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A REVIEW OF TROPOSPHERIC STUDIES WITH MICROBAROGRAPHS, SODAR AND FM-CW RADAR

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SUMMARY

Recently, new instruments like acoustic radars (SODAR), old instruments used for new purposes like the FM-CW radars, and very old instruments used in a completely different way like the micro barographs, have been developped by many laboratories and employed together to improve our knowledge of the lower troposphere. In Torino, at the Politecnico and at the two seats of the Istituto Elettrotecnico Nazionale Galileo Ferraris, three sodars are already working, connected to a central computer, and an array of microbarographs is under construction; furthermore, plans have been made to build an FM-CW radar. This set of instruments gives information on many atmospheric parameters: infrasonic waves and gravity waves are detected by the microbarographs together with their direction of arrival and phase velocity; the characteristics of the turbulence, the distribution of thermal gradients and wind shears are measured by the sodar; finally, the FM-CW radar is more sensitive to water vapor content. Evidently, the three instruments together give a set of information complementary and extremely valuable. The present paper describes briefly the most interesting results obtained in various laboratories together with some original and new results obtained in Torino.

INTRODUCTION

The physics of the atmospheric boundary layer is the object of a very profound interest because it affects the human activities and, in turn, may be strongly modified and polluted. For these reasons, it is very important to monitor the meteorological situation not only at the ground but also as a function of height and in a continuous way. The presence of temperature gradients, wind shears etc. create small and large scale local turbulence: small scale turbulence may be detected with acoustic waves; large scale turbulence generates pressure fluctuations in the infrasonic range, detected at the ground. In order to describe in the most complete way the boundary layer, it is convenient to have the possibility of correlating the two sets of measurements. This can be done with the combined use of sodars and microbarographs.

The SODARS are acoustic "radars" usually operating in the frequency range 500 Hz to 3000 Hz; acoustic bursts at a chosen frequency are sent upwards and backscattered by the local turbulence. The microbarographs are very sensitive barographs usually of the condenser type, with low internal noise and thermally very stable. However, one of the most important parameters in boundary layer, is humidity and temperature. These two quantities are not easily detected with SODARS, that senses only mechanical alterations of the medium. Indeed, electromagnetic waves seem more suitable to sense changes in the dielectric constant of the medium that is influenced by variations in the humidity content and in the temperature of the air. For these reasons, two instruments have been recently developped, namely the FM-CW radar and the RASS (Radio Acoustic Sounding System).

INFRASONIC WAVES - THE MICROBAROGRAPHS ARRAY

In what follows, we will be concerned in pressure fluctuations with time scales longer than 1 sec. The transducer for the detection of such infrasonic signals is not a normal microphone; a microbarograph or a specially designed microphone should be used. The electric signal is proportional to the force applied on the sensitive element, that in turn is proportional to $p + 1/2\,\rho v^2$ (Bernoulli's law) where p is the pressure and ρ is the density of the air moving with velocity v (1). In this force, terms are present due to pressure and wind fluctuations caused by turbulence, and pressure variations caused by wave motions, that is by coherent motions of air masses characterized by a well defined wavelength for each period. Usually, the wave terms are smaller than the turbulence terms and therefore are difficult to detect. In order to have an idea of the sensitivity needed, fig. 1 shows the pressure values vs. period both in a very quiet situation and in a disturbed one. It is quite evident the need of an instrument with an extremely large dynamic range if the whole set of periods from 1 sec to, let us say, 1 h needs to be examined. Of course, the situation is much less critic if a differential microbarograph is used (2). In order to reduce the contribution of the second term in the Berloulli's law, a specially designed noise-reducing spatial filter is inserted on the sensitive element (3). Such a filter consists of a long pipe, the length of which is shorter than the shortest wavelength to be detected, perforated at regular intervals by small capillary tubes. In this way, the turbulence is spatially averaged out, while waves may be detected. However, in order to deduce source position, phase velocity and direction of arrival of the wave fronts, arrays of at least 3 microbarographs are needed. Such arrays need to be located several kilometers apart, and give the possibility to study weather fronts, thunderstorms, waves generated by winds on the mountains, etc.. In Torino, a microbarograph array is going to be built; the data will be collected and analyzed with a computer. Fig. 2 shows an example of a large event recorded in Torino; the period of the wave is of the order of 400 sec and the peak-to-peak amplitude is about 120 µbar. In figure 3 shock waves possibly generated by a plane has been recorded: it is interesting to note the three echoes delayed respectively by 733 sec, 1266 sec and 1433 sec, corresponding to a round-trip distance of 12.5 km, 21.7 km and 24.6 km. Of course, nothing can be precisely stated on the nature and position of the reflecting regions. However, data of this type collected through an array of microphones, may be used to study the entire tropospheric structure (4).

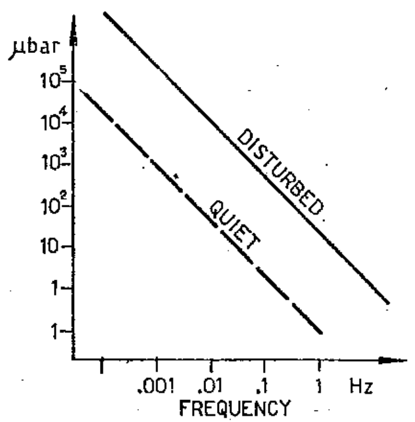

Fig. 1 - Infrasound pressure peak values vs. frequency.

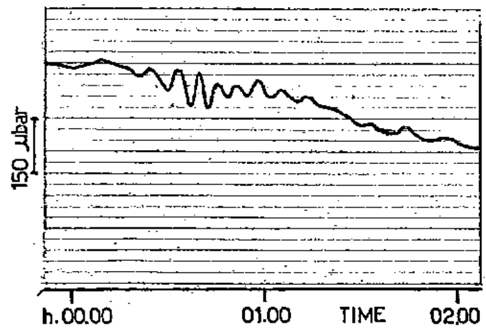

Fig. 2 - Pressure wave train detected in Torino.

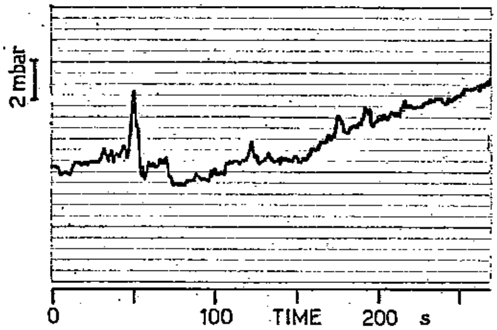

Fig. 3 - A shock wave and three delayed echoes.

TURBULENCE DETECTION: THE SODAR

The Kolmogorov theory (5) (6) of turbulence has been used (7) to explain the possibility of scattering of acoustic waves from atmospheric layers. This theoretical possibility suggested the implementation of an acoustic radar; its practical feasibility has been shown by the pioneering works of McAllister (8). It is well known that the turbulence responsible for the scattering of a sound with wavelength λ has a characteristic length equal to $\lambda/2$. Furthermore, the power backscattered is proportional to a cross-section σ (9). Only a quantitative measure of σ may give a quantitative evaluation of the turbulence that may be used to evaluate diffusion coefficients, needed in the numerical modelling of the environment for pollution studies. However, up to now, only relative measurements have been made. Indeed, the calibration of a SODAR could transform a qualitative instrument in a quantitative apparatus, but it is a difficult process since many parameters of the equipment need to be accurately measured (e.g. the radiation diagram, the effective radiated power, the free-field sensitivity of the apparatus). At the present time, the output of a SODAR is usually a facsimile representation of the echoes. In order to improve the capability of the system, it is necessary to make a numerical treatment of the received signal. Fig. 4 shows an echo, averaged over 10 pulses, detected in Torino using a 2000 Hz - 100 W acoustic SODAR. The diagram presents the characteristic signature of a thermal inversion. Even the analysis of a few received pulses, shows that the echo level does not remain constant. Such "scintillations" may be analyzed numerically (10) (11). Their characteristic period is often very long and may be related to pressure fluctuations measured at the ground with a microbarographs array (12). It is to be noted that even in this case a numerical treatment of the data may show periodicity not otherwise detectable. Fig. 5 shows the autocorrelation of the echo received by a well-defined height level equal to 240 m: the two peaks show the presence of a pseudo-periodic motion of about 3 minute period. The monostatic SODAR permits also to measure the vertical component of the wind through Doppler shift effects. The system may be further extended in order to measure the horizontal components of the wind by us-

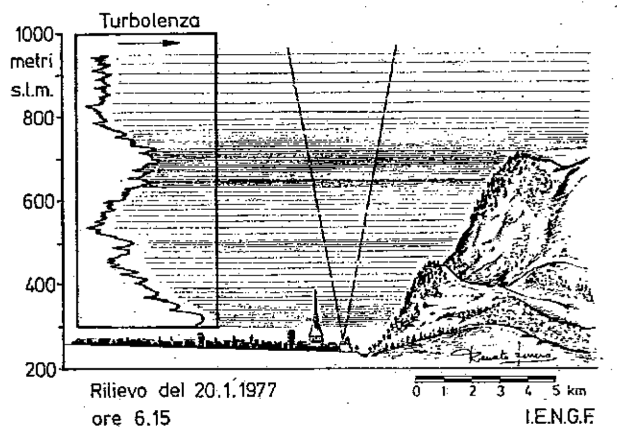

Fig. 4 - Sodar echo averaged over 10 pulses detected in Torino.

ing two more receivers at a fixed horizontal distance from the transmitter (13).

Finally, it is to be remembered that some possibilities exist (even though they have not been pursued up to now) to study the boundary layer by passive systems measuring the acoustic noise generated by human activities, like traffic and industrial noise. Fig. 6 shows the acoustic "brightness" measured by moving a paraboloid on a vertical plane. As expected, the maximum noise level has been reached at an elevation angle of 0°. However, a secondary maximum is present at 60° - 70°, followed by a minimum at the zenith. The apparatus was placed in the middle of a farming land surrounded by housing quarters: the secondary maximum may be attributed to refraction effects. Analysis of this type may be useful to study the boundary layer structure, to give reasonable specifications for the acoustic screen surrounding the sodar apparatuses, and finally to state criteria for noise pollution.

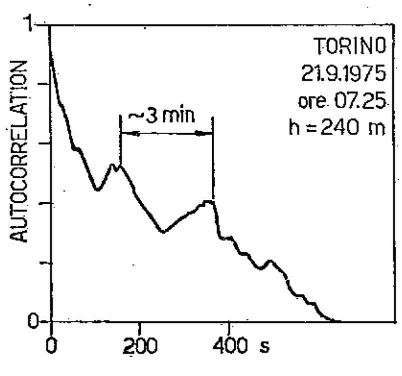

Fig. 5 - Autocorrelation of echoes obtained from an height of 240 m.

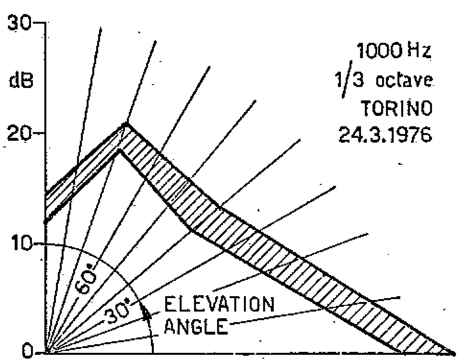

Fig. 6 - Acoustic "brightness" as a function of elevation angle.

OTHER SYSTEMS - THE RASS AND THE FM-CW RADAR

Evidently, the measure of temperature as a function of height is a very important goal for meteorological research. However, up to now such a parameter could be measured only by ballons, without the possibility of a continuous monitor ing. A remote sensing device called RASS has been recently developped and consists of an acoustic transmitting device and an electromagnetic continuous wave doppler radar. The acoustic wave pulse with wavelength is directed upward and constitues the target for the electromagnetic waves with wavelength 2 . In this case, it is possible to receive a backscattered electromagnetic signal, with Doppler shifted frequency. The Doppler shift is directly related to the velocity of the acoustic target that depends on temperature. Systems of this type are not of common use because many practical and theoretical problems are still open; for example, it is necessary to introduce corrections in the measurements to take into account vertical wind effects.

Finally, even more recently, the FM-CW radar normally used for various detection problems, have been modified and employed in geophysical research (15). This system is particularly indicated to detect atmospheric turbulence in the boundary layer since has a very good noise and ground clutter rejection. The transmitter sends a continuous frequency-shifted wave beams in the atmosphere. The scattered received signal is different in frequency from the signal transmitted in the same instant: such a difference is proportional to the distance of the scattering elements.

The Fourier analysis of the signal received gives the cross--section of the scattering centers as a function of distance.

CONCLUSIONS

This brief review of the new instruments and techniques for boundary layer monitoring, is certainly not complete. The references listed may give more detailled explanations. It is to be remembered that in this field many new developments are to be expected in the near future.

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