2.6. Measurements on Tall Towers

Measurements of mixing ratios of CO_2 and other trace species were made on a 610-m tall TV transmitter tower in North Carolina (NC, site code ITN) from June 1992 until June 1999. These measurements were discontinued because the TV company required the space occupied by our equipment on the tower and in the transmitter building in order to install HDTV as mandated by Congress. Measurements began on a 447-m tall tower in Wisconsin (WI, station code LEF) in October 1994 and are ongoing.

The CO_2 mixing ratio data through 1997 were presented in *Bakwin et al.* [1998]. Figure 2.22 provides an update of the data through 1999. *Bakwin et al.* [1998] discuss a method to account for excess fossil fuel CO_2 at the towers relative to the "background" marine boundary layer (MBL). The difference between the CO daily means at the towers and a MBL reference for CO is divided by an estimated CO/CO_2 molar emission ratio for fossil fuel combustion of 0.023 [*Bakwin et al.*, 1994]. This value is subtracted from the CO_2 mixing ratios at the towers. The results provide a means to compare more directly CO_2 mixing ratios over the continent with those in the MBL. Table 2.10 updates these data through 1999. The annual mean CO_2 mixing ratios at the towers are generally higher than in the MBL at the same latitude [*Bakwin et al.*, 1998]. However, it is estimated that excess fossil fuel CO_2 typically accounts for

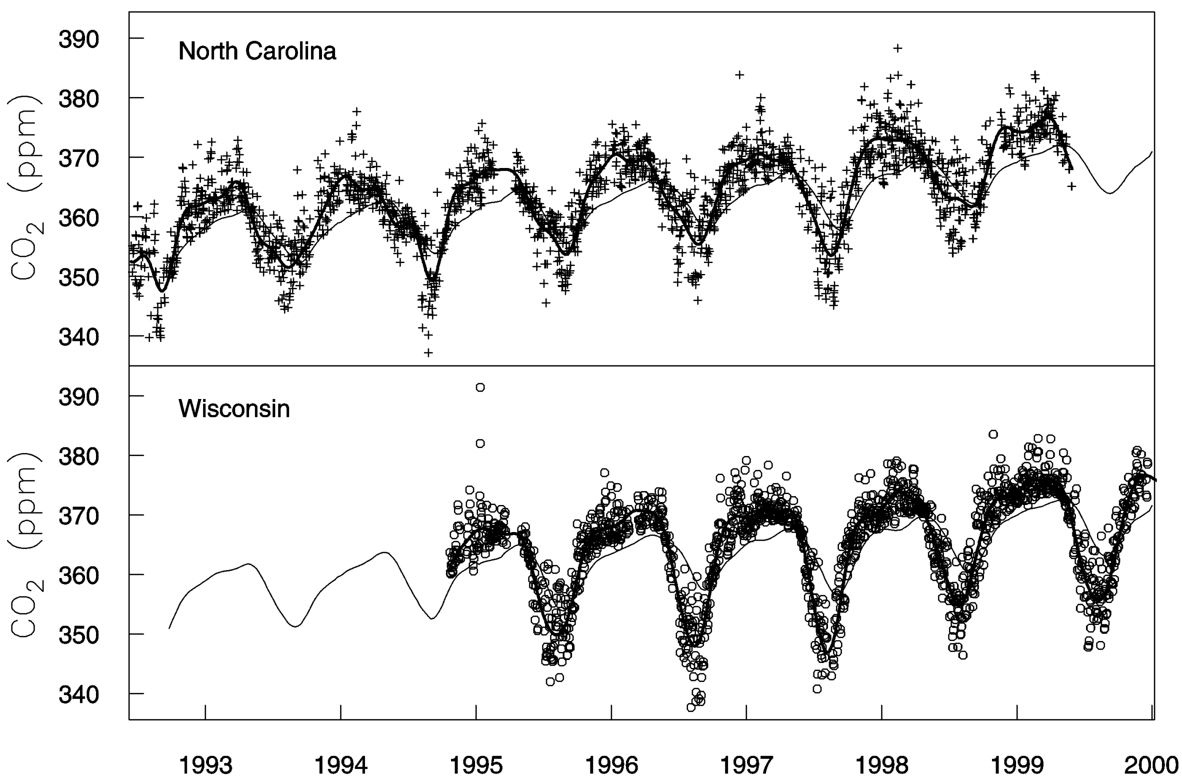

Fig. 2.22. Daily mean CO_2 mixing ratios at 496 m above the ground on the North Carolina tower and 396 m on the Wisconsin tower (points). The data are fit with smooth curves (heavy) as described by *Thoning et al.* [1989]. The thin lines show the MBL reference curves [*Globalview-CO_2*, 2000] for the latitudes of the towers.

TABLE 2.10. Carbon Dioxide Mixing Ratios (ppm) at Two Tall Towers With and Without the Estimated Fossil Fuel Contribution Subtracted as Described in the Text*

Year	NC	NC-FF	MBL at NC	WI	WI-FF	MBL at WI
1995	363.1	360.7	360.9	361.9	na	360.7
1996	364.7	362.4	363.0	363.8	362.4	363.1
1997	365.7	363.5	364.0	364.4	363.6	363.9
1998	368.9	366.8	366.7	367.6	366.6	366.5
1999	na	na	368.8	369.4	368.5	369.0

*Uncertainty of the annual mean CO_2 mixing ratios at the towers is roughly 0.2 ppm.
NC = North Carolina; FF = fossil fuel; MBL = marine boundary layer; WI = Wisconsin

2.1-2.4 ppm CO_2 at the NC tower and 0.8-1.5 ppm CO_2 at the WI tower. Subtracting these values gives annual mean values for CO_2 at the towers that are a few tenths of a ppm lower than in the MBL, suggestive of a biogenic sink for CO_2 on the continent. It is interesting that both towers show a smaller than average difference from the MBL in 1998, a year when the global atmospheric CO_2 growth rate was exceptionally large. This implies that the biogenic sink for CO_2 in North America in 1998 may have been smaller than in other years. An alternative explanation could be that interannual changes in atmospheric circulation affect the annual means. However, the contribution of recent fossil fuel-derived CO_2 did not change much at either tower.

A large program has evolved around the WI tower to study processes that regulate the carbon balance of the surrounding temperate/boreal mixed forest and to understand how the signal of CO_2 exchange at the terrestrial surface propagates to the regional and global atmosphere. The program, known as the Chequamegon Ecosystem/Atmosphere Study (ChEAS), includes scientists from several universities and government research laboratories and is funded mainly by NOAA, U.S. Department of Energy (DOE), National Science Foundation (NSF), NASA and U.S. Department of Agriculture (USDA). The backbone of the project is the CCGG measurements of the exchange of CO_2 between the atmosphere and the forest using eddy covariance and atmospheric budget methods. Information about the studies involved in ChEAS can be found at [http://cheas.umn.edu]. The first publications utilizing the CMDL measurements are *Yi et al.* [2000] and *Berger et al.* [2000].

During 1998-1999 significant progress was made towards quantifying the forest carbon balance and understanding the biophysical processes that drive interannual changes in net ecosystem exchange of carbon (NEE). Figure 2.23 shows cumulative NEE for 1997 and 1998. During the wintertime modest net release of CO_2 by the forest, due to respiration, was observed. Since the soils are mostly frozen, the rate of respiration is fairly small; the average for January 1997 is 0.3 µmol m^{-2} s^{-1}, compared to nighttime respiration of 5.0 µmol m^{-2} s^{-1} in July. The timing of leaf-out is well predicted by degree-days, the integral of temperatures greater than 0ºC starting from April 1. The spring of 1998 was unusually warm, and leaf-out occurred about 1 month earlier than in 1997. During the summer rapid photosynthesis by the vegetation leads to net uptake by the forest. The rate of uptake in midsummer was similar in 1997 and 1998. A severe drought occurred in the region during mid-to-late summer of 1998, and the moisture content of the surface soil dropped to about 25% of that in 1997. The drought suppressed both photosynthesis and respiration by the forest, and the daily NEE became approximately zero about 1 month earlier than in 1997. The drought reduced annual NEE by about 15 g C m^{-2} compared to the well-watered year. However, because of the early spring, the forest still took up about 50% more carbon in 1998 than in 1997. The conclusion is that weather conditions during the transition seasons of spring and fall are particularly important in setting the annual rate of carbon sequestration by the forest. The forest was a net sink for carbon during both 1997 and 1998.

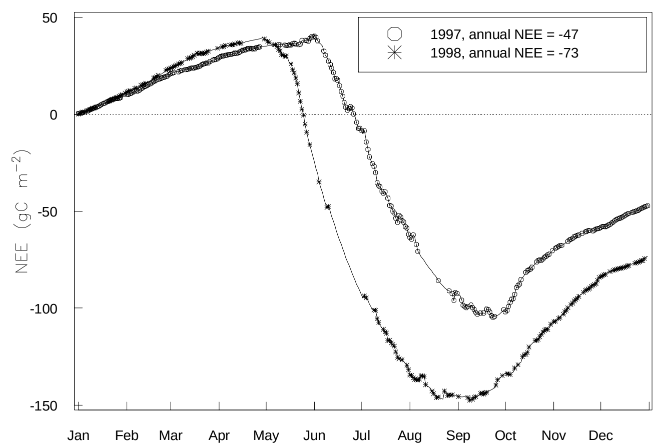

Fig. 2.23. Cumulative net ecosystem exchange of CO_2 measured at the Wisconsin tower during 1997 and 1998. Points are measured data and lines are cumulative sums of curve fits to the measured daily net ecosystem exchange (NEE).

The finding that the forest surrounding the WI tower was a significantly larger net sink for CO_2 in 1998 than in 1997 is especially interesting in light of the results discussed previously that terrestrial systems in North America, as a whole, may have been a smaller net sink in 1998. The NEE data (Figure 2.23) are representative of a fairly small area, roughly a few km^2. The CO_2 mixing ratio data obtained at 400-500 m above the ground on these towers is representative of a much larger area of the order of 1×10^6 km^2 (M. Gloor et al., What's the footprint of a tall tower?, *Journal of Geophysical Research*, in review, 2000).

Linking the local-to-regional NEE to the larger scale mixing ratios is a topic of current investigation using the WI tower data. That is, CCGG is working to understand how the signal of surface exchange propagates into the regional and global atmosphere. This requires a detailed understanding of the dynamics of the planetary boundary layer (PBL) and the mechanisms by which the PBL exchanges air with the overlying free troposphere. Using data from the tall tower and from a PBL sounding radar system, there is a detailed study of seasonal changes in PBL mixing (C. Yi et al., Long-term observations of the dynamics of the continental planetary boundary layer, *Journal of Atmospheric Science*, in review, 2000). It was found that the PBL height is maximum in spring when driven by high surface sensible heat fluxes. Later in summer the surface energy partition is dominated by turbulent fluxes of latent heat because of transpiration by the forest, and sensible heat fluxes are reduced. In future work the seasonal covariance between surface fluxes of CO_2 and the depth and venting (exchange with the free troposphere) of the PBL, which is critical information for efforts to diagnose the global carbon cycle by inverse methods, will be determined.