An Evaluation of the Uncertainties of CO₂ and Sensible Heat Flux Measurements from a Light Aircraft Platform and Comparison to Tower-Based Measurements


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I. Introduction

Aircraft measurements of CO₂ and sensible heat fluxes are useful in that they bridge the data gap between local-scale tower-based measurements and regional or global-scale, satellite-based measurements. Aircraft measurements are inherently expensive due to operational costs and the expense limits the number of measurements that can be conducted. Therefore, it is useful to minimize the cost by using a lightweight, operationally flexible aircraft. Here, we present data collected over a 3-day intensive during the summer of 2006 over northern Michigan and evaluate the overall uncertainty of the measurements and the extent to which reliable flux measurements can be made from the piloted airborne platform.

II. Methods

Fluxes of CO₂ and sensible heat are calculated using the eddy covariance method over a suitable averaging length. Vertical wind was measured using a nine-pressure port hemispherical probe known as the Best Air Turbulence (BAT) probe. The sensed wind vector and the 3-D motion vector from an INS/GPS system of the aircraft are combined to produce the winds in a geographic-frame reference, after coordinate rotations (Garman et al., 2006).

Dry Mol Fraction of CO₂ was measured at 2Hz using an NDIR system from AOS, Inc. The lag time of the CO₂ measurement was determined by maximizing the absolute value of the cross covariance of vertical wind and CO₂ and shifting the data accordingly. The temperature was measured using a fast, ultra-sensitive thermocouple just below the hemispherical probe.

III. Uncertainty in the Flux Measurements

A suite of wind-tunnel calibrations and in-flight tests have been conducted to assess the uncertainty in vertical wind measurement (Garman et al., 2006). It was shown that the measurement uncertainty in v is a very weak function of true air-speed. An additional uncertainty is due to the system error from changes in lift-induced upwash caused by airflow distortion in front of the fuselage and wings. Most investigators treat lift-induced upwash (Crawford et al., 1996) as a constant that does not influence the uncertainty in v.

By propagating the uncertainties from the vertical wind measurements, CO₂ concentration, and temperature during in-flight measurements, the total calculated uncertainty in the CO₂ flux is ±0.6 g mol m⁻² s⁻¹ and the total calculated uncertainty in the sensible heat flux is ±13 W m⁻². These uncertainties are adequate when comparing aircraft flux measurements with tower-based measurements. Thus, the aircraft flux measurements represent reliable data for scaling up to regional spatial scales.

IV. Flight Description

Here, we discuss a suite of flights that were conducted over a relatively homogeneous deciduous forest in northern Michigan above a 46m Ameriflux tower at the University of Michigan Biological Station. Nine flights were conducted between July 19-July 24, 2006. Each flight consisted of a series of five legs ~4.5km in length on an oval racetrack encircling the Ameriflux tower and a vertical profile throughout the depth of the boundary layer. Each flight consisted of a series of flat legs ~4.5km in length on an oval racetrack encircling the Ameriflux tower and a vertical profile throughout the depth of the boundary layer.

V. Analysis Considerations

For this study, the upward CO₂ flux was calculated based on the assumption that the time response of the system was fast compared to the time scale of the process. To determine the magnitude of the uncertainty in the CO₂ flux calculation, we took into account the impact of vertical flux divergence and the effect of non-stationary conditions.

The magnitudes of the calculated fluxes from the aircraft can be compared to those obtained from the Ameriflux tower if we take into account the impact of local flux divergence and differences in footprint. Preliminary analyses, however, show the fluxes from the two platforms are comparable and quite variable from one flight to another due to the nature of our instruments, differences in the flux footprint of the two platforms, and the tower averaging time being addressed.

We have just begun analysis of the first-ever flux measurements from this platform. The work presented is preliminary and full analysis of uncertainties, conditions, and relationships between aircraft and tower-based fluxes of all of the fluxes is on-going. Additional flights during this intensive have yet to be analyzed. Known limitations in our flux calculations due to flux attenuation from the time response limitations of our instruments, differences in the flux footprint of the two platforms, and the tower averaging time are being addressed.

The ALAR aircraft is a low-cost, operationally flexible flux measurement platform that would be a valuable component of the Mid-Continent Intensive.

VI. Results

VII. Discussion


10. X. Acknowledgements

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