

WMO GREENHOUSE GAS BULLETIN

The State of Greenhouse Gases in the Atmosphere
Based on Global Observations through 2025

No. 22, 27 October 2026

ISSN 2078-0796

Increasing levels of anthropogenic greenhouse gases in the atmosphere continue driving changes in the global climate, with the last 11 years being the warmest recorded [1]. Increases in carbon dioxide (CO_2) and methane (CH_4) surface concentrations continue to dominate the changes in the radiative forcing of Earth's climate. As countries respond and take steps to transform their energy systems towards decarbonization, careful attention should be given to two potent but less abundant trace gases closely related to electricity production and distribution: molecular hydrogen (H_2) and sulfur hexafluoride (SF_6). SF_6 has been rising steadily over the past three decades in proportion to increased global electrification, as SF_6 is used primarily as a spark suppressant in electricity distribution. The reasons for the increase of H_2 over the past decade are currently unknown, but H_2 has begun to be used as an energy storage medium that has strong potential in intermittent carbon-free energy production modes such as solar and wind.

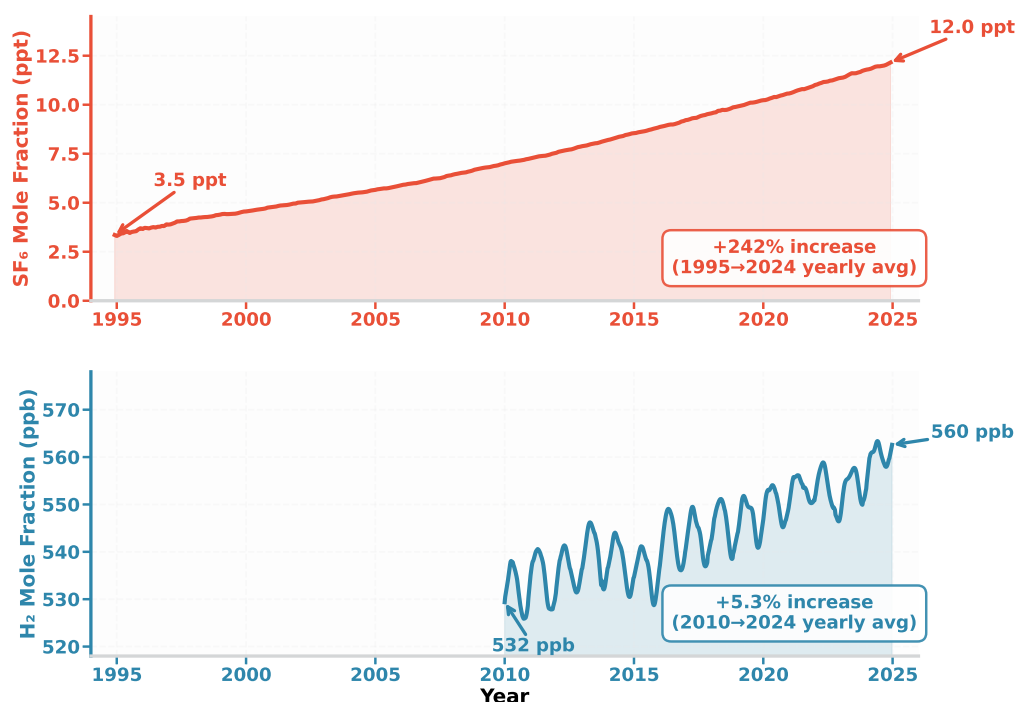


Figure 1. Globally averaged mole fractions of SF_6 (in parts per trillion (ppt))⁽ⁱ⁾ and H_2 (in parts per billion (ppb))⁽ⁱⁱ⁾ as estimated on the basis of direct observations in the atmosphere by the United States of America National Oceanic and Atmospheric Administration (NOAA) Global Monitoring Laboratory [2], [3], [4]

Atmospheric SF₆ is a synthetic fluorinated compound with an atmospheric lifetime of up to 3 200 years according to the Intergovernmental Panel on Climate Change (IPCC) (with recent model estimates between about 1 900 and 2 650 years). Of all the greenhouse gases, it has the highest 100-year global warming potential (GWP), of approximately 24 300 times that of CO₂ [5]. Observations of SF₆ concentration in the atmosphere are carried out within the Global Atmosphere Watch (GAW) Programme by its contributing networks and partners (NOAA, Advanced Global Atmospheric Gases Experiment (AGAGE) and Integrated Carbon Observing System (ICOS)). The observational record shows a persistent and accelerating increase from an average of 3.5 ppt in 1995 to 12.24 ppt in 2025, representing a 249% increase over three decades (Figure 1), which is parallel to the increase in electricity generation in different parts of the world. The increase of SF₆ within 2025 was a record high, at 0.48 ppt per year [2].

Atmospheric SF₆ originates almost entirely from anthropogenic activities, arising primarily from its use as an electrical insulator in high-voltage switchgear, with smaller contributions from magnesium and electronics industries [6] and very small contributions from natural sources [7]. The only significant sink is photochemical destruction in the mesosphere [8]. Given its dominant anthropogenic sources, SF₆ has also been used as a tracer for atmospheric transport studies [9]. Due to its very long atmospheric lifetime, current emissions will contribute to radiative forcing for thousands of years. Encouragingly, emerging alternatives have a GWP 98% lower than SF₆ [10]. Meanwhile, the existing stores of SF₆ in electrical equipment represents a significant and latent climate liability.

Hydrogen is being used as an energy storage medium for hard-to-decarbonize sectors (such as steelmaking, shipping and long-duration energy storage), as well as for renewable sources and as an energy source for transport [11]. Yet its leakage into the atmosphere from production facilities, pipelines, storage tanks and fuel cells poses a growing concern [12]. Hydrogen is not a greenhouse gas, and unlike fossil fuels, its combustion produces no CO₂. However, it has a strong indirect radiative forcing effect through its influence on atmospheric chemistry, with 20-year and 100-year GWPs of 37±18 and 11±4 times that of CO₂ [13]. H₂ reacts with hydroxyl radical (OH), the atmosphere's primary cleansing agent, thereby potentially reducing the oxidative capacity for removing atmospheric species such as CH₄ and carbon monoxide. This extends the atmospheric lifetime of

CH₄ and can impact the efficiency of mitigation efforts to reduce CH₄ emissions. Additionally, H₂ oxidation contributes to tropospheric ozone formation and increases stratospheric water vapour, both strong short-lived greenhouse gases [14].

The atmospheric H₂ record exhibits a strong seasonal cycle driven by seasonality of sources and sinks superimposed on a rising baseline. Annual H₂ concentration increased from 532 ppb in 2010 to 560 ppb in 2024, a growth of 5.3% (Figure 1). The global atmospheric H₂ budget is dominated by chemical production from CH₄ and non-methane volatile organic compounds (NMVOC) (~38 teragrams (Tg) year⁻¹) and direct emissions from fossil fuel combustion, biomass burning and biological nitrogen fixation (~27 Tg year⁻¹) as the primary sources. Soil uptake (~50 Tg year⁻¹) serves as the dominant sink, nearly three times the amount removed by OH oxidation (~18 Tg year⁻¹), with tropical regions thought to contribute the largest share of both sources and sinks [13]. The observed upward trend reflects growing CH₄ concentration and direct emissions in the atmosphere. If hydrogen is to deliver its promised climate benefit, leakage must be minimized [15]. Modelling studies [16] suggest that operational and fugitive hydrogen emissions alone could contribute 0.05–0.1 °C of warming by 2100 (at consumption levels of 500–1 000 Tg of H₂ per year, emission rates of 10% and absent CH₄ mitigation).

Here, we highlight contrasting aspects of anthropogenic influence on atmospheric composition: SF₆ represents the challenge of irreversible, long-lived greenhouse gas accumulation from industrial processes, while H₂ illustrates the subtle but potentially significant indirect climate effects of a gas used as an energy carrier. Both H₂ leakage and SF₆ persistence represent potential threats that could undermine the climate benefits of the energy transition. Careful monitoring of the composition of Earth's atmosphere is essential to detect, understand and prevent unintended consequences of these changes.

WMO, through its GAW Programme, coordinates global observations of both gases and supports a stable and internationally recognized calibration scale for atmospheric SF₆ and H₂ measurements. High-quality, sustainable observations are essential to track small spatial and temporal changes in atmospheric SF₆ and H₂. The robust WMO GAW framework allows for joint data utilization across different programmes around the world, enabling researchers to confidently track changes in atmospheric SF₆ and H₂ concentrations and investigate changes in their sources and sinks.

Executive summary

The latest analysis of observations from the WMO Global Atmosphere Watch (GAW) in situ observational network shows that the globally averaged surface concentrations⁽ⁱⁱⁱ⁾ for carbon dioxide (CO₂), methane (CH₄) and nitrous oxide (N₂O) reached unprecedented highs in 2025, with CO₂ at 426.8±0.2 ppm,^(iv) CH₄ at 1948±2 ppb and N₂O at 339.1±0.1 ppb. These values constitute, respectively, increases of 53%, 167% and 26% above pre-industrial (before 1750) levels. The increase in CO₂ from 2024 to 2025 was lower than the anomalously high increase from 2023 to 2024 but slightly higher than the average annual growth rate over the last decade (2016–2025). For CH₄, the increase from 2024 to 2025 was lower than that observed from 2023 to 2024 and also lower than the average annual growth rate over the last decade. For N₂O, the increase from 2024 to 2025 was the same as that observed from 2023 to 2024 and close to the average annual growth rate over the last decade. The NOAA Annual Greenhouse Gas Index (AGGI) [17] shows that from 1990 to 2025, radiative forcing by long-lived greenhouse gases (LLGHGs) increased by 56%, with CO₂ accounting for about 81% of this increase.

Overview of observations from the GAW in situ observational network for 2025

This twenty-second annual WMO Greenhouse Gas (GHG) Bulletin reports atmospheric abundances and rates of change of the most important LLGHGs – carbon dioxide, methane and nitrous oxide – and provides a summary of the contributions of other greenhouse gases. CO₂, CH₄ and N₂O, together with dichlorodifluoromethane (CFC-12) and trichlorofluoromethane (CFC-11), account for approximately 97%^(v) [14] of radiative forcing due to LLGHGs (Figure 2).

The WMO GAW Programme coordinates systematic observations and analyses of GHGs and other trace species. Sites where greenhouse gases have been measured in the last decade are shown in Figure 3. Measurement data are reported by participating Members and archived and distributed by the World Data Centre for Greenhouse Gases (WDCGG) at the Japan Meteorological Agency.

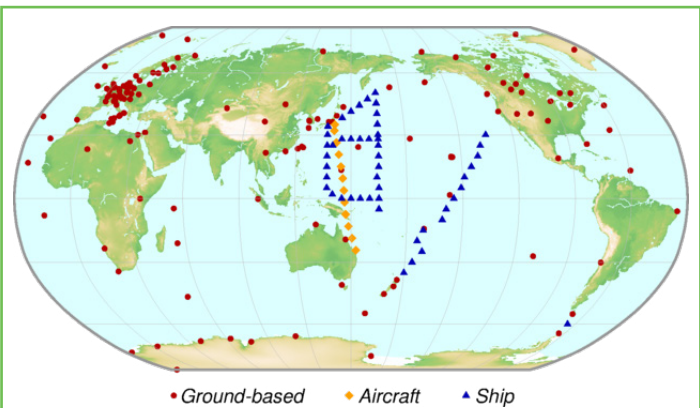


Figure 3. The GAW global network for CO₂ in the last decade. The network for CH₄ is similar. The in situ network for N₂O and other LLGHGs is far less dense. Source: Third-party map. This map was provided by the WDCGG on 1 October 2026 and may not fully align with United Nations and WMO map guidance.

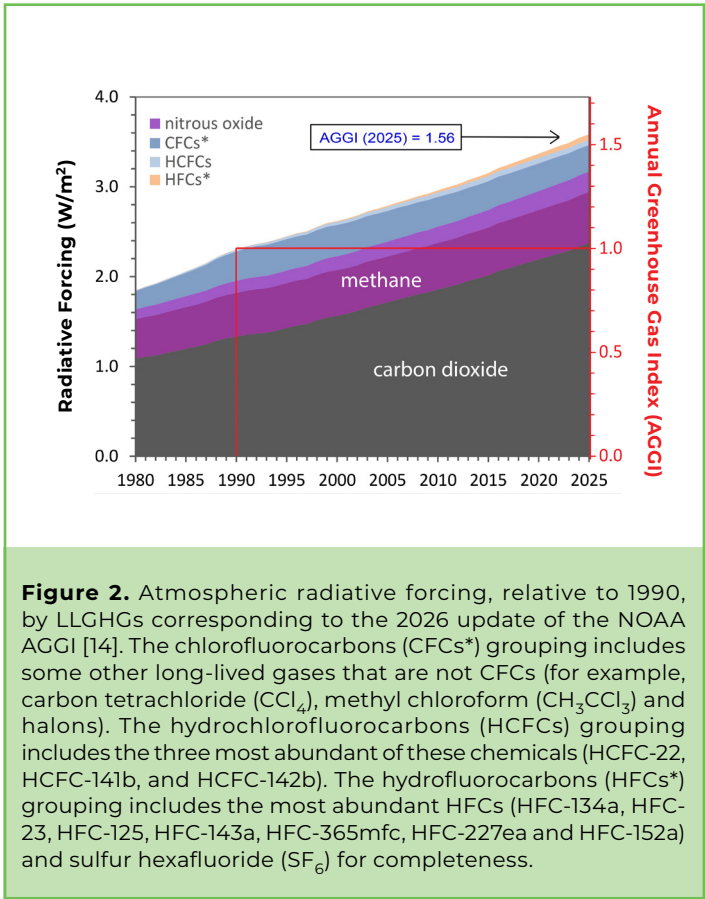


Figure 2. Atmospheric radiative forcing, relative to 1990, by LLGHGs corresponding to the 2026 update of the NOAA AGGI [14]. The chlorofluorocarbons (CFCs*) grouping includes some other long-lived gases that are not CFCs (for example, carbon tetrachloride (CCl₄), methyl chloroform (CH₃CCl₃) and halons). The hydrochlorofluorocarbons (HCFCs) grouping includes the three most abundant of these chemicals (HCFC-22, HCFC-141b, and HCFC-142b). The hydrofluorocarbons (HFCs*) grouping includes the most abundant HFCs (HFC-134a, HFC-23, HFC-125, HFC-143a, HFC-365mfc, HFC-227ea and HFC-152a) and sulfur hexafluoride (SF₆) for completeness.

The results reported here by WMO WDCGG for the global average and growth rate are slightly different from the results reported by NOAA for the same years [18] due to differences in the stations used and the averaging procedure, as well as a slight difference in the time period for which the numbers are representative. WMO WDCGG follows the procedure described in detail in [19] and [20]. Materials additional to the analysis presented in the present Bulletin are available at https://gaw.kishou.go.jp/publications/summary_figures.

The table provides globally averaged atmospheric abundances of the three major LLGHGs in 2025 and changes in their abundances since 2024 and since 1750.

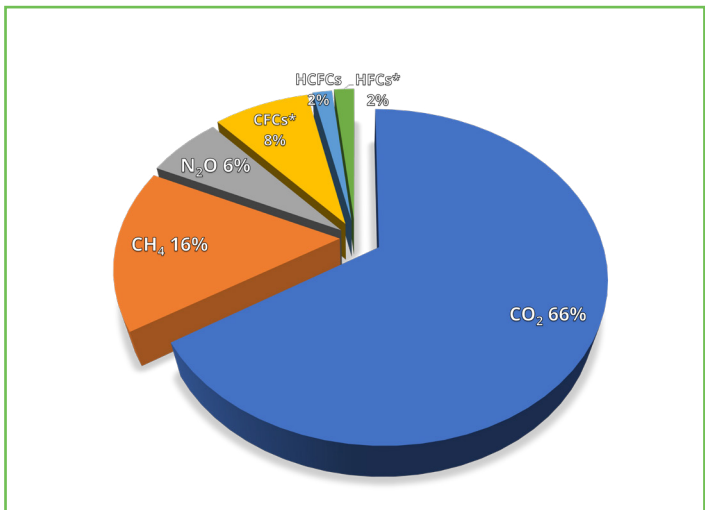


Figure 4. Contribution of the most important long-lived greenhouse gases to the increase in global radiative forcing from the pre-industrial era to 2025 [17]

Table. Global annual surface mean abundances (2025) and trends of key greenhouse gases from the GAW in situ observational network for GHGs. The units are concentrations in dry air, and the uncertainties are 68% confidence limits. The averaging method is described in [19], [20].

	CO ₂	CH ₄	N ₂ O
2025 global mean abundance	426.8±0.2 ppm	1 948±2 ppb	339.1±0.1 ppb
2025 abundance relative to 1750 ^a	153%	267%	126%
2024–2025 absolute increase	2.8 ppm	6 ppb	1.1 ppb
2024–2025 relative increase	0.66%	0.31%	0.33%
Mean annual absolute increase over the past 10 years	2.63 ppm y ⁻¹	10.2 ppb y ⁻¹	1.08 ppb y ⁻¹

^a Based on pre-industrial concentrations of about 278 ppm for CO₂, 729 ppb for CH₄ and 270 ppb for N₂O [5]. The number of stations used for the analyses was 180 for CO₂, 172 for CH₄ and 124 for N₂O.

The three GHGs shown in the table are closely linked to anthropogenic activities and interact strongly with the biosphere and the oceans. Predicting the evolution of the atmospheric content of GHGs requires a quantitative understanding of their many sources, sinks and chemical transformations in the atmosphere, as well as climate predictions. Observations from GAW provide invaluable constraints on the budgets of these and other LLGHGs. They are increasingly used to improve emission estimates and to evaluate satellite retrievals of LLGHG column averages. The [Integrated Global Greenhouse Gas Information System \(IG³IS\)](#) provides further insights on the sources and sinks of GHGs at the national [21], and especially urban [22], scales.

The NOAA AGGI measures the increase in total radiative forcing due to all LLGHGs since 1990 [17]. The AGGI reached

1.56 in 2025, representing a 56% increase in total radiative forcing^(v) from 1990 to 2025 and a 1.2% increase from 2024 to 2025 (Figure 2). The relative contributions of the most important LLGHGs in the total radiative forcing since the pre-industrial era are presented in Figure 4.

Carbon dioxide (CO₂)

Carbon dioxide is the single most important anthropogenic greenhouse gas in the atmosphere, accounting for approximately 66%^(v) of the radiative forcing by LLGHGs. It is responsible for about 83%^(v) of the increase in radiative forcing over the past decade. The pre-industrial level of 278.3 ppm represented a balance of fluxes among the atmosphere, the oceans and the land biosphere. The globally averaged CO₂ concentration in 2025 was 426.8±0.2 ppm (Figure 5a), a 53% increase above pre-industrial level. The increase in the annual mean from 2024 to 2025, 2.8 ppm, was smaller than the record high 3.6 ppm increase from 2023 to 2024 and slightly higher than the average growth rate for the past decade (2.62 ppm year⁻¹) (Figure 5b). The more modest growth rate from 2024 to 2025 compared to the previous year likely reflects a recovery of land carbon sink and reduced fire carbon emissions in 2025. However, a 2.8 ppm annual increase is still a substantial addition of carbon to the atmosphere, reflecting continuing large emissions from fossil fuel burning and still reduced biospheric uptake at the tail end of the 2023/2024 El Niño.

Of the total emissions from human activities during the 2015–2024 period, about 50% accumulated in the atmosphere, 29% in the ocean and 21% on land, with a near zero budget imbalance (0.1%, <0.1 gigatons of carbon (GtC) year⁻¹) [23]. The portion of CO₂ emitted by fossil fuel combustion that remains in the atmosphere (the airborne fraction (AF)), varies inter-annually due to the high natural variability of (mainly terrestrial) CO₂ sinks, although there is little evidence for a long-term AF trend (see the cover story in the [WMO Greenhouse Gas Bulletin, No. 17](#)).

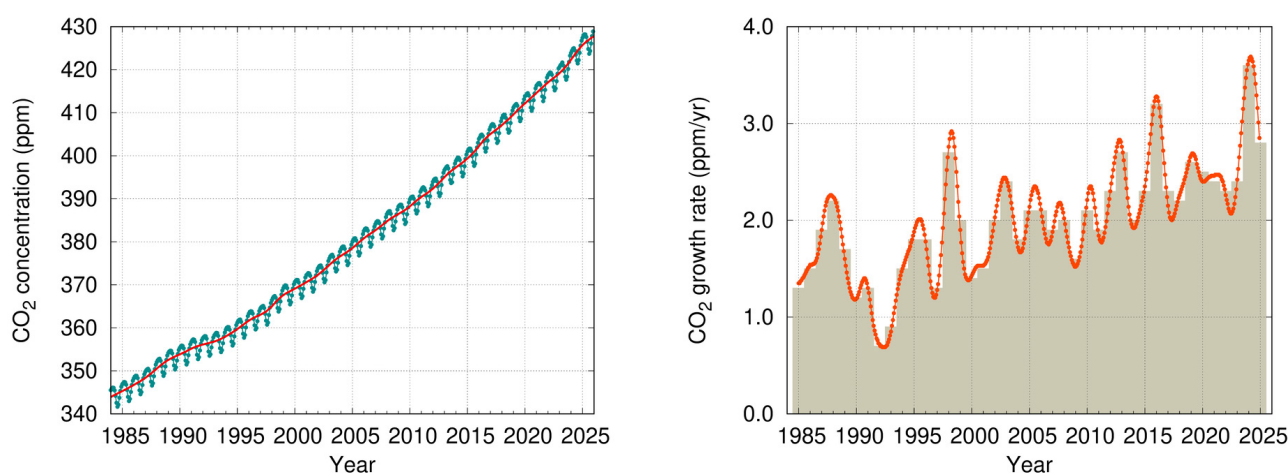


Figure 5. Globally averaged CO₂ concentration (a) and its growth rate (b) from 1984 to 2025. Increases in successive annual means are shown as the shaded columns in (b). The red line in (a) is the monthly mean with the seasonal variation removed; the blue dots and blue line in (a) depict the monthly averages. Observations from 180 stations were used for this analysis.

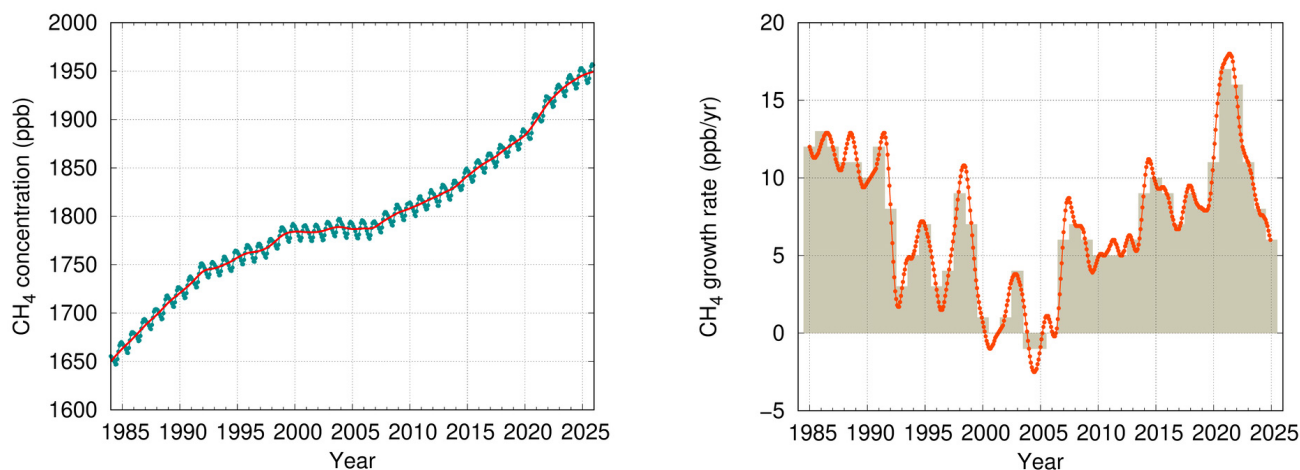


Figure 6. Globally averaged CH₄ concentration (a) and its growth rate (b) from 1984 to 2025. Increases in successive annual means are shown as the shaded columns in (b). The red line in (a) is the monthly mean with the seasonal variation removed; the blue dots and blue line in (a) depict the monthly averages. Observations from 172 stations were used for this analysis.

Methane (CH₄)

Methane accounts for about 16%^(v) of the radiative forcing by LLGHGs. Approximately 35% of methane is emitted into the atmosphere by natural sources (for example, wetlands and termites), and about 65% comes from anthropogenic sources (for example, ruminants, rice agriculture, fossil fuel exploitation, landfills and biomass burning) [24]. The globally averaged CH₄ concentration calculated from in situ observations reached a new high of 1 948±2 ppb in 2025, an increase of 6 ppb with respect to the previous year (Figure 6a). This increase is lower than both the increase of 8 ppb from 2023 to 2024 and the average annual increase of 10.2 ppb over the past decade.

The mean annual increase of CH₄ decreased from approximately 12 ppb year⁻¹ during the late 1980s to near zero during 1999–2006 (Figure 6b). Since 2007, average atmospheric CH₄ has been continuously increasing. It reached 267% of the pre-industrial level in 2025. It is critical to remember that unlike the case with CO₂, anthropogenic sources of CH₄ are not dominated by fossil fuel-related emissions at the global

scale; agricultural and waste sources play the most important role among anthropogenic sources. Studies using GAW CH₄ measurements indicate that increased CH₄ emissions from wetlands in the tropics and from anthropogenic sources at the mid-latitudes of the northern hemisphere are the likely causes of the recent increase since 2007 (see [WMO Greenhouse Gas Bulletin, No. 20](#)). The utilization of the isotopic analysis for the identification of sources and sinks of CH₄ is presented in the insert story in the present Bulletin.

Nitrous oxide (N₂O)

Nitrous oxide accounts for about 6%^(v) of the radiative forcing by LLGHGs. It is the third most important individual contributor to the combined forcing of LLGHGs. N₂O is emitted into the atmosphere from both natural sources (approximately 65%) and anthropogenic sources (approximately 35%), including oceans, soils, biomass burning, fertilizer use and various industrial processes [25]. The globally averaged N₂O concentration reached 339.1±0.1 ppb in 2025, which is an increase of 1.1 ppb with respect to the previous year (Figures 7a and 7b) and 126% of the pre-industrial level

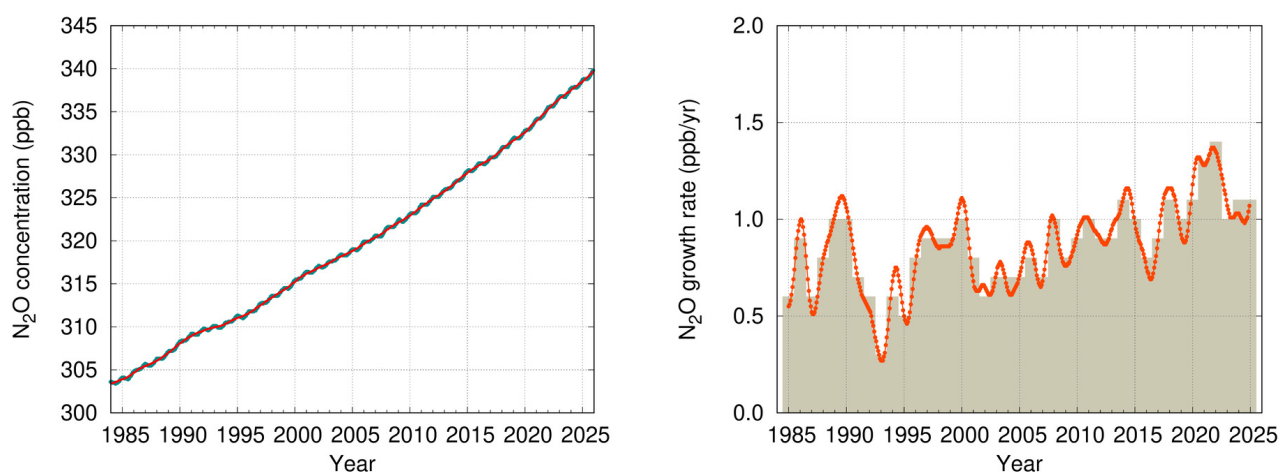


Figure 7. Globally averaged N₂O concentration (a) and its growth rate (b) from 1984 to 2025. Increases in successive annual means are shown as the shaded columns in (b). The red line in (a) is the monthly mean with the seasonal variation removed; in this plot, the red line overlaps the blue dots and blue line that depict the monthly averages. Observations from 124 stations were used for this analysis.

Anomaly in stable carbon isotopes in atmospheric methane reflects previously unobserved changes in sources and sinks

By Peter Sperlich, Xin Lan, Sylvia Englund Michel

Molecules of atmospheric methane contain a wealth of information at the atomic level: methane (CH_4) emitted from microbial, fossil or biomass burning sources differs systematically in its isotope ratios. Likewise, methane removed from the atmosphere through reactions with OH, soils, the stratosphere and marine chlorine change the isotopic composition of the methane remaining in the atmosphere. Consequently, the isotopic composition of the methane we observe in the atmosphere provides insight into the impact of global source and sink processes on methane mole fractions and methane stable carbon isotope ratios ($\delta^{13}\text{C}\text{-CH}_4$). Measuring $\delta^{13}\text{C}\text{-CH}_4$ can therefore be used to decipher changes in the strengths of methane sources and sinks [28], [29].

$\delta^{13}\text{C}\text{-CH}_4$ has been monitored alongside methane mole fractions within a global network of WMO GAW stations for almost three decades (Figure 9). Global averages of both observations show distinct seasonal variability as well as

longer-term trends, such as interannual changes. While methane mole fractions and $\delta^{13}\text{C}\text{-CH}_4$ values increased until 1999, both time series plateaued between 1999 and 2006. Since then, global $\delta^{13}\text{C}\text{-CH}_4$ levels continuously decreased while atmospheric mole fractions increased. Accelerating emissions from microbial methane sources (e.g. wetlands and agriculture) is the most likely explanation for the steady increase in methane mole fractions and the concurrent decrease in $\delta^{13}\text{C}\text{-CH}_4$ values [28], [30], [31], in concert with smaller contributions from fossil fuel emissions [29], [32].

However, the most recent $\delta^{13}\text{C}\text{-CH}_4$ data show a distinct upward change from mid-2023 to the end of 2024. Importantly, methane concentration continued to rise at the same time, although a slightly lower increase rate of 8 ppb year⁻¹ in 2023–2024 followed the record high increase of 15 ppb year⁻¹ in 2020–2022. The decoupling of methane mole fractions and $\delta^{13}\text{C}\text{-CH}_4$ lasted approximately two years until $\delta^{13}\text{C}\text{-CH}_4$ started to decrease again in 2025. This anomalous $\delta^{13}\text{C}\text{-CH}_4$ event highlights the unique value of methane isotope observations for detecting significant changes in the sectoral methane budget: CH_4 observations alone would not be able to inform us on this.

What source or sink processes may have caused the $\delta^{13}\text{C}\text{-CH}_4$ anomaly?

The present Bulletin aims to highlight this significant event from recent measurements and to provide a tentative view on changes in methane sources that may have caused the observed $\delta^{13}\text{C}\text{-CH}_4$ anomaly.

It is most likely that increasing methane emissions from biomass burning are the primary cause of the $\delta^{13}\text{C}\text{-CH}_4$ anomaly. Methane produced in biomass burning has sufficient leverage to shift atmospheric $\delta^{13}\text{C}\text{-CH}_4$ towards more positive values (Figure 10) while exerting relatively little influence on global methane mole fractions [33]. This is supported by independent observations showing that the years 2023 and 2024 were marked by record-breaking wildfires in North America [34] and the Amazon [35], respectively. Dominant drivers of these wildfires were El Niño–Southern Oscillation [36] and anthropogenic climate change [34], causing the highest temperatures on record and extensive droughts. These hot, dry conditions simultaneously triggered a reduction of microbial methane emissions from wetlands during 2023 and 2024 in the affected regions [36]. This aligns with both the $\delta^{13}\text{C}\text{-CH}_4$ signal and the observed reduction in CH_4 growth rate.

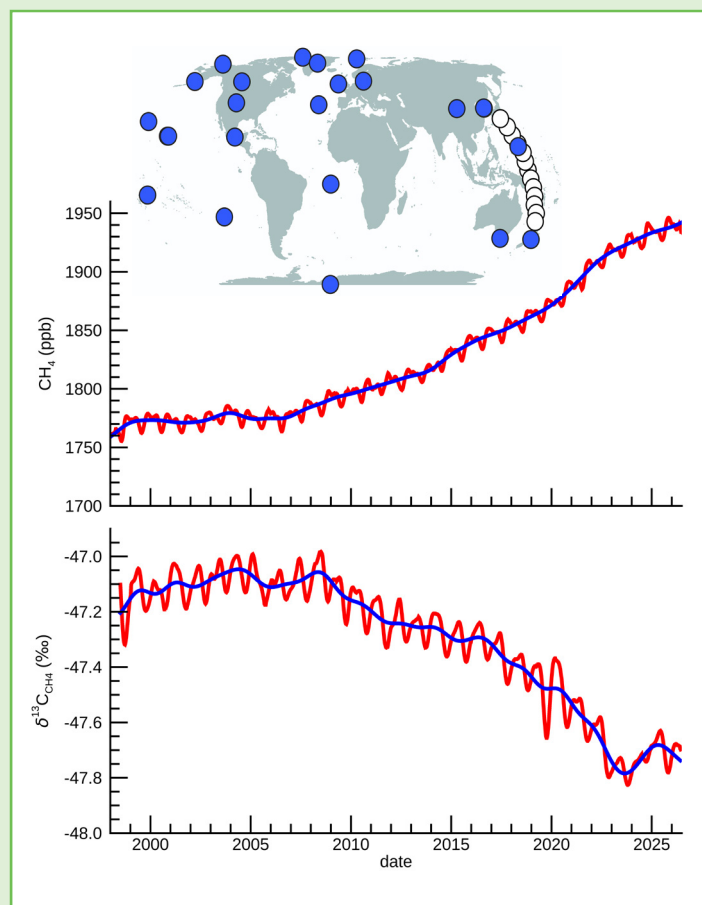
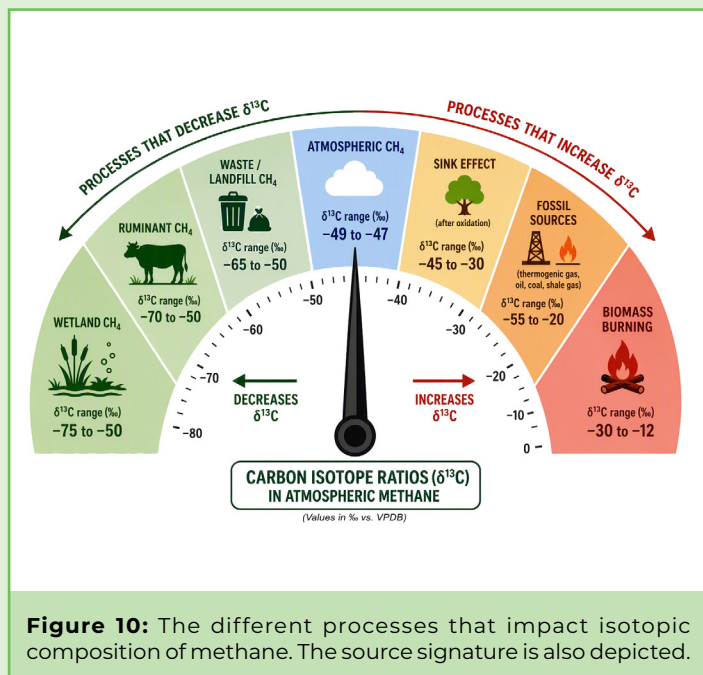


Figure 9: Average mole fractions (upper panel) and $\delta^{13}\text{C}$ (lower panel) of CH_4 as observed within the NOAA Cooperative Air Sampling network of stations shown on the map insert. Blue symbols show 24 active sites, while open circles show sampling sites on discontinued ship transects.



In contrast, it seems unlikely that changes in fossil fuel emissions could have caused the observed $\delta^{13}\text{C}\text{-CH}_4$ event, as these showed little change in 2023 and 2024 [37]. While a rebound of the primary global methane sink (OH) has been suggested for 2023 and 2024 [38], [39], it is unlikely to be the dominant driver of the $\delta^{13}\text{C}\text{-CH}_4$ anomaly, as it does not have sufficient leverage on $\delta^{13}\text{C}\text{-CH}_4$ [40] (Figure 10).

In summary, it is most likely that the $\delta^{13}\text{C}\text{-CH}_4$ event was driven by changes in methane sources rather than sinks, with an increase in methane emissions from biomass burning and a small decrease in microbial emissions from wetlands as the most likely cause. The $\delta^{13}\text{C}\text{-CH}_4$ anomaly therefore reveals

a climate change feedback of a deteriorating terrestrial carbon sink, at continental scales [41], [42], [43].

Importance of isotope observations to understand methane

Tracking changes in methane emissions is essential to supporting climate mitigation, particularly given the recent policy emphasis on reducing fossil methane emissions. This is all the more important since independently determined emission estimates generally exceed reported emission values, suggesting that vast underreporting is common across many sectors [44], [45], [46]. In an era preparing for the overshoot in global warming [47], [48], robust tools to assess emissions are critical for a fair assessment of mitigation successes, for observing natural variation and for early detection of possible climate change feedbacks.

Methane isotopic composition observations in baseline air are routinely undertaken by a growing number of laboratories. While differences between laboratories exist, because measurement standards are not globally available, data from laboratories following the WMO GAW recommendations can be merged for analysis if those offsets are carefully considered [49], [32]. WMO GAW laboratories provide high-quality methane isotope data that are ideally suited for quantitative analysis of changes in the global methane system. Any source–sink scenario that seeks to explain changes in atmospheric methane mole fractions must be scrutinized for consistency with methane isotope observations [24]. The $\delta^{13}\text{C}\text{-CH}_4$ anomaly highlights that observations of methane isotopes can detect changes that may not be noticed from mole fraction observations alone. This emphasizes the undisputable value and analytical power of methane isotope observations.

(270.1 ppb). The annual increase from 2024 to 2025 was the same as the increase from 2023 to 2024 and close to the mean growth rate over the past 10 years (1.08 ppb year⁻¹). Global human-induced N₂O emissions, which are dominated by nitrogen fertilizer additions to croplands, increased by 30% over the past four decades to 7.3 (range: 4.2–11.4) teragrams of nitrogen per year. This increase was mainly responsible for the growth in the atmospheric burden of N₂O [26].

Other greenhouse gases

Stratospheric ozone-depleting CFCs, which are regulated by the Montreal Protocol on Substances that Deplete the Ozone Layer, together with minor halogenated gases, account for approximately 12%^(v) of the radiative forcing by LLGHGs. While CFCs and most halons are decreasing (Figure 8b), some HCFCs and HFCs, which are also potent greenhouse gases, are increasing at relatively rapid rates; however, they are still low in abundance (at ppt levels). Although at a similarly low abundance, SF₆ is an extremely potent

LLGHG. It is produced by the chemical industry, mainly as an electrical insulator in power distribution equipment. Its concentration is rising at a quite constant rate and is now three times the level observed in the mid-1990s (Figure 8a and cover story).

The present Bulletin primarily addresses long-lived greenhouse gases. Relatively short-lived tropospheric ozone has a radiative forcing comparable to that of the halocarbons [27]; because of its short lifetime, its horizontal and vertical variability is very high, and global means are not well characterized with a network such as that shown in Figure 3. Many other pollutants, such as carbon monoxide, nitrogen oxides and volatile organic compounds, although not referred to as greenhouse gases, have small direct or indirect effects on radiative forcing. Aerosols (suspended particulate matter) are short-lived substances that alter the radiation budget. All the gases mentioned in the present Bulletin, as well as aerosols, are included in the observational programme of GAW, with support from WMO Members and contributing networks.

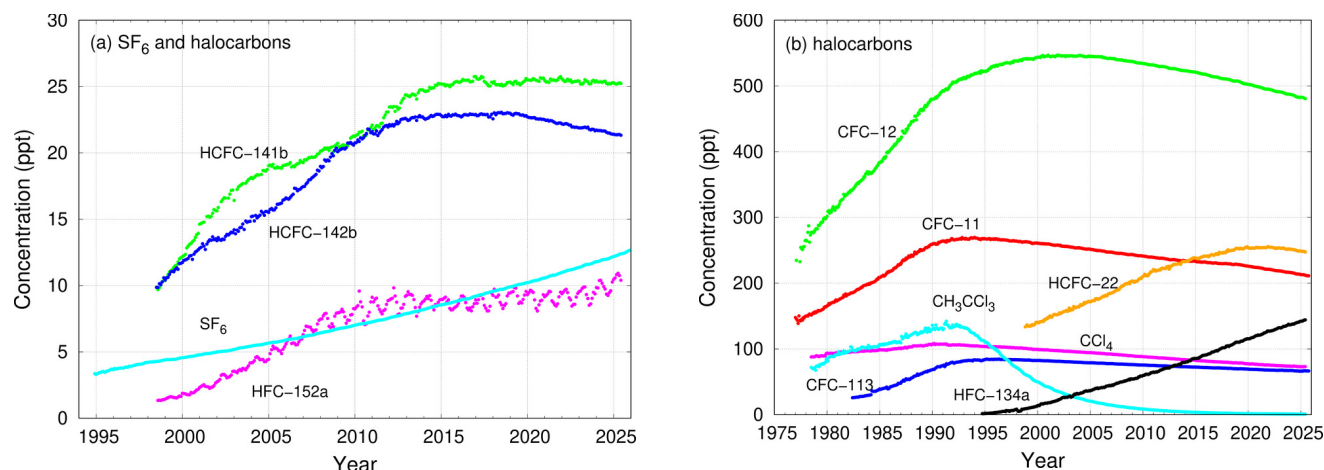


Figure 8. Monthly mean concentration of sulfur hexafluoride (SF₆) and the most important halocarbons: (a) SF₆ and lower concentrations of halocarbons and (b) higher halocarbon concentration. For each gas, the number of stations used for the analysis was as follows: SF₆ (93), CFC-11 (26), CFC-12 (28), CFC-113 (23), CCl₄ (25), CH₃CCl₃ (26), HCFC-141b (12), HCFC-142b (16), HCFC-22 (16), HFC-134a (12), HFC-152a (12).

Acknowledgements and links

Fifty-six WMO Members contributed CO₂ and other greenhouse gas data to the GAW WDCGG. Approximately 41% of the measurement records submitted to WDCGG were obtained at sites of the NOAA Global Monitoring Laboratory cooperative global air-sampling network. For information about the GAW GHG network and methodologies, see [GAW Report No. 317](#). The AGAGE and ICOS also contributed observations to the present Bulletin. The GAW observational stations that contributed data to the Bulletin, shown in Figure 4, are included in the list of contributors on the [WDCGG web page](#). They are also described in the [GAW Station Information System \(GAWSIS\)](#), supported by MeteoSwiss, Switzerland. The present Bulletin has been prepared under the oversight of the GAW Scientific Advisory Group on Greenhouse Gases.

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Notes:

- (i) ppt = the number of molecules of a gas per trillion (10^{12}) molecules of dry air
- (ii) ppb = the number of molecules of a gas per billion (10^9) molecules of dry air
- (iii) The scientifically correct term to use for the abundance in the atmosphere of compounds such as carbon dioxide and other (greenhouse) gases is dry air **mole fraction**, expressed as the number of moles of each gas per mole of dry air, often with units of ppm or ppb. However, in the GHG Bulletin, we use the more popular term **concentration** to avoid possible confusion for the public.
- (iv) ppm = the number of molecules of a gas per million (10^6) molecules of dry air
- (v) This percentage is calculated as the relative contribution of the mentioned gas(es) to the increase in global radiative forcing caused by all long-lived greenhouse gases since 1750. Radiative forcing is the perturbation to the Earth's energy budget resulting from the increased burdens of greenhouse gases since the pre-industrial (1750) period after allowing stratospheric temperature to quickly adjust. "Effective" radiative forcing also includes fast tropospheric adjustments. Note that the numbers presented here account only for the direct radiative forcing of CH_4 and CO_2 , as opposed to the emission-based forcings used in the Intergovernmental Panel on Climate Change (IPCC) **AR6 WGI report**, which include estimated indirect forcings due the atmospheric chemistry of CH_4 , influencing other atmospheric constituents.

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SELECTED GREENHOUSE GAS OBSERVATORIES



Photo credit: BOM

Fiftieth anniversary of Kennaook/Cape Grim station

The Kennaook/Cape Grim Baseline Air Pollution Station (CGO, 40.68°S, 144.69°E) is a fully operational WMO GAW global station. It sits atop a 94-metre cliff at the far north-west corner of Tasmania, Australia. The prevailing south-westerly winds have typically traversed over long fetches of the Southern Ocean, having minimal or no contact with land or anthropogenic sources for long time periods, providing an ideal location for baseline sampling in the mid-latitudes of the southern hemisphere. At other times, wind events from the north (from Melbourne), or from the east (rural/agricultural) allow for sampling under a range of conditions. The station is operated by the Australian Bureau of Meteorology (BOM) with the science programme jointly managed by BOM and the Commonwealth Scientific and Industrial Research Organization (CSIRO).

This year marks the fiftieth anniversary of the station, with high-precision observations of atmospheric CO₂ and other parameters beginning in 1976. The station has a comprehensive GHG measurement programme, with in situ measurements of CO₂, CH₄, N₂O, CO and H₂, along with stable isotopes of CO₂ and CH₄ and (through collaborative projects) CO₂ radiocarbon. The station is also part of the AGAGE network, measuring more than 60 non-CO₂ greenhouse gases and other tracers, including CFCs, HCFCs, HFCs, perfluorocarbons (PFCs) and SF₆ among others. Other measurements include particles and multiphase atmospheric chemistry, spectral

and passive radiation, ozone/reactive gases, radon and the longest dedicated air archive in the world.

Cape Point station

Cape Point, one of the few GAW stations in the southern hemisphere, constitutes a critical component of the global atmospheric observing system. Situated at the southern tip of Africa and designated as a WMO GAW station in 1995, it occupies a strategically important location within a region where long-term atmospheric observations are sparse, and significant observational gaps persist. Its exposure to well-mixed marine air masses originating over the South Atlantic and Southern Ocean enables the collection of measurements that are representative of vast background regions largely unaffected by direct anthropogenic emissions.

The station hosts some of the longest continuous atmospheric trace gas records in the southern hemisphere, including carbon monoxide (CO) measurements dating back to 1978 and methane (CH₄) and surface ozone (O₃) observations extending to the early 1980s. These unique long-term datasets provide an invaluable basis for quantifying changes in atmospheric composition and distinguishing natural variability from anthropogenic influences. Sustained observations over multiple decades are essential for detecting gradual environmental change, evaluating the effectiveness of international environmental agreements, and validating climate and atmospheric chemistry models. The scientific value of these records increases with their longevity, as



Photo credit: South African Weather Service

they provide the temporal context necessary to identify emerging trends and assess their significance. As global efforts to address climate change intensify, the Cape Point record represents a vital scientific asset, underpinning evidence-based policy development and contributing to the long-term sustainability of climate and environmental stewardship.

Izaña Observatory

The century-old Izaña Observatory (IZO) is managed by the Izaña Atmospheric Research Centre – Emilio Cuevas (IARC) of the State Meteorological Agency of Spain (AEMET). Due to its geographical location and altitude, IZO is an excellent place to measure the composition of the subtropical atmosphere under free-tropospheric conditions. IZO began its series of in situ measurements of CO₂ and CH₄ in 1984 when it joined the WMO Background Air Pollution Monitoring Network

(BAPMoN). In 1989, IZO joined the GAW Programme, which was created by merging the BAPMoN with the Global Ozone Observing System (GO₃OS), and is currently one of its global stations. In situ measurements of N₂O and SF₆ were added in 2007.

Izaña also contributes GHG data to the WDCGG through NOAA, by participating in the Cooperative Air Sampling Network programme since 1991. Furthermore, IZO has been an Integrated Carbon Observation System (ICOS) station since 2021, with independent instrumentation. ICOS, as a contributor to the WDCGG, independently provides in situ measurements of CO₂, CH₄ and N₂O. In addition, the GHG programme is complemented by more than 20 years of observations of the main GHGs, carried out with the Fourier Transform Infrared Spectroscopy (FTIR) technique under the Network for the Detection of Atmospheric Composition Change (NDACC) framework.

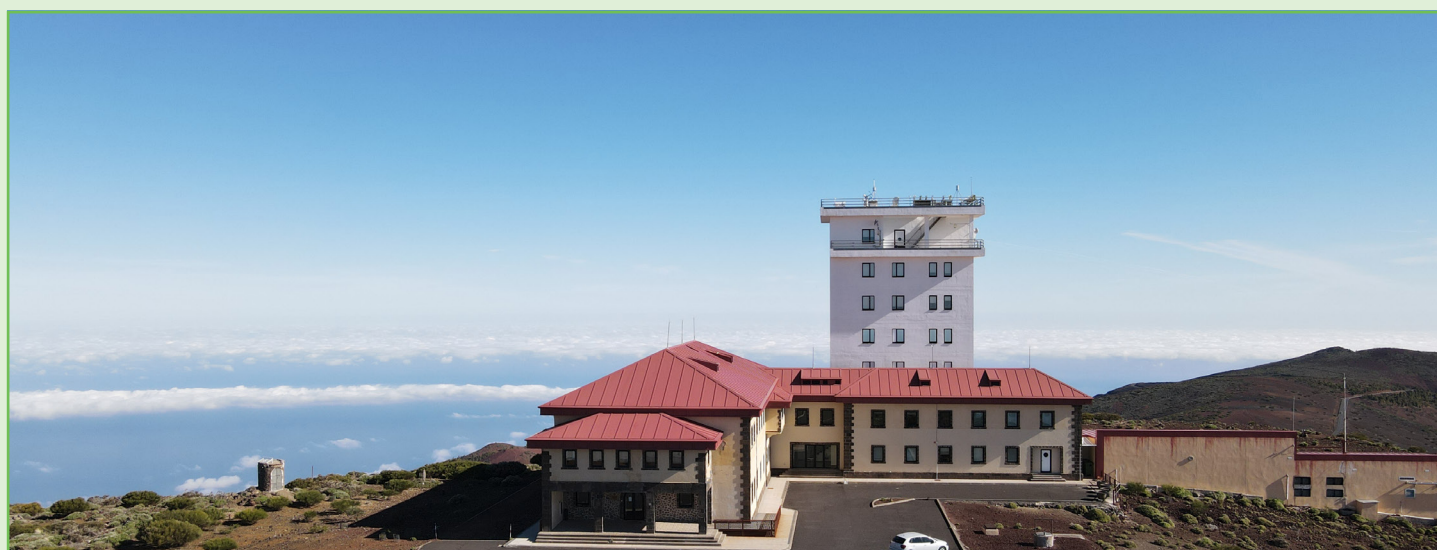


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