OBSERVED RELATIONSHIPS BETWEEEN LARGE-SCALE ATMOSPHERIC VARIABILITY AND THE CARBON CYCLE

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ABSTRACT
Various patterns of large-scale climate variability have exhibited trends over the past few decades. These patterns of variability are known to have contributed substantially to recent trends in, for example, surface temperatures and precipitation. However, it is less clear to what extent the climate impacts of these patterns extend to the carbon cycle. Here we summarize the observed relationships between monthly and daily mean variations in concentrations of atmospheric carbon dioxide and the dominant pattern of variability in the extratropical circulations, the so-called Northern and Southern Hemisphere Annular Modes. The observed relationships are compared with results derived from surface flux estimates from the Atmospheric Tracer Transport Model Intercomparison Project (TransCom).

INTRODUCTION

Uncertainties about the effects of climate change on the sources and sinks of the global carbon cycle continue to impede our abilities to predict future atmospheric carbon dioxide (CO_2) concentrations. Large-scale climate patterns, such as the Northern Annular Mode (NAM) and Southern Annular Mode (SAM), may have important impacts on CO_2 fluxes. The NAM and the SAM are the dominant modes of variability of the sea-level pressure, geopotential height, or the zonal wind fields in the Northern and Southern Hemispheres, respectively (*Thompson and Wallace*, 2000). The positive polarity of both the NAM and SAM is defined by westerly wind anomalies in the mid- to high-latitudes and easterly wind anomalies in subtropical latitudes, and an associated anomalous poleward shift in the mid-latitude jet. These patterns of large-scale climate variability have exhibited trends towards positive polarity over the past few decades, and a large fraction of recent climate trends in the Northern and Southern Hemispheres are linearly congruent with the trends in the NAM and SAM, respectively (*Thompson et al.*, 2000; *Thompson and Solomon*, 2002). We investigate to what extent the climate impacts of these patterns extend to the carbon cycle. The observed relationships are compared with results derived from TransCom surface flux estimates.

RESULTS

A high index NAM implies a stronger polar vortex, leading to less cold outbreaks over high-latitude Northern Hemisphere (NH) land regions and warmer temperatures over much of Siberia, northern Europe, and parts of Canada, allowing an advance of spring budburst and a longer growing season, and thus higher annual CO_2 drawdown by the terrestrial biosphere (*Russell and Wallace*, 2004). We find that in general the best correlation between the NAM and monthly mean CO_2 tendency anomalies (derivatives of the concentration anomalies) in the NH occurs with a high index NAM leading atmospheric CO_2 uptake by 3-6 months, in agreement with this theory (not shown). Correlations between the winter NAM and the spring CO_2 TransCom flux estimates also suggest uptake by the biosphere over Europe, Boreal Asia, and Boreal North America following high index NAM winters (not shown).

Due to lack of nearby land regions with significant vegetation in the Southern Hemisphere (SH), the SAM is thought to impact atmospheric CO_2 via air-sea flux exchange. The key mechanism is unclear, but one major hypothesis is described here for the high index SAM scenario: increased westerly winds below 50S lead to anomalous equatorward Ekman drift and increased upwelling along the Antarctic coast, drawing anomalously cold and iron-rich water up to the surface, thereby increasing both solubility and phytoplankton productivity and resulting in an uptake of atmospheric CO_2 by the ocean below 50S (*Hall and Visbeck*, 2002). Correlations between the SAM and monthly mean CO_2 tendencies at SH stations show little relationship at any lag (not shown), possibly due to the dominance of the El Niño Southern Oscillation (ENSO) and Mt. Pinatubo eruption signals in the SH.

To isolate the effects of the SAM at stations where the amplitude of the SAM is thought to be greatest, we take the monthly CO_2 tendency anomalies and subtract the global mean tendency anomalies to create "departure" CO_2

tendencies about the global mean. Fig. 1 shows the lag correlation between the SAM and the departure CO_2 tendencies, for an average of the stations north of 30S to the equator (circles) and the stations south of 30S (crosses). Dashed lines represent 95% significant levels. An uptake of atmospheric CO_2 occurs about 3 months after a positive SAM event for stations south of 30S. TransCom flux estimates also suggest CO_2 uptake 3-5 months after a positive SAM for the South Indian, South Atlantic, and South America regions (not shown). We also examine daily CO_2 concentrations. We composite the difference in 500 hPa heights using daily CO_2 concentrations at Palmer Station (at zero lag), subtracting heights for days when CO_2 is less than 1 standard deviation about the mean from days when CO_2 is greater than 1 standard deviation about the mean. This composite (Fig. 2) shows a SAM-like pattern with low pressure over the pole and high pressure over subpolar regions. This suggests that changes in advection due to the SAM are influencing day-to-day changes in atmospheric CO_2 concentrations at Palmer Station, located on the Antarctica Peninsula, by transporting air rich in CO_2 from lower latitudes to the ice-covered high latitudes.

CONCLUSIONS

Relationships between the annular modes and atmospheric CO_2 are examined. Consistent with previous studies, lag correlations suggest that a high index NAM leads atmospheric CO_2 uptake in the NH by 3-6 months. Monthly mean CO_2 tendencies in the SH are overwhelmed with the signals from ENSO and volcanic eruptions, so "departure" CO_2 tendencies are created to isolate local effects of the SAM. A positive SAM event is associated with a decrease in the departure CO_2 tendencies 3 months later. The relationship between daily CO_2 concentrations at Palmer Station and 500hPa heights suggests that advection may be driving short-term (and even long-term) variations in CO_2 on the Antarctica Peninsula. TransCom flux estimates look promising as a way to examine how the NAM and the SAM may affect regional CO_2 fluxes.

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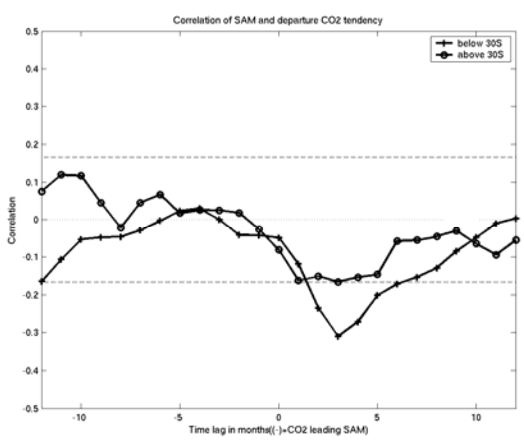

Fig. 1

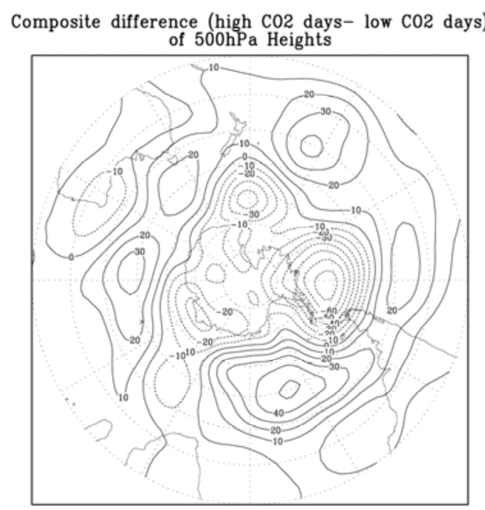

Fig. 2

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