# An Iterative Procedure for Estimating Areally Averaged Heat Flux Using Planetary Boundary Layer Mixed Layer Height and Locally Measured Heat Flux

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Measurements at the central facility of the Southern Great Plains (SGP) Cloud and Radiation Testbed (CART) are intended to verify, improve, and develop parameterizations in radiative flux models that are subsequently used in General Circulation Models (GCMs). The reliability of this approach depends upon the representativeness of the local measurements at the central facility for the site as a whole or on how these measurements can be interpreted so as to accurately represent increasingly large scales. The variation of surface energy budget terms over the SGP CART site is extremely large. Surface layer measurements of the sensible heat flux (H) often vary by a factor of 2 or more at the CART site (Coulter et al. 1996).

The Planetary Boundary Layer (PBL) effectively integrates the local inputs across large scales; because the mixed layer height (h) is principally driven by H, it can, in principal, be used for estimates of surface heat flux over scales on the order of tens of kilometers. By combining measurements of h from radiosondes or radar wind profiles with a one-dimensional model of mixed layer height, we are investigating the ability of diagnosing large-scale heat fluxes.

We developed a procedure using the model described by Boers et al. (1984) to investigate the effect of changes in surface sensible heat flux on the mixed layer height. The one-dimensional model is based on the equation

$$\frac{dh}{dt} = \frac{A_F \sigma_w}{A_T + \frac{g}{T}\frac{\Delta\theta}{\sigma_w^2} - \frac{A_{p(\Delta u)^2}}{\sigma_w^2}} \tag{1}$$

where t is time, $\Delta\theta$ and $\Delta u$ are temperature and velocity jumps at the top of the mixed layer and $A_T$, $A_F$, and $A_P$ are parameters associated with the model. $\sigma_w$ is given by

$$\sigma_w^3 = w_*^3 + \frac{A_s}{A_F} u_*^3 \tag{2}$$

where $u_*$ is the friction velocity and $w_*$ is the convective velocity scale,

$$w_*^3 = \frac{g}{T_0}\frac{H}{\rho c_p} h \tag{3}$$

The objective of the study is to invert the sense of the model. That is, we wish to estimate a value of sensible heat flux representative of scales on the order of tens of kilometers rather than that available from local measurements (from the energy balance Bowen ratios [EBBRs], for example) by comparing the output of the model with measurements of h from radar wind profiler and/or radiosonde data. Conceptually, the system operates as follows: The model is run with locally measured heat flux values (available at 30-min intervals) and all available temperature and wind profile data from radiosonde data (8 per day during intensive operating periods). Both sets (heat flux and balloon borne sounding system) of measured data are interpolated to the model time intervals, and the model then provides values of h as a function of time of day. These modeled estimates of h are compared with measured values determined from vertical time sections of signal-to- noise ratio (proportional to the structure function of the index of refraction, $C_n^2$) from the radar wind profiler. The difference (or the variance of the difference) between measured and modeled h is used as a correction factor in the sensible heat flux and the model is run again. This iterative procedure is continued until a relative minimum in the difference values is obtained.

Although the method is not yet completely satisfactory, the accompanying figures show that it works in principle. Figures 1, 2, and 3 show the modeled mixed layer height as a function of time of day compared with profiler-determined values for three days during a summer IOP in 1995.

In fact, the values of $A_T$, $A_F$, and $A_P$ are not absolutely determined. Thus the iteration procedure was applied for a range of values of each of the parameters to find the best set of values for each case.

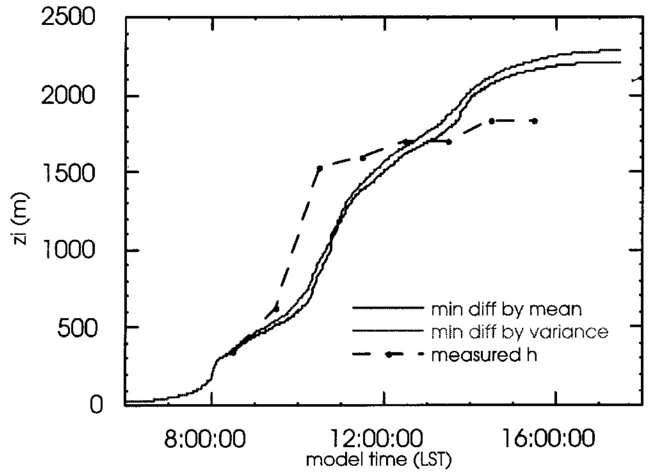


**Figure 1**. Model output for June 27, 1995. Sensible heat flux was calculated iteratively (through successive model runs) to minimize mean or variance of difference between modeled and actual mixed layer height.

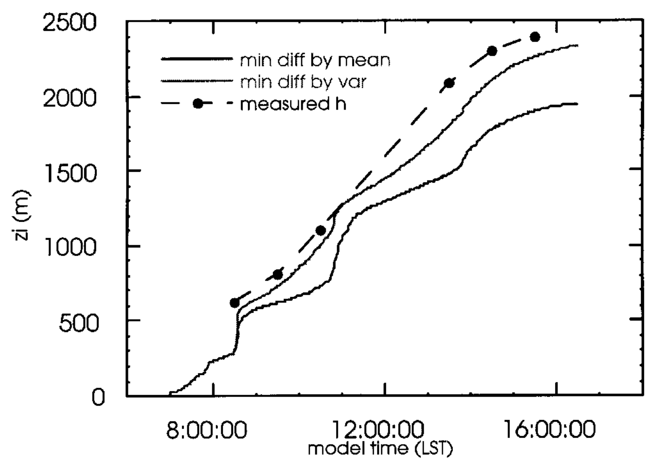


**Figure 2**. As in Figure 1 for July 7, 1995.

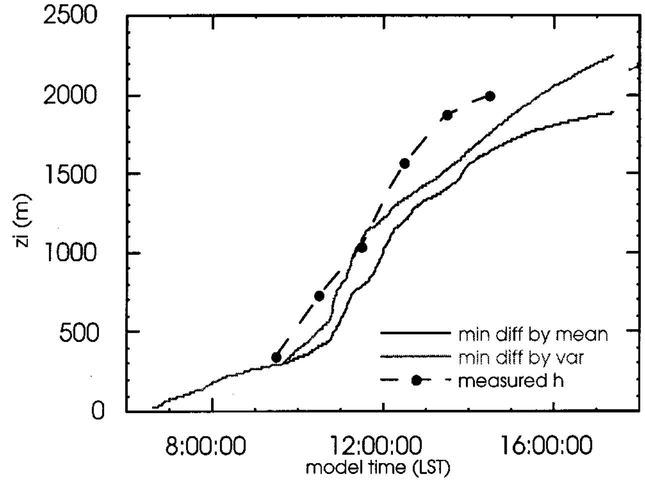


**Figure 3**. As in Figure 1 for July 12, 1995.

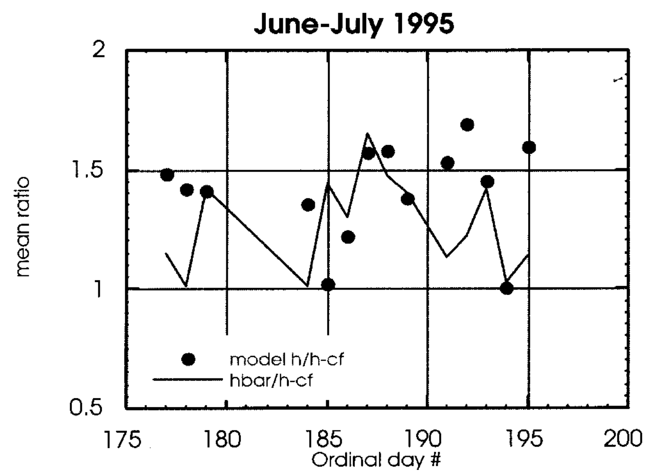


**Figure 4**. Ratio of the mean of locally measured values across the Southern Great Plains CART site determined from the EBBR stations to sensible heat flux measured at the central facility (solid line) and the ratio of modeled heat flux necessary to "match" measured mixed layer height to the central facility value.

Figure 4 illustrates that this approach consistently diagnoses that the values of sensible heat flux measured at the central facility are apparently significantly less than an areal average would obtain.

This result agrees with the observation that mean values from measurements at multiple locations across the site were consistently larger (by as much as a factor of 2) than those at the central facility during the time period under investigation. Because the measurements at the central facility were made above rangeland grass and the wheat fields surrounding the central facility had recently been harvested, a greater portion of the energy budget above the rangeland was devoted to latent heat rather than sensible heat. For the same reason, our model results indicate that this factor may be even larger, depending upon the status of the crops with regard to harvest, irrigation, and plowing when measurements over crops are available for the analysis.

## References

Boers, R., E. W. Eloranta, and R. L. Coulter, 1984: Lidar observations of mixed layer dynamics: Tests of parameterized entrainment models of mixed layer growth rate. *J. Appl. Meteorol*., **23**, 247-266.

Coulter, R. L., T. J. Martin, and D. J. Holdridge, 1996: Using remotely sensed planetary boundary layer variables as estimates of areally averaged heat flux. *Proceedings of the Fifth Atmospheric Radiation Measurement (ARM) Science Team Meeting*, pp. 59-62. CONF-9503140, U.S. Department of Energy, Washington, D.C.