National greenhouse accounting

SIR — Various methods of estimating national contributions to global warming of emissions across different greenhouse gases have been proposed and discussed in anticipation of an international agreement aimed at slowing climate change. An understandable, comprehensive, technically based accounting method delineating national contributions to global warming is fundamental to a climate agreement. The method should reflect the relative warming ability of different greenhouse gases and assign responsibility for past, present and future contributions from different countries.

Two approaches to such an index have been proposed. The first, based on the work of Lashof and Ahuja[1] and adopted by the Intergovernmental Panel on Climate Change (IPCC)[2], creates a common potential warming unit, referred to as global warming potential (GWP), among the various greenhouse gases by integrating the unit radiative forcing over various future time periods for each gas relative to CO_2. The second, proposed by Hammond *et al.*[3], avoids estimating the uncertain future radiative forcing of the GWP by examining an annual contribution to the atmospheric burden of greenhouse gases weighted by their instantaneous forcing relative to CO_2. This index has been called the global forcing contribution (GFC)[4].

These approaches, although useful first steps, contain weaknesses which, when placed within the rubric of policymaking, may undermine efforts at agreement. I would like to propose a third method, based on an integrated forcing contribution, borrowing from the IPCC approach but emphasizing comprehensive national accounting in the distribution of global warming responsibility.

The national GFC of a particular greenhouse gas can be expressed as

$$\mathrm{GFC}_{ij} = e_{ij} a_i / a_{CO_2} Af_i \qquad (1)$$

where a_i and a_{CO_2} are the instantaneous radiative forcing of a unit increase in the concentration of gas i and CO_2, respectively, and Af_i is the airborne fraction of gas i. The airborne fraction can be simply expressed as

$$Af_i = \Delta c_i / E_i \qquad (2)$$

where Δc_i is the observed change in the concentration of gas i in the atmosphere in a given year, and E_i is the year's total global emissions of gas i.

The use of the airborne fraction, although attractive in relying on observable phenomena, has problems[5–7]. Gas removed from the atmosphere in a given year is mostly tied to emissions in previous years, not the year in which the airborne fraction is calculated. This means that if a nation's emissions in a given year were smaller than emissions in previous years, the airborne fraction would under-penalize that country. Furthermore, if the relative share of global emissions across all nations changed, the airborne fraction would produce unfair assignment of responsibility because the total atmospheric burden has been contributed to disproportionately in the past by all emitting nations. Finally, by using the observable change in the concentration of a greenhouse gas, non-anthopogenic emissions, shared out according to a nation's share of anthropogenic emissions, are included in the accounting and assignment of responsibility. Thus, the airborne fraction reflects past and present emissions but may assign responsibility for those emissions incorrectly.

Use of the GWP as an accounting method was suggested by the IPCC and can be expressed as

$$e_{ij}\mathrm{GWP}_i = e_{ij} \frac{\int_0^\infty c_i(t) a_i \, dt}{\int_0^\infty c_{CO_2}(t) a_{CO_2} \, dt} \qquad (3)$$

where e_{ij} is the emissions of gas i by country j; $a_i(t)$ is the instantaneous radiative forcing due to a unit increase in the concentration of gas i; N_f is the integration time horizon and $c_i(t)$ is the fraction of gas i remaining at time t which can be expressed as $c_i(t) = e^{-t}\tau_i$, assuming the rate of removal is proportional to concentration. The parameter τ_i is the average lifetime of gas i, considered to be the time required to achieve a $1/e$ decrease in concentration.

Calculation of the GWP has been performed by the IPCC for 20-, 100- and 500-year integration time horizons. The GWP contains uncertainties, including quantifying the instantaneous radiative forcing, the lifetimes of various greenhouse gases and the difficulty associated with choosing an appropriate integration time horizon. As well as these, which have already been discussed[1,8], there is one crucial problem: The present and future radiative forcing from past emissions of greenhouse gases is left unaccounted for. Ignoring these past emissions will change the relative assignment of responsibility for greenhouse forcing, favouring large past emitters. The GWP itself is a useful quantity but should be incorporated into an expression that comprehensively accounts for past, present and future contributions to the burden of greenhouse gases in the atmosphere.

An alternative method, integrated forcing contribution (IFC), emphasizing comprehensive assignment of responsibility, might be formulated as

$$\mathrm{IFC}_i = C_{ij}(t)\,\mathrm{GWP}_i \qquad (4)$$

where $C_{ij}(t)$ is the concentration of gas i at time t resulting from emissions from country j. Rather than the use of CO_2 as a reference gas in the GWP, it would be best to use a gas with a more certain lifetime, such as CFC-11 or CFC-12.

$C_{ij}(t)$ can be expressed as

$$C_{ij}(t) = e^{-t/\tau_i} \int^t e^{t'/\tau_i} E_{ij}(t')\, dt' \qquad (5)$$

which is a solution to the conservation of gas i in the atmosphere, where $E_{ij}(t)$ is the anthropogenic emissions from country j and boundary condition $C_{ij}(0) = 0$ applies. $E_{ij}(t)$ can be determined from historical data of national emissions or from records of energy use and land alteration, if direct emissions are not available. The data can be fitted to an emissions expression of the form

$$E_{ij}(t) = E_0 e^{r(t)t} \qquad (6)$$

where E_0 is the emissions at time $t = 0$ and $r(t)$ governs the rate of change of emissions. This rate value can be expressed as a constant or include time dependance depending upon the nature of individual nation's emission patterns. Given an adequate statistical fit, incomplete data sets and data gaps can be overcome.

By quantifying past contributions to present greenhouse gas concentrations, and considering the present and future radiative forcing of those contributions, the IFC emphasizes a comprehensive accounting of national contributions to greenhouse warming. It avoids some of the weaknesses of the IPCC and GFC methods while including the necessary elements. Before considering the difficult but inevitable issues in creating an international climate convention, such as environmental equity, development rights and national control, an accounting method must be agreed upon. The IFC could provide additional framing of the relevant issues involved in creating such a method for the accounting and management of potential greenhouse warming.

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