Greenhouse Gases in Algeria

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Taha Bouhoun

Aaron Shildrick

Abstract

For the past 25 years, Assekrem station (located in the heights of Huggar in Southern Algeria) has been taking measurements of the most prominent greenhouse gases in the atmosphere as part of NOAA's global monitoring initiative. This paper aims to develop a model that best fit the trends highlighted in data using Facebook's Prophet forecasting engine. Furthermore, we present a concise explanation of the periodic patterns in greenhouse gas emissions, their sources, sinks, and global warming potential. Finally, we discuss the current abundance of the gases in the atmosphere and forecast their levels for the next two decades.

1 Data

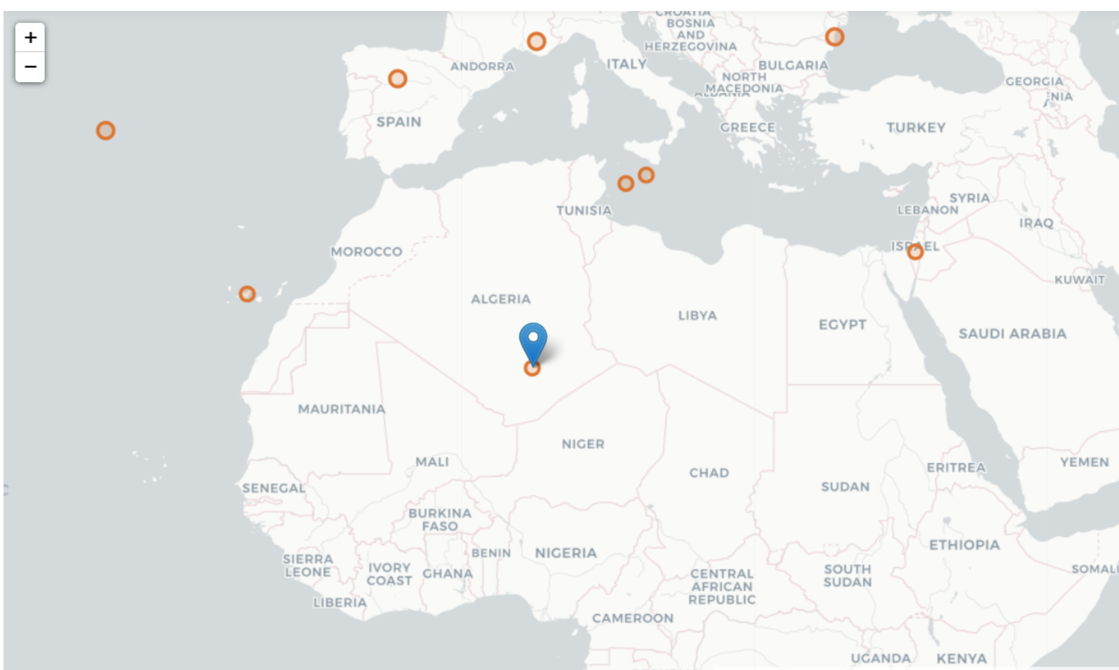
The Assekrem station allows us to get a clean read with little local bias due to the location's remoteness. This allows us to get atmospheric readings of the specific gases as opposed to local short-lived and erratic gas emissions. For example, CO_2 travels and mixes in the atmosphere due to its long lifetime, allowing us to see this value instead of having a station right next to an industrial city, where readings will largely depend on the production for that specific factory. The station's high position can indicate that the readings are safe from biases induced from the thermal inversion layer of the atmosphere, including breeze, wind changes, and reduced or enhanced molecular transport. This provides a firm ground for atmospheric readings.

1.1 Limitations and strengths of the data

The data is collected from the Assekrem station in Algeria. Located at 23.2625° North, 5.6322° East, and at a 2710 meter elevation, this is one of the most remote stations and the only one in the entire Saharan region. Many different techniques are used to monitor gases on Earth, but all have some type of limitations. For this specific case, the station uses in-situ measurements, which involve a single location using high quality, wide set of instrumentation, which can take precise measurements of a small and specific geographical point. two main limitations arise from this method:

- Lack of certainty for generalizations as we only look at one location
- Gaps between measuring sites make understanding complex processes difficult

In-situ measurements provide what is best described as direct observations of the system. The great advantage is the way we can make use of a diverse set of instrumentation, which can take the most accurate readings we can get.



2 Methodology

Prophet is an algorithm developed by Facebook's data team in order to automate the process of forecasting seasonal trends given equally spaced data points (Taylor et al., 2017). The strategy is to frame the forecasting problem as a curve-fitting exercise by disentangling two components:

- **Non-linear trends:** Using a logistic growth model containing a time-varying capacity and a growth rate.
- **Periodic seasonalities:** Using a standard Fourier series for decomposing periodic patterns such as yearly, monthly, and daily seasonalities.

The model parameters are adjustable (eg., adding seasonalities, specifying forecast frequency, etc.), which offers us the advantages of the Bayesian approach since the forecasts are derived from the posterior distribution.

3 Carbon Dioxide

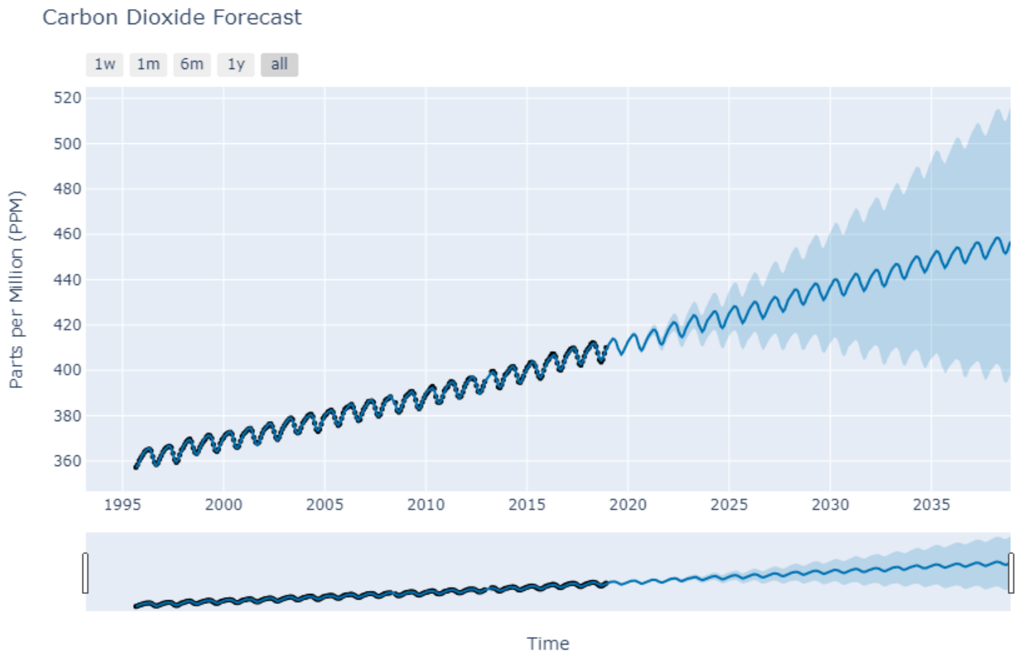
3.1 Gas measurements oscillations

CO_2 data points show a distinct seasonality in the measurements. Most of the landmass on Earth lies in the northern hemisphere, and when we look closely at the data, we are able to see that the smaller downward trends coincide with the northern hemisphere spring and summer and the upward trend coincides with autumn and winter. This is because of the natural carbon cycle, often referred to as Earth's breathing. [1][2]. Spring and summer bring increased plant life, allowing them to remove carbon from the atmosphere, acting as a strong sink for CO_2. On the other hand, autumn and winter represent many of these seasonal plants' demise, removing the carbon sink and releasing organic carbon found in plants to the atmosphere.

3.2 Sink and sources

Human activity is one of the primary drivers of CO_2 increase over time. CO_2 exists in the atmosphere in a balance between generation and removal of the gas, driven by different processes. Common sources of CO_2 include natural and anthropogenic activity, namely, respiration, decomposition, volcanism, industrial activity, and transportation. More specific to the station's region, we see strong human activity stemming from transportation and the power sector [3].

Equally important, the sinks represent a way for the environment to deposit, remove, or disperse a specific chemical in the atmosphere. Some of the most important sinks of CO_2 include outward transport, chemical removal, ocean absorption, soil deposition, and plant respiration. Broadly speaking, the most active carbon pools on land are living biomass and soil organic carbon. Taking into consideration the region, we have to account for desert sinks, which are limited due to the lack of vegetation. However, desert basins also act as carbon sinks and store it underground. As explained in Li et al. (2015), dissolved inorganic carbon is leached from irrigated arid land and deposited in saline/alkaline aquifers found under the desert. Since this region has limited local sources and sinks of carbon, we can expect to regard transport as one of the main drivers of data patterns in the region having industrial activity and ocean absorption as some of the most significant balancing processes in action [4][5].



3.3 Important facts

CO_2 has a long lifetime, which is one of the biggest reasons why it is such a powerful greenhouse gas, and is present globally, as opposed to locally isolated over industrial areas. This long lifetime means that identifying specific sources for this station is quite complex, specifically since large urban areas are not particularly close to it.

Wind patterns are particularly important for high CO_2 levels in this region as they blow industrial activity into the desert from coastal cities in North Africa and even Europe. These distances are possible due to the long lifetime of CO_2 in the atmosphere.

3.4 Global Warming Potential (GWP)

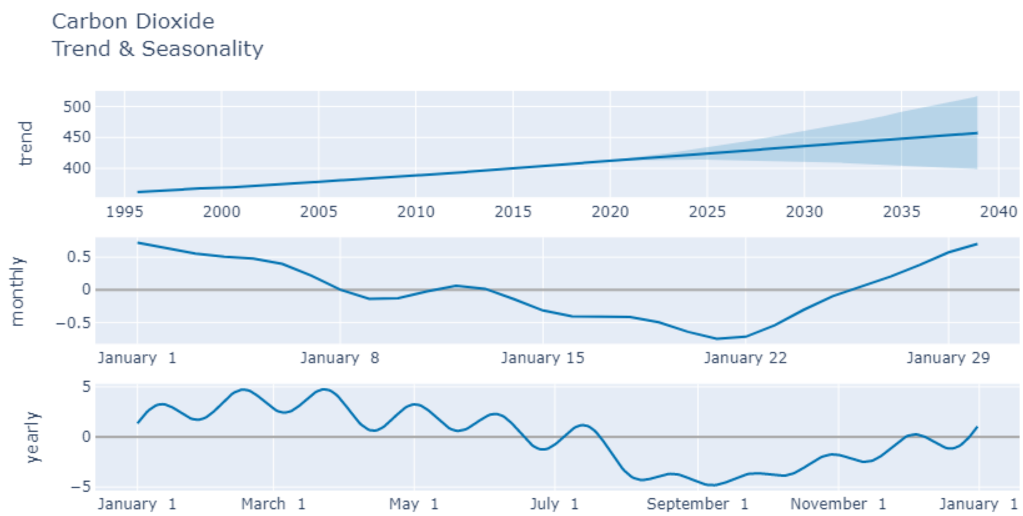
The Global Warming Potential (GWP) indicator relates to the heat absorbed by a greenhouse gas in the atmosphere. GWP depends on the following factors:

- The absorption of infrared radiation by a given gas
- The spectral location of its absorbing wavelengths
- The atmospheric lifetime of the gas

Being the most prominent greenhouse gas in terms of quantity, CO_2 is set as the baseline for GWP with a given value of 1. This means that other gases are measured as multipliers if we were to have the same amount. This information is relevant to understanding the GWP of the other gases targeted in this report [6].

3.5 Current state

In 2018, the global average carbon dioxide concentration was 407.4 ppm. This is the highest value of CO_2 over the past 800,000 years. Since we are concerned with the anthropogenic impact on CO_2 concentrations, it's most relevant to look at stable pre-industrial carbon concentrations, which stand at around 280 ppm [7][8].



Given human activity, it is clear from data collected in this station that there is an upward trend that extends all the way since the start of the industrial revolution. In modern times, levels continue to accelerate with the rise of developing industrial economies. CO_2 is a naturally occurring and necessary gas for conserving the conditions needed for a warm habitable planet; however, humans have changed the natural course drastically, threatening to accelerate natural processes such as sea-level rise, melting ice caps, and climate change.

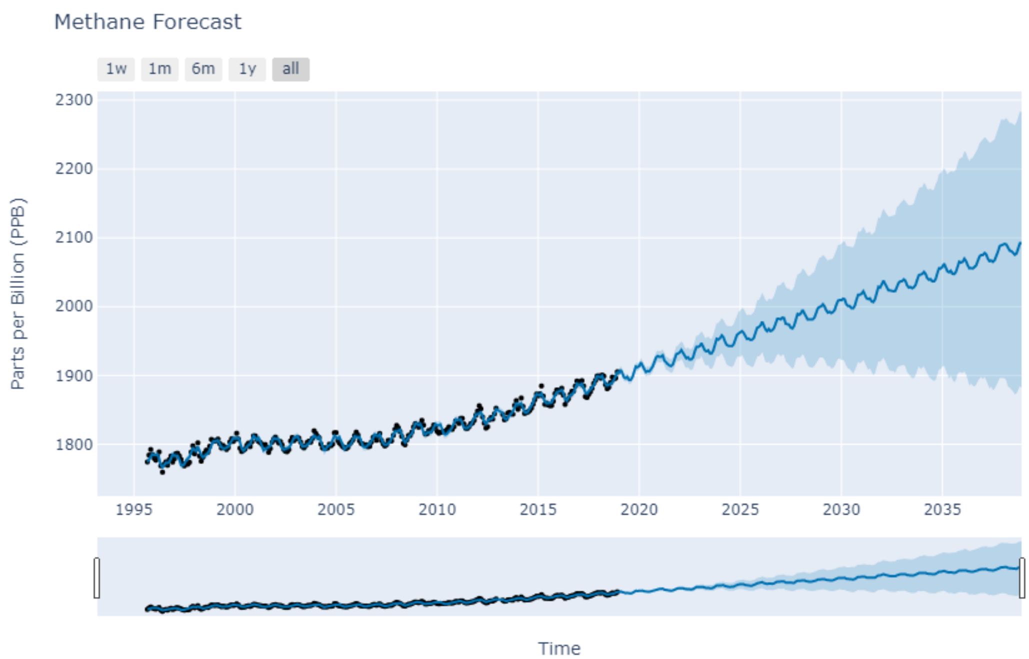
4 Methane

4.1 Gas measurements oscillations

Atmospheric Methane can be seen to have seasonal oscillations and values over time, in addition to its upward trend in recent years. Seasonality is significant and relevant with regards to atmospheric methane concentrations. On average, there is 25-34 ppb less Methane in the northern hemisphere during the summer as compared to the rest of the year.

The general origins trend comes from indirect effects of climate change such as sustained flooding of marshlands and wetlands, but mostly, recent variance has originated mainly from anthropogenic sources such as industry and sources of power. Methane is one of the primary components in natural gas, meaning both industries and households use it as fuel for energy and heat.

The observed seasonal variations are consistent with the seasonal cycle of OH. OH is one of the primary drivers of methane oxidation, which removes it from the atmosphere [9][10].



4.2 Sink and sources

Many sources for methane exist, but not all are equally significant. To be slightly more brief, the main natural sources include emissions from wetlands, which depend mainly on temperature. The main anthropogenic sources include ruminants, gas and oil industrial activity, landfills and waste, agricultural practices, and burning of biomass. Significant to the region is the extraction and consumption of oil and natural gas.

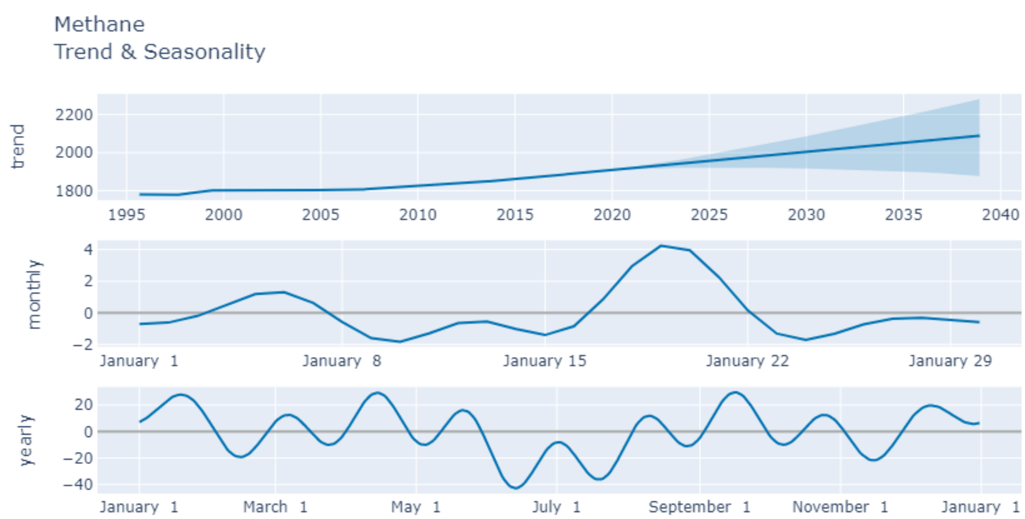
Methane oxidation is a significant parameter because it accounts for the vast majority of methane emissions globally. The role of the hydroxyl OH radical is complex, but increased concentrations are linked with increased solar UV radiation, which is more abundant in the summer. This leads to a summer drop in atmospheric methane concentration on a global basis; even locations far from natural gas production and consumption show a summer decline and winter increase in atmospheric methane concentration. Methane oxidation effectively removes methane but depletes the atmosphere's oxidation capacity and extends the lifetime of remaining methane, as well as freeing more CO_2. Much smaller and less significant sinks include stratospheric oxidation, and methane-oxidizing bacteria in soils.

4.3 Global Warming Potential (GWP)

In terms of global warming potential, methane is one of the most powerful greenhouse gases on our planet. The 100-year global warming potential of methane is 28-36, while methane's 20-year global warming potential is 84. This means that over a 20-year period, it traps 84 times more heat per mass unit than carbon dioxide.

4.4 Current state

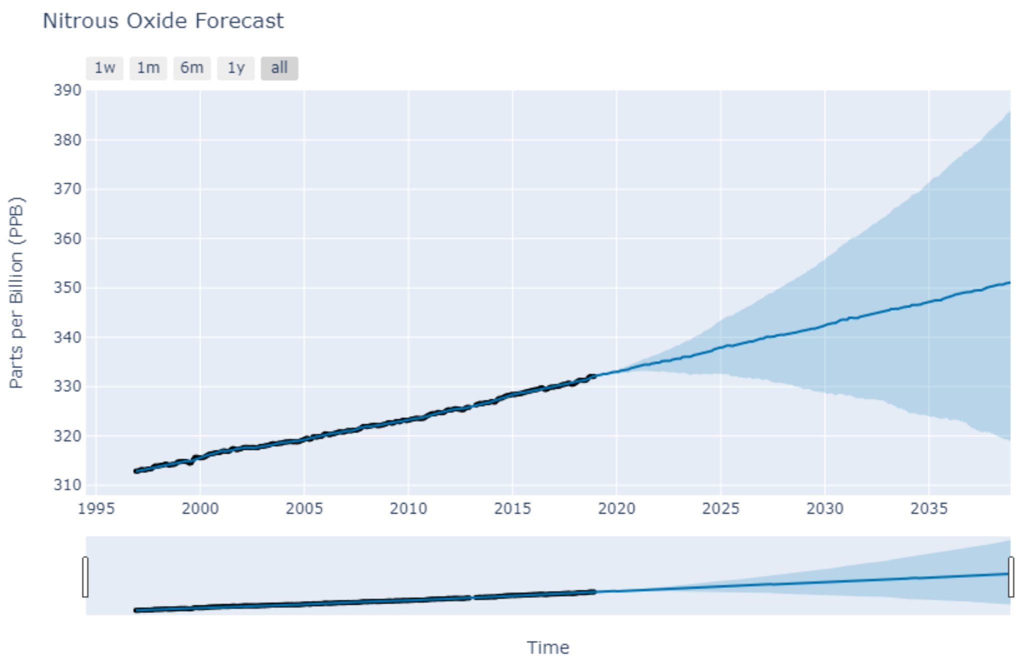
Today, methane accounts for around one-fifth of global warming effects. Pre-industrial values stand at 750 ppb, and we currently record 1870 ppb. This is not only alarming as the rates have more than doubled, but it is also the highest value in the past 800,000 years. Addressing methane is considered "low-hanging fruit" due to the ease and short term impact of effective policies. Although its lifetime is shorter than CO_2, the global warming potential is still massive due to the effectiveness with which it absorbs heat and radiation [11][12].



5 Nitrous Oxide

5.1 Gas measurements oscillations

N_2O is the third most important greenhouse gas after carbon dioxide and methane. As we can see from the plot, there are no notorious or visible seasonal oscillations as there are with methane and carbon. This is mostly due to the mass balance of the gas, further discussed as sources and sinks. We do note, however, the increase of the concentration values over time.



5.2 Sink and sources

For the sources of nitrous oxide, as with most gases, we have both natural and anthropogenic sources. The primary anthropogenic sources are agricultural practices, such as nitrogen-based fertilizers and the burning of fossil fuels, but also include biomass burning, water treatment, the decay of livestock manure, and transportation. Naturally, the largest source comes from the oxidation of ammonia from the atmosphere, and from the soil, which is found predominantly in tropical settings. The ocean also produces large quantities of N_2O to be released into the atmosphere. Smaller natural sources include biogenic sources and lightning.

More relevant to the data seen in the Assekrem station, is that the primary source of global atmospheric nitrous oxide, which is agriculture and soil practices, is not found in the region. However, nitrous oxide possesses an extremely long lifetime in the atmosphere, with the most recent data showing the gas to linger in the atmosphere for around 114 years.

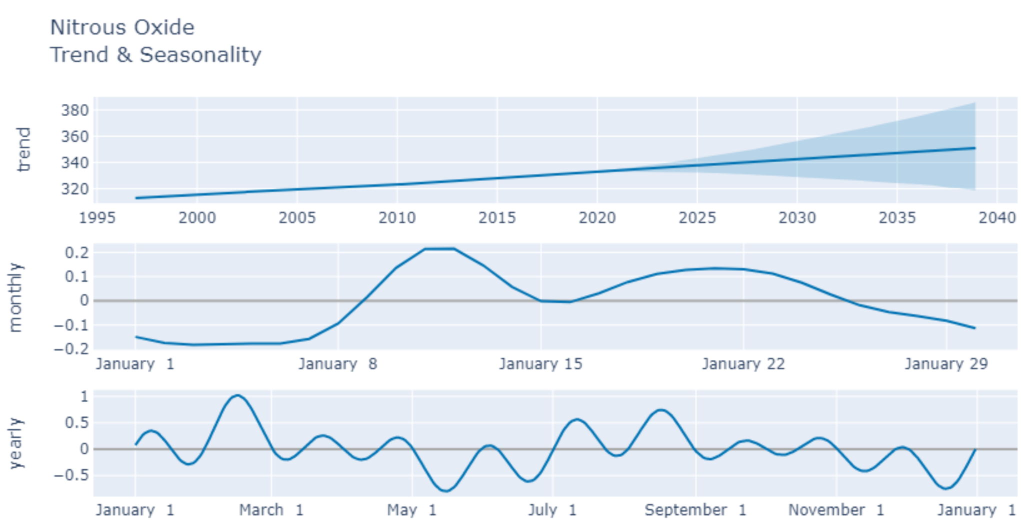
The sinks for N_2O are few. The main process is stratospheric photolytic decomposition, which breaks down the molecule as a reaction to radiation in the stratosphere. Now, this is an extremely important point for this gas, because it is this process which sets off the ozone-depleting catalytic cycle. This is also the reason why the lifetime is so long, as there is a lack of significant sinks in the troposphere, and the main driver is up in the stratosphere. The photolytic process separates the molecule as it reacts with radiation and sets off the chain of reactions that lead to ozone loss, further driving the temperature up. A much smaller sink exists in soils, through oxidizing bacteria.

5.3 Global Warming Potential (GWP)

Over a 100 year time period, nitrous oxide is 310 times more potent than carbon dioxide in its ability to affect the climate. This means that in unit volume, this gas is a much more powerful greenhouse gas than both methane and carbon dioxide. Additionally, this gas is considered to be the leading ozone-depleting substance being emitted due to its complex relationship with the ozone-depleting catalytic cycle.

5.4 Current state

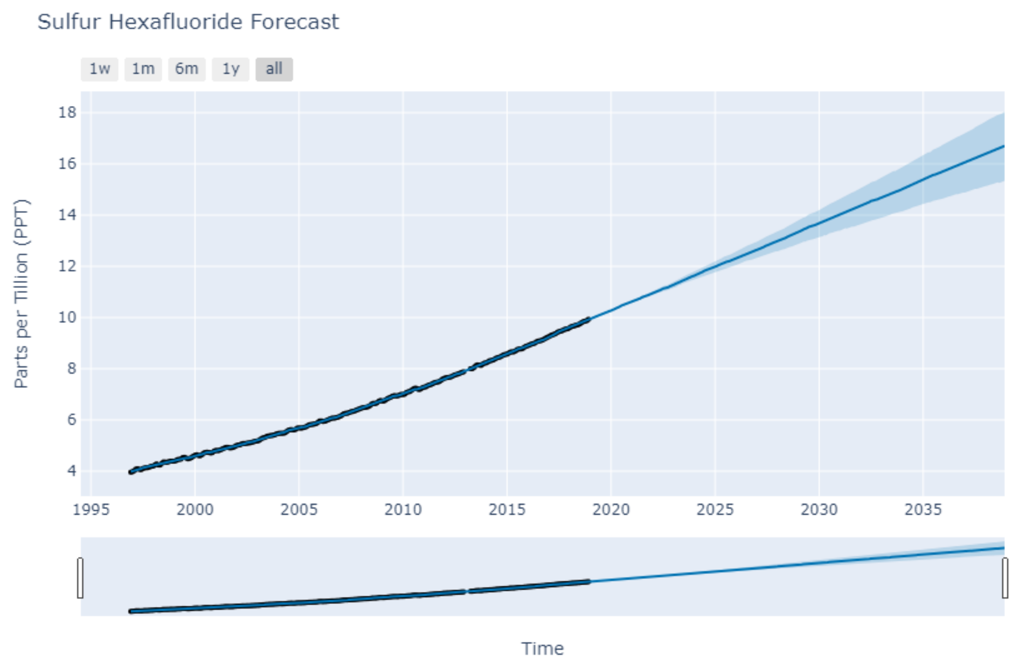
The exact effects of nitrous oxides on climate are hard to assess, as there are many complex direct and indirect processes and interactions occurring. We do know that the concentration of N_2O has risen sharply with the exploitation of soils, rise in nitrogen-based fertilizers, and increased fossil fuel burning, and are seeing the effects in terms of warming and ozone depletion. Current levels oscillate around 330 ppb [13].



6 Sulfur Hexafluoride

6.1 Gas measurements oscillations

Since SF_6 is a synthetic gas, no seasonalities or oscillations are observed in the data. More than that, we see more of a cumulative pattern as levels have risen steadily over time. The importance of this trend cannot be overstated, as particular properties of this gas make it very different from the other gases mentioned in this report. Due to the potency and the lifetime, SF_6 is one of the most dangerous greenhouse gases, but atmospheric concentrations are still relatively low.



6.2 Sink and sources

The only source: SF_6 is a synthetically created compound for its specific low cost, highly effective insulator and energy retention, and low risk for ground and water contamination. The vast majority of its emissions come from the electrical/electronic industry. During industrial processes for technology and electronics, SF_6 tends to leak into the atmosphere, making it hard to quantify directly.

The only sink: As the compound is built for its resistant properties, there are no natural ways of breaking it down. With carbon dioxide, methane, and nitrous oxide, natural sources and sinks exist, meaning that the removal process is constantly happening, such as the hydroxyl reactions, or ocean absorption. This is different, with the only way of removing this compound from the atmosphere being photolysis, which is estimated to take 3200 years. Solar radiation in the upper atmosphere breaks up the molecule, but the transport process and the time it takes is overwhelming when compared to other greenhouse gases.

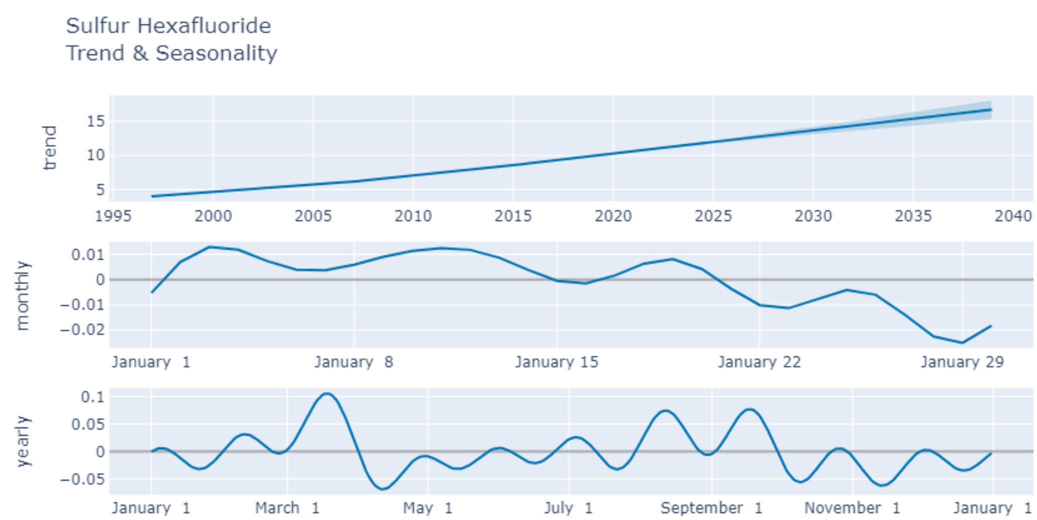
The chemical robustness of the molecule comes from its octahedral geometrical shape, where six fluorine atoms are bonded tightly around a central sulfur atom, preventing its interaction and reaction with other molecules in the atmosphere. Although the Saharan region does not have much of a significant impact on emissions, the extremely long lifetime and chemical stability of the compound make it a well-mixed chemical in the atmosphere, meaning it disperses well and can be measured and observed in similar quantities across the globe.

6.3 Global Warming Potential (GWP)

Over a 100 year period, SF_6 is estimated to have a GWP value of 23,500. This makes this the most powerful greenhouse gas to date. With increasing values, this compound could be one of the most dangerous gases to the environment due to its lack of natural sinks.

6.4 Current state

SF_6 values have never been this high in Earth's history. The need for policy to contain SF_6 emissions is imperative, taking into consideration the GWP and the lifetime. As this compound is synthetic and generated in a lab, historical values of SF_6 do not exist [15][16].



7 Appendix

1. Measurements

- CO_2: Carbon Dioxide measurements are reported in units of micromol/mol (10^{-6} mol CO_2 per mol of dry air or parts per million (ppm)). Measurements are directly traceable to the WMO X2007 CO_2 mole fraction scale.
- CH_4: Methane measurements are reported in units of nanomol/mol (10^{-9} mol CH_4 per mol of dry air (nmol/mol) or parts per billion (ppb)) relative to the NOAA 2004A CH_4 standard scale.
- N_2O: Nitrous Oxide measurements are reported in units of nanomol/mol (10^{-9} mol N_2O per mol of dry air (nmol/mol) or parts per billion (ppb)) relative to the NOAA 2006A N_2O standard scale.
- SF_6: Sulfur Hexafluoride measurements are reported in units of picomol/mol (10^{-12} mol SF_6 per mol of dry air (pmol/mol) or parts per trillion (ppt)) relative to the NOAA 2014 SF_6 standard scale.

2. Data Source

- National Oceanic and Atmospheric Administration (NOAA)
- Earth System Research Laboratory (ESRL)
- Global Monitoring Division (GMD)
- Carbon Cycle Greenhouse Gases (CCGG)

3. Cooperating agencies

- Office National de la Meteorologie (National Office of Meteorology, Algeria)

8 References

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