Response to referee comments (in red):

Anonymous Referee #2
Received and published: 25 March 2016

This study takes an important step beyond the well-documented increase in atmospheric CO2 seasonal amplitude at Arctic monitoring sites and asks whether this amplitude increase actually reflects a net gain in CO2 uptake in boreal and Arctic regions. The methodology involves exploring trends in NEE fluxes inferred from 2 different inversion systems over the common period 1986-2006 (and also 1985-2012 for one of the inversions). In general, the study is well presented and documented and I support publication with minor revision. Some of my more important (although still relatively minor) concerns are that the results differ substantially between the two inversions in many aspects, leading to doubts about the robustness of either.

Added: " *These differences are not unexpected given the differences in atmospheric transport and model structure between the inversion models. In this analysis we try to focus on the most robust features were the models do tend to agree on the trends in anomalies from the mean."*

Also, the Arctic zone>60N is the region with the most unequivocal increase in CO2 amplitude, yet the inversions estimate significant trends in net CO2 uptake mainly in the boreal zone (50-60N), not the Arctic zone. The CO2 amplitude increase at Barrow, AK (71N) in particular has been the subject of much attention, yet it doesn't seem to be associated with an actual increase in CO2 uptake in the surrounding region. A particularly interesting result is that the inversions suggest that increased CO2 respiration and release in fall may largely balance increased CO2 uptake in summer (although they don't agree where the increased fall respiration is occurring). I am curious about the heavy focus on midsummer (July) at the expense of late spring/early summer, when the CO2 cycle (e.g., at Barrow) indicates an earlier onset of photosynthesis. Could this be when some of the net gain in CO2 uptake is occurring?

I think the reviewer is confusing trends in concentration amplitude with flux amplitude. The inversion should be able to separate influence in the spring from the mid-summer.

Re: the 2 time periods chosen: 1986-2006 and 1985-2012. I suggest making the second period 1986-2012, to remove ambiguity about why the results differ between the 2 periods. With the 1985 start year, we don't know whether the changes in the trends are due to the influence of starting in 1985 vs. 1986 or due to more recent changes from 2006-2012. The latter possibility seems more relevant to global change, therefore I suggest eliminating this ambiguity by starting both periods in 1986. Trend calculations of this sort can be sensitive to the starting year, especially when operating on the margins of statistical significance, as is the case here. On a related note, is the legend in Fig 3b (86-12) a typo?

Regarding the start year and periods of trend calculations, we agree with the reviewer's comments about sensitivity to start year. That's why we think it is a more robust estimate to use the longest records possible. It is not our intension to comment on the difference between 86-06 and 85-12 as a measure of processes from 06-12. Rather, the intension to use as much information as possible to examine the longterm trends. Fixed the 86-12 typo. Should be 85-12.

Some specific comments
Abstract, there are a couple of grammatical errors or typos that interfere with smooth reading:
AbL17-18 "Here we examine CO2 fluxes from northern boreal and tundra from 1986 to 2012 ..."

edited

AbL29-31 sentence beginning with "Meanwhile . . .

edited

P2L35 (1997)?

citation fixed

P3L20-26 Please define what exactly is meant by "browning" and "greening," e.g., does this refer to changes in seasonality of NDVI, or does it refer to an annual mean index?

Some studies examine maximum and others the growing season integrated NDVI. This comment was added.

The Introduction in general is quite good and informative, but is marred by the paragraph on L8-17. I have several suggestions for improving it:
P4 L8-17 The emphasis on aboveground vs. belowground in the first sentence seems incongruous because it is

not mentioned earlier as a strength of inversions. Perhaps start this paragraph with a more general statement about the strengths of forest inventories.

The reviewer's comment was valid. We edited the entire paragraph to improve the context with the rest of the introduction.

P4 L13 For clarity, should "several studies" be "several process-based model studies"?

change made

P4 L11-17 Can we believe these results? What are the weaknesses of process-based model studies? (Referring back to earlier statement that, "Each of these methods has its strengths and weaknesses.")

The models need to be validated and atmospheric inversions can help in that effort.

P4L18 ". . .50N, using the atmospheric inversion method."

Moved the second sentence forward to introduce the inversion method at the start.

P4L35 What is "It" ?

RIGC

P5L7 What period?

1985-2006

P5L9 Temporal coverage of what? Years, months, weeks? What is the time resolution?

It varies by station and time period, but at least monthly resolution was the aim.

P5L21 What is LPJ?

The Lund-Potsdam-Jena model is commonly referred to a LPJ in the literature.

P5L30 What are the units of NDVI? Are they mass units, e.g., kg/m2 or flux units, e.g., in kg/m2/s?

Unitless. It's a ratio of light reflectance in different wavelengths. This is described briefly now.

P6L10- Perhaps I am missing something, but I don't see the 2 different analysis methods for trends and significance reported in Table 2 described anywhere in this section. There is only a brief mention of them in the Table 2 caption, which is not very informative.

We added a paragraph in section 2.3, Analysis Approach, that describes each of these statistical methods and cites the sources.

P6L15 In Figure 1 the boreal forest stippling extends well north of 60 degrees. Does this mean that the so-called Arctic zone consists largely of boreal forest? This is somewhat confusing and perhaps should be noted here. Other parts of the text seem to suggest the Arctic zone is mainly tundra, but later p.12 mentions that tundra covers only 25% of the Arctic zone.

Added a comment on this.

Figure 3c,d. Should the Y-axis units be gC/m2/day per year?

Yes. Fixed.

P7L33. Probably should note that $P < 0.1$ is significant at only 10% level, which is a weak standard. In general $p < 0.05$ is the standard level required for significance.

Added a comment on this to the new paragraph on statistics in section 2.3.

P9L13. How were these 40-50 and 55-65N bands chosen?
Figure 7 seems to suggest net release and net uptake for 40-55N and 55-75N, respectively. Also, please check P13L10 for consistency.

From comparing July and fall trends in Fig 7b. Changed 55-65 to 55-70N.

P9L25 In order to . . .

Fixed.

P10L27 "We found significantly strong positive correlations between July CO2 flux and April through August temperatures of the same year. . ." The next sentence is confusing because it suggests lower CO2 uptake (more

release) in warm years, in contrast to the quoted sentence – please clarify that "positive correlation" means the July flux is weaker not stronger.

This is confusion about the sign convention of NEE. Added: *"It is also important to remember that NEE is negative when there is net CO_2 uptake from the atmosphere when interpreting the sign of correlations."*

P12L17-20 "Increased summer CO2 uptake cannot be explained by earlier spring leaf-out, but rather points to changes in mid-summer photosynthetic and respiration fluxes themselves." Where is this sentence supported in the Results?

We decided to cut this sentence because the point about increased summer uptake was already made. Relating that model prediction to spring leaf out was confusing.

P12L31-33 "This difference could reflect the importance of structural ecosystem changes due to warming on the long time scale increasing photosynthesis (Graven et al., 2013), but on the short time scale, respiration is the dominant control." This seems like a core conundrum of this study (together with the fact that no apparent increase in net CO2 uptake is occurring in the band where the CO2 amplitude is increasing). Both of these points might be worth discussing more.

Actually, the July CO_2 uptake is increasing in the boreal zone, as shown in Fig 5, it's just smaller when expressed as a % increase in the seasonal flux amplitude in Fig 4. Graven et al. (2013) showed that the summer boreal CO_2 uptake must be increasing as well from atmospheric constraints. Atmospheric transport can cause somewhat of a disconnect between observed amplitude changes and the region of fluxes. It has been shown that even far northern flask stations are somewhat influenced by more southerly fluxes.

I don't find the different drivers for long-term trends and short-term interannual variability to be contradictory. Added: "*This difference could reflect the importance of structural ecosystem changes due to warming on the long time scale increasing photosynthesis (Graven et al., 2013), but are also consistent with respiration as the dominant control of NEE on short time scales (Schaefer et al., 2002)."*

Response references:

Graven, H. D., Keeling, R. F., Piper, S. C., Patra, P. K., Stephens, B. B., Wofsy, S. C., Welp, L. R., Sweeney, C., Tans, P. P., Kelley, J. J., Daube, B. C., Kort, E. A., Santoni, G. W. and Bent, J. D.: Enhanced seasonal exchange of CO_2 by northern ecosystems since 1960, Science, 341(6150), 1085–1089, doi:10.1126/science.1239207, 2013.

Schaefer, K., Denning, A. S., Suits, N., Kaduk, J., Baker, I., Los, S. and Prihodko, L.: Effect of climate on interannual variability of terrestrial CO_2 fluxes, Global Biogeochemical Cycles, 16(4), 49–1–49–12, doi:10.1029/2002GB001928, 2002.