Inverse parameter estimation of the atmospheric surface layer

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Abstract

An inverse estimation method is applied to a proper cost function to obtain both turbulent fluxes and roughness parameters of the atmospheric surface layer from single level meteorological data and surface radiative temperature.

Resumo. Aplica-se um método de estimação inversa de parámetros a uma apropriada função custo para obter os fluxos turbulentos e os parámetros de rugosidade da camada atmosférica superficial usando medidas meteorológicas de um nivel e temperatura radiativa de superficie.

1. Introduction

The turbulent transfer of energy and momentum between atmosphere and surface determines the structure of the atmospheric boundary layer , dry and moist convection, then affecting also the hydrological surface budget through evaporation. Although in recent years several turbulent transfer measurement projects spread out a good number of fast-response instrumented meteorological towers, a global flux measurement network is far from being implemented for various reasons (costs, management complexity etc.). On the contrary a good deal of continuous operating surface weather stations cover several areas of the globe, routinely collecting averaged single-level data of wind speed, temperature, humidity, solar radiation and precipitation. Modelling fluxes from these routine single-level data typically implies the introduction of site-dependent parameters (surface roughness, resistances etc..) that must be otherwise estimated (e.g.: Van Ulden and Hostlag, 1985). Here a method based on inverse parameter estimation is proposed to estimate both fluxes and parameters in the atmospheric surface layer from measurements at a single level z of wind speed U and variance σ_u, air temperature T_a and humidity Hr, total energy flux E (sum of latent and sensible heat fluxes, estimated as net radiation minus soil heat flux) and surface radiative temperature T_0.

2. The cost function

The proposed approach looks for the unknown surface parameters throughout the minimisation of the following cost function between modelled and measured variables:

$$S^2 = n^{-1} \sum [(\Delta T_m - \Delta T)^2/e_{\Delta T}^2 + (U_m - U)^2/e_U^2] \qquad (1)$$

where $\Delta T = T_0 - T_a$, the sum $\sum$ is over the n available measurements and $e_{\Delta T}$, e_U are the expected estimated errors for ΔT and U.

Using Monin-Obukov (MO) similarity the modelled wind speed U_m can be written

$$U_m = (u_*/k)[ln(z/z_0) - \psi_m(z/L)] = (1/k)\ \sigma_u\ \varphi\ [ln(z/z_0) - \psi_m(z/L)] \qquad (2)$$

where φ and ψ are known functions of the MO length L.

Using the Pennman-Monteith (PM) equation for the evaporation flux, and the MO bulk transfer expression for the sensible heat flux (e.g.: Garratt, 1992) the modelled temperature difference ΔT_m can be written as:

$$\Delta T_m = [R_a E - \sigma C_p q_s (1-H_r)]\ [\sigma C_p (dq_s/dT + \gamma(1+R_s/R_a))]^1 =$$
$$[(k^2 U)^{-1}[ln(z/z_0) - \psi_m(z/L)]\ [ln(z/z_{0T}) - \psi_h(z/L)]\ E - C_p\ q_s(1-H_r)]$$
$$[\sigma\ C_p(dq_s/dT + \gamma\ (1+R_s/R_a))]^{-1} \qquad (3)$$

The fluxes and z/L are expressed with the (MO) theory by U, Ta, To and the roughness lengths z_0 and z_{0T}. The ratio Rs/Ra between the surface and the atmospheric resistance is expected to depend on the soil moisture and the wind speed, and must be parameterized in terms of the measured variables. After some trials two candidate non-dimensional groups: $Qs/E = \sigma C_p(To-Ta)/(Ra*Ea)$ and $(\sigma Ts^4 - \sigma Ta^4)/E$ have been combined in the following expression: $R_s/R_a = R\ [\sigma C_p(T_0-T_a)/(E\ R_a(z_0, z_{0T}))]\ [(\sigma T_0^{\ 4} - \sigma T_a^{\ 4})/E]$ where R is a constant to be determined. Using this expression together with (2) and (3) in (1) the unknown (non-dimensional) parameters are $ln(z/z_0)$, $ln(z/z_{0T})$, and R.

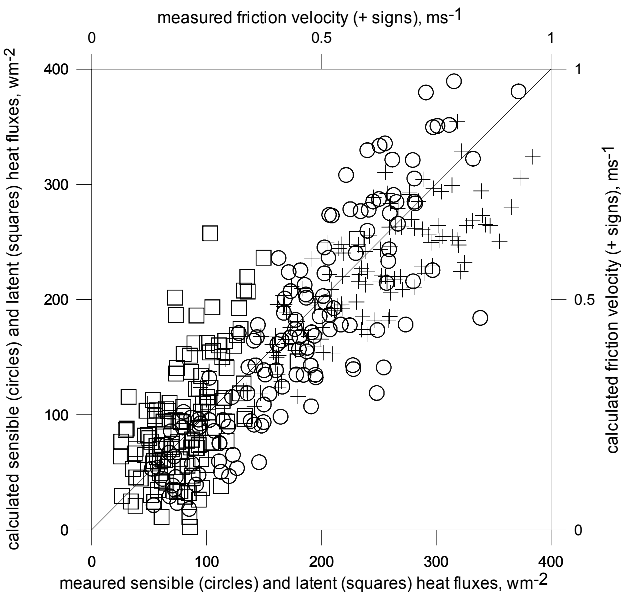
3. Results and conclusions.

The Marquardt-Levemberg approach [Beck and Arnold, 1977] has been used to search the three parameters $ln(z/z_0)$, $ln(z/z_{0T})$, and R that minimise S from (1) over a data set of measurements taken in the university campus of Lecce (South-Eastern Italy), a Mediterranean landscape mixed vegetation area covered with shrubs and partially with trees. As described in detail elsewhere (Martano, 2000) a 16 m mast was equipped with standard meteorological instruments collecting half-hour averages of the aforementioned meteorological variables, including To, measured by a surface thermoradiometer, and fast response sensors measuring half-hour averaged turbulent fluxes by eddy correlation, for comparison of the results.

Some results are shown in the figure, for 18 days of hourly averaged daily data of sensible, latent and momentum fluxes, in May 2005.

The parameters from the minimization of (1) are respectively found to be $ln(z/z_0)=2.7\pm0.1$, $ln(z/z_{0T})=14\pm1$, and $R= 80\pm14$. They compare well with the average values directly calculated from the MO and PM relations using the measured fluxes that, are $ln(z/z_0)=2.7\pm0.4$, $ln(z/z_{0T})=15\pm4$, $R=65\pm10$.

The method can be used to calculate the turbulent fluxes from single level meteorological data when flux measurements are not possible and information over the surface roughness are lacking, provided that estimations of the horizontal wind variance, total energy flux and surface temperature are available.



4. Acknowledgements

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5. References

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