1.3 AIRCRAFT AND TOWER-MEASURED FLUXES OVER RAPIDLY GROWING CORN AND SOYBEAN CROPS IN CENTRAL IOWA

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1. INTRODUCTION

The Soil Moisture-Atmosphere Coupling Experiment (SMACEX) was a four-week field campaign that significantly expanded the objectives of the Soil Moisture Experiment 2002 (SMEX02). The main objective of SMEX02 was to provide data sets for the development and verification of alternate passive microwave soil moisture retrieval algorithms in a region with significant agricultural crops. SMACEX was a boundary layer experiment within SMEX02 that used the NRC Twin Otter atmospheric research aircraft, LIDARS, and an array of 14 flux towers to examine water and energy cycling across the land-atmosphere interface. In particular, the aircraft and tower data will form a multi-scale dataset with which to evaluate Land-Atmosphere-Transfer-Schemes (LATS) that have been developed to directly integrate the spatial information provided by remotely sensed data. An overview of SMACEX is presented by Kustas *et al.* (2003). This paper summarizes the flux aircraft program and presents preliminary data from the aircraft and some of the towers.

2. TWIN OTTER INSTRUMENTATION

The NRC Twin Otter atmospheric research aircraft (Figure 1) was instrumented to measure the 3-axis components of atmospheric motion and the fluxes of sensible and latent heat, momentum, CO_2 and ozone. It also carried several remote-sensing instruments that will be used to relate the measured fluxes to surface conditions and to measurements made by the other remote sensing aircraft and satellites used in SMEX02 (experiment plan, http://hydrolab.arsusda.gov/smex02/). These included a Heitronics KT-19 pyrometer for surface temperature, an Exotech Satellite Simulator operated in the TM mode, a Skye Industries Greenness Indicator, and radiometers for incident and reflected visible, IR and net radiation. Further details on the aircraft instrumentation and subsequent processing of the recorded data are presented in MacPherson and Wolde (2002).

Fig. 1: NRC Twin Otter atmospheric research aircraft

3. FLIGHT OPERATIONS

SMACEX was conducted in the Walnut Creek Watershed southwest of Ames, Iowa. This area is representative of a much larger region in the U.S. Upper Midwest in which the primary crops are

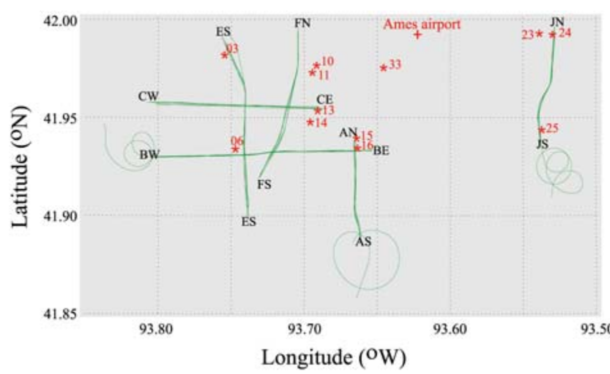

Fig. 2: Twin Otter flux lines (green) and SMACEX flux tower locations (numbered red asterisks)

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corn and soybean. The Twin Otter flew 16 missions in the period June 15 to July 6, 2002. Fluxes were measured at an altitude of approximately 40 m on repeated passes over six tracks ranging in length from 5.7 to 12.2 km. The selection of the flight tracks involved considerations of FAA rules regarding low-altitude flights near highways, dwellings and built-up areas. Although all of these tracks did not fall entirely within the very small Walnut Creek Watershed, they are representative of that watershed, and passed as many of the SMACEX flux towers as possible.

Figure 2 shows GPS flight tracks for all of the flux runs flown on Flight 16. Each of the six tracks was flown six times on this flight. The tight grouping of the plotted green flight tracks for each line demonstrates the repeatability the pilots were able to achieve, even though some of the tracks required gentle turns to avoid dwellings. The numbered red asterisks depict the locations of the flux towers. Tracks A and B were chosen to cross as close as possible to tower site 16, which was co-located with the LIDAR site. The spiral flight tracks south of Tracks A and J and west of Track B depict the locations of soundings flown on this flight. Most flights included at least two soundings to profile the atmosphere from about 20 m above the surface to about 300 m above the top of the mixed layer.

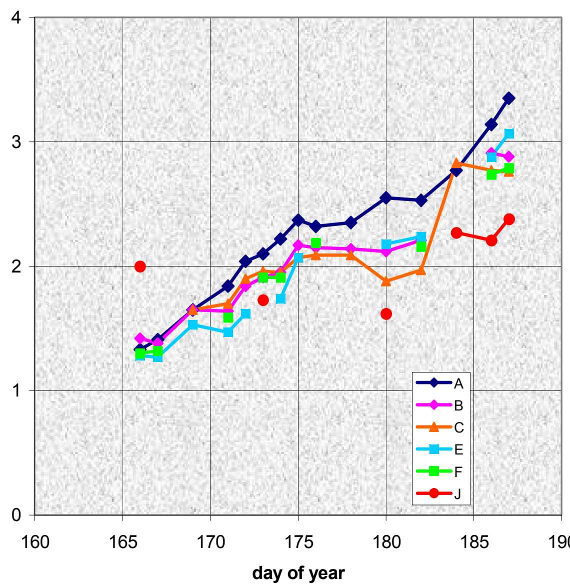

Fig. 3: Greenness Index versus day of year for the six Twin Otter flight tracks

With the exception of Track J, the majority of the crops overflown on the flux runs were either corn or soybean. Track A had the largest proportion of corn, perhaps 75 percent, while Track E had the least at about 40 percent. Track J, to the east of the main project area, had a large section of pasture land in the middle of the run which didn't change significantly during the experiment.

4. AIRCRAFT DATA

In the first half of the experiment, the leafout of the soybean appeared to be well behind that of the corn, particularly on Track E, which may have been planted late. This can be observed in Figure 3, which shows the greenness index (GI) remotely measured by the aircraft from the ratio of reflected radiation at 730 and 660 nm. Track A shows the highest GI for most of the experiment, while Track E lags at first but catches up as the soybean foliage fills in.

During the first 18 days of the experiment, the only precipitation in the project area consisted of scattered showers on the evening of Day 171. Nevertheless, there was vigorous growth by the dominant crops of corn and soybean, with the midday CO_2 uptake increasing from about 0.35 $mg/m^2/s$ to in excess of 1.3 $mg/m^2/s$ (Figure 4). This growth suggests that there was a sufficient store of soil moisture from springtime precipitation in the area, and there was some rainfall on Day

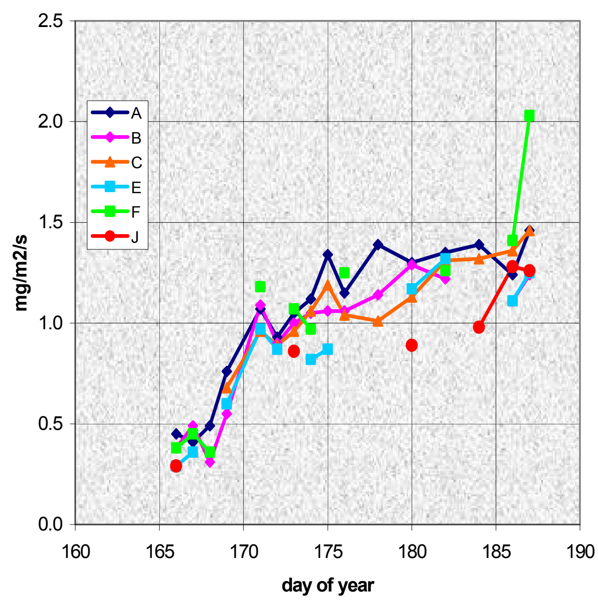

Fig. 4: CO_2 uptake versus day of year

163, three days before project flights commenced. Prior to the final two flights (Days 186, 187), the project area received precipitation ranging from 0.5 to 50 mm from several localized storms, which produced a significant response from the soil-vegetation system. With its larger proportion of corn coverage, Track A had the largest CO_2 uptake through most of the experiment. After the rains, some of the largest CO_2 fluxes ever measured by the Twin Otter were measured on Track F. It should be noted that these fluxes represent the average of six runs for each track, so the very large fluxes are not a result of a single pass with above-average turbulence or an exceptional number of large eddies. In most cases, the standard deviation of the run-to-run variations in the CO_2 fluxes was 10-15 % of the mean (see MacPherson and Wolde, 2002, for details and data from each flux run).

Figure 5 shows the Bowen Ratio (BR, ratio of sensible to latent heat flux) versus Day of Year for the six flux tracks. Tracks E and Track F had more bare soil early in the experiment, likely due to late planting of the soybean in that area, and thus a higher proportion of the sun's energy was converted to sensible heat rather than evaporation. Despite the lack of rain, BR fell through the first week of the experiment, as the vegetation grew and transpired more water vapor. It then stabilized at about 0.3 for all tracks by Day 176, followed by a slight rise until the precipitation on the evenings of Day 185 and 186. On the final flight of the experiment, BR had dropped to the range 0.08 (Track F) to 0.16. On Track F, very large latent heat fluxes, in excess of 460 W/m^2, accompanied the record CO_2 fluxes shown in Figure 4. It is also interesting to note that records indicate that Track J received no rain on the night of Day 185, hence its BR stayed high relative to the other tracks until after the heavier rains on the evening of Day 186.

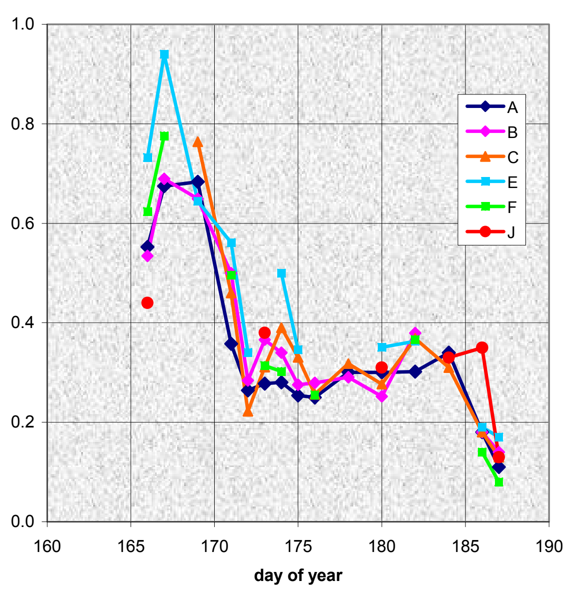

Fig. 5: Bowen Ratio versus day of year for the six aircraft flux tracks

One of the objectives of SMACEX is to obtain watershed averages of the radiation and energy fluxes from the aircraft and from the array of flux towers, and to not only intercompare these values, but also to compare them with model predictions (see Anderson *et al*., 2003). For the Twin Otter data, the area-average estimates were computed by averaging the radiation and energy flux components over all runs flown on each day. Figure 6 shows the sensible heat flux H, latent heat flux LE, and their total, adjusted for flux divergence (FD), i.e., heat storage in the atmospheric layer between the surface and flight level (8 to 19 W/m^2). Also shown on Figure 6 is a plot of the available energy, Rn-G, where the Rn is the net radiation measured by the wingtip radiometer on the aircraft, and G is the soil heat flux derived from averaging the 1100-1300 CST measurements

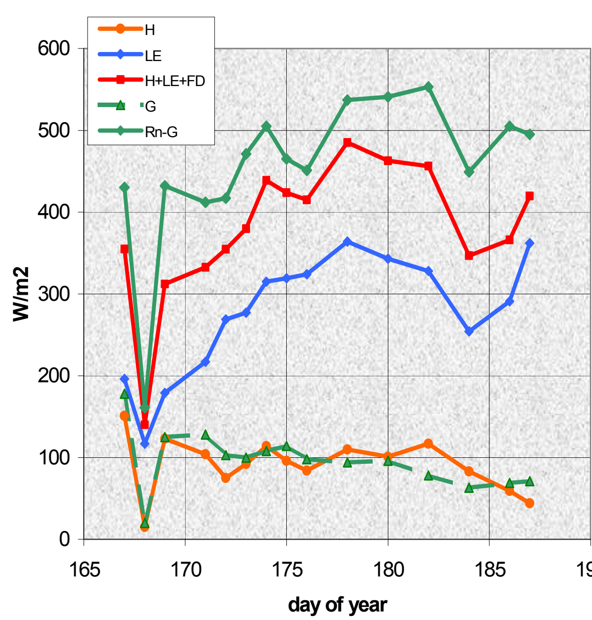

Fig. 6: Area-averaged energy components versus day of year. The aircraft-measured total energy (H+LE+FD) includes a small correction for flux divergence. The Rn-G is derived from Rn measured by the wingtip radiometer and the soil heat flux G averaged from measurements made at six of the flux tower sites

from the six tower sites closest to the Twin Otter flight tracks.

The closure ratio (CR=[H+LE+FD]/[Rn-G]) averaged 0.833, typical of earlier work over flat agriculture land, with values of approximately 0.9 experienced over forested areas (Desjardins *et al.*, 1997). The highest CR's (>0.9) were attained in middle of the experiment (Days 175-178). In an attempt to explain this, CR was plotted against wind speed, Rn and turbulent gust levels (not shown), but no significant correlation was found (highest $r^2 < 0.01$). The archived Twin Otter fluxes used in this paper were calculated using linearly detrended time history data. However, in the post-flight processing of the Twin Otter data, three sets of fluxes are produced using raw, detrended and high-pass filtered time histories. To investigate whether significant flux long-wavelength contributions were lost in detrending the time histories, the CR was also computed using the H and LE from the raw, unmodified time histories. CR increased by less than 0.5 %, suggesting that the long wavelength components have been adequately represented in the data used in this paper.

Figure 6 shows that between Days 178 and 184, the area-average LE decreased. This can also be seen in Figure 5, where there was a slight rise in the Bowen Ratio during this period, until the rains on the evenings of Days 184 and 185. This is likely an indication of some plant stress due to a lack of water, as reported in Kustas *et al.*, (2003).

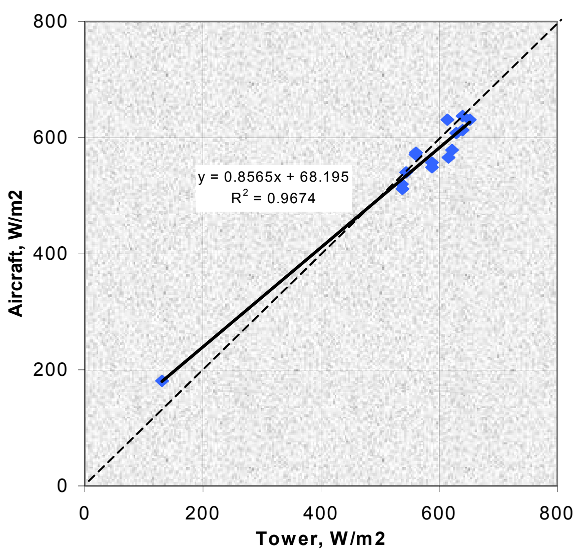

Fig.7: Comparison of aircraft versus tower net radiation

5. AIRCRAFT-TOWER COMPARISONS

Net radiation is an important parameter in the above study of energy closure, thus it was the subject of the first intercomparisons between the aircraft and tower data. Figure 7 shows the flight-averaged Rn from the aircraft's new wingtip CNR-1 radiometer plotted against the 1100-1300 CST average Rn from towers sites WC03, 06, 15, 16, 24 and 25 (Fig. 2). The generally good agreement suggests that use of either the aircraft or the tower Rn in Figure 6 would lead to the same observations.

At the time of this writing, only preliminary flux data were available for three days from six of the flux towers, WC06, 11 and 15 over corn, and WC03, 10 and 16 over soybean (Figure 2). Figure 8 shows the aircraft H and LE averaged for all tracks and the data averaged for the six towers. As was the case for the SGP97 study (MacPherson *et al.*, 1999), the agreement between aircraft and tower is better for H than LE. On these three days, the LE for the towers over corn was much higher than that over soybean, and was quite close to the aircraft values.

6. FINAL COMMENTS

This paper has presented a first look at the flux aircraft data from SMACEX. As it was written relatively early in the project analysis period, it uses only limited and preliminary data from the

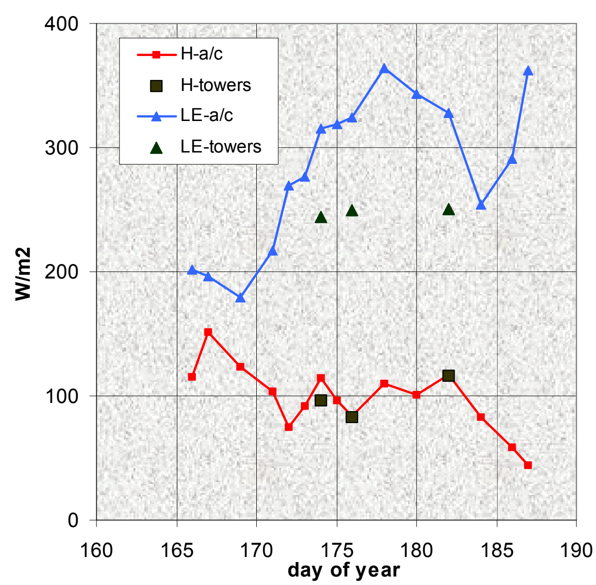

Fig. 8: Comparison of preliminary flux tower H and LE with aircraft data

towers. It is intended to present more complete aircraft/tower intercomparison data at the symposium.

Once all of the tower data are available, the intention is to perform at least two types of aircraft-to-tower intercomparisons. In the first, the aircraft flux data will be segmented and compared with individual towers, as was done in MacPherson *et al*. (1999). In the second, which will focus on area-averaged estimates, remote-sensing data and land-use maps will be used to determine the proportion of each of the Otter's flight tracks that consist of corn and soybean. Then the tower-estimated fluxes can be weighted by these proportions for comparison with the aircraft-measured fluxes.

7. ACKNOWLEDGEMENTS

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