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Atmospheric Chemistry and Physics
Discussions

Interactive comment on "Signs of reduced biospheric activity with progressing global warming: evidence from long-term records of atmospheric CO_2 mixing ratios in Central-Eastern Europe" *by* Łukasz Chmura et al.

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Subject 1: "Authors conclude that the changes in the SCA have been driven only by an increase in biospheric fluxes in summer and fossil fuel emissions in winter."

Response:

In Xu et al., 2015 (https://doi.org/10.3389/fpls.2015.00701) one can read a summary of the respiration and photosynthesis reaction to elevated CO2 level and it should be taken into the account when analyzing the CO2 record. According to Tomczyk et al.

(2018) (doi:10.1007/s00704-018-2450-4), the season is getting longer by 0.5 days/year what makes it longer by 10days on average during the last 20 years. It is consistent with MOPIT satellite estimates or other hyperspectral methods. According to EEA Report No 10/2017, the land-use change is on the constant level and hasn't substantially changed during the last 20 years contributing to total anthropogenic CO2 release rate by approx. 15% (IPCC, 2019). There is no statistical evidence of the acceleration of land-use change in the recent 20 years, which would also contribute to SCA. Zhu et al. (2016) (https://doi.org/10.1038/nclimate3004) is suggesting that there are significant changes in LAI (leaf area index) over Europe. According to Haverd et al. (2020) (https://doi.org/10.1111/gcb.14950), we expect that during the last 20 years rate of photosynthetic activity might rise by 5%. It should be included in our discussion and it will be.

Certainly, we are aware of the changes occurring on the market of fossil fuel consumption and its influence on carbon dioxide budget (Agora Energiewende and Sandbag, 2018). We are going to discuss it deeper, especially the changes in its seasonal pattern. Most of the databases do not include updated, high temporal resolution emission rates, however, we will try to look at the relation of temperature-energy consumption to retrieve the changes and we will add 14C analysis which helps in better understanding of fossil-fuel emission trend.

References:

Agora Energiewende and Sandbag (2018): The European Power Sector in 2017. State of Affairs and Review of Current Developments.

EEA Report No 10/2017, Landscapes in transition. An account of 25 years of land cover change in Europe, ISSN 1977âĂŚ8449, European Environment Agency, 2017, doi:10.2800/81075

Haverd, V, Smith, B, Canadell, JG, et al. Higher than expected CO2 fertilization inferred from leaf to global observations. Glob Change Biol. 2020; 00: 1– 13.

https://doi.org/10.1111/gcb.14950

IPCC, 2019: Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems [P.R. Shukla, J. Skea, E. Calvo Buendia, V. Masson-Delmotte, H.-O. Pörtner, D. C. Roberts, P. Zhai, R. Slade, S. Connors, R. van Diemen, M. Ferrat, E. Haughey, S. Luz, S. Neogi, M. Pathak, J. Petzold, J. Portugal Pereira, P. Vyas, E. Huntley, K. Kissick, M. Belkacemi, J. Malley, (eds.)]. In press.

Tomczyk, A. M., Szyga-Pluta, K. "Variability of Thermal and Precipitation Conditions In the Growing Season In Poland In the Years 1966–2015." Theoretical and applied climatology, v. 135,.3-4 pp. 1517-1530. doi:10.1007/s00704-018-2450-4

Xu Z, Jiang Y and Zhou G (2015), Response and adaptation of photosynthesis, respiration, and antioxidant systems to elevated CO2 with environmental stress in plants., Front. Plant Sci. 6:701. doi:10.3389/fpls.2015.00701

Zhu, Z., Piao, S., Myneni, R. et al. Greening of the Earth and its drivers. Nature Clim Change 6, 791–795 (2016). https://doi.org/10.1038/nclimate3004

Subject 2: "If the increase in biospheric fluxes is a major cause in the increase of summer minimum atmospheric CO2, it is due to the reduction of photosynthesis or increase in respiration?"

Response:

We thank the reviewer for raising this important question.

Using the atmospheric observations of CO2 alone cannot yield an answer to that question. Support either from other tracers or isotopes (see e.g. Zimnoch et al. 2012) might yield additional information, but the results are characterized by high uncertainty. Another option is to use modeling frameworks, but current state-of-the-art models do not even provide sufficiently accurate estimates of the fluxes. For example, an overview of the global vegetation models available in Global Carbon Budget 2018 shows that in

general, the global models performance is medium for GPP and ecosystem respiration, and low-to-medium for estimating NEE (Le Quere et al., 2018).

In our paper, we wanted to keep the analysis primarily data-driven, therefore we only discuss temporal patterns of net biospheric flux (or net ecosystem exchange, NEE). This approach will be underlined in the revised text.

References:

Le Quéré, C., Andrew, R. M., Friedlingstein, P., Sitch, S., Hauck, J., Pongratz, J., Pickers, P. A., Korsbakken, J. I., Peters, G. P., Canadell, J. G., Arneth, A., Arora, V. K., Barbero, L., Bastos, A., Bopp, L., Chevallier, F., Chini, L. P., Ciais, P., Doney, S. C., Gkritzalis, T., Goll, D. S., Harris, I., Haverd, V., Hoffman, F. M., Hoppema, M., Houghton, R. A., Hurtt, G., Ilyina, T., Jain, A. K., Johannessen, T., Jones, C. D., Kato, E., Keeling, R. F., Goldewijk, K. K., Landschützer, P., Lefèvre, N., Lienert, S., Liu, Z., Lombardozzi, D., Metzl, N., Munro, D. R., Nabel, J. E. M. S., Nakaoka, S., Neill, C., Olsen, A., Ono, T., Patra, P., Peregon, A., Peters, W., Peylin, P., Pfeil, B., Pierrot, D., Poulter, B., Rehder, G., Resplandy, L., Robertson, E., Rocher, M., Rödenbeck, C., Schuster, U., Schwinger, J., Séférian, R., Skjelvan, I., Steinhoff, T., Sutton, A., Tans, P. P., Tian, H., Tilbrook, B., Tubiello, F. N., van der Laan-Luijkx, I. T., van der Werf, G. R., Viovy, N., Walker, A. P., Wiltshire, A. J., Wright, R., Zaehle, S., and Zheng, B.: Global Carbon Budget 2018, Earth Syst. Sci. Data, 10, 2141–2194, https://doi.org/10.5194/essd-10-2141-2018, 2018

Zimnoch M., Jelen D., Galkowski M., Kuc T., Necki J., Chmura L., Gorczyca Z., Jasek A., Rozanski K., (2012): Partitioning of atmospheric carbon dioxide over Central Europe: insights from combined measurements of CO2 mixing ratios and their carbon isotope composition, Isotopes in Environmental and Health Studies, DOI:10.1080/10256016.2012.663368

Subject 3: "How about feedbacks, e.g. fertilization effects (only one sentence about fertilization in the conclusion)?"

Response:

Considerations about feedback processes, such as, for example, the effect of fertilizing the atmosphere with carbon dioxide, is not the purpose of the analysis presented here. Of course, the authors are aware of the existence of such processes as well as the complex nature of changing the mechanisms that control these processes in the context of progressive climate change. However, the beginning of the 21st century indicates that the fertilization process is weakening. Yin et al. (2018) point out that the correlation between CO2 seasonal cycle amplitude and the temperature became negative around the year 2000 at most northern stations. It seems to confirm a limit to the "warmer spring – bigger carbon sink" mechanism. This finding highlights a dynamic temperature sensitivity of the terrestrial ecosystem to climate warming and cautions the use of current carbon-climate response to constrain future projections. This issue will be elaborated in the revised version.

References:

Yin, Y., Ciais, P., Chevallier, F., Li, W., Bastos, A., Piao, S., et al. (2018). Changes in the response of the Northern Hemisphere carbon uptake to temperature over the last three decades. Geophysical Research Letters, 45, 4371–4380. https://doi.org/10.1029/2018GL077316

Subject 4: "The authors have concluded that the trends and events of the changes in the SCA are associated with climate conditions, but did not discuss in detail the effects of anthropogenic actions, such as land-use change and policy or economic conditions."

Response:

We thank the reviewer for pointing this out. We would like to point out that the effects of anthropogenic actions mentioned by the reviewer have been taken into the account in our analysis indirectly, by comparing the analyzed SCAs to multi-annual patterns in European fossil fuel emissions of CO2. These take into account land-use change as

well as economic conditions.

However, we agree that the discussion on patterns of anthropogenic emissions needs to be expanded in the revised manuscript.

Subject 5: "References to show that fossil fuel emissions have decreased is missing (CTE and thus its prior is from a model). Also, the seasonal cycle of anthropogenic emissions could have changed as well – warmer winter and more severe summer could cause a shift in fossil fuel emissions from winter heating to summer cooling."

Response: a) "References to show that fossil fuel emissions have decreased is missing (CTE and thus its prior is from a model)."

We would like to thank the reviewer for pointing the missing reference.

We would like to point out that the emissions used in CTE are based on the bottom-up statistical approach and not from a model; specifically, these were not optimized by the inversion system. From CarbonTracker system description (https://www.carbontracker.eu/documentation_cte2018.pdf): "The fossil fuel emission inventory used in CarbonTracker Europe is the one constructed for the CARBONES project by USTUTT/IER. It uses emissions from the EDGAR 4.2 database together with country and sector specific time profiles derived by IER. A detailed description of the construction of the product is found here. The global total emissions for 2000-2017 were scaled to the global totals used in the GlobalCarbon Budget 2017. An individual trend per continent/Transcom region was applied in this scaling." The text will be modified to clarify the source of fossil-fuel data.

b) "In addition, the seasonal cycle of anthropogenic emissions could have changed as well – warmer winter, and more sever summer could cause shift in fossil fuel emissions from winter heating to summer cooling."

Thank you for pointing it out. Indeed, there is evidence that the pattern of CO2 emissions is changing in some countries. However, this response is far from uniform. For example, in Poland, the power production from combustible sources (most of the coal power plants) in winter has remained stable since 2000 (approx. 12.5 GWh/month), while the summer power production values have increased by approx. 15%, from 9.2 GWh/month in June 2000 to 10.6 in June 2019). On the other hand, in the largest EU economy – Germany – the amplitude of power generation from combustible sources has not changed significantly (Jan-Jun amplitude of 9.0 GWh in 2000 and 9.3 GWh for 2018), and at the same time, the overall power production from fossil fuels fluctuated without showing any clear trend (annual means between 29-34 GWh/month), which is probably related to larger fraction of power used by industry and not individual users. Source: "IEA Monthly electricity statistic, Revised Historical Data", version from November 2019. Overall, while the "winter-heating summer-cooling" effect indeed occurs in certain areas of Europe, this is definitely not the case throughout the continent. We will analyze this in more depth in our revised manuscript.

Subject 6: "The evaluation with flux sources is done by comparing flux estimates from a model. As footprints of summer and winter are shown to dominate from Central-Western Europe, how much about Eastern Europe can you say? The CTE results are from the whole of Europe, so how do you incorporate your arguments considering the trajectories? To be more precise, source contributions should be calculated by running trajectories or transport models for each source separately."

Response:

We thank the reviewer for the recommendation.

We would like to first point out that the source of flux estimates is not a model, but rather bottom-up statistical data supported by model results. See the remark earlier in the text for details (response to subject 5a).

In our approach, we have decided to limit the usage of the model data to a minimum and focus on atmospheric observations instead. In particular, we did not envisage the expansion of the trajectory analysis, as this would shift the emphasis from data- to

model-driven analysis. Issues like transport error, prior source attributions and lateral boundary conditions need to be carefully analyzed and addressed. Expanding the analysis as per reviewer suggestions is a significant project that deserves a paper of its own, and it is beyond the scope of this study.

Instead, by our selection of measurement sites and data selection procedures (night-time data only, filtered for local influences by procedure described in Necki et al., (2003) and Chmura, (2010), we are interpreting the regional background representative of most of Central-Eastern Europe, even if this is not apparent from our footprint analysis. In the current version, the footprints represent only the frequency of single-member trajectories passing through any given grid cell. This approach is not sufficient to properly account for the areas of source influences, as we only simulate a single trajectory and do not take PBL height into the account. To do this, statistical ensemble models would be the appropriate tools (e.g. Stochastic Time-Inverted Lagrangian Transport Model STILT, Lin et al. (2003)). This will be clarified in the revised manuscript.

References:

Chmura L., Gazy cieplarniane w atmosferze Polski Południowej: zmienność czasowo-przestrzenna w okresie 1994-2007 (in Polish), PhD thesis, AGH – University of Science and Technology, 2010. Lin, J. C., Gerbig, C., Wofsy, S. C., Andrews, A. E., Daube, B. C., Davis, K. J., and Grainger, C. A. (2003), A nearâĂŘfield tool for simulating the upstream influence of atmospheric observations: The Stochastic TimeâĂŘInverted Lagrangian Transport (STILT) model, J. Geophys. Res., 108, 4493, doi:10.1029/2002JD003161, D16. Necki, J.M., Schmidt, M., Rozanski, K., Zimnoch, M., Korus, A., Lasa, J., Graul, R. and Levin, I. Six year Record of Atmospheric Carbon Dioxide and Methane at a High-altitude Mountain Site in Poland. Tellus Ser. B 55: 94–104, 2003.

Subject 7: "Using results from only one model in evaluation should be done with caution. Any models have their own features, and results may be biased. In addition, if those studied sites were assimilated in the CTE inversion (i.e. has influence on the flux results), the evaluation is not independent of the measurements. Please specify and justify the choice, and if possible, use other sources, such as results from Global Carbon Project for biospheric fluxes and UNFCCC reports for anthropogenic emissions as additional source of evaluation."

Response:

We thank the reviewer for making this point.

We wholeheartedly agree that the results of the models need to be treated with care, and we will revise the text in order to underline the potential biases and known issues of the CT-Europe system.

We have selected CarbonTracker-Europe (CTE), as it is (i) a state-of-the-art modelling system, (ii) it is representative of the mean of other similar systems in our latitudes (see Table A3 and Figure B3 in Global Carbon Budget 2018, Le Quere et. al. (2018), and (iii) data from CTE are readily available. We will also underline the reasons for selecting CTE in the revised manuscript.

Both KAS and HUN stations were indeed assimilated by the CTE system. However, we do not believe this is an issue for our analyses for two reasons: first, we are focusing on the regional phenomena, specifically by analyzing the net CO2 fluxes from the complete TRANSCOM-Europe area. Second, we use the model only to test if the net biospheric prediction over the TRANSCOM area corroborates our results. We do not have the means of directly validating the model against observations, as this would require a forward run of the underlying transport model using the optimized fluxes. We will clarify this relation in the revised manuscript.

References:

Le Quéré, C., Andrew, R. M., Friedlingstein, P., Sitch, S., Hauck, J., Pongratz, J., Pickers, P. A., Korsbakken, J. I., Peters, G. P., Canadell, J. G., Arneth, A., Arora, V. K.,

Barbero, L., Bastos, A., Bopp, L., Chevallier, F., Chini, L. P., Ciais, P., Doney, S. C., Gkritzalis, T., Goll, D. S., Harris, I., Haverd, V., Hoffman, F. M., Hoppema, M., Houghton, R. A., Hurtt, G., Ilyina, T., Jain, A. K., Johannessen, T., Jones, C. D., Kato, E., Keeling, R. F., Goldewijk, K. K., Landschützer, P., Lefèvre, N., Lienert, S., Liu, Z., Lombardozzi, D., Metzl, N., Munro, D. R., Nabel, J. E. M. S., Nakaoka, S., Neill, C., Olsen, A., Ono, T., Patra, P., Peregon, A., Peters, W., Peylin, P., Pfeil, B., Pierrot, D., Poulter, B., Rehder, G., Resplandy, L., Robertson, E., Rocher, M., Rödenbeck, C., Schuster, U., Schwinger, J., Séférian, R., Skjelvan, I., Steinhoff, T., Sutton, A., Tans, P. P., Tian, H., Tilbrook, B., Tubiello, F. N., van der Laan-Luijkx, I. T., van der Werf, G. R., Viovy, N., Walker, A. P., Wiltshire, A. J., Wright, R., Zaehle, S., and Zheng, B.: Global Carbon Budget 2018, Earth Syst. Sci. Data, 10, 2141–2194, https://doi.org/10.5194/essd-10-2141-2018, 2018

Subject 8: "P2 L42-43: The advantage of GHG observations are useful not only for studying last decades, but also present and future. It is true that "currently available" observations can only see the past, but findings from those studies can be used for future predictions as well."

Response:

That is, of course, true, so we added one more sentence and now the relevant part of the text may look like that:

The availability of dense GHG observation networks allows scientists to analyze both long-term trends and anomalies in carbon balance as well as the response of the biosphere to changes in climate observed during the last decades. The advantage of GHG observations is useful not only for studying the last decades but also present and future. Currently available observations can only see the past, but findings from those studies can be used for future predictions as well.

Subject 9: "P2 L48-49: What was their main conclusion?"

Response:

The first one is that global climate models underestimate climate extremes (2003 European heatwave event can be useful as an example). The second one pointed out that the 2003 heatwave event significantly reduced the primary productivity of the European biosphere. The text will be modified accordingly.

Subject 10: "P2 L50-53: Please rephrase. It is not clear whether you wish to say that KAS is a useful site and can represent Central-Eastern Europe, or rise problem about the lack of observations. Please also be more specific about what you mean by "this" - you have not discussed this problem before."

Response:

The whole section will be modified as follows:

The lack of proper representation of Central-Eastern Europe in present GHG observation networks is partly compensated by the Kasprowy Wierch greenhouse gas monitoring station. The station is located in the High Tatras mountain range of southern Poland, at the level of 1989 m a.s.l. This high elevation of the measuring point and lack of strong CO2 sources in the direct vicinity of the station assure that the measured CO2 signal is representative for Central-Eastern European background.

Subject 11: "P2 L54-55: Please add references to such studies ('Long-term time series of CO2 and CH4 available for this site, in combination with relevant data from other stations, especially the Mace Head baseline station (monitoring greenhouse gas characteristics of maritime air masses entering Europe), enabled to study the impact of continental sources and sinks of GHGs on the observed atmospheric levels of those gases in the interior of the European continent.')."

Response:

A proper reference (Rozanski et al., 2016) will be added to the text.

Rozanski K., Chmura L., Galkowski M., Necki J., Zimnoch M., Bartyzel J., O'Doherty S., Monitoring of Greenhouse Gases in the Atmosphere: a Polish Perspective PAPERS on GLOBAL CHANGE, 23, 111–126, 2016, DOI: 10.1515/igbp-2016-0009

Subject 12: "Section 2: Please put information about the data gaps and gap-filling methods in this section for all sites. (Those of KAS is presented in the capture of Figure 1, but please move it to this section). If there has been no gap in the data, please also notify."

Response:

Appropriate information will be added to the text in section 2.1, 2.2 and 2.3 for Kasprowy Wierch, Mace Head and Hegyhatsal respectively:

"In the entire period of operation of the greenhouse gas monitoring station at Kasprowy Wierch (from September 1994 to December 2018), the data coverage amounts is equal to 71% of the total working time. At KASLAB station due to instrument malfunction, there was one longer period with lack of measurement. Data between July and December 1997 have been gap-filled with a mean annual cycle calculated from period 1996 – 2018, added to a long-term linear trend."

"In the years 1994-2017, CO2 concentration data for Mace Head stations cover 81% of the period discussed here. There were no major technical problems at the station during this time, so there was no need to fill gaps in the measurement data."

"Available CO2 concentration data cover 85% of the given period. In the case of Hegyhatsal station also there were no major technical problems at the station during this time, so there was no need to use any procedures to fill gaps in the measurement data."

Subject 13: "P2 L61: Please add information about KAS data availability in this section."

Response:

The following information will be added:

“The data for both stations were retrieved from the GLOBALVIEW-CO2 NOAA ESRL Carbon Cycle Cooperative Global Air Sampling Network (http://www.esrl.noaa.gov/gmd/dv/data/ – Dlugokencky et al., 2018).”

Subject 14: “P3 L94: Please specify which European network it belongs to.”

Response:

The tower is the NOAA/CMDL global air sampling network site (site code: HUN) (Conway et al., 1994). It was part of the CHIOTTO network. This network was nowadays replaced by ICOS, and HUN site does not belong to it. The text will be modified accordingly

References

Conway, T. J., Tans, P. P., Waterman, L. S., Thoning, K. W., Kitzis, D. R., Masarie, K. A., and Zhang, N. (1994), Evidence for interannual variability of the carbon cycle from the National Oceanic and Atmospheric Administration/Climate Monitoring and Diagnostics Laboratory Global Air Sampling Network, J. Geophys. Res., 99 (D11), 22831– 22855, doi:10.1029/94JD01951.

Subject 15: “P4 L122: Please be more specific about “periods of interest”. You probably did not run footprints of the whole study period, but part of it?”

Response:

The sentence will be rephrased in the revised manuscript:

“Assessment of the area of influence (footprints) for Kasprowy Wierch and Hegyhatsal stations has been carried out for the three month periods (June, July and August) 2003 and 2010 with hourly resolution as described in the figure captions. Each frequency plot was created based on 2208 individual trajectories.”

Subject 16: “P4 L126: Please justify your choice of “96-hours”.”

Response:

The trajectory length selected for analysis depends on the specific application. In general, the shorter the time, the better the accuracy. However, the too-short trajectory will represent a smaller area surrounding the reception point. While 24-48 hours is a good choice for the identification of possible pollution sources located close to the reception point, a statistical regional analysis like frequency of clustering requires a longer time. The length of 96 hours was assumed based on the recommendation in Hysplit FAQ (https://www.arl.noaa.gov/hysplit/hysplit-frequently-asked-questions-faqs/backward-trajectories-starting-at-a-rural-east-coast-site/), (Rolph et al., 1990).

References:

Rolph, G. D., Draxler R. R., "Sensitivity of Three-Dimensional Trajectories to the Spatial and Temporal Densities of the Wind Field." Journal of Applied Meteorology (1988-2005) 29, no. 10 (1990): 1043-054. Accessed February 14, 2020. www.jstor.org/stable/26185789.

Subject 17: “P5 L127, L137: You have used two different meteorological datasets (NCEP Reanalysis and ERA- Interim). Could you comment on those choices, how much differences there are, and whether the differences could possibly affect your analysis?.”

Response:

NCEP data was chosen to drive the Hysplit model for several reasons: it was readily available for both periods of interest (2003, 2010), had low disk space requirements and was already well established. While it is true that ERA-Interim (or even newer datasets like ERA5) represent the actual atmospheric state conditions better, we believe that the difference between calculated footprint areas would not be significant enough to warrant extra work necessary for the conversion of data.

At the same time, we recognize that the overall quality of the ERA-Interim dataset to be higher, which is why we used it in the - more critical to the discussion - analysis of the state of the soil during the analyzed period.

Subject 18: "P5 L137: Please specify from which layers/level of air temperature data you have used (I could see that it is 2 m temperature from figures, but please also note in the text). It could be good to specify it for soil humidity also in the beginning."

Response:

Thank you for pointing this out. Indeed, the 2m air temperature was used for the analysis. We modified the text to include the information as per your suggestion.

Following the comment by another reviewer, the calculation of soil humidity was also changed from using the first level only to the weighted arithmetic mean of soil humidity profile obtained by using four levels available in ERA-Interim data. The weighting function was scaled using the depth of soil layers. A detailed description was added in section 3.3.

Subject 19: "P5 L151-L152: Please explain what is included in the "biospheric fluxes" (biomass burning can also be considered as "biosphere" in some context)."

Response:

In the CarbonTracker model, the biospheric module is based on the Simple-Biosphere-Model-Carnegie-Ames Stanford Approach (SiBCASA) model, and optimizes the net ecosystem exchange (NEE), "derived directly from Gross Primary Production (GPP) and ecosystem respiration (R) from SiBCASA" (https://www.carbontracker.eu/documentation_cte2018.pdf).

Biomass burning emissions are included in the separate fire module in the CarbonTracker system, driven by GFEDv4 (Global Fire Emission Database v4) and output

from SiBCASA biosphere model (i.e. seasonally changing vegetation and soil biomass stocks). The fire emissions calculated in CarbonTracker over the Transcom Region Europe were never higher than 0.02 PgC /year (usually 0.01 Pg/C) and did not show significant variability. We have therefore excluded the emissions from biomass burning from our analysis.

Subject 20: "P5 L152: The authors mention that ocean fluxes were negligible, but some (or actually quite many) MHD observations capture signals from the ocean. Did you apply any specific filtering to such observations?"

Response:

The referee is of course right – MHD station in the major part captures the signal from the Atlantic Ocean (clean section for this site is in the range for 180o to 300o). It is a costal station so the signal from the ocean-atmosphere flux is evident. But the aim of our article is to show how the atmosphere reacts to changes over time in CO2 exchange fluxes between land and the atmosphere itself. In that context, the concentration of carbon dioxide measured at MHD station is a kind of input data for our analysis. That is the reason why we decided to choose the European TrnasCom region for biospheric and fossil-fuel CO2 fluxes. In that range ocean-atmosphere flux is negligible.

Subject 21: "P6 L169: Please consider adding the following sentence before "It is apparent from Fig. 1b...": Therefore, seasonal cycle amplitude and annual level is much lower for KAS than HUN."

Response:

Good point. Thank you. The sentence will be added to the text.

Subject 22: "P7 L183-L185: How well do we know about seasonality of the anthropogenic emissions and their contribution to the measured seasonal cycles at those sites?"

Response:

The seasonality of the anthropogenic emissions is discussed partially in the answer to the previous comment of the reviewer (see in particular response to subject 5b) and will be further discussed in the revised manuscript. A limited-time study by Zimnoch et al. (2012) has used isotopic information to derive monthly means of fossil and biogenic additions to the large-scale background (for 2008-2009) and concluded that the anthropogenic addition to the signal at KAS varied between 0 to 4 ppm, with maximum values observed in winter. The revised text will contain this additional information.

References:

Zimnoch M., Jelen D., Galkowski M., Kuc T., Necki J., Chmura L., Gorczyca Z., Jasek A., RóÅijański K., Partitioning of atmospheric carbon dioxide over Central Europe: insights from combined measurements of CO2 mixing ratios and their carbon isotope composition, Isotopes in Environmental and Health Studies, Vol. 48, Issue: 3, 421-33. doi: 10.1080/10256016.2012.663368., 2012

Subject 23: "P8 L195: "uncertainty" $\rightarrow$ "standard error" (or deviation). In all the regression analysis, it was not very clear how you decide significances. For example, you mention that MHD peak-to-peak amplitude (0.05$\pm$0.04) is not significant, but KAS summer min. (0.09$\pm$0.04) is. If you have some additional quantitative values (e.g. p-value), that would help to better understand your arguments."

Response:

Dear reviewer, according to the "International vocabulary of metrology – Basic and general concepts and associated terms (VIM), 2012" ant other GUM standards, uncertainty seems to be the more correct expression in this case.

Thank you very much for drawing attention to the study of statistical hypotheses. The p-values will be quoted in the text where necessary. However, in the case of numerous samples, such as this, analysis comes down to a comparison of values (for example,

curve slope coefficients) and their uncertainty. If the value differs from zero by less than two sigma, it is obvious that the p-value will be significantly greater than 0.05 and the hypothesis of a difference of the coefficient from zero can be rejected. Therefore, in our approach, we did not consider giving p-values. We also plan to graphically mark the uncertainty of the fits on the charts.

Subject 24: "P9 L205-208: You already know the answer to these sentences. It would be better to go directly to the results, i.e. remove this sentence or rephrase."

Response:

We thank the reviewer for pointing this out. We have revised the discussed sentence, and now it reads: "We believe that these decreasing amplitudes are a result of two main physical effects: (i) higher mixing ratios of CO2 recorded during peaks of summer seasons, and/or (ii) lower CO2 mixing ratios recorded during winter periods."

Subject 25: "P13 L253: The authors meant to say that peak-to-peak amplitude is "low" in some years compared to average. Please rephrase the sentence to be more clear."

Response:

The first paragraph of this section has been changed as suggested and now it has the following form: The average CO2 seasonal cycle amplitude at Kasprowy Wierch and Hegyhatsal station is equal to 16.6 $\pm$ 0.5 ppm and 32.8 $\pm$ 1.0 ppm respectively. The years in which CO2 seasonal cycle amplitude was lower than 14 ppm for Kasprowy Wierch and 30 ppm for Hegyhatsal were considered to be anomalously low values of this parameter. As discussed above, low peak-to-peak amplitudes of the seasonal CO2 cycle recorded in a given year at stations located in Central-Eastern Europe indicate weak biospheric CO2 sink during summer and reduced fossil-fuel flux of CO2 into the regional atmosphere during winter, both considered within the area of influence (footprint) of the given station. Weak biospheric sink during summer may result from heat waves and/or reduced availability of moisture in the soil profile. As can be seen in Fig. 4a, there were five years in the data record available for Kasprowy Wierch, with peak-to-peak amplitudes of the seasonal CO2 cycle smaller than 14 ppm: 2003, 2010, 2012, 2014, 2015. The years 2003, 2012 and 2015 also stand out as years with the lowest peak-to-peak amplitude in the CO2 record of the Hegyhatsal station. Also, carbon dioxide seasonal cycle amplitude below 30 ppm was also recorded in 2002 and 2008 at this station (Fig. 3).

Subject 26: “P14 L272-274: The authors explain that there are clear differences in the direction of footprints, but I see strong influences from western Europe at both sites in Fig. 10. In addition, footprint of HUN show that the air is not coming much from northward directions. Could you explain these in a better way?”

Response:

Analysis of the overall shape of footprint calculated for KAS and HUN stations may suggest that both stations were influenced by emissions originating from areas impacted by heatwave located in western Europe. However, most of the HUN footprint representing France, northern Italy and the United Kingdom have frequency values below 1% constituting a small contribution to the station signal. The shape of the area representing more than 1% of trajectories frequency, in the case of HUN station, represents a much smaller region impacted by a heatwave. Appropriate changes will be made in the text.

Subject 27: “P20 L343-344: Please also rephrase “luck of strong biospheric signals”. The station captures biospheric signals, but mostly from the western direction. Maybe you could say “luck of biospheric signals from eastwards”?”

Response:

We thank the reviewer for the suggestion. We have modified the sentence in question. It now reads: “From this perspective, high-altitude mountain station Kasprowy Wierch appears to be better suited for tracing subtle, long-term changes of carbon cycle over

the European continent than low-altitude Hegyhatsal station, for which a smaller footprint and stronger local signals influencing CO2 mixing ratios in the PBL effectively mask larger-scale effects.”

Subject 28: “Conclusion: It would be good to add a conclusion about our actions to be taken. Shall we be more urgent in reducing anthropogenic emissions, if plants are suffering more from sever summers, and fertilization effect may be weakening?”

Response:

We thank the reviewer for this suggestion. We believe, however, that the urgency of the matter is obvious for readers of the ACP Journal and further emphasis is not needed.

Subject 29: “Figures 4 and 5: Please put each of them into one figure (i.e. without panels), and use the same color codes.”

Response:

Figures 4 and 5 will be changed, to follow your suggestion. Thank you.

Subject 30: “Figure 7: Why do you compare only with KAS?”

Response:

We decided to compare CO2 net biospheric flux and fossil fuel flux for European region only with maximum and minimum of CO2 from Kasprowy Wierch because the Hungarian station is under much more stronger influence of local signals and the footprint for Hegyhatsal station is distinctly smaller than in case of Kasprowy Wierch station (see Fig. 10).

Subject 31:

“Figure 8, 9, 11: Is it necessary to show all the years? You could consider showing only those important years.”

Response:

We aimed to show how strong could be the differences between separate years. In our opinion, the easiest way to point these differences is to show the thermal or soil moisture anomalies for the whole period, year by year.

Subject 32: "P20 L343: Please rephrase "...Hegyhatsal station because of the larger footprint of Kasprowy Wierch and lack of" as "...Hegyhatsal station because of smaller footprint and...", i.e. be consistent with the subject"

Response:

We thank the reviewer for the suggestion. We have modified the sentence in question. It now reads: From this perspective, high-altitude mountain station Kasprowy Wierch appears to be better suited for tracing subtle, long-term changes of carbon cycle over the European continent than low-altitude Hegyhatsal station, for which a smaller footprint and stronger local signals influencing CO2 mixing ratios in the PBL effectively mask larger-scale effects.

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