Trends in seasonal high northern latitude CO₂ fluxes from 1986 - 2007 from a time dependent inversion and compared with NDVI

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MOTIVATION

CO₂ mixing ratios observed at high northern latitudes have been increasing in seasonal peak-to-trough amplitude over the last several decades in the SIO CO₂ network station observations and GLOBALVIEW-CO₂ product. It is unclear where and what changes in the terrestrial biosphere have led 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 CO₂ uptake or increased CO₂ release from respiration. These ecosystems are likely to first become CO₂ sinks as longer growing seasons promote more vegetation growth, and over time, switch to sources of CO₂ as massive quantities of carbon stored in permafrost become available for microbial respiration (Con et al., 2000; Schuur et al., 2008).

Satellite monitoring of NDVI gives clues about changing photosynthetic rates and where increased CO₂ uptake may occur. From 1982-1997, NDVI in the boreal forest and tundra ecosystems were growing, but since then, the boreal forests trend has reversed, although tundra NDVI continues to increase (Geert et al., 2005). Here, we examine the long-term variability in inferred CO₂ 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 (v3.2), terrestrial fluxes from CASA (Randerson et al., 1997), and oceanic fluxes from Takahashi et al. (2009) which we optimized to match atmospheric CO₂ observations from GLOBALVIEW-CO₂. The inversion used interannually varying winds in the NIES/FGOCC atmospheric tracer transport model following Patra et al. (2005).

We limited the CO₂ data used to constrain the fluxes to 26 observation stations with nearly continuous records over the period of interest including Barrow (71°N), Alert (82°N) and Station M (66°N) above 60°N and Cold Bay (55°N) and Shemya (52°N) above 50°N. 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 CO₂ fluxes in two roughly zonal bands in the far north (Fig 1, in blue).

We compared CO₂ fluxes with satellite-derived monthly normalized difference vegetation index (NDVI) measured by AVHRR (1981-1999) and MODIS (1998-2007) sensors that were homogenized and supplied at the 1° x 1° resolution (Tucker et al., 2005).

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REFERENCES

CONCLUSIONS

of north of 60°N

Seasonal peak-to-trough amplitude of atmospheric CO₂ mixing ratio increased by roughly 8% (Fig 2a) and the monthly TDI CO₂ 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 CO₂ flux north of 60°N. 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 productivity by the tundra in the summer range from 0.7 to 5.6 g C m⁻² day⁻¹ (Carnell et al., 2005; Fox et al., 2008, LaBelle and Humphreys, 2008; Zimov et al., 1999). Therefore, this trend represents an approximate doubling of peak summer CO₂ uptake.

Increased CO₂ release in the full effect the gain in July (Fig 3d) resulting in no change in the annual net carbon exchange (Fig 2c).

50°N to 60°N

There was no trend in the seasonal amplitude of the atmospheric CO₂ (Fig 2a) and while the trend in monthly TDI CO₂ fluxes showed increased growing season uptake (Fig 3c), the flux amplitude increase was not statistically significantly (Fig 2b).

Annual CO₂ uptake increased over the 22 years of this study by 11 Tg C y⁻¹ (Fig 2c). This is in spite of increased fire frequency and widespread burning identified from previous NDVI studies (Gove 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 CO₂ fluxes of as of 2007 (Fig 2c).

Figure 1. The major basis regions used in the time dependent inversion based on the TransCom-2 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 60°N, and dark blue, 59°N to 60°N. The European basis region, in red, is not divided at 60°N (yellow line) and therefore not included in this analysis. Stepping inside the boreal forest biome. The tundra biome is north of the stippling.

Figure 2. For the two latitudinal zones of interest: (a) Seasonal amplitude of atmospheric CO₂ from GLOBALVIEW-CO₂ stations used in this analysis, divided by the mean. (b) Seasonal TDI CO₂ flux amplitude divided by the mean. (c) Annual TDI CO₂ 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 autocorrelation, was done using the method of Ebbettzka et al. (1997). NS = not significant.

Figure 3a: Ensemble mean monthly CO₂ fluxes and standard deviation from 1986 to 2007 from land regions (a) from 59°N to 60°N and (b) north of 60°N. Linear trends from least squares fitting of the monthly CO₂ flux over this period from land regions (c) from 59°N to 60°N and (d) north of 60°N. In the 59° to 60°N zone, CO₂ uptake increased throughout the entire growing season. In the north of 60°N, increased July uptake was offset by enhanced full release of CO₂ resulting in no trend in the annual net flux (Fig 2a).

Figure 4a: Trends in NDVI for the month of July from 1986 to 2007. July is the month of the largest trend towards increased CO₂ uptake north of 60°N. The tundra regions have shown the largest greening over this period.

Figure 4b: Correlations between July TDI CO₂ fluxes from the north of 60°N region and 1° x 1° NDVI in July from 1986 to 2007. Tundra NDVI has been increasing (Fig 4a) while the north of 60°N July TDI CO₂ flux has been becoming more negative over this period (Fig 4d). Panel (a) is the temporal correlation of the July observations. In (c), these long-term trends have been removed by lineare detrending. The blue line shows anomalies which are growing CO₂ 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).