Using continental, continuous CO_2 observations in a time-dependent inversion to infer regional fluxes in North America

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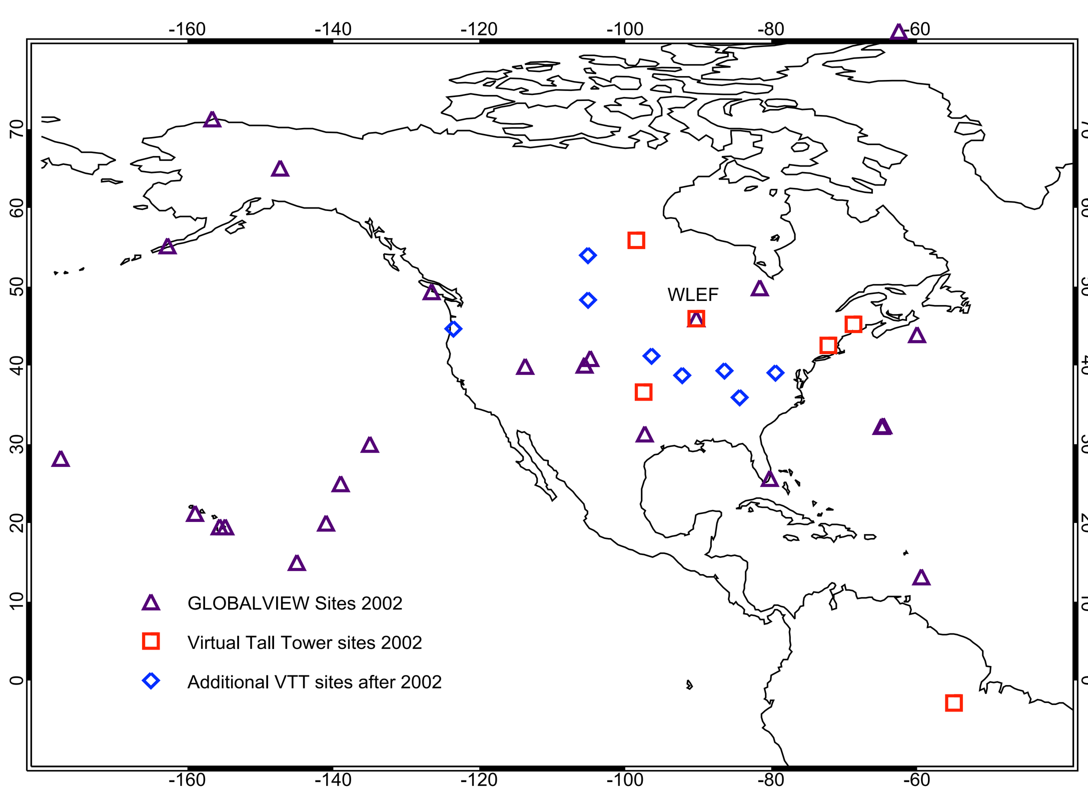
Adding Continental Sites to the Network



Global inversions typically use data products compiled from observations of carbon dioxide (CO_2) mixing ratio from the global measurement network to infer surface fluxes of carbon for continents and ocean basins. The North American portion of the network is shown above (GLOBALVIEW-CO_2, 2004). With relatively few continental sites in this global network, these data are adequate to resolve the latitudinal gradient of global sources and sinks, but insufficient to constrain the longitudinal distribution of sources and sinks at sub-continental resolution.

Continuous, high-frequency measurements of CO_2 mixing ratio are also being made at hundreds of flux towers all over the world. At a few of these towers (noted on the map), CO_2 mixing ratio measurements are also carefully calibrated to global standards.

Here we use mixed layer similarity theory (Wyngaard and Brost, 1984) to estimate the tall tower (~400m) CO_2 mixing ratio given the mixing ratio at a typical flux tower height (~30m). The result is a time series of selected hours, preserving the inherent synoptic variability but without high frequency surface layer variability.

$$\frac{\partial C}{\partial z} = -g_b\left(\frac{z}{z_i}\right)\frac{\overline{wc_0}}{w_* z_i} - g_t\left(\frac{z}{z_i}\right)\frac{\overline{wc_{z_i}}}{w_* z_i}$$

where
g_b and g_t are bottom-up and top-down gradient functions scaled by boundary layer depth
z_i is the boundary layer depth
w_* is the convective velocity scale, and
wc_0 and wc_{zi} are the surface and entrainment fluxes of the scalar C

Moeng and Wyngaard (1989) and Patton et al. (2003) have calculated g_b and g_t functions for no-canopy and canopy schemes in large eddy simulation (LES) studies.

Testing the VTT Concept at WLEF

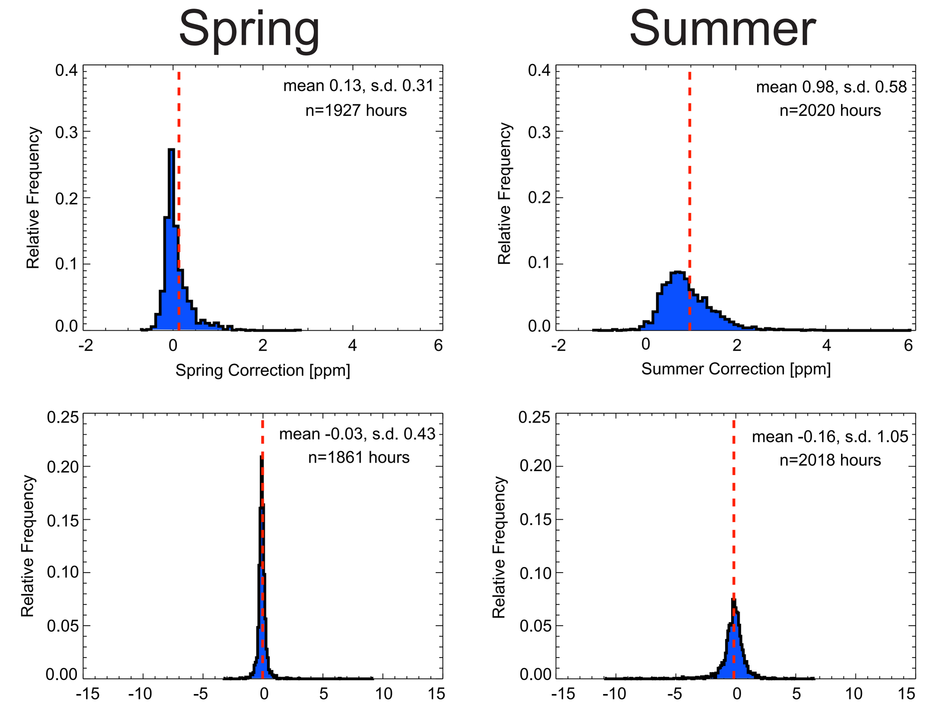
We test the virtual tall tower (VTT) concept at WLEF, correcting 30m CO_2 mixing ratio measurements to 396m and comparing to observations at 396m. The correction algorithm requires input data readily available at flux towers:
displacement height and tower top CO_2 mixing ratio, CO_2 flux, sensible heat flux, and temperature

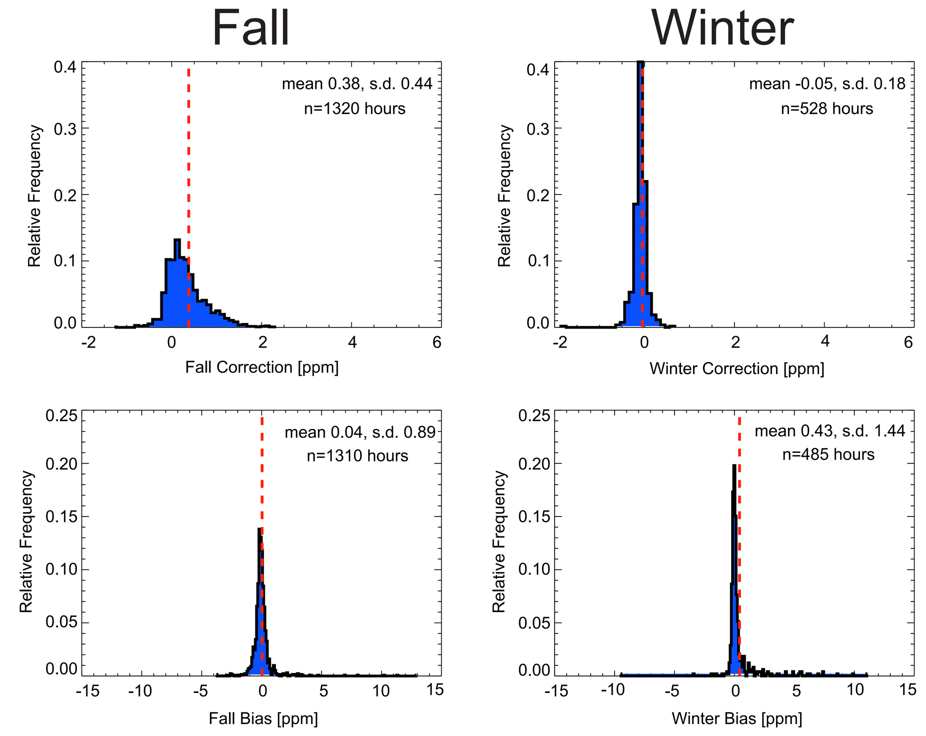
$$\Delta C = -\frac{\overline{wc_0}}{w_* z_i}\int_{z_0}^{z_{VTT}} g_b\left(\frac{z-d}{z_i}\right)dz - \alpha\frac{\overline{wc_0}}{w_* z_i}\int_{z_0}^{z_{VTT}} g_t\left(\frac{z-d}{z_i}\right)dz$$

where
ΔC is the correction to the 30m CO_2 mixing ratio
g_b and g_t are the bottom-up and top-down gradient functions from the empirical fit of Wang et al. (in preparation)
z_0 is the measurement height, 30m
z_{VTT} is the virtual tall tower height, 396m
z_i is the boundary layer depth calculated after Yi et al. (2001)
α is a fraction of the surface flux representing entrainment flux

We calculate for 3-6 mid-day hours depending on the time of year, and screen for minimum sensible heat flux, boundary layer depth, and convective velocity scale.

Below are correction and bias statistics for 6 years of hourly data at WLEF (1997-2001 and 2003).
Note that the mean correction is not significantly different from zero in all seasons except summer.

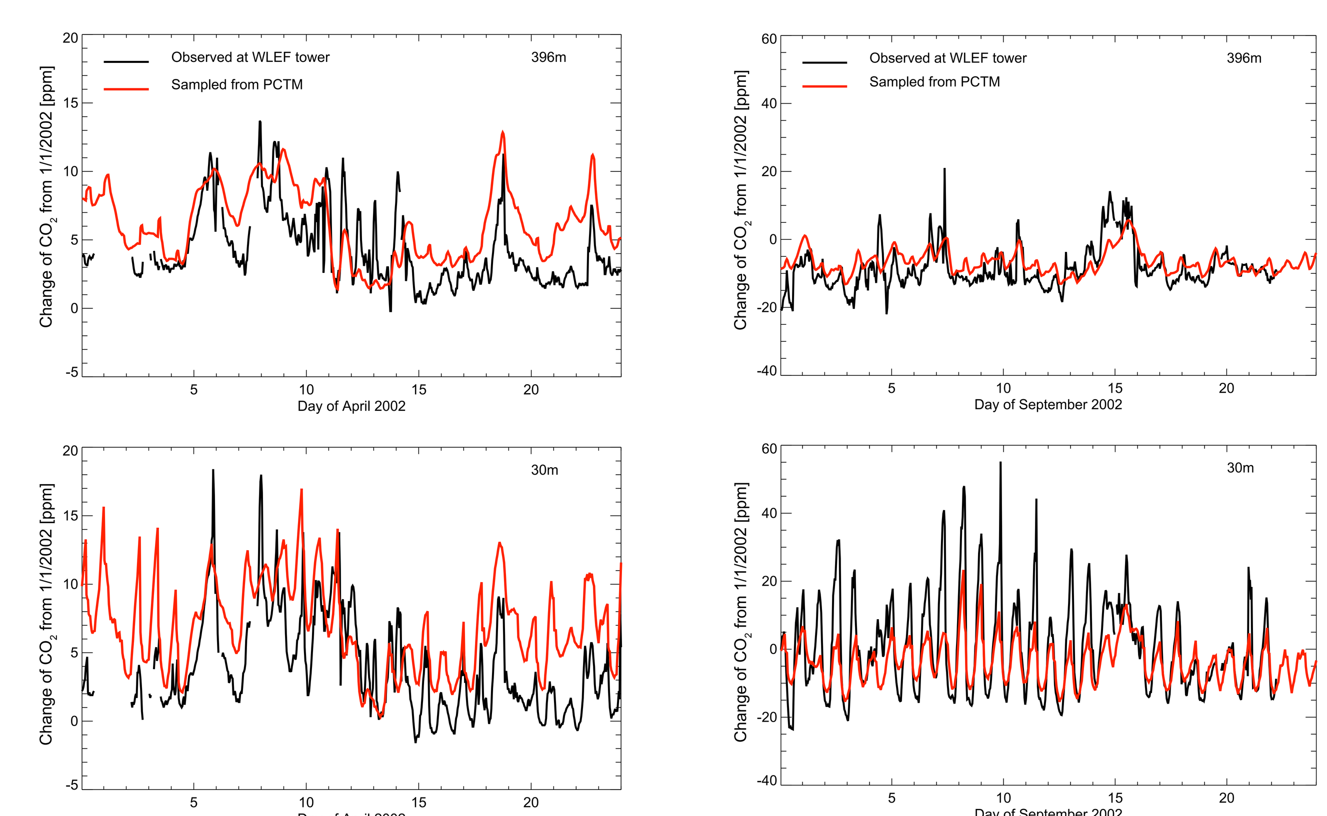




Time Resolution of the VTT Data Product

What is the appropriate time resolution of a VTT CO_2 data product for use in other applications, for example in a global inversion? The hourly mid-day mid-boundary layer VTT mixing ratios can be averaged into daily, weekly, or monthly products. What is the best match of the time resolution of the inversion, the time resolution of the data, and the sensitivity of the forward tracer transport model to seasonal and synoptic variability?

Here are example comparisons of observations at WLEF in 2002 to the sampled output of the NASA GSFC PCTM tracer transport model using GEOS-4 meteorological fields (Kawa et al., 2004) from the recent TransCom continuous experiment. Model samples are a sum of fossil emissions, air-sea flux, and a balanced terrestrial flux. Note that an inversion seeks to find the corrections to these background fluxes that best match the observation data.



Next Steps:

- Create VTT CO_2 mixing ratio data products for each of the North American flux towers with well-calibrated measurements for 2002 (the red squares on the map).
- Execute a synthesis inversion for 2002, testing the sensitivity of the results to the presence of these additional continental sites.
- In a ‘perfect data’ test, examine the sensitivity of the inversion results to the presence of additional North American flux tower sites (the blue diamonds on map). These sites are targeted for upgraded calibrations.
- Explore the time resolution limits of the batch approach for this synthesis inversion. The tracer transport model and background fluxes can simulate diurnal and synoptic variability (as shown above). How much information do we lose using longer term averaging?

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