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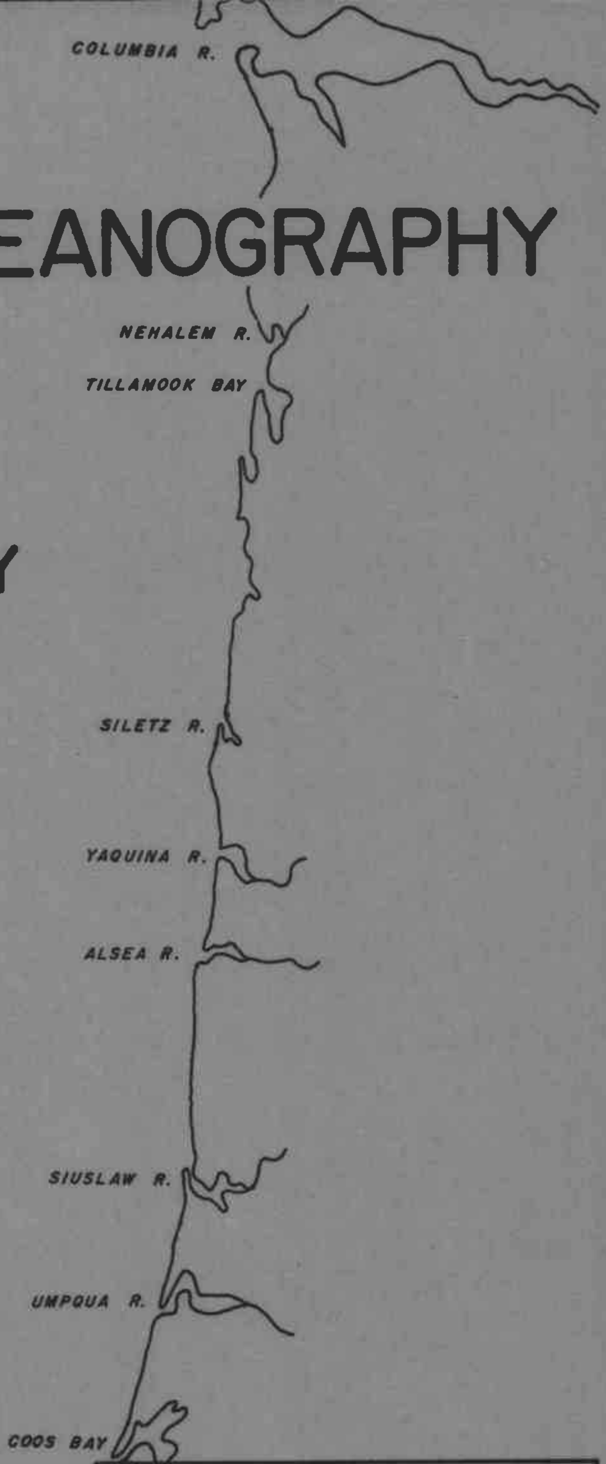

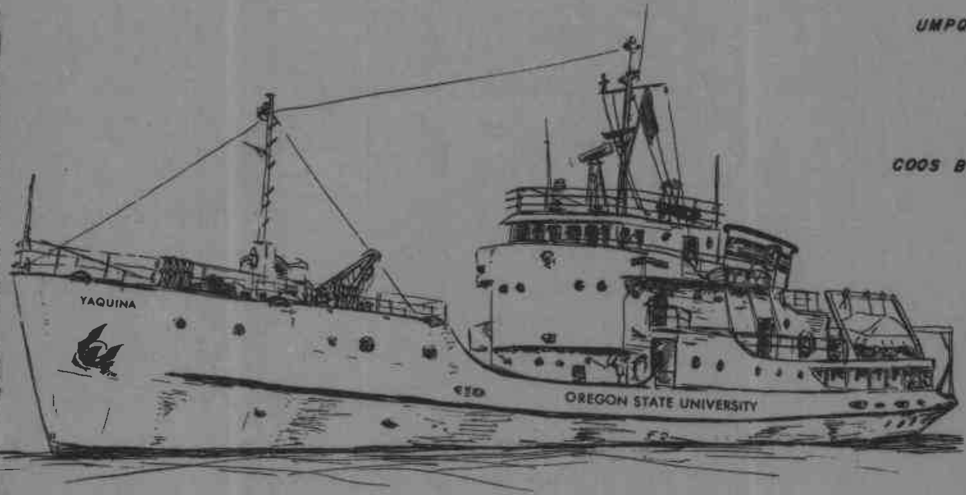

Report on

INSTITUTE OF ATMOSPHERIC PHYSICS, ACADEMY OF SCIENCES, USSR

by
G. Stephen Pond

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INSTITUTE OF ATMOSPHERIC PHYSICS, ACADEMY OF SCIENCES, USSR

Report by

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INTRODUCTION

Most of the period of my visit was spent working in the turbulence section of the Institute of Atmospheric Physics. Brief visits were made to the Institute of Oceanology, Academy of Sciences in Moscow, to some departments of Moscow State University, and to one department of the Institute of Oceanology located in Leningrad. Most of this report is on the work done in turbulence with emphasis on air-sea interaction. The air-sea interaction work is done jointly by the Institutes of Atmospheric Physics and Oceanology.

The visit was made on the scientific exchange program between the Academy of Sciences, USSR, and the National Research Council of Canada.

THE INSTITUTE OF ATMOSPHERIC PHYSICS: Director A. M. Oboukhov

This Institute with a total staff of about 200 is rather small by Academy of Sciences standards. The majority of the staff is located in Moscow, but about one-third is located outside the city. In the past, various sections of the Institute in Moscow have been in different parts of the city, but all the sections are being moved into one building. Only the optics department is elsewhere until alterations to the building are completed.

The work done at this Institute is extremely good on the whole and the scientific staff are highly competent. They are working on the frontiers of research in atmospheric physics, developing new techniques and instruments for measurements and new theoretical ideas on small scale turbulence and atmospheric boundary layers, etc. Until recently experimental work at the Institute has been almost entirely over land, but in the last three or four years the staff have begun investigations of the interaction between the atmosphere and the ocean, with particular emphasis on the measurement of the turbulent transfers of momentum and sensible heat. They are using the instruments developed for work over land but with some modifications.

Other developments include aircraft techniques and the instruments for aircraft measurements for use over land. Some checks have been made between aircraft and tower measurements which show good agreement. Near future plans call for use of aircraft for measurements over the sea.

The investigators think this method can be developed into one of the most satisfactory means of making turbulent flux measurements over the sea, particularly over wide areas.

Communication between senior and junior staff members is extremely good. This communication is made easier by the fact that the Institute is fairly small and separated into departments such as turbulence, optics, theory, etc. At the same time communication among various sections is good, and the director and the associate director for science take active interest in the work being done. This strong intercommunication is an extremely important factor in producing very high quality work.

Like other institutes of the Academy of Sciences, this Institute plays a teaching role in addition to its primary purpose of research. The teaching is at the 'aspirant' or graduate student level. The number of students is quite small which allows very personal instruction. Practical training and research form part of the research program of the Institute. At least in this Institute, the system appears to work very well and I think it is a very good one. In contrast to North American practice, after completing his degree, the student usually joins the staff of the Institute and remains there more or less permanently. A number of the staff members, for example Professors Oboukhov and Yaglom, teach at the university as well as work at the Institute.

One problem of the Institute is that they must design and make almost all their equipment rather than buy it 'off the shelf.' Hence a larger staff is required for the same amount of work done and more time between the conception of an experiment and its completion. On the other hand the equipment is designed especially for the job. The best example is the transducers used for acoustic anemometers which are much better for turbulence measurements than anything commercially available. Most of their electronics circuits use tubes rather than transistors.

Another problem has been the lack of a good instrumentation tape recorder. Much of the analysis must be done in the field, requiring much equipment and hence many personnel, or the analysis must be done from chart recordings. The investigators are now developing a semi-automatic system for reading these records, but in the past they have been read by hand and processed on a digital computer. This technique is very laborious and can only be used on a limited amount of data. The Institute is now in the process of developing a four-channel tape recorder system. The mechanical parts were obtained commercially and the staff have made their own electronics. They are using pulse width modulation as they feel it is simpler than FM and also avoids the requirement of a carefully controlled frequency for the power supply, which can be a problem in the field. The present bandwidth is 0-25 hz and plans are to increase this to 0-250 hz. This recorder will help reduce recording problems and will also provide a library of field data, which is invaluable for testing new ideas and new types of equipment.

INSTRUMENTATION

Some of what I consider to be the Institute's more interesting instrumentation will be described briefly. Descriptions of this and other equipment are given in the literature, although not always in easily obtained publications, and there have been some modifications. Trudy, Institute of Atmospheric Physics, No. 4, 1962, contains detailed descriptions of much of their equipment.

Electronic Multiplier

The signal from one channel controls the pulse height, and the signal from the other controls the pulse width of a square wave. The square wave is integrated to give the product. The circuit has good linearity with less distortion than a system with breakpoints of diodes to give an approximate square law. The circuit is normally used for products of turbulence quantities such as uw and wT. For this use there is an RC filter on the output with a time constant of 100 s to provide averaging. The output circuit has recently been converted to a balanced system to reduce drift so that it is negligible over periods of an hour or more.

An alternative output circuit is available to give an 'instantaneous' product for frequencies up to 200 hz. By using a second multiplier it is then possible to obtain the cube or a triple product. The circuit is being tested in this form to see if it behaves satisfactorily. The circuit can then be used to produce quantities such as $(\partial w/\partial t)^3$, the statistics of which are of considerable interest.

Spectral Analyzer

Normally the electronic multipliers are not used for spectral analysis because they are quite large and complex. Data must be obtained simultaneously at a large number of frequencies since analysis is normally done in the field. A series of RC filters are used (1/2 octave bandwidth, $Q = 2.9$) with frequency steps of $2^{1/2}$. The output of the filters is full wave rectified and averaged with an RC circuit which has a 100 s time constant. The researchers relate the mean square to the average of the absolute value by assuming the output of a filter over a narrow bandwidth is a Gaussian random variable. For a Gaussian process, $\overline{x^2} = \pi/2\,|\overline{x}|^2$. This assumption is probably sound but it will be checked, either from the tape records or in the field by direct measurement of both quantities. Filters of this type require considerable correction for spectral shape because of their relatively slow cut-off. The filter constant is calculated for a slope of -5/3 (the typical slope over much of the range of turbulence spectra) and corrections are made if the slope differs from -5/3.

Using the heating of a resistance which is measured by a thermocouple in a vacuum tube, the staff are also planning to make true squaring circuits.

Infrared Absorption Hygrometer

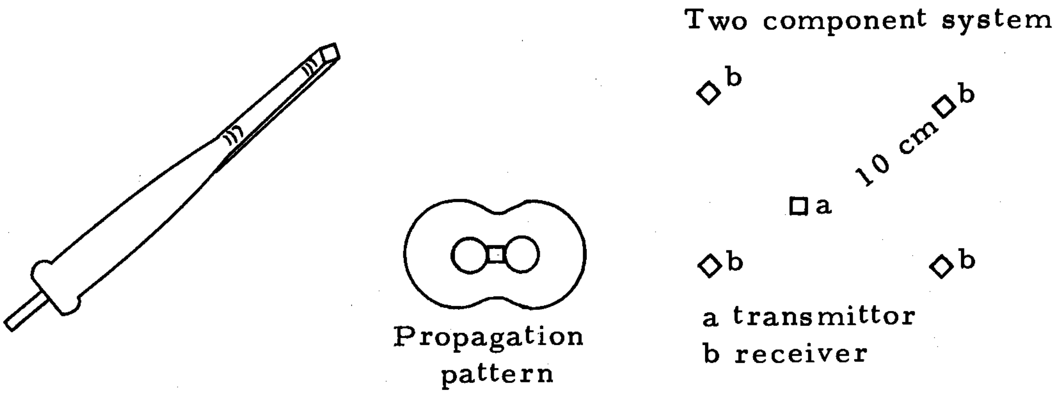
This device has been developed to measure humidity fluctuations and so enable the measurement of the turbulent flux of water vapor. The hygrometer has a path length of about 70 cm and uses multiple reflections to give an effective path length of many meters in order to achieve adequate sensitivity. The mirrors must be mounted on a very large rigid base to eliminate vibrations so the device is very large and heavy. Also, 70 cm is a rather large scale size if all scales contributing to the flux are to be measured. However, it may be sufficient. Some preliminary results of humidity fluctuations have been obtained which indicate that the device works satisfactorily. Observations of the water vapor flux over land were planned for last summer.

The instrument is far too large to be used at sea, yet it may be possible to develop one based on the same principles but with a stronger absorption band. A smaller, lighter device would be much better for use over land, too. The Institute of Oceanology is also working on a device using absorption of radiation but in the ultraviolet; it will be described later.

Acoustic Anemometer

This Institute has done a great deal of work to develop acoustic anemometers for turbulence measurements. The staff have made their own transducers which are extremely good, because they are much smaller than those available commercially and have a more suitable shape. These transducers are small enough to be used not only for measurements of the vertical velocity but also for the velocity fluctuations in the direction of the mean velocity with an instrument base of only 20 cm.

Thus they can be used for measurements of the Reynolds stress or momentum flux, $\overline{uw}$. The base size which can be used depends on the transducer size--for commercially available transducers the horizontal base would be too large to obtain all contributions to $\overline{uw}$.



Two component system

a transmittor
b receiver

Propagation pattern

Figure 1. Acoustic anemometer transducers.

The transducers are of a cylindrical type with active area about 2 by 5 mm. The cross section of the present ones is actually rectangular with rounded corners as this shape makes construction simpler. Two opposite sides have a metal coating over the plastic probe. These plates are connected to a central conductor at the top. The top is insulated and a terylene film which has been coated with gold by vacuum deposit techniques is wrapped around the probe and glued along one of the sides without metal coating. The film is electrically connected to the metal housing which forms the lower part of the probe. Because the film can be attached where there is no metal coating underneath, it is fairly easy to avoid shorting the inner plates and the outer conductor. The early type was cylindrical in shape which gave a more symmetrical output but it was more difficult to avoid shorting. The film does not have to be especially tight as the operation depends in part on the existence of a thin film of air between the plates and the terylene film. The propagation is such that one transmitter is sufficient even for a two component system--see Figure 1.

The principle of operation depends on the doppler shifts induced in the wave fronts by the velocity fluctuations in the air. The speed of sound is also a function of density, so two paths must be used with the sound waves traveling in opposite directions. The simplest system is to have the transmitter in the middle and receivers on each side of it. The phase difference between the two signals is then a function of the velocity component along the base of the device. The sum of the phases is a function of the density, and this technique has been used to measure temperature at high altitudes where the humidity is too small to affect the density. The instrument of course only measures correctly fluctuations whose scale size is somewhat larger than the base of the instrument.

The acoustic anemometers developed by this Institute are extremely good devices for measuring turbulent fluctuations of scales of a few centimeters and larger. They cannot be used for the very small scales of a few millimeters where the dissipation of energy occurs; for this measurement hot wire anemometers must be used. However with this limitation, acoustic anemometers are probably the best instrument available for measuring turbulent velocities and particularly for measuring the Reynolds stress. The output of the anemometers is a linear function of velocity; their calibration is stable and independent of the particular transducer used; and they are reasonably robust. Hot wires do not have these properties, although the difficulties can be overcome if it is necessary to obtain the full spectrum of velocity fluctuations.

The acoustic anemometer developed by A. S. Gurvich for small scale measurements is described in detail in Trudy, Institute of Atmospheric Physics, No. 4, 1962. It has a base of only 2. 5 cm with the two paths side by side. However, this device is rather complex and difficult to keep operating. Different frequencies have to be used in the two paths, and frequency multiplication is required to get sufficient sensitivity with such a short path length. For most measurements such a small base is not required, e. g., Reynolds stress, so a simpler system is used with a transmitter in the center and receivers at either side. The overall size is 20 cm. The frequency is 100 khz. The received signals are heterodyned with 97. 5 khz, and the phase difference between the two 2. 5-khz signals is measured by producing pulses from them which alternately turn a multivibrator on and off. The area under the resulting square wave form is proportional to the phase difference. The phase difference can be shifted through 360 degrees to compensate for zero changes such as those produced by the mean velocity when fluctuations in the direction of the mean velocity are measured. The sensitivity is

± 2.8 m/s and it can be reduced to ± 5.6 m/s by only using every second pulse. For recent measurements (such as, $\partial w/\partial t$) which require the smallest possible instrument size, a single 5-cm path (sensitivity ± 5.6 m/s) is used under conditions for which the density fluctuations will be too small to produce any significant effects.

AIRCRAFT MEASUREMENTS: B. M. Koprov, L. R. Tsvang

The Institute has been using aircraft for some time to make measurements of the vertical velocity, w, the temperature fluctuations, T, and the heat flux, $\overline{wT}$. The measurements are made over land from heights of 20 - 50 m up to 3 - 5 km. They have been checked against measurements from a fixed tower and the agreement is very good. One problem with measurements from aircraft is that the vertical velocity must be corrected for the vertical motion of the plane and for the changes in inclination which introduce a signal $U \sin \phi$. An acoustic anemometer measures w and the corrections are made by subtracting an integrated accelerometer signal and a signal $U \sin\phi$ which is measured with an inclinometer. T is measured with a coil of 20-micron platinum wire with overall size of about 2 cm.

The staff are also planning to measure the two horizontal components of velocity fluctuations so that they can obtain the Reynolds stress. A hot wire anemometer will be used for the component in the direction of flight, as an acoustic anemometer produces too much flow interference at aircraft speeds. The hot wire anemometer is being designed so that an <u>in situ</u> calibration can be obtained as often as necessary. The calibration will be done by oscillating the probe back and forth while the aircraft is in flight.

Aircraft are extremely useful for obtaining data on the turbulence to much greater heights than is otherwise possible. The Institute plans to use this method over the sea as well.

AIR-SEA INTERACTION: C. L. Zubkovski, Yu. A. Volkov

Air-sea interaction measurements have been made in the Black and the Mediterranean Seas with a small ship of about 300 tons. The instruments are mounted on a buoy about 50-60 m upwind of the ship and connected to it by a float-supported cable. The orientation of the instruments is maintained by letting the ship drift with the wind.

Measurements of u and w are made with acoustic anemometers and of T with a fine wire (20 micron) platinum resistance thermometer. The wind profile is measured with cup anemometers and the mean air and water temperatures with resistance thermometers. Their accuracy at present is not sufficient to obtain very good estimates of the temperature gradient in the air. In addition, measurements of the wave spectrum are made on a second buoy by the Institute of Oceanology; their wave recorder will be described later. The acoustic anemometer consists of one transmitter and four receivers each 10 cm from the transmitter. The high humidity and the spray have caused leakage of the transducers which requires placement of the generator of the acoustic signal closer to the transmitter and providing heating coils around the base of the probes. The Institute of Oceanology has recently produced hermetically sealed transducers by using the same materials as used by the Institute of Atmospheric Physics. However these transducers are not quite as convenient and are more difficult to make. I think it is possible to seal the present ones without too much difficulty and so retain their advantages.

The buoy is of the spar type; the float is a long plastic cylinder. A six-meter mast is on top of the float. A weight and a 2 m by 2 m damping plate at a depth of 50 m are attached to the float by a steel cable. Such buoys work very well and their motion is quite small. Pitch and roll are of the order of 5-10 degrees, occasionally a little larger; and the vertical motion is only a very small fraction of the wave height. The vertical motions are measured with an accelerometer but are almost negligible; a very small peak is found in the spectrum of w at wave frequencies, but it is not significant. The turbulence instruments are mounted at a height of 2 m above the mean surface level. The cup anemometers and resistance thermometers are at heights of 1/2, 1, 2, 4, and 6 m.

The signals are recorded on charts which can later be read by hand (usually at 1/10 s intervals) for digital analysis. Usually the fluxes $\overline{uw}$ and $\overline{wT}$ are also measured in the field by electronic multipliers. The spectra can also be measured directly by the analog spectral analyzer. A system is now being developed that will read the charts automatically; and a four-channel tape recorder will be available.

In the future the staff plan to make similar measurements from a platform in the Caspian Sea where the water depth is 10 m. The effects of buoy motion will be eliminated; there may be some effects from the platform itself, although it should be possible to minimize them. The investigators plan to use aircraft at the same time to test this method of measuring turbulent fluxes over the sea which they feel has great promise.

There is one rather marked difference between the results obtained both at this Institute and those obtained at the University of British Columbia from a fixed platform (by using hot wire and thrust anemometers) and those obtained by the Meteorological Institute of the University of Hamburg from a buoy with a stabilized mast and corrected for the vertical motion (with hot wire anemometers). For the Institute of Atmospheric Physics results, the drag coefficient C_d ($C_d = \frac{\overline{uw}}{U^2}$, where $\overline{uw}$ is the Reynolds stress and U is the mean wind speed at some reference height) increases with the wind speed while for the other results it is apparently independent of wind speed. There is considerable scatter in all the results but this difference in trend is very clear.

One possible cause of this difference is the fact that the IAP measurements are made from a moving platform, the motions of which increase with the wind speed. I did some simple calculations to test this idea and found that the effects of the motion for a buoy like the one used by the Institute are almost negligible for both the Reynolds stress and the wind profile (provided that the mean tilt is very small, as intended). If the motions are somewhat larger--tilts of ± 20 degrees--the effect is to reduce the measured value of C_d by about 15%. A correction would make C_d a somewhat stronger function of the wind speed. A short note on this calculation, which was very kindly translated for me by the staff there, will be published later this year in Izvestia, Physics of Atmospheres and Oceans.

This difference must have some other explanation; either the site and mean conditions or instrumentation are possibilities. It would be extremely useful to make some joint measurements to find out if the differences are real or instrumental. Dr. R. W. Stewart has suggested this to the Institute so it should be possible to arrange some joint work in the near future.

Like the results obtained at UBC, little, if any, correlation exists between the Reynolds stress and the stress inferred from the wind profile by similarity theory. Thus it appears that over the sea, unlike over land, direct measurements of the turbulent stress are necessary.

INSTITUTE OF OCEANOLOGY: Director A. S. Monin

This Institute is much larger than the Institute of Atmospheric Physics. It has sections in all branches of oceanography and operates most of the Russian deep-sea research ships. Most of the effort of this Institute is still in large scale surveying and map making, synoptic physical oceanography and synoptic marine meteorology. However, recently much more work has been done on modern problems, particularly since Professor Monin became director about a year and a half ago. For example such problems as air-sea interaction on both large and micro scales, time dependent ocean currents, large scale ocean turbulence, etc. are being attacked.

There seems to be close collaboration between the theoreticians and the experimentalists so that experiments are being done to test theoretical ideas. S. A. Kitaygorodski who is scientific head of the air-sea interaction group is primarily a theoretician but takes active interest in the experimental work and in the interpretation of the measurements. Two scientists from the theoretical group are now working in the Indian Ocean on a program to study large scale turbulence over periods of four to five weeks.

Professor Monin is interested in turbulence measurements both in the ocean and in the air-sea boundary layer. He believes that we should attack both the small scale and the large scale (general circulation) problems simultaneously. For the large scale interactions the ocean and the atmosphere must be treated as a single system. The study of the large scale interactions, principally by numerical methods, is still to a considerable extent a mathematical exercise done by varying the parameters which must be used to represent the small scale interactions. However when further observations of small scale turbulence lead to a better understanding and parameterization of these processes, we shall have the knowledge and techniques available to apply them to the general circulation.

Monin says that many more observations of turbulent fluxes are required, particularly of the flux of water vapor about which almost nothing is known. Many charts of evaporation are published, based on empirical laws which are very crude approximations and which have been obtained from very dubious experiments, but these charts are really only speculation. The Institute is now working on methods of measuring the turbulent flux of water vapor. Clearly this is a very important problem.

SMALL SCALE AIR-SEA INTERACTIONS: A. S. Kitaygorodski

A small group of the marine meteorology section (most of which is concerned with large scale survey work particularly in tropical regions) has been making measurements of the wind profile in the region very close to the sea surface. Small buoys are used which follow the surface quite closely. Cup anemometers are mounted at heights of 20, 50, 100, 200, and 250 cm. Because the observations are made from a moving platform the results cannot be interpreted in terms of the usual Eulerian system. Kitaygorodski has been working on this problem. The results and the method of interpreting them should be published soon.

Much of their air-sea interaction work is being done in collaboration with the Institute of Atmospheric Physics which makes the measurements of fluxes and profiles in the air while the Institute of Oceanology measures the wave field. Last year considerable field work was done on a joint cruise in the Mediterranean. The results of this work have recently appeared in Izvestia, Physics of Atmospheres and Oceans (references 5 and 8).

For this work they have developed or are developing some very good instrumentation, some of which I shall describe briefly.

Acoustic Anemometers

The basic circuitry is like that of the Institute of Atmospheric Physics but they have produced new transducers which are hermetically sealed and so overcome the leakage problems of the IAP ones; they can be used in water as well as in the air.

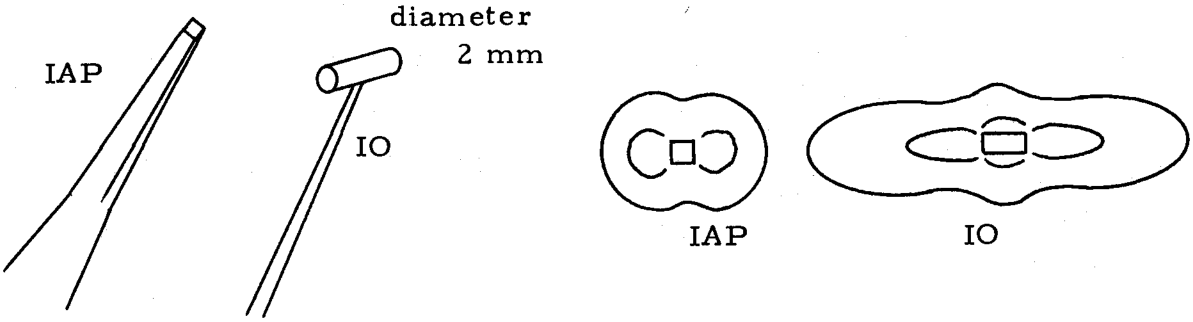


Figure 2. IAP and IO acoustic transducers.

The materials used are the same, but the shape of the IO transducers is more like a conventional capacitance microphone--actually there are two transducers for the transmitters, one facing each way. They are very small so that flow interference, as for the IAP design, is very small. The output is much more directional giving a larger signal at the receiver for the same input power, but two transmitters at right angles are required for a two component system. However, this is only a minor complication.

The construction is somewhat more difficult (a paper on the details will be published soon in Izv. Phys. of Atmos. and Oc.) so that the IAP transducers would be preferable if they could be hermetically sealed.

Resistance Wire Wave Recorder

For wave recorders the Institute uses the resistance rather than the capacitance method as they feel it is somewhat easier. To obtain a linear device a constant current source is used; the voltage across the resistance wire then changes linearly with the wave height. The device is mounted on a spar buoy similar to the IAP one described previously and operated simultaneously with the IAP buoy--one from the bow and one from the stern. To correct for the vertical motion of the buoy the researchers have a differential pressure recorder mounted on the weight at a depth of 50 m. In practice the motion is only a few percent of the wave height, and the correction is almost negligible.

Analysis of the high frequency part of the spectrum is usually done in the field by a spectrum analyzer of the IAP type (see above). It is necessary to prewhiten the signal by differentiation (which multiplies the spectrum by k^2), as a single RC filter will not work on a spectrum of slope k^{-5} (the usual form at high frequencies). The low frequency portion of the spectrum is obtained later by digital analysis of chart records.

Ultraviolet Absorption Hygrometer

Recent developmental work has been started on the method of measuring humidity fluctuations by absorption of the α-Lyman line of hydrogen, an idea initially suggested by Randall, Naval Research Laboratory, Washington. The equipment is only at the early stage of development but it has considerable promise. Path lengths of only 1-2 cm should be possible, which is more than adequate to measure all contributions to the water vapor flux.

At the moment the investigators need a better receiver and plan to try a proportional counter. They must keep the output level of the source very low as otherwise the crystal window used for transmission is broken down. This low power makes detection rather difficult. At the same time a frost point hygrometer is under construction; it will be used for calibrating the absorption equipment. It is still too early to tell what effects temperature changes will have. Also, the windows must be protected from spray without undue flow interference. If the difficulties can be overcome this will be an extremely valuable instrument. At present there are no reliable ways of measuring humidity fluctuations so that an accurate measure of the water vapor flux can be obtained.

LARGE SCALE AIR-SEA INTERACTION: D. L. Laikhtman

This section of the Institute of Oceanology has about twelve scientific staff and is located in Leningrad. They are trying to find better ways to parameterize the turbulent exchanges of momentum and energy so that more realistic solutions of the general circulation of the atmosphere and the oceans can be obtained. This problem of the sources and sinks is fundamental if better long range predictions are to be possible. In large scale numerical experiments a 500 by 500 km grid over the whole globe is used with continents as realistic as possible under the restrictions of the grid size.

The staff are also doing considerable work on the problem of relating the large scale mean flow to the turbulence. They have recently completed an analysis of all the IAP data over land to get better constants for the Monin-Oboukhov Law of the wind profile. Attempts to fit this law to data obtained over the sea have not been successful--the scarcity of data being one of the problems. The investigators have also been making attempts to find the parameters which determine the roughness over the sea, but this problem is very difficult and there are no satisfactory results as yet. Kitaygorodski has also been working on this problem.

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