We thank the anonymous referee for the review and comments, which have been very useful to improve our manuscript.

Here below, our replies to the referee's comments.

In the introduction we have provided several references regarding the NAO influence on gas pollutants [PAG 2 LL 1-15] and aerosol concentrations [PAG 2 LL 16-22] in order to give a clear view to the reader about the effects of the NAO on tracer transport. However, we will also contextualize better our results in the conclusions, as suggested by the referee.

The simulation analysed in this work does not include interactive aerosols nor aerosol scenarios, but only a climatology of them is present in the model simulation [PAG 4 L 26], as described in Jöckel et al. (2016), thus our study does not look into aerosol effects. We will specify this better in the Methodology Section.

Major Comments

1. We agree with the points raised by the referee. From the correlation analysis we estimated where European and Eastern USA CO-like tracers concentrate/deplete during positive/negative NAO phases. Therefore, higher correlations (in absolute value) imply that an increase/decrease of the PC1 will drive a higher/lower stagnation of such pollutants on specific regions. For this reason we suggest that changes in the NAO index (PC1) could impact certain locations. On the other side, this work is related only on the transport of CO-like tracers with constant lifetime and emissions and does not account for a possible (and probable) decrease of pollutant emissions both in Northern America and in Europe. Therefore, as suggested by the referee, we will reformulate parts of the text to be more coherent with the rest of the manuscript.

   Indeed, as written in pag. 7, the anti-correlation area over northern Europe is stronger (i.e. higher absolute values) in the future than in the past [PAG 7 LL 21-22]; we will improve our explanation in the light of the new regression analysis (see next paragraph).

   As suggested by the referee, we have now performed the analysis of the extremes. More precisely, we have computed the temporal averages of CO_25 winter surface concentrations for high and low NAO events, both in the recent past (1980-2010) and in the future (2070-2100). We have chosen to define "high NAO" and "low NAO" those (winter) periods when PC1 is higher than 0.5 and lower than -0.5, respectively. In this way, we have obtained 12 high and 8 low NAO phases in the recent past and 9 high and 11 low NAO phases in the future (thus, averages have always been computed over at least 8 values). In order to investigate how the CO_25 concentrations change in the future, we have plotted the differences between future and recent past concentrations during high and low NAO periods (Fig. 1). We can observe that in the future, during high NAO (Fig. 1, left), concentrations increase by 10% over north Africa and Mediterranean and even by 15% over some areas of the Iberian Peninsula, Greece and Aegean Sea. Concentrations are lower than in the past over northern Europe and Greenland (in the range down to -10%). On the other hand, during low NAO (Fig. 1, right) we find that CO_25 concentrations increase over north-east Africa and west-centre Europe (up to 15%) and decrease between the north Scandinavian and the Arctic and over small areas on North America and Atlantic Ocean (down to -10%). Therefore, this analysis provides further evidence for our conclusions and will be added to the manuscript (in Section 4) to add more strength to our study.

Following the suggestion of both referees, we have computed the regression between the PC1 and CO_25 mixing ratio in the recent past (Fig. 2, left) and in the future (Fig. 2, right). The patterns and the evolution at the end of the century observed with the regression analysis are very similar to what we have already noted with the correlation plots. To corroborate our analysis we will add these new plots in our manuscript.

Our results show a shift of the NAO centres of action, in agreement with the results obtained by Ulbrich et al. (1999) and Hu et al. (2003) for a climate change global warming scenario [PAG 5 LL 24-25]. However the investigation of NAO shift falls outside the scope of our study, which focuses on NAO effects on tracer transport [PAG 8 LL 13-14].

2. Following the hint of studying the pollutant transport changes in the future, we have computed (and we will add in the manuscript) the vertically integrated tracer transport vector, defined as:

$$\vec{Q} = \frac{1}{g} \int_0^{ps} r\vec{u}dp \tag{1}$$

where r is the concentration of CO_25 in mol/mol, $\vec{u}$ is the horizontal wind speed, p is the pressure, ps is the surface pressure and g is the gravitational acceleration. Also in this case, we have computed the temporal averages of $\vec{Q}$ of all winters with high and low NAO (defined as in the previous point) both in the recent past and in the future. In Fig. 3 we can observe that during high NAO (top) the northward shift of CO_25 transport in the future is more pronounced over the North Atlantic Ocean, from the Northern America coast towards Ireland, while it gets weaker over south Greenland, Mediterranean and west Europe. During low NAO (bottom), the eastward CO_25 transport over the North Atlantic Ocean extends farther eastwards in the future, while it decreases over the Mediterranean Sea; differently from the high NAO case, transport gets slightly stronger over south Greenland in the future. The primary findings of the transport of CO_25 which gets generally stronger over the North Atlantic Ocean and weaker over the Mediterranean region is in line with the changes observed in the correlation and regression plots.

3. We agree with the referee and will be adding the plot of the entire PC1 (1950-2100), computed after subtracting the SLP climatology of 1980-2010. The result is shown in Fig. 4.

In order to study how the distribution of (extreme) NAO phases will change in the future, we have computed the frequencies of (winter seasonal) NAO phases in the recent past and in the future. The histograms with frequencies for 1980-2010 and 2070-2100 are shown in Fig. 5 (left and right respectively). We have preferred not to compute the probability density function (PDF) of NAO phases given the low statistics. In the recent past (Fig. 5, left) the distribution covers a large PC1 interval ($[-3; 2.5]$) and the number of NAO phases is at most 3, except in the interval $[0; 1]$ where it is clearly higher (equal to 9 and 10). Differently, in the future the distribution is skewed toward positive values of PC1 (the interval is $[-1.5; 2.5]$), with number of NAO phases between 4 and 7 in the interval $[-1.5; 1]$ and between 1 and 3 in the interval $[1; 2.5]$. Thus, at the end of the century the number of negative NAO phases is increased (15 in the future vs. 10 in the past), vice-versa, the number of positive

NAO phases is decreased (16 in the future vs. 21 in the past). However, the number of "high NAO extreme" events (PC1 > 1.5) increases in the future (4 in the future vs. 1 in the past), while the number of "low NAO extreme" events (PC1 < −1.5) decreases (0 in the future vs. 3 in the past). These observations are linked to the analysis of CO_25 concentration commented in the first point. We will include these new plots and comments in the new version of the manuscript in order to make our analysis more interesting and our conclusions more supported.

4. We agree with the points raised by the referee. Indeed, the internal variability of the model does not imply a perfect agreement between model results and observations. As the capability of the model to reproduce NAO is already described in Christoudias et al. (2012), we will remove this paragraph and the relative plots (Fig. 2 in the manuscript) as they do not add any additional information. Rather we will mention briefly in the introduction that the model does reproduce the NAO, according to Christoudias et al. (2012).

Replies to Minor Comments

Subscript Thanks for the note. However, we noticed that in Eyring et al. 2013 (pag. 48-66) the notation is: "CO_25" and "CO_50". Thus, for consistency, we will change to this notation in our manuscript.

PAG 1 LL 15-16 Indeed, the referee is correct. Thus, we will substitute [PAG 1 LL 14-16] with: "It is a swing between two pressure systems, the Azores high and Icelandic low, which redistributes atmospheric masses between the Arctic and the subtropical Atlantic influencing weather conditions (Walker et al. 1932)."

PAG 4 L 28 We will change the text as requested.

PAG 4 LL 29-34 We would prefer to leave this paragraph because here we explain that coupled models are better than GCM forced with SST to simulate the NAO phenomenon itself, besides future scenarios.

PAG 5 LL 12-21 Yes, this percentage refers to the whole time series. We will specify it better in [PAG 5 L 20].

PAG 5 L25 We thank the referee and we will add the new reference.

PAG 5 L28 The text will be modified.

PAG 6 L33 Thanks for the remark. We will change the text accordingly.

CO_50 figure Thanks to the referee comments, we have performed other plots which enhance our analysis and will be added in the manuscript (Fig. 1 - 5). Thus, we prefer to leave the figures for CO_50 in the electronic supplement. The analysis of CO_50 is worth to be shown because getting similar results with CO_25 confirms the robustness of our results, which are not affected by changing lifetime of the tracer analysed [PAG 6 LL 30-31 and PAG 7 LL 5-6].

PAG 7 L22 We will modify the text using: "recent past" and "future".

PAG 8 L8 We will added the citations and a relative discussion.

aerosols concentrations Indeed the referee is correct. As predicted by most of the Representative Concentration Pathways (RCP, Lamarque et al. (2011) and references therein) the Mediterranean area will have a better air quality due to lower primary aerosol and aerosol precursors emissions. It must be however stressed that in this work we do focus on trace gases rather than aerosols transport/distribution. On the other side, we fully agree with the referee and we will mention this in the manuscript.

References

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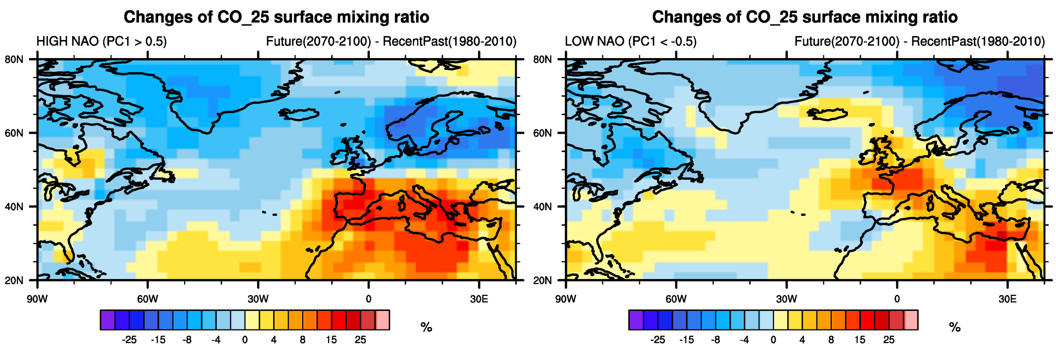

Figure 1: Differences between future (2070-2100) and recent past (1980-2010) temporal averages of CO_25 winter surface mixing ratio, both in the case of high NAO (PC1 > 0.5) (*left*) and low NAO (PC1 < -0.5) (*right*). More precisely, plots show the results of $[(CO\_25^{fut}_{ave} - CO\_25^{past}_{ave})/CO\_25^{past}_{ave}] * 100$, so the colobars indicate the pecentages.

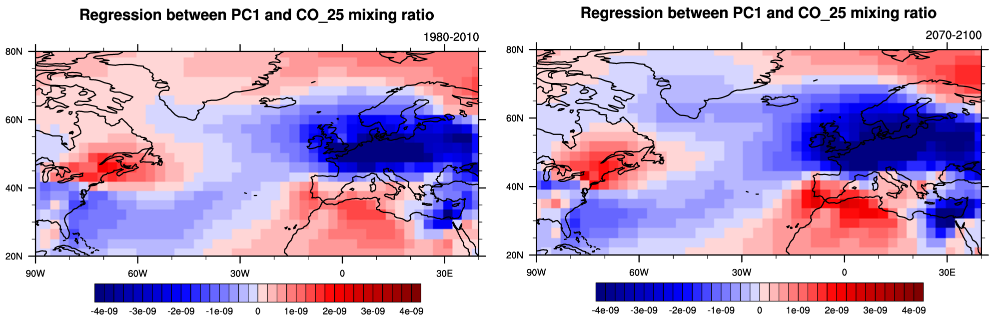

Figure 2: Regression between the winter seasonal CO_25 mixing ratio anomalies at surface level and the PC1 computed for the recent past (*left*) and future (*right*) periods.

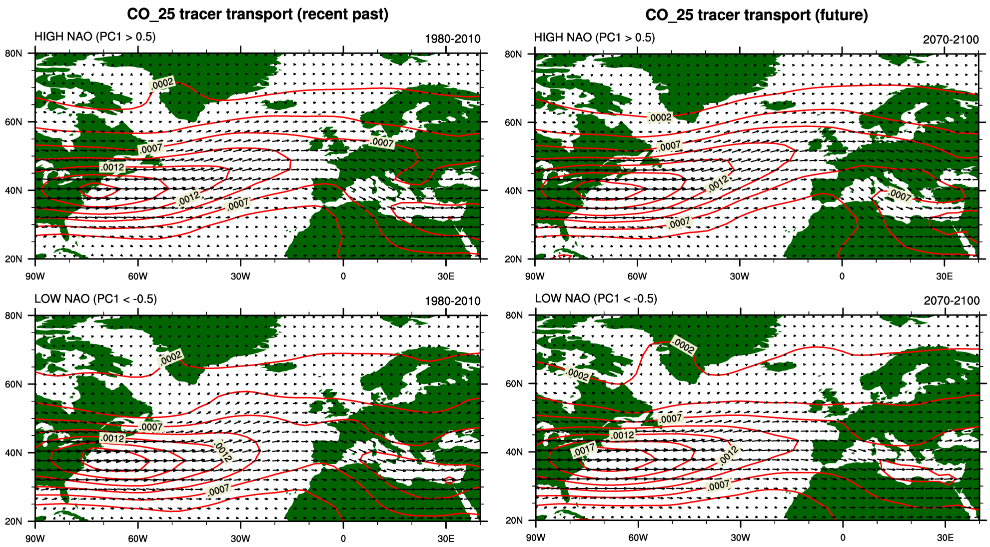

Figure 3: Temporal averages of vertically integrated CO_25 tracer transport vectors for winters with high NAO (PC1 $>$ 0.5) (*top*) and low NAO (PC1 $<$ -0.5) (*bottom*), both in the recent past (*left*) and in the future (*right*).

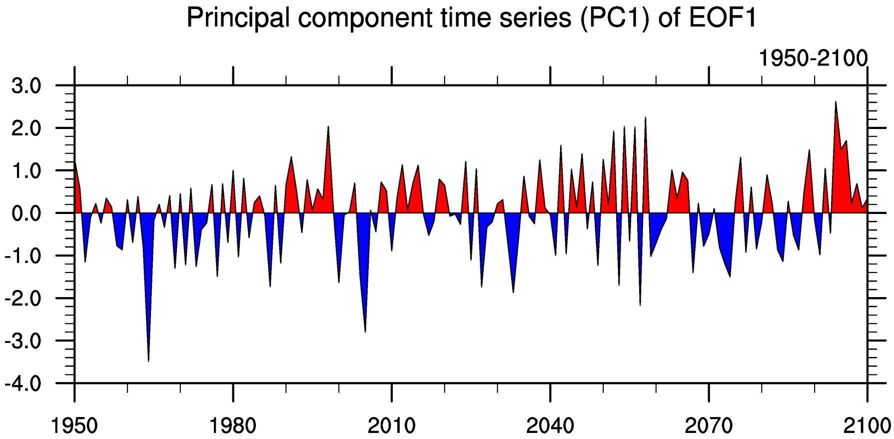

Figure 4: Principal component time series (PC1) of the leading empirical orthogonal function (EOF1) of the winter mean sea level pressure (SLP) anomalies for the entire simulation period (1950-2100). The PC1 has been computed after removing the SLP climatology for the recent past (1980-2010).

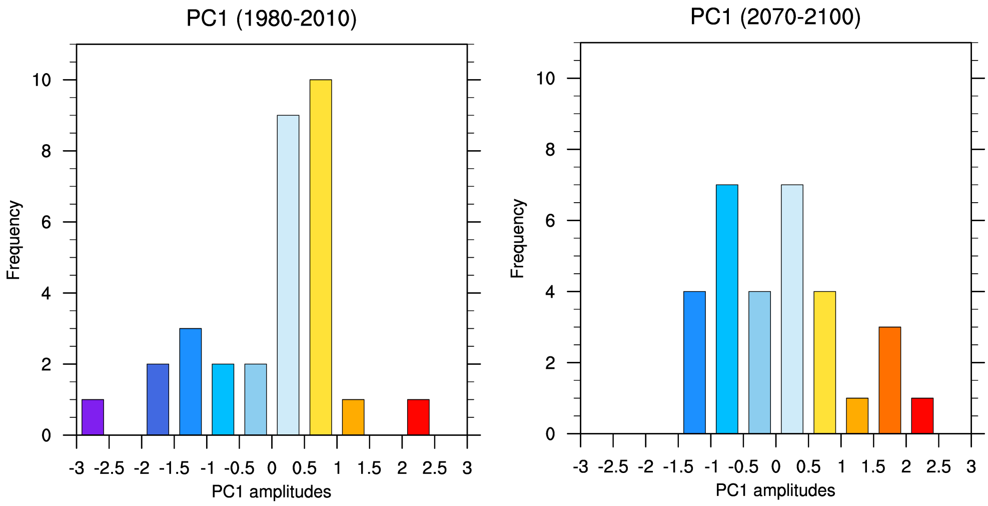

Figure 5: Histograms of the PC1 frequencies computed in the recent past (*left*) and future (*right*) periods.