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Factsheet for ***two*** papers that will appear in Nature's 18 February 2021 issue:

A decline in global CFC-11 emissions during 2018-2019

Authored by:
Stephen A. Montzka, Geoffrey S. Dutton, Robert W. Portmann, Martyn P. Chipperfield, Sean Davis, Wuhu Feng, Alistair J. Manning, Eric Ray, Matthew Rigby, Bradley D. Hall, Carolina Siso, J. David Nance, Paul B. Krummel, Jens Mühle, Dickon Young, Simon O'Doherty, Peter K. Salameh, Christina Harth, Ronald G. Prinn, Ray F. Weiss, James W. Elkins, Helen Walter-Terrinoni, and Christina Theodoridi.

A decline in emissions of CFC-11 and related chemicals from eastern China

Authored by:
Sunyoung Park, Luke M. Western, Takuya Saito, Alison L. Redington, Stephan Henne, Xuekun Fang, Ronald G. Prinn, Alistair J. Manning, Stephen A. Montzka, Paul J. Fraser, Anita L. Ganesan, Christina M. Harth, Jooil Kim, Paul B. Krummel, Qing Liang, Jens Mühle, Simon O'Doherty, Hyeri Park, Mi-Kyung Park, Stefan Reimann, Peter K. Salameh, Ray F. Weiss, and Matthew Rigby.

These new publications update regional- and global-scale atmospheric CFC-11 measurements from 2018 through early 2020, immediately following the discovery of an apparent violation of the Montreal Protocol. They provide an early assessment of intensive regional and global efforts to address the problem of increasing CFC-11 emissions that emerged 3 to 4 years after the 2010 ban on its production globally.

Main findings, global emission paper (Montzka *et al*., 2021):

Global emissions of CFC-11, the second most abundant ozone-depleting gas controlled by the Montreal Protocol, dropped sharply from 2018 to 2019. The drop is comparable to the emission increase that occurred from 2012 to 2017, which may have resulted from new, unreported production after the 2010 global production ban. The results indicate that the long-term downward trajectory of CFC-11 emissions has been restored and a substantial delay in ozone layer recovery from increased emissions has been avoided.

Main findings, regional emission paper (Park *et al*., 2021):

Emissions of CFC-11 from eastern China also decreased after 2017, and by 2019 had returned to pre-2013 levels. The emission decrease from eastern China accounted for 60 ± 30% of the decline in global total emissions by 2019, relative to 2014-2017 values. Results for related chemicals (CCl_4 and CFC-12) suggests unreported CFC production in eastern China after 2010, and a reduction of that production during 2017-2018.

***Background:**

The global phase-out of production of CFCs and other gases under the Montreal Protocol has caused the atmospheric concentration of ozone-depleting chlorine to decrease since 1994 by about 15%. CFC-11 has been the second largest individual contributor to the overall drop in atmospheric chlorine, accounting for about 4% of that decline. Continued declines in atmospheric chlorine concentrations are required for stratospheric ozone to recover by the mid- to late-21st century.

The global average CFC-11 concentration peaked in the early 1990s and continues to decrease today. Even with this decrease, however, CFC-11 remains the second most abundant ozone-depleting substance in the atmosphere. CFC-11 is also a very powerful greenhouse gas.

The Montreal Protocol requires that all CFC production be reported to the UNEP Ozone Secretariat. This reporting indicated that CFC production had been successfully phased out by the start of 2010. In the absence of production, the decline in global CFC-11 concentrations was expected to accelerate even though a large reservoir of CFC-11 (bank) still exists in foams and chillers that sustains emissions of CFC-11 at non-negligible rates.

By 2013, however, CFC-11 concentrations were observed to be declining ***more slowly,*** not more rapidly. The slowdown was attributed to increased emissions, and about half of the global emission increase was coming from eastern Asia.

The global emission increase suggested new, unreported production of CFC-11 after the 2010 phase-out, indicating a violation of the controls of the Montreal Protocol.

Following the announcements in 2018 and 2019 of this unexpected development, the Parties to the Montreal Protocol and individual countries reinvigorated efforts to eliminate any CFC production and associated emissions to ensure the timely recovery of the ozone layer.

***Methods:**

Global emissions of CFC-11 are derived from ongoing atmospheric concentration measurements by two networks at a total of 13 remote sites throughout the globe: the National Oceanic and Atmospheric Administration (NOAA) and the Advanced Global Atmospheric Gases Experiment (AGAGE).

Global emission magnitudes are estimated from the measured concentrations and their annual change at the remote sites, and an understanding of CFC-11's atmospheric lifetime and its variability inter-annually, which is provided by global 3-dimensional modeling of CFC-11's atmospheric loss and year-to-year variability in that loss.

Regional emissions are derived from measured concentration enhancements of CFCs and CCl_4 in pollution plumes reaching two network sites in eastern Asia. Using 3-dimensional wind information, the origin of recent pollution in those plumes is tracked back to the source (inverse modeling). Regional emission magnitudes are also determined from this analysis.

***What the updated global-scale results indicate:**

Since mid-2018, the global atmospheric CFC-11 concentration declined much faster than it had in the preceding 5 years. The global CFC-11 concentration decline in 2019 and early 2020 was -1.0 ± 0.1 % yr^{-1}, which is the fastest decline measured for this gas since observations began in the late 1970s. This decline is more than twice as fast as the -0.4 ± 0.1 % yr^{-1} decline observed from mid-2015 to mid-2017 and the -0.3 ± 0.1 % yr^{-1} rate measured from 2017 to 2018. The larger decline rate since 2018 was reported by both measurement networks, as was a concurrent decline in the hemispheric concentration difference back to values observed before 2012. These changes are consistent with a decline in northern-hemispheric CFC-11 emissions after 2018.

***Global CFC-11 emissions were sharply lower in 2019, following the announcement in 2018 of an apparent violation of the Montreal Protocol*.** Global emissions in 2019 were 17 ± 7 Gg yr^{-1} (25 ± 10 %) lower than mean emissions during 2014-2018 and 18 ± 6 Gg yr^{-1} lower than emissions during 2018.

Global emissions in 2019 of 52 ± 10 Gg yr^{-1} were similar to those measured during 2008-2012, the years immediately preceding the apparent violation. The emission decrease from 2018 to 2019 (18 ± 6 Gg yr^{-1}) was similar to the increase that occurred from 2008-2012 to 2014-2017 (13 ± 7 Gg yr^{-1}). Mean emissions during 2008-2012 were 56 ± 10 Gg yr^{-1}.

Emissions in 2019, while lower than previous years, may still be elevated above expectations. We do not understand precisely how rapidly emissions would have declined after 2010 in the absence of unreported new production. Given these uncertainties, 2019 emissions may be elevated by as little as 2 Gg yr^{-1} or by as much as 24 Gg yr^{-1} above expectations. Some evidence suggests that the unreported CFC-11 production was used to make insulating foams. As a result, continued excess emission is expected as CFC-11 in these foams slowly escapes to the atmosphere.

The reduced emissions in 2019 suggest a substantial decrease in unreported global total CFC-11 production. However, we cannot eliminate the possibility that some production and use continues (see discussion of regional results), adding to emissions in 2019.

CFC-11 banks (the amount of CFC-11 produced but not yet emitted) have been augmented by 90-725 Gg globally as a result of several years of unreported production. The bank values are derived by assuming that the excess CFC-11 emission is associated with manufacturing new insulating foams, and estimates for a range of leakage rates during CFC-11 production, foam manufacturing, foam blowing, and foam installation. These leakage rates suggest that the cumulative amount of unreported CFC-11 production is likely to be substantially larger than the cumulative emission enhancement observed to date.

***What the updated results from eastern-Asian stations indicate:**

Updated data from eastern Asian network sites reveal decreasing concentrations of CFC-11 in pollution plumes originating from eastern China after 2017. Enhanced concentrations in pollution plumes measured at these sites in 2018-2019 were comparable to the enhancements measured during 2008-2013.

Emissions derived for eastern China in 2019 were 10 ± 3 Gg yr^{-1} lower than the 2014-2017 mean. This drop accounts for 60 ± 30 % of the concurrent global decrease in emission by 2019 and was attributed to emission declines primarily in the Shandong and Hebei provinces of eastern China. These were the same provinces where emission increases were detected from 2013 to 2017 in earlier work. The region(s) responsible for the remaining emissions have not been identified, owing to gaps in global observation capabilities.

Emission changes derived for additional chemicals that are potentially emitted during CFC-11 production imply production in eastern China after the 2010 phase-out, and a subsequent decline in that production during 2017-2018. The production of CFC-11 starts with carbon tetrachloride, and CFC-12 is typically co-produced. Emission rates of these chemicals from eastern China, inferred with the same regional modeling techniques used for CFC-11, showed similar changes as CFC-11 from 2013 to 2019, suggesting that those changes could be related to renewed CFC-11 production.

***CFC-11 banks in eastern China were estimated to be 75 (46-112) Gg larger in 2019 compared to pre-2013 levels*.** Banks represent the amount of CFC-11 added to newly produced products that has not yet escaped to the atmosphere. This estimate was derived from consideration of emission changes for CFC-11, CFC-12, and CCl_4, and estimates of how the CFC-11 was likely used (i.e., in the manufacture of insulating foams).

***Implications, take-home messages:**

The ozone depletion associated with the unexpected emission and renewed production is likely limited, provided that the reductions in emission and unreported production quantified in the new papers are sustained. Future enhancements in total atmospheric chlorine from this pulse of CFC-11 emission and production will likely be limited to less than 60 ppt (or less than 2.5% of atmospheric chlorine from all long-lived gases).

The structures that inform the Parties to the Montreal Protocol detected an issue, and positive change resulted. Scientific and industry expertise added insight as to the likely causes and its scope.

***High-quality monitoring networks and interpretive capabilities were key to drawing attention to this issue, thus enabling a response*.**

Future observations will provide an understanding of compliance with the Montreal Protocol by continuing to track emissions of CFC-11, other ozone-depleting chemicals, and chemicals that influence climate, and by identifying other emerging issues relevant to the Parties.

A quick reference: Updated emissions and emission changes from the new papers:

(*All values are in units of Gigagram or 1x10^{12} gram, and 1 Gigagram = 1000 metric tonnes, and 1000 metric tonnes = 1102 US tons)*

Years	global emissions	east China emission
Emissions before apparent problem:		
2008-2012	56 ± 10	7.2 ± 1.5
Emissions during elevated years:		
2014-2017 or 2014-2018	70 ± 10	15 ± 4
Emissions for latest year:		
2019 alone	52 ± 10	5 ± 1
The emission increase:		
2014-2017 or 2014-2018 compared to 2008-2012:	13 ± 7	7 ± 4
The emission decrease:		
2019 compared to 2014-2017 or 2014-2018:	17 ± 7	10 ± 3

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Notes to reference Table:

East China emissions in 2018 were determined to be “intermediate between those derived for 2014-2017 and 2019”, whereas global emissions in 2018 were comparable to the 2014-2017 mean.

* Global values quoted above represent best estimates after accounting for variability in atmospheric processes that can influence observationally-derived global emission values.

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