Norrköping, 2014-07-11

We thank the referee for her/his constructive comments and suggestions that lead to the improvement of the manuscript. Please find below point-by-point reply to your comments. Also, please have a look at the revised manuscript for updates.

This study links the pollution transport into the Nordic countries seen by AIRS CO anomalies to eight typical circulation and meteorological states near that region (from ECMWF's ERA-Interim data). I believe the subject is very important, and I particularly like the discussion on the different periods of persistency of the circulation/weather systems (3, 5, and 7 days). However, I have some major concerns and I recommend publication if the authors can address them.

We thank the referee for encouraging words.

1. It is known that CO is a tracer and the transport of pollutants is correlated with the wind patterns and the motions of air masses, as the authors summarized in the Introduction. So in this sense, the result of this study is intuitively known knowledge to many readers. It would make this study more significant if more challenging issues are examined. One example is that it would be very interesting to know whether or not these pollution transport events actually affect the air quality of the Nordic countries.
This would require near surface in situ measurements of pollutants (not necessarily CO). See study by Lin et al., 2011.

We appreciate the referee's suggestion, but would like to point out that the scope of the present study is different. We aimed at providing ***purely observational perspective on how CO and weather states co-vary in the free troposphere. We also studied different persistency periods.*** To our knowledge, such information is not available in the literature. Especially the latter part is entirely novel.

We agree that it would be interesting to know how this translates in influencing near-surface air quality (as for example done in Lin et al., 2011). But we believe that providing observational foundation and trying to understand possible mechanisms, as much as possible, using observations is an important first step before examining any impact on air quality. For the latter, apart from in-situ measurements, we would need to employ chemistry transport model which is beyond the scope of the present study. ***Our study does however present valuable information that can be used for process-oriented evaluation of CTMs.***

2. Another challenging issue is the vertical transport of pollutants. This study used AIRS CO at 500hPa (reason explained in the text), but winds are shown at 850hPa. Would the conclusions be different if the winds at 500hPa were used? Would vertical transport from nearby areas play a role in any of the eight meteorological states to explain the CO anomalies?

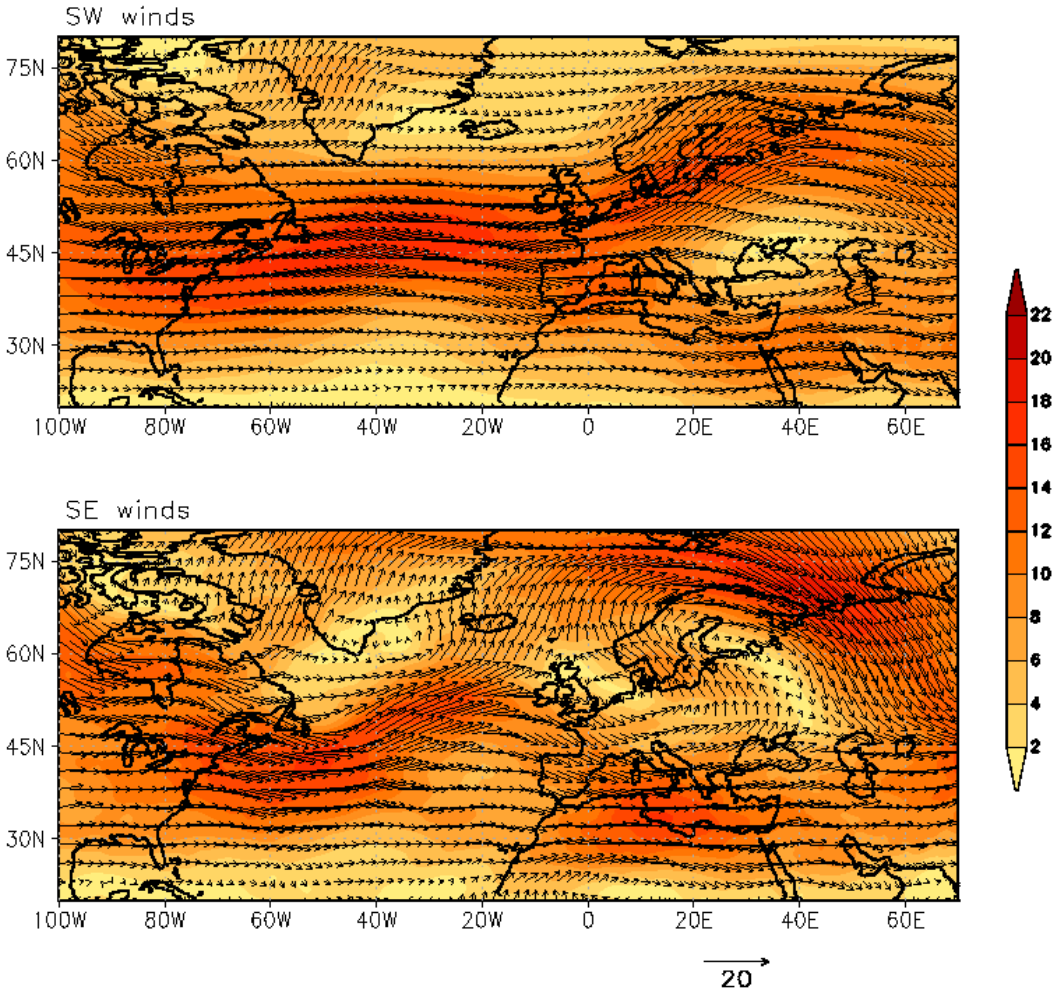
We have actually analysed CO at four different vertical levels, namely 850hPa, 700hPa, 500hPa and 400hPa, but the results are shown only for 500hPa. The tendencies in CO observed at these four vertical levels and corresponding wind patterns are not significantly different. This is not very surprising since many of the weather states, when they are persistent, affect the entire free troposphere. For example, When the NAO is strong and persistent; it affects the circulation pattern of the entire free troposphere in a systematic manner. Therefore, although the magnitude of winds may slightly be, the patterns themselves are not significantly different at 850hPa and 500hPa over the study area. The same applies for the cases when strong anticyclonic and cycloninc events persist for longer periods (>3days) over the study area.

In order to demonstrate this, we show wind patterns at 500 hPa for some of weather states below. As the referee may notice, they are quite similar to patterns at 850 hPa and thus will not change our interpretations of the results. We prefer to show the latter in the manuscript simply because winds at 850 hPa are often used to study lower tropospheric variability.

While addressing one of the comments by referee#1, we found out that even the total column CO shows similar response. This further confirms that the persistent weather states affect the entire troposphere.

With regard to convection, it is well-known that the convective mixing of pollutants over the Nordic countries is weak for the following obvious reasons, a) the boundary layer is decoupled from the free troposphere most of the year due to presence of temperature and humidity inversions, b) the circulation patterns manifest themselves in such a way that the Nordic countries are at the receiving end of the large-scale energy descend or the eventual intercontinental or hemispheric transport of pollutants to the Arctic is dominating in the free troposphere, c) the likelihood of strong episodic injections of pollutants exists only during summer months (via dry or moist convection), but it is very small since such events are usually few in number (e.g. forest fires, biomass burning etc).

The Warm Conveyor Belts (WCBs) might be contributing to the transport of pollutant in some of the weather states studied here, but we do not see any conflict or inconsistency in our interpretations since, irrespective of the mechanism that initiates the transport of the pollutants, it is local weather state at the receiving end (e.g. our study area) that will regulate the distribution of these pollutants.


SW winds
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SE winds
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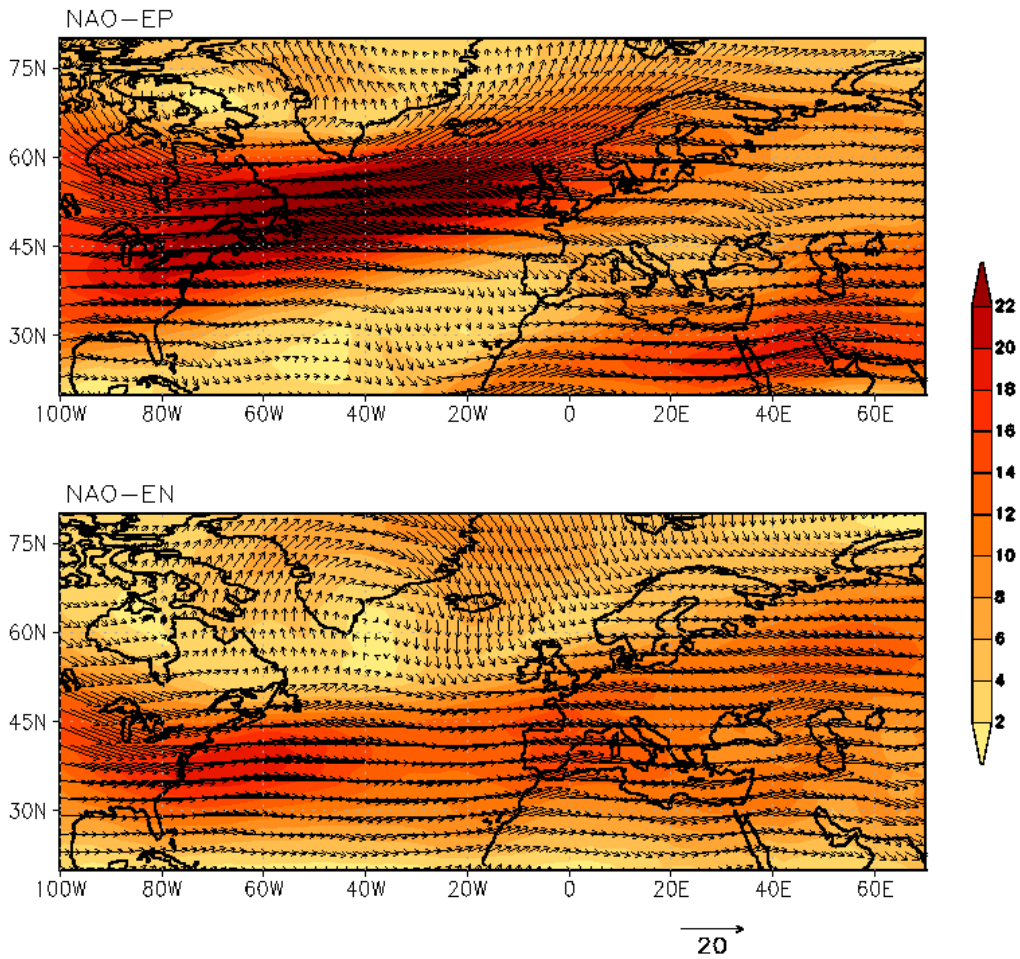


3. The temperature and water vapor anomalies (from AIRS?) are shown, but not clearly integrated nor sufficiently explained to support the focus of this study. Perhaps they will help in Sect. 4 to explain the sources of the transported pollutants.

This part is now revised. In response to similar comment from Referee #1, the water vapour anomalies are removed from the plot since they tightly co-vary with temperatures.

4. “The fate of the pollutants
...
” were emphasized, but not discussed. I believe this discussion should involve: subsidence of the pollutants, outflow from the study area, and/or CO removing processes.

We acknowledge the importance of these issues. But we would really need chemistry transport model to address those. Within the scope of this study, we have tried our best to provide information on possible transport pathways and relevant meteorological conditions using observations. To eventually link our results to the fate of the pollutants in consideration to their source/receptor has to be done using models.

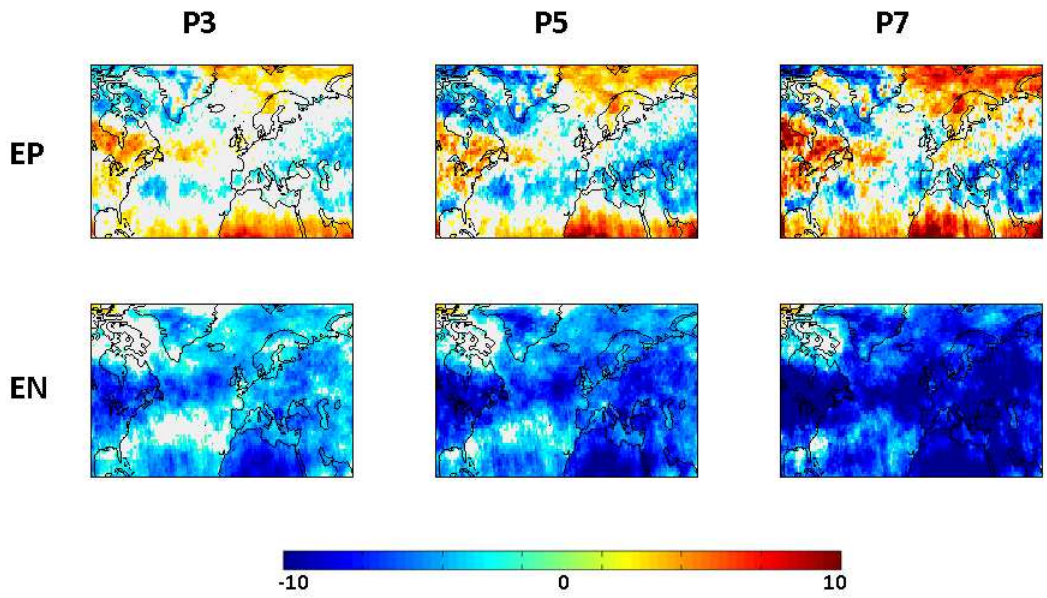
5. I suggest using larger area maps, as shown in the supplemental file, and over-plot a box indicating the study area. This way it is clearer where the pollutants are from. Similarly, if larger AIRS CO maps were used, it would be more obvious where the pollutants are from. There are too many places the authors had to “speculate” where the sources of the transport by using terms: “most likely” or “this may be because the air masses

...
”

Following the reviewer suggestion, we have used larger wind maps in Section 3 of the revised manuscript with our region of interest highlighted on them. But we chose not to do the same for CO for the following reasons. We believe more time is required to reprocess the entire satellite record and properly analyse the results. We would also need to take into account the lag correlation since the CO anomalies observed in our study region have to be correlated with 3-, 5- and 7-day lag with CO in the North American and European regions. So it would be premature to present these results without in-depth analysis. There is also a possibility that this exercise turning into another big study and may not fit into the timeframe of the present study.

However we genuinely liked the referee’s suggestion and we tested it for the NAO case. The preliminary results, shown below, are fascinating. Following circulating patterns, we clearly see enhanced pollution outflow from North American continent over the North Atlantic transporting towards northern Europe and its Arctic sector during positive NAO phase. This tendency is strengthened as the positive phase persists for longer periods. The large-scale accumulation of CO in the Eurasian Arctic sector is also vividly visible.

This result actually confirms that our interpretations of CO variability over the original study area based on wind patterns are right.



6. I suggest listing the number of incidents in each year for all the eight states (in a table?), not just the normalized frequency. Are these all the cases that fit to the eight states, or are they selected as typical cases?

A new table listing the number of incidences for all cases is added in the revised manuscript. These are all cases we could find during the last 11 years when AIRS CO data is available.

7. This manuscript reads, in general, as qualitative descriptions. More quantifying is needed. Examples are: “higher than normal”, “colder than average temperature”, “a much lower trajectory”, “above normal CO concentrations”, “based on averages”, etc.

To allow more quantitative inferences, we have now shown only those anomalies that exceed one standard deviation. Furthermore, the exact values of anomalies and/or percentage changes are added in the descriptions.

8. Sect. 3 is difficult to read. More care and details are needed to be clear, e.g., page 9257 lines 3-17 and page 9259 lines 1-6.

These parts of Section 3 are revised to improve clarity.

9. “Figures 1-3 show

...
” on page 9256 line 2 was introduced without giving descriptions. Should introduce in the later paragraphs where they were discussed. Also, Fig. 3 was discussed before Fig. 2.

Inconsistency is removed in the revised draft.

10. The study area should be defined consistently with the figures. Should they be 40N, 42N, or 45N, since they were all used in different places?

Corrected.

Reference: Lin, M., A. Fiore, L. W. Horowitz, O. R. R. Cooper, V. Naik, J. S. Holloway, B. J. J. Johnson, A. M. Middlebrook, S. J. J. Oltmans, I. B. Pollack, T. B. Ryerson, J. Warner, C. Wiedinmyer, J. Wilson, and B. Wyman, (2012), Transport of Asian ozone pollution into surface air over the western United States in spring, J. Geophys. Res., 117, D00V07, doi:10.1029/2011JD016961.

Thanks for the useful reference.