# State of the Science FACT SHEET

## Greenhouse Gases and Climate

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION • UNITED STATES DEPARTMENT OF COMMERCE

*Greenhouse gases (GHGs) are several of many gases in Earth's atmosphere. Their unique feature is their ability to trap heat in the form of radiation (Figure 1), thereby maintaining the Earth's atmosphere at a habitable temperature - a process known as the greenhouse effect. Levels of GHGs in excess of those present due to natural cycles disturb Earth's energy balance and change climate, including raising atmospheric temperature and altering rainfall patterns. Since the industrial revolution, atmospheric concentrations of GHGs, especially $CO_2$, $N_2O$, and $CH_4$, have been increasing due to extraction and burning of fossil fuels and land use changes. About half of the excess emission of $CO_2$ is absorbed by the terrestrial biosphere and the ocean (where it leads to ocean acidification). Although all GHGs are present in the atmosphere in trace amounts (collectively less than 0.05%), some of the most abundant ones are $CO_2$ and $CH_4$, while some of the most potent ones are CFCs. Overall, the major GHGs (those with high enough concentrations and absorption to affect climate) are listed in the table below.*

**NOAA monitors the following major GHGs**

| | |
|---|---|
| $CO_2$ | carbon dioxide |
| $CH_4$ | methane |
| Halocarbons | chlorofluorocarbons (CFCs), hydrochlorofluorocarbons (HCFCs), and hydrofluorocarbon (HFCs) |
| $SF_6$ | sulfur hexafluoride |
| $N_2O$ | nitrous oxide |
| $O_3$ | ozone |
| $H_2O$ | water vapor |

*Concentrations of $CO_2$, $CH_4$, and $N_2O$ have been, with few exceptions, steadily increasing on global and regional scales. NOAA is dedicated to understanding the cause of these trends and has been measuring GHGs in the atmosphere and ocean for decades (Figure 2). NOAA data, computer models and science products on local to global scale inform climate mitigation strategies by helping to estimate GHG emissions and sinks, providing attribution of emissions by specific regions and economic sectors. NOAA efforts also provide independent and accurate verification of mitigation actions such as carbon dioxide removal (CDR).*

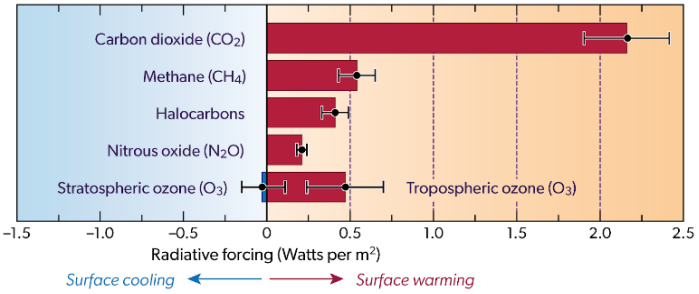


***Figure 1.*** *GHG Radiative Forcing (RF), or heat energy per unit area trapped as infrared radiation, in the present day (2019) relative to preindustrial (1750)*

### GHG sources and sinks

Human sources of GHGs include fossil fuel combustion, and industrial and agricultural processes. Natural sources include wildfires, geological sources, and plant decomposition. Water vapor is not directly emitted, but rather is a feedback to changes in the Earth system due to human and natural activity. Many GHGs remain in the atmosphere from decades to centuries, well mixed throughout the atmosphere, thus making rapid removal difficult. GHGs are removed from the atmosphere by the land and ocean through physical and biological processes, as well as by chemical interactions, which transform them into other gases.

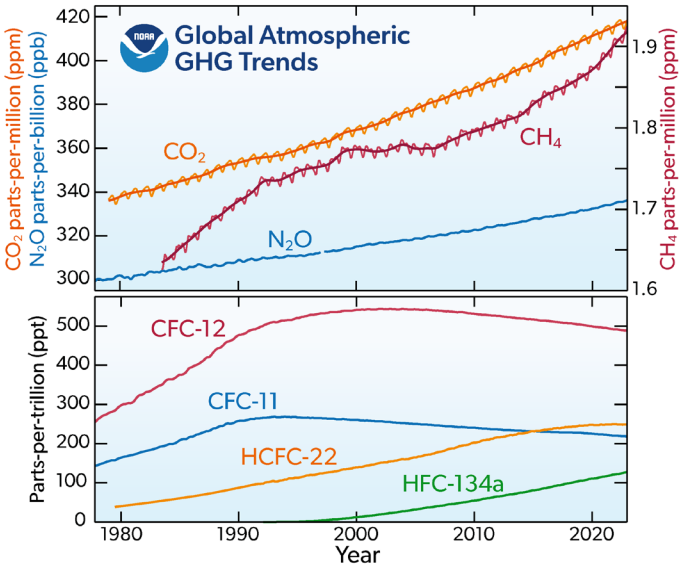


***Figure 2.*** *Global record of atmospheric GHG concentrations*

### NOAA's role in monitoring GHGs: measurements and models

- *GHG atmospheric monitoring* – The Global Greenhouse Gas Reference Network (GGGRN) (Figure 3) measures atmospheric distributions and trends of the three main long-term drivers of climate change, carbon dioxide ($CO_2$), methane ($CH_4$), and nitrous oxide ($N_2O$). NOAA serves as the World Meteorological Organization (WMO) Central Calibration Laboratory for $CO_2$, $CH_4$, $N_2O$, and $SF_6$ in air. This is a decades-long global collaborative effort to monitor GHGs in the atmosphere. NOAA is also involved in monitoring global $O_3$ trends through a regular Tropospheric Ozone Assessment Report (TOAR).
- *GHG emissions* - NOAA conducts research studies via aircraft, mobile laboratories, and other measurements and regional to global models to determine GHG sources, thus quantifying the amount and attribution of emissions by specific regions and economic sectors, and improving emission inventories that guide decision-making.
- *GHG and Earth system interactions* - In addition to its monitoring efforts, NOAA conducts observational process studies and modeling to understand GHG interactions to both estimate historical GHG fluxes through assimilation of environmental data (e.g. CarbonTracker, HYSPLIT) and project long-term interactions in the land-atmosphere-ocean system of historical (hindcast) and future timescales (prediction and projection) with Earth system models. NOAA develops Earth system models including the biogeochemical processes crucial for understanding and projecting GHG concentrations.

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**The NOAA Annual Greenhouse Gas Index (AGGI)** is a measure that tracks the increasing amount of heat being added to the atmosphere by human-related greenhouse gas (GHG) emissions. It is based on the highest quality measurements of GHGs in the atmosphere from sites around the world. Its uncertainty is very low. Each year the increasing AGGI reminds us that our ongoing emission of long-lived GHGs (e.g. CO2, CH4) results in more of the sun's heat being trapped in the Earth system.

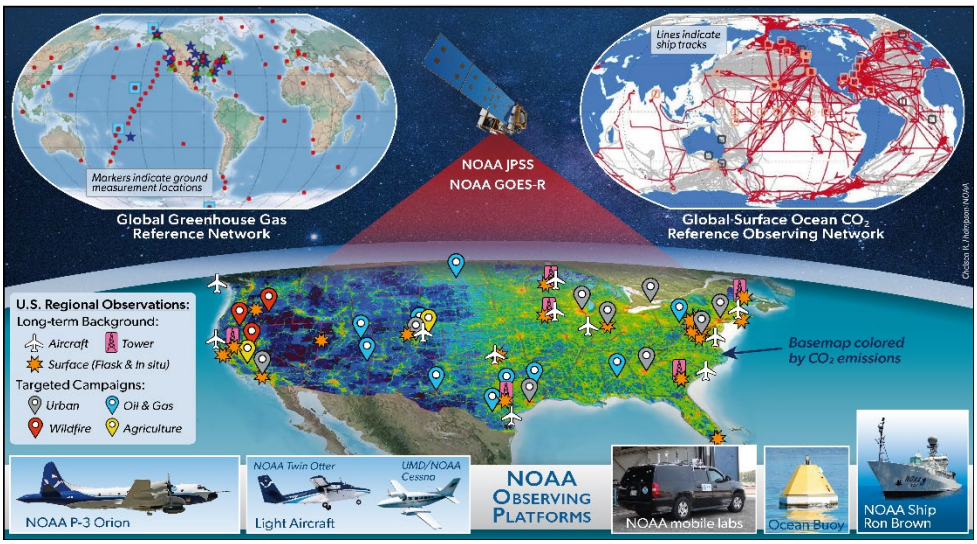


***Figure 3.*** *Greenhouse gas measuring and monitoring activities at NOAA.*

- *GHG and the ocean* - Sustained global ocean carbon observations monitor the critical role of the ocean in taking up GHGs and help quantify how ocean carbon uptake and storage may change in the future. This work also includes preparing society to respond to GHG-caused ocean acidification through observing systems and modeling, marine species sensitivity experiments, socioeconomic and cultural impact studies, and interdisciplinary partnerships.
- *GHG observations from satellites* - NOAA satellites monitor fires that release GHGs. Daily observations could support Global Stocktake (GST) efforts, both from monitoring and modeling (e.g. CarbonTracker) perspectives. NOAA satellites observe GHGs in the middle troposphere that are useful to track long-term global trends and when combined with other GHG measurements in a modeling system, they can provide fluxes at Earth's surface. NOAA curates and archives long-term records of satellite data.

## Resources for Additional Information

**Air Resources Lab** [arl.noaa.gov]: Aircraft, mobile, and surface measurements of GHGs and modeling activities to track GHG transport and dispersion (HYSPLIT) and improve GHG flux estimates. Urban Scale GHG monitoring.

**Atlantic Oceanographic and Meteorological Lab** [aoml.noaa.gov] and **Pacific Marine Environmental Lab** [pmel.noaa.gov]: Air-sea $CO_2$ observations on ships, buoys, and uncrewed surface vehicles to contribute annually to Surface Ocean $CO_2$ Atlas (SOCAT) and Global Carbon Budget (GCB) products. Surface-to-seafloor surveys from ships monitor $CO_2$ in the ocean.

**Center for Satellite Applications and Research** [star.nesdis.noaa.gov]: Science and applications to transform satellite observations, including GHGs, into information.

**Chemical Sciences Lab** [csl.noaa.gov]: Laboratory and field measurements using aircraft, mobile labs, and ground-based instruments and use of satellite observations to measure, model, and map GHG concentrations and quantify sources and sinks for emission inventories.

**Climate Program Office** [cpo.noaa.gov]: Competitive research support for all types of GHG measurement and modeling studies.

**Geophysical Fluid Dynamics Lab** [gfdl.noaa.gov]: Development and application of numerical models to advance understanding of historical and future drivers of changes in GHGs and their influence on the Earth system.

**Global Monitoring Lab** [gml.noaa.gov/ccgg]: Long-term monitoring networks with a continuous record of GHGs for trend studies and process understanding. Development of CarbonTracker modeling system, which provides CO2 and methane fluxes on a regular, typically annual, basis.

**Global Ocean Monitoring and Observing Program** [globalocean.noaa.gov]**:** Support for sustained, high-quality global ocean carbon observations, research, and products.

**National Centers for Environmental Information** [ncei.noaa.gov]: Repository of U.S. and global environmental data, products, and monitoring and assessment services that collectively characterize Earth and beyond.

**Ocean Acidification Program** [oceanacidification.noaa.gov]**:** Support for NOAA's ocean acidification observing network.

**Office of Low Earth Orbit** [nesdis.noaa.gov/about/our-offices/office-of-low-earth-orbit-observations]: Development of the Next Generation of Polar-Orbiting and Low-Earth-Orbiting Operational Environmental Satellites.

**Office of Satellite and Product Operations** [nesdis.noaa.gov/about/our-offices/office-of-satellite-and-product-operations-ospo] The primary intermediary between civil sector users of data and operational environmental satellites, and is also responsible for transmitting data to remote receiving stations.