Work Package 2: How do the dynamics of the troposphere affect the chemistry of the stratosphere?

In this work package the effects of tropospheric dynamics and changes thereof due to different forcings (e.g. GHG concentration) were studied. The possibility of reducing the phase space to few variability modes has been investigated based on reanalysis data. Such data were also used to study fundamental variability modes and teleconnections in dependence of stratospheric state. Model runs have been performed for evaluation purposes and will be further analysed in the next future. Multiple regression analyses relating tropospheric parameters to stratospheric ozone were performed. A major tool developed in this WP was a programme package to analyse wave number–frequency behaviour in models and in reanalysis data.

Contribution of MPI-PROVAM

MPI-PROVAM studied reanalysis (NCEP) data from 1949-2000.

A **physical reference system** was used to study the variability of the global atmospheric circulation (Castanheira et al., 2002). The mass and the horizontal motion fields were projected onto the free oscillations (normal modes) of a set of linearised primitive equations. Using this projection we were able to decompose the global circulation into one barotropic and several baroclinic components as well as into gravity-inertial and planetary (Rossby) waves. This procedure allows for a physically self-consistent filtering of the mass and the horizontal motion fields. Although the analyses were performed using global data, the discussion mainly focused on results for Northern Hemisphere winter. The barotropic component was represents the tropospheric circulation, the lower stratospheric circulation is represented by the 2nd baroclinic component.

The variability patterns of the circulation were uncovered by means of a Principal Component Analysis (PCA) performed in the phase space of the projections (ω^{α}_{msl} coefficients). Only the Rossby modes and the Kelvin modes did show appreciable variability and were therefore retained in the analysis. The first mode of variability of the tropospheric circulation (barotropic component) represents a PNA-like structure (Wallace and Gutzler, 1981), and the second mode is similar to the summer NAO pattern (Glowienka-Hense, 1990), but considerably differs from the observed winter NAO pattern. The first PC of the lower stratospheric circulation (2nd baroclinic component) represents the variability of the undisturbed stratospheric polar vortex, and the second mode of variability represents a wave number one disturbance of the polar vortex.

We have also explored the concept of **dynamical coupling between the tropospheric and the stratospheric circulation** as known from linear wave theory (Charney-Drazin theorem). The connection between the stratospheric and tropospheric circulation was studied by means of a multiple linear regression between the strength of the polar vortex (PC1 of the lower stratospheric circulation) and the first 10 PCs of the tropospheric circulation. We refer to this coupling of variability between the two circulation fields as the barotropic-baroclinic pattern (Fig. WP 2-1). The tropospheric circulation field of the latter pattern resembles the winter NAO pattern more closely than does the PC2-pattern of the barotropic (tropospheric) circulation. This result suggests that the observed winter NAO pattern results from the modulation of the barotropic Rossby modes by the stratospheric polar vortex. Most climate models do present a too cold and strong polar winter vortex and therefore they will also have an important bias in the variability structure. Dynamic analysis of the streamfunction tendency (Walter, 2003; Walter and Graf, 2004, in prep.) clearly shows that there is no simple mechanism of changing variability structure of the main teleconnections over the Northern Hemisphere (see below).

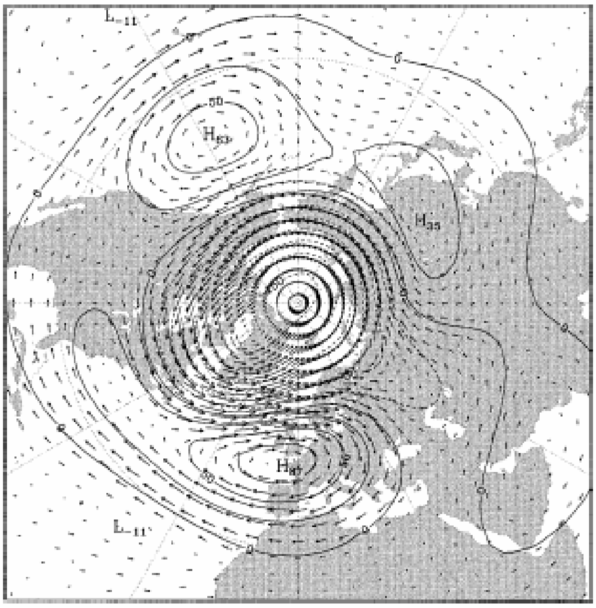


Figure WP2-1: Canonical correlation pattern of the tropospheric circulation PCs 1-10 associated with the strength of the stratospheric polar vortex.

We have also studied the possibility of **explaining the observed trend pattern in 850 hPa temperature** (T850) either by the barotropic or by the coupled barotropic-baroclinic NAO-like patterns. The barotropic-baroclinic pattern explains a higher amount of the observed T850 trend pattern in Eurasia, whereas the barotropic mode explains a higher fraction of the trend over the Western Hemisphere. Comparing the obtained regression patterns of the T850 field upon the PC of each mode with the with the results of Perlwitz et al. (2000) (see their Fig. 5), it may be stated that the regression pattern for the barotropic-baroclinic coupling resembles more closely the regression pattern they obtained for the weak polar vortex regime (their Fig. 5a). In turn, the regression pattern associated with the barotropic NAO mode resembles more closely the pattern for the strong polar vortex regime (their Fig. 5b). Since Graf et al. (1998), Shindell et al. (1999), and Perlwitz et al. (2000) showed that the increasing greenhouse effect, possibly coupled to ozone depletion in early spring, may lead to an intensified polar vortex, we may expect for the future a change in the trend patterns towards the one for which the barotropic Rossby mode is responsible. However, this perspective is not the only one possible as seen in model simulations performed with E39/C as discussed below (Schnadt et al., 2002).

Based on a linear regression/correlation analysis of monthly mean atmospheric sea level pressure data from the NCEP reanalysis (1948-2000) we find a significant anti-correlation between pressure in the northern North Atlantic and North Pacific only if the stratospheric circulation is in the ”strong polar vortex” regime, but not when the vortex is weak (Figure WP2-2). Since some general circulation models (e.g. ECHAM4) are biased towards the strong vortex regime, they tend to reproduce this anti-correlation already in the mean. The pattern of the “Arctic Oscillation” is shown to be consistent with the mean surface pressure differences between the two stratospheric regimes. The typical southwest-northeast tilt of the node line of the North Atlantic Oscillation in Northern Hemisphere winter is due to a superposition of correlation patterns based on physical processes working in the troposphere (a strictly meridional dipole and the pattern resulting from planetary wave refraction in the strong vortex regime) and those produced by the rapid transition from one stratospheric regime to the other with subsequent downward propagation of the signal (Castanheira and Graf, 2002).

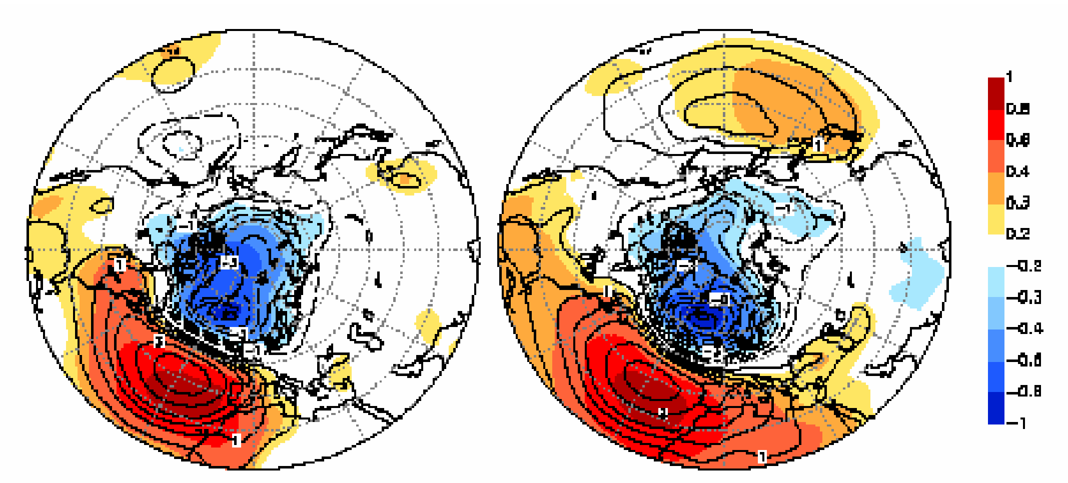
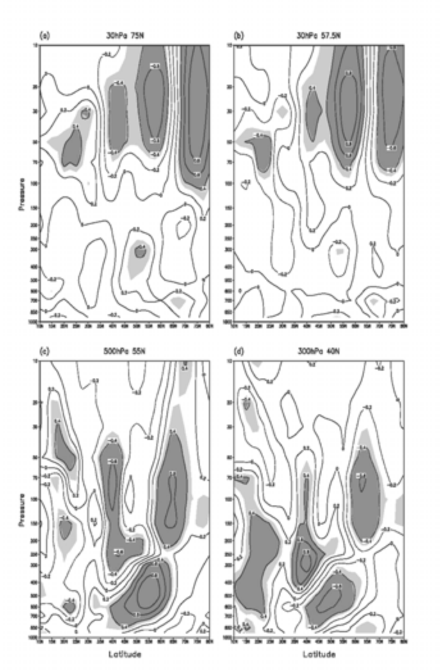


Figure WP2-2: Correlation (colour) and regression (isolines) of the pressure at surface near Iceland with the pressure elsewhere for weak (left) and strong (right) polar vortex.

This result is especially relevant for the disturbance of the polar vortex by vertically propagating planetary waves. While in the case of a stronger polar vortex it can be expected that planetary wave activity of wave 2 will increase in mid latitudes, for a mean weaker vortex it is wave 1 in higher latitudes. Wave one can more easily disturb the vortex than wave 2, hence we have a positive feedback leading to more stable regimes (either strong or weak vortex).

Two **tele-connection patterns in the EP flux divergence** field due to planetary waves with wavenumbers (WNs) 1 to 3 were studied in the Northern Hemisphere winter (Wen et al, 2003). One dipole evolves in the stratosphere (stratospheric inter-annual oscillation (SIO)), the other in the troposphere (tropospheric inter-annual oscillation (TIO)). TIO and SIO are associated with anomalous meridional planetary wave propagation in the troposphere and stratosphere, respectively, and tropical (SIO) or mid latitude (TIO) SST (Chen et al., 2002a;b). Tropical SST is related to upper stratospheric EP flux divergence, mid latitude SST to tropospheric, influencing the relation between polar and subtropical jet, and determining the strength of the lower stratospheric polar vortex. SIO and TIO are not significantly correlated, hence we may take them as independent processes. While tropical SST anomalies lead upper stratospheric processes by 3 seasons, there is no time lag relationship between mid latitude SST and EP-flux divergence on a monthly time scale. TIO is significantly correlated with the NAO/NAM index (r=0.69), SIO is with the PNA index (–0.39). It is suggested, however, that while the TIO-NAO relationship is based on a direct physical process, the SIO-PNA relationship is not. Both are influenced by tropical SSTs, the PNA due to planetary wave propagation and the Hadley circulation, SIO due to influences of the deep tropical convection on the residual stratospheric meridional circulation.



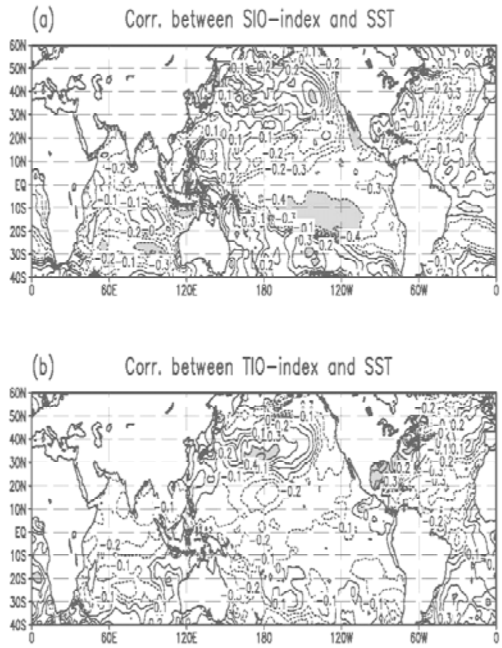


Figure WP2-3: One point correlation maps between EP flux divergence at 30 hPa, 75°N and 57.5°N (SIO, top) and 500 hPa, 55°N and 300 hPa, 40°N (TIO, bottom).

Figure WP2-4: Correlation of SIO and TIO global 1958-1998, de-trended, shaded areas are statistically significant at 95%/99%.

Tele-connections of North Atlantic geopotential heights of the middle to upper troposphere were examined separately for winter months (December to March) characterized by either a strong or a weak stratospheric polar vortex (Walter, 2003, Walter and Graf, 2004, Graf and Walter, 2004). In both cases, the major teleconnection patterns have north-south dipole structures with opposing centres of action in subpolar and subtropical latitudes. The middle to upper troposphere in the strong vortex regime (SVR) is characterized by a single teleconnection pattern over the central North Atlantic with a basically dipolar structure, the NA-SVR pattern. In contrast, there are two dipole patterns in the weak polar vortex regime (WVR): One over North Eastern Canada and the western North Atlantic (western NA-WVR pattern) and one over the eastern North Atlantic (eastern NA-WVR pattern). In the lower troposphere, however, the NA-SVR and the eastern NA-WVR patterns are very similar, in particular concerning their northern centres of action.

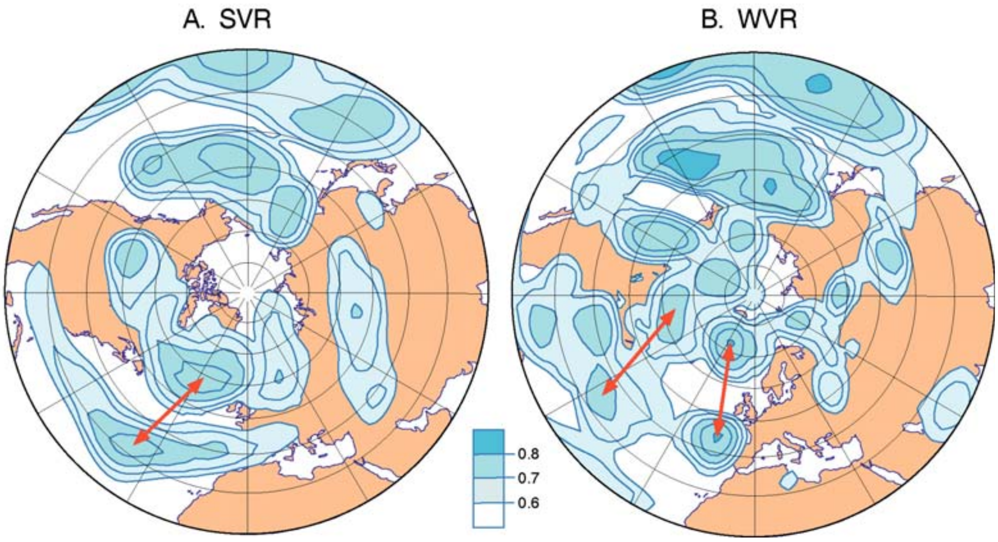


Figure WP2-5: Teleconnectivity of 300 hPa under strong (SVR) and weak (WVR) polar vortex. The fluctuations in both, the **North Atlantic storm track and the precipitation rates**, show significant differences between the two polar vortex regimes. Composites of the winter North Atlantic storm track and precipitation rates for the two polarities of a "classic" NAO index (without considering the polar vortex regimes in the stratosphere) mainly correspond to the composites of the positive phase of the NA-SVR pattern index and the negative phase of the eastern NA-WVR pattern index, respectively.

The composites of the negative phase of the NA-SVR pattern index, however, describe a blocking situation over the North Atlantic with a very strong North Eastward tilt of the storm track axis and reduced precipitation over Western Europe. This situation is consistent with results of Rogers (1997). He showed that one of the two polarities of the leading mode of the North Atlantic storm track variability corresponds to a blocking high situation, which is not captured by a classic NAO index composite. This emphasizes the need to consider the state of the polar vortex for describing the atmospheric variability in the North Atlantic region. While a classic NAO index may be appropriate for a statistical description of fluctuations in the lower troposphere (like the advection of warm and cold air masses leading to near surface temperature anomalies), it should not be used for examining processes in higher tropospheric layers - like the propagation of synoptic storms and the precipitation connected therewith. A substantial subset of variability will be missed if the dynamic processes in above-tropospheric layers associated with the strength of westerly winds in the polar vortex are not considered. Climate forecast based on a forecast of the NAO and statistical downscaling of its effects would lead to wrong conclusions when the state of the stratosphere is not taken into account.

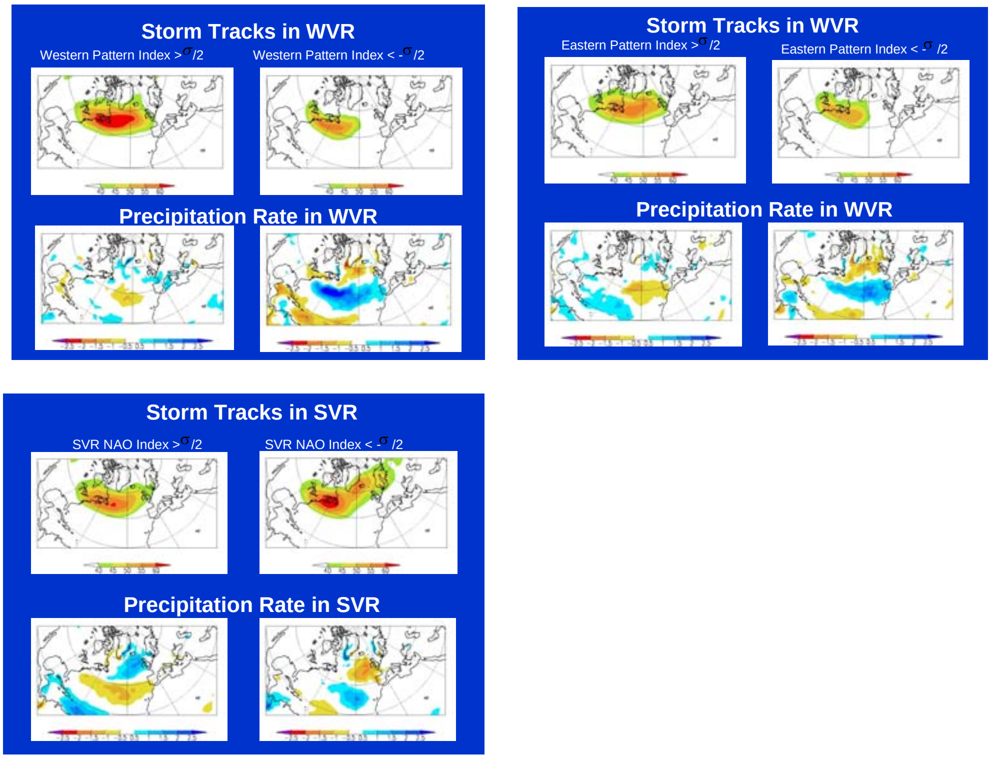


Figure WP2-6: Storm track and precipitation rate composites for the three different teleconnections shown in Figure WP2-5.

Our conclusion from the above analysis is that the state of the polar stratospheric vortex has an important effect on the horizontal structure of the main NA tropospheric variability mode, and that the structural change affects the coupling between atmosphere and ocean. If the polar vortex is strong, one single tele-connection emerges over the central NA. This tele-connection is associated with large wind anomalies over the northern part of the NA. Circulation varies from strong cyclonic in the positive phase (deep Icelandic low) to anticyclonic in the negative phase (blocking high over the northeast Atlantic). These differences would not be found in an analysis using a "classic" NAO index based on surface station data. If the polar vortex is weak, two tele-connection patterns exist which are only weakly coupled. Both WVR teleconnections mostly are associated with the wind field of the subtropical high. If the index is positive, the anticyclonic circulation is stronger, if it is negative, it is weaker.

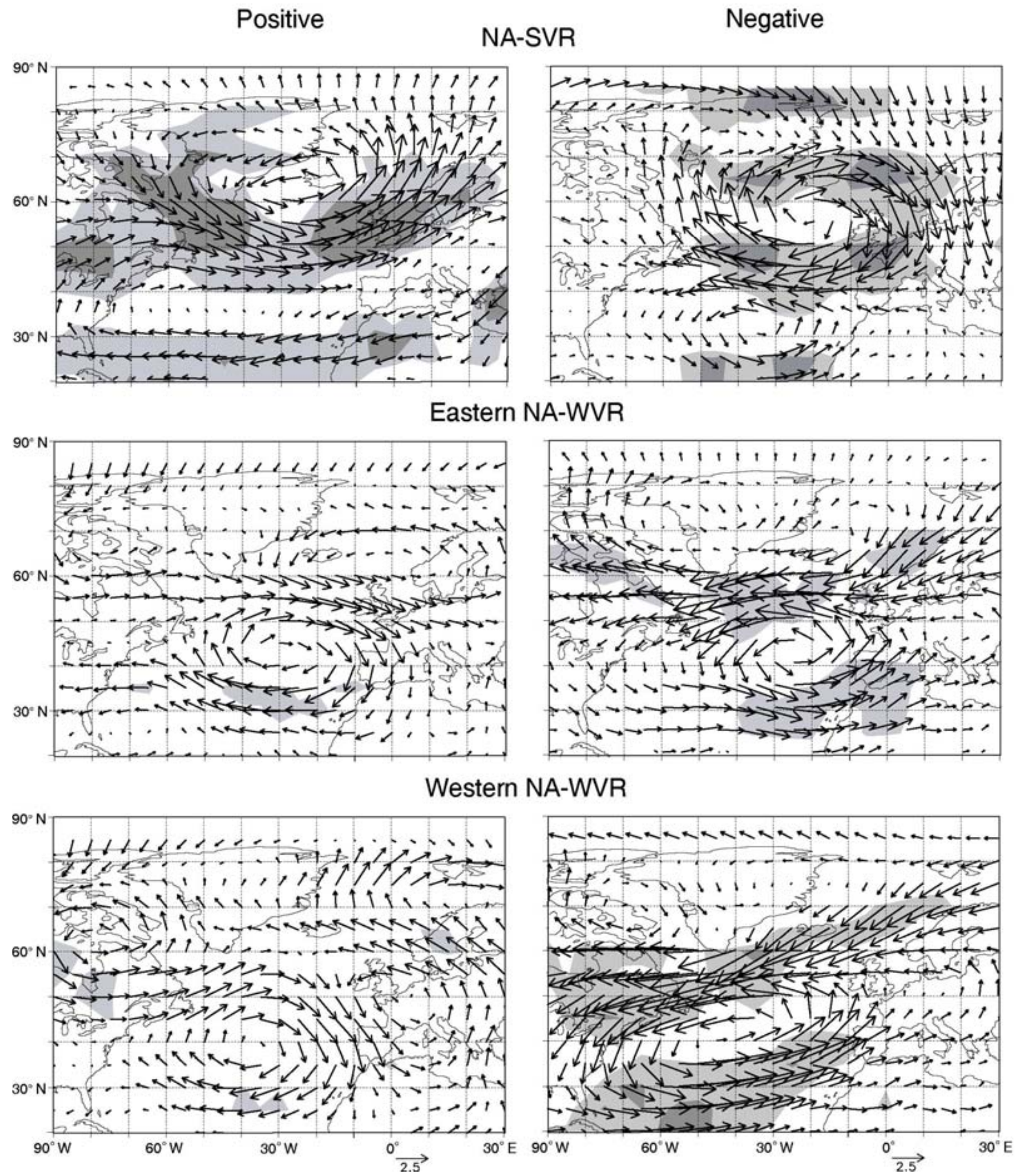


Figure WP2-7: Wind anomaly composites for the three different tele-connections shown in Figure WP2-5.

Only during periods of strong stratospheric vortex the tropospheric variability mode reveals a clear tripole correlation pattern with NA SST, while the eastern NA-WVR index mainly correlates to the sub polar gyre and the western NA-WVR index to the sub tropic gyre. The ensembles used to calculate the above correlations are rather small due to the short time series of available data and are to be taken with caution. However, supporting results were found in a coupled ocean atmosphere model (Raible et al., 2001) and using 100 years of surface observations (Walter and Graf, 2002).

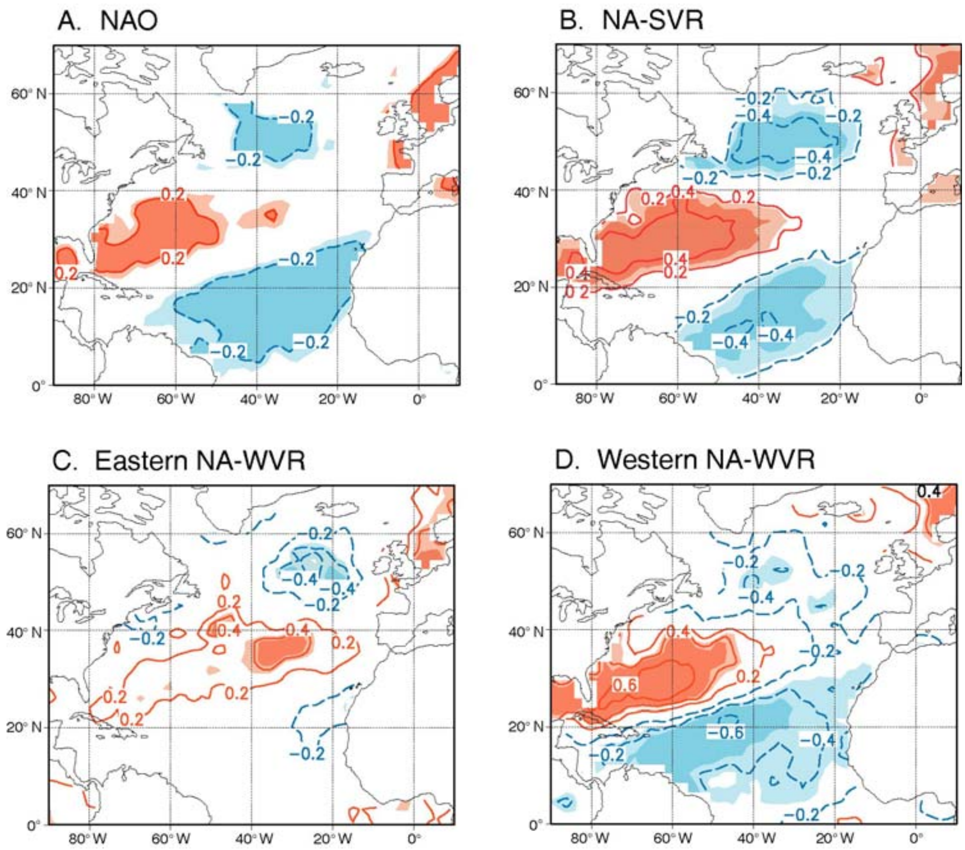


Figure WP2-8: Correlation of the three different teleconnection indices with North Atlantic sea surface temperature. Shaded areas statistically significant at the 95(99)% level.

Western and eastern NA-WVR probably describe processes which are only weakly coupled and only during the SVR a statistical connection exists between the North Pacific and North Atlantic sub polar lows (Castanheira and Graf, 2003, Perlwitz and Graf, 2001). Hence it is important to consider the role of the polar vortex in winter in process studies of atmospheric variability and also of ocean atmosphere coupling. Coupled ocean-atmosphere models must include these processes and it is necessary to prove that they capture the relationships described in this study before they can be used as forecast tools of future climate.

Fluctuations of the three North Atlantic teleconnection patterns (one in the SVR and two in the WVR) have typical timescales of about two weeks. **Lifecycle analyses** of low frequency (periods >10 days) stream function anomalies associated with the North Atlantic teleconnection patterns exhibited that the forcing mechanisms dominating the decay phase are basically the same in the two polar vortex regimes. The decay is mainly driven by low frequency divergence whereas synoptic (periods 2.5 to 6 days) eddy vorticity fluxes act to maintain the anomaly against decay. However, the lifecycle analyses also revealed that, during the growth phase, the relative importance of the forcing mechanisms is very different in the two polar vortex regimes. In the WVR, the anomaly growth is mainly driven by transient eddy vorticity fluxes in particular from the low frequency domain. In the SVR, however, a different forcing mechanism is of similar importance: the forcing related to low frequency advection of (relative) vorticity which results from the interaction of low frequency eddies with the zonally asymmetric part of the time mean flow, i.e. with the stationary eddies. This means that the different teleconnection structures cannot simply be explained by a reorganization of the transient eddies in the different regimes but are also related to a modified interaction of the transient eddies with the (changed) background flow. The latter can mainly be attributed to different stationary eddy structures in the two polar vortex regimes. Hence, there are fundamental differences in tropospheric dynamics associated with the generation of North Atlantic teleconnection patterns in the two stratospheric polar vortex regimes.

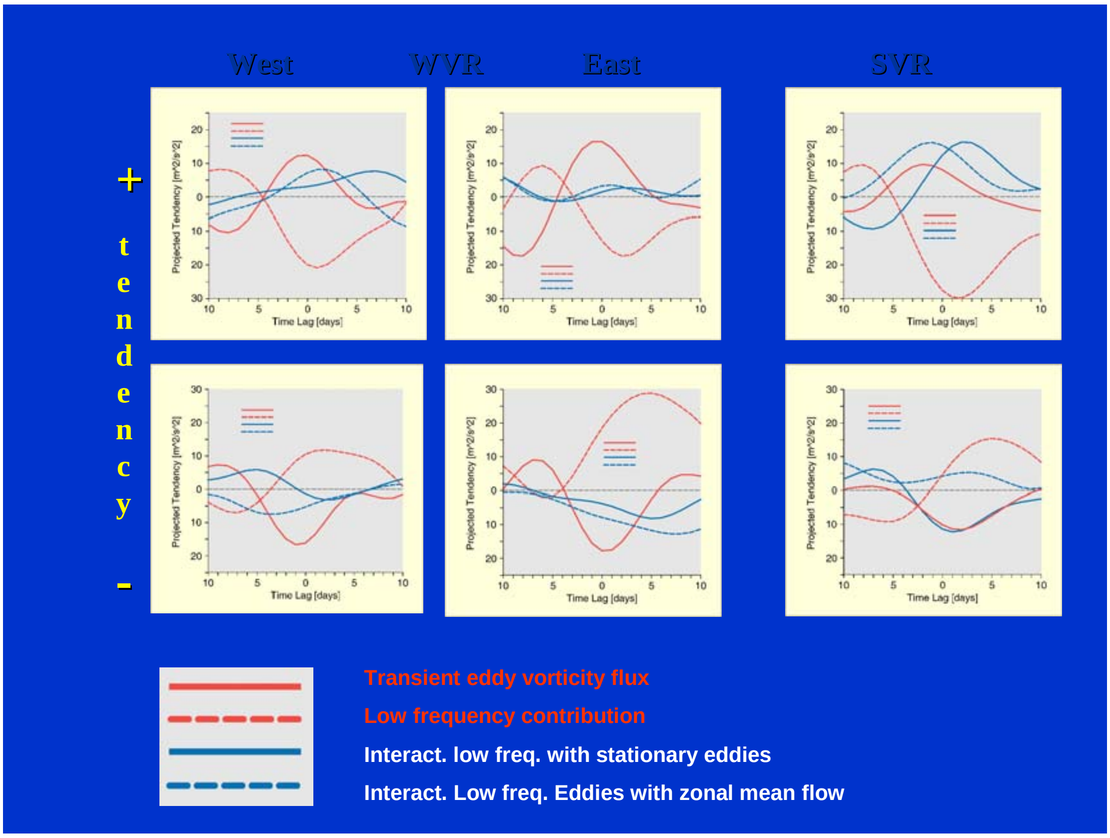


Figure WP2-9: Contribution of different processes to the build-up (top) and decay (bottom) of anomalies of the NA teleconnections under different polar vortex regimes.

Contribution of DWD

A stepwise multiple regression method has been used by DWD to estimate the influence of various factors on ozone variations observed over Hohenpeissenberg. The analysis was based on monthly mean ozone measured from 1967 to 2001 by Brewer/Mast Sondes in the altitude range 1 to 30 km and by Differential Absorption Lidar from 1987 to 2001, over the altitude range 25 to 50 km. The following influences (termed predictors in multiple regression) were investigated: A linear trend, the 11 year Solar Cycle, the QBO, stratospheric aerosol loading, ENSO and, in particular, tropospheric circulation indices (http://www.cpc.ncep.noaa.gov/data /teledoc/teleintro.html). The circulation indices are used to account for the important influence of tropospheric dynamics on the stratospheric ozone layer.

The stepwise multiple regression was carried out for 1 km altitude layers from 1 to 50 km and for the four seasons. Only influences significant at the 90% level were left in the regression. Figure WP1-4 (see above) shows the combined influence of the tropospheric circulation patterns as determined by this method. White areas indicate no significant influence at these heights and seasons (with a level of significance of 90%).

However, throughout the lower stratosphere (10 to 20 km) ozone fluctuations associated with tropospheric circulation indices are very large and highly significant, contributing ozone fluctuations of typically 20 to 40%. The strongest influence is found in winter just above the tropopause. The tropospheric influence disappears almost entirely above 20 km. Only in winter, there is a small effect between 25 and 45 km. We feel that the latter is a manifestation of the well-known stratospheric/tropospheric coupled circulation modes.

The influence of the other predictors on observed ozone variability has also been analysed, but will not be discussed here.

Contribution of MPI-MAECHAM

A climate simulation with the MAECHAM4 model is ongoing; so far 20 years have been completed (without interactive chemistry). This is a simulation of the atmospheric circulation of the troposphere, stratosphere and mesosphere at a resolution of T30/L39. Present conditions have been specified for the uniformly mixed greenhouse gases, and the ozone distribution (Fortuin and Kelder, 1996). Climatological sea surface temperature and sea ice distributions (1981-1990, Hadley data set) have been prescribed as lower boundary condition. This simulation is the basic control experiment for the evaluation of the following experiments with interactive chemistry. The 2-daily data of this simulation have been provided to MPI-PROVAM for their analysis.

Contribution of MPI-C

The data of the 20 year timeslice experiments for 1960 and 1990 conditions with interactive chemistry (see also WP1) will be provided to MPI-PROVAM for pattern analyses and to look for differences due to interactive chemistry. At MPI-C charts of ozone mixing ratio at 70 hPa of individual days in March of every model year have been analysed visually for pattern changes due to advection of ozone poor air from low latitudes or other dynamical influences driven from the troposphere like 'miniholes'. This has been done also for a 2000 scenario and a 1990 sensitivity experiment with sea surface temperatures representative for 1960 (Hadley centre data set). Some of these sequences have been presented at the SPARC conference 2000. Different species have been used to separate dynamical from chemical effects.

Contribution of DLR

At DLR the investigations of convective transports in different model simulations carried out with the coupled chemistry-climate model ECHAM4.L39(DLR)/CHEM have been started recently. Currently we analyse model data of so-called timeslice experiments. The results of four distinct numerical experiments will be compared, which have each been integrated for 20 model years in a quasi-stationary mode, i.e. keeping the physical and chemical boundary conditions constant (concentrations of greenhouse gases, sea surface temperatures, upper boundary conditions for chemical species). The model simulations have been defined with respect to atmospheric conditions related to the time-slices (years) "1960", "1980", "1990", and "2015". A detailed description of the employed model system is given by Hein et al. (2001).

A program for a wave frequency analysis (WFA) has been implemented at DLR. This was carried out in close co-operation with the Institut für Geophysik und Meteorologie der Universität zu Köln (Dr. U. Ulbrich, Dipl. Met. M. Klawa). The original WFA spectra program, which was constructed in Cologne was handed over to DLR. Necessary changes with respect to data structures (formats) have been made at DLR. An intensive comparison of analysis results was conducted on the basis of the ECMWF re-analysis data (ERA). The aim of this comparison was to check the consistency of the programs employed in Cologne and at DLR. After a successful comparison of the WFA

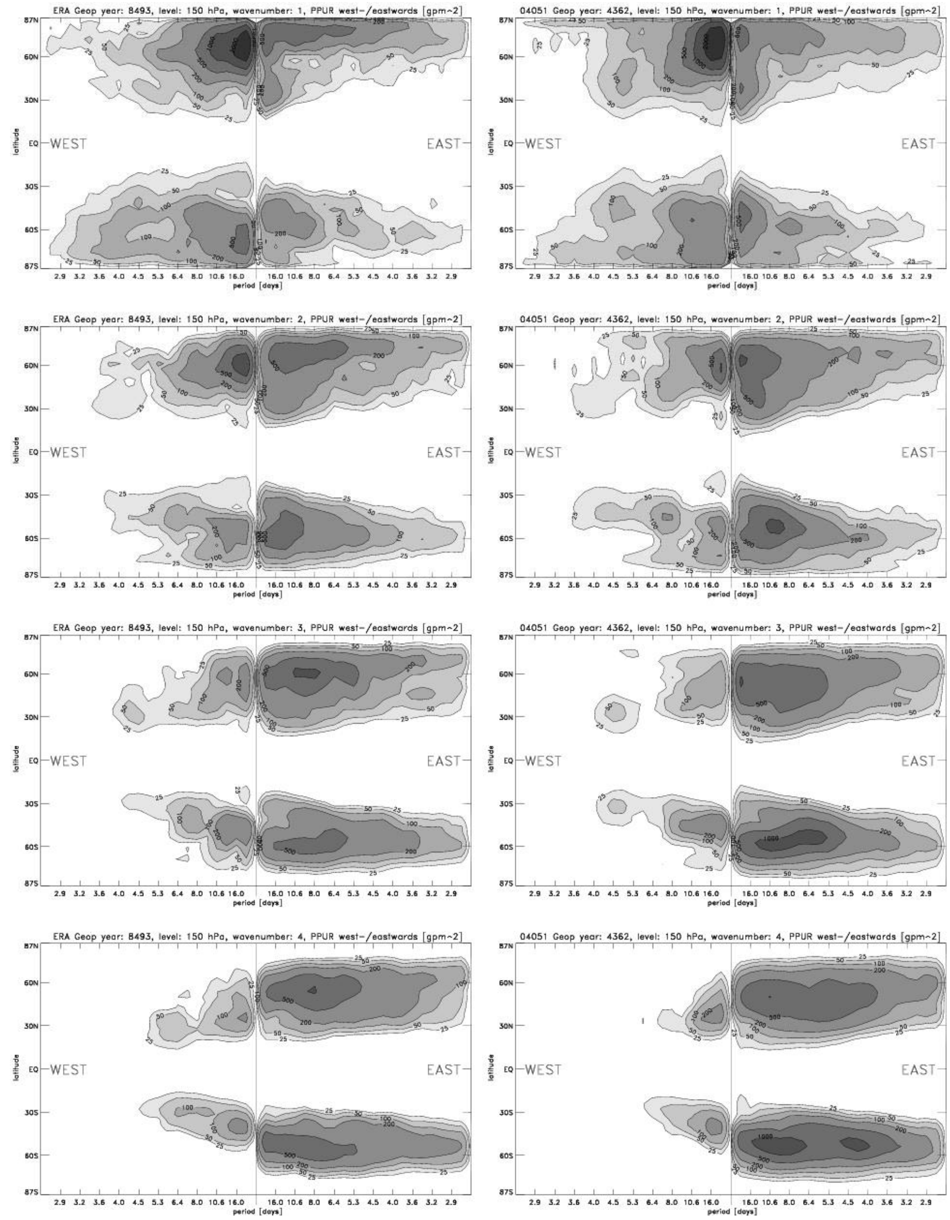


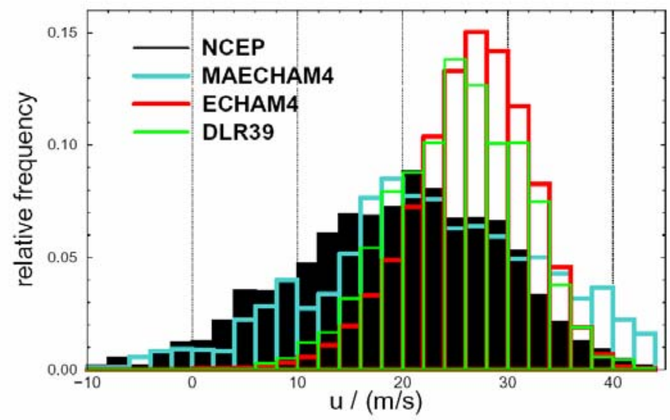
Figure WP2-10: Wave frequency analysis (WFA) of measured and modelled data. The figure shows the variance of west- and eastward travelling waves multiplied by frequency, for wave number 1-4 (from top to bottom) in northern winter (DJF). Left: ERA data, mean values for the years 1984-1993. Right: ECHAM4.L39 (DLR)/CHEM data of the "1990" simulation, mean values of 20 model years.

results (i.e. identical results when using the same data series) first analyses have been carried out with respect to model data of ECHAM4.L39(DLR)/CHEM. Data of the so-called reference simulation ("1990") have been analysed. The results show fair agreement with the respective analysis of ERA data, i.e. the distribution of frequencies and the calculated amplitudes (Figure WP2-10). Therefore, it can be assumed that the planned analyses of the other model simulations will yield some interesting information with respect to changes of planetary wave forcing and propagation in recent times (see WP4). Currently the transfer of model data (ECHAM4.L39(DLR)/CHEM) from DLR to MPI-PROVAM is being prepared.

Joint contribution of MPI-PROVAM and DLR

E39/C zonal wind data of the timeslice scenario "1990" were provided for MPI to carry out a comparison of frequency distributions of the 50 hPa zonal wind at the polar circle (50°N). In this investigation, NCEP reanalysis data of the period 1948-2000 were compared to standard ECHAM4, the middle atmospheric version MAECHAM4, and E39/C model data (figure WP2-11).

Figure WP2-11: Relative frequency of zonal mean wind at 50 hPa and polar circle in different models and NCEP reanalysis data for the years 1958-1998.



Clearly, the models with upper boundary at 10 hPa are biased towards too high wind speeds, while the MAECHAM has a frequency distribution of 50 hPa winds at the polar circle which is much closer to observations. Since 20 m/s can be seen as the critical velocity for the vertical propagation of planetary waves with zonal wave number 1 under climatic conditions, the bias of the wind speeds has strong impact on the modelled variability structures (see below in contribution of MPI-PROVAM). Other models, including the coupled ocean-atmosphere-chemistry models ECHAM4-OPYC and ECHAM4-HOPE were also studied and lead to similar results.
Figure WP2-12 shows that the sensitivity of the coupled MAECHAM/CHEM model, which interactively simulates dynamics and stratospheric ozone chemistry, to observed SST changes is even stronger than to observed GHG concentrations during the last 3-4 decades of the 20th century. Hence, the forecasted SST changes in a future climate will be especially important for the forecast of at least arctic ozone behaviour.

Currently, differences of the frequency distribution of the refractivity index in reanalysis data and in different models are studied. Here we find significant differences which may allow to interpret the cold polar bias of the models, including the stronger polar vortex, as the result of differences in the vertical structure of the wind field and of stability between observations and models.

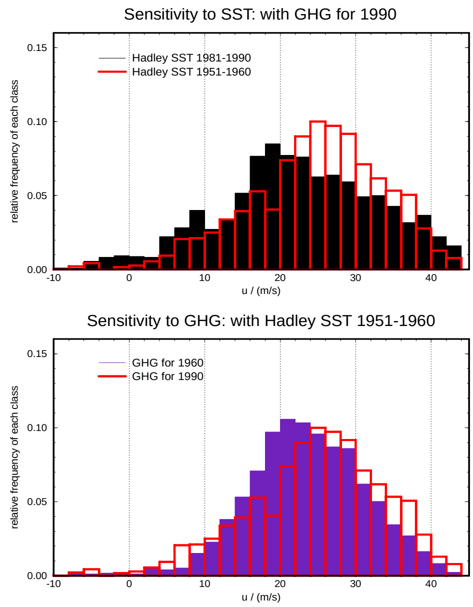


Figure WP2-12: The sensitivity of the zonal mean wind at 50 hPa and Polar circle for given GHG concentration (1990) and different observed global sea surface temperatures (1951-60 vs. 1981-90), top, and for the same SST (1951-1960), but different GHG concentrations (1960 vs. 1990), bottom.

Contribution of DLR

In previous investigations, it was found that E39/C simulates an accelerated recovery of the stratospheric ozone layer in the polar northern hemisphere in the near future (scenario "2015") (KODYACS annual report 2001, Schnadt, 2001; Schnadt et al., 2002). This regeneration of the ozone layer had not been expected as other publications on this issue (Austin et al., 1992; Shindell et al., 1998) had suggested that ozone recovery would be delayed by the cooling of the stratosphere associated with increasing greenhouse gas concentrations. The simulated ozone recovery in E39/C resulted from an enhanced vertical propagation of planetary stationary waves from the troposphere to the middle atmosphere, which, in turn, caused the polar stratosphere to warm adiabatically by moment transfer from the waves to the mean flow. Under these conditions, less polar stratospheric clouds were formed and less chlorine was activated, resulting in a reduced chemical ozone depletion in spring in "2015".

In continuous work, the causes for this behaviour have been explored in more detail. Specifically, the relationship between changes in the model's North Atlantic Oscillation (NAO) and the simulated ozone recovery has been investigated. For this purpose, an extreme NAO index composite study of the winter seasons of the timeslice scenarios "1990" and "1990" without nitrogen oxide emissions from aircraft ("1990NOAIRC"), as well of the ECMWF reanalysis data set (ERA, 1979-1993) has been carried out.

The results show that in the positive NAO phase the stratospheric polar vortex is stronger and colder than in the negative NAO phase. In the troposphere, the subtropical jet streams are weaker around the globe, whereas the mid-latitude storm track over the North Atlantic is shifted north-eastward and shows stronger zonal winds. Associated with the circulation patterns in the troposphere, the positive NAO phase is characterised by a reduced vertical propagation of stationary waves from the troposphere to the stratosphere. At the same time, transient wave activity is enhanced in the troposphere. The described patterns are found in both the reanalysis as in the model data indicating that E39/C reproduces the dynamical relationships related to the NAO.

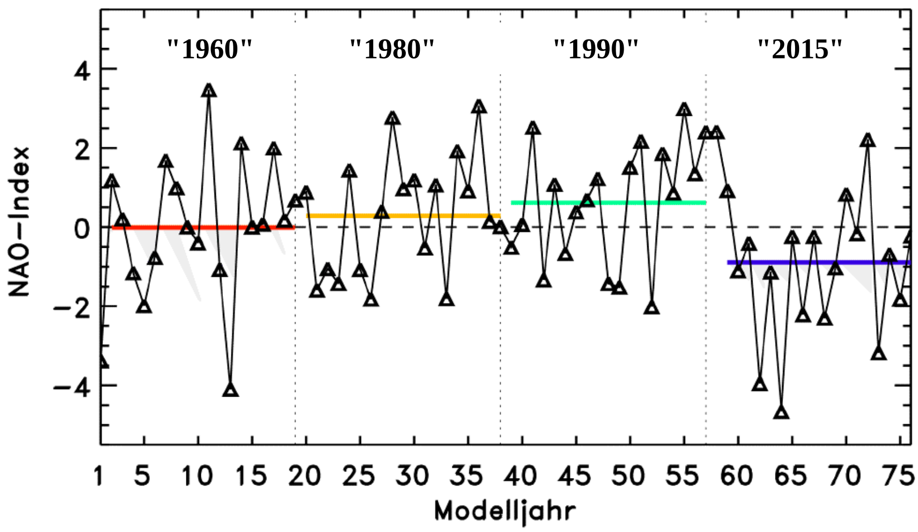


Figure WP2-13: Temporal evolution of the wintertime (DJF) E39/C NAO index for the timeslice scenarios "1960", "1980", "1990", and "2015". Each scenario contributes 19 winters. The anomalies were calculated with respect to the mean of the four scenarios.

The temporal evolution of the model NAO index (figure WP2-13) shows a slight increase from "1960" to "1990" consistent with the observed upward trend of the NAO index since approximately 30 years. From "1990" to "2015", the model index decreases markedly. Assuming that in all model scenarios the role of the NAO as the dominant climate variability mode does not change, the NAO index changes are consistent with the enhanced vertical propagation of stationary waves and the dynamical warming of the northern hemisphere polar stratosphere in winter from "1990" to "2015". The results thus indicate that changes in tropospheric circulation systems as modulated by the North Atlantic Oscillation might be steering changes in stratospheric dynamics and thus stratospheric ozone recovery in the northern hemisphere. Since the modelled tropospheric circulation changes predominantly arise as a result of prescribed changes in sea surface temperature (SST), the investigation also stresses the influence of SSTs on stratospheric dynamics on the climatological scale, as well as the need of correct future SST projections for a realistic simulation of the future ozone layer (for details see Schnadt and Dameris, 2003).

After the implementation of the wavenumber-frequency analysis (WFA) and its verification at DLR, numerous applications have been developed. These applications aim at a) identifying how accurate the chemistry-climate model E39/C represents transient large-scale Rossby waves in comparison to ECMWF reanalyses (ERA) and b) how these waves change through the different timeslice experiments "1960", "1990" and "2015" (Mager, 2004; Mager and Dameris, 2004).

The model represents well the observed wave amplitudes not only in the different considered frequency bands but also in the sum over all frequencies. E39/C tends to underestimate the amplitudes of eastward travelling waves at small periods while enhancing these waves at greater periods. However, it simulates well the baroclinic character of these waves in respect to vertical amplitude growth and inclination (Figure WP2-14, upper part). A remarkable feature of the model is its ability to simulate so-called "normal modes" very accurately (Figure WP2-14, lower part).

The northern hemisphere wave activity in the timeslice experiments shows a correlation with the NAO index (see above). This index increases from "1960" to "1990" and decreases even stronger from "1990" to "2015". Similarly, the sum of transient waves over all frequencies increases and decreases through the timeslice experiments (Figure WP2-15).

The WFA tool will be employed in the future to investigate the transient wave activity simulated by a transient climate run from 1960 to 2000 with E39/C. Comparisons with the wave activity derived from ERA-40 data will certainly yield more details about the accuracy of the model and give further insights into atmospheric dynamics. A planned publication aims at reviewing this valuable analysis tool; DLR will provide technical support for the community in order to apply the WFA to results of other chemistry-climate models.

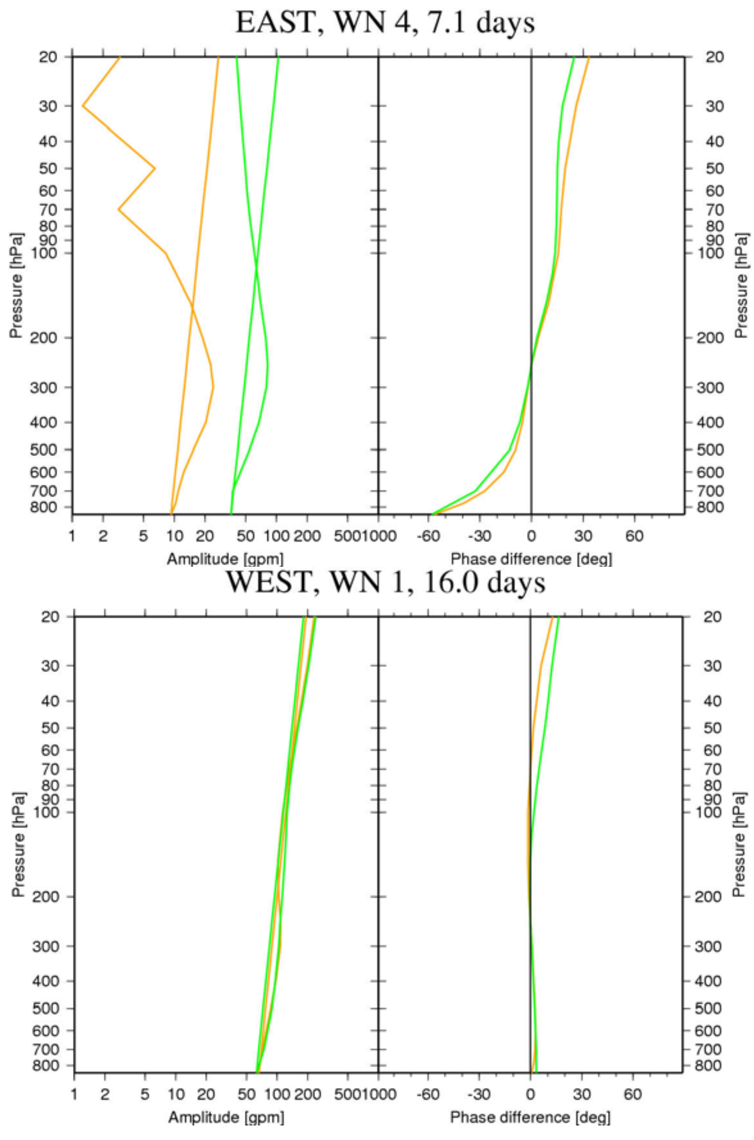


Figure WP2-14: Vertical amplitude growth (top) and phase difference relative to 250 hPa (bottom) from the "1990" experiment with E39/C (green) and ERA data 1984-93 (orange). Straight amplitude lines show the vertical growth of the Lamb wave. Negative phase differences indicate an eastward position, positive differences a westward position relative to 250 hPa.

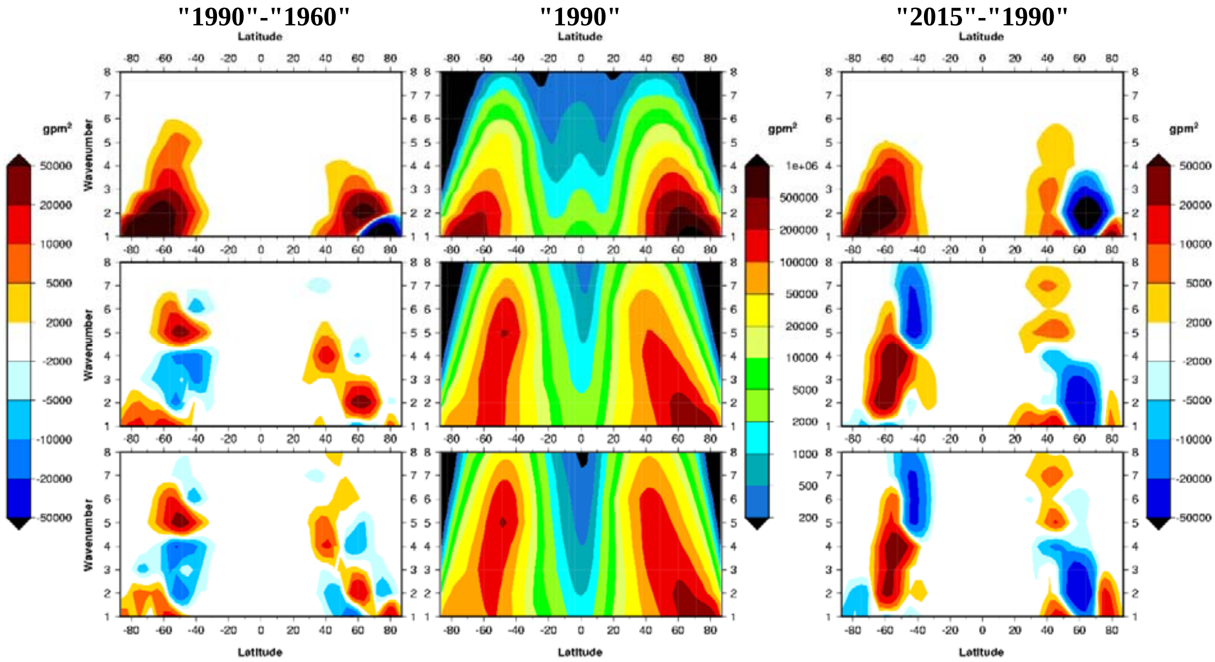


Figure WP2-15: Variance of the geopotential of transient waves summed over all frequencies as calculated from timeslice experiments in 50, 150 and 300 hPa (top to bottom).

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