Intergovernmental Oceanographic Commission
Workshop Report No. 21

Second IDOE Symposium on Turbulence in the Ocean

Liège, Belgium, 7-18 May 1979

Held under the auspices of

The International Association for the Physical Sciences of the Ocean (of ICSU); and
The Scientific Committee on Oceanic Research (of ICSU)

With the support of

The United Nations Educational, Scientific and Cultural Organization; and
The Intergovernmental Oceanographic Commission (of Unesco)

Unesco

INTERGOVERNMENTAL OCEANOGRAPHIC COMMISSION

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SUMMARY REPORT

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No.	Title	Publishing Body	Languages
1.	CCOP-IOC, 1974, Metallogenesis, Hydrocarbons and Tectonic Patterns in Eastern Asia /Report of the IDOE Workshop on/; Bangkok, Thailand, 24-29 September 1973. UNDP (CCOP), 138 p.	Office of the Project Manager UNDP/CCOP c/o ESCAP Sala Santitham Bangkok 2, Thailand	English
2.	CICAR Ichthyplankton Workshop, Mexico City, 16-27 July 1974. (Unesco Technical Paper in Marine Science, No. 20)	Division of Marine Sciences, Unesco, Place de Fontenoy, 75700 Paris, France	English Spanish
3.	Report of the IOC/GFCM/ICSEM International Workshop on Marine Pollution in the Mediterranean, Monte Carlo, 9-14 September 1974.	IOC, Unesco Place de Fontenoy 75700 Paris, France	English French Spanish
4.	Report of the Workshop on the Phenomenon known as "El Niño", Guayaquil, Ecuador 4-12 December 1974	FAO Via delle Terme di Caracalla, 00100 Rome, Italy	English Spanish
5.	IDOE International Workshop on Marine Geology and Geophysics of the Caribbean Region and its Resources, Kingston, Jamaica, 17-22 February 1975	IOC, Unesco Place de Fontenoy 75700 Paris, France	English Spanish
6.	Report of the CCOP/SOPAC-IOC IDOE International Workshop on Geology, Mineral Resources and Geophysics of the South Pacific, Suva, Fiji, 1-6 September 1975.	IOC, Unesco Place de Fontenoy 75700 Paris, France	English
7.	Report of the Scientific Workshop to initiate planning for a co-operative investigation in the North and Central Western Indian Ocean, organized within the IDOE under the sponsorship of IOC/FAO (IOFC)/UNESCO/EAC, Nairobi, Kenya, 25 March- 2 April 1976.	IOC, Unesco Place de Fontenoy 75700 Paris, France	Full text (English only) Extract and Recommendations: French Spanish Russian

No.	Title	Publishing Body	Languages
8.	Joint IOC/FAO (IPFC)/UNEP International Workshop on Marine Pollution in East Asian Waters, Penang, 7-13 April 1976	IOC, Unesco Place de Fontenoy 75700 Paris, France	English
9.	IOC/CMG/SCOR Second International Workshop on Marine Geoscience, Mauritius, 9-13 August 1976	IOC, Unesco Place de Fontenoy 75700 Paris, France	English French Spanish Russian
10.	IOC/WMO Second Workshop on Marine Pollution (Petroleum) Monitoring, Monaco, 14-18 June 1976	IOC, Unesco Place de Fontenoy 75700 Paris, France	English French Spanish Russian
11.	Report of the IOC/FAO/UNEP International Workshop on Marine Pollution in the Caribbean and Adjacent Regions, Port of Spain, Trinidad, 13-17 December 1976	IOC, Unesco Place de Fontenoy 75700 Paris, France	English Spanish
11. Suppl.	Collected contributions of invited lecturers and authors to the IOC/FAO/UNEP International Workshop on Marine Pollution in the Caribbean and Adjacent Regions, Port of Spain, Trinidad, 13-17 December 1976	IOC, Unesco Place de Fontenoy 75700 Paris, France	English Spanish
12.	Report of the IOCARIBE Interdisciplinary Workshop on Scientific Programmes in Support of Fisheries Projects, Fort-de-France, Martinique, 28 November-2 December 1977	IOC, Unesco Place de Fontenoy 75700 Paris, France	English Spanish
13.	Report of the IOCARIBE Workshop on Environmental Geology of the Caribbean Coastal Area, 16-18 January 1978	IOC, Unesco Place de Fontenoy 75700 Paris, France	English Spanish
14.	IOC/FAO/WHO/UNEP International Workshop on Marine Pollution in the Gulf of Guinea and Adjacent Areas, Abidjan, Ivory Coast, 2-9 May 1978.	UNEP Palais des Nations 1211 Geneva 20 Switzerland	English French
15.	CPPS/FAO/IOC/UNEP International Workshop on Marine Pollution in the South-east Pacific Santiago de Chile 6-10 November 1978	IOC, Unesco Place de Fontenoy 75700 Paris, France CPPS Dir. de Soberania Maritima Ministerio de Relaciones Exteriores Lima Peru	English Spanish

No.	Title	Publishing Body	Languages
16	Workshop on the Western Pacific Tokyo, 19-20 February 1979	IOC, Unesco Place de Fontenoy 75700 Paris, France	English French Russian
17.	Joint IOC/WMO Workshop on Oceanographic Products and the IGOSS Data Processing and Services System (IDPSS) Moscow, 9-11 April 1979	IOC, Unesco	English
17. Suppl.	Papers submitted to the Joint IOC/WMO Seminar on Oceanographic Products and the IGOSS Data Processing and Services System Moscow, 2-6 April 1979	IOC, Unesco	English
18.	IOC/Unesco Workshop on Syllabus for Training Marine Technicians Miami, 22-26 May 1978	Division of Marine Sciences, Unesco	English French Spanish Russian
19.	IOC Workshop on Marine Science Syllabus for Secondary Schools Llantwit Major, South Wales	Division of Marine Sciences, Unesco	English French Spanish Russian
20.	Second CCOP-IOC Workshop on IDOE Studies of East Asia Tectonics and Resources Bandung, Indonesia, 17-21 October 1978	Office of the Project Manager UNDP/CCOP c/o ESCAP Sala Santitham Bangkok 2, Thailand	English
21.	Second IDOE Symposium on Turbulence in the Ocean Liège, Belgium, 7-18 May 1979	IOC, Unesco	English French Spanish Russian

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1. List of participants
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Summary

The Second Symposium on Turbulence in the Ocean was held at the University of Liège (Belgium), 7-18 May 1979. Twenty experts participated in the meeting. Six invited review lectures, twenty-eight contributed papers and ten informal talks on the most recent research data were presented and discussed in detail. It was concluded that, after an unprecedented advance in the understanding of mixing processes on different scales during the 1970s it was now possible to focus attention on to the interaction between the motions at vastly different scales, notably the quasi-geostrophic eddies ($L \sim 100$ km), the semi-geostrophic mesoscale fronts ($L \sim 1$-10 km), ageostrophic intrusive layers ($L \sim 1$-30 km), microscale turbulence ($L < 1$ metre) and double diffusive instabilities ($L \sim 10$ cm). The 1979 Symposium was designed to bring together experts in these topics and in surface and internal waves. The result was a great success with a lively interaction of ideas leading to identification of priorities for future research, and tentative steps towards a new synthesis of phenomena hitherto treated separately.

In view of the practical problems encountered in studying the interaction of processes involving a wide variety of scales, which will involve multiship experiments, it is recommended that a new working group on Turbulence in the Ocean should be formed by SCOR.

1. Introduction

1.1 The role of turbulence studies in oceanography

The concepts of mixing of water masses, dispersion of anomalies, transport of momentum and vorticity and the dissipation of kinetic energy by turbulent motions in the ocean play a central role in almost every aspect of oceanography. The action of turbulence appears not only in the circulation models of physical oceanographers but equally in the models of chemical distribution, of biological production and of sedimentation. It is also becoming increasingly clear that the existence and form of fronts, fine structure and microstructure in physical, chemical and biological distributions are inseparably related to the action of turbulent stirring within the ocean. The interaction between atmosphere and ocean - with its important consequences for climate variation - can only be modelled by taking into account the transport of heat, salt and momentum by turbulent motions in the wind-mixed surface layer and the underlying thermocline.

To sum up, the success of oceanographers' models of phenomena in the ocean almost invariably depend critically on an understanding of the role of turbulence in transporting momentum and scalar constituents of seawater across the mean streamlines of the gyrescale circulation. And, accepting that the scales of turbulent motions range from millimetres to megametres, there is scarecly any application in which its effects can be neglected or crudely parameterized with any hope of success.

The aim of research into the properties of turbulence in the ocean is to discover economical ways of describing them in the equations used for ocean modelling, taking account of the particular characteristics that dominate in different regions of the ocean and at different depths, seasons or weather conditions as well as at different space and time scales.

1.2 Early history

The earliest oceanic application of ideas about turbulent transport followed remarkably soon after the classical studies by Reynolds a hundred years ago. At the turn of the century Ekman developed his famous model of the oceanic boundary layer based on Boussinesq's concept of eddy viscosity, which had been published just five years earlier. The earliest attempts to interpret the role of turbulent friction in dissipating the kinematic energy of tides were published in 1918 by Taylor and Jeffries. Soon afterwards Taylor showed that the bulk distributions of heat, salt and current speed in Jacobsen's Kattegat data were consistent with Richardson's (1920) ideas about the role of density stratification in suppressing the vertical component of turbulence. The concept of large horizontal and small vertical eddy diffusivities was incorporated by Wüst in his analysis of the Meteor expedition survey of the Atlantic Stratosphere published in 1935.

Following the success of these diagnostic studies, it became accepted practice to incorporate strong lateral and weak vertical diffusivities of heat, salt and momentum in diagnostic and prognostic models of oceanic circulation. The biological community also adopted the concept of vertical turbulent diffusion of nutrients and plankton in models of primary production. And vertical transport by turbulence was generally assumed to modify the gravitational settling of plankton and inanimate particles in studies of oceanic sedimentation.

1.3 Exploration of turbulent motions

Although the oceanographic literature includes a number of papers reporting earlier attempts to explore turbulent motion, it is only in the past two decades that systematic attempts have been made to discover the relationship between the bulk effects of turbulence described above and the detailed flow properties. The investigations have been concentrated in three main areas:

I. Small-scale motions involving overturning.

II. Eddies of order 100 km horizontal scale.

III. Fronts, intrusive layers and associated fine structure in distributions of scalars.

Some of the early results of these investigatons were discussed at the First Symposium on Turbulence in the Ocean in Vancouver, 1968. Since then there has been a rapid expansion in experimental and theoretical studies in each of the three areas listed above. Notable achievements in the respective areas have included:

I. (i) Resolution of temperature and velocity variance spectra to their dissipation limits.

(ii) The discovery by in situ flow visualization that most of the seasonal thermocline is in laminar flow (i.e. no local overturning motions) at any instant.

(iii) The identification of double-diffusion as a source of convective overturning, buoyant intrusion and entrainment in the interior of the ocean.

(iv) The identification of Kelvin-Helmholtz instability as a source of mechanical overturning leading to three-dimensional turbulence in the interior of the ocean.

(v) Direct measurement of velocity profiles and turbulent fluctuations in the wind-mixed layer and benthic boundary layer.

II. (i) The discovery using neutrally buoyant Swallow floats that 90-99% of the kinetic energy of the oceanic circulation is concentrated into a spectral peak centred at about 50 km horizontal scale.

(ii) The demonstration that the eddy motions responsible for this kinetic energy peak are in quasi-geostrophic balance.

(iii) The development of geostrophic turbulence theories consistent with the observations made in Polymode, and hence the introduction of dynamics into the concept of lateral eddy transport.

(iv) The demonstration in numerical models that quasi-geostrophic turbulence greatly influences the gyre-scale circulation.

III. (i) The recognition that fine structure in oceanic scalar distributions is intimately related to the presence of fronts, on the one hand, and internal waves, on the other.

(ii) The identification of fine structure in velocity (using in situ flow visualization).

(iii) The discovery that some fine structure has characteristics consistent with double-diffusive convection.

(iv) The application of isopycnal analysis techniques to reveal three-dimensional patterns of fine structure despite the presence of internal wave noise.

(v) The demonstration that the distribution of small-scale turbulence events are related to the three-dimensional distribution of fine structure in (a) density and (b) thermohaline anomaly.

(vi) The demonstration in a dynamical model that frontogenesis driven by geostrophic turbulence can create fine structure with many of the features observed in the ocean.

1.4 The state of oceanic turbulence research in 1979

The major advances that have been made in the past decade have revolutionalized our thinking about turbulence in the ocean. The bulk effects of turbulence that were known fifty years ago can now for the first time be discussed in terms of models of the responsible flow patterns based on an understanding of the underlying dynamics and physics, whether it be geostrophic turbulence or double-diffusive convection, frontogenesis or hydrodynamic instabilities, or wave-eddy interaction. Much work needs to be done to establish these new ideas on a sounder foundation of theory and observation. But it is already apparent that the individual mixing elements responsible for turbulence in the ocean cannot be understood in isolation. There are strong interactions between all scales from the largest to the smallest. These interactions go in both directions. On the one hand, the geostrophic eddies create sharp fronts which determine the distribution of micro-scale turbulence events, powered both by the available potential energy of frontal baroclinicity and by the latent potential energy of frontal thermoclinicity. While, on the other hand, the release of latent potential energy by double diffusion can give rise to convective layers tens of metres thick and vigorous intrusions that may extend for many kilometres. Equally, the geostrophic eddies appear to be responsible for driving some of the gyre-scale circulations.

The state of oceanic turbulence research at the end of the 1970s is characterized by a rapidly improving understanding of the detailed mechanisms responsible for mixing the ocean accompanied by the first steps towards an understanding of the mechanisms by which motions on different scales interact with one another. It is clear that the influence of the Earth's rotation, curvature, topography and of the ocean's stratification and thermohaline distribution make turbulence in the ocean quite different from turbulence as understood by aerodynamicists, chemical engineers and even by meteorologists. Analogy with these other systems has proved beneficial in the past, but as we enter the 1980s, it is possible to say that enough progress has been made in understanding turbulence in the ocean that we can in the future study it as a phenomenon in its own right.

2. The IAPSO-SCOR Second IDOE Symposium on Turbulence in the Ocean

2.1 Aims of the Symposium

The aim of the Second Symposium on Turbulence in the Ocean was to review the progress made during the International Decade of Ocean Exploration (IDOE) to identify priority areas for research in the 1980s and to make recommendations to the sponsoring bodies concerning the need for international support to achieve these research aims.

The special theme of the Symposium was the interaction between turbulence motions on different scales in the overall range: millimetres to magametres.

2.2 Background

IAPSO sponsored the First International Symposium on Turbulence in the Ocean in 1968. The meeting of invited experts was held in the University of British Columbia, Canada, with Professor R.W. Stewart as Chairman. A report on the meeting was issued in 1970. (Editor: T.R. Osborn: UBC Institute of Oceanography manuscript report no. 24.) That first meeting was marked by a relaxed informality, with time to inspect original research results and extended discussion on topics sparked off by participants' research talks.

Some of the themes revealed by the UBC Symposium were subsequently discussed at the Stockholm and the La Jolla meetings of the IUCRM in 1969 and 1972. The proceedings of these meetings (in Radio Science, Vol. 4(12) and Boundary Layer Meteorology Vols. 4 and 5, respectively) contain a number of contributions related to turbulence and microstructure in the ocean (but the main purpose of the meetings was to discuss atmospheric turbulence and structure). A number of other international meetings have been devoted to problems of larger scale mixing in the ocean (in particular the various Polymode meetings and the Chapman Conference on on Oceanic Fronts).

The IAPSO General Assembly in Grenoble (1976) accepted a proposal submitted by the British National Committee to sponsor a Second Symposium on Turbulence in the Ocean, at which the emphasis would be on seeking a synthesis across the whole spectral band from millimetres to megametres. This proposal was subsequently discussed by SCOR which agreed to co-sponsor the meeting and by the IOC which offered support. A number of Member States recommended that the Symposium should be recognized as a IDOE meeting. It was therefore designated the IAPSO-SCOR Second IDOE Symposium on Turbulence in the Ocean, with support from the IOC.

2.3 Organization of the meeting

The original plan was to restrict the Symposium to a small number of invited experts, following the precedent set by the First Symposium (UBC, 1968). However, publicity in the SCOR Proceedings and Unesco publications led to so many requests to participate that it was decided to make the first week an open meeting, during which both invited and contributed papers could be presented and discussed in open sessions to be attended by all comers. The plan was to follow this by a closed session during the second week when a small number of invited experts could consider the new results and their impact on oceanography in greater detail.

Following an approach by the Chairman of the International Organizing Committee, Professor J.C.J. Nihoul kindly agreed to host the full two-week meeting. In order to accommodate the idea of an open first week, it was agreed that this would be combined with the annual Colloquium on Ocean Hydrodynamics held in Liège University. Consequently, the 11th Liège Ocean Hydrodynamics Colloquium was scheduled for 7-11 May 1979 and it was announced that the theme for the Colloquium would be "Turbulence in the Ocean, millimetres to megametres". This Colloquium thus became an integral part of the IAPSO-SCOR-IDOE Symposium.

Professor Nihoul also kindly arranged for the facilities of the beautiful Château de Colonster (owned by the University of Liège) to be made available for the closed session during the second week (14-18 May 1979).

2.4 Attendance at the Symposium

Twenty invited experts attended the full two weeks of the IAPSO-SCOR Second IDOE Symposium on Turbulence in the Ocean. In addition, a further 43 scientists attended the Colloquium during the first week. (See list of names in Annex 1).

The meeting was honoured by the participation of the President of SCOR and the Assistant Secretary of the IOC.

2.5 Scientific papers

Invited review papers were presented by the following experts:

C. Rooth[x]	Oceanic Turbulence from a Gyre Scale Perspective
G. Kullenberg	Turbulent Diffusion in the Sea: Recent Ideas and Observations
P.B. Rhines	Geostrophic Turbulence
J.D. Woods	Mesoscale Turbulence
A.S. Monin	Small-Scale Three-Dimensional Turbulence
J.S. Turner	The Influence of Molecular Processes on Turbulence and Mixing in the Ocean

(x Written version circulated and discussed in absentia)

In addition, 28 contributed scientific papers on the subject of "Turbulence in the Ocean" were presented during the first week. (See list in Annex 2). Many of these papers announced for the first time the results of major new advances in particular aspects of the subject. Others reported continuing refinement of ideas and methods that have already been established.

During the second week, participants gave a number of informal talks on the most recent research (see list in Annex 2).

2.6 Publication

The results of the meeting will be reported in three publications.

2.6.1 IOC Workshop Report No. 21

This report describes the organizational aspect of the meeting, lists of participants and the scientific presentations, and summarizes the principal results of the meeting including recommendations for future activities by the sponsoring organizations.

2.6.2 Turbulence in the Ocean (editor: J.D. Woods)

The invited review lectures will be revised in the light of discussions at the Symposium and then published as a book in the Spring-Verlag series "Topics in Applied Physics". The aim of this book is to provide a balanced review of the subject as a base line for research and application in the 1980s.

2.6.3 Marine Turbulence (Editor: J.C.J. Nihoul)

The contributed papers presented at the 11th Liège Colloquium on Ocean Hydrodynamics (see Appendix 2) will be published by Elsevier in their Marine Science Series. This will constitute the Proceedings of the Liège Colloquium.

3. Conclusions and recommendations

The IAPSO-SCOR Second IDOE Symposium on Turbulence in the Ocean, University of Liège, 7-18 May 1979, reached the following conclusions and made the following recommendations to the sponsoring bodies, namely to:

1. The International Association for Physical Sciences of the Ocean
2. The Scientific Committee for Oceanic Research
3. The Intergovernmental Oceanographic Commission of Unesco.

3.1 Conclusions

1. Models of oceanic circulation, air-sea interaction, primary production, sedimentation and many other aspects of the ocean are sensitive to the way in which the effects of turbulence are included in the model equations.

2. It has been shown in the past decade that the present methods of parameterizing turbulence, normally based on Boussinesq's ideas developed in the last century, are often seriously wrong. Examples of the more serious errors include: (1) using a positive eddy viscosity when a detailed study of the processes involved momentum would be more consistent with a negative viscosity; (2) the assumption that vertical turbulent transport is identical to cross-isopycnic transport; (3) the neglect of double diffusive effects.

3. Although there have been great advances in the past decade in describing mixing elements, much remains to be done to show how they are related. For example, (1) the detailed mechanisms relating mesoscale fronts to geostrophic eddies, on the one hand, and three-dimensional turbulence on the other; (2) the nature and close association of cross-frontal intrusive process with double-diffusion and its dependence on frontal thermoclinicity and sensitivity to frontal baroclinicity; (3) the influence of internal waves on fine structure and vice versa.

4. There is a need to develop statistical theories of the relationship between geostrophic turbulence, mesoscale fronts and microscale turbulence (including double diffusive effects).

5. Experimental apparatus available at present makes it possible to measure the fine structure of the ocean in density, salinity and temperature and the microstructure in temperature and velocity. Further instrumental improvements are needed before it will be possible to measure the fine structure in velocity and the microstructure in salinity and density.

6. Improved methods are needed unambiguously to relate observations of fine/microstructure to theoretical models of oceanic turbulence. In particular, there is an urgent need to provide tests for double-diffusive driven motions (convection, intrusion, entrainment) that are suitable for large-scale surveys.

7. It is necessary to interpret records of microstructure in terms of three-dimensional distributions of fine structure. Profiles (one-dimensional) and sections (two-dimensional) are not adequate for this purpose.

8. The role of internal wave breaking in generating ocean mixing depends critically on assumptions concerning the high wave number cut-off and on the form of the turbulent density fine structure. Further research is needed before this problem can be resolved.

9. The field study of interactions between motions on greatly different scales poses serious experimental problems that can probably only be overcome by multiship expeditions such as JASIN. This will call for international collaboration.

3.2 Recommendations

3.2.1 The Symposium recommends that IAPSO and SCOR should consider establishing a working group on "Turbulence in the Ocean" with the following specific aims:

(a) Rapid diffusion of new results and ideas concerning the interaction of turbulent motions on different scales.

(b) Encouragement of improvement and intercaliboration in instruments and methods for measuring oceanic turbulence.

(c) Initiation of joint expeditions and research projects.

(d) Organization of meetings and workshops related to the problems of turbulence in the ocean.

3.2.2 The Symposium requests the IOC to support the activities of the proposed SCOR Working Group on Turbulence in the Ocean.

4. Acknowledgements

It is a pleasure to acknowledge the friendly help provided by the local organizers at the University of Liège, led by Professor J.C.J. Nihoul. Financial support was provided by IAPSO, IOC and Unesco.

ANNEX 1

A. INVITED PARTICIPANTS (both weeks)

1.	V.S. Belyaev	P.P. Shirshow Institute of Oceanology, Moscow, USSR.
2.	K.F. Bowden[x]	University of Liverpool, Liverpool, U.K.
3.	M. Coantic	Institut de Mécanique Statistique de la Turbulence, Marseille, France.
4.	K.N. Fedorov	Institute of Oceanology, Moscow, USSR.
5.	C.H. Gibson[x]	University of California, La Jolla, U.S.A.
6.	A.E. Gill	University of Cambridge, Cambridge, U.K.
7.	S. Kitaigorodskii	Institute of Physical Oceanography, Copenhagen, Denmark.
8.	G. Kullenberg[x]	Institute of Physical Oceanography, Copenhagen, Denmark.
9.	J.L. Lumley	Cornell University, Ithaca, U.S.A.
10.	J.C.J. Nihoul[x+]	Université de Liège, Liège, Belgium.
11.	D. Olbers	Institut für Meereskunde, Kiel, F.R.G.
12.	T.R. Osborn	Institute of Oceanography, Vancouver, Canada.
13.	R.V. Ozmidov	Institute of Oceanography, Moscow, USSR.
14.	S. Panchev	University of Sofia, Sofia, Bulgaria.
15.	P.B. Rhines[x]	Woods Hole Oceanographic Institution, Woods Hole, U.S.A.
16.	C.G.H. Rooth[x]	University of Miami, Miami, U.S.A.
17.	H. Tennekes	Royal Netherlands Meteorological Institute, De Bilt, The Netherlands.
18.	J.S. Turner[x]	Research School of Oceanographic Sciences, Canberra, Australia.
19.	K.F. Voigt	Intergovernmental Oceanographic Commission, Paris, France.
20.	J.D. Woods[xx]	Institut für Meereskunde, Kiel, F.R.G.

x Member of the International Planning Committee.
xx Chairman of the International Planning Committee.
\+ Local organizer.

B. PARTICIPANTS IN THE OPEN MEETING (first week)

1.	ADAM, Y.	Ministère de la Santé Publique et de l'Environnement, Belgium.
2.	BAH, A.	Institut Polytechnique de Conakry, République de Guinée.
3.	BELYAEV, V.S.	Institute of Oceanology, Moscow, USSR.
4.	BERGER, A.	Université Catholique de Louvain, Belgium.
5.	BOWDEN, K.F.	University of Liverpool, U.K.
6.	BURT, W.V.	Office of Naval Research, London, U.K.
7.	BUTTI, C.H.	Rijkswaterstaat, 's Gravenhage, The Netherlands.
8.	CALDWELL, D.R.	Oregon State University, U.S.A.
9.	CHABERT d'HIERES, G.	Institut de Mécanique de Grenoble, France.
10.	COANTIC, M.	Institut de Mécanique Statistique de la Turbulence, Marseille, France.
11.	COLIN DE VERDIERE, A.	C.O.B., Brest, France.
12.	DELCOURT, B.	Université de Liège, Belgium.
13.	DERENNE, M.	Université de Liège, Belgium.
14.	DESAUBIES, Y.J.F.	University of Washington, Seattle, U.S.A.
15.	DILLON, T.M.	Oregon State University, U.S.A.
16.	DISTECHE, A.	Université de Liège, Belgium.
17.	FEDOROV, K.	Institute of Oceanology, Moscow, USSR.
18.	FERGUSON, S.R.	University of Liverpool, U.K.
19.	GIBSON, C.H.	University of California, U.S.A.
20.	GOODMAN, L.	O.N.R., Washington, U.S.A.
21.	GORDON, C.M.	Naval Research Laboratory, Washington, U.S.A.
22.	GREGG, M.C.	University of Washington, Seattle, U.S.A.
23.	HAUGUEL, A.	Electricité de France, Chatou, France.

24.	HOPFINGER, E.	Institut de Mécanique de Grenoble, France.
25.	JOSSERAND, M.	Institut de Mécanique de Grenoble, France.
26.	KITAIGORODSKII, S.A.	University of Copenhagen, Denmark.
27.	KRUSEMAN, P.	K.N.M.I., De Bilt, The Netherlands.
28.	KULLENBERG, G.E.B.	University of Copenhagen, Denmark.
29.	LEBON, G.	Université de Liège, Belgium.
30.	LE PROVOST, C.	Institut de Mécanique de Grenoble, France.
31.	LEWALLE, A.	Université de Liège, Belgium.
32.	LOFFET, A.	Université de Liège, Belgium.
33.	LUMLEY, J.L.	Cornell University, Ithaca, U.S.A.
34.	MAHRT, K.H.	Universität Kiel, F.R.G.
35.	MICHAUX, T.	Université de Liège, Belgium.
36.	MITCHELL, J.B.	U.K. Meteorological Office, Bracknell, U.K.
37.	MULLER, P.	Harvard University, Cambridge, U.S.A.
38.	NIHOUL, J.C.J.	Université de Liège, Belgium.
39.	NIZET, J.L.	Université de Liège, Belgium.
40.	OAKEY, N.S.	Bedford Institute of Oceanography, Dartmouth, Canada.
41.	OLBERS, D.J.	Universität Kiel, F.R.G.
42.	ORLANSKI, I.	Princeton University, U.S.A.
43.	OSBORN, T.R.	University of British Columbia, Vancouver, Canada.
44.	OSTAPOFF, F.	Sea-Air Interaction Laboratory, Miami, U.S.A.
45.	OZER, J.	Université de Liège, Belgium.
46.	OZMIDOV, R.V.	Institute of Oceanology, Moscow, USSR.
47.	PASMANTER, R.	Rijkswaterstaat, Den Haag, The Netherlands

48.	PIACSEK, S.A.	NORDA, Bay St. Louis, U.S.A.
49.	PICHOT, G.	Ministère de la Santé Publique et de l'Environnement, Belgium.
50.	RENIER, I.	Université de Liège, Belgium.
51.	REVAULT d'ALLONNES, M.	Museum d'Histoire Naturelle, Paris, France.
52.	RHINES, P.B.	Woods Hole Oceanographic Institution, Woods Hole, U.S.A.
53.	ROISIN, B.	Université de Liège and Florida State University, U.S.A.
54.	RONDAY, F.C.	Université de Liège, Belgium.
55.	RUNFOLA, Y.	Université de Liège, Belgium.
56.	SMITZ, J.	Université de Liège, Belgium.
57.	STROSCIO, M.A.	Johns Hopkins University, U.S.A.
58.	SWIFT, M.R.	University of New Hampshire, U.S.A.
59.	THOMASSET, F.	IRIA Laboria, Le Chesnay, France.
60.	TURNER, J.S.	University of Cambridge, U.K.
61.	VETH, C.	N.I.O.Z., Texel, The Netherlands.
62.	WOODS, J.D.	Universität Kiel, F.R.G.
63.	WOLF, J.	I.O.S. Bidston, U.K.

ANNEX 2

SCIENTIFIC PAPERS

A. Presented during the first week

John L. Lumley: Fundamental aspects of turbulence with implications in geophysical flows.

Jacques C.J. Nihoul: Specific aspects of marine turbulence.

Claes Rooth: Ocean gyres.

Peter B. Rhines: Mid ocean eddies.

Peter Müller: Eddy-mean flow interaction in the mid ocean.

Alain Colin de Verdière: Rectification of Rossby waves in bounded and unbounded homogeneous oceans.

K.N. Fedorov: Intrusive fine-structure in frontal zones.

V.S. Belyaev: Shear instability generation of the turbulence in the ocean (experimental evidences).

John D. Woods: 2D-turbulent cascade.

F. Ostapoff and S. Worthem: Microstructure instabilities in the main thermocline.

I. Orlanski and C.P. Cerasoli: Resonant and non-resonant wave-wave interactions for internal gravity waves.

Carl H. Gibson: Fossil temperature, salinity and vorticity turbulence in the ocean.

M.C. Gregg: Vertical patchiness of temperature miscrostructure.

D.R. Caldwell and T.M. Dillon: The shape and scaling of vertical temperature gradient spectra.

Andrei Monin, R.V. Ozmidov and N.K. Fedorov: 3D ocean turbulence.

Sergei Kitaigorodskii: Wind generated turbulence in the upper layer.

Maxence Revault d'Allonnes: Open sea experimental study of the effects of a gust of wind. General results and theoretical problems.

N.S. Oakey: Dissipation in the mixed layer.

Thomas M. Dillon and Douglas R. Caldwell: Kinetic energy dissipation observed in the upper ocean.

Cornelis Veth: A laser doppler velocimeter for small scale turbulence studies in the sea.

Michel Coantic: Exploration of oceanic turbulence by means of Doppler processing of scattered sonar signals.

Douglas R. Caldwell and Terry Chriss: The benthic viscous sublayer.

S.A. Piacsek and J. Toomre: Non-linear evolution and structure of salt fingers.

Stewart Turner: Molecular effects in marine turbulence.

K.F. Bowden and S.R. Ferguson: Variations with height of the turbulence in a tidally induced bottom boundary layer.

M.R. Swift: The influence of turbulent kinetic energy distribution on profiles of stress and current in tidal channels.

Judith Wolf: Eddy viscosity and bottom stress in tidally induced shallow sea turbulence.

(i) Determination of the bottom stress from current measurements. Application to the Irish Sea.

B. Roisin, Y. Runfola and Jacques C.J. Nihoul: Eddy viscosity and bottom stress in tidally induced shallow sea turbulence.

(ii) Determination of the bottom stress from mathematical model. Memory effect at tide reversal.

G. Kullenberg: Turbulent diffusion in the ocean.

J.P. Benque, A. Hauguel and A. Warluzel: Turbulent diffusion and shear effect in a tidal sea.

(i) Dispersion dans une mer à marée.

Y. Runfola, B. Roisin and Jacques C.J. Nihoul: Turbulent diffusion and shear effect in a tidal sea.

(ii) Application of a three-dimensional hydrodynamic model to the determination of the shear effect diffusivity tensor.

S. Panchev: Spectral structure of horizontal oceanic turbulence. A semi-empirical model.

Sergei Kitaigorodskii: Wind generated turbulence in the upper layer.

B. Presented during the second week

A.E. Gill: Gyres.

P.B. Rhines: Quasi-geostrophic turbulence.

J.D. Woods: Fronts.

R.V. Ozmidov: 3D turbulence.

G. Kullenberg: Diffusion.

H. Tennekes: Dissipation.

D. Olbers: Internal waves.

Sergei Kitaigorodskii: Seasonal change.

M. Coantic: Surface waves.

K.F. Bowden: Bottom boundary layer.

P.B. Rhines: Rossby waves.

J.S. Turner: Molecular effects.

J.L. Lumley: Turbulence models.

S. Panchev: The turbulent cascade.

C.H. Gibson: Fine structure and microstructure.

J.S. Turner: Intrusions and fronts.