White paper for„TACTS/SALSA“

TACTS: Transport and Composition in the UT/LMS

SALSA: Seasonality of Air mass transport and origin in the Lowermost Stratosphere using the HALO Aircraft

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January 2010

TACTS/SALSA: A HALO mission to study the seasonality in the UT/LS

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1. Scientific Rationale

1.1 Scientific background on the UTLS region

The Upper Troposphere / Lower Stratosphere (UTLS) represent a nexus for troposphere stratosphere coupling as well as for chemistry-climate coupling (e.g. Shepherd 2007). Greenhouse gases such as water vapour and ozone exhibit strong gradients across the tropopause (e.g. Pan et al. 2004). Additionally, the cold tropopause temperatures cause radiative forcing to be very sensitive to the distribution of greenhouse gases in the UTLS (e.g. Forster and Shine 1997). The tropical UTLS and its chemical composition therefore set the boundary condition for stratospheric trace gases that have their origin in the troposphere (e.g. water vapour, halocarbons). Likewise, most stratosphere-to-troposphere transport (STT) takes place through the extratropical tropopause which sets the boundary condition for tropospheric trace gases with stratospheric origin (e.g. ozone, hydrogen chloride) and plays a role for the understanding of upper tropospheric oxidation capacity and chemical burden. A quantitative description of the time-scales and seasonalities of the stratosphere-troposphere exchange (STE) is one of the most challenging tasks in understanding of transport across the tropopause.

The extratropical UTLS can be divided into dynamically and chemically distinct regions. A layer of mixed tropospheric and stratospheric tracer characteristics exists in the proximity of the extratropical tropopause: the so-called extratropical tropopause transition layer (ExTL) (Fischer et al. 2000). This chemically distinct layer roughly coincides with a layer of strongly enhanced thermal stratification: the so-called tropopause inversion layer (TIL) (Birner 2006), indicating distinct dynamical UTLS characteristics. Both ExTL and TIL are embedded into the so-called lowermost stratosphere (LMS) – the part of the stratosphere that shares isentropic surfaces with the troposphere, i.e. the region between the local tropopause and roughly 380 K. The LMS above the ExTL, also named the free LMS (Bönisch et al., 2009) is more strongly decoupled from the extratropical troposphere. This region is mainly influenced by quasi horizontal transport of tropical air from the upper troposphere and lower stratosphere as well as downwelling from the extratropical overworld.

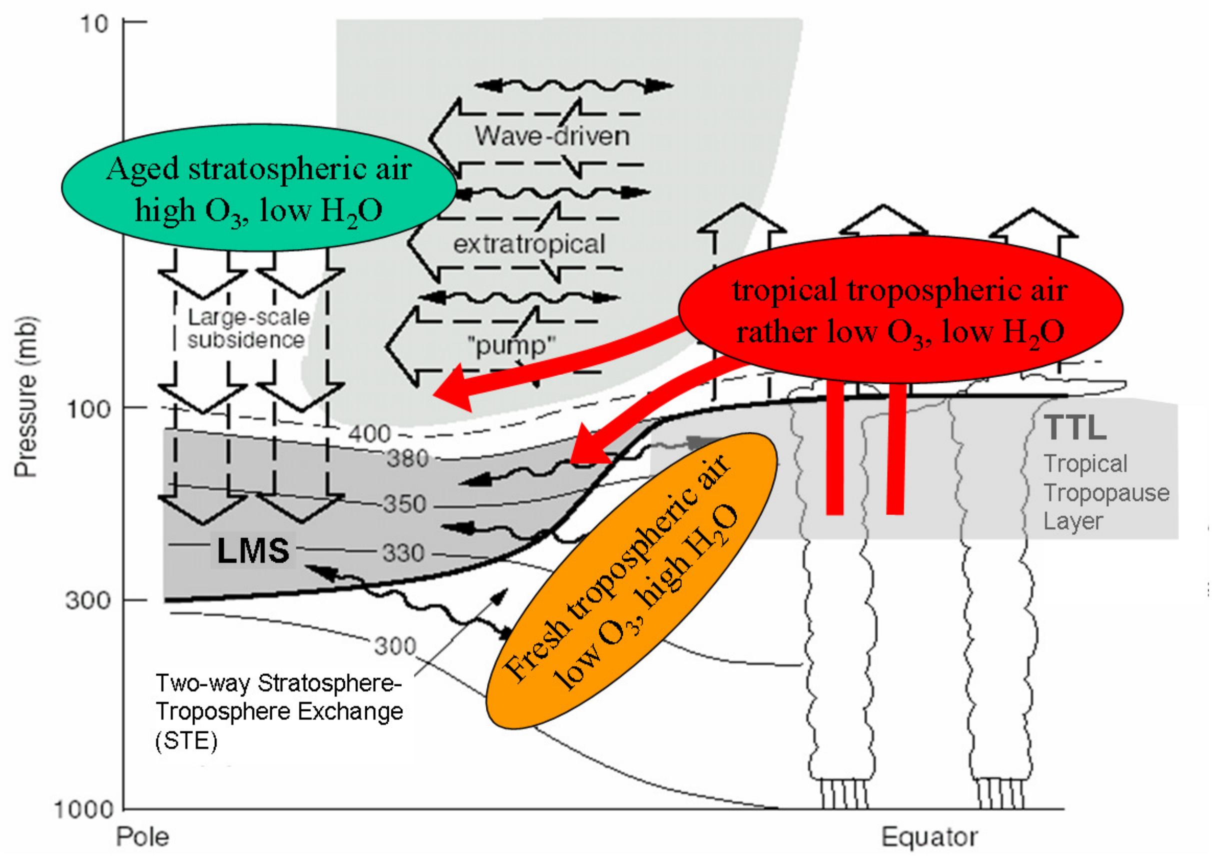

Figure 1: Schematic of transport pathways affecting the UTLS. Indicate different pathways of importance in UTLS transport. 1: air is transported upwards in the TTL and into the lower tropical stratosphere, from where it is circulated in the stratosphere via the lower branch of the Brewer Dobson circulation (thick red line); 2: air is transported into TTL and from there it is mixed (two-way transport) horizontally across the subtropical jet with air from the lowermost stratosphere; 3: air is exchanged quasi-horizontally below the subtropical jet from the extratropical upper troposphere into the lowermost stratosphere. 4: air is subsiding from the extratropical overworld into the LMS via the upper branch of the Brewer-Dobson circulation.

1.2 Seasonality of the UTLS region

The general features of the UTLS are explained above. Upon closer inspection, however, strong seasonal cycles and variabilities are found in the UTLS. These seasonalities need to be characterised and understood in terms of the driving processes, in order to better understand the implications of the UTLS and possible feedbacks with global climate change. The first systematic observational study of extratropical UTLS seasonality was the SPURT campaign (Engel et al., 2006) funded under the German AFO 2000 programme. The effects of this seasonality are highlighted by two examples, both based on results of the SPURT project.

Hoor et al. (2005) quantifies the fraction of air masses located in the LMS associated with the different pathways explained in Figure 1. This mass balance study has been derived mainly from observations of carbon monoxide (CO) taken during the SPURT campaigns. As a result it shows that the fraction of air from the overworld is larger in spring (when subsidence from the winter still has a significant impact) but lower in summer. On the other hand, the fraction of air masses which have been transported via the tropical upper troposphere/lower stratosphere is significantly larger during the summer period.

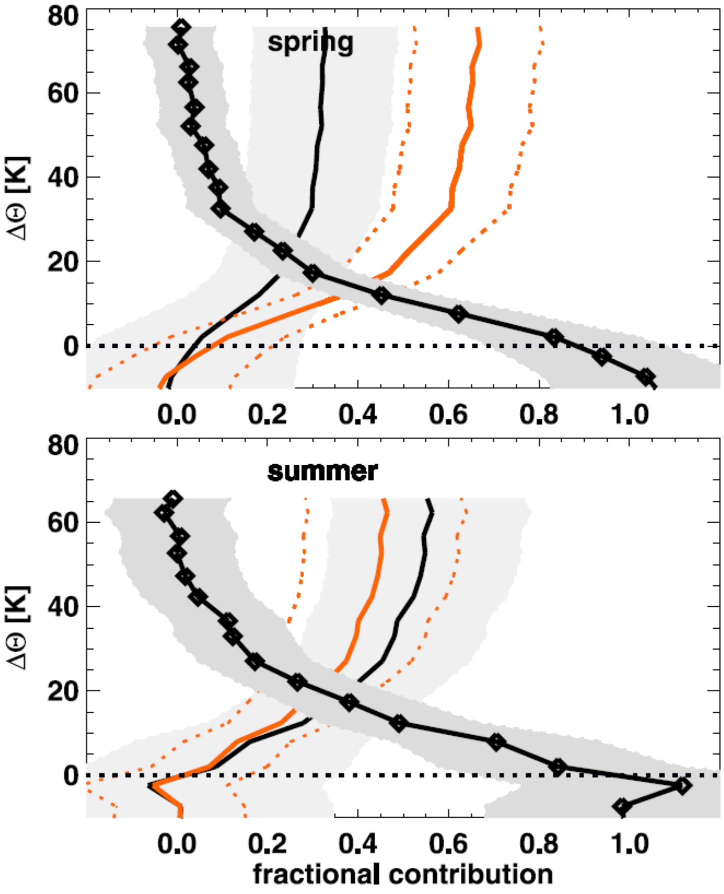

Figure 2: Fraction of air of different origins derived from SPURT observations. The black line with diamonds shows the fraction of air of extratropical origin, the solid black lines the tropical contribution and the orange line the fraction of air descended from the stratospheric overworld (Hoor et al., 2005).

Also based on data from SPURT, Bönisch et al. (2009) investigated mass fractions and mean transport times for the tropical fraction (corresponding roughly to the black line shown in Figure 2) using SF_6 and CO_2 data. They found a clear seasonality, with minimum transport times during August, and longest transport times during May, indicating that the majority of air mass transport into the lowermost stratosphere via the tropical pathway seems to occur during summer. Both studies highlight that the transport of air into the UTLS has a very significant seasonal cycle and a temporal pattern, which can only be derived if observations over the entire annual cycle are available.

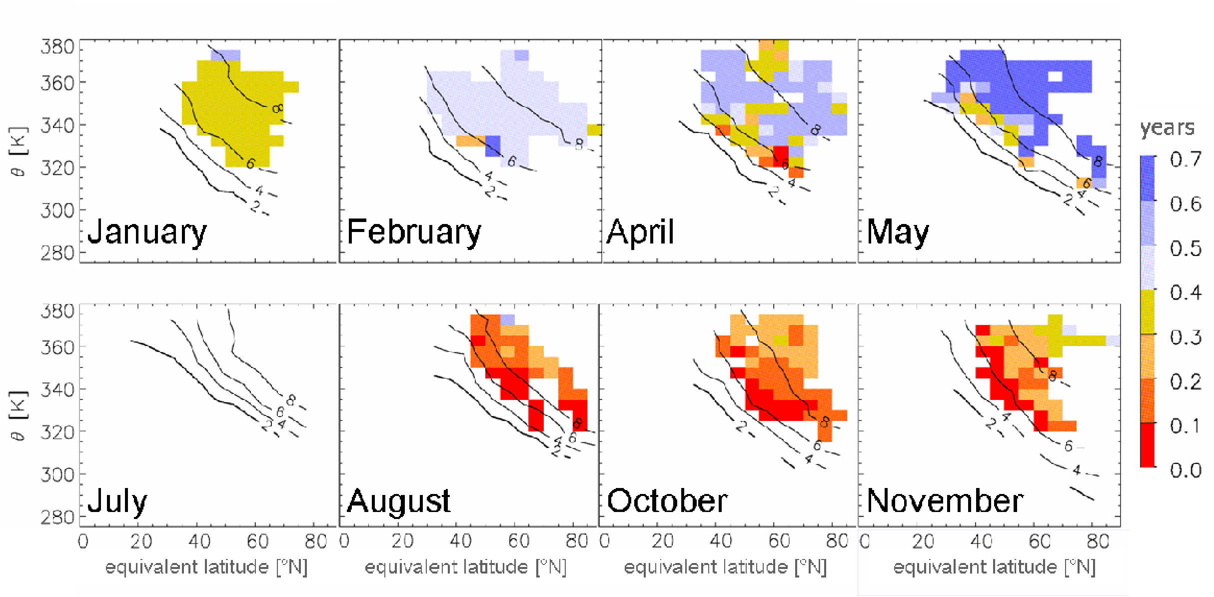

Figure 3: Transit times of air masses from the tropical troposphere into the LMS as function of equivalent latitude and potential temperature. The shortest transit times are found in August, while the longest transit times have been found in May (Bönisch et al., 2009).

Satellite data from the ACE-FTS instrument have been used in combination with model data to investigate the seasonality of N_2O-ozone correlations (Hegglin and Sheppard, 2007) which is mainly driven by the relative strengths of downward transport from the stratospheric overworld and quasi-horizontal transport in the lower stratosphere, the latter bringing younger tropical air into the lowermost stratosphere.

ACE-FTS data also provide a global view of the ExTL from correlation plots between CO, water vapour and ozone (Hegglin et al., 2009). This study shows an increase in the thickness of the ExTL with latitude, increasing from about 2 km in the sub-tropics to about 4 km at higher latitudes. The seasonal variation of the ExTL found in this study is rather small, with somewhat higher values during summer/autumn than during winter/spring. As in SPURT data (Krebsbach et al., manuscript in preparation), the thickness derived for the ExTL depends on the tracers used for determining it. Based on satellite observations, Hegglin et al. (2009) found a thinner CO-ozone derived ExTL than H_2O-ozone derived one. They speculate that the reason for this could be the limited lifetime of CO, which implies that longer transport/mixing times would be less visible in CO-ozone space then in H_2O-ozone space.

Hegglin et al., (2009) also compared the seasonality in the ExTL with that derived for the TIL based on GPS occultation data (Randel et al., 2007) from the CHAMP satellite. They noted that the vertical gradient in water vapour shows close behaviour to the static stability N^2 derived from GPS occultation data, corroborating the results of Randel et al. (2007) and Kunz et al. (2009) that radiative processes involving mainly water vapour and to a lesser extend ozone play a crucial role in determining the high static stability just above the extratropical tropopause. Kunz et al. (2009) suggest that the ExTL contains on the one hand air masses with high N^2 values, which are part of the TIL, but also on the other hand air masses influenced by more recent mixing which have characteristically low N^2 values.

1.3 Other associated aspects

Studying the seasonality of transport and mixing in the UTLS region in order to identify the driving processes as described above using in-situ measurements is the main goal of the SALSA mission. However there are at least three major questions which are strongly associated with the understanding and the quantification of this seasonality in the UTLS region, so that they will also be covered as a side aspect in SALSA.

1.3.1 Long term change of dynamics?

Several modelling studies have recently predicted an increase in the Brewer Dobson circulation of the stratosphere in association with a change in climate (Butchart et al., 2006, Garcia and Randel, 2008, Shepherd 2008). This should lead to shorter transport times in the atmosphere (McLandress and Shepherd, 2008, Austin and Li, 2006). The observational evidence for this is however rather weak. Randel et al. (2004, 2006) investigated ozone and meteorological data in the TTL (Tropical Tropopause layer) and interpreted these to show an increased tropical upwelling, with a particular step-like change around the year 2001. Temperature trends derived for the tropical lower stratosphere are also in agreement with increased upwelling in this region (Fu et al., 2009). On the other hand Engel et al. (2009) could not confirm the decrease in mean age predicted by most climate models due to the enhancement in Brewer Dobson circulation using long term observations of mean age of stratospheric air at mid latitudes above 24 km altitude. The SPURT data, collected during the years 2001 to 2003, showed enhanced N_2O and CO concentrations and different correlations slopes between N_2O and O_3 in the lowermost stratosphere for the respective season than previous observations in the years between 1992 and 1998 as shown in Figure 4 (Bönisch et al., in preparation, 2010). Note that the seasonal variation needs to be resolved and quantified in order to be able to assess such interannual variability or even long term change.

In general, the difference in the N_2O-ozone correlations is indicative of a change in transport pathways providing air to the lowermost stratosphere with enhanced quasi-horizontal poleward transport of tropical N_2O-rich air into the lower stratosphere relative to downward transport from the stratospheric overworld into the lowermost stratosphere (Bönisch et al., in preparation, 2010). It is, however, not clear if the observed change was a short term variation or a long term change.

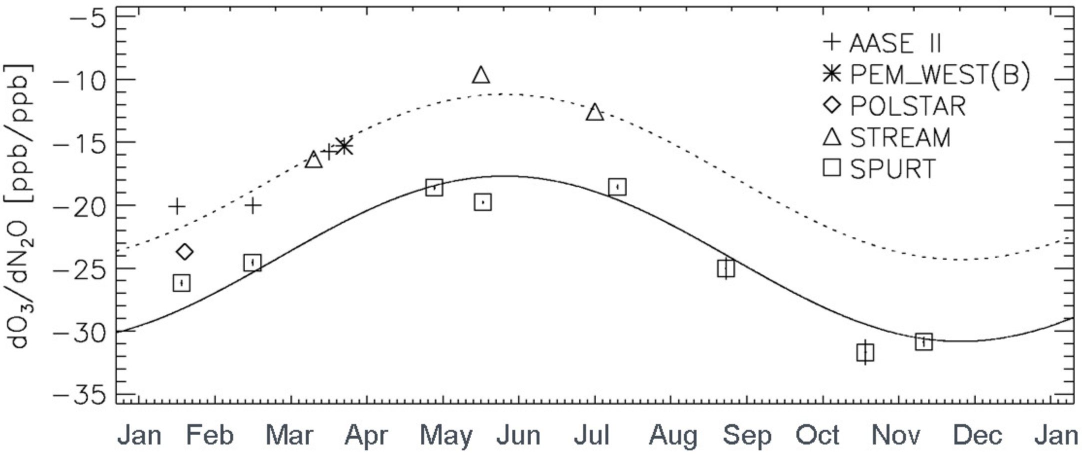

Figure 4: Seasonality of the slope of the N_2O-ozone correlation derived from different aircraft campaigns before (dashed curve based on AASA II, PEM_West(B), POLSTAR and STREAM data) and after 2001 (solid curve based on SPURT data).

1.3.2 Uncertainties in model based process studies?

Generally, transport in the atmosphere can be divided into two parts: (1) advection caused by horizontal and vertical winds and (2) diffusion, which is often referred to as mixing. Whereas the large-scale, horizontal winds in the UTLS region are well captured by models, the vertical velocities and mixing, in particular in the vicinity of the tropopause, are poorly understood. The common praxis in diagnosing results obtained from CCMs and CTMs is to derive vertical velocities from the mass conservation equation. The most important disadvantage of this procedure is that the physical properties of the derived vertical velocities are strongly disturbed by the deficiencies of the assimilation procedures (e.g. ECMWF or NCEP data sets) and by numerical errors of the ill-conditioned mass conservation equation (e. g. Schoeberl et al., 2003; Konopka et al., 2007; Wohltmann and Rex, 2008). On the other hand, some CCMs and the new version of the ECMWF re-analysis (ERA-Interim) allow to use the vertical energy balance (the so-called temperature tendencies) in order to determine more realistic vertical velocities (e.g. Fueglistaler et al., 2009; Plöger et al., 2010). Furthermore, the Chemical Lagrangian Model of the Stratosphere (CLaMS) uses a physically motivated parameterization of mixing that can be varied in a broad range, from a no-mixing case to an exaggerated mixing (Konopka et al., 2004; 2007). By this approach, the impact of the most uncertain components of transport (i.e. vertical velocities and mixing) on the distribution of all relevant species can be analyzed.

1.3.3 Chemical processes and budgets?

The UTLS region is the gateway between the troposphere and the stratosphere. The transport related phenomena of the UTLS region described above thus effect the fluxes of trace gases between the troposphere. In particular the influx of ozone from the stratosphere to the troposphere plays an important role for the oxidative capacity of the atmosphere. Nitrogen oxides are formed in the stratosphere due to the reaction of N_2O with excited oxygen atoms and in the UTLS due to lightning and due to aircraft emissions. The exchange of air between the stratosphere and the troposphere via the UTLS is thus also important in determining the nitrogen budgets of the troposphere.

On the other hand, the stratosphere is fed with many gaseous compounds from the troposphere. Next to greenhouse gases this also includes possibly ozone depleting substances (ODS), in particular the influx of shorter lived halogenated compounds. The transport processes, in particular in the Tropical Tropopause Layer (TTL) thus have strong impact on the influx of halogens into the stratosphere. As air mass transport from the lowermost stratosphere into the stratospheric overworld is not effective, it is not expected that the transport processes into the lowermost stratosphere have a significant influence on the chemical composition of the stratospheric overworld. This will however, effect the chemistry in the lowermost stratosphere and the lifetimes of chemical species in this region. A better knowledge of the chemical processes and composition of the UTLS, including more reactive species which do not serve as tracers for atmospheric transport, is necessary to improve the understanding of the UTLS.

2. The TACTS/SALSA mission

The TACTS mission, which has already been approved by the WLA (Scientific Steering Committee; Wissenschaftlicher Lenkungsausschuss) is aimed at investigating one specific aspect of the seasonal variability explained above: The change in the composition of the UTLS during the transition from summer to fall. Which role do transport and mixing across the subtropical jet play during this transition and can this be quantified? We will measure a wide range of tracers with different source/sink characteristics, spanning very different chemical lifetimes. A payload has been carefully put together and consolidated during many discussions with the partners, which allows to measure the most important trace gases which can give the relevant information on dynamical and some information on chemical aspects of the UTLS. Details on the payload are explained below. Three transects from Germany to the Cape Verde islands are planned in order to measure the chemical composition on both sides of the subtropical jet during this transition. This will provide a new data set, as the mission range is extended to the subtropics and to higher altitudes and as we will measure a much wider suite of trace species then previously available.

As an extension to TACTS we propose two further transects with the same payload to the Cape Verde islands in order to cover an annual cycle instead of just two seasons. This extension is called SALSA. TACTS/SALSA will allow to investigate the UTLS composition with a minimum of seasonal resolution. In particular variability of the exchange across the subtropical jet and of the TIL and ExTL over the year can be studied due to this extension. A better seasonal coverage then proposed here would be scientifically desirable, but does not seem feasible from a logistical and technical point of view at this stage. We therefore intend to include similar information from e.g. the START08 mission (Pan et al., 2010) which has recently become publically available. This mission was aimed at investigating the UTLS during the spring to early summer period. As detailed below, we will by combining modelling studies and observations investigate the seasonality and the underlying processes.

2.1. General Questions related to TACTS/SALSA

The complex interplay between radiation, dynamics, and chemistry in the UTLS needs to be understood in detail in order to improve Chemistry Climate Models (CCM) which represent the main tool for future climate prediction. Even though there have been significant advances in recent years in understanding UTLS composition and its relation to radiation and dynamics there remain a number of outstanding questions, including: What determines the variability of UTLS composition on seasonal to interannual time scales and what are the crucial factors in determining potential trends in UTLS composition and their effect on climate variability and change? What is the impact of potential changes in stratosphere troposphere exchange as well as changes in tropospheric and stratospheric circulations on UTLS composition? Which processes determine the UTLS dynamics, e.g. what drives the depth of the ExTL and TIL?

2.2 Specific scientific questions and planned studies related to TACTS/SALSA

The general scientific questions to which TACTS/SALSA should make contributions are explained above. A number of specific questions which are planned to be studied with the data gained during the missions are explained here. To progress towards the broad general objectives defined in section 2.1. many complex and specific studies are necessary. The questions listed below can of course not be answered only based on the TACTS/SALSA data or by the TACTS/SALSA community. However, the data and the TACTS/SALSA consortium are expected to make a significant contribution to the most of the questions detailed below, with the overall goal of improving the understanding of UTLS composition, its seasonality and the driving processes. The possibility to contribute to the different aspects listed here will depend on the actual outcome of the observations.

How far into the LMS does troposphere to stratosphere transport (TST) occur?

The thickness of the ExTL was determined using different pairs of tracers. One tracer needs to have high values in the troposphere and low values in the stratosphere (tropospheric tracers), the other tracer visa versa (stratospheric tracer). In addition to ozone as stratospheric tracer, we suggest to use NO_y and HCl also. Possible other tropospheric tracers next to water vapour and CO are halogenated hydrocarbons. As these have very different lifetimes, they will give information on different time scales involved in transport and mixing of tropospheric air masses to a certain depth of the lowermost stratosphere. Tracers to be used include $CHCl_3$ (lifetime 150 days), CH_2Br_2 (lifetime about 120 days), $CHBr_2Cl$ (lifetime 78 days), $CHBr_3$ (lifetime 26 days) and CH_3I (lifetime 5 days). Also measurement of other volatile organic compounds (VOC) and their different isotopologues can provide additional constraints on possible transport timescales and pathways. These tracers can e.g. be used to differentiate chemically between more recently mixed air masses and air masses which were mixed some time ago. As detailed below, these tracers could also be used to study the age spectrum of air in the lowermost stratosphere.

Which processes contribute to the formation and to the maintenance of the tropopause inversion layer (TIL)?

Physical processes which are responsible for the formation of the TIL are a subject of current scientific debate whereas the following mechanisms are discussed: baroclinic dynamics on synoptic time scales (Wirth et al., 2003), seasonal variability of the Brewer-Dobson circulation (Birner, 2009) and radiative effects on a seasonal time scale within the extratropical mixing layer (Randel et al., 2007). Kunz et al. (2009) have shown that transport and mixing on a seasonal time scale (weeks to months) are responsibly for the composition of air within the TIL and that the water vapour plays the most important role in radiative adjustment (cooling) occurring in these air masses. Observations of water vapour and its isotopologues can provide insight into the dehydration pathways and the underlying processes (e.g. Fueglistaler et al., 2009 and references within). Recently, high values of H_2O within the TIL on the summer hemisphere were also derived from the satellite observations (ACE-FTS) (Hegglin et al., 2009). The seasonal and interannual variability of the TIL, its interaction with the Brewer-Dobson circulation and its impact on the weather systems like storm tracks play an important role in understanding of the climate variability and climate change. Still an open question is how well the enhanced stability and the chemical composition of the TIL are reproduced by the models. TACTS/SALSA could give new insight into this topic using the combination of in-situ temperature profiles and measurements of chemical tracers spanning a wide range of lifetimes from days to years. Especially, the very short lived tracers could give information about recently mixed air and its interference with the enhanced stability in the TIL.

Can long term changes in transport patterns be observed?

As explained above, seasonal variabilities in transport patterns have been identified using N_2O-ozone correlations (Hegglin and Shepherd, 2007). However, it is unclear as yet if the difference in the correlation slopes observed before and after the year 2001 is interannual variability or could be indicative of long term change (Bönisch et al., 2010 in preparation). Further data covering, a wider geographical range and with some seasonal resolution will help to understand if the observed differences should be classified as variability or could be a long term change due to changing relative importance of different transport pathways, i.e. down welling versus quasi-horizontal transport.

Can convection lead to direct transport from the extratropical lower troposphere into the LMS? Can warm conveyor belts transport air masses close to the tropopause or even into the lowermost stratosphere?

Based on the tracers with different chemical lifetimes and different source characteristics, we will be able to determine if air masses of very recent tropospheric boundary layer origin have been transported close to the tropopause or even mixed across the tropopause. E.g. most bromine and iodine species have only major maritime sources. Tracers like $CHCl_3$ which is mainly of anthropogenic origin are enhanced in continental air masses and species like CH_3CN are especially emitted from biomass burning. Different tracer patterns will provide information on the source region of the air masses observed near the tropopause and in the lowermost stratosphere. If convection is a relevant process for UTLS composition then this influence would be predominantly expected in the Northern hemisphere during the summer months. This means that flights in non-convective season as suggested by SALSA are a prerequisite as reference for this kind of study.

Which processes contribute to mixing on small scales across the tropopause?

A large fraction of stratosphere-to-troposphere exchange appears on small scales, such as rapid upward transport of surface or boundary layer air by the passage of frontal systems or by large-scale convective events or such as mixing across isentropes at mid and high latitudes due to Rossby wave breaking generating filaments and intrusions.

These events occur on scales of down to less than 100 km, with transitions in tracer values at the edge of such filaments over much smaller scales (e.g., Balluch and Haynes, 1997). The morphology of such structures is neither captured by satellite remote sensing measurements nor by in-situ measurements. This 'observational gap' can be closed by (tomographic) measurements of GLORIA-AB. Depending on the variability of the background atmosphere, full 3-D pictures of such events can be obtained with a 10 by 10 km horizontal and 200 m vertical resolution. This data will be used to quantify the volume as well as the structure of such events.

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What are the age spectra in the lowermost stratosphere?

In order to quantify transport across the tropopause in comparison between models and observations, we need to develop and implement appropriate tools. In the past, transport schemes of CCMs and GCMs have been frequently compared based on vertical-latitudinal cross sections of mean age-of-air values. Here, we propose to use the novel age spectrum approach that provides a surrogate of all relevant transport properties of the atmosphere (Waugh and Hall 2002; Schoeberl et al., 2005; Ehhalt et al., 2007). This method and the appropriate and available tracers (e.g. CO, HCl and halocarbons with different lifetimes) have to be implemented into CLaMS model. This allows quantifying the percentages of the tropospheric air in the stratosphere and vice versa. In particular, the time scales of transport, their seasonality as well as the origin of air can be determined based on this approach. Note that both the shape and the seasonality of the age spectrum can be validated by comparison with the experimental data (Ehhalt et al., 2007) derived by simultaneously measured CO_2 and SF_6 mixing ratios (Bönisch et al., 2009).

What is the halogen budget in the UTLS?

Evidently cross UTLS transport is also relevant for the budget and photochemistry of ozone destroying stratospheric bromine and iodine (WMO, 2007). In particular, it can be expected that more detail information on the UTLS transport, transformation and photochemistry of organic and inorganic halogenated compounds then yet available. New detailed observations of halogenated compounds will thus help to provide new insights into possible causes for the larger stratospheric inorganic bromine content then expected from the known source gas concentrations, and conversely the much lower stratospheric inorganic iodine then previously suspected (Dorf et al., 2008; WMO, 2007; Butz et al., 2009).

Can correlations tell us where the troposphere-to-stratosphere transport occurs?
Correlations between chemical species with different source-sink characteristics which are observed in the lowermost stratosphere often show near linear behaviour. In an ideal case, where a mixing line is linear, it can be extrapolated to the "end members", which would represent the reservoirs from which the mixing occurs. By flying on both sides of the subtropical jet (tropical tropospheric side and extratropical stratospheric side) in-situ measurements from the aircraft can provide the fine scale information on the mixing lines. While satellite measurements allowing determination of the global features of the seasonal and geographical distribution of the tropospheric end members have recently become available for species like CO and ozone, such information is not available for CO_2, which can not yet be measured with sufficient precision from satellites. The in-situ measurements especially for CO_2, which has the best defined tropospheric seasonal cycle, has not been investigated before close to the subtropical jet. Tracer correlation of NO_y vs. O_3, NO_y vs. N_2O could also be used to study budget and air mass origin of reactive nitrogen species in the lowermost stratosphere (e.g. Ziereis et al., 2000).

What is the role of Nitrogen Oxides in the UTLS region?
Nitrogen oxides play a key role in atmospheric photochemistry, particularly in controlling the cycling of OH and the production of ozone in the UTLS. The budget of nitrogen oxides there is controlled by a variety of different sources and processes, chiefly: long-range transport, lofting from the boundary layer, biomass burning, lightning, air traffic emissions and STE. The measurements of large scale distributions of NO, NO_x, and NO_y during SALSA will be used to investigate the contribution of the different sources to the nitrogen oxides budget in the UTLS (e.g. Ziereis et al., 2000; Huntrieser et al., 2005 and 2007).

2.3 Campaign Strategy

The objectives defined above can to a large degree be obtained if the variability of the UTLS chemical composition is well captured and represented by our observations. A possible vertical transect between Oberpfaffenhofen and the Cape Verde islands is shown in Figure 5. We intend to use the CLaMS model in order to investigate the best possible sampling strategy for TACTS/SALSA. The model can be used as a tool prior to the campaigns to find out the best spatial and temporal coverage of the HALO flights. For this purpose, the statistical analysis as described by Kunz et al. (2008) will be applied to a multi-year CLaMS run (2001-2008) in order to compare the variance information derived from CO, O_3, CO_2, CH_4 and mean age for daily sampling along the suggested flight pattern (see Figure 5) with the variance information of temporarily sub-sampled possible transects during TACTS/SALSA. Based on the results of these studies we will adapt the flight strategy to the best achievable seasonal coverage of the observations in order to meet the scientific goals.

The possible flight pattern depicted in Figure 5 consists of a transect from Oberpfaffenhofen to ~10°N where maximum altitude is reached and (after a refuelling stop) a return flight to Oberpfaffenhofen at different levels, in order to cover the entire LMS. On the return flight, the aircraft shall reach its maximum altitude at mid-latitudes. A single mission should be ~17 flight hours. Three such transects are planned in TACTS, preferably in early August, mid September and late October (with a time difference of 5-6 weeks). Depending on other users requests, the time steps between these transects can be adapted. As explained above, we propose to perform two additional transects in order to sample an entire annual cycle. This extension (SALSA) still needs to be approved by the WLA. It has the great advantage, that the work load and the costs involved in certifying a payload will only be required once and that the scientific goals described above can be reached much better if information over an entire annual cycle is available.

For the actual flight planning during the campaign, it will be important to sample air masses on both sides of the subtropical jet and to ensure that the dives planned to derive vertical profiles reach at least 1 km below the tropopause. For particular objectives described above (e.g. the tomography of active exchange regions like a tropopause fold) it is necessary to locate such events in the best possible way and to adapt the flight planning at rather short notice. For this purpose we intend to use both the flight planning tool for which a proposal will be submitted to the DFG priority programme "HALO" and also the CLaMS model. In order to optimise the representativeness of the observations, the planning tools should be used to maximise the captured equivalent latitude range during each transect.

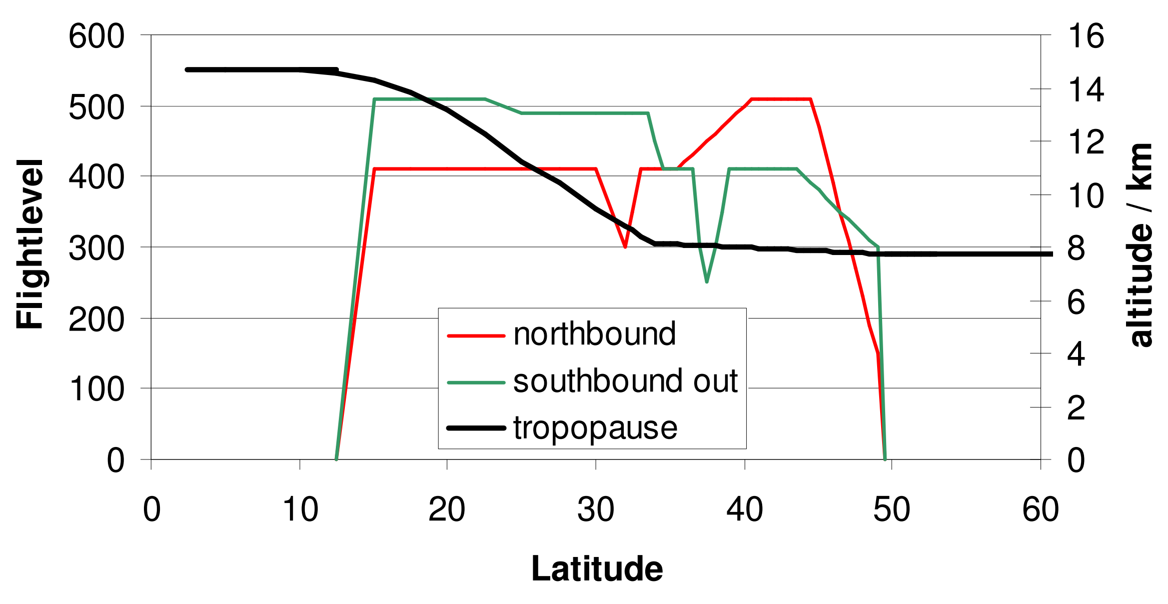

Figure 5: possible flight track for a north-south transect. This flight pattern should be repeated three times during the time period between August and October.

2.4 Instrumentation

The instrumentation for TACTS/SALSA will allow observing a very wide range of trace gases with different source/sink characteristics and different lifetimes. As explained above, such a payload can be used to differentiate between different transport processes and pathways. The instrumentation consists mainly of in-situ measurements. Two remote sensing instruments (GLORIA-AB and mini-DOAS) will provide a wider view around the aircraft. The payload is sufficiently comprehensive to provide the observations needed to answer the questions raised above, yet it is still sufficiently light weight that HALO should be able to reach the maximum cruise altitude at the end of each flight leg. The complete payload is shown in Table 1.

The payload listed above will thus be able to provide observations of the most important transport tracers like CO, N_2O, CO_2, NO_y, SF_6, ozone and water vapour, some of these even with redundancy from several instruments, allowing for internal quality control. With the exception of SF_6 all of these tracers will be available at temporal resolution of 1 Hz or better. For water vapour we will not only be able to measure the concentration but also the isotopic composition and distinguish between gas phase and total water. The in-situ mass spectrometers AIMS and ITMS will provide high temporal resolution information on some selected transport tracers like HCl and CH_3CN) and chemically important species. The in-situ GC/MS GhOST-MS will measure a wide suite of chemical tracers. For the halocarbons (e.g. CH_3Br, CH_2Br etc.) the temporal resolution will be between 3 and 5 minutes, while SF_6, N_2O and CFC-12 will be measured with a temporal resolution on the order of 1 minute. The whole air sampler MIRAH will provide samples from the flights, which will mainly be used to measure isotopic compositions, but can also be used for Hydrocarbon and Halocarbon analysis. Gloria as an imaging FTIR spectrometer can provide high resolution (200 m vertical resolution; 10 km horizontal) information on the chemical composition below the aircraft, allowing much better coverage then previously available. In addition, Gloria will also provide temperature information below the aircraft. Although this temperature will probably only have a true vertical resolution of about 1 km, it is expected to allow us to deduce information on the static stability N^2, which is of great importance in investigation of the TIL (see section above "Which processes contribute to the formation and to the maintenance of the tropopause inversion layer (TIL)". Temperature information below the aircraft with higher vertical resolution would be highly desirable, but this will probably not be possible with the present mission.

Table 1: TACTS/SALSA payload

Instrument	Species	PI	Org.
TDL	CO, N_2O, CH_4	Fischer	MPI
NDIR	CO_2	Fischer	MPI
FISH Ly-a	H_2O	Schiller	FZJ
HAI	H_2O	Ebert	FZJ/UHd
ANEAS	NO_x/NO_y	Ziereis	DLR
ISOWAT TDL	$H_2{}^{16}O$, $H_2{}^{18}O$, HDO	Dyroff	FZK
FAIRO O3	O_3	Zahn	FZK
mini DOAS	O_3, NO_2, CH_2O, O_4, BrO, OClO, IO, OIO	Pfeilsticker	IUP
ITMS	SO_2, CH_3CN, HCN	Schlager	DLR
GhOST-MS	SF_6, N_2O, F12, CH_3Br, $CHBr_3$, CH_3I, $CHCl_3$ etc.	Engel	UFRA
MIRAH	Hydrocarbons, Halocarbons, Isotopic composition	Koppmann	Uni Wu
Gloria	N_2O, CH_4, H_2O, HDO, SF_6, CFCs, O_3	Oelhaf, Preuß	FZK/FZJ
AIMS	HCl, HNO_3, $ClONO_2$, SO_2	Voigt	DLR

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