Expected scientific achievements from HALO missions

Atmospheric Chemistry and Global Pollution

Providing fundamental data on the oxidising power of the atmosphere.

Oxidation processes that "clean" the atmosphere are controlled by hydroxyl (OH) radicals. Oxidation by OH limits the lifetime of most gases so that they do not build up, a vital atmospheric property to safeguard life on our planet. The major source of hydroxyl radicals is in the tropical troposphere up to about 16 km altitude. Controlling processes include short-wave solar radiation transfer (UV penetration through the stratosphere), ozone formation, water vapour abundance and a host of reactions with reduced and partly oxidised gases. Nitrogen oxides (NO_x) play an important role in the recycling of OH radicals. Hydroxyl recycling is key in preventing the chemical system from becoming unstable. This recycling stabilises the system, for example, by buffering it against OH depletion by the anthropogenic increases of methane and carbon monoxide. At present, there are almost no measurements of OH and controlling variables in the tropical troposphere, so that our understanding of this vital system is based exclusively on models untested by observations. Advances in this area of research require simultaneous *in situ* measurements of many atmospheric variables. Auxiliary information can be obtained from ground-based measurement stations and satellites. HALO is crucial to accommodate the comprehensive instrumentation needed, and to reach polluted (continental) as well as clean (maritime) environments throughout the tropical troposphere.

Exploring UTLS chemistry and dynamics.

The availability of HALO would enable studies of the chemistry and dynamics of the upper troposphere and lower stratosphere (UTLS) between about 8 and 15 km altitude. Recent work has indicated that the UTLS contains much more reactive gases than anticipated (e.g., carbonyls and peroxides). This cannot be reconciled with the earlier conception that this part of the atmosphere is relatively inert. In addition, the residence time of gases in the UTLS is probably misrepresented in models by about as factor of two. This has important implications, for example, for the calculated lifetime of aircraft exhausts and ozone changes in the extra-tropical lower stratosphere. HALO would enable wide-ranging coverage of the UTLS region from the subtropics to the poles. HALO will be unique in providing the flight range to perform case studies of synoptic weather systems (i.e., fronts and cyclones with a scale of ~1000 km) that control the cross-tropopause exchange processes. HALO could systematically sample the UTLS region, required to quantify chemical processes as well as dynamical transport and mixing across into and within the UTLS, required to quantify chemical and transport processes, through the measurement of chemical tracers, coupled to meteorological information available from the European Centre for Medium-range Weather Forecasts.

Reducing the uncertainty about the amount of lightning produced nitrogen oxides.

Tropospheric photochemistry depends strongly on ambient levels of nitrogen oxides (NO_x). Lightning in deep convective clouds contributes considerably to the global NO_x budget, in particular in the tropics. Present estimates of the global lightning NO_x source range from 1 to 20 Tg(N)/yr. Using the best estimate of 5 Tg(N)/year, models compute that lightning contributes about 80% to the NO_x abundance in the upper tropical troposphere. At present there are no in-situ measurements of NO_x in the upper tropical troposphere at altitudes above 12 km. Measurements with HALO along the oceans downwind of the continents, where most convection occurs, will help determine the NO_x -lightning relationship and strongly reduce the uncertainty of source estimates. Improved knowledge of the lightning NO_x formation rate is needed, e.g., to assess the importance of growing anthropogenic sources. For instance, aircraft emissions presently contribute about 0.8 to 1 Tg(N)/yr to the NO_x budget, less than lightning.

Atmospheric Dynamics and Transport

Uncovering stratosphere-troposphere coupling.

Recently, the role of the stratosphere in the control of weather and climate in the troposphere has taken an unexpected turn. The stratospheric ozone layer is quite sensitive to variations in solar and cosmic radiation. Dynamic coupling between the stratosphere and troposphere (ST) may provide an amplifying feedback that links climate variability to the influence of the Sun. This ST coupling has been substantiated for climate change during the Holocene through measurements of cosmogenic nuclides. Quantifying the relevant ST feedbacks will even improve seasonal weather forecasting, in particular in the North Atlantic region and adjacent continents. Furthermore, ST-exchange is a major source of ozone to the troposphere, and thus also plays an important role in the OH cycle, however, the uncertainties in flux estimates are very large. Improvement will help quantify the tropospheric ozone budget. Dynamic ST coupling can be studied by measuring long-lived trace gases in the lower stratosphere, a region that would be reached by HALO. Other aircraft cannot reach the stratosphere, or in the case of the American ER2 and Russian Geophysica aircraft (that reach 21 km), cannot carry large payloads and operate in the turbulent tropopause region (e.g., along the jet stream).

Quantifying transport effects of deep convection.

Deep thunderstorm convection is a main tropospheric mixing mechanism, exchanging heat, momentum, water vapour and reactive species between the lower and upper troposphere. Deep convective clouds are moreover the main precipitation source in the tropics and subtropics. Firstly, satellite measurements have indicated that pollutant aerosols, e.g., from biomass burning in the tropics, can modify convective clouds to the extent that precipitation formation and lightning are considerably changed. Satellite observations however are limited to the upper parts of clouds, and it is well-known that these parameters vary with altitude. HALO would enable measurements over the entire cloud depth up to 15 km. The observed cloud and aerosol microphysical parameters could thus be linked to satellite measurements. Secondly, convective outflow includes gases and aerosols that interact with ice clouds, a topic that has only recently been explored. Thirdly, tropical convection plays a key, yet poorly understood role in drying the stratosphere, e.g., through freeze-drying of the tropical tropopause. In fact, the lower stratosphere appears to have moistened relatively rapidly in the past decades, and the cause is unclear. Finally, a several kilometre thick tropical transition layer above 13 km altitude has been discovered recently. Transport processes across this layer and the role of convection are currently debated. In contrast to currently available aircraft, HALO could perform the needed measurements even at the cloud tops and in the convective outflow region, which would help resolve these important issues.

Measuring intercontinental pollution transports.

In the extra-tropical free troposphere (up to about 13 km altitude) hemispheric pollution transport is often fast, with wind speeds exceeding 100 km/hr. This implies that trace species with a lifetime of about a week or more can be distributed hemispherically. Although pollutant emissions in Europe and North America have been reduced with some degree of success, emissions from other regions grow largely unabated. In the northern hemisphere the following picture emerges. Through the prevailing westerly winds, emissions from the USA contribute in particular to the background pollution levels in Europe, for example, of ozone and carbon monoxide (lifetime 1-2 months). Europe on the other hand exports part of its pollution toward Asia. In Asia, rapidly growing pollution emissions from a population of several billion are observed, particularly in association with emerging economies in the south and east. The large emission sources west and east of the North Atlantic and North Pacific Oceans contribute to intercontinental plumes that affect air quality and climate on a hemispheric scale. In the southern hemisphere similar large-scale pollution transports can occur from savannah and forest fires during the dry season, e.g., in southern Africa and South America. HALO will provide the aircraft needed, i.e., the platform with a global range to determine pollution transports with a global dimension.

Cloud Research

Improving the understanding of cirrus clouds.

Ice clouds in the upper troposphere play an important role in the climate system. For example, an increase of cirrus clouds under climate change conditions would contribute to a warming tendency that may amplify the effect of increasing greenhouse gases. Cirrus microphysical and radiative properties are nevertheless poorly quantified. Influences of pollutant aerosols on ice crystals and the lifetime of cirrus, including aircraft condensation trails, are potentially very strong. In addition, the cirrus representation in weather forecasting models needs to be improved based on observations. This has the potential of substantially improving medium- to long-range weather forecasts. A major improvement is needed in the observation of cirrus crystal size. Size dependent sedimentation of cirrus often determines the onset of precipitation. Furthermore, heterogeneous reactions between cirrus ice and gases involved in ozone chemistry, similar to polar stratospheric clouds, have been speculated about; hence *in situ* measurements are urgently needed. Redistribution of water vapour, aerosols and dissolved gases through the sedimentation of ice crystals is another unresolved issue. HALO would provide the measurement capability to reach the upper troposphere with comprehensive instrumentation, required to facilitate cirrus cloud research.

Providing crucial cloud data for reducing uncertainty in climate modelling.
The present capability of quantifying climate change, including scenario studies of future developments, suffers from uncertainties in representing cloud effects in climate models. State-of-the-art-models predict a cloud radiative forcing feedback at the top of the atmosphere ranging from –1 to + 2 W/m^2 for a doubling of CO_2. This uncertainty must be reduced for more reliable climate modelling. Together with satellite and ground-based observations HALO would provide data sets that can be used to test and improve cloud models, which can subsequently be used to advance the cloud representation in climate models. Case studies are needed, in particular of tropical cloud systems, for which the three-dimensional cloud fields can be quantified (geometry, liquid and ice water content, and vapour distribution) and the reflected solar and outgoing infrared radiative fluxes above the cloudy atmosphere determined. Such data sets, combined with data from satellites and ground based remote sensing, would help to improve models and hence to reduce the uncertainty of climate change predictions.

Meteorological research

Improving weather prediction.

Numerical weather forecast models have improved significantly the prediction of several key parameters over the past ten years, including temperature, wind, and even cloud cover. No progress has been made, on the other hand, in the prediction of precipitation, indicating that essential cloud processes are still poorly understood and parameterised in models. The basic problem in the understanding and prediction of cloud processes lies in the fact that clouds are multi-scale, multi-process, multi-phase systems in which interacting microphysical, dynamic, chemical and radiation processes need to be understood. Convective systems, in particular, are extensive, highly complex three-dimensional systems with crucial roles in the global water cycle, global energy balance and the vertical transport of trace substances. The development of improved cloud parameterisations and sufficient constraints on complex cloud models require the acquisition of comprehensive multi-disciplinary and highly resolved in situ data sets that reach from the aerosol (gases + particles) input and precipitation output in the planetary boundary layer (PBL) via a large number of cross sections at different cloud levels to the aerosol output near the tops of convective systems. Only a research aircraft such as HALO with large payload, long and effective endurance from the PBL to the tropopause region can fulfil this task.

Climate Research

Closing the energy balance of the atmosphere.

Atmospheric absorption is a key component in the energy balance of the atmosphere. To date this parameter is determined from satellite and ground based radiation measurements. These data rely on an inadequate mixture of satellite and surface results. Significant discrepancies exist between modelled and experimentally derived radiation balances. To resolve this problem, internally consistent radiation data sets covering the full atmospheric wavelength range are required over the complete tropospheric column. For the deployment of the adequate radiation payload a large capacity and long endurance, high ceiling airborne platform such as HALO is urgently needed. German radiation research has the critical mass to develop the necessary HALO instrumentation, its deployment and also for the interpretation of the results with state of the art radiation models.

Narrowing uncertainty in climate system sensitivity.

Since 1990, little progress has been made in assessing the global-mean near-surface temperature increase predicted as a consequence of an enhanced greenhouse effect. The range still given (1.5 to 4.5K for a doubling of CO_2 concentration) can be narrowed mainly through better parameterisations of cloud processes in climate models. Major unknowns are the dependence of tropical anvil cloud microphysics on surface temperature and aerosol characteristics and the precipitation formation in areas with intense convection in cold air outbreaks over remote ocean areas with strong horizontal sea temperature gradients. For both mission types, a high flying and long endurance aircraft is needed. Another key issue for climatology is the search for the negative feedback mechanism that keeps the greenhouse effect of the Earth in rather narrow bands (± 5K) over many million years. The hypothesis that it is due to microphysical cloud processes that are influenced by emissions from the terrestrial and marine biosphere can be proven or falsified only if satellite sensors (e.g., Earth Care) are combined with HALO missions.

Global Carbon Cycle

Estimating biospheric and oceanic carbon uptake.

There are three large sinks among which anthropogenic CO_2 is being partitioned: the atmosphere, the oceans, and the terrestrial biosphere. While the atmospheric and oceanic carbon reservoirs are quite accurately known, the terrestrial sink remains very difficult to quantify. In particular, attempts to measure uptake of CO_2 by the Amazon forest using eddy covariance (EC) techniques have resulted in estimates ranging from 0 to 5 Pg C per year, a range so wide as to make these estimates meaningless. Hence alternative measurement methods are needed. HALO would make two alternative approaches feasible: First, the use of airborne eddy covariance, which would remove the spatial bias suspected in the tower-based EC measurements, and allow measurements over more representative spatial scales. Second, HALO would also make possible the large-scale application of the boundary layer (BL) budget techniques, which are based on an analysis of the temporal and spatial distribution of CO_2. These techniques essentially determine the amount of CO_2 removed from the BL by photosynthesis and the amount added to the BL by respiration during the diurnal cycle. The long endurance of HALO would enable CO_2 profiling over a complete diurnal cycle, something that has not been possible so far because of the limitations of current aircraft. HALO would also permit Lagrangian or quasi-Lagrangian experiments, where the BL budget of CO_2 is followed in an air mass over several days.

Performing high latitude climate change and carbon cycle research.

Climate change, as induced by increasing greenhouse gases, is predicted to lead in particular to the warming of boreal regions, in part associated with the high-latitude ice-albedo positive feedback. Over the last three decades, rapid climate change has been observed in Siberia and Alaska, reaching warming rates as high as 1ºC per decade. Such change will affect permafrost, which underlies 25% of the land surface in the northern hemisphere. Modelling studies suggest a 15% reduction in the permafrost area by the middle of this century. An additional major positive climate feedback at high latitudes is that permafrost thawing will release carbon dioxide and methane, and alter the vegetation and surface hydrology. The massive amounts of carbon stored in high-latitude soils (peats) can have a pronounced impact on the atmospheric CO_2 burden, even if only a modest fraction is released as a consequence of climate change. Another important aspect is that about a third of the past and present anthropogenic CO_2 emissions may be re-assimilated by the terrestrial biosphere. It has been speculated that either the North American or Eurasian continents play an important role, while others claim that the tropics are important. The present dramatic warming rates in the boreal zone, caused by anthropogenic effects or natural climate fluctuations, offer a unique opportunity to study the response of the biosphere to a changing climate. The lessons from these investigations will be central to predicting and mitigating the effects of climate change on the biosphere. As part of an integrated research program, these issues would be studied with HALO by performing long flight tracks over the Siberian forests and tundra's, measuring CO_2 and CH_4 fluxes and evaporation by combining high-resolution concentration and 3D wind measurements. In addition, carbon isotopes will be measured to help identify sources and sinks.

Polar Research

Observing changing Arctic sea ice thickness and distribution.

Fluxes of energy, mass and momentum between the polar ocean and the atmosphere are strongly influenced by the thickness and extension of sea ice. The development of climate models as well as regional polar forecast models requires detailed information about the sea ice extent. Especially for the summer and marginal sea ice zones the presently available information is insufficient. The prediction of sea ice, important for example for high latitude ship traffic, is only possible if the initial state of the ice is known with high accuracy and resolution. Furthermore, sea ice thickness is an important parameter in climate change detection, in particular because climate change is expected to be relatively strong at high latitudes. In the past decade, ice data have been collected mainly from satellite passive microwave sensors with a spatial resolution of about 25-100 km. Some case studies have aimed at higher resolution, including recent measurements from submarines with upward looking sonars. Previously, measurements with small aircraft have been performed as well, however, the operational range was restricted to 300-400 km. HALO would help quantify Arctic sea ice properties at high spatial resolution, improve dynamic sea ice models based on aircraft measurements, and contribute to high-latitude climate change detection. This includes the inner Arctic region, which has yet hardly been explored.

Detecting Arctic air pollution.

Arctic aerosols and trace gases play an important role in polar air pollution and climate change, in particular during springtime “Arctic haze”. The specific conditions in the Arctic (aerosol composition, transport altitude, surface albedo, long radiation paths through the atmosphere) are complex and poorly understood. It is for example unclear if the aerosol pollution contributes to a cooling or a warming tendency of the surface and lower atmosphere. The Arctic Ocean furthermore contributes to atmospheric chemistry through the release of organohalogens from algal blooms. Subsequent release of reactive halogen compounds at the ice surface through heterogeneous processes leads to tropospheric ozone depletion events. At higher altitudes, i.e. in the stratosphere, ozone depletion is caused by anthropogenic halogen compounds, mediated by polar stratospheric clouds (PSCs). Recently "giant" ice particles have been discovered in the Arctic stratosphere, of which the formation and role in ozone depletion are yet unclear. Additional uncertainties regarding future recovery of stratospheric ozone involve PSC formation and the role of bromine compounds, especially if recent downward temperature and upward water vapour trends continue into the future. HALO would be able to deeply penetrate the Arctic stratosphere as well as the troposphere toward the pole to determine ozone destruction and quantify climate effects of Arctic aerosols.

Earth Observation

Searching for signatures of terrestrial impacts of extraterrestrial objects

Impacts of extraterrestrial objects on Earth have been recognised as a major factor in geological history. They have also triggered regional and global climate effects. The impacts of large asteroids or comets have significantly shaped the surface and the structure of the Earth’s upper crust. They had enormous impact on the evolution of the biosphere and, therefore, were of first order relevance for the evolution of life on Earth. The records of extraterrestrial impacts is still being deciphered. They should be statistically equally distributed on surfaces of the same geological ages. However, the mapped terrestrial impacts on Central Africa, Siberia and South America suggest less impacts in these regions than over the rest of the world. This wrong image, however, is mainly generated by the lack of suitable geophysical and geological data, e.g. gravity field data. HALO will be an ideal platform for searching impacts sites over these poorly accessible regions of the globe because of it’s long-range and high-speed cruising performance. Large impacts can be better detected by a combination of aerogravimetric and aeroemagnetometric sensing systems. HALO will provide the opportunity to operate such large instrument payloads – in combination with other Earth observation instruments – during long-range missions over remote areas of the globe.

Geomorphology and land-use changes

Natural and anthropogenic processes of Global Change may cause substantial changes in land-use and vegetation cover, in particular in the tropical regions. They are generally accompanied by processes such as soil erosion or land degradation that are e.g. triggered by biomass burning. Of particular importance for an assessment of the geomorphological and geoecological effects of such changes is the quantification of their temporal evolution, i.e. the rate change. Digital processing of photo images obtained from airborne and space- borne platforms is a suitable technique to investigate and monitor surface pattern and surface dynamics and their variation. HALO will provide the opportunity to collect multispectral photo-images with spatial resolutions that fill the gap between low-scale satellites images and high scale images obtained from small aircraft or small tethered balloons. Due to it’s long-range performance at altitudes up to 14000 m HALO is an ideal tool for systematic studies of the ‘nested scales’ of these changes, in particular over remote regions of the globe for which even conventional images are not available.

Earth gravimetry and GPS navigation

Bridging the gap between satellite and surface gravity.

Just recently, a new stage of gravimetric and magnetometric earth observation has been entered. CHAMP is operative since 18 months and a complementary mission will be launched in March 2002: GRACE. CHAMP observes the gravity and magnetic field, GRACE and another ESA mission, GOCE, will measure the gravity from space with yet unprecedented precision and coverage. The results of these missions will be combined with existing and upcoming satellite altimetry data over the oceans. Yet, there is no such data set to fill in the gap between surface and spaceborne gravity measurements over the continents. This gap in wavelengths and amplitudes could be filled in using HALO as a platform for aerogravimetry and aeromagnetometry observations. Especially over South America (Andes), Africa (East African Ridge System), the Near East (Dead Sea Rift) and Asia (Himalaya), HALO could easily cover large areas of missing or possibly doubtful data (terrain correction problems). Also large marine areas lacking high density data coverage could be monitored with HALO’s capabilities in range and speed. Such aerogravity programs would not only contribute to a much more detailed geoid (and precise navigation) but also to a much better understanding of main geophysical processes and driving forces.

Enhancing GPS, navigation and cockpit guiding tools.

HALO would be an excellent test bed for university and industry research on the next generation of GPS systems. Online kinematic GPS tracking from satellites only, without using fixed ground reference systems, could be tested in different environmental settings using various sets of receivers and frequencies. Already now, the industry offers GPS receivers with kinematic positioning on 10 Hz and soon on 20 Hz data rates. Using antenna arrays on HALO, heading, pitch and roll could be computed from GPS only. The radio link of HALO might as well be used to test new cockpit information systems for "roll-over" weather forecast systems as well for the detection of ionospheric disturbances using magnetometers on-board and off-ground. Other GPS techniques as GPS altimetry and especially limb-sounding in the higher atmosphere are challenging targets that could be tackled using HALO as an experimental platform.