Trends in seasonal high northern latitude CO_2 fluxes from 1986 - 2007 from a time dependent inversion and compared with NDVI

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MOTIVATION

CO_2 mixing ratios observed at high northern latitudes have been increasing in seasonal peak-to-trough amplitude over the last several decades in the SIO CO_2 network station observations and GLOBALVIEW-CO_2 product. It is unclear where and what changes in the terrestrial biosphere have lead to this amplitude increase, and how these changes have affected the net carbon balance in northern ecosystems.

There is the potential for positive and negative feedbacks in these temperature limited ecosystems as warming can lead to both increased photosynthetic CO_2 uptake or increased CO_2 release from respiration. These ecosystems are likely to first become increased CO_2 sinks as longer growing seasons promote more vegetation growth, and over time, switch to sources of CO_2 as massive quantities of carbon stored in permafrost become available for microbial respiration (Cox *et al.,* 2000; Schuur *et al.,* 2008).

Satellite monitoring of NDVI gives clues about changing photosynthesis rates and where increased CO_2 uptake may occur. From ~1982-1997, NDVI in the boreal forest and tundra ecozones were greening, but since then, the boreal forests trend has reversed, although tundra NDVI continues to increase (Goetz *et al.,* 2005). Here, we examine the long-term variability in inferred CO_2 fluxes and compare with spatially variable NDVI to identify likely regions of change.

METHODS & DATASETS

We used a 64-region time-dependent inverse (TDI) method to infer regional and temporal carbon source/sink distribution from 1986 through 2007. The inverse calculation started with *a priori* estimates of monthly fossil fuel emissions from EDGAR (v4.0), terrestrial fluxes from CASA (Randerson *et al.,* 1997), and oceanic fluxes from Takahashi *et al.* (2009) which we optimized to match atmospheric CO_2 observations from GLOBALVIEW-CO_2. The inversion used interannually varying winds in the NIES/FRCGC atmospheric tracer transport model following Patra *et al.* (2005). We limited the CO_2 data used to constrain the fluxes to 26 observation stations with nearly continuous records over the period of interest including Barrow (71ºN), Alert (82ºN) and Station M (66ºN) above 60ºN and Cold Bay (55ºN) and Shemya (52ºN) above 50ºN. This avoided creating spurious trends in the inversion results from adding new stations mid-way through the period. We focused our analysis on the interannual variability of land CO_2 fluxes in two roughly zonal bands in the far north (Fig 1, in blue).

We compared CO_2 fluxes with satellite-derived monthly normalized difference vegetation index (NDVI) measured by AVHRR (1985-1999) and MODIS (1999-2007) sensors that were homogenized and supplied at the 1º x 1º resolution (Tucker *et al.,* 2005).

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1 Inversion basis regions

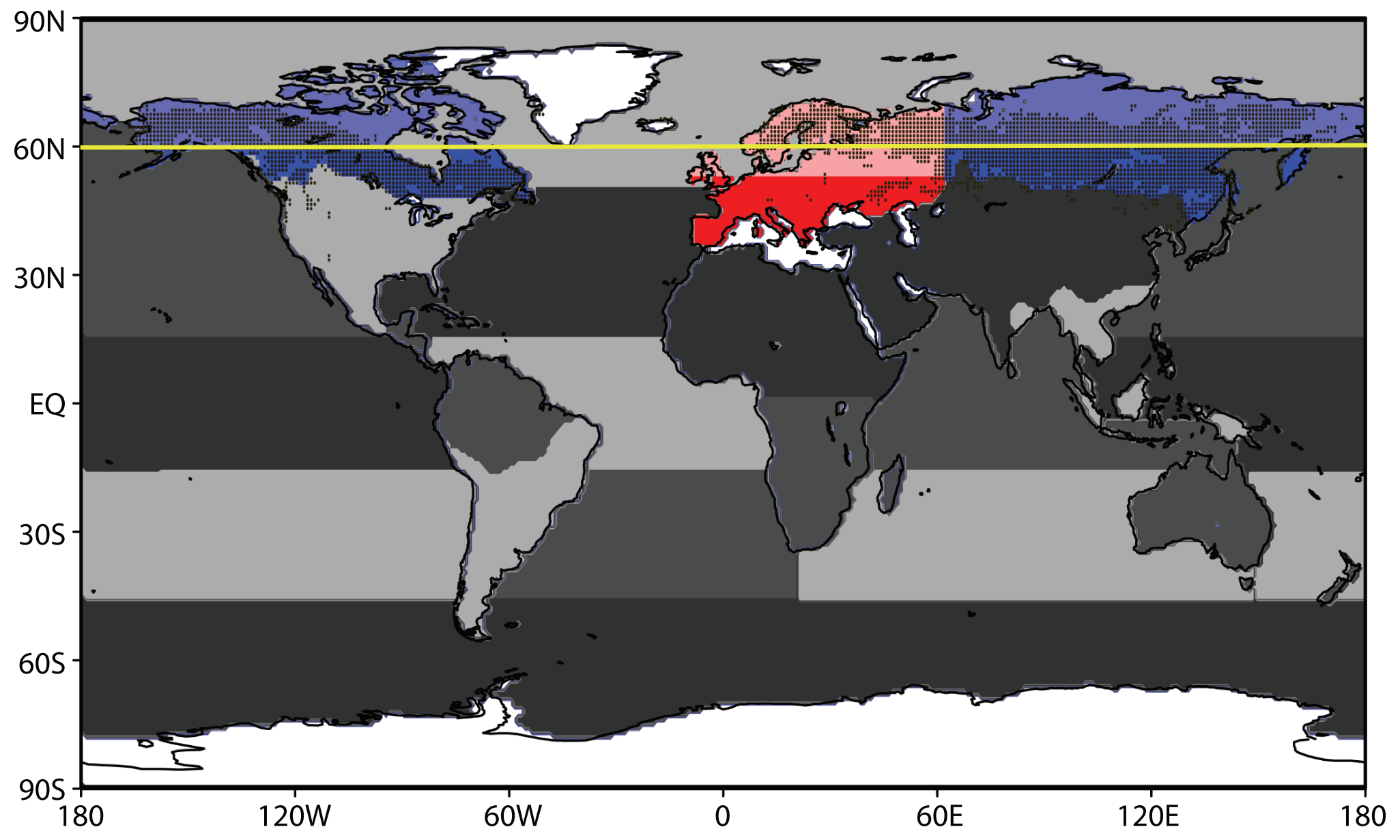

Figure 1. The major basis regions used in the time dependent inversion based on the TransCom-3 regions. Further divisions within the northernmost land regions are shown in color. The two zones that we discuss cover Boreal North America and Boreal Asia and are marked in light blue, north of 60ºN, and dark blue, 50ºN to 60ºN. The European basis region, in red, is not divided at 60ºN (yellow line) and therefore not included in this analysis. Stippling indicates the boreal forest biome. The tundra biome is north of the stippling.

2 Annual trends

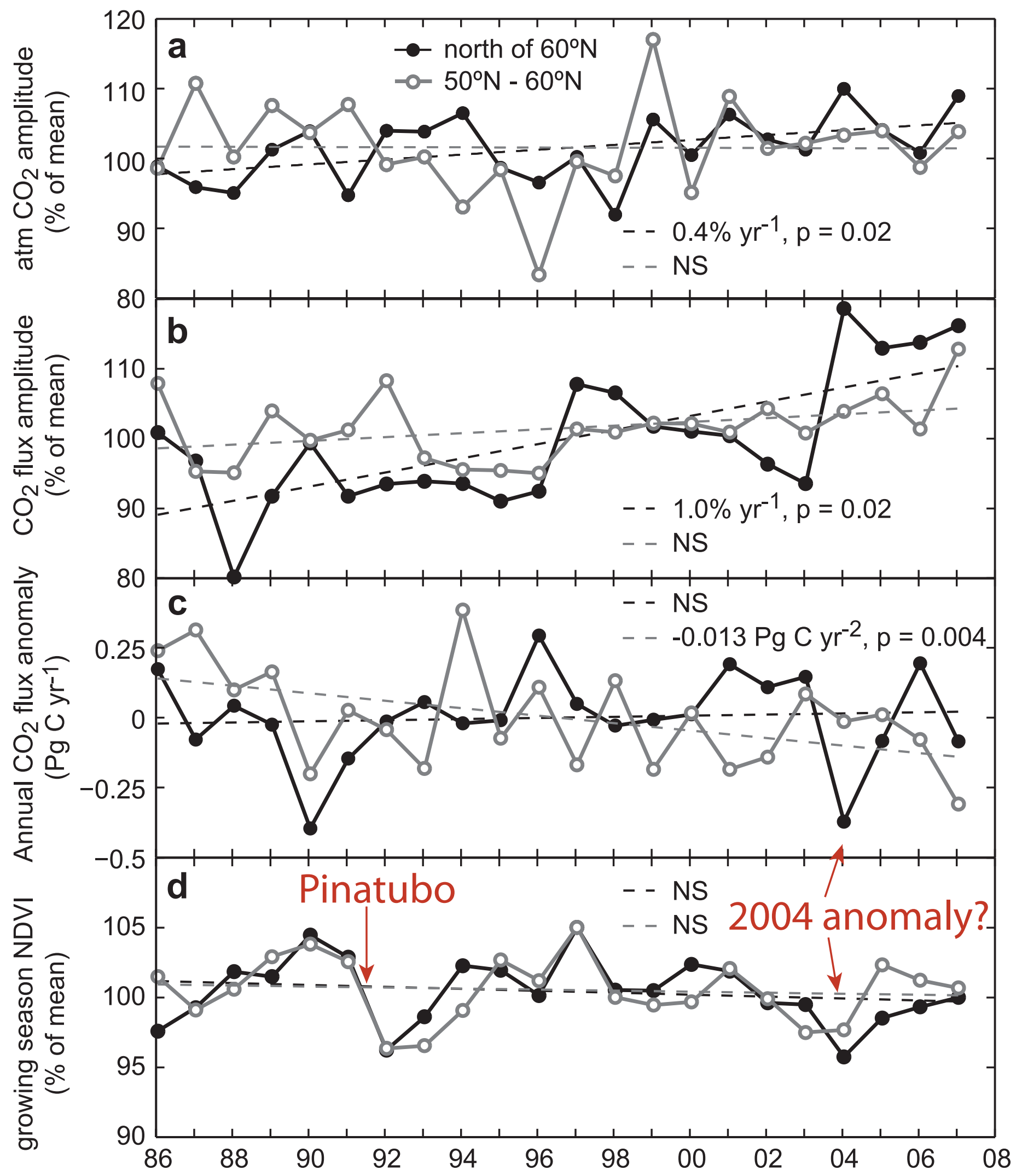

Figure 2. For the two latitudinal zones of interest: (a) Seasonal amplitude of atmospheric CO_2 from GLOBALVIEW-CO_2 stations used in this analysis, divided by the mean. (b) Seasonal TDI CO_2 flux amplitude divided by the mean. (c) Annual TDI CO_2 flux with the means subtracted. Negative fluxes are into the biosphere. (d) Mean growing season (Apr - Oct) NDVI integrated over the latitudinal zones, divided by the mean. Statistical significance at the 95% CI, accounting for auto-correlation, was done using the method of Ebisuzaki *et al.* (1997). NS = not significant

3 Monthly flux trends

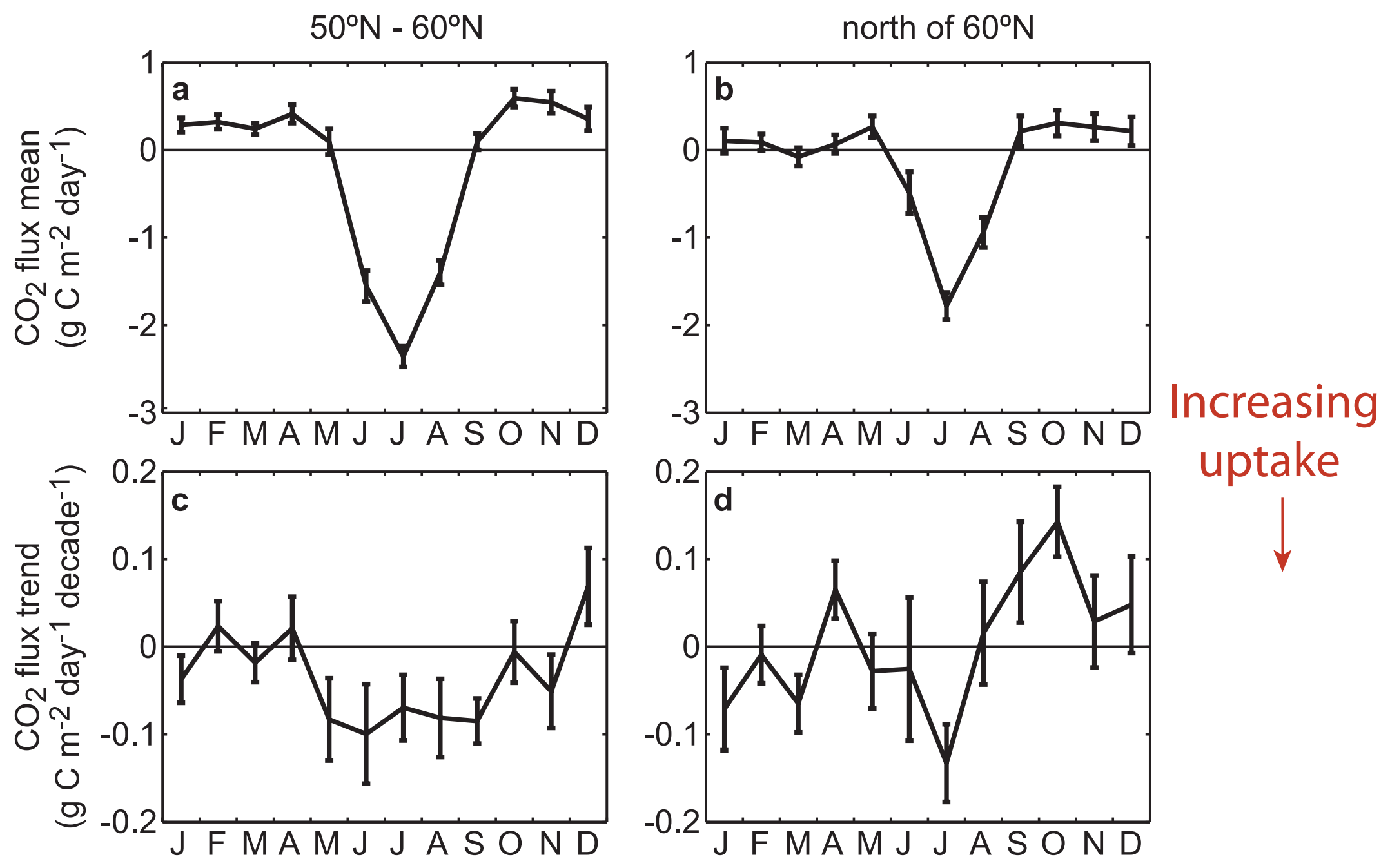

Figure 3: Ensemble mean monthly CO_2 fluxes and standard deviation from 1986 to 2007 from land regions (a) from 50ºN to 60ºN and (b) north of 60ºN. Linear trends from least squares fitting of the monthly CO_2 fluxes over this period from land regions (c) from 50ºN to 60ºN and (d) north of 60ºN. In the 50ºN to 60ºN zone, CO_2 uptake increased throughout the entire growing season. In the north of 60ºN zone, increased July uptake was offset by enhanced fall release of CO_2 resulting in no trend in the annual net flux (Fig 2c).

4 Correlations with NDVI

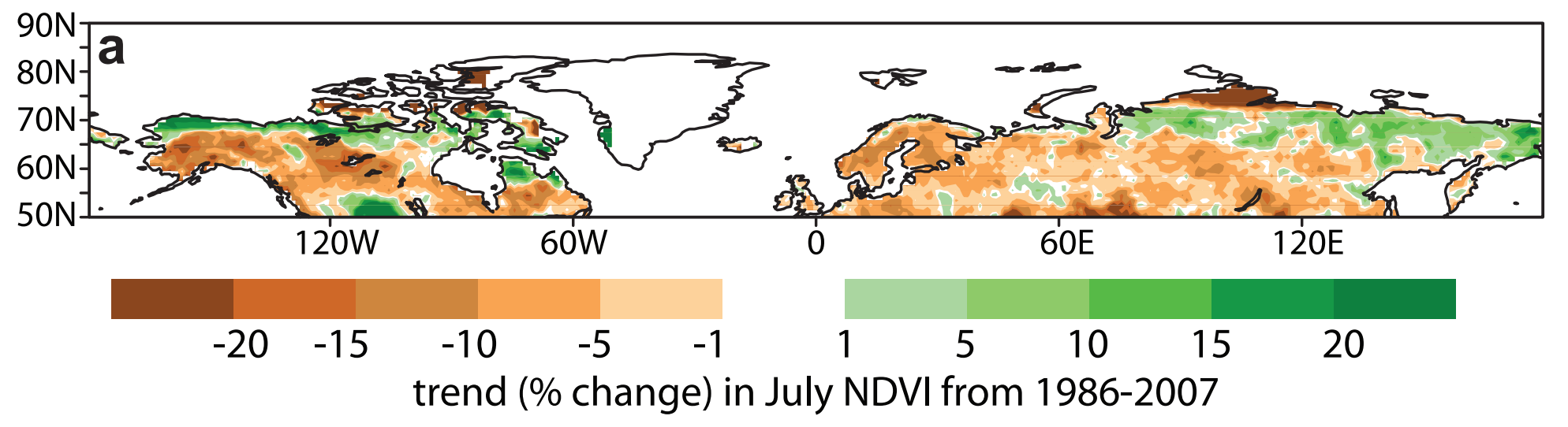

Figure 4a: Trends in NDVI for the month of July from 1986 to 2007. July is the month of the largest trend towards increased CO_2 uptake north of 60ºN The tundra regions have shown the most greening over this period.

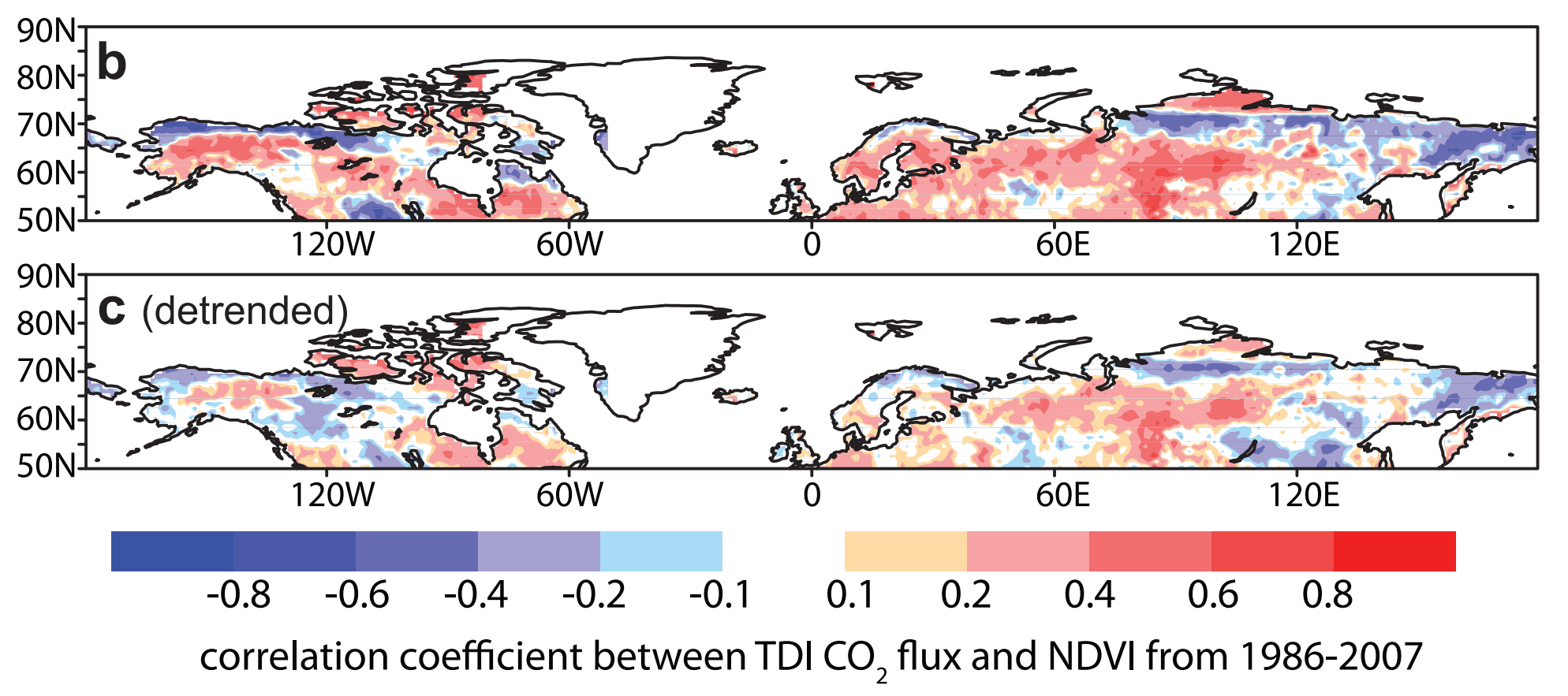

Figure 4bc: Correlations between July TDI CO_2 fluxes from the north of 60ºN region and 1º x 1º NDVI in July from 1986 to 2007. Tundra NDVI has been increasing (Fig 4a) while the north of 60ºN July TDI CO_2 flux has been becoming more negative over this period (Fig 3d). Panel (b) is the temporal correlation of the July observations. In (c), these long-term trends have been removed by linear detrending. The blues show gridcells that are greener when CO_2 uptake is greater (negative correlation) and these areas are mostly within the tundra biome. Detrending the data sets decreased the correlation coefficients, but did not eliminate them in (c).

CONCLUSIONS

north of 60ºN

Seasonal peak-to-trough amplitude of atmospheric CO_2 mixing ratio increased by roughly 8% (Fig 2a) and the monthly TDI CO_2 fluxes increased by 22% over the 22 years of this study (Fig 2b).

July uptake increased by 0.29 g C m^{-2} day^{-1} (Fig 3d) and was most strongly correlated with NDVI in the tundra regions (Fig 4). Changes in tundra regions are likely the dominant cause of changes in the July CO_2 flux north of 60ºN. This would require an increased sequestration of 1.2 g C m^{-2} day^{-1} during the peak of the growing season in the tundra and would imply major changes in productivity. Estimates of net ecosystem production by the tundra in the summer range from 0.7 to 5.6 g C m^{-2} day^{-1} (Corradi *et al.*, 2005; Fox *et al.,* 2008; Lafleur and Humphreys, 2008; Zimov *et al.,* 1999). Therefore, this trend represents an approximate doubling of peak summer CO_2 uptake.

Increased CO_2 release in the fall offset the gains in July (Fig 3d) resulting in no change in the annual net carbon exchange (Fig 2c).

50ºN to 60ºN

There was no trend in the seasonal amplitude of the atmospheric CO_2 (Fig 2a) and while the trend in monthly TDI CO_2 fluxes showed increased growing season uptake (Fig 3c), the flux amplitude increase was not statistically significantly (Fig 2b).

Annual CO_2 uptake increased over the 22 years of this study by 13 Tg C yr^{-2} (Fig 2c). This is in spite of increased fire frequency and widespread browning identified from previous NDVI studies (Goetz et al., 2005). Over this study period, we did not observe a trend in growing season NDVI in this latitudinal zone (Fig 2d).

Summary

Overall, the TDI fluxes showed no indication of a large-scale positive climate-carbon feedback caused by warming temperatures in the high northern latitude terrestrial CO_2 fluxes as of 2007 (Fig 2c).

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