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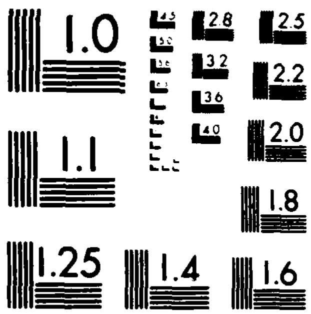

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OFFICE OF NAVAL RESEARCH

BRANCH OFFICE LONDON ENGLAND

SECOND INTERNATIONAL SYMPOSIUM ON ACOUSTIC REMOTE SENSING OF THE ATMOSPHERE AND OCEANS
DR. CHESTER MC KINNEY
26 September 1983

UNITED STATES OF AMERICA

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This report discusses papers dealing with sodar (for sound detection and ranging), which is used for atmospheric echo ranging. In addition, work on underwater acoustic remote sensing is examined.

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SECOND INTERNATIONAL SYMPOSIUM ON ACOUSTIC REMOTE SENSING OF THE ATMOSPHERE AND OCEANS

Introduction

The Second International Symposium on Acoustic Remote Sensing of the Atmosphere and Oceans (ISARSAO) was held at the Consiglio Nazionale Delle Recerche (CNR), Rome, Italy, from 29 August through 1 September 1983. This meeting was hosted by CNR and the University of Rome. Prof. G. Fiocco was in charge of the program organization as well as local arrangements. There were 38 registrants (plus about five local students) from 13 countries, and 44 papers were presented (see Table 1 and the appendix). Most of the papers dealt with using acoustic echo ranging equipment to probe the atmosphere, while only seven papers involved underwater acoustic measurements. These few sonar papers were largely from the civilian oceanography community, with only a single representative from a navy activity. Sodar (analogous to radar) appears to be the accepted acronym for atmospheric echo ranging equipment, although some of the participants used terms such as acoustic radar (not very logical) and air sonar.

The first ISARSAO was held at Calgary, Canada, in 1981. There had been six prior meetings involving only atmospheric sensing, but these usually had been special sessions at other meetings (e.g., two such sessions had been at meetings of the Acoustical Society of America). The sponsoring group is not an official organization and has no officers, membership roster, or bylaws, but E.H. Brown (University of Colorado, Boulder) seems to be the accepted permanent chairman. The group is small but clearly international. The six sessions of the symposium were marked by a welcome informality. All of the papers were presented in English in an informal manner (none were read, including those presented by surrogates), adequate time was allowed for each paper, and the discussion was lively. All of this made for an interesting small symposium which was, in fact, like a workshop. Prof. Fiocco plans to publish the papers either as a special section of an appropriate

Table 1

Participation in the 2nd ISARSAO

Country	No. of Participants	No. of Papers
US	9	15
Canada	6	7
Italy	6	5
Japan	4	1
France	3	5
Hong Kong	3	2
Australia	1	2
Greece	1	2
India	1	2
Poland	1	1
South Africa	1	1
Sweden	1	0
West Germany	1	1
TOTAL	38	44

journal or as a proceedings volume, but the publication schedule is vague. (The proceedings of the Calgary symposium have been published and are available for $25 each from Prof. T. Mathews, Department of Physics, University of Calgary, Calgary, Alberta, Canada, T2N IN4.)

Acoustic Remote Sensing in the Atmosphere

The technique of echo ranging (ER) or echo location must be one of the most important and popular measurement methods known to man. Fundamentally ER, which involves the interaction of waves and matter, calls for projecting a tagged wave packet (e.g., a pulse) into a medium (of known propagation speed for the particular wave) and measuring the time of arrival of an echo wave scattered back from an object embedded in, or from a boundary of, the medium. Although certain mammals (e.g., bats and porpoises) must have learned to use the ER technique early in the development of the species, man has used it only since about the time of World War I, when some work was done in underwater acoustic echo ranging. Radar development began in the early twenties (object detection and ionospheric sounding) and probably is the most important and widely used application.

The major application for acoustic ER remains sonar, but in recent decades ER has been used extensively for nondestructive testing (NDT), medical imaging, and microscopy. There has been relatively little use of acoustic ER in the atmosphere for several good reasons. (Prior to World War II, a pulsed acoustic altimeter was developed for aircraft, but it was no match for the new radar altimeter.) For most tasks requiring atmospheric echo ranging, acoustic ER is very inferior to radar because of the relatively slow propagation speed, high attenuation, and narrow bandwidth of acoustic waves. However, there is a useful role for acoustic atmospheric ER or sodar (for sound detection and ranging), and this role has been developed largely in the past 15 to 20 years. It has been fully demonstrated that sodar can be used to measure, by remote sensing, the height of temperature inversion layers, wind speed, turbulence, and other related atmospheric features for altitudes up to about 800 m with good resolution. This altitude regime is one for which radar is less well suited. Typically, sodar equipment is comparatively inexpensive, reliable, and easy to maintain and use. It fills a complementary niche with radar, radio sondes, and tower-supported instruments.

In any ER system, for an echo to be generated the projected propagating wave must encounter a change in impedance in the medium, which will cause a scattering of a small portion of the incident wave. A gradual changing of the medium impedance will result in refraction but little scattering. Acoustic impedance is the product of sound speed and density; thus for sodar, echo generation depends on there being fairly sharp changes in one or both of these two quantities. In the atmosphere the significant cause for impedance change is temperature variation. Basically sodars measure temperature gradients in the atmosphere. Since the gradients usually are small, for a sodar to have a useful signal-to-noise ratio (SNR) it usually is necessary to integrate the echo signal over as large a volume and for as long a time as possible, while still providing acceptable spatial and temporal resolution. Sodars generally attempt to detect and locate boundary reverberation. The detection of particles and objects (e.g., birds) is much easier for sodar, but that is not the application of interest.

A typical sodar operates at a frequency between 1 and 4 kHz (λ = 30 to 7 cm), with a few being perhaps an octave higher. Pulse lengths range from 50 to 200 ms (for a range resolution of 7 to 30 m). Beamwidths are on the order of a few degrees. A common type of transducer array (used for both transmission and reception) is a tweeter loudspeaker driving a parabolic reflector, typically less than 1.0 m in diameter. The array is shielded on the sides and bottom with a box-type baffle to attenuate local noise. Integration periods are typically on the order of minutes. Signal processing seems to be fairly conventional and includes filtering, averaging, and spectrum analysis (for Doppler measurement). Some include digital signal processing. Displays generally are CRT (black and white and color) and hard (paper) copy recorders.

There are at least three popular sodar configurations. The most elementary type is a single beam system, normally oriented to point upward. Such a system can provide information on the location of atmospheric boundary layers, which relate to changes in temperature. If a Doppler measurement feature is added, vertical wind speeds can be computed. A second configuration is either a two- or three-axis (beam) system, with the three arrays being essentially co-located. By measuring Doppler effects, this system can provide three-dimensional measurement of wind speeds as a function of altitude. A disadvantage of this configuration is that the three sodars are looking at different volumes of the atmosphere at the same altitude. A third general configuration is the bi-static sodar, in which one beam is directed upward while a second sodar is displaced horizontally and directs its beam so as to intercept the first beam at the altitude of interest. Some such systems operate with two transmitters and one receiver, and some with two receivers and one transmitter. A two-axis bistatic system employs a third array, also displaced, but 90 degrees from the first in the horizontal plane. The primary advantage of the bistatic configuration is that the echoes for all receivers are generated in the same volume. The main disadvantage is that the arrays must be separated; consequently, more real estate is required.

Sodars are commercially available, there being at least four US sources and others in France, Japan, Finland, and Sweden. Prices start in the $5000 to $10,000 range for elementary single beam systems, and in the $50,000 to $100,000 range for Doppler and multibeam systems; prices depend heavily on the signal processing features. Some of the research activities have developed their own special systems, and these generally have more capability than most off-the-shelf systems.

There does not seem to be any significant trend to either higher or lower frequencies or higher resolution. Lower frequencies would yield increased ranges, but the resolution would be degraded. Frequencies above 10 kHz suffer unacceptable attenuation. Higher resolution would be desirable but would adversely affect the SNR. There seems to be little interest in using wider bandwidths, probably because to do so would complicate Doppler measurements. In brief, the system parameters appear to be fairly well fixed. Equipment hardware and software development seems to be concentrated primarily in the signal processing area. Heavy reliance is placed on both first and second order statistics, which are essential if one is to fully exploit the sodar data.

A very different type of atmospheric remote sensing device is the radio acoustic sensor system (RASS), which involves the interaction of sound and electromagnetic waves. In this scheme a ground-based, high-power sound source is beamed upward. The passing sound wave dynamically changes the density of the air by compression and rarefaction, with the spatial period being a function of the speed of sound at the particular altitude. The sound speed is, of course, a measure of temperature. This acoustic signal spatially modulates the index of refraction as sensed by an electromagnetic wave. A microwave radar, co-located with the sound source, probes the same air column as the sound beam. The changing index of refraction results in electromagnetic wave echo generation, modulated at the acoustic frequency. The RASS system is considerably more complex than the conventional sodar but has the advantage of providing echoes from altitudes up to 3000 m for a strong wind. The accuracy of wind-vector measurements is comparable to that obtained with other instruments. G. Borino (Italy) gave an excellent review paper on this sensing system and referenced work done in the US (by the National Oceanographic and Atmospheric Administration [NOAA]), West Germany, USSR, Japan, Italy, and Switzerland. M. Fukushima (Japan) gave an unscheduled paper on the same topic.

There are two major applications for sodar in addition to its use as a good general-purpose tool for atmospheric research. The first involves the measurement of low-altitude wind speed and direction (three dimensional) and turbulence. The most important use is at airports; Mathews (University of Calgary) discussed this application in a review paper. He contends that the capability of sodar for this application has been well demonstrated, but that operational acceptance has been disappointingly low. Data presented in several papers support his view that sodar capability has been demonstrated. The importance of providing the data in a form which is directly useable by control tower operators was emphasized.

The second application is to measure and monitor air pollution. A major use seems to be in selecting sites for power plants and for mapping atmospheric pollution around existing industrial sites. About a dozen of the papers dealt, at least in part, with such applications. Marzorati (Italy) described an operation in which an array of sodar monitors provided information to help schedule a five-unit power plant for minimum air pollution in critical areas.

It is evident that the small sodar community has collected a vast quantity of sodar atmospheric data in a wide variety of locations--including industrial sites, airports, urban areas, Antarctica, coastal areas, and remote mountain peaks. Some of the data collection programs have run for at least 5 years. Most of the sodar sites are on land, but some work has been done on NOAA ships. One general finding is abundantly clear: in most locations, the lower kilometer of the atmosphere is very complex in terms of wind shear, turbulence, and thermal structure, and varies rapidly in time and space. For maximum benefit, sodar needs to be used in conjunction with instrumented towers and other remote sensors, but the contribution of sodar has been demonstrated. One author listed 21 sites where research is being done, about half being in the US. Another speaker estimated that 300 to 400 single beam sodars, 100 Doppler systems, and 10 to 50 more advanced systems are in use. In summary, sodar can be used to measure the following parameters:

1. Temperature and wind velocity structure parameters.
2. Inversion height.
3. Mean profile of vector wind shear.
4. Turbulent energy dissipation rate.
5. Rate of destruction of turbulent temperature fluctuations.
6. Sensible heat flux profile.
7. Vertical velocity variance profile.
8. Vertical velocity skewness profile.
9. Friction velocity.
10. Stable or inversion layer entrainment.
11. Various characteristics of gravity waves.
12. Various statistics of thermal plumes.
13. Total kinetic energy budget.
14. Various stability and diffusion parameters.

Some of these measurements require inputs from other measurement systems. Also, not all of these types of measurements have been demonstrated.

In a paper authored by Thompson but given by R.L. Coulter (US) the major technical advances since the last meeting of the group were given:

1. Improvements in the measurement of wind parameters.

2. Advances in theoretical work (i.e., mathematical models)
3. Active integration of sodar into air monitoring work.
4. Advances in the interpretation of pollution data.
5. Improvements in using sodar simultaneously with radar, lidar, meteorological towers, and radio sondes.

Underwater Acoustic Remote Sensing

The papers dealing with underwater acoustic remote sensing were small in number but high in quality and interest. All of the papers described experimental work, but some included theoretical models.

D.M. Farmer (Canada) described four techniques for measuring water flow and turbulence. His equipments depend on measuring the scattering from particles (bodies) in the water which are assumed to move at the same velocity as the water current. (This assumption is the same for all of the papers dealing with underwater ER devices). Other motions of these bodies result in a "noise" component. First, he presented data showing that a simple, downward-directed, wide-beam (22 degree), 50-kHz depth sounder could be used to infer horizontal current speed (not direction) as a function of depth. Echoes from scattering in the water provide hyperbolic-shaped traces as a function of time (as they move through the sonar beam). For a given depth (and for a known beamwidth) the detailed shape of a hyperbolic trace can be correlated with the cross-beam motion of the scattering body. The results correlated well with Doppler-derived data. Next he discussed the use of a narrow-beam (3 degree), 100-kHz system, directed forward at a depression of 45 degrees. Echo traces were slanted short lines, and again the shape (slope) was correlated with the cross-beam speed of the scattering. There was good agreement with Doppler current measurements (Farmer, 1983). The third technique involved a correlation sonar, similar to a system described by Dickie and Edward (1979). This technique basically does the same thing as a multibeam Doppler current profiler but may have some advantages. In the correlation sonar the data are in terms of space and time, while with the Doppler device they are in frequency and time. The equipment arrangement includes a ship-mounted, downward-directed transmitting beam and an array of several hydrophones, all mounted in the same horizontal panel but not in a line. Two pulses are projected in sequence. The outputs of the hydrophones are cross-correlated. The shift in correlation patterns relates to the horizontal speed of the scatterer, and a minimum of three hydrophones can give direction as well. Correlation of the two sequential pulses relates to vertical speed of the scatterer. The correlation system is advantageous because small, wide-beam transducers can be employed. Also, the sensitivity is best when the water motion is perpendicular to the beam axis. If the system is mounted on a ship, the platform motion must be known and taken into account, but for bottom-mounted arrays this is not relevant. The fourth technique involved cross-correlation and forward scattering. The arrangement is to project sound across a channel of water and cross-correlate the output of several hydrophones. Forward scattering by particles moving with the current shifts the correlation patterns. Experimental results were presented for 213 kHz using a 12.5-m path, but it appears that the system could be designed for paths up to a few kilometers.

Roger Lhermitte (US) described a five-beam (N, E, S, W, Up), bottom-mounted, high-resolution, pulsed Doppler sonar which can be used to measure the three-dimensional water-current field. This is a short-range system which operates at 200 kHz with a 4-cm range gate. Data collected through several tidal cycles in a channel were presented.

Ted Brown (US) described a technique for acoustically measuring the temperatures in a water column as a function of depth. The technique is a modification of his earlier work to remotely measure air temperature (Brown and Keeler, 1982). Basically the scheme is as follows. A linear array of sound projectors, mounted in the horizontal plane and with a spacing between elements of several wavelengths, simultaneously transmits two signals, separated in frequency by about 1.0 percent. This array normally is mounted near the bow of the ship, and the beams are directed toward the stern inclined about 45 degrees below the horizontal. The several transmitting beams form radial interference fringes in the vertical plane. The location of the fringes is slightly different for the two frequencies. Near the stern of the ship a narrow beam receiver is directed downward. The receiver beam intersects the various interference fringes at different depths. Scattering particles at these points of intersection generate echoes which can be used to measure the speed of sound at each of these points relative to the speed at the transducers. The key element in the scheme is the use of two slightly different frequencies which have slightly displaced constructive interference fringes and slightly different propagation paths. A measure of the phase difference of the two signals provides a means of calculating the sound velocity in the volume of beam intersection relative to the velocity at the transducers. There are several approximations in the calculation and several known sources of error. The technique is in an early stage of development, but tests at sea have shown rather good agreement with sound-speed profiles measured with other instruments. Accepted formulas are used to correlate sound-speed data with temperatures.

H. Medwin (US) presented experimental data on the generation of a boundary wave when a conventional volume sound wave propagates along a slightly rough boundary at near grazing angle. The forward scattered wave combines with the volume wave to form the boundary wave. A theory due to Tolstoy predicts such a wave, and Medwin's work confirms it. The roughness of the boundary is small compared with the wavelength of the sound wave. Since the boundary wave suffers cylindrical spreading only, it can grow relative to the volume wave and may become the dominant component. Medwin's experimental data were obtained in a tank using frequencies from 4 to 40 kHz and ranges up to 4 m. A wide variety of rough boundary types were employed, and it was shown that the amplitude of the boundary wave is a function of the roughness magnitude. Thus, in principle a measurement of the boundary wave can be used to infer the nature of the boundary roughness.

There were two interesting papers dealing with the relation of wind speed and underwater ambient noise in shallow water. Farmer presented results of measurements at frequencies of 4.3, 8.0, 14.5, and 25 kHz in water depths of 200 to 300 m. For wind speeds of 12 m/s or less, the spectrum shape was essentially the same as for deep water measurements and agreed with the accepted relation between wind speed and ambient noise. For speeds above 12 m/s the bottom-measured spectra showed a much more rapid fall with increasing frequency. Farmer attributes this change to the absorption of the higher frequencies by a thin layer of surface bubbles associated with whitecapping. He presented a theoretical model to support his view. He also presented data on ambient noise due to rain. To resolve the rain-contributed ambient noise, he subtracted the normal wind-related spectrum from the total measured noise field. The resulting spectrum was used with the Franz model to calculate precipitation rates, but it was found that the calculated values were lower by a factor of two than direct measurments for rainfall rates. He also found that there was better correlation of ambient noise with wind speed than with wave amplitude.

B.R. Kerman (Canada) described the status of his work to develop a model which relates hydrodynamical features of the ocean-air interface to ambient noise spectra above 1.0 kHz. The hydrodynamical sources are considered to be: oscillating bubbles, splashing waves and water droplets, bubble cavitation, turbulence, bubble shattering and coalescence, and nonlinear interaction of water waves (not very likely). His model is basically a bubble model which starts with a single bubble, and then an ensemble of bubbles. These are considered to be dipole oscillators (monopole plus surface reflection). His model considers bubble distribution in whitecaps. He showed general agreement in structure and order of magnitude between model and measurements. He presented some interesting data on bubble measurements made with a 1.0 MHz upward-looking sonar and some good photographs of whitecaps.

John Proni (US) presented a good review of the NOAA program of the past decade to use acoustics to measure and study ocean pollution. Most of the data have been taken with downward-looking sonars operating at 20, 200, and 3000 kHz. Many of the materials dumped into the ocean can be detected and tracked acoustically. Some of these normally are not good reflectors of sound, but when mixed with seawater they form components which can be detected. Much of the work has been directed toward locating naturally occuring materials in the ocean, and it has been found that these usually concentrate around boundaries of various kinds, e.g., the ocean floor, thermoclines, sharp changes in depth. It is predicted that pollutants put into the oceans by man will tend to accumulate in the same locations. Major pollutants include oil spills, drilling mud (which contains bacteria), and sewage. One part of NOAA's program has been to inject known materials (sewage and certain chemicals) into the ocean and monitor them acoustically to determine the capability of the equipment. One interesting data set showed the existence in the Gulf of Mexico of "spires" of pollutants which extended from the surface to depths of 70 m, and separated by about 200 m.

Concluding Remarks

I found the symposium to be interesting and informative. It is my belief that the sodar work is not well known in the Navy acoustics community, and for that reason in this report I have elected to give a general summary of the field rather than a sequential summary of the papers.

It is my feeling that the communication link between those doing underwater acoustics research for the US Navy and those using acoustics for civilian oceanographic research is a weak one at best. I have the impression that the oceanographic community has not exploited the use of acoustics to the extent that one might have expected. More interaction between the civilian and naval sectors would be mutually beneficial.

Titles and authors of the symposium papers are listed in the appendix to this report. Publication of the proceedings cannot be expected for at least a year. Readers interested in more details about specific papers should write the authors directly. Upon request I can provide copies of abstracts for specific papers.

Unless the ISARSAO group can develop more interest in the underwater sound sector, it would seem appropriate to restrict the scope of future meetings to the atmosphere only; otherwise the name is somewhat misleading.

References

Brown, E.H., and R.J. Keeler, "Acoustic Remote Sensing of Temperature," in *Proceedings, International Symposium on Remote Sensing of Atmosphere and Oceans* (University of Calgary, 1982).

Dickie, F.R., and J.A. Edward, *Proceedings of IEEE 1978 Position Location and Navigation Symposium* (San Diego, 1979), 225-264.

Farmer, D.M., and G.B. Crawford, "Measurement of Acoustic Correlation in the Ocean With a High-frequency Echo-sounder," *Nature*, Vol 301, No. 5902 (24 February 1983), 698-700.

APPENDIX

Authors and Titles of Papers
Second International Symposium on Acoustic Remote Sensing of the Atmosphere and Oceans

Title	Author	Address
A General Review of Active Remote Sensing	T. Mathews	The University of Calgary 2500 University Drive, N.W. Calgary, Alberta, CANADA T2N 1N4
Atmospheric Applications of Sodar: A Review	A. Weill	CNET/CRPE/CNRS 3 Avenue de la République 92131 Issy Les Moulineaux FRANCE
Preliminary Results Obtained with a High Frequency Sodar System	R. Cordesses G. Dubloscard D. Ramond P. Waldteufel	I.O.P.G. du Puy de Dôme 12, Avenue des Landais 6300 Clermont-Ferrand FRANCE
Wind Shear Studies with Forward Scattering Sodar System	B.S. Gera S.K. Aggarwal S.P. Singal	National Physical Laboratory New Delhi-110012 INDIA
The Development and Application of Acoustics Doppler Techniques for the Measurement of Wind and Turbulence in the Lower Troposphere	W.D. Neff	Wave Propagation Laboratory Environmental Research Labs Nat'l Oceanic & Atmospheric Administration Boulder, CO, USA
Detailed Spectral Analysis of Acoustic Records Obtained at Capanna Margherita (4559 m A.S.L.)	G. Fiocco G. Mastrantonio	P. le A. Moro S 00144 Roma, ITALY or C.P.27, 00044 Frascati ITALY
Acoustic Sounding at the Top of a High Altitude Steep Summit	G. Dubloscard R. Cordesses D. Ramond H. Sauvageot	I.O.P.G. du Puy de Dôme 12 Avenue des landais Clermont-Ferrand FRANCE
A Comparison of Velocity Techniques with Field Data	R.L. Coulter T.J. Martin K.H. Underwood	Argonne National Laboratory Argonne, IL 60439 USA
A Short-Term Study of the Wind Climatology of Calgary Using a Doppler Sodar	P.B. Hicks P.J. Irwin	Department of Physics The University of Calgary Calgary, Alberta, CANADA T2N 1N4

Investigation of Doppler Sodar Measurement of Wind	I. Akita Y. Okada K. Naito	Meteorological Research Inst. Tsukuba Science City JAPAN
Non-Doppler Frequency Shifts in Acoustic Sounding	A.D. Surridge	Nat'l Physical Research Lab P.O. Box 395 Pretoria 0001, SOUTH AFRICA
Doppler Acoustic Sounding Performance Test	P. Thomas R. von Holleuffer-Kypke W.G. Hübschmann	Kernforschungszentrum Karlsruhe Ombli Hauptabteilung Sicherheit/ Umweltmeterororoligie Postfach 3640, D-7500 Karlsruhe 1, West Germany
Correlation Measurements in Forward and Back-Scatter Sonar Systems for Oceanographic Measurements	D.M. Farmer	Institute of Ocean Sciences P.O. Box 6000 9860 West Saanich Road British Columbia, CANAD VOL 4B2
Remote Sensing of Wind Speed and Momentum Flux at the Air-Sea Interface by Bottom-Mounted Hydrophones	B.R. Kerman	Atmospheric Environ. Se ce 4905 Dufferin Street Downsview, CANADA
Remote Acoustic Detection of Buoyant Plume from Submarine Fresh Water Spring in Cambridge Fjord Baffin Island (Not Presented)	A.E Hay	Department of Physics *Memorial Univ. of Newfoundland* St. John's, Newfoundland CANADA A1b 3X7
Forward Scattering Determination of Surface Roughness	H. Medwin	Naval Postgraduate School Monterey, CA 93940 USA
Acoustics Remote Sensing of Oceanic Pollution	J. Proni	Atlantic Oceanographic & Meteorological Laboratory Ocean Acoustics Division 4301 Rickenbacher Causeway Miami, FL 33149 USA
The Sound of Wind and Rain Off the British Columbia Coast	D.M. Farmer	Institute of Ocean Sciences P.O. Box 6000 9860 West Saanich Road Sidney, British Columbia CANADA VOL 4B2
Monostatic Acoustic Observations of Nonlinear Internal Waves in Davis Strait (not presented)	A.E. Hay B. de Young	Memorial Univ. of Newfoundland St. John's Newfoundland CANADA A1B 3X7
High Resolution Doppler Sonar	R. Lhermitte	University of Miami Miami, FL USA

Acoustics Remote Sensing in Air-Pollution Meteorology	D.W. Thomson (Given by Coulter)	Pennsylvania State Univ. University Park, PA 16802 USA
Shoreline Fumigation and Internal Boundary Layer Structure Studies Using Acoustic Sounding	B.R. Kerman R.E. Mickle N.B. Trivett P.K. Misra	4905 Dufferin St., Downsview, CANADA, or 880 Bay Street Toronto, CANADA
Acoustic Remote Sensing for Environment Control in Thermal Power Plants	G. Brusasca G. Elisei A. Marzorati M. Maini	ENEL DSR/CRA Milano, ITALY
Acoustic Remote Sensing of Temperature in the Atmosphere and Oceans	E.H. Brown	CIRES University of Colorado Boulder, CO 80309 USA
Observation, Origin, and Modelling of Elevated Turbulent Echo Layers, in Nocturnal Temperature Inversion	W.D. Neff	Wave Propagation Laboratory Environmental Research Labs Boulder, CO 80302 USA
Tri-Axial Doppler Sodar System Detecting the Vertical Structure of Gravity-Waves in the Boundary Layer: A Case Study	D. Fuà G. Mastrantonio	Istituto di Fisica dell'Atmosfera-CNR C.P. 27, 00044 Frascati ITALY
Inversion Layer Oscillations and Turbulence Analysis with an Acoustic Doppler Sounder	M. Blez	CNET/CRPE/CNRS 38-40 rue du Général Leclerc 92131 Issy-les-Moulineaux FRANCE
Engineering Problems in Acoustic Remote Sensing	I.A. Bourne	University of Melbourne Parkville, Vic. AUSTRALIA
Analysis and Prediction of Mean and Fluctuating Sound Pressure Levels of Sound Refractively Propagated in the Surface and Planetary Boundary Layer	D.W. Thomson	Department of Meteorology Pennsylvania State Univ. University Park, PA 16802 USA
Quantitative High Resolution Acoustic Sounding	G.G. Helmis D.N. Asimkopoulos D.P. Lalas	Department of Physics University of Athens GREECE
Interpretation of Monostatic Acoustic Radar Records Using Wind Field Generated by a 3-Component Doppler Acoustic Radar	E. Koo W.L. Chang C.M. Tam	Royal Observatory HONG KONG
Quantitative Study of Sea-Breeze Front with a High Resolution Acoustic Sounder	D.N. Asimakopoulos G.G. Helmis D.G. Deligiorgi	Dept. of Physics University of Athens GREECE

A Comparison of Sounder Velocity Statistics Across the Australian Continent	P.R. Best M. Kanowski P.T. Morland L. Stümer	Queensland Electricity Generating Board Brisbane, AUSTRALIA
Comparison of Mixing Height Obtained Using a Monostatic Acoustic Radar and by Direct Measurement in a Tropical Coastal Environment	E. Koo W.L. Chang C.M. Tam	Royal Observatory HONG KONG
Vertical Velocity Statistics and Spectra from a Doppler Sodar	K.H. Underwood R.L. Coulter	Florida State University Tallahasse, FL 32306 USA & Argonne National Lab
Remote Sensing of the Thermal Profile in the Lower Atmosphere by Radio Acoustic System	G. Bonino	Laboratorio Cosmo-Geofisica CNR Corso Fiume, 4 10133 - TORINO
Sodar Observations During Risö 78	K.H. Underwood	Florida State University Tallahassee, FL 32306 USA
Heat Flux Derived from Sodar Amplitude and Frequency Data: A Comparison	R.L. Coulter K.H. Underwood T.J. Martin	Argonne National Laboratory Argonne, IL 60439 USA
Structure of the Vertical Field Analyzed with a Doppler Sodar	A. Ricotta M. Berico S. Mazzola	Istituto di Fisica dell' Atmosfere, CNR, Frascati ITALY
Thermal Plume Structures Observed by a Doppler Sodar	K.H. Underwood R. Coulter	Florida State University Tallahassee, FL 32306 USA
Studies of the Boundary Layer at Delhi Using Sodar	S.P. Singal B.S. Gera S.K. Aggarwal	National Physical Laboratory New Delhi - 110012 INDIA
Acoustic Sounding of the Atmosphere for Inversion-Layer Climatology Over an Urban Area	J. Walczewski	Institute of Meteorology & Water Management Crawcow, POLAND
Sodar Observations of Arctic Frontal Passages	T. Mathews P.F. Lester	University of Calgary Calgary, Alberta, CANADA
Sodar Signal Processing Techniques: A Critical Study	K.H. Underwood	Florida State University Tallahassee, FL 32306 USA
The Design and Application of a Multi Axis, Self Adaptive Acoustic Sensor	J.A. Kleppe L.G. Yori R.L. Hines	College of Engineering University of Nevada Reno, Nevada USA

A Summary of Doppler Sodar Observation on the North Florida Coast	K.H. Underwood	Florida State University Tallahassee, FL 32306 USA
Real Time Measurement of Diffusion Parameters Using a Doppler Sodar and Its Use in Real Time Atmospheric Modelling	Remetech	2/4 Avenue de l'Europe 78140 Velizy FRANCE

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