Numerical Simulation Study on the Scientific and Methodological Aspects of the Brazilian Proposal*

HU Guoquan (胡国权)1, DAI Xiaosu(戴晓苏)2, Greg BODEKER3, and Andy REISINGER4

1Laboratory for Climate Studies of China Meteorological Administration, National Climate Center
Beijing, 100081, China
2China Meteorological Administration, Beijing 100081, China
3National Institute of Water and Atmospheric Research, New Zealand
4Climate Change Office, Ministry for the Environment, New Zealand

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ABSTRACT

In this paper, by using a simple climate model (SCM), a numerical simulation study has been conducted on the scientific and methodological aspects of Brazilian Proposal. First the initial check of simple climate model has been done, then we do some sensitivity studies on timeframes (attribution start and end dates, and evaluation date), and three attribution methods (marginal attribution method, proportional attribution method, and time-sliced attribution method), at last we get the main conclusions as follows: The simple climate model can represent the results of more complex climate model (e.g., HadCM3), and it is thus used to study the scientific and methodological aspects of the Brazilian Proposal. Because of the limited knowledge of science and data, although attributing a part of temperature increase to different GHG (greenhouse gas) emission source, there is considerable temperature increase unattributed to regional emissions. Therefore it is uncertain to make Brazilian Proposal as the method for the responsibility share of future GHG decrease emission. The choices of different timeframes (attribution start and end dates, and evaluation date) and future emission SRES (Special Report on Emission Scenarios) make great influence on the regional contributions to global climate changes, but different attribution methods have only a little influence.

Key words: simple climate model (SCM), scientific and methodological aspects, Brazilian Proposal

1. Introduction

Observations of surface air temperature indicate that a significant global average warming has occurred during the 20th century. The Intergovernmental Panel on Climate Change (IPCC, 2001) concludes that there is new and stronger evidence that man has influenced the climate. International negotiations have led to a first step in combating climate change with the United Nations Framework Convention on Climate Change (UNFCCC) and the Kyoto Protocol, but further steps are needed in order to achieve the ultimate objective of UNFCCC for stabilizing the greenhouse concentrations at non-dangerous levels (UNFCCC, 1992). To reach this objective in the long-term, global emissions have to peak and then decrease substantially to a very low level within this century. Within this period, the burden to reduce greenhouse gas emissions has to be shared among countries and regions. During the negotiations on the Kyoto Protocol, the delegation of Brazil made a proposal, in May 1997, to set differentiated emissions reduction targets for Annex I Parties of the UNFCCC according to the impact of their historic emissions on temperature rise (UNFCCC, 1997). The proposal’s central idea was that there exists a functional link between greenhouse gas emissions and global temperature increase, or other indicators along the cause-effect chain of climate change so that the indicator can be calculated from the emissions using a simple model or set of models.

The Third Conference of the Parties (COP-3) requested the Subsidiary Body on Scientific and Technical Advice (SBSTA) to further study the methodological and scientific aspects of the proposal. This led to continued debate and analysis (Enting, 1998; Enting and Law, 2002; Den et al., 2002; Höhne, and Blok, K.,...)

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2005; Trudinger and Enting, 2005) and frequent expert meetings organized by the UNFCCC secretariat (UNFCCC, 2001, 2002). The objective of these meetings was to review the scientific and methodological aspects of the proposal and to co-ordinate an inter-comparison of attribution results using a set of simple climate models in an exercise called the Assessment of Contributions to Climate Change (ACCC).

With the Kyoto Protocol becoming effective on February 16, 2005, the topic about the Brazilian Proposal will become more important. In this paper, we will use a simple climate model to study the scientific and methodological aspects of the Brazilian Proposal.

2. Model description

To trace the causal chain of emissions to changes in concentrations to changes in radiative forcing to changes in temperature and finally to changes in sea level, a simple climate model, consisting of a number of components, has been used. The model requires input time series of the three primary anthropogenic GHGs (e.g., CO$_2$, CH$_4$, and N$_2$O) and sulphate aerosol. The model is referred to as a ‘simple’ climate model to differentiate it from the complex atmosphere-ocean general circulation models (AOGCMs). AOGCMs are extremely computationally demanding, often requiring months of processing on massively parallel computers to complete a single climate simulation. AOGCMs therefore cannot be used for long or complex analyses, e.g., those requiring multiple model runs for different scenarios based on different input data sets. Simple climate models have been used extensively in the IPCC Second Assessment Report (SAR) and Third Assessment Report (TAR) for the calculation of global warming potentials etc. They reproduce the essential behaviour of the far more complex AOGCMs by parameterizing key processes that are dealt with in detail by AOGCMs. The result is that simple climate models cannot reproduce the detailed spatial variability in climate change nor reproduce the detailed observed variability in climate change as AOGCMs do. Simple climate models are therefore used to model changes in global parameters such as change in global concentrations of GHGs, changes in global radiative forcing, changes in global mean surface temperature, and changes in sea level. Further information on the use of simple climate models in IPCC assessment reports can be found in Houghton et al. (1997).

Our model is developed from the DELPHI vision Simple Climate Model of New Zealand, which includes the cause-effects chain “emissions→concentrations→radiative forcing→surface temperature change→sea level change”, and a new SO$_2$ radiative forcing method was added. To discuss influence of the non-linearities on the climate system, the marginal method and time-sliced attribution method are added into the model.

2.1 Emissions to concentrations

The pulse substitute version of the Bern Carbon Cycle (CC) model was used to convert CO$_2$ emissions to atmospheric CO$_2$ concentrations (Joos et al., 1996). This version of the Bern CC model is a slightly simpler model than the full Bern CC model and has been tuned to precisely mimic the response of the Bern CC model to changes in CO$_2$ emissions. Specifically, an ocean mixed-layer pulse response function is derived to characterize the exchange of carbon between the surface and deep ocean by tuning to the HILDA ocean model that is what is used in the Bern CC model. The ocean mixed-layer pulse response function shows what fraction of CO$_2$ remains in the surface layer of the ocean as a function of time after a pulse of CO$_2$ from the atmosphere.

Calculations commenced at the end of 1750 when it is assumed that atmospheric CO$_2$ concentrations are at their pre-industrial level (278 ppm), the partial pressure of CO$_2$ in the surface layer of the ocean is in equilibrium with atmospheric CO$_2$ concentrations, and the net flux of CO$_2$ between the atmosphere and biosphere is zero. By the end of 1751, however, CO$_2$ emissions during the previous year raise atmospheric CO$_2$ concentrations. The excess CO$_2$ loading is calculated by taking the CO$_2$ emissions in PgC and dividing by 2.123, the conversion factor for PgC to ppm of CO$_2$. The elevated atmospheric CO$_2$ concentration drives a flux of CO$_2$ between the atmosphere and oceans. The magnitude of the flux is calculated from Joos et al.
(1996):

$$f_{as} = k_g(\Delta p\text{CO}_2,a - \Delta p\text{CO}_2,s),$$

where $\Delta p\text{CO}_2,a$ is the perturbation to atmospheric CO$_2$ concentrations, $\Delta p\text{CO}_2,s$ is the current perturbation to sea water CO$_2$ concentrations, and $k_g$ is the air-sea gas exchange coefficient.

The elevated atmospheric CO$_2$ concentration also stimulates plant growth and thus results in a flux of carbon from the atmosphere into the biosphere. However, this is partially offset by CO$_2$ returned to the atmosphere as a result of the decay of the enhanced plant growth resulting from the higher CO$_2$. The net primary production and decay of biospheric material is therefore treated separately as follows:

$$f_{net} = \Delta f_{npp} - \Delta f_{decay},$$

where $f_{net}$ is the biospheric fertilization, $\Delta f_{decay}$ is the return flux as a result of decay, and $\Delta f_{npp}$ is the change in net primary production as a result of elevated CO$_2$ concentrations (Joos et al., 1996).

Changes in CH$_4$ and N$_2$O concentrations resulting from changing emissions were calculated by integrating the ordinary differential equations describing their budgets, i.e.,

$$\frac{d[\text{CH}_4]}{dt} = \text{CH}_4\text{emissions} - \frac{[\text{CH}_4]}{T_{\text{CH}_4}},$$
$$\frac{d[N_2O]}{dt} = N_2O\text{emissions} - \frac{[N_2O]}{T_{N_2O}},$$

where $[\text{CH}_4]$ and $[N_2O]$ are the concentrations, and $T_{\text{CH}_4}$ and $T_{N_2O}$ are the atmospheric lifetimes of CH$_4$ and N$_2$O.

2.2 Radiative forcing

The change in radiative forcing was calculated as the sum of the changes in radiative forcing from changes in CO$_2$, CH$_4$, N$_2$O, and sulphate aerosol concentrations. The formulae used for CO$_2$, CH$_4$, and N$_2$O radiative forcing are those given in the IPCC Third Assessment Report (IPCC, 2001), viz.,

$$\text{RF(CO}_2) = 5.35\ln([\text{CO}_2(t)]/[\text{CO}_2(t_0)]),$$

where $[\text{CO}_2(t)]$ is the CO$_2$ concentration at time $t$, and $[\text{CO}_2(t_0)]$ is the unperturbed CO$_2$ concentration (278 ppm). Radiative forcing for CH$_4$ (in ppb) is

$$\text{RF(CH}_4) = 0.036\sqrt{\text{CH}_4(t) - \sqrt{\text{CH}_4(t_0)}} - f[\text{CH}_4(t) , N_2O(t_0)] - f[\text{CH}_4(t_0) , N_2O(t_0)],$$

where $[\text{CH}_4(t)]$ is the CH$_4$ concentration at time $t$, and $[\text{CH}_4(t_0)]$ is the unperturbed CH$_4$ concentration (700 ppb), and the function $f$ accounts for the overlap in CH$_4$ and N$_2$O bands and is

$$f(M,N) = 0.47 \cdot \ln(1 + 2.01 \cdot 10^{-5} (MN)^{0.75} + 5.31 \cdot 10^{-15} (MN)^{1.52}).$$

A similar formula is used to calculate the radiative forcing due to N$_2$O (in ppb), viz.,

$$\text{RF(N}_2\text{O}) = 0.12\sqrt{N_2O(t) - \sqrt{N_2O(t_0)}} - f[\text{CH}_4(t) , N_2O(t_0)] - f[\text{CH}_4(t_0) , N_2O(t_0)].$$

Estimates of direct and indirect aerosol radiative forcing were based on a UK Meteorological Office Hadley Centre climate model run (HadCM3). Model results were used to determine factors relating sulphate emissions in the EDGAR database to radiative forcing. The direct radiative forcing, assumed to be proportional to instantaneous emissions, results from the absorption of incoming solar radiation. Indirect effects result from changes to the optical properties of clouds as sulphate aerosols are important cloud condensation nuclei.

We added a new sulphate radiative forcing method into the model, which used a similar approach and derived simple expressions for direct and indirect sulphate aerosol radiative forcing based on SO$_2$ emissions (Joos et al., 2001).

2.3 Temperature increase

The change in global mean surface temperature resulting from changes in radiative forcing was calculated using a double exponential impulse response function model. This is a two-box linear model that has been fitted to HadCM3 model run for a 4×CO$_2$ scenario. The equation can be written as

$$\Delta T(t) = \frac{\Delta T_{2\times}}{Q_{2\times}} \int_{t_0}^{t} Q(t') \left[ \sum_{s=1}^{2} l_s (1/\tau_s) e^{-(t-t')/\tau_s} \right] dt',$$
where the coefficients \( l_1, l_2, \tau_1 \) and \( \tau_2 \) are obtained from the fit to the HadCM3 run. The double exponential response function is essentially the climate response function to the change in radiative forcing and acts as a long-term integrator of the radiative forcing.

### 2.4 Sea level rise

An approach similar to that used to calculate the temperature response to radiative forcing changes was used to calculate the sea level rise response to global mean surface temperature changes, i.e., a double exponential impulse response function was used where the four coefficients required were obtained from fits to a Hadley Centre climate model run (HadCM3) for a 4\( \times \)CO\(_2\) scenario.

### 3. Initial check

In the first phase, we assess whether our simple model can represent the results of more complex carbon cycle and climate models. To this end, we calculate the increase in global-average surface temperature for historical emissions and the SRES A2 future emission scenario.

#### 3.1 Data

Three kinds of data are used in the initial check.

##### 3.1.1 Historical emission data

Version 1.4 of the Emission Database for Global Atmospheric Research (EDGAR) and the Hundred Year Database for integrated environmental assessment (HYDE) provides the global total CO\(_2\) emissions, Global CH\(_4\) and N\(_2\)O emission database (Van Aardenne et al., 2001; Olivier and Berdowski, 2001). Since SO\(_2\) emissions are not available in the version 1.4 EDGAR/HYDE database, emissions from the version 1.3 EDGAR/HYDE database are used.

##### 3.1.2 A2 future emission scenario

For this study the future emission data are taken from the SRES (Special Report on Emission Scenarios): http://www.grida.no/climate/ipcc/emission/index.htm. Emission estimates are available from 1990 to 2100.

##### 3.1.3 Complex climate model results

In the study, HadCM3 coupled model results are used. HadCM3 is an improved version of the Hadley Centre coupled model and produces a realistic and stable climate simulation without flux adjustments (Gordon et al., 2000). A climate model study is designed to evaluate the forced response to anthropogenic emissions over the historical period from 1860 to the present, the projected climate change response up to 2100, using updated scenarios (A1FI, A2, and B2) and an improved modeling methodology.

In our study, simulate the climate between 1760 and 2100. Prior to 1990 historical concentrations, derived from historical emissions are used. Beyond 1990 the concentrations are derived from the A2 emission scenarios (Fig.1).

Emissions are classified into each of the four regions: OECD90, REF, ASIA, and ALM in the terminology of SRES. These regions are explicitly identified for SRES and for the EDGARHYDE database we have assumed the correspondence:

- ‘OECD90’ includes Canada, USA, OECD Europe, Oceania, and Japan;
- ‘REF’ includes eastern Europe and Former USSR;
- ‘ASIA’ includes India Region, China, and Southeast Asia;
- ‘ALM’ includes Latin America, Africa, and Middle East.

### 3.2 Results

For validating the simple climate model, the results of simple climate model and HadCM3 are compared.

##### 3.2.1 Concentration changes

Comparison of the concentration changes calculated with simple climate model (SCM) and HadCM3 is shown in Fig.2. Concentration changes are above baselines in 1750 (pre-industrial level): CO\(_2\) is 278 ppm, CH\(_4\) is 700 ppb, and N\(_2\)O is 270 ppb. Figure 2 shows that the concentration changes calculated by the SCM are very close to those by HadCM3.

##### 3.2.2 Radiative forcing

Comparing the values of radiative forcing calculated by SCM and HadCM3 in Fig.3, we find that they are close to each other. And for the SCM, the results of the two radiative forcing methods are similar, indicating that the new radiative forcing method added into the SCM is correct.
Fig. 1. GHG (CO$_2$, CH$_4$, and N$_2$O) emissions. (the globe is divided into 4 regions. Emissions prior to 1890 are not attributed to any region.)

Fig. 2. Concentration changes of GHG (CO$_2$, CH$_4$, and N$_2$O) calculated by the two models of SCM and HadCM3.

3.2.3 Temperature changes

Figure 4 illustrates the comparison of the temperature change by the two models. The results by the SCM are similar to those of the HadCM3 but the value of SCM changes smoothly and the HadCM3 changes complicatedly, which means that in a certain extent the SCM can be used to do some research on climate change instead of complex climate model.
3.2.4 Sea level changes

Figure 5 displays the comparison of the sea level changes calculated by the two models. In Fig. 5, SCM is similar to HadCM3 before 1990 but there is a little difference between their results after 1990. This is maybe caused by calculating only for the change in sea level resulting from thermal expansion of the ocean and excluding the effects of melting glaciers and melting grounded ice sheets.

4. Sensitivity study

Some sensitivity studies on different timeframes, attribution methods, and future emission scenarios have been done and analyzed their influence on the results of different shares of responsibilities for groups of countries.

4.1 Timeframes

Time choices are important to the calculation of historical responsibility. The first two choices are the attribution start and end dates, which define the time interval for the emissions that will be attributed to regions (hereafter also referred to as the attribution period, i.e., start and end dates). Emissions that occurred before or after the attribution period are included in the model but not attributed (Fig. 6). The next choice is the evaluation date, for which attribution is performed. Usually the attribution is determined at the end of the attribution period. The evaluation date can also be after the attribution end date (Fig. 6). This would allow consideration of the long-term effects of emissions, but would only be relevant to indicators that have unrealized effects, i.e., in the cause-effect chain from concentrations onwards. The composition of the atmosphere after the attributed emissions stopped has an effect on decay processes and therefore may influence the outcome of the attribution.

In Fig. 6, emissions within the attribution period are attributed to the regions/countries. Emissions before and after the attribution period, as well as emissions of other gases and agents are included in the model but “unattributed”. Consequently not all temperature increase is attributed to regions/countries.

In our study, the attribution start date is 1890, 1950, and 1990, and the attribution end date is 2000, 2050, and 2100. The evaluation date is 2100. The choice of the attribution start date is mainly considering history responsibility or more now and future responsibility, and the end date is mainly considering long life GHG. Four cases are chosen including...
1890-2000, 1890-2100, 1950-2050, and 1990-2000. After GHG emitting, they will stay in the atmosphere for a period, in which GHG will make influence on the concentration increase, radiative forcing, temperature change, and sea level rise. Consequently, after stopping emission, the temperature and sea level still increase. In order to consider the long-term climate effects of GHG, we choose 2100 as the evaluation date.

Figure 7 shows regional contributions to the global-mean surface temperature changes in 2100 for different attribution dates. Different attribution dates make great influence on the results of the relative contribution of regions. For the evaluation date of 2100, with attribution dates from 1890 to 2000, the relative contribution for the OECD90 region is the largest, and the ASIA region is the second; but with attribution dates from 1890 to 2100, the conclusion changes as the relative contribution for the OECD90 region drops to the second and the ASIA region rises to the largest.

Note that comparing with the total temperature increase, the unattributed one occupies a great proportion especially when considering history responsibility or short attribution dates. For example, during attribution dates from 1890 to 2000, the unattributed temperature increase occupies to 83%, and during dates from 1990 to 2000, the unattributed rises to 96%. At present, the study of the international science group only gives the result of the attribution parts and does not give the unattributed. Based on it, they get the relative contribution of different regions for the climate change. Therefore we can draw the conclusion that because of limited knowledge of science, it is uncertain to make the Brazilian Proposal as the method for the responsibility share of future GHG decrease emissions.

4.2 Attribution methods

Calculation of regional responsibility is not straightforward, because the climate system, including the biogeochemistry controlling greenhouse agents is not linear. Some stages in the cause-effect chain are nonlinear, and there are feedbacks between different
parts of the climate system. As a consequence, the sum of the effects of emissions from individual sources or regions (considered separately) is not equal to the effect of all emissions together. There are a number of different approaches to attribute the nonlinear changes to the different sources. Trudinger and Enting (2005) presented a detailed description and comparison of seven attribution methods and rated them against a set of criteria. Choice of attribution method has both policy-related and scientific components. Different attribution methods deal with the effect of the nonlinearities differently, so choosing between the methods is partly a policy choice. On the other hand, some attribution methods have obvious difficulties, e.g., the results of one attribution method depend on the degree of disaggregation of the considered sources, and it could therefore be ruled out with scientific arguments.

In this study, we will compare three of the attribution methods: 1) marginal attribution method (new added in SCM); 2) proportional attribution method; and 3) time-sliced attribution method (new added in SCM). The details about the methods can be found in the paper of Trudinger and Enting (2005).

Figure 8 illustrates regional contributions to the global-mean surface temperature increase for different attribution methods in 2100. There is difference in the results of 3 attribution methods, but it is less than the results of other methodologies. The choice of different indicators (e.g., temperature or sea level rise), different attribution dates or evaluation date makes more influences on the relative contributions for regions to the global climate change than the choice of different attribution methods. Comparing Fig.8 with Fig.9, we will find that the different indicators—temperature increases and sea level rise make more influences on the value of the relative contributions for regions to the global climate change than the choice of attribution methods.

4.3 Future SRES

There are 4 future emission scenarios (A1, A2, B1, and B2) used in our study. The results are shown in Fig.10. The choice of different future SRES makes great influence on the relative contributions for regions to the global climate change.

5. Conclusions

After the initial check of simple climate model and sensitivity study on timeframes (attribution start and end dates, and evaluation date), and 3 attribution methods (marginal attribution, proportional attribution, and time-sliced attribution methods), the main conclusions can be drawn as follows:

![Graph showing regional contributions to the global temperature increase in 2100 for 3 attribution methods (attribution dates from 1890 to 2100).](image)
Fig. 9. Regional contributions to the global sea level rise in 2100 for 3 attribution methods (attribution dates from 1890 to 2100).

Fig. 10. Regional contributions to the global temperature increase in 2100 for 4 future SRESs (attribution dates from 1890 to 2100).

(1) Simple climate model can represent the results of more complex climate model (e.g., HadCM3). Thus we can use the SCM to study the scientific and methodological aspects of the Brazilian Proposal. The new radiative forcing method combining into the model is good.

(2) Because of the limited knowledge of science and data, although attributing a part of temperature increase to different GHG emission sources, there is considerable temperature increase unattributed to regional emissions. Therefore it is uncertain to make the Brazilian Proposal as the method for the responsibility share of future GHG decrease emissions.

(3) The choice of different timeframes (attribution start and end dates, and evaluation date) and future emission SRES make great influence on the regional contributions to the global climate changes, but different attribution methods have only a little influence.

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