

Mid-Continent NACP Intensive Campaign in 2005

A. Scientific goals

As scientists we are expected to provide answers to the three major questions (not repeated here) posed in the NACP plan (Wofsy and Harris, 2002, p. 2). The answers have to be robust enough to inform policy in the near future. Uncertainty estimates need to be well defined and scientifically defensible. This is a formidable task and we are not being given a whole lot of time in the President's Carbon Cycle Science Plan.

The primary issue of both the magnitude and the possible mechanisms of the northern hemisphere terrestrial carbon sink have remained unsettled for well over a decade. Typically, "bottom-up" estimates based on ecosystem models and/or inventories have tended to come up with magnitudes for the sink substantially smaller than what we deduce from "top-down" inverse models used to interpret atmospheric concentration patterns, at least when the evidence is not mixed through the use of "prior estimates." As long as these different approaches independently produce quite divergent answers, we can have no real confidence in any of the estimates. Thus far, atmospheric data have always been too sparse to be conclusive on a regional or even continental scale, and they have additionally been hampered by atmospheric model shortcomings. From the other side, it has proven very hard to sufficiently verify the scaling up of local measurements using models, or to validate satellite estimates over large regions. To make progress the different approaches need to be confronted in a region and at a time where we can maximize the information content and credibility of each method, so that they can each stand on their own feet. This approach allows the cross comparison of data and models. Multiple models will be applied to both the top-down and bottom-up data sets. Needed areas of improvement will then be apparent, and we will be in a much better position to see how the approaches can strengthen each other.

Goal 1. Gather enough atmospheric data to provide a mass balance for net carbon fluxes during the intensive measurements to an accuracy of 10% over a large region.

Goal 2. Use the atmospheric data to enable significant improvements in the parameterization of transport/mixing processes in the lower atmosphere.

Goal 3. Use the variance structure of the same data to enable design and implementation of an optimized and efficient system to monitor future regional carbon fluxes.

Goal 4. Use a variety of "bottom-up" techniques to enable significant improvements of measured data based on soil and vegetation characteristics and processes. These data sets will be tested and made applicable to larger landscapes by using models that include ecosystem, crop growth and process models. Eddy-covariance flux data, and spatially detailed satellite remote sensing estimates of a number of variables will also be used to estimate the net carbon fluxes over the same region.

Goal 5. Investigate techniques for constructing “carbon flux maps” at various levels of spatial and temporal detail.

B. Place and time

The center of the North American continent, the Midwest agricultural belt in the northern U.S. and Canada, is a large region in which the daunting complexities and the small-scale variability of ecosystems, soils, microclimates, topography, land use and land use history, are perhaps a bit more manageable. The area of the campaign will be eastern South Dakota, eastern Nebraska, eastern Kansas, northern Missouri, Iowa, southern Minnesota, southern Wisconsin, and Illinois (Figure 1). The difficulties of interpreting atmospheric measurements with transport models are minimized over flat terrain. The area is covered by the NOAA wind profiler network (www.profiler.noaa.gov/jsp/profiler.jsp), which provides hourly wind velocities from 500 m above the surface to 16 km altitude. The area is also a significant portion of the most intensively farmed region of the continent, with relatively low population density, but with several concentrated metropolitan centers. Crop growth models making use of satellite imagery have been applied to a part of Iowa, and have been compared to end-of-season yield statistics. Daily estimates of evapotranspiration are already routinely available for a large part of the area (www.soils.wisc.edu/wimnext/water.html). There will be an intensive study during the peak season of CO₂ uptake (July) and in the fall when CO₂ respiration continues but most plant photosynthesis has ceased (October-November). In July the leaf cover is fairly uniform between corn and soybeans, which avoids non-linearity effects in averaging over remote sensing pixels. The campaign will be embedded both in space and time within a long-term observing system that is being developed to detect net annual sources/sinks. In the Carbon Sequestration Rural Appraisal, carried out in Iowa, it was estimated that on cropland under no-till the net annual carbon uptake is about 0.6 ton C/ha/year, and on land in the Conservation Reserve Program about 1.3 ton C/ha/year. The highest participation in the CRP occurs in the area straddling the state border with Missouri.

C. Requirements

1. Long-term atmospheric monitoring. Species concentrations in the atmospheric boundary layer tend to be offset from those in the free troposphere as they “integrate” to a varying degree the effect of sources/sinks over large regions. There is significantly more variance in boundary layer concentrations than in the free troposphere. For these reasons boundary layer atmospheric sampling will be more intense than in the free troposphere. During the growing season peak, daily average depletion of CO₂, if confined to the lowest 1.5 km of the atmosphere, is about 6 ppm, which includes respiration at night.

In the area of the campaign CMDL expects to instrument 6 tall towers starting in 2004 with high accuracy continuous in-situ CO₂ measurements, meteorological variables, and daily flask sampling (CO₂, CH₄, CO, H₂, N₂O, SF₆, and isotopic ratios). Thus, estimates of N₂O and CH₄ fluxes will also be produced from the monitoring system. CMDL expects to fly vertical profiles twice a week with flask samples and continuous CO₂, water vapor, temperature and ozone. Vertical profile locations will be coordinated with tall tower and flux measurement sites (Figure 1). Additional measurements on the

tall towers will be carbon monoxide and Radon-222, but both are contingent on the availability of suitable robust instrumentation. Development work is ongoing for the analysis of a suite of volatile organic compounds in the flask samples in addition to the species already measured. They will be added when possible. CMDL is considering intensifying the above spatial and temporal coverage during the campaign. Perhaps additional tall towers will be added as a test of possible long-term sampling strategies. The addition of measurements of near-surface CO₂ vertical concentration gradients to existing sites of the USDA Soil Climate Analysis Network is an attractive option.

In order to better define the large scale atmospheric concentration fields used by atmospheric models, CMDL has started in late 2003 two regular vertical profiles sites on the west coast, one on the Texas Gulf coast, two on the east coast, and expects to add profiles over the BERMS site in Saskatchewan. The ground-based measurements elsewhere in the world will continue, with the addition of several volunteer observing ships (commercial vessels on regular routes) and NOAA hopes to add continuous CO₂ and delta-pCO₂ measurements on buoys in the coastal waters of North America.

Eddy covariance flux measurement sites will start making high accuracy CO₂ mole fraction measurements by adopting careful calibration procedures. These measurements will be used to define mid-boundary layer concentrations under well-mixed conditions. The values will be compared to tall tower measurements and aircraft profiles in several cases.

2. Dedicated scientific aircraft. Two types of dedicated aircraft will play a role. A highly capable aircraft outfitted with a large suite of chemical measurements will probe the large-scale atmospheric variance of multiple species and their relationships. For example, CO and CH₃CN are tracers for biomass burning, CO is in many cases also a good proxy for the recent addition of fossil fuel derived CO₂. There are whole series of anthropogenic tracers such as PCE, benzene, toluene, chlorinated compounds, certain ratios of hydrocarbons, and likewise plants and soils have their own characteristic emissions and deposition. In principle this allows for a considerable amount of air mass characterization, which will sharpen up the interpretations. A second role for the “chemistry” aircraft is to fly patterns that will allow direct estimates of net CO₂ uptake. An aircraft such as the Lear Jet is rated to fly in all weather conditions, and may need to fill in some of the large scale patterns when the airplanes regularly rented by CMDL can not fly. A second type of aircraft, especially the low- and slow flying Ultra-lights such as Sky Arrow, Long-EZ, can measure fluxes of CO₂ and water vapor on relatively small scales. These results will be compared with flux measurement sites, crop model predictions and estimated patterns of evapotranspiration.

3. Long-term soil measurements. Benchmark, permanent, soil quality monitoring sites will, with sufficient spatial density, be able to detect trends in soil organic carbon that are expected to result from changing management practices. These will be established across the area shown in Figure 1 relative to tower and other atmospheric measurements. They will be representative of the various soil type- vegetation ecosystems involved and include standardization of instrumentation and measurement techniques so crucial for inter-site comparisons. The grid setup will take advantage of presently available long-term sites such as the LTER sites in Kansas and Minnesota as well as University and

Federal Research Stations. These sites have a wealth of long-term crop and soils data and in some cases a great deal of the ecosystem process data required for the modeling of the data. Some of the soil sites also will have CO₂ measurement instrumentation somewhat similar to that being developed for oceanic measurements to measure the soil and near ground gas transfers.

4. *Crop growth models, soil models and remote sensing data.* Some examples of the type of modeling approaches that will be necessary are given here. A crop growth model was run during the SMEX02 soil moisture investigation in Iowa. Inputs were detailed LANDSAT vegetation classification, MODIS 8-day composite reflectances, soil physical and chemical properties available from the STATSGO database, initial soil moisture status, and weather and climate data. Measured yields on selected fields were used to calibrate model yield parameters, and at the Walnut Creek Watershed, crop yields have been compared with cumulative eddy covariance and soil flux measurements. A different type of model, the Century soil organic matter model uses databases for climate, soil properties, topography, and land use history, has crop growth and water submodels, predicts yields to estimate residue input to the soil, and predicts carbon and nitrogen in various soil compartments. The Atmosphere-Land Exchange Inverse (ALEXI) model uses GOES data and weather data (temperature, pressure, humidity) to estimate fluxes of sensible heat and water vapor on a daily basis. Visible in the resulting evapotranspiration maps are patterns that are coherent over large areas, sometimes as elongated bands more than a thousand km long and a few hundred km wide. When integrated with a canopy resistance model, daily predictions of carbon assimilation can be made. This approach has been developed furthest for crop systems. A model such as BIOME-BGC has been used to estimate daily GPP, NPP, and evapotranspiration, based in part on MODIS observations. Thus far it has been mostly applied to forested land, and more recently to grassland. A model such as SiB-2 simulates stomatal conductance, and thus the latent heat flux and the partitioning between latent and sensible heat fluxes, which has a significant influence on atmospheric dynamics. At the same time it provides GPP.

To the east and to the north of the intensive study are extensive grassland and forested areas respectively. The atmospheric data will register the impact of those areas. Modeling of those ecosystems, including the use of flux measurements, maximizes use of the data gathered in the campaign and likely improves the results for cropland areas.

5. *Transport models.* Needed for converting observed concentration patterns into source estimates are atmospheric transport models. Assimilated meteorological data at the highest resolution available from weather forecast models will be essential. Important current weaknesses are convective mixing, detailed land surface description including the physiological response of vegetation, mixing and stability of the nocturnal boundary layer, (lack of) conservation of tracer mass, representation and impact of cloud systems. The meteorological fields and mixing schemes will be used to calculate the transport of species in global models, high-resolution regional models, and in nested models (e.g. MM5, RAMS, TM5), all run in inverse mode. Receptor models such as STILT also use assimilated meteorological data, and they provide yet another way to estimate sources.

6. *Land use and history.* The Landsat Thematic Mapper has been in use since 1982, and can give a comprehensive picture for the last two decades. County level data from the National Resource Inventory and the USDA National Agricultural Statistics Service can be used for data before 1982 and as a crosscheck of the Landsat data. MODIS data also give a comprehensive view of current land use.

7. *Fossil fuel inventory.* Data for fossil fuel use need to be separated by type (coal, oil, and natural gas), and algorithms need to be developed to disaggregate their use into more detailed spatial and temporal patterns, including large point sources such as power plants. It may help that in the area of the intensive campaign the population density is relatively low, and that there are some very concentrated metropolitan areas nearby (Minneapolis/St. Paul, Chicago, St. Louis, Kansas City). This will give opportunities for verification of the use algorithms, chemical signatures, and perhaps even the magnitude of the emissions. The large fossil fuel component will have to be quantitatively accounted for when annual estimates of carbon sequestration/loss are made for a region. In addition, since September 2000 there is an ongoing geological sequestration project whereby CO₂ from a synfuels plant in Beulah, N. Dakota, is injected into the Weyburn oil field in south eastern Saskatchewan. Every day, the emissions equivalent of 100,000 people is injected into the 180 km² oil field. If there are significant leaks they would be detectable both in the amount of CO₂ and its isotopic signature.

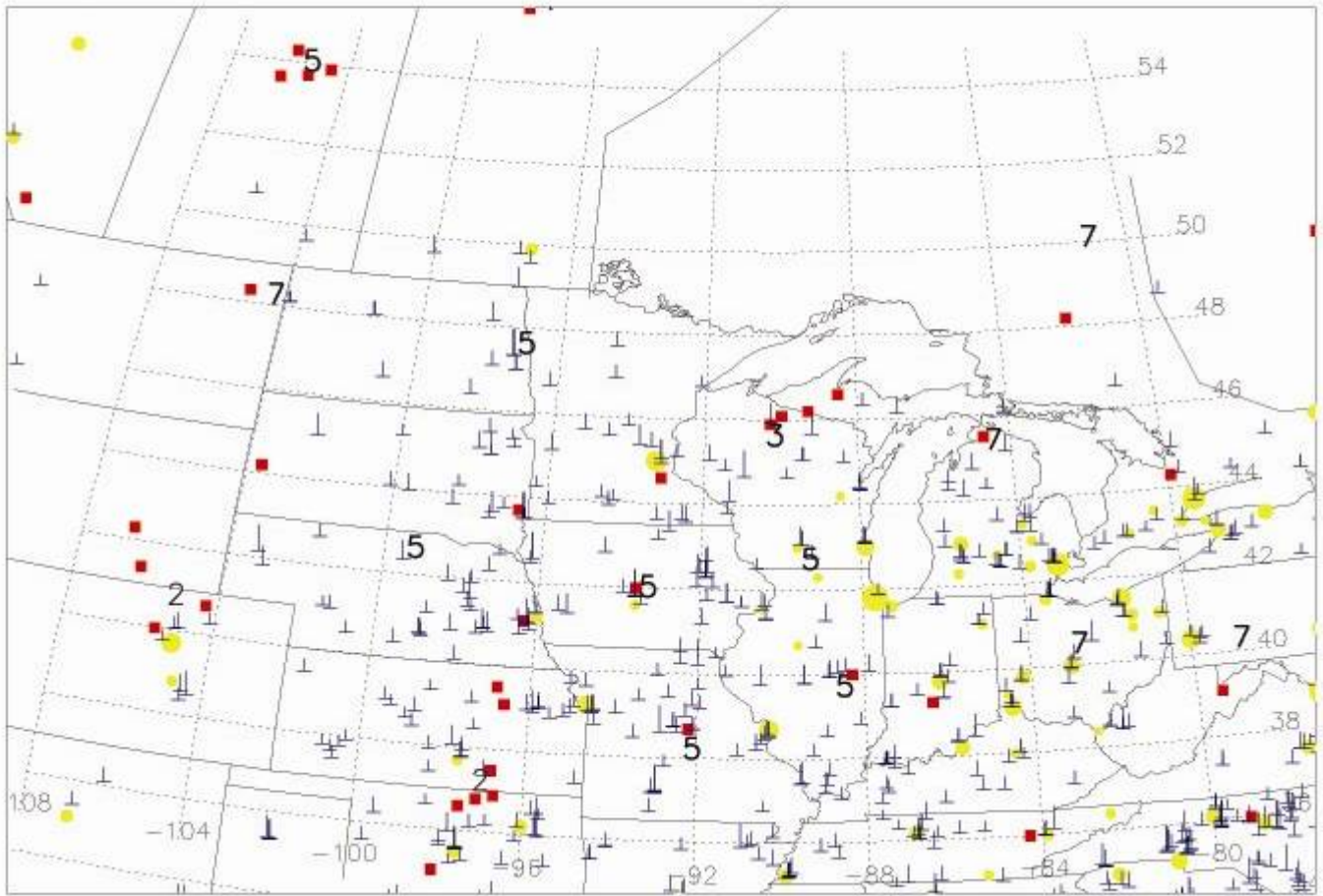


Figure 1. U.S. upper Midwest and southern Canada. Yellow dots: metropolitan areas; red squares: eddy covariance flux measurement sites; blue: TV and FM towers taller than 800 ft and up to 2000 ft, with length of vertical line indicating height of tower; numerals 2,3,5,7 indicating the (possible) location of frequent vertical profiles by aircraft, existing before 2002, starting in 2003, etc.