The covariation of northern hemisphere summertime CO_2 with surface temperature at boreal latitudes

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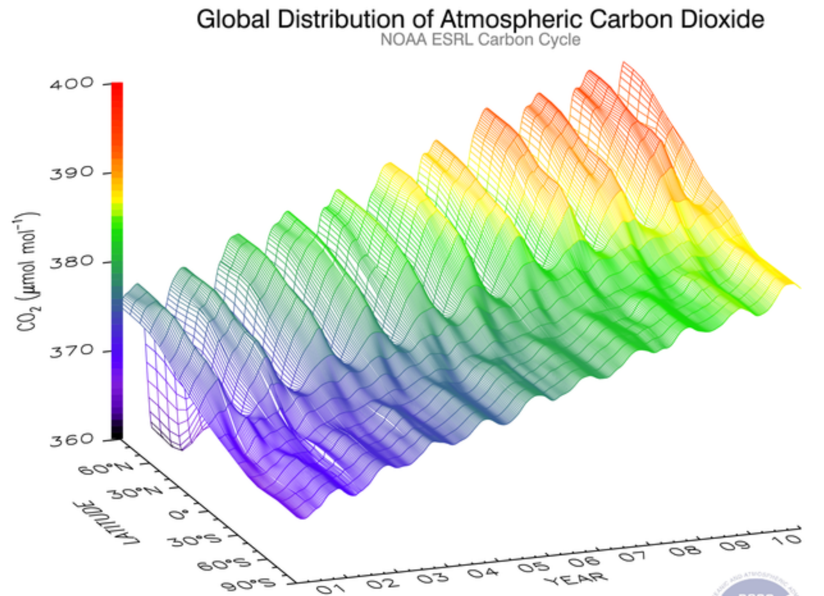
IWGGMS, May 29-31, 2013

Yokohama, Japan

Interannual variability in surface in situ CO_2

- Interannual variability in atmospheric CO_2 is apparent in surface in situ measurements
- Surface CO_2 is known to be related to surface temperature
- The highest sensitivity to interannual variability in surface temperature is in the boreal region (40-60°N)



Three-dimensional representation of the latitudinal distribution of atmospheric carbon dioxide in the marine boundary layer. Data from the Carbon Cycle cooperative air sampling network were used. The surface represents data smoothed in time and latitude. Contact: Dr. Pieter Tans and Thomas Conway, NOAA ESRL Carbon Cycle, Boulder, Colorado, (303) 497-6678, pieter.tans@noaa.gov, http://www.esrl.noaa.gov/gmd/ccgg/.

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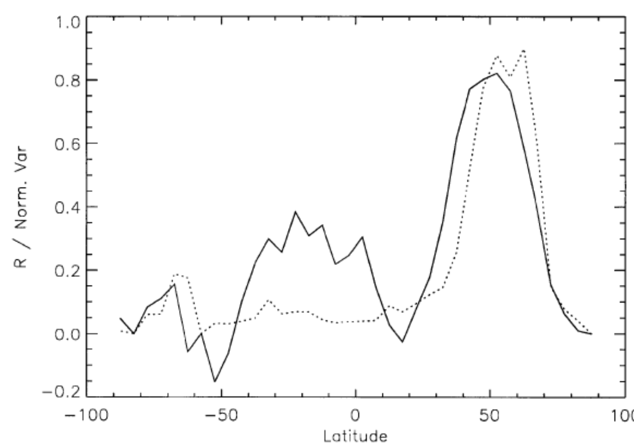
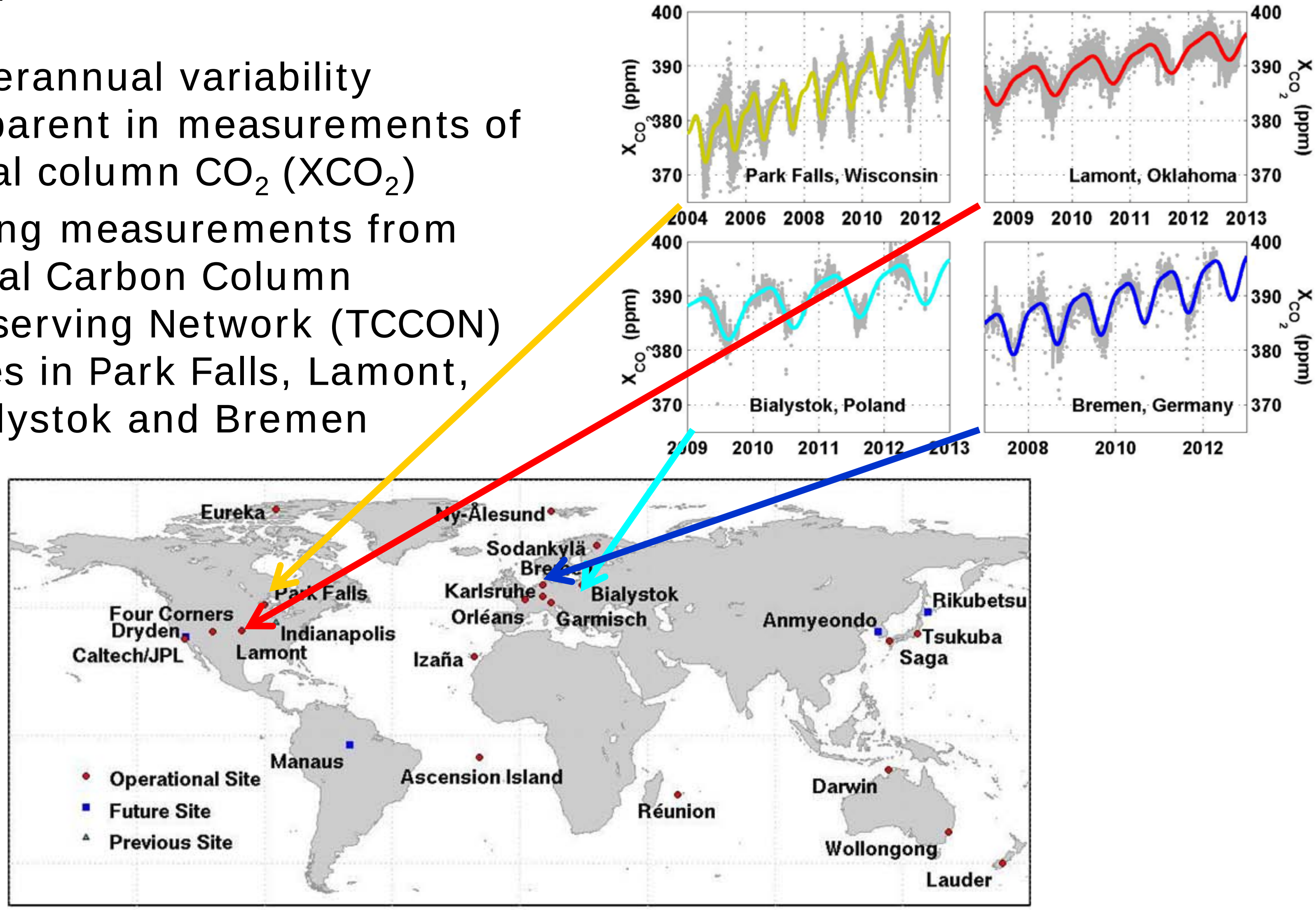


Fig. 9. The latitudinal distribution of the temperature forcing. The correlation between area-weighted temperature anomaly for each 1° latitude band and the global area-weighted mean (solid line) appears to be greatest in the mid-to-high northern latitudes (40N–60N), with a smaller peak in the tropics. A similar pattern can be seen in the area-weighted variance of the *T* anomaly time series for each latitude band (dotted line). Together, these analyses suggest that the greatest forcing due to interannual temperature variability occurs in the northern temperate zone. Note that while the pattern in the tropics "resembles" the global mean, its overall variability is very low.

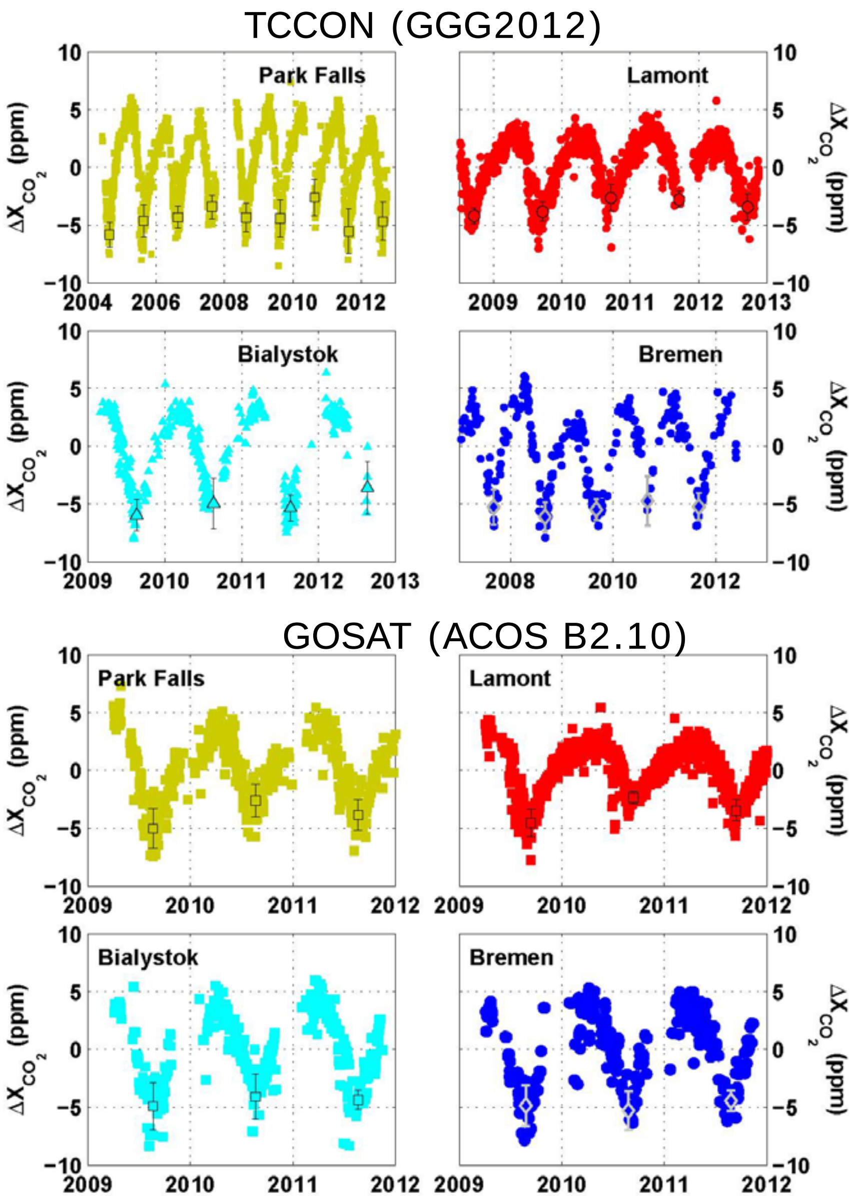
Interannual variability in total column CO_2

- Interannual variability apparent in measurements of total column CO_2 (XCO_2)
- Using measurements from Total Carbon Column Observing Network (TCCON) sites in Park Falls, Lamont, Bialystok and Bremen



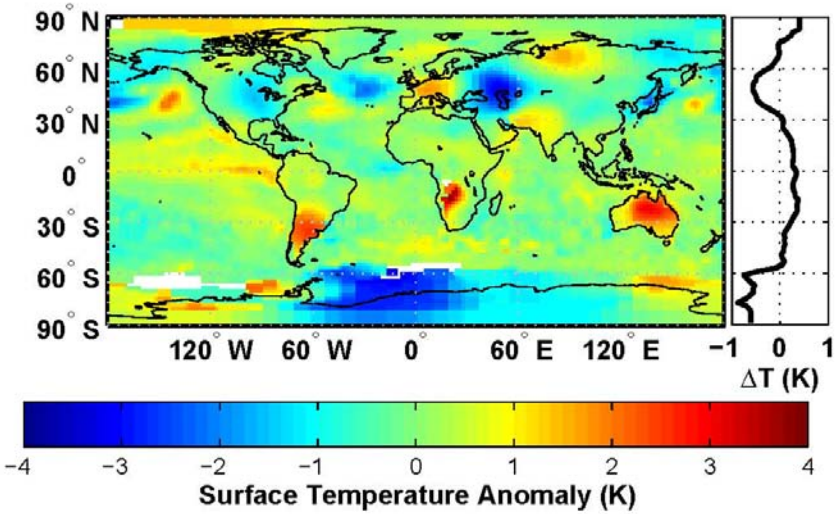
Interannual variability in de-trended XCO_2

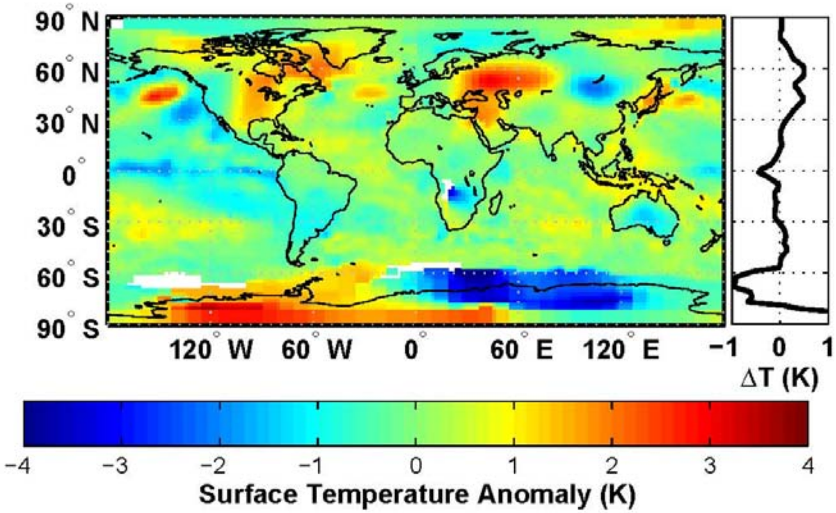
- Removing the secular trend from the TCCON and GOSAT data reveals patterns of the seasonal cycle minima that are similar between sites
- Weak drawdown in 2010
- Strong drawdown in 2009
- Seen also by Guerlet et al. GRL 2013.



Interannual variability in surface temperature

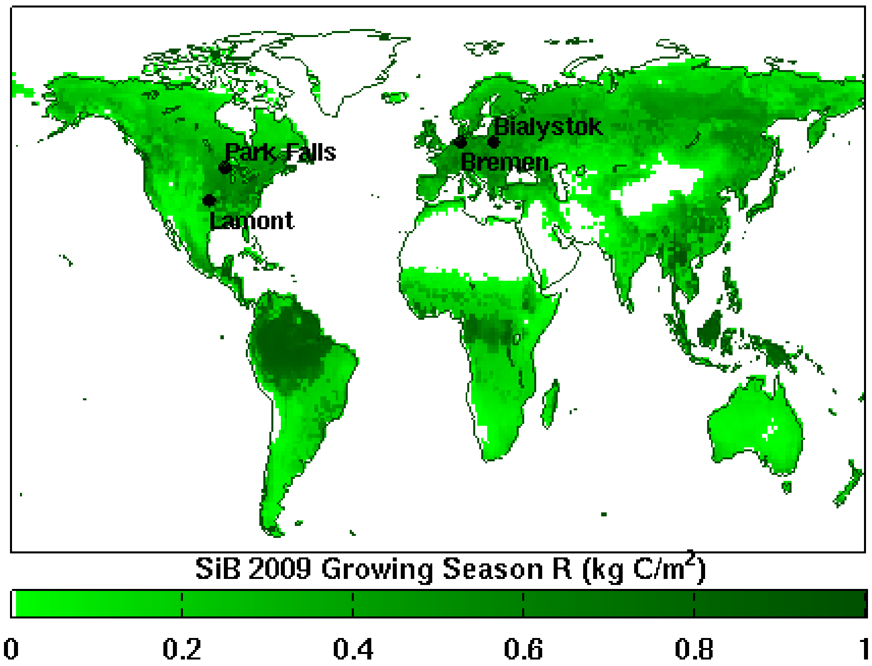
- Surface temperature anomalies from GISS show differences in northern hemisphere temperatures between 2009 (top) and 2010 (bottom)
- 2009 was a cool year
- 2010 was a warm year
- (Recall that 2009 had a strong drawdown, and 2010 had a weak drawdown)





Relating interannual variability in surface temperature to the biosphere

- To relate the surface temperatures to XCO_2, we weight the temperature anomalies by the SiB respiration field
- This weights the temperature anomalies higher where there is an active biosphere, and de-weights regions where there is little biospheric activity (snow-covered regions, deserts, oceans)
- We call this the respiration-weighted surface temperature (δT, units K)

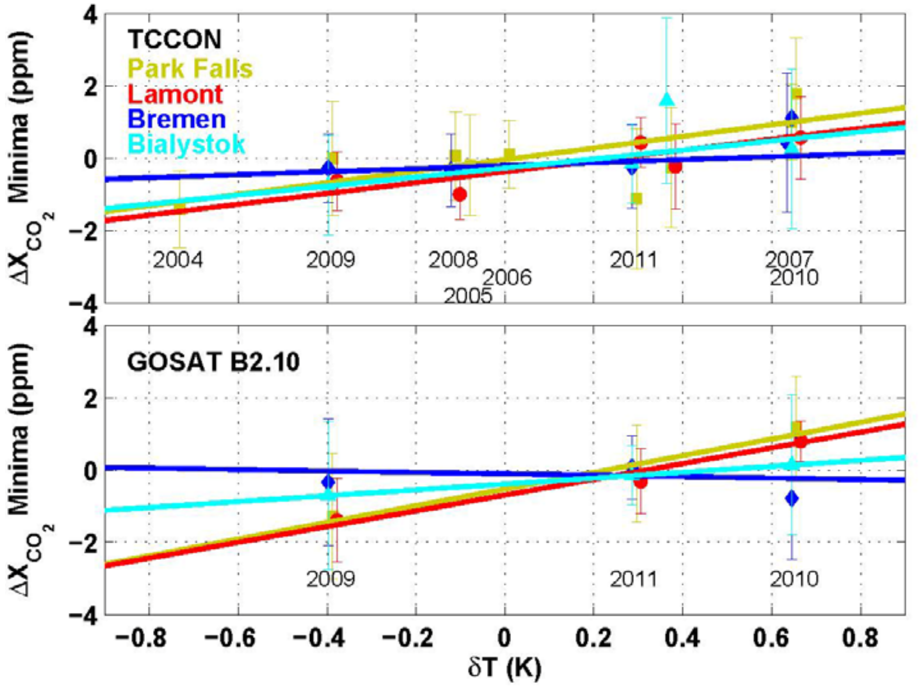


$$\delta T_y = \frac{\sum_{j=180°W}^{180°E} \sum_{i=30°N}^{60°N} R_{e_{ij}}^{2009GS} \Delta T_{ij}^{y} \Delta a_{ij}}{\sum_{j=180°W}^{180°E} \sum_{i=30°N}^{60°N} R_{e_{ij}}^{2009GS} \Delta a_{ij}}$$

where i is the latitude, j is the longitude, Δa_{ij} is the grid area (in m^2). The value δT has units of temperature (K).

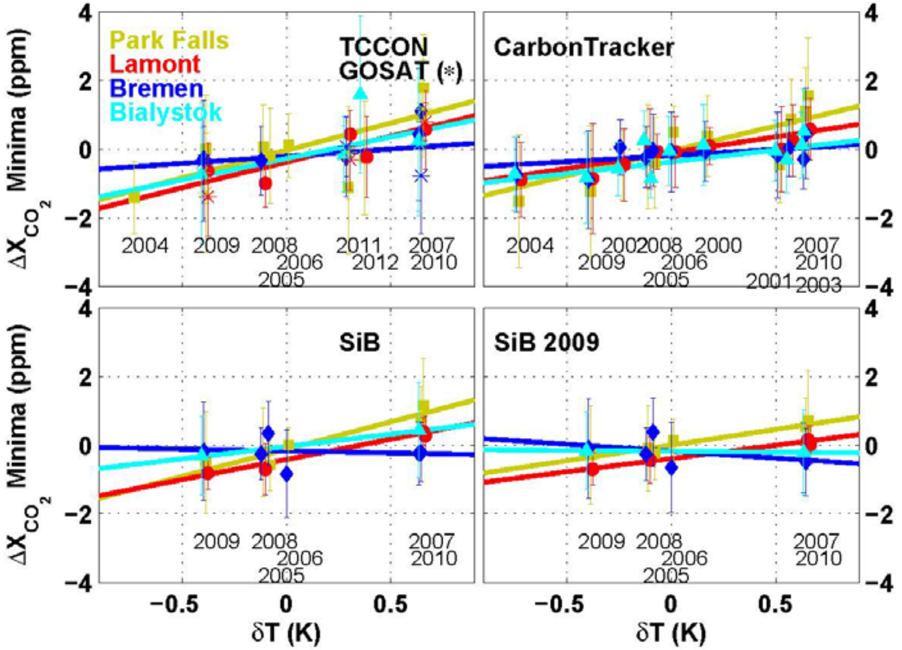
Are surface temperature and summertime XCO_2 related?

- Significant positive slope from TCCON measurements
- Slopes within error from GOSAT measurements, processed by ACOS B2.10 retrieval, filtered and bias-corrected by Chris O'Dell.
- Weighted mean TCCON slope: 1.3±0.7 ppm/K



What do models show?

- Simple Biosphere (SiB) model driven by GEOS-Chem
- CarbonTracker2011
    - Fires Module
    - Fossil Fuel Module
    - Terrestrial Biosphere Module
    - Ocean Module (negligible interannual variability)
- Models show positive slopes between XCO_2 seasonal cycle minima and respiration-weighted surface temperature
- Slopes are generally smaller than the measurements suggest



Slopes of $\Delta X_{CO_2} - \delta T$ relationship in ppm K^{-1} calculated from the TCCON measurements and the model runs. The errors are the standard errors on the linear fits.

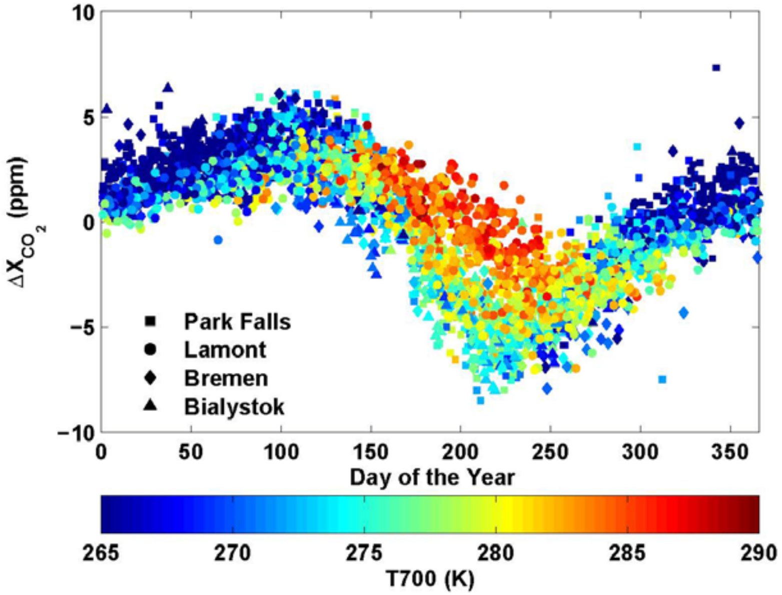
Site	TCCON	SiB	SiB 2009	CarbonTracker
Park Falls	1.60 ± 0.92	1.59 ± 1.16	0.91 ± 1.13	1.45 ± 0.99
Lamont	1.50 ± 1.11	1.18 ± 0.53	0.77 ± 0.53	0.92 ± 0.67
Bremen	0.51 ± 1.39	−0.11 ± 1.03	−0.40 ± 1.10	0.35 ± 0.71
Białystok	1.25 ± 2.06	0.71 ± 1.72	−0.05 ± 1.62	0.69 ± 0.70
Weighted Mean	1.27 ± 0.72	0.91 ± 0.59	0.43 ± 0.58	0.81 ± 0.39
Weighted Mean without Bremen	1.49 ± 0.84	1.21 ± 0.71	0.66 ± 0.68	0.97 ± 0.46

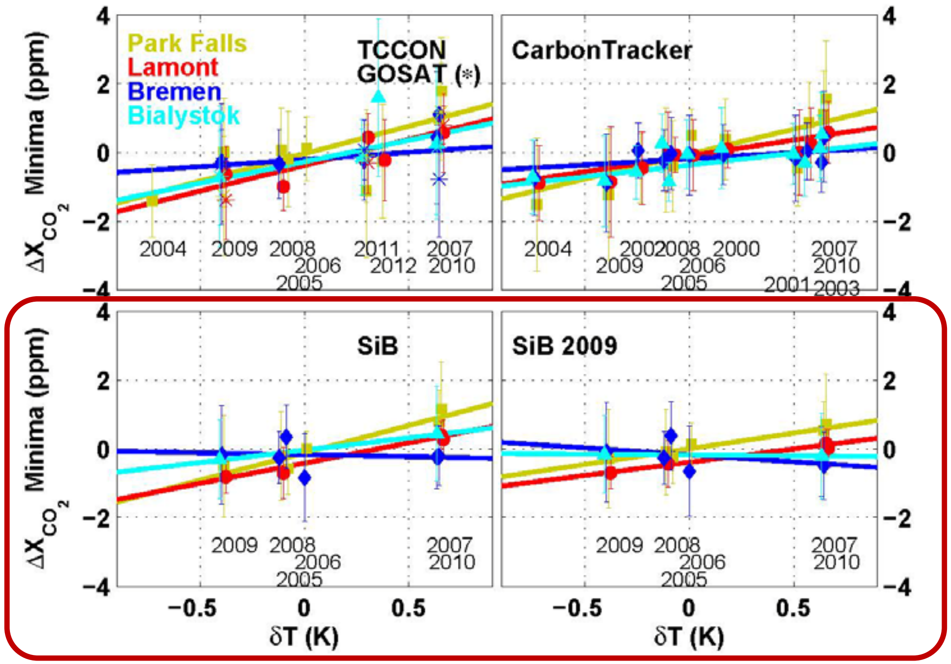
Possible causes of the XCO_2-temperature relationship

- Dynamics
  - Persistent northerly winds may bring lower XCO_2, for example
- Fires
  - Increases in fires increase CO_2 fluxes to the atmosphere
- Fossil fuel use
  - Burning more fossil fuels increases CO_2 to the atmosphere
- Drought
  - Drier conditions impede plant growth, increasing CO_2 to the atmosphere
- Biospheric reaction to temperature changes

Dynamics

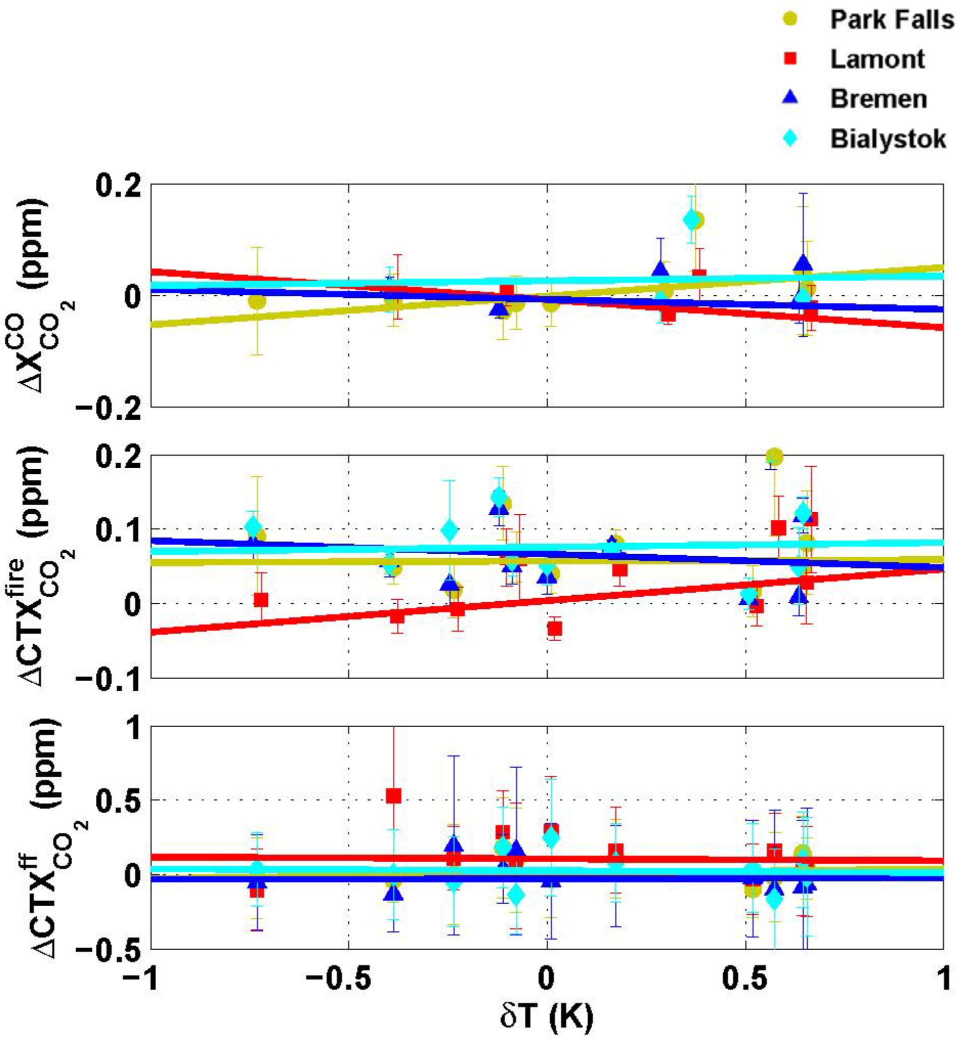
- Column CO_2 measurements are insensitive to boundary layer dynamics; sensitivity to dynamics must be large-scale
- Use Simple Biosphere model (SiB) driven by GEOS-Chem with static 2009 fluxes and year-dependent fluxes
- The run with static 2009 fluxes shows a positive relationship with column CO_2
  - Implies that variability in the atmospheric mixing contributes to the drawdown strength (~50%)
- The run with year-dependent fluxes has a slope that is larger, and more consistent with the measured values





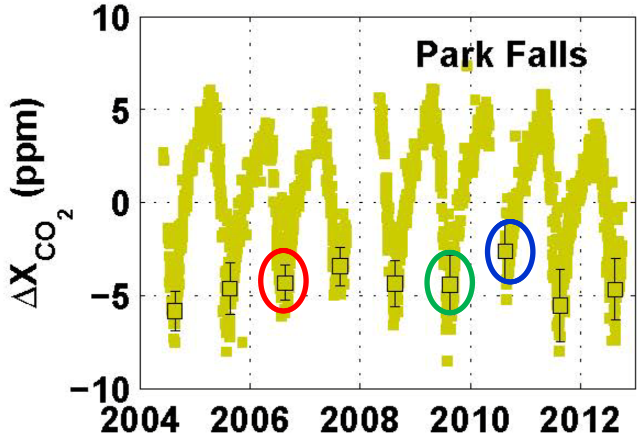
Fires and fossil fuel use

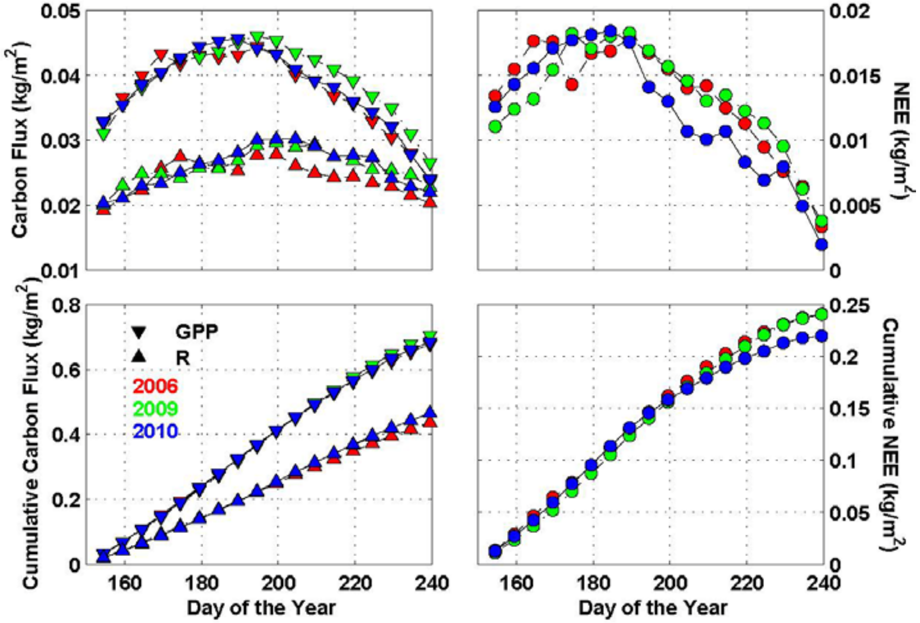
- TCCON measures CO columns simultaneously with XCO_2
- Use CO as a fire tracer; convert the CO into XCO_2 from biomass burning following Akagi et al. (ACP, 2011)
- Very weak slope between fire-related XCO_2 and surface temperature
- Consistent with the CarbonTracker 2011 fire contribution to XCO_2
- The CarbonTracker 2011 fossil fuel contribution to XCO_2 also shows weak to no relationship with surface temperatures



Net ecosystem exchange (NEE)

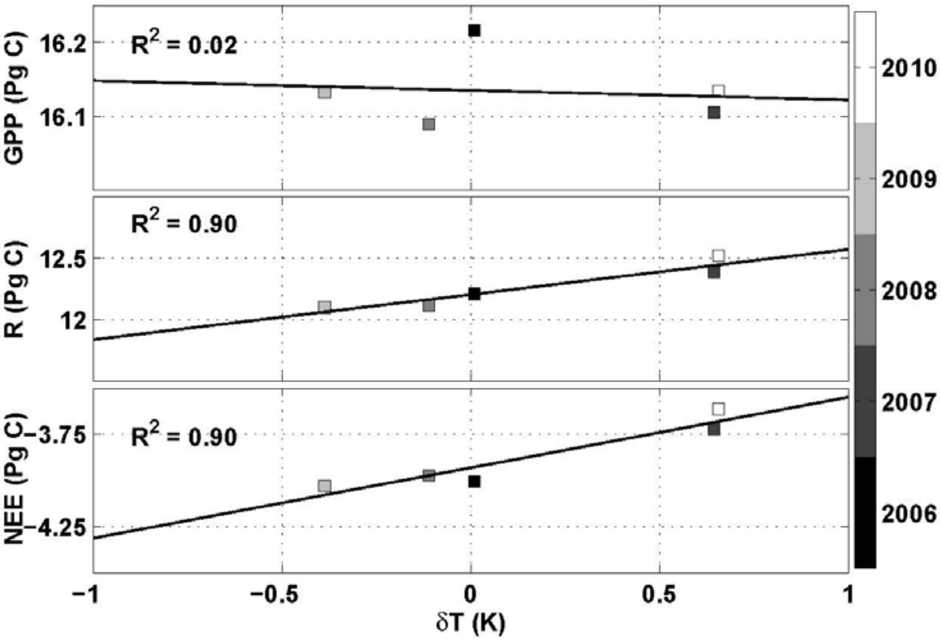
- NEE has significant interannual variability
- Interannual variability in NEE is from both gross primary productivity (GPP) and respiration (R)
- NEE=GPP-R
- Years 2006 and 2009 have similar drawdowns and growing season NEE, both larger than 2010
  - 2006 has smaller R
  - 2009 has larger GPP





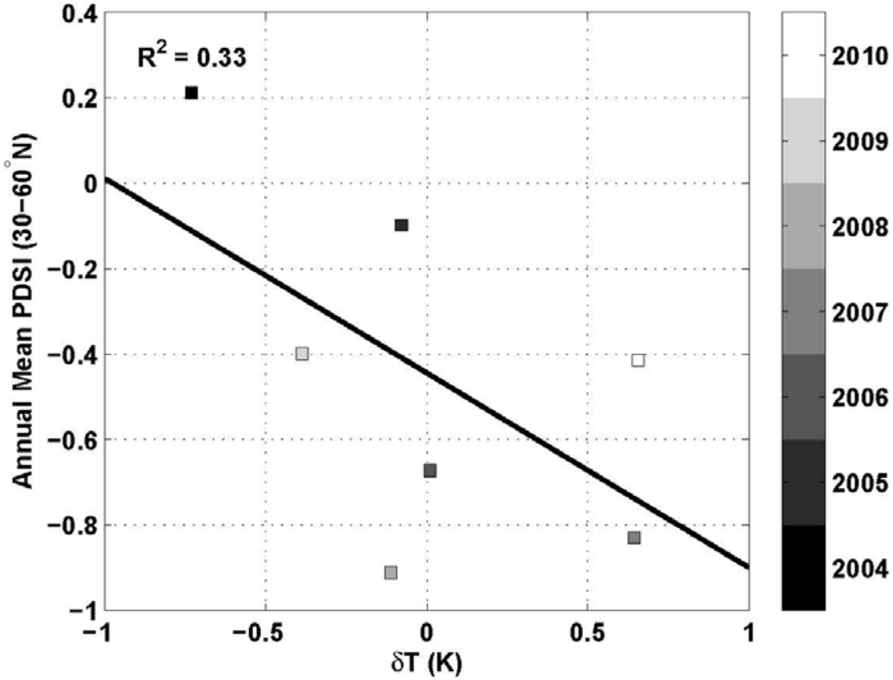
Net ecosystem exchange

- In SiB, only respiration is significantly correlated with surface temperatures
- GPP is not significantly correlated with surface temperature
- Suggests that respiration is the stronger driver of the temperature sensitivity (in SiB, at least)



Net ecosystem exchange and drought

- Net ecosystem exchange is related to soil moisture through respiration and GPP
- The Palmer Drought Severity Index (PDSI) is a measure of drought
  - Negative is dry
  - Positive is wet
- Has the expected relationship with surface temperature
- However, PDSI relationship with XCO_2 is difficult to compute due to lack of sufficient data overlap



Summary and future work

- Interannual variability in the seasonal cycle minima of XCO_2 is correlated with δT in boreal forests.
- The GEOS-Chem SiB simulations suggest that this relationship is caused by dynamical mixing and biospheric activity, roughly equally.
- CarbonTracker2011 and the GEOS-Chem driven SiB $XCO_2 - \delta T$ relationships are generally weaker than observed.
- The effects of emissions from fossil fuel combustion and fires appear to be small and uncorrelated with surface temperature.
- Need further investigation with alternative dynamical models.
- Need to probe GPP/R further, by using other models and chlorophyll fluorescence measurements.

Acknowledgments

- NASA's Carbon Cycle Program
- TCCON partners
- The three parties (JAXA, NIES, MOE) for providing the GOSAT spectra to the scientific community
- The ACOS/OCO-2 team for the B2.10 data
- Chris O'Dell for the B2.10 filtered and bias-corrected data
- Aiguo Dai for the PDSI data