Feedback on Lab 1 ("Time Series Analysis"). EAS 471, 2007

This assignment served several purposes: as an introduction to scientific computing, as an introduction or review of the calculation of statistics, and you may also have learned a little about the idealized atmospheric surface layer.

Everyone got most or all of the calculations done correctly. The most significant axis of differentiation was this: did you offer a perceptive and thoughtful view/conception of the exercise and was it more or less faithful to reality? Or did you ('technician approach') simply offer the answers?

1. Many of you focused your reports around this statement and question in the task definition: "The atmospheric surface layer is often called the 'constant flux layer'. Considering the heat and momentum fluxes you have deduced, is the name justified at this site?"

   The only direct evidence as to flux constancy is to compare the magnitudes of fluxes at the two heights. In hindsight I realize you had no reason to know that it is the *vertical* fluxes that are of interest in this regard. I think everyone found realistic mean vertical heat flux densities of about 190 and 170 $\mathrm{W\,m^{-2}}$, and noting that these do not differ at the 10% level we *could* justifiably say the vertical heat flux was roughly constant. As a matter of fact we don't, anyway, expect it to be exactly constant, for the mean heat budget (assuming horizontal uniformity and neglecting possible radiative flux convergence) reads[1]

$$\frac{\partial \overline{T}}{\partial t} = -\frac{\partial}{\partial z}\,\overline{w'T'} \tag{1}$$

which says that unless the vertical heat flux changes with height, you can't have any temperature trend. As you all noted, there was a warming trend, and $\overline{w'T'} > 0$ at both levels, with a smaller flux at the higher level. The warming rate implied by your measured fluxes is about

$$\frac{\partial \overline{T}}{\partial t} = -\frac{0.17 - 0.19}{23} \times 3600 = +3\,\mathrm{K\,hr^{-1}} \tag{2}$$

which is fairly plausible.

When we turn to the question of whether vertical momentum fluxes ($\overline{u'w'}$, $\overline{v'w'}$) were height independent, we find the measurements say they were not. This is a harder measurement. If the coordinate system of each anemometer is rotated to make $W = 0$ (a common strategy in experiments like this, based on the supposition that W truly is zero and if the sonic says otherwise, it was mis-levelled) the momentum fluxes remain very different at the two levels, and in particular $\overline{u'w'} > 0$ at the upper level, which is flatly counter to what is expected (gusts in u' should correlate with downdrafts $w' < 0$).

2. In the paradigm of the ideal surface layer, u_*, T^*, L are height independent — that is, ideally, these statistical properties (as well as R_{ij})

[1] No mysteries here I hope: storage term on the left, minus the flux divergence on the right, and no source/sink. By virtue of our restrictions the heat flux is by carried by turbulent convection only (implicitly, $W = 0$, so no vertical transport by the mean wind), and only the vertical flux contributes.

would have been very similar (say, within 10% of each other) at both levels (this is not true, however, of mean windspeed, which is expected to increase with distance from ground). It is not expected to measure such very different the friction velocities as were seen here (the very different u_*'s flow through to very different Obukhov lengths and T^*'s), and perhaps there was an instrument problem with this record (students were not expected to deduce that).

3. Some of you concluded that since the numbers in the Reynolds stress tensor are 'small' (say, compared to the mean windspeed) they are somehow unimportant, physically... Not so! For example $R_{33} \equiv \sigma_w^2$ is the variance of vertical velocity, and if this was zero, all our pollutants would hang around at ground level to snuff us out. And if R_{13} were zero, we'd have frictionless flow about the planet and no boundary-layer... this is the flux of momentum to the ground that is the corollary of 'drag'.

4. I appreciated that some of you gave references - however Wikipedia is far less satisfactory than a reference to a textbook or journal article.

5. Don't forget to report your results with an appropriate number of sig.figs. Of course, what is appropriate depends on the context, and this was an unfamiliar one for most students[2]. In most circumstances three

[2]One might reason along lines like this: with windspeeds of around $5\,\mathrm{m\,s^{-1}}$ and if we assume it is meaningless to quibble over speeds of order $0.01\,\mathrm{m\,s^{-1}}$, then relative uncertainty levels are of order .01/5, a bit less than one part in 100.

or four sig.figs. will do. An example where people sometimes slipped up was off-diagonal components of the Reynolds stress, eg. $\overline{u'w'} = -0.0094$ at the lower level where one needed to output to at least the fourth decimal place to secure even 1% precision. The fact that this number is small does not mean it is physically insignificant.

6. The columns u, T were large numbers and produced cross products like $6 \times 20 = 120$ which needed to be added 72,000 times over. Better accuracy is attained for $\overline{u'T'}$ by forming fluctuation matrices and then cross multiplying, rather than by performing $\overline{uT} - \overline{u}\,\overline{T}$

7. The vertical velocity variance σ_w^2 was smaller than σ_u^2, σ_v^2 (expected) and larger at the higher level. I had said in class that in a neutral ASL one expects $\sigma_w \sim 1.3 u_*$ which was not seen here. In an unstable ASL one expects

$$\sigma_w^2 = u_*^2 \, \Phi_{ww} \left(\frac{z}{-L} \right) = 1.7 u_*^2 \, \left(1 - \; 3 \, \frac{z}{L} \right)^{2/3} \tag{3}$$

($\Phi_{ww}()$ is an empirical function, and the evaluation given is one of several suggested on the basis of experiments on flat land). The largish values of $z/(-L)$ at this site would lead us to expect bigger values of σ_w^2/u_*^2 than the neutral limit 1.7

8. In hindsight, it would have sufficed to have asked you two plot only one or two of the time series, and over a shorter interval of a few minutes. For example I regret not having asked that you plot $w(t)$ and $T(t)$

between which (if plotted together) you might have been able to notice a correlation.

9. In future labs, I'll regard a flowchart as mandatory. One should avoid giving a verbal discussion of the program structure. A reader can get this far more economically from a flowchart. In creating your flowchart, you need to economize on space: thus (for example) one might lump together as one item all the outputs - rather than having an entry 'output —' every second step.

10. Because variance (eg. σ_u^2) and standard deviation (σ_u) have different units, they can't properly be plotted on the same graph — we may plot $u(t)$, $\overline{u}$, σ_u on the same chart, but not σ_u^2

11. In an unstable boundary layer the value of $z/|L|$ determines whether buoyancy is an important influence on the flow. If $z/|L| \ll 1$ it is not (the energy of the turbulence stems mostly from the wind shear), while at $z/|L| \gg 1$ buoyancy-generated turbulence dominates