used for driving general circulation models (GCMs) to develop future climate change scenarios. The IS92 were the first scenarios to provide estimates for the full set of greenhouse gases. These scenarios provided input to the IPCC Second Assessment Report (SAR). Projections of future climate from forcing IS92 scenarios experiments using several coupled atmosphere-ocean general circulation models (AOGCMs) were reported by Kattenberg et al. [1996]. The model calculations indicated an increase in global mean temperature relative to the present value of about 1° to 4.5°C by 2100 for a full range of IPCC scenarios. Because of the increase of the understanding of possible future greenhouse gas emissions and climate change in 1996 the IPCC developed a new set of emission scenarios (SRES), which provided input to the TAR. Cabuschi and Meehi [2001] reported a large number of AOGCM climate simulations with various forcings scenarios from the SRES that provided estimates of possible future climate change [see Albritton and Metta Filho, 2001, box 6]. The models projected an increase in global mean temperature from 1.4°C to 5.8°C by 2100 for a full range of new emission scenarios. Temperature increases are higher than those in the SAR due partly to the increase of radiative forcing and primarily to the lower projected emissions in the SRES scenarios relative to the IS92 scenarios. In particular for the A1IFI, the highest SRES greenhouse level scenario, which takes into account fossil fuel intensive energy emission sources, the temperature increase by 2100 is from 3.2°C to 5.7°C. Later studies have been devoted to investigate the uncertainty in the IPCC TAR temperature changes. Uncertainty in upper limits for temperature change by 2100 of less than 5°C were obtained by Wigley and Raper [2001] (1.7°–4.9°C), Rock et al. [2001] (1.1°–4.5°C) and Frame et al. [2005] (1.4°C–4.1°C). In a recent IPCC Expert Meeting on Emission Scenarios there was a consensus that the range as given by IPCC remains large and recent studies have widened the range of uncertainty for climate sensitivity [Hogewijk, 2005].

In the model experiments reported at the SAR and TAR the IPCC scenarios took into account simultaneously the estimates of the future changes in the full set of greenhouse gases concentration. As pointed out by Kattenberg et al. [1996], the change in the radiative forcing since 1900 is approximately equivalent to that given by a 40% increase in CO2. The equilibrium response to the trace gases and an equivalent increase in CO2 are broadly similar. Since CO2 is the main anthropogenic greenhouse gas, the equilibrium distribution of warming due to increases in CO2 concentration has been discussed more extensively in the IPCC’s reports. However, some differences in the pattern of changes may occur when changes in equivalent CO2 are used instead of changes in the other trace gases [Wang et al., 1992]. Thus the effect of the changes in the trace gases concentration on future climate deserves a detailed investigation. Earlier studies using simple models have examined the role of individual gases on climate by doubling or quadrupling their atmospheric concentration. Radiative convective models (RCMs) were used for studying the effects of the changes in CH4 and N2O on the energy radiative budget [Donner and Ramanathan, 1980; Wang et al., 1976] and the role of O3 in the tropospheric-surface energy balance [Ramanathan and Dickinson, 1979; Ramanathan, 1976]. However, the relative importance of future changes on climate due to the main anthropogenic greenhouse gases must be investigated in more detail than has been done earlier using the recent IPCC scenarios. In particular, the projected future climate change from the more drastic SRES forcing scenario deserves to be examined.

The objective of the present paper is to study the relative contributions of the changes in the radiation budget and surface air temperature caused by the increase of anthropogenic greenhouse gases concentration predicted for 2100 according to IPCC SRES A1FI (the highest greenhouse scenario). We propose to evaluate separately each of the four major greenhouse gases (CO2, O3, CH4, and N2O) in order to quantify their contribution to the future climate change. Such a study has not been done earlier. For this purpose, a zonally averaged statistical-dynamical model (SDM) with a detailed parameterization of the radiative processes is used. This kind of model is essentially mechanistic, being directed toward understanding the dependence of a particular mechanism on the other parameters of the problem. Thus a SDM is better suited for the present study. In GCMs, since many mechanisms are included simultaneously, the cause and effect relationship is not always possible to trace.

In section 2 the SDM is presented and the numerical experiments concerning the effects of greenhouse gases are
shown in section 3. Section 4 contains the summary and conclusions.

2. Model and Experiments

2.1. Description of the Model

The SDM used in this study is the same as that developed by Moraes et al. [2004]. The SDM is a later version of the coupled biosphere-atmosphere climate model developed by Varejão-Silva et al. [1998] in which a detailed parameterization of the radiative processes [Chou and Suarez, 1994, 1999] which takes into account the effects of the main absorbing and emitting gases in the atmosphere is included. This allows a detailed study of the radiative effects of greenhouse gases on climate.

The model is a two-layer global primitive equation model in sigma-coordinate and includes parameterizations of friction, diabatic heating, and large-scale eddies. The energy fluxes such as solar radiation, thermal infrared radiation, sensible and latent heat fluxes, and surface heat flux are computed separately for the land fraction and the remaining part (covered by ocean-ice-snow) of the latitude belt. The parameterizations of the biosphere model based on BAT: (Biosphere-Air Transfer Scheme) [Zhang, 1994] are used for the land fraction of the latitude belt. Detailed description of the coupled biosphere-atmosphere model is given by Varejão-Silva et al. [1998].

The thermal infrared and solar radiation parameterization schemes used in the SDM are those developed by Chou and Suarez [1994] and Chou and Suarez [1999], respectively. In a recent version of the model, the surface emissivity in 10 spectral bands is considered. These schemes use several broadband parameterization schemes for thermal infrared and solar radiation to produce a computationally fast and accurate representation of radiation processes. Details of the radiation schemes are given by Chou and Suarez [1994, 1999] and details of the input data for the radiation models and the coupling with the SDM are given by Moraes et al. [2004].

The SDM has 10° latitude resolution and employs a latitudinal centered finite-differencing scheme. The strategy for running the SDM is the same as that given by Moraes et al. [2004]. The SDM is run in two steps. First, the original SDM of Varejão-Silva et al. [1998] is integrated without the inclusion of the biosphere parameterization using as initial condition an isothermal atmosphere (270 K) at rest. Explicit time integration was used with a time step of 30 min. The SDM is integrated for a six month period forced by mean annual conditions in order to obtain stationary solutions. In a second step, the SDM is run for a six month period including the effects of the biosphere and the new radiation models for obtaining new stationary solutions. Since the values of the 300 hPa temperature and the wind speed are necessary to run the biosphere-atmosphere coupled SDM they cannot be zero in the initial conditions. So, the mean annual zonally averaged simulation obtained earlier is used as an initial condition for running the coupled biosphere-atmosphere model. The new stationary solutions correspond to the simulation of the mean annual zonally averaged climate with the coupled biosphere-atmosphere SDM.

2.2. Numerical Experiments

In the control experiment the actual concentration of the greenhouse gases used in the radiation models is obtained from the TAR, i.e., 360 ppm (CO₂), 1760 ppb (CH₄) and 316 ppb (N₂O) [Houghton et al., 2001]. These values are for the year 2000. The vertical profiles of ozone mixing ratios are obtained from M.-D. Chou (personal communication, 2000). They are based on the optical properties of the atmosphere defined by McClatchey et al. [1972] and correspond to the standard atmosphere in tropical, middle and high latitudes. Results of Moraes et al. [2004] showed that the mean annual zonally averaged radiative fluxes and climate characteristics for the actual climate are well simulated by the SDM. These simulations will be compared with the results of the perturbed experiments.

To study the relative contributions of the changes caused by the increase of the anthropogenic greenhouse gases concentration predicted for year 2100, the contributions of the four major anthropogenic greenhouse gases are changed from their actual values (values for year 2000) to those from the more drastic IPCC SRES scenario for year 2100 (A1FI-2100). Five experiments are carried out with the SDM considering the changes in the concentration of (1) CO₂ (experiment 1), (2) CH₄ (experiment 2), and (3) N₂O (experiment 3), (4) O₃ (experiment 4), and (5) CO₂, CH₄, N₂O and O₃ together (experiment 5). In experiments 1 to 3 the concentrations of CO₂, CH₄, and N₂O are changed from 360 ppm to 970 ppm, from 1760 ppb to 3730 ppb, and from 316 ppb to 460 ppb, respectively; in the case of the change in the concentration of tropospheric O₃ (experiment 4) the values given by McClatchey et al. [1972] are increased by 62%. In experiment 5 the changes in the concentration of CO₂, CH₄, N₂O and O₃ are taken into account simultaneously. Additional experiments considering the doubling and quadrupling of the actual concentration of CO₂, N₂O and CH₄ are also made.

The strategy for running the SDM with the A1FI-2100 is the same as that in the control case.

3. Model Results

In experiments 1–5 the climate changes are considered as the perturbed case minus the control experiment. Figures 1a–1e show the mean global planetary absorbed solar radiation, net thermal infrared radiation and net radiation, respectively. The changes (perturbed minus control) in these variables and the percentages of the changes in relation to the control case are presented in Table 1. As can be seen, in the case of the concentration of anthropogenic greenhouse gases predicted in A1FI-2100 (experiment 5) slight changes occur in the planetary absorbed solar radiation while for the net outgoing thermal infrared radiation the changes are higher. The increase in the CO₂ concentration in the atmosphere causes a reduction of 0.12 W m⁻² (0.05%) in the planetary absorbed solar radiation. The interaction between CO₂ and solar radiation provokes a slightly increase of planetary albedo (0.03%) (figure not shown). Since N₂O and CH₄ do not interact with solar radiation,
Figure 1. Mean global planetary (a) absorbed solar radiation, (b) net outgoing thermal infrared radiation, and (c) net radiation at the surface (Wm$^{-2}$). Shown are the values for experiments 1–5.

the change in their concentrations do not influence on the planetary absorbed solar radiation. However, the increase in the concentration of $O_3$ predicted in A1FI-2100 shows an opposite effect to that is verified in experiments 1, 2 and 3, i.e., there is an increase of 0.22 Wm$^{-2}$ (0.10%) in the mean global planetary absorbed solar radiation. This may be due to the interactions between solar radiation and the troposphere $O_3$, which has high absorption in the spectral bands where the emission of solar radiation is maximum. Thus the increase of tropospheric $O_3$ concentration causes larger storage of solar radiation in the Earth-atmosphere system and a slight reduction in the mean global planetary albedo (0.04%) (Figure not shown). Since the effect of the tropospheric $O_3$ is higher compared with the changes in the concentrations of the other three anthropogenic gases, there is an increase of 0.11 Wm$^{-2}$ (0.05%) in the mean global planetary absorbed solar radiation.

[14] The increase of greenhouse gases concentration leads to a reduction in the net thermal infrared radiation emitted by the Earth-atmosphere system to space in the five experiments (Figure 1b). The increase of the concentration of $CO_2$, $CH_4$, $O_3$ and $N_2O$ predicted in A1FI-2100 provokes a decrease of 1.51 Wm$^{-2}$ (0.73%) in the mean global planetary net outgoing thermal infrared radiation. The change in $CO_2$ is responsible for a reduction of 1.45 Wm$^{-2}$ (0.71%) while the changes in the other three anthropogenic gases are smaller: $N_2O$ (−0.07%), $CH_4$ (−0.06%), and $O_3$ (−0.02%). Comparing experiments 1, 2, 3 and 4 it can be noted that among the anthropogenic gases $CO_2$ plays a major role in controlling the planetary net outgoing thermal infrared radiation.

[15] Because of the changes in planetary solar radiation and net outgoing thermal infrared radiation the planetary net radiation increases in the five experiments, as shown in Figure 1c and Table 1. An increase of 1.61 Wm$^{-2}$ (11.9%) is noted when the concentration of the four anthropogenic greenhouse gases predicted in A1FI-2100 are taken into account together. The alteration in $CO_2$ concentration is responsible for an increase of 1.34 Wm$^{-2}$ (9.8%) showing the important role of this gas in controlling the change of the planetary net radiation. As a consequence of the planetary radiation balance there is a warming of the

<table>
<thead>
<tr>
<th>Mean Global Control Value</th>
<th>Changes for the A1FI-2100 Scenario</th>
</tr>
</thead>
<tbody>
<tr>
<td>Planetary absorbed solar radiation</td>
<td>$220.6$ Wm$^{-2}$</td>
</tr>
<tr>
<td>Planetary net outgoing thermal infrared radiation</td>
<td>$207.0$ Wm$^{-2}$</td>
</tr>
<tr>
<td>Planetary net radiation</td>
<td>$13.6$ Wm$^{-2}$</td>
</tr>
<tr>
<td>Surface air temperature</td>
<td>$282.12$ K</td>
</tr>
</tbody>
</table>

*Also shown are the mean global values in the control experiment.*

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Earth-atmosphere system. As shown in Figure 2a and Table 1 there is an increase of 0.50°C (6.6%) in the mean global surface air temperature in the case of the concentrations of CO₂, CH₄, O₃, and N₂O predicted in A1FI-2100. When only the change in the concentration of CO₂ is considered the increase is of 0.49°C (5.5%) while the changes due to CH₄, N₂O, O₃, and are responsible for an increase of 0.76%, 0.55%, and 0.43% in relation to the control case, respectively. As shown in Figure 2b, the change in CO₂ concentration plays the major role in all the latitude belts compared with the other greenhouse gases. The change in the surface air temperature is higher in the polar regions, mainly in the Southern Hemisphere. As shown in Table 2 and Figure 2b, when all the changes in gas concentration are included the surface air temperature increases by 2.15°C (at 85°S) and 1.55°C (at 85°N). The changes in CO₂ are responsible for increases of 1.9°C (at 85°S) and 1.25°C (at 85°N).

[9] In addition to the five experiments concerning the effects of the change in the concentration of the anthropogenic greenhouse gases predicted in A1FI-2100, other experiments considering 2 × CO₂, 4 × CO₂, 2 × N₂O, 4 × N₂O, 2 × CH₄ and 4 × CH₄ are also made. The control experiment is the same as that in the previous case. Figure 3a and Table 3 show the mean global surface temperature for the doubling and quadrupling the actual concentrations of these greenhouse gases. The latitudinal changes (perturbed minus control) are shown in Figure 3b. As shown in Figure 3a and Table 3 the doubling of the amount of CO₂ concentration is responsible for an increase of 0.50°C in the mean global surface air temperature while in the case of the doubling of CH₄ and N₂O the increase is less than 0.1°C. The difference between the mean global surface air temperature in the cases 2 × CO₂ and 4 × N₂O is less than 0.1°C. The changes are also similar for 4 × CH₄ and 2 × N₂O experiments. The difference in the mean global surface air temperature between the 4 × CO₂ experiment and the experiment considering simultaneously the concentrations of CO₂, CH₄, N₂O and O₃ predicted in A1FI-2100 is less than 0.1°C, as seen in Table 3. From Figure 3b, in the polar regions the effect on the surface air temperature caused by the increase of the four anthropogenic greenhouse gases concentrations is similar as that in the case of 4 × CO₂. For the other latitude belts the increase is somewhat higher for 4 × CO₂.

Table 2. Changes in Surface Air Temperature (°C) in Polar Regions Due to the Increase of Anthropogenic Greenhouse Gases for the A1FI-2100 Scenario

<table>
<thead>
<tr>
<th>Experiment</th>
<th>ΔT at 85°S, °C</th>
<th>ΔT at 85°N, °C</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO₂</td>
<td>+1.99</td>
<td>+1.25</td>
</tr>
<tr>
<td>CH₄</td>
<td>+0.13</td>
<td>+0.16</td>
</tr>
<tr>
<td>N₂O</td>
<td>+0.17</td>
<td>+0.21</td>
</tr>
<tr>
<td>O₃</td>
<td>+0.20</td>
<td>+0.23</td>
</tr>
<tr>
<td>All</td>
<td>-2.15</td>
<td>-1.55</td>
</tr>
</tbody>
</table>

*Shown are the values at the latitude belts centered at 85°N (S) for the five experiments.
model results correspond to the simulation of a future scenario of climate change due to the increase of anthropogenic greenhouse gases concentration, the comparison between the model predictions and observed data is a difficult task. To our knowledge, for the first time in this study, the effects of the increase of the main anthropogenic gases concentration predicted in A1FI-2100 are investigated all together using a SDM. Also, the relative importance of different gas concentration predicted in A1FI-2100 is examined which was not studied earlier even with GCMs. Comparing with the model results presented by the TAR, the SDM projects a lower increase of temperature for the A1FI scenario. The results of $2 \times CO_2$ and $4 \times CO_2$ experiments are consistent with the current evidence [Mitchell, 1989] and GCM studies, which show higher increase of the surface air temperature near the poles. The increase of the surface air temperature due to the doubling of CO$_2$ concentration in the present study ($0.37^\circ$C) is less than that according to the TAR, which varies from 1.5$^\circ$C to 4.5$^\circ$C [Kattenberg et al., 1996]. The change in surface air temperature in the SDM is also less than results of fifteen models presented in the TAR, which project an equilibrium temperature increase from 2$^\circ$C to 5.1$^\circ$C [Cubasch and Meeth, 2001]. However, it is similar to those obtained by Lindzen [1995, 1998] ($0.3^\circ$C and 0.55$^\circ$C, respectively).

[11] The lower values of temperature increase obtained with the SDM compared to the GCM results may be attributed to the differences between the models such as the resolution, the treatment of radiative processes and clouds, planetary boundary layer modeling and coupling of the surface to the atmosphere, treatment of snow and ice, etc. Also it should be born in mind that the SDM is a zonally averaged mean annual climate model and so a greater response can hardly be expected. As mentioned earlier, the SDM is essentially mechanistic: being directed toward understanding the dependence of a particular mechanism on other parameters of the problem. The change in surface air temperature in the SDM is in better agreement

### Table 3. Increase of Surface Air Temperature ($^\circ$C) for $2 \times CO_2$, $4 \times CO_2$, $2 \times N_2O$, $4 \times N_2O$, $2 \times CH_4$ and $4 \times CH_4$; Mean Global Values and Latitudinal Variation of the Changes

<table>
<thead>
<tr>
<th>Experiment</th>
<th>$\Delta T$ at $85^\circ$S $^\circ$C</th>
<th>$\Delta T$ at $85^\circ$N $^\circ$C</th>
</tr>
</thead>
<tbody>
<tr>
<td>$2 \times CH_4$</td>
<td>+0.04</td>
<td>+0.11</td>
</tr>
<tr>
<td>$4 \times CH_4$</td>
<td>+0.09</td>
<td>+0.32</td>
</tr>
<tr>
<td>$2 \times N_2O$</td>
<td>+0.10</td>
<td>+0.42</td>
</tr>
<tr>
<td>$4 \times N_2O$</td>
<td>+0.23</td>
<td>+1.23</td>
</tr>
<tr>
<td>$2 \times CO_2$</td>
<td>+0.37</td>
<td>+1.59</td>
</tr>
<tr>
<td>$4 \times CO_2$</td>
<td>+0.65</td>
<td>+2.22</td>
</tr>
<tr>
<td>Change in the four greenhouse gases for A1FI-2100</td>
<td>+0.59</td>
<td>+2.15</td>
</tr>
</tbody>
</table>

*Shown are the mean global values and the latitudinal variation of the changes corresponding to the concentrations of CO$_2$, CH$_4$, N$_2$O and O$_3$ for the A1FI-2100 scenario.*
with results obtained with RCMs, where the increase of surface air temperature varies from +0.48°C to +4.2°C (see Schlesinger and Mitchell [1987, Table 1], which presents results of seventeen RCMs).

The results presented above showed that the changes are in qualitative agreement with those obtained from more complex GCMs and simpler RCMs. This indicates that the present SDM is a good complement to GCMs and can play an important role in generalizing and confirming results of RCM simulations.

4. Summary and Conclusions

In this paper the relative contributions of the changes in the radiation budget and surface air temperature caused by the increase of anthropogenic greenhouse gases concentration predicted for 2100 according to the more drastic IPCC SRES scenario (A1FI-2100) were investigated. For this purpose a coupled biosphere-atmosphere SDM with a detailed parametrization of solar radiation and thermal infrared radiation fluxes was used. This kind of model is directed toward understanding the dependence of a particular mechanism on the other parameters of the problem. The simulation of the mean annual zonally averaged climate was taken as the control experiment. In the control experiment the concentrations of greenhouse gases are for year 2000. Five experiments were made for studying the relative contributions of the effects of the increase of the four major anthropogenic greenhouse gases concentration: changes in (1) CO₂, (2) CH₄, (3) N₂O, (4) O₃, and (5) all the changes together. Additional experiments considering the doubling and quadrupling of CO₂, CH₄, and N₂O were also made.

The results showed that when the concentrations of the four major anthropogenic greenhouse gases predicted in A1FI-2100 were taken into account slight changes occurred in planetary absorbed solar radiation while in the planetary net thermal infrared radiation the changes were higher. The change in CO₂ was responsible for decrease of 0.05% in the planetary absorbed solar radiation and for a slight increase in the mean global planetary albedo occurred (0.03). However, the change in tropospheric O₃ concentration provoked an increase in planetary absorbed solar radiation (0.1%). This is due to the effect of O₃ absorptions, because it has high absorption in the spectral bands where the solar radiation emission is maximum. Since the effect of tropospheric O₃ is higher than that of CO₂, CH₄, and N₂O, there was an increase in the mean global planetary absorbed radiation (0.05%).

Because of the increase of the opacity of the atmosphere the planetary net outgoing thermal infrared radiation decreased in the five experiments. As a consequence of the changes in planetary absorbed solar radiation and net thermal infrared radiation there was an increase of planetary net radiation. In the case of the concentrations of CO₂, CH₄, O₃, and N₂O predicted in A1FI-2100 there were a decrease of 0.73% in the mean global planetary thermal infrared radiation and an increase of 11.9% in the mean global planetary net radiation. Among the anthropogenic gases CO₂ played a major role in controlling the changes in the mean global planetary net outgoing thermal infrared radiation (−0.7%) and net radiation (+9.8%). The alterations in the concentrations of N₂O, CH₄, and O₃ were responsible for −0.67%, −0.66% and +0.02% in the mean global planetary net outgoing thermal infrared radiation and for −1.64%, −0.9% and +1.28% in the mean global planetary net radiation, respectively.

The mean global surface air temperature response to the increase of the concentrations of CO₂, CH₄, O₃, and N₂O predicted in A1FI-2100 was +0.59°C (±0.6%). The change in the concentration of CO₂ was responsible for an increase of +0.49°C (±0.5%) while the changes due to the other greenhouse gases concentrations were smaller (less than ±1%). The changes in surface air temperature due to CO₂ concentration are higher in the polar regions, mainly in the Southern Hemisphere. The additional experiments considering the doubling and quadrupling of the concentrations of CO₂, CH₄, and N₂O showed that the difference in mean global surface air temperature between 4 × CO₂ and in the case of the concentration of greenhouse gases predicted in A1FI-2100 was less than 0.1°C. In the polar regions the changes in surface air temperature were equivalent in these two cases while in the other latitudes the increase is somewhat higher for 4 × CO₂. The results also showed that the effects on the surface air temperature were similar in the cases 2 × CO₂ and 4 × N₂O, and in the cases 2 × N₂O and 4 × CH₄.

Since the model results correspond to a simulation of future scenario of climatic change due to the increase of anthropogenic gases concentration in the atmosphere a comparison with observed data is difficult. For the first time a SDM was used to investigate the relative effects of changes in the main anthropogenic greenhouse gases concentration predicted for 2100 (IPCC SRES A1FI scenario). Although the magnitude of changes is lower, the SDM gives credible predictions consistent with more complex and expensive GCM experiments. Also, the surface air temperature increase in the SDM is in good agreement with that obtained from earlier RCMs. This indicates that the SDM is valuable for estimating climatic response to future changes in greenhouse gases concentration in the atmosphere.

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