

The Polar Stratosphere in a Changing Climate (POLSTRACC)

Proposal for a HALO demo-mission

Introduction

Although the loading of halogen in the stratosphere appears to have reached a maximum in response to the Montreal protocol and its amendments, the catalytic destruction of stratospheric ozone by man made halogen compounds and global climate change is not simple to predict. The significant achievements of the last two decades have established the dominant chemical mechanisms but the predictions about the future development of the Arctic stratosphere and its response to changing dynamics remain of limited accuracy. The speed and extent of the recovery of the ozone layer will not only depend on the future decline of CFCs, but also on the future and currently not known development of the stratospheric temperatures, the global circulation as well as the stratospheric water and bromine content. There is a clear need to forecast the depletion of stratospheric ozone in polar regions and mid latitudes in a changing climate. Currently models disagree as to whether the stratosphere will cool or warm as a result of climate change.

Most EU- and national programs seem to focus on the low latitudes such as the injection of water into the stratosphere near the tropical tropopause. The last major field campaigns for studying the Arctic polar vortex took place in 2000 and, less extensive, in 2003. In view of the changing climate and the importance of the Arctic for Europe we think therefore, that comprehensive studies of the polar regions are needed towards the end of this decade.

The HALO demo-mission POLSTRACC with a payload of remote-sensing and in-situ instruments aims at providing new scientific knowledge on the evolution of ozone, cirrus clouds, denitrification and stratosphere-troposphere exchange in the Arctic in a changing climate. The envisaged time frame of the demo-mission is the winter 2009/10 divided into two short deployments likely in December 2009 and February/March 2010.

Mission objectives

Denitrification

Denitrification, the permanent removal of reactive nitrogen from a certain altitude through sedimentation of HNO₃ containing particles, hinders the chlorine deactivation and is therefore responsible for the prolonged ozone depletion towards the end of the polar winter. In the Arctic, average temperatures are higher and denitrification is more variable than over Antarctica. The degree of denitrification can be quantified from the change of the concentration of the NO_y compounds.

In previous polar campaigns (SOLVE/THESEO2000 and EUPLEX in 2003) it has been found that few large NAT containing particles (NAT-rocks) can explain the denitrification. However, the particle nucleation mechanism responsible for NAT rock formation has not yet been identified. It has been shown that in early winter after the onset of PSCs the sensitivity of denitrification on the nucleation rate is largest. During that time, assumptions for the nucleation rate can be best derived from NO_y observations.

Due to the well-known increase of CO₂ and other greenhouse gases, the stratospheric temperatures are expected to decrease. It can thus be speculated that the denitrification will increase over the next decades with the consequence of prolonged ozone loss.

During the POLSTRACC mission we plan to measure the actual degree of denitrification twice. The first observation period should take place during the onset of PSC formation and denitrification and the second period would be after the PSCs disappeared at the end of the

polar winter. With this we can deduce information about the nucleation rate and the total denitrification. During the second period, it should be possible to observe the nitrification on lower flight levels, caused by the evaporation of the sedimented NAT particles.

Ozone depletion / Chemistry

Over the past decade, the understanding of chemical ozone depletion in the winter polar stratosphere has increased significantly. Nevertheless, important processes are still not resolved as the large ozone loss rates observed in cold Januaries. Only part of the discrepancy between observations and simulations is understood. Due to the realization of the Montreal protocol and its later amendments, the stratospheric chlorine loading should have started to decrease by the time of the mission. This is not likely for the stratospheric bromine loading. Therefore the balance between chlorine- and bromine-catalyzed ozone losses will change. Also, larger ozone loss is expected due to the decrease of stratospheric temperatures. We will investigate chemical ozone loss by comparing remote observations of two periods, the unperturbed condition around the onset of PSC formation and the processed air with depleted ozone towards the end of the polar winter. Chemical ozone loss will be deduced by two methods:

- (a) Tracer correlations using remote observations of ozone and inert tracers, e.g. N₂O.
- (b) Comparison of ozone observations with CTM simulations of a passive ozone tracer initialized at the beginning of the winter.

Cirrus clouds at high latitudes

The coverage of cirrus clouds in the Arctic upper troposphere/lower stratosphere (UTLS region, 10 - 14 km) may reach up to 20%. The ice particles may sediment down, thereby transporting water and other trapped trace species to lower altitudes. This irreversible process could lead to a vertical redistribution of water (dehydration and hydration) and other trace species. Can we quantify the sedimentation flux of water by Arctic cirrus clouds? What is the variability in the water profile and the ice saturation ratio inside and outside of cirrus clouds? Has ice sedimentation an impact on the lower stratospheric water budget?

The Arctic UTLS region regularly becomes extremely cold in winter with temperatures below 210 K. Studies on subtropical cirrus clouds at similar low temperatures show that ice particles can take up large amounts of the available nitric acid (up to 100%) and suggest that enhanced trace gas uptake also can occur on cold Arctic cirrus clouds. The uptake of nitric acid on cirrus particles at low temperatures, sedimentation and redistribution may lead to denitrification. Can we measure denitrification or a temperature dependent nitric acid flux?

Laboratory measurements suggest that the uptake of trace gases occurs on the surface of ice films, whereas recent model studies treat it as an uptake into the bulk ice. Is the atmospheric uptake of trace gases on continuously growing and evaporating ice particles in the UTLS mainly a surface or a bulk controlled process? Despite its impact on UTLS chemistry, trace gas transport by Arctic cirrus clouds has not been experimentally quantified.

Depletion in the reservoir gas nitric acid due to sedimenting ice particles may change the ratio between reactive nitrogen species in the UTLS region, which under certain conditions could lead to ozone depletion. Ozone loss in the UTLS region may further be enhanced by the activation of halogen species on cold cirrus clouds. Due to a paucity of measurements of reactive nitrogen and halogen species in the Arctic UTLS, experimental verification and quantification of those processes is rare. It is therefore necessary to determine atmospheric uptake of trace gases on cold ice particles, trace gas redistribution through sedimentation, halogen activation and ozone loss in the Arctic UT/LS region.

Ice particles absorb infrared radiation emitted by the Earth's surface, thereby heating the UT/LS and isolating the polar troposphere against extreme cooling down. The radiative properties of cirrus particles are determined by their size, number density, composition and

temperature. Despite a polar cirrus cloud coverage of up to 20 %, little is known on the radiative effects of cirrus clouds in polar regions and a detailed microphysical, chemical and optical characterization is missing. Which influence do cirrus clouds have on the radiation budget and atmospheric dynamics?

Outflow

The wintertime polar vortices are characterized by diabatic subsidence with typical subsidence rates of 1.0 K/day, i.e. roughly 1.0 km/month around 21 km and 2.0 km/month around 30 km. The air flowing out of the vortex at the bottom (around 380 K or 14 km) may chemically be processed, i.e. may be depleted in ozone and/or enriched in chlorine nitrate. Clearly, this outflow will largely enter the lowermost stratosphere (LMS). In particular because HALO (in contrast to other aircraft) can cruise for a long time within the LMS and close to the bottom of the Arctic polar vortex, i.e. at 360-400 K, POLSTRACC can help to answer the following questions:

- What is the chemical composition of the outflow of the Arctic polar vortex into the LMS?
- Where and under which meteorological situation (e.g. pressure system, mixing within streamers) does outflow occur?
- What is the seasonal variation of the outflow of the Arctic polar vortex?
- How does the outflow influence the chemical composition of the LMS?

What are the transport pathways of the outflow within the LMS, where and when is it mixed with LMS air and what amount reaches where the troposphere?

Answering these questions will strongly help to validate relevant CTMs and GCMs and also to identify the reason for the known gradual decline of ozone in the mid-latitude lower stratosphere of 7% per decade at 15 km.

Test of precursors for future satellite experiments

A further objective of the missions is to test precursors of future satellite experiments and to use the measurements for the validation of existing satellite data.

Deployments

The questions related to ozone depletion, cirrus clouds, UTLS transport (outflow) and denitrification in the changing polar atmosphere will be addressed in flights with HALO in winter 2009/2010. The mission base will be at DLR in Oberpfaffenhofen from where the Arctic polar vortex can be reached. The measurements will be made during two 3-week periods, for example in December 2009 and February/March 2010, with several flights in each period. In the second deployment refilling is foreseen in Kiruna or an other appropriate airport at high latitudes. The flights patterns will be simple: long tracks at high altitude for continuous remote profiling, slow ascent, descent and possibly a dive for in-situ profile measurements.

After the demo-mission it is envisaged to perform further Arctic HALO deployments in the framework of future EU programs to cover a larger period of observations. In a later stage the capacity of HALO could be used for an Antarctic mission from South America (Ushuaia, Punta Arenas) or New Zealand (Christchurch) as part of an international cooperation. In contrast to earlier airborne campaigns with the ER-2 and the Geophysica, the long range of HALO could, for the first time, enable to cross the entire vortex and not just to touch the border and a fragment of the inner region.

Payload and modeling activities

Properties of gas phase species and particles will be obtained from HALO by in-situ and remote-sensing techniques. Integration of field data and process studies within a modeling framework will enable a detailed understanding on Arctic cirrus clouds, trace gas transport and polar ozone destruction.

Payload:

Participating Institutions: DLR-IPA, FZJ-ICG, FZK-IMK, JWGU-Frankfurt-IMG, Uni-Heidelberg-IUP, Uni-Bremen-IUP, MPI-Ch and Uni-Mainz-IPA

The payload proposed covers all relevant atmospheric parameters. The combination of in-situ and remote sensing instruments is mandatory for precise measurements at flight altitude and for continuous profiling above and below.

Temperature:

In-situ (DLR, standard payload)

MTP-type temperature profiler

(At the moment there is no German institution running a Microwave Temperature Profiler but such an instrument should be developed for HALO).

In-situ chemical and tracer measurements:

Ozone (FOX, DLR-IPA and FAIRO, FZK-IMK)

Water vapor and total water (FISH and OJSTER, FZJ-ICG)

Water isotopes (ISOWAT, FZK-IMK)

Inert tracers (HAGAR and/or GhOST, JWGU-Frankfurt-IMG)

(Both gas chromatographs will be available for the demo-mission)

BrO and chlorine species (HALOX, FZJ-ICG)

NO and NO_y (NO-NO_y, DLR-IPA)

HNO₃ and SO₂ (ITCIMS, DLR-IPA)

Remote chemical and tracer measurements:

Lidar: Ozone and/or water vapor (DLR-IPA).

(Both Lidar measurements are important for the mission. Preferred is an integration of both measurements to a single instrument in 4+2 racks)

The mid-infrared FTS GLORIA-AB: Ozone, H₂O, tracers and chemicals in the UTLS

(Satellite precursor currently developed for HALO by FZK-IMK and FZJ-ICG,

Back-up and for intercomparison: CRISTA-NF by FZJ-ICG)

The submillimeter wave spectrometer ASUR (Uni-Bremen-IUP): O₃, HNO₃, ClO, HCl, N₂O

(Alternatively, if ASUR is not available, TELIS, DLR-IMF)

AMAXDOAS: high temporal sampling data of stratospheric columns, concentrations at flight

altitude and coarse altitude profiles of O₃, NO₂, BrO, IO, OIO, OCIO, O₄, O₂, SO₂

(Uni-Bremen-IUP and Uni-Heidelberg-IUP)

Mini-DOAS: profiles of O₃, NO₂, BrO, IO, OIO, OCIO, O₄, O₂, H₂O (Uni-Heidelberg-IUP)

(We propose that the DOAS UB and UH groups develop an optimal package of

AMAXDOAS and mini-DOAS. Currently we plan with 2 lower racks for this package.)

In-situ aerosol and ice particle measurements:

FSSP 300, FSSP 100 (MPI-Ch and Uni-Mainz-IPA): aerosol size distribution

AIS (FZJ-ICG): cloud composition

AMPM (DLR-IPA): concentration, size distribution and absorption coefficients of volatile and non-volatile particles

PHIPS: number, size, structure and scattering of ice particles (FZK-IMK)

Remote aerosol measurements

Lidar (DLR-IPA) and GLORIA-AB : cloud mapping (FZK-IMK and FZJ-ICG)

Modeling activities

Participating Institutions: DLR-IPA, FZJ-ICG, FZK-IMK

A comprehensive set of models will be available to achieve the mission objectives. The models will support the POLSTRACC mission by forecasting the stratospheric conditions with respect to the meteorological and chemical short term behavior. In addition, they will be used in the interpretation of the measurements performed by the instruments aboard HALO.

For forecasting purposes the models MM5 (a mesoscale model with focus on the prediction of lee-wave processes), CLaMS (a chemistry-transport-model (CTM)), and ECHAM/MESSy (a global-circulation-model (GCM) which will be run in a nudged mode with stratospheric chemistry) will be available. These three models have demonstrated their ability in forecasting the Arctic stratosphere for flight planning in recent campaigns.

The interpretation of the measurements of the payload will be performed on a seasonal as well as long-term time scale with different types of models. Microphysical processes of polar stratospheric clouds and of cirrus particles will be studied with a box-model with a detailed representation of these processes. On a global scale the CTM CLaMS, which is a Lagrangian type of CTM, and KASIMA being an Eulerian type of CTM as well as a nudged version of the GCM ECHAM/MESSy are available to investigate the measurements related to polar processes with respect to chemistry and dynamics issues. CLaMS, KASIMA, and ECHAM are state of the art models which complement each other by the different model architectures.

Due to the possibility of the GCM ECHAM/MESSy to be run in a nudged mode this model can act as link between classical CTMs and GCMs as the parameterizations used can be validated by the measurements and also be compared by the results of the CTMs. This possibility enhances the reliability of the GCM ECHAM/MESSy and enables an improved forecast of the development of the ozone layer in the next decades.

General remarks

In our opinion POLSTRACC is extremely well suited as demo-mission for HALO. It fulfils the criteria defined by the WL of HALO:

- It contributes to important scientific issues which are also of public interest
- It has a unique combination of remote-sensing and in-situ equipment which can only be flown on HALO and which is currently not foreseen for HIAPER
- It uses all capacities that HALO offers: long flights at high altitude with a large payload
- It involves a large number of research groups from different institutions

Without doubt the mission can be performed in winter 2009/2010 because

- The groups involved have a long tradition in flying similar equipment on aircraft
- Back-up solutions have been defined
- The logistic requirements for a demo-mission are fulfilled