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Atmospheric Chemistry and Physics Discussions

Interactive comment on "Analysis of CO_2 mole fraction data: first evidence of large-scale changes in CO_2 uptake at high northern latitudes" *by* J. M. Barlow et al.

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We thank the two reviewers for providing useful feedback on our submitted manuscript. Below we respond to general and specific comments (shown in italics) provided by these reviewers.

Response to Referee 1

"Barlow et al. present an atmospheric CO2 time-series data analysis focussing on Northern hemisphere high latitudes. They use wavelet analysis for this purpose. They focus on changes in characteristics of the seasonal drawdown - release characteristics. They find evidence for increases in carbon uptake during summer. The paper is interesting and the approach seems sound. As such I recommend publication of the study.

Minor issues:"

"Formulations are not sufficiently precise."

The reviewer raises as one of their primary examples, our less-than-clear distinction between the benefits of using wavelet analysis to detrend the CO2 mole fraction data and using the first derivative of CO2 for this analysis. Indeed, it is our use of the first derivative that means our analysis reflects changes that are more closely related to the flux of CO2 at the beginning and end of the carbon uptake period. We have revised the paper so that the scientific formulation of the paper, including the example described here, is more precise.

"Too many abbreviations."

At the time of writing we consciously minimized the number and use of abbreviation. Unfortunately, the nature of this work necessitates some abbreviations. To address this reviewer concern we have moved the discussion of the analysis of CO2 mole fraction

to the appendix and focused in the main text on our analysis of the first derivative of CO2 mole fraction.

Line 46 – "not sure what you are trying to say - do you mean wavelet analysis is superior to fourier analysis - or do you mean analysing the first derivative of CO2 is better at capturing .. than CO2 ? please rewrite to clarify"

Analysing the first derivative of CO2 to estimate changes in phase of the seasonal cycle is more accurate than using the DZCP and UZCP values inferred from the CO2 mole fraction data, which have been used by previous studies. We show in Figures 12, 13 and 14 that there can be a significant trend in the CO2 DZCP and UZCP, even when the timing of the beginning and end of the period of net carbon uptake has not changed.

The wavelet transform has a number of advantages over the Fourier transform. First, it can be used for non-stationary and stationary time series analysis without the need for additional curve-fitting procedures. Second, it provides three-dimensional information about the respective amplitudes of frequency components within a signal and how they change with time. For the purpose of estimating phase changes and amplitude, the differences between using classical filtering methods and wavelet filtering are likely to be small.

Line 54 – "difficult to understand - my understanding of aliasing is that harmonics maybe erroneously interpreted as 'ground' frequency; please explain better what you mean"

We use aliasing to define the misidentification of a signal frequency, introducing distortion or error. We show in our work that the zero-crossing points of the CO2

concentration can only be estimated from the de-trended seasonal cycle. The long-term increase in CO2 is driven by changes in net flux. De-trending results in the seasonal cycle being shifted up or down relative to the zero line, such that the annually integrated flux (of the detrended cycle) is equal to zero. As such, an increase in net uptake in one year will cause a shift to the CO2 DZCP and UZCP even if there is NOT a real change in phase. As the first derivative is closely related to the actual flux, it is less affected by this seasonal cycle shifting relative to the zero-line. We demonstrate this aliasing error in Figures 12, 13 and 14. We have clarified our definition of aliasing error in the manuscript.

Line 64 – "do you mean 'from the two continents' - also if yes how do you know?"

We refer to the seasonal contributions of CO2 fluxes from different geographical regions to high-latitude monitoring sites. Figure 2 shows using prior emissions and an atmospheric transport model that the seasonal cycle is driven by high-latitude fluxes, and that the magnitude of the contributions from boreal regions in Eurasia and North America are approximately equal.

Line 127 – "why is this an attractive property - can you explain a bit ?"

The Morlet wavelet is non-orthogonal, which means that the transform is redundant at large scales, where the wavelet spectrum is highly correlated at adjacent times. It is more useful for time series where smooth, continuous variations in wavelet amplitude are expected such as atmospheric CO2 mole fractions. This is supported by our analysis of synthetic time series shown in the Appendix.

Line 262 – "can you comment whether this casts doubt on the NDVI data / their

interpretation ?"

This depends on the interpretation of the NDVI data. The key point here is that more greening does *not* necessarily mean higher net CO2 uptake.

Line 265 – "by the end of this paragraph it is not clear to what extent the remote sensing results should be trusted given that they are not in full agreement with your CO2 time-series analysis - can you add a sentence which tells the reader what he should now take home wrt to the satellite data?"

It might be intuitive to think that the period of net carbon uptake would extend with an extension of the growing season, however this is not the case. The edges of the growing season are warmer and it is inferred from the NDVI data that greening has extended at both ends of the growing season, which indicates higher rates of photosynthesis. Conversely, we find that the carbon uptake period has shifted earlier in the year but has retained its length. If photosynthesis has increased at the end of the growing season, and it is a change in net ecosystem exchange that explains the change in CO2 phase, this implies that respiration must have increased more than photosynthesis towards the end of the growing season.

Response to Anonymous Referee 2

"This paper has applied wavelet analysis for decomposing atmospheric CO2 time series.They have then analysed the growth rates, and seasonal cycle amplitude and phase measured at various locations by NOAA. The topic of this research is interesting and ongoing for long time. Using the wavelet analysis tools, the authors did find results well established in the community. However, the authors often did not give due

credits to many of the earlier studies where decadal mean growth rates have been discussed, or the other statistical tools that have been in the market for decomposing CO2 time series and gap filling. This is evident from very short list of references. For me the paper was hard to read and extract novel scientific information. All through the manuscript sounded like a technical document. Unless a complete overhaul is made to the manuscript, I do not see the manuscript getting published in general section of ACP. The manuscript however can be published as technical note section of ACP."

This is primarily a science-led paper with a clear science focus. To achieve that result we have had to necessarily characterize the spectral method we used and the use of the first differential of CO2 for interpreting the CO2 data. To a large extent we have formatted the paper so that the reader is spared the mathematics, with most of the technical details relegated to appendices. Here, we have addressed the reviewer comments associated with the readability of the paper. We have improved this by further clarifying statements/formulations used throughout the paper.

Line by line adjustments to paper

Title Page, Page 1 (7089)

Abstract, Page 2 (7090)

Line 2 – Added sentence

Line 15 – changed "corresponding uptake" to "corresponding net uptake".

Line 18 – Corrected units (added yr^{-1})

Line 20 – added "in spring and summer".

Page 3 (7091)

Line 2 – removed “variation”.

Line 7 – removed “biosphere”.

Line 11 – changed “have” to “has”.

Line 11 – added citation

Line 16 – changed “Analysis of atmospheric measurements of CO2 to describe changes in the seasonal cycle has been explored in previous studies” to “Many previous studies have used atmospheric measurements of CO2 to analyse changes in the seasonal cycle.”

Line 20 – added a sentence: “The most commonly used method to extract a smoothed seasonal cycle is a combination of curve-fitting and spectral filtering as outlined by Thoning et al. (1989).”

Line 24 – rewrote sentence about wavelet transform.

Line 26 – removed sentence.

Page 4 (7092)

Line 1 – Rewrote sentence to clarify that it is the use of the first derivative of CO2 that results in the more accurate estimates of phase changes.

Line 17 – Removed “high latitude”.

Line 18 – Changed “Cooperative Global Air Sampling Network” to “Global Greenhouse Gas Reference Network”.

Line 20 – Changed “transport is relatively zonal so that observed variations of CO2 are due to CO2 fluxes at the same latitude band” to “seasonal contributions of CO2 are predominantly driven by boreal vegetation”.

Page 5 (7093)

Line 4 – Changed “higher” to “longer”.

Line 8 – Changed “simultaneously” to “within 20 seconds of one another”.

Line 8 – Added a sentence.

Line 8 – Rewrote sentence.

Line 13 – Rewrote sentence. Added statement: “This ensures that gradual changes in the seasonal cycle amplitude/phase are preserved”.

Line 18 – Changed “unreliable” to “unrepresentative of real changes”.

Page 6 (7094)

Line 5 – Added “(mol/mol)”

Line 6 – Added “of the internationally accepted Pee Dee Belemnite”.

Line 6 – Removed sentence: “(a substance with a known, unchanging. . .)”.

Page 8 (7096)

Line 12 – Rewrote and reordered some of paragraph to better explain effect of padding with synthetic data.

Page 9 (7097)

Line 17 – Changed “1980 to 2009” to “1980s to 2000s”

Line 21 – Changed “partially” to “primarily”

Line 22 – Removed “the collapse of the Soviet Union but also due to”

Line 24 – added “compared to later years . . . “

Page 10 (7098)

Line 9 – Added that growth rates are averaged across all sites and uncertainty is 1 sigma.

Line 20 – Simplified sentence.

Page 11 (7099)

Line 17 – I rewrote this paragraph. I wanted to spell out more clearly the problem with using the CO2 ZCPs.

Line 28 – Rewrote section beginning “To address this. . . “ to be more concise.

Page 12 (7100)

Line 9 – removed “of the wavelet transform” as this is relevant to any technique used to isolate the seasonal cycle.

Line 13 – Rewrote sentence for clarity.

Line 28 – Moved comment on phase estimates from the detrended CO2 seasonal cycle to the appendix. Focus in main paper is on ΔCO2.

Page 13 (7101)

Line 7 - changed δ^{13} to $\Delta\delta^{13}$

Line 9 – changed “surface temperature analyses” to “surface temperature reanalyses”

Line 17 – split sentence starting line 17 in two, “In contrast . . .”

Line 18 – added the word “photosynthetic”

Line 26 – added sentence to clarify interpretation of NDVI data.

Line 29 – removed “when using the wavelet transform” as this is applicable to other methods too.

Page 14 (7102)

Line 7 – cited Figure showing trend in amplitude vs trend in net uptake and release respectively

Line 15 - Changed “transport is relatively zonal so that observed variations of CO2 are due to CO2 fluxes at the same latitude band” to “seasonal contributions of CO2 are predominantly driven by boreal vegetation”.

Line 26 – Rewrote this sentence to make it easier to read.

Page 22 (7110)

Line 11 – Rewrote sentence for clarity.

Page 22 (7111)

Line 14 – Corrected typo and missing word: “significantly different”

Line 23 – Corrected typo: “spring”

Page 42 (7130)

Figure caption – the first differential CO2 phase metrics are compared with the first differential isotope metrics. I revised the text to make this clear.

Please also note the supplement to this comment:
http://www.atmos-chem-phys-discuss.net/15/C8069/2015/acpd-15-C8069-2015-supplement.pdf

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