

Potential of the NDSC in support of the Kyoto Protocol: Examples from the station Jungfraujoch, Switzerland

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Keywords: atmospheric composition, monitoring, greenhouse gases, Montreal and Kyoto Protocols

ABSTRACT: This paper gives a brief description and “raison d’être” of the Network for the Detection of Stratospheric Change (NDSC) as well as its key research tasks to address the broader goal of monitoring atmospheric changes and to identify their causes and related impacts on mankind’s environment. While the Network has primarily focussed, thus far, on monitoring the ozone layer and assessing global compliance with the Montreal Protocol, ongoing implementations and new capabilities have enabled it to adapt to more recent political developments such as the Kyoto Protocol on substances affecting the climate system. Examples of activities in support of the latter are reported, based on infrared solar observations at the Jungfraujoch station.

1 INTRODUCTION

The main objective of the international Network for the Detection of Stratospheric Change (NDSC) is to monitor, from pole to pole, the temporal and spatial variability and evolution of the chemical and physical state of the stratosphere, including the ozone layer, and to understand the causes (i.e., natural versus anthropogenic; chemical versus dynamical;...) of the observed changes and their impacts upon the troposphere and at the ground. It was inceptioned in 1986, in response to worldwide concerns following the discovery of the “ozone hole” over the Antarctic as well as substantial ozone losses over the northern polar regions and at midlatitudes, and the request, from policymakers, for the scientific community to investigate and document such perturbations, many of them thought to be of mankind origin. This dual goal of long-term monitoring and understanding has led to the implementation and coordination of a ground-based network which started formal operation in 1991 and currently comprises over 60 research locations, fully (primary stations) or partly (complementary sites) equipped with a suite of remote sensing instruments including various types of UV/Visible monochromators, Lidar systems, Fourier transform infrared spectrometers, microwave radiometers, *in situ* radiosondes, etc. As evoked in the next sections, their synergistic operation allows to study, quasi simultaneously, a large number of chemical compounds (sources, sinks and reservoirs combined) and physical parameters of the middle atmosphere.

The NDSC has been recognized as a major component of the international upper atmospheric research program and as such, it has been endorsed by national and international scientific organizations, including UNEP, IAMAS and WMO.

Table 1. NDSC Measurement Priorities and Rationale

<u>Measurements</u>	<u>Instrument Types</u>	<u>Rationale</u>
O ₃ total column	Dobson; Brewer; other UV/Visible and FTIR ^(*) spectrometers	Controls penetration of UV radiation to troposphere and ground
O ₃ profile 0-18 km 15-60 km 12-65 km 0-32 km	DIAL ^(**) ($\lambda < 300$ nm) DIAL ($\lambda > 300$ nm) μ wave ^(***) radiometers ozone sondes	Determines stratospheric temperature structure; influences circulation and climate; important greenhouse gas in the troposphere
Temperature 15-35 km 30-95 km	Raman lidars Rayleigh lidars	Determines rates of chemical reactions; controls vertical transport and H ₂ O content near tropopause; influenced by greenhouse gases
ClO profile 25-45 km	μ wave radiometers	Catalyzes O ₃ destruction
H ₂ O profile 0-15 km 0-30 km 40-80 km	Raman lidars hygrometer sondes μ wave radiometers	Controls radiative and chemical balance of the stratosphere; tracer of troposphere-stratosphere exchange; main source of OH in the stratosphere; affects climate
Aerosols 0-30 km	backscatter lidars backscatter sondes	Influence climate; initiate heterogeneous processes in particular at high latitudes; affect optical sensor data reduction
NO ₂ stratospheric column	UV/Vis and FTIR spectrometers	Provides catalytic control of O ₃ ; couples NO _x , HO _x and Cl _x cycles
HCl and ClONO ₂ columns	FTIRs spectrometers	Main inorganic chlorine (Cl) reservoirs; key roles in heterogeneous activation processes
N ₂ O, CH ₄ , CFC and HCFC columns and stratospheric profiles	FTIRs spectrometers; μ wave radiometers	Tracers of atmospheric transport; provide reference systems for interpretation of ozone changes; greenhouse gases
HNO ₃ and NO columns	FTIRs spectrometers	Important compounds of the NO _y family
HF and COF ₂ columns	FTIRs spectrometers	Main inorganic fluorine (F) species in the stratosphere
Other species (OH, HO ₂ , OCS, CO, ...)	UV fluorescence lidars; μ wave radiometers; FTIR spectrometers	Regulate stratospheric oxidation capacity, sulphate aerosol loading, ...
UV radiation at the ground	UV spectroradiometers	Increases as O ₃ decreases; affects oxidation capacity of the troposphere and thus lifetimes of greenhouse gases

(*) Fourier transform infra-red; (**) Differential Absorption Lidar; (***) Microwave

2 NDSC MEASUREMENT CAPABILITIES AND RATIONALE

NDSC priority measurements and rationale are listed in Table 1. Stations and sites currently affiliated to the Network, details on their individual measurement capabilities and related data archives and publications can be found on the web site <http://www.ndsc.ws>. The instrument types have been primarily selected on the basis of their remote-sensing, state-of-the-art operational performances for specific measurements over given altitude ranges, and on their demonstrated stability for continuous, long-term field operation.

Beside investigations that specifically characterize the state of the stratosphere (in particular ozone; key reservoirs and sinks such as NO₂, NO, HNO₃, HCl, ClONO₂; aerosols; H₂O; temperature; ...), numerous long-lived tropospheric constituents are also included in the Network's monitoring activities as source gases and as tracers of atmospheric circulation, to help establish family budgets and identify short-term composition changes caused by meridional transport and/or local dynamics. While the former are of direct relevance to the "Montreal Protocol on substances that deplete the ozone layer", the latter bear relevance to the "Kyoto Protocol on substances that influence the radiative forcing of the climate system".

As can be noticed in Table 1, and as already evoked during NCGG-1 (Zander et al., 1994), high spectral resolution, broadband FTIR spectrometers equipped with cryogenic detectors have developed into powerful ground-based, remote-sensing instruments for detailed soundings of both the stratosphere and the troposphere. Using the sun as source of radiation, they allow to investigate, quasi simultaneously, over two dozen atmospheric constituents for their total column abundances, and even partial tropospheric- and stratospheric columns for many of them [e.g., Pougatchev et al., 1998; Rinsland et al., 2000; Barret et al., 2001]. Within the context of the NDSC, nearly 20 such FTIRs are operated at fixed locations, while 4 others are "mobile" instruments used during programmed inter-comparison and validation campaigns, ship cruises or/and site evaluations. Examples of NDSC potentialities for direct contributions to greenhouse gas monitoring are demonstrated in the next section.

3 EXAMPLES OF GG MONITORING AT THE NDSC STATION JUNGFRAUJOCH

Since 1989, the international scientific station of the Jungfraujoch (Switzerland; 46.5°N, 8.0°E, 3580 m asl) is part of the composite NDSC primary "Alpine Station" for monitoring the state of the atmosphere at northern mid-latitudes. Among various affiliated instruments located there, two high resolution FTIR spectrometers are operated under the responsibility of the University of Liège group. Table 2 gives details about the molecules accessible with the latter instruments through high-resolution solar observations in the 2 to 5.5 μm and 8 to 14 μm atmospheric windows.

Table 2. List of Molecules Studied in FTIR Solar Observations at the Jungfraujoch^(*)

Reference gas:	N ₂ (≈1%)
Minor constituents:	CO ₂ (<2%), N ₂ O (≤2%), CH ₄ (≈2%), CO (≤4%), O ₃ (≤5%), [H ₂ O]
Trace constituents:	
Halogenated species:	HCl (≤4%), ClONO ₂ (≈ 20%), CCl ₂ F ₂ (≤4%), CHClF ₂ (≤6%), HF (≤3%), COF ₂ (≤20%), SF ₆ (≈30%)
Nitrogenated species:	NO (≤6%), NO ₂ (≤10%), HNO ₃ (≈5%), HNO ₄ (monthly avg.)
Others:	C ₂ H ₆ (≤6%), C ₂ H ₂ (≈20%), HCN (≤8%), OCS (≤8%), H ₂ CO (multi-month avg.), [H ₂ CO ₂ , CH ₃ Cl, CCl ₄ , CCl ₃ F,...];

^(*) (...%) give the precision with which total column abundances can be derived routinely from current individual observations; XX are primarily stratospheric; YY and ZZ are tropospheric source gases; [ZZ] are species under evaluation.

Figures 1, 2 and 3 reproduce the timely evolution above the Jungfraujoch of the burdens of a series of atmospheric source gases which directly or indirectly affect the radiation balance of the atmosphere, thus climate on Earth. Each symbol represents mean total vertical column abundances derived from all observations made during individual months. Details on trend evaluations can be found in the figure captions as well as in previous publications (e.g., Mahieu et al., 1997; Rinsland et al., 2000; Zander et al., 2000).

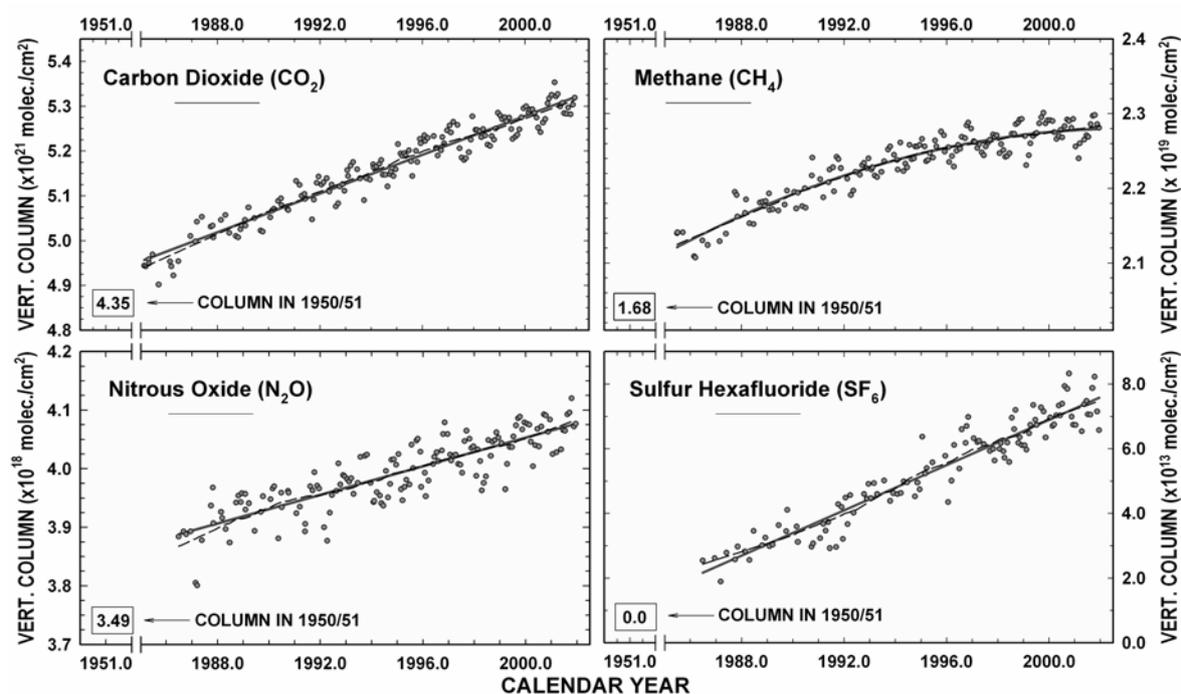


Figure 1. Timely evolution of monthly mean vertical column abundances monitored above the Jungfraujoch of four atmospheric constituents to be regulated by the Kyoto Protocol. Notice the different multiplication factors on the ordinate scales. 1950-51 columns measured for CO₂, CH₄ and N₂O above the same site are given in the lower left corner of the related frames. The continuous lines represent best least-squares polynomial fits to the data points, and discrete trends calculated from these fits are given in Table 3. The mean rate of change for CO₂ (not reported in Table 3) is equal to 0.42 ± 0.01 %/yr over the 1985-2001 time period.

Table 3. Total column abundance changes for source gases monitored above the Jungfraujoch

Species	Annual changes in molec./cm ² and in (%) over specified periods			
	1987-1988	1991-1992	1995-1996	1999-2000
CCl ₂ F ₂	2.08xE14 (3.66)	1.36xE14 (2.14)	0.79xE14 (1.16)	0.35xE14 (0.50)
CHClF ₂	7.06xE13 (6.65)	8.12xE13 (5.95)	8.75xE13 (5.13)	8.93xE13 (4.34)
CH ₄	1.55xE17 (0.72)	1.14xE17 (0.51)	0.73xE17 (0.32)	0.32xE17 (0.14)
N ₂ O	1.22xE16 (0.31)	1.22xE16 (0.31)	1.22xE16 (0.30)	1.22xE16 (0.30)
SF ₆	3.49xE12 (12.9)	3.49xE12 (8.53)	3.49xE12 (6.36)	3.49xE12 (5.07)
CO	-7.15xE15 (-0.56)	-7.15xE15 (-0.57)	-7.15xE15 (-0.59)	-7.15xE15 (-0.60)
C ₂ H ₆	-2.96xE14 (-2.01)	-2.96xE14 (-2.19)	-2.96xE14 (-2.40)	-2.96xE14 (-2.65)
C ₂ H ₂	-3.45xE13 (-1.86)	-3.45xE13 (-2.01)	-3.45xE13 (-2.18)	-3.45xE13 (-2.39)

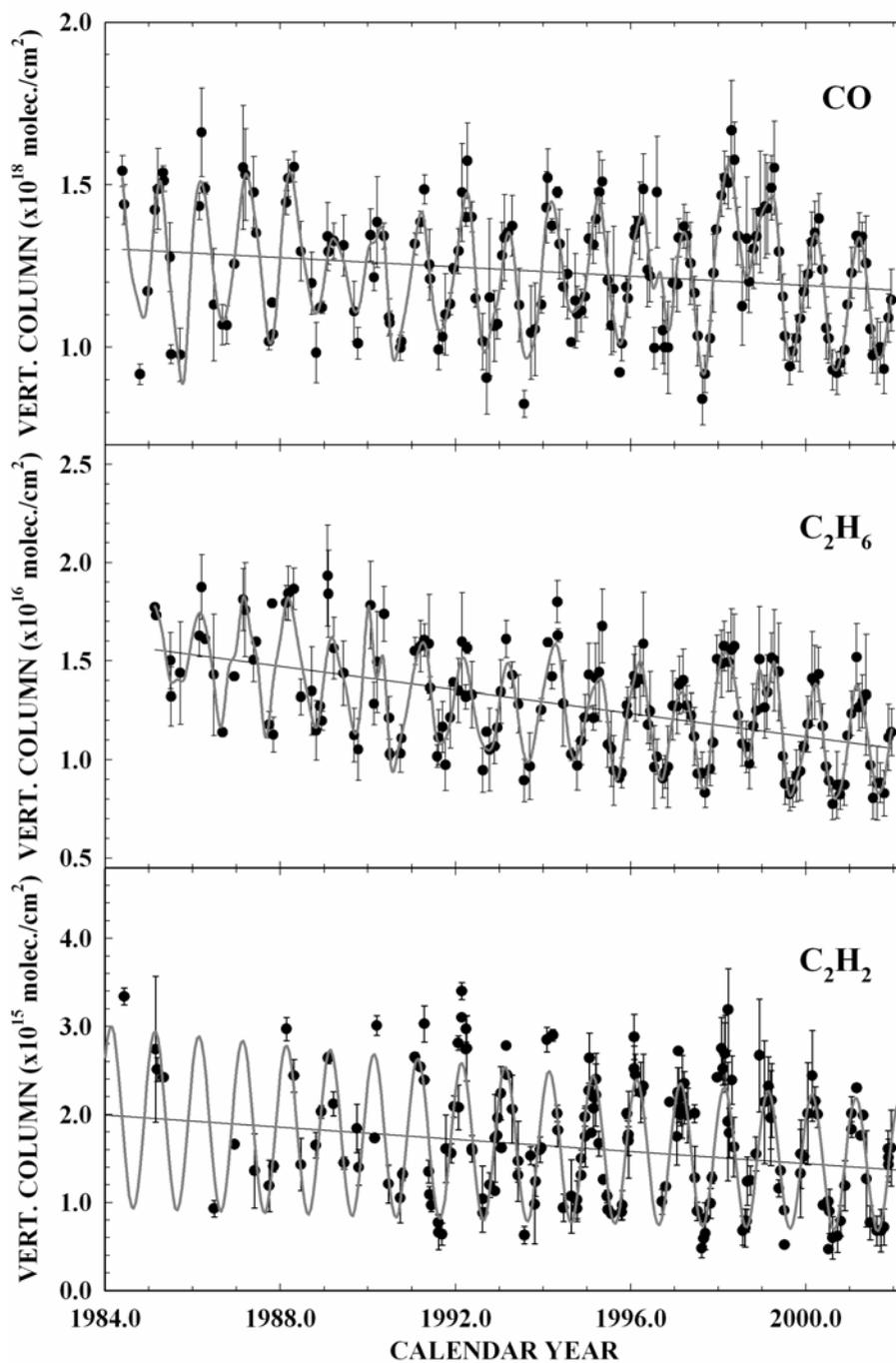


Figure 2. Timely evolution of monthly mean vertical column abundances of three species whose oxidizing capacity in the troposphere affects lifetimes of more potential greenhouse gases (e.g., CH_4). Continuous gray curves drawn through the various sets of data points (non-parametric least-squares fits with weighting factors of 2% for CO and C_2H_6 and a sinusoidal fit to the less homogeneous C_2H_2 data base) show significant seasonal variations for all species. The straight black lines through the data sets lead to mean yearly rates of decrease reported in Table 3. The peculiar behaviour of CO and C_2H_6 in 1998-99 has been discussed by Rinsland et al. (2000).

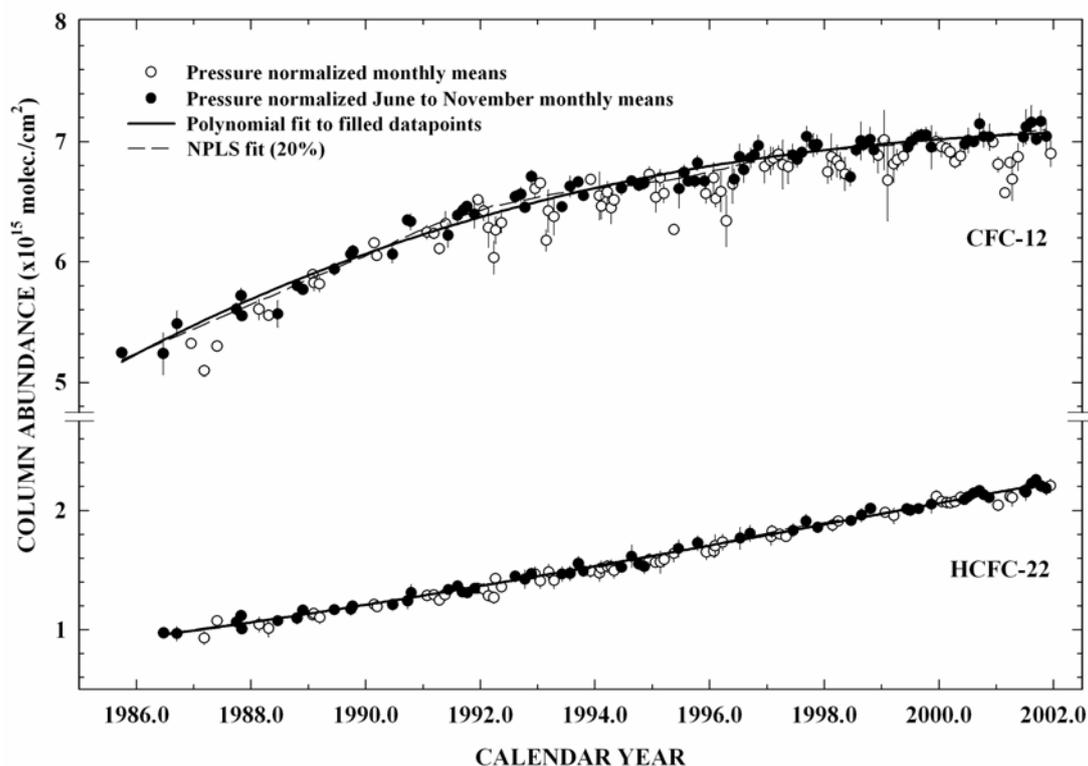


Figure 3. Evolution of the vertical column abundances of CFC-12 (CCl_2F_2) and HCFC-22 (CHClF_2) above the Jungfraujoch during the past 16 years. Notice the discontinuity in the vertical scale. Continuous- and dashed black lines (distinguishable for CFC-12 only) represent, respectively polynomial- and non parametric least square fits to the June to November monthly mean columns (filled symbols; to avoid significant variability frequently caused by transport and subsidence during winter and spring time). Discrete rates of change derived from the polynomial fits are reported in Table 3.

Acknowledgements: This work has been primarily supported by the Belgian federal government through the Office of Scientific, Technical and Cultural Affairs, and by the European Commission, both in Brussels. Acknowledgements are further extended to the Internationale Stiftung HFJG, Switzerland, for accommodations at the Jungfraujoch.

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