Chlorine declining in the stratosphere, but is China producing illegal CFC11?

Article 6 of the Montreal Protocol protecting the Ozone Layer mandates that „at least every four years ..., the Parties shall assess the control measures ... on the basis of available scientific, environmental, technical and economic information“. For this assessment “the Parties shall convene appropriate panels of experts” - the Scientific Assessment Panel (SAP), Environmental Effects Assessment Panel (EAP), and Technology and Economic Assessment Panel (TEAP). Every 3–4 years, these three panels prepare major assessments, updating the state of understanding in their respective areas. Recently, in November 2018, the SAP published the Executive Summary of its 2018 Scientific Assessment of Ozone Depletion (https://www.esrl.noaa.gov/csd/assessments/ozone/2018/). Release of the comprehensive full assessment is expected in late December.

What are major findings of the new assessment? Fig. 1 shows, on the basis of EESC (=Equivalent Effective Stratospheric Chlorine and Bromine), that the stratospheric abundance of ozone-depleting substances has been declining slowly for about 20 years, thanks to the controls by the Montreal Protocol. However, this decline is about 3-times slower (and will remain slower) than the preceding fast increase from the 1960s to the mid-1990s. Thus, low chlorine abundance, as before 1980, is expected only for the second half of the current century!

Without the Montreal Protocol, stratospheric chlorine (and bromine) would have increased until today (to, e.g., 8 or 10 ppb EESC above Antarctica). This would have caused dramatic ozone loss world-wide. Above Germany, for example, the total ozone column would have been depleted by 20% or more, much more seriously than the observed loss of „only“ about 6% so far.

The first positive effect of the beginning decline of ozone-depleting substances is an observed increase of ozone in the upper stratosphere. This was already reported in the last assessment. The new assessment is now finding first signs of recovering ozone above Antarctica. For ozone columns at mid-latitudes, above the Arctic and in the Tropics, however, the expected increases are still masked by natural variability and noise.

**Figure 1**: Abundance of EESC (=Equivalent Effective Stratospheric Chlorine and bromine) above Antarctica. The filled curves give the contribution of the most important source gases to EESC. The top curve gives the total EESC. Curves at mid-latitudes look very similar, but peak at lower values, about 2 ppb maximum. Data before 2017 are based on observations. Data after 2017 are based on model simulations and assume compliance with the Montreal Protocol. Adapted from Executive Summary WMO/UNEP Ozone Assessment 2018.
Unfortunately, the new assessment also reports troubling news: Near surface trace gas measurements from the independent NOAA and AGAGE networks show that, for a number of years, the world-wide emission of ozone-depleting CFC 11 (also known as Freon 11, F11, CCl$_3$F) has not been declining as expected. Although it is not quite clear how much CFC 11 is emitted by existing “banks” (old foams, old refrigerators, air conditioners, etc.), the measured emissions (red and black curves in Fig. 2) have clearly exceeded reasonable bank-emission estimates (dashed grey lines in Fig. 2) in all recent years. Observed emissions are also much higher than reported production (green curve in Fig. 2). The only explanation seems to be illegal use (and production) of CFC 11 in East-Asia / China (see also https://www.nature.com/articles/d41586-018-07269-1). CFC 11 is a banned substance under the Montreal Protocol, but the recent observations indicate illegal emission of about 20 kilo-tons per year (equivalent to 100 or 200 large railway tank cars). Illegal production of CFC11 must be even larger!

So far this does not endanger the expected recovery of the ozone layer, because we are talking about just a few percent of the total amount of CFC 11 produced in the past. However, the illegal production will delay ozone recovery dates by a few years (see the small slope of the EESC curve in Fig. 1). The Parties of the Montreal Protocol need to act fast and need to end this illegal production!

The unfortunate CFC11 development clearly shows that success of the Montreal Protocol is not automatically guaranteed. Efficient controls are necessary, as are regular assessments of the success of the control measures. This requires continuing precise measurements of all relevant trace gases and atmospheric parameters. It requires scientists and appropriate tools to analyze the measurements and to understand them. It requires assessments feeding back the acquired information to the Parties of the Protocol. Overall, however, the Montreal Protocol is successful: Ozone depleting substances are declining in the atmosphere. Ozone recovery has started. Monitoring of the Protocols success is working. Now it is up to the Parties, politicians and diplomats, to make sure that the illegal production of CFC 11 is ended.

![Figure 2: Global emission or production of ozone-depleting CFC 11 (=Freon 11, F11, CCl$_3$F). Green Curve: production reported under the Montreal Protocol. Red and black curves: emission derived from near surface trace gas measurements by NOAA and AGAGE. Dashed gray lines: expected emission from banks, i.e. old foams, old refrigerators, air conditioners, etc.. Source: Executive Summary WMO/UNEP Ozone Assessment 2018.](image-url)