# Climate Forcing

## Identification

### 1. Indicator Description

This indicator measures the levels of greenhouse gases (GHGs) in the atmosphere between 1979 and 2010 based on their ability to cause changes in the Earth's climate. Results are reflected in the Annual Greenhouse Gas Index.

### 2. Revision History

April 2010: Indicator posted
December 2011: Indicator updated with data through 2010
October 2012: Indicator updated with data through 2011

## Data Sources

### 3. Data Sources

GHG concentrations are measured by a cooperative global network of monitoring stations overseen by the National Oceanic and Atmospheric Administration's (NOAA's) Earth System Research Laboratory (ESRL). The indicator uses measurements of 20 GHGs.

### 4. Data Availability

This indicator is based on NOAA's Annual Greenhouse Gas Index (AGGI). Annual values of the AGGI (total and broken down by gas) are posted online at: www.esrl.noaa.gov/gmd/aggi/, along with definitions and descriptions of the data. EPA obtained data from NOAA's public website.

The AGGI is based on data from monitoring stations around the world. Most of these data were collected as part of the NOAA/ESRL cooperative monitoring network. Data files from these cooperative stations are available online at: www.esrl.noaa.gov/gmd/dv/ftpdata.html. Users can obtain station metadata by navigating to: www.esrl.noaa.gov/gmd/dv/site/, viewing a list of stations, and then selecting a station of interest.

Methane data prior to 1983 are annual averages from Etheridge et al. (1998). Users can download data from this study at: http://cdiac.ornl.gov/trends/atm_meth/lawdome_meth.html.

# Methodology

## 5. Data Collection

This indicator is based on measurements of the concentrations of various long-lived GHGs in ambient air. These measurements have been collected following consistent high-precision techniques that have been documented in peer-reviewed literature.

The indicator uses measurements of five "major" GHGs and 15 other GHGs. The five major GHGs for this indicator are carbon dioxide ($CO_2$), methane ($CH_4$), nitrous oxide ($N_2O$), and two chlorofluorocarbons: CFC-11 and CFC-12. According to NOAA, these five GHGs account for about 96 percent of the increase in direct radiative forcing by long-lived GHGs since 1750. The other 15 gases are CFC-113, carbon tetrachloride ($CCl_4$), methyl chloroform ($CH_3CCl_3$), HCFC-22, HCFC-141b, HCFC-142b, HFC-23, HFC-125, HFC-134a, HFC-143a, HFC-152a, sulfur hexafluoride ($SF_6$), halon-1211, halon-1301, and halon-2402.

Monitoring stations in NOAA's ESRL network collect air samples at about 80 global clean air sites, although not all sites monitor for all the gases of interest. Monitoring sites include fixed stations on land as well as measurements at 5-degree latitude intervals along specific ship routes in the oceans. Monitoring stations collect data at least weekly. These weekly measurements can be averaged to arrive at an accurate representation of annual concentrations.

For a map of monitoring sites in the NOAA/ESRL cooperative network, see: www.esrl.noaa.gov/gmd/aggi. For more information about the global monitoring network and a link to an interactive map, see NOAA's website at: www.esrl.noaa.gov/gmd/dv/site.

## 6. Indicator Derivation

From weekly station measurements, NOAA calculated a global average concentration of each gas using a smoothed north-south latitude profile in sine latitude space. NOAA averaged these weekly global values over the course of the year to determine an annual average concentration of each gas. Pre-1983 methane measurements came from stations outside the NOAA/ESRL network; these data were adjusted to NOAA's calibration scale before being incorporated into the indicator.

Next, NOAA transformed gas concentrations into an index based on radiative forcing. These calculations account for the fact that different gases have different abilities to alter the Earth's energy balance. NOAA determined the total radiative forcing of the GHGs by applying radiative forcing factors that have been scientifically established for each gas based on its global warming potential and its atmospheric lifetime. These values and equations have been recommended by the Intergovernmental Panel on Climate Change (IPCC) (2001). In order to keep the index as accurate as possible, NOAA's radiative forcing calculations considered only direct forcing, not additional model-dependent feedbacks such as those due to water vapor and ozone depletion.

NOAA compared present-day concentrations with concentrations circa 1750 (i.e., before the start of the Industrial Revolution), and this indicator shows only the radiative forcing associated with the *increase* in concentrations since 1750. In this regard, the indicator focuses only on the additional radiative forcing that has resulted from human-influenced emissions of GHGs.

Figure 1 shows radiative forcing from the selected GHGs in units of watts per square meter. This forcing value is calculated at the tropopause, which is the boundary between the troposphere and the stratosphere. Thus, the square meter term refers to the surface area of the sphere that contains the Earth and its lower atmosphere (the troposphere). The watts term refers to the rate of energy transfer.

The data provided to EPA by NOAA also describe radiative forcing in terms of the AGGI. This unitless index is formally defined as the ratio of radiative forcing in a given year compared with a base year of 1990, which was chosen because 1990 is the baseline year for the Kyoto Protocol. Thus, 1990 is set to a total AGGI value of 1. An AGGI scale appears on the right side of Figure 1.

NOAA's monitoring network did not provide sufficient data prior to 1979, and no attempt has been made to project the indicator backward before that start date. No attempt has been made to project trends forward into the future, either.

This indicator can be reconstructed from publicly available information. NOAA's website (www.esrl.noaa.gov/gmd/aggi) provides a complete explanation of how to construct the AGGI from the available concentration data, including references to the equations used to determine each gas's contribution to radiative forcing. See Hofmann et al. (2006a) and Hofmann et al. (2006b) for more information about the AGGI and how it was constructed. See Dlugokencky et al. (2005) for information on special steps that were taken to adjust pre-1983 methane data to NOAA's calibration scale.

### 7. Quality Assurance and Quality Control

The online documentation for the AGGI does not explicitly discuss quality assurance and quality control procedures. NOAA's analysis has been peer-reviewed and published in the scientific literature, however (see Hofmann et al., 2006a and 2006b), and users should have confidence in the quality of the data.

## Analysis

### 8. Comparability Over Time and Space

With the exception of pre-1983 methane measurements, all data were collected through the NOAA/ESRL global monitoring network with consistent techniques over time and space. Pre-1983 methane measurements came from stations outside the NOAA/ESRL network; these data were adjusted to NOAA's calibration scale before being incorporated into the indicator.

The data for this indicator have been spatially averaged to ensure that the final value for each year accounts for all of the original measurements to the appropriate degree. Results are considered to be globally representative, which is an appropriate assumption because the gases covered by this indicator have long residence times in the atmosphere and are considered to be well-mixed. Although there are minor variations among sampling locations, the overwhelming consistency among sampling locations indicates that extrapolation from these locations to the global atmosphere is reliable.

### 9. Sources of Uncertainty

This indicator is based on direct measurements of atmospheric concentrations of GHGs. These measurements are of a known and high quality, collected by a well-established monitoring network.

NOAA's AGGI website does not present explicit uncertainty values for either the AGGI or the underlying data, but exact uncertainty estimates can be obtained by contacting NOAA.

The empirical expressions used for radiative forcing are derived from atmospheric radiative transfer models and generally have an uncertainty of about 10 percent. The uncertainties in the global average concentrations of the long-lived GHGs are much smaller, according to the AGGI website documentation at: www.esrl.noaa.gov/gmd/aggi.

Uncertainty is expected to have little bearing on the conclusions for several reasons. First, the indicator is based entirely on measurements that have low inherent uncertainty. Second, the increase in GHG radiative forcing over recent years is far greater than the estimated uncertainty of underlying measurement methodologies, and it is also greater than the estimated 10 percent uncertainty in the radiative forcing equations. Thus, it is highly unlikely that the trends depicted in this indicator are somehow an artifact of uncertainties in the sampling and analytical methods.

## 10. Sources of Variability

Collecting data from different locations could lead to some variability, but this variability is expected to have little bearing on the conclusions. Scientists have found general agreement in trends among multiple data sets collected at different locations using different program designs, providing some assurance that the trends depicted actually represent atmospheric conditions, rather than some artifact of sampling design.

## 11. Statistical/Trend Analysis

The increase in GHG radiative forcing over recent years is far greater than the estimated uncertainty of underlying measurement methodologies, and it is also greater than the estimated 10 percent uncertainty in the radiative forcing equations. Thus, it is highly likely that the trends depicted in this indicator accurately represent changes in the Earth's atmosphere.

## 12. Data Limitations

Factors that may impact the confidence, application, or conclusions drawn from this indicator are as follows:

1. The AGGI and its underlying analysis do not provide a complete picture of radiative forcing from the major GHGs because they do not consider indirect forcing due to water vapor, ozone depletion, and other factors. These mechanisms have been excluded because quantifying them would require models that would add significant uncertainty to the indicator.
2. This indicator does not include radiative forcing due to shorter-lived GHGs and other radiatively important atmospheric constituents such as black carbon, aerosols, and sulfates. Reflective aerosol particles in the atmosphere can reduce climate forcing, for example, while tropospheric ozone can increase it. These spatially heterogeneous, short-lived climate forcing agents have uncertain global magnitudes and thus are not included in NOAA's index to maintain accuracy.

## References

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