Inconsistencies on in situ velocity spectra and momentum fluxes during DYCOMS

During DYCOMS-II field experiment, the NCAR C-130 probed the stratocumulus-topped boundary layer (STBL) off the coast of southern California. 60 km diameter circles were flown at different level: near cloud top (CT), just above cloud base (CB), between cloud base and the surface (SC) and 100 m above the ocean surface. In order to study the characteristics of the turbulence, the turbulent longitudinal component u and transverse components v and w in the aircraft coordinate system were analyzed. Each leg was divided in 2.5 minute segments, and the energy density spectrum of each segment was computed. Then, a mean spectrum was calculated for each leg and each component, from the dozen segments that composed a leg. Figures 1, 2, 3 and 4 display the mean spectra for u, v and w components for each leg of one of the nocturnal flights (RF07). We observed the following unusual aspects on these spectra:

- the ratio between a transverse spectrum S_v or S_w and the longitudinal spectrum S_u does not take the expected value of 4/3 in the inertial subrange;
- S_w follows a -2 slope rather than the theoretical -5/3 slope in the inertial subrange;
- S_u shows some noise, displayed by an excess of energy in the highest frequencies.

The same aspects were observed during the daytime flight RF08. We suspect an instrumental source to explain these spectra and wonder if any problem was detected during the verification maneuvers.

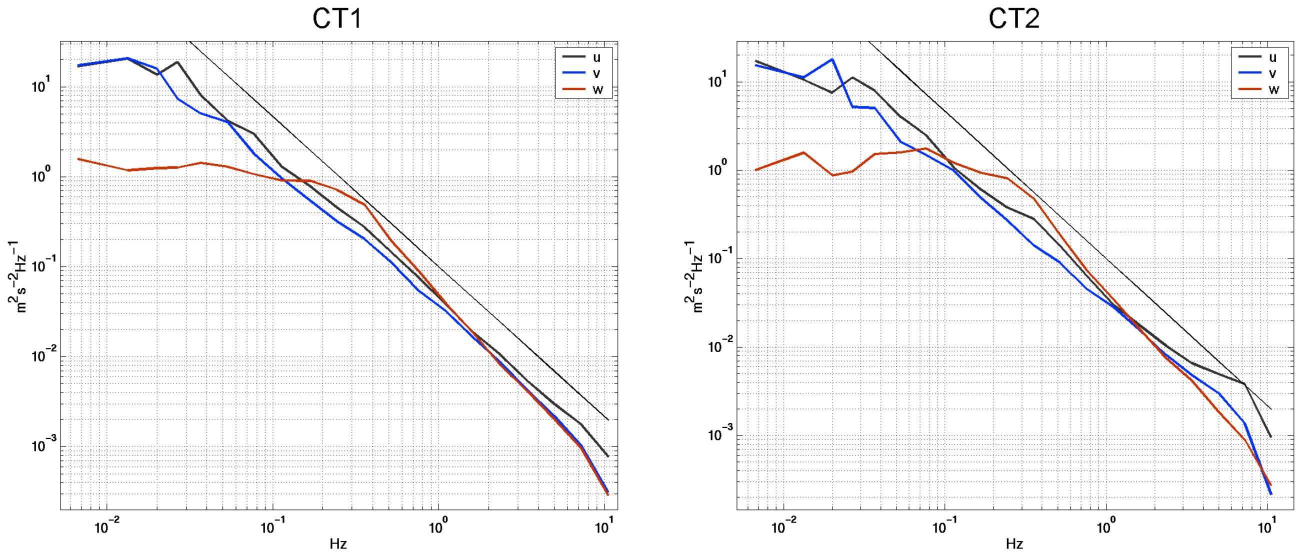

Figure 1: Mean spectra of u (black), v (blue) and w (red) for the two CT legs.

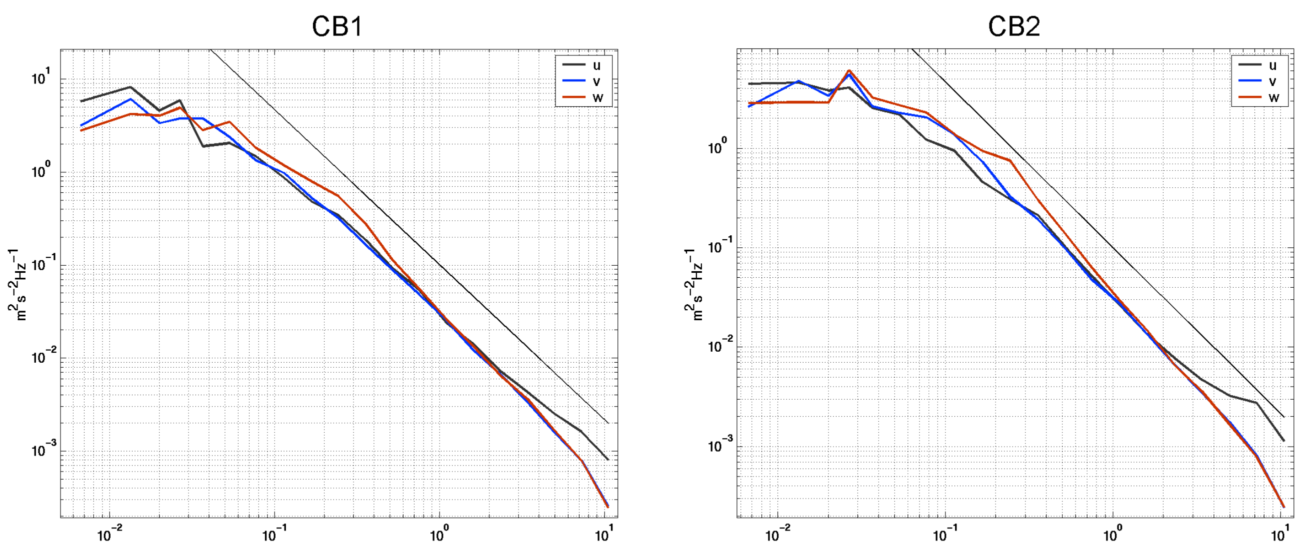

Figure 2: Mean spectra of u (black), v (blue) and w (red) for the two CB legs.

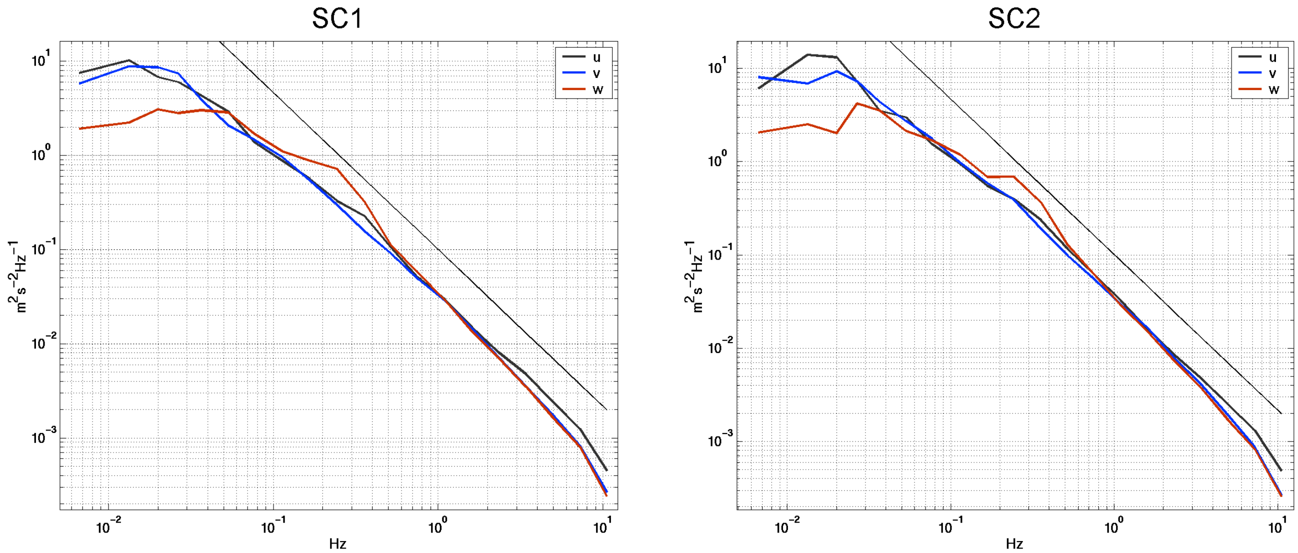

Figure 3: Mean spectra of u (black), v (blue) and w (red) for the two SC legs.

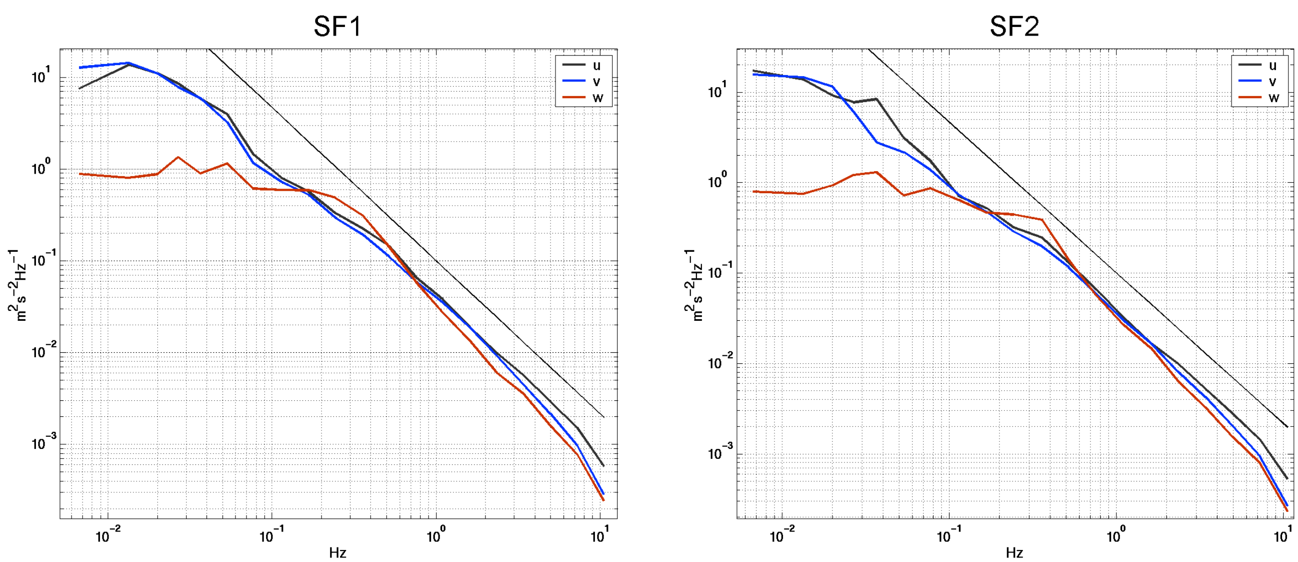

Figure 4: Mean spectra of u (black), v (blue) and w (red) for the two SF legs.

Figure 5 displays the three average spectra, which were calculated from an average of the spectra of all the circles of 7 flights during DYCOMS, (RF01, RF02, RF03, RF04, RF05, RF07 and RF08) after normalizing each spectrum by its associated variance. It shows the same patterns that we saw previously in the case of flight RF07.

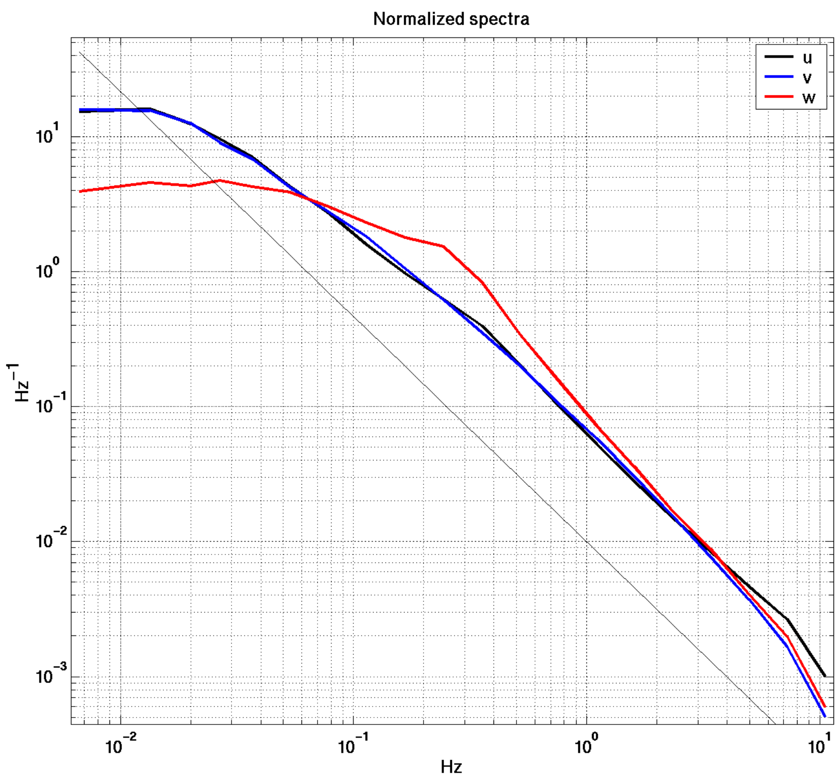

Figure 5:

We can estimate the momentum fluxes along the circle. If we neglect the variation of the true heading angle during one 2.5 minutes segment, we can write for each segment:

$$\begin{aligned} \overline{u'w'} &= \sin\psi\,\overline{U'w'} + \cos\psi\,\overline{V'w'} \\ \overline{v'w'} &= -\cos\psi\,\overline{U'w'} + \sin\psi\,\overline{V'w'}, \end{aligned} \tag{1}$$

where ψ is the true heading angle associated with the segment, u and v are respectively the longitudinal and the lateral components of the wind (relative to the aircraft referential), U and V are respectively the East and North component of the wind and w is the vertical velocity of the air. The previous system of equations can be written inversely:

$$\begin{aligned} \overline{U'w'} &= \sin\psi\,\overline{u'w'} - \cos\psi\,\overline{v'w'} \\ \overline{V'w'} &= \cos\psi\,\overline{u'w'} + \sin\psi\,\overline{v'w'}, \end{aligned} \tag{2}$$

$\overline{U'w'}$ and $\overline{V'w'}$ can be calculated along all the circles flown at different level and for different flights. They should not depend on ψ. If a systematic error exists, a dependance on ψ should be detected. An error associated with a biased measurement of u or w would lead to an error e_{uw}. An error associated with a biased measurement of v or w would lead to an error e_{vw}. And we would have

$$\begin{aligned} \overline{U'w'}_{obs} &= \overline{U'w'}_{real} + \sin\psi\,e_{uw} - \cos\psi\,e_{vw} \\ \overline{V'w'}_{obs} &= \overline{V'w'}_{real} + \cos\psi\,e_{uw} + \sin\psi\,e_{vw} \end{aligned} \tag{3}$$

Figures 6 and 7 show the momentum fluxes $\overline{U'w'}_{obs}$ and $\overline{V'w'}_{obs}$ which are calculated from equations (2) and normalized by $\sigma_u\sigma_w$ for all the 2.5 min segments of the circles flown during the 7 same DYCOMS flights. The dependance on the true heading angle seems stronger than the momentum fluxes themselves. An estimate of the error can be made from a least square analysis using the equations (3). The least square analysis of the first equation leads to

$$\begin{aligned} \frac{\overline{U'w'}_{real}}{\sigma_u \sigma_v} &= -0.0226 \\ \frac{e_{uw}}{\sigma_u \sigma_v} &= -0.1282 \\ \frac{e_{vw}}{\sigma_u \sigma_v} &= 0.0033 \end{aligned} \tag{4}$$

The least square analysis of the second equation leads to

$$\begin{aligned} \frac{\overline{V'w'}_{real}}{\sigma_u \sigma_v} &= 0.0209 \\ \frac{e_{uw}}{\sigma_u \sigma_v} &= -0.1291 \\ \frac{e_{vw}}{\sigma_u \sigma_v} &= 0.0115 \end{aligned} \tag{5}$$

The corresponding sinusoidal function of ψ is represented by a red line on figures 6 and 7. e_{uw} is much larger than e_{vw} and than the fluxes estimates. This does lend support to a bias introduced by a possible erroneous measurement of the longitudinal component u. Consistently, both least squares analyses lead to two very close estimates of e_{uw}. There may be no bias due to the lateral component, since the two estimates of e_{vw} are different, beside being much smaller than e_{uw}. This method does not allow to detect any inconsistencies in the measurement of w.

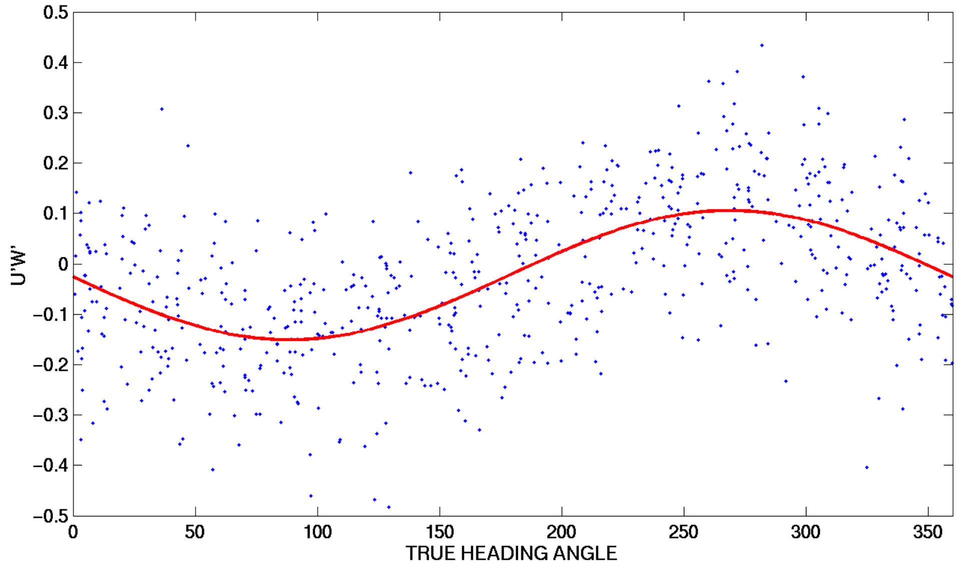

Figure 6:

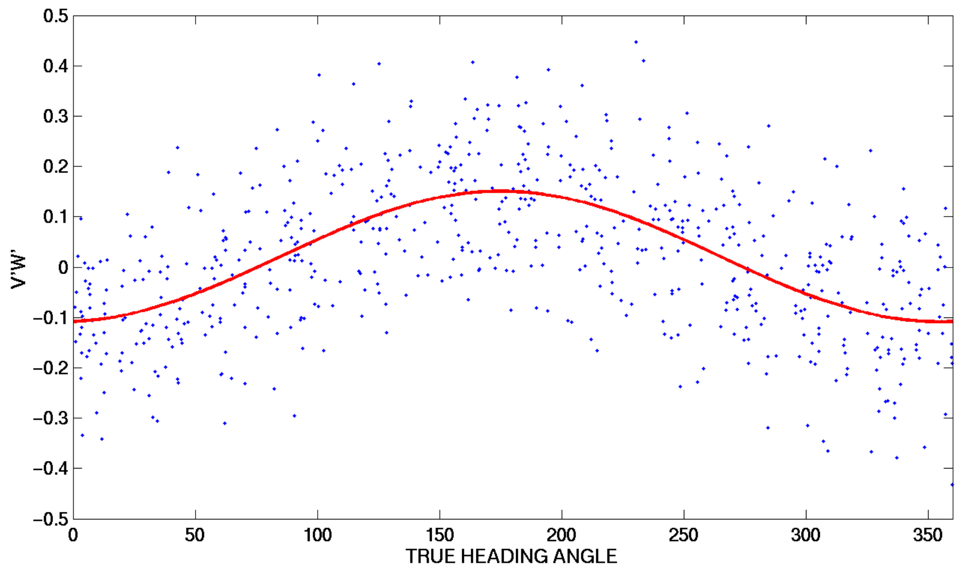

Figure 7: