

Name of research institute or organization:

EMPA Materials Science and Technology

Title of project:

Monitoring of halogenated greenhouse gases

Project leader and team

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Project description:

In-situ measurements of the complete dataset of non-CO₂ greenhouse gases are continuously running at the Jungfraujoch since 2000 for halocarbons and since February 2005 for methane, nitrous oxide and sulphur hexafluoride. When combining these data with other long-term time series of greenhouse gases, our long-term measurements allow to evaluate the current radiative forcing of the species and to assess the effect of the replacement of ozone-depleting substances due to their restriction within the Montreal Protocol.

A large number of gases that are at least partly emitted by human activities do change the Earth's radiation balance. Besides CO₂, other greenhouse gases (GHGs) like methane (CH₄), nitrous oxide (N₂O), and sulphur hexafluoride (SF₆) as well as halocarbons also have a considerable potential to alter the Earth's radiation balance. Whereas the chlorinated halocarbons such as chlorofluorocarbons (CFCs), hydrochlorofluorocarbons (HCFCs) also contribute to the stratospheric ozone-depletion, chlorine-free species like hydrofluorocarbons (HFCs) and perfluorocarbons (PFCs) do only affect the surface climate.

Since these chlorinated species were identified as the major players in the stratospheric ozone depletion, regulations were negotiated to regulate the use and the emissions of these species. As a result, the Montreal Protocol on substances that deplete the ozone layer became legally binding in 1987. It regulated the phase out of halons (bromine-containing halocarbons) for developed countries by the end of 1993 and CFCs, carbon tetrachloride and methyl chloroform by the end of 1995, respectively. The CFCs were replaced by either HCFCs or HFCs, i.e. compounds with only minor (HCFCs) or even no ozone depletion potential (HFCs). Thus, negative trends are measured in the last years for methyl chloroform (Reimann *et al.*, 2005) and CFC-11 (Reimann *et al.*, 2004), and at least a change from increasing to stagnant concentrations is detected for CFC-12, CFC-113 (decreases world-wide) and CCl₄ (decreases world-wide). At the same time, positive trends in the background concentrations were observed for the CFC-substitutes (HCFCs, HFCs) (Reimann *et al.*, 2004).

As the Montreal Protocol-regulated species as well as their replacement products are greenhouse gases but with different radiative efficiencies, their regulation influences climate change, too. In the present work, we tried to identify and quantify these effects by means of continuous measurements at the Jungfraujoch in comparison with long-term datasets from known databases.

Our long-term measurements show that ozone-depleting substances were partly replaced by chlorine-free species (i.e. HFCs), which do not only reduce the atmospheric ozone depletion but also do improve the situation in terms of global warming.

We extrapolate the observed trends of CFCs before the Montreal Protocol became legally binding (Prinn *et al.*, 2000), assuming a business-as-usual scenario and compare the extrapolated concentrations with the observed values (see Figure 1). The recent difference between the extrapolated and the observed concentration is defined as the prevented increase for each species.

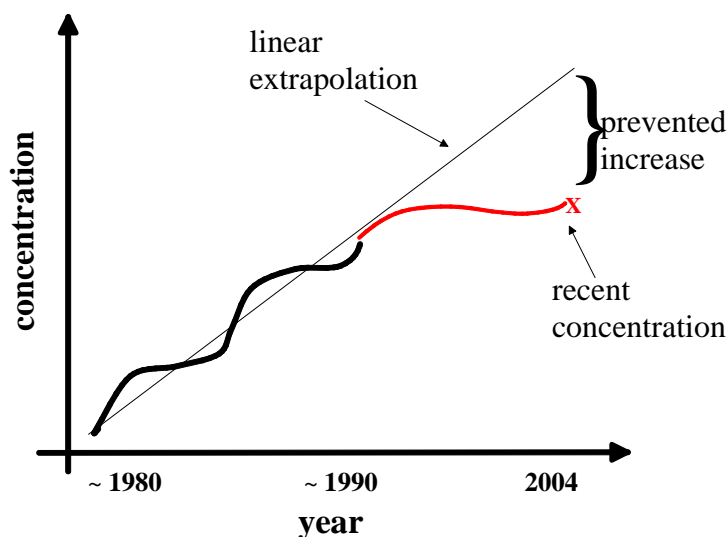


Figure 1: Sketch illustrating the concept of the prevented increase (data before the Montreal protocol became legally binding can be taken e.g. from the ALE/GAGE/AGAGE network (Prinn *et al.*, 2000).

Table 1 shows the trends for the most important halogenated greenhouse gases observed at the Jungfraujoch. The trends for the major GHGs are northern hemispheric averages for the last 15 years (IPCC, 2001 and WDCGG, 2005). Additionally, the prevented increases of the Montreal Protocol regulated species are listed, too. We multiply the observed trends of the major GHGs and the replacements products as well as the prevented increases with the radiative efficiencies of the respective gases. We consider the radiative efficiencies rather than their global warming potentials (GWPs) since we investigate the changes on the current situation. The radiative efficiencies denote the instantaneous change of the radiative forcing due to the increase of a specific compound whereas the GWPs represent the integral of the radiative efficiency for a chosen time horizon. Subsequently, the GWPs imply a decision regarding the climate processes and impacts of interest.

Table 1: Trends of greenhouse gases, prevented increases for the Montreal Protocol regulated species as well as trends of the radiative and the prevented radiative forcing, respectively. Trends of CO₂, N₂O and CH₄ are taken from IPCC, 2001 and WDCGG, 2005. Other trends are extracted from measurements at the Jungfraujoch. Radiative efficiencies are taken from IPCC, 2001.

Species	Trend [ppt yr ⁻¹]	prevented increase [ppt yr ⁻¹]	Radiative efficiency [W m ² ppb ⁻¹]	trend: radiative forcing [Wm ⁻² yr ⁻¹]	trend: prevented radiative forcing [W m ⁻² yr ⁻¹]	sum: radiative forcing per class
Major GHGs + SF₆						2.88E-2
CO ₂	+1'560'000		1.54E-5	2.31E-2		
N ₂ O	+ 800		3.70E-3	2.96E-3		
CH ₄	+ 7'000		3.70E-4	2.59E-3		
SF ₆	+ 0.3		0.52	1.56E-4		
HCFCs, HFCs						1.53E-3
HFC134a	+ 4		0.15	6.00E-4		
HCFC142b	+ 0.6		0.2	1.20E-4		
HCFC22	+ 3.5		0.2	7.00E-4		
HFC125	+ 0.47		0.23	1.08E-4		
CFCs + CH₃CCl₃ + CCl₄						-8.25E-3
CFC11	- 1.5	- 9	0.25		- 2.25E-3	
CH ₃ CCl ₃	- 5	-12	0.06		- 7.20E-4	
CFC113	0	- 5	0.3		- 1.50E-3	
CFC12	0	- 11	0.32		- 3.52E-3	
CCl ₄	0	- 2	0.13		- 2.60E-4	

The presented approach using the unique comprehensive dataset of Montreal and Kyoto regulated species measured at the Jungfraujoch results in a prevented yearly increase of the radiative forcing of $8.25 \cdot 10^{-3} \text{ W m}^{-2}$ due to the phase-out of CFCs and the chlorinated solvents. It is to approximately 18.5% compensated by the increase of CFC-replacement compounds (HCFCs and HFCs). The net effect due to the Montreal regulations counterbalances around 23% of the rising greenhouse effect related to the major greenhouse gases CO₂, CH₄, N₂O, and also SF₆ that are part of the Kyoto Protocol.

We conclude that long-term measurements of halocarbons can be used to assess the consequences of international treaties regulating their emissions. The Montreal Protocol did not only succeed to reduce the ozone depletion but also contributed to lower the increasing atmospheric greenhouse effect already before the Kyoto Protocol came into force.

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Key words:

Air pollution, long-term measurements, halocarbons, Kyoto Protocol, Montreal Protocol

Internet data bases:

<http://www.empa.ch/abt134>

http://www.empa.ch/plugin/template/empa/700*/---/1=2

<http://www.nilu.no/soge/>

Collaborating partners/networks:

Bundesamt für Umwelt (BAFU)/ Federal Office for the Environment (FOEN)

Global Atmosphere Watch (GAW)

SOGE (System for observation of halogenated greenhouse gases in Europe)

AGAGE (<http://agage.eas.gatech.edu/home.htm>)

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Scientific publications and public outreach 2005:

Refereed journal articles

Reimann S., Manning A. J., Simmonds P. G., Cunnold D. M., Wang R. H. J., Li J., McCulloch A., Prinn R. G., Huang J., Weiss R. F., Fraser P. J., O'Doherty S., Grealley B. R., Stemmler K., Hill M., Folini D., (2005) Low European methyl chloroform emissions inferred from long-term atmospheric measurements. *Nature* 433 506-508.

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Conference contributions

Reimann, S., Folini, D., Vollmer, M.K., Ubl, S., Buchmann, B., Stemmler, K., O'Doherty, S. European Emission Estimates of Halogenated Greenhouse Gases from Continuous Measurements at Jungfrauoch, Switzerland. Invited talk at the ACCENT symposium, Urbino, 2005.

Reimann, S., Folini, D., Vollmer, M.K., Ubl, S., Buchmann, B., Stemmler, K., O'Doherty, S. European Emission Estimates of Halogenated Greenhouse Gases from Continuous Measurements at Jungfrauoch, Switzerland. Invited talk at the ACCENT symposium, Urbino, 2005.

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Buchmann, B., Reimann, S. and Hüglin, Ch., The GAW-CH Greenhouse and Reactive Gases Programme at the Jungfraujoch, Veröffentlichung Nr. 70, MeteoSchweiz (Editor), ISSN: 1422-1381, 2005.

Magazine and Newspaper articles

Tages-Anzeiger, 03.02.2005, Ozon-Schadstoff über Europa

NZZ, 03.02.2005, Europa emittiert noch immer verbotene Ozonabbaustoffe

Walliser Bote, 03.02.2005, Deutlich tiefer – Emissionen von Ozon-Abbaustoff

Handelsblatt, 03.02.2005, Ozonkiller geringer als angenommen

NZZ am Sonntag, 06.02.2005, Abschied vom Ozonloch

Umwelt Focus, Februar 2005, Trichlorethan-Emissionen korrigiert

Gesundheit und Umwelttechnik Nr. 1, April 2005 (Organ der Schweiz. Vereinigung für Gesundheits- und Umwelttechnik SVG), Trichlorethan-Emissionen in Europa nach unten korrigiert. Neuste Resultate der Empa

Radio and television

MTW, SF1, 03.02.2005, Eine gute Nachricht für unsere Ozonschicht: Weniger Trichlorethan

DRS2 aktuell am Abend, DRS2, 03.02.2005, Wider das Ozonloch

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