On the temperature-humidity similarity in a forest canopy in well-watered and water-stressed conditions

Eric Lamaud, Mark Irvine

3.3 ON THE TEMPERATURE-HUMIDITY SIMILARITY IN A FOREST CANOPY IN WELL-WATERED AND WATER-STRESSED CONDITIONS

Eric Lamaud* and Mark Irvine

Unité de Bioclimatologie, Institut National de Recherche Agronomique
Villenave d'Ornon, France

1. INTRODUCTION

Forests play an important role in biosphere-atmosphere mass and energy exchanges, given that they occupy a significant portion of the land surface. Characterizing forest-atmosphere transfer processes is thus important to our understanding of global exchanges. When modeling biosphere-atmosphere exchanges an analogy between heat and water vapor transfer is often used to both simplify modellng and to take advantage of our knowledge concerning heat transfer. However, this analogy may not always be true, especially for forest canopies, where the architecture creates a spatial distribution of sources and sinks which may be different for heat and water vapor.

2. MATERIALS AND METHODS

This question was investigated during an intensive measurement campaign conducted from the 28th of July to the 24th of October 1999 at Le Bray (CarboEurope flux site FR2), a 30 year old maritime pine stand (Pinus pinaster Ait) located in the south-west of France. This forest canopy exhibits three distinctive layers: the upper layer, between 13 and 19 m at the time of the experiment, which consists of a dense vegetation layer of branches and needles; the middle layer, between 1 and 13 m, corresponding to the trunks and dead branches; the lower layer or understorey, which consists of grass (Molinia coerulea (L.) Moench).

The experimental set-up consisted primarily of turbulent measurements of 3D wind, temperature and humidity above the forest canopy (z = 40m) and in the trunk region (z = 5m).

From the beginning of the campaign up until the 12th of September no rainfall occurred, so that the water stress increased during this period. Important rainfall was observed on the 13th of September and subsequently several times until the end of the campaign, resulting in a decrease in water stress. Consequently, our data set exhibits a large range of the Bowen ratios (from 0.1 to 10) which has strong consequences on the temperature-humidity similarity.

Corresponding author address:
Eric Lamaud, INRA BP 81,
33883 Villenave d'Ornon France
email lamaud@bordeaux.inra.fr

3. RESULTS AND DISCUSSION

The temperature(T)-humidity(q) similarity was investigated through the analysis of the correlation coefficients R_{Tq}, R_{wT} and R_{wq} (where w is the vertical wind velocity) above and beneath the forest canopy.

We first plotted these coefficients against the stability index $-z/L$ (not illustrated here). Our results, for data obtained during daytime above the forest, are very similar to those obtained by De Bruin *et al* (1993) for a dry stony desert (La Crau, France). R_{wT} values range from 0.2 for $-z/L=0.01$ to 0.6 for $-z/L=1$ with a regular increase in R_{wT} with $-z/L$. R_{wq} ranges from 0.1 to 0.5 but with a scattered relationship between R_{wq} and $-z/L$. Finally, the correlation coefficient R_{Tq}, which ranges from about 0.1 to 0.9 (with a median value of 0.7), does not exhibit any relationship with the stability index.

At the understorey level, the various correlation coefficients exhibit the same behavior, but with a different range of variation for each of them (R_{wT} from 0 to 0.5, R_{wq} from 0.05 to 0.4 and R_{Tq} from 0 to 0.8, with a median value of 0.6).

Further investigation revealed that the coefficient correlation R_{Tq} depends on the Bowen ratio at both levels. Generally, data for which R_{Tq} is lower than 0.5 above the forest corresponds to Bowen ratios higher than 1.2 or lower than 0.8 (see Figure 1), i.e when the sensible heat and water vapor fluxes are significantly different.

In order to investigate the relationship between the temperature-humidity correlation and the respective efficiencies of vertical transfer of heat and water vapor, we plotted the ratio R_{wT}/R_{wq} against R_{Tq}, for the whole forest canopy (Figure 1) and the understorey (Figure 2). As the

Bowen ratio was found to have a strong influence on R_{Tq} we classified the data according to the values of Bo obtained above the forest. For clarity only a limited number of classes are represented.

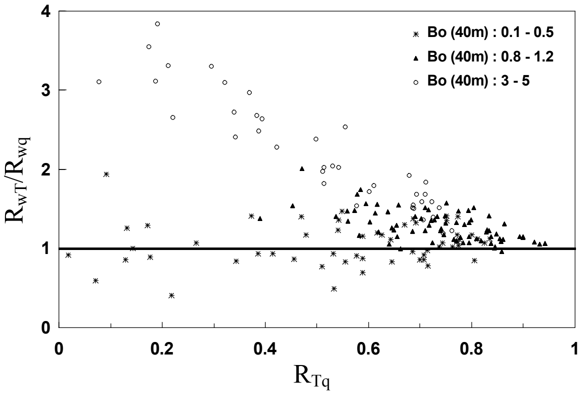

Figure 1. Ratio of the correlation coefficients R_{wT} and R_{wq} vs R_{Tq} obtained between 10h and 12h above the forest

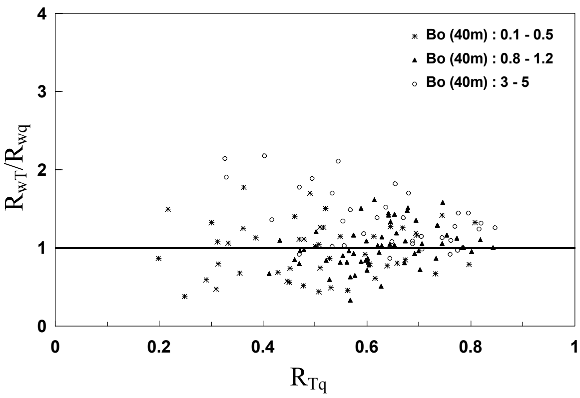

Figure 2. Ratio of the correlation coefficients R_{wT} and R_{wq} vs R_{Tq} obtained between 10h and 12h in the understorey

The ratio R_{wT}/R_{wq} above the forest is generally higher than 1 - which seems to be the limit value when R_{Tq} approaches 1 - and increases when R_{Tq} decreases. This corresponds with the observations of Roth and Oke (1995) over a patchy urban surface. Beside the fact that the higher values of R_{Tq} correspond to Bowen ratio around 1, this parameter also influences the relationship between R_{wT}/R_{wq} and R_{Tq}. The slope of the relationship is zero when Bowen ratio is lower than 0.5 and clearly increases with Bo. In other words, when the latent heat flux is more than twice the sensible heat flux, the efficiencies of heat and water vapor transfer are similar even when the T-q correlation is low.

Results from the understorey seem to exhibit a different behavior. However, it must be noted that because of the lower sensitivity of grass to water stress, the values of the Bowen ratio obtained in the understorey are about four times lower than above the forest. Consequently the first two classes of Figure 2 correspond to a local Bo lower than 0.3 and the results are therefore in agreement with those from the first class of Figure 1. The same is true for class 3 of Figure 2 which must be compared to class 2 of Figure 1.

4. CONCLUSION

From their measurements over a dry site, De Bruin *et al* (1993) concluded that poor R_{Tq} correlations were due to the entrainment of dry air at the top of the boundary layer being stronger than the surface evaporation, while from data obtained on a patchy vegetated surface, Andreas *et al* (1998) concluded that the reason for such low R_{Tq} correlations was the metre-scale heterogeneity of the surface, on which the sources for heat and water vapor differ.

The hypothesis of De Bruin *et al* (1993,1999) is not valid in our case, especially when the Bowen ratio values are low, i.e when the evaporation flux is largely predominant over the sensible heat flux. Furthermore it must be noted that even when the Bowen ratio is quite large (about 3) the latent heat flux can reach values of about 150 W/m² and we obtain nevertheless values of R_{Tq} lower than 0.6.

It can be concluded that in our case, and probably more generally for forest canopies, poor R_{Tq} correlations result from the heterogeneity of the forest where the spatial distribution of sources and sinks are probably different for heat and water vapor.

5. REFERENCES

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