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Heat Flux in Urban Areas Measured by Sodar Techniques: Preliminary Results

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1. *Introduction.*

During the recent years experimental studies of the atmospheric boundary layer have been developed by means of acoustic soundings performed by a system denominated SODAR. This system consists of electronic instrumentation that transmits and reveives acoustic pulses by an acoustic antenna (MCALLISTER, 1968; LITTLE, 1969).

The system, jointly operated in Turin by Politecnico (Istituto di Elettronica e Telecomunicazioni) and Istituto Elettrotecnico Nazionale Galileo Ferraris, is monostatic, i.e. it has one parabolic antenna for transmitting and receiving (PERONA *et al.*, 1975, 1976, 1977).

Usually the received echoes are recorded in the facsimile mode to obtain a qualitative, but very suggestive, representation (BEAN *et al.*, 1973; CREASE *et al.*, 1977).

However, one can obtain quantitative results concerning many characteristics of the boundary layer by a quantitative analysis of the echoes (PERONA *et al.*, 1977; ASIMAKOPOULOS *et al.*, 1976).

The purpose of this work is to determine the sensible heat flux rising from an urban area.

2. *Free and forced convection in the atmosphere.*

Convection in the lower atmosphere is present when the ground temperature is greater than that of the air layer above. This situation is mainly due to the solar irradiation and in build-up areas may arise as a consequence of man-made heat generation (for example: house-heating, cars, factories, etc.). In this situation, a heat flux rises from the ground together with bulk transport of air. According to TATARSKIJ (1971), LUMLEY & PANOFSKY (1964) and BUSINGER (1972), it can be assumed that the potential temperature profile is proportional to $z^{-1/3}$ in a superadiabatic layer over the forced convection level, whereas higher up the potential temperature becomes constant.

The mean wind interfering with the buildings generates turbulence that modifies the heat transport. The similarity theory of Monin and Obhukov (OBHUKOV, 1946) introduces a parameter L that represents the height level at which the power per unit mass produced by bouyancy is equal to the power per unit mass generated by shear stresses; for $z < L$ the shear stresses prevail over bouyancy.

The Monin-Obhukov length L is

$$L = \frac{\rho_0 \, c_p \, T_0 \, u^{*3}}{k \, g \, H_0} \tag{1}$$

where ρ_0 is the mean density of the air in kg m^{-3}; c_p is thermal capacity at constant pressure in cal kg^{-1} °K^{-1}; $k = 0.4$ is the von Karman's constant; g is the gravity acceleration in m sec^{-2}; T_0 is the absolute mean temperature of the air in °K; H_0 is the sensible heat flux rising from the ground in cal m^{-2} sec^{-1}; u^* [m sec^{-1}] is the friction velocity depending upon the mean wind and the surface roughness.

Therefore the boundary layer can be divided in two sublayers: one, from the ground to an height of order L, where the forced convection is present, i.e. where the weight of the shear stresses predominates; the other, above the height L, where free convection is present, i.e. where the bouyancy is the more important term.

3. *Sodar echo in convective conditions.*

The acoustic backscattered power from the atmosphere is (TATARSKIJ, 1971; LITTLE, 1969):

$$\begin{cases} P_r = 39 \cdot 10^{-4} \, \eta_t \, P_t \, \dfrac{c\,\tau}{2} \, A_r \, l \, \eta_r \cdot \\ \cdot \left(\dfrac{2\pi}{\lambda} \right)^{1/3} \left[\dfrac{C_T(z)}{(z - h_r) \, T_0(z)} \right]^2 \end{cases} \tag{2}$$

where P_r [W] is the electrical power of the echo; η_t, η_r are the transducer efficiencies, valuable at 10%; $P_t = 100$ W is the electrical transmitted power; $c = 340$ m/sec is the sound speed; $\tau = 50$ msec is the pulse length; A_r [m^2] is the effective area of the transmitting-receiving paraboloid (1.2 m diameter); l is an attenuation factor taking into account the sound absorption of the air (LITTLE, 1969); $\lambda = 17$ cm is the sound wavelength; T_0 is the absolute mean temperature of the atmosphere in °K; C_T [°K m$^{-1/3}$] is the structure constant for the temperature; z is the height in meters above street level and h_r is the roof height where the Sodar is placed.

The structure constant is (TATARSKIJ, 1971):

$$C_T^2 = \frac{K_T}{K_M^{1/3}} \, \frac{(d\vartheta_0/dz)^2}{(du_0/dz)^{2/3}} \tag{3}$$

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where K_T [$m^2 sec^{-1}$] and K_M [$m^2 sec^{-1}$] are the eddy thermal and mechanical diffusivities; θ_0 is the mean potential temperature in °K; and u_0 [m sec^{-1}] is the mean wind speed.

The Sodar echoes received from the three regions in which the lower atmosphere has been assumed to be subdivided, are qualitatively and quantitatively different.

In the forced convection region, the wind shear cannot be neglected: therefore, using some approximations (BUSINGER, 1972), it can be found that received echo decreases as $s^{-5/6}$. In the upper region, where the free convection prevails, the echo is proportional to $z^{-5/3}$ (PERONA *et al.*, 1977) and the structure constant for the temperature is:

$$C_T^2 = \frac{T_0^{2/3}}{k^{4/3} g^{2/3}} \left(\frac{H_0}{c_p \rho_0} \right)^{4/3} z^{-4/3} \qquad (4)$$

where all the symbols have already been defined.

The top of free convection is a region where the gradient of the mean potential temperature vanishes: consequently, the echo from this region vanishes too.

Therefore the aspect of the ideal mean echo in convective conditions is represented in Fig. 1, where h_r indicates the height of the roofs; h_b is the blanking height, i.e. the height above which the receiver is able to operate; h_{FC} represents the transition height

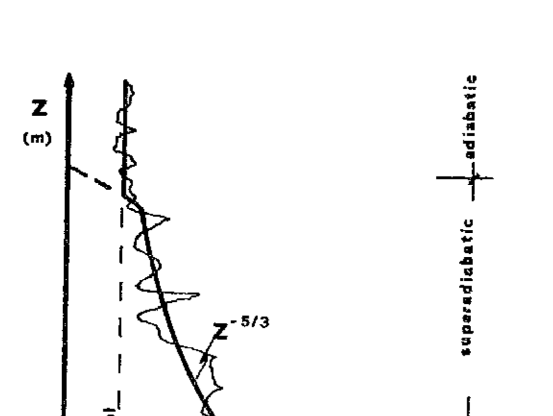

Fig. 1 – *An example of a Sodar echo (light line) superimposed on the schematic echo (heavy line), used in the data analysis, as a function of height* z (h_r = *roof level*; h_b = *blanketing level*; h_{FC} = *forced convection limit*). S *is proportional to the square root of the received power.*

between forced and free convection and conventionally is assumed equal to L.

It is necessary to emphasize that h_{FC} [Fig. 1] is not always present in the records because h_{FC} may be lower than h_b; moreover, the noise level (the acoustic environmental noise plus the electronic noise) may hide the transition between the superadiabatic and adiabatic region.

4. *Experimental results.*

According to the preceding sections, two methods for determining the sensible heat flux are possible: one using the height level of forced convection, the other using the received echo level.

The first method makes use of eq. (1) provided an estimate of $h_{FC} = L$ is possible; the heat flux H_{OFC} (where FC stands for Forced Convection) comes out equal to:

$$H_{OFC} = \rho_0 c_p \frac{T_0 u^{*3}}{k g h_{FC}} \qquad (5)$$

where T_0 should represent the mean temperature of the whole region of forced convection: however, if the value at ground is used instead, the error will still be small; u^*, the friction velocity, is, for hypothesis, constant in the whole region and it is determined by the mean wind at a certain altitude according to the following formula (PLATE, 1971)

$$u_0(z) = \frac{u^*}{k} \ln \frac{z - h_r}{z_0} \qquad (6)$$

where h_r is the height of the buildings and z_0 is the rougheness length, that may be assumed equal to $z_0 \cong 0.15\ h_r$ (PLATE, 1971). In the surroundings of the Sodar system, the height h_r is roughly 25 m: therefore $z_0 = 3.75$ m; the mean wind u_0 has been measured 10 m above the roof level.

With the second method the sensible heat flux is deduced by the mean received echo-level in the region of free convection.

When the trend of the plotted echo decreases approximately as $z^{-5/3}$, we assume that in the corresponding region a free convective regime is present; the average level at any height in that region may be used in computing H_{OS} (where S stands for the initial of Sodar). Indeed, $S = 10 \log_{10} (V_r/V_0)$ where V_0 is the reference voltage (5 or 10 V) for that particular experiment. The received power P_r appearing in eq. (2) may than be computed since $V_r = (Z P_r)^{1/2}$, where Z is the input impedance of the amplifier. It is evident that this method requires the calibration of the electro-acoustical system.

A sample of data relative to April 1977, has been examined. The number of cases is limited, but the choice has been made in such a way that different situations in different hours may be represented: sunny days (when free convection is present) with