Review of "Abrupt seasonal transitions in land carbon uptake in 2015" by Chao Yue et al.

Matthias Forkel, 2017-03-08

1. Does the paper address relevant scientific questions within the scope of ACP?

The article by C. Yue et al. addresses annual and seasonal variabilities in global land carbon uptake and the relations with climate and vegetation. This paper is within the scope of ACP.

2. Does the paper present novel concepts, ideas, tools, or data?

The paper is based on well established datasets and methods to generate such data (CO_2 measurements, NDVI data, atmospheric inversion). The title and the abstract of the paper mainly highlights one finding of the study about "abrupt seasonal transitions in land carbon uptake". This finding is not really new (except the focus on 2015) but the results of the study are a good opportunity to remind the land carbon cycle community about such mechanisms and to point to the year 2015 as a remarkable example of such seasonal transitions.

3. Are substantial conclusions reached?

The entire study is focussed on anomalies of the land carbon uptake in the year 2015 relative to the period 1981 to 2015. Consequently, the conclusions are very specific for climate/carbon cycle mechanism in this year. To make this paper more interesting for the land carbon cycle community and to reach more substantial and less specific conclusions, I would recommend to perform similar analyses also for other years and to finally draw conclusions about general mechanisms in comparison to specificities in single years. In this point, I completely agree with Anonymous Referee #1.

[Response] We examined extensively the relationship between anomalies in land carbon uptake, NDVI and climate variations. These new analyses are incorporated in the substantially revised results and discussion section.

4. Are the scientific methods and assumptions valid and clearly outlined?

Overall, yes. For some datasets, I would expect scientific references additionally to the URLs from which the data was obtained (especially in Sections 2.2.2 and 2.2.3). The only exception is the analysis of NDVI data (Section 2.2.1): For example, the authors calculated "seasonal mean standardized NDVI". Although I have some experience with NDVI data (Forkel et al., 2013), I cannot imagine what this term means. How were NDVI values standardized? Why? Furthermore, mean NDVI values of winter seasons in northern regions are not very useful to draw conclusions about vegetation productivity or land carbon uptake. As NDVI is a land surface property it is not only affected by vegetation but outside the peak of the growing season strongly by changes in snow cover and soil reflectance. Consequently, a certain ranking in a season espcially in northern regions might be due to the variability in snow cover but not in vegetation. The authors need to appropriate filter the NDVI time series to separate vegetation signals from other non-vegetation distortions (Hird and McDermid, 2009; Holben, 1986; Kandasamy et al., 2013). Furthermore, NDVI datasets from different sensors show large differences which are especially important for seasonal anomalies that are outside of the peak of the growing season (D'Odorico et al., 2014; Fensholt and Proud, 2012; Kern et al., 2016; Scheftic et al., 2014). Consequently, I'm wondering if the shown ranking of seasonal NDVI values (Fig. 1) is a robust result given the noise of NDVI data and the differences between datasets. This rises the question if 2015 is indeed the greenest year.

[Response] The scientific citations for MEI and NDVI are provided in additional to URL links. NDVI reflects in general vegetation green fraction, and is considered as a proxy of green leaf area (Gamon et al., 1995; Ide et al., 2010) Its temporal magnitudes have been used to infer changes in vegetation productivity (Myneni et al., 1997; Zhao and Running, 2010). In response to the reviewer's comments, we have updated our results by using a new NDVI data set that went through rigorous quality control, with the cloud- and snow-contaminated pixels being removed and gap-filled. Note that the original NDVI values, rather than standardized anomalies, are used. Seasonal NDVI values lower than 0.1 were further removed to make sure the used NDVI values reflect the dominance of vegetation information.

Because of filtering NDVI values by a minimum of 0.1, we are cautiously confident that the vegetation greenness reflects (at least partly) the vegetation information even in the first (Q1) and fourth (Q4) trimester of the year when snow is present in the northern hemisphere. In fact, October is frequently considered within the growing season and some evergreen coniferous forests show significant photosynthetic activities in March in regions of mild winter, e.g., Tanja et al., 2003). Here we show that, most of the grid cells where 2015 shows the highest NDVI for northern land (Fig. CS1, region with latitude > 30°N) are in fact dominated by Q2 (April–June) and Q3 (July–September), corresponding roughly to northern hemisphere growing season. The vegetated land area (i.e., with a seasonal NDVI value higher than 0.1 in either of the four seasons of 2015) with the highest NDVI rank in 2015 in the northern land accounts for 36% of all land area, in contrast with an expected mean of 6.25% if the land is equally green over all years of 2000–2015. This highlights again the extreme greening during the growing season in the northern hemisphere in 2015, as has been examined in more detail in Bastos et al. (2017).

Q1 and Q4 account for 34% of the land area where 2015 NDVI ranks the highest in northern land. These grid cells are either dominated by evergreen forests (central Canada, northwestern Europe), or by oceanic climate where evergreen forests prevail (eastern Canada and US, Europe) (Fig. CS2). As shown in Fig. CS3, the land north to 23.5°N contributes primarily to the overall highest annual NDVI in 2015, whereas in tropics (23.5°S–23.5°N) and southern extra-tropics (latitude > 23.5°S), the NDVI in 2015 is only moderately high (0–23.5°N) or around the multi-annual mean value (southern hemisphere).

Therefore, we conclude that, globally, 2015 is the greenest year of 2000–2015, in terms of both the mean annual NDVI value, and the number of grid cells where NDVI shows the highest rank in 2000–2015. This greenest signal is dominated by the extreme greenness in the growing season of the northern hemisphere, which has been examined in details in Bastos et al. (2017) and identified as a robust phenomenon independent of different satellite sensors used, or quality control procedures of the data. The Fig. S1 in Bastos et al. (2017) confirmed that both data from Terra and Aqua sensors show that 2015 has the highest growing season NDVI in 2000–2015. They also confirmed that such a conclusion is consistent among three quality control strategies of the Terra MODIS data used (Page 3, Bastos et al. 2017).

As the extreme greenness in 2015 is used as a starting point for our study and the main objective of our paper is to report the carbon dynamics and seasonal shifts in land carbon uptake associated with climate variations. We're fairly confident that sufficient evidences have been provided regarding the vegetation greenness for this specific year.

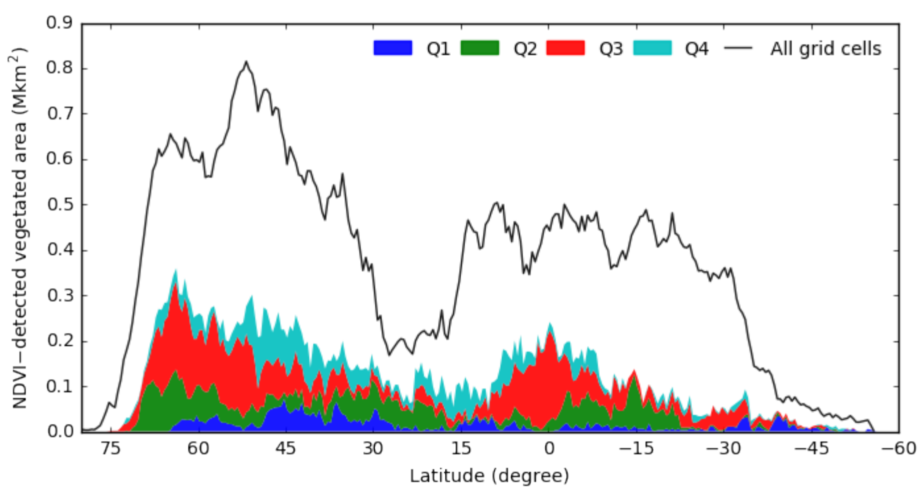

Fig. CS1 Seasonal distributions of land areas where 2015 shows the highest NDVI since 2000 as a function of latitude. Shaded areas represent different seasons stacked on top of each other.

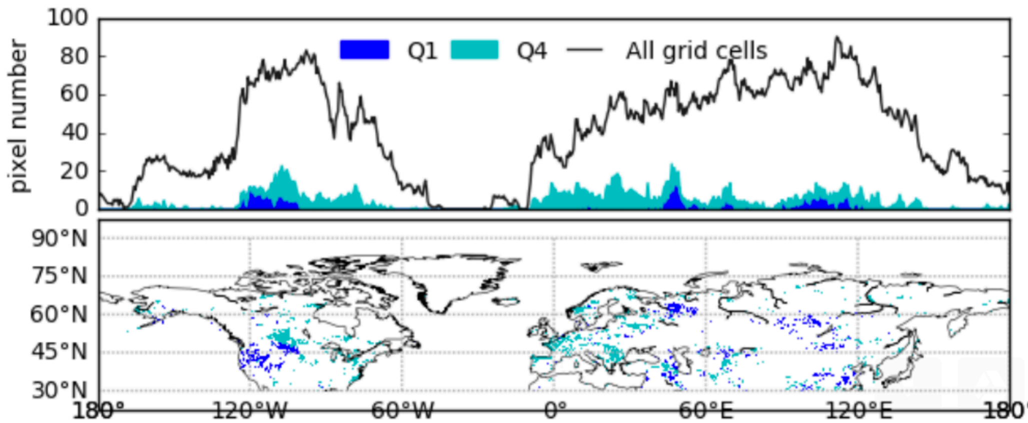

Fig. CS2 (Top) Longitudinal distribution of the number of grid cells where 2015 NDVI ranks the highest in Q1 or Q4 of 2015 for the northern lands (latitude > 30°N). (Bottom) Spatial distribution of grid cells where NDVIs rank the highest for 2015 in Q1 or Q4 for the northern land (latitude > 30°N).

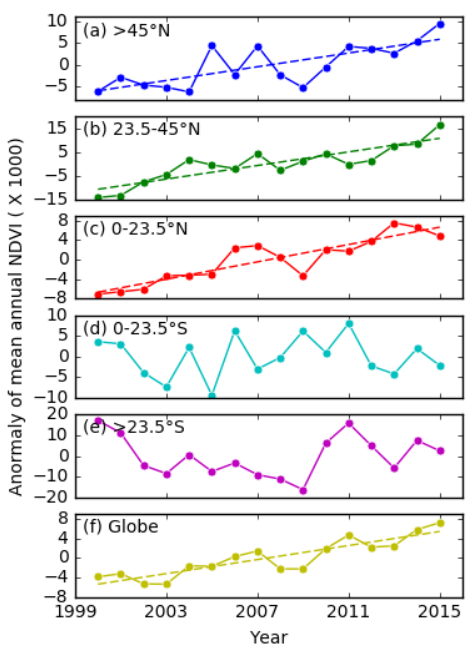

Fig. CS3 Annual NDVI anomalies for different latitudinal bands. The trend line is shown only for regions where significant simple linear regression over time is obtained.

5. Are the results sufficient to support the interpretations and conclusions?

Apart from the NDVI issues described above, the results are described in great detail and support the interpretation and conclusions.

[Response] Please refer to the responses to the comment above regarding the NDVI.

6. Is the description of experiments and calculations sufficiently complete and precise to allow their reproduction by fellow scientists (traceability of results)?

The calculations are mostly well described. The calculation of seasonal NDVI ranks seems to be a new approach to analyse NDVI time series (at least no reference is provided). Therefore I would recommend that the authors present some more details on this approach (at least in the Supplement) and ideally could provide also the code.

[Response] The NDVI ranking is mainly used to show the spatial distribution of abnormal greening in 2015, and that 2015 is in general the greenest year over 2000-2015 across the globe, which is dominated by extreme greening in northern land. Please also refer to our responses to the Comment 4 for more information. Fig. S3 in the revised Supplement shows the NDVI anomalies for different latitude bands, which clearly indicate that the highest annual NDVI over the globe is driven by the extreme green anomaly in the northern land (>23.5°N). The code used to generate Figure 1 in the texts is made available through a public repository (https://github.com/ChaoYue/ACPD-2016-1167).

7. Do the authors give proper credit to related work and clearly indicate their own new/original contribution?

Yes. The cited literature is relevant for this study. The own contributions of the authors are clear. However, I would recommend to provide a more detailed discussion on the link between vegetation greenness from satellites and carbon cycle or atmospheric CO_2 variability in order to improve the discussion section that is currently strongly focussed on the specificities of the year 2015. The results of this paper could be for example discussed with respect to the following relevant papers (Angert et al., 2005; Forkel et al., 2016; Gonsamo et al., 2017; Keenan et al., 2016; Myneni et al., 1997; Thomas et al., 2016).

[Response] We have substantially strengthened the discussion by making new analysis regarding the links among vegetation greenness, land carbon uptake anomalies and climate variations (Fig. 3, Fig. 4 in revised manuscript, Fig. S4, S5, S7 in the revised Supplement). Please also refer to our responses to the #2 Response to the #1 reviewer.

8. Does the title clearly reflect the contents of the paper?

Yes. However, I recommend to extent the analysis to more years to draw less specific concluisons for a single years. This might imply to change the title accordingly.

[Response] We extended the analysis by including more years and provided new figures in both main texts and the Supplement. Please also refer to our responses to the first and second comment by #1 reviewer. The manuscript title is also changed to: Vegetation greenness and land carbon flux anomaly associated with climate variations with a special focus on 2015.

9. Does the abstract provide a concise and complete summary?

Yes. The abstract is well written.

[Response] The abstract is updated to reflect the extra analysis conducted.

10. Is the overall presentation well structured and clear?

Yes.

11. Is the language fluent and precise?

Yes (as far as I can judge this). Some sentences are however too long and thus difficult to read, for example: lines 74-78, 90-93,

[Response] These sentences are re-phrased to enhance their readability.

12. Are mathematical formulae, symbols, abbreviations, and units correctly defined and used?

Yes. Units and proper axis descriptions are missing in Fig. 4.

[Response] This is fixed.

13. Should any parts of the paper (text, formulae, figures, tables) be clarified, reduced, combined, or eliminated?

Lines 71-74 are repeating lines 58-61 and can be merged.

[Response] Lines 58–61 are removed as they're repeated in section 2.1.1.

Lines 81-93: The affect of station network density on the inversion is well described for the CarboScope product. According to my understanding, the CAMS inversion should have the same problems. Please clarify how these issued are handled in the CAMS inversion.

[Response] The CAMS inversion uses sites with at least 5-year worth of data. It therefore has a denser (during the recent decade) but temporally evolving data coverage than Carboscope. The evolving network in CAMS causes changes in inverted CO2 fluxes that are superimposed on changes from biogeochemical drivers during the whole period.

Lines 131-139: Please make clear why the conversion from ppm to PgC was done and if there is any relevant uncertainty in this conversion factor.

[Response] The conversion of ppm to PgC is to express the atmospheric 'sink' of CO_2 in the same unit as carbon fluxes diagnosed from inversions, in order to coherently assess contributions from different fluxes to the AGR in 2015. This is explained in the revised texts. We used a conversion factor of 1ppm CO_2 = 2.12 Pg C (Ciais et al., 2014; Prather et al., 2012). For multi-decadal analysis, this ratio is correct given the sufficient mixing of CO_2 in the atmosphere because the value of 2.12 Pg C ppm^{-1} considers the effect of a flux equilibrated with the troposphere (mixed in ≈ 1.2 years) and the stratosphere (mixed in ≈ 5 years). However we used this ratio on an annual basis, with the assumption that the entire atmosphere is well mixed within one year. This approximation is explicitly stated in the main text.

Such a ratio is mainly based on Ballantyne et al. (2012) & Le Quéré et al. (2016). We admit there are uncertainties in this ratio. Ballantyne et al. (2012) gave a relatively detailed discussion in their methods. On the one hand, the stratosphere is less well mixed with CO_2 than the troposphere, using CO_2 measurements at marine boundary layer (MBL) might overestimated the atmospheric CO_2 sink (thus implying a ratio that should be smaller than 2.12). But on the other hand, there is also CO_2 gradient from the continental boundary layer to marine boundary layer, which could compensate for the insufficient mixing in the stratosphere. Ballantyne et al. (2012) finally reached the conclusion that these two factors roughly cancel out each other by citing the close estimated MBL and whole atmosphere CO_2 concentrations. In our case, the partitioning of the AGR anomaly in 2015 is not our central purpose. The majority of conclusions reached by our analysis in the paper are based on the inversion-based land carbon uptake anomalies by the two inversion data sets used. Thus we argue the uncertainty of this conversion factor does not significantly impact our results.

Lines 163-164: What do you mean with "numerical instability"? Why could such an instability happen and why in 1993?

[Response] We mean rounding errors that accumulate rather than cancel. We have been experiencing these artifacts more often with increasing assimilation periods over the years, because the grid-point scale inversion problem becomes larger. To our knowledge, there is no particular reason why it happens in 1993 rather than in another year. We usually manage to remove these instabilities by re-running the inversion under slightly changed inversion configuration parameters, but this has not been done for this version.

Line 296: I thought that the Jena inversion system uses flat land prior fluxes. Are results from the LPJ model really used?

[Response] LPJ is used as a time-average spatial pattern, but concerning time variability as relevant here, the CarboScope prior is indeed flat (no prior interannual variations by periodical seasonal variations).

Figure 4: The figure could be much easier to read if you do some changes: #1 The red-green colour scale is not needed because the same information is already provided by the x-axis. Additionally, this colour scale might be not visible for colour-blind people. #2 The main purpose of this figure is to compare distributions of seasonal transitions from CAMS and Jena04. Overlaid histograms are not a good graphical choice. I would recommend to rather show distributions in terms of density lines, boxplots or violins which would make it easier to compare the distribution of CAMS and Jena04. The vertical lines for the year 2015 can be still added if you want to keep the focus on this year. #3 Please provide labels and units for the x-axis.

[Response] We removed the color in the vertical bars, and changed this plot into line plot of histograms for clarity. Labels and units are provided for x-axis.

14. Are the number and quality of references appropriate?

Yes, but also refer to my answer to the question #7.

[Response] We expanded substantially the discussion by citing relevant previous studies. The reference list is updated accordingly.

15. Is the amount and quality of supplementary material appropriate?

Yes, but an improved processing and uncertainty assessment of NDVI data might require more details in the supplementary material.

[Response] We provide further figures in the Supplement regarding the 2015 extreme greening.

References

Angert, A., Biraud, S., Bonfils, C., Henning, C. C., Buermann, W., Pinzon, J., Tucker, C. J. and Fung, I.: Drier summers cancel out the CO2 uptake enhancement induced by warmer springs, Proc. Natl. Acad. Sci. U. S. A., 102(31), 10823–7, doi:10.1073/pnas.0501647102, 2005.

D'Odorico, P., Gonsamo, A., Pinty, B., Gobron, N., Coops, N., Mendez, E. and Schaepman, M. E.: Intercomparison of fraction of absorbed photosynthetically active radiation products derived from satellite data over Europe, Remote Sens. Environ., 142, 141–154, doi:10.1016/j.rse.2013.12.005, 2014.

Fensholt, R. and Proud, S. R.: Evaluation of Earth Observation based global long term vegetation trends — Comparing GIMMS and MODIS global NDVI time series, Remote Sens. Environ., 119, 131–147, doi:10.1016/j.rse.2011.12.015, 2012.

Forkel, M., Carvalhais, N., Verbesselt, J., Mahecha, M., Neigh, C. and Reichstein, M.: Trend Change Detection in NDVI Time Series: Effects of Inter-Annual Variability and Methodology, Remote Sens., 5(5), 2113–2144, doi:10.3390/rs5052113, 2013.

Forkel, M., Carvalhais, N., Rödenbeck, C., Keeling, R., Heimann, M., Thonicke, K., Zaehle, S. and Reichstein, M.: Enhanced seasonal CO2 exchange caused by amplified plant productivity in northern ecosystems, Science, aac4971, doi:10.1126/science.aac4971, 2016.

Gonsamo, A., D'Odorico, P., Chen, J. M., Wu, C. and Buchmann, N.: Changes in vegetation phenology are not reflected in atmospheric CO2 and 13C/12C seasonality, Glob. Change Biol., n/a- n/a, doi:10.1111/gcb.13646, 2017.

Hird, J. N. and McDermid, G. J.: Noise reduction of NDVI time series: An empirical comparison of selected techniques, Remote Sens. Environ., 113(1), 248–258, doi:10.1016/j.rse.2008.09.003, 2009.

Holben, B. N.: Characteristics of maximum-value composite images from temporal AVHRR data, Int. J. Remote Sens., 7(11), 1417–1434, 1986.

Kandasamy, S., Baret, F., Verger, A., Neveux, P. and Weiss, M.: A comparison of methods for smoothing and gap filling time series of remote sensing observations – application to MODIS LAI products, Biogeosciences, 10(6), 4055–4071, doi:10.5194/bg-10-4055-2013, 2013.

Keenan, T. F., Prentice, I. C., Canadell, J. G., Williams, C. A., Wang, H., Raupach, M. and Collatz, G. J.: Recent pause in the growth rate of atmospheric CO2 due to enhanced terrestrial carbon uptake, Nat. Commun., 7, 13428, doi:10.1038/ncomms13428, 2016.

Kern, A., Marjanović, H. and Barcza, Z.: Evaluation of the Quality of NDVI3g Dataset against Collection 6 MODIS NDVI in Central Europe between 2000 and 2013, Remote Sens., 8(11), 955, doi:10.3390/rs8110955, 2016.

Myneni, R. B., Keeling, C. D., Tucker, C. J., Asrar, G. and Nemani, R. R.: Increased plant growth in the northern high latitudes from 1981 to 1991, Nature, 386(6626), 698–702, doi:10.1038/386698a0, 1997.

Scheftic, W., Zeng, X., Broxton, P. and Brunke, M.: Intercomparison of Seven NDVI Products over the United States and Mexico, Remote Sens., 6(2), 1057–1084, doi:10.3390/rs6021057, 2014.

Thomas, R. T., Prentice, I. C., Graven, H., Ciais, P., Fisher, J. B., Hayes, D. J., Huang, M., Huntzinger, D. N., Ito, A., Jain, A., Mao, J., Michalak, A. M., Peng, S., Poulter, B., Ricciuto, D. M., Shi, X., Schwalm, C., Tian, H. and Zeng, N.: CO2 and greening observations indicate increasing light-use efficiency in northern terrestrial ecosystems, Geophys. Res. Lett., doi:10.1002/2016GL070710, 2016.

References in the response:

Ballantyne, A. P., Alden, C. B., Miller, J. B., Tans, P. P. and White, J. W. C.: Increase in observed net carbon dioxide uptake by land and oceans during the past 50 years, Nature, 488(7409), 70–72, doi:10.1038/nature11299, 2012.

Bastos, A., Ciais, P., Park, T., Zscheischler, J., Yue, C., Barichivich, J., Myneni, R. B., Peng, S., Piao, S. and Zhu, Z.: Was the extreme Northern Hemisphere greening in 2015 predictable?, Environ. Res. Lett., 12(4), 044016, doi:10.1088/1748-9326/aa67b5, 2017.

Ciais, P., Sabine, C., Bala, G., Bopp, L., Brovkin, V., Canadell, J., Chhabra, A., DeFries, R., Galloway, J., Heimann, M. and others: Carbon and Other Biogeochemical Cycles, Clim. Change 2013 Phys. Sci. Basis Contrib. Work. Group Fifth Assess. Rep. Intergov. Panel Clim. Change, 465–570, 2014.

Gamon, J. A., Field, C. B., Goulden, M. L., Griffin, K. L., Hartley, A. E., Joel, G., Peñuelas, J. and Valentini, R.: Relationships Between NDVI, Canopy Structure, and Photosynthesis in Three Californian Vegetation Types, Ecol. Appl., 5(1), 28–41, doi:10.2307/1942049, 1995.

Ide, R., Nakaji, T. and Oguma, H.: Assessment of canopy photosynthetic capacity and estimation of GPP by using spectral vegetation indices and the light–response function in a larch forest, Agric. For. Meteorol., 150(3), 389–398, doi:10.1016/j.agrformet.2009.12.009, 2010.

Myneni, R. B., Keeling, C. D., Tucker, C. J., Asrar, G. and Nemani, R. R.: Increased plant growth in the northern high latitudes from 1981 to 1991, Nature, 386(6626), 698–702, doi:10.1038/386698a0, 1997.

Prather, M. J., Holmes, C. D. and Hsu, J.: Reactive greenhouse gas scenarios: Systematic exploration of uncertainties and the role of atmospheric chemistry, Geophys. Res. Lett., 39(9), L09803, doi:10.1029/2012GL051440, 2012.

Le Quéré, C., Andrew, R. M., Canadell, J. G., Sitch, S., Korsbakken, J. I., Peters, G. P., Manning, A. C., Boden, T. A., Tans, P. P., Houghton, R. A., Keeling, R. F., Alin, S., Andrews, O. D., Anthoni, P., Barbero, L., Bopp, L., Chevallier, F., Chini, L. P., Ciais, P., Currie, K., Delire, C., Doney, S. C., Friedlingstein, P., Gkritzalis, T., Harris, I., Hauck, J., Haverd, V., Hoppema, M., Klein Goldewijk, K., Jain, A. K., Kato, E., Körtzinger, A., Landschützer, P., Lefèvre, N., Lenton, A., Lienert, S., Lombardozzi, D., Melton, J. R., Metzl, N., Millero, F., Monteiro, P. M. S., Munro, D. R., Nabel, J. E. M. S., Nakaoka, S., O'Brien, K., Olsen, A., Omar, A. M., Ono, T., Pierrot, D., Poulter, B., Rödenbeck, C., Salisbury, J., Schuster, U., Schwinger, J., Séférian, R., Skjelvan, I., Stocker, B. D., Sutton, A. J., Takahashi, T., Tian, H., Tilbrook, B., Laan-Luijkx, I. T. van der, Werf, G. R. van der, Viovy, N., Walker, A. P., Wiltshire, A. J. and Zaehle, S.: Global Carbon Budget 2016, Earth Syst. Sci. Data, 8(2), 605–649, doi:10.5194/essd-8-605-2016, 2016.

Tanja, S., Berninger, F., Vesala, T., Markkanen, T., Hari, P., Mäkelä, A., Ilvesniemi, H., Hänninen, H., Nikinmaa, E., Huttula, T., Laurila, T., Aurela, M., Grelle, A., Lindroth, A., Arneth, A., Shibistova, O. and Lloyd, J.: Air temperature triggers the recovery of evergreen boreal forest photosynthesis in spring, Glob. Change Biol., 9(10), 1410–1426, doi:10.1046/j.1365-2486.2003.00597.x, 2003.

Zhao, M. and Running, S. W.: Drought-Induced Reduction in Global Terrestrial Net Primary Production from 2000 Through 2009, Science, 329(5994), 940–943, doi:10.1126/science.1192666, 2010.