

Inter-annual variability in the interhemispheric atmospheric CO₂ gradient: contributions from transport and the seasonal rectifier

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ABSTRACT

The observed interhemispheric gradient in atmospheric carbon dioxide (CO₂) indicates the distribution of CO₂ sources and sinks, and for recent decades is evidence of a Northern mid-latitudes sink, a tropical source and southern hemisphere sink. As such, the variability in the gradient also reflects how these fluxes vary with time. However, the variability in the gradient is sensitive to the network of stations used to calculate the gradient. Also, an important consideration when dealing with variability in atmospheric measurements is the contribution due to the variability in the atmospheric transport. Most previous studies have ignored transport variability. Using an atmospheric tracer transport model driven with analysed circulation products, we demonstrate here that the interannual variability in the interhemispheric gradient due to transport alone is significant when compared with the observations. Model experiments show that interannually varying transport combined with both cyclostationary terrestrial biosphere fluxes and time-constant fossil CO₂ fluxes generates significant interannual variability, but that the component due to the interannually varying transport and the ocean CO₂ fluxes is small. The key contributor to the transport generated interannual variability is due to the variability in the seasonal rectifier (the covariance between the seasonality in the terrestrial biosphere fluxes and atmospheric transport, which results in non-zero surface CO₂ concentrations despite the fluxes balancing at each gridpoint). This study shows that the rectifier variability is complex, with different regions displaying different modes of variability. We also investigate the role of the Pearman Pump (gradient due to the seasonal covariance in the fluxes and cross-hemispheric transport) and show that while it appears to be a process occurring in the atmosphere, it is of second-order importance in forcing the interhemispheric gradient.

1. Introduction

The interhemispheric gradient of atmospheric CO₂ provides important constraints on the sources and sinks of carbon from the land surface and ocean (Tans et al., 1989). Because most of the CO₂ from fossil fuel burning is released in the northern hemisphere, sur-

face atmospheric CO₂ levels are higher in the north than in the south by on average about 2.0–2.5 ppmv at surface stations. Transport model simulations predict significantly higher hemispheric differences for simulations with fossil fuel sources alone (~5 ppmv) (TRANSCOM, Law et al., 1996), from which has been deduced the presence of a significant, mostly terrestrial northern hemispheric sink (Tans et al., 1989; Rayner et al., 1999a; Bousquet et al., 2000). The picture is complicated somewhat by the potential for hemispheric carbon transport within the ocean (Broecker and Peng, 1982) and the so-called seasonal rectifier,

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which is the result of the covariance of terrestrial CO₂ fluxes and atmospheric circulation. Both of these processes can contribute to an atmospheric CO₂ gradient in the absence of anthropogenic perturbation.

The observed interhemispheric gradient, or as calculated in this study, the interhemispheric difference (IHD), varies from year to year, reflecting a combination of variability in carbon sources/sinks and atmospheric transport. Here we examine the influence of atmospheric circulation variability on IHD, focusing in particular on the seasonal rectifier and cross-equatorial transport. The impact of atmospheric circulation variability on observed IHD arises in two fashions, horizontal exchange of CO₂ between the hemispheres and vertical and horizontal redistribution of CO₂ within a hemisphere. The latter effect occurs because atmospheric CO₂ is measured currently at the surface for a relatively few number of stations. Using a high-resolution, three-dimensional numerical simulation, we quantify the magnitude of transport driven, interannual IHD variability and the role of the specific mechanisms.

A growing number of forward and inverse model studies use atmospheric measurements of CO₂ to deduce the spatial variability of surface sources and sinks of this important greenhouse gas (Tans et al., 1989; 1990; Enting et al., 1995; Fan et al., 1998). A few have attempted to calculate the temporal variability as well (Rayner et al., 1999a,b; Bousquet et al., 2000). In each of these cases only a single year of atmospheric dynamics was used, therefore ignoring the contribution of interannual variability in transport to the atmospheric observations.

Dargaville et al. (2000) made a preliminary study using just eight years of ECMWF data to drive a coarse resolution transport model. Results showed that the IHD of CO₂ varied significantly due to transport alone. In this study we use 30 years of NCEP reanalyses and a high resolution, state of the art atmospheric transport model to make a more detailed investigation.

One of the key differences among current atmospheric transport models is the strength of the seasonal rectifier (Law et al., 1996) typically marked by spatial anomalies in the annual mean surface CO₂ field produced in a simulation where the surface fluxes have a seasonal cycle, but a net exchange of zero at each grid-point. The rectifier is the result of the covariance between the terrestrial CO₂ sources and the atmospheric transport, both in the vertical (Denning et al., 1995) and the horizontal (Taguchi, 1996). For the vertical case, in winter the biosphere releases CO₂ which is

concentrated close to the surface as the mixed layer depth is small, while in summer the biosphere CO₂ drawdown is diluted though a relatively deep mixed layer. Atmospheric transport models without explicit boundary layer meteorology formulation tend not to produce a strong rectifier. An alternate theory is presented by Taguchi (1996) which shows that the covariance between the surface wind direction and surface CO₂ fluxes may also contribute to the rectifier pattern. The presence or absence of a strong rectifier translates into significantly different source/sink patterns in atmospheric CO₂ inverse calculations (Gurney et al., 2002).

In this study we show that the IHD varies significantly from year to year due to the transport interannual variability. The transport driven variability is often out of phase with that in the observations, suggesting that when the transport interannual variability is taken into account, more source variability is required to match the observations. The main reason for the variation due to transport is the variability in the strength of the seasonal rectifier, and that the variability of the rectifier is complex and the modes of variability vary with region.

2. Model and data description

2.1. Match

The atmospheric tracer transport model used here is the Model of Atmospheric Transport and Chemistry (MATCH Mahowald et al., 1997; Rasch and Lawrence, 1998). The model simulates the transport of trace gases by solving the tracer continuity equation. The model reads in dynamics fields such as the horizontal winds, temperature and moisture fields, and solves for horizontal and vertical advection and diffusion and convection. The advection scheme used is the SPITFIRE (Split Implementation of Transport Using Flux Integral Representation) transport scheme (Rasch and Lawrence, 1998). This transport scheme uses a control volume approach to update each tracer via a sequence of one-dimensional operations in each spatial direction. The fundamental prognostic variable is the mean tracer density within each cell. Like a semi-Lagrangian method, the one-dimensional update is stable for Lipschitz numbers less than 1 and any Courant number. The method proceeds by fitting a polynomial to the integral of the tracer density. The integral of the tracer density field is monotonic, and a monotonic

polynomial is fitted to this integral function. The tracer flux through a grid cell boundary is estimated from evaluation of the mass integral at the boundaries and at the respective departure points of the cell air masses. The interpolation required to calculate the mass integral is done using a fourth-order accurate cubic interpolant. The subgrid scale processes of convection and diffusion are parameterised using the Hack (1994) and Holtslag and Boville (1993) schemes.

2.2. NCEP dynamics

The National Centers for Environmental Prediction (NCEP) reanalyses are described in detail in Kalnay et al. (1996). An advantage of a reanalysis product over the original meteorological analyses is that consistent machinery is used throughout including the circulation model, assimilation scheme, and physical parameterisations. Although reanalysis products provide the best estimate of the historical state of the atmosphere, significant problems do remain. One potential drawback is that the model skill changes with time simply because of the evolving data coverage.

Some discontinuities and biases have been noted when the NCEP reanalyses are compared with independent observations (Trenberth and Guillemot, 1998; Trenberth et al., 2000). These problems have been related back to issues with satellite measurements, and are mostly to do with the hydrological cycle in the tropics. In this study we focus much of our attention in the higher latitudes, but the biases in the NCEP reanalyses should be kept in mind.

In this configuration we run at T63 (192 grids in longitude, 94 in latitude with a Gaussian distribution) and 28 levels in the vertical on sigma coordinates (nine levels below approximately 750 mb). Atmospheric circulation statistics are available at 6 h intervals and the model is run with a time step of 30 min. Simulated CO₂ concentrations were archived globally each month, and at every time step at the observing stations.

2.3. CO₂ data

The observational data we have used in this study are derived from two sources. Firstly we use the monthly flask data for South Pole and Mauna Loa from the Scripps Institute of Oceanography (SIO) network (Keeling and Whorf, 2002). These time series extend back before 1970 and so cover the full period of our simulations. We also use the GLOB-

Table 1. *Stations used in the 16 station case, their positions and percentage of 'real' data in the GLOB-ALVIEW product*

Station name	Latitude	Longitude	% Record
South Pole	−90.0	−24.8	91.3
Palmer Station	−64.9	−64.0	77.8
Cape Grim	−40.7	144.7	70.5
Samoa	−14.3	−170.6	100.0
Ascension Island	−7.9	−14.4	95.1
Seychelles	−4.7	55.2	73.7
Guam	13.4	144.8	96.9
Kumukahi	19.5	−154.8	97.3
Mauna Loa	19.5	−155.6	97.2
Key Biscayne	25.7	−80.2	91.6
Niwot Ridge	40.1	−105.6	97.2
Cape Meares	45.5	−124.0	75.8
Cold Bay	55.2	−162.7	100.0
Station M	66.0	2.0	87.7
Point Barrow	71.3	−156.6	100.0
Mould Bay	76.3	−119.4	92.8

ALVIEW (GLOBALVIEW-CO₂ 2001) data product. In the GLOBALVIEW product, data gaps in the observed record are filled using the method described in Masarie and Trans (1995). Two subsets of the network are used here; firstly a subset where only stations which have 70% or more original data for the period 1979 to 1996 (16 stations, Table 1), and secondly a network with at least 50% of original data, increasing the number of stations to 28 (additional 12 stations in Table 2). The impact of the data filling procedure is to avoid biases which may be introduced by a changing network, which may be result in an incorrect

Table 2. *Additional 12 stations used in the 28 station case*

Station name	Latitude	Longitude	% Record
Halley Bay	−75.7	−25.5	49.3
Syowa	−69.0	39.6	47.0
Amsterdam Island	−38.0	77.5	40.5
Christmas Island	1.7	−157.2	56.7
Ragged Point	13.2	−59.4	48.3
Virgin Islands	17.8	−64.8	59.5
Midway	28.2	−177.4	63.3
Bermuda West	32.3	−64.9	41.1
Bermuda East	32.4	−64.7	43.8
Azores	38.8	−27.1	62.5
Shemya	52.7	174.1	56.0
Alert	82.5	−62.5	64.0

interpretation of the interannual variability. There is also the potential that the GLOBALVIEW-CO₂ interpolation introduces spurious variability because of the use of the climatological seasonal anomaly from the zonal mean in the data interpolation.

We calculate the IHD for the SIO data by taking the difference between the two monthly records. As there are several missing data in each time series, there are also several gaps in the difference calculation. For comparison, we also calculated the Mauna Loa minus South Pole measure from the GLOBALVIEW-CO₂ data. For the two GLOBALVIEW-CO₂ networks we calculate the IHD by fitting a smoothing spline to the data against latitude for each week of data (48 equally spaced time steps per year), and then taking difference of the area weighted averages in each hemisphere. In each of the four cases, the observed IHD exhibits a seasonal cycle of the order of 8 ppmv resulting mainly from the seasonal cycle of biosphere uptake in the northern hemisphere. We remove this signal by applying a one year running mean to each time series. Also, due to the increase in fossil fuel burning with time, there is an increasing trend in the observed IHD which we remove with a linear regression fit. The effect of this is to normalise the IHDs to 1970 values.

2.4. Circulation indices

We focus on two indices of the atmospheric circulation, the Southern Oscillation Index (SOI, Trenberth, 1984) and the North Atlantic Oscillation (NAO, Visbeck et al., 2001). The SOI is the normalised difference between the surface atmospheric pressure at Darwin and Tahiti and reflects variations in the tropical Walker Circulation and Pacific sea surface temperatures. The NAO is the normalised difference in pressure between Lisbon and Reykjavik and is related to the winter climate variability ranging from Greenland to Florida. It is interesting to note that the NAO has been increasing over the period 1960 to the present.

2.5. Method

The model simulations were made by running MATCH with three monthly surface source components. Net ecosystem production (NEP) and the fossil fuel source for 1990 were the same as the source distributions used in the TransCom3 experiment (Gurney et al., 2002). The NEP distribution is from the CASA model (Randerson et al., 1996) and has an annual net flux of zero at each grid point. The ocean flux field is

from a pre-industrial control run of the NCAR Ocean Model (Doney et al., 2001; 2002). In each case only one year of fluxes was used, and the only source of interannual variability in the model simulations is due to the atmospheric transport. The model simulation was started with the 1970 NCEP winds, and run to the end of 1999. In the analysis we discard the results from 1970 as the model was spinning up over that period.

In this paper we perform several correlations of time series which are autocorrelated. To estimate the statistical significance limits of these correlations we use the random phase test of Ebisuzaki (1997). Take for example two time series A and B. The test takes the spectral signature of time series A and randomly generates new time series with the same spectral pattern. Each of these series is correlated with the time series B. The correlation required for significance at the 95% level between A and B is that which only 5% of the randomly generated time series achieve.

3. Results

3.1. Observed variability in IHD

Figures 1a, b and c show the detrended, deseasonalised time series of IHD for the three measures described above along with, in each case, the simulated transport driven IHD sampled at the same stations. The detrending normalises the IHD to that of 1970. The model simulations in this case are the sum of the three model components (NEP, fossil and ocean). Significant variation in the the magnitude and phasing of the interannual IHD variability exists among the three observational estimates, reflecting aliasing due to the number and location of stations used. The impact of data filling can especially be seen for the Mauna Loa – South Pole case, where the GLOBALVIEW-CO₂ data show significant features where there are gaps in the Scripps data. Where both networks have data, there are also differences evident which are presumably due to differences in measurement technique, sampling strategy and calibration standards. The GLOBALVIEW-CO₂ network with 16 stations shows the most variability, with the IHD varying by between 1.4 and 3.0 ppmv. The 28 station network shows similar, though somewhat damped variability to the 16 station network, while the Mauna Loa – South Pole measure sometimes looks quite different (i.e. 1982, 1986). The values in the figure legends refer to the standard deviation of each time series, and in the 28 station case

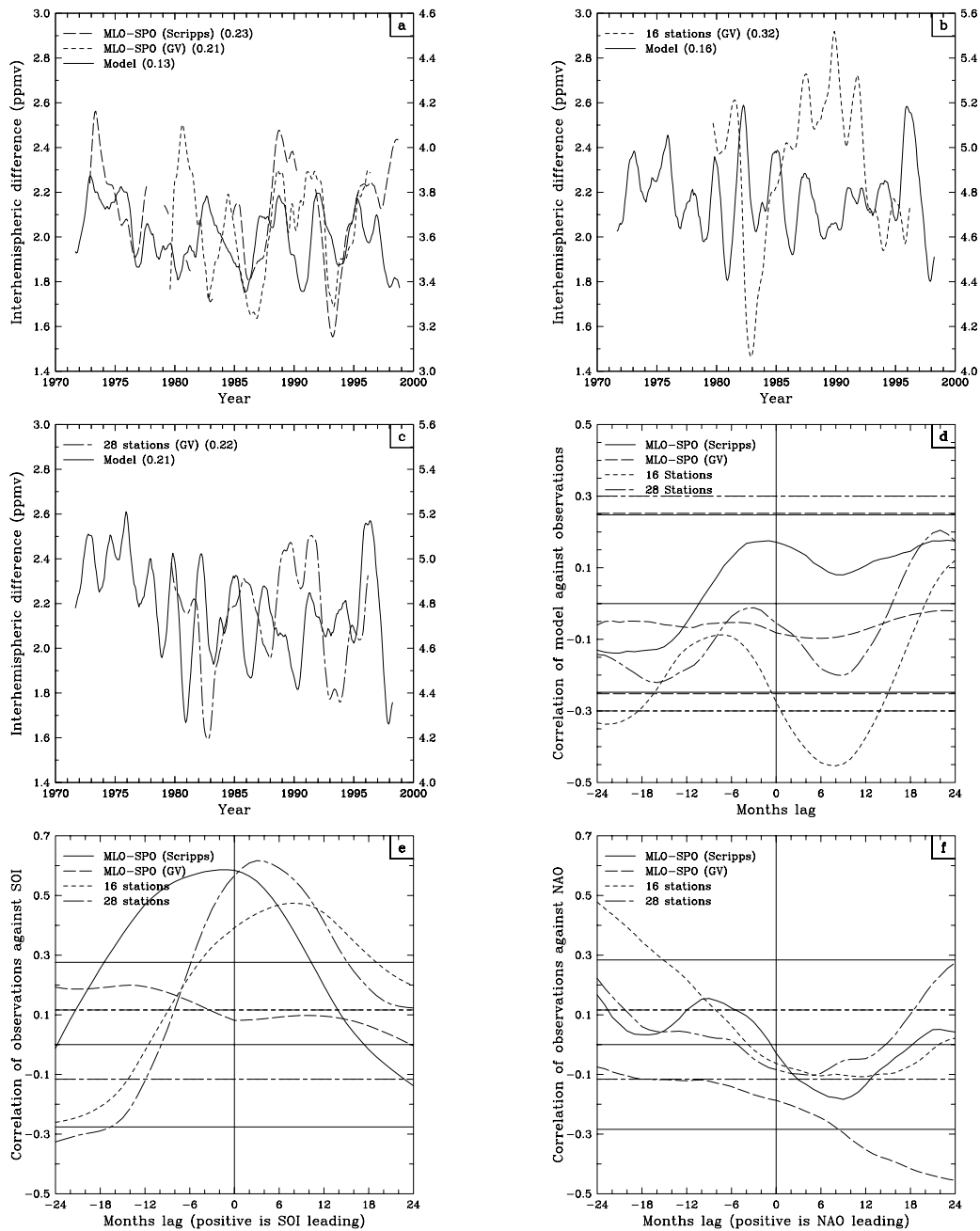


Fig. 1. (a–c) Time series of interhemispheric differences (detrended and deseasonalised) for three observing networks (Mauna Loa and South Pole, 16 Globalview stations and 28 Globalview sites) and the simulated IHD for each set of stations. Values in each legend are the standard deviations. (d) The correlations of each observed IHD against the simulation. (e and f) The lagged correlations of the observed IHD against the SOI and the NAO.

the modeled IHD shows almost as much variability as the observations. Figure 1d shows the lagged correlations of each of the observed measures against the model simulations. Only in the 16 station case is there any significant correlation. That correlation is negative, and indicates that similar mechanisms may be acting of both the source variability and the transport, but that the effect on the IHD for each is opposite.

An important consideration is that we have compared flask measurements with simulated concentrations without selection criteria. To determine baseline conditions and simulate the selection criteria in the model is beyond the scope of this study. There is therefore the potential for bias in the simulations. It is possible in these plots that the model variability is exaggerated relative to the observations, as we have not considered the net uptake of carbon in the midlatitude biosphere (as indicated by the atmospheric inversions, as well as ocean and terrestrial biosphere measurements). The result of this is that the modeled gradient is larger than in reality, and so the atmospheric variability in the model could have a larger impact.

The final two panels of Fig. 1 show the lag correlations of the observed IHDs against the SOI and the NAO. Each of the three measures apart from the MLO-SPO (GV) case shows a significant positive correlation with the SOI, but the lag at which the maximum correlation occurs in each case is quite different, varying by almost a year. This suggests that the lag is sensitive to the network selection and is not robust. Dargaville et al. (2000) found a correlation between the SOI and observed IHD, and found that interestingly, the IHD led the SOI. It is evident from this analysis that the lag there was probably an artifact of the data network selected and the short time period examined. None of the observed IHD timeseries correlates with the NAO, which is consistent with the view that a majority of the source variability is in the tropics, especially in respect to the terrestrial systems (Dargaville et al., 2002).

3.2. Transport-driven IHD variability

As shown in Fig. 1, the transport-driven variability in the surface IHD is substantial, with the standard deviation as large as that observed, depending on the sampling network used. The transport component is often out of phase with the observed time-series, suggesting that the variability in the sources and sinks would need to be larger when the effects of atmospheric circulation are accounted for. However, given the sensitivity of the measured IHD to the network se-

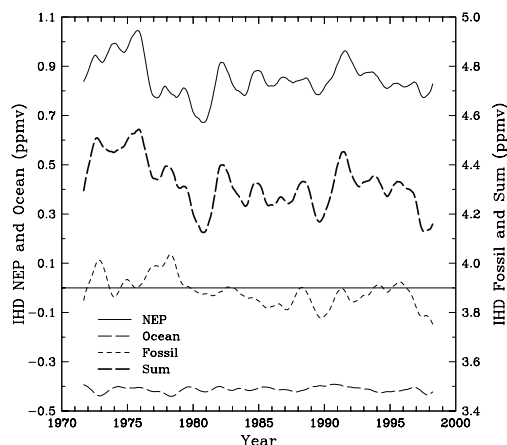


Fig. 2. Deseasonalised time series of hemispherically averaged IHD at the surface for the model simulations using MATCH with NCEP winds for three carbon components (Net Ecosystem Exchange, Ocean and Fossil) and the sum of the three.

lection, it is difficult to pursue this theory further. In the remainder of this study we will focus on the modelled variability and examine the main modes and regions driving the variability.

The simulated, transport-driven IHD is a linear combination of contributions from the fossil fuel, terrestrial biosphere and ocean sources. Figure 2 shows the model IHD computed using the hemispheric surface averages (in contrast to Fig. 1, where the model is sampled at specific station locations) for the total and the individual components. The ocean component contributes very little to the interannual variability in the gradient, while the fossil source variability is slightly more. The pattern is dominated by the variability in the NEP case. The lagged correlations for each of these time-series were calculated against the SOI and NAO indices. With the exception of the relatively weak ocean component and the SOI, the maximum correlations are at or below the statistical significance level (not shown). The strong correlations between the observed IHD variability and the SOI, therefore, appears to be generated primarily by sources and sinks, not transport. Correlations against the NAO also do not yield any statistically significant values, indicating that the patterns are complex.

3.3. Spatial variability patterns and the seasonal rectifier

In this section we focus in more detail on the spatial patterns of transport-induced surface CO₂ variability

and the relationship to the seasonal rectifier. Several studies (Denning et al., 1995; Law et al., 1996; Dargaville et al., 2000) have shown that the covariance between the seasonal cycle in transport and terrestrial biosphere fluxes generates positive concentration anomalies in the northern hemisphere even when the flux field has a net annual flux of zero. The top two panels of Fig. 3 show the surface concentrations averaged over the period 1971–1999 for the MATCH NEP and fossil simulations. For the NEP case, over North America and Northern Eurasia simulated surface concentrations are around 3 ppmv higher than the global average surface concentrations. There is also an area of negative concentration anomalies over tropical Africa, due to the covariance between the fluxes and the position of the ITCZ. As expected, in the fossil case there are positive anomalies close to the regions of highest fossil-fuel consumption, mainly in Europe but also over North America. It is clear that the remote marine observing sites have lower surface CO₂ concentrations than continental sites, and so IHD calculated using the GLOBALVIEW network (Fig. 1) must necessarily be lower than that using hemispheric averages (Fig. 2).

The two lower panels of Fig. 3 show the standard deviation of the deseasonalised surface concentrations from the NEP and fossil simulations. In the NEP case, the standard deviations are 0.2–0.5 ppmv over much of the northern hemisphere continental interiors, with values as high as 0.6–1.0 ppmv in four localised regions: Alaska and northwest Canada, Europe, eastern Siberia and equatorial Africa. These zones of high variability, not unexpectedly, coincide with areas of large seasonal rectifier anomalies and surrounding steep gradients in the rectifier pattern. This suggests that that circulation-driven changes in strength of the rectifier (e.g., intensity of boundary layer mixing) are also responsible for a good portion of the transport component of the IHD interannual variability. In the fossil source case, again the highest standard deviations occur where the largest concentrations are, namely over Europe, and to a lesser extent over the USA.

We performed a Principal Component Analysis (PCA, Preisendorfer, 1998) of the pattern of surface CO₂ concentration anomalies from the NEP simulation. The analysis produced a first EOF explaining only 20.9% of the variance. The pattern (not shown) has negative values across the northern high latitude north of the Arctic Circle, and a positive area in the southern United States. The time series coefficient has a strong correlation with the NAO index (0.59). The

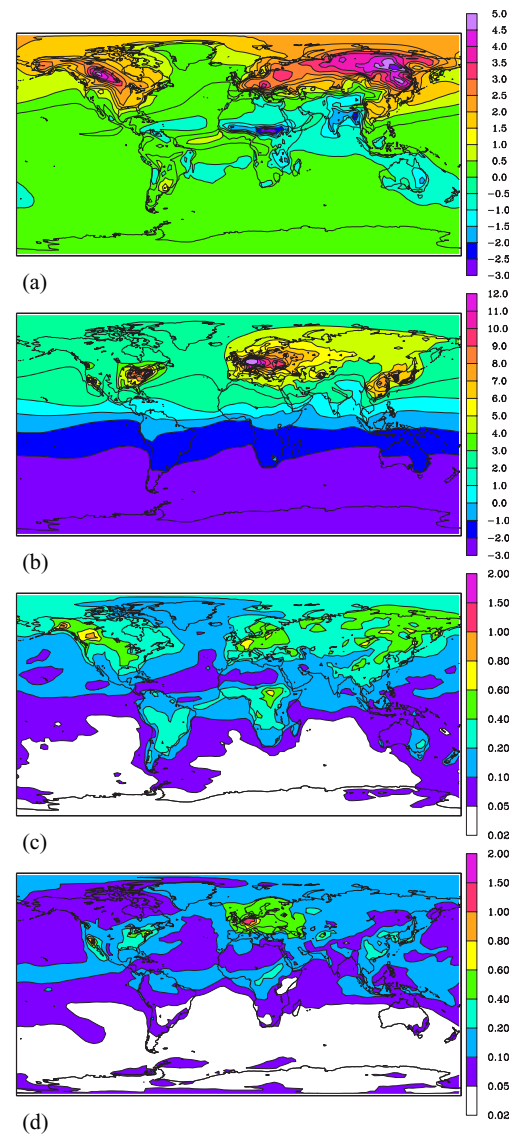


Fig. 3. The average surface concentrations for the NEP (a) and the fossil (b) simulation (in ppmv) after subtracting the average surface values, and the standard deviations of the deseasonalised simulated concentration time series at each point for the NEP (c) and fossil (d) cases.

NAO impacts rainfall patterns on the east Coast of the US, and the convection patterns associated are also likely to impact the depth of the mixing layer. The small amount of variability explained by the dominant EOF suggests that the processes affecting the pattern variability are not acting on large regions, and

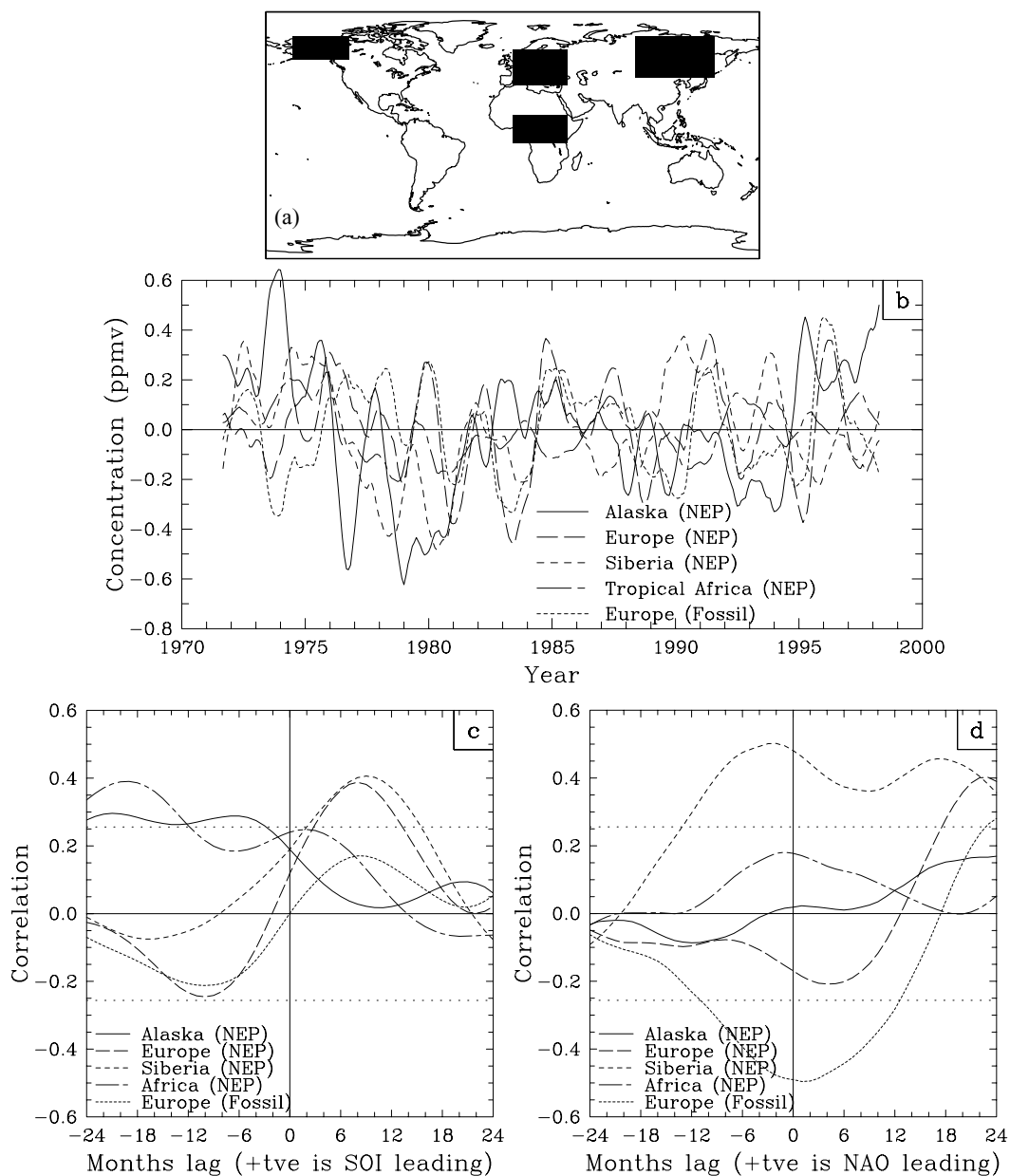


Fig. 4. (a) Map showing small regions and the time series of CO₂ concentration anomalies averaged over each region (b), and their correlations against the SOI (c) and NAO (d).

also helps to explain the lack of correlations of the zonally averaged modeled IHDs with the SOI and NAO.

As an alternative to the large-scale PCA analysis, we now focus on the four regions discussed above.

Figure 4a shows four areas approximately covering the regions where the largest variability occurs in the NEP and fossil surface distributions cases. The middle panel shows the time series of concentration anomalies averaged (area-weighted) over each region for the

NEP cases and the European fossil case. This pattern demonstrates why the previous attempts at correlating the variability with indices proved difficult. Each region displays quite different variability. The lower two plots show the correlation between the four NEP regions and the European fossil region (we have ignored the other fossil source regions as they contribute little variability). Both the Siberian and European regions for the NEP case show significant positive correlations with the SOI, while the European fossil case has a significant negative correlation with the NAO. The Boreal America region NEP case exhibits the most variability but correlates with neither index. By dividing the time series into two sections, pre-1985 and post-1985, we can demonstrate that in the early part of the record the region had a significant positive correlation with the NAO, which swapped to a negative correlation in the later part.

3.4. Column CO₂ concentrations, the Pearman Pump and interhemispheric CO₂ exchange

In the simplest formulation, the vertical component of the seasonal rectifier of the surface CO₂ concentration reflects a redistribution of CO₂ in the vertical by boundary layer mixing; the column pressure average CO₂ inventory should remain unchanged. The first panel in Fig. 5 shows the vertical averaged CO₂ concentration from the NEP run for the period 1971–1999. The patterns show some similarities to those in the surface CO₂ rectifier (Fig. 3a), however the positive anomalies have shifted further to the north, and the magnitude of the anomalies is substantially less in the column average. This demonstrates that the terrestrial biosphere rectifier is mainly due to vertical redistribution, but that the horizontal transport is also playing a part. The horizontal component creates a rectifier

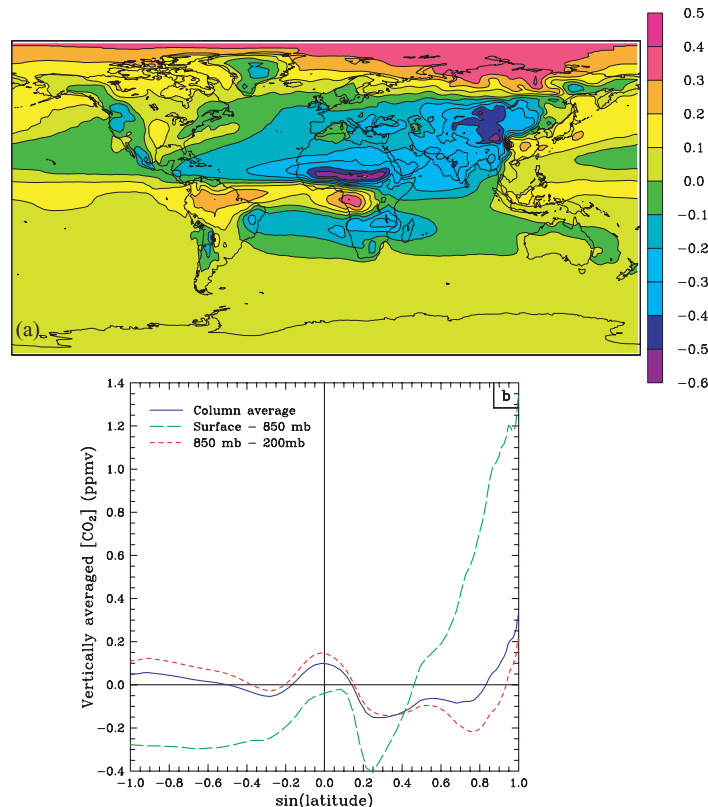


Fig. 5. (a) The column averaged, time-averaged (1971–1999) CO₂ concentration (in ppmv) for the NEP run and (b) the zonal average against sine of latitude for the column integral, surface layer (up to 850 hPa) and the free troposphere and above (above 950 hPa).

of the opposite sign to the vertical process, which is consistent with the ANU model in the Transcom experiment (Law et al., 1996; Taylor, 1998) which without vertical mixing also produces a small negative rectifier.

Using a two-dimensional transport model, Pearman and Hyson, (1980) suggested that the seasonal covariance between the cross equatorial flow and natural CO₂ fluxes at the surface could result in higher CO₂ concentrations in the southern hemisphere, a process we refer to as the "Pearman Pump". Figure 5 shows the column averages (pressure weighted) and the zonal averages. The figure shows that the column average is, on average, higher in the Southern Hemisphere than the Northern Hemisphere. Therefore, at least in this simulation, the Pearman Pump cannot be ruled out, but that at the surface the effect is overwhelmed by the vertical seasonal rectifier discussed above.

4. Discussion and conclusions

Interannual variations in climate and atmospheric circulation cause year-to-year differences in the mixing of CO₂ in the atmosphere as well as in the CO₂ sources and sinks. In this paper, we focused on the circulation effects by modelling the CO₂ distributions resulting from repeating background CO₂ exchanges, fossil fuel emissions and interannually varying circulation from NCEP. Uptake by land and oceans is explicitly excluded, both in terms of decadal means and interannual variations.

At the observing sites, the modeled year-to-year differences in the CO₂ IHD are of the same order of magnitude as those observed, confirming the non-negligible role of transport in CO₂ variations. However, the magnitude and phasing of the IHD varies with the choice of sampling sites in the IHD definition. This is not surprising as El Niño, the North Atlantic Oscillation and other interannual phenomena are characterised by regional as well as hemispheric and global scale variations in circulation. From sampling CO₂ concentrations from only two stations (MLO and SPO) to full two-dimensional coverage in each hemisphere, the modelled IHD shows different phasing thus highlighting the regionally varying circulation differences.

Our results show that interaction between the varying circulation and the background seasonal biosphere (NEP) is the largest contributor to CO₂ variability at a

site, as compared to those from fossil and background ocean alone. The CO₂ variability is greatest where the mean amplitude of the CO₂ seasonal cycle and seasonal rectifier are both large. The phasing of the rectifier variability differs from region to region, and is dominated by local and regional meteorology.

The implications of these results are significant. If the rectifier varies significantly, and the strength of the rectifier influences the distribution of sources and sinks in the Northern Hemisphere, then inversions trying to quantify the variability in the sources need to use interannually varying analysed winds. The task is not simple, as to run the Bayesian style inversions with the real winds requires a new set of response functions to be run for each year. A recent study (Rödenbeck et al., 2003) has done just this. Rodenbeck shows considerably different flux results (up to 2 GtC at times for some regions) depending on the year of winds used. This result is similar but more dramatic to the result of Dargaville et al. (2000) using a mass balance inversion.

As with all modelling studies, this one has several caveats. We are using an imperfect model, and the sub-grid scale processes which are paramount to the season rectifier are parameterised and subject to large uncertainty. In its defence, in the configuration presented here, MATCH is among the highest resolution and physically realistic of the transport models currently in use. It produces the largest rectifier of any of the models participating in TRANSCOM (Gurney et al., 2002) (note, however, that in the TRANSCOM comparison, the models are compared at the lowest layer of the model, and the high vertical resolution of the NCEP fields means that MATCH's surface layer is closer to the ground than others). It is possible that the MATCH rectifier is overestimated due to the NCEP dynamics or the model parameterisation. Comparisons of other tracers such as SF₆ and O₂ (not published) show that MATCH does a good job of simulating the observations.

Perhaps the biggest potential problem with this study is the use of the NCEP winds prior to the mid-1980s. The change in the observing network due to the increase in satellite platforms may have resulted in an interannual variability in the dynamics fields which is not real. Unfortunately, the reanalyses are the best representation of the full global meteorology, and if we wish to understand the interannual variability it is necessary to examine long time periods to take into account the natural oscillations in the atmosphere.

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