2.4 USE OF THE R.E.A. TECHNIQUE TO MEASURE SCALAR FLUXES ON GROUND-BASED AND MOBILE PLATFORM

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1. INTRODUCTION

Increasing interest in dry deposition of air pollutant and trace gas flux determination has widely encouraged the development of the Relaxed Eddy Accumulation (or conditional sampling) technique. This technique remains very attractive since many trace constituents cannot be measured fast enough to allow the application of the eddy correlation method.

The Relaxed Eddy Accumulation (REA) method, developed by Businger and Oncley [1990], involves sampling turbulent air according to vertical wind fluctuations (w'), in order to collect at a constant flow rate updraft air in one reservoir and downdraft air in another. This conditional partitioning is also dependent of a threshold w_0 which is proportional to the standard deviation of the vertical velocity σ_w. In the first reservoir, upward air parcels are accumulated ($w > w_0$), the second reservoir contains downward air parcels ($w < -w_0$), and when $|w|<w_0$, the air is rejected. At the end of the sampling period, the mean concentration in each container is measured and the vertical flux can be written by:

$$\Phi_x = \beta\, \sigma_w (X^+ - X^-),$$

where Φ_x is the flux of scalar x, β is an empirical constant varying with the threshold of air selection (Bowling at al., 1999) and X^+/X^- represent the average concentration of scalar x corresponding to updrafts and downdrafts respectively.

This method, which is now commonly used for land surface measurements still remains difficult to implement on mobile platforms. This paper will present the development and results of a REA system which can be used to evaluate scalar fluxes from both a ground-based or a mobile platform (research vessels).

Our system has been tested during two major experiments in the year 2001:

- During the oceanographic campaign POMME (spring 2001) which took place in the Atlantic ocean, off the Azores coasts, we used the REA system to measure latent heat values since those fluxes can be easily compared with measurements from other methods. These comparisons are necessary to determine the degree of confidence we can have in the measurements achieved with the REA prototype.
- During the ESCOMPTE experiment, the same REA system was used above a maize field in the hinterland of Marseille from June until mid-July to determine carbon dioxide, nitrogen oxide and water vapor fluxes.

Comparisons with scalar fluxes computed by other techniques (eddy correlation, gradient and bulk methods) will allow to validate our REA system.

2. SPECIFICITY OF THE REA SYSTEM ABOARD RESEARCH VESSELS.

The main problem encountered when a REA system is implemented aboard a research vessel is the availability, in real time, of the vertical wind velocity, corrected from ship motions. Actually, the accuracy of the flux measurement by REA relies on an efficient conditional sampling: upward and downward air parcels must be correctly separated to precisely evaluate the difference of gas concentration between updrafts and downdrafts. So, a special emphasis has been put on the computation of a corrected and filtered vertical wind speed.

Onboard the research vessel L'Atalante, the three components of the relative wind were measured by a sonic anemometer located at the top of a mast, at the front of the deck. Besides, a motion package was used to provide pitch, roll and heave of the ship. In the Earth frame coordinate system, the corrected vertical velocity is:

$$W_{cor} = \sin\theta * u_s + \cos\theta\sin\varphi * v_s + \cos\theta\cos\varphi * w_s + \dot{p}, \qquad [1]$$

Where θ, φ, $\dot{p}$ are respectively the pitch of the ship, the roll and the time derivative of heave,

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and u_s, v_s, w_s are the measured wind components.

For the real time computation of vertical velocity, any time lag between signals must be avoided. So, the motion package data were transferred to the analog input of the sonic anemometer in order to ensure a perfect synchronization and a precise GPS (Network Time Protocole) was used to reset time of the data recording system.

3. DESCRIPTION OF THE RELAXED EDDY ACCUMULATOR CYCLE.

The figure 1 explains the functioning of the Relaxed Eddy Accumulator. A computer dedicated to the REA system gathered the data and processed them while running the air selection algorithm, and it also controlled each stage of the automatic device.

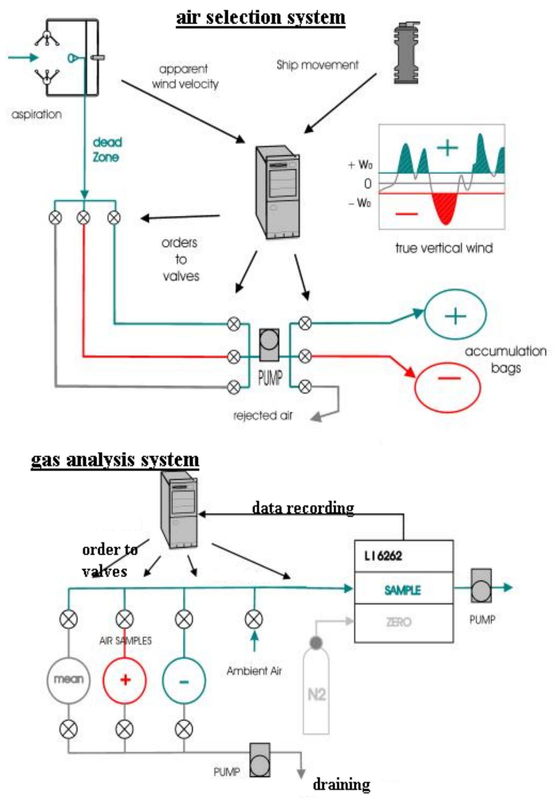

Figure 1: Scheme of the REA system aboard the ship. Crossed circles corresponds to valves. The gas analyzer is a licor LI6262 which is represented by two cells (sample and zero). Nitrogen is the reference gas.

The REA cycle lasts 30 minutes: the air selection and conditional sampling last 20 minutes and the 10 minutes left are used for the gas analysis and the draining of the bags so as to prepare a new cycle.

First, the data from the motion package and the sonic anemometer are collected by the data acquisition system. Then, a "true" vertical wind velocity is computed, and corrected for ship motions according to [1]. This velocity is also band-pass filtered in order to remove any bias on the average signal (theoretically, the mean vertical wind value is zero) and to limit valves switching.

The computer also triggers the air selection at a 10Hz frequency. The processed vertical wind signal is compared to a threshold $w_0=0.2\sigma_w$ and the air is sent to the corresponding bag or rejected if $|w|<w_0$. This case corresponds to a deadband when the vertical velocity is considered to be too small to be representative of the air parcel direction.

The second part of the REA cycle is the gas analysis. At the end of the sampling period, the computer sends orders to stop air sampling and to start gas analysis. The gas of each bags is analyzed by the Li6262 analyzer for 1 to 2 minutes and the CO_2 and water vapor concentrations are measured. For the REA prototype used during ESCOMPTE, a nitrogen oxides analyzer (42-CTL thermo environmental) was added in parallel to the Li6262 analyzer to estimate NO_x concentrations at the same time. Then, the bags are drained and a new cycle can start.

4. RESULTS

Figure 2 presents the time series of latent heat flux measured by REA (dots) and computed by a bulk algorithm (crosses) during the POMME experiment. The latent heat fluxes derived by the two methods look similar but the REA method provides values slightly weaker than the bulk method. The linear fit between the fluxes computed with the two methods show that the difference between fluxes is about 12%. However, the correlation r between the two methods for latent heat flux computation is 0.83.

Such a correlation is relatively good as we compare turbulent measurements (REA) with an empirical method which derives flux by using parameterizations of transfer coefficients and mean meteorological parameters. Moreover, there is still a lot of uncertainties on the parameterization of the neutral Dalton coefficient Ce_n which is the transfer coefficient for latent heat flux, and those uncertainties are reflected on bulk fluxes. This can explain the correlation value between bulk and REA fluxes but it is assumed that the difference of flux estimates between the two methods is probably caused by time lag and pneumatic losses in the tubes.

The ESCOMPTE experiment was an opportunity to test the REA system in better conditions. No correction for platform motions was needed so the computation of the true vertical velocity has been switched off in the air selection algorithm. This experiment allowed to validate the gas analysis system and the band-pass filtering applied on the vertical wind speed.

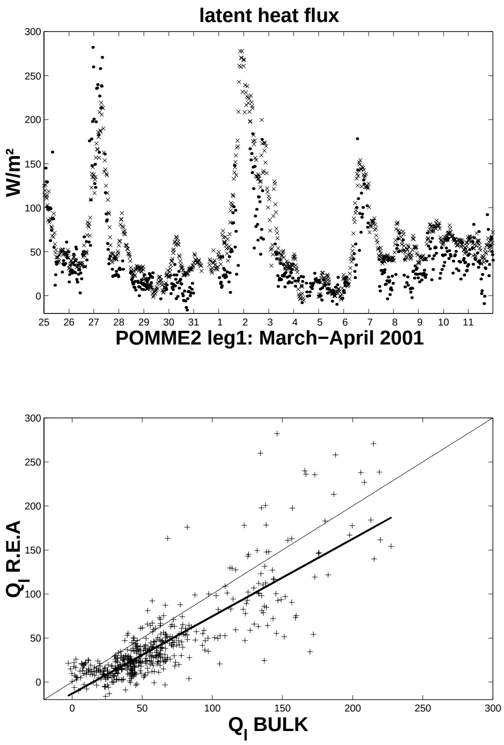

Figure 2: (top) time series of latent heat flux during the POMME experiment. Crosses and dots represent respectively the flux computed with a bulk algorithm and the flux measured with our REA system. (bottom) We observe a linear fit of the fluxes derived from the two methods with a slope of 0.88.

Figure 3 presents the time series of the fluxes measured by REA during the ESCOMPTE experiment. Nitrogen oxides, carbon dioxide and water vapor fluxes were measured for 4 weeks above a maize field. The time series show the automatic device was operational nearly continuously.

During the ESCOMPTE experiment, latent heat fluxes were also measured with the eddy covariance method (EC) on two masts (INRA & CNRM) in the same area. Figure 4 shows the comparisons between REA and EC latent heat flux. The two panels (a & b) include the linear fit between methods. Panel (a) is the comparison between REA (dotted line) and EC (solid line) by the CNRM system. The correlation is 0.94 and the slope of linear fit is 0.99. Panel (b) represents latent heat flux measured by REA (dotted line) and EC (solid line) by the INRA system. The correlation r is 0.93 and the slope is 1.03.

The eddy correlation method is still the reference technique to perform turbulent flux measurement in the atmospheric boundary layer. So, since the correlations between the flux estimates by REA and by ECM are very high and no bias is observed between the results of the two methods measurements, the REA system can be considered as validated and confidence in flux measurement by Relaxed Eddy Accumulation is allowed.

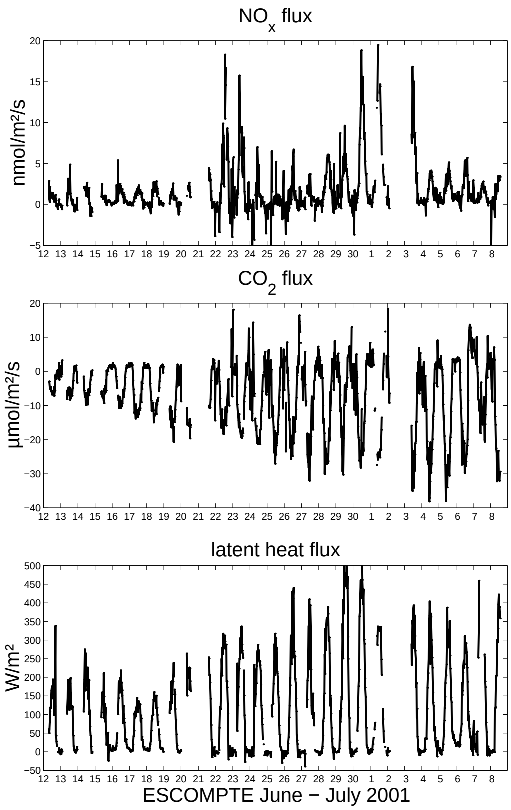

Figure 3: time series of fluxes during the ESCOMPTE experiment. Fluxes of nitrogen oxides, carbon dioxide and water vapor were measured from the 12^{th} of June to the 8^{th} of July with the REA system.

5. CONCLUSION

The REA system developed at the CNRM provided interesting results of scalar flux measurements both on land and aboard research vessel. The gas analysis system has been validated through the results of the ground-based system and flux comparisons with the reference method of eddy covariance. Concerning the REA system on mobile platform, uncertainties remain on the measurement and technical improvements must be carried out in order to reduce the loss of flux. However, the results of the POMME experiment are really encouraging for the use of this method to measure chemical compounds aboard ships.

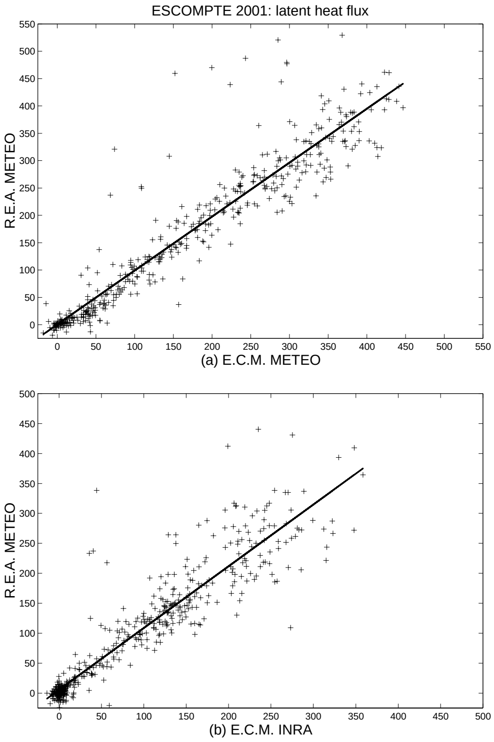

Figure 3: linear fit of latent heat flux measured by REA and EC (2 masts are used for EC, one by INRA and the other by CNRM). (a) is the comparison of REA flux with EC data from the CNRM and (b) is the comparison of REA flux with the EC data from INRA. The correlations are respectively 0.94 and 0.93, and the slope is very close to 1 in each case.

6. REFERENCES

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