Atmospheric science

# Cause of the 2020 rise in atmospheric methane

**George H. Allen**

Atmospheric methane concentrations rose unexpectedly during the lockdowns of 2020. It now seems that this was due to warm, wet weather in the Northern Hemisphere and, ironically, a slowdown in air-pollutant emissions. **See p.477**

The mysterious acceleration in the growth of atmospheric levels of methane ($CH_4$) in 2020 received widespread media attention and has been a topic of ongoing speculation (see go.nature.com/3xvv5at). This acceleration was puzzling, considering that methane emissions decreased as a result of the economic slowdown during the COVID-19 pandemic lockdowns. On page 477, Peng *et al.*[1] make considerable headway in explaining the cause of the phenomenon.

Methane is a potent greenhouse gas that is responsible for about one-fifth of the atmospheric warming associated with human activities[2]. Its atmospheric concentration has nearly tripled since pre-industrial times, from 700 parts per billion (p.p.b.) to more than 1,900 p.p.b. today[3] (see also go.nature.com/3xm1dx4). During 2007–19, the concentration rose at a rate of 7.3 ± 2.4 p.p.b. per year. Then, in 2020, the methane growth rate increased dramatically to 15.1 ± 0.4 p.p.b. per year. This jump surprised some scientists, given that the pandemic lockdowns were thought to have reduced anthropogenic methane emissions.

Knowledge of the sources and sinks of methane in the atmosphere is key to understanding the causes of changing methane concentrations. The largest sources of methane in the atmosphere are wetlands, freshwater areas, agriculture, fossil-fuel extraction, landfills and waste, and fires[2]. Once in the atmosphere, methane persists for an average of nine years (ref. 4) before it breaks down through reaction with short-lived hydroxyl radicals ($\mathrm{OH}^{\bullet}$), which are the main sink for methane. Small changes in $\mathrm{OH}^{\bullet}$ concentration cause large changes in the methane sink.

Peng *et al.* analysed the causes of the anomalously high atmospheric methane growth observed in 2020 by combining two approaches: bottom-up and top-down methane estimates. Bottom-up estimates involve using inventories of methane sources and sinks and then applying process-based models to estimate the amount of methane entering and exiting the atmosphere. Top-down estimates typically use an atmospheric-inversion model to infer the spatial distribution of methane fluxes by extrapolating from observations of atmospheric methane.

By updating and expanding bottom-up inventories, Peng *et al.* show that there was only a slight decrease in anthropogenic methane emissions (those associated with fossil fuels, agriculture, landfill and waste) in 2020 compared with 2019. Wetland emissions rose sharply because of unusually warm and wet weather in the Northern Hemisphere (Fig. 1a), especially in the Arctic, whereas emissions due to fires dropped in 2020. Emissions from other natural sources of methane (freshwater and melting permafrost) remained relatively unchanged. Cumulatively, the bottom-up estimates account for only about half (47 ± 16%) of the observed increase in atmospheric methane growth rate from 2019 to 2020.

To assess the changes in the atmospheric methane sink in 2020, the authors adopted a top-down approach using an atmospheric-inversion model to simulate the chemistry and physics of the atmosphere. This model accounts for the formation and chemical interactions of $\mathrm{OH}^{\bullet}$, as well as the lower-than-normal emissions from fires and reduced fossil-fuel combustion that accompanied the pandemic lockdowns. The levels of $\mathrm{OH}^{\bullet}$ in the atmosphere depend in part on the concentrations of carbon monoxide and nitrogen oxides, pollutants that are released from fossil-fuel combustion. Reduced emissions of carbon monoxide and nitrogen oxides decrease $\mathrm{OH}^{\bullet}$ concentrations, thereby increasing methane levels. Ultimately, the top-down estimate indicates that the reduced $\mathrm{OH}^{\bullet}$ sink (Fig. 1b) accounted for approximately half

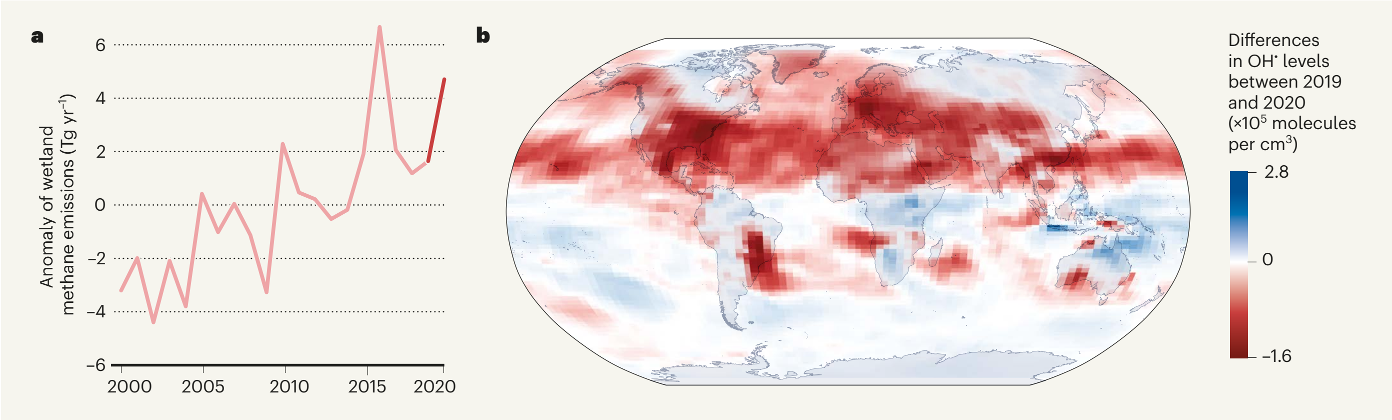

**Figure 1 | The main contributors to the rapid increase in atmospheric methane concentrations in 2020.** Peng *et al.*[1] quantified changes in the sources and sinks of atmospheric methane between 2019 and 2020, to establish why methane levels increased so quickly when human activities had been curtailed by pandemic lockdowns. **a**, About half of the increase was due to a rise in emissions from Northern Hemisphere wetlands associated with high temperatures and precipitation in that region in 2020. Data shown are for the anomaly of wetland emissions (the difference between average measured emissions and the historical annual average) at latitudes of 30° N to 90° N, measured in teragrams of methane per year (1 Tg is $10^{12}$ grams). **b**, The other approximately half of the increase was due to an overall reduction in global atmospheric levels of hydroxyl radicals ($\mathrm{OH}^{\bullet}$, which break down methane), caused by reduced levels of atmospheric pollutants. The map shows the difference in $\mathrm{OH}^{\bullet}$ levels (molecules per cubic centimetre) between 2019 and 2020, plotted across the globe. (Graphics adapted from Fig. 2a and Fig. 3c of ref. 1.)

(53 ± 10%) of the observed growth in atmospheric methane in 2020.

Scientists often struggle to balance top-down and bottom-up methane estimates. Peng and colleagues' study is remarkable in that it successfully matches the two estimates in a geographically accurate analysis. The findings allow us to understand the relative contributions from changes in sources and the OH$^\bullet$ sink during the pandemic.

Despite these advances, some sources of uncertainty remain. For example, Peng *et al.* used only rough estimates for methane emissions from freshwater areas (lakes, reservoirs, ponds, rivers) and melting permafrost, which are thought to be major sources of natural emissions — arguably, just as important as wetlands[2]. A more refined approach that considered, for example, the length of time for which lakes were covered by ice in 2019 compared with that in 2020 would have produced a more accurate emissions estimate. To be fair to the authors, there is still substantial uncertainty associated with estimates of methane emissions from these sources, making it difficult to incorporate such emissions into methane budgets.

Generally, it remains challenging to achieve a predictive understanding of the complex sources, sinks and feedbacks in the global methane budget. More field observations are needed to constrain bottom-up estimates, and more observations from networks of surface sensors and satellites are required to better constrain atmospheric-inversion models — particularly in Central and South Asia, the Middle East, Africa and tropical South America, as the authors recognize.

Peng and colleagues' findings imply that wetland methane emissions are sensitive to a warmer, wetter climate, and thus might fuel a positive feedback loop between methane emissions and global warming. The findings also suggest that future improvements in air quality, resulting in reduced emissions of carbon monoxide and nitrogen oxides, could extend the lifetime of methane in the atmosphere. Thus, a greater reduction in methane emissions than is currently targeted would be required to meet the goal of the United Nations 2015 Paris climate agreement to keep global warming to within 1.5 °C of pre-industrial levels.

The concentration of atmospheric methane surged again (see go.nature.com/3xm1dx4) to 18.2 ± 0.5 p.p.b. per year in 2021 — another mysterious acceleration without a clear cause, and the fastest rate of increase ever recorded. Further investigations into the sources and sinks of methane are clearly needed.

**George H. Allen** is in the Department of Geosciences, Virginia Polytechnic Institute and State University, Blacksburg, Virginia 24061, USA.
e-mail: geoallen@vt.edu

1. Peng, S. *et al. Nature* **612**, 477–482 (2022).
2. Pörtner, H.-O. et al. (eds) *Climate Change 2022: Impacts, Adaptation and Vulnerability. Working Group II Contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* (Cambridge Univ. Press, 2022).
3. Saunois, M. *et al. Earth Syst. Sci. Data* **12**, 1561–1623 (2020).
4. Prather, M. J., Holmes, C. D. & Hsu, J. *Geophys. Res. Lett.* **39**, L09803 (2012).

**The author declares no competing interests.**

## Plant sciences

# How roots go with the flow

### Christa Testerink & Jasper Lamers

How do environmental cues steer the branching of plant roots? Insights into how water availability shapes root growth reveal an unexpected mechanism behind the hormone-mediated regulation of this process.

Plants need their roots to branch out in different directions so that they can explore the soil in their search for nutrients and water. Writing in *Science*, Mehra *et al.*[1] have uncovered the system that determines whether the main root of a plant invests in a new side branch for exploration or continues growing and waits for a better opportunity for side branching. The regulation of this process depends on water flow in the root.

In natural soils, plants experience variation in water availability. When root tips that are growing downwards lose contact with moist soil (for example, in an air gap), they respond by halting the formation of side (lateral) roots that branch out horizontally until contact of the root tip with moisture is re-established. The suppression of root branching in air gaps in soil is called xerobranching[2]. This response was previously proposed to depend on the hormone ABA, which is made in response to drought. ABA inhibits both the initiation and the growth[3] of lateral roots in many plant species, including the model plant *Arabidopsis thaliana*, maize (corn) and barley[2]. The hormone auxin must accumulate in what are called the pericycle cells of the root for lateral roots to develop[4]. During xerobranching, ABA stops the formation of lateral roots by inhibiting auxin accumulation[2].

**"This principle might have relevance for other aspects of directed root growth."**

Mehra *et al.* confirmed that when the roots of tomato and maize plants cross an air cavity in soil, they need ABA for a xerobranching response — ABA-deficient plant mutants made lateral roots in air gaps. To predict how water flows through the root depending on external water availability, the authors carried out simulations. Their findings indicate that when there is sufficient water, it flows in an inward direction, and when the roots are exposed to drought, the flow is reversed. In drought, a water-stressed root depends on water from shoots that reach the root tissues through a water-conducting internal tissue network called the vasculature (or vascular tissue). On the basis of these results, the authors hypothesized that ABA would travel with this water flow from the vasculature to the outer root tissues if the root crosses an air gap.

Previously, xerobranching could be studied only in soil, which limits the options for using *A. thaliana*, high-throughput analyses and tools such as plants with fluorescent markers because of the opacity of the soil. To overcome these constraints, the authors developed a laboratory approach to mimic root exploration over an air gap using an *in vitro* plate assay. Mehra and colleagues used this set-up to explore the role of ABA in *A. thaliana* seedlings that expressed a newly developed set of engineered proteins — ABACUS2 biosensors that offer a way to monitor ABA through use of an imaging process called fluorescence resonance energy transfer (FRET). These biosensors are reported[5] to have a higher affinity for ABA than did the previous generation of ABA biosensors, and so provide greater sensitivity. This work revealed that ABA does indeed move from the vasculature to the outer root layers (Fig. 1a), showing that, on traversing the air gap, ABA gradually accumulates in the outer root tissues while becoming depleted in the vasculature.

Next, the authors investigated plants with signalling deficiencies in ABA arising from mutations in the *SnRK2* gene family. As was the case for plants with mutations affecting ABA production, the mutant plants did not show xerobranching. To elucidate which tissues require ABA signalling, Mehra and colleagues selectively restored ABA signalling in a *snrk2* mutant; they did this using engineered