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Global Warming Potential & its Importance

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Abstract

Global warming potential (GWP) is a measure of how much heat a greenhouse gas traps in the atmosphere up to a specific time horizon, relative to carbon dioxide. It compares the amount of heat trapped by a certain mass of the gas in question to the amount of heat trapped by a similar mass of carbon dioxide and is expressed as a factor of carbon dioxide.

Keywords: Global Warming; Global Temperature Change; Importance of Time Horizon; Water Vapor.

1. Introduction

A GWP is calculated over a specific time horizon, commonly 20, 100, or 500 years. User related choices such as the time horizon can greatly affect the numerical values obtained for carbon dioxide equivalents. In the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, methane has a lifetime of 12.4 years and with climate-carbon feedbacks a global warming potential of 86 over 20 years and 34 over 100 years in response to emissions. For a change in time horizon from 20 to 100 years, the GWP for methane therefore decreases by a factor of approximately 2.5.

The GWP depends on the following factors:

1) the absorption of infrared radiation by a given species
2) the spectral location of its absorbing wavelengths
3) the atmospheric lifetime of the species

Thus, a high GWP correlates with a large infrared absorption and a long atmospheric lifetime. The dependence of GWP on the wavelength of absorption is more complicated. Even if a gas absorbs radiation efficiently at a certain wavelength, this may not affect its GWP much if the atmosphere already absorbs most radiation at that wavelength. A gas has the most effect if it absorbs in a "window" of wavelengths where the atmosphere is fairly transparent. The dependence of GWP as a function of wavelength has been found empirically and published as a graph.

Because the GWP of a greenhouse gas depends directly on its infrared spectrum, the use of infrared spectroscopy to study greenhouse gases is centrally important in the effort to understand the impact of human activities on global climate change.

The substances subject to restrictions under the Kyoto protocol are either rapidly increasing their concentrations in Earth's atmosphere or have a large GWP.

2. Calculating the Global Warming Potential

Just as radioactive forcing provides a simplified means of comparing the various factors that are believed to influence the climate system to one another, global warming potentials (GWPs) are one type of simplified index based upon radioactive properties that can be used to estimate the potential future impacts of emissions of different gases upon the climate system in a relative sense. GWP is based on a number of factors, including the radioactive efficiency (infrared-absorbing ability) of each gas relative to that of carbon dioxide, as well as the decay rate of each gas (the amount removed from the atmosphere over a given number of years) relative to that of carbon dioxide.

The radioactive forcing capacity (RF) is the amount of energy per unit area, per unit time, absorbed by the greenhouse gas that would otherwise be lost to space. It can be expressed by the formula:

$$RF = \sum_{n=1}^{100} Abs_i \cdot F_i / (pathlength \cdot density)$$

Where the subscript i represents an interval of 10 inverse centimeters. Absi represents the integrated infrared absorbance of the sample in that interval, and Fi represents the RF for that interval.

The Intergovernmental Panel on Climate Change (IPCC) provides the generally accepted values for GWP, which changed slightly between 1996 and 2001. An exact definition of how GWP is calculated is to be found in the IPCC's 2001 Third Assessment Report. The GWP is defined as the ratio of the time-integrated radioactive forcing from the instantaneous release of 1 kg of a trace substance relative to that of 1 kg of a reference gas:

$$GWP\left(x\right) = \frac{\int_0^{TH} a_x \cdot \left[x(t)\right] dt}{\int_0^{TH} a_r \cdot \left[r(t)\right] dt}$$

where TH is the time horizon over which the calculation is considered; ax is the radiative efficiency due to a unit increase in atmospheric abundance of the substance (i.e., Wm−2 kg−1) and [x(t)] is the time-dependent decay in abundance of the substance following an instantaneous release of it at time t=0. The denominator contains the corresponding quantities for the reference gas (i.e. CO2). The radiative efficiencies ax and ar are not necessarily constant over time. While the absorption of infrared radiation by many greenhouse gases varies linearly with their abundance, a few important ones display non-linear behavior for current and likely future abundances (e.g., CO2, CH4, and N2O). For those gases, the relative radiative forcing will depend upon abundance and hence upon the future scenario adopted.

Since all GWP calculations are a comparison to CO2 which is non-linear, all GWP values are affected. Assuming otherwise as is done above will lead to lower GWPs for other gases than a more detailed approach would. Clarifying this, while increasing CO_2 has less and less effect on radiative absorption as ppm concentrations rise, more powerful greenhouse gases like methane and nitrous oxide have different thermal absorption frequencies to CO_2 that are not filled up (saturated) as much as CO_2, so rising ppms of these gases are far more significant.

3. Global Temperature Change Potential (GTP)

The Global Temperature Change Potential is another way to quantify the ratio change from a substance relative to that of CO_2, in global mean surface temperature, used for a specific time span.

4. Importance of Time Horizon

A substance's GWP depends on the time span over which the potential is calculated. A gas which is quickly removed from the atmosphere may initially have a large effect, but for longer time periods, as it has been removed, it becomes less important. Thus methane has a potential of 34 over 100 years but 86 over 20 years; conversely sulfur hexafluoride has a GWP of 22,800 over 100 years but 16,300 over 20 years (IPCC Third Assessment Report). The GWP value depends on how the gas concentration decays over time in the atmosphere. This is often not precisely known and hence the values should not be considered exact. For this reason, when quoting a GWP it is important to give a reference to the calculation.

The GWP for a mixture of gases can be obtained from the mass-fraction-weighted average of the GWPs of the individual gases.

The global warming potential of perfluorotributylamine (PFTBA) over a 100-year time horizon has been estimated to be approximately 7100. It has been used by the electrical industry since the mid-20th century for electronic testing and as a heat transfer agent. PFTBA has the highest radiative efficiency (relative effectiveness of greenhouse gases to restrict long-wave radiation from escaping back into space) of any molecule detected in the atmosphere to date. The researchers found an average of 0.18 parts per trillion of PFTBA in Toronto air samples, whereas carbon dioxide exists around 400 parts per million.

5. Water Vapor

Water vapor is one of the primary greenhouse gases, but some issues prevent its GWP to be calculated directly. It has a profound infrared absorption spectrum with more and broader absorption bands than CO_2, and also absorbs non-zero amounts of radiation in its low absorbing spectral regions. Next, its concentration in the atmosphere depends on air temperature and water availability; using a global average temperature of ~16 °C, for example, creates an average humidity of ~18,000ppm at sea level (CO_2 is ~400ppm and so concentrations of $[H_2O]/[CO_2]$ ~ 45x). Unlike other GHG, water vapor does not decay in the environment, so an average over some time horizon or some other measure consistent with "time dependent decay," q.v., above, must be used in lieu of the time dependent decay of artificial or excess CO2 molecules. Other issues complicating its calculation are the Earth's temperature distribution, and the differing land masses in the Northern and Southern hemispheres.

6. Conclusion

The Global Warming Potential (GWP) was developed to allow comparisons of the global warming impacts of different gases. Specifically, it is a measure of how much energy the emissions of 1 ton of a gas will absorb over a given period of time, relative to the emissions of 1 ton of carbon dioxide (CO2).

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