Factsheet:
May 10, 2018

An unexpected and persistent increases in global emissions of ozone-depleting CFC-11

Paper by
Stephen A. Montzka, Geoff S. Dutton, Pengfei Yu, Eric Ray, Robert W. Portmann, John S. Daniel, Lambert Kuijpers, Brad D. Hall, Debra Mondeel, Carolina Siso, J. David Nance, Matt Rigby, Alistair J. Manning, Lei Hu, Fred Moore, Ben R. Miller, James W. Elkins

Publication to appear in the 17 May issue of *Nature*.

Main finding:
Emissions of CFC-11, the second most abundant ozone-depleting gas controlled by the Montreal Protocol, have unexpectedly increased in recent years despite a global ban on production since 2010. These emissions partially offset gains made by the Montreal Protocol by slowing the decline of ozone-depleting chlorine concentration in the atmosphere. The increased emissions may stem from new, unreported production of CFC-11.

***Background:**
The global phase-out of chlorofluorocarbon (CFC) production 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 contributor to the overall drop in atmospheric chlorine, accounting for about 4% of the decline in total chlorine. Continued declines in atmospheric chlorine concentrations will be needed if stratospheric ozone is 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 today.

The Montreal Protocol requires that all CFC production be reported to the UNEP Ozone Secretariat. This reporting would suggest that all production of CFC-11 has been very small for over a decade (<0.5 kiloton (metric) per year since 2010). By comparison, production in the 1980s peaked at about 350 kilotons per year.

Despite the near complete phase-out of CFC-11 production, emissions are not yet zero. Emissions of CFC-11 are sustained by leaks from a reservoir (or bank of ~1000 kt) of CFC-11 existing in foam insulation in buildings and appliances manufactured before the mid-1990s. A smaller amount of CFC-11 also exists today in chillers. Some small increase in emissions might be expected as older buildings containing CFC-11 are destroyed, but any increase in emissions from this source should be small, change only very gradually over time, and arise primarily from developed countries.

***Methods:**
Global emissions of CFC-11 were derived from NOAA's long-term, high-quality atmospheric measurements at 12 remote sites throughout the globe with well-established methods.

***Expectations vs. what we observed:**
Without continued CFC-11 production, and with broad use of chemicals used as substitutes, emissions of CFC-11 were expected to decrease slowly over time as the reservoir sustaining those emissions became depleted. With decreasing annual emissions, atmospheric concentrations would decline more rapidly each year until they reached the limit (~2% per year) set by the lifetime of CFC-11 in the atmosphere (~50 yr).

After 2002, however, the global atmospheric CFC-11 concentration did not decline more rapidly each year. Instead, the global CFC-11 concentrations declined at a constant rate in the decade after 2002.
(The rate of decline was –2.1 ppt/yr, or –0.8%/yr, over 2002-2012).

Beginning in 2013, CFC-11 concentrations began decreasing more slowly, rather than more rapidly, opposite to expectations. CFC-11 concentrations declined only about half as fast over the past 3 years compared to the rate measured during the previous decade. This decline during the past 3 years was substantially slower than expected.
(The decline over the past three years (2015-2017) was –1.1 ppt/yr or –0.4%/yr, while the expected decline over this period was more than two times faster: –2.5 ppt/yr, or –1.1%/yr).

Also beginning in 2013, the concentration difference measured between the northern and southern hemispheres increased by 50% *(with more measured in the north)*. This observation suggests that CFC-11 emissions have increased, because emissions of CFCs and other human-produced gases arise primarily from the more populated Northern Hemisphere.

The last time CFC-11 was declining this slowly and its hemispheric concentration difference was this large was in the late 1990s, when reported global production of CFC-11 was substantially larger than it is today.

Also beginning in 2013, plumes of polluted air reaching Hawaii suddenly contained elevated concentrations of CFC-11. An analysis of wind speeds and direction throughout the Pacific Ocean basin suggests that the pollution plumes originated from eastern Asia. The unique mix of chemicals with elevated concentrations in these plumes also suggests a source in eastern Asia. Eastern-Asian-influenced pollution events reaching Hawaii before 2013 did not contain elevated concentrations of CFC-11.

***Implications:**
Emissions of CFC-11 have increased in recent years despite the reported elimination of CFC-11 production under the Montreal Protocol. The annual emissions during 2014 to 2016 were as much as 13 +/- 5 kt/yr (or 25%) higher than average emissions estimated over 2002 to 2012. An emission increase is quite surprising given that reporting to

UNEP suggests that the global production of CFC-11 have been negligible for nearly a decade.

Three-dimensional chemistry-climate models confirm that the slower observed decline of CFC-11 concentrations and the enhanced hemispheric concentration difference reflect increasing CFC-11 emissions after 2012. Natural changes in winds and chemistry likely contributed to the slowing of the CFC-11 concentration decline, but in these models the observations are well represented only when a CFC-11 emissions increase is included.

The emission increase suggests new unreported CFC-11 production. To explain an increase in CFC-11 emissions without new production over the past decade requires either 1) increased releases of CFC-11 from its 'bank' or 2) some increasing use or market for existing CFC-11 stockpiles. Neither of these possibilities seems likely, further supporting the conclusion that the recent observed changes for CFC-11 indicate the presence of new production. For example, leakage rates to the atmosphere of CFC-11 from the entire global bank that consists primarily of foams in buildings, appliances, and landfills would have had to approximately double over the past 10 years, from 3.5%/yr of the CFC-11 bank to 7%/yr, to explain the observations. Such a doubling is considered very unlikely. Furthermore, the amount of CFC-11 in stockpiles not trapped in foams is believed to be small, so substantial new uses with "banked", relatively accessible CFC-11, are precluded.

The existence of any new CFC-11 production would be inconsistent with the Montreal Protocol agreement to eliminate production of CFCs by 2010. While only production for dispersive uses of CFC-11 is controlled by the Protocol, these results demonstrate that additional amounts of CFC-11 have escaped to the atmosphere in recent years. Furthermore, Parties to the Protocol are obligated to report production for all uses (dispersive and non-dispersive), yet production totals reported for CFC-11 to the Ozone Secretariat have been negligible for all uses since 2007.

If the source of these emissions can be identified and mitigated soon, the increased damage to the ozone layer should be minor. If not remedied soon, however, delays in ozone recovery would be expected.