Novel approaches to estimating regional CH$_4$ fluxes from a very tall tower

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Introduction
Can we estimate regional CH$_4$ land surface flux with:

(a) Column CO$_2$ and CH$_4$ observations from the Total Carbon Column Observatory Network (TCCON) solar spectroscopic FT-IR instrument?

(b) Tall eddy covariance flux tower (WLEF) net ecosystem exchange (NEE) of CO$_2$ observations?

in a heterogeneous upland-wetland-lake landscape where CH$_4$ fluxes are likely to be significant but poorly constrained?

Observations
Daytime averaged column observations of CO$_2$ and CH$_4$ from 2005-2009 in Park Falls, WI USA reflect global and regional sources and sinks (left).

Total column CH$_4$ observations (red points) were corrected for stratospheric influence to estimate troposphere-only CH$_4$ (black points) using HF column (Washenfelder et al., 2003)

Fossil fuel signal was removed by simple linear fit (green line) and gaps filled with spline interpolation (blue line) for both CO$_2$ and CH$_4$.

Methods
Neglecting entrainment, the time rate of change in atmospheric column should be proportional to flux. Assuming this proportion is the same for CO$_2$ and CH$_4$, we can write a simple equation for NEE CH$_4$:

\[
\text{NEE}_{\text{CH}_4} = \text{NEE}_{\text{CO}_2} \cdot \frac{\text{dCH}_4}{\text{dCO}_2} = \text{NEE}_{\text{CO}_2} \cdot \frac{\partial \text{CH}_4}{\partial \text{CO}_2}
\]

Entrainment can be neglected when averaged over multiple synoptic cycles (Helliker et al., 2004) and by using total column observations. Time derivative of 14-day average CO$_2$ (bottom left) shows pattern that reflects flux. Term in bracket above was estimated from slope of NEE to dCO$_2$/dt fit (bottom right), which shows strong correlation.

Results
Estimated regional CH$_4$ flux (right, red line) has a seasonal pattern of uptake in winter and emissions in late summer, in contrast to NEE CO$_2$ (blue line).

CH$_4$ fluxes are of similar magnitude to chamber observations of CH$_4$ efflux (green crosses) measured at three wetlands in tower footprint in 2006-2007, but seasonality is offset.

Annual CH$_4$ flux (right, red stars) has high interannual variability, alternating from sink to source, but is positively correlated to CO$_2$ flux interannual variability (blue crosses).

Discussion
Seasonal uptake of CO$_2$ NEE (bottom left, blue line) appears to lag CH$_4$ NEE uptake (red line) by 3-6 months and CH$_4$ maximum efflux occurs in late summer. While seasonal NEE of CO$_2$ and CH$_4$ are anti-correlated, annual fluxes of CO$_2$ and CH$_4$ are positively correlated. These results imply complex biogeochemical mechanisms occurring at regional scale.

CH$_4$ flux magnitudes were at lower bounds of those estimated by modified-Bowen ratio technique (bottom right, black line) and nocturnal column accumulation (black dots) from tower GC observations of CH$_4$ and CO$_2$ in 1997 (Werner et al., 2003). Dual peak pattern of CH$_4$ emissions seen in Werner et al. (2003) not apparent in our results.

Conclusion
Future work is needed to test sensitivity of method to assumptions on averaging, fossil fuel estimate, entrainment, linearity of ratio of NEE to column change, difference in footprint between tall tower NEE, column and chamber observations, and observation error.

New measurements of tall tower eddy covariance CH$_4$ initiated in fall 2010 and ongoing model-based upscaling of chamber observations will provide independent estimates of magnitude and pattern of regional methane flux and applicability of our technique.


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